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Assessment of Water Resources and Watershed Conditions in Moores Creek National Battlefield, North Carolina

Natural Resource Report NPS/SECN/NRR—2009/132

ON THE COVER
The braided channel of Moores Creek interspersed with riparian swamp forest

Assessment of Water Resources and Watershed Conditions in Moores Creek National Battlefield, North Carolina

Natural Resource Report NPS/SECN/NRR—2009/132

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Please cite this publication as:

Mallin, M. A., and M. R. McIver. 2009. Assessment of water resources and watershed conditions in Moores Creek National Battlefield, North Carolina. Natural Resource Report NPS/SECN/NRR—2009/132. National Park Service, Fort Collins, Colorado.

NPS 324/100182, July 2009

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Executive Summary

The purpose of this report was to locate and examine existing information pertaining to the water quality in and around Moores Creek National Battlefield (MOCR), assess the present and likely future water conditions of the park, and make recommendations to fill in existing information gaps. Water quality and quantity, habitat issues, potential for invasive species, and trends in park resource usage are addressed.

MOCR is a reasonably small park (87.75 acres or 36 ha) with only one significant water body in it, which is its namesake Moores Creek. This is a low pH, low conductivity 3rd order blackwater creek that feeds into the 5th order Black River about 3.2 km downstream. Within the park the creek presents a braided channel through riparian forested wetlands; its average depth is about 1.5 m, but has deep spots up to 5 m, and at its widest the channel is about 20 m. In historic times much of the area between the present Visitor's Center and the battlefield itself was believed to be a wet pine savanna, which was drained and converted to a meadow early in the 20th century. Recently a 4.5 acre (11.1 ha) section of the meadow has been hydrologically restored to savanna, with these efforts continuing. The savanna area is host to several rare plant species, including pitcher plants, Carolina bog mint, spring flowering goldenrod and Carolina Grass of Parnassus. The water table in the park is only about 1 m from the surface, and seeps are common in the area. Within the park there are three artesian wells that are capped and have valves. These wells are not used for drinking purposes, only for periodic equipment washing. Other springs and seeps exist in the park as well. The quality of the spring water has not been monitored; however, spot sampling by the authors of this report show that the quality of the spring water is quite different from the creek water. Drinking water for MOCR is drawn up from the Pee Dee Aquifer via 200 ft. (60 m) deep wells and chlorinated.

There are several invasive terrestrial plant species in the park, including wisteria, mimosa, Japanese honeysuckle and privet. Although small, the park has a relatively high number of reptile and amphibian species, due to the diverse habitats present on site. An assessment of the benthic macroinvertebrate community of Moores Creek led to a 'moderate stress' rating by the NC Division of Water Quality, which is considered to be supporting of aquatic life. A 2004 NPS-sponsored survey found 12 fish species in Moores Creek, with the community dominated by lake chubsucker, bluegill and golden shiner. However, there is a fish consumption advisory for parts of Moores Creek initiated by the North Carolina Division of Water Quality (NCDWQ) due to mercury contamination. No invasive aquatic animal species have been documented in the park. In terms of listed aquatic species of concern, both North Carolina and the Federal government have listed one resident fish species, the Carolina darter, as a species of concern. At least 30 species of mammals have been verified as park inhabitants or visitors. No rare or endangered terrestrial animal species have been noted within the park. No non-native invasive terrestrial animal species have been seen in the park either. A list of bird species that have been seen in the park is available in the Visitor's Center.

Past sampling has shown that nutrient concentrations are generally low in the creek water. The presence of algal blooms as chlorophyll *a* has not been monitored, and this represents an important data gap that should be rectified. Historical data shows that the creek is periodically subjected to turbidity pulses that are well above those commonly seen in area blackwater streams and rivers. Additionally, the creek has been subjected to occasional elevated fecal coliform

bacteria counts that exceed the North Carolina standard for human contact waters. During summer, dissolved oxygen concentrations can fall below the North Carolina swamp water standard of 4.0 mg/L, and BOD concentrations have at times been somewhat elevated in comparison to area creeks and rivers.

There are several potential sources of pollution to the creek. Within MOCR, runoff from the lower parking lot near the picnic area flows directly into the creek without any pre-treatment. Runoff from the parking lot could contain fecal coliform bacteria, nitrogen and phosphorus, and toxicants such as polycyclic aromatic hydrocarbons (PAHs). Probably the largest potential pollution source to the park's stretch of creek is upstream land use. At least 10 swine concentrated animal feeding operations (CAFOs) with a combined permitted capacity of over 53,000 animals are in the watershed upstream of MOCR, and are potential sources of nitrogen, phosphorus, BOD and fecal bacteria. Poultry CAFOs are undergoing a rapid expansion in Pender County and this poses a further threat to Moores Creek. Traditional agriculture upstream is a potential source of nutrients and suspended sediments. Depending upon hydrological connectivity, nutrient contamination of park groundwater from nearby CAFOs is also a potentiality. The human population is increasing in this area, and with land development comes the potential for anthropogenic pollution in the form of suspended sediments and turbidity, nutrient and fecal bacteria loading, and other toxicants including metals. Airborne pollutants are another threat to the park environment. Airborne ammonium is a common byproduct of CAFOs and can affect water bodies as far as 60 miles distant, and there are numerous CAFOs in the Black River watershed. As mentioned, there is a fish consumption advisory for several species due to high mercury content; mercury is commonly airborne and may come from distant power plant smokestacks, and is converted to methyl mercury in blackwater swamps such as the ones characterizing the Black River watershed. Table 1 shows current and potential stressors that are affecting, have affected or may in the future affect the Moores Creek aquatic habitats.

Table 1. Current and potential stressors that have affected or may affect Moores Creek National Battlefield habitats [EP – Existing problem, OK – Low or no problem, PP – Potential problem, ND – No data to make judgment].

Stressor	Moores Creek	Drinking Well Water	Groundwater	Savanna
Algal blooms	ND	OK	OK	ND
Toxic algae	ND	OK	OK	ND
Nutrient loading	PP	OK	PP	ND
Excessive nitrate	OK	OK	PP	OK
Airborne ammonium	PP	OK	OK	ND
Hypoxia	EP	OK	OK	ND
Sedimentation	PP	OK	OK	OK
Erosion	EP	OK	OK	OK
Fecal Bacteria	EP	OK	ND	ND
Metals contamination	EP(Hg)[1]	OK	ND	ND
Toxic compounds	ND	OK	ND	ND
Invasive species	OK	OK	OK	EP
Habitat disruption	EP	OK	OK	OK

[1]Fish tissue consumption advisory by NC Division of Water Quality.

Drinking water is chlorinated and is thus not at risk from fecal bacteria. Furthermore, septic contamination, nutrient loading, or toxin contamination of drinking water is not a possibility due to the depth (60 m) of the wells (all OK). Groundwater has not been systematically studied on site (ND). However, NPS has noted that the water table is within one meter of the surface in the park, and is thus subject to potential contamination. Potential pollutants (PP) that could impact groundwater include nitrate or ammonium. Less likely, but untested possibilities as groundwater contaminants include fecal bacteria from septic systems, and organic or metallic toxins. The MOCR staff has not noted algal blooms in the savanna through normal visual observation. Standing water is present in the wetland according to rainfall, and perennial water is limited to the old ditch. The savanna does receive floodwaters from the creek, as well as any of the airborne pollutants. Fecal pathogens are not likely to be a problem in the savanna, as humans have minimal contact with standing water within it and, barring polluted floodwaters, sources would only be local wildlife. As noted within, park staff to prevent spreading periodically burns out invasive plant species such as sweetgum and blackberry (EP). Further disruption to this habitat is not in park plans, and is not likely to occur from any outside source (OK).

Recommendations

A priority recommendation (Table 2) would be to conduct a yearlong sampling program of Moores Creek, within the park. The last NC DWQ – supported sampling effort occurred in 1988. Population (human and swine) has increased in the area and impacts to the park's water resources are likely to have increased as well. We recommend that Moores Creek be sampled (from the reproduced battlefield site bridge) for standard water quality parameters (water temperature, dissolved oxygen, pH, salinity, fecal coliform bacteria, enterococcus, total nitrogen, ammonium, nitrate, total phosphorus, orthophosphate, BOD5, chlorophyll *a*) on a monthly basis for one year. Monthly sampling (n = 12) would make the data comparable to the NCDWQ-required monthly sampling by the Lower Cape Fear River Program conducted at nearby Colly Creek and the Black River at Highway 210. Sampling the creek sediments for potential toxins (metals, pesticides, PCBs, PAHs) should be performed at least once to judge whether the benthic and fish communities are at risk from these pollutants.

Table 2. List of Prioritized Recommendations.

1. Conduct yearlong monthly water quality monitoring study of Moores Creek
2. Conduct yearlong monthly water quality monitoring of artesian wells
3. Park staff needs to monitor for signs of increased stream bank erosion
4. Park staff should continue to monitor for streamside tree damage from beavers
5. Park should consider monitoring for airborne ammonia from regional CAFOs.

The artesian wells present an opportunity to monitor the quality of groundwater in the park. Since the water table is so close to the surface, it is susceptible to pollution from watershed sources including septic systems, CAFOs and traditional agriculture. We recommend that two of the wells also be monitored concurrently with the creek waters, for the same parameters as the creek water. Our recommendations of conducting a sampling program on the creek and the groundwater wells are in concurrence with the NPS, which made similar recommendations recently (NPS 2006).

Erosion does occur within MOCR along the banks of Moores Creek. One report indicated that tidal activity might be responsible for this (a natural activity). Park staff needs to monitor the creek bank for erosion, because if it should accelerate this may be related to upstream watershed activities.

Beavers - clearly there is tree damage occurring due to beaver activity. The park should continue to monitor for streamside tree damage and when it occurs within a key area of the stream (between 100 ft. upstream of the boardwalk and 100 ft. downstream of the bridge) this may result in increased streamside erosion due to loss of streamside trees. In such a case removal of one or more beavers by professional trappers may be warranted to protect the site from increased erosion. Also, construction of beaver dams within MOCR should not be permitted as this will increase on-site flooding and threaten the cultural resources in the park.

Another recommendation concerns sampling for airborne ammonia. The Black River watershed contains many swine and increasing number of poultry CAFOs, which are large producers of airborne ammonia. The NPS should consider installing an airborne ammonia sampler to monitor the influx of this pollutant onto park property.

Acknowledgments

This study was funded by the National Park Service, Southeast Coast Network. In addition to the individuals listed as interviewed, we thank Eva DiDonato and Joe DeVivo of the National Park Service and Dr. JoAnn Burkholder of North Carolina State University for facilitation and many helpful review comments. Trish MacPherson of NC DWQ supplied the benthic macroinvertebrate information used in this report. Ann Childress of MOCR was especially helpful to us both as a technical resource and as a guide to local areas of concern. Amanda Maness and Brad Rosov of UNCW provided technical help to the authors. We also thank Tara MacPherson Croft and Samuel Watson of the NC DWQ Aquifer Protection Section for groundwater information.

Commonly Used Abbreviations

BOD	Biochemical Oxygen Demand
CAFO	Concentrated Animal Feeding Operation
CFS	Cubic Feet per Second
CFU	Colony-Forming Units
DO	Dissolved Oxygen
EPA	United States Environmental Protection Agency
GPD	Gallons per Day
ha	Hectares
m	Meter
mg/L	Milligrams per Liter (= parts per million)
µg/L	Micrograms per Liter (= parts per billion)
NC	North Carolina
NCDENR	North Carolina Department of Environment and Natural Resources
NCDMF	North Carolina Division of Marine Fisheries
NCDWQ	North Carolina Division of Water Quality
N	Nitrogen
NPS	National Park Service
NTU	Nephelometric Turbidity Unit
P	Phosphorus
MOCR	Moores Creek National Battlefield
Park	Moores Creek National Battlefield
SAV	Submersed Aquatic Vegetation
UWL	Unique Wetland
WRD	Water Resources Division

Park Description

Background

Location, Size, and Boundaries

Moores Creek National Battlefield (MOCR) contains 36 ha (87.75 acres) of land, and is located in Pender County, on the North Carolina coastal plain, near the town of Currie (Figure 1). It is most easily accessed from either Highway 421 or Interstate 40 by exiting either of these highways onto NC 210, which goes directly to the park. This National Battlefield is under the jurisdiction of the U.S. National Park Service (NPS), and there is a Park Superintendent office on-site (http://www.nps.gov/mocr). The coordinates of the Park Visitor's Center are N34.45776, W78.10937. Presently the NPS maintains the Visitor's Center and museum, two interpretive trails, a reconstructed bridge over Moores Creek, a boardwalk over the creek and through the riparian swamp (Plate 1), remains of an historic causeway and earthworks, six monuments, and nine archeological features (Capps and Davis 1999).

Plate 1. Boardwalk over Moores Creek.

History of the Park

Moores Creek came to the public notice in 1776, when it was known as Widow Moores Creek, named after an early settler in the area. During the early stages of the American Revolution a force of Loyalists (1600 Scottish Highlanders under the command of Brigadier General Donald MacDonald) were marching from the interior of North Carolina to the coast, planning to rendezvous with British forces under the command of Lord Cornwallis. Their route took them toward the Moores Creek Bridge. However, a force of 150 Wilmington militiamen commanded by Colonel Alexander Lillington arrived at the bridge first (February 25), building earthworks on the east side of the bridge. The next day Colonel Richard Caswell arrived with 800 additional men and established earthworks on the west side of the creek (Capps and Davis 1999). Caswell subsequently abandoned these earthworks and moved his men to the east side of the creek,

removing planks from the bridge and greasing the remains of the bridge. The Highlanders arrived at the west side of the creek near dawn on February 27. The Highlanders had only 500 muskets among their troops, so they attempted a broadsword charge across the bridge remains, under the command of Captain Donald McLeod. When the Highlanders reached the far side of the creek the Patriots opened fire with muskets and two cannon, devastating the attackers and routing the charge. Thirty loyalists were killed and 40 wounded, and 850 more were captured in the following days. The patriots lost only one man dead and one wounded (Capps and Davis 1999). This brief battle was significant in that it reduced organized Loyalist opposition in North Carolina and boosted the morale of the patriots. Subsequent to the victory the North Carolina Provincial Assembly voted to instruct the colony's delegates to the Continental Congress to vote for independence from Great Britain (Capps and Davis 1999).

Creation of the Park

The site was granted to John Jones in 1791, who became the first private owner of the site. Public ownership in terms of a park did not materialize until 1897, when the State of North Carolina acquired 10 acres, including the remains of the earthworks on the east bank (Capps and Davis 1999). Administration of the park began in 1899 under a private group, the Moores Creek Monumental Association (MCMA), funded in part by state appropriations. The site was developed as a recreational facility for picnics and celebrations, with a caretaker-in-residence hired in 1907. Ten more acres were purchased in 1907, and the site soon consisted of two pavilions, two concession stands, two artesian wells, a keeper’s residence, a jail, a stable and fencing, several monuments, and two new latrines in 1922 (Capps and Davis 1999). In 1926 the State of North Carolina deeded the now 30-acre site to the United States, and the War Department took on the responsibility of managing Moores Creek National Military Park on August 23. It was managed as a commemorative park for recreational usage until 1933, when it was transferred to the National Park Service with the Department of the Interior (Capps and Davis 1999). In subsequent years the recreational nature of the site was slowly converted to an historical site, with attempts to reestablish some of the original earthworks. The name of the park was officially changed to Moores Creek National Battlefield in 1980. Land continued to be acquired, and the size of the park totaled 87.75 acres (217 ha) in 1997 (Figure 1). In 1992 the reconstruction of the historical bridge across Moores Creek was completed. The park was placed within the Fort Sumter Group in 1994, and in 1998 on-site residency for the Park Superintendent was created (Capps and Davis 1999). Visitation at Moores Creek has increased over the years from 8,000 in 1949 to 26,000 in 1956 to 49,000 in 2005.

Figure 1. Moores Creek National Battlefield.

Hydrologic Information

Moores Creek

Moores Creek is the only perennial water body within MOCR. This is a third order stream that is a tributary of the Black River, a fifth order stream that itself is a tributary of the sixth order Cape Fear River. MOCR lies about 2 miles (3.2 km) upstream of the Black River. Thus, the Moores Creek watershed (about 93 mi^2 or 241 km^2) total, of which 85 mi^2 (220 km^2) drain into the MOCR section of creek is part of the Black River watershed, which is part of the Cape Fear River watershed. The streams in this area typically have sandy bottoms interspersed with patches of organic matter, lack rapids or riffles; have a low vertical gradient and normally low flow. The water is darkly stained from organic leachate from riparian swamp vegetation; and pristine blackwater streams are characterized by low pH. At the Moores Creek bridge the creek is approximately 20 m (60 ft.) wide, with an average depth (as of July 31, 2006) of 1.5 m. Upstream of the bridge the creek presents a braided channel interspersed by riparian swamp forest characterized by cypress trees and their knees (Plate 2). Near the picnic area, about 500 m (1650 ft.) upstream of the bridge, the creek has deep areas that extend to 5 m (Wilson 1997). The substrata are a combination of silt, sand and gravel, with areas of clay, and some cobbles and boulders (Wilson 1997). There is extensive woody debris clearly visible from the banks throughout the creek in MOCR. Moores Creek is influenced by tides from the Cape Fear River, but is entirely freshwater.

Plate 2. The braided channel of Moores Creek interspersed with riparian swamp forest.

Wetlands in the Park

During the time of the battle a portion of the site was believed to be a type of wetland known as wet pine savanna. During the period that the site was managed by the MCMA some of this area was drained via an installed ditch and tile system and kept mowed as a partially wet meadow. In the 1990s several interested parties, including MOCR staff, the NPS Water Resources Division (WRD), the Nature Conservancy, the North Carolina Heritage Program and the US EPA Region IV made plans for restoring the artificially drained meadow to a wet pine savanna (Woods and Wagner 2001). The site lies just west of and downslope from the present Visitor's Center, about 120 m from Moores Creek (Plate 3). The drainage ditch had intercepted groundwater movement along a 75 m length of the hillside behind the Visitor's Center (Woods and Wagner 2001). However, the partially wet conditions in the meadow allowed for survival of populations of several rare species in wetter areas (Smith and Patti 1995; Woods and Wagner 2001), including pitcher plants (*Sarracenia* spp.), Carolina bog mint (*Macbridea caroliniana*), spring flowering goldenrod (*Solidago verna*) and Carolina Grass of Parnassus (*Parnassia caroliniana*).

Following a species inventory of the site (Smith and Patti 1995), partial restoration of the area's original hydrology was begun by blocking a drainage ditch to re-establish the hydrologic connection from the groundwater moving downslope from the hillside behind the Visitor's Center to the proposed restoration area. Also, drainage from the parking lot that formerly flowed into the ditch was redirected to bypass the meadow area and enter the drainage ditch beyond the savanna. This resulted in a statistically significant increase in water levels throughout most of the targeted meadow (Woods and Wagner 2001). The water levels in the restored area (totaling 4.5 acres or 11.1 ha) also now fluctuate in a manner similar to undisturbed wet pine savannas.

There is always standing water in the unplugged remains of the old drainage ditch (Plate 4). Water may or may not be present in the rest of the savanna depending on rainfall. Some restoration success has been seen botanically, as undesirable plants such as blackberry and sweetgum are declining, and the Carolina bogmint has one of the highest quality populations in the world (Woods and Wagner 2001). Some key savanna bunchgrasses were not recolonizing the site, however, and planting of nursery stock was suggested (Woods and Wagner 2001). Replanting is currently ongoing (Ann Childress, NPS, personal communication). Periodically, undesirable species (such as sweetgum and blackberry) are burned by hand to keep them from respreading throughout the wetland, and prescribed burns are undertaken occasionally as well (Ann Childress, NPS, personal communication).

Plate 3. Restored wet pine savanna behind the Visitor's Center at Moores Creek National Battlefield.

Hydrology Affecting the Park

Mean annual rainfall in Wilmington, N.C., 20 miles (32.4 km) from OCR, is 57 inches or 45 cm (Woods and Wagner 2001). MOCR is a low elevation area (<100 ft. above sea level) and the creek overflows its banks on a yearly basis, with longer lasting flooding during hurricanes and/or El Nino years (Ann Childress, NPS, personal communication). Maximum water surface elevations range from 12 ft mean sea level for the two year frequency storm to 32 ft. for the 100 year frequency storm (USACOE 2000). Velocities around the stream bank range from approximately 1.0 ft./sec for the two year frequency storm to 1.5 ft./sec for the 100 year frequency storm, while maximum discharges range from 1,150 CFS for the two year frequency storm to 5,940 CFS for the 100 year frequency storm (USACOE 2000). MOCR has been impacted by hurricanes with Hurricanes Fran in 1996 and Bonnie in 1998 downing approximately 100 trees, and flooding from Hurricane Floyd in 1999 was the most extreme since 1946 (Ann Childress, NPS, personal communication). Besides rainfall and surface water issues, groundwater is significant in that a number of springs and seeps exist in the park, in addition to the large savanna wetland.

Plate 4. Standing water in former drainage ditch in restored savanna, September 2006.

Ground Water Resources

The surficial water table at MOCR is approximately one meter below the surface, thus there is a potential for contamination of groundwater (NPS 2006). Although well water is used for drinking water in the park, it is drawn from 200 ft. (60 m) depth. This places the source of the drinking water as the PeeDee Aquifer. The water is treated on-site by chlorination. There are several artesian wells in the park as well. These are not used except for occasionally as cleaning water (Ann Childress, NPS, personal communication). Two wells were sampled by the authors of this report. Artesian well #1 is located about 30 m from the bridge at coordinates N34.45939, W78.11393 (Plate 5), and artesian well #2 is located in a mowed area of meadow behind the Visitor's Center near the restored savanna at N34.45776, W78.10937. A third well is located in the forested area between the savanna and the earthworks and several more are located between the park's water tower and Highway 210.

Plate 5. Artesian well located near the bridge over Moores Creek.

Biological Resources

Phytoplankton

There have been no published studies of the phytoplankton in Moores Creek, and no historical chlorophyll *a* data are available (NPS 1997). Some data on phytoplankton were collected as part of a series of nutrient addition bioassays in 1996 and 1997 from the Black River (Mallin et al. 2001a). The phytoplankton community was dominated by the class Chlorophyceae (green algae), especially *Selenastrum westii, S. minutum, Scenedesmus quadricauda, S. bijuga, S. acuminatus, Spermatozoopsis* sp., *Actinastrum Hantschii, Microspora* sp., *Coelastrum sphaericum, Oocyctis borgei* and *Dictyosphaerium pulchella.* Cryptomonads (Cryptophyceae) and pennate diatoms (Bacillariophyceae) were also abundant. Some dinoflagellates (Dinophyceae), euglenoids (Euglenophyceae) and Cyanobacteria (Cyanophyceae or blue-green algae) were present but in low numbers. Annual average phytoplankton biomass as chlorophyll *a* is typically low (1-2 μg/L) in nearby pristine Colly Creek (Mallin et al. 2001a) and the Black River at Highway 210 (Mallin et al. 2004). However, following a clearcut elsewhere in the Black River watershed (Goshen Swamp) a blackwater stream expressed blue-green algal blooms alternating with severe dissolved oxygen crashes for the following two years (Ensign and Mallin 2001).

Aquatic Macrophytes

There has been no recent survey of aquatic macrophytes in the creek. A brief visual survey in August 2006 by the authors did not note any significant coverage of creek waters by macrophytes.

Terrestrial Vegetation

Sieren (1982) performed a comprehensive survey of the vegetation of MOCR. Regarding the habitats, he noted that elevations ranged for 1.5 m to 10 m and a wide variety of habitats were represented including alluvial woods, old fields, ditches, sandy xeric woods, lawn, a pond, pine woods, mixed wooded slopes, creek banks, roadside ditches and meadows. As a result Sieren (1982) described the number of different vascular plant species found as relatively large for the size of MOCR; finding a total of 539 species representing 297 genera and 108 families. Sieren (1982) found two species of special concern: Spring Flowering Goldenrod *Solidago verna* and Venus' Fly Trap *Dionaea muscipula* Ellis.

Presently, the park is periodically planting longleaf pine in MOCR (Ann Childers, NPS, personal communication).

Rare and Threatened Plant Species

Three Rare and Endangered plant species have been recorded as appearing in the Park (Sieren 1982; Smith and Patti 1990; Woods and Wagner 2001). Carolina bog mint *Macbridea caroliniana* and spring flowering goldenrod *Solidago verna* are listed as species of special concern in North Carolina. Carolina Grass of Parnassus *Parnassia caroliniana* is considered endangered in North Carolina and is a federally listed species of concern (Smith and Patti 1990).

Invasive Plant Issues

Several plants, all terrestrial, are non-native and can be considered invasives in MOCR. These include *Wisteria* sp., *Mimosa* sp., Japanese Honeysuckle *Lonicera japonica* Thunb. and Privet *Ligustrum* sp. (Ann Childress, NPS, personal communication).

Benthic Macroinvertebrates

The Biological Assessment Unit (BAU) of the NCDWQ has performed two benthic macroinvertebrate surveys on Moores Creek (from NCDWQ BAU records). One was done in March 1998 near NC53 and the other in February 2003 at SR1128. The BAU considers the site(s) to be swamp water, and the sediments in both surveys consisted of 60% sand and 15-20% silt. During the two surveys a total of 64 taxa were found, 41 in 1998 and 38 in 2003. In the two surveys combined, the taxa were dominated by midge larvae (Diptera, Chironomidae) with 18 taxa, of which four were considered abundant. Mayfly larvae (Ephemeroptera) were represented by nine taxa (four abundant), crustaceans by six taxa (three abundant), caddisfly larvae (Trichoptera) by six taxa (none abundant), dragonfly and damselfly larvae (Odonata) by six taxa (none abundant) and other types of true fly larvae (Diptera) by five taxa (two abundant) especially blackfly larvae. Several other taxonomic groups were represented, none abundant (NCDWQ BAU records). The BAU uses several indices to classify the biological communities of stream waters (detailed in the BAU SOP – see NCDENR 2006)). The 1998 survey yielded an EPT (Ephemeroptera, Plecoptera, Trichoptera) richness of 11, an EPT abundance of 46, and a Biotic Index of 6.65; the 2003 survey yielded an EPT Richness of 10, an EPT Abundance of 36, and a Biotic Index of 6.89, slightly worse than the 1998 index (BAU records). The BAU combines the indices (total taxa richness, EPT richness and Biotic Index) in a formula considering habitat type to produce an overall site score, or bioclassification. Bioclassifications are Natural (unimpacted), Moderate (moderately stressed), and Severe (severely stressed). In both cases the bioclassification or stress category of Moores Creek was rated Moderate, which is considered by NC DWQ as Supporting aquatic life. A Severe rating would be considered Non-supporting, and the stream would then have to be targeted by NC DWQ for a pollutant TMDL (NCDWQ 2005).

Fish

The National Park Service sponsored fish sampling at two stations in MOCR on July 7, 2004. Coordinates of the two sites were N34.4598705, W78.1129698 and N34.4610629, W78.1121144. The report is still in preparation but an unverified species list is available (Table 3). A total of 12 taxa were found, seven at the first site and nine at the second site. For the two sites combined a total of 82 individuals were found, with the most common fish collected being lake chubsucker, bluegill and golden shiner (Table 3). No exotic species were collected, but Carolina darter is both a Federal and North Carolina species of concern.

Table 3. Fish species collected at MOCR during NPS project, July 7, 2004 (Johnston et al. 2006).

Species	Percentage of Community
Lake chubsucker *Erimyzon sucetta*	52.4
Bluegill *Lepomis macrochirus*	14.6
Golden shiner *Notemigonis crysoleucas*	7.3
Carolina darter *Etheostoma collis*	7.3
Eastern mosquitofish *Gambusia holbrooki*	6.1
Everglades pygmy sunfish *Elassoma evergladei*	3.7
Warmouth *Lepomis gulosus*	2.4
American eel *Anguilla rostrata*	1.2
Banded pygmy sunfish *Elassoma zonatum*	1.2
Sawcheek darter *Etheostoma serrifer*	1.2
Largemouth bass *Micropterus salmoides*	1.2
Black crappie *Pomoxis nigromaculatus*	1.2

The North Carolina Division of Marine Fisheries (NCDMF) does not sample Moores Creek, but annually samples the Black River (Fritz Rohde, NCDMF, personal communication). The most abundant species are listed in Table 4. The ten most abundant species comprised 71.1% of the total catch, 2000-2005. The taxa are a mix of freshwater and estuarine species; although that area of the Black River is freshwater it is strongly tidally influenced. No threatened or endangered species were found. Four introduced species were found; common carp, grass carp, blue catfish and flathead catfish. The flathead catfish is considered a problem, as it most likely was responsible for decimating native bullheads and has also impacted populations of sunfish and shad (Fritz Rohde, NCDMF, personal communication).

Table 4. Most abundant fish species at two stations in the Black River, 2000-2005 (data courtesy of Mr. Fritz Rohde, North Carolina Division of Marine Fisheries, Wilmington, N.C 2006).

Species	Percentage of Community
Hogchoker *Trinectes maculatus*	19.2
Bluegill *Lepomus machrochirus*	11.0
Threadfin shad *Dorosoma petenense*	7.8
Southern flounder *Paralichthys lethostigma*	7.6
Freshwater goby *Gobionellus shufeldti*	7.6
Bay anchovy *Anchoa mitchilli*	4.8
Blue catfish *Ictalurus furcatus*	4.7
Coastal shiner *Notropus petersoni*	3.1
Redear sunfish *Lepomis microlophus*	2.7
Spotfin mojarra *Eucinostomus argenteus*	2.6

Mussels

Presently there is considerable concern for the presence of endangered mussels in the waters of North Carolina. The North Carolina Wildlife Resources Commission conducted a survey of

Moores Creek within MOCR by SCUBA to look for mussels (Wilson 1997). No live mussels, shells, or shell fragments were found at MOCR. Commission biologists noted that freshwater mussels are not found in waters with pH values less than 6.0, and concluded that the low pH that naturally typifies these waters excludes mussels.

Reptiles and Amphibians

A total of 48 native reptiles and amphibian species have been documented at MOCR (Table 5), of which none are introduced species (Tuberville et al. 2005). There have been 25 species of reptiles noted, including 12 snakes (two poisonous, the cottonmouth *Agkistrodon piscivorus* (Plate 6) and the copperhead *A. contortrix*), seven lizards and six turtles (Tuberville et al. 2005). Of the 23 total amphibian species found 18 were frogs and toads and five were salamanders (Tuberville et al. 2005). Tuberville et al. (2005) noted that MOCR contained an unusually rich assemblage of amphibians and reptiles due to the high diversity of habitat types.

Plate 6. Water moccasin at edge of restored savanna, September 2006.

Table 5. Amphibian and reptile taxa verified from MOCR (from Tuberville et al. 2005).

Amphibians
Southern cricket frog *Acris gryllus*
Southern toad *Bufo terrestris*
Fowler's toad *Bufo fowleri*
Eastern narrowmouth toad *Gastrophyne carolinensis*
Gray treefrog *Hyla chrysoscelis*
Green treefrog *Hyla cinerea*
Pine woods treefrog *Hyla femoralis*
Barking treefrog *Hyla gratiosa*
Squirrel treefrog *Hyla squirella*
Spring peeper *Pseudacris crucifer*
Little grass frog *Psuedacris ocularis*
Ornate chorus frog *Psuedacris ornate*
American bullfrog *Rana catesbeiana*
Green frog *Rana clamitans*
Pickerel frog *Rana palustris*
Southern leopard frog *Rana sphenocephala*
Eastern spadefoot *Scaphiopus holbrookii*
Marbled salamander *Ambystoma opacum*
Twotoed amphiuma *Amphiuma means*
Slimy salamander *Plethodon glutinosus*
Lesser siren *Siren intermedia*
Greater siren *Siren lacertian*
Reptiles
Striped mud turtle *Kinosternon baurii*
Eastern mud turtle *Kinosternon subrubrum*
River cooter *Pseudemys concinna*
Stinkpot *Sternotherus odoratus*
Eastern box turtle *Terrapene carolina*
Pond slider *Trachymys scripta*
Green anole *Anolis carolinensis*
Sixlined racerunner *Cnemidophorus sexlineatus*
Common fivelined skink *Eumeces fasciatus*
Southeastern fivelined skink *Eumeces inexpectatus*
Broadheaded skink *Eumeces laticeps*
Eastern fence lizard *Sceleporus undulates*
Little brown skink *Scincella lateralis*
Copperhead *Agkistrodon contortix*
Cottonmouth *Agkistrodon piscivorus*

Mammals

Dr. David Webster of the University of North Carolina at Wilmington has been retained by the NPS to perform a mammal assessment of MOCR and other parks. His report is still in preparation, but he has supplied the authors of this report with the following species list (Table 6). Part A contains mammals for which there is solid evidence of their presence at MOCR (voucher specimens, etc.) and notations on their abundance. Part B is a list of mammals that various individuals have claimed to see over the years in the area of the park, but for which there is no evidence.

Table 6. Mammal species known to be and potentially present at MOCR (*Dr. W. D. Webster, UNC Wilmington Department of Biology, personal communication*).

Species	Status
Species Present in Park	
Virginia opossum *Didelphis virginiana virginiana*	ABUNDANT
Southeastern shrew *Sorex longirostris fisheri*	COMMON
Least shrew *Cyptotis parva parva*	COMMON
Northern short-tailed shrew *Blarina brevicauda knoxjonesi*	ABUNDANT
Eastern mole *Scalopus aquaticus howelli*	ABUNDANT
Star-nosed mole *Condylura cristata parva*	UNCOMMON
Eastern cottontail *Sylvilagus floridanus mallurus*	COMMON
Marsh rabbit *Sylvilagus palustris palustris*	UNCOMMON
Eastern gray squirrel *Sciurus carolinensis carolinensis*	ABUNDANT
Southern flying squirrel *Glaucomys volans volans*	COMMON
American beaver *Castor canadensis carolinensis*	UNCOMMON
Marsh rice rat *Oryzomys palustris palustris*	COMMON
Eastern harvest mouse *Reithrodontomys humulis humulis*	COMMON
Cotton mouse *Peromyscus gossypinus gossypinus*	ABUNDANT
White-footed mouse *Peromyscus leucopus leucopus*	ABUNDANT
Golden mouse *Ochrotomys nuttalli nuttalli*	ABUNDANT
Hispid cotton rat *Sigmodon hispidus hispidus*	COMMON
Woodland vole *Microtus pinetorum pinetorum*	COMMON
Norway rat *Rattus norvegicus norvegicus*	RARE
House mouse *Mus musculus domesticus*	UNCOMMON
Coyote *Canis latrans frustror*	UNCOMMON
Red fox *Vulpes vulpes fulva*	RARE
Gray fox *Urocyon cinereoargenteus cinereoargenteus*	COMMON
Northern raccoon *Procyon lotor lotor*	ABUNDANT
Long-tailed weasel *Mustela frenata olivacea*	RARE
American mink *Mustela vison mink*	UNCOMMON
Northern river otter *Lontra canadensis lataxina*	UNCOMMON
Domestic cat *Felis catus*	COMMON
Bobcat *Lynx rufus carolinensis*	UNCOMMON
White-tailed deer *Odocoileus virginianus virginianus*	ABUNDANT
Species Potentially Present in Park	
Southern short-tailed shrew *Blarina carolinensis carolinensis*	NO EVIDENCE
Eastern fox squirrel *Sciurus niger niger*	NO EVIDENCE
Eastern woodrat *Neotoma floridana floridana*	NO EVIDENCE
Muskrat *Ondatra zibethicus macrodon*	NO EVIDENCE
Black rat *Rattus rattus* sspp.	NO EVIDENCE
Red wolf *Canis rufus floridanus*	EXTIRPATED, NO EVIDENCE
Black bear *Ursus americanus americanus*	EXTIRPATED, NO EVIDENCE
Striped skunk *Mephitis mephitis elongata*	NO EVIDENCE
Mountain lion *Puma concolor cougar*	EXTIRPATED, NO EVIDENCE

Birds

Numerous birds have been observed at MOCR. A recent checklist notes several that extensively utilize the aquatic habitat (NPS 2004). These include the Great Blue Heron *Ardea herodias*, Green-Backed Heron *Butorides virescens*, Great Egret *Casmerodius albus*, White Ibis *Eudocimus albus*, Wood Duck *Aix sponsa*, Black Duck *Anas rubripes*, Canada Goose *Branta canadensis*, Belted Kingfisher *Megaceryle alcyon*, and Red-Winged Blackbird *Agelaius phoeniceus*. Caution should be used when utilizing the species list, as some species may have

been observed only rarely and should not be considered common park residents or visitors (Walker Golder, Audubon Society, personal communication).

Rare and Threatened Animal Species

The American alligator *Alligator mississippiensis* (Threatened for both State and Federal status) is commonly seen in the nearby Black River by UNCW researchers during summer sampling. However, park personnel have not reported seeing alligators in MOCR, nor have other researchers (Tuberville et al. 2005). The Black River contains several rare mussels (NCDENR 2005), but as mentioned above, mussels do not exist in MOCR because of the low pH of the creek. The Black River contains two rare fish species (NCDENR 2005) - the broadtail madtom (*Noturus* sp.) and the Santee chub (*Cyprinella zanema*) but these were not found in Moores Creek during the NPS 2004 fish survey. As mentioned, in 2004 the Carolina darter, a State and Federally listed species of concern was found in Moores Creek in the park.

Invasive Animal Species

According to park personnel, invasive animal species, terrestrial or aquatic, have not been noted in MOCR.

Assessment of Park Water Resources

Sources of pollutants

Point Source Pollution

Moores Creek lies within Subbasin 03-06-20 in the Cape Fear River watershed (NCDENR 2005). There are no NPDES dischargers in the park or elsewhere in the Moores Creek drainage basin (NCDENR 2005). There are two minor NPDES discharges elsewhere in subbasin 03-03-20 with a combined permitted flow of 0.82 MGD.

Non-point Source Pollution

There are 18 registered swine operations (concentrated animal feeding operations, or CAFOs) in Subbasin 03-06-20; thus, concentrated livestock waste runoff is a potential water quality issue. There are 10 swine CAFOs in the Moores Creek watershed, and all are located upstream of MOCR (Figure 2). Permitted total capacity for these swine CAFOs is 53,172 animals (Appendix A). Runoff from these facilities or an accident releasing waste from these facilities has the potential to degrade park water quality. Cultivated cropland covers approximately 18% of the subbasin (NCDENR 2005), so runoff from these farms is a potential issue as well.

Impervious surface coverage, which concentrates pollutants and increases stormwater runoff pollution, is presently very low in this subbasin. As of 2000, the human population was approximately 14,400 – however, the population is expected to grow by 55,000 people in counties with portions of or all of their areas in Subbasin 04-06-20 by 2020 (NCDENR 2005). Locally, there is a parking lot within the park near the picnic area and runoff from this lot directly enters Moores Creek untreated, and may be a problem at times (Plate 7). Typically a parking lot accumulates various pollutants (fecal coliform bacteria, nutrients, petrocarbons from motor vehicles, any airborne pollutants, etc.) between rains. During and following a rain these pollutants are conveyed off impervious parking lots into the nearest water body. Thus Moores Creek would likely be impacted by such pollution after rain events, with petrocarbon pollution inputs being most concentrated during periods of heaviest parking lot usage. When stream discharge is lowest, such as in summer, such non-point source pollution will be most concentrated in the receiving water body. There are five septic systems in use in the park that may be sources of nutrients to nearby wells and surface waters.

Plate 7. Parking lot near picnic area. Drainage from the back of the lot flows directly into Moores Creek.

Atmospheric deposition of nitrogen can cause increases in coastal phytoplankton biomass (Paerl et al. 1990), and ammonia from CAFOs located as far as 80 km upwind can be deposited in fresh, estuarine and coastal waters (Walker et al. 2000). Several of the creeks to the north, west, and east of Moores Creek have numerous swine CAFOS in their watersheds (Mallin et al. 2001b; Mallin and Cahoon 2003) as well as turkeys and chickens (N.C. Department of Agriculture records). Thus, there is a distinct possibility for atmospheric ammonia deposition to impact Moores Creek in the park. A number of locations in the Cape Fear and Neuse River basins downwind of CAFO concentrations have experienced ammonium increases in recent years (Burkholder et al. 2006). Loading of ammonium to blackwater streams can lead to increased BOD from increased algal growth (Mallin et al. 2001a; 2004) or it can directly increase biochemical oxygen demand (nitrogenous BOD).

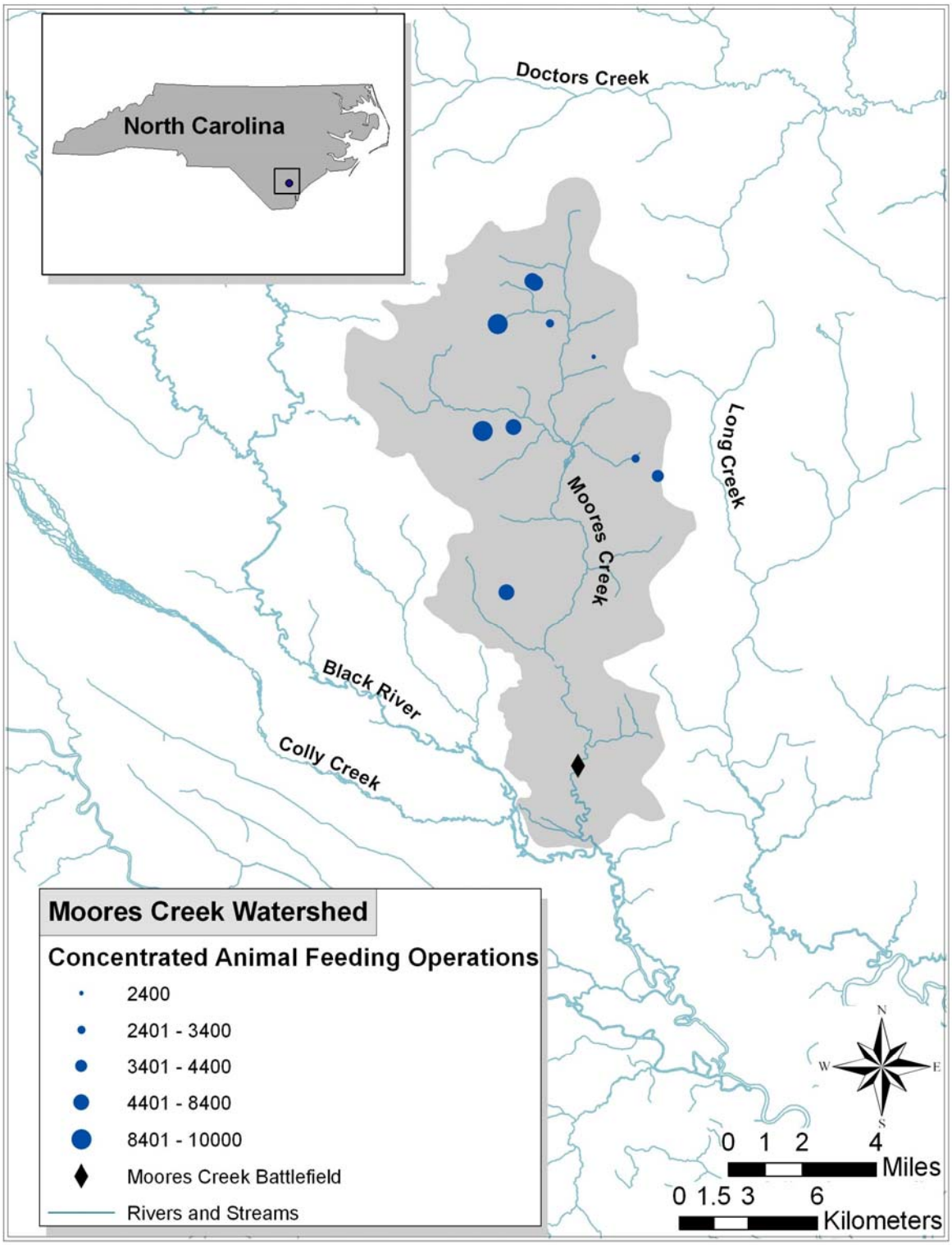

Figure 2. Location of swine CAFOs within the Moores Creek watershed.

Assessment of Biological Resources with Respect to Water Quality (Both Surface and Groundwater)

Water Quality Standards

The State of North Carolina has ambient water quality standards (NCDENR 1999) for common water quality parameters including dissolved oxygen (5 mg/L, for swamp water 4 mg/L), turbidity (50 NTU for freshwater, 25 NTU for brackish and salt water), and chlorophyll *a* (40 μg/L). Microbiological water quality standards are discussed in a subsequent section. North Carolina also has standards for metals and various toxic compounds (NCDENR 1999). North Carolina does not have ambient nutrient concentration srtandards for receiving waters. There is an Environmental Protection Agency standard of 10 mg/L for nitrate-N for drinking water, to protect infants from potentially fatal methemoglobinemia (blue-baby syndrome).

Surface Water Quality

No active North Carolina Division of Water Quality (NCDWQ) ambient water quality monitoring stations are located within the park boundaries; however, there are historical records from a station located within the park (NPS 1997). There is an active ongoing program run by the University of North Carolina Wilmington (the Lower Cape Fear River Program) analyzing water samples from nearby Colly Creek and the Black River; this sampling program is required by NC DWQ and the data are supplied to that organization.

Water Quality in Moores Creek. Data generated by NC DWQ are available from 1985-1988 (Table 7). The samples were collected at the old Highway 210 crossing in MOCR at coordinates N34.460004, W78.112227. The number of observations varied considerably depending upon parameter, with the fewest (7) for ammonia, nitrate, and TKN and the most (28) for temperature, dissolved oxygen, and specific conductance (see NPS 1997 for details). The creek was characterized by low specific conductance, low turbidity, and low pH, which is typical of lowland blackwater streams (Meyer 1990; Mallin et al. 2001a; 2004). Dissolved oxygen concentrations fell below the NC swamp water standard of 4.0 mg/L on 21% of the occasions sampled (NPS 1997). Low dissolved oxygen will be discussed later under Ecosystem Effects. Average BOD5 was typical of streams in the Black River basin (about 1.0 mg/L - Mallin et al. 2006) but on occasion exceeded 2.0 mg/L. Nutrient concentrations were low during the period sampled (Table 7), lower than concentrations from 2005 sampled in nearby pristine Colly Creek and the fifth order Black River (Tables 8 and 9). NC DWQ collected no chlorophyll *a* data during that sampling period, however. Fecal coliform data collected on 22 occasions during that period exceeded the NC standard of 200 CFU/100 mL NC standard on two occasions, indicating that some polluting source was periodically operational. The mean, standard deviation and range of fecal coliform counts from Moores Creek in that period were all higher than those from Colly Creek and the Black River in 2005 (Tables 8 and 9). On 11 occasions during 1985-1988 water column metals (arsenic, cadmium, chromium, copper, lead, nickel and zinc) were analyzed, but none exceeded water quality standards (NPS 1997).

A set of *in situ* observations (6-8) was collected by the NPS Water Resources Division at the boardwalk over the creek in MOCR (coordinates N34.459365, W78.113254) during spring of 1996, using a Hydrolab (Table 10). Specific conductance and pH were low, similar to previous measurements. However, turbidity was unusually high for a blackwater stream (median = 27.2 NTU), with one of the measurements exceeding the NC freshwater turbidity standard of 50 NTU.

Turbidity in unimpacted coastal blackwater streams is typically much lower (Ensign and Mallin 2001; Mallin et al. 2001a). Streamflow in Moores Creek appeared to have been high during this period (Table 10), partially explaining the high turbidity. Upstream land disturbing activity may have been ultimately responsible for the elevated turbidity.

UNC Wilmington researchers collected water quality data on Moores Creek from the bridge in MOCR (coordinates N34.45893, W78.11359), on July 31 and September 13, 2006. Specific conductance, pH, and turbidity were all low (Table 11). Dissolved oxygen levels were relatively low (5.2 mg/L in July and 4.7 mg/L in September) but not at levels stressful to the native fauna. Fecal coliform bacteria counts were below the NC standard of 200 CFU/100 mL. On both occasions total nitrogen and total phosphorus concentrations were low to moderate compared with blackwater streams in the area (Mallin et al. 2001a; 2004), and inorganic N and P were low (Table 11). In September we tested the savanna for nutrient concentrations, and total nitrogen was double that of the creek (1.379 mg-N/L) and total phosphorus was similar to the creek (0.017 mg-N/L). The nitrogen in the savanna was primarily organic as nitrate and ammonium were 0.018 mg-N/L and 0.082 mg-N/L, respectively. Orthophosphate in the savanna was low, 0.005 mg-P/L.

Table 7. Moores Creek water quality, 1/85 - 6/88, collected at the old Highway 210 crossing. Data presented as mean ± standard deviation / range / median (NCDWQ data summarized in NPS 1997).

Parameter	n	Average Value (+/- SD)	Min	Max	Median
Conductivity (µmho/cm)	28	59.4±15.0	41	110	57.5
pH	24	5.5±0.4	4.9	6.2	5.5
Turbidity (NTU)	13	3.1±1.6	1.5	6.5	2.3
Dissolved oxygen (mg/L)	28	5.9±2.7	1.7	11.6	5.1
BOD5 (mg/L)	26	1.1±0.5	0.3	2.5	1.2
Nitrate-N (mg-N/L)	7	0.06±0.03	0.02	0.10	0.05
Ammonium-N (mg-N/L)	7	0.04±0.04	0.01	0.11	0.02
Total nitrogen (mg-N/L)	7	0.46±0.92	0.32	0.60	0.45
Total phosphorus (mg-P/L)	7	0.033±0.011	0.02	0.05	0.03
Fecal coliform bacteria (CFU/100 mL)	22	94±105	5	410	70

Note: Orthophosphate-P (n = 7) was measured but all samples showed below detection limit of 0.01 mg/L.

Table 8. Recent Colly Creek water quality, January – December 2005. Data presented as mean ± standard deviation / range / median, n = 12 (Mallin et al. 2005a; 2006).

Parameter	Average Value (+/- SD)	Min	Max	Median
Conductivity (µmho/cm)	70.0±0.0	**60**	**70**	**70.0**
pH	3.8±0.3	**3.2**	**4.0**	**3.8**
Turbidity (NTU)	1±1	**0**	**3**	**1**
Dissolved oxygen (mg/L)	6.8±1.9	**3.6**	**10**	**6.8**
BOD5 (mg/L)	1.2±0.6[1]	**0.3**	**2.3**	**1.1**
Nitrate-N (mg-N/L)	0.058±0.140	**0.005**	**0.520**	**0.015**
Ammonium-N (mg-N/L)	0.046±0.040	**0.010**	**0.120**	**0.025**
Total nitrogen (mg-N/L)	1.172±0.324	**0.660**	**1.630**	**1.135**
Total phosphorus (mg-P/L)	0.073±0.104	**0.005**	**0.400**	**0.035**
Fecal coliform bacteria (CFU/100 mL)	35±23	**5**	**84**	**27, 28[2]**

[1]From 2003.
[2]Geometric Mean.

Note: Phosphate means were 0.011±0.011, range 0.0-0.040; 0.025±0.13, range 0.010-0.050 mg-P/L.

Table 9. Recent Black Creek water quality, January – December 2005. Data presented as mean ± standard deviation / range / median, n = 12 (Mallin et al. 2005a; 2006).

Parameter	Average Value (+/- SD)	Min	Max	Median
Conductivity (µmho/cm)	90.0±0.10	60.0	100.0	90.0
pH	5.5±0.4	5.2	6.3	6.1
Turbidity (NTU)	4±1	2	6	4
Dissolved oxygen (mg/L)	7.1±2.3	4.6	10.6	6.2
BOD5 (mg/L)	1.0±0.2	0.5	1.3	1.0
Nitrate-N (mg-N/L)	0.152±0.120	0.040	0.500	0.115
Ammonium-N (mg-N/L)	0.022±0.130	0.010	0.050	0.020
Total nitrogen (mg-N/L)	0.968±0.289	0.620	1.500	0.910
Total phosphorus (mg-P/L)	0.068±0.043	0.010	0.170	0.065
Fecal coliform bacteria (CFU/100 mL)	56±27	9	95	52, 48[1]

[1]Geometric Mean.

Note: Phosphate means were 0.011±0.011, range 0.0-0.040; 0.025±0.13, range 0.010-0.050 mg-P/L.

Table 10. Moores Creek water quality, 3/96-7/96, collected by NPS WRD at boardwalk over creek. Data presented as mean ± standard deviation / range / median (NCDWQ summarized from NPS 1997).

Parameter	n	Average Value (+/- SD)	Min	Max	Median
Conductivity (µmho/cm)	8	50.7±2	48	55	50.0
pH	8	5.8±0.8	5.0	7.2	5.6
Turbidity (NTU)	8	31.2±21.4	12.4	74.4	27.2
Dissolved oxygen (mg/L)	6	10.2±3.0	6.4	13.4	11.2
Stream Discharge (CFS)	6	75.7±23.8	46	117	77.0

Note: measurements were collected by a Hydrolab multiparameter unit.

Table 11. Recent Moores Creek water quality in MOCR, collected by the authors on July 31 and September 13, 2006.

Parameter	7/31/2006	9/13/2006
Water temperature (^{o}C)	26.1	21.3
Conductivity (µmho/cm)	43	48
pH	5.8	5.7
Turbidity (NTU)	5	4
Dissolved oxygen (mg/L)	5.2	4.7
Nitrate-N (mg-N/L)	0.045	0.047
Ammonium-N (mg-N/L)	0.024	0.018
Total Nitrogen (mg-N/L)	0.663	0.751
Orthophosphate (mg-P/L)	0.003	0.005
Total phosphorus (mgPN/L)	0.019	0.014
Chlorophyll *a* (µg/L)	1.0	1.7
Fecal coliform bacteria (CFU/100 mL)	69	35

Water Quality in Colly Creek. Colly Creek is a nearby third order blackwater stream that is considered to be nearly pristine. It drains into the Black River about 4.8 km from where Moores Creek enters the river. Its watershed contains only 6 CAFOs, and has over 55% wetlands coverage (Mallin et al. 2001b). Thus, this stream provides a good "near natural" baseline against which to compare other more impacted area steams, including Moores Creek (which has less wetlands coverage and more CAFOs than Colly Creek). The Lower Cape Fear River Program (LCFRP) based at the University of North Carolina Wilmington Center for Marine Science has been sampling Colly Creek monthly since 1996 at the Highway 53 bridge, coordinates N34.46500, W78.26553). Data for 2005 (Table 8) are typical from this stream. It, like Moores Creek, is characterized by low specific conductance, low turbidity, and very low pH (mean = 3.8). The low pH is entirely natural, however. Dissolved oxygen on occasion will drop below 4.0 mg/L, but BOD5 averages approximately 1.0 mg/L, typical of blackwater streams in the Black River drainage (Mallin et al. 2006). Inorganic nutrient concentrations are low (Table 8) and the majority of the TN and TP are organic N and P. It is notable that TN and TP of this nearly pristine stream are considerably larger than that of Moores Creek in the 1985-1988 periods (Table 7). The LCFRP regularly measures chlorophyll *a* in Colly Creek, and it averages about 2.0 µg/L (Mallin et al. 2006). Fecal coliform bacteria counts in this creek are usually well below the state standard (Table 8). There are several publications containing further in formation on Colly Creek water quality (Mallin et al. 2001b; 2002; 2004; 2006).

Water Quality in the Black River. Moores Creek is in the Black River Watershed and flows into this river 3.2 km downstream from MOCR. The State of North Carolina considers the Black River to be an Outstanding Resources Water (NCDENR 2005). The watershed is largely rural with a low human population (NCDENR 2005). However, there are approximately 5,000,000 head of swine housed in CAFOs in the Cape Fear River basin, largely in the Black and Northeast Cape Fear River basins, presenting a pollution threat to its waters that may occur from groundwater inputs, surface runoff, or airborne deposition (Mallin and Cahoon 2003).

The UNC Wilmington LCFRP has sampled the Black River at the Highway 210 bridge (N34.43138, W78.14462) monthly since June 1995. The Black River can be characterized as having low specific conductance, low turbidity, and low pH, although pH is considerably higher than in Colly Creek (Table 9). Dissolved oxygen is often between 4.0 and 5.0 mg/L in summer, but rarely drops below 4.0 mg/l under normal conditions. However, following hurricanes or anthropogenic waste spills DO has dropped to severely hypoxic levels, leading to fish kills (see subsequent Ecosystem Effects section for more on this). Normally BOD5 averages 1.0 mg/L, typical of this river's tributaries (Mallin et al. 2006). Inorganic nutrient concentrations are low, and most of the TN and TP are in the form of organic nutrients (Table 9). Fecal coliform bacteria counts are generally low, and very seldom exceed the state standard (Mallin et al. 2006). A number of publications (Mallin et al. 2001a; 2002; 2004; 2006; NCDENR 2005) contain water quality information about the Black River.

Groundwater Quality

In July and September 2006 UNCW researchers collected water samples from artesian wells #1 and #2. The data show that the water chemistry is very different from the creek water chemistry, within 30 m from the well (Table 12). In contrast to the creek, the well water is characterized by high pH (8.6 or higher) and conductivity (> 730 μmho/cm), with measurable salinity (0.35 psu or more – Table 12). The well water was several degrees cooler than the creek water as well (Table 12). Nitrogen was present almost entirely as ammonium, and phosphorus was almost entirely in the form of orthophosphate. The July ammonium concentration of 0.30 mg-N/L can be considered somewhat elevated.

The nitrogen concentrations in the two wells were similar to each other on both occasions sampled in 2006. However, total phosphorus in well #2 was higher than in well #1 on both occasions (Table 12). Also, the physical conditions of the well water differed in September 2006; well #1 had water that was both cooler and contained more dissolved oxygen than well #2 (Table 12).

Nitrate concentrations in the well water were negligible on the two occasions the wells were sampled in summer 2006 (Table 6), with nitrogen primarily in the form of ammonium (Table 12). Fecal coliform bacteria contamination was not detected in the two summer 2006 samples

Table 12. Recent Moores Creek artesian well water quality, July 31 and September 13, 2006 [ND – No Data Available].

	July 31, 2006		September 13, 2006	
Parameter	**Well 1**	**Well 2**	**Well 1**	**Well 2**
Water temperature (^{o}C)	19.5	ND	19.0	24.3
Conductivity (µmho/cm)	470	ND	720	757
Salinity (psu)	0.36	ND	0.35	0.7
pH	8.6	ND	8.8	9.2
Turbidity (NTU)	0	ND	1	1
Dissolved oxygen (mg/L)	2.5	ND	2.9	1.3
Nitrate-N (mg-N/L)	<0.005	<0.005	ND	ND
Ammonium-N (mg-N/L)	0.308	0.308	0.262	0.252
Total nitrogen (mg-N/L)	0.308	0.311	0.343	0.292
Orthophosphate (mg-P/L)	0.018	0.038	ND	ND
Total phosphorus (mgPN/L)	0.018	0.036	0.005	0.024
Fecal coliform bacteria (CFU/100 mL)	0	0	0	0

Ecosystem Effects

Water quality issues that could affect the flora and fauna of park waters include natural or anthropogenically caused hypoxia, excessive nutrient loading leading to eutrophic conditions (and subsequent hypoxia) and toxic compounds in the surface or groundwaters that could affect plant survival or growth.

Hypoxia and Anoxia. Blackwater streams in coastal lowland areas are often afflicted with hypoxia (< 4.0 mg/L DO) during summer. This is because these streams have abundant sediment bacteria populations, are fed by drainage from swamp water already low in dissolved oxygen, and have high organic carbon (principally dissolved) loads that exert a biochemical oxygen demand on the water (Meyer 1992). Because these streams already have low summer DO levels, they are especially sensitive to additional anthropogenic inputs of BOD that can drive DO concentrations even further stressful levels (Mallin et al. 2004). Since these streams are often shallow, they do not stratify or provide a surface refuge of elevated DO. Stressful hypoxic conditions occur most frequently in summer when elevated water temperatures hold less dissolved oxygen. An analysis of marine benthos demonstrated that DO concentrations < 2.0 mg/L are capable of causing death of sessile marine organisms and displacement of mobile species (Diaz and Rosenberg 1995).

A series of studies on nearby blackwater streams, including Colly Creek and the Black River, have demonstrated that, contrary to outdated dogma, shallow blackwater streams can host algal blooms provided nutrients and sufficient light are available (Mallin et al. 2001a, 2002, 2004). These experiments demonstrated that phytoplankton growth was stimulated by nitrogen, but not phosphorus additions, and that bacterial growth was stimulated by phosphorus, especially organic phosphorus. Significantly increased BOD occurred due to the indirect photosynthetic pathway of nitrogen inputs stimulating algal growth, which in turn dies and becomes organic matter, stimulating bacterial growth and BOD. Phosphorus inputs increased BOD by directly stimulating bacterial growth (heterotrophs). Thus, Moores Creek, a blackwater stream, may be subject to periods of hypoxia due to nutrient inputs, either through surface runoff, groundwater inputs, or airborne inputs. There is a potential for toxic blue-green algal blooms or nuisance algal blooms of those or other taxa groups to occur in the park. These could occur if there is an

upstream clearcut that will increase nutrient inputs to the stream and allow for greater illumination of the creek for phytoplankton photosynthesis. This scenario occurred in the Goshen Swamp, a blackwater stream in the Black River basin (Ensign and Mallin 2001). However, no organization has previously collected chlorophyll *a* or algal species data from MOCR and this represents an important data gap.

A survey of fish kill reports (1997-2004) assembled by NCDWQ showed that fish kills have not been reported from Moores Creek specifically, but a number of fish kills have occurred in the Black River basin (http://www.esb.enr.state.nc.us/Fishkill/fishkillmain.htm). These kills have primarily been caused by DO depletion from natural or anthropogenic reasons. In June 1996 a kill of 6,000+ fish occurred in Great Coharie Creek and the Black River following an accidental discharge of organic waste from a cattle farm and subsequent DO depletion. In September of that year fish kills were reported in Six Runs Creek and Great Coharie Creek following Hurricane Fran. In 1997 a kill of 3,000+ fish occurred in Great Coharie Creek at Singletary Lake, with no official cause attributed to it. In 1998 a small kill occurred in Great Coharie Creek following Hurricane Bonnie, and subsequent hypoxia from the storm. In 1999 a small kill was reported from the South River in August due to low DO conditions. Major fish kills were not reported from the area between 2000-2004.

In late July 2006 dissolved oxygen readings were taken by the authors of this report at mid-day in Moores Creek from the bridge (Table 11). Concentration was 5.2 mg/L (65% saturation) during a period of high flow and relatively high water temperatures (26.1 ^{o}C). In September dissolved oxygen concentrations had decreased to 4.7 mg/L (Table 11).

Sediment Toxicity and Quality. Exposure to toxicants such as metals, pesticides and other organic contaminants can cause toxicity to benthic organisms and adversely impact living habitat of invertebrates and fish. There is presently no sediment chemical quality information available for Moores Creek, and this represents another important data gap.

Groundwater Toxicity. There were previously a number of storage fuel tanks onsite that were removed in the 1980s. Assessments were done of the nearby soils and groundwater by NCDWQ, and no removal of contaminated soil was deemed necessary (Ann Childress, NPS, personal communication).

Human Health Issues

Waterborne factors potentially influencing human health can be assessed by several metrics. These metrics include water contact safety in terms of either fecal coliform bacterial or enterococci counts, and water contact or aerosol safety in terms of toxic algal blooms, and finfish or shellfish toxicant body burdens. Human contact with toxic or otherwise dangerous chemicals in surface or groundwaters is another potential issue.

Microbial Pathogens and Human Contact. Humans can contract illness through contact with microbially contaminated waters while swimming, wading, or working in contaminated water if pathogenic viruses, bacteria or protozoans enter the individual through the mouth, nose, eyes, or open wounds. The North Carolina freshwater standard for human contact is 200 CFU/100 ml of fecal coliform bacteria (NCDENR 1999). As indicated in Table 5, the creek periodically has had fecal coliform bacterial counts that exceed this standard. The sources may be agriculture or land

disturbing activity upstream of the park, but parking lot runoff within the park may contribute as well.

There are five septic tanks in the park, which are potential sources of fecal pathogens. However, all are well away from the creek and should pose no threat to the creek water quality. Since the drinking well water is drawn from over 60 m depth in the Pee Dee Aquifer, these septic systems pose no threat to the well water (which is chlorinated regardless).

Exposure to Toxic Algae. Humans can also be adversely affected by skin contact with water containing toxic algae or breathing aerosols containing toxins from such algae. In freshwater systems, a number of cyanobacterial (blue-green algal) species contain toxins injurious to humans (Burkholder 2002). There is presently no information available on the presence or absence of algal blooms, including toxic blooms, in the waters of MOCR. As mentioned above, an algal bloom in the creek in MOCR would likely occur following an upstream clearcut or major land disturbance.

Fish Toxicant Body Burdens. Eating fish with body burdens high in contaminants can be a human health hazard. Several fish species in this region have high mercury body burdens and consuming more than four meals per month of these fish is considered hazardous (see the following section for details on fish consumption warnings). The author's laboratory (the UNC Wilmington Aquatic Ecology Laboratory) collected clams and bottom feeding fish (bowfin) samples from Six Runs Creek, a tributary of the Black River located 55 km from Moores Creek, for toxicant analysis (Mallin et al. 2005b). The results showed that fish and clam tissue concentrations of arsenic, cadmium, mercury, selenium, PCBs and the pesticide Dieldrin were above levels considered safe for human consumption by the U.S. EPA and the N.C. Health Director's Office. Thus, it is possible, but untested, that fish in Moores Creek may also have high body burdens of these toxicants.

List of impairments (State and Federal listings)

Subbasin 03-06-20 has no impaired waters in terms of the aquatic life category (NCDENR 2005). Moores Creek from source to Buxton Branch (13 miles) is rated as Supporting aquatic life, because of a Moderate benthic community rating at site BB244 (NCDENR 2005).

Moores Creek from Buxton Branch to the Black River (9.9 miles) in Subbasin 03-06-20 is Impaired by a fish consumption advisory for bowfin, catfish, chain pickerel, largemouth bass and warmouth based on mercury (NCDENR 2005). The fish consumption advisory in coastal North Carolina waters is described in (http://www.schs.state.nc.us/epi/fish/contaminants.html). There is a segment similarly Impaired for fish consumption on the Black River between the subbasin boundary and the Cape Fear River (40.5 miles or 65.6 km).

List of water bodies with undocumented conditions/status

A large percentage of the major streams in subbasin 03-06-20 are Not Rated for aquatic life because of naturally occurring conditions that cause the waters to violate NC standards (NCDENR 2005). These include 40.5 miles of the Black River (low DO) and 34.9 miles of Colly Creek (low pH). Lake Drain and Singletary Lake in subbasin 03-06-20 are also Not Rated for aquatic life.

Other areas of concern

Coastal Plain Development Trends

Population

As mentioned earlier, in 2000 the human population of Subbasin 03-06-20 was approximately 14,400 with a density of 42 persons/mi^2 – however, the population is expected to grow by 55,000 people in counties with portions of or all of their areas in this subbasin by 2020 (NCDENR 2005). Population growth in Pender County is expected to increase by 36% from 2000-2020, by 30% in nearby Sampson County, and by 16% in nearby Bladen County (NCDENR 2005). While the Black River watershed is presently only about 4% urbanized (NCDENR 2005), increasing populations will increase land disturbance and water pollution, and increase the sources of bacterial, nutrient, and urban toxicant contamination.

Land Use

Land use affecting Moores Creek includes both the immediate area within MOCR, and the watershed upstream that drains into MOCR. The Moores Creek watershed contains a total of 72,315.3 ha - within that area lies 16,316.5 ha of wetlands. Thus, 22.6% of the watershed is covered in wetlands. This is good in that these wetlands serve as a buffer to reduce overland runoff pollution to the creek. The challenge is to keep these wetlands from being drained and developed.

MOCR Land Use Issues. One potential concern is stormwater runoff from impervious surfaces, leading to increased loading of pollutants into Moores Creek. Pollutants that are often associated with stormwater runoff include fecal coliform bacteria, nutrients, BOD, PAHs and airborne pollutants. The parking lot near the picnic area (Figure 1; Plate 7) drains directly into Moores Creek upstream of the boardwalk and historic area, thus rain events, particularly those which follow high use periods, are likely to add pollutants to the creek. The parking lot near the Visitor's Center is likely not a problem to the creek in terms of pollutant runoff. The runoff drains through a series of underground drains into a lengthy surface ditch that conveys the runoff several hundred meters to the creek. The ditches are well vegetated, and we suspect most pollutants are filtered out before reaching the creek. Presently there are five septic systems used to treat human sewage in MOCR. But as mentioned, their location appears to pose no threat to the creek or drinking well water.

Watershed Land Use Issues. As mentioned, the Moores Creek watershed contains 10 swine CAFOs, all of which are located upstream of MOCR. These have the capacity for > 53,000 head of swine (Appendix A). CAFOs are reservoirs of concentrated nutrients, BOD and fecal microbes (Mallin and Cahoon 2003) and runoff from these facilities or accidents concerning their waste lagoons may severely degrade water quality in MOCR. Pender County is in the process of increasing the number of chickens raised in poultry CAFOs by as many as 4.4 million birds annually (Talton 2006). Thus, the reservoir of potential pollutants in Pender County will be increasing accordingly. If some of these facilities are located in the Moores Creek watershed, they will have the capacity to pollute Moores Creek through accidents or major runoff events.

Surface and Groundwater Withdrawals

Surface waters are not utilized for drinking purposes. Well water is used for drinking, drawn up from a 60 m depth. Groundwater is abundant, based on the seeps entering the surface in areas of the park, the presence of the savanna, and the artesian wells. Thus, removal of groundwater for human use is not a problem in the park.

Nuisance and Invasive Species

Non-native aquatic organisms such as fish, nuisance bivalves, or other food web-altering organisms would most likely enter Moores Creek through the Black River. As mentioned, this has not occurred in Moores Creek within MOCR

Physical Impacts

Physical changes to the landscape may impact fresh or brackish water quality. Disturbances such as hurricanes and nor'easters are natural phenomenon that the flora and fauna are adapted to and will not be considered further here.

Continuous Land Impacts

Within MOCR there are nature trails used by the public, which need to be surveyed periodically to see if overuse and degradation of the resource occurs (NPS 2006). There is also a picnic area near the lower parking lot that is used, sometimes by large groups. Active construction is not occurring at present.

Presently, the MOCR staff is allowing the restored savanna to expand slightly through passive means, simply by not mowing a section adjoining the savanna (about 0.04 ha or 0.1 acre). No earth moving activity is planned.

There is a concern among park personnel that erosion around the bridge is occurring and will become more problematic. On a site visit July 31 of 2006 UNCW researchers and the park Superintendent witnessed an uprooted tree lying as a snag against the bridge (Plate 8); the Superintendent noted that the tree was recently standing along the immediate bank. The US Army Corps of Engineers performed a study (USACOE 2000) in which they estimated creek discharge, flow velocity and surface height under various scenarios and concluded that the velocities were insufficient to cause the erosion. They concluded that tidal fluctuations may be causing the slow erosion.

Plate 8. Streamside tree that was undercut by erosion and recently fallen into Moores Creek.

Another physical impact of concern to park personnel is beaver damage to streamside trees (Plate 9). This has resulted in the removal of one beaver from the park. (Ann Childress, NPS, personal communication). Beavers are a natural part of the ecosystem, and their behavior is normal. However, beavers kill trees by gnawing off the bark at or near the water's edge. The bends in Moores Creek near the historic bridge crossing are anchored by stands of trees. The US Army COE study (USACOE 2000) determined that as long as these stands of trees remain intact (alive and healthy), they serve as buffers to protect the bridge crossing site from major erosion. If beaver actions kill these trees, one of the park's primary cultural resources is seriously threatened.

Therefore, the beaver activity of chewing is acceptable, as long as they stay away from the area that ranges from about 100 feet upstream of the boardwalk to about 100 feet downstream of the bridge crossing. Beaver dams are common upstream of the park, but if beavers were to build a lodge in MOCR, effectively damming the creek on-site, that would seriously threaten the cultural landscape because of the flooding it would create.

Plate 9. Damage to streamside tree caused by beavers; these animals have dams upstream of the Park in Moores Creek and occasionally become a nuisance in the park.

Acute Land Impacts in the Park

There is presently no construction activity ongoing within the park that can impact water quality. As mentioned previously, land clearing or watershed construction activity upstream of the park has the potential to impact Moores Creek within the park, especially in terms of suspended sediments and turbidity.

Synopsis of Stressors to Moores Creek National Battlefield Water Bodies

Moores Creek

The creek is not presently experiencing surface algal blooms, according to periodic visual observations by park staff. However, there are no existing chlorophyll a data to verify this, and such data are needed to fulfill this critical information gap (studies performed by the lower Cape Fear River Program have shown algal blooms do occur in other area blackwater streams). Since 10 swine CAFOs are located upstream (Appendix A), and more poultry CAFOs moving into the area there is a potential for nutrient loading to occur in the creek from CAFO runoff or accidents. Hypoxia is a known problem in Moores Creek in summer (Table 1). The reasons for this are several-fold, but increased land disturbing activity upstream and nutrient inputs would exacerbate this situation. There is a potential problem with elevated suspended sediments entering the park from upstream sources, based on 1996 turbidity data (Table 10) which showed turbidity concentrations well in excess of those of a typical blackwater stream during that period. Upstream activities such as housing construction, road building, or agriculture are likely sources. Previous data also show periodic loading of fecal bacteria into the creek as well (Table 7). Potential sources include upstream CAFOs, land disturbing operations, and possibly runoff from the picnic area parking lot into the creek on site. We again note that the increase in poultry CAFOs in the area will pose an additional potential threat. There is a periodic problem with erosion, which was strong enough to uproot a streamside tree as witnessed by these researchers and the Park Superintendent (Plate 8). The presence of toxic compounds has not been studied on site. However, there is an area fish consumption advisory due to high mercury levels, and UNCW researchers have found high metals, PCBs, and pesticides in fish and clams in the Black River system. Furthermore, parking lot runoff may input metals and/or PAHs (polycyclic aromatic hydrocarbon) to the creek and its sediments (automobiles are major sources of PAHs and metals). Aquatic invasive species have not been found in the creek. Habitat disruption on site occurs from periodic beaver incursions, creating tree damage (Plate 9), which, if unchecked, could increase erosion

Drinking Water

Drinking water is chlorinated and is thus not at risk from fecal bacteria. Furthermore, septic contamination, nutrient loading, or toxin contamination of drinking water is not a possibility due to the depth (60 m) of the wells.

Groundwater

Groundwater has not been systematically studied on site. However, NPS has noted that the water table is within one meter of the surface in the park, and is thus subject to potential contamination. Potential pollutants that could impact groundwater include nitrate or ammonium; more remotely possible groundwater pollutants include fecal bacteria from septic systems and organic or metallic toxins.

Savanna

The MOCR staff has not noted any algal blooms in the savanna through normal visual observation. Standing water is present in the wetland according to rainfall, and perennial water is limited to the old ditch. The savanna does receive floodwaters from the creek, as well as any

of the airborne pollutants. Fecal pathogens are not likely to be a problem in the savanna, as humans have minimal contact with standing water within it and, barring polluted floodwaters, sources would only be local wildlife. However, water quality parameters have not been sampled in the savanna. As noted within, park staff to prevent spreading periodically burns out invasive plant species such as sweetgum and blackberry, which are an existing problem. Further disruption to this habitat is not in park plans, and is not likely to occur from any outside source.

Recommendations for Addressing Impairments, Potential Impacts, and Undocumented Water Bodies

A priority item would be to conduct a yearlong sampling program of Moores Creek, within the park. The last NC DENR – supported sampling effort occurred in 1988. Population (human and swine) has increased in the area and poultry numbers will be increasing significantly shortly, and impacts to the park's water resources are likely to increase as well.

We recommend that Moores Creek be sampled (from the reconstructed battlefield are bridge) for standard water quality parameters (water temperature, dissolved oxygen, pH, salinity, fecal coliform bacteria or enterococcus, total nitrogen, ammonium, nitrate, total phosphorus, orthophosphate, BOD5, chlorophyll *a*) on a monthly basis for at least one year. Monthly sampling (n = 12) would make the data comparable to the monthly sampling by the Lower Cape Fear River Program conducted at nearby Colly Creek and the Black River at Highway 210 (the LCFRP monitoring frequency is required by NCDWQ). Additionally, monthly monitoring is the frequency recommended for nutrients and other parameters for trend detection (Reckhow and Stow 1990). Sampling the creek sediments for potential toxins (metals, pesticides, PCBs, PAHs) should be performed at least once.

Because the groundwater table is located as close as one meter below the surface the groundwater is subject to pollutant loading (NPS 2006). Thus, we recommend that two of the artesian wells be sampled for nutrients and fecal coliform bacteria concurrently with the creek. Our recommendation of conducting a sampling program on the creek and artesian well water is in agreement with the recommendations of the National Park Service (NPS 2006).

Erosion does occur within MOCR along the banks of Moores Creek. One report indicated that tidal activity might be responsible for this (a natural activity). Park staff needs to monitor the creek bank for erosion, because if it should accelerate this may be related to upstream watershed activities.

Beavers - clearly there is tree damage occurring due to beaver activity. The park should continue to monitor for streamside tree damage and when it occurs within a key area of the stream (between 100 ft upstream of the boardwalk and 100 ft. downstream of the bridge) this may result in increased streamside erosion due to loss of streamside trees. In such a case removal of one or more beavers by professional trappers may be warranted to protect the site from increased erosion. Also, construction of beaver dams within MOCR should not be permitted as this will increase on-site flooding and threaten the cultural resources in the park.

Another recommendation concerns sampling for airborne ammonia. The Black River watershed contains many swine and increasing number of poultry CAFOs, which are large producers of airborne ammonia. The NPS should consider installing an airborne ammonia sampler to monitor the influx of this pollutant onto park property.

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Meyer, J.L. 1992. Seasonal patterns of water quality in blackwater rivers of the coastal plain, southeastern United States. In Becker, C.D. and D.A. Neitzel (eds.) Water Quality in North American River Systems. Batelle Press, Columbus. (This article provides water quality information on the Ogeechee and Satilla Rivers in Georgia, and discusses various characteristics of blackwater streams).

NCDENR. 1999. Classification and Water Quality Standards Applicable to Surface Waters and Wetlands of North Carolina. Administrative Code Section: 15A NCAC 2B .0100. North Carolina Department of Environment and Natural Resources, Division of Water Quality, Raleigh, N.C. (Legal document providing information on water quality standards for fresh and brackish waters of North Carolina).

NCDENR. 2005. Cape Fear River Basinwide Water Quality Plan. North Carolina Department of Environment and Natural Resources, Division of Water Quality, Planning Section, Raleigh, N.C. (A document providing detailed information on land use, demographics, water quality, water body use ratings, and water sampling programs in the Cape Fear River watershed).

NCDENR. 2006. Standard Operating Procedures for Benthic Macroinvertebrates, Biological Assessment Unit. North Carolina Department of Environment and Natural Resources, Division of Water Quality, Environmental Sciences Section, Raleigh, N.C. (This manual presents the methods for monitoring benthos in various areas of North Carolina, the differing indices used to assess community health, and the key indicator organisms. Swamp water on the Coastal Plain is assessed differently than the Piedmont, and Mountains).

North Carolina Department of Environment and Natural Resources, Division of Water Quality. North Carolina index of biotic integrity: http://h2o.enr.state.nc.us/esb/IBIrate.htm

NPS. 1997. Baseline Water quality data inventory and analysis, Moores Creek National Battlefield. Technical Report NPS/NRWRD/NRTR-97/120, National Park Service, Water Resources Division, Fort Collins, CO. (this is a report by the Park Service that collects any official on-line water quality data (i.e. STORET) for stations within 3 miles upstream and one mile downstream of the Park. Data are presented for MOCR for five sites providing basic statistics and graphs, and relation to State or federal water quality standards. An ecological analysis is not provided).

NPS. 2004. Birds observed at Moores Creek National Battlefield. National Park Service, Department of the Interior, Moores Creek National Battlefield, North Carolina. (This

checklist includes observations reported by National Park Service employees and visitors, and includes residence status of the birds - permanent, summer, winter, visitor, transient, etc.).

NPS. 2006. Moores Creek National Battlefield Geologic Resource Evaluation. National Park Service, Geologic Resources Division, Denver, CO., available at this website: http://www2.nature.nps.gov/geology/inventory/publications/reports/mocr_gre_rpt_view.pdf (This report describes the historical and present geological setting of the region of the southeast wherein MOCR is located. A series of maps and definitions are provided, along with recommendations for research needs, including monitoring the surface and groundwaters and determining sources of potential pollutants. In that regard, it is noted that the water table at MOCR is typically only a meter from the surface).

Paerl, H.W., J. Rudek, and M.A. Mallin. 1990. Stimulation of phytoplankton productivity in coastal waters by natural rainfall inputs; nutritional and trophic implications. Marine Biology 107:247-254. (Presents results of experiments demonstrating that the nitrogen content of continentally derived rainfall was often high enough to significantly stimulate phytoplankton growth in nearshore coastal ocean and Neuse Estuary waters).

Reckhow, K. and C. Stow. 1990. Monitoring design and data analysis for trend detection. Lake and Reservoir Management 6:49-60. (The authors of this paper analyzed data collected by the North Carolina Division of Water quality in various reservoirs and rivers to assess differences and trends, and how other impacts are separated out from seasonal trends).

Sieren, D.J. 1982. A floristic study of the vascular plants of Moores Creek National Battlefield. Prepared for the U.S. Department of the Interior, national Park Service, Atlanta, GA. Contract number CX-5000-1-0244. (This report is the most comprehensive floristic survey of the park available, totaling 539 species from 297 genera and 108 families).

Smith, B.S. and H.M. Patti. 1995. A floristic study of the meadow habitat at Moores Creek National Battlefield. Unpublished white paper, prepared for NPS Atlanta Office, Contract Number 1443PX5550-94-006. (This was a survey of the meadow that later became the restored savanna, provides species lists, plant locations, and discussion of plant of special concern).

Talton, T. 2006. Poultry industry flocks to Pender. Wilmington Star-News, Wednesday, July 5. (This article notes that a poultry processing company is contracting with several Pender County farmers to build 40 chicken houses in 2006, each of which can hold as many as 22,000 birds).

Tuberville, T.D., J.D. Wilson, M.E. Dorcas and J.W. Gibbons. 2005. Herpetofaunal species richness of southeastern national parks. Southeastern Naturalist 4: 537-569. (This paper provides a series of lists of reptile and amphibian species found at 16 southeastern national parks, broken down by taxa, with introduced species noted. There was a significant correlation between park area and species richness.)

USACOE. 2000. Moores Creek at Moores Creek Battlefield: Hydrology and Hydraulics Evaluation. U.S. Army Corps of Engineers, Wilmington District. White paper prepared for

NPS MOCR. (Presents and analysis of flow velocities to determine if flood events lead to erosion of the steam bank. The results suggested flow velocities were not responsible. And the report suggested tidal action probably caused the erosion).

Walker, J.T., V.P. Aneja and D.A. Dickey. 2000. Atmospheric transport and wet deposition of ammonium in North Carolina. Atmospheric Environment 34:3407-3418. (This paper demonstrates statistical relationships between atmospheric ammonia concentrations and swine populations in eastern North Carolina, and assesses trajectories and distances that deposition of ammonia from these sources occurs, showing deposition as far as 80 km from the source).

Wilson, R.C. 1997. Freshwater mussel survey of Moores Creek in Pender County. Order Number 1443PX5550-96-006. North Carolina Wildlife Resources Commission, Raleigh, NC. 2 pgs. (The results of this survey showed no mussels or mussel remains in MOCR, which was attributed to the naturally low pH of the creek).

Woods, S.W. and J. Wagner. 2001. Hydrologic restoration of a wet pine savannah at Moores Creek National Battlefield, North Carolina. Unpublished white paper, National Park Service, Water Resources Division, Denver, CO. (This report discusses the initiation and implementation of the Park's efforts to restore the wet pine savannah to approximate what it was like during the Revolutionary War. The blocking of a drainage ditch was useful in returning the hydrology of the area to normal conditions; as of the writing of that paper some of the native savannah species were doing well whereas others had failed to recolonize).

Appendix A. Individuals Providing Information through Interviews During the Preparation of this Report

Dr. JoAnn Burkholder, Center for Applied Aquatic Ecology, North Carolina State University, Raleigh, N.C., 919 515-2346. http://www.ncsu.edu/wq.

Mr. Fritz Rohde , North Carolina Division of Marine Fisheries, Wilmington, N.C. 910 395-3900. http://www.ncfisheries.net/

Mr. Walker Golder, North Carolina Audubon Society, Wilmington, N.C. 910 798-8376. http://www.ncaudubon.org/

Dr. W. David Webster, University of North Carolina Wilmington Department of Biology and Marine Biology, Wilmington, N.C. http://www.uncw.edu/bio/faculty_webster.htm

Appendix B. Concentrated Animal Feeding Operations

Table B-1. Concentrated animal feeding operations (CAFOs) in the Moores Creek Watershed, Pender County, North Carolina. Only swine CAFOs are listed. From NC Division of Water Quality.

CAFO Name	Design Capacity	Latitude	Longitude
Fennert & Brewster Nursery	5,200	N34.5275	W78.1469
Gary Pridgen Farm #3	3,672	N34.5728	W78.0742
Debose Nursery	2,600	N34.5797	W78.0850
Pender I and II	10,000	N34.5911	W78.1575
Hairr II	5,100	N34.5925	W78.1428
2601	2,400	N34.6200	W78.1044
DeBose Farm	2,600	N34.6333	W78.1250
Bull Tail #1 & #2 (Sow)	10,000	N34.6333	W78.1500
Stanley Farms	5,200	N34.6492	W78.1319
Porter Farms	6,400	N34.6500	W78.1333
Total Capacity in Watershed	**53,172**		

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NPS 324/100182, July, 2009

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