THE WACCAMAW DRAINAGE SYSTEM:
GEOLOGY AND DYNAMICS
OF A COASTAL WETLAND,
SOUTHEASTERN NORTH CAROLINA

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COVER PLATE: Southeastern North Carolina and the Waccamaw region from the 1733 map of Edward Moseley (Cumming, 1966).

The little lake, out of which the long and crooked river with its dark cypress waters flowed to the sea. --- The paper canoe shot into the whirling current which rushes out of the lake through a narrow aperture into a great and dismal swamp. --- Down the tortuous, black, rolling current went the paper canoe with a giant forest covering the great swamp and screening me from the light of day. --- Festoons of gray Spanish moss hung from the weird limbs of monster trees, giving a funeral aspect to the gloomy forest, while owls hooted as though it were night. The creamy, wax-like berries of the mistletoe gave a Druidical aspect to the woods.

Such is the character of the Waccamaw, this most crooked of rivers.

N.H. Bishop, 1878, Voyage of the Paper Canoe

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DISCLAIMER

The contents of this report reflect only the authors’ views, who are responsible for the accuracy of the data, the data interpretations, and the recommendations presented herein. The contents do not reflect the official views or policies of the N.C. Department of Environment, Health, and Natural Resources, N.C. Geological Survey, or East Carolina University.

1. CONCLUSIONS

> *The stewardship of environment is a domain on the near side of metaphysics where all reflective persons can surely find common ground....An enduring environmental ethic will aim to preserve not only the health and freedom of our species, but access to the world in which the human spirit was born.*
>
> *The Diversity of Life: E.O. Wilson, 1992*

The Waccamaw drainage system is composed of many parts, all of which are intimately interrelated and operate in consort with each other like the parts of a living organism. However, this complex system is under severe and conflicting pressures by many different societal user groups. Many land-use modifications and practices by specific user groups are creating long-term and irreversible modifications of this delicately balanced water-dependent ecosystem. In order to protect this unique and critical coastal resource for future utilization, this multifaceted ecosystem must be managed as a single entity with a focus on the main component that drives this wetland system—-water. Thus, management of the Waccamaw drainage basin must be guided by a complete understanding of the complex interactions between all parts of this dynamic wetland system.

Before European colonization, North Carolina contained about 11 million acres of wetlands (Dahl, 1990) including estuarine and fresh-water marshes, riverine-floodplain swamp forests, and upland swamp forests (Fig. 1-1). Of this original 11 million acres, about 2.5 million acres consisted of upland swamp forests (Richardson et al., 1981) that occur in pocosins, an Algonquin word meaning “swamp on a hill”. Green Swamp is a superb example of a pocosin. However, these vast coastal plain wetlands have been under attack since European colonization began. According to Dahl (1990), by the mid-1980s only about 5.7 million total acres (51%) of wetlands remained in North Carolina, including an estimated 700,000 acres of unaltered pocosins (Environmental Defense Fund, 1989) or 28% of the original 2.5 million acres.

Wetlands in the vast Waccamaw drainage system originally represented 7.3% of the original total wetlands in North Carolina. However, today the Waccamaw system is in serious jeopardy due to centuries of extreme land-use modifications resulting from growth and development pressures (Fig. 1-2). This unrelenting assault has included ditching and draining of vast wetlands; withdrawal from and decline of associated groundwater aquifer systems; replacement of natural, high diversity ecosystems with monoculture pine plantations; and ever-increasing amounts of runoff including massive volumes of sediment, fertilizers and pesticides, industrial waste, and human and agricultural sewage. The continued assault upon remaining wetlands, modification of stream flow, and withdrawal of groundwater will continue to impact the base flow of the Waccamaw drainage system. This will create greater oscillations in riverine flow with time causing it to become flashier with longer periods of low water and more frequent periods of higher high water. In addition, increased growth and development will continue to degrade water quality.

FIGURE 1-1. Map showing the distribution of wetlands and deepwater habitats in North Carolina. Notice that the wetlands, which include coastal marshes, riverine swamp forests, and upland pocosin swamp forests, are concentrated almost totally within the Coastal Plain province. Map is from Dahl (1996).

FIGURE 1-2. Satellite image of southeastern North Carolina showing the Brunswick and Columbus County portions of the Waccamaw drainage system. Notice the extensive pattern of drainage ditches for agriforestry throughout the Green Swamp region. In addition, the photo shows the Brunswick County barrier islands; Cape Fear; the Cape Fear, Black, and Northeast Cape Fear Rivers that flow together to form the Cape Fear River estuary; and the city of Wilmington. This is a 1996 IRFAN satellite image obtained from the website of NOAA.gov.

To optimize and integrate the utilization, development, and preservation of the Waccamaw drainage system (WDS) and its resources, it is imperative that public, private, and management sectors have a basic comprehension of the natural system. This must include understanding the following concepts:

1. Spatial and temporal inter-relationships between the many and diverse regions and physical, chemical, and biological components of the WDS ecosystem,

2. Driving forces operating within each region and component and the interactive dynamics between regions and components of WDS ecosystem, and

3. Human processes and their short- and long-term consequences upon the WDS ecosystem.

Our basic goal in this monograph is to provide the initial framework for understanding and integrating the fundamental scientific processes and responses within the Waccamaw drainage system. We have not answered all questions or solved all problems, but we have begun to define the components and synthesize the dynamics of this complex system. We sincerely hope that this will represent a platform for guiding future research and understanding of this awesome water-dependent coastal system, as well as form the seeds for initiating a management scheme that might save this incredible wetland system for future generations.

2. RECOMMENDATIONS

> *The time has come, when scientific truth must cease to be the property of the few, when it must be woven into the common life of the world; for we have reached the point where the results of science touch the very problem of existence....*
>
> *L. Agassiz, 1862*

The environmental problems within the Waccamaw drainage system (WDS) did not happen overnight. Therefore, restoring this precious resource will not only take time, but must be citizen driven, involve all user groups, and be based upon good science and a complete understanding of the entire plumbing system of the WDS. To accomplish this, it is imperative that a program be undertaken to educate both the public, private, and political sectors about the importance for making changes and necessity for getting involved in the River. The action or inaction that begins today will determine the character and quality of the Waccamaw drainage system for our children and grandchildren.

1. Implement a basin-wide study to determine the interaction and linkages between the ground- and surface-water systems and define the water budget for the WDS.

The entire WDS is either perched on top of or incised into the extensive Cretaceous Pee Dee aquifer. The Pee Dee groundwater system represents a net discharge into the WDS that impacts both the water chemistry and river flow through time, even during the driest periods and in spite of massive development of drainage ditches. Thus, the WDS water budget is interdependent upon both the surficial and groundwater systems, but these linkages are very poorly understood. Due to the critical role of groundwater to the surface drainage system dynamics, the regional water management scheme must include the long-term impacts of urban, agricultural, and industrial utilization of groundwater.

2. Establish a Regional Water Management Council for the Waccamaw Drainage Basin.

A. Composition of the Council.

The Council should be composed primarily of local citizens representing public and private user groups of all interests within the WDS, and key scientists and State and Federal personnel representing relevant disciplines and agencies.

B. Focus of the Council.

The Council should be charged with developing the regional water management policy for the entire WDS including the tributary drainages, Lake Waccamaw, Green Swamp pocosin, the upper and lower Waccamaw River, and groundwater utilization. The Council should work closely with existing branches of various State agencies (i.e., Division of Water Resources, Division of Water Quality, etc.) to formalize and implement the management plan.

C. Establish and Fund the Following Positions.

a. **Director.** The purpose of the director should be to coordinate the efforts of developing and implementing the regional watershed management plan, to oversee and carry out the work of the Council, and to coordinate efforts between the local citizenry and user groups, town and county offices, and the various State and Federal Agencies, etc.

b. **River and Lake Keeper.** The River and Lake Keeper should organize a volunteer staff of citizens who regularly patrol the lake, river, tributaries, and associated wetlands looking for pollution and flow problems, monitoring water quality, and reporting their findings to the River and Lake Keeper and other appropriate authorities.

c. **Education Coordinator.** The Education Coordinator should organize a volunteer staff of citizens to develop information packages for the WDS with a focus on all aspects of watershed dynamics and the integrated basin management approach. Strategies should be developed for educating local groups utilizing workshops and outreach programs that concern all age groups ranging from grade school children to the various user groups and general public.

3. The Regional Water Management Council should develop a Watershed Management Plan for the WDS that includes the following components.

The Council should have the responsibility for defining a set of goals, establishing mechanisms for accomplishing these goals, determining procedures for implementing the plan within a specified time framework, and monitoring the implementation of the proposed changes. The goal of this plan should be to successfully put water back into the Waccamaw drainage system and keep sediment and other pollutants out.

A. Water use plan.

The Council should work with all user groups to develop a water use plan that includes taking water out, modifying, or putting water and associated pollutants into the drainage system. The goal should be to maximize water retention in the Waccamaw wetlands, while at the same time maximizing utilization by multiple user groups. This would allow the water to seep slowly into the river system through time and restore the “sponge effect” of the surrounding wetland system.

a. **Formulate a model to integrate patterns of climatic conditions and water availability for present and future water user needs.** This model should include the natural seasonal rainfall patterns, timing sequence for planting and harvesting of forestry and agricultural crops, patterns of changing land use, and existing uses (silvaculture, agribusiness, urban development, hunt clubs, and sport fishing, etc.) and new or unconventional uses associated with developments such as ecotourism. The goal would be to define the carrying capacity of the WDS from a water-use perspective.

b. **Develop a maintenance plan for temporary reestablishment of sheet flow conditions by managing the closing and opening of drainage ditches and road dams.** Various procedures that could be considered for modification of drainage ditch/road dam maintenance might include close ditches at key discharge points and culverts, encourage beaver dam construction within drainage ditches, and breach key road segments to open specific areas to sheet flow.

c. **Improve land use practices adjacent to streams, drainage ditches, road beds, and steep-sloped banks.** Improved land-use management techniques will diminish rapid runoff and associated erosion and increase the slow-water release. This can be accomplished through increased use of best management practices (BMPs), no-till agriculture, use of riparian buffers along drainage ditches and tributary streams, and use of flashboard risers and weirs to maintain instream wetlands in the low-gradient streams, etc. At the same time, these practices will allow the soil to retain soil moisture and reduce soil erosion, which in turn will diminish pollution due to sediments, associated nutrients, and other toxic chemicals.

B. Sediment Pollution Plan.

The Council should work with all user groups to develop a plan to minimize the input of sediment and other pollutants into the major waterways of the WDS. As the water plan is implemented, there should be a significant decrease in pollutant input into the WDS. However, in addition to the related components within the water plan, the following approaches are specifically recommended for consideration to minimize the sediment pollution problem within the Waccamaw River.

a. **Modify timber practices on all steep-sloped banks along river channels and riverine floodplains.** The present clear-cutting practices used on sloped land adjacent to floodplains and streams should be abandoned and replaced by selective logging practices without the use of heavy equipment.

b. **Plant vegetative buffer zones along stream banks.** Effective vegetative buffer zones will stabilize sediment banks along rivers and streams and reduce shoreline erosion and sediment pollution.

c. **Establish 'no wake zones' with speed limits on specific portions of the Waccamaw River during intermediate to high water stage.** This will minimize high bank erosion and decrease the problems resulting from downed trees and sediment entrapment.

d. **Implement a snagging plan for specific river segments.** Certain portions of downed trees should be removed to prevent sedimentation and shallowing of the river and improve river navigation. However, some portions of downed trees should be left in the water for wildlife habitat.

e. **Evaluate the possibility of developing a limited dredging scheme for river segments with severe sediment problems.** This evaluation should include both an economic and environmental assessment. If there is enough sediment, it could be sold to pay for dredging and utilized for other purposes such as sand for much needed Brunswick County beach nourishment projects.

C. Recreational Plan.

The Council should develop a plan to cultivate new business opportunities based upon the WDS water resources in Brunswick and Columbus Counties. Examples of new ecotourism businesses include blackwater river and wilderness trips including hunting and fishing, canoeing and kayaking, tubing and snorkeling, wildlife tours, wilderness adventures in hiking and camping, high-water float trips, etc. New businesses for local development might include construction and management of base camps, boat drop-off and pick-up sites, hiking/backpacking trails into significant natural areas with swamp platforms for camping, river and wilderness guides, boat rentals, equipment outfitters, and development and sale of necessary guidebooks, maps, aerial photos, etc.

4. Obtain designations of Outstanding Resource Waters (ORW) and National Scenic River status for the Waccamaw River system.

The Council should work towards establishing ORW status for the entire Waccamaw River drainage system. It is imperative that the WDS be re-evaluated for ORW designation using different criteria than previous efforts. The Waccamaw drainage is a different kind of drainage system and using criteria concerning low pH and the ephemeral nature of many portions of the streams is not adequate justification to deny ORW status. The water quality problems associated with elevated levels of mercury should be defined and evaluated in order to maintain OWR designation for this critical drainage system. Also, the Council should work towards obtaining National Scenic River status for the Waccamaw River system.

5. Define sensitive habitats for specific management consideration.

The WDS contains many sensitive habitats due to the unique evolutionary history of the drainage basin and the important role and chemical character of groundwater input into this vast wetland system. Two different aspects of sensitive habitats should be considered for inclusion within any regional management plan.

A. Unique geomorphic habitats and biological ecosystems that will be destroyed and gone forever with continued development.

This type of habitat ranges from Lake Waccamaw to the subtle paleo-ridge and swale structures of ancient stream meanders that occur within the antecedent floodplain of the lower Waccamaw River. Other sensitive habitats might include Carolina Bay depressions, paleo-lake shorelines, outcrops of specific rock units such as the Waccamaw Limestone bluffs on the north shore of Lake Waccamaw, etc. Due to the unique characteristics of these morphological habitats, they often contain sensitive biological communities including rare and endangered organisms.

B. Present or future land use of specific habitats that seriously compromises some component of the WDS.

This category includes forest and farm land adjacent to stream banks, the high banks bordering swamp forests, and areas of high storm-water runoff such as paved urban areas, etc. Within such habitats, management methods could include the use of buffer zones, establishment of holding ponds, controlled methods of logging, or complete bans on logging. These management practices will decrease the amount of direct runoff and associated pollutants.

3. INTRODUCTION

> *I seemed to have left the real world behind me,*
> *and to have entered upon a landless region of*
> *sky, trees, and water.*
>
> *N.H. Bishop, 1878*

The Waccamaw drainage system is composed of many parts. All of these parts are intimately interrelated and operate in consort with each other like the parts of a living organism. Therefore, to understand and manage this drainage system we must first comprehend the complex plumbing system. The plumbing consists of numerous inputs and outputs that determine the ultimate composition and volume of water flowing through the piping system.

3.1 Description of The Waccamaw Watershed

The Waccamaw watershed is one of several small Coastal Plain watersheds in the southeast corner of North Carolina that has been included within the larger Lumber River Basin. The Waccamaw watershed is situated on the narrow interstream divide between two major Piedmont-draining fluvial systems: the Cape Fear River to the northeast and the Great Pee Dee River to the southwest (Figs. 3-1 and 3-2). During periods of lowered sea level, the Waccamaw River developed as a tributary stream system to the Great Pee Dee River just northeast of Georgetown, SC.

3.1.1. Waccamaw Drainage System (WDS) in North Carolina

The WDS consists of three headwater streams: White Marsh Swamp on the west, Juniper Creek and the associated Green Swamp on the east, and the upper Waccamaw River which drains Lake Waccamaw and surrounding Friar, Boggy, and River Swamps in the north and central portions of the drainage system (Fig. 3-3). These three drainages combine south of Crusoe Island to form the lower Waccamaw River. The lower Waccamaw flows southwest into South Carolina where it joins the Pee Dee River to form Winyah Bay, a drowned-river estuarine water body which ultimately flows into the Atlantic Ocean south of Georgetown, South Carolina (Fig. 3-2). For the purposes of this report, the North Carolina portion of the WDS will be subdivided into four physiographic components: Green Swamp, Lake Waccamaw, upper Waccamaw River, and lower Waccamaw River (Fig. 3-3).

The North Carolina portion of the WDS is approximately 1,044 mi^2 or 668,160 acres in size, including 1,028 mi^2 of land and 16 mi^2 of water (NC DWQ, 1999) situated primarily within Brunswick and Columbus Counties. Table 3-1 compares the general pattern of land use in the two counties between 1982 (NC DEM, 1994) and 1992 (NC DWQ, 1999). The 1990 population of the WDS was approximately 48,586 as compared to 42,691 in 1970 (NC DWQ, 1999). This represents a 12.1% growth rate as compared to the statewide average of 12.7% (NC DWQ, 1999). The projected population growth rates for Brunswick and Columbus Counties to year 2015 are 79.3% and 3.5%, respectively (NC DWQ, 1999). Most of the projected growth in Brunswick County will occur along the Atlantic coast and within the Coastal Drainage System, rather than within the WDS. However, there will be long-term indirect consequences of this growth to both the surface-water and ground-water systems within the WDS as the demand for and use of inland fresh water increases along the coastal zone.

FIGURE 3-1. Map of the drainage basins of North Carolina showing the location of the Waccamaw River Watershed within the Lumber River Basin.

FIGURE 3-2. Map of the Lumber River drainage basin in North and South Carolina.

FIGURE 3-3. Schematic map of the Waccamaw drainage system showing the three headwater streams: White Marsh Swamp on the west, Juniper Creek and associated Green Swamp on the east, and the upper Waccamaw River which drains Lake Waccamaw and surrounding swamps in the north and central portions of the drainage system. These three drainages combine south of Crusoe Island to form the lower Waccamaw River. The following four physiographic components of the WDS will be addressed in the text: Green Swamp, Lake Waccamaw, upper Waccamaw River, and lower Waccamaw River.

TABLE 3-1. General land uses in the North Carolina portion of the Waccamaw watershed in 1982 (NC DEM, 1994) and 1992 (NC DWQ, 1999).

	1982	1992
Forest	63.2%	66.5%
Agriculture	27.1%	24.4%
Urban Development/Roads	3.7%	3.4%
Other	2.1%	5.7%

3.1.2. Wetlands

The WDS is situated primarily within Brunswick and Columbus Counties, which consist of 58% hydric soils. Hydric soils are defined as “soils that are saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions in the upper part” (US SCS, 1987). The water content of hydric soils is generally sufficient to support wetland vegetation. A large portion of the hydric soils within the WDS remain as wetlands in spite of the severe ditching and draining done for expansion of the agriculture and forestry industries.

The WDS includes many blackwater streams bordered by extensive bottomland swamp forests, a very large bay lake, and vast areas of poorly drained interstream divides called pocosins. Pocosin is an Algonquin word that means "swamp-on-a-hill" (Richardson et al., 1981). Since the entire WDS is situated on the outer coastal plain, it is a black-water drainage system characterized by low hydraulic gradients and dominated by wetlands. All of these wetland habitats are characterized by high water tables, long hydroperiods, and organic-rich, hydric soils overlying clay-based sediments. The WDS is “a showcase of biological richness” due to the diverse and extensive wetland habitats characterized by a wide variety of plant communities(NC DWQ, 1999). The extensive character of these wetlands resulted in minimal growth within the basin with development limited largely to forestry and agriculture.

Wetlands are generally transitional lands between dry upland regions and aquatic habitats. They have a water table that is usually at or near the land surface and often are covered by shallow water. The WDS contains three general types of wetlands (Cowardin et al., 1979): palustrine, riverine, and lacustrine.

1. Palustrine wetlands account for most of the wetland acreage in the Waccamaw and are dominated by emergent vegetation that includes swamp forests, scrub-shrub swamps, savannas, and fresh-water marshes. Palustrine wetlands form as pocosins, Carolina bays, and riverine floodplains.

2. Riverine wetlands are the freshwater habitats within the river channels including the margins that may contain emergent vegetation. All major drainages and associated tributary streams within the Waccamaw watershed fall into this category of wetland. Many portions of small stream channels within the Green Swamp pocosin disappear as the water shifts from channel flow to sheet flow, causing riverine wetlands to grade into palustrine wetlands.

3. Lacustrine wetlands include the natural lakes and reservoirs dominated by submergent vegetation within the water and emergent vegetation around the perimeter. Lake Waccamaw is a natural Carolina bay and represents the only major lacustrine habitat within the WDS.

The Waccamaw River below Old Dock is a well-developed stream that drains an extensive and complex set of upland swamp areas or pocosins (Fig. 3-3). Above the “narrows” at Old Dock and Crusoe Island, is a very large pocosin system that will be referred to generally as the Green Swamp pocosin. Green Swamp is a very young and immature drainage system that formed during the last few tens of thousands of years. The resulting flat, perched wetlands are contained totally within small basins defined by the underlying geologic framework and have formed in response to the climatic fluctuations during the last glacial and interglacial episodes.

3.1.3. Classification of Surface Waters

Both the Waccamaw River and Lake Waccamaw are nationally famous for their diversity and abundance of faunal populations. “Perhaps no other water body in eastern North America contains such a number of endemic fishes and mollusks” (NC DEM, 1995), along with a high diversity of other vertebrates including snakes, alligators, and wading birds. Fuller (1977) summed up the importance as follows. “The Waccamaw basin in southeastern North Carolina and northwestern South Carolina supports more unique non-marine mollusks than any other locale in the state....protection of Lake Waccamaw is the single most important goal of conservation in the state.” Portions of the upper Waccamaw River drainage were previously considered for inclusion in the North Carolina Natural and Scenic Rivers System, however, no formal proposal was ever made due to local opposition.

The waters in the Waccamaw River are generally classified as C Sw, whereas Lake Waccamaw is classified as B Sw (NC DEM, 1994). The water quality classification of C represents secondary recreation waters, while the B classification represents primary recreation waters capable of supporting swimming. The Sw designation is the supplemental classification for swamp waters characterized by low velocity flows, low pH and dissolved oxygen, and high organic content. The waters in both the Waccamaw River and Lake Waccamaw have been under consideration for reclassification as Outstanding Resource Water (ORW) by the NC DEM. This supplemental classification would designate these water bodies as “unique and special waters having exceptional water quality and being of exceptional state or national ecological or recreational significance”.

In 1987 NC DPR recommended that Lake Waccamaw, the Waccamaw River, and portions of White Marsh and Bogue Swamp be given Outstanding Resource Water (ORW) designation to provide additional protection for the water quality in this system. This recommendation was based on the large number of rare and endangered aquatic species and importance of associated bottomland forest ecosystems, which possess qualities of state and national significance. In 1995 NC DEM agreed with this recommendation for Lake Waccamaw. However, they did not recommend ORW designation for the Waccamaw River or its tributaries because only one river site had an “Excellent Bioclassification”. All other river sites were classified as “Good”, and “many tributary streams were difficult to rate because of very low pH values (Juniper Creek) or ephemeral flow (Big Creek, Bogue Swamp)”. NC DEM (pers. Comm., 1997) did not pursue ORW status for any portion of the WDS due to a 1994 limited fish consumption advisory that included Lake Waccamaw (NC DEM, 1997). The advisory was based upon elevated mercury levels in fish tissues within the entire Lumber River basin. However, in response to public concerns, ORW designation was formally established in 1999, but only for Lake Waccamaw.

3.1.4. Sediment Pollution

According to Rudek et al. (1998) “the biggest threat to North Carolina’s lakes and rivers is---dirt---sediment washed into streams from adjacent land.” Sediment appears to be a benign substance; however, it can dramatically impact water quality, stream dynamics, and the aquatic organisms living within stream systems. Rudek et al. (1998) claim that “sediment pollution remains the primary cause of stream degradation in North Carolina.” The leading causes of sediment pollution are agriculture, forestry, and urbanization. Agriculture and forestry generate sediment pollution in three ways: clearing and plowing open the soil and subject it to erosion, drainage ditches deliver sediment laden runoff directly into streams, and stream bank destabilization leads to severe erosion. Urbanization increases the amount of land clearing and subsequent construction, resulting in significant increase in impervious surfaces and sediment-laden storm water runoff.

According to the NC DEM (1994) "sediment is the most widespread cause of impairment to stream water quality and biological integrity in the (Lumber River) basin. While much has been done to reduce sedimentation resulting from construction, agriculture and other land-disturbing activities....further improvements and/or more widespread application of sediment control measures....are needed." Upland regions within and around the swamps and pocosins of the WDS are utilized largely for agricultural production while large portions of the lowland regions are extensively utilized for timber production. Since both the uplands and lowlands are poorly drained, they generally require extensive ditching and draining. Consequently, drainage programs have essentially been in effect in much of Brunswick and Columbus Counties since European settlement. The long-term result of these drainage programs is the lowering of the groundwater table and the shunting of surface water directly through ditches into the adjacent streams. Once the vegetative cover is broken, then surface sediment is eroded and delivered to the streams along with the surface water.

Table 3-2 demonstrates the severity of the soil erosion problem within the North Carolina drainage basins. The table summarizes the average amount of sediment that is eroded per acre of land annually for different geographic regions of the state. These data are presented to give an overview of the general volumes of sediment and the potential extent of the sediment pollution problem. The two categories that are most relevant to the WDS are the coastal plain and coastal flatwoods regions with an average of 3.9 and 3.2 tons of sediment/acre/year, respectively. Within the WDS, the coastal plain category would include most of the upland agricultural areas, whereas the coastal flatwoods would include most of the drained lands utilized for forestry purposes. Once the sediment is eroded off the land, suspended sediment in the water column and subsequent sedimentation processes can have significant

TABLE 3-2. Soil erosion trends in North Carolina. Data are from 1992 National Resources Inventory (USDA-NRCS, 1994).

REGIONAL CATEGORY	TONS SEDIMENT/ACRE/YEAR 1982	1987	1992
BLUE RIDGE MOUNTAINS	12.7	20.8	18.3
PIEDMONT	12.3	12.0	10.5
SAND HILLS	6.0	5.6	5.1
COASTAL PLAIN	3.9	3.9	4.0
COASTAL FLATWOODS	3.2	3.1	3.2
TIDEWATER AREA	1.4	1.5	1.6

impacts upon drainage systems. Some of the major types of impacts are summarized in Table 3-3.

According to the NC DEM (1994) the problem of sedimentation is too widespread and is caused by too many sources to present sediment control strategies for targeted water bodies. Thus, they describe more than 19 State and Federal sediment control-related programs. Sedimentation, “deposition of sediment in surface waters”, is a widespread nonpoint source-related water quality problem which results from land-disturbing activities including agriculture, forestry, land development, and mining. The NC DEM (1994) recommends the installation of acceptable best

TABLE 3-3. Potential impacts of suspended and bed load sediments and the processes of sedimentation to riverine and lacustrine systems.

1. Fills river, stream, and ditch channels and diminishing discharge capacity
2. Fills lakes and diminishes holding capacity
3. Decreases light penetration diminishing plant production
4. Increases water temperatures effecting type and functions of organisms
5. Smothers benthic organisms
6. Clogs gills of nektonic animals and chokes filter-feeding benthic organisms
7. Changes the texture and composition of benthic habitats
8. Buries hardbottom habitats
9. Decomposing organic sediments reduce oxygen concentrations
10. Carries and stores pollutants
    a. Nutrients (P and C)
    b. Toxic Metals (Pb, Hg, Cu, Cd, etc.)
    c. Toxic Organic Compounds (PCB, dioxin, etc.)
    d. Pesticides and Herbicides
11. Increases cost of water treatment

management practices (BMPs). BMPs are aimed at minimizing the area of land-disturbing activity and the amount of time the land remains unstablilized; setting up barriers, filters or sediment traps to reduce the amount of sediment reaching surface waters; and recommending land management approaches that minimize soil loss such as conservation tillage, terraces, diversions, crop conservation grasses and trees, filter strips, field borders, grass waterways, water-control structures, and livestock exclusions. In spite of all the efforts of numerous State and Federal programs, there were still 116 miles of streams in the Lumber Basin found to be impaired by sediment, and thus underscoring the need for improvements in sediment control (NC DEM, 1994).

3.2. Study of the Waccamaw Drainage System (WDS)

3.2.1 Purpose and Scope

Citizens of Brunswick and Columbus Counties expressed concern about water quality, stream flow characteristics, and the generally poor water and biological conditions in the Waccamaw River. Along with these concerns is the perception that the Waccamaw River is filling with sediment. Residents describe "deep fishing holes that are no longer there" and "river reaches that are no longer navigable during low water conditions". However, there is no documentation concerning sediment filling or studies to define the source and rates of this process of sedimentation.

According to the NC DEM (1994) "sediment is the most widespread cause of water quality use support impairment in the Lumber Basin." Much of this sediment pollution is related to major changes in land-use patterns, increasing the role of both point and nonpoint sources entering the river. During the recent past there has been an increased utilization of these poorly drained lands for expanded agricultural and timber production, along with growing industrial and urban development. This has lead to an accelerated rate of ditching and draining. In addition, growth and development throughout the region has lead to major increases in groundwater withdrawals. All of these changes impact the water flow patterns of the surface drainage system and natural role of intervening swamplands.

To help understand the problem and develop possible solutions for future management of the Waccamaw drainage system, it is imperative to understand both the dynamics of the natural drainage system and define the societal demands and alterations to this system. As one of a series of studies funded by the North Carolina General Assembly to address these concerns, the Geology Department of East Carolina University, in cooperation with the North Carolina Department of Environment, Health, and Natural Resources, Division of Water Resources, initiated two investigations in 1995 concerning the Waccamaw River. The two studies concerning the Waccamaw River and their objectives were as follows.

1. **SEDIMENTATION IN THE WACCAMAW RIVER DRAINAGE SYSTEM:** to define the problem of sediment pollution by relating it to the geologic framework and changing land-use patterns, and to evaluate the long-term impact upon the drainage system.

2. **LAND-USE PATTERNS AND GEOLOGIC FRAMEWORK OF THE WACCAMAW DRAINAGE SYSTEM:** to determine the general pattern of land-use change during the past 60 years and relate this change to the geologic framework.

To realize these objectives, we 1) verified the extent of the problem; 2) collected, analyzed, and evaluated the supporting data, and 3) developed this report with a set of recommendations for potential corrective measures. Implementation of the recommendations was not within the purview of these studies.

3.2.2. Approach to the Study

Our study of the WDS was carried out in four phases during the time period of 1995 through 1999. Following an initial literature review (Phase I), we undertook a major field program during the first two years of the study (Phase II). A laboratory analysis of the field data, along with an analysis of old aerial photograph sets (Phase III) was carried out during the second two years. This report represents the final product of Phase IV of the project, which was the synthesis and integration of data resulting from the previous phases.

When funded, the study was to be a two-year project considering only the lower Waccamaw River. After our initial evaluation at the end of Phase I, it became clear that we had to expand the study to include a larger portion of the WDS. Consequently, we expanded the field and laboratory analysis (Phases II and III) to include the upper Waccamaw River, Green Swamp, and Lake Waccamaw regions. In order to meet our initial project objectives, we also expanded our efforts to consider and understand the geologic framework and hydrodynamics of larger WDS, which more than doubled the time commitment for the project.

4. METHODOLOGY

> *In my hands at least, fluvial geology was an improvised discipline, like history or psychology or economics---it could provide an explanation, or the appearance of an explanation, for why things were as things were, but it had no predictive value at all, and its chief function, perhaps, was to occupy the mind.*
>
> *F. Burroughs, 1992*

4.1. Data Base

Table 4-1 summarizes the data base developed for the study of the North Carolina segment of the WDS. To develop the basic framework understanding of the WDS dynamics, we carried out seven different subprograms that included both field and laboratory components. The field component included the following: 1) evaluation of the North Carolina portion of the WDS under different hydrologic conditions, 2) establishment of riverine stations, 3) measurement of cross-sectional profiles at the riverine stations, 4) obtaining vibracores for sedimentologic and stratigraphic control, and 5) running ground-penetrating radar surveys for subsurface stratigraphic information. The lab component included the following: 1) analyses of sediment texture and composition, 2) evaluation of stratigraphic units from vibracore and GPR data, 3) development of geologic cross-sections through key segments of the drainage system, 4) analyses of aerial photo sets through time, and 5) a re-evaluation of the USGS hydrologic data.

Since the first project objective was to evaluate the source, transport, and deposition of sediment within the Waccamaw River, we considered all potential sediment sources and their pathways into and through the entire WDS. Consequently, we carried out appropriate field investigations within each of the following morphological regions of the Waccamaw drainage basin to address this objective.

1. The Waccamaw River channel, floodplain swamp forests, and tributary stream systems.

2. Lake Waccamaw and the surrounding areas of urban development.

3. Associated pocosins that are extensively drained and used for timber production.

4. Adjacent upland regions that are extensively used for agricultural production.

Sediment pollution is intimately tied to processes associated with different land uses and patterns of changing land use, which in turn is directly dependent upon the geologic framework of the WDS. Thus, we used a two-pronged approach to our study. First, we defined the regional morphological units, defined the underlying stratigraphic framework, and then developed a plausible evolutionary history for the region. By doing this we defined the inter-relationship between the different morphological features and specific ecosystems such as the different kinds of wetlands, parts of the riverine system and lakes, and the different land uses including urban, agricultural, and silvacultural uses.

TABLE 4-1. Summary of the data base developed by the present study for the North Carolina portion of the Waccamaw drainage system.

1. VIBRACORES	80	Cores
Lake Waccamaw	26	
Upper Waccamaw River and Green Swamp	14	
Lower Waccamaw River	35	
Antecedent Floodplain	5	
2. GROUND-PENETRATING RADAR	100	km
Lake Waccamaw	20	
Green Swamp	22	
Waccamaw River	26	
Antecedent Floodplain	32	
3. RADIOCARBON AGE DATES	31	Dates
Lake Waccamaw	9	
Green Swamp	6	
Waccamaw River	7	
Antecedent Floodplain	9	
4. SEDIMENT ANALYSES	94	Samples
5. GEOLOGIC CROSS-SECTIONS	41	Sections
Lake Waccamaw	10	
Green Swamp	4	
Waccamaw River	15	
Regional	9	
Highway Bridges	3	
6. AERIAL PHOTO ANALYSES	6	Sets
	1938, 1951, 1955, 1981, 1983, 1988	

The second approach evaluated aerial photo surveys through time. Within the WDS, ditching and draining of wetlands and modification of the natural drainage system was of greatest importance to the problem of sediment pollution. These modifications greatly changed the processes and rates of drainage and systematically lowered the groundwater table, allowing the basic changes in land use to take place. Consequently, we used the changing pattern of drainage ditches and associated roads through time as the indicator for the second objective.

4.2. Field Surveys

The Waccamaw River is relatively remote with few access points, has dramatic variations in water level and flow conditions, and large segments are dominated by severe channel meandering. These latter segments are extremely narrow with extensive point-bar sand shoals and rapidly eroding cut banks that frequently cause large trees to block the channel and trap extensive sand shoals. Low water usually occurs in the dry months of late spring to fall except when tropical storms influence the drainage basin. Moderate to high water flow occurs after tropical storms in the dry months and during the wet months from late fall to early spring. During low-water stages we used a light weight, 14-foot aluminum jon boat with a 4 hp engine that could readily be portaged over sand shoals and downed trees. During high-water stages, a heavy gauge, 16-foot aluminum jon boat with a 25 hp engine was used to navigate the fast-flowing water. Canoes were used on small streams characterized by channeled flow. On Lake Waccamaw we used the 16-foot jon boat and a 25-foot boat with a 50 hp engine and cabin.

The vast wetlands surrounding the riverine channels are criss-crossed with logging roads supplying basic access into the wetlands. However, the presence of deep drainage ditches on one or both sides of all roads and very dense vegetation often limited direct access into the wetlands. In addition, this severe ditching and draining led to major land use changes in which logging and planting procedures broke down the organic soil and destroyed the original surface morphology of subtle features such as the fossil scroll-bar topography.

4.2.1. Lower Waccamaw River Profiling and Sampling

River profiles were surveyed along the lower Waccamaw River during low-water conditions of summers 1995 and 1996 (Fig. 4-1). The 15 profiles represent straight and highly sinuous channel morphologies and were measured from a marked horizontal rope installed perpendicular to the channel. River water levels were used as a base line for measuring bank heights, with changing water levels corrected relative to water level measured daily at a water-level gauge attached to the NC Highway 130 bridge. Depth from the horizontal ropes to the channel bottom was measured using a marked stainless-steel rod at regular intervals across the channel.

The geologic section on both banks and along the bottom of the channel was described and sampled for subsequent sediment analysis. Four types of sediment samples were collected. Hand samples were obtained from the exposed banks, ponar grab samples were obtained from the subaqueous river channel. Auger and vibracore samples were obtained on the natural levee on each side of the channel (Fig. 4-1).

The 7.6 cm diameter by 5-9 m long aluminum irrigation pipe was used to obtain the vibracores. Length of the vibracore samples obtained varied tremendously depending upon the sediment type. The vibracore pipe was driven into the sediment using a 3 hp engine attached to a modified cement vibrator. The vibrator generated a low amplitude standing wave that fluidized and displaced sediment adjacent to the core pipe, permitting the pipe to penetrate with minimal resistance and sediment disturbance. The upper empty portion of the core pipe was cut off, filled with water, and sealed with a plumber’s helper to create a vacuum and aid in holding the sediment during retrieval. The cores were retrieved using a 4-ton winch attached to a 5 meter high stainless-steel tripod. The bottom of the core barrel was capped, the core was labeled and cut into 1.5 m sections, and transported to the lab for subsequent analysis. We obtained 30 vibracores along the 15 river profiles and an additional 5 cores in paleo-ridge and swale structures in the antecedent floodplain (Fig. 4-1).

FIGURE 4-1. Location map of 30 vibracores on the 15 cross-sectional profiles of the lower Waccamaw River channel and 5 vibracores located on the antecedent floodplain.

4.2.2. Lake Waccamaw Profiling and Sampling

Lake Waccamaw profiles were obtained during the summer of 1995 using a recording fathometer and a GPS navigational system for location. The fathometer transducer was mounted to the side of 25-foot boat and ten bathymetric profiles were run on a grid across the lake (Fig. 4-2). Twenty six vibracores were obtained in the lake at key locations on the fathometer profiles (Fig. 4-2). The cores in the lake were driven into the lake bottom and retrieved by SCUBA divers using the same equipment described in section 4.2.1. The work was done off the stern of the anchored boat, which was used as a platform for the equipment. From these profiles and vibracores, we produced geologic maps of the lake bottom and cross sections across Lake Waccamaw.

4.2.3. Green Swamp and Upper Waccamaw River Sampling

Fourteen vibracores were obtained at several key locations within Green Swamp using the same procedures outlined in section 4.2.1 (Fig. 4-3). These vibracores were limited to a few key areas due to the problems of access along the upper Waccamaw River and within Green Swamp. Consequently, most shallow subsurface samples and stratigraphic information was obtained utilizing hand augers. From these cores and samples, three geologic cross sections were produced across the upper Waccamaw River and one across Driving Creek.

4.2.4. Ground-Penetrating Radar Survey

A 100 km ground-penetrating radar (GPR) survey was carried out on many segments of the WDS (Table 4-1; Fig. 4-4). The GPR survey utilized a Geophysical Survey System Inc. (GSSI) Subsurface Interface Radar System-2 (SIR-2) with 100 and 200 mHz antennas. On the roads the SIR-2 was used out of the back of a 4-wheel drive pickup truck towing the antenna at about 3 mph. The water segments of the survey were run from a 16-foot jon boat with a 25 hp engine. The survey was run with the current at just above idle speed and towed an 8-foot Avon with the antenna resting directly on the rubber bottom. Figure 4-5B displays the uninterpreted GPR data obtained in the river and Figure 4-5A shows the geologic interpretation of the data. From these data, interpreted cross-sectional profiles were constructed along the roads and bridges across various portions of the Waccamaw drainage system (Fig. 4-4).

4.3. Aerial Photo Mapping

All sets of aerial photography available in Brunswick and Columbus Counties were initially evaluated. Many sets were incomplete or in poor condition. Therefore, the photo sets were selected based upon both availability of high quality and completeness, and time intervals that showed the dramatic changes for the Waccamaw drainage system. The following photo and data sets were utilized for this study.

1. 1938 black and white aerial photography flown by the U.S. Department of Agriculture between March 19 and April 4.

2. 1955 black and white aerial photography flown by the U.S. Department of Agriculture on April 8.

3. 1990 data from the U.S. Department of Commerce, Bureau of Census.

FIGURE 4-2. Location map of the 10 fathometer profiles across Lake Waccamaw and the 28 vibracores in Lake Waccamaw.

FIGURE 4-3. Location map of the 12 vibracores and associated geologic cross sections of the upper Waccamaw River and adjacent Green Swamp.

FIGURE 4-4. Location map of the 100 km of ground-penetrating radar lines run in the Waccamaw drainage system, as well as location of the interpreted portion of these GPR lines that are included as figures in this volume. The pink dotted lines show the location of three topographic profiles through Green Swamp.

FIGURE 4-5. Ground penetrating radar (GPR) surveys obtained in the Waccamaw drainage system.

PANEL A. Geologic interpretation of the raw GPR data.

PANEL B. Example of the raw GPR data.

4. 1983 infrared aerial photography flown by the High Altitude Program of the U.S. Department of Agriculture on March 29.

5. 1995 infrared 35 mm photography flown by the ASCS office in Columbus County for the U.S. Department of Agriculture on August 9.

The relevant black and white photo sets that existed within the U.S. Department of Agriculture offices of Brunswick and Columbus Counties were photo copied utilizing bulk 35 mm black and white film and standard copy stands. The film was processed and photos printed to form a duplicate set of the relevant photo series. Mosaics of each photo set were produced for photo analysis. Specific frames were scanned into the computer for subsequent production of photographs for this report.

To develop the history of drainage ditches and roads in the Waccamaw drainage system through time, three time periods were utilized: 1938, 1955, and 1990. The data sources for producing these maps include the following.

1938: Data was digitized from aerial photos obtained by the U.S. Department of Agriculture in March and April 1938; and all weather road designation based on the 1941 U.S. Geological Survey topographic maps.

1955: Data was digitized from aerial photos obtained in April 1955 by the U.S. Department of Agriculture.

1990: Data from the U.S. Department of Commerce, Bureau of Census, Washington DC.

4.4. Geologic Framework Analysis

4.4.1. Sediment Analysis

The vibracores were split, photographed, described, and subsampled for subsequent analysis which included the following: microscope description, sieving for textural characterization, organic carbon composition, and radiocarbon age dating. Representative sediment samples obtained from the vibracores and surface samples were analyzed utilizing standard laboratory procedures as delineated in Folk (1974). All sediment data were entered into Microsoft Excel spreadsheets for statistical analysis based upon Krumbein and Pettijohn (1988).

4.4.2. Radiocarbon Age Dating

Thirty one, in situ and stratigraphically-constrained subsamples obtained from vibracores were submitted to Beta Analytical, Inc., Miami, FL for radiocarbon age dating (Table 4-2). Samples included calcareous shells, organic-rich mud, peat, and specific wood fragments. Dating was based on carbon remaining after relevant pretreatment procedures for calcite shell and organic material. Both standard and accelerator mass spectrometer (AMS) techniques were used to provide age dates used to establish an absolute chronostratigraphy for the WDS.

All age dates used in the present study are calibrated ^{14}C years before present (cal BP), where present is 1950 AD based upon the

Table 4-2. Radio carbon data.

Pretoria Calibration Procedure (Vogel et al., 1993). Beta Analytical, Inc. supplied the conventional ^{14}C ages and the conversions to calibrated ages in years before present. The mean of the calibrated age range was used in this study (Table 4-2).

4.4.3. Stratigraphic Analysis

Sediment lithofacies were assigned to specific sediment units based upon the textural, compositional, and sediment structural analyses. All stratigraphic data were put into Corel Draw for development of interpretive maps and cross-sectional profiles. Stratigraphic correlation was based upon integrating the lithofacies analysis with the interpreted GPR profiles and based upon time control developed by radiocarbon age dating.

5. GEOLOGIC FRAMEWORK

> *Every surficial drainage system is unique and as different from the others as the variation between individual people. Similar to humans, the character and health of each drainage system is dependent upon its inheritance from the gene pool—its physical location relative to the geometry, lithology, and paleotopography of the underlying geologic units and the types, magnitudes, and patterns of energy flow through the ecosystem.*
>
> *S.R. Riggs, 2000*

5.1. Regional Structural Setting

The Waccamaw drainage system (WDS) is situated on the outer coastal plain and on top of a major structural feature called the Carolina Platform (Fig. 5-1). This structural high in the crystalline basement rocks separates the adjacent Southeast Georgia Embayment to the south and Salisbury Embayment to the north (Grow and Sheridan, 1988). The Carolina Platform is interpreted to be an Early Mesozoic syn-rift, tectonic block left behind during the continental breakup of North America and Africa as rifting began about 225-200 million years ago (Grow and Sheridan, 1988; Riggs et al., 1990; Olsen et al., 1991; Snyder, 1994). The Carolina Platform is responsible for creating the major seaward protrusion along the mid-Atlantic continental margin that forms North Carolina and it’s unique coastal system.

Extensive seismic studies on the modern continental shelf suggest the Carolina Platform is a fairly stable structural feature with only minor instability through most of the Tertiary (Mateucchi, 1984; Popenoe, 1990; Riggs et al., 1990; Snyder, 1994). These researchers believe that the Carolina Platform is a topographically high erosional feature that formed an oceanic headland and controlled coastal deposition and development of the Carolina continental margin for the last 100 million years (Figs. 5-1 and 5-2). Historically, the high portion of the Carolina Platform has been called the Cape Fear Arch. However, since the Carolina Platform is an structural block with an eroded paleotopographic surface, Snyder (1982) renamed the topographically highest portion as the mid-Carolina Platform High (Snyder, 1982).

Many researchers believe that the emerged coastal plain has been tectonically active along the Cape Fear Arch initially upwarping during the Cretaceous and continuing to rise sporadically through to the Holocene (Zullo and Harris, 1979; Winker and Howard, 1977; Sollier, 1988; Prowell and Obermier, 1991; and Soller and Mills, 1991). Winker and Howard (1977) demonstrated that elevations of the Orangeburg, Surry, and Suffolk scarps and associated sediments were topographically higher on the western flank of the arch and decreased away from the arch. They defined three upwarping events during the Pleistocene. Zullo and Harris (1979) established that elevations of the Hanover, Suffolk, and Alligator Bay scarps and associated sediments were topographically higher on the east flank of the arch. They hypothesized three upwarp episodes at three million, 75,000, and 30,000 years ago. Soller (1988) delineated five river terraces within the Cape Fear River valley that

FIGURE 5-1. Geologic map for the continental shelf from South Carolina northward to Cape Lookout, North Carolina and showing the regional structural features and distribution of stratigraphic units around the mid-Carolina Platform High or Cape Fear Arch. This geologic map represents those units that either crop out on the seafloor or that occur in the shallow subsurface (below < 1 m of surficial sediment). Figure is from Riggs et al. (1990).

FIGURE 5-2. Geologic map of the North Carolina coastal plain. Map is modified from the N.C. Geological Survey (1985).

formed in response to episodic uplift of the river during the Pleistocene. Location of the river terraces along the northeast side of the river valley and the ongoing southwest movement of the river within its valley, suggested to Soller that uplift of the arch occurred throughout the Quaternary and continues into the Holocene. Cronin (1981) used biostratigraphic data from marine deposits throughout the southeastern US coastal plain to calculate a net post-Miocene, vertical upwarp rate of 1-3 cm/1000 years.

5.2. Stratigraphic Framework

Table 5-1 is a geologic column showing the basic stratigraphic units that occur within the subsurface or crop out within the WDS. This is the terminology that will be used in the present report.

5.2.1. Cretaceous Through Miocene Stratigraphy

The Cretaceous stratigraphic units were deposited over the Carolina Platform and constitute an extensive sediment sequence that forms the geologic framework underlying the WDS (Figs. 5-1 and 5-2). Three Cretaceous stratigraphic units form the basement sequence of sediments that occur as seaward dipping units as depicted in Figure 5-3. Only the youngest Pee Dee Formation crops out and has a direct impact upon the modern dynamics within the WDS.

The Pee Dee Fm. is generally a 400 foot-thick unit of interbedded sequences of 1) dark green to gray glauconitic clayey sand, 2) massive dense clay, and 3) calcareous sand that grades into impure limestone (Swift and Heron, 1969). Most of the lithofacies contain concentrations of microfossils that range up to 25% of the total sediment. Dr. Scott W. Snyder (East Carolina University) prepared numerous samples of these sediment facies for micropaleontological examination. Based upon the foraminiferal assemblages, Dr. Snyder determined that all samples evaluated were Cretaceous in age (Pers. Comm., 2000).

Most of Green Swamp, associated streams, and Lake Waccamaw are either underlain by or incised into the Cretaceous Pee Dee Formation, a thick sequence of calcareous cemented sandstone, sandy moldic limestone, and tight mudstone. The clays of the Pee Dee Formation act as a seal for much of Lake Waccamaw and the surrounding Green Swamp pocosin. However, the Pee Dee sandstone and limestone aquifers discharge significant volumes of ground water into the surface water system wherever the unit is dissected by the surface drainage system. The surface of this very tight mud has a significant amount of paleotopography that probably reflects the incisement of an earlier phase of the modern drainage system.

Throughout the Tertiary, shallow marine and coastal sediments were deposited around the headland of Cretaceous rocks occurring on the mid-Carolina Platform High (Riggs et al., 1990). Most Tertiary units on the North Carolina coastal plain occur as a seaward thickening sedimentary wedge deposited off the northeast flank of the Cretaceous units. These Tertiary units crop out on the continental shelf as they wrap around the seaward nose of the structure (Figs. 5-1 and 5-2) (NCGS, 1985; Riggs et al., 1990; Snyder et al., 1993). However, the WDS is situated high and along the axis of the mid-Carolina Platform High with no Tertiary units of Paleocene through Miocene age occurring within the region. Thus, there was up to 60 million years of time when the Cretaceous sediments were severely weathered and eroded.

FIGURE 5-3. Geologic map shows the distribution of Cretaceous formations in southeastern North Carolina and northeastern South Carolina. These formations occur primarily in the subsurface below a thin, but variable layer of younger surficial sediments. Map is modified from DuBar et al. (1974).

The first Tertiary deposits preserved in the WDS were deposited during the Pliocene (sometime after 5 million years ago) when major sea-level oscillations alternately flooded and drained the WDS (Table 5-1). Coastal marine sediments were repeatedly deposited during sea-level highstands and severely eroded during subsequent sea-level lowstands. The result is a highly dissected series of Pliocene and Quaternary coastal sediments perched on top of a severely eroded surface with significant paleotopography and a paleodrainage system cut into the Cretaceous sediments.

The sediments lying on top of the Pee Dee Fm. within the WDS are of either Pliocene or Quaternary age resulting in a major erosional unconformity between the two sets of sediments. Since the top of the Pee Dee Fm. has been severely eroded for up to 60 million years during the Tertiary, the paleotopography on the Pee Dee surface exerted a major control over the modern drainage system, including the deposition, erosion, and preservation patterns of all subsequent sediment units.

TABLE 5-1. Geologic column for the Waccamaw drainage system as used in this report.*

PERIOD	**EPOCH**	**AGE**	**FORMATION OR GEOMORPHIC UNIT (GMU)**	**APPROX. AGE IN YEARS BP**
QUATERNARY	HOLOCENE		Holocene GMU	< 10,000
	PLEISTOCENE	Late	Wando GMU	10-100 thous
		Middle	Socastee GMU	100-400 thous
			Penholoway GMU	400-700 thous
		Early	Waccamaw Fm.	0.7-1.7 mill
TERTIARY	PLIOCENE	Late	Bear Bluff Fm.	2.2-2.0 mill
			Duplin Fm.	3.0-3.5 mill
CRETACEOUS	Late	Maastrichtian	Pee Dee Fm.	75-66 mill
		Campanian	Black Creek Fm.	84-75 mill
		Santonian	Middendorf Fm.	88-84 mill

* Data composited from Heron and Wheeler (1964); Swift and Heron (1969); DuBar et al. (1974); NCGS (1985); Sollier (1988); Owens (1991); Sohl and Owens (1991); Ward et al. (1991).

5.2.2. Pliocene and Early Pleistocene Stratigraphy

Unconformably overlying the Pee Dee Fm. are a series of very fossiliferous sandstone and sandy limestone units defined as the Pliocene Duplin and Bear Bluff Fm. and the Early Pleistocene Waccamaw Fm. (Table 5-1). These units are irregularly preserved throughout the WDS. Figure 5-4 is a geologic map of the Waccamaw watershed showing the local areas where Pliocene and early Pleistocene sediments are preserved.

The Pliocene and early Pleistocene sediments are generally thin (< 5 m) and basically occur in the subsurface in the higher topographic regions. The Waccamaw Fm. crops out and forms cliffs in two places including the north shore of Lake Waccamaw and west margin of the Waccamaw River at Old Dock (Johnson and DuBar, 1964). Due to the high concentration of fossil marine shells, these units are commonly quarried for use as aggregate or as sources of lime (e.g., Crusoe and Snake Islands).

5.2.3. Pleistocene and Holocene Stratigraphy

Superimposed upon the geologic framework formed by the Cretaceous and Pliocene stratigraphic units, is a surficial layer of Pleistocene and Holocene sediments. These surficial deposits consist of a complex sequence of interbedded sand, mud, and peat sediments. This surficial layer of sediments occurring throughout the upland areas was interpreted by DuBar et al. (1974) to be a series of barrier and back-barrier deposits that formed in response to high sea-level events during Pleistocene interglacials.

These Pleistocene deposits were subsequently reinterpreted by Sollier (1988), Owens (1991), and Sollier and Mills (1991) based upon their geomorphic character and elevation. The basal Pleistocene sediment sequence contains marine fossils and was defined as the Waccamaw Formation. The overlying Pleistocene sediments consisted of a complex sequence of nonfossiliferous sand and mud facies and were subdivided into three formations based largely upon elevation and equated to age. The units include the Penholoway, Socastee, and Wando Formations that occurred at +15 to +21 meters, +9 to +15 meters, and +6 to +9 meters above mean sea level, respectively.

Our research suggests that the Penholoway, Socastee, and Wando Formations are lithologically indistinguishable and little can be done lithologically without a major subsurface research effort involving extensive drilling and remote sensing. Since these three units are not lithologic formations, we suggest that they are at best geomorphic units (GMU). Consequently, we will consider the Penholoway, Socastee, and Wando to be GMUs in this report (Table 5-1). Each unit has been defined on the basis of elevation with the highest being the oldest and sequentially younger units cut into or occurring below the previous. Resolving the complex stratigraphy of the Penholoway, Socastee, and Wando GMUs is beyond the scope of this study. The remainder of this report will focus on the Wando and Holocene GMUs that are incised into the Penholoway and Socastee GMUs.

Figure 5-5 is a map showing the distribution of the four geomorphic units within the WDS. Also on this figure are the locations of four schematic geologic cross sections through the WDS that display the relative spatial relationships between the four GMUs and the

FIGURE 5-4. Geologic map of the Waccamaw drainage system. These formations occur primarily in the subsurface below a thin, but variable layer of Quaternary surficial sediments. Map is modified from the N.C. Geological Survey (1985).

FIGURE 5-5. Map showing the distribution of Pleistocene geomorphic units and locations of four geologic cross sections through the Waccamaw drainage system. The four geologic cross sections are presented in Figures 5-6 and 5-7.

Cretaceous Pee Dee Fm. The four sections are presented in Figures 5-6 and 5-7. Contacts between the GMUs and the Cretaceous are generalized and are based upon many different lines of evidence including field relationships from outcrop data along rivers and in quarries, vibracore and auger holes, ground-penetrating radar surveys, NC Dept. of Transportation bridge bore holes, and topographic characteristics. Most of these relationships for the upland areas and the Penholoway and Socastee GMUs are speculative at best; the relationships of the Wando and the Holocene GMUs are fairly well documented.

The uplands around the Green Swamp Pocosin and Waccamaw River are referred to as the Penholoway Geomorphic Unit (Figs. 5-5, 5-6, and 5-7). This uppermost plain was interpreted to be a marine terrace formed during the Sangamon interglacial when sea level was up to 27-30 meters above present (Cooke 1931; Doering 1960; Johnson and DuBar 1964; DuBar et al. 1974). The Penholoway GMU includes all land in the WDS that is greater than 15 meters above mean sea level and extends southeast from the Surry Scarp and Effingham Sequence of sand ridges of Winker and Howard (1977) and includes their Chatham Sequence of sand ridges. The latter sand ridges parallel the Atlantic Ocean and constitute the high land on the landward side of the modern estuarine system and upon which much of U.S. highway 17 is situated.

The Socastee GMU is defined by the land areas that occur between +9 and +15 meters above mean sea level. Figures 5-6 and 5-7 demonstrate that the Socastee is a narrow zone that is totally incised into the Penholoway GMU and occurs along the outer perimeter of the very broad, paleo-Waccamaw River valley. The Penholoway and Socastee GMUs together form the upland regions around the WDS. They are characterized by extensive flat, poorly drained areas that are now dominated by agriculture. Scattered and irregularly shaped sand ridges, perched pocosins, and Carolina bays occur on the surface throughout the distribution of these units.

Incised within the Socastee is what appears to be the modern Waccamaw River with its very broad floodplain (Figs. 5-6 and 5-7). However, this valley fill does not all represent modern floodplain and can be further subdivided into the Wando GMU and Holocene GMU. Most of the valley fill represents the Wando GMU, an antecedent floodplain that has slightly higher elevations (+6 to +9 meters above mean sea level) and is dominated by paleo-channels and associated pointbar scrolls. The Holocene channel and active floodplain constitute a small portion of the total valley fill occurring less than 6 meters below mean sea level. Wherever the modern Waccamaw River is incised down into the Wando GMU the channel is wide, deep, and fairly straight with broad sweeping meanders. These channels are usually rock bound along one or more sides and are very high so that they are not overtopped during normal flooding conditions.

The Holocene GMU and the associated sediments of the Waccamaw River occur within those river segments dominated by highly meandering channels bounded by active point bars and low cut banks. These active sediment-choked portions of the Waccamaw River have narrow, shallow channels with low banks and broad modern floodplains. Since these floodplains are flooded during most of the yearly wet season, they are characterized by wetland vegetation and are rarely converted to forestry use.

FIGURE 5-6. Three schematic, west to east geologic cross sections through the Waccamaw drainage system show the relative relationship between geomorphic units used in this report. See Figure 5-5 for location of cross-sectional profiles.

PANEL A. Profile A-A′ is along highway 904 and crosses the lower Waccamaw River.

PANEL B. Profile B-B′ extends from Butler Crossroads to highway 211 and crosses the lower Waccamaw River.

PANEL C. Profile C-C′ extends from highway 905 east to the county line and crosses White Marsh, the upper Waccamaw River, and the Green Swamp pocosin.

FIGURE 5-7. One schematic, south to north geologic cross section through the Waccamaw drainage system showing the relative relationships between the geomorphic units used in this report. See Figure 5-5 for location of the cross-sectional profile.

PANEL D. Profile D-D’ extends from Horse Pen Ridge north to the town of Lake Waccamaw and crosses Juniper Creek, the Green Swamp pocosin, and Lake Waccamaw.

5.3. Geologic Framework--Waccamaw Drainage System

The Waccamaw drainage system is defined for this report as that portion of the Waccamaw River watershed occurring within Brunswick and Columbus Counties of North Carolina. The WDS and associated habitats and sediments are either incised into or perched on top of an inherited geologic framework of older stratigraphic units. Composition, distribution, morphology, and evolutionary history of these older stratigraphic units control the geometry and dynamics of the modern WDS.

The lower Waccamaw River today is an underfit stream with a modern channel that is significantly smaller than the overall river valley or the paleochannels that occur within the antecedent floodplain of the Wando GMU. The lower Waccamaw River drains the Green Swamp pocosin through the Old Dock narrows formed by the Crusoe Island ‘cork’. This ‘cork’ is the result of more resistant deposits of Plio-Pleistocene sediments that occur on both Crusoe Island and adjacent upland areas (Fig. 3-3). Consequently, the entire character of the drainage system changes dramatically from a broad sheet-flow dominated pocosin system above Crusoe Island to primarily an incised riverine system below the Island.

6. DYNAMICS OF THE MODERN WACCAMAW DRAINAGE SYSTEM

6.1. Physiographic Provinces

> *It was as though there were two impulses at work: one favored complication, circumlocution, and obliquity, and was always correcting and being corrected by the other, which appealed to common sense, and urged the straightforward, direct path from the source to the sea. Elaboration and simplification continually explained each other away, and neither held the advantage.*
>
> *F. Burroughs, 1992*

The upper portion of the Waccamaw drainage system consists of the Green Swamp basin, which includes Lake Waccamaw and the upper Waccamaw River as well as many other components (Fig. 3-3). The Green Swamp basin drains into the well-developed riverine system of the lower Waccamaw River (Fig. 3-3). The juncture point of these two systems is south of Crusoe Island where the upper Waccamaw River, White Swamp, and Juniper Creek all join to form the lower Waccamaw River. Crusoe Island, which is situated within the lowermost portion of the Green Swamp basin, is like a stopper in a vinegar bottle with well-developed streams flowing along both sides of the island. A stream valley profile from the headwaters of Green Swamp to the NC-SC border (Fig. 6-1-1) shows generally uniform gradients with significant breaks in slope occurring only at Lake Waccamaw and the Old Dock--Crusoe Island bridge.

Green Swamp is like a shallow saucer that is tilted gradually uphill and away from Crusoe Island. The saucer-like basin is dominated by swamps along the entire sloping surface and is broken only by a series of irregular sized and shaped sand ridges or ‘islands’ rising above the Green Swamp wetlands (Fig. 6-1-1). Wherever the drainage system passes through narrows between sand ridges, the streams have well-defined channelized flow. However, away from these sand ridges, each stream channel has been subsequently filled and the modern drainage shifts to sheet flow. Of course, this drainage character has now been extensively modified by ditching of the wetlands.

South of Crusoe Island, the lower Waccamaw River occupies a well-defined riverine valley that consists of three components. The broad expanse of the floodplain composed of older sediments with slightly higher elevations was formed during an earlier phase of riverine deposition under different climatic conditions than exist today. This portion of the riverine system constitutes the antecedent floodplain or the Wando geomorphic unit (Figs. 5-6 and 5-7). Incised into the antecedent floodplain is the active channel of the modern Waccamaw River and small segments of active floodplain (Figs. 5-6 and 5-7). The latter forms wherever the modern Waccamaw River is not incised into the underlying Cretaceous Pee Dee Formation, but rather flows on top of it and is able to develop an active meandering channel that reworks the antecedent floodplain sediments.

FIGURE 6-1-1. Profile of stream gradient extending from the interstream divide at Seven Mile Bay, south through Buckhead Branch, Friar Swamp, Big Creek, Lake Waccamaw, and down the length of the upper and lower Waccamaw Rivers to the Carolina state boundary. Notice the relationships between 1) Green Swamp pocosin, Lake Waccamaw, and the upper Waccamaw River to the presence of Pleistocene age sediments on top of the Cretaceous Pee Dee Formation; and 2) the lower Waccamaw River to the Cretaceous Pee Dee Formation throughout its length. Profile data were obtained from the U.S. Geological Survey 1:24,000 scale topographic maps—notice the extremely large vertical exaggeration on this drawing.

For the purposes of this report, we will subdivide the WDS into four physiographic components: Lake Waccamaw, Green Swamp, upper Waccamaw River, and lower Waccamaw River (Fig. 3-3). The upper Waccamaw River runs through the Green Swamp extending from the Old Dock-Crusoe Island bridge northward to the weir dam on the southeast corner of Lake Waccamaw. Lake Waccamaw, a large Carolina bay lake is an important and distinct component of the WDS. The name Green Swamp will be used as a general term to include the entire and very large pocosin area north of the Old Dock--Crusoe Island--Freeland bridge road and including the following swamps (Alligator, Boggy, Bogue, Friar, Gray, Green, Lake, Little, Rattlesnake, and River), along with various Bays (Alligator, Bee Island, Good Luck, Singletree, and Wide), and Openings (Big, Reedy Branch, etc.). White Marsh, a major riverine input to Green Swamp, will not be discussed directly. The fourth physiographic province is the lower Waccamaw River, which extends from the Old Dock--Crusoe Island bridge, southwest to the Carolina state boundary.

6.2. Lake Waccamaw

> *The shore was low, scarcely a foot above water, and as perfectly flat as the lake itself. It was lined with summer houses, each house basically a box on stilts at the water's edge, and each with a dock extending a hundred feet or so out into the lake. Each dock had a boatshed at the end, and a big outboard runabout suspended from the rafters of the shed, so that the effect was of coming upon a lake where all the boats had gone to roost....smoke from the charcoal grills would waft along the waterfront and the boats and water skiers would buzz round and round, like waterbugs in a birdbath.*
>
> *F. Burroughs, 1992*

6.2.1 Introduction

Lake Waccamaw is one of the largest natural Carolina bay lakes in North Carolina, however it is distinctly different than most bay lakes. A rock bluff shoreline (Fig. 6-2-1) and the nearly neutral to slightly alkaline pH of the lake waters (Casterlin et al., 1984; Stager and Cahoon, 1987; Cahoon et al., 1993) make Lake Waccamaw a truly unique North Carolina lake. A portion of the north lake shore is characterized by an eroding rock bluff that ranges from 3 to 5 meters in height (Fig. 6-2-2). The rock bluff is composed of the early Pleistocene Waccamaw Fm., a poorly indurated fossiliferous limestone that is highly porous and readily weathered by shallow groundwater flow (Fig. 6-2-2). This limestone unit underlies much of the lake and the entire upland area north of the lake shore (Fig. 5-4).

Due to the nearly neutral to slightly alkaline pH of Lake Waccamaw, there is a remarkable array of endemic fish and mollusks with a high diversity of other plant and animal species in the surrounding swamps. Consequently, the NC DEM (1995) concluded "without question, Lake Waccamaw is the single-most significant lake in North Carolina from a biological point of view". Porter (1985) stated that the 21 plus known species of endemic fresh-water mollusks make the lake "one of the most species-rich lakes in the Western Hemisphere". The abundance and diversity of biota are intimately interdependent upon and are the direct results of two factors: 1) the origin and evolutionary development of this unique lake system and 2) the daily to millennial scale hydrodynamic processes that maintain the lake. To maintain and preserve the lake and its living resources requires that we understand both the lake history and its dynamics.

6.2.2 Regional Setting

Lake Waccamaw is an elliptical-shaped, Carolina bay lake (Fig. 3-3) that is about 5.5 miles by 3.5 miles in diameter with a surface area of 8,950 acres and a volume of 44,000 acre-feet. It is a shallow water body with an average depth of 1.5 m and a maximum depth of 3.3 m with a hydraulic retention time of 242 days (NC DEM, 1995). Big Creek drains into Lake Waccamaw from Friar Swamp to the north (Fig. 6-2-3) and the upper Waccamaw River drains out of the lake on the south side (Fig. 6-2-4). A weir dam built in 1943 (Fig. 6-2-5) maintains water level in Lake

FIGURE 6-2-1. Aerial photographs of the north shoreline of Lake Waccamaw. The star indicates the same location on both photos.

PANEL A. North shoreline showing the following features: 1) sandy limestone bluff formed by the outcropping Waccamaw Formation, 2) development of the town of Lake Waccamaw on top of the bluff, 3) shallow perimeter platform shelf actively eroding into the rock bluff, and 4) small sand waves on the perimeter platform that are being derived from the erosion of the sandy limestone bluff. Photograph was flown in spring 1988 by the Columbus County ASCS office, U.S. Department of Agriculture.

PANEL B. Infrared photograph of the same area along the north shoreline showing the extensive submerged aquatic vegetation that is growing on the eroded perimeter platform. Photograph was flown on 8/9/1995 by the Columbus County ASCS office, U.S. Department of Agriculture.

FIGURE 6-2-2. Photographs of the Lake Waccamaw north shoreline.

PANEL A. Eroding rock bluff composed of fossiliferous sandy limestone of the early Pleistocene Waccamaw Formation. The bluff is approximately 5 m high.

PANEL B. Close-up photograph of the Waccamaw Fm. showing the fossiliferous character of the sandy limestone. The whole shell in the lower right side of the photo is approximately 10 cm in diameter.

FIGURE 6-2-3. Infrared aerial photograph of Big Creek flowing out of Friar Swamp and into the NE corner of Lake Waccamaw River. Notice that 1) the sheet flow dominated character of Friar Swamp changes to channeled flow in Big Creek as the generally unmodified drainage approaches Lake Waccamaw, 2) the growth of swamp forest and accumulation of peat is slowly “drowning” the old Carolina Bays. Photograph was flown on 3/29/1983 by the High Altitude Program of the U.S. Department of Agriculture.

FIGURE 6-2-4. Infrared aerial photograph of the upper Waccamaw River flowing out of the south shore of Lake Waccamaw and into Lake and River Swamps. Notice the following features: 1) high density of shoreline development to the west and natural swamp forest shoreline of the Lake Waccamaw State Park to the east of the dam at the upper Waccamaw River discharge point, 2) character of the generally unmodified drainage within a fairly natural portion of Green Swamp pocosin, 3) development of a drainage system and initial deforestation in the southeast corner of the photo, and 4) the growth of swamp forest and accumulation of peat slowly “drowns” the old Carolina Bays. Photograph was flown on 3/29/1983 by the High Altitude Program of the U.S. Department of Agriculture.

FIGURE 6-2-5. Photographs of the southern shoreline of Lake Waccamaw.

PANEL A. Aerial photograph of the south and southeastern shore showing the mouth of the upper Waccamaw River and location of the weir dam. Notice the following features: 1) undeveloped shoreline of the Lake Waccamaw State Park and developed shoreline north of the weir dam, 2) shallow perimeter platform covered by an active sand sheet dominated by NW-SE oriented sand waves, and 3) aquatic grasses growing on smaller sand waves at the river mouth and along the developed shoreline. Photograph was flown in spring 1988 by the Columbus County ASCS office, U.S. Department of Agriculture.

PANEL B. Photograph of the weir dam at the upper Waccamaw River mouth and looking north into Lake Waccamaw. Notice the black water being discharged through the dam and the vast areas of aquatic grasses growing on shallow sand waves on top of the perimeter platform. The line of grasses in front of the boat occurs near the edge of the perimeter platform.

Waccamaw. Lake Waccamaw State Park occupies 1.5 miles of shoreline along the southeastern portion of the lake and adjacent swamplands (Fig. 6-2-5). The remainder of the lake consists largely of private residential sites with a vast array of boat docks reaching into the lake (Fig. 6-2-1).

Figure 6-2-6 is a map of Lake Waccamaw showing the general bathymetry and distribution of 28 vibracore holes and six geologic cross sections. The six geologic cross sections are presented in Figures 6-2-7 and 6-2-8. Figure 6-2-9 presents the bathymetry on top of the Cretaceous Pee Dee Fm. and a paleodrainage system that is incised into the surface of the Cretaceous sediments. Geologic cross sections (Figs. 6-2-7 and 6-2-8) demonstrate that the lake is essentially an erosional feature that has two basic parts. The one-meter water depth contour line (Fig. 6-2-6) generally defines the shallow perimeter platform like a lip around the deeper, flat-bottomed portion of the bowl that forms the central basin of the lake. Both parts of the bowl, as well as the lake shoreline, are erosional features that are actively being scoured by storm waves with only local and minor areas of sediment deposition.

It is also interesting to note that Big Creek (Fig. 6-2-3), which drains Friar Swamp into the NE side of Lake Waccamaw, is significantly deeper than the floor of the Lake (Figs. 6-2-7 and 6-2-8). However, there is a paleodrainage system underlying Lake Waccamaw (Figs. 6-2-7 and 6-2-8) that is severely incised into the older sediment units and was subsequently back-filled with riverine sediments. The depth of incisement within Lake Waccamaw is similar to the present depth of Big Creek NE of the Lake (Fig. 6-2-8). Neither the deeper channel of Big Creek nor the shallower Lake Waccamaw basin are accumulating significant amounts of modern sediment on their respective floors.

6.2.3. Sedimentation in Lake Waccamaw

Figure 6-1-1 diagrams the stream gradient profile for both the upper and lower Waccamaw Rivers. The uppermost interstream divide occurs in the Seven Mile Bay with the stream profile heading down Buckhead Branch, through Friar Swamp, Big Creek, Lake Waccamaw, and the upper Waccamaw River. The dam on Lake Waccamaw forms a temporary base level for the upper portion of the drainage system (Fig. 6-2-5B).

Big Creek is a deep (> 5 m), black-water creek draining upper Green and Friar Swamps. The floor of Big Creek is eroded into the dense fossiliferous sediments of the Cretaceous Pee Dee Fm. (Figs. 6-1-1, 6-2-7, and 6-2-8) with minor amounts of modern sand and organic detritus scattered on the eroded sediment surface. Through time, the eroding sandy limestone bluff along the north lake shore supplied enough sand by longshore transport along the perimeter platform to form a subaerial sand spit (Fig. 6-2-3). This migrating spit formed a dam across the swamp, closing off the Lake everywhere except for the Big Creek channel itself. The bottom of Big Creek steps up into the much shallower bottom of Lake Waccamaw.

As stated previously, the Big Creek channel and Lake Waccamaw are basically erosional bottoms with only local sites of modern sediment accumulation. In Big Creek modern sediment is generally less than 10 cm thick and is clean quartz sand with some large organic detritus. In Lake Waccamaw there is less than 1 m of clean quartz sand that has accumulated on the shallow perimeter platform along the north, east, and south side of the lake (Figs. 6-2-1, 6-2-5, and 6-2-10B). Minor amounts

FIGURE 6-2-6. Bathymetric map of Lake Waccamaw shows the location of 28 vibracores and six geologic cross sections of the lake. The bathymetry data is based upon a survey utilizing a recording fathometer.

FIGURE 6-2-7. Two geologic cross sections of Lake Waccamaw. See Figure 6-2-6 for location of vibracores and cross-sectional profiles.

PANEL A. Geologic cross section P8 that runs NW-SE across the N side of Lake Waccamaw.

PANEL B. Geologic cross section P7 that runs NW-SE across the middle of Lake Waccamaw.

FIGURE 6-2-8. Four geologic cross sections of Lake Waccamaw. See Figure 6-2-6 for location of vibracores and cross-sectional profiles.

PANEL C. Geologic cross section P9 that runs NW-SE across the S side of Lake Waccamaw.

PANEL D. Geologic cross section P6 that runs SW-NE across the W side of Lake Waccamaw.

PANEL E. Geologic cross section P4 that runs SW-NE across the middle of Lake Waccamaw.

PANEL F. Geologic cross section P11 that runs SW-NE across the E side of Lake Waccamaw.

FIGURE 6-2-9. Bathymetric map on top of the Cretaceous Pee Dee Fm. showing the occurrence of a paleodrainage system that existed before Lake Waccamaw formed. See Figures 6-2-7 and 6-2-8 for the channel geometry and geologic character of the sediments that backfilled these channels.

FIGURE 6-2-10. Aerial photographs of the Lake Waccamaw paleo-shorelines.

PANEL A. The NW shore of Lake Waccamaw showing the paleo-shoreline of a former and larger lake. The old portion of the lake bed is now filled with swamp forest wetlands and peat. Cove canal was dug to supply fill dirt for development of the coastal lake rim around this portion of the lake (Figs. 6-2-7 and 6-2-8). Photograph was flown in spring 1988 by the Columbus County ASCS office, U.S. Department of Agriculture.

PANEL B. The SE shore of Lake Waccamaw and Lake Waccamaw State Park showing the paleo-shoreline of a former and larger lake. This photo shows the following features: 1) paleo-sand ridge of a former and larger lake, 2) minor sand ridge associated with the present lake shoreline, 3) shallow perimeter platform covered with an extensive and modern sand sheet, 4) active sand waves that are parallel with the orientation of the lake, and 5) sand spit and offshore sand waves associated with the mouth of Big Creek. Photograph was flown in spring 1988 by the Columbus County ASCS office, U.S. Department of Agriculture.

of this surficial sand occur off the flank of the platform to and thin into the deeper lake basin (Figs. 6-2-7 and 6-2-8). This layer of modern sand has two possible sources. Some of the sand is obviously being derived from the ongoing erosion of the sandy limestone bank along the north shore (Figs. 6-2-1 and 6-2-2). It is also possible that Big Creek, flowing under drier climatic conditions that predate development of the Friar pocosin, deposited deltaic sands that were subsequently reworked along the shoreline (Fig. 6-2-3).

The remainder of the deep basin in Lake Waccamaw has received less than 10 cm of very fine grained, detrital organic matter (Figs. 6-2-7 and 6-2-8). Some of this surficial layer of soft sediment is probably routinely resuspended and redeposited by major storm events. There are three possible sources of this fine organic detritus: 1) erosion of the swamp forest shorelines along the southern segment of the Lake (Figs. 6-2-4 and 6-2-5), 2) erosion of peat banks that crop out in shallow water on the perimeter platform along the SW to NW lake segment (Fig. 6-2-10), and 3) import of organic detritus from upstream swamp forests during major flood events.

Certain types of Lake Waccamaw shorelines are slowly eroding for the following reasons. The N coast consists of a very porous sandy limestone bluff of the Waccamaw Fm. The limestone is actively weathered by chemical processes resulting from interaction with the groundwater flow. As the rock is weakened, large segments of the bluff subsequently collapse. But dense vegetative armoring occurs on the bluff (Fig. 6-2-2A), as well as the swamp forest shorelines, which slows the erosion process significantly against direct wave attack. The sand shorelines of the E and SE end of the lake have ample beach sediment to cover old substrate and absorb wave energy. The remaining portion of the developed shoreline along Cove Canal represents dredged sediments that are heavily armored with grass and cypress and the shore is often bulkheaded. Some sediment is produced through this slow, but ongoing erosional process.

Fine organic matter and minor amounts of clay go into suspension during storms and are flushed from the lake by the blackened flood waters. Any quartz sand in the system stays behind as residual sediment and accumulates along the shoreline and on the shallow perimeter platform. All carbonate sediments are quickly lost to chemical weathering. During nonstorm periods, fine sediment in the water column settles out as a thin floc layer on the lake bottom. Continued discharge of alkaline groundwaters from the underlying Waccamaw and Pee Dee Formations causes the black waters to become clear and more alkaline (higher pH). The next storm erodes the shoreline and flushes organic-rich waters out of adjacent swamps causing the water to become black colored and more acidic (lower pH). However, much of the fine organic material in suspension is either flushed from Lake Waccamaw with the discharging flood waters or temporarily settles out on the Lake bottom.

Several possible explanations exist for lack of sediment accumulation in the Big Creek deep channel and Lake Waccamaw. First, is the possibility that little or no sediment (either sand, mud, or organic matter) has been transported by Big Creek during modern times. This is not likely since upstream Friar and Green Swamps represent major sources of at least organic detritus, as well as sands from previous highway construction through the swamp. However, if there had been sediment input, the deep channel portion of Big Creek at the mouth and behind the shallow water lake floor, would have filled in to the base level of the lake. However, persistence of the deeply incised channel, absence of fine organic detritus, and thin accumulation of clean quartz sand suggests that there is a continuous and major flow of groundwater from the underlying Cretaceous Pee Dee Formation into Big Creek. Discharge from groundwater springs winnow the sands and keep fine organic detritus in suspension.

6.2.4. Old Lake Shorelines

The NW and SE shores of the Lake display old shorelines that were occupied during previous geologic times when lake level was significantly different than present (Fig. 6-2-10). The eroded platform on the NW side of the Lake (Fig. 6-2-10A) was eroded into the Waccamaw limestone that occurs between 1-2 m below the present Lake level. The eroded surface slopes from something less than 1 m below present Lake level at the paleo-shoreline to about 2 m at the modern shoreline (Fig. 6-2-7 and 6-2-8). The low slope of this paleo-perimeter platform resulted in the formation of a long-term wetland that formed 1-2 meters of in situ peat. Today, this paleo-perimeter platform remains a swamp forest habitat behind the stabilized modern shoreline built from dredged material in the construction of Cove Canal (Fig.6-2-10A).

The eroded platform below the paleoshoreline on the SE side of the Lake was filled with sand and small dunes and became heavily forested (Fig. 6-2-10B). Above the paleoshoreline is a larger topographic ridge consisting of more extensive aeolian dunes and vegetated with upland hardwood scrub forest (Fig. 6-2-10B). The well drained quartz sand soil that constitutes this topographic ridge is about 2-3 m thick, thins to the south, and disappears as both ridge and paleoshoreline approach the S shore.

The abundant sand in the subaerial ridge extends offshore where the sand has been eroded and reworked on the shallow platform producing the zone of maximum sand waves. The sand waves diminish in abundance and size in both the NE and SW directions. The sand waves occur at oblique angles to the shoreline (Figs. 6-2-5A and 6-2-9B) and are oriented NW-SE, parallel to the axis of the lake itself. Examination of the 1938 (Fig. 6-2-11), 1955 (Fig. 6-2-11), and 1988 (Figs. 6-2-5A and 6-2-10B) aerial photos demonstrate several interesting points. First, the sand waves persist through time with the same orientation. Second, there is an apparent increase in both the size of sand waves and the lateral distribution of sand on the perimeter platform from 1938 to the present. The latter is most obvious along the northern portion between Lake Waccamaw State Park and Big Creek (Fig. 6-2-10B). Extensive development of both the modern shoreline and the area where the paleo-sand ridge coincides with the modern shoreline has taken place between 1955 (Fig. 6-2-11) and 1988 (Fig. 6-2-10B).

6.2.5. Paleo-Drainages in Lake Waccamaw

Figure 6-2-6 is a general bathymetric map of Lake Waccamaw. The deepest portion of the lake is elongated N-S and NE-SW, reflecting an old, pre-lake drainage system. Figure 6-2-9 shows the depth to the top of the Waccamaw Formation or older units depicting the paleo-bathymetry prior to formation of Lake Waccamaw and subsequent fresh water sedimentation associated with the Green Swamp drainage system. This paleo-topography was produced by the paleo-drainage system that existed on this ancient land surface. Several channel structures were cored along these drainages as indicated on the cross sections in Figures 6-2-7 and 6-2-8. Interpretation of the paleobathymetry and the associated

FIGURE 6-2-11. Aerial photographs of the SE shore of Lake Waccamaw show the paleo-shoreline of a former and larger lake.

PANEL A. Notice the 1) large paleo-sand ridge and associated dunes landward of the paleo-shoreline, 2) the minor and heavily vegetated sand ridge associated with the modern lake shoreline, and 3) the small and partially preserved Carolina Bay features around the lake perimeter. Photograph was flown between 3/19/1938 and 4/4/1938 by the US Department of Agriculture.

PANEL B. Notice the 1) large paleo-sand ridge and associated dunes landward of the paleo-shoreline, 2) the minor and heavily vegetated sand ridge associated with the modern lake shoreline, and 3) the water flow structures in the swamp around the lake perimeter. The latter structures are believed to be wind driven fire debris flotsom following a severe fire that burned Green Swamp the prior month in 1955. The high water levels resulted from decreased levels of vegetative transpiration following the fire. Also, notice that the Carolina bays that were barely visible in the 1938 aerial photograph (Fig. 6-2-10) are no longer visible in 1955. Photograph was flown on 4/8/1955 by the U.S. Department of Agriculture.

channel structures suggest that prior to formation of Lake Waccamaw, the main paleochannel connected Big Creek with the upper Waccamaw River.

The paleodrainage channels appear to be Late Pleistocene in age based upon the following three pieces of evidence (Figs. 6-2-7 and 6-2-8). 1) They cut through the early Pleistocene sediments (Waccamaw Fm. and associated units) and are incised into the Cretaceous Pee Dee Fm. 2) They have been backfilled with fining upward sequences of riverine sediments that all date between 35,000 and 32,000 BP (Table 4-2). 3) The channel fill sediments are overlain by Holocene age sediments with radiocarbon ages that are < 9,000 years BP and dampen the paleobathymetry producing a much flatter central basin (Fig. 6-2-6).

The 30,000 year radiocarbon dates on the channel fill sediments have large error bars (Table 4-2) since they are in the questionable time period for this dating technique. However, they do tell us that these channels were active prior to and were backfilled during the warming climatic conditions of the mid-Wisconsin interglacial. This set the stage for development of Lake Waccamaw during the cold climatic regime associated with the last glacial maximum, which occurred between 20,000 to 14,000 years BP. The evolutionary history of these channels and the formation of Lake Waccamaw will be discussed in a later section.

6.3. Green Swamp Pocosin

> *In time of freshet, the water could spread out horizontally for miles, and so rose very little. At present, the floor of the swamp was out of the water, although you would stop short of calling it dry land. It was dank and oozing....the closeness of the swamp....added to the afternoon’s feeling of emptiness and abandonment.*
>
> *F. Burroughs, 1992*

6.3.1. Introduction

Green Swamp is a broad, irregularly circular pocosin system that surrounds Lake Waccamaw and the upper Waccamaw River drainage system (Fig. 3-3). This Pocosin is situated in a shallow, bowl-shaped basin with the upper rim occurring at about 21 meters above mean sea level. The entire slope of this shallow basin, as well as the upper flat rim, contain extensive wetlands. The discharge point occurs at the south end of the ‘narrows’ around Crusoe Island at about 9 meters above mean sea level (Figs. 3-3 and 6-3-1). The upper Waccamaw River, in combination with White Marsh and Juniper Creek, form the trunk streams of the pocosin drainage system (Figs. 6-3-2, 6-3-3, and 6-3-4). Many small tributary streams drain specific portions of the vast pocosin including Driving Creek (Fig. 6-3-5), Friar Swamp and Big Creek (Fig. 6-2-3), River and Lake Swamps (Fig. 6-2-4), along with numerous others.

The vast Green Swamp pocosin is generally underlain by a dense clay with minor paleotopography that forms the higher ridges and islands such as Riegel, Clewes, Long, Big, and Horse Pen Ridge, etc. and Honey, Kentuck, Caison, and Big Islands (Figs. 6-3-2, 6-3-3, and 6-3-5). Based upon limited vibracore data (Fig. 6-3-6), the central portion of the pocosin appears to be underlain by the tight, sandy mud of early Pleistocene age, interpreted to be lake deposits. Both higher along the upper rim of the basin and lower within the ‘narrows’ around Crusoe Island, the lake sediments thin onto the Cretaceous Pee Dee Fm. (Fig. 6-3-6C and 6-3-6D). In these areas the Cretaceous sediments rise to within 1 to 2 m of the land surface with channels of the upper Waccamaw River and Juniper Creek in the Crusoe Island area incised through the Pleistocene and Cretaceous sediments. Consequently, in these areas the streams are locally rock-bound within the underlying Cretaceous sandstones (Figs. 6-3-2, 6-3-3, and 6-3-4).

The fossiliferous limestone of the Waccamaw Formation forms the highland associated with both Crusoe and Snake Islands. The unit crops out locally along the river banks and is quarried for shell aggregate. It is the presence of the Waccamaw Fm. preserved on the Cretaceous Pee Dee Fm. that produces the Crusoe Island ‘Narrows’ and is responsible for the formation of the Green Swamp pocosin. The overlying Holocene sand and peat sediments constitute between 1-2 m of fill throughout most of the Green Swamp except in the major riverine valleys where the fill can increase to 3 to 4 m.

FIGURE 6.3.1. Profile of stream gradient extending from Crane Savannah, south through Honey Island Swamp, Juniper Creek, and to the confluence with the upper Waccamaw River. A land gradient profile, that runs parallel to the stream gradient profile, demonstrates the topography through which the streams have eroded. Profile locations are on Figure 4-4. Data were obtained from the U.S. Geological Survey 1:24,000 scale topographic maps.

FIGURE 6-3-2. Infrared aerial photograph of the upper Waccamaw River and White Marsh drainages through the River and Boggy Swamp portions of the Green Swamp pocosin. Notice the character of the generally unmodified drainage within a fairly natural portion of the pocosin. Photograph was flown on 3/29/1983 by the High Altitude Program of the U.S. Department of Agriculture.

FIGURE 6-3-3. Infrared aerial photograph shows the upper Waccamaw River, White Marsh, and Boggy Swamp as they flow between Snake and Crusoe Islands. Notice 1) how Boggy Swamp pinches down to the ‘narrows’ at the Old Dock-Crusoe Island bridge and 2) the generally unmodified drainage within a fairly natural portion of the pocosin. Photograph was flown on 3/29/1983 by the High Altitude Program of the U.S. Department of Agriculture.

FIGURE 6-3-4. Infrared aerial photograph shows the junction of upper Waccamaw River and Juniper Creek to form the lower Waccamaw River. Notice the ‘narrows’ formed by the land areas of Old Dock—Crusoe Island—Juniper. Highway 1928 forms a road dam across the ‘narrows’, which results from the Waccamaw Formation occurring near the land surface on each of these land areas (Figs. 5-4 and 6-1-1). Notice the 1) initial stages of drainage ditch development and logging along the southern margin and 2) remnants of paleo-channels and meander ridge and swale features that are in the process of being ‘buried’ by the accumulation of swamp forest peat. Photograph was flown on 3/29/1983 by the High Altitude Program of the U.S. Department of Agriculture.

FIGURE 6-3-5. Infrared aerial photograph of the well-developed channel flow of Driving Creek as erodes into the sand ridge forming Caison, Big, and Little Islands. The steeper gradient of the channeled portion connects to the lower gradients in the pocosins dominated by sheet flow on the Penholoway GMU to the east and the Socastee GMU to the west. Figure 6-3-1 shows the change in stream gradient across this same sand ridge slightly to the north. Photograph was flown on 3/29/1983 by the High Altitude Program of the U.S. Department of Agriculture.

FIGURE 6-3-6. Four geologic cross sections of the Green Swamp. See Figure 4-4 for location of vibracores and cross-sectional profiles.

PANEL A. Geologic cross section across the channel of the upper Waccamaw River at 1.5 km south of the Lake Waccamaw dam.

PANEL B. Geologic cross section across the channel of upper Waccamaw River at ‘burnt-out-bridge’ on the Red Bug logging road.

PANEL C. Geologic cross section of the eastern half of the ‘narrows’ along the Old Dock--Crusoe Island bridge (NC Hwy 1928) over the upper Waccamaw River.

PANEL D. Schematic geologic cross section along highway 211 across Driving Creek, Green Swamp pocosin.

6.3.2. Relationship of Geomorphic Units (GMU) to Wetlands

Figure 5-5 shows the lateral distribution of the four GMUs within the WDS. Cross-sections B-B′, C-C′, and D-D′ (Figs. 5-6 and 5-7) show the cross-sectional relationship through various portions of Green Swamp. Based upon the distribution and morphological character of the GMUs, we can generally define four levels of wetland deposits within Green Swamp (Fig. 5-5).

The uppermost wetlands (approximately 15 meters above mean sea level and greater) occur above a major break in the slope of the basin (Fig. 6-3-1). The Penholoway wetlands (Figs. 5-5, 5-6, and 5-7) occur on top of the drainage divides with the outer portion of the swamps flowing either into the Cape Fear River basin on the N and E or into the coastal drainage system on the S (Figs. 3-1 and 3-2). The swamps on the Penholoway GMU were the first wetlands targeted for serious ditching for agricultural purposes back in the 1920's.

Prior to human development, drainage within the Penholoway GMU was dominated by sheet flow without distinct channels. Stream gradients increase significantly over the break in slope of the Penholoway surface with the drainage changing to well developed and deep channel flow. Channeled flow over this break in slope has caused the streams to incise into and erode through the sand ridge as demonstrated in Figure 6-3-1. Stream gradients decrease below the slope break causing the smaller drainages to revert to sheet flow. A good example of this is Driving Creek at Hwy 211, which drains The Nature Conservancy's Big Opening area (Fig. 6-3-5). However, larger streams such as Honey Island Swamp maintain good channeled flow below the slope break (Fig. 6-3-1).

The geomorphic break results from the paleotopographic rise of the underlying Cretaceous Pee Dee Fm. (Fig. 6-3-6D). Also, the late Pleistocene lake deposits that fill the lower Green Swamp basin (Fig. 6-3-6A, 6B, and 6C) grade upslope to an irregular sand ridge (Riegel Ridge, Honey, Caison, Big, and Little Islands) that is perched along the upper break in slope (Fig. 6-3-1) of the Penholoway GMU surface (Fig. 5-5). This rim of sandy soil varies in thickness from 0.5-1.5 meters and tends to have slightly lower water tables relative to the adjacent areas underlain by clay and humic (peat) soils. Consequently these sandy areas are dominated by longleaf pine and grass savanna habitats and historically have been called islands.

The middle group of wetlands occur approximately between 9 to 15 meters above mean sea level (Fig. 6-3-1), are located on the Socastee GMU, and occur through the central portion of Green Swamp (Figs. 5-5, 5-6, and 5-7). These wetlands have low gradients and are dominated by sheet flow, except for the major streams such as the upper Waccamaw River and Juniper Creek—Honey Island Swamp. The lower boundary of the Socastee wetlands occur above a major decrease in slope (Fig. 6-3-1 and 6-1-1) that occurs in the Old Dock, Crusoe Island, and Juniper areas (Figs. 6-3-3 and 6-3-4). This lower slope break is created by the occurrence of the Waccamaw Fm. that underlies the adjacent land areas (Figs. 5-4, 5-5, and 6-3-6C). The Socastee perched swamps were the second group of pocosins to be extensively ditched and drained.

The lower group of wetlands are subdivided into Wando and the Holocene GMUs (Figs. 5-5, 5-6, and 5-7). The Holocene GMU represents the modern drainage system and includes the channel and active floodplain (Fig. 5-5) that is incised into the Wando GMU. The Wando is an older, slightly higher, and inactive floodplain referred to as the antecedent floodplain. The antecedent floodplain is topographically too high to be active except during the most extreme events (Figs. 5-6A and 5-6B). It is a fossil floodplain that formed in response to a dramatically different set of climatic and hydraulic conditions during the Late Pleistocene.

The antecedent floodplain, or Wando GMU, occurs throughout and is the dominant component of the lower Waccamaw River valley (Fig. 5-5). Remnants of the Wando GMU can still be seen within the lowermost reaches of Green Swamp in the ‘Narrows’ on either side of Crusoe Island (Figs. 6-3-3 and 6-3-4). However, if the Wando existed above Crusoe Island, it has either been totally reworked by the modern floodplain system or systematically buried with modern peat development in the active floodplain swamp forest (Figs. 6-3-2, 6-3-3, and 6-3-4). The geology and genesis of both the antecedent Wando and Holocene GMUs will be discussed in a subsequent section of the paper.

6.4. Upper Waccamaw River (UWR)

> *The great forest that rose with its tall trunks and weird, moss-draped arms, out of the water. The owls were still hooting. Indeed, the dolorous voice of this bird of darkness sounded through the heavy woods at intervals throughout the day. I seemed to have left the real world behind me, and to have entered upon a landless region of sky, trees, and water.*
>
> *N.H. Bishop, 1878*

6.4.1 Introduction

The upper Waccamaw River begins at the spillway of a weir dam on the southwestern corner of Lake Waccamaw (Figs. 3-3, 6-2-4, and 6-2-5B). It flows southward through the Lake, River, and Boggy Swamps, which are part of the extensive Green Swamp pocosin wetlands, to the Old Dock bridge south of Crusoe Island (Figs. 6-3-2 and 6-3-3).

6.4.2. Stream Characteristics

The upper Waccamaw River has a small meandering channel cut into a vast and low swamp forest floodplain (Figs. 6-2-4, 6-3-2, and 6-3-3). The small stream channel is mostly buried below a vast forest canopy that allows little light through (Fig. 6-4-1A). The narrow, low-flow river channel is generally incised into and bounded by low banks of swamp forest peat (Fig. 6-4-1B). Along the straight reaches, trees and their extensive roots bind the channel bank and prevent active meandering and minimize bank erosion (Fig. 6-4-2A). The shallow meanders are characterized by small and poorly developed point bar deposits (Fig. 6-4-2B).

As the upper Waccamaw River approaches Crusoe Island, it locally becomes wide, deep, and straight (Figs. 6-3-2 and 6-3-3). Along these river segments, the river channel is rockbound and incised into the Pleistocene Waccamaw and Cretaceous Pee Dee Formations. The stream gradient profile (Fig. 6-1-1) flattens out on the erosionally resistant indurated to semi-indurated rock units between ‘Burnt-Out-Bridge’ and the Old Dock-Crusoe Island Bridge. The upper Waccamaw River dramatically changes character in response to changes in the underlying geologic units as can be seen in Figures 6-4-3A And 6-4-3B. The stream gradient increases downstream from the Old-Dock-Crusoe Island bridge to the junction of Juniper Creek. Below Juniper Creek, the slope becomes very gentle and uniform and the underlying Cretaceous Pee Dee Fm. totally controls the lower Waccamaw River.

Several important features can be observed by comparing aerial photographs of the broad floodplain valley above Crusoe Island (Fig. 6-3-2) with the floodplain valley in the ‘narrows’ produced by the rockbound uplands at Old Dock and Crusoe Island (Fig. 6-3-3). Photographs of the northern segment have very uniform textures resulting from the dominance of sheet flow and a swamp forest characterized by Holocene sediment deposition. Within the ‘narrows’ segment of the floodplain, the Cretaceous Pee Dee Fm. approaches the surface and controls the riverine processes. In the latter segment, the floodplain is dominated by paleochannels and paleomeanders of a former

FIGURE 6-4-1. Photographs of narrow, shallow, and vegetation-bound segments of the upper Waccamaw River.

PANEL A. This portion of the river is narrow, shallow, and generally flows beneath a vast forest canopy with banks that are totally dominated by vegetation. The emergent grass beds and submerged aquatic vegetation are growing on sand bars in the river.

PANEL B. The vegetation bound river channel is incised into a low sloping swamp forest peat bank covered with a thin natural levee deposit of sand.

FIGURE 6-4-2. Photographs of narrow, shallow, and vegetation-bound segments of the upper Waccamaw River.

PANEL A. Close-up view of a vegetation bound shoreline segment with extensive trees and roots that bind the channel bank and prevent bank erosion and meandering.

PANEL B. A shallow, sand-filled channel has a poorly developed point bar on the right side or inside of a broad river bend with a vegetation-bound cut bank on the left.

FIGURE 6-4-3. Photographs of wide, deep, rock-bound segments of the upper Waccamaw River that are incised into the underlying Waccamaw and Pee Dee Formations.

PANEL A. Winter photo of the ‘fishponds’, a straight river reach that occurs off the northwest tip of Crusoe Island.

PANEL B. Summer photo of another wide and deep river segment that occurs off the southwest corner of Crusoe Island.

Waccamaw River with a different climatic regime. The former is the Holocene GMU that grades downstream into the Wando GMU.

The patterns characteristic of the Wando GMU become more prevalent southward and dominate the entire lower Waccamaw River floodplain. These features will be discussed in the section on the lower Waccamaw River. Northward, the old channel features of the Wando GMU have been buried by the formation of Holocene peat deposits in response to swamp forest sheet flow dynamics through time. This is the same process that systematically buries Carolina Bays within many Green Swamp wetlands.

White Marsh (Fig. 6-3-2) drains the Whiteville area and northern-most portions of the Waccamaw drainage basin. White Marsh flows into the upper Waccamaw River just north of the Old Dock-Crusoe Island bridge (Fig. 6-3-3). Locally on Figure 6-3-2, White Marsh has a small channel similar to that of the upper Waccamaw River. However, throughout most of the marsh, the channel disappears as White Marsh spills out over the floodplain with the drainage dominated by sheet flow. This was the general character of much of the Green Swamp drainage prior to human intervention and drainage program development, which began slowly in the 1930’s.

6.4.3. Geologic Framework

As the upper Waccamaw River approaches Crusoe Island, rock begins to play an increasingly important role in defining the morphology and dynamics of the river. Portions of the river channel adjacent to Crusoe Island are significantly wider with straight channels and are generally rock floored. The upland areas of Old Dock, Crusoe Island, and Freeland (Fig. 5-5) close down the drainage off the Green Swamp pocosin and form the bounding framework for the main stem of the lower Waccamaw River. Crusoe Island acts as a stopper in the throat of the bottle and further closes down the drainage system. These upland areas, as well as Crusoe Island, generally act as a partial dam across the drainage---construction of the road across the floodplain finished the dam. Sheet flow that once characterized much of the pocosin drainage is now forced out of the floodplain and into channeled flow in the upper Waccamaw River and Juniper Creek channels as they pass through the small bridge openings in the road dam.

Three geologic cross sections across the upper Waccamaw River channel (Fig. 6-3-6) were developed based on limited vibracore and auger hole data. The Old Dock--Crusoe Island section (Fig. 6-3-6C) demonstrates the erosional character of the pre-Holocene sediment surface. Fossiliferous sandy mud of the Cretaceous Pee Dee Fm. forms the ‘basement’ surface with eroded remnants of the Pleistocene Waccamaw Fm. preserved on the river channel flanks. The Waccamaw Fm. is a fossiliferous limestone that crops out in the east bank of the Waccamaw River just south of the bridge. Also, it has been quarried from both Crusoe Island on the east and the Old Dock to Snake Island areas on the west (Fig. 6-3-3).

Distribution of the Waccamaw Fm. plays an extremely important role in the formation of the Green Swamp pocosin. The extensive outcrop area of this unit (Fig. 5-4) was breached by both the Waccamaw River (Fig. 6-1-1) and Juniper Creek (Fig. 6-3-1) forming a narrow constriction within the drainage. The ‘narrows’ chokes down all of the drainage coming out of Green Swamp (Fig. 5-5), producing a well developed channel with confined flow that characterizes the lower Waccamaw River (Fig. 6-3-4). Also, the more resistant character of the semi-indurated to indurated unit, forms a shallow dam or temporary base level along the Old Dock-Crusoe Island-Freeland road, changing the stream gradients as demonstrated in Figure 6-1-1. This natural dam was and still is critical to the hydrodynamics of the Green Swamp pocosin.

The shallow dam produced by the Waccamaw and Pee Dee Formations in the Crusoe Island ‘narrows’ resulted in the upstream deposition of a thin sequence of Late Pleistocene and Holocene sediments on top of the older erosional surface. Figures 6-3-6A and 6-3-6B are two short, schematic cross sections across the upper Waccamaw River channel (Fig. 4-3). Figure 6-3-6A is 1.5 km south of the Lake Waccamaw dam and Figure 6-3-6B is at ‘burnt-out-bridge’ on Red Bug road just north of Crusoe Island. In both sections the upper Waccamaw River is cut down into a weathered surface on the pale blue, dense, sandy mud. This Early Pleistocene mud forms the base for the Green Swamp region. The Late Pleistocene and Holocene infill sediments consist of about one meter of clean, well sorted, graded coarse to fine to muddy quartz sand (Fig. 6-4-4A) with disseminated organic fragments overlain by one meter of twigs, leaves, and in situ roots in an organic mud with thin quartz sand laminae (Fig. 6-4-4B). The surficial modern floodplain peat layer is a low-grade peat that only locally exceeds 0.25 m in thickness.

FIGURE 6-4-4. Photographs of sand and organic matter sediments in the upper Waccamaw River.

PANEL A. Active sand ripples occur on the flank of a point bar. Notice that the tea-colored water is clear with no suspended sediment load, but has enough flow velocity to actively transport bedload sand. The ripples have approximately 10 cm wave lengths.

PANEL B. A cross-sectional view of a subaerial point bar that has been eroded to expose the interbedded character. The two alternating components are clean quartz sand (white) and layers of leaf litter (dark) from the forest canopy. Scale: 1 cm on the photograph = 5 cm in the sediments.

6.5. Lower Waccamaw River

> *Over the course of centuries and scores of centuries, the river would writhe slowly but continuously across the floodplain, making its way in moving coils and loops, smoothing and shifting sand and earth the way an eel would, if you put the eel on a beach, and let him squirm back to the sea.*
>
> *F. Burroughs, 1992*

6.5.1. Introduction

The lower Waccamaw River (LWR) valley is a linear feature that flows from the Old Dock-Crusoe Island-Freeland road dam, southwest into the Winyhah Bay estuary (Fig. 3-2). The North Carolina portion of the LWR contains several different morphological components that are rock controlled and into which the drainage system is incised. Due primarily to this underlying rock control, the character and processes of the LWR are very different than that of the UWR and associated Green Swamp. Figure 6-3-4 shows the junction of the upper Waccamaw River and Juniper Creek to form the lower Waccamaw River. The next three Figures (Figs. 6-5-1 through 6-5-3) are infrared aerial photos that show representative segments down the lower Waccamaw River.

In 1878, Bishop recognized two dramatically different patterns within the lower Waccamaw River and described them as follows.

> **REACHES** --- *which in this vicinity are called wretches .... were so long and straight as to afford open passages for wind to blow up them, and these fierce gusts of head winds give the raftsmen much trouble while poling their rafts against them.*
>
> **MEANDERS** --- *So I followed the winding stream, which turned back upon itself, running north and south, and east and west, as if trying to box the compass by following the sun in its revolution. .... The swamps were submerged, and as the water poured out of the thickets into the river it would shoot across the land from one bend to another, presenting in places the mystifiying spectacle of water running up stream.*

These two types of river channels reflect the origin and evolutionary history, as well as the modern dynamics of the lower Waccamaw River and will be used as the basis for further discussion.

6.5.2. Channel Segments

The entire modern channel of the LWR is incised into and flows within the broad antecedent floodplain of the Wando GMU, an older riverine-floodplain sediment unit. However, as described by Bishop, the LWR has two different morphologies that will be referred to as actively meandering and incised river segments (Fig. 6-5-4). The modern and active component of the lower Waccamaw River is Holocene in age and will be referred to as the Holocene GMU (Figs. 5-6 and 5-7). The

FIGURE 6-5-1. Infrared aerial photograph of the upper portion of the lower Waccamaw River including N.C. highway 130 bridge at New Britton. Notice the 1) highly modified drainage within the Wando GMU due to construction of drainage ditches for initial logging and land clearing, 2) actively meandering river channel segments within the modern floodplain or Holocene GMU, 3) incised or rock-bound channels within the antecedent floodplain or Wando GMU, and 4) paleo-channels and paleo-meanders with their ridge and swale structures within the Wando GMU. Photograph was flown on 3/29/1983 by the High Altitude Program of the U.S. Department of Agriculture.

FIGURE 6-5-2. Infrared aerial photograph of a segment of the lower Waccamaw River between N.C. highways 130 and 904 bridges and including Gore Lake and Seven Creeks. Notice the 1) generally unmodified drainage within a fairly natural portion of the Wando GMU, 2) actively meandering river channel segments within the modern floodplain or Holocene GMU, 3) incised or rock-bound channels within the antecedent floodplain or Wando GMU, and 4) paleo-channels and paleo-meanders with their ridge and swale structures within the Wando GMU. Photograph was flown on 3/29/1983 by the High Altitude Program of the U.S. Department of Agriculture.

FIGURE 6-5-3. Infrared aerial photograph of the lower Waccamaw River in the area of N.C. highway 904 bridge. Notice the 1) generally unmodified drainage within a fairly natural portion of the Wando GMU, 2) actively meandering river channel segments within the modern floodplain or Holocene GMU, 3) incised or rock-bound channels within the antecedent floodplain or Wando GMU, and 4) well developed paleo-channels and paleo-meanders with their ridge and swale structures within the Wando GMU. Photograph was flown on 3/29/1983 by the High Altitude Program of the U.S. Department of Agriculture.

FIGURE 6-5-4. Schematic cross sections of the two types of channel systems within the lower Waccamaw River.

PANEL A. An actively meandering river segment that occurs totally within a modern floodplain of the Holocene GMU.

PANEL B. An incised river segment in which the channel is cut into the antecedent floodplain of the Wando GMU.

two different types of river segments are determined by the underlying geologic characteristics of the antecedent floodplain. Within the portions of the antecedent floodplain where the underlying Cretaceous Pee Dee Formation is topographically high, the channel is incised into the rock and forms the straight, wide, and deep rock-bound river segments. Within the portions of the antecedent floodplain where the Cretaceous Pee Dee Formation is topographically low, the modern channel is actively meandering and reworking the old floodplain sediments. This process has resulted in a narrow and shallow, highly sinuous channel that has developed an adjacent zone of low, modern floodplain which is incised into the higher antecedent floodplain.

Wherever the modern river channel flows totally within its own active floodplain it constitutes the Holocene GMU (Fig. 6-5-5). These river segments are characterized by an actively meandering channel (Fig. 6-5-4A) with a high sinuosity, active point bars, and low cut-banks. During the annual wet season and small flood events, the Holocene portion of the floodplain is regularly flooded and dominated by sheet flow. About 50% of the river length is dominated by an actively meandering channel and associated active floodplain (Fig. 6-5-6).

However, the modern riverine system does not always have an active floodplain. About 50% of the river length (Fig. 6-5-6) has a channel that is incised into and flows through the antecedent floodplain of the Wando GMU (Fig. 6-5-7). This active channel is also cut down into the older and underlying sediment units of the Waccamaw and Pee Dee Formations. Consequently, the incised river segments have high sediment banks with no modern or active floodplain except during large flood events, the channels are generally rock bound on one or more sides and tend to be straight to slightly meandering, and are generally wide and deep (Figs. 6-5-4B, 6-5-6, and 6-5-7).

Infrared aerial photographs demonstrate the difference between channel types and associated antecedent or modern floodplains (Figs. 6-5-1, 6-5-2, and 6-5-3). These photographs readily display the presence of paleo-channel and paleo-ridge and swale structures, as well as a mixed assemblage of upland and wetland vegetation characteristic of the antecedent floodplain (Wando GMU). Wherever the channel develops its own active floodplain (Holocene GMU), it is characterized by high sinuosity and is dominated by wetland vegetation. Since the antecedent floodplain has slightly higher elevations than the modern floodplain, it can be ditched and drained and is readily logged and converted to pine plantations. The modern floodplain is slightly lower, is flooded for extended periods during each high-water season. The latter areas are dominated by wetland tree species such as cypress, gum, and swamp maple.

Seven basic rock and sediment types constitute the banks of the lower Waccamaw River as outlined in Table 6-5-1. River banks of the actively meandering streams are dominated by lithologies 5-7, which generally overly the hard rock surfaces of the Pee Dee Formation (lithologies 2 or 3) at depth (Fig. 6-5-4). Cut banks of incised river segments are characterized by lithofacies 5 and 6 overlying extensive outcrops of the Pee Dee Formation (lithologies 1 through 3) with rare, preserved segments of the Waccamaw Formation (lithology 4).

FIGURE 6-5-5. Schematic cross section of an actively meandering river channel and associated active floodplain, which is incised into the Wando GMU. Notice the relationship between the Wando GMU, Socastee GMU, and Cretaceous Pee Dee Fm.

FIGURE 6-5-6. Map of the lower Waccamaw River showing the general distribution of the two types of river channels: 1) incised channel with an antecedent floodplain and 2) actively meandering channel with an active floodplain.

FIGURE 6-5-7. Schematic cross section of an incised river channel that is incised into the antecedent floodplain of the Wando GMU. Notice the relationship between the Wando GMU, Socastee GMU, and Cretaceous Pee Dee Fm.

TABLE 6-5-1. Major rock and sediment units that characterize the incised and actively meandering segments of the lower Waccamaw River.

WANDO AND HOLOCENE GMUs: Upper sand sequence

7. Crossbedded and interbedded sequences of fine to medium quartz sand and organic detritus
6. Fining upward sequences ranging from coarse to medium quartz sand to interbedded sand and organic-rich mud to laminated fine sandy mud and fine sandy peat
5. Homogeneous, slightly organic-rich, fine quartz sand; the organic matter and/or opaque minerals in this unit weather to an iron-stained, mottled to clean fine quartz sand

WACCAMAW FORMATION: Preserved locally in topographic lows

4. Fossiliferous, muddy and gravelly fine quartz sand

PEE DEE FORMATION: Basal rock units

3. Dark greenish gray to blue gray, dense, very fine quartz sandy mudstone to mudstone
2. Indurated, calcareous cemented, fine quartz sandstone; often occurs as discontinuous laminae or irregular nodules within lithology one
1. Slightly muddy, tight, fine quartz sandstone

Ground-penetrating radar (GPR) data collected along the Waccamaw River were utilized to determine the paleo-topography of the underlying rock surface within the Waccamaw River valley. The data were collected on a single day (January 25, 1997) with the water level at about mid-stage. The following interpretations are based upon two assumptions: 1) the water surface was constant during the survey period and 2) the boat stayed in the middle of the channel throughout the survey. The latter assumption is an approximation at best, causing the data to have more variability than really exists. Figure 6-5-8 shows the distribution of two different channel segments surveyed.

The GPR data recorded a hard reflective surface throughout the survey area that is interpreted to be the top of the Cretaceous Pee Dee Formation. This interpretation is based upon vibracoring and cross-sectional river profiles of Brant (1998). The incised and actively meandering channel segments have distinctive river patterns (width, depth, and sinuosity) that reflect their relationship to the Pee Dee Formation and the general character of this rock surface. Table 6-5-2 summarizes the characteristics for the two channel types based upon the GPR data.

FIGURE 6-5-8. Map of the lower Waccamaw River delineating the regions used in the ground-penetrating radar survey of the river and the distribution of two types of river channels: 1) incised or rockbound channel and 2) actively meandering channel.

TABLE 6-5-2. Channel characteristics of the lower Waccamaw River based upon ground-penetrating radar survey within the riverine channel. Figure 6-5-8 shows the river regions and their relationship to the two major channel types.

RIVER REGION	DEPTH TO CRETACE. METERS	DEPTH TO CRETACE. AVERAGE METERS	RELIEF CRETACE. SURFACE METERS	SED. THICK. METERS	SED. THICK. AVE. METERS	CHANNEL WIDTH	CHANNEL SINUOSITY
UPSTREAM							
A-IC*	4.0-8.1	6.2	4.1	0-2.5	0.8	Medium	Medium
B-AM**	3.9-6.5	5.0	2.6	0-3.0	0.8	Narrow	High
C-IC*	3.6-6.8	5.3	3.2	0-2.0	0.5	Medium	Medium
D-AM**	3.6-7.3	5.2	3.7	0-3.0	1.0	Narrow	High
E-IC*	4.7-10.4	6.9	5.7	0-1.8	0.3	Wide	Low
DOWNSTREAM							
SUMMARY							
AM**	3.6-7.3	5.1	2.6-3.7	0-3.0	0.9	Narrow	High
IC*	3.6-10.4	6.1	3.2-5,7	0-2.5	0.6	Med-Wide	Med-Low

* IC = Incised Channel
** AM = Actively Meandering Channel

6.5.3. Rock-Bound River Segments

Extensive reaches of the lower Waccamaw River are rock floored with sidewalls composed of pre-Holocene stratigraphic units (Figs. 6-5-9, 6-5-10, and 6-5-11). The basal rock unit is the Cretaceous Pee Dee Formation with remnants of the early Pleistocene Waccamaw Formation locally preserved (Table 5-1). The rocks in the river bank are overlain by a 1 to 3 meter thick sequence of unconsolidated sands (Fig. 6-5-9) that were deposited by a former Waccamaw River during different climatic conditions of the early Pleistocene (> 10,000 years before present). These surficial sand deposits constitute the antecedent floodplain of the Wando GMU into which the modern river is incised.

The rock-bound channels (Fig. 6-5-12) tend to occur as wide, deep, and fairly straight (region E in Fig. 6-5-8) to slightly meandering river segments (regions A and C in Fig. 6-5-8). However, the banks of these paleo-meanders are vegetatively bound (Fig. 6-5-12) with no active meandering taking place today and only locally do they have minor point bar development associated with them. The apparent meanders tend to occur within paleo-meanders of the fossil channel system that is being reoccupied by the modern channel. The incised channel segments appear to be occupying ancient river channels within paleotopographic valleys that were cut into the top of the Cretaceous Pee Dee Formation during some previous geologic period.

The incised channels have high river banks (Figs. 6-5-9 and 6-5-11) that are rarely overtopped during normal high-water periods. Thus, the river flow is totally constrained within the channel (Fig. 6-5-4 and

FIGURE 6-5-9. Photographs of an incised or rock-bound channel during low-flow stage on the lower Waccamaw River.

PANELS A and B. High banks of the antecedent floodplain, the Wando GMU, composed of soft sand sediment deposited by a paleo-Waccamaw River. Notice the 1) severe rate of bank recession that occurs when the river is in intermediate- to high-flow stage, 2) upland vegetation that occurs on top of the high bank, and 3) active undercutting below the modern surficial root mat and associated slumping of sediment and vegetation off the bank. The eroding banks are about 5 m and 3 m high, respectively.

FIGURE 6-5-10. Close-up photographs of an incised or rock-bound channel during low-flow stage on the lower Waccamaw River.

PANELS A and B. High banks of the antecedent floodplain, the Wando GMU, composed of the Cretaceous Pee Dee Formation. This unit consists of dark greenish gray to blue gray, dense, fine quartz sandy mudstone that contains discontinuous interbeds of calcareous cemented, fine quartz sandstone. Notice in Panel A the stair-step geometry along the contact (yellow line on left side of photo) between the hard Pee Dee Formation and overlying soft sand sediments that have receded due to bank erosion. Panel B is a close-up of the rocks in the Pee Dee Formation. The river bank in Panel A is about 2 m high and the photograph in Panel B is about 0.5 m high.

FIGURE 6-5-11. Photographs of incised or rock-bound channels during low-flow stage on the lower Waccamaw River.

> PANELS A and B. High banks of the antecedent floodplain, the Wando GMU, composed of the Cretaceous Pee Dee Formation. This unit consists of slightly muddy and poorly iron-cemented, fine quartz sandstone. The river bank in Panel A is about 5 m high with the contact (yellow line on right side of photo) between the more resistant Pee Dee Formation and overlying soft sand sediments that have receded due to bank erosion. Panel B is about 4 m high with the contact (yellow line) between the more resistant Pee Dee Formation and the overlying 2 m of soft surficial sand. Notice how the surficial 0.5 to 1 m is bound by the dense root mass of overlying vegetation and is slumping into the river as a cohesive mat as the underlying sand is eroded away during intermediate- to high-stage water flow.

FIGURE 6-5-12. Photographs of rock-bound segments of incised channels on the lower Waccamaw River. Notice the wide and straight character of the rock-bound channels and the dominance of upland vegetation along the banks.

PANEL A. Photo was taken in summer.

PANEL B. Photo was taken in winter.

6-5-7) except during the largest flood events. The high river banks that consist of 1 to 3 meters of unconsolidated surficial sands overlying the rock, are actively being eroded (Fig. 6-5-9). This erosion takes place very slowly on a continuous day-to-day basis. However, rates of erosion increase significantly during intermediate to high stages of river flow when the river level intersects or floods this soft sediment bank. Bank erosion is at a maximum during intermediate stages of river level when the river is not too high for boat traffic and boat wakes interact directly upon the sands and severely accentuating the erosional processes. Bank erosion of the upper sand beds of the Wando GMU supply a major volume of sand to the river channel.

The strong channelized flow during intermediate to high level flow regimes tends to keep the rock-floored channels swept clean of sand. The sand is transported downstream through the rock-bound sections and into the actively meandering segments where velocity decreases and sand accumulates. However, if there is a major source of sand from either an upstream tributary or a highly eroding river bank, minor sand will locally be deposited on the inside of a meander forming small-scale point bars within the rock-bound segments.

6.5.4. The Antecedent Floodplain (Wando GMU)

A major portion of the antecedent floodplain, or Wando GMU, is characterized by paleo-channel structures and paleo-ridge and swale topography (Figs. 6-5-1, 6-5-2, and 6-5-3). These large fossil channel and point bar deposits were produced by a former Waccamaw River with a geometry between two to four times larger than similar features being produced by the modern Waccamaw River (Brant, 1998). The ridge and swale topography reflects the migration of an actively meandering river between 10,000 and 3,000 years before present based upon radiocarbon age dating of the sediments in the channels and scroll deposits. We believe that the ancient system that produced the antecedent floodplain had very different hydrologic conditions than the modern river. The much smaller Waccamaw River system, that existed from about 3,000 years ago to the present, has been incised down into the antecedent floodplain.

The ridge and swale structures occurring on the Wando GMU are large-scale, extremely low-slope morphological features with decimeter-scale relief. They produce distinctive alternating and arcuate habitats that cause dramatic variations in the resulting plant communities. This can be readily seen on old aerial photographs (Figs. 6-5-11 and 6-5-12). The light zones are the sandy ridges from the old point bar deposits that are dominated by grasses, scattered long-leaf pine, and carnivorous plants. Whereas, the dark zones are the swales between accreting point bars and are dominated by wetlands and the associated plant community of cypress, gum, and swamp maple. The hydric soils in the swales are composed of thin peats and organic detritus that have accumulated over the years from the dominantly forest community.

The subtle ridge and swale features were very striking and stood out both on the ground and in old aerial photos (Fig. 6-5-13) due to the great differences between these plant communities. However, use of ever larger logging equipment and the extensive construction of drainage ditches on the Wando land surface over the last several decades have eliminated most evidence of these paleo-geomorphic features. Along with the loss of the geomorphic features, conversion of these diverse habitats to the ubiquitous monoculture pine plantations, are rapidly destroying the unique biological habitats of the Waccamaw River valley.

FIGURE 6-5-13. Aerial photographs of two segments of the lower Waccamaw River and associated antecedent floodplain (Wando GMU).

> PANELS A AND B. Notice the 1) prominent paleo-ridge and swale structures with alternating plant habitats: sand ridges are light colored and dominated by a grass community while the swales are dark colored and dominated by wetlands with a plant community composed of cypress, bay, and gum; 2) highly meandering character of the modern channel and associated active floodplain; and 3) different scales of modern riverine features compared to those of the antecedent floodplain. Photographs were flown on 4/8/1955 by the U.S. Department of Agriculture.

6.5.5. The Actively Meandering Segments and Modern Floodplains

In between the rock-bound stretches are river segments characterized by an actively meandering river channel (Fig. 6-5-6) within a modern floodplain sequence (Figs. 6-5-2 and 6-5-5). These river segments (regions B and D in Fig. 6-5-8) tend to be narrow, relatively shallow, and highly sinuous (Fig. 6-5-13) due to their active meandering processes. The rivers have cutbanks in modern riverine sediments (Fig. 6-5-14A) and extensive point bar development associated with each meander (Fig. 6-5-14B). Within the meander the river is shallow due to abundant deadfall (Fig. 6-5-14A) that plays an important role in trapping sand. The cutbanks are composed totally of unconsolidated sands of sediment types 5 through 7 (Table 6-5-1) and are topped with natural levees and large trees.

During high-flow conditions, much of the water flowing into the sediment-filled meanders is forced to leave the channel and move as sheet flow through the adjacent modern floodplain. During these high-flow periods, the cut-bank is rapidly eroded supplying large volumes of new sediment to the stream and causing extensive bank collapse along with many large trees. These trees fall into the channel forming natural jetties that cause serious navigation problems and effectively trap more sediment as the thalweg fills with sand, forcing even more water out of the channel and into the adjacent swamp forest sheet flow. Thus, sedimentation becomes the dominant process within the highly sinuous river segments during high water seasons and specific storm events. Consequently, the apex of each meander is dominated by shallow, narrow channels (Fig. 6-5-4) with extensive and active point bar and levee development.

Within the actively meandering river segment, channels in both the upstream and downstream reaches between meanders are generally rock floored, but the channels are not incised into the rock. Thus, the channel flanks contain only riverine sands allowing the river to actively meander and rework the antecedent floodplain. This results in sediment deposition within the apex of tight meanders and formation of well-developed point bars. Figures 5-6, 5-7, and 6-5-5 demonstrate that the actively meandering river segments have eroded into and reworked significant portions of the antecedent floodplain to form the modern floodplain. Development of a modern floodplain probably occurs within paleotopographic lows in the underlying Cretaceous Pee Dee Fm.

Many active point bars contain several groups of river birch trees that are zoned into different sizes with the smallest close to the river and getting larger into the floodplain (Fig. 6-5-15A). Each zone is separated by an erosional surface that contains a thick layer of decomposing leaf litter (Fig. 6-5-15B). Based upon the distribution pattern of various size birch trees and the erosional surfaces with associated leaf litter, the point bars do not appear to be active on a daily or even seasonal basis, but rather appear to be related to major storm events. Thus, the storm history of the river and accretion history of each point bar should be recorded within these point bar deposits. Understanding these inter-relationships is critical towards developing a management program based upon the riverine system dynamics. Resources were not available in our project to undertake this detailed analysis, but it would be a very important to do in a future research program.

FIGURE 6-5-14. Photographs of an actively meandering segment of the lower Waccamaw River.

PANEL A. The outside of a sharp meander contains a 2 meter high cut bank that is eroding into riverine sediments of the Holocene GMU. Active cut bank erosion has under cut the trees, which form dams across the channel trapping sediment and impairing navigation.

PANEL B. The inside of a sharp meander contains an active point bar. Notice at least two erosional or nondepositional surfaces delineated by a thick accumulation of leaf litter that was buried by sand during a subsequent storm event.

FIGURE 6-5-15. Photographs of a point bar within an actively meandering segment of the lower Waccamaw River.

PANEL A. An active point bar covered with a stand of river birch. Notice that the 1) point-bar sand continues below the water surface and 2) dark tea color of the water.

PANEL B. Close-up photograph of a trench through the point bar showing multiple interbedded layers of sand accretion and periods of nonstorm periods when leaf litter accumulated. Vertical height is about 1 m.

6.5.6. Geomorphic Framework

The geomorphic relationship of the lower Waccamaw River to its river valley and morphology of adjacent upland areas is demonstrated in Figures 5-5, 5-6, and 5-7. The LWR valley consists of two geomorphic units (GMUs): the Holocene GMU and Wando GMU. These two units occupy the present river valley and are incised into the Socastee GMU, which is incised into the upland Penholoway GMU (Figs. 5-7). Contact relationships between the GMUs are partly based upon ground-penetrating radar profile data across these unit boundaries.

Considering the geomorphic framework, it becomes clear that the lower Waccamaw River is an underfit stream (Dury, 1964). The modern channel system is up to four times smaller than the paleo-channels in the antecedent floodplain of the Wando GMU. Similar ‘underfit’ paleo-riverine features occur on many other riverine floodplains throughout the southeast Atlantic and Gulf coastal plains. Bernard (1950) named the terrace that the ‘underfit’ drainage is incised into as the Deweyville Terrace. Gagliano and Thom (1967) mapped the Deweyville Terrace in the Brazos, Trinity, Sabine, Ouachita, Pearl, Pascagoula Rivers, as well as the Great Pee Dee, Little Pee Dee, and Waccamaw Rivers of the Carolinas. Sexton (1999) mapped the paleo-riverine features in the alluvial valleys of the middle coastal plain of South Carolina including the Santee, Conagaree, and Wateree river valleys.

Within the lower Waccamaw River valley, there are infilled paleo-channels located against the sides of the river valley suggesting that this larger paleo-riverine system of the Wando cut the valley walls into the Socastee GMU. The Wando paleo-riverine system, which formed during the last glacial maximum of the late Pleistocene, existed under an extremely different climatic and hydrologic regime than exists at present. Consequently, the much larger hydrologic system combined with minimal vegetative cover to produce a stream with maximum development of the meandering process. The hydrologic results were a wide floodplain that filled the valley with extensive point-bar ridge and swale structures and associated channels (Figs. 6-5-1, 6-5-2, 6-5-3).

With todays climatic and hydrologic regime, the valley floor is bound by a heavy vegetative cover that minimizes the meandering process. This, in combination with a much more uniform hydrologic regime driven by the pattern of rainfall and increased importance of groundwater has led to incisement into the Wando. The modern lower Waccamaw River has reoccupied some of the old rock-bound channels and locally has produced a small modern floodplain resulting from a minimum amount of active meandering stream processes (Fig. 6-5-3). Gagliano and Thom (1967) believed the paleomeander scars of the lower Waccamaw River are similar to the Deweyville Terraces in the Gulf coast, which formed by rivers with significantly larger discharges than their modern equivalents (Gagliano and Thom, 1967; Alford and Holmes, 1985).

7. MODIFICATION OF THE WACCAMAW DRAINAGE SYSTEM

> *You work the log woods in them days, and you wouldn’t think money growed on the trees around here. Trees was all the money they was. ... Course the river had a heap more water in it then ... the steamboats used to come up from Conway, right up here to Freeland on the high water. Couldn’t do that now. Waccamaw Lumber Company and St. Regis and G.P. must of spent a billion dollars altogether ditchin’ and draining that swamp. What they done was taken water away from the Waccamaw and give it to the Cape Fear River. That’s why the Waccamaw’s got so much sand in it now. Back then the freshets would flush it right out. And of course there weren’t no trees laying in the water then; the rafters kept it cleant out.*
>
> *Mr. K. Babson in F. Burroughs (1992)*

7.1. Land-Use History of the Waccamaw Drainage System

The brief history of development within the Waccamaw drainage system summarized below is based upon two general sources of information. Several reports were obtained from various timber companies and many conversations were held with numerous long-time employees who actually carried out much of the drainage work. The accuracy of the following summary can not be supported since all sources wished to remain anonymous with the unpublished company information unreferenced.

7.2. Green Swamp Pocosin

Early courthouse records suggest that prior to 1795, the swamp next to John Green’s field, referred to as Green’s Swamp, was approximately 200,000 acres. From 1795 to 1889, Green’s swamp was owned by W. Collins, S. Williams, and B. Powell. In 1889 the three owners sold the land to Pennsylvania and North Carolina Land and Timber Co. In 1906, it was sold again to Waccamaw Lumber Company. In 1937, Riegel Paper Corp. bought 139,000 acres of the original 200,000 acres and subsequently sold it to Federal Paper Board Co. in 1972, who in turn sold it to International Paper Corp. in 1995. Consequently, the major portion of Green Swamp has been associated with the timber industry for at least the past two centuries.

All early logging operations were dependent upon the Waccamaw River for rafting shingles and logs to Conway and Georgetown, South Carolina. In the 1850’s an east-west railroad was constructed from Wilmington to Fair Bluff with a spur line built to a pier in Lake Waccawmaw. Timber was harvested in the swamp using steam skidders to gather logs to collecting points and removed from the swamp by railroad tram spurs to the strategic mainline tram railroad (Fig. 7-2-1). Tram railroads were built by laying rails directly on a bed of logs. No ditching and draining of the wetlands was done in those days. Logging operations were weather and water-level dependent, and therefore carried out only during the yearly dry seasons and were based upon old-growth timber.

FIGURE 7-2-1. A 1955 aerial photograph of Friar Swamp showing the character of dry season logging operations utilizing steam skidders. This technique predated the period of agriforestry based upon extensive land-use alteration by ditching and draining the wetlands. Photograph was flown on 4/9/1955 by the U.S. Department of Agriculture.

The first series of drainage canals were dug into the wetlands east and southeast of Lake Waccamaw during the 1920’s in a major effort to develop farmland (Fig. 6-2-3). However, these ditches, which include the Main Line Canal and A through H lateral canals, could not adequately drain the soil for standard agricultural purposes. Consequently, only minor agriculture happened until a Civilian Conservation Corps (CCC) camp was established in Green Swamp in 1938. With CCC labor, there was a burst of road, bridge, and trail construction, as well as a significant boost in pine planting programs.

Roads that existed within the Waccamaw watershed during the pre-World War II era were few and mostly unpaved. Three paved roads existed (Fig. 7-2-2) including highways 214 north of Lake Waccamaw, 17 south of the Waccamaw watershed, and 130 across the lower Waccamaw River at New Britton. The unpaved or ‘dry-weather’ roads were built with minimal ditching and infilling. Consequently, the flow of surface water was relatively unimpeded, allowing infiltration and recharge of the surficial ground water aquifer, as well as overland sheet flow. Thus, the storage capacity of the wetlands remained largely in tact and the roads minimally impacted the Waccamaw River base flow.

Following World War II, growth and development began to occur slowly within the Waccamaw watershed. The growing demand for pulpwood increased the rate and amount of timber production from Green Swamp. Pulpwood continued to be shipped to mills in adjacent states until a pulp mill was constructed at Riegelwood on the Cape Fear River.

Post World War II development led to increased needs for ‘all-weather’ roads (Fig. 7-2-2). New roads were built and old roads were ‘flood proofed’ by elevating them. Due to the low topography, flood proofing occurred by ditching one or both sides of the road and building an elevated roadbed with the excavated dirt. The impact of this process upon the surface water was two fold. First, the major ditches lowered the surficial water table and effectively set the stage for subsequent drainage programs of interior swamplands. Second, elevated roads acted as road dams, decreasing sheet flow and shunting surface drainage and associated eroded sediment and chemical pollutants directly and rapidly out of the swamplands and into channels. The 1955 panel in Figure 7-2-2 demonstrates this increased development activity since 1938. By 1962, Wilson estimated that more than 1 million miles of drainage ditches and canals had been constructed throughout the North Carolina coastal plain.

However, the most extensive period of drainage alteration within the WDS didn’t begin until 1955 when a major fire burned through 117,000 acres of Green Swamp. In an effort to salvage usable pulpwood and timber, Riegel Paper Corp. began a short-range program building drainage ditches and associated roads. At that time the company committed to develop a long-term program in which they would turn their wetland holdings in Green Swamp into an agricultural-style pine plantation. Other companies quickly followed suit. This long-term management program continues today, however, at much reduced levels since the majority of land had already been ditched, drained, logged, and put into pine plantations by the mid-1980’s (Fig. 7-2-3). To accomplish this major habitat modification, the companies carried out an extensive program that generally included the following components (Figs. 6-3-5 and 6-5-1):

FIGURE 7-2-2. Development history of drainage ditches and roads in the Waccamaw drainage system in three time periods: 1938, 1955, and 1990.

FIGURE 7-2-3. Infrared aerial photograph of a segment of Green Swamp that has been extensively drained by a large integrated network of ditches and associated road dams. Notice that this area of natural pocosin wetland has been totally converted to a monoculture of controlled pine plantation. This figure demonstrates various stages of harvesting and planting (shades of black and gray), as well as compartments with different stages of pine growth (shades of red). Photograph was flown on 3/29/1983 by the High Altitude Program of the U.S. Department of Agriculture.

1. Primary drainage laterals (3 to 7 meters deep by 12 meters wide) were designed and constructed on approximately 0.4 to 1.6 kilometer spacing with access logging roads built on the adjacent dredge-spoil banks (Fig. 7-2-3);

2. Secondary drainage ditches (1 to 2 meters deep by 2 to 3 meters wide) were constructed on spacing that ranged from 30 to 300 meters through individual fields depending upon the wetness (Fig. 7-2-3);

3. Residual brush was chopped and burned, organic and mineral soils were bedded and fertilized, and seedling pine trees were planted.

This has resulted in development of a ‘window-pane’ drainage pattern of wetlands that can be seen in a completed stage throughout much of Green Swamp (Fig. 7-2-3) and in all stages of modification in the Simmons Bay area (Fig. 6-5-1).

Construction of all thoroughfare roads, as well as logging roads, were associated with ditching and draining and built on elevated road fill derived from the ditches. By 1990 there was a vast network or ‘window-pane’ roads and drainage ditches (Fig. 7-2-2) throughout Green Swamp and antecedent floodplain of the lower Waccamaw River. Only a few portions of the Waccamaw drainage system survived this period of massive modification: portions of White Marsh (Fig. 6-3-2), Friar Swamp (Fig. 6-2-3), upper Waccamaw River and Juniper Creek (Fig. 6-2-4, 6-3-3 and 6-3-4), the actively meandering portion of the lower Waccamaw River floodplain (Figs. 6-5-1 and 6-5-2), and Driving Creek preserve of The Nature Conservancy (Fig. 6-3-5).

7.3. Lower Waccamaw Riverine Floodplain Drainage

Modification of the lower Waccamaw riverine floodplain only began on a big scale during the late 1970’s and into the 1980’s as indicated in the 1983 photos (Figs. 6-5-1 and 6-5-2). Initial drainage began on the antecedent floodplain of the Wando GMU along the western side of the lower Waccamaw River. Figure 6-5-1 shows various stages of drainage ditch—road construction, swamp forest clearing, and pine planting in the Simmons Bay area. Today, almost this entire portion of the antecedent floodplain is in extensive pine plantations, which have obliterated the paleotopography of the antecedent floodplain.

To date minimal ditching and draining of the Holocene GMU has taken place (Fig. 6-5-2). This low and active modern floodplain of the lower Waccamaw River is truly wet during the wet season when it is dominated by sheet flow conditions. To prevent further habitat loss, water level declines, and increased flooding problems, this portion of the Waccamaw riverine system should not be modified as the remainder has been.

7.4. Upland Swamp Drainage

During the mid-1900’s, the U.S. Soil Conservation Service began channelizing the upland areas on the Socastee and Penholoway surfaces for the expansion and improvement of agricultural croplands (Figs. 6-3-3, 6-5-1, and 6-5-2). Initially the farmland was developed on the high sandy rims adjacent to the Waccamaw River (Figs. 6-5-5 and 6-5-7). However, with time the perched swamps behind the sand rims were increasingly channelized and drained for agricultural purposes. These wetlands were converted to marginal agricultural lands by straightening and deepening tributary stream channels and then field drains were installed in wetlands that discharged directly into the tributary channels.

Ditching of upland wetlands and channelization of associated tributary streams lowers the surface-water aquifer. The new drainage network moves the water drained from this surface aquifer downstream through a system of increasingly larger ditches. During major rainfall events, surface water runs off, eroding and transporting topsoil, along with portions of the applied fertilizers, insecticides, and pesticides from the agricultural fields, through the new and efficient plumbing system, and discharges it directly into the trunk stream. Prior to channelization, rain water soaked into the shallow groundwater system, minimizing runoff and its resulting erosion. The surface water that did flow through the swamp forest had a significant proportion of eroded sediment and associated chemicals filtered out.

8. HYDROLOGIC DYNAMICS

> *All the rivers run into the sea;*
> *Yet the sea is not full;*
> *Unto the place from whence the rivers come,*
> *Thither they return again.*
>
> *Ecclesiastes 1:7*

8.1. The Hydrologic Cycle

The blue planet contains over 1.4 billion km^3 of water on its surface. This water occurs in a tightly interactive system that continuously moves in an endless cycle that is powered by energy from the sun and the force of the earth’s gravity. Water moves readily between three different states of matter (solid, liquid, and gas) and through the various earth’s spheres (hydrosphere, atmosphere, lithosphere, and biosphere).

The oceans are the greatest water reservoir, containing about 98% of the earth’s water supply. The atmosphere is the vital link between the salt water of the oceans and fresh water of the continents through the never-ending processes of evaporation and precipitation. About 2% of the earth’s water has been precipitated onto the continents as fresh water. Of this 2%, about 1.6% is tied up in glacial ice, another 0.36% has infiltrated into the surface layers of sediment and rocks to form the groundwater system, while 0.04% constitutes the surface water runoff. Most surface water flows downhill towards the oceans in response to gravity and in the process forms the earth’s intricate system of rivers and lakes. Some ground and surface water are taken up and used by plants and subsequently transpired back into the atmosphere through the process of evapotranspiration.

Running water forms a complex network of streams and rivers that are the single most important sculpting agent creating the unique morphology of the earth’s land surface. The water supply feeding all streams is from a combination of surface runoff and ground water, both of which had their sources as rain or snow. Runoff initially flows across the ground as thin sheets of water called sheet flow. With irregularities of the land surface, the sheet becomes broken with water becoming concentrated into small channels that begin to erode into the land forming rills. The downhill flow of these channeled waters further erode the rills into gullies and finally into an organized stream. Many small streams coalesce downhill into larger streams and finally into the main trunk river that ultimately discharges the water back into the ocean or similar water body. These larger water bodies act as base level controlling the stream gradients, geometry, and flow characteristics within a drainage system.

8.2. Function of Rivers and Associated Swamplands

8.2.1. Components of a Watershed

A watershed is a basin-shaped geomorphic feature in which all the land area contributes water to the stream that occupies the low valley floor. Each stream and its watershed are separated from adjacent watersheds by an upland ridge called an interstream divide. Many small watersheds form collection systems that coalesce into ever-larger streams. The sum of these many small watersheds, discharging their collected water downstream, produces ever-larger drainage basins.

The geometry of a drainage basin is like an open-ended, elongate bowl tipped on its edge forming a concave upward slope. The headwaters of the basin consist of many small streams with steep gradients (vertical drop per horizontal distance). The downstream mouth consists of fewer, larger streams flowing into a trunk river with gentle gradients controlled by the base level of the receiving water body. Within any stream, there is an inverse relationship between the gradient and water discharge (volume passing a point/unit of time). Where the gradient is steep, in the headwaters, discharge is small, and where discharge is large, the gradient is low such as at the mouth.

The basin valley contains the primary channel occupied by the flowing water on a day to day basis. During specific storm events or during seasonal increases in rainfall, there is too much water for the primary channel to carry. The water flow now spills into a secondary channel, or floodplain. The type of riverine channel and associated floodplain is dictated by the type and load of sediment, frequency and intensity of storm events, geology surrounding the stream valley, and the latitude and elevation of the basin. These factors interact to determine the riverine character (braided, meandering, incised, etc.), geometry and number of floodplains and associated terrace development, degree of floodplain wetness, and type of vegetation occupying the floodplain.

8.2.2. Concept of Sheet, Channeled, and Base Flows

Initially rainfall moves downslope as sheet flow over the land surface or it seeps into the ground and moves downslope as shallow groundwater. The surface water travels rapidly (centimeters to meters/second) as sheet flow and ultimately feeds a gully, stream, or river where it moves as channeled flow. After a rain event, runoff feeds a stream quickly as overland sheet flow and is then moved downstream swiftly within the confined stream channel. This results in a flashy flow in response to the rapid rises and falls in water level. Shallow groundwater flows at much slower rates (centimeters to meters/day) and continues to feed the stream long after the overland flow is gone. The latter is referred to as a stream’s base flow, which responds slowly to rain events and keeps the stream filled long after a storm has passed. In some drainage systems, such as the Waccamaw, deep groundwater aquifers are also important contributors to the base flow of streams. Base flow is a crucial component of flow dynamics within stream systems. In general, about two thirds of the total stream discharge in the North Carolina coastal plain streams is estimated to be base flow (Wilder et al. 1978).

The amount of rain that runs off as sheet flow or infiltrates into the soil is a function of many variables including land slope, soil composition, vegetative cover, degree of soil saturation, and character of each rainfall event. Decreasing land slope and increasing vegetation significantly decreases surface water flow and increases infiltration. If the land surface has low relief with clayey soils, such as occurs throughout eastern North Carolina, extensive palustrine wetlands develop with associated swamp forests (Cowardin et al., 1979). This type of wetland covers vast portions of the North Carolina coastal plain (Fig. 1-1), form on uplands between stream valleys, and are commonly referred to as pocosins, which means “swamp on a hill”. Much of Green Swamp is a pocosin.

The hydrologic flow within the Green Swamp pocosin prior to human modification was probably dominated by sheet flow with only local areas of channeled flow. The sheet flow was funneled into discrete channel flow as the gradient steepened or as channels passed through narrow zones in the paleotopography. For example, this still occurs where Driving Creek has eroded a steeper channel through the Socastee GMU at Caison Island (Fig. 6-3-5). Once past the constriction the flow reverts back to sheet flow. The entire flow out of Green Swamp pocosin is ultimately funneled into the channeled flow of both the upper Waccamaw River (Fig. 6-3-3) and Juniper Creek (6-3-4) as they pass through the 'narrows' on either side of Crusoe Island and into the main stem of the lower Waccamaw River.

8.3. Role of Groundwater Discharge

8.3.1. Geologic Setting

The major portion of the Waccamaw drainage basin is superimposed upon and occurs within the paleotopography of the Cretaceous Pee Dee Formation (Fig. 5-3). The Pee Dee is a thick sequence of calcareous cemented sandstone, sandy moldic limestone, and sandy mudstone that is an important deep, groundwater aquifer in the North Carolina coastal plain. Both Lake Waccamaw and the Waccamaw River drainage system are incised into sediments of the Pee Dee Formation.

Springs that flow from Pee Dee outcrops along the river banks during low water are direct evidence that this aquifer is discharging into the Waccamaw drainage system. However, little research has been done concerning the importance and role of groundwater discharge from the Pee Dee aquifer within the Waccamaw drainage basin. It is well known that stream beds intersecting a groundwater aquifer with a significant hydraulic head are recipients of groundwater discharge from that aquifer. NC DWQ (1999) states that "the Waccamaw River has longer peak flows than most other rivers in the state, which suggests that a large majority of the stream flow originates as groundwater discharge". This deep aquifer discharge, in consort with the surficial aquifer discharge, constitutes the base flow for the Waccamaw River.

Aquifer discharge continues as long as it is recharged and the water table (hydraulic head or potentiometric surface) remains above the level at which discharge occurs. As the water table drops, the discharge declines and will eventually go to zero when the water table falls below the level of the stream bottom. Local lore commonly refers to large springs along the Waccamaw River banks that used to be far more extensive than today. Today, there are many small springs that slowly weep from river outcrops of the Pee Dee Formation, suggesting a general decline in the water table.

8.3.2. Stream Flow and Base Flow

Stream flow consists of base flow plus the overland surface flow. According to Bales and Pope (1996) the average base flow of the Waccamaw River at the USGS gauging station (Freeland) was 53.3% of total stream flow between 1940-1994 with ranges from 28% in 1942 and 1981 to 72% in 1953 and 1958. Plots of their base flow and runoff data, using both the 95th and 75th percentiles, suggest that there is a:

1. General increase in variability and range of runoff

beginning in 1970 to 1994 as compared to pre-1958 data, and

2. Major decline in base flow in 1985 to 1994 as compared to the pre-1984 data.

These data (Bales and Pope, 1996) suggest an increase in variability of runoff with a declining input of base flow through time. Changes in runoff probably reflect the extensive drainage ditching that has impacted the Waccamaw drainage system during the past several decades (Fig. 7-2-2). The recent decline in base flow reflects a general decline in the Pee Dee groundwater table with decreasing discharge into the Waccamaw River system. These changes are demonstrated by the period of 1991-1994 when precipitation was greater than average but stream flow was less than average.

8.3.3. Chemistry of the Groundwater Base Flow

The Cretaceous Pee Dee Formation is generally an interbedded sequence of calcite-cemented sandstone, calcite-rich sandy mudstone, and fossiliferous sandy limestone (Fig. 6-5-9A). Outcrops of the Pee Dee along the river banks display extensive evidence of ongoing dissolution and reprecipitation of the mineral calcite. For example, secondary cementation by calcite produces the pattern of weird-shaped nodules that characterize the incised river banks (Fig. 6-5-9B). Therefore, water discharging from this unit into the streams is probably alkaline due to abundance of calcium carbonate. Pelletier (1985) measured the calcium (Ca) contents of Pee Dee groundwater in Horry Co., SC and found ranges between 59-89 mg/l, which is significantly higher than any other Cretaceous aquifers.

The black-water streams of eastern North Carolina are generally characterized by high acidity due to the dominance of organic matter in the associated floodplains and swamp forests. Black waters generally have a pH = 5 or less within North Carolina. If a significant volume of Pee Dee groundwater were being discharged into the Waccamaw drainage system, it would cause the surface waters to have a higher pH than expected for swamp waters. In fact, this is the case and is the primary reason for development of the very unique characteristics of this drainage system. This is why the waters of the Waccamaw have “exceptional water quality” and are a “showcase of biological richness” (NC DWQ, 1999) with a high diversity and abundance of biota that has “national ecological or recreational significance” (NC DEM, 1995).

Lake Waccamaw is distinct among the bay lakes due to a pH range from 6.8 to 7.5 (Cahoon et al., 1993) as compared to a pH of 3.2 to 4.8 for most North Carolina bay lakes (Weiss and Kuenzler, 1976). Big Creek, the main blackwater stream that feeds Lake Waccamaw, and its tributary streams have pH’s of 6.0 and 6.1 to 6.6, respectfully (Casterlin et al., 1984; Stager and Cahoon, 1987). The NC DEM (1994) reports pH for three stations along the main stem of the Waccamaw River. Table 8-3-1 presents a summary of pH at three monitoring stations along the Waccamaw River. The station at Freeland has the lowest pH in response to the large volume input of water from the vast wetlands in the Green Swamp, most of which is sealed from the underlying Pee Dee aquifer by extensive clay beds. However, within the Waccamaw River the pH increases significantly downstream (Longs, SC) in response to the groundwater input since the river is largely rockbound within the Pee Dee Formation.

TABLE 8-3-1. Summary of pH data from three monitor stations along the main stem of the Waccamaw River between 1988-1992 (NC DEM, 1994).

Station	Minimum pH	Maximum pH	Mean pH
Lake Waccamaw dam	6.1	7.5	7.0
Freeland (hwy 130)	4.3	6.3	5.5
Longs, SC	5.4	7.4	6.1

Frey (1948) and Cahoon et al. (1993) attributed the high alkalinity of Lake Waccamaw to the occurrence and chemical weathering of the Waccamaw Formation that forms a limestone bluff along a portion of the northern shoreline. Cahoon et al. (1993) calculated that subaqueous chemical weathering could contribute approximately 15% of the total lake water alkalinity, but does not account for the remaining alkalinity. Some alkalinity within the Waccamaw drainage system may come from the surficial groundwater discharge through porous carbonate-rich sediments of the Waccamaw Formation. However, the Waccamaw Formation is only locally preserved and has limited lateral extent. The majority of alkalinity within Lake Waccamaw is unaccounted for by previous workers.

More importantly, the Waccamaw River, which receives water from the swamps throughout the entire drainage basin, has a pH of over 7.0 (Casterlin et al., 1984). Therefore, it is highly probable that the unique levels of alkalinity throughout the Waccamaw drainage system results largely from groundwater discharge out of the underlying Cretaceous Pee Dee Formation. A water well in the Cretaceous aquifers at Nakina school, about 7 miles west of the lower Waccamaw River, records a pH of 8.7 (Knobel, 1985). The Cretaceous Pee Dee aquifer in Horry County, South Carolina, the downstream segment of the lower Waccamaw River, contains groundwater with pH that ranges from 6.9 to 9.6 and high calcium concentrations in three different wells (Pelletier, 1985).

If the Pee Dee Formation is an important contributor of groundwater to Lake Waccamaw, the pH and consequent color of the lake would fluctuate depending upon the relative amounts of groundwater discharge and surface water inflow from the surrounding swamps. Hubbs and Raney (1946) and Frey (1948) described the Lake as ranging from a dark color with 400 ppm suspended solids to a rather light brown color with 159 ppm suspended solids and to almost colorless with 0 ppm suspended solids. With ever increasing utilization pressure and declining hydraulic heads of the Pee Dee aquifer through time, there will be decreasing groundwater discharge and declining pH of the surface waters. This would be reflected by the darkening color of lake water as organic-rich, acidic waters of the surrounding swamps (400 ppm; Frey, 1948) become an increasingly larger component.

8.3.4. Prognosis for the Waccamaw Drainage System

The Cretaceous aquifer system, including the Pee Dee aquifer, represents an economically important source of groundwater throughout the central portion of the North Carolina coastal plain. It is under severe utilization pressure with the potentiometric surface generally declining at average annual rates up to 1 to 5 meters per year in the major urban areas of Jacksonville, Kinston, Goldsboro, and Greenville

(Winner and Lyke, 1989). The Pee Dee aquifer is also under severe utilization pressure in the high growth areas of Wilmington (Winner and Lyke, 1989; Giese et al., 1991; and Lautier, 1998) and Myrtle Beach (Pelletier, 1985). Brunswick and Columbus Counties and the entire Waccamaw drainage system are situated between these two major urban areas that are rapidly sprawling towards each other. This growth will result in ever-increasing pressure on the Pee Dee aquifer for high-quality groundwater. Even if there is not major urban growth in Brunswick and Columbus Counties, continued development of golf courses, hog farms, and agricultural irrigation are all water intensive operations.

Since groundwater discharge (base flow) represents a major input of water into the Waccamaw drainage system, there will also be an ever-increasing impact upon the river system through time. Increased withdrawals from the Pee Dee aquifer will lead to declines in the potentiometric surface and decreases in base flow into the Waccamaw drainage system. The combined consequences of decreased base flow and increased drainage ditches, will be general decreases in mean river flow, increases in river flow flashiness with rain events, and an overall degradation in water quality through time.

8.4. Wetland Dynamics

8.4.1. Sponge Effect of Swamp Forests

Swamp forests are nature’s sponges that slow down overland flow, filter the water, raise the water table, and increases evapotranspiration of water by the vegetation. In the humid, mid-latitude regions of the Atlantic coastal plain, extensive swamp forests are the dominant type of fresh water wetland habitat. These wetlands have low slopes, heavy vegetative cover, and peat substrates that act like great sponges, absorbing and holding tremendous amounts of shallow groundwater.

Disruption of this unique water system can have dire effects upon the associated stream systems. If a swamp is dissected by a dense network of ditches, the surficial groundwater leaks out faster and the water table is lowered—this is the basic purpose for ditching and draining these wetlands. Draining of adjacent uplands into ditches that bypass the swamp eliminates a major portion of water input into that swamp system. Also, if trees or other vegetation are removed from a swamp or adjacent uplands, particularly if there is any slope to the land, there is little to hold the water and the water flows off rather than soak into the sponge. Thus, the lower the water flow into and adsorbed by a swamp forest, the less water held by the swamp for the slow, long-term, base-flow release to adjoining drainage systems.

Water stored in a swamp is slowly discharged as base flow into adjacent streams allowing them to flow even during periods with little rainfall. This results in a more uniform stream flow through time with slower responses to individual storm events and continued flow during dry seasons. To damage or eliminate the sponge effect of a swamp results in extremely rapid water flow responses to individual storms with quicker and longer low-flow periods. Thus, swamps tend to produce “uniform flow” and their elimination results in “flashy flow” of a drainage system. A good analogy is to pour water onto a dry sponge until it is saturated and set it on a table--it slowly leaks onto the table and drips onto the floor. Then take the same amount of water in a cup and pour it directly onto the table and watch it quickly flow off the table and onto the floor.

8.4.2. Role of Vegetation and Fire

Major attributes of coastal plain pocosins are the large and contiguous size of many of these systems and their location within the uppermost reaches of drainage systems (Brinson, 1991). Because of these attributes, Brinson believes that “individual impacts to small areas are relatively inconsequential until their cumulative effects begin to encroach upon the landscape-level processes and functions that they display. Fragmentation by drainage ditches and roads and interspersion of agriculture and silvaculture expose the organic soils to peat fires and biological oxidation. The historically slow rate of organic matter accretion is reversed to a more rapid process of degradation. Accelerated oxidation and subsidence create a net efflux of carbon to the atmosphere in contrast to the net influx that has been occurring for millennia.”

Pocosins are characterized by poor drainage that is initially determined by the large-scale geologic framework. The detailed drainage within any given pocosin will be quite complex and will be determined by the paleotopography and composition of underlying sediments. Due to very low slopes and the resulting immature drainages, the overall character of the wetland system can be greatly modified by very small perturbations upon the wetland system. Fires, hurricanes, and beaver activity become acute factors that can either temporarily lower or raise water tables and associated patterns of evapotranspiration (Brinson, 1991). Also, the accumulation of fallen trees either through episodic hurricane events or by beaver activity can greatly influence the drainage conditions by blocking and damming low gradient streams. Dube et al. (1995) demonstrated significant “watering up” of wetland water tables due to reduced evapotranspiration in direct response to clear-cutting. Clear cutting on poorly drained soils on the North Carolina coastal plain caused a water table rise of several meters (Wilde et al., 1953).

Fires play a major role in pocosin hydrology. Fires that kill vegetation, but do not burn peat are often followed by an abrupt rise of water table due to transient decreases in evapotranspiration until leaf area is reestablished (Brinson, 1991). This was dramatically demonstrated in the April 8, 1955 aerial photographs of Green Swamp that followed the major fire that burned 117,000 acres of the pocosin. Figures 6-2-11 and 8-4-1 show the after effects as vegetation debris was photographed forming dramatic arcuate flow structures. These flow structures formed in response to sheet flow of the extremely high water table within the devegetated pocosin resulting from the dramatic decrease in evapotranspiration. Inspection of rainfall data for spring 1955 show no anomalous rain events that could have resulted in such high water levels within the pocosin.

Vegetation and evapotranspiration also play very important roles in the seasonal pattern of runoff. Figure 8-4-2 (Bales and Pope, 1996) compares mean monthly percentage of 1940-1994 mean precipitation at Elizabethtown with mean monthly stream flow at the Waccamaw River stream gauge at Freeland. An important inter-relationship exists between rainfall, river flow, and seasonal growth patterns of vegetation and

FIGURE 8-4-1. April 8, 1955 aerial photograph of Green Swamp shows prominent water-flow patterns. The interpretation of these patterns is that they were formed during a very high water table event that followed a major forest fire burn through large portions of Green Swamp during March 1955. The subsequent rise in the water table resulted from decreased evapotranspiration due to lost vegetation at the beginning of the growing season (Fig. 8-4-2). Sheet flow transported and deposited the vegetation debris into the flow patterns observed in the photograph. This resulted in slight topographic variations, which are lost with time due to their decomposition. These features were not visible in any subsequent photographs available to the study. Photograph was flown on 4/8/1955 by the U.S. Department of Agriculture.

FIGURE 8-4-2. Plot of mean monthly percentage of 1940-1994 mean precipitation at Elizabethtown, N.C. (black) and 1940-1994 mean stream flow at the lower Waccamaw River at Freeland, N.C. (gray). Letters along the horizontal axis represent the months of the year from January through December. This plot shows the inter-relationship that exists between rainfall, river flow, and seasonal growth patterns of vegetation and associated evapotranspiration. Notice that the low rainfall months of January through April have the highest river flow due to minimum vegetative growth and evapotranspiration. In contrast, the high rainfall months of June through September have the low river flow due to maximum vegetative growth and evapotranspiration. Figure is modified from Bales and Pope (1996).

associated evapotranspiration. During the months of January through April, 30% of the average annual rain falls with 57% of the average annual river flow, because evapotranspiration is at low levels. In contrast, during the months of June through September 44% of the average annual rain falls with about 25% of the average annual river flow, due to high rates of evapotranspiration during this period. March is the month with minimum vegetation growth, whereas June is the maximum period. March has < 9% of the average annual rainfall but discharges over 17% of the average annual river flow. Whereas, June has about the same rainfall (< 10%) but discharges less than 4% of the average annual river flow.

8.4.3. Ditching and Draining of Pocosins

Wholesale ditching and draining of pocosin wetlands has a dramatic and irreversible, long-term effect upon the overall water table and associated wetland habitats. Water table position is a vital control over the formation, accumulation, and preservation of organic peat deposits in pocosins. When the water table is significantly dropped on a permanent basis through the process of cutting of drainage ditches, any existing organic peat horizons will begin to oxidize, particularly as timbering operations break down and disrupt the surficial root mass. Additionally, fires during periods of drought can more effectively burn the surficial organic matter.

Ditching and draining pocosins results in permanently lowered groundwater table. There are several major consequences once organic peat soils have been dried out due to permanent lowering of the surficial groundwater table. The peat undergoes increased oxidation of organic matter and decreased concentrations of organic carbon drain from the former wetlands. Oxidation of the organic matter results in the ultimate loss of the peat deposit and leads to regional land subsidence. Oxidation processes are accentuated by today’s logging techniques utilizing heavy equipment that severely disrupts the surficial organic soils during both the planting and harvesting phases (Fig. 9-1-3). The thin layer (< 0.5 m) of poorly developed surficial peat that occurs within most of Green Swamp (Ingram, 1987) is thought to be a result of extensive oxidation over the past half century of ditching, draining, and intensive logging operations.

Waters draining relatively undisturbed pocosins typically have high concentrations of organic carbon and organic nitrogen, and low concentrations of essential nutrients such as phosphorus, inorganic nitrogen, and metallic cations (Brinson, 1991). Humic matter in surface water is dominated by allochthonous bacteria which provides an abundant source of high quality food resulting in solid surfaces in blackwater streams being very productive

However, most portions of the Waccamaw drainage system can no longer be classified as “natural” or “in transition” according to Brinson (1991). Rather, most of the system would be classified as “totally developed” since it has been extensively ditched and drained with native vegetation removed, and soils prepared for commercial use. Brinson believes that this has several major consequences upon the downstream surface water system.

1. Changes water runoff and flow characteristics,

2. Increases amount and rate of denudation and downstream

sediment pollution, and

3. Decreases downstream water productivity.

8.4.4. Moderating Role of Floodplain Road Dams

Road dams within the Waccamaw drainage system have two general occurrences: 1) logging roads associated with construction of drainage ditches within the pocosin and floodplains and 2) highway dams across major streams and associated floodplains. Table 8-4-1 estimates the extent of road dams at the three major highway crossings of the lower Waccamaw River based upon the primary or active and secondary or antecedent floodplains.

For decades an integrated network of drainage ditches were dug within Green Swamp to lower the water table and increase rates of water delivery downstream. The small field ditches connected to ever-larger main ditches, which discharged into tributaries and ultimately the trunk river. However, with each ditch came a road dam that subdivided the swamp into a network of compartments (Figs. 7-2-2 and 7-2-3) connected by minimal-sized culverts through the roads. The growth in number of roads mushroomed in parallel with the construction of drainage ditches.

In addition, the North Carolina Department of Transportation built three major roads across large portions of riverine floodplains (Table 8-4-1). The broad floodplains were filled for construction of new raised highways utilizing minimal-sized culvert and bridge openings. These roads were engineered to balance the flow of a specific size rain event against the minimization of economic cost. The primary bridges are largely over the main riverine channel and parts of the active floodplain. There is minimal effect from these road dams for normal flow conditions and on a day to day basis. However, the antecedent floodplain is very broad with only a few minor channels that are either crossed with minimal bridges or culverts. None of the latter openings are capable of carrying the greatly increased water discharge during high flow conditions. Consequently, the road fill acts primarily as a road dam filling large portions of the antecedent floodplain.

However, during high-flow events, sheet flow is minimized as water backs water up behind the road fill along large stretches of the floodplain as the road begins to act as a dam. The water must now flow along the dam and into the limited flow-through areas causing much of the floodplain to become a temporary holding basin. The extremely high percentage of road fill across the antecedent floodplains suggests that the road dams within the Waccamaw drainage system could have a positive effect upon the Green Swamp pocosin.

Drainage ditches and roads are intimately paired. Construction of a drainage ditch automatically forms an adjacent road bed, which is the disposal site for excavated sediment. Drainage ditches are engineered to lower the surficial water table and move that water off the land surface as rapidly as possible. The ditch drains and lowers the day-to-day surficial water table and converts the sheet flow that normally flows slowly across the wetland into channelized flow that moves rapidly and directly off the land, bypassing the adjacent wetlands. However, under heavy rainfalls the adjacent road dam boxes in some surface water and forces excess water to move as sheet flow across the road dams and temporarily impounds water for a slower release through time.

TABLE 8-4-1. Examples of road dams across the Waccamaw drainage system.

ROAD SYSTEM	PRIMARY FLOODPLAIN			ANTECEDENT FLOODPLAIN		
	Bridge Length m	Road Length m	Road Dam %	Bridge Length m	Road Length m	Road Dam
Old Dock Road	60	360	17%	20	2,900	99.9%
Highway 130	29	29	0%	20	6,100	99.9%
Highway 904	95	95	0%	0	4,670	100 %

The role of the road dams is poorly understood and should be studied to determine the critical interrelationship between them and the ditching, precipitation, and discharge within different parts of the drainage system. In certain situations, it is possible that road dams play a significant role in offsetting water retention problems resulting from drainage ditches.

8.5. Historical Precipitation and Stream Flow Patterns

Bales and Pope (1996) used the average daily flow data base (discharge in cubic feet per second) to develop an historical stream flow analysis of the lower Waccamaw River. The data were from the U.S. Geological Survey stream gauge station at Freeland, N.C. The gauge is located 1 mile southwest of Freeland in Brunswick County, and is situated on the east bank of the lower Waccamaw River, 50 meters downstream of the N.C. highway 130 bridge. Bales and Pope (1996) used data for the period from July 1939 through September 1993 for their analysis. They concluded that “the relation between changes or trends in Waccamaw River flow characteristics identified in this study and human activities is very difficult to determine because of the absence of quantitative information on changes in basin land use, irrigation, and drainage practices during 1940-1994.”

Precipitation data for the years of 1946-1949 are from Elizabethtown (Table 8-5-1), located just over the interstream divide in the adjacent Cape Fear drainage basin and about 22 miles due north of Lake Waccamaw. Precipitation data for the period of 1995-1998 are from Whiteville (Table 8-5-1), located in the Waccamaw drainage basin and about 10 miles due west of Lake Waccamaw. Whiteville was not used for the earlier period since complete data was only available since 1949. Elizabethtown was used for the latter period except for 1995 due to an incomplete data set. Consequently, the 1995 data are from Whiteville. However, both data sets are presented for 1996-1998 (Table 8-5-1) to demonstrate the similarity in precipitation between the two sites. Precipitation for the years of 1946-1949 was similar to the average annual precipitation for Elizabethtown (annual mean = 46.7 inches per year) and ranges from 43 to 48 inches per year (Bales and Pope, 1996). Precipitation for the years of 1996-1998 for Whiteville was similar to that in Elizabethtown. However, the total rainfall for this latter period had a slightly broader range that extended from 41 to 65 inches per year (Table 8-5-1).

TABLE 8-5-1. Summary of rainfall (Whiteville and Elizabethtown) and discharge (lower Waccamaw River) data for two representative four year periods from 1946-1949 and 1995-1998. These two time periods have similar rainfalls but quite different flow responses as demonstrated in Figure 8-5-1.

YEAR	[1]WHITEVILLE TOTAL PRECIP INCHES	[1]ELIZABETHTOWN TOTAL PRECIP INCHES	MEAN PRECIP IN/YR	[2]TOTAL DISCHARGE CFS	MEAN DISCHARGE CFS/YR
1946		48		421 thou	
1947		45		437 thou	
1948		48		451 thou	
1949		43		301 thou	
1946-1949		184	46	1.610 mil	402 thou
1995	50	incomp		372 thou	
1996*	65	64		486 thou	
1997	41	48		149 thou	
1998	63	59		471 thou	
1995-1998	219	171	54/57	1.478 mill	393 thou
Elizabethtown		46.7**			

* Data includes one extreme event: Hurricanes Fran (12/9/96).

** Mean annual precipitation from 1940-1994, from Bales and Pope (1996).

[1] Data for the Whiteville 7NW and Elizabethtown Lock 2 stations were provided by the State Climate Office of North Carolina at NC State University, Raleigh, NC.

[2] Discharge data are from the National Water Information System files, U.S. Geological Survey Historical Streamflow Daily Values for Waccamaw River at Freeland, NC (# 02109500).

Bales and Pope (1996) demonstrated that the Waccamaw River had a greater variability of total flow than the Lumber River and the variability in runoff generally exceeded the variability in base flow within the Waccamaw River. They also demonstrated an apparent increase in low flow volumes within the Waccamaw River through time which they attributed to the increased “channelization and artificial drainage in the Waccamaw Basin”. They go on to say “it has been demonstrated that both channelization and artificial drainage lead to an increase in base, or low, flows”. Mason et al. (1990) and Heath (1975) found that channelization of small streams and development of artificial drainages in the North Carolina coastal plain could increase base flow almost 10 fold above pre-existing conditions.

However, within the Waccamaw drainage system, ditching and draining of the surficial sediments directly impacts only the surficial aquifer, which represents the short-term base flow to the Waccamaw River. It is the surficial water aquifer that creates the vast Waccamaw wetland system. The surface water infiltrates into the sediments, flows laterally into the streams through time, and supplies a portion of the base flow on a short-term basis (days to months). This water represents the “sponge-effect” of swamp forests that ditches are designed to eliminate by lowering the surficial water table and moving this short-term stored water off the land more rapidly.

The shallow aquifer water appears to represent only a portion of the base flow feeding the lower Waccamaw River. Another important, but poorly understood input component to the river’s base flow is from the deep groundwater aquifer system of the Cretaceous Pee Dee Formation. The Waccamaw drainage system is intimately linked with the morphology and lithology of the underlying Cretaceous sediment units; the drainage system flows on top of and is incised into this extensive geologic unit. Consequently, ever-increasing demands upon the water in this deep aquifer system lowers the water table through time resulting in major changes in the long-term (years to decades) base flow to the Waccamaw drainage system. The changes in flow depicted in Figure 8-5-1 are interpreted to reflect these large-scale, long-term results.

If there is a decline in deep aquifer base flow through time, not only will this have a severe impact upon the river’s low-flow dynamics, but there will also be a long-term decrease in overall water characteristics. As the Cretaceous aquifer base flow declines, decreased volumes of this basic (high pH; Table 8-3-1) water will result in an overall increase in water acidity (low pH) within the lake and river waters. This change in water chemistry will threaten the biological uniqueness of Lake Waccamaw and the Waccamaw River as compared to most other North Carolina coastal wetland systems. With time and loss of the Cretaceous input to the base flow, the Waccamaw River system will become just another black-water drainage!

Figure 8-5-1 plots the daily precipitation data from Elizabethtown (years 1946-1949 and 1996-1998) and Whiteville (year 1995) against the discharge for the lower Waccamaw River at Freeland. Two time segments, 49 years apart, were selected to represent the periods of pre- and post-ditching and draining (pre- and post-1958, respectively). Figure 8-5-1 demonstrates that the two time segments were characterized by similar precipitation conditions. If this is true, then the differences in the discharge patterns between the two time periods should reflect the long-term flow response to alterations of both the surficial and deep water aquifers that control base flow within the drainage system. Figure 8-5-1 demonstrates the following characteristics for the two time periods relative to each other.

<u>1946-1949</u>

1. The day to day precipitation pattern is generally uniform with all rainfall events having less than 3 inches per day.
2. River discharge is generally uniform with lower-high flows and higher-low flows.
3. The River generally has a moderately high level of base flow with only a few short periods characterized by really low-flow conditions.

FIGURE 8-5-1. Daily precipitation data from Elizabethtown and Whiteville plotted against the discharge data for the lower Waccamaw River at Freeland for two similar four-year time segments. The plots demonstrate the critical role of seasonality and vegetative evapotranspiration in controlling the Waccamaw River discharge. Seasonal growth is indicated with black bars for periods of lowest vegetative growth and rates of evapotranspiration (primarily months of January through April) and green bars for periods of highest vegetative growth and rates of evapotranspiration (primarily months of June through September). The similar precipitation patterns between the two time periods suggest that additional differences in discharge patterns should reflect the long-term flow response to alterations of both the surficial and deep water aquifers controlling the river's base flow.

> PANEL A: The plot for years 1946-1949 represents the pre-1958 period with minimal development and land modification through ditching and draining.
>
> PANEL B: The plot for years 1995-1998 represents the post-1958 period with rapid development and land modification through ditching and draining.

1995-1998

1. The day to day precipitation pattern was generally uniform, however, 6 rainfall events exceeded 3 inches per day.
2. River discharge was generally flashier with higher-high flows and lower-low flows. This apparent change in base flow is attributed to drainage system modifications and lowered water tables of both the surficial and deep aquifer systems.
3. In spite of ample day to day rainfall, the river’s base flow appears to have decreased resulting in more and longer time periods with very low discharge.
4. The largest rainfall occurred in response to Hurricane Fran (in 1996) that produced record discharges with a very rapid rise and fall response.

The plots in Figure 8-5-1 also demonstrate the critical role of seasonality and vegetation in controlling the Waccamaw River discharge. During the winter low-growth season (primarily the months of January through April), runoff is the dominant process and discharge is high. Whereas, during the summer high-growth season (primarily the months of June through September), evapotranspiration is the dominant process and discharge is low and totally dependent upon both base flow and major rainfall events such as tropical storms and hurricanes. If ditching and draining continues to increase, rates and volumes of runoff will continue to increase resulting in the stream flow becoming even flashier with time. Also, if the base flow is decreasing through time, the height of low flow will continue to decrease and the number and duration of low-flow events within the streams will continue to increase.

Individual hurricanes have significant impacts upon the Waccamaw River flow characteristics. In September 1996, hurricane Fran came ashore in southeastern North Carolina with heavy rainfall that resulted in severe and widespread flooding (Fig. 8-5-1). Peak flow in the Waccamaw River occurred on 9/12/96 and was about 20% higher than the previous record peak flow, which occurred as a result of hurricane Diane in 1955 (Bales and Childress, 1996). Hurricane Fran produced a peak flow for the Waccamaw that represented a 100-year flood recurrence interval, whereas the same storm developed only a 10-year recurrence interval in peak flow on the neighboring Lumber River with similar rainfalls (Bales and Childress, 1996).

This significant difference between the peak flows of the Waccamaw and Lumber Rivers probably reflects two conditions. First, slightly higher amounts of post-Fran rain fell in the Waccamaw drainage than in the Lumber Basin, which is a somewhat larger drainage basin. Generally, both basins received < 6 inches of rainfall between 9/3 and 9/12; however, a very small portion of the uppermost Waccamaw drainage basin received < 8 inches of rainfall (Bales and Childress, 1996). More importantly, the difference probably reflects the vast amount of drainage ditching within the Waccamaw basin, which moved more water off the land faster than occurred within the Lumber basin. Bales and Pope (1996) concluded that “runoff per unit drainage area is greater in the Waccamaw Basin than in the Lumber Basin” and that probably “artificial drainage has increased the efficiency of the drainage network in the Waccamaw Basin relative to that of the Lumber Basin”.

9. SEDIMENT POLLUTION IN THE MODERN WACCAMAW RIVER

Erosion and sedimentation are the most widespread causes of nonpoint source pollution and freshwater stream impairment in North Carolina's river basins.

NC DWQ, 1996

9.1. SEDIMENT SOURCES TO THE WACCAMAW RIVER

Many different sources supply sediment pollutants to the modern Waccamaw River. The actual source and amounts at any specific location depends upon the location within the overall system and the underlying geologic framework. Each of the following sources was documented during our study. However, it was beyond the scope of the present research project to quantify volumes and rates of sediment input from each of the recognized sources into the Waccamaw River.

9.1.1. Sand Sediment in Lake Waccamaw

A shallow perimeter platform extends from the shoreline lakeward to about 1 meter water depths where the lake bottom drops into the broad and flat central basin with depths between 2 to 3 meters. The perimeter platform surrounds Lake Waccamaw and is generally covered with varying amounts of clean quartz sand. This surficial sand is particularly extensive along the southern and eastern lake shores where large NW-SE oriented sand waves occur at oblique angles to the shoreline (Figs. 6-2-5A and 6-2-10B).

Prior to construction of Cove Canal (Figs. 6-2-4 and 6-2-10A) and formation of the dredge-spoil rim for lakefront housing along the southwest shore, there was a broad swampy spillway where water drained from the lake into the UWR and adjacent Lake Swamp (Fig. 6-2-4). The southwestern perimeter platform was dominated by cypress trees and aquatic plants that baffled the lake sands and kept them largely within the lake. However, with construction of the canal and subsequent development, the discharge became focused at the modern outlet and the abundance of trees and other vegetation along the drowning shoreline diminished. Significant amounts of sand could now be contributed to the river system during storms and subsequently transported downstream by high-energy flood waters.

Construction of the first dam at the mouth of the upper Waccamaw River temporarily curtailed sediment contribution to the river. However, longshore transport moved a significant volume of sand along the extensive sand waves on the shallow perimeter platform at the SE end of the lake (Fig. 6-2-5A) and deposited it in the area above the dam. During storms, the sand accumulated in the shallow flats behind the dam was transported (Fig. 6-2-5B) and over the weir dam and into the mouth of the upper Waccamaw River. The large volume of quartz sand that occurs below the weir dam and generally decreases downstream away from the lake is clearly coming from Lake Waccamaw.

Lake Waccamaw does supply sand sediment to the upper Waccamaw River. However, it is not clear how much sediment is derived from the Lake or how fast this sediment is being delivered to the river. Nor is it clear how much sand is ultimately being transported downstream to the lower Waccamaw River. We do know that Lake Waccamaw was produced as an erosional feature and continues to erode today producing sand sediment, particularly around the shorelines and shallow perimeter platforms. Also, ongoing development along the Lake Waccamaw shoreline, as well as urban and agricultural development on adjacent upland regions during the 20th century has increased rates of shoreline recession, land erosion, and resulting sand production. The increased amounts of sand along the SE perimeter platform of the Lake are obvious when the aerial photographs in Figures 6-2-11A (1938) and 6-2-11B (1955) are compared with 6-2-5A (1988).

9.1.2. Sedimentation in the Upper Waccamaw River

Abundant sand deposits occur within the UWR (Fig. 6-4-4A) and consist of interbeds of two major components (Fig. 6-4-4B). During storm events, quartz sand is transported downstream from Lake Waccamaw and deposited as natural levees, mid-channel bars, and meander point bars. These sand deposits are subsequently buried by thick layers of autumn leaf litter that settles out in the river bottom. The next storm moves more sand downstream burying the dense matted layers or organic debris and produce thick interbedded accumulations within and along the channel. Downed trees and logs within the channel often control the locus of sediment accumulation. These channel sand deposits are very soft as the organic matter compresses and decomposes with time. Each new slug of sand into the UWR buries the previous accumulation of leaf litter. Thus, the accumulation of sand and large volumes of leaf litter tend to fill the channel within the upper reaches of the river.

The upper Waccamaw River is not an actively meandering channel system. Rather, the river has shallow channels incised into the adjacent swamp forest peats. The peat banks are severely bound and largely protected by tree roots. Consequently, very little if any bank erosion is taking place within this portion of the river and little to no sand is produced by riverine bank erosion of these peat-dominated floodplain deposits.

The recent period of human modification within Lake Waccamaw is recorded within the floodplain sediments. Formerly, flooding conditions did not transport significant sediment loads. Consequently, the floodplain deposits were dominated by the accumulation of fairly pure organic peat. However, during recent times, flood waters that spill over low channel banks and inundate the adjacent floodplain carry a significant sediment load. The increased suspended sediment load is deposited as water velocity rapidly decreases forming small natural levees along the river banks and crevasse splays into the floodplain. Today the floodplain deposits adjacent to the channel consist of mixed layers of organic detritus and fine grained quartz sand reflecting increased sand input.

9.1.3. Sediment Production in Green Swamp

Human modification and development of an artificial drainage system has dramatically changed the hydrology of the Green Swamp system. Extensive ditching and draining of Green Swamp over the past four decades (Figs. 7-2-2 and 7-2-3) has created a situation where the dominant hydraulic flow is channelized through a massive network of drainage ditches. Today, sheet flow on the day-to-day scale is only important in a few local and unaltered areas such as White Marsh (Fig. 6-3-2) and above Driving Creek (Fig. 6-3-5).

However, on the larger scale of extreme storm events, sheet flow is still important. For example, sheet flow was observed as a dominant component throughout Green Swamp in 1996 with Hurricanes Bertha and Fran (Figs. 9-1-1 and 9-1-2), in 1998 with Hurricane Bonnie, and in 1999 with Hurricane Floyd. During these major events, water levels within many parts of Green Swamp exceeded the ditch capacity and ultimately overtopped the road dams and sheet flow became an important process again (Fig. 9-1-1). Commonly, the sheet flow eroded channels through the road dams and ultimately blowing out large road segments (Fig. 9-1-2).

The basic purpose of a drainage ditch is twofold. First, it lowers the surficial water table and dries out the upper portion of the hydric soils to allow growth of nonwetland species. Second, it facilitates access for heavy equipment to work the cropland. Lowering the water table totally dehydrates organic-rich hydric soils, which don’t readily rehydrate (Brinson, 1991). Because of the extreme land-altering techniques used by the modern timber industry, the devegetated and dehydrated land surface at various stages of the clearing, planting, and harvesting process is severely broken and opened to extensive erosion by sheet flow (Fig. 9-1-3).

If a major flooding event occurs when the land is in these vulnerable conditions, the resulting sheet flow erodes vast amounts of sediment from the opened fields. Also, significant amounts of sediment are eroded out of roads and ditch banks as the sheet flow blows out road dams. During peak storm flow, unknown volumes of sand are transported through the drainage ditches and discharged directly into downstream tributaries and ultimately into the trunk river channel (Fig. 9-1-4). During the waning stages of each storm, the decreasing flow deposits the bed load sand that fills the ditches (Fig. 9-1-5).

Thus, two major sources of sand exist for sand deposits in the upper Waccamaw River. First, shoreline recession and erosion of the adjacent uplands around Lake Waccamaw is ultimately transported along the shallow perimeter platform and delivered to the UWR over the weir dam at the river mouth. Second, sheet flow erosion during timber planting and harvesting within the surrounding Green Swamp pocosin delivers large volumes of sediment via the network of drainage ditches to the UWR. As previously discussed, both areas represent major sediment inputs into the riverine system. However, to quantify actual volumes of sand being introduced from these two sources will require an extensive research project monitoring sediment dynamics.

9.1.4 Drainage Ditches in Antecedent Floodplain

Two different geomorphic units or GMUs (Fig. 5-6) characterize the lower Waccamaw River valley. The Holocene GMU is the modern floodplain dominated by: actively meandering river segments, very low topography, well developed wetland vegetation, and characterized by seasonal flooding (Fig. 6-5-4A and 6-5-5). The Wando GMU is an antecedent floodplain dominated by: paleo-ridge and swale structures, slightly higher topography, marginal wetland vegetation, and an active floodplain only during extreme flood events (Figs. 6-5-4B and 6-5-7). Because the antecedent portions of the floodplain are topographically higher, some of this area has already been ditched and drained for timber production (Fig. 6-5-1). Whereas, the active floodplain has rarely been modified to date (Fig. 6-5-2).

FIGURE 9-1-1. Photographs of sheet flow over road dams in the Green Swamp pocosin during flood-stage flow of Hurricane Fran (9/1996).

PANEL A. Sheet flow over logging road. Notice the abundance of bedload sand being eroded from the recently logged area on the left side of the road. Flow is from left to right.

PANEL B. Sheet flow over a state highway. Notice that both sides of the road are highly vegetated resulting in the total lack of bedload sand. Flow is from right to left.

FIGURE 9-1-2. Photographs of sheet flow eroding through a logging road dam in the Green Swamp pocosin during flood-stage flow associated with Hurricane Fran (9/1996).

PANEL A. Early stages of sheet flow as rising water begins to overtop the road dam. Notice the vegetative cover in the recently planted (one to two year old) logging area to the left of the road and the absence of sand on the road.

PANEL B. The same road as Panel A after the flow breached the road resulting in channelized stream flow through the road dam.

FIGURE 9-1-3. Photographs of the land preparation process by timber companies in the Green Swamp pocosin.

PANEL A. The land is cleared of swamp forest that still exists in the background. At this stage all vegetation has been eliminated, exposing the soil to erosive processes.

PANEL B. The land is being prepared for planting after harvesting a stand of planted pine as can be seen in the background. At this stage the land is most vulnerable to soil erosion processes. Notice how the heavy equipment breaks up the soil.

FIGURE 9-1-4. Photographs of the post-storm sediment deposited in the streams during the waning stages of storm flow associated with Hurricane Fran (9/1996).

PANEL A. Abundant sand bars deposited in a ditch and on the banks where the ditch enters a small and modified tributary stream.

PANEL B. A new sand bar formed at the mouth of a drainage ditch discharging from the left into the upper portion of the Waccamaw River.

FIGURE 9-1-5. Photographs of the post-storm sediment deposited in the ditches in the Green Swamp pocosin during the waning stages of storm flow associated with Hurricane Fran (9/1996).

PANEL A. Sand deposited upstream of a road dam with a minimal sized culvert associated with a recently logged area in the upstream block of land.

PANEL B. A roadside ditch downstream from a recently logged block of land with the ditch totally filled with sediment.

Drainage ditches in the antecedent floodplain of the LWR cut directly through the extensive ridge and swale deposits (Fig. 6-5-1). These deposits are paleo-pointbars deposited by the Waccamaw River during a former time when the climate was significantly different than the present climate. The point bars are composed of clean, loose quartz sand that is readily eroded and supply large volumes of sand to the eroding ditch. During floods, the sand is discharged from the ditch into the LWR.

9.1.5. Upland Agriculture and Silvaculture

Several logging operations were observed along the steep banks between the Holocene and Wando GMUs and the Wando and Socastee GMUs that occur within several hundred meters of the LWR channel. These banks are often 4 to 7.5 meters high, quite steep, and occasionally are proximal to the river channel. Clear-cut logging of these banks produces a situation that is conducive to bank erosion and sediment production. In all cases observed along the LWR, large plumes of sediment were carried into the lower swamp forest and into the LWR if a drainage ditch or natural stream drained through the area. This results in fan deltas of sand deposited at the mouth of the ditch or tributary stream (Fig. 9-1-4B).

The poorly drained upland surfaces of the Socastee and Penholoway GMUs are partially drained by a series of tributary streams that flow into the LWR and include Bear Branch, Wet Ash Swamp, Gore Creek and Seven Creeks to name a few (Fig. 4-1). These upland surfaces were ditched and drained decades ago for agricultural development with the drainage water being piped directly into the tributary streams. Severe soil erosion is generally associated with this type of agriculture (Table 3-2). In every case, where the tributary stream flows through the Wando and Holocene GMUs, the stream channel and associated floodplain has been filled with sand sediment. For example, in the lower floodplain of Bear Branch, the stream channel has been filled with > 3.3 meters of medium to coarse sand.

Wherever large volumes of bedload sediments are delivered to the River by either natural tributary streams or by major drainage ditches, there is a large accumulation of sand in the downstream river segment below the discharge point. For example, the LWR below the confluence of Bear Branch is often too shallow for navigation, highly meandering, and locally referred to as “the narrows”.

9.1.6. Erosion of the River Banks

Large segments of the lower Waccamaw River are deeply incised into the antecedent floodplain (Fig. 6-5-6). Consequently, much of the incised portion of the river has high banks occurring along the channel. The lower part of these banks is rockbound and composed primarily of indurated Cretaceous Pee Dee Formation (Figs. 6-5-8 and 6-5-10). Overlying this rock unit is 1 to 3 m of clean loose sand that comprises the sediments of the antecedent floodplain. The surface has a thin and poorly developed soil, commonly bound by a dense root mass. As the sandy portion of the bank erodes, large curtains of the root mass drape down across the bank face providing telltale evidence of bank erosion (Fig. 6-5-8 and 6-5-10B). The exposure of root crowns of many trees along the lower bank also suggests bank erosion.

Analysis of river profile geometry in rock-bound segments suggest that they have been actively receding but at amounts varying from 3 to

12 meters (Brant, 1998). These banks had between 2 to 3 meters of sand on top of the Cretaceous unit. Based upon the size of undercut banks and soil drapes, as well as location or relict stumps and roots, etc., a conservative number can be calculated for the amount of sand potentially eroded from the river bank. Based upon the range of numbers, there is a potential for somewhere between 6,000 and 36,000 m^3 of sand supplied to the river per kilometer of river bank eroded.

Actively meandering river segments generally would develop a balance between the ongoing erosion and recession of the cut bank and deposition and progradation of the point bar. However, due to the active meandering process, cut bank erosion brings down many big trees during both the winter high-water season and storms. These trees effectively trap the bed-load sediment, concentrating more sediment within the meander segments and further aggravating the navigation.

Boat wakes play an important role in the erosion of river banks and contribution of sand to the river bottom. During normal to low water levels, boat wakes break largely on nonerodible portions of the river bank: underlying rock units (Figs. 6-5-8 and 6-5-10), active point bars (Fig. 6-5-15B and 6-5-15A), and highly vegetated root masses along low banks. When the river is in high-water stage, water impacts directly on the vegetatively bound upper portion of the bank or actually overtops the bank and spreads out into the floodplain. In addition, there are few boats on the river during high-water stage. Thus, boat wakes are not serious problems during either low- or high-water stages.

However, when the river is at intermediate-water stage, there are lots of boats on the river and their wakes directly impact on the soft sand portion of the bank. At this stage, boat wakes are devastating to the bank as wakes severely erode the sand and undercut the vegetatively bound surface layer and associated trees. Then during the next storm, these trees are blown down across the river, effectively trap sand, and cause the river channel to shallow (Fig. 6-5-15A).

Boat wakes were probably not a significant factor in the eroding sediment banks prior to 1975 due to the small sizes of outboard engines and the fewer number of boats on the river. However, with development of modern high-speed outboard engines and increased popularity of boating and fishing during the last quarter century, erosion along river banks caused by boat wakes has become a significant factor in sediment production. This source of sediment pollution to the river will continue to increase if the economy remains strong, unless some controls are placed upon when and how the river is to be used by boaters.

9.2. Sediment in Lower Waccamaw River

9.2.1. Thickness and Distribution of Sediment

A general survey of sand thickness was made down the axis of the lower Waccamaw River using ground-penetrating radar. Figures 9-2-1 and 9-2-2 show the portion of the LWR that was surveyed and summarizes the general distribution of sediment thickness. The river channel has been subdivided into four categories based upon sediment thickness as follows (Table 9-2-1).

1. River segments that are rock-bound with 0 to 0.25 m of surface sand,

2. River segments with 0.25 to 1 m of surface sand

3. River segments with 1 to 2 m of surface sand, and

4. River segments with > 2 m of surface sand.

The distribution of each of these categories for the river segments surveyed is displayed on Figures 9-2-1 and 9-2-2. The location of Figures 9-2-3 through 9-2-9, which displays examples of the GPR data, is also indicated on Figures 9-2-1 and 9-2-2.

Table 9-2-1 estimates the volume of sediment occurring within each of the four different sediment thickness categories for the portion of the lower Waccamaw River surveyed. These data were periodically checked in the field with sediment probes and at measured cross-sectional profiles (Fig. 4-1), which were control points for the GPR survey data. The GPR survey data represent a first approximation of the total volume and distribution of sand in the river since they are based upon a single-track line down the center of the river channel.

TABLE 9-2-1. Approximation of the average volume of sand occurring within the river channel within the four different sediment thickness categories for the North Carolina portion of the lower Waccamaw River surveyed (Figs. 9-2-1 and 9-2-2).

SEDIMENT GROUP	SEDIMENT THICKNESS CATEGORY	RIVER DISTANCE SURVEYED		AVE CHANNEL WIDTH*	SEDIMENT VOLUME m^3/River km
<1.0 m	0.0 -0.25 m	5.6 km	22%	22.7 m	0- 5,675
	0.25-1.0 m	8.4 km	33%	22.7 m	5,675-22,700
>1.0 m	1.0 -2.0 m	7.9 km	31%	14.0 m	14,000-28,000
	2.0 –4.5 m	3.4 km	13%	14.0 m	28,000-63,000
TOTAL		25.3 km	99%		

* Average stream width for river segments (Fig. 6-5-4) is based upon measured river widths during low flow stage at 15 river cross sections (Brant, 1998).

FIGURE 9-2-1. Map of sediment distribution and thickness within the northern portion of the lower Waccamaw River channel. Also indicated on the map are the locations of Figures 9-2-4, 9-2-7, and 9-2-8, which display examples of the ground-penetrating radar data and its interpretation.

FIGURE 9-2-2. Map of sediment distribution and thickness within the southern portion of the lower Waccamaw River channel. Also indicated on the map are the locations of Figures 9-2-3, 9-2-5, and 9-2-6, which display examples of the ground-penetrating radar data and its interpretation.

FIGURE 9-2-3. Ground-penetrating radar (GPR) data and data interpretation for a portion of the lower Waccamaw River that is incised into the Cretaceous Pee Dee Formation. Location is just south of the highway 904 bridge and is indicated on Figure 9-2-2.

PANEL A. Raw GPR data.

PANEL B. Interpreted GPR data showing a major flat rock surface covered by surficial sand waves with wave heights of 0.5 to 1 m and wave lengths from 3 to 8 m. The geometry and downstream facing steep side indicates active downstream migration. Notice that in some places the troughs of the sand waves are on the rock surface.

FIGURE 9-2-4. Ground-penetrating radar (GPR) data and data interpretation for a portion of the lower Waccamaw River along a straight reach downstream from the drainage ditch in Figure 9-2-9. Location is indicated on Figure 9-2-1.

PANEL A. Raw GPR data.

PANEL B. Interpreted GPR data showing a major, slightly undulating rock surface, Cretaceous Pee Dee Formation, covered by surficial sand waves with wave heights of 0.5 to 1 m and wave lengths of 20 to 25 m. The geometry and downstream facing steep side indicates active downstream migration.

FIGURE 9-2-5. Ground-penetrating radar (GPR) data and data interpretation for a segment within a tight meander of the lower Waccamaw River. The upstream side of the panel is located at both the apex of a meander and point where a tributary stream enters the Waccamaw River. Location is indicated on Figure 9-2-2.

PANEL A. Raw GPR data.

PANEL B. Interpreted GPR data showing a large (1 to 2.5 m thick) lobe of sand at the mouth of a small tributary stream. Notice that the rock surface beneath the sand lobe crops out in the upstream side, which is the meander apex.

FIGURE 9-2-6. Ground-penetrating radar (GPR) data and data interpretation for a segment within a tight meander of the lower Waccamaw River. The upstream side of the panel is located at both the apex of a meander and point where a drainage ditch enters the Waccamaw River. Location is indicated on Figure 9-2-2.

PANEL A. Raw GPR data.

PANEL B. Interpreted GPR data showing a large (2 to 2.5 m thick) lobe of sand accumulated on the downstream side of the meander apex. This sand lobe probably represents the lower portion of the well-developed point bar that occurs on the downstream side of the meander. Notice that the rock surface, Cretaceous Pee Dee Formation, beneath the point bar sand lobe drops off into the meander apex where it crops out on the upstream side. A drainage ditch discharges into the river at this point and could partly be responsible for deposition of this sediment lobe.

FIGURE 9-2-7. Ground-penetrating radar (GPR) data and data interpretation for a segment within a straight reach of the lower Waccamaw River that crosses the entrance of two tributary streams. Location is indicated on Figure 9-2-1.

PANEL A. Raw GPR data.

PANEL B. Interpreted GPR data showing a deposit of sand on the downstream side of each tributary. The largest sand lobe is about 100 m long by 1 to 2 m thick. Downstream of this large lobe, the river is incised into the Cretaceous Pee Dee Formation and is dominantly rock floored with little to no sand. Location of these data are indicated on Figure 9-2-1.

FIGURE 9-2-8. Ground-penetrating radar (GPR) data and data interpretation for a segment within a straight reach of the lower Waccamaw River across the entrance of a major drainage ditch. Location is indicated on Figure 9-2-1.

PANEL A. Raw GPR data.

PANEL B. Interpreted GPR data showing a 3 to 4.5 m thick lobe of sand sediment, which has accumulated just downstream of the drainage ditch mouth. Notice that the Cretaceous Pee Dee Formation forms the floor of the River channel in the meander where the ditch enters. This river segment is incised in rock and is dominantly rock floored with little to no sand both upstream and downstream of this figure. This is the thickest sediment pile recognized in the portions of the river surveyed.

9.2.2. River Segments With < 1 m Surface Sand

Along river segments with generally 1 m of sand or less, the channel occurs essentially on the rock surface with thin and variable amounts of sand either scattered on the surface or filling depressions within the rock. These channel segments have two general occurrences.

River segments with < 1 m of sand occur most extensively within wide, straight reaches that are incised into the underlying rock (Fig. 6-5-6). Figures 9-2-3 and 9-2-4 display typical GPR data of rock-bound portions of the lower Waccamaw River where it is incised into the Cretaceous rocks. The attenuation of the GPR signal below the surficial sand layer indicates a major lithologic change. This was confirmed with probes and cores along the measured cross-sectional profiles and determined to be the Pee Dee Formation throughout the extent of the GPR survey (Brant, 1998). The flat rock surface is covered by surficial sand (< 1 m thick) that occurs as waves with wave heights of 0.5 to 1 m and wave lengths from 3 to 25 m. The geometry and downstream facing steep slopes indicate active bedform migration in the downstream direction.

River segments with < 1 m of sand also occur in the narrow, actively meandering portions of the lower Waccamaw River (Fig. 6-5-6). Figures 9-2-5 and 9-2-6 present GPR data that demonstrate the occurrence of exposed rock within the apex of meander bends. Both of these figures are located on short river segments where water velocity increases around the outside of a meander bend forming a cut bank adjacent to a deep, rock-floored surface within the river channel. In these situations, sand being eroded from the cut bank (Fig. 6-5-15A), as well as that moving downstream with the river flow, is transported to the inside and slightly downstream of the meander apex. As water velocity decreases, sediment is deposited to form extensive point bars on the inside and downstream of the meander apex (Figs. 6-5-15B and 6-5-16A). The result is a deep, narrow, rock-floored river channel on the cut bank side.

9.2.3. River Segments With > 1 Surface Sand

A lot of sand occurs within the actively meandering river segments. This sand generally has three occurrences. The straight reaches between tight meanders usually contain channel-floor sand deposits that are between 1 to 3 m thick. Figures 9-2-5 and 9-2-6 demonstrate the sediment relationship between the reaches and meanders.

Occasionally, the deep portion of a meander will fill with sand as one or more trees severely modify the riverine processes and make the river virtually impassible. Because actively meandering river segments are narrow, erosional processes along the cut bank frequently cause trees to fall completely across the river channel. During high-water conditions the channel sands are actively transported downstream. However, downed trees cause increased current flow within the active floodplain and baffles the river current flow, causing sand to be actively trapped by the trees, filling the meander.

Incised river segments generally contain < 1 m of surficial sand on top of the rock floor. Locally, the incised river segments may contain between 1 m to 3 m of surficial sand. The presence of abundant sand is frequently related to the discharge of a tributary stream or drainage ditch immediately upstream of the sediment (Figs. 9-2-7 and 9-2-8). Both the tributaries and ditches flow off higher-level swamplands, which have been extensively drained for both agriculture and silvaculture. Visual inspection during storm events and probing surveys in the mouths of tributaries and ditches demonstrated large sand bodies filling their lower reaches with significant amounts of sand deposited into the adjacent swamp forest. Wherever such a stream or ditch actually enters the lower Waccamaw River, the channel is deep and rock floored with a major pile of sand immediately downstream. Figure 9-2-8 shows the rock floor of the river where a major drainage ditch enters the river and a 3 to 4.5 m thick lobe of sediment just downstream of the ditch and little to no sand upstream of this figure. This is the thickest sediment pile recognized in the portions of the River surveyed. Figure 9-2-4 is located on the straight reach immediately downstream of Figure 9-2-8.

Thus, there appears to be a major and continuous source of sand that maintains the large piles immediately downstream of specific tributaries and drainage ditches. It is assumed that this sand is related to upland erosion and delivered into the Waccamaw River as point source discharge during significant erosional events. The sand is then systematically mobilized and transported downstream as major sand waves during high flow, flood conditions. Thus, the persistent occurrence of these piles of sediment below the mouths of tributary streams and ditches suggests that the tributaries and ditches represent major and ongoing sources of new sand into the Waccamaw River with each major discharge event.

9.2.4. Sediment Problem Areas

If the volume of sediment being deposited within the lower Waccamaw River is adequate to cause the River to significantly shallow, it will hinder navigation during low-water flow conditions. Table 9-2-1 demonstrates that within the portion of the River surveyed, 13% has a serious problem with sedimentation within the channel, 31% has minor problems, and 55% has no problems (Figs. 9-2-1 and 9-2-2). Assuming that the distribution of sediments within the total length of the lower Waccamaw River is proportional to the portion of the River surveyed, a total river distance with sediment problems can be estimated, along with the total volume of sand that has infilled the River.

The total River length from the Old Dock--Crusoe Island bridge to the South Carolina line is about 60 km. Thus, approximately 8 km of River have serious sedimentation problems with greater than 2 m of sediment infill, while 19 km have local sedimentation problems with 1 to 2 m of sediment infill. About 33 km are either rock floored or have less than 1 m of sediment cover and do not represent a sediment problem.

Table 9-2-2 presents a first approximation of the total amount of river channel sand within the North Carolina portion of the lower Waccamaw River. These data suggest that about 8 km of river channel with serious sedimentation problems contain between 218,000 and 491,000 m^3 of sand. About 19 km of intermediate river segments contain between 260,000 and 521,000 m^3 of total sand within the channel. The no problem segments contain a total of less than 112,000 and 450,000 m^3 of total sand within the channel which is widely spread over 33 km of the river.

TABLE 9-2-2. Estimation of the total volume of sand occurring within the active channels of the four different sediment thickness categories within the lower Waccamaw River between the Old Dock—Crusoe Island bridge and South Carolina border.

SEDIMENT GROUP	SEDIMENT THICKNESS	EST TOTAL RIVER DISTANCE		SEDIMENT VOLUME* m^3/River km	TOTAL EST CHANNEL SEDIMENT IN LWR m^3 in 60 km
<1.0 m	0.0 -0.25 m	13.2 km	22%	0- 5,675	0- 75,000
	0.25-1.0 m	19.8 km	33%	5,675-22,700	112,000- 450,000
SUBTOTAL		33.0 km	55%		112,000- 450,000
>1.0 m	1.0 -2.0 m	18.6 km	31%	14,000-28,000	260,000- 521,000
	2.0 –4.5 m	7.8 km	13%	28,000-63,000	218,000- 491,000
SUBTOTAL		26.4 km	44%		478,000-1,012,000
TOTAL		59.4 km	99%		590,000-1,537,000

* From Table 9-2-1.

9.3. Sediment Characteristics

The channel sediment within the Waccamaw River was characterized by analyzing 14 surface samples from three cross-sectional profiles (Table 9-3-1). The grain size ranges from 0.29 phi (coarse sand) to 2.72 phi (fine sand) with a mean of 1.47 phi (medium sand). The sorting ranged from 0.54 phi (moderately well sorted) to 1.90 phi (poorly sorted) with a mean of 1.14 phi (poorly sorted). The samples from each of the three profiles ranged from fine to coarse sand and from moderately to poorly sorted. The coarsest sediment is generally in the deepest part of the channel and on the adjacent point bar with the sediments fining into shallower water or towards the cut bank.

TABLE 9-3-1. Mean sediment grain size (in phi units) of 14 channel sands collected along three cross-channel transects in the lower Waccamaw River. Data are from Brant (1998). Profiles are located on Figure 4-1.

PROFILE	**SPL A**	**SPL B**	**SPL C**	**SPL D**	**SPL E**	**MEAN PHI**
P7	1.00	0.87	0.55	1.47	2.26	1.23
P13	1.28	0.29	1.88	2.72		1.54
P9	2.53	2.51	1.05	1.07	1.16	1.66

TOTAL SAMPLES = 14

MEAN GRAIN SIZE: MODERN CHANNEL SANDS = 1.47 phi
= 0.30 mm or MEDIUM SAND

The channel samples were composed dominantly of quartz with up to a few percent heavy minerals and variable amounts of coarse organic detritus in the form of leaves, sticks, and seeds. Organic detritus usually constitutes less than < 1% of the sediment, but occasionally it will range up from 5% to 10%. Occasional beds or laminae, particularly in accretionary point bars (Figs. 6-4-4B, 6-5-15B, and 6-5-16B) may represent up to 90% organic detritus.

The modern channel sands have similar textural and compositional character as the sands within both the modern and antecedent floodplain sand sediments. The big difference between the channel sand and the floodplain deposits is the amount of mud and organic matter that dilutes the sand to produce the various facies. Modern channel sands also have similar characteristics as the sand component of the Cretaceous Pee Dee Formation into which the modern Waccamaw River is incised (Brant, 1998).

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