Abstract

LUGINBUHL, SARAH CHRISTEN. Surface and subsurface hydrology of a drained Carolina Bay prior to restoration. (Dr. James Gregory, chair; Dr. Michael Vepraskas, co-chair)

Juniper Bay is a 330 ha Carolina Bay located 13 km southeast of Lumberton in Robeson County, North Carolina. Carolina Bays are elliptical depressions in the landscape primarily located in the Coastal Plain region of North and South Carolina and Georgia. They are oriented with major axes northwest to southeast and their origin is unknown. Juniper Bay was drained beginning in the 1970’s for agriculture. In the year 2000 the North Carolina Department of Transportation bought the bay to restore to a wetland. North Carolina State University wrote a proposal to do research at Juniper Bay and the overall goal is to evaluate the strategy and performance of the restoration of wetland functions in Juniper Bay and to test alternative restoration methods. This research focuses on the hydrology of the bay prior to restoration. The objectives are the determination of the current ground water flow paths and the water table regime both inside and outside the bay, the identification of a strategy for hydrologic restoration, the documentation of the variability in the properties of the water table regime across Juniper Bay and the reference bays that will affect the success of the restoration, and the assessment of the usefulness of reference ecosystems for defining required hydrologic factors necessary for long-term restoration success.

There are three reference Carolina Bays, located in neighboring Bladen County, North Carolina. The hydrologic properties of these bays is the hydrologic goal of Juniper Bay once restoration is complete. Twenty-nine water table
monitoring wells were installed to a depth of 2.44 meters in and around Juniper Bay in early 2001, and four water table monitoring wells were installed in each of the reference bays. Seventeen piezometers equipped with pressure transducers were installed in and around Juniper Bay along two main transects, with depths ranging from 2.44 to 10.36 meters. The results from the water table wells show that 4% of Juniper Bay in 2001 and 22% in 2002 met wetland hydrology requirements, which are that the water table is within 30 cm of the soil surface continuously for 12.5% of the growing season in most years. The percentages of the reference bays that meet the wetland hydrology requirements range from 20% to 100%. Results show that ground water may be entering Juniper Bay from the northwest and southeast boundaries of the bay, which are higher in elevation, and exiting the bay through the northeast and southwest boundaries of the bay, which are lower in elevation. The ditches likely have a significant influence on the water table and the ground water, and the hydrology of the bay will likely be altered once they are plugged. The reference bays provide useful information in the determination of what conditions were probably like prior to disturbance and what the restoration effort in Juniper Bay should try to accomplish.
SURFACE AND SUBSURFACE HYDROLOGY OF A DRAINED CAROLINA BAY PRIOR TO RESTORATION

by

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A thesis submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the Degree of Master of Science

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Approved by:

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__________________________________________  ________________________________

Chair of Advisory Committee
Dedication

I dedicate this thesis is to my husband, who without his comic relief, I may not have made it through, and to my parents who have given me great advice and perspective.
Biography

I grew up in Raleigh and graduated from Enloe High School in 1991. I attended the University of North Carolina at Greensboro and graduated with a Bachelors of Science degree in Leisure Studies. I moved to Atlanta for a year and then moved back to North Carolina. I started at North Carolina State University in the masters program in Natural Resources in the summer of 2000. This is also the year I got married. In February of 2003 I got a full time job as an environmental scientist with a small environmental consulting company and continued to work on finishing my thesis. This was accomplished in May 2004, the month I was also expecting my first baby.
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**Introduction**

Wetlands are important ecosystems on the earth (Mitsch and Gosselink, 2000). They help regulate and maintain the hydrology of rivers, lakes, and streams by storing and slowly releasing flood waters, they help maintain the quality of water by storing nutrients, reducing sediment loads, and reducing erosion (Dahl and Johnson, 1991; Committee on Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy, 1992; Mitsch and Gosselink, 2000). At the time of Colonial America, the area that is now the conterminous U.S. had an estimated 89.44 million hectares of wetlands (Dahl and Johnson, 1991). Twenty-two states have lost at least 50% of their wetlands since the 1780s, and 10 states have lost at least 70% (Dahl and Johnson, 1991). The average rate of wetland loss from the mid-1950s to the mid-1970s was nearly 186,162 hectares per year (C.R.A.E., 1992).

During the mid-1970s to mid-1980s, federal, state, and local government programs and policies began to affect wetland use and conversion (Dahl and Johnson, 1991). Prior to the mid-1970s, the drainage and destruction of wetlands were accepted practices in the United States and were even encouraged by specific government policies (Mitsch and Gosselink, 2000). In the mid-1970s there were an estimated 42,900,000 hectares of wetlands, and in the mid-1980s there were an estimated 41,800,000 hectares of wetlands in the conterminous United States, with 95% being freshwater (inland) wetlands and 5% being estuarine (coastal) wetlands (Dahl and Johnson, 1991). By the early to mid-1990s, negative impacts, such as declining waterfowl populations, were becoming apparent (Dahl and Johnson, 1991).
In the 1970s and 1980s people started to change their thinking about the value of wetlands. It was becoming clearer that wetlands had values that were beneficial to human life, such as storing flood waters, removing nutrients and sediment from flood waters, and as breeding and living ground for important wildlife such as fish and birds. Federal agencies and Congress started to place greater emphasis on protection and maintenance of natural values (Dahl and Johnson, 1991). In general, through a series of congressional actions in the mid-1980s, federal incentives to destroy or alter aquatic ecosystems were significantly reduced (Dahl and Johnson, 1991). The Swampbuster program of the 1985 Food Security Act eliminated U.S. Department of Agriculture (USDA) benefits in many circumstances where farmers cleared and drained wetlands for crop production (Dahl and Johnson, 1991). The 1986 Water Resources Development Act (P.L. 99-662) placed major new cost burdens on the beneficiaries of water project construction, often states and their political subdivisions (Dahl and Johnson, 1991). In the mid-1980s, Florida initiated its “Restore the Everglades” program, and in 1988 the governor of Louisiana established an office to coordinate all of the state’s coastal management and restoration efforts. In 1990, Congress enacted the Coastal Wetlands Planning, Protection, and Restoration Act (United States Senate, 1990) that established a joint federal-state task force to identify and implement wetland restoration projects in Louisiana and a joint planning group to devise an overall plan for the restoration of coastal Louisiana (Dahl and Johnson, 1991). In 1990, Congress also adopted the Agricultural Wetland Reserve Program as part of the 1990 Food, Agriculture, Conservation, and Trade Act (P.L. 101-624) that could help
to reconvert one million acres of cropland to wetlands (Dahl and Johnson, 1991). For the first time, Congress had established a significant wetland restoration program (Dahl and Johnson, 1991).

At least four actions of Congress in 1990 suggested that federal water development agencies may begin to become actively involved in actual wetland restoration projects. Two of these actions were Section 306 of the 1990 Water Resources Development Act (WRDA) that said that “environmental protection” was now a central mission of the U.S. Army Corps of Engineers (Corps), and Section 307 of the 1990 WRDA called upon the Corps to develop a wetland plan “within one year” (Committee on Restoration of Aquatic Ecosystems, 1992). Programs such as that provided by Section 404 of the Clean Water Act and the Swampbuster program, however, were intended to retard loss of wetlands, not restore them (Committee, 1992). Even though Section 404 permit writers typically seek to avoid or minimize impacts resulting from activities in wetlands, some impacts are unavoidable. In cases where impacts do occur, other forms of mitigation such as enhancement, restoration, or creation of replacement habitat are often employed to offset the losses (Committee, 1992). Research on wetland restoration has focused on techniques of species establishment and of development of species composition and wetland community structure (Committee, 1992). The establishment of wetland structure does not necessarily restore all the functions of a wetland ecosystem (NRC, 2001). The functional values of wetlands are often not evaluated, and mitigation efforts have not yet been able to duplicate lost wetland functional values (Committee, 1992). Some functions that are frequently overlooked in wetland
restoration and creation activities include hydrologic functions, water-quality functions, support of vegetation, support of habitat for fauna, and soil functions (NRC, 2001). Wetlands are complex because they are difficult to define, there is a wide variety of hydrologic conditions in which they are found, and they combine attributes of both aquatic and terrestrial ecosystems but are neither (Mitsch and Gosselink, 2000).

The restoration of wetlands has the general goal of returning the system to a close approximation of the predisturbance ecosystem that is persistent and self-sustaining (Committee, 1992). The Corps and the United States Environmental Protection Agency (EPA) defined restoration, in 1990, as “measures undertaken to return the existing fish and wildlife habitat resources to a modern historic condition. Restoration then includes mitigation as well as some increments of enhancement” (Committee, 1992). Mitsch and Gosselink define restoration as “the return of a wetland from a disturbed or altered condition by human activity to a previously existing condition”.

Wetland creation and restoration can range from the relatively simple building of farmland freshwater marshes by plugging existing drainage systems to the construction of more extensive wetlands for coastal protection or estuarine enhancement. Reasons for creating or restoring wetlands range from interest in restoring a major part of our wetland resources and their societal values to response to government policies such as “no net loss” that require the replacement of wetlands for those unavoidably lost by activities such as highway construction, coastal drainage and filling, and commercial development. These constructed
wetlands are called mitigation wetlands and are built with the intent of replacing the wetland “function” lost by the development, usually in the same or an adjacent watershed. These constructed wetlands are designed to be at least the same size as the lost wetland and often a mitigation ratio is applied so that more wetlands are created or restored than are lost. An estimated 50,000 hectares of wetland and associated uplands in the U.S. were gained from October 1993 through September 1999 due to enforcement of Section 404 of the Clean Water Act through wetland mitigation. It is, however, impossible to tell just how successful the constructed wetlands are in mimicking the functions lost from the destroyed wetlands (Mitsch and Gosselink, 2000).

Wetland restoration failures are due in part to a lack of preliminary research on the site to be restored, or due to unusual conditions at the site during the year(s) the site is monitored. Variability of the weather may make it necessary to monitor water tables for a long period of time to be sure that the results represent normal conditions. Even if the water table is monitored during a year, or a month, with “normal” rainfall, the results may not be accurate. Limiting the analysis for assessing wetland hydrologic status to months with near-average rainfall produces distinctly different results than basing the determination on long-term water table records under all rainfall conditions. Confining the analysis to periods of near-average rainfall often leads to the conclusion that wetland sites do not satisfy the wetland hydrologic criterion, and, therefore, have upland hydrology (Hunt et al., 2001).

Short-term site evaluation of the hydrology may be misleading, and it may be beneficial to gather as much long term data around the site as possible, such as
weather data. Models such as DRAINMOD can help in the evaluation of wetland hydrology. DRAINMOD was developed for shallow water table soils with agricultural drainage systems. It can also be used for undrained lands and for conditions where drainage occurs by vertical or lateral seepage (Hunt et al., 2001).

Every site will have its own set of factors that made it a wetland prior to its destruction or degradation, and if these factors are understood then the probability of the site becoming a wetland again is greatly increased. Restoring wetlands is still a relatively new activity, and more is being learned every day about wetlands and the processes involved in restoring their functions. Wetland mitigation as practiced by the North Carolina Department of Transportation (DOT) is the restoration of wetlands to replace those altered or destroyed in the course of road construction and maintenance (Vepraskas et al., 2000). To get full credit for wetland restoration efforts, Corps permits usually specify that wetland hydrology, hydric soils, and a plant community similar to the reference ecosystem be restored (Vepraskas et al., 2000).

The research described here addresses the hydrologic issues of wetland restoration through study of a large Carolina Bay, known as Juniper Bay, which was once a wetland and is now a mitigation site of the DOT. The overall goal of the research being done at Juniper Bay is to evaluate the strategy and performance of the restoration of wetland functions and to test alternative restoration methods (Vepraskas et al., 2000). The hydrologic research being done at Juniper Bay will add to the growing bank of knowledge of hydrologic influences in wetland systems,
which will hopefully aid future researchers and wetland restorers when considering restoring wetland hydrology.

There are two principal elements involved in the overall study of Juniper Bay and the reference bays. The first is the comparison of the hydrologic character of Juniper Bay prior to the installation of restoration practices (pre-restoration) to the hydrologic character of the bay after installation of restoration practices is completed (post-restoration). Pre-restoration hydrologic data will be collected for two years and post-restoration data will be collected for 3 to 5 years. A network of shallow water table monitoring wells was installed inside and outside the bay to determine the water table regime across the bay and adjacent land and to determine lateral hydraulic gradients in the near surface ground water. A network of piezometers, nested with the water table monitoring wells, was installed inside and outside the bay to determine vertical and lateral hydraulic gradients below the near surface clay layers. Another goal was to determine how the water table regime is affected by rainfall, soil characteristics, topographic variation, and near-surface hydraulic gradients.

The second principal element in the study is the comparison of the water table regime in the reference bays to the pre- and post-restoration water table regime in Juniper Bay. In each reference bay, a series of water table monitoring wells was installed along one transect that was cut from the rim (at the halfway point along one of the long sides of the bay) to the center of each bay, perpendicular to the long axis of the bay. The goal was to determine how the water table regime was affected by rainfall, soil characteristics, and vegetation type. Three bays were
selected as the reference bays to provide data on the variability among natural Carolina Bays.

This work in the overall project was to study the pre-restoration surface and ground water hydrology at Juniper Bay and monitor the water table at the three reference bays. I analyzed the differences in water table behavior among the bays and among the different soil types within each bay. I determined the effects of varying rainfall amounts and topography on the water table regime. Wetland hydrology criteria were also tested to determine whether parts or all of the bays meet wetland hydrology requirements. These data would be useful in the determination of the current ground water flow paths and water table regime in and around Juniper Bay in order to better determine the next step in the restoration process.

The restoration of Juniper Bay is a long-term project. The research objectives for the entire duration of the project are:

- Document the variability in the properties of soils and sediments and the water table regime across Juniper Bay and the reference bays that will affect restoration success,
- Determine current groundwater flow paths and water table regime both inside and outside Juniper Bay, and identify a strategy for hydrologic restoration,
- Assess the recovery rate of key hydrologic, biogeochemical, and plant community functions that are necessary for a sustainable wetland ecosystem,
- Assess the usefulness of reference ecosystems for defining required hydrologic and soils factors and target vegetation composition necessary for long-term restoration success,
• Identify soil chemical and physical properties and hydrologic requirements for optimum growth of Carolina Bay vegetation,

• Determine the effect of tree species type and diversity for achieving sustainable growth of desired vegetation and soil characteristics in the restored Carolina Bay,

• Test different restoration methodologies.

My research relates to the first, second, and fourth objectives stated above.

More specifically, the objectives of this study were to:

1) Determine the pre-restoration water table hydroperiod of Juniper Bay and the three reference bays, assess whether wetland hydrology criteria were met, and determine how site factors influenced the water table hydroperiod,

2) Determine characteristics of groundwater inflow and outflow, such as where groundwater may be entering or exiting the bay,

3) Assess the usefulness of reference ecosystems for defining required hydrologic factors necessary for long-term restoration success.
Literature Review

Carolina Bays

Carolina bays are oval- or elliptical-shaped shallow depressions in the landscape that occur on the Coastal Plain region predominately in North and South Carolina and Georgia, though some speculate the range is broader, with bays occurring from northern Florida to Delaware (Grant et al., 1998) and even New Jersey (Lide et al., 1995; Brooks et al., 1996). The Coastal Plain region occupies about 45% of the land area of North Carolina (Daniels et al., 1999). Soils in the Coastal Plain sediments are on sandy to clayey unconsolidated marine and fluvial deposits (Daniels et al., 1999). The shapes of Carolina Bays vary from elliptical to ovoid, or egg-shaped, to nearly circular (Johnson, 1942). They are all oriented in a general northwest-southeast fashion, with the long axis varying from S 65° E to N-S (Johnson, 1942). The long axis of bays in southeastern North Carolina and northeastern South Carolina averages (by individual bays) S 46° E and more elliptical in shape (Johnson, 1942). Bays in southeastern South Carolina and northeastern Georgia average (by individual bays) S 20° E and more ovoid in shape (Johnson, 1942). The bays can range in size from one mile or less across the long axis to at least four miles long (Johnson, 1942). Most bays have sand rims encircling sections of them, which are often most prominent in the east to southeast quadrant (Grant et al., 1998; Brooks et al., 1996; Johnson, 1942; Gamble et al., 1979; Daniels et al., 1999).

Carolina bays were first given special attention by Dr. L. C. Glenn in 1895. He observed that bays near Darlington, South Carolina, exhibited peculiarities, such
as the asymmetry of the sand rims, which called for explanation, and published a brief account of them (Johnson, 1942). The following paragraph was written by Dr. Glenn and quoted from Johnson (1942):

“First, aerial photographs of various portions of the Atlantic Coastal Plain were made as a basis for the disposal of timber and timber lands, for military studies, and for other uses. Second, these photographs were examined by Dr. F. A. Melton and Dr. William Schriever of the University of Oklahoma, who discovered that they revealed the existence of hundreds of bays of beautifully oval outline, bordered by rims of sand usually heaped up most abundantly near the southeastern ends of the depressions, the long axis of the ovals being remarkably parallel to each other and oriented northwest-southeast. Third, after study of the photographs and examinations on the ground Melton and Schriever published a paper in 1933 in which they attributed the origin of the oval bays not to terrestrial causes but to bombardment of our planet by a great shower of meteorites, possibly forming the nucleus of a comet which collided with the earth, the direction of approach having been from the northwest. Immediately popular curiosity was aroused and world-wide publicity was given to the “meteorite scars”. Aerial photographs of typical oval bays appeared in the daily press, in magazines, and later in books. Scientific curiosity was equally stimulated, and “the origin of the Carolina bays” began to be debated in scientific meetings and in technical magazines. The remarkable craters of the Carolina coast had at last been brought to popular and scientific attention, and efforts to solve the problem of their origin were in progress” (Johnson, 1942).

Melton and Schriever (Johnson, 1942), who proposed the meteorite hypothesis, believed that any hypothesis put forth to explain the Carolina Bays would have to explain the following characteristics: 1) elliptical plan, 2) nearly
parallel alignment, 3) elevated rims completely encircling some of the bays, 4) elevated rims invariably predominating at the southeastern end, 5) ellipticity increasing with size, 6) double and triple rims, 7) intersecting bays; in some cases one bay formed in part or all of another bay, and the integrity of the shape of one bay, presumed to be the latter-forming bay, is intact, 8) similarity between the sand in the rims and that found by drilling through the carbonaceous soil in the bottom of the bays, and 9) absence of bays in the Piedmont upland (Johnson, 1942).

The meteorite hypothesis proposed by Melton and Schriever and by Prouty (Johnson, 1942) suggested that a shower of meteorites striking the earth at angles between thirty-five and fifty-five degrees from the vertical would produce indentations that were elliptical in shape. As the meteors in a single shower would move in nearly parallel paths, the axes of the indentations should approach parallelism. The material of the earth would be thrown out of the depressions in all directions to give rims, with more material being thrown on the southeast ends due to the masses coming from the northwest. Multiple rims could be formed by the successive impacts of two or more meteors striking approximately in the same place. They date the formation of the bays prior to the formation of sand ridges that formed when the ocean last receded, approximately 20,000 years ago. But if meteorites hit the earth, formed the Carolina bays and their characteristic sand rims, and then the seas rose and then fell again, the Carolina bays and sand rims would have been destroyed by the ocean. Due to knowledge gained about Carolina Bays after this hypothesis was made and critical analysis of deductions which may properly be made from the meteorite hypothesis, the hypothesis, as put forth by
Melton and Schriever, only satisfactorily explains one of the nine “facts which any theory of origin must explain”, and therefore does not explain the origin of the Carolina Bays (Johnson, 1942). The one fact that they satisfactorily accounted for is the explanation of the fact that craters intersect and that the craters last formed, whether large or small, will be the more perfect in outline (Johnson, 1942).

Johnson (1942) also describes several other hypotheses put forth by scientists. These include the hypothesis of Dr. L. C. Glenn, who said the depressions were formed in processes associated with the eastward retreat of the sea and shore, and suggested the oval basins might represent former stream valleys flooded by a re-advance of the sea to give drowned valleys or bays, which later were blocked on the southeast with bay-mouth bars of sand built by the ocean waves. Dr. C. Wythe Cooke (Johnson, 1942) thought the elliptical sand ridges were in part bars and beaches built up in shallow lagoons during a higher stand of the sea and in part crescent-shaped keys formed in shallow lakes. Cooke goes on to say that the lagoons were transformed into chains of oval lakes through the action of waves and currents set in motion by the wind, and the observed parallelism of the oval forms is ascribed to “a constancy in the direction of the wind while they were being shaped” (Johnson, 1942).

Johnson’s hypothesis on the origin of Carolina bays near Myrtle Beach, South Carolina, is that the bays represent earlier freshwater lakes formed on a beach plain approximately at the present level of the bays. The symmetrical form of the bays that are perfectly oval resulted from “exceptionally complete development of the normal mature lake shoreline in soft unconsolidated sands of uniform texture. Elongation of
the lake basin in a northwest-southeast direction and the tendency for sand to accumulate in maximum quantities about the southeastern shores of the lakes were attributed to winds of maximum velocity coming from the southeast and setting up an undertow along the shallow lake bottoms directed toward the southeast. The rims of sand were regarded as dune ridges due to the transportation by variable winds of dry sand exposed along the shores of the lakes (Johnson, 1942). In 1936, Johnson did more field work on Carolina bays in North Carolina, with results confirming his original hypothesis that the bays represent freshwater lake basins and the oval rims accumulations of wind-blown sand. In addition, it was possible to present for the first time much evidence tending to show that the lake basins were in many places intimately associated with sinkholes and other solution phenomena over large areas and that in certain localities every gradation from typical sinkhole to typical oval bay could be found.

It was accordingly suggested by Johnson (1942) that the Carolina bays might represent in part a peculiar type of karst phenomenon, in which removal of underlying soluble beds permitted slumping of overlying sands or loam to give depressions of fairly symmetrical form in some localities, while uprising waters passing through the sandy cover elsewhere would remove finer material and thus contribute to the deepening of certain of the lake basins. Karst is a type of landscape found on carbonate rocks or evaporites and is typified by a wide range of closed surface depressions, a well-developed underground drainage system, and a paucity of surface streams (G.C.R.I.O., 2002). Macpherson (1996) states that the term “karst” usually refers to “a terrain or to land forms created by dissolution of
soluble rock, or to a landscape in which there is a distinctive hydrology as well as land forms in which vertical drainage and well-developed secondary porosity play a critical part”. Wave action along the lake shores that sometimes formed in these karst formations would perfect the oval form, the elongation of which in a northwest-southeast direction might be due either to wind control or to the direction of groundwater movement down the slope of the Coastal Plain beds (Macpherson, 1996).

This “complex hypothesis” (solution-lacustrine-aeolian hypothesis) of bay origin was first published in 1936 by Johnson (described in Johnson, 1942). In 1937, Johnson expanded on his earlier hypothesis (Johnson, 1942). It was shown that artesian springs, fed by uprising shallow artesian waters before stream incision in the Coastal Plain had lowered the groundwater level, would produce basins or craters, similar to those observed, partly by solution and partly by removal of finer sediment. Lakes for a time occupied many of the developing basins, while lake waves smoothed the contours of the basins and built beach ridges about portions of their borders (Johnson, 1942). Sand blown from beaches and beach ridges by the winds built more extensive dune ridges, some of these being superposed on preexisting beach ridges within the basins, others upon the Coastal Plain strata at their margins. Lowering of groundwater levels consequent upon incision of Coastal Plain streams later extinguished most of the lakes and will in time extinguish the few that remain (Johnson, 1942).

Studies by Brooks et al. (1996), and Grant et al. (1998), suggest the Carolina bays evolved during the Holocene. The Holocene is the name given to the last
11,000 years of the Earth’s history, the time since the end of the last major glacial epoch, or “ice age” (Waggoner, 1996). Holocene history in the southeastern United States has been pieced together from paleoecological and geoarchaeological records from a limited number of small lakes, alluvial wetlands and isolated wetland ponds (Gaiser et al., 2001). Archaeological dates established time scales for depositional processes on the rim of the basin, and radiocarbon dates established time scales for depositional processes at the center of the basin (Brooks et al., 1996). In the study of a Carolina bay called Flamingo Bay in South Carolina, Brooks et al. (1996) extrapolated from sedimentation rates a date of 10,000 yr B. P. for the basal sediments, and estimated the infilling of the basins to have occurred in the early Holocene or late Pleistocene. Aerial photographs, topographic maps, and grain size analyses on the eastern rim of Flamingo Bay strongly support the inference that at least the upper sediments of the rim are of eolian origin, additionally, the archaeological and radiometric dates from Flamingo Bay establish partial chronologies for Holocene changes in the rim and basin of the bay (Brooks et al., 1996).

Gamble et al. (1979), say the secondary rims appear to be developed by modification of the primary rim by eolian or aqueous activity, or both, and that the secondary rim would be a shore feature of a bay lake, which is part of the “artesian-solution-lacustrine-aolian hypothesis” suggested by Johnson (1942).

The placement of bays may have to do with the textural characteristics of the sediment, with bays common where the surficial Coastal Plain sediments are sandy
(east of the Goldsboro ridge) and are absent or few in number in areas of silty or clayey materials (west of the Goldsboro Ridge) (Gamble et al., 1979).

A recent study about Carolina Bays describes the stratigraphy of Chapel Bay in South Carolina consisting of sandy surface soils, clayey subsurface soils (argillic horizon), and a number of sandy and sandy clay unconsolidated layers under the subsurface soils (Trettin et al., 1999). This study also describes two aquifers that appear to be involved in the hydrology of Chapel Bay. The first aquifer is a near-surface unconfined aquifer connected to the surface water above the argillic horizon. The second aquifer is the groundwater that is in the sand layer below the clayey aquitard. These two aquifers were identified by the stratigraphy characterization, and both showed dynamic hydraulic head changes (Trettin et al., 1999). The study also indicates that the overall trends of the shallow groundwater head fluctuation followed precipitation and evapotranspiration patterns. Surface water around the bay recharges the shallow groundwater and is transported to the bay by flow through the sandy aquifer. The estimation of the groundwater unit recharge area indicated that the potential groundwater drainage area could extend far beyond the rim of the bay, 450 m in this study (Trettin et al., 1999). The report describes a dynamic surface-groundwater interaction, as described later in the literature review. Thus, the hydrology of a Carolina Bay may be far more complicated than what is simply happening inside the rim of the bay. This emphasizes the importance of detailed hydrologic studies of Carolina Bays.

Some bays have peat soils and some do not. Schalles and Shure (1989) suggest the reason bays in the upper Coastal Plain region of South Carolina do not
have peat soils is due to periodic drawdown and oxidation of exposed substrates due to dynamic and responsive water levels in this region. Sites at lower elevations frequently have peat soils, presumably due to the less dynamic water levels at lower elevations. They also found a strong relationship between precipitation and water level. Subsurface hydrologic exchange does exist, and the bay they studied, Thunder Bay, occurs within a persistent groundwater gradient. There is a surface-groundwater connection during periods of high groundwater, and elevated groundwater levels in winter and spring resulted from increased precipitation and decreased terrestrial evapotranspiration losses. The location on the Coastal Plain landscape may play a role in the hydrology of each bay.

Carolina Bays have formed where the exposed strata of Plio-Pleistocene sediments are sandy. Bay sediments overlie the Yorktown formation (Pliocene) in some locations, a clayey member (possibly the Morgarts Beach) at another location, and the Black Creek formation (Cretaceous) at another location, suggesting there could be a fair amount of relief and erosion on pre-bay sediments (Zanner et al., 2001). The Middle Coastal Plain fluvial (river deposited) and marine sediments can be greater than 10 m thick beneath the upland soils. The well to moderately well drained soils occur near the edges of the upland flat with more poorly drained soils on the broad flats near the interstream divide. The fluvial sediments become finer toward the surface with the coarsest sand and gravel near the base, and sandy clay loam and clay textures common in the upper one-third of the deposit (Daniels et al., 1999).
Carolina Bays are present in the uplands that are composed of fine-loamy and sandy fluvial, eolian and marine sediments, and rarely occur in areas dominated by clays or by soils with high silt contents. Bays are absent on valley slopes and modern flood plains. Many Carolina Bay floors have a fine textured layer that may have been deposited during erosion of the bay into its oval shape. The bay floor may have both organic soils and poorly drained soils of fine to coarse texture typically found in the wet areas outside the bays. The southeast bay edges are usually prominent nearly white sand that rises one to three meters above the bay bottom. The rims usually are eolian sand derived from the adjacent beach when the bay was filled with water. Low bay rims have soils with sandy surfaces and B horizons that are the result of normal soil development on the finer materials of the uplands (Daniels et al., 1999).

Carolina Bays are complex phenomena with no concrete explanation of their origin, few detailed studies of their hydrology and soils, with not many undisturbed sites left to study.

**Wetlands**

North America has always had an abundance and diversity of wetlands, although the existing wetlands are only a fraction of what existed 200 years ago. There were marshes and wet meadows in the east, peatlands and prairie potholes in the north plains in what is now Michigan, Wisconsin, Minnesota, and the Dakotas, and there were old-growth cypress swamps and bottomland hardwood forests in the south (Mitsch and Gosselink, 2000). Some of the wetland types that are of interest here in this study are prairie potholes, fens, pocosins, and cypress domes. These
are of interest because of their similarity to the Carolina Bays and their hydrologic influences. They are all depressions in the landscape, without tidal influence, where surface and ground water may interact, with precipitation the main hydrologic input.

Prairie potholes were formed by glacial action during the Pleistocene. Wet-and-dry cycles are a natural part of their ecology, and it is estimated that 50 to 75 percent of all the waterfowl originating in North America in any given year comes from this region (Mitsch and Gosselink, 2000). Most of these wetlands have no stream inlets or outlets and have limited interaction with groundwater because they are underlain by slowly-permeable till. Most of the input of water is from precipitation, with precipitation during the autumn months most influential, and most of the output is from evapotranspiration (Winter et al., 2001). There may be some exchange between surface and ground water (Schalles and Shure, 1989). Carolina Bay hydrology is similar in the fact that precipitation is the main hydrologic input and evapotranspiration is the main output (Schalles and Shure, 1989; Lide et al., 1995). Some bays have a stream outlet, or did historically, while some do not, but ground water is influential in Carolina Bays (Schalles et al., 1989; Trettin et al., 1999).

Fens are open peatland systems that generally receive some drainage from surrounding mineral soils and are often covered by grasses, sedges, or reeds. Fens are distributed in cold temperate climates of high humidity, mostly in the Northern Hemisphere where precipitation exceeds evapotranspiration, leading to moisture accumulation. Two primary processes necessary for peatland development are that precipitation is greater than evapotranspiration and that there is a surplus of peat production over decomposition, or accumulation greater than decomposition (Mitsch
and Gosselink, 2000). The area of distribution of fens and Carolina Bays is not the same, with fens in predominately cooler, northern areas and Carolina Bays on the southeastern coastal plain. They are similar in that precipitation exceeds evapotranspiration in the regions where they exist.

Pocosins are raised areas and are particularly dominant in North Carolina (Mitsch and Gosselink, 2000). The word pocosin comes from the Algonquin phrase for “swamp on a hill”. They are waterlogged, acid, nutrient poor, sandy or peaty soils located on broad, flat topographic plateaus, usually removed from large streams and subject to periodic burning” (Mitsch and Gosselink, 2000). The areas where pocosins are found were originally nearly flat and poorly drained with shallow water tables, with precipitation being the main input of water (Skaggs et al., 1991). Pocosin soils are generally organic or mineral with a high organic surface horizon (Skaggs et al., 1991). Pocosins do not receive runoff water (Skaggs et al., 1991) since they are the highest point on the landscape, occurring generally at the divide between two river systems. Pocosins and Carolina Bays occur in the same region of the U.S. and both have precipitation as the main hydrologic input. Carolina Bays, however, are depressions and may receive water entering along the surface from outside as a water input, and ground water input is sometimes influential. Both pocosins and Carolina Bays have acidic soils.

Cypress domes in north-central Florida usually have a low-relief, closed watershed, from which they receive sheet flow in heavy rainstorms. The water levels in the domes naturally fluctuate widely during the year following seasonal changes in the amounts of rainfall. There is usually no significant vertical water
movement through a sandy clay layer, indicating that evapotranspiration and radial groundwater flow out of the domes into the sand layer are the main hydrologic losses from cypress domes. Surface water in a cypress dome is closely coupled to groundwater in the underlying water table aquifer, and domes usually represent a high in the water table, with water spreading radially outward from them, recharging the water table. The cypress swamps can also be recharged by groundwater when water tables in adjacent uplands are higher than surface water levels in the depressions (Heimburg, 1984).

Carolina bays share some similarities with the cypress domes. However, Carolina bays do not represent a high in the water table and do not usually recharge the surrounding water table. Some Carolina bays do receive overland flow from surrounding areas during rain events.

There are many other wetland types but the ones listed above are most like Carolina Bays. The origin of Carolina Bays is unknown, and hydrologic processes are not well understood. Complex stratigraphy makes hydrologic studies even more difficult. Most of them have been drained, leaving only a small percentage left to study in their natural state. Even many of the bays still in their natural state have their current hydrology different from historical conditions due to alterations of adjacent lands to practices such as drainage.

**Ground Water, Saturated Hydraulic Conductivity, Effects of Ditches**

Ground water is defined as water stored in the zone of saturation (Bowen, 1986; Fetter, 2001). It then moves as ground water flow through the rock and soil layers of the earth until it discharges at a spring or as seepage into a body of water
such as a lake, stream, river, or the ocean (Fetter, 2001). Ground water is composed of water from different origins, but the most important sources of ground water are surface and atmospheric water (Bowen, 1986). Ground water can be a major hydrologic influence in a wetland system, and therefore needs to be understood to as great a degree as possible. Ground water, however, is often one of the least measured parts of the wetland system. Some reasons for this are that aquifer heterogeneities complicate flow patterns, the complex hydraulic properties of peat are hard to measure, and seasonal variations in hydraulic gradients necessitate long-term studies (Hunt and Krabbenhoft, 1996). Accurate measurements of ground water flow are difficult to obtain (Mann and Wetzel, 2000).

The potential for ground water inflow results when the hydraulic head in a wetland is lower than the hydraulic head of the surrounding land, and the potential for outflow results when the hydraulic head in a wetland is higher than the water table of the surrounding land (Mitsch and Gosselink, 2000; Bowen, 1986; Fetter, 2001). Total head is the sum of two parts, one, the gravitational head, which is determined by the height of the point (where the measurement is being taken) relative to an elevation datum, and two, the pressure head, which is determined by the height of a static water column resting on that point (Hillel, 1998). Ground water generally flows away from topographical high spots and toward topographic lows (Fetter, 2001), which generally coincides with water flowing from areas of higher total head (topographic highs) to areas of lower total head (topographic lows).

The rate of ground water flow will be subject to the hydraulic conductivity in an aquifer and also the hydraulic gradient (Bowen, 1986, Mitsch and Gosselink,
Natural flow rates are usually very slow, varying from meters per day to meters per year (Bowen, 1986).

One way to evaluate saturated hydraulic conductivity of aquifers is through slug tests. Slug tests can be performed in a small-diameter monitoring well or piezometer to determine the hydraulic conductivity of the formation in the immediate vicinity of the well or piezometer (Fetter, 2001; Bouwer, 1989; Butler et al., 1996). A known volume of water is quickly drawn from or inserted into the well or piezometer, and the rate at which the water level rises or falls is measured (Fetter, 2001; Bouwer, 1989). Two critical things regarding the initiation of a slug test are that the head change should be introduced in a manner that can be considered near instantaneous relative to the formation response and that an estimate of the magnitude of this initial head change should be obtained (Butler, 1998).

One factor probably affecting the ground water movement in Juniper Bay is the ditch network, installed from the 1970s through the 1990s, to drain excess water for agriculture. The benefits of drainage include improved aeration, which aids crop growth, and the ability to use heavy machinery on the land over a longer period of the year (Dunn and Mackay, 1996). The consequence of drainage is that the surface and sub-surface flows leaving the drained area are modified. The two main effects of drainage are to increase the proportion of the total runoff that is transported to a channel by sub-surface flow rather than surface flow, and to increase the speed of the surface runoff. The increase in sub-surface flow acts to lower the water table, allowing greater infiltration to the soil column and reducing the amount of direct surface runoff. The presence of ditches also generates a surface
flow across the line of the slope and this surface flow has a reduced distance to travel before reaching the channel system, resulting in a faster response. Although there is only a small head difference that drives the sub-surface flow into the ditches, the volume of sub-surface flow is large, because the ditches intersect with the sub-surface over a great distance. This also means that a small change in the head level results in a fairly large change to the sub-surface flow. Thus, fluctuations in both the sub-surface flow and the water table occur much more frequently than in undrained systems and the water table drops to a lower level in the drained system during the driest periods (Dunn et al., 1996).

In a study done by Amatya et al. (1996), three different drainage treatments were performed on three neighboring pine plantation watersheds. They found that during the three year treatment period, drainage outflow volumes and peak rates were reduced by controlled drainage. The controlled drainage treatments consisted of varying the heights of outflow weirs depending on the season. The weirs were positioned higher in the summer to keep more water in the watershed for tree growth and were set lower in the winter, the wet season. They also found that before the treatments were in place, about 28% of the gross rainfall for each watershed was accounted for as drainage, and after the treatments were in place, one of the watersheds with controlled drainage had a reduced drainage volume of 21.5% of gross rainfall.

Kao et al. (2001) suggest that the water table elevation depends on the ditch spacing and on the part of total infiltrated flow reaching the water table surface. The part of the infiltrated water, which participates in the horizontal unsaturated flow...
above the water-table, depends on the total hydraulic head distribution in the
unsaturated zone. This distribution closely depends both on the drainage capacity
of the system and on the soil hydraulic properties close to saturation. The slope of
the water table controls the horizontal gradients in the transition zone and generates
horizontal unsaturated flow. The transition zone is a zone of “variable pressure head
where horizontal unsaturated flow can potentially occur because of the existence of
horizontal hydraulic gradients controlled by the water table slope (Kao et al., 2001).

Ground water hydrology is very important to Carolina Bay hydrology because
the surface water of the bay is supported by the shallow groundwater, and the
shallow groundwater is recharged by the surrounding uplands. In a study done at
two Carolina Bays in South Carolina (Trettin et al., 1999), the ground water
dynamics were greatly influenced by precipitation, evapotranspiration, and the local
groundwater hydrology. In that study, during the dry period, usually summer, ground
water head decreased due to the lack of additional recharge from the surrounding
area, and no upward movement was observed. During the wetting phase, the
surface water table and shallow ground water head increased. High hydraulic
gradients were evident between the rim and the center of the bay and between the
surface and shallow ground water, but no upward water flow was observed. During
the wet period, usually winter, when the surface and subsurface soils were
saturated, upward ground water movement (seepage) was observed and this was in
part helping maintain the high surface water table. During the drying phase,
evapotranspiration caused a decrease in the surface water, but if this phase
occurred during the growing season, a strong hydraulic gradient was possibly
created between the surface water and shallow ground water due to the high evapotranspiration demand and high ground water head. If rain did not occur, however, the high ground water head and strong upward water movement would gradually decrease (Trettin et al., 1999).

Groundwater exchange in Carolina Bays is primarily lateral rather than vertical (Schalles and Shure, 1989), due to clay layers that occur below the soil surface that are restrictive to vertical water movement (Schalles et al., 1989, Johnson, 1942). Lateral exchanges between surface and groundwater are also important in the prairie potholes, Florida cypress domes and northern peatlands as well as Carolina Bays (Schalles et al., 1989).

**Wetland Restoration**

The Corps makes its decisions regarding mitigation requirements within a framework of multiple statutes, regulations, guidance, and policy documents (NRC, 2001). These provisions include general mitigation requirements (i.e., ones that derive from sources other than the Clean Water Act (CWA) and that may apply to all federal agencies in general); general Corps policies form evaluating permit applications (i.e., requirements that apply to all permit programs the Corps administers); and CWA-specific mitigation requirements (i.e., obligations that apply solely in the Section 404 context and that flow from the CWA, the section 404(b)(1) guidelines, and policy documents) (NRC, 2001). A principal objective of the CWA is “to restore and maintain the chemical, physical, and biological integrity of the Nation’s waters” (NRC, 2001). The CWA prohibits the discharge of materials, such as soil or sand, into waters of the United States, unless authorized by a permit.
issued under Section 404 of that act (NRC, 2001). The Corps, or a state program approved by the EPA, has authority to issue such permits and to decide whether to attach conditions to them (NRC, 2001). To achieve no net loss of wetlands within the Section 404 program, a permittee is first expected to avoid deliberate discharge of materials into wetlands and then to minimize discharge that cannot be avoided (NRC, 2001). When damages are unavoidable, the Corps can require the permittee to provide “compensatory mitigation”, specifically referring to restoration, creation, enhancement, and sometimes preservation, as a condition of issuing a permit (NRC, 2001).

Mitigation is done to offset the impacts of dredging and filling projects (NRC, 2001). Prior to making Section 404 permit decisions, the Corps must discuss with the FWS a proposal’s impact on wildlife resources. The act calls on the FWS to advise federal agencies about proposed projects’ impacts on fish and wildlife habitats and to recommend compensatory mitigation measures. Agencies are not, however, required to follow the FWS’s recommendations (NRC, 2001).

The National Environmental Policy Act (NEPA) of 1969 also requires federal agencies to consider mitigation measures before taking action, including the granting of federal permits, that may have adverse environmental consequences (NRC, 2001). The Corps must discuss mitigation options in its NEPA documentation when examining alternatives to the proposed action (NRC, 2001). NEPA largely imposes procedural requirements (NRC, 2001).

In contrast to the FWS and the NEPA, the Endangered Species Act (ESA) has more substantive mitigation requirements (NRC, 2001). When a federal agency
proposes to take an action (including the granting of a permit), the agency may need to consult with the FWS or the National Marine Fisheries Service (NMFS) to ensure that the proposed action will not violate the ESA (NRC, 2001). After consultation, the FWS or NMFS may issue a biological opinion that contains “reasonable and prudent alternatives” that the agency must follow to comply with the ESA (NRC, 2001).

The mitigation requirements of the Food Security Act (FSA) are limited to agricultural activities and are not directly applicable to the CWA Section 404 program (NRC, 2001). To discourage farmers from converting wetlands into agricultural areas, the FSA, through its swampbuster program, penalizes landowners who plant agricultural commodities in converted wetlands (NRC, 2001). Such landowners may become ineligible for certain federal agricultural loans and payments (NRC, 2001). A landowner may retain eligibility for federal benefits, however, by performing compensatory mitigation: restoring, enhancing, or creating wetlands (NRC, 2001).

The terms “mitigate” and “mitigation” do not appear in CWA Section 404, nor does Section 404 expressly authorize the Corps to require mitigation of permit applicants (NRC, 2001). Nevertheless, by virtue of the interplay between Sections 404(b)(1) and 403(c), the statute does provide implicit authority for the Corps to require permit applicants to avoid and minimize wetland impacts (NRC, 2001). Section 404(b)(1) requires EPA, in conjunction with the Corps, to develop the criteria that the Corps uses in its Section 404 permit decisions. These criteria, known as the 404(b)(1) guidelines, must be based on criteria identified in CWA Section 403(c).
A wetlands mitigation bank is a wetland area that has been restored, created, enhanced, or preserved, which is then set aside to compensate for future conversions of wetlands for development activities (EPA, 2002). Mitigation banks may be established by permittees who anticipate having a number of future permit applications or by third parties who develop wetland credits for sale to permittees needing to provide compensatory mitigation (NRC, 2001). Benefits of mitigation banks include the consolidation of numerous small, isolated mitigation projects into a single parcel that may have greater ecological benefit, the elimination of the temporal losses of wetlands that occur when restoration takes place after development, and the consolidation of scientific and planning expertise and financial resources which may increase the likelihood of success (EPA, 2002).

There are many factors that come into play when selecting a site for wetland restoration (Mitsch and Gosselink, 2000). These factors are (1) wetland restoration is generally more feasible than wetland creation, (2) the surrounding land use and the future plans for the land must be taken into account, (3) a detailed hydrologic study of the site, including a determination of the potential interaction of groundwater with the proposed wetland must be undertaken, (4) a site where natural inundation is frequent must be found, (5) the soils must be inspected and characterized in some detail to determine their permeability, texture, and stratigraphy, (6) the chemistry of the soils, groundwater, surface flows, flooding streams and rivers, and tides that may influence the site water quality must be determined, (7) on-site and nearby seed banks must be evaluated to ascertain their viability and response to hydrology conditions, (8) the availability of necessary fill material, seed, and plant stocks and
access to infrastructure must be ascertained, (9) the ownership of the land and, hence, the price, must be determined, (10) it must be determined if the wetland site is along ecological corridors such as migratory flyways or spawning runs, (11) the site must be assessable, (12) an adequate amount of land must be available to meet the objectives, and (13) the position of the proposed wetland in the landscape must be evaluated.

There is some debate over whether wetland mitigation and restoration is successful. In the mid-1980s, some scientists involved in wetland restoration and mitigation believed that mitigation was working, others suggested the need for more research. In south Florida, of 40 mitigation projects involving wetland creation and restoration, only about half of the required 430 ha of wetlands had been constructed and 24 of the 40 projects (60%) were judged to be incomplete or failures. The leading cause of the unsuccessful mitigation projects was improper water levels and hydroperiod. Vegetation may be the easiest way to measure the success of mitigation wetlands because vegetation is easily accessible and establishes quickly in a wet environment (Mitsch and Gosselink, 2000).

In a study investigating 2,700 ha of prairie potholes that were restored in the Midwest, it was found that the restored wetlands were generally wetter than the prairie potholes that had remained undisturbed. Eighteen percent of the restorations were carried out by breaking drainage tiles and 20% of the restorations were hydrologic failures. In another study on the success of wetland mitigation in the Chicago area, it was found that 52% of the wetlands had excessive or unplanned open water, and 9% had insufficient hydrology. Mitsch and Gosselink (2000)
attribute the failures to three things, (1) little understanding of wetland function by those constructing the wetlands, (2) insufficient time for the wetlands to develop, and (3) lack of recognition or underestimation of the self-design capacity of nature.

The permittees responsible for the mitigation need some time frame that clearly defines the length of their mitigation responsibility, hydrological performance standards may be based on 5 years or less of water-table monitoring (NRC, 2001). However, the hydrological regime in some wetlands varies not only seasonally but also from year to year (NRC, 2001). Water levels in the short monitoring period may not meet the hydrological standards even though the wetland could satisfy criteria over the long term (NRC, 2001). Knowing this, practitioners tend to err toward the wet end of the range, creating wetlands that are much wetter than normal for the given landscape position (NRC, 2001). This approach has resulted, in many cases, in the creation of open-water areas as compensation for loss of intermittently inundated or saturated wetlands (NRC, 2001). Mitigation projects that stress the wet end of the range will not replace the functions provided by much drier impact sites (NRC, 2001).

The committee concludes that current permitting procedures do not always result in permit conditions that are clear and enforceable and lead to the development of viable mitigation that compensates for the functions and values of the permitted impact. Instead, permits typically contain performance standards that measure only one or several easily measured parameters of a mitigation site that often do not reflect the overall viability of the mitigation site (NRC, 2001).
One way to gain an understanding of the pre-disturbance hydrology, soils, and vegetation at the site to be restored is to use reference wetlands. Reference wetlands are wetlands that are as close to an undisturbed state as possible that possess the same or similar wetland functions as the site to be restored possessed prior to disturbance. Evaluations of ecological equivalency between mitigation sites and reference sites are rarely conducted as part of a programmatic review (NRC, 2001). Sixty-five percent of the permits surveyed by Kentula et al., (1992b) in Oregon and Washington required a functional assessment, but these assessments lacked detail (NRC, 2001). Monitoring the hydrology of a reference site would provide a more realistic view of what the water table regime should be in the restored site, and could be used in the permit in deciding what percentage of the growing season should meet the hydrologic criterion. This might prevent some sites from becoming too wet due to practitioners fearing their site may not meet the criterion for 12.5% of the growing season. Information on the soils and vegetation at a reference site would also help practitioners restoring or creating a wetland avoid mistakes such as filling the site with an inappropriate soil type or planting the incorrect type of vegetation or spacing trees too close together.
Methods

Study Area

Regional Characteristics

Climate

The Coastal Plain region of North Carolina is in what Akin (1991), describes as a “humid subtropical climate”. Monsoonal circulation causes an onshore flow of moist tropical maritime air during summer months and the equatorward shift of middle latitude cyclonic storm tracks in the westerlies generally brings some precipitation in the cool season. This pattern of atmospheric circulation assures mild, moist or relatively dry winters, and hot humid summers. The southeastern United States sometimes has slightly more precipitation in the winter than in the summer, due to moisture feeding off the Gulf of Mexico (Akin, 1991).

The average annual rainfall for the Coastal Plain region of North Carolina is approximately 119 cm, the average annual maximum temperature is between 21 and 22.8 degrees Celsius, the average annual minimum temperature is roughly 10 degrees Celsius, with the average relative humidity about 55% (Shaw, 1982).

The climate normals for the Lumberton Municipal Airport (approximately 11 km north northwest of Juniper Bay) are listed in Table 1. A climate normal is defined, by convention, as the arithmetic mean of a climatological element computed over three consecutive decades (World Meteorological Organization (WMO) as referenced by the National Oceanic and Atmospheric Administration (NOAA), 2002).
Table 1: Climate Normals for the Lumberton Municipal Airport, 1971-2000

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<th>Max Temperature (Celsius)</th>
<th>Min Temperature (Celsius)</th>
<th>Precipitation normals (cm)</th>
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<td>13.8</td>
<td>0.3</td>
<td>8.18</td>
</tr>
<tr>
<td>Annual</td>
<td>23.0</td>
<td>9.1</td>
<td>121.87</td>
</tr>
</tbody>
</table>

Topography

The Coastal Plain, where Juniper Bay is located, is an area where rivers and oceans deposited large amounts of sediments from about 130 million years ago to the present time. The region represents about 45% of the area of North Carolina and elevations range from sea level to about 200 meters (650 feet) (Daniels et al., 1999). The rivers developed large valleys due to trenching after uplift and lowering of sea level. There are three major units of the Coastal Plain, the Upper, Middle, and Lower units, that are separated by scarps. Scarps are related to high stands of sea level. Each unit of the Coastal Plain has distinctive topography, sediments, altitude range and suite of soils (Daniels et al., 1999). Robeson County is located in the Middle Coastal Plain, which ranges in elevation from about 29 to 94 m. The Coats Scarp at an average elevation of 94 m marks the upper boundary and the
Surry Scarp at an average elevation of 29 m marks the lower boundary of the Middle Coastal Plain. This region is traversed from northwest to southeast by moderately deep to shallow river valleys. In the Middle Coastal Plain, the smooth, gently undulating, plateau-like uplands dominate the landscape. The maximum relief from the uplands to the valley floors rarely exceeds 30 m. Most valley floors are nearly level, with streams commonly flowing along the south side of the valley in east-west valley segments or along the west bank in north-south segments. This results in long, gentle south-facing slopes and steep north-facing slopes in the east-west valley systems and long, gentle west-facing slopes with short and steep east-facing slopes in the north-south systems (Daniels et al., 1999).

**Geology**

The Coastal Plain of the Carolinas, extending from the Fall Line to the modern coastline, is underlain by a veneer of Cretaceous and Cenozoic sediments which, in turn, overlie pre-Mesozoic crystalline rocks and tilted sedimentary rocks in buried Triassic-Jurassic basins. At times in the geologic past, essentially all of the Coastal Plain has been submerged beneath the Atlantic Ocean. The basement surface on which Coastal Plain sediments were deposited is characterized by broad structural upwarps (arches) and downwarps (basins). Episodic differential movement and lateral shifting of arch and basin axes have controlled deposition of Mesozoic and Cenozoic sediments in the Coastal Plain. Field study of the Cretaceous and Tertiary geology of the Coastal Plain sediments is hampered by a paucity of outcrops, resulting from low relief and a nearly continuous blanket of
surficial sediments and soils, and mapping in the region has relied heavily on biostratigraphic data (Horton, Jr. et al., 1991).

Beginning in the middle Eocene, roughly 54 million years ago, the sea transgressed over most of the Coastal Plain, reaching its greatest extent in the late Eocene. After the regression of the Eocene sea, the Carolina Coastal Plain did not experience another major inundation until the Pliocene, roughly 5 million years ago. Pliocene marine sediments are widely distributed from the coast to the Fall Line and document the last major transgressions of the sea over the Coastal Plain (Horton, Jr. et al., 1991).

**Juniper Bay**

The study site, Juniper Bay, is a 330 ha Carolina Bay located in Robeson County, NC, about 13 km south of Lumberton, N.C. in the Coastal Plain physiographic region (Figure 1). The bay is bordered to the north by a wooded Carolina Bay used for hunting, and to the southeast, south, and west by farm land. Juniper Bay was drained for agriculture from the 1970s through the early 1990s. It was sold to the NCDOT in 2000 and has not been farmed since.

Juniper Bay was chosen for restoration by the NCDOT because it occurs in the vicinity where road projects are destroying wetlands. It is a very large Bay, which, if the restoration is successful, should give the NCDOT a lot of mitigation points which can be applied towards other road construction projects that destroy wetlands in that area.
Topographic Setting

Ground elevations in and around Juniper Bay range from about 35 to 41 m above sea level, with the mean elevation of the bay floor at about 36.2 m (Figure 2 and Figure 3). The elevation surveying was conducted on August 27, 2002, by the Locations and Surveys Division of the NCDOT. The bay is located at the head of a broad, shallow northeast-southwest oriented valley and juts into the ridge to the west. The northern rim of the bay appears to be an approximate surface drainage basin divide. First order streams that originate north of the bay flow northwestward or northeastward and a first order stream that originates at the southeast corner of
the bay flows southwestward. The bay has a distinctive rim that rises about 1.5 m above the bay floor on the north and west sides, grades into the much higher ridge to the southwest, and rises about 1 m above the bay floor on the south side. There is no rim on the northeast border of the bay where it joins and appears to slightly overlap the bay to the north, nor is there a rim on the southeast border of the bay where there is evidence of historical overland flow from the bay.

Surface elevations outside the bay are higher than the bay floor to the northwest, west, and southwest, rising to a high of about 43 m (about 7 m above the bay floor) on the ridge to the southwest. A ridge east of the bay is about 3.5 m higher in elevation than the bay floor. Surface elevations are lower than the bay floor to the south of the bay. The floor of the bay is virtually flat with some slight depressional areas. Surface elevation measurements made at the water table wells vary a total of about 0.6 m.

**Soils**

There are four different soil series found in Juniper Bay (Figure 4 and Table 2). They are Leon sand, Rutlege loamy sand, Pantego fine sandy loam, and Ponzer muck (U.S.D.A., 1978) (see Appendix A for series descriptions).
Table 2: Soils information for Juniper Bay

<table>
<thead>
<tr>
<th>Series Name and abbreviation</th>
<th>Taxonomic Classification</th>
<th>Percentage of area in Juniper Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leon sand, Le</td>
<td>sandy, siliceous, thermic Aeric Alaquods</td>
<td>40</td>
</tr>
<tr>
<td>Pantego fine sandy loam, Pg</td>
<td>fine-loamy, siliceous, semiactive, thermic Umbric Paleaquults</td>
<td>10</td>
</tr>
<tr>
<td>Ponzer muck, Pr</td>
<td>loamy, mixed, dysic, thermic Terric Haplosaprists</td>
<td>30</td>
</tr>
<tr>
<td>Rutlege loamy sand, Ru</td>
<td>sandy, siliceous, thermic Typic Humaquepts</td>
<td>20</td>
</tr>
</tbody>
</table>

The Ponzer soil found in Juniper Bay is actually Ponzer muck, siliceous subsoil variant. Most mapped areas are irregularly oval in shape and cover 40 to 90 ha (U.S.D.A., 1978). Some small areas within this mapping unit have a surface layer of muck less than 40 cm thick, while other small areas of soils lack a loamy subhorizon within a depth of 152 cm. This variant consists of level, very poorly drained soils in large bays on uplands (U.S.D.A., 1978). The Ponzer muck, siliceous subsoil variant profile description has a buried A horizon below a thin layer of silt loam (U.S.D.A., 1978) while the official Ponzer series description does not.
Figure 2: Topographic map of Juniper Bay and the surrounding area. This figure was scanned from the following USGS 7.5 Minute Quadrangles: SW Lumberton 1982, SE Lumberton 1986, Fairmont 1962, and Evergreen 1986. Contours are in feet above sea level.
Figure 3: Ground surface elevations (meters above sea level) at well locations in and around Juniper Bay. Lines running northwest to southeast represent lateral ditches while the two darker lines running northeast to southwest represent deeper collector ditches.

Other soil series around Juniper Bay include Norfolk (No), Rains (Ra), and Lynchburg sandy loam (Ly). Norfolk occurs to the northwest and southeast of Juniper Bay, where the elevation is locally the highest. The Rains series occurs to the northeast and southwest of Juniper Bay, where the elevation is slightly lower than in Juniper Bay. The Lynchburg series occurs around Juniper Bay in areas that are slightly lower in elevation.
Figure 4: Soils map of Juniper Bay. Map scanned from the USDA Soil Survey of Robeson County, 1978.

Field verification of these soil types was done in the summer of 2001 in Juniper Bay. Pits were dug in 40 fields in the bay, one pit in the center of the field and one pit by the ditch. Photos of the profiles and horizons were taken, and profile descriptions were recorded to 1 meter depth in all pits. Horizon samples and Uhland
cores were taken for analysis. Chemical properties such as phosphorus, potassium, calcium, magnesium, and sodium content, pH, CEC, base saturation, humic matter content, and physical properties such as bulk density and texture were analyzed. For detailed soils information on Juniper Bay and the reference bays, see Ewing (2004).

Stratigraphy

The pattern of layers of different soil textures (sand, silt and clay) affects water movement. To determine the stratigraphy of Juniper Bay, soil cores were taken at 17 locations inside the bay and 12 locations outside the bay using an equilateral triangle grid system (Vepraskas, personal communication, 2003) for the determination of the core locations (Figure 5). A grid composed of equilateral triangles was randomly placed on a map of Juniper Bay and soil coring locations were selected at grid intersections. This system provided a systematic grid of coring points that gave a good representation of the different soil series located in the bay.

At each core location two soil cores were taken, one at the crown of the field between ditches and one adjacent to the ditch using a drill rig with hollow stem augers. Cores were taken to a depth of approximately 6.1 - 7.3 m in most locations and to 15.3 m at 6 locations. Each core sample was analyzed in the field by first determining transitions between different textures, or defining the horizons, and then determining by hand the texture of each horizon using the ribbon method, or “texture-by-feel” (Brady and Weil, 2000).
Figure 5: Soil core locations in and around Juniper Bay. Map source: Soil Science Department, North Carolina State University.

The texture-by-feel method is a way to determine the texture of a soil by rubbing a moist soil sample between the thumb and forefingers and squeezing it out to make a “ribbon” (Brady and Weil, 2000). The length of the ribbon and grittiness, or lack thereof, of the soil determines the texture. The data from these soil cores were used, in part, in the determination of the location of water table wells inside Juniper bay. The stratigraphy, as determined from the core data, is extremely varied. It therefore seemed necessary to locate the water table wells as close to the soil core locations as possible in order to have an idea of what the stratigraphy is like.
at each well location. Examples of the variation in stratigraphy among coring sites is shown in Figure 6.

![Figure 6: Soil core examples. Sands are shown in yellow colors and clayey soils are shown in reddish and brown colors. Muck is shown in black while zones of no recovery are shown in white.](image)

**Description of Vertical Stratigraphic Zones**

The soils in Juniper Bay are a mixture of mineral and organic soil materials (Figure 7). Where the soil transitions from mineral to organic it is a mineral soil with a histic epipedon. The organic soils occur mostly in the center of the bay, the mineral soils with histic epipedons encircle the organic soils, and the mineral soils occur closest to the rim of the bay. Beneath the surface at varying depths and
thicknesses are clay layers. These clay layers occur between 0.3 and 4.3 m below the surface and may act as restrictive layers to water movement. The sandy or organic material above this clay layer and below the soil surface we have called aquifer “zone 1” (Figure 8). Below this restrictive layer of clayey material more sandy material occurs, in most areas, and this area of sandy material is called aquifer “zone 2”. Below zone 2 is the top of the Black Creek Formation, a clay layer that acts as another restrictive layer and the bottom of the bay. Beneath the top of the Black Creek Formation is alternating sand and clay material and is called “zone 3”. Within zone 2 there are thin clay layers in some locations. This “zone” system will be used in discussing hydrology later in this thesis.
Figure 7: Mineral soils, mineral soils with a histic epipedon (red color on map), and organic soils (green color on map) in Juniper Bay. The years indicate when that part of the bay, divided by the black lines, was ditched.

Source: Justin Ewing, PhD student, NCSU, 2003.
Figure 8: The side boundary (perimeter ditch that encircles the bay) and bottom boundary (bottom clay layer that presumably exists across the entire bottom of the bay) of Juniper Bay in which surface and ground water movement is studied. Water table monitoring wells were installed in zone 1 and piezometers were installed in zones 2 and 3.

Hydrologic Character

The drainage system in Juniper Bay consists of four elements (Figure 9):

1) A perimeter ditch about 2.5 m deep encircles the bay and discharges to the main outlet ditch. Designed to intercept near surface subsurface flow into the bay, the effectiveness of the perimeter ditch has been reduced during the study period due to partial blockages by sediment and beaver dams.
2) The main outlet ditch traverses the bay from north to south and cuts through the south rim. About 4 m deep at the outlet, this ditch collects and discharges all drainage water from the bay to a large ditch that flows southward.

3) A system of collector ditches to which the lateral ditches discharge and transport the drainage water to the main outlet ditch. Lateral ditches to the west of the main outlet ditch discharge directly to the main outlet ditch. Lateral ditches to the east of the main outlet ditch discharge to a perpendicular collector ditch that, in turn, discharges to two east-west transport ditches that discharge to the main outlet ditch.

4) The lateral ditches that average about one meter deep constitute the main land drainage element.

Due to the ditches, there is no significant surface water movement, even though there may be a water table gradient from one area to another. The deep main outlet ditch that was constructed through the bay rim on the south side created a channel flow gradient to that point in the ditch system. There may have been a gradient in the near surface ground water towards the southeast side of the bay long ago, mimicking the regional gradient for water to move towards the southeast in the coastal plain of the Carolinas and Georgia. Lack of a rim and evidence of surface scouring outside the bay indicates that there was once a surface flow outlet at the southeast end of the bay. Once the ditches are plugged, near surface ground water movement towards the southeast may begin again.
Figure 9: Juniper Bay ditch network.

The data from the water table wells give clues to where current mounds and valleys in the water table may occur, and how the water table gradient may behave once the ditches are plugged.

Reference Bays

In this study, three reference Carolina Bays were selected from neighboring Bladen County, northeast of Robeson County (Figure 1). These bays represent the best examples in the region of undisturbed Carolina Bays that have soils, hydrology, and vegetation similar to what Juniper Bay is thought to have had before it was
drained for agriculture. Two of the reference bays, Tatum Millpond Bay and Charlie Long Millpond Bay, are in Bladen Lakes State Forest. The third reference bay, Causeway Bay, is on private land near White Lake, approximately 7.5 km from Tatum Millpond Bay.

**Topographic Setting**

The reference bays are located in the Middle Coastal Plain region. The elevation of the rim of Charlie Long Millpond Bay is approximately 27.4 m, with the interior being slightly lower in elevation than the rim. The elevation of the rims of both Tatum Millpond Bay and Causeway Bay is approximately 24.4 m, with the interior being slightly lower in elevation than the rims. All three bays are north of the Cape Fear River.

**Sampling Plan**

Data on soils, vegetation, and the water table regime were collected along one straight line transect from the rim to the center of each reference bay. Beginning at the approximate center of the southern rim of Tatum Millpond Bay and Causeway Bay and the northern rim of Charlie Long Millpond Bay, a straight-line trail was cleared in the dense vegetation on a northeast/southwest bearing to the longitudinal axis of each bay. Soils, vegetation, and water table data were then collected at points along that transect that were representative of the different soils and vegetation types.
Soils

There are roughly five different soil types found in each reference bay that range from excessively drained sandy soils on the rims to very poorly drained organic soils in the center (Table 3). At the edges of the bays are mineral soils (less than 20 cm of organic matter at the surface), a little farther into the bay, the soils have a histic epipedon (between 20 to 40 cm of organic matter at the surface). Even farther into the bay, the soils are shallow organic, which means the surface has greater than 40 cm of organic matter at the surface but less than 130 cm. Towards the centers of the bays are deep organic soils, with surfaces of more than 130 cm of organic matter. These soil types were field verified in June, 2002, with hand augers and a McCauley Peat Sampler.

The soils found in the reference bays by field methods varied from what was mapped by the NRCS. The transition of soils from the rim to the center of each bay consists of mineral soil on the rim and just into the bay, then a mineral soil with a histic epipedon (organic material 20 – 40 cm thick on the soil surface), then a shallow organic soil (organic material 40 to 130 cm deep), then a deep organic soil (organic material greater than 130 cm deep) in Causeway Bay and Tatum Millpond Bay. The soils mapped in Tatum Millpond Bay by the NRCS consists of a mineral soil on the rim and just inside the bay (but no histic epipedon), then two shallow organic soils closer to the center of the bay. The soils mapped by the NRCS in Causeway Bay and Charlie Long Millpond Bay include a mineral soil on the rim and then a shallow organic soil in the center. The deep organic soils found in the field were not mapped by the NRCS. Charlie Long Millpond Bay does not have the deep
organic soil in the center but instead has a swath of deep organic soil in the middle of the shallow organic soil. In Charlie Long Millpond Bay the shallow organic soil is the dominant soil in the center of the bay, while in Causeway Bay and Tatum Millpond Bay the deep organic is the dominant soil in the centers of the bays.

The organic soil unit in Juniper bay is predominantly shallow organic (40 to 130 cm of organic material at the surface). There may have been deep organic soil in Juniper Bay at one point. However, after years of drainage and farming practices, the thickness of the organic layer has likely decreased due to subsidence and oxidation. The dominant soil found in the reference bays is organic, while in Juniper Bay the organic soil is not the dominant soil. The mineral soils make up a larger percentage of the area of Juniper Bay than in the reference bays.

Table 3: Soils information for the reference bays

<table>
<thead>
<tr>
<th>Series Name and abbreviation</th>
<th>Taxonomic Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Croatan muck</td>
<td>Loamy, siliceous, dysic, thermic Terric Haplosaprists</td>
</tr>
<tr>
<td>Kureb</td>
<td>Thermic, uncoated Spodic Quartzipsamments</td>
</tr>
<tr>
<td>Leon</td>
<td>Sandy, siliceous, thermic Aeric Alaquods</td>
</tr>
<tr>
<td>Lynn Haven</td>
<td>Sandy, siliceous, thermic, Typic Haplaquods</td>
</tr>
<tr>
<td>Pamlico muck</td>
<td>Sandy or sandy-skeletal, siliceous, dysic, thermic Terric Haplosaprists</td>
</tr>
<tr>
<td>Torhunta</td>
<td>Coarse-loamy, siliceous, acid, thermic Typic Humaquepts</td>
</tr>
</tbody>
</table>

Tatum Millpond Bay has the Pamlico muck series in most of the bay (Figure 10). Towards the rim of the bay on the southwest and northwest sides there is the Croatan Muck series, and on the rim is the Torhunta and Lynn Haven series’ (see Appendix A for complete soil series descriptions). Charlie Long Millpond Bay has
predominantly Pamlico muck soils in the center with Lynn Haven and Leon soils on the rim (Figure 11). Causeway Bay is predominantly Pamlico muck, with Lynn Haven, Leon, and Kureb sand soil series on the southwestern rim (Figure 12).

Figure 10: Soils map of Tatum Millpond Bay. Map was scanned from the Soil Survey of Bladen County, North Carolina, 1990.
Figure 11: Soils map of Charlie Long Millpond Bay. Map was scanned from the Soil Survey of Bladen County, North Carolina, 1990.
Figure 12: Soils map of Causeway Bay. Map was scanned from the Soil Survey of Bladen County, North Carolina, 1990.

Vegetation

The vegetation data were collected in the spring and summer of 2002.

Sampling plots were located along the main transect that was cut from the rim to the
center of each reference bay. Shrub plots were 5m by 5m, and tree plots were 0.0405 hectare. There were four tree plots in each soil type, with two shrub plots within each tree plot, for a total of 16 tree plots and 32 shrub plots in each bay. In each shrub plot the species were identified, their relative coverage assessed, the density of the shrub layer to 2 m high, canopy cover, and leaf litter, were also characterized. In the tree plots, data on the overall density and density of deciduous versus evergreen trees, ground truth density, and growth rate and age data were taken (Lees, personal communication, 2002).

The vegetation communities in the reference bays are named in accordance with the nomenclature of Schafale and Weakley (1990).

There are three predominant vegetation types in Tatum Millpond Bay: pond pine (Pinus serotina) woodland on mineral soils, nonriverine swamp forest on shallow organic soils, and bay forest on deep organic soils. The nonriverine swamp forest on histic and shallow organic soils consisted of the canopy of swamp black gum (Nyssa biflora) and understory dominated by Lyonia lucida/Vaccinium corymbosum (fetterbush/highbush blueberry). The bay forest vegetation was dominated by Gordonia lasianthus (loblolly bay) and Magnolia virginica (sweet bay) in the canopy, Lyonia lucida in the understory), and high pocosin.

Vegetation types in Causeway Bay consist of pond pine woodland (dominated by pond pine trees in the overstory and Ilex coriacea/Lyonia lucida in the understory) on mineral soils and pocosin vegetation consisting of scattered pond pine trees (Pinus serotina) with a thick understory of Ilex coriacea/Lyonia lucida (gallberry/fetterbush) shrubs) on the deep organic soils.
Vegetation types in Charlie Long Millpond Bay include pond pine woodland (pond pine trees and *Ilex coriacea/Lyonia lucida*) and High Pocosin.

**Water Table Regime**

Four water table monitoring wells were installed in each reference bay; one in each soil type. The wells were installed along the transect trails that were cut in the vegetation from the rim to the center of each bay. Water table data from the wells in the mineral soil, the mineral soil with a histic epipedon, and those in the shallow organic soil were used in the comparison with the water table data from the wells in Juniper Bay. The wells in the deep organic soil in the reference bays were not used because there is no deep organic soil in Juniper bay. The wells were located near the vegetation sample plots and soil sampling sites. The types of wells, installation procedures, data collection, and data analysis were the same as for the wells in Juniper Bay and are described later. The wells in the reference bays were installed in winter of 2001-2002. The data used from the wells dates from late March through Fall, 2002. This coincides with the growing season (March 20 – November 16) of 2002.

**Rainfall Measurement**

Precipitation data were collected with three tipping bucket rain gauges at Juniper Bay, one each in the northwest and southeast sections of the bay and one in the middle of the bay at a weather station. In addition to precipitation data, soil temperature at 50 cm depth, wind velocity and direction, direct solar irradiance, net irradiance, air temperature, and relative humidity are collected at the weather
station. Rainfall totals were recorded hourly by the rain gauge datalogger at the weather station. The rain data were used with the water table data to see how much and how fast the water table rose after a rain event, and if there was variability among the different soil types.

Rain gauges were installed in each of the reference bays in the year 2002 after the time period of the hydrology data reported in this thesis. Therefore, rainfall data from gauges located nearest to the reference bays, Bladen Lakes State Forest and Elizabethtown, North Carolina, were used for comparison to the rainfall in Juniper Bay.

**Juniper Bay sampling design**

The network of shallow water table monitoring wells in Juniper Bay was designed to measure the water table inside and outside the bay and to determine water table variation across the bay. Wells were located to provide straight line transects across the bay on many axes and to sample the water table regime in different soil types and different stratigraphic types. There are a total of 25 automatic recording monitoring wells and 3 wells read manually, installed in the spring and summer of 2001 (Table 4 and Figure 13). Water table data were collected from summer 2001 through fall 2002 for this part of the study.
<table>
<thead>
<tr>
<th>Well</th>
<th>Location (inside/outside of bay)</th>
<th>Soil type (Mineral/Organic)</th>
<th>Ground Elevation (meters above sea level)</th>
<th>Additional soils information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inside, NW section</td>
<td>Organic</td>
<td>36.189</td>
<td>Muck on top of sand</td>
</tr>
<tr>
<td>1A</td>
<td>Inside, NW section</td>
<td>Mineral</td>
<td>36.377</td>
<td>-*</td>
</tr>
<tr>
<td>1B</td>
<td>Outside, NW of bay</td>
<td>Mineral</td>
<td>-*</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Inside, NW section</td>
<td>Mineral</td>
<td>36.279</td>
<td>Muck on top of sand</td>
</tr>
<tr>
<td>2A</td>
<td>Inside, NW section</td>
<td>Mineral</td>
<td>36.469</td>
<td>-</td>
</tr>
<tr>
<td>2B</td>
<td>Outside, N of bay</td>
<td>Mineral</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Inside, middle section</td>
<td>Mineral</td>
<td>36.485</td>
<td>Sand on top of clay</td>
</tr>
<tr>
<td>5</td>
<td>Inside, NW section</td>
<td>Organic</td>
<td>36.29</td>
<td>Sand on top of muck on top of clay</td>
</tr>
<tr>
<td>5A</td>
<td>Inside, NW section</td>
<td>Organic</td>
<td>36.266</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Inside, middle section</td>
<td>Organic</td>
<td>36.111</td>
<td>Sand on top of clay</td>
</tr>
<tr>
<td>7</td>
<td>Inside, middle section</td>
<td>Mineral</td>
<td>36.368</td>
<td>Sand</td>
</tr>
<tr>
<td>8</td>
<td>Inside, SE section</td>
<td>Organic</td>
<td>36.068</td>
<td>Muck on top of clay</td>
</tr>
<tr>
<td>8A</td>
<td>Outside, NE of bay</td>
<td>Mineral</td>
<td>36.771</td>
<td>-</td>
</tr>
<tr>
<td>8B</td>
<td>Outside, NE of bay</td>
<td>Mineral</td>
<td>37.082</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>Inside, middle section</td>
<td>Organic</td>
<td>36.217</td>
<td>Clay</td>
</tr>
<tr>
<td>11</td>
<td>Inside, middle section</td>
<td>Organic</td>
<td>36.038</td>
<td>Muck on top of sand</td>
</tr>
<tr>
<td>12</td>
<td>Inside, SE section</td>
<td>Mineral</td>
<td>36.241</td>
<td>Sand on top of clay</td>
</tr>
<tr>
<td>15</td>
<td>Inside, middle section</td>
<td>Organic</td>
<td>36.193</td>
<td>Sand</td>
</tr>
</tbody>
</table>
Table 4 (continued)

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Inside, SE section</td>
<td>Organic</td>
<td>36.094</td>
<td>Muck on top of sand</td>
</tr>
<tr>
<td>16A</td>
<td>Inside, south side</td>
<td>Mineral</td>
<td>36.394</td>
<td>-</td>
</tr>
<tr>
<td>16B</td>
<td>Outside, south of bay</td>
<td>Mineral</td>
<td>36.946</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>Inside, SE section</td>
<td>Mineral</td>
<td>36.428</td>
<td>Muck on top of sand</td>
</tr>
<tr>
<td>17B</td>
<td>Outside, SE of bay</td>
<td>Mineral</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>Outside, north of bay</td>
<td>Mineral</td>
<td>-</td>
<td>Sand on top of clay</td>
</tr>
<tr>
<td>23A</td>
<td>Inside, NW section</td>
<td>Mineral</td>
<td>36.689</td>
<td>-</td>
</tr>
<tr>
<td>25</td>
<td>Inside, south side</td>
<td>Mineral</td>
<td>36.526</td>
<td>Sand</td>
</tr>
<tr>
<td>25A</td>
<td>Outside, south of bay</td>
<td>Mineral</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25B</td>
<td>Outside, south of bay</td>
<td>Mineral</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* (-) indicates no information available.*
Inside Juniper Bay there is approximately an equal number of water table wells located in mineral and in organic soils. Due to the variety of soil profiles, it was also necessary to have wells in as many different locations as possible. Water entering the soil through the surface will behave differently in soils with different profiles. Some areas of the bay have a thick clay layer near the surface that may be restricting water flow while others have a sandy profile the entire length of the well.
Restricted downward seepage of water may cause one area to meet wetland hydrology while areas with more sand will not exhibit wetland hydrology. This becomes important when trying to restore the bay to a wetland. Topography may also influence the water table regime. Elevations within the bay vary by about 0.6 meter, but even small differences in elevation can cause lateral water movement in the soil.

**Water table measurement**

Several factors were taken into account in deciding where to install the shallow water table wells inside Juniper Bay. These factors were soil type (mineral or organic), elevation, and adequate coverage of the bay. Thirteen of the wells are located near soil coring sites. The wells were installed at the crown of the field, in order to be equal distance from the ditches on both sides.

RDS WL-80 Series wells (Remote Data Systems, Inc. Whiteville, N.C.) with a 8.89 cm (3.5 in.) outside screen diameter, sampling range of 0 – 203.2 cm (80 in.) (almost entire length of well is screened), and slots 0.025 cm (0.01 in.) wide were installed by hand using bucket augers and sand augers to auger a hole in each location approximately 2.34 m (92 in.) deep. The well casing was inserted, assuring the calibration line was level with the ground surface. The calibration line is an actual line around the well casing that should be level with the ground surface when the well is installed. This line is also where the water level recorder (capacitance sensor) that is inserted inside the casing is programmed to read a zero water level (meaning the water level is at the ground surface). The instrument is not designed
to accurately read the amount of water above this line. If the reading the instrument
gives is above zero, the water table is above the ground surface but may not be
exactly where the instrument is recording it to be. The instrument is designed to
accurately read the water level below the calibration line; or below the ground
surface. Sand (no. 2 well sand) was poured around the outside of the well to
provide a sand envelope around the well screen to block fines from getting into the
slots. The screened portion starts a little below the calibration line, which should be
level with the ground surface, and runs the entire length of the well. Bentonite was
then poured around the rest of the well and in a cone shape above the ground
around the well to insure a tight seal so that no water moves down the side of the
well. The capacitance sensor was then inserted into the well casing and the
datalogger was set to record water levels hourly. Water level data were downloaded
every two or three weeks and stored in a spreadsheet database for analysis. Each
downloaded set of data was added to the master dataset to provide a single
spreadsheet with all data in chronological order. Collection of water level data
began in April 2001 and data through December 2002 are included here.

Available storage is a measure of how much water the soil pores can hold
after a rain event. It can be estimated by dividing the amount of rainfall by the rise in
the water table. A large rise in the water table due to a rain event indicates low
available storage, or small pores, which causes them to fill with water quickly.
Available storage was estimated for the water table at each water table well.
Testing Wetland Hydrology Criteria

Water table hydrographs from each well were studied to determine how temporal variation of the water table at each well and water level differences among wells were related to soil type, rainfall, season, and elevation. The data were also analyzed to determine the number of successive days that each well had a water table shallower than 30 cm during the growing season. Then these periods were compared to the different wetland hydrology requirements to determine which areas of the bay, represented by the wells, met which requirements.

U. S. Army Corps of Engineers (Corps)

The hydrology criterion for Corps jurisdictional wetland determinations is the water table within 30 cm (12 in.) of the soil surface at least once annually for a continuous period of days equal in duration to at least 5% of the growing season length (Corps 5% criterion) (USACE, 1987). Average annual frequency of occurrence of that hydroperiod must be greater than 50% or more than 1 out of 2 years. The growing season definition used by the Corps is the average annual frost free period: the period between the latest time in the spring with 50% probability and the earliest time in the fall with 50% probability of the occurrence of a minimum daily temperature of -2.2°C (28°F). Current growing season climate data for 1971-2000 are found at the web page of the Natural Resources Conservation Service, National Water and Climate Center: http://www.wcc.nrcs.usda.gov/climate/wetlands.html. That climate data are not available for a site in Robeson County, so the data used were from a station in Bladen County at about the same latitude as Juniper Bay and which is located near the reference bays. That growing season is March 20 to
November 16 or 240 days. Therefore, the Corps 5% criterion refers to a period at least 12 days long between March 20 and November 16.

The Corps criterion for wetland hydrology on wetland restoration sites is the same as above except the minimum duration in days must be at least 12.5% of the growing season length (Corps 12.5% criterion). The reasoning behind requiring the much longer hydroperiod for wetland restoration is to provide a large margin for error in the wetland restoration process. Jurisdictional wetland determinations are carried out on existing wetlands where wetland characteristics and functions already exist. When carrying out a wetland restoration project, there is much uncertainty about how much of the site will have wetland hydrology, the degree of development of different hydrologic functions, and how long it may take for hydrologic functions to be restored. In addition, in the early years of a wetland restoration project, the site has relatively low annual ET losses compared to that for the eventual restored wetland with forest vegetation. If the water table regime of a portion of the restored wetland fails to meet the Corps 12.5% criterion in the first 5 years (standard monitoring period), there is a high probability that it will still meet the Corps 5% criterion. The Corps 12.5% criterion for Juniper Bay requires a period at least 30 days long between March 20 and November 16.

Food Security Act (FSA)

For agricultural lands subject to the Food Security Act of 1985, the wetland hydrology criteria (FSA criteria) are described in the National Food Security Act Manual (NFSAM, 1994): (1) inundation (flooding or ponding) occurs for 7 consecutive days or longer during the growing season in most years (50% chance or
more); or (2) saturation at or near the surface occurs for 14 consecutive days or longer during the growing season in most years (50% chance or more). Soils may be considered to be saturated to the surface when the water table is within:

(a) 15 cm (0.5 ft) of the surface for coarse sand, sand, or fine sandy soils; or

(b) 30 cm (1.0 ft) of the surface for all other soils (NFSAM, 1994).

The growing season specified by the NFSAM is the same as that specified by the Corps.

Ground Water Flow in Juniper Bay

Sampling Design

Objectives of this research included estimating vertical hydraulic gradients in areas with different soil types and stratigraphy and estimating the lateral hydraulic gradients and relative rates of subsurface flow entering, exiting, and within Juniper Bay. Piezometers installed below the clay layers are being used to measure hydraulic heads to estimate ground water flow dynamics, (direction, magnitude, gradients). There are between eight and 10 piezometers located in the zone 2 region where ground water may be entering and exiting the bay. The exact number of piezometers in zone 2 is unclear because of the complex nature of the stratigraphy. In some soil cores it is unclear which clay layer is the division between zone 2 and zone 3, such as core 25. In other locations there may not be a real division between zones 1, 2 and 3. Other soil cores were not dug deep enough to clearly tell where the division is, such as core 22. This all makes ground water movement difficult to determine. Water depths below the surface in the piezometers
were converted to water level elevation to estimate the direction of ground water flow. Saturated hydraulic conductivity was also estimated at most piezometer locations using the slug test method to determine the rate at which water may flow in this zone 2 region. With these data, Darcy’s Law can be used to estimate the magnitude of ground water flux. With ground water direction and magnitude estimated, the approximate amount of ground water entering and exiting the bay can be calculated. If water is exiting the bay, either through this zone 2 region or downward into the zone 3 region, it is important to know before starting the restoration process. The deeper collector ditches may be influencing the ground water gradients and, once they are plugged, the ground water dynamics may shift. The pre- and post-restoration comparison of ground water dynamics will help to determine the impacts of the ditches on hydrology of the bay.

**Hydraulic Head Measurement**

**Piezometer Installation**

The piezometers at Juniper Bay were installed along two main transects (Figure 14). The long transect starts at the northwest end of the bay and ends at the southeast end. There are 10 piezometers along this transect, eight automated with pressure transducers and dataloggers, and two read manually. The short transect runs from the northeast side, roughly in the middle, to the southwest side of the bay. There are nine piezometers along this transect, all of them automated with pressure transducers with dataloggers. All but two of the piezometer nests are located adjacent to water table wells, approximately 1.8 meters from the well. The two nests
of piezometers not closely adjacent to wells are located within 6.1 m (20 feet) of a well because it was not possible for the drill rig to get any closer to the well. Locating piezometers beside water table wells allows for the vertical direction of ground water movement between those two instruments to be calculated. There are two sets of nested piezometers (two piezometers at one location) along the long transect that give information about vertical water potentials between the two piezometers at that location. There are three sets of nested piezometers along the short transect, giving information on vertical potentials at those locations.

Piezometers were installed along these transects because this arrangement was thought to give a good representation of ground water movement, where it was entering the bay, where it was leaving, if it was leaking vertically downward out of the bay, and of the gradients within the bay and between the bay and the surrounding area.

With two piezometers at the same location, installed at different depths with a clay layer in between the two depths, it can be determined if water is moving up or down in the soil profile between those two piezometers and if the clay layer is restrictive in nature. With one piezometer and one well at the same location, with a clay layer between the two, the restrictive nature of that clay layer can also be determined. If the water level an/or fluctuations from the instrument above the clay layer and the one below the clay layer are the same or nearly the same, then both zones are responding to the same head control.
Table 5 shows the depths of all piezometers. The bottom 0.76 meters (2.5 feet) of each piezometer is screened.

Figure 14: Piezometer locations and numbers in and around Juniper Bay. Two piezometers at one location represent a nest, with one piezometer installed to a shallower depth (S) and one deeper (D). All piezometers are located next to a water table monitoring well.
Table 5: Information on piezometers in Juniper Bay

<table>
<thead>
<tr>
<th>Piezometer</th>
<th>Location (inside/ outside of bay)</th>
<th>Soil Type (mineral/organic)</th>
<th>Depth from ground surface to bottom of piezometer (m), and elevation of screened section (m above sea level)</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>P 1 Shallow</td>
<td>Inside, NW section</td>
<td>Mineral</td>
<td>4.51, 31.68-32.44</td>
<td>2</td>
</tr>
<tr>
<td>P 2 Shallow</td>
<td>Inside, NW section</td>
<td>Mineral</td>
<td>2.46, 33.82-34.58</td>
<td>2</td>
</tr>
<tr>
<td>P 3</td>
<td>Inside, middle</td>
<td>Mineral</td>
<td>4.42, 32.07-32.83</td>
<td>2</td>
</tr>
<tr>
<td>P 6</td>
<td>Inside, middle</td>
<td>Organic</td>
<td>5.95, 30.16-30.92</td>
<td>2</td>
</tr>
<tr>
<td>P 10 Shallow</td>
<td>Inside, middle</td>
<td>Organic</td>
<td>2.46, 33.76-34.52</td>
<td>2</td>
</tr>
<tr>
<td>P 10 Deep</td>
<td>Inside, middle</td>
<td>Organic</td>
<td>5.12, 31.1-31.86</td>
<td>2</td>
</tr>
<tr>
<td>P 11</td>
<td>Inside, middle</td>
<td>Organic</td>
<td>4.51, 31.53-32.29</td>
<td>2</td>
</tr>
<tr>
<td>P 12</td>
<td>Inside, SE section</td>
<td>Mineral</td>
<td>4.88, 31.36-32.12</td>
<td>2</td>
</tr>
<tr>
<td>P 17</td>
<td>Inside, SE section</td>
<td>Mineral</td>
<td>9.14, 27.29-28.05</td>
<td>3</td>
</tr>
<tr>
<td>P 20 Shallow</td>
<td>Outside, N of bay</td>
<td>-*</td>
<td>4.27, -*</td>
<td>2</td>
</tr>
<tr>
<td>P 20 Deep</td>
<td>Outside, N of bay</td>
<td>-*</td>
<td>7.32, -*</td>
<td>3</td>
</tr>
<tr>
<td>P 22</td>
<td>Outside, N of bay</td>
<td>Mineral</td>
<td>7.32, -*</td>
<td>3</td>
</tr>
<tr>
<td>P 25 Shallow</td>
<td>Outside, S of bay</td>
<td>Mineral</td>
<td>8.23, 29.27-30.03</td>
<td>3</td>
</tr>
<tr>
<td>P 25 Deep</td>
<td>Outside, S of bay</td>
<td>Mineral</td>
<td>10.21, 27.29-28.05</td>
<td>3</td>
</tr>
</tbody>
</table>

*-* indicates no available data.
All piezometers were constructed of 5.08 cm (2 in.) PVC casing with a 76 cm (2.5 ft) long screened section on the bottom. This screened section is the zone in which the hydraulic heads will be determined. One piezometer indicated the head at its location. The difference in heads between two locations, along with the separation distance, gives the gradient. The piezometers were installed with the aid of a drill rig using a hollow-stem auger. The depths of the piezometers had been pre-determined using data from the soil coring. The piezometers were placed 1.8 meters away from the well, and where there are two piezometers, the second one is 1.8 meters from the first one, 3.7 meters from the well.

The bore hole for the piezometer was drilled to the desired depth with the bottom of the auger closed with a wooden plug. The piezometer was then inserted and the plug pushed out. Well sand was poured around the screen and bentonite was poured around the casing to the surface as the auger was withdrawn in stages.

**Water level measurement**

Water levels in the piezometers were measured with Solinst Leveloggers, model LT 3001. This model of pressure transducer has a cable to the surface for downloading data with a computer but is sealed at one atmosphere of pressure. Barometric pressure corrections of the Levelogger readings were accomplished by recording barometric pressure with a Solinst Barologger. The Barologger is a pressure transducer similar to the Levelogger but is mounted in air. Both the Levelogger and Barologger are gauge pressure transducers, with one atmosphere as the reference (zero) pressure, as opposed to absolute or differential pressure transducers.
The Levelogger dataloggers were set to record water levels at one hour intervals. They were lowered in the piezometers to a known depth. The cable that connected each datalogger to the cap that was put on top of each piezometer came at the same length, approximately 7 meters (23 feet) long. Most piezometers, however, were not this deep. This meant the cables had to be shortened. This was done by wrapping the cables up until they were short enough that they would not rest on the bottom of the piezometer but would stay continuously submerged. Then twist ties were used to secure the length of the cables. The data from the dataloggers were downloaded every couple of weeks by pulling up the dataloggers and attaching them to a port that transferred the data to a laptop computer. This method of downloading the data, however, presented a problem. The cables would lengthen slightly each time they were pulled up, and may have also lengthened while hanging in the piezometers. This added to the error in the measurements from these dataloggers. Pressure readings corrected for barometric pressure variation and converted to water depth were stored in a spreadsheet database. Manual readings were also taken in each piezometer most times the data were downloaded from the dataloggers. Manual readings and readings from the dataloggers were compared to assess the amount of error associated with the method of shortening the cables. Piezometer data from January 2002 though December 2002 were used in this research.

Data Analysis

The piezometer water level data were used to study horizontal and vertical ground water flow. To determine the direction of the vertical flow, hydrographs of
water level depth were compared among the well and piezometers at particular sites. Horizontal gradients was determined by comparing water level elevations among piezometers at different locations along a transect.

**Hydraulic Conductivity Measurement**

Hydraulic conductivity measurements, utilizing slug tests, were conducted in summer 2002 in most piezometers to estimate saturated hydraulic conductivity in the vicinity of the screened portion (the bottom 76 cm) of the piezometer (Table 6). The slug test can be based on quickly withdrawing a volume of water from the well and measuring the subsequent rate of rise of the water level in the well, or by adding a slug of water and measuring the subsequent rate of fall of the water level in the well (Bouwer, 1989). The method can be used for confined or stratified aquifers (Bouwer, 1989). Most piezometers in which slug tests were performed were in zone 2, which is the region of interest in trying to determine the direction and magnitude of ground water movement in Juniper Bay. The saturated hydraulic conductivity values obtained from the slug tests will aid in determining the rate of possible ground water movement in zone 2.

Slugs were made out of PVC pipe that was 2.54 cm in diameter. Lengths of pipe were cut to make two slugs that were each 79.7 cm long, including the caps. The pipes were filled with sand and caps that were 4.13 cm long were glued on both ends. On each slug, a rope was attached through a hole drilled in a cap to raise and lower the slug.
Table 6: Location and depth of slug tests

<table>
<thead>
<tr>
<th>Piezometer</th>
<th>Depth of instrument, meters</th>
<th>Zone</th>
<th>Section of bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>P 1 Shallow</td>
<td>4.51</td>
<td>2</td>
<td>Northwest</td>
</tr>
<tr>
<td>P 1 Deep</td>
<td>10.36</td>
<td>3*</td>
<td>Northwest</td>
</tr>
<tr>
<td>P 2 Shallow</td>
<td>2.46</td>
<td>2</td>
<td>Northwest</td>
</tr>
<tr>
<td>P 2 Deep</td>
<td>4.42</td>
<td>2</td>
<td>Northwest</td>
</tr>
<tr>
<td>P 3</td>
<td>4.42</td>
<td>2</td>
<td>Middle</td>
</tr>
<tr>
<td>P 6</td>
<td>5.95</td>
<td>2</td>
<td>Middle</td>
</tr>
<tr>
<td>P 10 Shallow</td>
<td>2.46</td>
<td>2</td>
<td>Middle</td>
</tr>
<tr>
<td>P 10 Deep</td>
<td>5.12</td>
<td>2</td>
<td>Middle</td>
</tr>
<tr>
<td>P 11</td>
<td>4.51</td>
<td>2</td>
<td>Middle</td>
</tr>
<tr>
<td>P 12</td>
<td>4.88</td>
<td>2</td>
<td>Southeast</td>
</tr>
<tr>
<td>P 17</td>
<td>9.14</td>
<td>3*</td>
<td>Southeast</td>
</tr>
<tr>
<td>P 20 Shallow</td>
<td>4.27</td>
<td>2</td>
<td>North, outside bay</td>
</tr>
<tr>
<td>P 20 Deep</td>
<td>7.32</td>
<td>3*</td>
<td>North, outside bay</td>
</tr>
<tr>
<td>P 22</td>
<td>7.32</td>
<td>3*</td>
<td>North, outside bay</td>
</tr>
<tr>
<td>P 25 Shallow</td>
<td>8.23</td>
<td>2</td>
<td>South, outside bay</td>
</tr>
<tr>
<td>P 25 Deep</td>
<td>10.21</td>
<td>3*</td>
<td>South, outside bay</td>
</tr>
</tbody>
</table>

* slug tests were not performed in piezometers located in zone 3.

The pressure transducer was taken out of the piezometer in which the slug test was about to be performed to be reprogrammed for the slug test. The transducers were programmed to record the water level every second. The pressure transducer was lowered into the piezometer to a depth beneath the surface of the water in the piezometer and greater than the depth that the slug was to be lowered. The cable attached to the transducer was taped to the side of the piezometer pipe sticking up out of the ground so its elevation would not change.
when the slug was dropped in or pulled out of the piezometer. The depth of the transducer was also measured. The slug was then lowered into the piezometer slowly until it was just above the transducer. The slug was left in the piezometer for a couple of minutes while the water level equilibrated. The pressure transducer was recording the water level from the time it was programmed, which was prior to being lowered into the piezometer.

Once the water level was thought to have equilibrated, the slug was yanked very quickly out of the hole, and five minutes was given to allow the water level to equilibrate again. After five minutes had elapsed, the slug was quickly dropped into the piezometer until it rested on top of the pressure transducer. Another five minutes was given to allow the water to equilibrate again. Then the slug was quickly pulled out again as the last slug test in the series. The pressure transducer remained submerged during the entire series of slug tests and recorded the water level every second. After the last time the slug was pulled out of the piezometer and five minutes was allotted for the water level to equilibrate, the pressure transducer was pulled up and the data downloaded. This same series of slug tests was performed in most piezometers at Juniper Bay. It was recommended by Bouwer (1989) that to begin the series of slug tests, the slug be lowered into the piezometer and the water level be allowed to equilibrate. Then the first in the series of slug tests would be to quickly remove the slug from the piezometer. Five minutes was thought to be an adequate amount of time to let the water level equilibrate between tests because the portion of the data used in calculating saturated hydraulic conductivity occurs within the first minute or two due to the fact that after that the drawdown of
the ground water table around the well becomes increasingly significant and begins to influence the test (Bouwer, 1989).

**Data analysis**

The Bouwer and Rice slug-test method was used to analyze the data and get a saturated hydraulic conductivity (K) value. The equation used is:

\[
K = \left( r_c \ln \left( \frac{R_e}{r_w} \right) \right) \left( \frac{2L_e}{2} \right) \left( \frac{1}{t} \right) \ln \left( \frac{y_0}{y_t} \right) \tag{1}
\]

where: 
- **K** is hydraulic conductivity (cm/s);
- **r\(_c\)** is the radius of the casing (cm);
- **R\(_e\)** is the effective radial distance over which y is dissipated (cm);
- **r\(_w\)** is the radial distance of the undisturbed portion of the aquifer from the centerline (cm);
- **L\(_e\)** is the length of the screened portion of the piezometer (cm);
- **y\(_0\)** is the distance between the normal water level in the piezometer and the water level at time zero (cm);
- **y\(_t\)** is the distance between the normal water level in the piezometer and the water level at time t (cm);
- **t** is the time from the start of the test (s).

\(\ln \left( \frac{R_e}{r_w} \right)\) is expressed in the following equation:

\[
\ln \left( \frac{R_e}{r_w} \right) = \left[ \frac{1.1}{\ln \left( L_w / r_w \right)} + (A + B \ln \left( \frac{H - L_w}{L_w / r_w} \right) / L_w / r_w) \right]^{-1} \tag{2}
\]

where: 
- **L\(_w\)** is the distance from the top of the water table to the bottom of the piezometer (cm);
- **A** and **B** are dimensionless numbers taken off the graph shown in Bouwer, 1989.
H is the distance from the top of the water table to the top of the restrictive layer below the bottom of the piezometer (cm).

Because y and t are the only variables in equation (1), a plot of ln \( y_t \) versus t must show a straight line (Bouwer, 1989). The straight line through the data points can be used to select two values of y, namely, \( y_0 \) and \( y_t \), along with the time interval t between them for substitution into equation (1). Only the straight line portion of the data points are used to evaluate \( \frac{\ln(y_0/y_t)}{t} \) for the calculation of K with equation (1) (Bouwer, 1989).

Once the K value is obtained by equation (1), ground water flow can be computed. Darcy’s Law is an equation that can be used to compute the quantity of water flowing through an aquifer (Fetter, 2001). Darcy’s Law applies to very slowly moving ground waters, which applies to most natural ground-water conditions (Fetter, 2001). Expressed in terms of hydraulic head, Darcy’s Law is:

\[
Q = -KA\frac{dh}{dl}
\]

(3)

where: Q is the discharge,

K is the saturated hydraulic conductivity,

A is the cross-sectional area perpendicular to the direction of flow,

dh is the change in hydraulic head,

dl is the distance between the measuring points.
**Reference ecosystem approach**

Objective three is to evaluate how useful a reference ecosystem approach is in the wetland restoration process. The water table regime in the reference bays will be compared to the water table regime in Juniper Bay and assessed with the Corps and FSA criteria. It may be shown that there is a large difference in the hydrology requirements of the different agencies and the hydrologic regime in the reference bays. If so, then this illustrates that reference ecosystems are important in understanding what the hydrology regime was in pre-disturbance conditions in the system to be restored.
Results and Discussion

Rainfall

The monthly and annual precipitation that falls between the 30th and 70th percentiles from the Red Springs station in Robeson County and from Elizabethtown in Bladen County, North Carolina (WETS, 2002), and monthly and annual precipitation totals during the study period at Juniper Bay and Bladen Lakes State Forest are shown in Table 7. Rain data from the weather station at Juniper Bay was used in the analysis. The other two rain gauges were not used because the data was suspect due to the gauges being clogged nearly every time the data from them were downloaded. Juniper Bay is about 36 kilometers southeast of Red Springs, Tatum Millpond Bay is about 12 km north of Elizabethtown, Charlie Long Millpond Bay is about 17 km north, and Causeway Bay is about 18 km east northeast of Elizabethtown. The 30th and 70th percentile range was used to assess whether the rainfall totals in the bays were within the normal range of rainfall over the last 30 years. This allows a better understanding of whether a month was dry, within the normal range, or wet in reference to long-term precipitation data.

As Table 7 shows, many of the months at Juniper Bay and the reference bays had below the normal range of precipitation in 2001 and 2002. The annual precipitation total for 2002 was also below the normal range. The annual total for 2001 is missing data for the first two months, so it cannot be said if the total was below the normal range. However, if the upper limit of the normal range for January and February 2001 from Red Springs is added to the annual total from Juniper Bay
the total is still below the normal range. A few months, however, had above the normal range of precipitation. August of 2001 and 2002 had above the normal range of precipitation, and October 2002 had rainfall amounts at the upper limit of the range. Some months were very dry. In Juniper Bay, September, November, and December of 2001 were either drier than the normal range or at the bottom of the range, and February through September (except April and August) of 2002 were below the normal range. In Juniper Bay in 2002, half of the year experienced below the normal range of rainfall, primarily in late winter through early summer. The precipitation totals from Bladen Lakes State Forest are primarily in the normal range, with two months, August and November 2002, having above the normal range of precipitation.
Table 7: Rainfall ranges between the 30th and 70th Percentiles for Robeson and Bladen Counties, N.C., and rainfall amounts at the bays during the study period

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>7.62-12.78</td>
<td>-</td>
<td>9.1</td>
<td>8.46-13.18</td>
<td>-</td>
</tr>
<tr>
<td>February</td>
<td>5.64-10.41</td>
<td>-</td>
<td>5.3^</td>
<td>5.41-10.29</td>
<td>-</td>
</tr>
<tr>
<td>March</td>
<td>8.20-12.95</td>
<td>9.4</td>
<td>7.7^</td>
<td>7.37-13.31</td>
<td>-</td>
</tr>
<tr>
<td>April</td>
<td>4.06-11.58</td>
<td>0.6^</td>
<td>6.25</td>
<td>4.59-10.74</td>
<td>-</td>
</tr>
<tr>
<td>May</td>
<td>5.89-10.11</td>
<td>6.2</td>
<td>3.8^</td>
<td>5.99-11.56</td>
<td>-</td>
</tr>
<tr>
<td>June</td>
<td>8.94-14.07</td>
<td>14.1</td>
<td>7.3^</td>
<td>7.69-13.26</td>
<td>11.89</td>
</tr>
<tr>
<td>July</td>
<td>11.30-18.44</td>
<td>17.8</td>
<td>9.7^</td>
<td>12.22-18.01</td>
<td>13.49</td>
</tr>
<tr>
<td>September</td>
<td>7.42-15.90</td>
<td>6.2^</td>
<td>3.4^</td>
<td>5.61-14.68</td>
<td>7.16</td>
</tr>
<tr>
<td>October</td>
<td>4.32-10.57</td>
<td>5.4</td>
<td>10.5</td>
<td>3.71-9.86</td>
<td>7.65</td>
</tr>
<tr>
<td>November</td>
<td>4.34-10.08</td>
<td>4.6</td>
<td>8.4</td>
<td>4.06-8.23</td>
<td>8.87^^</td>
</tr>
<tr>
<td>December</td>
<td>5.56-11.18</td>
<td>1.8^</td>
<td>8.3</td>
<td>5.84-11.61</td>
<td>6.5</td>
</tr>
<tr>
<td>Annual</td>
<td>108.51-127.20</td>
<td>85.4*</td>
<td>103.4^</td>
<td>101.06-125.76</td>
<td>83.058***</td>
</tr>
</tbody>
</table>

* only includes data from March through December, 2001.
** rain gauge located in Bladen Lakes State Forest.
*** data from June to December, 2002.
^ indicates month was below the normal range of precipitation.
^^ indicates month was above the normal range of precipitation.

Response of the Water Table to Precipitation Events

Well 2A is located in mineral soil, Leon series, near the rim in the northwest section of Juniper Bay close to a large ditch (Figure 13). The surface elevation at that well is the second highest of the wells in that section of the bay and that section has the highest surface elevation in the bay. In the last days of May and the beginning of June 2001, it rained approximately 8.1 cm over seven days. The water table in well 2A had a starting depth of 110 cm below the soil surface (Figure 15). The water table rose over 60 cm in those seven days. For two days in the middle of
the seven days there was no rain, and the water table remained at approximately 85 cm below the surface. Other wells showed similar behavior. The water table did not drop between the rain events, possibly due to water still percolating down through the soil profile. The water table did not respond immediately to the first rain event over the seven days, but it did rise immediately after the second rain event and then began to drop. Another rain event took place on August 17 and August 19-20. The rainfall total was approximately 12 cm. The water table rose between 35 and 40 cm, starting from around 80 cm below the soil surface, from the approximately 4.5 cm of rain that occurred on August 17th. After the rain ended the water level started to fall slowly. The water level in well 2A fell approximately 10 cm in the two days between the rain events. On August 19-20, when approximately 7.5 cm of rain fell, the water level in the well rose approximately 55 cm, and then began to fall more rapidly.

The above rainfall totals and subsequent water table rise indicate that in the last days of May and early June 2001, a rain event that produced over 8 cm of rain resulted in a water table rise of about 60 cm, and the larger rain event of 12 cm in late August of 2001 resulted in a water table rise of 90 cm (Figure 16: Water table response to rainfall in mid-summer, 2001). The rise in the water table due to the two rain events is about the same, indicating that the conditions that might be different in August versus late May/early June did not significantly affect the behavior of the water table.
Figure 15: Water table response to rainfall in late spring, 2001
Figure 16: Water table response to rainfall in mid-summer, 2001

Available storage estimates the water holding capacity of the soil, i.e. the available pore space, after a precipitation event. It is roughly estimated by dividing the amount of rainfall by the amount of rise in the water table after the rainfall, as measured in the wells. This will give an indication of how much pore space there is at the different well locations in Juniper Bay. Table 8 shows the estimated available storage after a rain event totaling 3.3 cm on August 19, 2001.

Available storage is generally greater in soils with larger pores, such as soils with a lot of sand or organic matter. A greater available storage number means the water table does not rise as much because of the larger pore space in which water
can inhabit. Mineral soils with more clay and silt, or those that have been impacted by agricultural practices, generally have smaller pores, less organic matter, and a smaller amount of available storage (Vepraskas, personal communication, 2004). The water table will rise more in soils with a small amount of available storage due to the smaller pore space available to fill. Wells 12 and 16 had the greatest available storage values (Table 8) and had the shallowest water tables of all the wells. The water table rose the least due to the rain event in these two wells indicating that the soil at those locations is capable of holding more water due to larger pores, or possibly, a gradient of water movement towards a head control such as a ditch. The water table at both locations is shallow enough to meet the wetland hydrology criteria in 2001 and 2002. Well 12 is in mineral soil and in close proximity to a collector ditch. This ditch may exhibit enough of a gradient near the well to draw enough of the water towards it to cause the lower rise in the water table and therefore the lower storage value. Well 16 is in organic soil and not as close to a large, deep ditch. The available storage is likely higher at this location because of the larger pores of the organic soil and possible the ineffectiveness of the ditch network in this part of the bay. Factors that likely influence the available storage and therefore the amount of rise in the water table after a rain event include the proximity to a large ditch, the effectiveness of the shallower lateral ditches in different parts of the bay, the spatial variability of the soil stratigraphy, and the natural variation in the behavior of the water table.
Table 8: Available storage in Juniper Bay

<table>
<thead>
<tr>
<th>Well #</th>
<th>Soil Type</th>
<th>0-25cm depth</th>
<th>25-50cm depth</th>
<th>50-75cm depth</th>
<th>75-100cm depth</th>
<th>&gt;100cm depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well 1</td>
<td>Organic</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 5</td>
<td>Organic</td>
<td></td>
<td>0.07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 5A</td>
<td>Organic</td>
<td></td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 6</td>
<td>Organic</td>
<td>-**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 8*</td>
<td>Organic</td>
<td>-**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 10</td>
<td>Organic</td>
<td>0.09</td>
<td></td>
<td></td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Well 15</td>
<td>Organic</td>
<td></td>
<td></td>
<td>0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 16</td>
<td>Organic</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 2</td>
<td>Mineral</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 2A</td>
<td>Mineral</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 3</td>
<td>Mineral</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 7</td>
<td>Mineral</td>
<td>0.07</td>
<td></td>
<td></td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Well 8A</td>
<td>Mineral</td>
<td></td>
<td></td>
<td>0.07</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Well 8B</td>
<td>Mineral</td>
<td>0.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 12</td>
<td>Mineral</td>
<td>0.45</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 16A</td>
<td>Mineral</td>
<td></td>
<td></td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 16B</td>
<td>Mineral</td>
<td></td>
<td></td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 20</td>
<td>Mineral</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 23A</td>
<td>Mineral</td>
<td></td>
<td></td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 25</td>
<td>Mineral</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 25A</td>
<td>Mineral</td>
<td></td>
<td></td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well 25B</td>
<td>Mineral</td>
<td></td>
<td></td>
<td>-**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0.3</td>
<td>0.075</td>
<td>0.066</td>
<td>0.073</td>
<td>0.094</td>
</tr>
</tbody>
</table>

* italics indicates the well is located in organic soil.
** indicates missing data

Seasonal Variation in the Water Table Regime in Juniper Bay

All water table wells show seasonal variation, as represented by selected wells in Figure 17: Seasonal variation in the water table in Juniper Bay. Summer 2001 had several months with rainfall at the upper limit of the normal range and August had above the normal limit (Table 7), which likely accounted for the shallower water table. In the fall of 2001, which saw rainfall totals at the bottom or below the range, the water table dropped steadily. During the
winter of 2001/2002, the water table recovered, due to more rain, and lower ET. The spring of 2002 saw the water table rise and fall rapidly, then steadily decline (with a few hydrograph spikes due to rain events) towards the summer of 2002. The summer of 2002 had below normal rainfall and the water table dropped significantly by mid-August. By the fall of 2002 the rainfall was closer to normal and the water table rose again.

![Seasonal variation in the water table in Juniper Bay](image)

**Figure 17**: Seasonal variation in the water table in Juniper Bay

**Water Table Variation**

**Water Table Variation and Corps of Engineers Wetland Hydrology Criteria**

**Juniper Bay**

Some of the factors that may influence the water table in Juniper Bay and the reference bays are rainfall, soil type, elevation, and vegetation. These will all be
examined to try to determine the main influences. The time period of most interest is the growing season, as this is when the water table must be shallow enough to meet the Corps criteria for wetland hydrology.

Different wetland types have different influences on their water balances. Carolina Bays typically have hydrologic inputs consisting mainly of precipitation and, as some suggest, ground water inflow (Lide et al., 1995; Schalles and Shure, 1989). Some bays have surface water from outside the bay (overland flow) as another input, but Juniper Bay is encircled by a perimeter ditch, which would intercept any overland flow towards the bay. The hydrologic outputs in Juniper Bay consist mainly of evapotranspiration, surface outflow in the drainage system, and possible ground water outflow. Soil type influences rainfall infiltration and percolation rates, and soil storage capacity. Topography influences direction of surface and ground water flow. The vegetation present on the site influences how much soil water is lost through evapotranspiration (ET) and what proportion of rainfall reaches the soil surface as throughfall. A dense canopy cover will result in some interception loss and reduce the proportion of rainfall that reaches the soil, as in the reference bays. The current vegetation in Juniper Bay is the early stage of old field succession dominated by early successional grasses and forbs. A small portion of the bay on the south side has a young longleaf pine (Pinus palustris) plantation. The water table in that portion of the bay with pine trees is lower than in other areas and that may be due to an increased amount of soil water lost through ET.

The percentages of the Juniper Bay area where the water table was shallow enough to meet the various criteria for wetland hydrology were determined by
creating area of influence polygons around the wells that met the specific criteria in ArcView 3.2, and obtaining an area measurement from the program. As shown in Table 9: Percentage of Juniper Bay that met the U.S. Army Corps of Engineers criteria for jurisdictional wetlands in 2001 and 2002, 15% of Juniper Bay in 2001 and 22% in 2002 had the water table shallow enough to meet the Corps 5% wetland hydrology criterion which is the minimum for jurisdictional wetland determination. In 2001 the early part of the growing season had normal or below the normal range of rainfall, the summer saw normal or above the normal range of rainfall, and the fall had normal to below the normal range of rainfall. Wells 8, 12, and 16 met the Corp's 12.5% criterion in 2001 (Figure 20), all meeting it later in the growing season (Table 10). These three wells were the only ones that had the water table starting in the 0-25 cm range for the drainable porosity calculations shown in Table 8. In 2002, most of the growing season, from March through September, had below the normal range of rainfall, excluding April, which had within the normal range of rainfall, and August, which had above the normal range of rainfall. October and November had within the normal range of rainfall, although October was at the upper limit of the range. Wells 3, 8, 12, 15, and 16, met the Corps 12.5% criterion (Figure 21). This is two more wells than in 2001, even though there was less rainfall. Well 3 met the criterion in the beginning and well 15 met it at the end of the growing season. The beginning of the growing season in 2002 had below normal rainfall on average while the end had on the high end of the normal range of rainfall.

Other factors may be influencing the water table to make these two wells meet the criterion in 2002. Well 3 is in the northern part of the bay near the
perimeter ditch as well as a ditch which is larger than the shallow lateral ditches. The perimeter ditch may have been blocked up by beaver dams. This could have had an effect on the water table in that area. Well 15 is in the southern part of the middle section and simply the continued degradation of the ditches may have been what made it meet the criterion in 2002.

Table 9: Percentage of Juniper Bay that met the U.S. Army Corps of Engineers criteria for jurisdictional wetlands in 2001 and 2002

<table>
<thead>
<tr>
<th>Percentage of:</th>
<th>Saturated to within 30 cm from soil surface for:</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5% of growing season (12 days)</td>
<td>8.75% of growing season (21 days)</td>
<td>12.5% of growing season (30 days)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juniper Bay</td>
<td>15%</td>
<td>22%</td>
<td>15%</td>
<td>22%</td>
<td>4%</td>
<td>22%</td>
</tr>
<tr>
<td>Mineral soil total</td>
<td>43%</td>
<td>43%</td>
<td>43%</td>
<td>43%</td>
<td>10%</td>
<td>43%</td>
</tr>
<tr>
<td>Mineral soil: Leon</td>
<td>43%</td>
<td>43%</td>
<td>43%</td>
<td>43%</td>
<td>10%</td>
<td>43%</td>
</tr>
<tr>
<td>Mineral soil: Pantego</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Mineral soil: Rutlege</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Mineral soil with histic epipedon: Leon</td>
<td>33%</td>
<td>33%</td>
<td>33%</td>
<td>33%</td>
<td>11%</td>
<td>33%</td>
</tr>
<tr>
<td>Organic soil: Ponzer Muck</td>
<td>14%</td>
<td>29%</td>
<td>14%</td>
<td>29%</td>
<td>0%</td>
<td>29%</td>
</tr>
</tbody>
</table>

Water table wells that met the Corps 5% criterion for a jurisdictional wetland are shown in Table 10: Wells in Juniper Bay that met the Corps 5% wetland hydrology criterion (12 consecutive days).

Ground surface elevations are shown in Figure 18. Water table wells 3, 8, and 12 (Figure 19: Wells in Juniper Bay that met the Corps 5% wetland hydrology criterion in 2001 and 2002 – Figure 21: Water table wells in Juniper Bay that met the Corps 12.5% criterion in 2002) show the water table staying above or just under
the soil surface for much of the winter and spring of 2002. All three wells are located in mineral soil. The soil profile at well 8 consists of a muck layer over a thin sand layer over a very thick clay layer. Water at this location cannot move as easily down through the soil profile due to the high clay content as compared to a location with a higher sand content, and therefore stays closer to the surface during the wetter months. Sandy soils generally have higher saturated conductivities than finer-textured soils, like clayey soils, because they usually have more macropore space (Brady and Weil, 2000).

Table 10: Wells in Juniper Bay that met the Corps 5% wetland hydrology criterion (12 consecutive days)

<table>
<thead>
<tr>
<th>Juniper Bay</th>
<th>Wells that meet minimum wetland hydrology requirements</th>
<th>Consecutive days requirements were met, 2001 growing season*</th>
<th>Consecutive days requirements were met, 2002 growing season (g.s.)*</th>
<th>Soil series; mineral, mineral with histic epipedon, organic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well 3</td>
<td>Did not meet criterion this year</td>
<td>30, start of g.s.</td>
<td>Leon, mineral</td>
<td></td>
</tr>
<tr>
<td>Well 8</td>
<td>35, September</td>
<td>35, start of g.s.</td>
<td>Leon, mineral with histic epipedon</td>
<td></td>
</tr>
<tr>
<td>Well 12</td>
<td>28, August 18-September 15</td>
<td>36, start of g.s.</td>
<td>Leon, mineral</td>
<td></td>
</tr>
<tr>
<td>Well 15</td>
<td>Did not meet criteria this year</td>
<td>19, start of g.s.</td>
<td>Ponzer Muck, organic</td>
<td></td>
</tr>
<tr>
<td>Well 16</td>
<td>28, August 19-September 14</td>
<td>33, start of g.s.</td>
<td>Ponzer Muck, organic</td>
<td></td>
</tr>
</tbody>
</table>

* Growing season for project site is March 20 through November 16.

The soil profile at well 3 consists of sandy material for about 1.2 m (4 ft) over a clay layer that is approximately 2.4 m (8 ft) thick. This clay layer may retard the downward movement of water. Well 3 is near the northern rim of the bay in the middle section. This area often had water ponded on the surface. The ditches in
this area are likely degraded and are not in good working order since no ditch maintenance has taken place since 2000. Wells 12 and 16 have similar soil profiles that consist of a thin muck layer at or near the surface over mainly sand, with thin clay lenses also present throughout the upper profile. These two wells are located in the southeast section. The factors influencing the water table in this section are probably the inefficient ditch network and the fact that the surface elevation is slightly lower than the rest of the bay. The northeastern portion of this section, where well 8 is located, was ditched last and has a high amount of clay at or very near the surface. This area, even with the ditches, was commonly wetter than the rest of the bay, often with water ponded on the surface. This section may also have some anomalies below the soil surface that are unknown at this time that may contribute to the greater “wetness”.

Well 15 is located in the southern part of the middle section. The soil profile at its location consists of a thick sandy layer over a thick clayey layer. Wells 15 and 16 are the only two wells that meet the wetland hydrology criterion that are located in organic soil.
Figure 18: Elevations of the ground surface at well locations (in meters above sea level) in and around Juniper Bay

Reference Bays

In this restoration project, the N.C.D.O.T. must use the Corps' 12.5% criterion as the hydrology standard for receiving mitigation credits, and that will likely ensure restoration of the relatively long amount of time the water table is within 30 cm of the soil surface in Juniper Bay.
The water table in the reference bays exceeds the Corps 12.5% criterion (30 days) at several of the wells (Table 11: Number of consecutive days the water table was within 30 cm of the soil surface in the reference bay wells), indicating that the water table in at least some parts of Juniper Bay prior to drainage was likely within 30 cm of the soil surface for consecutive periods longer than 30 days. A large percentage of the reference bay wells met the Corps 5% criterion, the wetland hydrology requirements for a jurisdictional wetland set by The Army Corps of Engineers (Table 11: Number of consecutive days the water table was within 30 cm of the soil surface in the reference bay wells).

Figure 19: Wells in Juniper Bay that met the Corps 5% wetland hydrology criterion in 2001 and 2002
Figure 20: Water table wells in Juniper Bay that met the Corps 12.5% criterion in 2001
Figure 21: Water table wells in Juniper Bay that met the Corps 12.5% criterion in 2002

Food Security Act Criteria

The Food Security Act wetland hydrology criterion based on soil saturation near the surface is slightly more restrictive than the Corps 5% criterion. During the 14-day hydroperiod, the water table must be within 15 cm of the soil surface for sandy soils. For all other soils the maximum depth of 30 cm is the same for all three wetland hydrology requirements. The application of the FSA criterion to Juniper Bay and the reference bays is shown in Table 12: Percentage of Juniper Bay that met the Food Security act criterion for wetland hydrology and Table 13: Wells in Juniper Bay that met the Food Security Act criterion for wetland hydrology.
Table 11: Number of consecutive days the water table was within 30 cm of the soil surface in the reference bay wells

<table>
<thead>
<tr>
<th>Reference bay water table wells</th>
<th>Consecutive days during 2002 growing season (March 20 – November 16) that the water table is within 30 cm of soil surface*</th>
<th>Soil type (mineral, histic mineral, shallow organic, deep organic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Causeway Bay (CB) well 1**</td>
<td>4</td>
<td>mineral</td>
</tr>
<tr>
<td>Causeway Bay (CB) well 2</td>
<td>1, 45***, 1, 4, 5, 13, 7, 1</td>
<td>histic mineral</td>
</tr>
<tr>
<td>Causeway Bay (CB) well 3</td>
<td>3, 45, 8, 4, 4, 5, 4, 4</td>
<td>shallow organic</td>
</tr>
<tr>
<td>Charlie Long Bay (CL) well 1</td>
<td>3, 1</td>
<td>mineral</td>
</tr>
<tr>
<td>Charlie Long Bay (CL) well 2</td>
<td>3, 45, 1, 8, 1, 21</td>
<td>histic mineral</td>
</tr>
<tr>
<td>Charlie Long Bay (CL) well 3</td>
<td>3, 16, 5, 3, 2, 2, 2</td>
<td>shallow organic</td>
</tr>
<tr>
<td>Charlie Long Bay (CL) well 4</td>
<td>3, 7</td>
<td>deep organic</td>
</tr>
<tr>
<td>Tatum Millpond Bay (TM) well 1</td>
<td>3, 21, 21, 25, 8, 21</td>
<td>mineral</td>
</tr>
<tr>
<td>Tatum Millpond Bay (TM) well 1A</td>
<td>3, 1, 4, 1, 2, 1, 4, 1, 30, 21</td>
<td>mineral</td>
</tr>
<tr>
<td>Tatum Millpond Bay (TM) well 2</td>
<td>3, 21, 21, 18, 12, 1, 5, 21</td>
<td>histic mineral</td>
</tr>
<tr>
<td>Tatum Millpond Bay (TM) well 3</td>
<td>3, 21, 21, 18, 13, 5, 9, 21</td>
<td>shallow organic</td>
</tr>
<tr>
<td>Tatum Millpond Bay (TM) well 4</td>
<td>33, 21, 2, 19, 8, 3, 8, 21</td>
<td>deep organic</td>
</tr>
</tbody>
</table>

* breaks in the well data meeting wetland hydrology requirements due to water table dropping below 30 cm or lack of data for that period of time, as shown in graphs.

** wells in italics indicate there was no period that wetland hydrology requirements were met.

*** bold numbers indicate an amount that meets the minimum wetland hydrology requirement of 5% set by the U.S. Army Corps of Engineers.
Table 12: Percentage of Juniper Bay that met the Food Security act criterion for wetland hydrology

<table>
<thead>
<tr>
<th>Juniper Bay</th>
<th>Saturation to within 15 cm from the soil surface for sandy soils or to within 30 cm of the soil surface for other soil types for 14 or more consecutive days during the growing season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2001</td>
</tr>
<tr>
<td>Juniper Bay</td>
<td>12%</td>
</tr>
<tr>
<td>Leon soil series</td>
<td>22%</td>
</tr>
<tr>
<td>(40% of Bay)</td>
<td></td>
</tr>
<tr>
<td>Pantego soil series</td>
<td>0%</td>
</tr>
<tr>
<td>(10% of Bay)</td>
<td></td>
</tr>
<tr>
<td>Rutlege soil series</td>
<td>0%</td>
</tr>
<tr>
<td>(20% of Bay)</td>
<td></td>
</tr>
<tr>
<td>Ponzer Muck soil series</td>
<td>20%</td>
</tr>
<tr>
<td>(30% of Bay)</td>
<td></td>
</tr>
</tbody>
</table>

Table 13: Wells in Juniper Bay that met the Food Security Act criterion for wetland hydrology

<table>
<thead>
<tr>
<th>Juniper Bay</th>
<th>7+ days of inundation</th>
<th>14+ days of saturation</th>
<th>Soil type (sandy or other)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well 3</td>
<td>-</td>
<td>-</td>
<td>Sandy (Leon)</td>
</tr>
<tr>
<td>Well 8</td>
<td>10</td>
<td>36</td>
<td>Other (Leon with histic epipedon)</td>
</tr>
<tr>
<td>Well 12</td>
<td>9</td>
<td>23</td>
<td>Sandy (Leon)</td>
</tr>
<tr>
<td>Well 16</td>
<td>-</td>
<td>22</td>
<td>Other (Ponzer Muck)</td>
</tr>
</tbody>
</table>

Spatial Influences on the Water Table in Juniper Bay

Location in the bay may have an effect on the water table regime. There is a general trend of the water table being, on average, closer to the surface from the northwest section to the southeast section. There is a very slight elevation difference, with the northwest section being the highest at 36.37 meters above sea
level, the middle section being in the middle with an average elevation of 36.28 m above sea level, and the southeast section the lowest with an average elevation of 36.21 m above sea level (Figure 22). This, however, does not likely have much of an influence on the water table. What is more likely to influence the water table is the effectiveness of the ditch network and the proximity to the larger, deeper collector ditches. The northwest and middle sections are closer to and probably more influenced by the main collector ditch. This may be why these sections have deeper water tables. The southeast section is farthest away from the main collector ditch. The lateral ditches have not been maintained at all since the acquisition of the bay in 2000 by the NCDOT and are not in good working order. Ditch effectiveness may have been worse in the southeast section prior to the acquisition, contributing to the shallow water table. Parts or all of this section likely were the wettest of the bay to begin with, which is probably why it was the last section to have ditches installed.

Throughout 2001 and 2002, the water table in the northwest section of Juniper Bay remained more than 50 cm deep most of the time (Figure 23: Water table depth in wells in the northwest section of Juniper Bay). The water table rose to or above the 30 cm depth infrequently in only four of the seven water table wells in this section and remained above that depth at most a few days at a time. Very brief periods of inundation occurred at a couple of wells for only a couple of rainfall events in the entire period of the data. In none of the wells did the water table ever meet any of the Corps or FSA wetland hydrology criteria.
The water table rose rapidly in response to rainfall and declined just as rapidly, creating sharp “spikes” in the water table hydrographs on the extended 22 month time scale. Those sharp spikes in the hydrographs could be indicative of effective drainage from the soil in that area, however, the available storage values from that section of the bay (Table 8) do not confirm this. The water table monitoring wells in the northwest section of the bay are primarily located in mineral soil, Leon sand, Rutlege loamy sand, and Pantego loam. This section has the
highest ground surface elevation (Figure 18: Elevations of the ground surface at well locations (in meters above sea level) in and around Juniper Bay), and the lateral ditches drain directly to the main outlet ditch. Aligned along the slight downward elevation gradient, the lateral ditches may have, if in decent working order, a higher hydraulic gradient to the outlet than the lateral ditches in the central and southeast sections of the bay.

The water table hydrographs of wells in the center section of the bay indicate that the water table in all wells but well 25 was generally much closer to the surface for much longer than in the northwest section of the bay (Figure 24: Water table depth in selected wells in the middle section of Juniper Bay). Well 25 is located very close to the south rim of the bay near the perimeter ditch, which likely has a drainage effect on the water table in the vicinity of the well. The perimeter ditch at this location is approximately 2.1 meters (7 feet) deep, and may influence the water table some 30 to 60 meters perpendicular from the ditch (Huffman, personal communication, 2004). Well 25 is within 30 meters (100 feet) of the perimeter ditch. There is, however, no data to prove that the ditch does influence the water table at well 25.

Soils in this section of the bay are both organic (Ponzer muck) and mineral (Leon sand). The water table hydrographs indicate that the water table was above (shallower than) the 30 cm depth much more often and for much longer periods of time in the middle section than in the northwest section of the bay. There were also extended periods of inundation in the vicinity of well 3, and frequent, brief periods of inundation in the vicinity of several additional wells. The water table in two wells in
this section of the bay (wells 3 and 15) met the Corps 5% criterion and the FSA wetland hydrology criterion. A possible explanation for the shallower water tables in this section is that the ditch network is not functioning as effectively as in the northwest section. This section had the ditches installed after the northwest section and may have been slightly wetter to begin with.

The water table hydrographs of wells in the southeast section of the bay indicate that this section has the shallowest water tables in the bay (Figure 25: Water table depth in wells in the southeast section of Juniper Bay). The water table did not fall below the 50 cm depth in several of the wells for a significant part of the study period. Periods of time with the water table within 30 cm of the surface were quite frequent and very long compared to the water table regime in other parts of Juniper Bay. There were very long periods of inundation in the vicinity of several wells. As noted earlier, all of the wells that met all of the wetland hydrology criteria are in this area of the bay. The rate of water table decline in the wells of the southeast section is much less than in the wells of the middle and northwest sections of the bay. This area is lowest in elevation and farthest from the main surface outlet. The ditches in this section, as well as the other sections, have degraded since. Well 16A, located in the southern part between the middle and the southeast section, has a much lower water table than the other wells. It is located in a young stand of longleaf pine trees near the perimeter ditch.
Figure 23: Water table depth in wells in the northwest section of Juniper Bay
Figure 24: Water table depth in selected wells in the middle section of Juniper Bay
Figure 25: Water table depth in wells in the southeast section of Juniper Bay
Rainfall, Available Storage, and Water Table Patterns in the Reference Bays

Rainfall patterns in the reference bays are similar to those in Juniper Bay (Table 7). The water table data from the wells in the reference bays (Figure 26: Water table depth in wells in Causeway Bay –Figure 28: Water table depth in wells in Tatum Millpond Bay) indicate that all three reference bays are wetter (have the water table closer to the surface) than Juniper Bay. Vegetation in the reference bays is much denser than in Juniper Bay, consisting of trees and shrubs whereas the vegetation in Juniper Bay consists mainly of early successional grasses and forbs. The water table, however, is closer to the surface in the reference bays than in Juniper Bay, with most wells meeting all wetland hydrology requirements (Table 11).

With the limited amount of water table data from the reference bays only preliminary comparisons can be made between the water table regimes in the reference bays and in Juniper Bay. In comparing a transect of water table data from Juniper Bay that starts at the rim in mineral soil and ends in the center in organic soil to the transect in Causeway bay, which also grades from mineral soil at the rim to organic soil in the middle, the data show how the water table in Causeway Bay is shallower at all times during the 2002 growing season, except for Well 2 (CB 2) during a brief period of time in the fall of 2002 (Figure 29). The water table in Causeway Bay does not fluctuate as dramatically as the water table in Juniper Bay. This is probably because there are no ditches in Causeway Bay and the roughly estimated available storage is between 0.25 and 0.34. This is much higher than the estimated available storage in Juniper Bay (Table 8). Since soils with more organic
matter tend to have greater drainable porosities due to the larger pore space, it makes sense that the reference bays would have greater available storage. The root mat and fibric organic layers at the soil surface in the reference bays that have very high available storage are not present in Juniper Bay. Table 14 lists the estimated available storage for the reference bays, calculated from a rain event totaling approximately 6 cm on June 14, 2002. With the limited and sporadic amount of data from the reference bays, calculating available storage from a rain event in the winter was not an option. Even so, the smallest available storage from the reference bays in the summer was greater than the greatest available storage from Juniper Bay in the winter. This attests to the fact that the reference bays have much more organic matter than Juniper Bay, even in the mineral soils, and that the absence of ditches and the fact that the reference bays have been left in their natural state for some time shows how much of an impact farming practices can have on an ecosystem, as indicated in the water table and soils data. The depth of the water table at the beginning of the rain event was shallower on average in the organic soils than in the mineral soils, as shown in Table 14. The water table started between 25 and 50 cm in all the wells in organic soil, whereas in Juniper Bay the water table started anywhere between 0 and 100 cm below the soil surface (Table 8).
Table 14: Available storage for the wells in the reference bays

<table>
<thead>
<tr>
<th>Well</th>
<th>Soil Type</th>
<th>Available storage (cm/cm)</th>
<th>Depth range of water table at start of rain event (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB 1</td>
<td>Mineral</td>
<td>-*</td>
<td>-*</td>
</tr>
<tr>
<td>CB 2</td>
<td>Mineral with histic epipedon</td>
<td>0.25</td>
<td>25-50</td>
</tr>
<tr>
<td>CB 3</td>
<td>Shallow Organic</td>
<td>0.34</td>
<td>25-50</td>
</tr>
<tr>
<td>CL 1</td>
<td>Mineral</td>
<td>0.2</td>
<td>75-100</td>
</tr>
<tr>
<td>CL 2</td>
<td>Mineral with histic epipedon</td>
<td>0.22</td>
<td>25-50</td>
</tr>
<tr>
<td>CL 3</td>
<td>Shallow Organic</td>
<td>-*</td>
<td>-*</td>
</tr>
<tr>
<td>CL 4</td>
<td>Deep Organic</td>
<td>-*</td>
<td>-*</td>
</tr>
<tr>
<td>TM 1</td>
<td>Mineral</td>
<td>0.32</td>
<td>0-25</td>
</tr>
<tr>
<td>TM 1A</td>
<td>Mineral</td>
<td>0.13</td>
<td>50-75</td>
</tr>
<tr>
<td>TM 2</td>
<td>Mineral with histic epipedon</td>
<td>0.16</td>
<td>25-50</td>
</tr>
<tr>
<td>TM 3</td>
<td>Shallow Organic</td>
<td>0.24</td>
<td>25-50</td>
</tr>
<tr>
<td>TM 4</td>
<td>Deep Organic</td>
<td>0.58</td>
<td>25-50</td>
</tr>
</tbody>
</table>

*- indicates that no water table data was available for the calculation

![Graph showing depth from ground surface (cm) over time (Date, 2002)](image-url)
Figure 26: Water table depth in wells in Causeway Bay
Figure 27: Water table depth in wells in Charlie Long Millpond Bay
Figure 28: Water table depth in wells in Tatum Millpond Bay
Within each reference bay, the wells in the organic soils had water tables closer to the surface, followed by wells in the mineral soil with a histic epipedon, and the wells in the mineral soil without a histic epipedon had water tables that were the deepest (as shown in Figure 29 where well CB 1 has the deepest water table of the three wells in Causeway Bay). The water tables in the mineral soils in the reference bays were generally shallower than those in Juniper Bay, with only occasional spiking of the water table in Juniper Bay above that in the reference bays. This is probably due to the smaller drainable porosities in Juniper Bay, meaning there is less pore space to be filled after a rain event. This causes the water table in Juniper Bay to exhibit spikes.
Soil Type and Stratigraphy Effects on the Water Table in Juniper Bay

The soil stratigraphy influences the fluctuations of the water table, affecting both degree and rate of rise and fall. To what degree, however, is unknown. Soil texture also influences the flow of water. The flow rate is affected by the geometric properties of the pore channels through which water moves (Hillel, 1998). A saturated sandy soil conducts water more rapidly than a clayey soil, and a well-aggregated soil conducts more than a poorly aggregated soil. However, the opposite is often the case in unsaturated conditions (Hillel, 1998). The available storage in Juniper Bay varies across soil type and location within the bay, indicating that there are other factors, such as the ditches, that influence the behavior of the water table. There is a wide variety of soil profiles at Juniper Bay, which adds to the complexity of its hydrology. Table 15: Percentage of the soil at Juniper Bay that is mineral, mineral with a histic epipedon, and organic outlines the percentages of the different soil types present in Juniper Bay.

Table 15: Percentage of the soil at Juniper Bay that is mineral, mineral with a histic epipedon, and organic

<table>
<thead>
<tr>
<th>Juniper Bay Percentage of Bay</th>
<th>Soil Series</th>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>Leon</td>
<td>Mineral</td>
</tr>
<tr>
<td>15%</td>
<td>Leon</td>
<td>Mineral with histic epipedon</td>
</tr>
<tr>
<td>10%</td>
<td>Pantego</td>
<td>Mineral</td>
</tr>
<tr>
<td>20%</td>
<td>Rutlege</td>
<td>Mineral</td>
</tr>
<tr>
<td>70%</td>
<td></td>
<td>Total Mineral soil</td>
</tr>
<tr>
<td>30%</td>
<td>Ponzer Muck</td>
<td>Organic</td>
</tr>
</tbody>
</table>

The soil profiles where the wells are located that met the Corps 12.5% wetland hydrology criterion show the soils having varying profiles, though most have
mostly sandy material. The location of well 8 has a muck layer about 45 cm thick at
the surface and is an organic soil. Under the muck is clay. Where well 12 is
located, the profile is mostly sand for 1.22 m with a muck layer about 15 cm thick
starting at about 20 cm from the soil surface. The location of well 16 has a muck
layer about 15 cm thick at the soil surface and a sandy layer below that for about 1.5
m. The locations of wells 12 and 16 exhibit mineral soils with muck layers near the
surface. All three wells are located in the southeast section of the bay where
elevations are slightly lower compared with the other sections of the bay (Figure 22:
Juniper Bay sections and average ground surface elevations (in meters above sea
level)). This, however, does not likely have much of an influence on the water table.
Other areas of the bay with similar soil profiles do not meet wetland hydrology
requirements. Therefore, the variation in wetness across the bay seems to be
affected less by soil character than by other factors such as the effectiveness of the
ditch network.

**Comparing Juniper Bay Soils to Reference Bay Soils**

The reference bays have a higher percentage of organic soil than Juniper Bay
(Table 16: Percentage of Charlie Long Millpond Bay in the three soil types - Table
18: Percentage of Tatum Millpond Bay in the three soil types).

**Table 16: Percentage of Charlie Long Millpond Bay in the three soil types**

<table>
<thead>
<tr>
<th>Percentage of Bay</th>
<th>Soil Series</th>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>Lynn Haven/Leon</td>
<td>Mineral</td>
</tr>
<tr>
<td>20%</td>
<td>Lynn Haven/Leon</td>
<td>Mineral with histic epipedon</td>
</tr>
<tr>
<td>50%</td>
<td></td>
<td>Total Mineral soil</td>
</tr>
</tbody>
</table>
Table 17: Percentage of Causeway Bay in the three soil types

<table>
<thead>
<tr>
<th>Percentage of Bay</th>
<th>Soil Series</th>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>7%</td>
<td>Lynn Haven/Leon/Kureb Mineral</td>
<td></td>
</tr>
<tr>
<td>3%</td>
<td>Lynn Haven/Leon/Kureb Mineral with histic epipedon</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>Total Mineral soil</td>
<td></td>
</tr>
<tr>
<td>90%</td>
<td>Pamlico Muck Organic</td>
<td></td>
</tr>
</tbody>
</table>

Table 18: Percentage of Tatum Millpond Bay in the three soil types

<table>
<thead>
<tr>
<th>Percentage of Bay</th>
<th>Soil Series</th>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>Lynn Haven/Torhunta Mineral</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>Lynn Haven/Torhunta Mineral with histic epipedon</td>
<td></td>
</tr>
<tr>
<td>30%</td>
<td>Total Mineral soil</td>
<td></td>
</tr>
<tr>
<td>70%</td>
<td>Pamlico Muck/Croatan Muck Organic</td>
<td></td>
</tr>
</tbody>
</table>

This may be reflecting the fact that the organic soil in Juniper Bay has experienced subsidence and oxidation since the ditch system was installed and the bay used for agriculture, resulting in a reduction in the thickness of the organic layer. This subsidence is likely the result of several factors:

1) Drainage and loss of water in the organic layer when the water table declines lower than previously. The soil loses the buoyant force when drained and the organic material compacts under its own weight.
2) Irreversible drying in the surface zone that results in aggregation of the organic muck.

3) Increased oxidation of the organic material may also occur. The classification of organic soils calls for a certain thickness of the organic layer to be present at the surface. When that layer shrinks in thickness it may not meet the classification requirements anymore.

Comparing Juniper Bay to other Carolina Bays

Thunder Bay, located in the Coastal Plain of South Carolina, is not a hydrologically perched system, instead water ponded in the bay is a surface expression of the ground water zone (Lide et al., 1995). The clayey hardpan beneath the bay remains saturated throughout when ponded water is present on the surface, indicating saturated conditions from the pond downward. When the water table declines, the bay dries completely. Juniper Bay, in the current drained condition, is never ponded, except for temporary ponding in a very few spots.

Pond stage in Thunder Bay was very responsive to prevailing weather, increasing with each rain storm and gradually declining during rain-free periods. This indicates that precipitation is a major input of water to the Carolina Bay system, with ET the major output of water. In Juniper Bay, the ditches are another major avenue for water to leave the system.

Juniper Bay is very large compared to Thunder Bay and Chapel Bay and the water table has more factors influencing it than the other two bays. The watershed for potential subsurface input is much larger relative to the size of the bay for Thunder and Chapel Bays than it is for Juniper Bay. Permanent alterations in the
regional landscape due to intensive agricultural use around Juniper Bay may affect the potential to restore the hydrology of Juniper Bay to its historic character.

**Ground Water Movement**

**Hydraulic Gradients**

Hydraulic gradient is defined as the change in total head with a change in distance in a given direction. A gradient can be determined for any direction. If the medium is isotropic, the direction of flow will be in the direction of the maximum gradient. In the field the hydraulic head is measured, which is the depth to water in a piezometer (Fetter, 2001). The elevation of the measuring point has to be known, and then the depth to the water is subtracted from the measuring point elevation to get the total head of water in the piezometer (Fetter, 2001). The direction of ground water flow is that which yields a maximum rate of decrease in head; in other words, ground water moves from regions of higher head to regions of lower head (Fetter, 2001). The local ground water flow patterns within Juniper Bay are complicated.

**Ground Water Movement in zone 1**

Zone 1 ground water is considered an unconfined aquifer in which the water level is free to fluctuate with no confining layer above it. The water table is defined as the surface at which the pressure of ground water equals atmospheric pressure (Hillel, 1998). In this study, the depth of the water table from the soil surface determined if certain wetland hydrology criteria were satisfied, and was just discussed in the previous section.
Ground water movement in zone 2

The piezometers located in zone 2 include piezometer 1S, 2S, 2D, 3, 6, 10S, 10D, 11, 12, and 20S (Figure 30). All total head calculations used the highest ground surface elevation (in meters above sea level) as the reference point (Figure 18). This occurred where piezometer 25 shallow and deep are located with a ground surface elevation of 37.5 meters.

![Zone 2 Lateral groundwater flow paths, 10/12/2001](image)

Figure 30: Total head in zone 2 piezometers in October 2001

Errors in Piezometer Data

The data from the pressure transducers and the manual measurements is sometimes in conflict, possibly due to the error involved in pulling up the
dataloggers, as described in the Methods section. The total head calculations shown in Figure 30 were done with the manual measurements. Appendix D has graphs for each piezometer comparing the manual measurements to the data from the dataloggers. Even though there are some discrepancies between the two data sets, the trends shown in the data are the same, regardless of whether the manual measurements or the data from the dataloggers were used. Where the discrepancies between the two data sets were large enough to conclude different results, the manual measurements were used to draw conclusions or hypotheses.

**Possible Ditch Effects**

Ground water in zone 2 appears to have a gradient to flow in different directions depending on where in the bay it occurs. The hypothesis is that the large collector ditches and possibly the perimeter ditch in one part of the bay are deep enough to intersect zone 2 and influence the movement of ground water (Figure 31). The main collector ditch is deep and may influence water as much as 30 to 60 meters (100 to 200 feet) on either side (Huffman, personal communication, 2004). Ground water in the middle section has a gradient towards piezometer 11, where two collector ditches meet nearby. The main collector ditch in this area of the bay, running northeast to southwest between piezometers 11 and 12, is likely deep enough to influence zone 2 ground water gradients. The perimeter ditch in the southwest part of the bay (near piezometer 25 shallow and deep) averages 2.24 meters (7.35 feet) deep and may also influence the movement of ground water by increasing the gradient towards it. The perimeter ditch in other parts of the bay is not deep enough (averaging 1.2 to 1.65 m or 3.9 to 5.4 feet) to cut into zone 2.
If ground water from zone 2 discharges into the main collector ditch from the northwest section, the ditch then serves to increase the hydraulic gradient into the bay compared to pre-drained conditions and to decrease the hydraulic gradient across the bay that influences subsurface drainage out of the bay. If ground water discharges into the ditch, this may raise the hydraulic head in the ditch, decreasing the gradient for zone 1 water draining to the ditch. Zone 1 is influenced hydrologically by rainfall within the bay while zone 2 may be influenced by direct rainfall on the site and rain falling outside the bay for some distance from the bay, making its way to zone 2 outside the bay, and possibly entering the bay in the northwest and southeast sections laterally from outside.

Once these ditches are plugged the water level in them will rise and the gradients towards them will disappear. This could be beneficial or detrimental to the restoration. It will stop any leakage that was taking place when zone 2 ground water was exiting the bay through the ditches, but it could also end up causing a reverse gradient so that ground water actually has a gradient out of the bay. This would be due to the higher head in the ditches causing the gradients to exist for ground water to flow away from them.
Figure 31: Possible Ditch Gradients in Zone 2. Green arrows indicate the direction in which it is hypothesized that ground water may move due to the depth of the ditch.

Continued Zone 2 Ground Water Movement

Ground water in the northern part of the bay (by piezometer 3) has a gradient both into and out of the bay to the north (-31). This may represent a mound in the ground water. The area to the north of Juniper Bay is lower in elevation than Juniper Bay, and ground water may be moving in that direction. The area to the south of the bay is also lower in elevation and ground water may also have a gradient to flow south, exiting the bay.
Ground water may be entering the bay near piezometer 1S and moving towards piezometers 2S and 2D and ultimately the main collector ditch (Figure 32). There is no piezometer in zone 2 outside the bay to the northwest to confirm the speculation that ground water has a gradient into the bay in this area. The gradient for ground water to move from piezometer 1S towards piezometer 2S and 2D led to the hypothesis that ground water may be entering the bay from the northwest and move towards piezometer 1S. The same reasoning is being used to say that ground water may be entering the bay from the southeast end and moving towards piezometer 12. Outside the bay to the northwest and southeast the elevation is higher, which is another reason that ground water is hypothesized to be entering the bay from those areas. This hypothesis, that ground water may be entering Juniper Bay from areas of higher elevation and exiting in areas of lower elevation, is used by Kreiser (2003) to account for one possible source of ground water into Juniper Bay. A water balance performed for Juniper Bay indicated more ground water was accounted for, as much as 36% of the total annual water input to the bay (Kreiser, 2003).

Zone 2 is where the majority of ground water gradients were calculated. The stratigraphy is so varied in the bay and there are likely breaks in the clay layers. This, along with other factors, makes the direction of ground water movement difficult to predict.
Figure 32: Zone 2 ground water gradients in January 2002

One way to try to determine what is influencing the ground water movement is to look at the data from the nests of wells and piezometers. If the fluctuations from the well and from a piezometer at the same location are very similar, then they are likely responding to the same hydrologic influences, such as rainfall or the presence of a deep ditch. In nest 1, the water level in the well and the shallow piezometer fluctuate very similarly, indicating they are likely responding to the same influences. The deep piezometer in nest 1, however, does not fluctuate.
nearly as greatly, and is probably not hydrologically influenced in the same way as the other two instruments in the nest. In nest 2, however, the well and both piezometers are influenced by the same things, as indicated by their similar fluctuations. Nests 1 and 2 are located in the northwest section of the bay, with nest 2 closer to the main collector ditch. This deep ditch may be the main influence on zone 1 and zone 2 ground water in nest 2.

In several nests, it appears that the water table and the ground water measured in the piezometer are not influenced by the same factors when precipitation is within the normal range (Appendix C). This changes, however, when the precipitation levels fall below the normal range, which happened in the summer of 2002. In nests 3, 6, 10, 11, 12, and possibly 17, the water level in the piezometer (the deep piezometer in nest 10) drops at approximately the same rate as the water level in the well, where before the summer of 2002 the two water levels were not responding with the same rate. This may be due to the level of water in the deeper collector ditches dropping low enough that there becomes a gradient within zone 2 towards these ditches, whereas when there was a normal range of rainfall, the water level remained high enough that they did not influence zone 1 water movement.

**Ground Water Movement within Nests**

There are five nests in Juniper Bay where there are two piezometers at different depths. These are nests 1, 2, 10, 20, and 25 (see Figure 14 and Appendix C). In these locations, the vertical direction of ground water movement can be estimated. Ground water will have a gradient from the area of higher hydraulic head
towards the area of lower hydraulic head. Where piezometer data show upward movement of water, ground water discharge is likely happening. Upward movement occurs in the northwest section of the bay, at nest 1 and nest 2, where ground water may be entering the bay laterally from outside the bay and/or where there are breaks in the clay layer that allow ground water discharge to occur. At nest 1 there is an upward gradient from the shallow piezometer (zone 2) to the water table well (zone 1) from late winter through at least the middle of the summer of 2002, and at nest 2 there is an upward gradient from the deep piezometer (zone 2) to the depth where the shallow piezometer and the well are located. Ground water may have a gradient inside the bay from the northwest in zone 2 and then upward into zone 1, ultimately leaving the bay as ET or as surface outflow through the ditch system. The thickness of the clay layer at nest 1 and 2 is approximately 0.305 m (1 foot) and they occur at different depths at the two nests. During a two-week period of no rainfall in August 2002, well 1 and 17, both in areas where ground water is hypothesized to be entering the bay, show a drawdown in the water table during the day due to ET and then a rise in the water table at night (Kreiser, 2003). This rise is thought to be due to ground water input from outside the bay (Kreiser, 2003).

Nest 10 has two piezometers, the shallow one is 2.44 m deep and the deep one is 5.1 m deep. There is also a water table monitoring well that is 2.44 m deep. Data indicate that in the early winter and in the mid-spring of 2002, there was a gradient from the deeper piezometer to the shallow piezometer. These time periods correspond to periods of below the normal range of rainfall (Table 7). Data from the well and the deep piezometer indicate an upward gradient during the early spring as
well. The water level in the well during that time declined while the water level in the deep piezometer continued to rise. It is possible that the water level in the deep collector ditch nearby had dropped low enough to increase the gradient towards it in zone 2 where the piezometer 10 deep is located. There may also be breaks in the clay layer that allow for upward gradients to become established (Kreiser, 2003). These breaks, if they occur, tend to be in areas where gradients are smaller, meaning that the zones the clay layer is dividing are hydraulically connected. A thick clay layer, or aquitard, usually allows significant gradients to exist without appreciable flow.

Data from the piezometers at nest 20 and 25 show that at both locations there is a gradient downward. The hydraulic head is consistently lower in the deeper piezometers than the shallow piezometers.

The hydraulic head in some piezometers, as shown in the pressure transducer data, fluctuates with the seasons, so that ground water movement may be changing direction (Figure 33: Ground water levels showing seasonal variation). Piezometers 20-S and 20-D are located outside the bay to the north of the rim (north of Piezometer 22), in what may be another Carolina Bay, and had very low hydraulic heads starting in the late spring and lasting through the fall of 2002. This area is lower in elevation than Juniper Bay and has dense vegetation (trees and shrubs). Thus, during the growing season the hydraulic head to the north of the bay is relatively low compared to that in Juniper Bay and the gradient towards the north
may be greater, while during the winter months the hydraulic head is higher and the
gradient towards the north may be less pronounced.
Figure 33: Ground water levels showing seasonal variation
Ground Water Movement in Zone 3

Ground water heads in zone 3 are shown in Figures 34 and 35. Manual measurements for all piezometers in zone 3 are shown in Figure 35. The gradient for movement is consistently the opposite across the northwest boundary and sometimes opposite across the southeast boundary of the bay from the direction hypothesized from zone 2 ground water data. There were not many readings taken at piezometer 17B, so the information is more limited from that side of the bay. It is also opposite over the northern border of the bay, where zone 3 data indicated a gradient entering the bay while zone 2 data indicated a gradient exiting the bay. With the limited amount of data and the lack of knowledge of connectivity in this zone, only preliminary findings at best can be stated.

Ground water in zone 3 may have several influences. West of Juniper Bay is Hog Swamp, where surface elevations are approximately 30 meters above sea level. Ground water in zone 3 in the northwest section of the bay may have a gradient towards Hog Swamp. East of Juniper Bay is Shelley Bay, and there may be a zone 3 ground water gradient towards it. There may also be a gradient upward into Juniper Bay. Data from piezometer and well nests indicate upward gradients, especially during periods of below normal rainfall (see Appendix C for individual nest graphs). This is seen in nest 6, 10, and 11, all located in the middle section of the bay where there are organic soils. This is also seen in nests 1 and 2. However, the limited number of piezometers in zone 3 and the uncertainty of exactly where this zone begins prohibits the determination of the direction of ground water movement in this zone.
Figure 34: Zone 3 groundwater heads for November 2001
Figure 35: Zone 3 groundwater heads for February 2002
Ground Water Movement between Zone 2 and Zone 3

Ground water levels are higher inside the bay than outside the bay along the north-south transect (Figure 37: Manual measurements along the north-south transect). This feature of having higher ground water levels inside the bay was also found in other Carolina Bay studies. This is due to the thick clay layer that exists below the surface of these bays. The clay layer below Juniper Bay exists between 6 and 10 meters deep. Ground water that may enter the bay (zone 2) through breaks in the clay layer from zone 3 may be exiting the bay to the north and south and through the ditch system as surface outflow.

Along the east-west transect, there are not as many piezometers outside the
bay as there are outside the bay along the north-south transect. There is one to the west and one to the east of the bay. There are also no soil cores from these two locations. This makes the determination of which zone the piezometers are in impossible.

<table>
<thead>
<tr>
<th>Date</th>
<th>Piez 3</th>
<th>Piez 6</th>
<th>Piez 10S</th>
<th>Piez 10D</th>
<th>Piez 20S</th>
<th>Piez 20D</th>
<th>Piez 22</th>
<th>Piez 25S</th>
<th>Piez 25D</th>
</tr>
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<td>📊</td>
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<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
</tr>
<tr>
<td>12/25/2001</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
</tr>
<tr>
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<td>📊</td>
<td>📊</td>
<td>📊</td>
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<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
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<tr>
<td>4/4/2002</td>
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<td>📊</td>
<td>📊</td>
<td>📊</td>
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<td>📊</td>
<td>📊</td>
<td>📊</td>
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</tr>
<tr>
<td>5/24/2002</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
<td>📊</td>
</tr>
</tbody>
</table>

**Figure 37:** Manual measurements along the north-south transect
Figure 38: Manual measurements along the east-west transect
Table 19: Gradients of ground water in nests of wells and piezometers

Vertical water gradients. When three instruments are present the top line of dates is between the well and the shallow piezometer and the bottom line is between the shallow and deep piezometers. When only two instruments are present the dates are between those 2 instruments.

<table>
<thead>
<tr>
<th>Instrument: Well/ Piezometer</th>
<th>Depth of instrument, (m), zone</th>
<th>Days gradient is up</th>
<th>Days gradient is down</th>
<th>Days gradient is neither up nor down</th>
</tr>
</thead>
<tbody>
<tr>
<td>W 1 P 1 Shallow P 1 Deep</td>
<td>2.44, 1 4.51, 2 10.36, 3</td>
<td>2/14/02-7/9/02</td>
<td>1/5/02-2/14/02</td>
<td>12/20/01-1/5/02</td>
</tr>
<tr>
<td>W 2 P 2 Shallow P 2 Deep</td>
<td>2.44, 1 2.46, 2 4.42, 2</td>
<td>3/16/02-4/10/02</td>
<td>12/20/01-3/16/02</td>
<td>4/10/02-7/14/02</td>
</tr>
<tr>
<td>W 3 P 3</td>
<td>2.44, 1 4.42, 2</td>
<td></td>
<td>12/20/02-7/14/02</td>
<td></td>
</tr>
<tr>
<td>W 6 P 6</td>
<td>2.44, 1 5.95, 2</td>
<td>6/4/02-7/24/02</td>
<td>8/27/01-6/4/02</td>
<td></td>
</tr>
<tr>
<td>W 10 P 10 Shallow P 10 Deep</td>
<td>2.44, 1 2.46, 2 5.12, 2</td>
<td>2/4/02-5/5/02</td>
<td>12/20/01-2/4/02</td>
<td>1/5/02-1/15/02, 1/20/02-6/4/02</td>
</tr>
<tr>
<td>W 11 P 11</td>
<td>2.44, 1 4.51, 2</td>
<td>7/19/01-8/5/01</td>
<td>8/5/01-5/15/02</td>
<td>5/15/02-7/14/02</td>
</tr>
<tr>
<td>W 12 P 12</td>
<td>2.44, 1 4.88, 2</td>
<td></td>
<td>12/20/01-7/14/02</td>
<td></td>
</tr>
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<td>W 17 P 17</td>
<td>2.44, 1 9.14, 3</td>
<td></td>
<td>12/20/01-7/14/02</td>
<td></td>
</tr>
<tr>
<td>P 20 Shallow P 20 Deep</td>
<td>4.27, 2 7.32, 3</td>
<td></td>
<td>12/20/01-7/14/02</td>
<td></td>
</tr>
<tr>
<td>P 25 Shallow P 25 Deep</td>
<td>8.23, 3 10.21, 3</td>
<td></td>
<td>12/20/01-7/14/02</td>
<td></td>
</tr>
</tbody>
</table>
Hydraulic Conductivity

As hypothesized before, ground water may be entering the bay in zone 2 from the northwest and the southeast sides of the bay, and possibly from underneath the bay through breaks in the clay layers. During the summer months of 2002, pressure transducer data suggests that ground water had a gradient out of the bay towards the north and possibly the south. Manual measurements of the water level in the piezometers on the north-south transect show that the water level was consistently lower outside the bay than inside the bay. The differences are great enough between the manual measurements and the data from the dataloggers that the definite direction of ground water movement cannot be stated. During the summer months of 2002, both data sets indicate a gradient out of the bay to the north. Within the bay, both data sets agree that ground water has a gradient towards the middle of the bay where piezometer 11 is located.

Slug tests were performed in most piezometers to determine saturated hydraulic conductivity in order to calculate ground water flow. Table 20: Saturated hydraulic conductivity values obtained through slug tests shows the saturated hydraulic conductivity measurements obtained from analysis of the slug test data in zone 2.

The slug tests show that the soil near piezometer 6 has the highest hydraulic conductivity, meaning ground water moves more easily at this location. The soil at this location is sandy and water can move faster through the larger pores of the sand than through soils with more clay and silt.
Table 20: Saturated hydraulic conductivity values obtained through slug tests

<table>
<thead>
<tr>
<th>Piezometer</th>
<th>Zone</th>
<th>Saturated hydraulic conductivity (cm/hr)</th>
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</thead>
<tbody>
<tr>
<td>1-S</td>
<td>2</td>
<td>0.1901</td>
</tr>
<tr>
<td>2-S</td>
<td>2</td>
<td>0.0367</td>
</tr>
<tr>
<td>2-D</td>
<td>2</td>
<td>0.1997</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>0.0582</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>0.3884</td>
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<tr>
<td>10-S</td>
<td>2</td>
<td>0.0185</td>
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<tr>
<td>10-D</td>
<td>2</td>
<td>0.2013</td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>0.0265</td>
</tr>
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<td>17</td>
<td>2</td>
<td>0.0758</td>
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<td>20-S</td>
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<td>20-D</td>
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<td>22</td>
<td>3</td>
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<tr>
<td>25-D</td>
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</table>

Comparing the Ground Water Hydrology of Juniper Bay and other Carolina Bays

Ground water behavior within Carolina Bays is not well understood due to limited research on bay hydrology. Precipitation and possibly ground water inflow are the main hydrologic inputs of water to these bays, but the debate remains. Several studies have suggested significant ground-water interactions in some bays (Lide et al., 1995). It was suggested that bay waters were strongly influenced by “surficial ground water” in 49 bays in North and South Carolina (Lide et al., 1995). More research is needed to clarify the relationship between surface and ground water in Carolina Bays, and it may be shown that each bay is different and no common interaction exists for all bays.
In Carolina Bays, reversal of the direction of ground water flow appears common, with net ground water outflow from the bay being the dominant direction (Lide et al., 1995). In Thunder Bay, South Carolina, downward hydraulic gradients were observed along the west, east, and south sides of the bay, indicating Thunder Bay occurs in an area where ground water outflow is the dominant direction of flow (Lide et al., 1995). In Juniper Bay, it cannot be stated if ground water reversal exists, but net ground water inflow seems to be the dominant direction. This could be due to the ditches, the surrounding land use, and the intermediate position of Juniper Bay in the local landscape.

Schalles and Shure (1989) postulated that a sediment layer of “gray clay-silt” 20 to 30 cm below Thunder Bay was an effective aquiclude to the vertical movement of ground water. Both near-surface (occurring between 3 and 6 m deep) and shallow ground water (occurring between 7 and 9 m deep) lie below an argillic horizon which serves as an aquitard or aquiclude in Chapel Bay (Trettin et al., 1999).

The surface water piezometric heads were consistently high during wet periods and had large fluctuations during dry periods in Chapel Bay (Trettin et al., 1999). An upward hydraulic gradient was also observed at the rim of the bay during wet periods (Trettin et al., 1999). During the dry summer of 2002 at Juniper Bay the water levels in the wells and piezometers dropped significantly, with the head in some of the wells dropping lower than the head in the piezometer(s) nested with them.

**Hydrologic Restoration**

The goal of the Juniper Bay mitigation project is to re-establish a stable
wetland system that will restore natural processes, structure, and species composition to mitigate for wetland functions and values that will be impacted by highway construction activities in the Lumber River Basin (N.C.D.O.T., 2001). The objective is to recreate, to the greatest extent possible, the conditions which existed on site prior to human disturbance. The mitigation plan will focus on the elimination of the drainage ditch network, soil surface resculpting to promote microtopography, and revegetation of the site with wetland forest vegetation (N.C.D.O.T., 2001). The hydrologic restoration will focus on plugging the ditches, lateral ones first so the site does not get too wet and inhibit growth of planted tree seedlings, and the deep collector ditches last once plants have grown sufficiently. The plan calls for the interior ditches to be plugged at bends, junctions, and other intervals with a plug that is a clay-based, low permeability material. Backfilling of ditches may occur where sufficient soil material is available (N.C.D.O.T., 2001). The above restoration strategy proposed by the N.C.D.O.T. will work to restore wetland hydrology to some of the site. The drainage ditch network must be eliminated in order for the water table to become shallow enough in most of the bay to meet wetland hydrology criterion. Plugging the shallow lateral ditches may be sufficient to restore the zone 1 unconfined aquifer hydrology. Most ditches do not cut deep enough through any clay layers into deeper sand layers beneath that might cause water to leak downward. Some of the deeper, collector ditches, however, do cut into the sand layers beneath the first clay layer. It is hypothesized that these ditches cause a gradient of ground water movement towards them. If these ditches are only plugged at certain locations there may still be some gradients towards them, preventing
some areas of the bay from meeting wetland hydrology requirements. Once the ditches are plugged and the water level in the ditches becomes shallower, there could develop a reverse gradient due to the increased head in the ditches. This is reversed from what has been happening prior to the restoration. The ground water will have to continue to be monitored once the ditches are plugged to see what the effect is on the gradients in zone 2.

If the NCDOT bought another drained Carolina Bay to restore, lessons should be taken from this study. For NCDOT purposes, they need to know across which boundaries water is entering and exiting the system, in this case, the Carolina Bay. Piezometers would be needed at more locations across the boundary than simply along two transects. These bays are too complex, as shown from this research, to only have two transects of ground water data to gather enough information to ensure restoration success. Piezometers would also be needed in the ditches to fully understand any gradients that those ditches may exert on surface and/or ground water. With this additional information the NCDOT would have more information on the surface and subsurface hydrology and could develop a restoration plan that had a greater chance for success.

Reference bay data is useful in the restoration process because they give real information on what the hydrology of a natural Carolina Bay is like. The water table in the reference bays is closer to the surface and for longer periods of time than most wells in Juniper Bay, and the length of time that the wells meet wetland hydrology requirements is longer than the 12.5% of the growing season criteria set by the Corps for wetland restoration. If the goal of the restoration project is to
restore the hydrology of Juniper Bay to what it was prior to disturbance, and the reference bays are the only ecosystem to go by, then the Corps criteria are not sufficient to do that.

**Conclusions**

There are many factors that influence the hydrology of Juniper Bay. Rainfall patterns, soil type and stratigraphy, elevation and location within the bay, and the ditch network all influence the water table and ground water movement. Well and piezometer data suggest that near surface ground water, and even deeper ground water to a degree, is influenced by seasonal rainfall patterns. Rainfall is the main hydrologic input affecting the water table in zone 1. In 2001, three wells met the wetland hydrology criterion. At least half of the year had rainfall within the normal range, (with data missing from January and February, six months still were within range), even though the year on a whole was probably below or at the bottom of the normal range of rainfall. During the dry summer of 2002 the water levels in the wells and piezometers declined substantially. Rainfall was below the normal range for all but one month from May to September of 2002. At the beginning and end of the 2002 growing season the water table remained shallow enough in five wells to meet the wetland hydrology criterion, even though the majority of 2002 had below the normal range of rainfall. Two more wells met the criterion in 2002 than in 2001 even though the year had less rainfall. This is likely due to the continued degradation of the ditch network. The main collector ditch in particular may influence the water table 30 to 60 meters on either side. The shallower lateral ditches also are likely to influence the water table. The water table in all reference bays was closer to the
surface for longer during both dry and wet periods. This suggests a ground water influence on the water table in the reference bays.

The effect of soil type on the water table regime in Juniper Bay is not clear. Some of the wells that met the wetland hydrology criterion are located in mineral soil and some are located in organic soil. Location within the bay does seem to affect the water table regime. Wells in the southeast section of the bay had the shallowest water table levels. This area is lower in elevation and farthest away from the main outlet, but the effectiveness of the ditch network is likely the most influential factor on the water table. The northeast part of that section was wet before the ditches were installed there and is still presently wet, with water often ponded on the surface. Wells in the middle section had water table levels that were somewhat deeper than those found in the southeast section, but shallower than those found in the northwest section. The water table in the middle and northwest sections may be influenced more by the main collector ditch.

Ground water occurs in different zones in Juniper Bay. Zone 1 is unconfined and the water table is its surface expression. Zone 2 ground water occurs below an initial clay layer that separates it from zone 1. Ground water may enter zone 2 laterally from the west and east sides, which are higher in elevation, and exit the bay to the north and south, which are lower in elevation. Ground water may also be moving into the bay from below. The deep collector ditches cut deep enough into zone 2 and are suspected to be influencing the ground water gradients, as seen by the lower total head in piezometer 11. They could also be transporting ground water
out of the bay through surface outflow. Zone 3 ground water is more difficult to predict due to the limited number of piezometers and soil cores in this zone.

The goal of the restoration of Juniper Bay is to re-establish a stable wetland system that will restore natural processes, structure, and species composition (N.C.D.O.T., 2001). The natural hydrology is being monitored in three reference Carolina Bays. Most of the water table wells in those bays show the water table closer to the surface and for longer periods of time than the water table in Juniper Bay. The 12.5% of the growing season criteria set by the Corps, in this case, is not long enough to restore Juniper Bay hydrology to its pre-disturbance regime.
References


Vepraskas, M.J., Gregory, J.D., Broome, S.W., Zanner, C.W. 2000. Methodology to assess soil, hydrologic, and site parameters that affect wetland restoration success. North Carolina State University, Raleigh, N.C.
WETS Station for Elizabethtown Lock 2, NC2732. 2002. 
ftp.wcc.nrcs.usda.gov/support/climate/wetlands/nc/37017.txt

WETS Station for Red Springs 1 SE, NC7165. 2002. 
ftp.wcc.nrcs.usda.gov/support/climate/wetlands/nc/37155.txt


Zanner, Bill, Farrell, Kathleen, Wysocki, Doug. 2001. Fitting Juniper Bay into the Landscape: Preliminary review based on what we have seen so far.
Appendix A: Official Soil Series Descriptions
CROATAN SERIES

The Croatan series consists of very poorly drained, organic soils that formed in highly decomposed organic material underlain by loamy textured marine and fluvial sediment. The organic material was derived from herbaceous plants. The soils are on the lower and middle Coastal Plain. Slopes are 0 to 2 percent.

TAXONOMIC CLASS: Loamy, siliceous, dysic, thermic Terric Haplosapri
ts

TYPICAL PEDON: Croatan muck--woodland.

(Colors are for moist soil unless otherwise stated.)

Oa1--0 to 9 inches; black (N 2/0) broken face and rubbed sapric material; about 8 percent fibers unrubbed and 2 percent rubbed; moderate fine granular structure; very friable; common fine and medium roots; common grains of clean sand; about 95 percent organic content; extremely acid; gradual wavy boundary.

Oa2--9 to 15 inches; black (N 2/0) broken face and rubbed sapric material; about 5 percent fibers unrubbed and 1 percent rubbed; weak medium granular structure; very friable; few fine and medium roots; few grains of clean sand; about 90 percent organic content; extremely acid; gradual wavy boundary.

Oa3--15 to 28 inches; black (10YR 2/1) broken face, (N 2/0) rubbed; sapric material; about 5 percent fibers unrubbed, less than 1 percent rubbed, massive; very friable; few fine roots; few grains of clean sand; about 75 percent organic content; extremely acid; diffuse wavy boundary. (Combined thickness of Oa horizon is 16 to 51 inches)
**Ag**—28 to 33 inches; black (5YR 2/1) mucky sandy loam; massive; very friable; few fine and medium roots; about 80 percent mineral content; extremely acid; gradual wavy boundary. (0 to 10 inches thick)

**Cg1**—33 to 38 inches; dark brown (7.5YR 3/2) sandy loam; massive; very friable; few nearly decomposed medium roots; extremely acid; gradual wavy boundary. (4 to 12 inches thick)

**Cg2**—38 to 60 inches; grayish brown (10YR 5/2) sandy clay loam; massive; slightly sticky, slightly plastic; few nearly decomposed medium roots; extremely acid; gradual smooth boundary. (10 to 30 inches thick)

**Cg3**—60 to 80 inches; mottled grayish brown (10YR 5/2) and dark gray (10YR 4/1) loamy sand; massive; very friable; extremely acid.

**TYPE LOCATION:** Jones County, North Carolina; 6.1 miles southeast of Maysville in Croatan National Forest; 3.9 miles east of intersection of NC 58 and SR 1105; 3.3 miles northeast of intersection of SR 1105 and Mirey Branch Road; 0.9 mile north of intersection of Stewart Road and USFS 606A; 50 feet east of the culvert over canal in woods.

**RANGE IN CHARACTERISTICS:** Thickness of the organic materials commonly is 16 to 35 inches but ranges to 51 inches. The organic materials are ultra acid to extremely acid. The underlying material horizons are extremely acid through slightly acid. Logs, stumps, and fragments of wood occupy 0 to 10 percent of the organic layers. Fiber content of the organic tiers is 3 to 30 percent unrubbed and less than 10 percent rubbed. Charcoal particles and pockets of ash occur in some pedons.
The Oa horizons have hue of 5YR to 10YR, value of 2 or 3, and chroma of 0 to 2. After several years of drainage and cultivations, a granular or blocky structure develops in all or part of the organic layers depending upon the nature and depth of the organic material as well as duration of drainage. Consistency, when moist, range from very friable to friable and, when wet, from slightly sticky to sticky (non-colloidal). In undrained areas the organic horizons in the root zone have weak to moderate granular or blocky structure while below the root zone the organic material is generally massive.

The 2Ag horizon has hue of 5YR to 5Y, value of 2 to 7, and chroma of 1 to 3. Textures are mucky sandy loam, mucky fine sandy loam, sandy loam, loam, and fine sandy loam.

The 2Cg horizons are similar in color to Ag but range to hues of 5GY to 5G, value of 4 to 7, and chroma of 1. Textures are variable and range from sand to clay.

**COMPETING SERIES:** There are no other known series in this family. Those in closely competing families are the Belhaven, Dare, Dorovan, Pamlico, Ponzer, Pungo, and Scuppernong series. Belhaven, Ponzer, and Scuppernong soils have mixed mineralogy. Dare, Dorovan, and Pungo soils have organic materials 51 inches or more in thickness. Pamilco soils have sandy mineral horizons under the organic horizons.

**GEOGRAPHIC SETTING:** Croatan soils are on the lower and middle Coastal Plain at elevations above about 25 feet. Elevation near the type location is about 38 feet above mean sea level. Slopes range from 0 to 2 percent. The soils formed under very poorly drained conditions from the remains of herbaceous and related woody
hydrophytic plants. The mean annual temperature is 65 degrees F. (18 degrees C.) and mean annual precipitation is 51 inches near the type location. The growing season is about 190 days.

**GEOGRAPHICALLY ASSOCIATED SOILS:** In addition to the competing Dare, Dorovan, and Pamilco series, these are the Bayboro, Pantego, Rains, and Torhunta series. Bayboro, Pantego, Rains, and Torhunta are mineral soils, and except for Rains, they have umbric epipedons.

**DRAINAGE AND PERMEABILITY:** Very poorly drained; runoff is very slow to ponded. Permeability is slow to moderately rapid. In drained areas, it is moderate in organic layers and moderate or moderately slow in mineral layers. Except where drained, Croatan soils are saturated for 8 to 10 months of the year.

**USE AND VEGETATION:** Much of the acreage is wooded and supports plant communities that reflect past history of treatment. Native vegetation consists of scattered pond pine with a dense understory of titi, gallberry, huckleberry, southern bayberry, greenbrier, sphagnum moss, redbay, sweetbay, switchcane, and giant cane. Croatan soils also support mixed hardwoods, mainly water and swamp tupelo, southern baldcypress, Atlantic white-cedar, and other hyperphytic species. Cultivated areas are pastured or cropped to corn, soybeans, small grain, and vegetable crops.

**DISTRIBUTION AND EXTENT:** Middle and Lower Coastal Plain of Alabama, North Carolina, South Carolina, Virginia, and possibly Florida and Mississippi. The series is largely extensive.

**MLRA OFFICE RESPONSIBLE:** Raleigh, North Carolina
SERIES ESTABLISHED: Jones County, North Carolina; 1978.

REMARKS: In some previous correlations these soils were correlated as Ponzer or were considered taxadjuncts to the Ponzer series.

Diagnostic horizons and features recognized in this pedon are:

Histic epipedon - the zone from the surface to a depth of 28 inches (the Oa1 horizons).

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U.S.A.
KUREB SERIES

The Kureb series consists of very deep, excessively drained, gently sloping to moderately steep soils on Coastal Plain uplands and on side slopes along streams and bays. They have formed in marine, aeolian, or fluvial sands. Slopes range from 0 to 20 percent. Near the type location mean annual precipitation is about 50 inches and mean annual temperature is about 63 degrees F.

TAXONOMIC CLASS: Thermic, uncoated Spodic Quartzipsamments

TYPICAL PEDON: Kureb sand--on a 4 percent slope under sparsely mixed hardwoods of turkey and bluejack oak and scattered longleaf pine. (Colors are for moist soil unless otherwise stated.)

A--0 to 3 inches; dark gray (10YR 4/1) sand; single grained; loose; organic matter and quartz grains have salt and pepper appearance; many fine and large roots; neutral; clear wavy boundary. (2 to 5 inches thick)

E--3 to 26 inches; light gray (10YR 7/1) sand; single grained; loose few large roots; neutral; clear irregular boundary. (4 to 45 inches thick)

C/Bh--26 to 51 inches; brownish yellow (10YR 6/6) sand; single grained; loose; few tongues of light gray (10YR 7/1) extend from above horizon; dark brown (7.5YR 4/4) and few bands and bodies (Bh) of dark reddish brown (5YR 3/2); bands are intermittent at horizon contact and vertically along walls of tongues; many clean and coated sand grains; neutral; gradual wavy boundary. (4 to 46 inches thick)

C--51 to 89 inches; pale brown (10YR 6/3) sand; single grained; loose, slightly acid.
**TYPE LOCATION:** New Hanover County, North Carolina; 1 3/4 miles south of U. S. 421 and N.C. 132 junction; 1/4 mile east and about 200 feet south.

**RANGE IN CHARACTERISTICS:** Thickness of the sandy horizons is more than 80 inches. Soil reaction is neutral to extremely acid throughout. All horizons are fine sand, sand, or coarse sand. Silt plus clay content is less than 5 percent.

The A horizon has hue of 10YR, value of 3 to 7, and chroma of 1 or 2.

The E horizon has hue of 10YR or 2.5Y, value of 5 to 8, and chroma of 1 to 3.

Tongues of E horizon are in old root channels in the C/Bh horizon.

The C part of the C/Bh horizon has hue of 10YR or 2.5Y, value of 5 to 7, and chroma of 2 to 8. The Bh part of the C/Bh horizon has hue of 5YR to 10YR, value of 2 to 6, and chroma of 2 to 4.

The C horizon has hue of 7.5YR to 2.5Y, value of 4 to 8, and chroma of 1 to 8. Few to common mottles in shades of brown, yellow, or gray are in the C horizon of some pedons. Gray mottles are the result of uncoated sand grains and not wetness.

**COMPETING SERIES:** Resota series is the only soil in the same family. Alaga, Alpin, Cainhoy, Centenary, Corolla, Foxworth, Fripp, Kershaw, Lakehurst, Lakeland, Lakewood, Newhan, Orsimo, Ousley, Paola, Resota, Rimini, and Welaka series are in closely related families. Resota soils are moderately well drained and have seasonal high water table at depths of 40 to 60 inches. Alaga, Alpin, Corolla, Foxworth, Fripp, Kershaw, Lakeland, Newhan, Paola, and Welaka soils lack an intermittent Bh horizon. In addition, Alaga soils have 10 to 25 percent percent silt plus clay in 10- to 40-inch control section. Alpin soils have lamella beginning at depths of 40 to 70 inches. Corolla and Newham soils are affected by salt spray.
Lakeland soils have 5 to 10 percent silt plus clay in the 10- to 40-inch control section. Ousley soils have a seasonal watertable at 1.5 to 30 feet. Paola soils are hyperthermic and Welaka have Bir horizons. Cainhoy soils have an E' horizon underlain by Bh horizon. Centenary soils have Bh horizon in subsoil. Lakehurst soils occur in mesic temperature regimes. Rimini soils have a thick sandy E horizon overlying a continuous spodic horizon.

**GEOGRAPHIC SETTING:** The Kureb soils are gently sloping to moderately steep and are on broad surfaces of the lower Coastal Plains. Gradients are 3 to 10 percent and may range to 20 percent on side slopes along streams and edges of bays. The regolith is marine, aeolian or fluvial sands. Near the type location mean annual precipitation is about 50 inches and mean annual temperature is about 63 degrees F.

**GEOGRAPHICALLY ASSOCIATED SOILS:** These are the competing Alaga, Kershaw, Lakeland, and Rimini series plus the Baymeade soils. Baymeade soils have sandy loam Bt horizons.

**DRAINAGE AND PERMEABILITY:** Excessively drained; Slow runoff. Rapid permeability. Depth to seasonal high water table is more than 6 feet during most of the year.

**USE AND VEGETATION:** Mainly wooded. Native vegetation is turkey oak, bluejack and a few live oak with scattered longleaf pine. The understory consists mainly of huckleberry and pineland threeawn.

**DISTRIBUTION AND EXTENT:** Lower Coastal Plains of North Carolina and possibly Georgia and South Carolina. The series is of moderate extent.
**MLRA OFFICE RESPONSIBLE:** Raleigh, North Carolina

**SERIES ESTABLISHED:** New Hanover County, North Carolina; 1974.

**REMARKS:** The Kureb soils were formerly included in the Lakewood series.

Diagnostic horizons and features recognized in this pedon are:

Ochric epipeon - the zone from the surface to a depth of 26 inches (A and E horizons)

**MLRA:** 153A SIR: NC0063

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U.S.A.
LEON SERIES

The Leon series consists of very deep, poorly and very poorly drained soils on upland flats, depressions, stream terraces, and tidal areas. They formed in sandy marine sediments of the Atlantic and Gulf Coastal Plain. Near the type location the mean annual temperature is about 68 degrees F., and the mean annual precipitation is about 55 inches. Slopes range from 0 to 5 percent.

TAXONOMIC CLASS: Sandy, siliceous, thermic Aeric Alaquods

TYPICAL PEDON: Leon sand - forested. (Colors are for moist soil)

A--0 to 3 inches; very dark gray (10YR 3/1) sand, rubbed; weak fine crumb structure; very friable; many fine and medium roots; many clean sand grains give a salt-and-pepper appearance; very strongly acid; clear smooth boundary. (2 to 9 inches thick)

E1--3 to 9 inches; gray (10YR 6/1) sand; common medium faint grayish brown (10YR 5/2) streaks of sand along root channels; single grained; loose; many fine and medium roots; very strongly acid; gradual wavy boundary.

E2--9 to 15 inches; light gray (10YR 7/1) sand; few medium faint grayish brown (10YR 5/2) streaks of sand along root channels; single grained; loose; few fine and medium roots; common medium pores; very strongly acid; clear wavy boundary.

(Bh1--15 to 18 inches; black (5YR 2/1) sand; weak medium subangular blocky structure that parts to weak fine granular; friable; many fine and medium roots and ...)
pores; more than 95 percent of sand grains have organic coatings; very strongly acid; abrupt wavy boundary.

**Bh2**--18 to 22 inches; dark reddish brown (5YR 2/2) sand; common medium faint black (10YR 2/1) masses with more organic matter than matrix; distinct brown (7.5YR 4/4) streaks having less organic carbon than matrix; weak fine subangular blocky structure that parts to weak fine granular; friable; few fine and medium roots; common fine pores; more than 95 percent of sand grains have organic coatings; very strongly acid; clear wavy boundary. (Combined thickness of the Bh horizons range from 6 to 35 inches.)

**Bh3**--22 to 30 inches; dark brown (7.5YR 3/2) sand; common medium distinct vertical streaks of dark reddish brown (5YR 2/2) sand along root channels; weak fine granular structure; friable; few fine and medium roots and pores; many coated sand grains; very strongly acid; gradual wavy boundary. (0 to 30 inches thick)

**BE**--30 to 33 inches; brown (10YR 5/3) sand; few faint streaks of light brownish gray (10YR 6/2) areas with less organic carbon than matrix; single grained; loose; few medium and fine roots; few fine pores; many uncoated sand grains; very strongly acid; gradual irregular boundary. (2 to 30 inches thick)

**E'**--33 to 66 inches; light brownish gray (10YR 6/2) sand; common medium faint dark grayish brown (10YR 4/2) masses with more organic carbon than matrix; single grained; loose; few fine and medium roots; many uncoated sand grains; very strongly acid; clear wavy boundary. (0 to 36 inches thick)
B'h--66 to 80 inches; very dark brown (10YR 2/2) sand; single grained; loose; common medium distinct light brownish gray (10YR 6/2) streaks and pockets having less organic carbon than matrix; many uncoated sand grains; very strongly acid.

**TYPE LOCATION:** Bay County, Florida. Approximately 0.75 mile north of Mine Testing Laboratory and U.S. Highway 98, about 3.0 miles south of West Bay along the west side of Woods Road; NW 1/4, SW 1/4, Sec. 19, T. 3 S., R. 15 W.

**RANGE IN CHARACTERISTICS:** The Bh horizon is within 30 inches of the soil surface. Reaction ranges from extremely acid to slightly acid throughout. In tidal areas, the soil reaction ranges from very strongly acid to moderately alkaline throughout.

The A or Ap horizon has hue of 7.5YR or 10YR, value of 2 to 4, and chroma of 1 or 2; or is neutral with value of 2 to 4. When dry, this horizon has a salt-and-pepper appearance due to mixing of organic matter and white sand grains. Texture is sand, fine sand, mucky fine sand, mucky sand, or muck.

The E horizon has hue of 7.5YR to 2.5Y, value of 4 to 8, and chroma of 1 to 4; or is neutral with value of 5 to 8. Redoximorphic features and streaks in shades of black or gray range from none to common. Texture is sand or fine sand.

Where present, a transitional horizon between the lower E horizon and the Bh1 horizon has hue of 10YR, value of 2 to 4, and chroma of 1. Thickness ranges from 0.5 to 2.0 inches. Texture is sand or fine sand.

The Bh horizon has hue of 5YR to 10YR, value of 2 or 4, and chroma of 1 to 4; or is neutral with value of 2 to 4. This horizon burns white on ignition. Vertical or
horizontal streaks or pockets of sand in shades of gray range from none to common. Texture is sand, fine sand, loamy sand or loamy fine sand.

The E' horizon, where present, has hue of 7.5YR to 2.5Y, value of 4 to 8, and chroma of 1 to 3. Texture is sand or fine sand.

The B'h horizon, where present, is similar in colors and texture to the Bh horizon but occurs below the BE or E' horizons.

The C horizon, where present, has of 7.5YR to 2.5Y, value of 4 to 8, and chroma of 1 to 6. Texture is sand or fine sand.

**COMPETING SERIES:** The [Witherbee](#) series is the only known series in the same family. The somewhat poorly drained Witherbee soils have less developed spodic horizons and would be placed in an Entic subgroup if available in Soil Taxonomy.

**GEOGRAPHIC SETTING:** Leon soils are on upland flats, depressions, stream terraces, and tidal areas of the lower Atlantic and Gulf Coastal Plain. They formed in thick beds of acid sandy marine sediments. The climate is humid semitropical. Slopes range from 0 to 5 percent. The average annual temperature ranges from 66 to 70 degrees F., and the average annual precipitation ranges from 50 to 60 inches.


Chipley, Foxworth, Kershaw, Lakeland, and Ortega soils are on higher positions and lack spodic horizons. In addition, Chipley soils are somewhat poorly drained, Foxworth soils are moderately well drained to excessively drained, Kershaw and Lakeland soils are excessively drained, and Ortega soils are moderately well drained.
drained. Hurricane and Pottsburg soils have a spodic horizon at depths greater than 50 inches. In addition, Hurricane soils are somewhat poorly drained and on higher positions and Pottsburg soils are somewhat poorly to poorly drained and on similar to slightly higher positions. Lynn Haven soils are on similar positions but have an umbric epipedon. Mascotte and Olustee soils are on similar positions but are underlain by argillic horizons under the Bh horizon. Osier soils are on flood plains and lack spodic horizons. Plummer soils are on similar to lower positions and are grossarenic. The very poorly drained Portsmouth are on lower positions and lack spodic horizons. Ridgeland and Wesconnett soils and lack E horizons between the A and Bh horizons. In addition, Ridgeland soils are on slightly higher positions and are somewhat poorly drained while Wesconnett soils are in lower depressional areas and are very poorly drained. The poorly drained Scranton soils are on similar to slighter higher positions and lack spodic horizons.

DRAINAGE AND PERMEABILITY: Poorly drained and very poorly drained; moderate to moderately rapid permeability in the Bh horizons, moderately slow to moderate in the B'h horizons, and rapid in the other layers.

USE AND VEGETATION: Most areas of Leon soils are used for forestry, range, and pasture. Areas with adequate water control are used for cropland and vegetables. Natural vegetation consists of longleaf pine, slash pine, water oak, myrtle, with a thick undergrowth of sawpalmetto, running oak, fetterbush, inkberry (gallberry), chalky bluestem, creeping bluestem, and pineland threeawn (wiregrass). In depressions, the vegetation is dominated by brackenfern, smooth sumac and
swamp cyrilla are common. Vegetation in the tidal areas includes bushy seaoxeye, marshhay cordgrass, seashore saltgrass, batis, and smooth cordgrass.

**DISTRIBUTION AND EXTENT:** The Atlantic and Gulf Coastal Plain from Florida, Maryland, South Carolina and Virginia. The series is of large extent.

**MLRA OFFICE RESPONSIBLE:** Auburn, Alabama.

**SERIES ESTABLISHED:** Leon County, Florida; 1905.

**REMARKS:** The water table is at depths of 6 to 18 inches for 1 to 4 months during most years. In low flatwoods or sloughs it is at a depth of 0 to 6 for periods of more than 3 weeks during most years. It is between depths of 18 and 36 inches for 2 to 10 months during most years. It is below 60 inches during the dry periods of most years. Depressional areas are covered with standing water for periods of 6 months or more in most years.

Diagnostic horizons and features recognized in this pedon are:

Ochric epipedon--the zone from the surface of the soil to a depth of approximately 15 inches (A, E1, and E2 horizons).

Albic horizons--the zones from approximately 3 inches to 15 inches and 33 inches to 66 inches (E1, E2, and E' horizons) (not required for Leon series).

Spodic horizon within 30 inches--the zone from 15 inches to 22 inches (Bh1, Bh2, and Bh3 horizons) and from approximately 66 inches to 80 inches or more (B'h horizons).

Aquic conditions--endosaturation throughout.
National Cooperative Soil Survey

U.S.A.
LYNN HAVEN SERIES

The Lynn Haven series consists of very deep, poorly and very poorly drained sandy soils are in low areas and depressions the Gulf Coast and Atlantic Flatwoods. They formed in thick deposits of sandy marine sediments. Near the type location, the mean annual temperature is about 68 degrees F., and the mean annual precipitation is about 55 inches. Slopes range from 0 to 5 percent.

TAXONOMIC CLASS: Sandy, siliceous, thermic Typic Alaquods

TYPICAL PEDON: Lynn Haven fine sand--range. (Colors are for moist soil)

A--0 to 12 inches; black (10YR 2/1) fine sand; weak fine granular structure; friable; many fine and medium roots; strongly acid; clear wavy boundary. (8 to 20 inches thick)

E--12 to 16 inches; gray (N 6/0) fine sand; single grained; loose; common fine and medium roots; many uncoated sand grains; very strongly acid; abrupt wavy boundary. (2 to 18 inches thick)

Bh1--16 to 22 inches; dark reddish brown (5YR 3/2) fine sand; weak fine granular structure; friable; many fine and medium roots; few fine and medium pores; sand grains coated with organic matter; very strongly acid; gradual wavy boundary.

Bh2--22 to 30 inches; dark brown (7.5YR 3/2) fine sand; weak fine granular structure; friable; few fine roots; few fine pores; most sand grains are coated with organic matter; few small pockets of uncoated sand grains; very strongly acid;
gradual wavy boundary. (Combined thickness of the Bh horizons is from 6 to more than 50 inches thick.)

C--30 to 75 inches; gray (5Y 6/1) fine sand; single grained; loose; common medium distinct brown (10YR 5/3) and light yellowish brown (10YR 6/4) masses of iron accumulation; very strongly acid.

**TYPE LOCATION:** Bay County, Florida. Approximately 1 mile south of intersection of U. S. Highway 98 and State Highway 392 and about 50 feet east of Highway 392 in Sec. 4, T. 4 S., R. 15 W.

**RANGE IN CHARACTERISTICS:** Reaction ranges from extremely to strongly acid throughout the profile.

The Oa, horizon, where present, has hue of 5YR to 10YR, value of 2 or 3, and chroma of 1 to 3. Texture is muck. Where present, this horizon is less than 7 inches thick.

The A horizon has hue of 10YR, value of 2 or 3, and chroma of 1 or 2; or is neutral with value of 2 or 3. When dry, this horizon has a salt-and-pepper appearance due to mixing of organic matter and white sand grains. Texture is fine sand or mucky fine sand.

The E horizon has hue of 10YR or 2.5YR, value of 4 to 7, and chroma of 1 or 2; or is neutral with value of 5 to 7. Some pedons have mottles of higher chroma. Total thickness of the A horizon is less than 30 inches.

A transitional layer about 1 inch thick occurs between the E and Bh horizons. Colors are dark gray through black with many uncoated sand grains.
The Bh horizon has hue of 10YR to 5YR, value of 2 or 3, and chroma of 1 to 4. Sand grains are coated with organic matter. Vertical or horizontal tongues or pockets of grayish sand occur in the Bh horizon in some pedons.

Some pedons have a C/B horizon with hue of 10YR to 5YR, value of 3 to 5, and chroma of 3 or 4 with redoximorphic features in shades of gray, brown, or yellow.

Some pedons have a bisequum of E' and B'h.

The C horizon has hue of 7.5YR to 2.5Y, value of 4 to 7, and chroma of 1 to 3. Redoximorphic features in shades of brown, yellow, or red range from few to many.

**COMPETING SERIES:** These include Boulogne and Wesconnett series. Boulogne and Wesconnett soils do not have continuous E horizons immediately below the A horizon.

**GEOGRAPHIC SETTING:** Lynn Haven soils are on low areas and in depressions of the Gulf Coast and Atlantic Flatwoods. They formed in thick beds of marine sand. The climate is warm and humid. Slopes range from 0 to 5 percent. The average annual air temperature ranges from 65 to 70 degrees F., and the average annual precipitation ranges from 50 to 60 inches.

**GEOGRAPHICALLY ASSOCIATED SOILS:** These include the Baymeade, Blanton, Hurricane, Kershaw, Kingsferry, Kureb, Lakeland, Leon, Mandarín, Murville, Olustee, Osier, Plummer, Pottsburg, Rutlege, Scranton, and Seagate series. The Baymeade, Blanton, Kershaw, Kureb, Lakeland, Osier, Plummer, Rutlege, and Scranton soils do not have Bh horizons. Hurricane and Pottsburg soils have a Bh horizon at depths greater than 50 inches. Kingsferry soils have a Bh horizon between a depth of 30 and 50 inches. Leon soils lack an umbric epipedon. Olustee soils have Bt horizons.
below the Bh horizon. Murville soils do not have continuous E horizons immediately below the A horizon. Seagate soils are better drained and have argillic horizons beneath the Bh horizons.

**DRAINAGE AND PERMEABILITY:** poorly or very poorly drained; moderately rapid or moderate permeability.

**USE AND VEGETATION:** Most areas of Lynn Haven soils remain in their natural state. A few small areas are used for truck crops and pasture land. The native vegetation consists of slash pine, longleaf pine, or cypress and bay trees with an undergrowth of sawpalmetto, gallberry, fedderbush, huckleberry, and pineland threeawn. In depressions, cypress and bay trees are denser along with blackgum, red maple, and Ogeechee lime. The shrubs include fetterbush, Virginia willow, buttonbush, and waxmyrtle. Common herbaceous plants and vines include muscadine grape, greenbriars, and poison-ivy, along with maidencane grass, cinnamon fern and sphagnum.

**DISTRIBUTION AND EXTENT:** Florida, Georgia, North Carolina, and South Carolina. The series is of moderate extent.

**MLRA OFFICE RESPONSIBLE:** Auburn, Alabama.

**SERIES ESTABLISHED:** Florence and Sumter Counties, South Carolina; 1969.

**REMARKS:** The water table is at 0 to 6 inches for periods of 2 to 6 months annually and within a depth of 40 inches for more than 6 months during most years; during extended dry periods it is below 40 inches. Depressional areas are ponded for long duration in most years.

Diagnostic horizons and features recognized in this pedon are:
Umbric epipedon - The zone extending from the surface to a depth of 12 inches. (A horizon).

Albic horizon - The zone between 12 and 16 inches. (E horizon).

Spodic horizon - The zone between 16 and 30 inches. (Bh1 and Bh2 horizons).

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PAMLICO SERIES

The Pamlico series consists of very poorly drained soils that formed in decomposed organic material underlain by dominantly sandy sediment. The soils are on nearly level flood plains, bays, and depressions of the Coastal Plain. Slopes are less than 1 percent.

**TAXONOMIC CLASS:** Sandy or sandy-skeletal, siliceous, dysic, thermic Terric Haplosaprist

**TYPICAL PEDON:** Pamlico muck, undrained--forested. (Colors are for moist soil unless otherwise stated.)

**Oi**--0 to 3 inches; very dark brown (10YR 2/2) fibric material; 75 percent fiber content after rubbing; friable; fibers are of moss, leaves, twigs, and roots; extremely acid; gradual wavy boundary. (0 to 4 inches thick)

**Oa1**--3 to 14 inches; black (10YR 2/1) sapric material; 10 percent fiber; weak coarse granular structure; friable; slightly sticky; common roots; sodium pyrophosphate extract is yellowish brown (10YR 5/4); extremely acid; gradual wavy boundary.

**Oa2**--14 to 30 inches; very dark grayish brown (10YR 3/2) sapric material; 20 percent fiber; less than 10 percent rubbed; massive; friable; slightly sticky; few roots; sodium pyrophosphate extract is light yellowish brown (10YR 6/4); extremely acid; gradual wavy boundary. (combined thickness of Oa horizon is 16 to 51 inches)

**Cg**--30 to 60 inches; very dark grayish brown (10YR 3/2) loamy sand; single grained; loose; extremely acid.
**TYPE LOCATION:** Wayne County, North Carolina; 8 miles east of Mt. Olive on North Carolina Highway 55; 0.6 mile south of intersection with county road 1948; 100 feet northeast of bridge crossing northeast Cape Fear River.

**RANGE IN CHARACTERISTICS:** Pamlico soils have 16 to 51 inches of organic material over dominantly sandy sediments. Reaction is extremely acid (less than 4.5 in 0.01 M calcium chloride) in the organic layers, and ranges from extremely acid to strongly acid in the underlying mineral layers.

The Oi or Oe horizon has hue of 10YR, 7.5YR, or it is neutral, value of 2 or 3, chroma of 0 to 2.

The Oa horizon has hue of 10YR, 7.5YR, or it is neutral, value of 2 or 3, chroma of 0 to 2. Fiber content is 10 to 33 percent unrubbed and less than 10 percent after rubbing. Structure is coarse granular or massive.

The Cg horizon has hue of 7.5YR or 10YR or it is neutral, value of 2 to 6, chroma of 0 to 2. The weighted average of the upper 12 inches of the Cg horizon, or of the part of the Cg horizon that is within a depth of 51 inches, whichever is thicker, is sandy. Textures are typically sand, fine sand, loamy sand, or loamy fine sand, but may also be mucky analogs of the same fine earth textures in some pedons. In some pedons, thin subhorizons of the Cg within a depth of 51 inches are loamy. Textures are typically sandy loam, fine sandy loam, or sandy clay loam. Below a depth of 51 inches, texture is variable, typically ranging from sand to sandy clay loam.

**COMPETING SERIES:** There is no other known series in this family. Belhaven, Croatan, Currituck, Dare, Dorovan, Ponzer, and Scuppernong series are in closely related families. Belhaven, Ponzer, and Scuppernong soils have mixed mineralogy.
and are underlain by dominantly loamy mineral soil material. Croatan soils are underlain by dominantly loamy mineral material. Currituck soils are less acid and have mixed mineralogy. Dare and Dorovan soils have organic layers more than 51 inches thick.

**GEOGRAPHIC SETTING:** Pamlico soils occur in the flood plains of tributaries of major streams and on level to depressional surfaces of the coastal plain. These soils are formed in decomposed organic matter overlying dominantly sandy mineral sediments. The mean annual temperature is 63 degrees F. and the annual precipitation is 48 inches near the type location.

**GEOGRAPHICALLY ASSOCIATED SOILS:** These include the Dare and Dorovan of the competing series, and Bibb, Johnston, Portsmouth, Rutlege, and Torhunta series. Bibb, Johnston, Portsmouth, Rutlege, and Torhunta soils are mineral soils with loamy surface layers high in organic matter.

**DRAINAGE AND PERMEABILITY:** Very poorly drained; ponded or very slow runoff; flooding is rare to frequent; permeability is moderate to moderately rapid in the organic layers and slow to very rapid in the mineral layers.

**USE AND VEGETATION:** In the natural stage, practically all of these soils are used for woodland and wildlife. The native vegetation consists of pond pine, tupelo gum, sweetbay, gumtrees, cypress, greenbrier, wax myrtle bushes, with undergrowth of gallberry and cut bamboo briers. These soils are used for improved pasture, corn, soybeans, oats, truck crops, and other cultivated crops when drained.
**DISTRIBUTION AND EXTENT:** Lower Coastal Plain areas of Alabama, Florida, Mississippi, North Carolina, South Carolina, and Virginia. The series is moderately extensive.

**MLRA OFFICE RESPONSIBLE:** Raleigh, North Carolina

**SERIES ESTABLISHED:** Pamlico County, North Carolina; 1935.

**REMARKS:** Pamlico muck, as mapped in the past, included a very wide range of conditions. The concept expressed in this description is restricted in thickness, degree of decomposition and nature of underlying materials.

Diagnostic horizons and features recognized in the typical pedon are:

- **Organic materials (terrific)** - the zone from the surface to a depth of 30 inches (the Oi, Oa1, and Oa2 horizons)

- **Sandy particle-size class** - mineral material within a depth of 51 inches that has weighted average of the sandy particle-size class in the upper 12 inches of the mineral material or within the control section (51 inches), whichever is thicker (the Cg horizon)

**MLRA(S):** 152A, 153A, 153B, 133A

**SIR(S):** NC0050, NC0154 (LOAMY SUBSTRATUM), NC0155 (PONDED), NC0159 (FLOODED), NC0270 (PONDED, LOAMY SUBSTRATUM)

**REVISED=6/10/96, MHC**

National Cooperative Soil Survey

U.S.A.
PANTEGO SERIES

The Pantego series consists of very deep, very poorly drained, moderately permeable soils that formed in thick loamy sediments on the Southern Coastal Plain and Atlantic Coast Flatwoods. Slopes are less than 2 percent. Near the type location mean annual temperature is 62 degrees F., and mean annual precipitation is 48 inches.

**TAXONOMIC CLASS:** Fine-loamy, siliceous, semiactive, thermic Umbric Paleaquults

**TYPICAL PEDON:** Pantego loam--cultivated field. (Colors are for moist soil unless otherwise stated.)

- **Ap**--0 to 10 inches; black (10YR 2/1) loam; weak fine granular structure; very friable; many fine roots; very strongly acid; gradual wavy boundary. (0 to 12 inches thick)
- **A**--10 to 18 inches; very dark gray (10YR 3/1) loam; weak fine granular structure; friable; very strongly acid; clear smooth boundary. (4 to 14 inches thick)
- **Bt**--18 to 27 inches; very dark gray (10YR 3/1) sandy clay loam; weak fine subangular blocky structure; friable; few faint clay films on faces of peds and in pores; very strongly acid; gradual wavy boundary. (0 to 18 inches thick)
- **Btg1**--27 to 42 inches; gray (10YR 5/1) sandy clay loam; few fine and medium distinct mottles of brownish yellow (10YR 6/6); weak fine and medium subangular blocky structure; friable; slightly sticky; few faint clay films on faces of peds; very strongly acid; gradual smooth boundary.
Btg2--42 to 55 inches; gray (10YR 6/1) sandy clay loam; few medium and coarse distinct mottles of yellowish brown (10YR 5/6); weak fine subangular blocky structure; friable, slightly sticky; few faint clay films on faces of peds; very strongly acid; gradual wavy boundary.

Btg3--55 to 65 inches; gray (10YR 6/1) sandy clay loam; weak coarse subangular blocky structure; friable; few faint clay films on faces of peds; very strongly acid. (Combined thickness of the Btg horizons is 30 to more than 60 inches.)

TYPE LOCATION: Pitt County, North Carolina; 1/2 mile south of Winterville, North Carolina, on Highway 11, 100 feet west from road.

RANGE IN CHARACTERISTICS: Solum thickness is greater than 60 inches. The soil is strongly acid, very strongly acid, or extremely acid except where the surface has been limed.

Some pedons have an Oa horizon that has hue of 10YR, value of 2 or 3, and chroma of 1; or it is neutral and has value of 2. It is less than 8 inches thick.

The A or Ap horizon has hue of 10YR or 2.5Y or is neutral, value of 2 or 3, and chroma of 0 to 2. It is loamy fine sand, loamy sand, fine sandy loam, sandy loam, loam, or mucky analogues of these textures.

Some pedons have an Eg horizon that has hue of 10YR or 2.5Y or is neutral, value of 4 to 6, and chroma of 0 to 2. It is loamy sand, loamy fine sand, sandy loam, fine sandy loam, or loam.

Some pedons have a BEg horizon that has hue of 10YR or 2.5Y, value of 4 or 6, and chroma of 1 or 2. It is loam, sandy loam, fine sandy loam, or sandy clay loam.
The Bt horizon, where present, has hue of 10YR or 2.5Y, value of 3, and chroma of 1 or 2. It has the same textures as the Btg horizon.

The Btg horizon has hue of 10YR to 5Y, value of 4 to 7, and chroma of 1 or 2 with few to common mottles of higher chroma. The Btg horizon is sandy clay loam, sandy loam, sandy clay, or clay loam, fine sandy loam, or sandy loam.

Some pedons have a BCg horizon that has hue of 10YR or 2.5Y, value of 4 to 7, and chroma of 1 or 2. It is sandy clay loam, clay loam, sandy clay, sandy loam, or fine sandy loam.

The Cg horizon, where present, has hue of 10YR or 2.5Y, value of 5 to 7, and chroma of 1 or 2 with higher chroma mottles. It is sandy clay loam, clay loam, sandy loam, fine sandy loam, loamy fine sand, fine sand, loamy sand, or sand.

**COMPETING SERIES:** There are no other series in the same family. Bayboro, Byars, Cape Fear, Ellabelle, Hyde, Johnston, Lumbee, Paxville, Pocomoke, Portsmouth, Rains, Surrency, Torhunta, and Weeksville series are in closely related families. Bayboro, Byars, and Cape Fear soils have Btg horizons containing more than 35 percent clay. Ellabelle and Surrency soils have arenic umbric epipedons. Hyde soils have mixed mineralogy. Johnston, Torhunta, and Weeksville soils lack Btg horizons. Lumbee and Rains soils have ochric epipedons and, in addition, Lumbee soils have thinner sola. Pocomoke soils have sandy BCg horizons at depths of 40 to 60 inches. Portsmouth soils have mixed mineralogy and a decrease in clay of 20 percent or more within 60 inches of the surface.

**GEOGRAPHIC SETTING:** Pantego soils are in nearly level and slightly depressional areas of the Southern Coastal Plain and Atlantic Coast Flatwoods. Slope gradients
are less than 2 percent. The soil formed in medium-textured Coastal Plain deposits. Mean annual temperature is 62 degrees F. near the type location, and mean annual rainfall is about 48 inches.

**GEOGRAPHICALLY ASSOCIATED SOILS:** In addition to the competing Byars, Rains, and Torhunta series, these include Coxville, Dothan, Dunbar, Duplin, Goldsboro, Lynchburg, Marlboro, Norfolk, and Rutlege series. Except for Rutlege, these soils lack umbric epipedons and are better drained than Pantego soils. Rutlege soils are sandy throughout.

**DRAINAGE AND PERMEABILITY:** Very poorly drained; ponded to very slow runoff; moderate permeability. The water table is at or near the surface during wet seasons.

**USE AND VEGETATION:** Most of the areas are in forests and the native vegetation consists of water tupelo, water, oaks, willow oak, sweetgum, blackgum, red maple, bald cypress, and pond, loblolly and slash pines. The understory includes inkberry, gallberry, sweetbay, greenbrier, southern bayberry, swamp cyrilla, switch cane and ferns. Cleared areas are used primarily for corn, soybeans, small grain, truck crops, hay, and pasture.

**DISTRIBUTION AND EXTENT:** Coastal Plain of Alabama, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Virginia. The series is of moderate extent.

**MLRA OFFICE RESPONSIBLE:** Raleigh, North Carolina

**SERIES ESTABLISHED:** Pitt County, North Carolina; 1969.

**REMARKS:** Diagnostic horizons and features recognized in this pedon are:
Umbric epipedon - the zone from the surface to a depth of 27 inches (the Ap, A and Bt horizons)

Argillic horizon - the zone from a depth of 18 to 65 inches (the Bt, Btg1, Btg2, and Btg3 horizons)

**MLRA:** 133A, 153A

**SIR:** NC0051, NC0218 (Flooded), NC0217 (Ponded)

National Cooperative Soil Survey

U.S.A.
PONZER SERIES

The Ponzer series consists of very poorly drained, organic soils in flats and depressions in the lower Coastal Plain. They formed in highly decomposed organic material underlain by loamy textured marine and fluvial sediment. The organic material was derived from herbaceous plants. Slope range from 0 to 2 percent. Mean annual temperature is 62 degrees F., and mean annual precipitation is 53 inches.

TAXONOMIC CLASS: Loamy, mixed, dysic, thermic Terric Haplosaprist

TYPICAL PEDON: Ponzer muck--cultivated. (Colors are for moist soils unless otherwise stated.)

Oap--0 to 5 inches; black (N 2/0) broken face and rubbed muck; less than 1 percent fibers unrubbed and rubbed; moderate fine granular structure; very friable; common fine roots; common very fine grains of clean sand; about 35 percent mineral content; very strongly acid; abrupt smooth boundary.

Oa1--5 to 9 inches; black (N 2/0) broken face and rubbed muck; less than 1 percent fibers unrubbed and rubbed; moderate medium subangular blocky structure; very friable; few fine and medium roots; common very fine grains of clean sand; about 35 percent mineral content; extremely acid; clear smooth boundary.

Oa2--9 to 20 inches; black (10YR 2/1) broken face; (N 2/0) rubbed muck; about 5 percent fibers less than 1 percent rubbed; moderate medium subangular blocky
structure; very friable; few fine and medium roots; common very fine grains of clean sand; about 30 percent mineral content; extremely acid; clear smooth boundary.

**Oa3**--20 to 24 inches; black (N 2/0) broken face and rubbed muck; about 5 percent fibers, less than 1 percent rubbed; moderate medium subangular blocky structure; very friable; few fine and medium roots; about 55 percent mineral content; extremely acid; clear wavy boundary. (The combined thickness of the Oa horizon is 16 to 48 inches)

**Cg1**--24 to 31 inches; dark gray (5Y 4/1) silt loam; moderate medium subangular blocky structure; very friable; few fine and medium roots; about 55 percent mineral content; very friable; few fine and medium roots; about 55 percent mineral content; extremely acid; clear irregular boundary. (4 to 10 inches thick)

**Cg2**--31 to 52 inches; gray (5Y 5/1) silt loam; weak medium subangular blocky structure; slightly sticky, slightly plastic; very strongly acid; clear smooth boundary. (10 to 24 inches thick)

**Cg3**--52 to 61 inches; gray (5Y 5/1) silty clay; common distinct strong brown and reddish brown mottles; massive; sticky, plastic; very strongly acid; clear smooth boundary.

**2Cg4**--61 to 72 inches; greenish gray (5BG 5/1) silty clay; massive; sticky, plastic; moderately acid.

**TYPE LOCATION:** Hyde County, North Carolina; 1 3/4 miles northeast of Ponzer; 200 feet south of intersection of Evans road and Fred Gall road in pasture.

**RANGE IN CHARACTERISTICS:** Thickness of the organic materials commonly is 16 to 30 inches but ranges to 51 inches. The organic materials are ultra acid to
extremely acid except where the surface has been limed. The underlying mineral horizons are extremely acid through mildly alkaline. Logs, stumps, and fragments of wood occupy 0 to 20 percent of the organic layers. Particles of charcoal and pockets of ash are in some pedons. Flakes of mica are few to common in the mineral horizons of some pedons.

The Oa1 or Oap horizons has hue of 10YR, value of 2 or 3, and chroma of 0 or 2. The lower tiers have hue of 7.5YR, 10YR, or 2.5Y value of 2 or 3 and chroma of 0 or 2. Fiber content of the organic tiers is 2 to 30 percent unrubbed and less than 10 percent after rubbing. The organic layers are typically massive under natural wet conditions. Upon drainage and cultivation a granular or blocky structure develops in all or part of the organic layers depending upon the nature and depth of the organic material as well as duration of drainage.

Some pedons have thin mucky loam A horizons that are less than 15 inches thick underlying the Oa horizons. Color is similar to the Oa horizons.

The Ag horizon, where present, has hue of 7.5YR to 5Y, value of 2 to 4 and chroma of 1 or 2. It is fine sandy loam, sandy loam, loam, silt loam, sandy clay loam or clay loam.

The Cg horizon has hue of 7.5YR to 5G, value of 4 to 7 and chroma of 1 or 2 or it is neutral. Texture is variable but it is loamy in the control section.

**COMPETING SERIES:** These are the Belhaven and Scuppernong series of the same family and the Croatan series in a closely related family. Belhaven and Scuppernong soils have greasy feeling and paste-like organic layers in hues of 5YR
and 2.5YR and in addition Scuppernong soils have mineral layers in the control section that are silty. Croatan soils have siliceous underlying mineral material.

**GEOGRAPHIC SETTING:** Ponzer soils are on nearly level to level areas of the Lower Coastal Plain. The soils formed in under very poorly drained conditions from the remains of herbaceous and related woody hydrophytic plants. Elevation near the type location is 15 feet above mean sea level. The mean annual temperature ranges from 51 to 72 degrees F. and mean annual precipitation ranges from 46 to 58 inches. The growing season is about 190 days.

**GEOGRAPHICALLY ASSOCIATED SOILS:** In addition to the competing Belhaven and Scuppernong series, these are the Arapahoe, Cape Fear, Conaby, Dare, Deloss, Fortescue, Hydeland, Pamlico, Pettigrew, Portsmouth, Pungo, Roper, Smithton, Wasda, and Weeksville series. Arapahoe, Cape Fear, Deloss, Fortescue, Hydeland, Portsmouth, and Weeksville soils are mineral soils with umbric epipedons. Conaby, Pettigrew, Roper, and Wasda soils are mineral soils with histic epipedons. Dare and Pungo soils have more than 51 inches of organic materials over mineral horizons. Pamlico soils have sandy mineral horizons within the control section. Smithton soils are mineral soils and lack a histic epipedon.

**DRAINAGE AND PERMEABILITY:** Very poorly drained; very slow runoff.

Permeability is slow. In drained areas it is moderate in plowed layers; the underlying mineral layers are moderately slow. Except in drained and developed areas, Ponzer soils are saturated near the surface for 8 to 12 months each year and ponded from November to May in most years.
USE AND VEGETATION: Native vegetation commonly consists of plant communities of scattered pond pine or loblolly pine with a dense understory of reeds, switchcane; giantcane, and scattered gallberry, huckleberry, southern bayberry, and green brier. Another common plant community consists of sweetgum, red maple, redbay, and sweetbay with a few baldcypress, and water tupelo and understory of southern bayberry and greenbrier. Another common plant community consists of red maple, redbay, and sweetbay with a few baldcypress, and water tupelo and understory of southern bayberry and greenbrier. Cultivated areas are pastured or cropped to corn, soybeans, small grain, and some vegetables.

DISTRIBUTION AND EXTENT: Lower Coastal Plain of Alabama, Florida, Georgia, Mississippi, North Carolina, and South Carolina. The series is moderately extensive.

MLRA OFFICE RESPONSIBLE: Raleigh, North Carolina

SERIES ESTABLISHED: Florence and Sumter Counties, South Carolina; 1969.

REMARKS: Diagnostic horizons and features recognized in this pedon are:

Histic epipedon-the zone from the surface to a depth of 24 inches. (the Oap, Oa1, Oa2, and Oa3 horizons)

Terric feature-absence of histic materials below a depth of 24 inches.

RUTLEGE SERIES

MLRA(s): 133A, 153A, 153B
MLRA Office Responsible: Raleigh, North Carolina
Depth Class: very deep
Drainage Class (Agricultural): very poorly drained
Internal Free Water Occurrence: very shallow, persistent
Index Surface Runoff: negligible
Permeability: rapid
Landscape: lower and middle coastal plain
Landform: flats, depressions, flood plains
Geomorphic Component: talfs, dips, treads
Parent Material: marine or fluvial sediments
Slope: 0 to 2 percent
Elevation (type location):
Mean Annual Air Temperature (type location): 63 degrees F.
Mean Annual Precipitation (type location): 45 inches

TAXONOMIC CLASS: Sandy, siliceous, thermic Typic Humaquepts

TYPICAL PEDON: Rutlege loamy sand - forested.

A--0 to 15 inches; black (10YR 2/1) loamy sand; weak medium granular structure; loose; common fine and medium roots; very strongly acid; gradual smooth boundary.

(Combined thickness of the A horizon is 10 to 24 inches)
**Cg1**--15 to 35 inches; dark gray (10YR 4/1) sand; single grain; loose; few fine roots; very strongly acid; gradual wavy boundary.

**Cg2**--35 to 70 inches; grayish brown (10YR 5/2) sand; single grain; loose; few fine roots in upper part; tends to flow when saturated; very strongly acid.

**TYPE LOCATION:** Marion County, South Carolina; 1.25 miles north of Nichols and 500 feet east of S. C. Highway 9.

**RANGE IN CHARACTERISTICS:**

Depth to Bedrock: Greater than 60 inches

Depth to Seasonal High Water Table: 0 to 6 inches, December to May

Soil Reaction: extremely acid to strongly acid, except where limed

Other Features: Silt plus clay in the 10 to 40 inch control section averages 5 to 15 percent

**RANGE OF INDIVIDUAL HORIZONS:**

A horizon:

Color--hue of 10YR to 5Y, value of 2 or 3, and chroma of 0 to 2

Texture (fine-earth fraction)-- sand, fine sand, loamy sand, or loamy fine sand and their mucky analogues

Cg horizon:

Color--hue of 10YR to 5Y, value of 4 to 7, and chroma of 0 to 2

Texture (fine-earth fraction)-- sand, loamy sand, fine sand, or loamy fine sand

Redoximorphic features (if they occur)-- have value of 5 to 8, and chroma of 1 to 6
COMPETING SERIES:

Cadelake soils - have Bg horizons and on average have less organic matter in the umbric epipedon

There are no other known series in the same family. The Dawhoo, Johnston, Osier, Pickney, Plummer, Lynn Haven, Scarboro, and Torhunta series are similar soils in related families. Dawhoo soils have mixed mineralogy. Johnston and Pickney soils have umbric epipedons that are more than 24 inches thick. Osier and Plummer soils do not have an umbric epipedon. The Lynn Haven soils have spodic horizons. Scarboro soils have average annual soil temperatures of 47 to 59 degrees F. Torhunta soils have sandy loam or fine sandy loam texture in the particle-size control section.

GEOGRAPHIC SETTING:

Landscape: Coastal Plain

Landform: upland flats or depressions, flood plains

Geomorphic Component: talfs, dips, treads

Parent Material: marine or fluvial sediments

Elevation: 0 to 300 feet

Mean Annual Air Temperature: 59 to 70 degrees

Mean Annual Precipitation: 38 to 60 inches

Frost Free Period: 190 to 300 days

GEOGRAPHICALLY ASSOCIATED SOILS:

Alaga soils-- are well drained and do not have an umbric horizon

Blanton soils-- have an argillic horizon and do not have an umbric horizon
Chipley soils-- moderately well drained and do not have an umbric horizon
Dragston soils-- have an argillic horizon and do not have an umbric horizon
Johnston soils-- have umbric epipedons that are more than 24 inches thick
Lakeland soils-- are excessively drained and do not have an umbric horizon
Leon soils-- have a spodic horizon and do not have an umbric horizon
Lynn Haven soils -- have spodic horizons
Pelham soils-- have an argillic horizon and do not have an umbric horizon
Plummer soils-- have an argillic horizon and do not have an umbric horizon
Rimini soils-- have a spodic horizon and do not have an umbric horizon
Rumford soils-- have an argillic horizon and do not have an umbric horizon

DRAINAGE AND PERMEABILITY:
Drainage Class (Agricultural): very poorly drained
Internal Free Water Occurrence: very shallow, persistent
Index Surface Runoff: negligible, ponding is common in depressional areas
Permeability: rapid

USE AND VEGETATION:
Major Uses: truck crops, forest
Dominant Vegetation: Where cultivated-- for corn, soybeans, blueberries, hay and pasture. Where wooded--blackgum, Carolina ash, red maple, sweetbay, tulip popular, water oak, pin oak, pond pine, slash pine, and loblolly pine. The understory is huckleberry, wax myrtle, greenbriar, grasses and sedges. Some ponded areas consist of entirely grasses and sedges.
DISTRIBUTION AND EXTENT:

Distribution: Virginia, North Carolina, South Carolina, Georgia, Florida

Extent: large

MLRA OFFICE RESPONSIBLE: Raleigh, North Carolina

SERIES ESTABLISHED: Camburton Soil Conservation District, New Jersey, 1943.

REMARKS: This revision changes the type location from Maryland to South Carolina to meet the temperature requirements for thermic. Diagnostic horizons and features recognized in this pedon are:

Umbric epipedon--The zone from the surface of the soil to a depth of 15 inches (A horizon).

ADDITIONAL DATA:

National Cooperative Soil Survey

U.S.A.
TORHUNTA SERIES

The Torhunta series consist of very poorly drained soils in upland bays and on stream terraces in Coastal Plain. Slopes range from 0 to 2 percent.

**TAXONOMIC CLASS:** Coarse-loamy, siliceous, active, acid, thermic Typic Humaquepts

**TYPICAL PEDON:** Torhunta fine sandy loam--cultivated.

(Colors are for moist soil unless otherwise stated.)

**Ap**--0 to 9 inches; black (10YR 2/1) fine sandy loam; weak medium granular structure; friable; many fine roots; strongly acid; abrupt wavy boundary. (0 to 12 inches thick.)

**A**--9 to 15 inches; very dark gray (10YR 3/1) loamy sand; weak medium granular structure; very friable; many fine roots; thin coats of organic matter on grains; very strongly acid; gradual wavy boundary. (4 to 15 inches thick.)

**Bg**--15 to 40 inches; dark grayish brown (10YR 4/2) fine sandy loam; weak fine subangular blocky structure; friable; slightly sticky and slightly plastic; many fine roots in upper part; thin silt coatings on sand grains; few loamy sand and sand pockets; extremely acid; gradual wavy boundary. (10 to 25 inches thick.)

**Cg1**--40 to 48 inches; dark grayish brown (10YR 4/2) loamy sand; common medium faint gray (10YR 5/1) and brown (10YR 5/3) mottles; single grained; very friable; few sand pockets; extremely acid; diffuse wavy boundary. (0 to 10 inches thick.)
Cg2--48 to 80 inches; grayish brown (10YR 5/2) sand; single grained; loose; uncoated sand grains; very strongly acid.

**TYPE LOCATION:** Wayne County, North Carolina; 1.5 miles south of New Hope; 0.4 mile northeast of intersection of Roads 1712 and 1713, 50 feet south of Road 1713 and 50 feet northeast of power line poles.

**RANGE IN CHARACTERISTICS:** Torhunta soil has loamy textured horizons that range from 20 to 50 inches thick. The soil reaction ranges from extremely acid through strongly acid, unless the surface has been limed.

The Ap or A horizon has hue of 10YR, 2.5Y, or it is neutral, value of 2 or 4, and chroma of 0 to 2. It is sandy loam, fine sandy loam, loam, loamy sand or their mucky analogues.

The Bg horizon has hue of 10YR, 2.5Y, or it is neutral, value of 4 to 6, and chroma of 0 to 2. Mottles are in shades of brown or yellow. It is sandy loam or fine sandy loam.

The BCg horizon, where present, has hue of 10YR, 2.5Y, or it is neutral, value of 4 to 7, and chroma of 0 to 2. Mottles are in shades of yellow or brown. It is sandy loam, fine sandy loam, loamy sand, or sand.

The Cg horizon has colors of the BCg horizon and in addition, has hue of 5GY or 5G, value of 4 to 6, and chroma of 1. It is loamy sand, loamy fine sand, sand, or sandy loam.

**COMPETING SERIES:** There are no other series in the same family. Arapahoe, Johnston, Mullica, Pickney, Pocomoke, Portsmouth, Rutlege, Weeksville, and Weston series are in closely related families. Arapahoe and Mullica have mixed mineralogy. Arapahoe is also nonacid. Johnston and Pickney soils have an umbric
epipedon more than 24 inches thick. Pocomoke, Portsmouth, and Weston soils have argillic horizons. Rutlege soils are sandy throughout. Weeksville soils are coarse-silty.

**GEOGRAPHIC SETTING:** Torhunta soils are on nearly level stream terraces and upland bay areas in the Coastal Plain. Slope gradients are less than 2 percent. The soil formed in coarse to medium textured, marine or fluvial deposits. At the type location, mean annual temperature is 63 degrees F. and mean annual rainfall is about 48 inches.

**GEOGRAPHICALLY ASSOCIATED SOILS:** In addition to the Rutlege series, these include Johns, Lumbee, Lynchburg, and Rains series. Johns, Lumbee, Lynchburg, and Rains soils have more than 18 percent clay in the Bt horizons and lack the thick, dark colored A horizons.

**DRAINAGE AND PERMEABILITY:** Very poorly drained; slow runoff; moderately rapid permeability. The water table is at or near the surface 2 to 6 months annually.

**USE AND VEGETATION:** Approximately 2/3 of these soils are in pine forest with pond and loblolly being the principal species. About 1/3 of the soil area has been drained and is used for growing corn, soybeans, small grain, and pasture grasses.

**DISTRIBUTION AND EXTENT:** Widely distributed over the Coastal Plain of Florida, Georgia, North Carolina, South Carolina, and Virginia. The series is extensive.

**MLRA OFFICE RESPONSIBLE:** Raleigh, North Carolina

**SERIES ESTABLISHED:** Robeson County, North Carolina; 1972.

**REMARKS:** Torhunta soils were formerly included in the Pocomoke series. CEC activity class added 4/99 by JAK.
Diagnostic horizons and features recognized in this pedon are:

Umbric epipedon - the zone from the surface to a depth of 15 inches. (The Ap and A horizons)

Cambic horizon - the zone between a depth of 15 to 40 inches.

(The Bg horizon)

Aquic moisture regime - chromas of 2 or less below a depth of 9 inches.

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Appendix B: Individual water table well graphs
Well 1A from April 1, 2001 to December 4, 2002

-240 -210 -180 -150 -120 -90 -60 -30 0 30

Day of year

Water table depth (cm)
Well 3 from April 1, 2001 to December 4, 2002

Day of year

Water table depth (cm)
Well 5A from April 1, 2001 to December 4, 2002

Day of year

Water table depth (cm)
Well 6 from April 1, 2001 to December 4, 2002

Water table depth (cm)

Day of year
Well 8A from April 1, 2001 to July, 2002

Water table depth (cm)

Day of year
Well 12 from April 1, 2001 to December 4, 2002

![Graph showing water table depth (cm) over the specified period, with peaks and troughs indicating fluctuations.](image-url)
Well 15 from April 1, 2001 to December 4, 2002

Day of year

Water table depth (cm)
Well 16 from April 1, 2001 to December 4, 2002

Day of year

Water table depth (cm)
Well 16A from April 1, 2001 to December 4, 2002
Well 16B from April 1, 2001 to December 4, 2002

Day of year

Water table depth (cm)
Well 20 from April 1, 2001 to December 4, 2002

Day of year

Water table depth (cm)
Well 23A from April 1, 2001 to December 4, 2002

Day of year

Water table depth (cm)
Well 25 from April 1, 2001 to December 4, 2002

Day of year

Water table depth (cm)
Well 25A from April 1, 2001 to December 4, 2002

Day of year

Water table depth (cm)
Well 25B from April 1, 2001 to December 4, 2002

Day of year

Water table depth (cm)
Appendix C: Graphs of individual nests of wells and piezometers
Nest 1 Hydrograph from December 20, 2001 to November 13, 2002

Water depth (cm)

P-1-D 34.1'
P-1-S 14.8'
Well 1 8'


Nest 1 Hydrograph from December 20, 2001 to November 13, 2002
Nest 2 hydrograph from December 20, 2001 to November 13, 2002
Nest 3 hydrograph from June 29, 2001 to November 13, 2002

Depth of water (cm)
Nest 6 hydrograph from June 27, 2001 to July 26, 2002

Depth of water (cm)

P-6 19.5'
Well 6 8'

Nest 6 hydrograph from June 27, 2001 to July 26, 2002
Nest 10 hydrograph from December 20, 2001 to July, 2002

Depth to water (cm)

-140 -120 -100 -80 -60 -40 -20 0 20

350 370 390 410 430 450 470 490 510 530 550

-140 -120 -100 -80 -60 -40 -20 0 20

P 10-D 16.8'

P 10-S 8.1'

Well 10 8'

Nest 10 hydrograph from December 20, 2001 to July, 2002
Nest 11 hydrograph from June 22, 2001 to November 13, 2002

Depth to water (cm)

P-11 14.8'
Well 11 8'
Nest 12 hydrograph from June 22, 2001 to July 26, 2002

Depth of water (cm)

-150  -135  -120  -105  -90   -75   -60   -45   -30   -15     0     15     30     45     60     75     90     105     120     135     150

P-12 16'
Well 12 8'

Nest 12 hydrograph from June 22, 2001 to July 26, 2002
Nest 17 hydrograph from June 22, 2001 to July 26, 2002
Nest 20 hydrograph from December 20, 2001 to November 13, 2002

Depth of water (cm)
Piezometer 22 data from December 20, 2001 to November 13, 2002
Nest 25 hydrograph from June, 2001 to November 13, 2002
Appendix D: Graphs comparing manual measurements to data from the Solinst Dataloggers in the piezometers
Day, 2002

Depth from ground surface (cm)

2S datalogger
2S manual
2D datalogger
2D manual

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Day, 2002

Depth from ground surface (cm)

12 datalogger
12 manual
Day, 2002

Depth from ground surface (cm)

20S datalogger
20S manual
20D datalogger
20D manual