Hydrogeologic Framework and Ground Water Conditions in the North Carolina Central Coastal Plain

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North Carolina Department of Environment and Natural Resources
Division of Water Resources
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This area has historically relied very heavily on the Cretaceous age Black Creek and Upper Cape Fear aquifers for water supply. Estimated total pumping rates from these aquifers have increased from 120,000 gallons per day in 1910 (Lyke, Winner and Brockman, 1986) to 116 million gallons per day at present (NC Division of Water Resources). As indicated by water level measurements from monitoring wells, the potentiometric surfaces of these aquifers have been declining since the year 1900. For the last 25 years, water levels have been dropping at a rate of 2 to 8 feet per year, forcing many well field operators to lower pump intakes in order to maintain water supply. Water level declines have resulted in a loss of yield of the aquifers in well fields, and over certain areas in the Central Coastal Plain have resulted in aquifer dewatering.

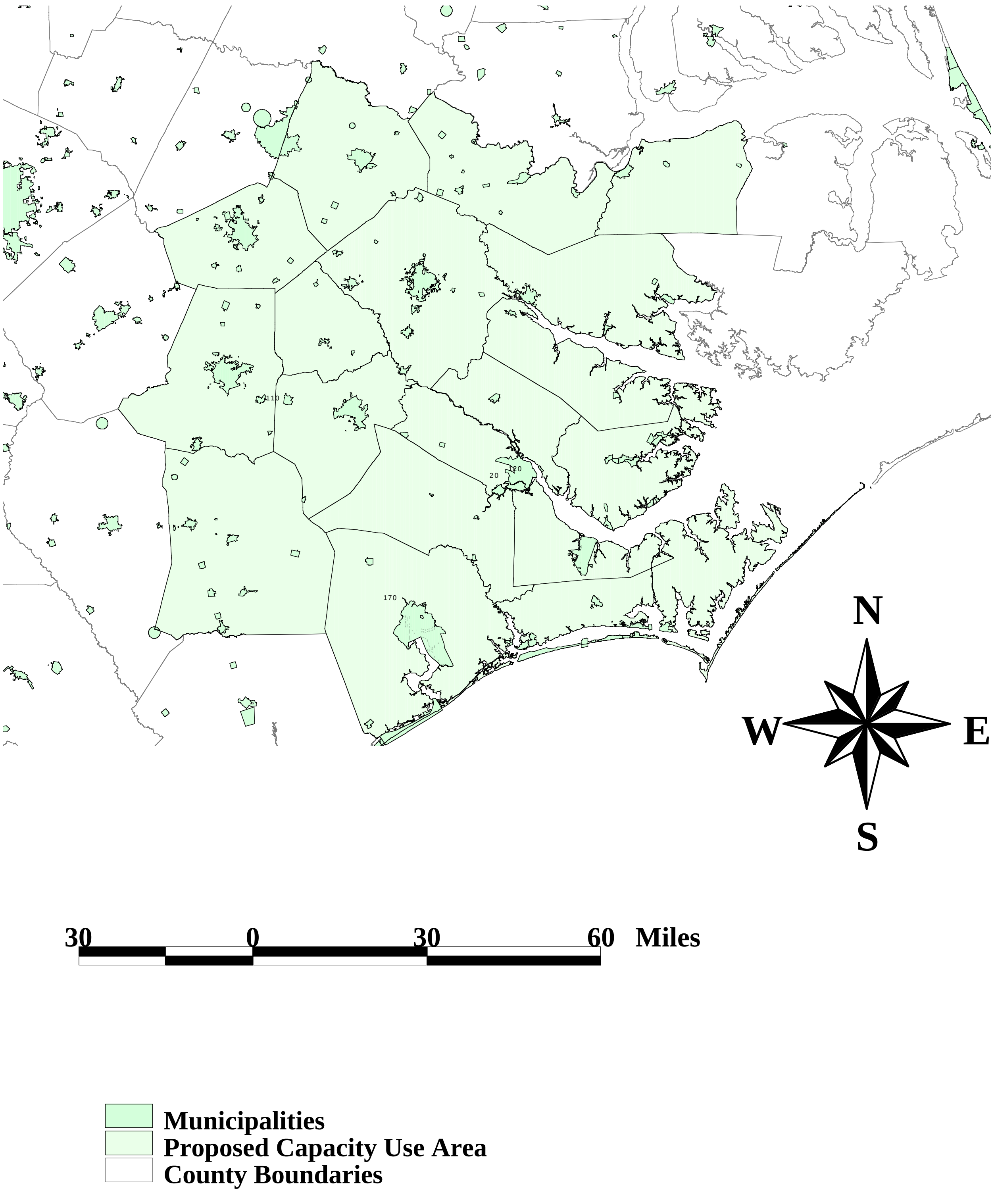
In response to this problem , the North Carolina Division of Water Resources has proposed a new Capacity Use Area in the Central Coastal Plain in order to deal with these declines through an effective ground water management strategy.

Concurrent with the development of capacity use rules for the North Carolina Central Coastal Plain, an up-to-date hydrogeologic framework study has been carried out in order to provide information necessary for planning and establishing a strategy for dealing with water level declines. The hydrogeologic framework study includes all of the area covered by the proposed rules, as well as some adjacent areas where well information was available to help with interpretations within the proposed capacity use area. The study was accomplished by correlation and interpretation of borehole geophysical and lithologic logs, water level and chloride measurements taken from observation wells, aquifer test data, and time domain electromagnetic soundings. Much additional information has been made available from new wells being added to the North Carolina ground water monitoring network by the Division of Water Resources, and by new public and private water system wells.

The geology of the North Carolina Central Coastal Plain may be characterized as a gently eastward dipping, and eastward thickening wedge of sediments and sedimentary rock ranging in age from Recent through Cretaceous which rests on an underlying basement complex of Paleozoic age rocks. The basement surface ranges in elevation between 100 feet above sea level to approximately 4500 feet below sea level within the area of study, and dips to the east southeast at an average rate of 37 feet per mile. The sediment wedge is comprised of layers and lenses of sand, clay, silt, limestone, gravel, shell material and combinations thereof which range in total thickness from zero at the fall line to approximately 4520 feet in the eastern part of the study area. In a successive manner, older stratigraphic units outcrop or subcrop immediately west of the updip limit of the next younger unit. Pliocene age deposits blanket the northern section of the study area and are absent to the south, while Quaternary age deposits blanket the entire area. Deposition occurred in cyclic fashion during alternating transgressions and regressions of the Atlantic Ocean, in marine to nonmarine environments.

The sedimentary column of the Central Coastal Plain is subdivided into geologic formations and formation members based upon position of layers in the sequence of sediments, lithology, and faunal composition. The subdivision of these deposits into aquifers and confining units is based on

Figure i: North Carolina Division of Water Resources
Central Coastal Plain Study Area and Proposed Capacity Use Area



the delineation of nonpermeable versus hydraulically connected permeable units, the boundaries of which sometimes, and sometimes do not, correspond to geologic formation boundaries. With the exception of the surficial aquifer, none of the aquifers are laterally continuous across the entire study region. This is due to the westward pinchouts of the geologic formations they contain and because of areas where confining beds that separate aquifers are absent because of facies changes or unconformities. Aquifers and confining units are commonly made up of more than one formation, or may include only part of a formation or parts of several formations due to the discontinuous distribution of strata in the Central Coastal Plain. The relationship of the geologic column to the system of hydrogeologic subdivisions as defined by this study is depicted in figure ii.

The hydrogeologic system in the study region, from basement to land surface, consists of eight regionally significant aquifers and the intervening confining units that separate them (figure 2). Included are the surficial, Yorktown, Castle Hayne, Beaufort, Peedee, Black Creek, Upper and Lower Cape Fear aquifers. Each aquifer was mapped and described in as much detail as available data would allow in order to define them in terms of regional elevation, thickness and lateral distribution, hydraulic properties, relationship to stratigraphic units, ground water movement, and chloride distribution. The approximate positions of the 250 and 1,000 parts per million chloride interfaces were plotted for each aquifer on cross sections and elevation maps prepared for the study.

Heavy withdrawals of ground water from the Black Creek and Upper Cape Fear aquifers, and to a limited extent, the Peedee aquifer, have been causing a steady, inexorable decline in water levels since the early 1900s in the Central Coastal Plain. Pumping rates from these aquifers have increased through the past century to a present estimated total of 116 million gallons per day. Hydrographs from observation wells in the North Carolina monitoring network indicate decline rates in the potentiometric surfaces up to 5.6 feet per year (table 3). Highest rates of decline have been occurring near the heaviest pumping centers in Lenoir, Wayne and Onslow Counties. In order to determine the latest position of the potentiometric surfaces of the Peedee, Black Creek, and Upper Cape Fear aquifers, the North Carolina Division of Water Resources conducted a synoptic survey of water levels in October, 1999. Static water levels were taken from wells in the North Carolina ground water monitoring station network, and from numerous public and private water supply wells. Static water level data from the synoptic survey was used to construct potentiometric surface maps of the aquifers as shown in plates 55 through 57. The potentiometric surface of the Black Creek aquifer depicts a series of coalescing cones of depression with major centers in Onslow, Lenoir and Pitt Counties. Cones of depression formed as a result of concentrated pumping from municipal, industrial, private and agricultural supply wells. Ground water levels in the Black Creek aquifer have dropped below the top of the aquifer in part of the Kinston well field, as shown in plate 56, and within a few feet of the top of the aquifer in much of western Lenoir, and parts of eastern Wayne Counties. The potentiometric surface of the Upper Cape Fear Aquifer depicts a series of coalescing cones of depression with major centers in eastern Wayne, Lenoir, and Pitt Counties. Ground water levels in the Upper Cape Fear aquifer have possibly dropped below the top of the aquifer over localized areas in western Lenoir and eastern Wayne Counties. A drop in the potentiometric surface to a level below the top of a confined aquifer results in a condition called dewatering. Dewatering produces compaction and loss of pore space in an aquifer, as a consequence of the reduction in hydraulic support of the weight of overburden sediments. Permanent reduction of the yield and storage ability of the aquifer are a result. If pumping is allowed to continue on its present course, dewatering will become widespread in the Black Creek and Upper Cape Fear aquifers.

Most of the aquifers in the Central Coastal Plain contain salt water over regions of variable extent. Salt water is defined for the purposes of this study as water containing greater than 250 ppm (parts per million chloride). As recognized by Winner and Coble (1989), the position of fresh water/ salt water interfaces within North Carolina Coastal Plain aquifers has a very complex pattern. Sediments were deposited during cyclic fluctuations of sea level over geologic time. The seaward limit of fresh water is unique for each aquifer as governed by variations in hydraulic properties, position and rates of recharge, thickness and hydraulic conductivity of overlying confining beds, and hydraulic gradients. Salt water interfaces are not sharply defined, but occur as transition zones of variable width due to diffusion between salty and fresh water. The movement of fresh ground water through deeper confined aquifers in the coastal plain causes interfaces to retreat slowly seaward over geologic time. However, in areas of heavy ground water pumping and resultant water level declines, saline ground water can move toward pumping centers due to a reversal of hydraulic gradient. Due to the existing rate of ground water withdrawals, the potential exists for salt water intrusion into pumping centers located near salt water interfaces in the Black Creek, Upper, and Lower Cape Fear aquifers due to reversals in hydraulic gradient.

It is evident by the results of this study that a ground water management strategy is needed in the Central Coastal Plain in order to halt ground water level declines and preserve the aquifers as sources of water supply for future generations.

INTRODUCTION

The area covered by this report encompasses fifteen counties of the North Carolina Central Coastal Plain, including Martin, eastern Edgecombe, Beaufort, Craven, Carteret, Jones, Lenoir, Pitt, Greene, Wayne, eastern Wilson, Duplin, Onslow, Carteret, and northern Pender Counties (figure 1).

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In response to this problem , the North Carolina Division of Water Resources has proposed a new Capacity Use Area in the Central Coastal Plain in order to deal with these declines through an effective ground water management strategy.

PURPOSE AND SCOPE

Concurrent with the development of capacity use rules for the North Carolina Central Coastal Plain, an up-to-date hydrogeologic framework study has been carried out in order to provide information necessary for planning and establishing a strategy for dealing with water level declines. The hydrogeologic framework study includes all of the area covered by the proposed rules, as well as some adjacent areas where well information was available to help with interpretations within the proposed capacity use area. The study was accomplished by correlation and interpretation of borehole geophysical and lithologic logs, water level and chloride measurements taken from observation wells, aquifer test data, and time domain electromagnetic soundings. Much additional information has been made available from new wells being added to the North Carolina ground water monitoring network by the Division of Water Resources, and by new public and private water system wells.

PREVIOUS STUDIES

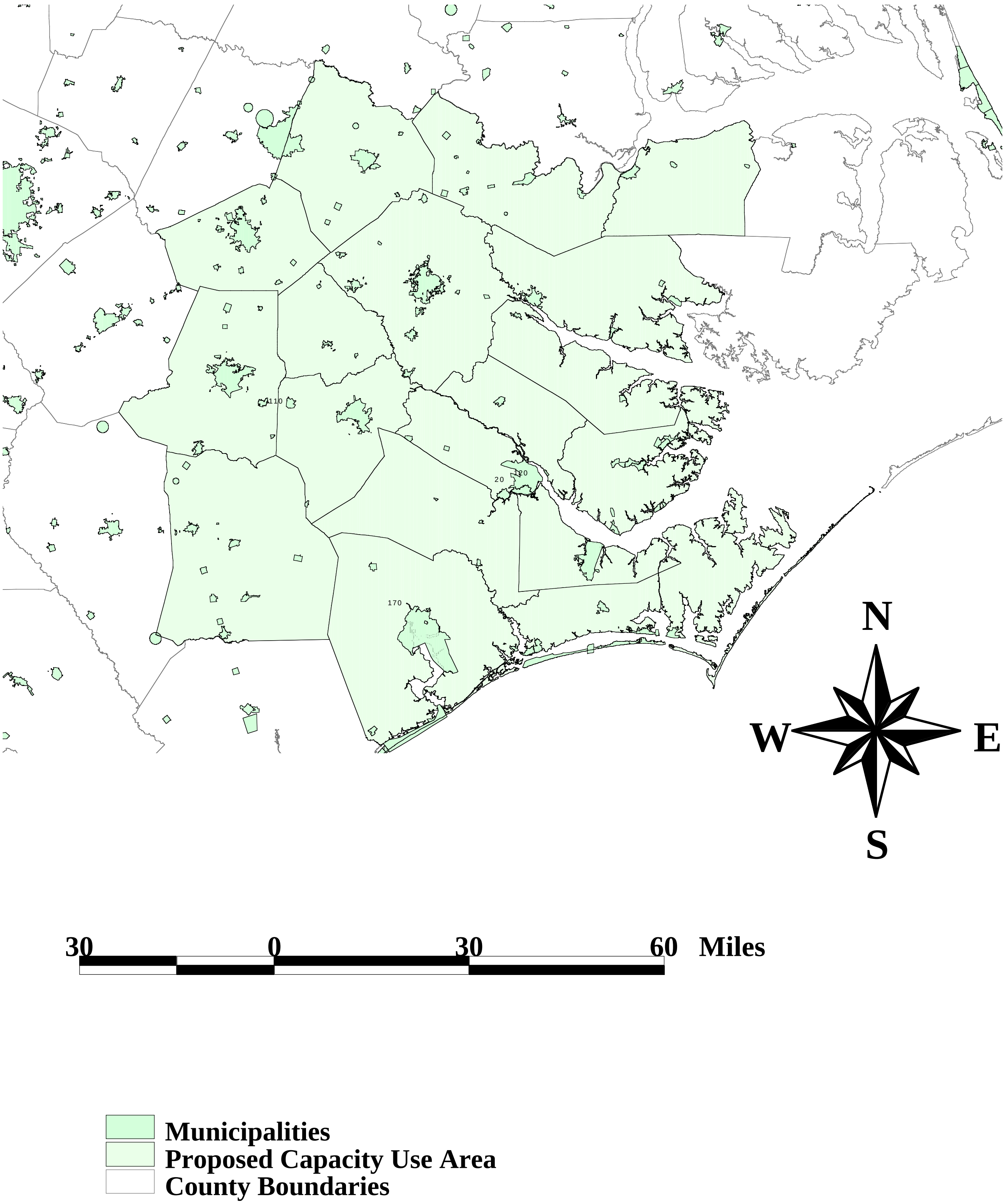
Of the numerous local and regional geologic and hydrogeologic studies concerning this region that have been published, the ones that most relate to this study are mentioned as follows:

Cardinell and Howe (1997). A hydrogeologic and ground water resources study of Seymour Johnson Air Force Base, North Carolina.

Eimers, Daniel, and Coble (1994). A hydrogeologic study and ground water flow simulation at the U.S. Marine Corps Air Station at Cherry Point, North Carolina.

Lawrence and Hoffman (1993). A geologic study of basement rocks present beneath the North Carolina coastal plain.

Figure 1: North Carolina Division of Water Resources
Central Coastal Plain Study Area and Proposed Capacity Use Area



Cardinell, Berg, and Lloyd (1993). A hydrogeologic framework study of the U.S. Marine Corps Base at Camp LeJeune, North Carolina.

Eimers, Lyke and Brockman (1990) A report concerning simulation of ground water flow in the Cretaceous aquifers of the NC Central Coastal Plain.

Lyke and Brockman (1990). A study of ground water pumpage and water level declines in the Peedee and Black Creek aquifers in Onslow and Jones Counties.

Winner and Coble (1989). A regional hydrogeologic framework study of the NC Coastal Plain aquifer system.

Winner and Lyke (1989). A hydrogeologic framework study of the Cretaceous aquifers in the NC Central Coastal Plain.

Winner and Lyke (1986). A regional study of ground water pumpage and water level declines in the Black Creek and Upper Cape Fear aquifers in the NC Central Coastal Plain.

Narkunas (1980). A regional evaluation of the hydrogeology and ground water conditions in the North Carolina Central Coastal Plain.

Winner (1976) A ground water resource evaluation of Wilson County.

Brown, Miller and Swain (1972) A regional structural and stratigraphic study of the Atlantic Coastal Plain.

Floyd and Long (1970) A report which supplied well records and other basic ground water data for Craven County.

Sumsion (1970) A study of the geology and ground water resources of Pitt County.

Floyd (1969) A ground water resources evaluation of Craven County.

Nelson and Barksdale (1965) A study of the hydrogeology and ground water resources of the Kinston area.

Pusey (1960) A study of the geology and ground water resources of the Goldsboro area.

Brown (1959) A study of the geology and ground water resources of the Greenville area.

ACKNOWLEDGMENTS

The author would like to thank the following colleagues and former colleagues in the North Carolina Division of Water Resources-Ground Water Branch, who contributed to this report, either by review, data collection and data entry, assistance with data analysis, discussion, etc. : Nat Wilson, Lewis Land, Stephen Webb, Greg Rudolph, Gabrielle Chianese, Danny Jones, Chris Kimbro, Jeffrey Walker, and Blake Rouse.

HYDROGEOLOGIC SETTING

The geology of the North Carolina Central Coastal Plain may be characterized as a gently eastward dipping, and eastward thickening wedge of sediments and sedimentary rock ranging in age from Recent through Cretaceous which rests on an underlying basement complex of Paleozoic age rocks. The basement surface ranges in elevation between 100 feet above sea level to approximately 4500 feet below sea level within the area of study, and dips to the east southeast at an average rate of 37 feet per mile. The sediment wedge is comprised of layers and lenses of sand, clay, silt, limestone, gravel, shell material and combinations thereof which range in total thickness from zero at the fall line to approximately 4520 feet in the eastern part of the study area. In a successive manner, older stratigraphic units outcrop or subcrop immediately west of the updip limit of the next younger unit. Pliocene age deposits blanket the northern section of the study area and are absent to the south, while Quaternary age deposits blanket the entire area. Deposition occurred in cyclic fashion during alternating transgressions and regressions of the Atlantic Ocean, in marine to nonmarine environments.

The sedimentary column of the Central Coastal Plain is subdivided into geologic formations and formation members based upon position of layers in the sequence of sediments, lithology, and faunal composition. The subdivision of these deposits into aquifers and confining units is based on the delineation of nonpermeable versus hydraulically connected permeable units, the boundaries of which sometimes, and sometimes do not, correspond to geologic formation boundaries. With the exception of the surficial aquifer, none of the aquifers are laterally continuous across the entire study region. This is due to the westward pinchouts of the geologic formations they contain and because of areas where confining beds that separate aquifers are absent because of facies changes or unconformities. Aquifers and confining units are commonly made up of more than one formation, or may include only part of a formation or parts of several formations due to the discontinuous distribution of strata in the Central Coastal Plain. The relationship of the geologic column to the system of hydrogeologic subdivisions as defined by this study is depicted in figure 2.

The hydrogeologic system in the study region, from basement to land surface, consists of eight regionally significant aquifers and the intervening confining units that separate them. They are mentioned from oldest to youngest as follows:

The Lower Cape Fear aquifer, which is comprised along with its confining unit, of the lower part of the Cape Fear Formation of Cretaceous age.

The Upper Cape Fear aquifer, which corresponds to the upper part of the Cape Fear Formation and sometimes the lower part of the Cretaceous Black Creek Formation. The confining unit is composed of clay or silt beds present in the lower part of the Black Creek or upper part of the Cape Fear Formation.

The Black Creek aquifer, which corresponds primarily to the Black Creek Formation. In some areas the aquifer includes the upper part of the Cape Fear Formation and the lower part of the Cretaceous Peedee Formation. The confining unit is made up of clay or silt beds in the upper part of the Black Creek or lower part of the Peedee Formations. To the west of the pinchout of the Peedee Formation, the confining unit of the Black Creek aquifer may include Pliocene age Yorktown or younger age deposits which directly overly the Black Creek Formation. In this area, the Black Creek aquifer can include permeable beds in the lower part of these younger formations.

Figure 2. -Relationship of Geologic and Hydrogeologic Units in the North Carolina Central Coastal Plain

North Carolina Central Coastal Plain Geologic Units			North Carolina Central Coastal Plain Hydrogeologic Units
System	**Series**	**Formation**	**Aquifers and Confining Units**
Quaternary	Holocene	Undifferentiated	Surficial Aquifer
	Pleistocene		
Tertiary	Pliocene	Yorktown Formation	Yorktown Confining Unit
			Yorktown Aquifer
	Middle Eocene	Castle Hayne Formation	Castle Hayne Confining Unit
			Castle Hayne Aquifer
	Upper Paleocene	Beaufort Formation	Beaufort Confining Unit
			Beaufort Aquifer
Cretaceous		Peedee Fm.	Peedee Confining Unit
			Peedee Aquifer
		Black Creek Formation	Black Creek Confining Unit
			Black Creek Aquifer
		Cape Fear Formation	Upper Cape Fear Confining Unit
			Upper Cape Fear Aquifer
			Lower Cape Fear Confining Unit
			Lower Cape Fear Aquifer

The Peedee aquifer, which is made up of the Peedee Formation. In some areas the aquifer includes all, or part of, the Paleocene age Beaufort Formation. The confining unit is generally present in the Beaufort Formation or upper part of the Peedee Formation.

The Beaufort aquifer and confining unit, which include the Beaufort Formation and sometimes the lower part of the Castle Hayne Formation.

The Castle Hayne aquifer, which is comprised primarily of the Eocene age Castle Hayne Formation, and includes the Oligocene age River Bend and Belgrade Formations in the eastern most part of the study area. The lower part of the Castle Hayne aquifer sometimes includes a portion of, or all of the Beaufort Formation. The confining unit varies in stratigraphic position between the upper Castle Hayne Formation and the overlying, variable younger units which overly this formation across the area.

The Yorktown aquifer, which is comprised principally of the Yorktown Formation. In certain areas where the confining bed is higher in the stratigraphic section the aquifer may include younger sediments.

The surficial, or water table aquifer, which is made up primarily of Quaternary age sediments. It also includes parts of older formations depending on the varying age of underlying sediments and the varying stratigraphic position of the uppermost confining layer.

GENERAL DESCRIPTION OF THE GROUND WATER SYSTEM

As indicated by the preceding discussion, the ground water system in the Central Coastal Plain is complicated because of the complex and variable nature of the stratigraphy, and how it affects the movement and storage of ground water. The ground water system is further complicated by the combined effects of large scale pumping from the Black Creek and Upper Cape Fear aquifers and its impact on flow and storage, and on the movement of salt water. A typical hydrogeologic cross section through the Central Coastal Plain is shown in figure 3, exhibiting the complexity of ground water flow patterns and salt water interfaces in relation to hydrogeologic units.

The area included in this study received a range of 43.7 to 59.6 inches of rainfall per year through the 1990s as indicated in table 1. Several inches of annual variation occur over the fifteen county area included in this report. Water, in the form of precipitation, enters the ground water system through recharge to the surficial aquifer in the interstream areas. The rate at which recharge occurs in any given area in the study region is dependant on several factors, including:

-differences in precipitation rates from one area to another.
-variations in soil types and their differing infiltration capacities.
-the position of the water table relative to land surface, which varies over time.
-the slope of the land surface.
-evapotranspiration rates, which vary across the region.

Heath (1980) calculated a variation of 5 to 21 inches per year of recharge to North Carolina Coastal Plain soils, assuming steady state conditions. This means that a range of 52 to 92 per cent of annual precipitation in the Central Coastal Plain is lost to the ground water system through the combination of runoff to surface water bodies and evapotranspiration. Most of the water that enters the surficial aquifer flows laterally from recharge to discharge areas such as the Neuse, Tar, and Roanoke Rivers, and the numerous other rivers, creeks, swamps, and estuaries. Estimations by Wilder and others (1978) and Heath (1980) indicate that less than two inches per year of ground water flows vertically downward in recharge areas to shallow confined aquifers, and less than .5 inches per year to deeper confined aquifers. This is supported by the findings of this study. Analysis of pump test data from numerous locations in the Central Coastal Plain, (table 2) using the Hantush-Jacobs method, indicate that very little to no leakance occurs across the confining unit of the Black Creek aquifer. Comparison of field data plots of drawdown versus time (figure 4) derived from the pump tests to the Hantush-Jacobs family of type curves show best fits with the non-leaky artesian curve. This indicates that little to no leakance took place across confining beds within the duration of the pump tests. Vertical hydraulic conductivity values of confining units (K') were calculated to be zero in every test. Hydrograph data from the regional monitoring network indicate that water levels in the Peedee aquifer show minimal, to no response to pumping from the Black Creek and Upper Cape Fear aquifers in areas where the Peedee is not being heavily used. This demonstrates the effective confinement of the deeper aquifers (figures 5, 6 and 7).

The assumption can be made that most of the recharge to the Cretaceous age aquifers occurs near their westward limits where they are close to the surface, and covered exclusively by Quaternary age deposits. These areas are depicted on plates 59, 60 and 61. Highest recharge rates occur where shallow confining beds are absent, as delineated in plates 35, 40 and 45. The rate of recharge depends on the difference in head values between the surficial aquifer and the deeper, confined aquifers, and on the thickness and vertical hydraulic conductivity of the confining beds.

Heavy withdrawals of ground water from the Black Creek and Upper Cape Fear aquifers, and to a limited extent, the Peedee aquifer, have been causing a steady, inexorable decline in water levels since the early 1900s in the Central Coastal Plain. Pumping rates from these aquifers have increased through the past century to a present estimated total of 116 million gallons per day. Hydrographs from observation wells in the North Carolina monitoring network indicate decline rates in the potentiometric surfaces up to 5.6 feet per year (table 3). Highest rates of decline have been occurring near the heaviest pumping centers in Lenoir, Wayne and Onslow Counties. In order to determine the latest position of the potentiometric surfaces of the Peedee, Black Creek, and Upper Cape Fear aquifers, the North Carolina Division of Water Resources conducted a synoptic survey of water levels in October, 1999. Static water levels were taken from wells in the North Carolina ground water monitoring station network, and from numerous public and private water supply wells. Static water level data from the synoptic survey was used to construct potentiometric surface maps of the aquifers as shown in plates 55 through 57. The potentiometric surface of the Black Creek aquifer depicts a series of coalescing cones of depression with major centers in Onslow, Lenoir and Pitt Counties. Cones of depression formed as a result of concentrated pumping from municipal, industrial, private and agricultural supply wells. Ground water levels in the Black Creek aquifer have dropped below the top of the aquifer in part of the Kinston well field, as shown in plate 56, and within a few feet of the top of the aquifer in much of western Lenoir, and parts of eastern Wayne Counties. The potentiometric surface of the Upper Cape Fear Aquifer depicts a series of coalescing cones of depression with major centers in eastern Wayne, Lenoir, and Pitt Counties. Ground water levels in the Upper Cape Fear aquifer have possibly dropped below the top of the aquifer over localized areas in western Lenoir and eastern Wayne Counties.

Many of the public and private water supply wells used to document the potentiometric surfaces were screened in both the Black Creek and Upper Cape Fear aquifers. In addition, the Upper Cape Fear confining unit is missing over parts of Lenoir County. Therefore, the

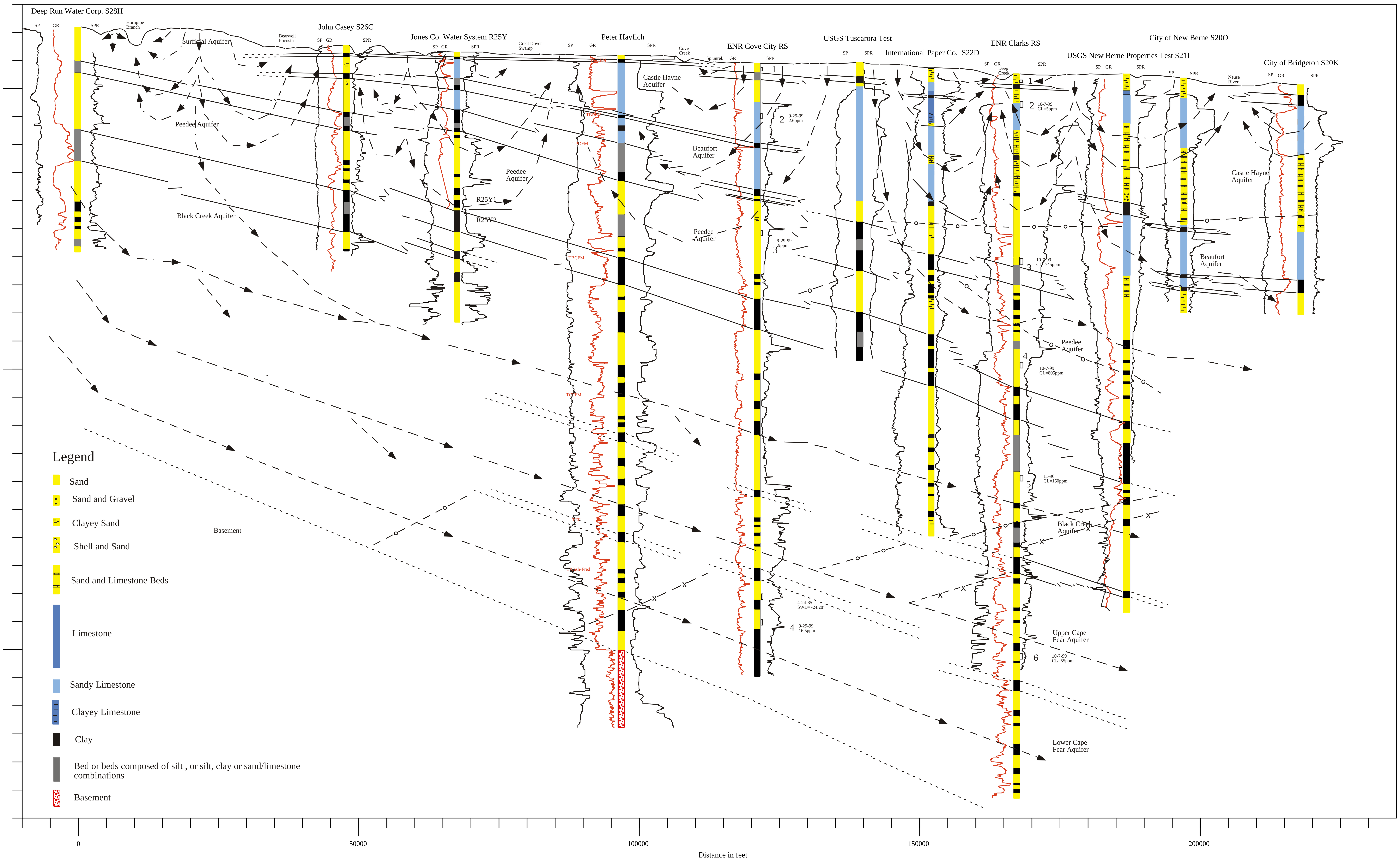


Figure 3: West to East Hydrogeologic Cross Section through Lenoir, Jones, and Craven Counties, NC showing idealized ground water flowlines and salt water interfaces

250 ppm chloride interface

1000 ppm chloride interface

Ground Water Flowlines

Hydrogeologic Unit Correlation Lines

TABLE 1: NATIONAL CLIMATIC DATA CENTER
ANNUAL PRECIPITATION DATA FOR THE NC CENTRAL COASTAL PLAIN

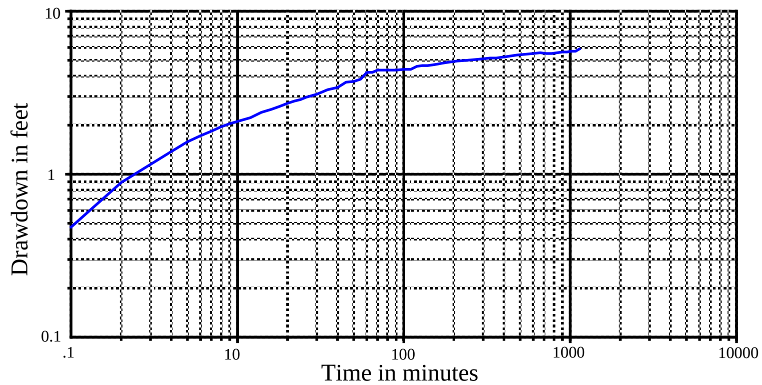
YEAR	ANNUAL PRECIPITATION (IN INCHES)
1990	43.7
1991	49.7
1992	50.8
1993	47.6
1994	44.5
1995	52.8
1996	59.6
1997	46
1998	59.2
1999	59.6
average	51.35

TABLE 2: Aquifer Test Data from the NC Central Coastal Plain

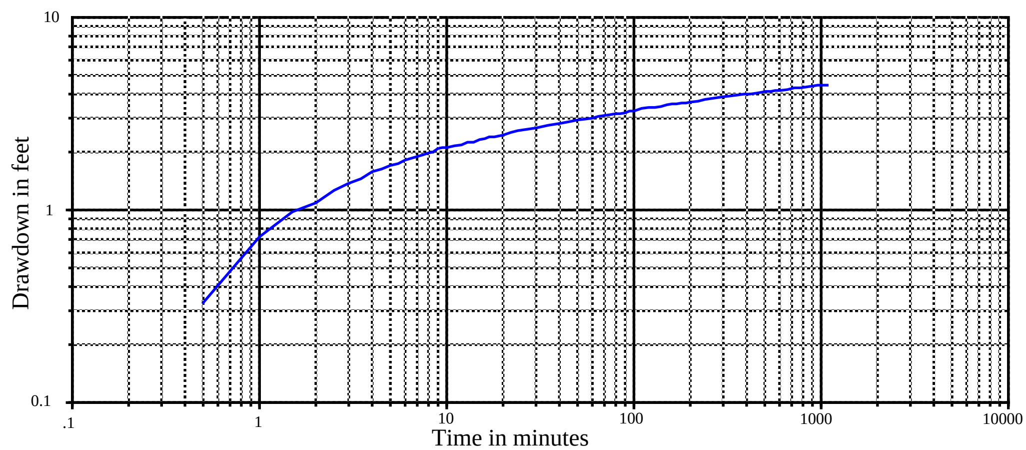
County	Well Name	Well Number	Screened Interval (in ft.)		Aquifer	Analysis	Pumping or Observation Well	Transmissivity	S	K (in ft/day)	K' (in ft/day)	Specific Capacity
						Method		in ft2/day				gpm/ft
Lenoir	ENR Kinston RS	Q27r9	355-365		Black Creek	HJ	Observation	1,700	0.00012		0	
Greene	ENR Maury RS	O27j5	98.4-108.4		Black Creek	Jacobs	Observation	779.8	0.00012	7.35		
Greene	ENR Maury RS	O27j6	295-321		Upper CF	Jacobs	Pumping	24.7				
Pitt	ENR Bethel RS	L24b2	98-108		Black Creek	HJ	Observation	706	0.00018	11	0	
Wayne	ENR Saulston RS	O30i2	86-96		Black Creek	HJ	Observation	437	0.000089	19	0	
Pender	ENR Burgaw RS	Y30s8	370-380		Black Creek	HJ	Observation	863	0.000095	2.6	0	
Pender	ENR Burgaw RS	Y30s4	120-130		Peedee	HJ	Observation	382	0.00018	1.5	0	
Duplin	ENR Rose Hill RS	V32v7	208-218		Black Creek	HJ	Observation	784	0.00015	10	0	
Duplin	ENR Pink Hill RS	T29g6	246-256		Black Creek	HJ	Observation	1,224	0.000078	6.5	0	
Duplin	ENR Pink Hill RS	T29g3	126-136		Peedee	Jacobs	Pumping	1,166	na	10	na	
Craven	ENR Palmetto Swamp RS	P22U	224-234		Peedee	Jacobs	Pumping	656	na	3.85	na	
Craven	ENR Palmetto Swamp RS	P22U	335-345		Peedee	Jacobs	Pumping	565	na	3.32	na	
Craven	ENR Palmetto Swamp RS	P22U	604-614		Black Creek	Jacobs	Pumping	481	na	4.45	na	
Beaufort	ENR Wilmar RS	P21k6	62-200		Castle Hayne	Jacobs	Observation	3,791	na	18.6	na	
Beaufort	ENR Bath RS	O17I3	477-482		Castle Hayne	Jacobs	Pumping	212	na	0.42	na	
					in Beaufort Fm							
Onslow	ENR Deppe RS	V23x4	620-630		Peedee	HJ	Observation	237	0.0056	1.3	0	
Onslow	ENR Hadnot Point RS	X24s9	120-130		Castle Hayne	Jacobs	Observation	2,543	0.0001	8.42	na	
Onslow	ENR Dixon RS	Y25Q3	150-240		Castle Hayne	HJ	Observation	9,930	0.0014	31		
Greene	ENR Snow Hill RS	O28K3	66-76'		Black Creek	HJ	Pumping	662	na	3.41	na	1.39
Greene	ENR Snow Hill RS	O28K4	224-234		U. Cape Fear	Jacobs	Pumping	437.5	na	3.77	na	0.94
Greene	ENR Snow Hill RS	O28K3	400-410		L. Cape Fear	Jacobs	Pumping	19.74	na	0.17	na	0.063
Lenoir	ENR Moss Hill RS	R29T4	400-410		U. Cape Fear	Jacobs	Pumping	166	na	1.1	na	0.6
Lenoir	ENR Moss Hill RS	R29T7	300-310		Black Creek	Jacobs	Pumping	565	na	2.62	na	1.78
Lenoir	ENR Moss Hill RS	R29T6	100-110		Peedee	Jacobs	Pumping	424	na	6.05	na	1.1

Figure 4: Examples of field data plots of drawdown vs. time for selected wells in the Black Creek Aquifer

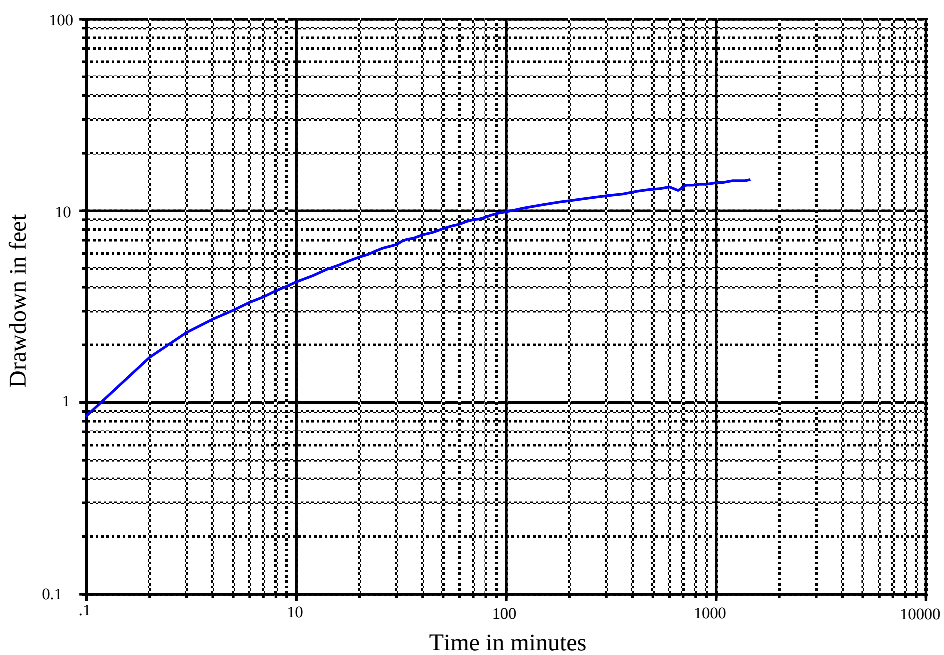
Kinston Yard Research Station Aquifer Test

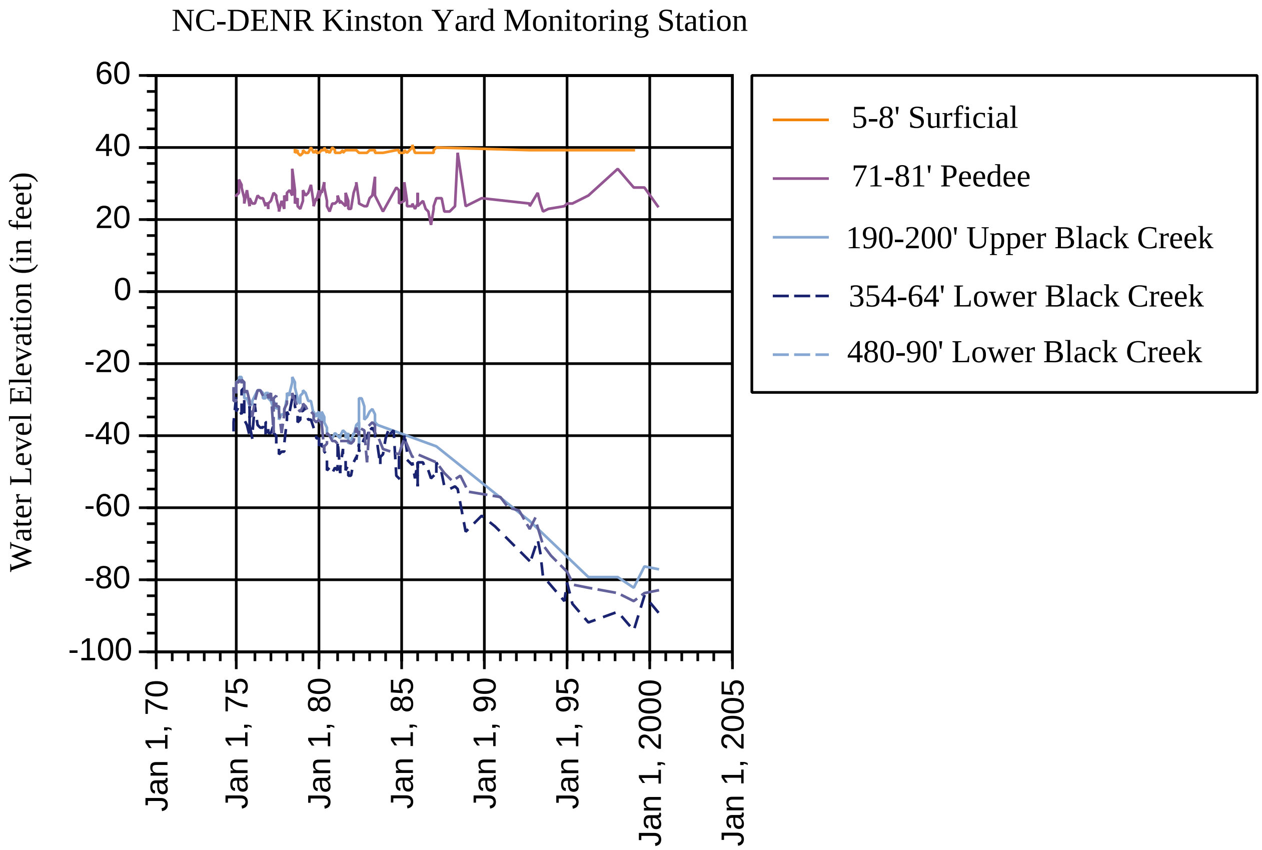


Pink Hill Research Station Aquifer Test



Saulston Research Station Aquifer Test





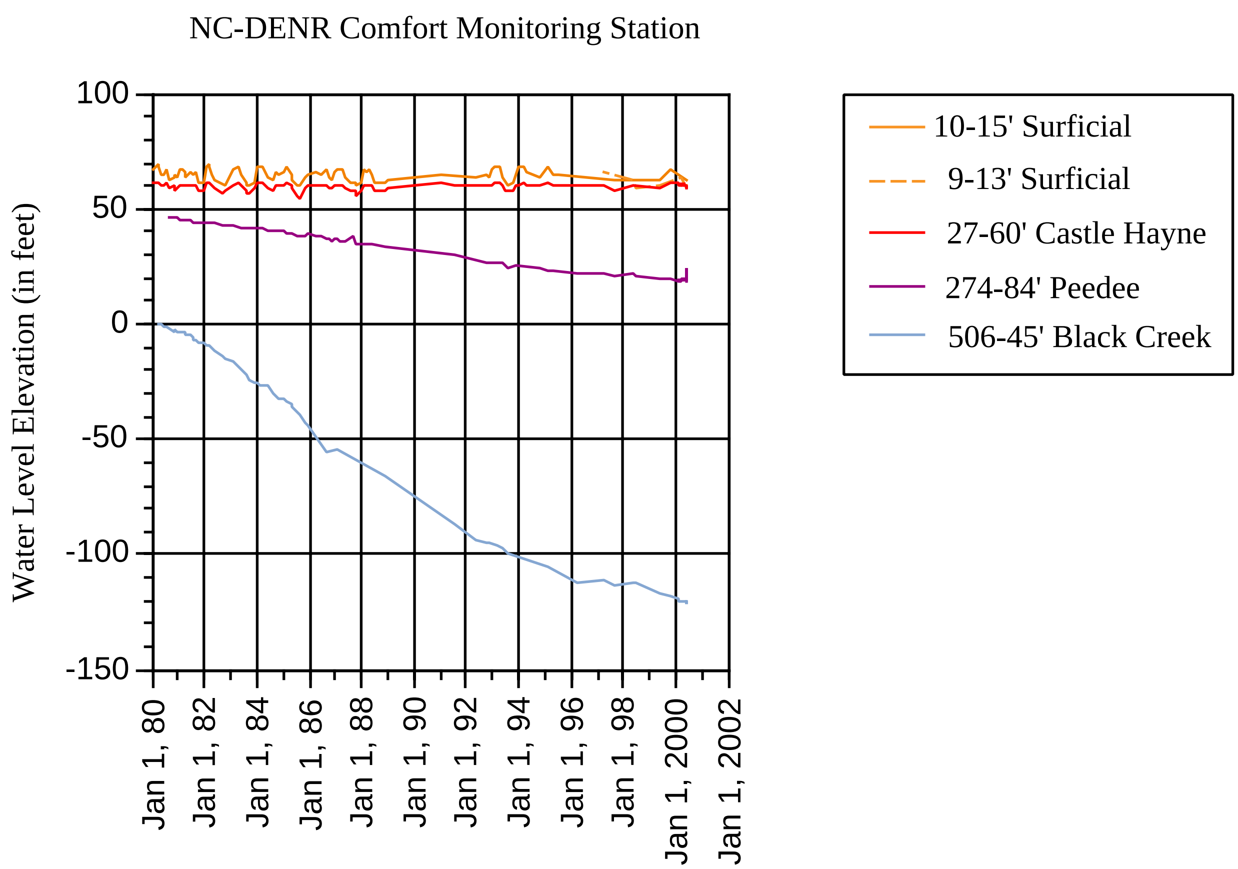
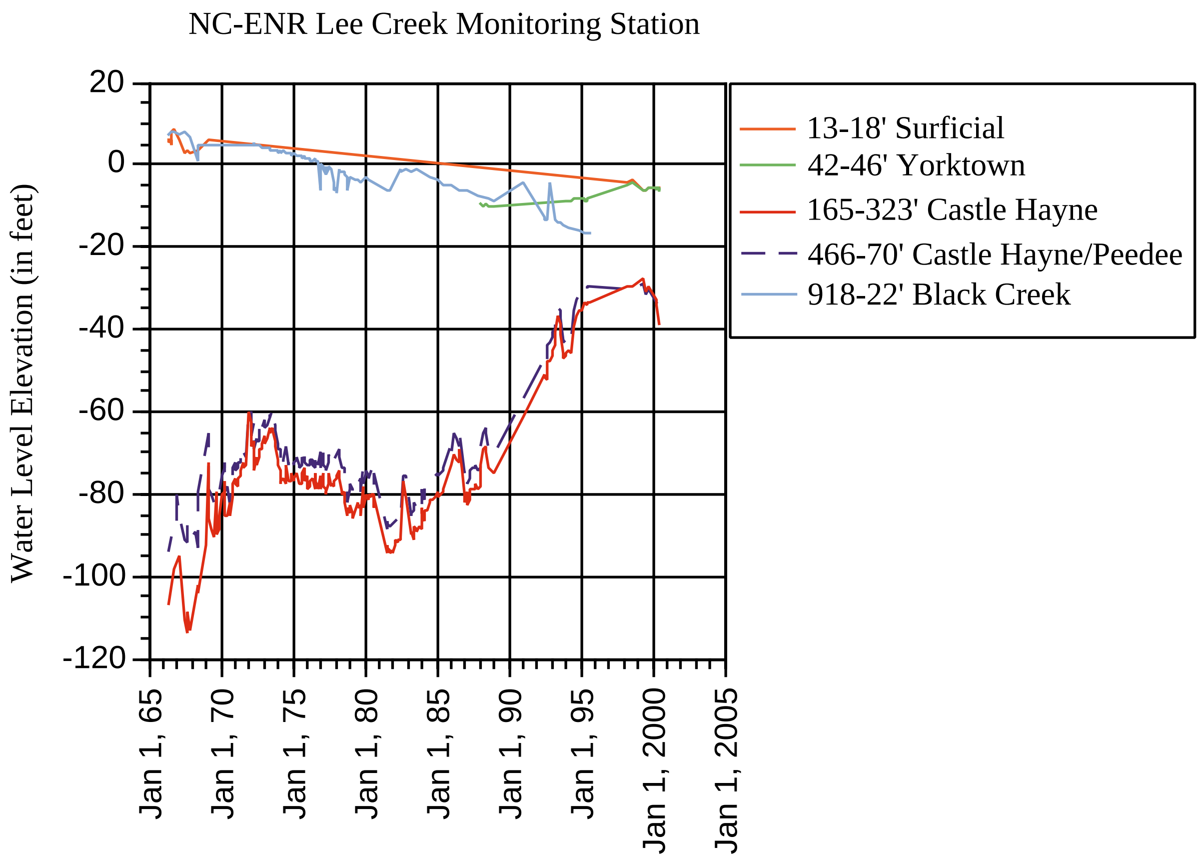


Figure 5: Hydrographs from NC-ENR Kinston Yard and Comfort Monitoring Stations



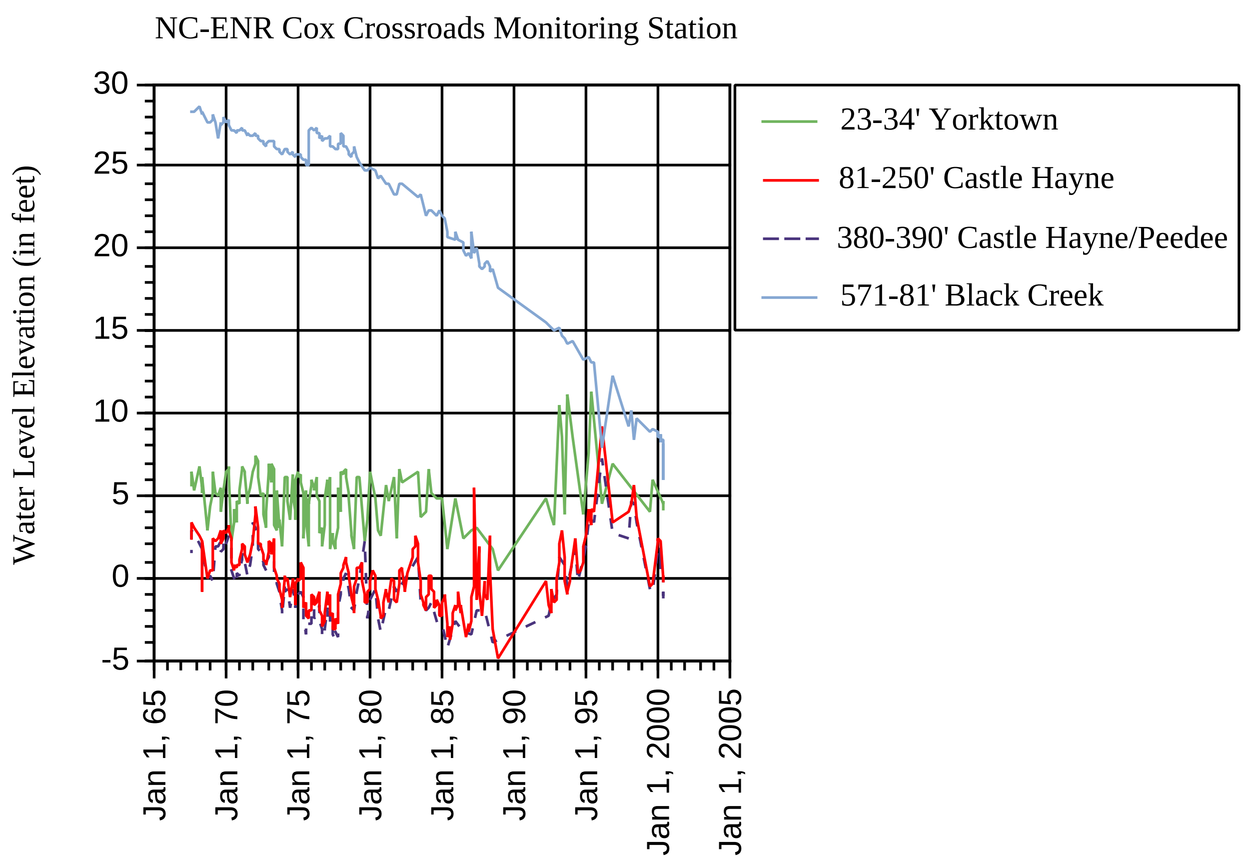


Figure 6: Hydrographs from NC-ENR Lee Creek Yard and Cox Crossroads Monitoring Stations

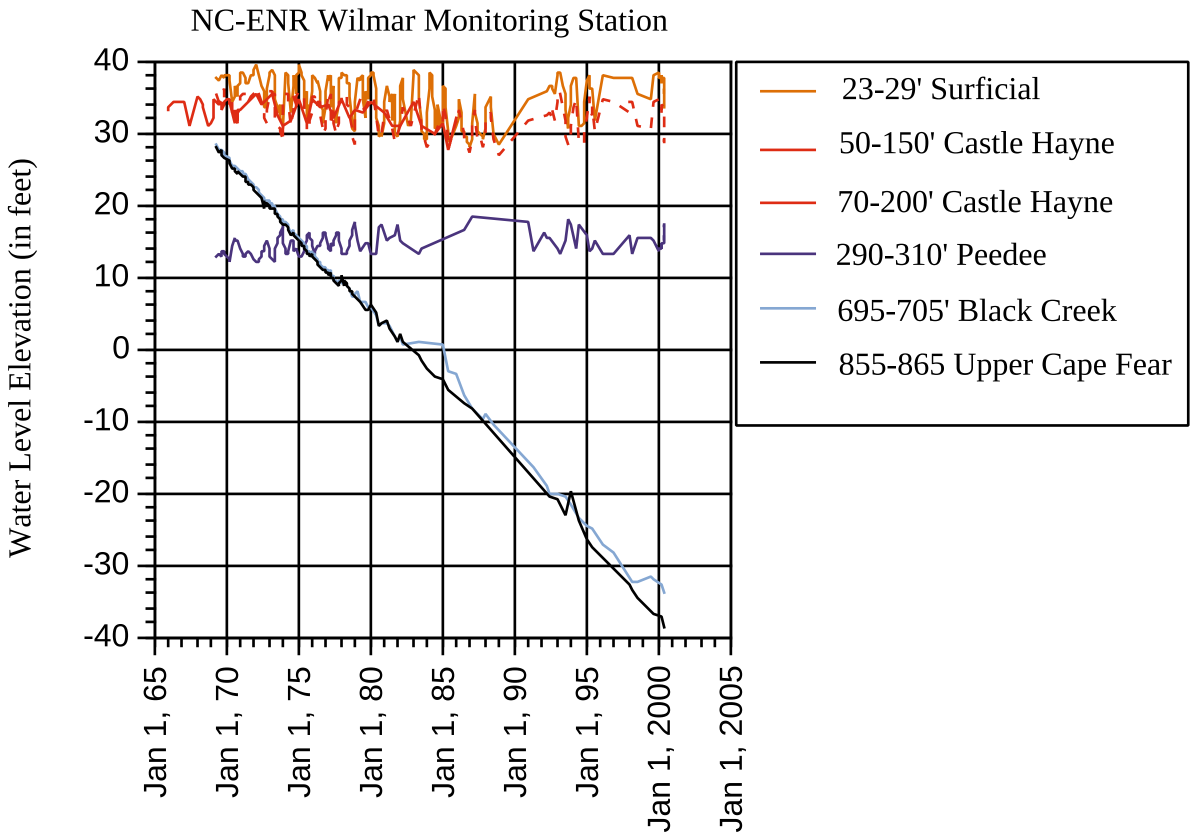


Figure 7: Hydrograph from NC-ENR Wilmar Monitoring Station

TABLE 3: Water Level Declines in feet per year measured in the Central Coastal Plain

County	Monitoring Station Name	Aquifer	Water Level Decline Rate in ft/year	Measurement Dates Begin	End
Beaufort	Lee Creek	Black Creek	0.84	Jun-66	Aug-95
Beaufort	Cox Crossroads	Black Creek	0.61	Aug-67	Jul-00
Beaufort	Wilmar	Black Creek	2	Mar-69	Jul-00
Beaufort	Wilmar	Upper Cape Fear	2.16	Mar-69	Jul-00
Jones	Comfort	Black Creek	6	Mar-80	Jun-00
Jones	Comfort	Upper Cape Fear	2	Dec-99	Jun-00
Lenoir	Kinston Yard	Black Creek	2	Aug-74	Jun-00
Lenoir	Kinston Yard	Upper Cape Fear	2.25*	Aug-74	Jun-00
Lenoir	Savannah School	Upper Cape Fear	1.8*	Nov-88	Jun-00
Craven	Clarks	Black Creek	2.64	Jul-79	Jun-00
Craven	Clarks	Upper Cape Fear	2.9	Apr-84	Jun-00
Duplin	Rose Hill	Black Creek	0.33	May-82	Jun-00
Duplin	Pink Hill	Black Creek	1.43	Jul-79	Jun-00
Duplin	Chinquapin	Black Creek	2.2	Jul-80	Jun-00
Wayne	Saulston	Black Creek	0.14	Jan-83	Jun-00
Wayne	Saulston	Upper Cape Fear	2	Feb-83	Jun-00
Wayne	Scotts Hill	Black Creek	0	Aug-72	Jun-00
Wayne	Scotts Hill	Upper Cape Fear	0	Feb-72	Jun-00
Pitt	D.H. Conley	Upper Cape Fear	0.41	Nov-88	Jul-00
Pitt	N. Pitt High School	Black Creek	0.08	Apr-80	Jun-00
Pitt	N. Pitt High School	Upper Cape Fear	1.35	Apr-80	Mar-00
Pitt	Farmville	Black Creek	0.12	Mar-72	Jul-00
Pitt	Farmville	Upper Cape Fear	1.5	Oct-76	Feb-98
Greene	Maury	Black Creek	0.1	May-79	Apr-93
Greene	Maury	Upper Cape Fear	2.9	May-79	Mar-93
Greene	Snow Hill	Upper Cape Fear	1.3	Nov-78	Jun-00
Onslow	Hadnot Point	Black Creek	2.28	Feb-87	Jun-00
Onslow	Jacksonville	Black Creek	5.6	Dec-86	Jun-00
Onslow	Jacksonville	Upper Cape Fear	5.4	Dec-86	Jun-00

*Black Creek and Upper Cape Fear combined as a single aquifer potentiometric surface maps show identical water levels in areas where there is no confinement between the two aquifers. It is assumed that water levels are the same in both aquifers in wells that are screened in both. This assumption had to be made due to the scarcity of more accurate data, and it is understood that this may not be correct in every case.

The potentiometric surface of the Peedee aquifer (plate 55) exhibits a prominent cone of depression in central Onslow County due to pumping from several water supply systems that use both the Peedee and Black Creek aquifers. The Peedee aquifer is not heavily used in the other Central Coastal Plain Counties, and declines have been minimal as indicated by hydrographs. An exception to this occurs at the EHNR Wilmar ground water monitoring station in western Beaufort County, where Peedee water levels have shown considerable decline due to mine depressurization operations.

Most of the aquifers in the Central Coastal Plain contain salt water over regions of variable extent. Salt water is defined for the purposes of this study as water containing greater than 250 ppm (parts per million chloride). As recognized by Winner and Coble (1989), the position of fresh water/ salt water interfaces within North Carolina Coastal Plain aquifers has a very complex pattern. Sediments were deposited during cyclic fluctuations of sea level over geologic time. The seaward limit of fresh water is unique for each aquifer as governed by variations in hydraulic properties, position and rates of recharge, thickness and hydraulic conductivity of overlying confining beds, and hydraulic gradients. Salt water interfaces are not sharply defined, but occur as transition zones of variable width due to diffusion between salty and fresh water. The movement of fresh ground water through deeper confined aquifers in the coastal plain causes interfaces to retreat slowly seaward over geologic time. However, in areas of heavy ground water pumping and resultant water level declines, saline ground water can move toward pumping centers due to a reversal of hydraulic gradient.
Current ground water conditions in the Central Coastal Plain can be summarized as follows:

-Water is being withdrawn from the Black Creek and Upper Cape Fear aquifers at a vastly higher rate than they are being recharged, and to a lesser extent, the Peedee aquifer. This has caused the ongoing development of extensive cones of depression. Recharge rates to the Black Creek and Upper Cape Fear aquifers are probably less than .5 inches per year where they are more deeply buried, and overlain by extensive, thick, generally non-leaky confining beds. The well confined nature of the aquifers has allowed for the widespread lateral transmission of drawdown effects.

-Water level declines have progressed to an extent in Lenoir and eastern Wayne Counties that the potentiometric surfaces of the Black Creek and Upper Cape Fear aquifers are close to the top of the aquifers in many areas. Active dewatering is taking place in the Black Creek aquifer in the city of Kinston well field, and will become more extensive across the area in a few years if allowed to progress.

-The decline of water levels in the Black Creek and Upper Cape Fear aquifers has caused some reduction in the amount of upward movement of ground water in discharge areas due to lowering of hydraulic head differentials between deeper and shallower aquifers.

-Due to the existing rate of ground water withdrawals, the potential exists for salt water intrusion into pumping centers located near salt water interfaces in the Black Creek, Upper, and Lower Cape Fear aquifers due to reversals in hydraulic gradient.

METHODS USED FOR INVESTIGATION OF THE SUBSURFACE

The following tools and techniques were used to separate the Quaternary through Cretaceous sedimentary section into component hydrogeologic units and to map and describe them across the study area.

1. Observation of significant differences in water levels across confining units, indicating hydraulic separation between aquifers, or the lateral persistence of water levels indicating the continuity of an aquifer.

2. Interpretation and correlation of borehole geophysical logs, including spontaneous potential, gamma ray, single point resistance, and resistivity logs.

   The spontaneous potential (SP) log is a recording versus depth of the difference between the potential of a movable electrode in the borehole and the fixed potential of a surface electrode. The SP is the resulting effect of several electromotive forces, including clay potential, liquid junction potential, and electrokinetic potential. The right-hand boundary of the curve generally indicates impermeable formations such as clay. The left-hand boundary generally indicates formations of higher permeability such as those made up of sand or porous limestone. The SP log was used in this study to determine permeable bed boundaries, and to estimate thickness and percentage of permeable materials. In addition, it permitted correlation of beds from well to well, in conjunction with gamma ray, resistivity and lithologic logs.

   The gamma ray curve is a measurement of natural gamma radiation emitted by a geologic formation. Higher curve values are reflective of higher amounts of clay and phosphate minerals in the area of study, whereas lower curve values were indicative of the presence of limestone and sand in the geologic section. Gamma ray curves in many cases were valuable for correlation, by virtue of having produced distinctive signatures across zones of phosphate mineralization.

   The single point resistance log is a measurement of electrical resistance, measured in ohms, between an electrode in a well and an electrode at the land surface, or between two electrodes in a well. The measurement does not take into account the length or cross-sectional area of the current travel path, and thus can not be used for quantitative interpretation (Keyes, 1990). However, the single point resistance curve was useful for interpreting lithology and for thin bed detection.

   Normal resistivity logs measure formation resistivity in ohm-meters, which takes into account the length and cross sectional area of the current travel path. Thus, short and long normal measurements take into account the intrinsic properties of the material and can be used for quantitative interpretation of formation fluids. The long normal curve provides a reading beyond the flushed zone of the borehole where formation fluids are generally undisturbed by drilling fluid.

   Resistivity curves in combination with SP and gamma ray curves helped to distinguish between fresh water and salt water bearing strata, and between permeable and nonpermeable strata. The combination of log types were used to identify and correlate aquifer and confining unit tops and bases, and to calculate the percentage of permeable material, and the net thickness, in feet, of permeable material in each aquifer.

3. Interpretation and correlation of lithologic logs from both core and cutting samples. Lithologic logs were used in combination with borehole geophysical logs to define vertical and lateral stratigraphic variations in the subsurface. Formation tops from North Carolina Geologic Survey lithostratigraphic logs were used in accordance with well log correlations to determine the relationship between stratigraphic and hydrogeologic units. Formation tops were plotted on a network of hydrogeologic cross sections (plates 1 through 18) prepared for this report.

4. Observation of differences in chloride concentrations across confining units, and chloride concentration similarities within the same aquifer.

5. Observation of drawdown effects observed from pump test data.

6. Observation of the lateral transmission of drawdown effects from pumping, indicating the lateral continuity of an aquifer. Pump test data was used to determine transmissivity, specific capacity, hydraulic conductivity, and storativity of aquifers, and vertical hydraulic conductivity of confining beds.

7. Interpretation of apparent resistivity measurements from Time Domain Electromagnetic Soundings (TDEM). This is a surface geophysical technique by which an electromagnetic field is induced at land surface. As soon as the transmitter current is stopped, eddy currents are propagated into the subsurface from a transmitter loop. A secondary magnetic field is generated that changes with time as the eddy currents propagate downward through the subsurface. A central receiver coil measures changes in the magnetic field, which are recorded by the TDEM system over the course of the sounding time. The velocity and decay rate of the eddy currents are directly related to the electrical resistivity of the subsurface, and are converted by TEMIX XL software into apparent resistivity values. The resistivity of a geologic formation is affected by the fluid contained within the formation, its effective porosity, and the percentage of clay (Keyes, 1990). Increases in fluid salinity, effective porosity, and clay content all have the effect of causing decreased resistivity values. Decreases in the same produce increased resistivity values. Therefore, it is important to understand how changes in these variables are affecting TDEM response. Employed in conjunction with borehole geophysical logs and chloride sample data, TDEM profiles provided information which allowed for interpretation of chloride distribution patterns between areas of well control.

A regional network of cross sections was constructed across the study area in order to trace the lateral distribution and thickness of hydrogeologic units. Maps of the elevation of the tops of units were constructed, along with maps of the thickness of aquifers and confining beds, and the percentage of permeable material and net thickness of permeable material of each aquifer. Potentiometric surface maps were prepared for the Peedee, Black Creek and Upper Cape Fear aquifers using water level data collected by the NC Division of Water Resources in October, 1999.

HYDROGEOLOGIC FRAMEWORK OF THE STUDY AREA

The system of eight regional aquifers and intervening confining units found in the Quaternary through Cretaceous age sedimentary wedge in the Central Coastal Plain were delineated in terms of their lateral distribution, thickness, hydraulic properties, and relationship to stratigraphic units. Moreover, aquifers were described in regard to ground water flow interactions, distribution of salt water and chloride concentrations, and natural or pump induced ground water movement.

Aquifers and confining layers are described as follows:

SURFICIAL AQUIFER

The surficial aquifer is the uppermost aquifer in the hydrogeologic system, is uniformly present across the Central Coastal Plain, and is made up primarily of sediments of Holocene to Pleistocene in age. It also contains parts of older formations depending on the varying age of underlying sediments and the varying stratigraphic position of the uppermost confining layer across the study area. This is illustrated on hydrogeologic cross sections prepared for this study (plates 1 through 18). The surficial aquifer is unconfined and thus, the water table is able to fluctuate with changes in ground water storage over time.

In the tidewater region of the Central Coastal Plain, sediments comprising the surficial aquifer were deposited in a marginal marine environment (Brown and others, 1973), consisting of fine grained sand, silt, clay, shell material, and combinations of these sediments. A large portion of the tidewater area is covered by a veneer of peat deposits which were laid down in coastal swamps and river floodplains. The underlying Yorktown, Belgrade, River Bend, and Castle Hayne Formations may also be part of the surficial aquifer where confining beds are absent between these formations and shallower Quaternary age sediments (plates 1 through 18). Shallow sediments in the tidewater region of the study area generally have poor to moderate infiltration capacities as determined from U.S. Soil Conservation Service maps (Tant and others, 1974). Over much of Craven County, conventional septic tanks will not function properly because of the low percolative capacity of shallow sediments. Vertical saturated permeabilities range between .06 to .2 inches per hour in the tidewater region. Recharge rates can be estimated from the saturated permeability to be as little as 5 inches per year (Heath, 1980;Winner and Coble, 1989).

To the west of the tidewater region, sediments of the surficial aquifer become increasingly nonmarine in origin, consisting of sand, sandy clay, clay, and scattered gravel units. Shallow sediments of the inner Central Coastal Plain have generally moderate to good infiltration capacities with vertical saturated permeability of .2 to 20 inches per hour (Tant and others, 1974). Recharge rates are estimated from this to be as high as 20 inches per year (Heath, 1980). In the inner Central Coastal Plain the upper portions of the Yorktown, Castle Hayne, Beaufort, Peedee, Black Creek and Cape Fear Formations sometimes make up part of the surficial aquifer where confining beds are absent between these formations and the shallower Quaternary age sediments (plates 1 through 18).

Over the wide range of the study area the surficial aquifer ranges in thickness between 4 and 224 feet, with areas of maximum thickness found in Craven, Carteret and Onslow Counties.

In order to determine the distribution of permeable versus nonpermeable sediments in the surficial aquifer, maps were prepared to show the percentage of permeable material (plate 25) and the net thickness in feet of permeable material (plate 26).

A limited number of wells were available for analysis of surficial sediments due to the presence of shallow casing in many wells. Where gamma ray or lithologic logs were available, they were used to determine sediment composition behind casing, Since the calculations of per cent and net thickness of permeable material were based on analysis of electric and gamma ray log curves and lithologic logs, the values are not reflective of the magnitude of permeability or hydraulic conductivity of the sediments.

The percentage of permeable material varies from 34 to 100 per cent across the study region. No apparent trends or patterns are discernable. The net thickness of permeable material varies between 1 and 171 feet. Maximum accumulations of permeable material are found in northeastern Onslow and north central Craven Counties.

The presence of salt water in the surficial aquifer is limited to the Tidewater region of the report area, and is found along the shoreline of the Atlantic Ocean, and along the high tide limits of the New, White Oak, Neuse, Pamlico Rivers and other rivers and streams that flow into the sounds and bays.

YORKTOWN AQUIFER AND CONFINING UNIT

The Yorktown aquifer and confining unit are present only in the northern and eastern parts of the study region including Edgecombe, Martin, Beaufort, Pitt, Carteret, northern Greene, northern Wayne, and eastern Craven Counties. The aquifer and overlying confining beds are generally made up of the Yorktown Formation, but sometimes contain younger Quaternary age sediments where the confining bed is higher in the stratigraphic section. The Yorktown Formation was deposited during a major marine transgression into the Central Coastal Plain during the Pliocene epoch.

The Yorktown confining unit can be described as a series of clay and silt beds which do not comprise a single unit, as these beds vary significantly in stratigraphic position. Over the extent of the study region, the lithology of the Yorktown aquifer consists of lenticular quartz sands which are interbedded with blue to gray colored clay. The Yorktown aquifer commonly contains layers of shell material and gray colored shell marls. As indicated by regional cross sections (plates 1 through 18), the Yorktown is not a continuous aquifer in the area where the Yorktown Formation is present. Sediments which comprise the aquifer are quite often part of the unconfined, or surficial aquifer, due to the discontinuous nature of overlying confining layers. Its thickness ranges between 4 and 87 feet over the extent of the study region, attaining maximum thickness in Beaufort County.

The percentage of permeable material in the Yorktown varies between 30 and 100 percent with maximum values most prevalent in Pitt County. The total thickness of permeable material varies between 4 and 64 feet across the study region. Thickest accumulations of permeable sediments are found in southern Pitt and central Beaufort County.

Water from this aquifer is moderately to excessively hard, and contains a considerable amount of iron. The Yorktown is not a heavily used aquifer in the study region due to its lower quality and lower yield in relation to deeper aquifers. It is a suitable source of ground water for domestic usage, or for larger scale usage if numerous wells are constructed over large land areas.

Salt water occurrence in the Yorktown aquifer occurs to the east of the area covered in this report (Winner and Coble, 1989).

CASTLE HAYNE CONFINING UNIT

The Castle Hayne confining unit consists of clay and silt beds that vary in stratigraphic position between the upper Castle Hayne Formation and the overlying, variable younger units which overly this formation across the area. Downdip, in the eastern part of the study region, the confining unit is sometimes in the upper part of the Belgrade or River Bend Formations. In the northern and eastern part of the study area, the confining unit is sometimes located in the lower part of the Yorktown Formation. As indicated on regional cross sections (plates 1-18), and an isopach map of its thickness (plate 30) the Castle Hayne confining unit is absent in a number of wells, leaving the Castle Hayne aquifer in direct hydraulic communication with the shallower Yorktown or surficial aquifers. Where multi-well monitoring station data was available to observe long term water levels variations across the Castle Hayne confining unit, head differences are generally from 3 to 6 feet. Hydrograph data indicates that the surficial and Castle Hayne aquifers show similar water level variations in response to seasonal recharge variations. This indicates that the Castle Hayne aquifer is not generally well confined, and is recharged at a only a slightly lower rate than the surficial aquifer.

A map of the elevation of the top of the Castle Hayne confining unit (plate 29) indicates that it dips to the southeast at a rate that varies between 2 feet per mile and 12 feet per mile, and ranges in elevation between 71 feet above sea level to 187 feet below sea level. The thickness of the confining unit varies between zero and 116 feet across the study area, with maximum accumulations found in Onslow County (plate 30).

CASTLE HAYNE AQUIFER

The Castle Hayne aquifer is present only in the eastern counties of the study area, and is made up primarily of the Eocene Castle Hayne Formation. The aquifer also includes the Oligocene Belgrade and River Bend Formations in Onslow, Jones, Craven and Beaufort Counties, and the underlying Beaufort Formation (Paleocene) in areas where confining beds are absent between the Castle Hayne and Beaufort aquifers. As indicated by a regional elevation map (plate 31), the top of the Castle Hayne aquifer dips gently to the southeast at a rate that varies between 2.5 and 14 feet per mile, and ranges between 65 feet above sea level to 245 feet below sea level in elevation.

In terms of lithology, the Castle Hayne aquifer may be generally described as a sandy, molluscan-mold limestone and a bryozoan-echinoid skeletal limestone, taking into account both the Spring Garden and Comfort members of the Castle Hayne Formation. In the easternmost counties of the study region, the Castle Hayne Formation is generally sand rich in its lower section as indicated on regional cross sections (plates 1-18). Where the Beaufort Formation is included, the aquifer is also composed of glauconitic sand and silty clay. Where the Belgrade and River Bend Formations make up the upper part of the aquifer in the eastern part of the study area, lithologies include oyster shell mounds in tan to orange sand matrix, calcarenite, and sandy, molluscan mold limestone.

The thickness of the aquifer varies between zero where it pinches out to the west in eastern Duplin, western Jones, eastern Pitt and Martin Counties, and 954 feet at the NCDENR Camp Glenn Research Station in western Carteret County. The aquifer thickens from west to east, and becomes more deeply buried toward the east as shown in regional cross sections (plates 2 through 10).

A map of the percentage of permeable material in the Castle Hayne aquifer (plate 32) indicates that values generally range between 60 and 100 per cent. A map of total thickness of permeable material indicates a range of 9 to 362 feet across the study region (plate 33), with thickest accumulations found in the easternmost counties. As pointed out by Winner and Coble (1989), the Castle Hayne aquifer is made up of rocks that have widely different hydraulic conductivities. The limestone portion of the aquifer has generally very high porosity and permeability because of extremely well developed dissolution porosity. Pump test data from the area indicate a transmissivity range of 212 to 9930 ft^2/day (table 2) and hydraulic conductivity range of .42 to 31 feet per day. Lower values are obtained where well screens are exclusively in the less permeable, non-limestone portions of the aquifer. Storativity values range between .0001 and .0014. Narkunas (1980) reported a range of transmissivity values from 6,100 to 12,100 ft^2/day, and storativity range of .000074 to .0026 from eleven pump tests. Yields of up to 1,000 gallons per minute from the Castle Hayne aquifer are not uncommon due to its high transmissivity. Yields are generally found to increase toward the east where the aquifer has a higher total thickness of permeable material.

The Castle Hayne aquifer is recharged by water that leaks through its confining layer from the shallower Yorktown and surficial aquifers. In the outcrop area of the Castle Hayne Formation in northern Craven, eastern Jones, Onslow and Pender Counties, the aquifer is overlain only by a thin veneer of post Yorktown age sediments, which allows for much greater recharge rates, especially where significant clay layers are absent in the shallow subsurface (plate 58). Hydrograph data from research stations where long term water level data was available was used for comparison of trends in the Castle Hayne, Yorktown and surficial aquifers. These data indicate that where the Castle Hayne is not deeply buried, nearly identical seasonal water level variations occur in the Castle Hayne and the shallow aquifers, indicating a similar rate of recharge to the Castle Hayne as to the shallower aquifers (figures 6 and 7).

The approximate intersection of the fresh water/salt water interface in the Castle Hayne aquifer with the base of the aquifer occurs along a meandering north to south line extending from western Beaufort County through eastern Craven County (plate 31). The interface is not easily discernable on TDEM profiles due to masking effects of clay in the lower part of the aquifer, which tend to suppress resistivity values in freshwater portions of the aquifer. Zones of reduced resistivity observed in the lower part of the aquifer can be caused by increased clay content, or increased chloride concentration, or both. Thus, the interface may be mapped with the best confidence where chloride data is available in conjunction with TDEM profiles.

The intersection of the interface with the top of the aquifer occurs farther to the east of the area of this study, and is documented by Winner and Coble (1989).

BEAUFORT CONFINING UNIT

The Beaufort confining unit consists of clay and silt beds which vary significantly in stratigraphic position between the lower part of the Eocene Castle Hayne Formation and the upper part of the Paleocene Beaufort Formation. As illustrated in regional cross sections (plates 1 through 18), the Beaufort confining unit is absent in many wells, allowing direct hydraulic communication between sediments that normally comprise the Beaufort aquifer and the Castle Hayne aquifer. Due to its inconsistent presence in the study area, the Beaufort confining unit was not considered to be a regionally mappable unit, and is depicted exclusively on hydrogeologic cross sections prepared for this study. Where present, this unit ranges in thickness between 4 and 180 feet, with maximum thicknesses encountered in the downdip portion of the study area.

BEAUFORT AQUIFER

The Beaufort aquifer is made up primarily of glauconitic, fossiliferous, sometimes clayey sands and intermittent limestones of the Beaufort Formation, but also includes over regions of varying extent, sandy limestone and sands of the lowermost Castle Hayne Formation. Sometimes included are the sands and clays of the uppermost part of the Peedee Formation. As indicated by geophysical logs and water level data, the Beaufort aquifer is not hydraulically separated from the Castle Hayne aquifer in many areas of the region due to the discontinuous presence of confining beds (plates 1 through 18). The Beaufort is therefore not a regionally continuous and distinct aquifer. Where present, the aquifer ranges in thickness between 10 and 200 feet, with thickest accumulations found in Beaufort and eastern Onslow, Jones, and Craven Counties. Percentage of permeable material averages 72 per cent with a range of 39 to 100 per cent. Net thickness of permeable material in the Beaufort aquifer averages 71 feet.

Usage of this aquifer within the study area is limited primarily to Pitt, Martin and Beaufort Counties where yields range from 15 to 150 gallons per minute (Brown, 1959).

Recharge to the Beaufort aquifer occurs through leakance across its confining bed from the overlying Castle Hayne and younger aquifers. It is recharged more directly, and probably at a higher rate, where it is overlain only by Quaternary age sediments in parts of western Lenoir and eastern Craven Counties.

The aquifer contains water of greater then 250 ppm chloride concentration in the eastern part of the study area as shown on hydrogeologic cross sections E-E'and G-G' (plates 6 and 8). The interface is not discernable on TDEM profiles, and is defined exclusively by chloride measurements from monitoring wells as exhibited on hydrogeologic cross sections.

PEEDEE CONFINING UNIT

The Peedee confining unit is comprised of beds of clay and silt with varying amounts of sand which are positioned stratigraphically near the contact of the Paleocene Beaufort and Upper Cretaceous Peedee Formations. West of the updip limit of the Beaufort Formation, beds which make up the Peedee confining unit are situated in the uppermost Peedee Formation or in the lower part of the Yorktown, or in the lower part of the Quaternary where the Yorktown Formation is absent. The unit dips gently to the southeast at a rate of 14 feet per mile as indicated by a regional map of its elevation (plate 34). As displayed by a contour map of its thickness (plate 35), this confining unit varies between 0 feet where it pinches out to the west in the study region, to a maximum of 121 feet in a well at Fort Barnwell in Craven County. Geophysical log correlation, and hydrograph data depicted in hydrogeologic cross sections (plates 5 and 6) and an isopach map of total thickness (plate 35), indicate that the Peedee confining unit is missing in several wells in Beaufort and Craven Counties. Direct hydraulic communication occurs in these areas between the Peedee and Beaufort, or Peedee and Castle Hayne aquifers.

Aquifers directly above and below the Peedee confining unit exhibit a maximum head difference of 35 feet at the NCDENR Jacksonville research station in Onslow County (plate 9, cross section H-H') and a minimum difference at Deppe research station of 3 feet (plate 9). Of the 9 research stations available in the study area to observe long term head differences across the unit, the average head difference was 11 feet. Hydrographs indicate that head differences have been maximized due to heavy pumping from the Black Creek and a smaller rate of pumping from the Peedee aquifer.

PEEDEE AQUIFER

The Peedee aquifer is comprised principally of the Upper Cretaceous Peedee Formation, but also includes over regions of varying extent, part of the of the Upper Cretaceous Black Creek Formation, and the lower part of the Beaufort Formation. Updip of the western limit of the Beaufort Formation, the Peedee aquifer also includes in some areas, sediments of Quaternary age. In the northern part of the study area, in Pitt, western Beaufort and Martin Counties, the Peedee aquifer sometimes includes part of the Yorktown Formation. Due to the number of formations included, the lithology of the aquifer is highly variable. In general terms, the lithology is characterized as glauconitic sand and clayey sand, with interbedded clays, greenish gray to olive black in color. Sandy molluscan limestones occur locally in the upper part.

As indicated by a contour map of the elevation of the top of the aquifer, it dips gently to the southeast at a rate of 12 feet per mile. The aquifer ranges in thickness from zero where it pinches out along a line indicated in plate 36, to 755 feet in a Colonial Oil and Gas Corp. well in eastern Onslow County. The average thickness across the study region is 128 feet. Aquifer test information calculated for the study area from single well tests indicates that the Peedee aquifer has a range of transmissivity between 237 and 1,166 ft^2/day (table 2). Narkunas (1980) reported a range of transmissivity of 400 to 1,950 ft^2/day, and a storativity range of .001 to .0017.

As indicated by hydrographs and geophysical log correlations, the Peedee aquifer is divided into two hydraulically distinct units designated as the Upper and Lower Peedee aquifers over parts of Lenoir, Pitt, Greene, and Beaufort Counties. Examples of this are depicted on regional cross sections (plates 5, 13, 15, 17). Head differences between the upper and lower units range between 15 and 22 feet. The Peedee aquifer is in direct hydraulic communication with the Beaufort, and sometimes the Castle Hayne aquifer, in areas where the Peedee confining unit is absent in Beaufort and Craven Counties. An example of this is illustrated on hydrogeologic cross section D-D' (plate 5) at the NCDENR Lee Creek and Cox Crossroads station sites where hydrograph data from screens in the Castle Hayne, Beaufort, and Peedee show similar water levels and similar long and short term water level variations. The Castle Hayne, Beaufort, and Peedee geologic section in this area are acting as a single aquifer.

The Peedee aquifer receives recharge by leakance across confining beds from overlying aquifers. Recharge occurs in interstream areas where heads are lower in the Peedee than in shallower aquifers, whereas discharge occurs to stream and rivers where the head is higher in the Peedee than in overlying aquifers. The rate of recharge is directly proportional to the vertical hydraulic conductivity and head difference across the confining bed and inversely proportional to the thickness of the confining bed. Regional differences in these factors, as well as variations in the transmissivity of the aquifer cause recharge rates to vary across the study region. As depicted in regional cross sections, the aquifer is dissected by numerous rivers and streams along its subcrop area, allowing direct discharge of ground water from the aquifer. Thus, much of the water gained by recharge is lost to surface water. Recharge rates are highest in Lenoir, central Duplin, western Onslow, Jones, and Craven Counties, and southern Pitt and Green Counties where the unit is overlain exclusively by a thin veneer of Quaternary age sediments (plate 59). This is depicted in regional cross sections (plates 4 through 9, and 12 through 14). As evidenced by a lack of seasonal variation influences on hydrographs, recharge rates are lowest where the Peedee is deeply buried and well confined.

A potentiometric surface map of the Peedee aquifer representing water levels taken from an October, 1999 synoptic survey is exhibited in plate 55. Evidence of pumping stress is apparent in Onslow County where withdrawals from the Onslow and Northwest Onslow County well fields have produced a drop in the Peedee potentiometric surface to approximately sea level. Water level declines of 1.4 feet per year are observed at the NCDENR Comfort research station since1980 (hydrograph in figure 5). As this station is located away from the well fields, decline rates were, in all probability, much higher at the pumping centers. As mentioned earlier, the Peedee aquifer merges with the Castle Hayne and Beaufort in parts of Beaufort County as observed from hydrograph and geophysical log data. In this area, water levels in this hydraulically connected system are being impacted from high volume pumping from mine pit dewatering operations. As pumping rates from the mining operation have varied over the years since the mid-1960s, in combination with variations in natural recharge and discharge, water levels have fluctuated in an almost identical manner at various screened intervals (hydrographs: figures 6 and 7).

Outside of Onslow County, usage of the Peedee aquifer is limited to a small number of domestic, industrial, and agricultural wells in the central coastal plain study area. The Peedee is an under-utilized aquifer in the area of concern, although it is generally thinner and less transmissive than the Black Creek aquifer. The Peedee is a logical alternative source of ground water for the region that would serve to reduce reliance on the Black Creek aquifer.

An approximate intersection of the fresh water/salt water interface in the Peedee aquifer with the top and base of the aquifer occurs along meandering north to south lines extending from eastern Martin and Beaufort County, through northern Craven County, eastern Jones and central Onslow Counties. The interface is defined by chloride measurements from monitoring wells and by TDEM soundings. As depicted in TDEM resistivity cross sectional profiles a-a', b-b', c-c', and d-d' (plates 20 through 23) the interface is defined where TDEM derived resistivity is consistently 10 ohm-meters or less. Similar values can however, occur in the fresh water portion of the aquifer in areas where clay percentages are high, or where thick clay layers are present. Due to limitations of the smooth modeling function of TDEM analysis software which allow a maximum of 19 layers, averaging affects are produced through interbedded sand and clay intervals. The presence of intersticial or interbedded clay in a formation will cause a suppression of resistivity values due to potassium content in clay, which causes high conductivity.

The interface is illustrated on regional hydrogeologic cross sections (plates 5 through 10, 14, 16, and 18) and on a map of the top of the Peedee aquifer (plate 36). The meandering nature of the interface is caused by differences in transmissivity in the aquifer, and by variations in recharge rates from place to place, which causes flushing of salt water in a seaward direction at varying rates over geologic time. The transition zone is much flatter and of greater width in northern Craven and Jones Counties, and southern Martin County, indicating higher transmissivity in these areas, and possibly higher recharge rates than elsewhere. The distance between isochlor positions at the aquifer top and base is much more narrow in the Peedee aquifer than the Black Creek (plate 41) due to the greater thickness and transmissivity of the Black Creek aquifer.

BLACK CREEK CONFINING UNIT

The Black Creek confining unit is a generally thick, massive section of clay and silt with variable amounts of sand, that was deposited in blanket-like fashion over a large area of the Central Coastal Plain. This unit is primarily within the Black Creek Formation, but also contains lower clay beds of the Peedee Formation. West of the updip limit of the Peedee Formation, in the area where the Yorktown Formation is absent, the Black Creek Formation is directly overlain by a thin veneer of Quaternary deposits. In this area, clay beds in the lower Quaternary are sometimes part of the Black Creek confining unit. Clay beds in the lower part of the Yorktown Formation can be included in the confining unit in northern Wayne and Greene, western Pitt, and Martin Counties.

In general, the Black Creek confining unit is easily recognized and correlated on borehole geophysical logs except in the westernmost counties where it is thinner and less continuous. This is illustrated on regional cross sections (plates 1-18). Where hydrograph data are available to observe long term water level variations above and below this unit, steep, pump induced declines in the Black Creek aquifer are contrasted sharply with shallower aquifers, which generally are not affected by pumping from the Black Creek. Head differences across this unit have escalated for decades with steady, inexorable decline in the potentiometric surface of the Black Creek aquifer. Differences of as much as 144 feet are noted at the NCDENR Jacksonville Station in Onslow County, with an average across the region of 44 feet, and range of 10 to 144 feet. Aquifer test analyses on the Black Creek aquifer very commonly follow a Theis curve (figure 4), indicating little to no leakance across the confining unit within the duration of pumping. The thickness and very low vertical hydraulic conductivity the Black Creek confining unit account for the negligible drawdown influence on overlying aquifers of large scale regional withdrawals from the Black Creek aquifer. However , it is evident that in Beaufort and Craven Counties, concentrated, large scale withdrawals from the Castle Hayne aquifer in support of mine dewatering operations have caused drawdown in the Black Creek aquifer. This has occurred in spite of the effectiveness of the confining unit. Water level responses in the Black Creek are illustrated on hydrographs at the NCDENR Lee Creek, Wilmar, and Cox Crossroads monitoring stations (figures 6 and 7). Drawdown effects in the Black Creek are largely due to the lack of confinement between the Castle Hayne, Peedee, and Beaufort aquifers in this area, allowing direct hydraulic communication between the aquifers above the Black Creek.

As indicated by a contour map of its elevation (plate 39), the Black Creek confining unit dips gently to the southeast at a rate of 17 feet per mile. The unit ranges in thickness from zero where it pinches out in the western part of the area along a line approximated on plate 40, to 292 feet in the Carolina Petroleum, Charles Bryan No, 1 well in Onslow County. The unit thickens prominently from east to west as displayed on an isopach map (plate 40), and has an average thickness of 46 feet.

BLACK CREEK AQUIFER

The Black Creek aquifer is made up primarily of the Upper Cretaceous Black Creek Formation, but also includes permeable beds from younger and older formations in the study area. Where overlain by the Peedee Formation, the aquifer may include in some areas, sands in the lower part of the Peedee. In northern Wayne and Greene, western Pitt, and Martin Counties the aquifer sometimes includes sands or shell beds in the lower part of the Yorktown Formation. Where the Yorktown and Peedee Formations are absent in the southwestern part of the study area, sands in the lower part of the Quaternary veneer often make up part of this aquifer. The lowermost Black Creek aquifer sometimes includes sands of the upper part of the Cape Fear Formation. The base of the aquifer is designated as the top of the Upper Cape Fear confining unit.

The Black Creek aquifer may be described in terms of lithology as alternating beds of gray, sometimes calcareous, glauconitic sand and black to gray clay. The Black Creek Formation is recognized in the subsurface by a high amount of organic material, particularly in the form of lignite. Individual sand bodies are discontinuous in the subsurface as indicated by well log correlations and may be described as lenticular in nature. However, permeable sediments in the aquifer are well connected hydraulically as evidenced by the widespread lateral transmission of drawdown effects in response to pumping (plate 56). Sand bodies are often interbedded with numerous, thin clay layers as interpreted on geophysical logs. The percentage of permeable material in the Black Creek aquifer varies between 53 and 88 per cent through the study area as indicated by a contour map shown in plate 42, with an average value of 64 per cent. Total feet of permeable material varies between 16 and 334 feet, with an average value of 107 feet (plate 43). Calculations were based on analysis of 114 borehole geophysical logs. The total thickness of the Black Creek aquifer varies between zero where it tapers to a feather edge along its western limit (plate 41) to 442 feet as measured in the NC Oil and Gas, Baucom No. 1 well in Onslow County.

The top of the Black Creek aquifer dips gently to the southeast at a rate that varies from 16 feet per mile in the western counties to 28 feet per mile in Jones and Onslow Counties (plate 41). The elevation range of the top of the aquifer as calculated from logs is between 166 feet above sea level in western Wayne County to 1207 feet below sea level in the Carolina Petroleum, Charle Bryan No. 1 well in Onslow County.

Hydrographs and geophysical log correlations indicate that the Black Creek aquifer is divided into two hydraulically distinct units designated as the Upper and Lower Black Creek aquifers over parts of Lenoir, Duplin, Wayne, and Pitt Counties. Examples of this are depicted on regional cross sections (plates 5, 8, 9, 11, 12 and 13). Head differences between the upper and lower units range between 9 and 35 feet as observed at six NCDENR monitoring station sites. Water level histories as depicted on the NCDENR Chinquapin station hydrograph (plate 9) indicate that the upper Black Creek aquifer potentiometric surface was not affected by regional declines, while during the same time period the lower Black Creek aquifer showed a water level decline of 2.2 feet per year. As more data becomes available in the Central Coastal Plain it will be easier to map the areal extent of the upper and lower units. This is an important consideration in terms of the future management of the aquifer.

The Black Creek aquifer has for decades, been the most heavily used aquifer in the North Carolina Central Coastal Plain due to its high quality water and negligible treatment costs. However, steadily increased reliance on this aquifer for municipal, industrial and agricultural usage has resulted in a persistent decline in its potentiometric surface to a level which in some areas of the Central Coastal Plain is causing dewatering to occur, or will bring about dewatering within a few year. An example of this is illustrated in cross section in figure 8, showing the Black Creek potentiometric surface in relation to the aquifer and confining unit through Greene and Lenoir County. A recent survey by the North Carolina Division of Water Resources (1999), estimated total ground water withdrawals from the combined Cretaceous aquifer system to be 116 million gallons per day. Previous estimates by the U.S. Geological Survey determined 1980 total usage in the Central Coastal Plain (excluding Onslow and Jones Counties) to be 21.4 million gallons per day (Winner and Lyke, 1986). Estimates in 1986 by the USGS for Jones and Onslow Counties

(Lyke and Brockman, 1990) amounted to 7.8 million gallons per day. Dramatic increases in usage are apparent.

Winner and Lyke (1986) compared prepumping water levels in the Black Creek and Upper Cape Fear aquifers with water levels taken between 1979 and 1981. Comparisons indicated a general water level decline of more than 50 feet, with declines of greater than 100 feet around the pumping areas at Farmville, Greenville and Kinston. Maximum observed declines were reported to be 150 feet at Kinston. From 1980 to present, hydrograph data indicate the continuation of rapid, regional declines as reported in table 4. Over the last 20 years, an average water level decline of 36.62 feet has occurred in the Black Creek Aquifer and 19.41 feet in the Upper Cape Fear aquifer based on measurements from NCDENR monitoring wells. As indicated in table 3, the highest declines have occurred in monitoring wells located near pumping centers. Much higher decline rates are occurring within the pumping centers. Rates of decline are reported by monitoring station and aquifer in table 3.

A regional potentiometric surface map was prepared for the Black Creek aquifer using data from an October, 1999 synoptic survey of the Central Coastal Plain that was conducted by the North Carolina Division of Water Resources (plate 56). The synoptic survey included data from NCDENR monitoring stations and various municipal wells in and around the pumping centers. Evident on the potentiometric surface map are prominent, coalescing cones of depression centered in Lenoir, Pitt and Onslow Counties. The development and growth of cones of depression in the Black Creek started around 1900, when significant pumping stresses began (Winner and Lyke, 1986). Pumping stresses and water level declines in the Cretaceous aquifers of the Central Coastal Plain were first addressed by Nelson and Barksdale (1965) in a study of ground water in the Kinston area. Since this time, the installation and monitoring of numerous ground water monitoring wells has provided water level data in order to accurately track regional declines. Hydrograph data from monitoring wells, as depicted on regional cross sections through the study area (plates 1-18) indicates that water levels in the aquifer have been dropping at a rate of 2 to 8 feet per year, with the fastest rate of decline observed at the NCDENR Comfort station in Onslow County. Decline rates are much faster within the pumping centers as determined from historic water level measurements in well fields. Ground water levels have dropped below the top of the Black Creek aquifer in part of the Kinston well field, as shown in plate 56, and were as of October 1999, within a few feet of the top of the aquifer in much of western Lenoir, and parts of eastern Wayne Counties. As a result of water declines, many well field operators have had to lower pumps. Declines in the potentiometric surface result in a gradual depressurization of the aquifer, and loss of yield. A drop in the potentiometric surface to a level below the top of a confined aquifer results in a condition called dewatering. Dewatering produces compaction and loss of pore space in an aquifer, as a consequence of the reduction in hydraulic support of the weight of overburden sediments. Permanent reduction of the yield and storage ability of the aquifer are a result.

High decline rates and widespread growth of cones of depression in response to pumping in the Black Creek aquifer are largely attributable to the high degree of confinement of the aquifer over

Figure 8
Hydrogeologic Cross Section Showing Oct. 1999 Black Creek Potentiometric Surface in Kinston and Surrounding Area

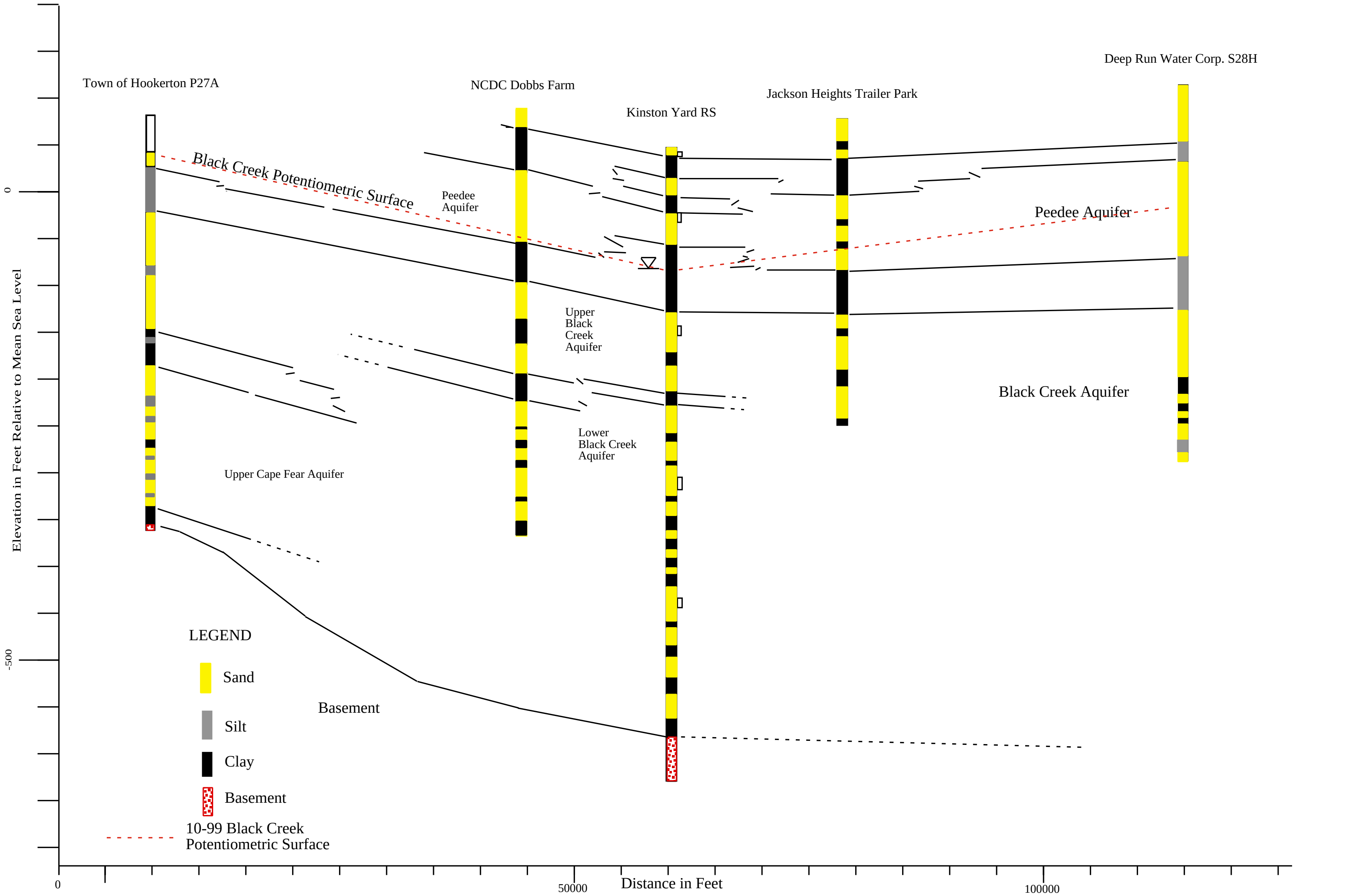


Table 4: Total Drawdown from 1980 to 2000 in selected wells from the Central Coastal Plain

NCDENR Monitoring Station	County	Black Creek Aquifer	Upper Cape Fear Aquifer
Wilmar	Beaufort	38.37	38.37
Cox Crossroads	Beaufort	16.17	16.17
Lee Creek	Beaufort	13.66	13.66
Clarks	Craven	52.74	
Comfort	Jones	120.58	
Scotts Hill	Wayne	0.63	9.09+
Kinston Yard	Lenoir	47.79	40.21*
Pink Hill	Duplin	29.7	
Chinquapin	Duplin	43.01	
Farmville	Pitt	3.55	17.18
		Average= 36.62	Average= 19.41

* Black Creek and Upper Cape Fear aquifers combined as a single aquifer
+ rise in water level

most of the study area, as discussed in the previous section of this report. The Black Creek confining unit was found to be non-leaky, as determined from aquifer test information evaluated in the study region (figure 4). As a result of low leakance rates through the confining bed, very little water is able to move into the aquifer in the form of recharge except in shallow confined or unconfined areas. Recharge rates are highest where the aquifer is close to the surface in the westernmost part of the study area (plate 60), and lowest in the easternmost counties where the aquifer is deeply buried. In the western part of the study area, as depicted in regional cross sections, the aquifer is dissected by numerous rivers and streams, allowing direct discharge of ground water from the aquifer. Thus, much of the water gained by recharge is lost to surface water.

Recharge rates to the Black Creek aquifer vary depending on variations in thickness and vertical hydraulic conductivity of the overlying confining unit, and on variations in the head differential across the confining unit within recharge areas. The regional average rate of recharge to the aquifer is probably less than 1 inch of ground water per year. Previous studies by Wilder and others (1978) estimated that the average recharge rate to deeper confined aquifers in the North Carolina coastal plain was 1 inch per year. Narkunas (1980) estimated the recharge rate to upper Cretaceous sediments in the Central Coastal Plain to be 56,000 gallons per day per square mile, or one inch per year.

The transmissivity of the Black Creek aquifer varies between 437 and 1,700 ft^2/day with an average of 820 ft^2/day. This is based on aquifer test data from 10 sites, as listed in table 2. Hydraulic conductivity ranges from 2 to 7.35 ft/day with an average of 6.25 ft/day. Storativity varies between .000078 and .00018, with an average of .00011. These values are comparable to calculations by Narkunas (1980) who found the transmissivity range to be 400 to 1,959 ft^2/day , and storativity between .0001 and .00017, based on four aquifer tests.

The approximate intersection of 250 ppm isochlors on the top and base of the Black Creek aquifer occurs along sinuous north to south lines extending from eastern Martin, western Beaufort, northern Craven, central Jones, and northern Onslow Counties (plate 41). The interface is defined both by chloride measurements taken from selected intervals as presented on a series of regional hydrogeologic cross sections (plates 2, 3, 5, 6, 7, 8, 9, 10, 12, 14, 16-18), and by analysis of TDEM cross sectional profiles. Locations of profiles are exhibited on plate 19. TDEM profiles a-a', b-b', c-c' and d-d' suggest the presence of the fresh water- salt water interface in the Black Creek aquifer where resistivity measurements are consistently 6 ohm-meters or less. Similar values can however, occur in the fresh water portion of the aquifer in areas where clay percentages are high, or where thick clay layers are present.

The distance between 250 ppm chloride isochlors varies between 4.3 and 17 miles throughout the extent of the fresh water-salt water transition zone across the Central Coastal Plain, with a greatly widened zone occurring in northern Onslow and central Jones Counties. In this area the distance between isochlors achieves a maximum of 17 miles, leaving most of northern Onslow County with a salt water wedge below the freshwater zone in the in the Black Creek aquifer. East of the intersection of the 250 ppm chloride interface with the top of the aquifer, the Black Creek contains nothing but salt water that increases in concentration toward the Atlantic coastline. The zone of widening corresponds to an area of increased thickness of permeable material, as exhibited on plate 43. Higher thickness of permeable material in this area makes the aquifer more transmissive, and thus more effective flushing of salt water has occurred over geologic time.

UPPER CAPE FEAR CONFINING UNIT

The Upper Cape Fear confining unit consists of beds of clay, silt and variable amounts of sand that are situated in the upper part of the Cretaceous age Cape Fear Formation and sometimes the lower part of the Black Creek Formation. Where the Yorktown Formation is present in the northern part of the study area, and directly overlies the Cape Fear Formation, clay or silt beds in the lower part of the Yorktown Formation sometimes make up all or part of the confining unit. In places where the Cape Fear Formation is directly overlain by the Quaternary veneer, semi-permeable beds in the lower part of the Quaternary section are sometimes part of the confining unit.

The top of the unit dips gently to the southeast at a rate that varies between 17.5 feet per mile in the western part of the study region, to 25 feet per mile in the western counties (plate 44). The confining unit varies in thickness across the region from 0, where it pinches out to the west (plate 45), and 128 feet in a Fork Township well in Wayne County. The unit maintains an average thickness of 36 feet based on interpretation of 131 geophysical logs, and achieves highest thicknesses in Onslow and Wayne Counties. The unit is missing in southern Beaufort and in parts of Lenoir County as depicted on regional cross section D-D' (plate 5) and an isopach map (plate 45). Hydrograph curves show nearly identical water levels and water level histories in screens above and below the unit in these areas, indicating that the Upper Cape Fear and Black Creek aquifers are in direct hydraulic communication.

The head differential across the Upper Cape Fear confining unit ranges between 16 and 108 feet with an average value of 56 feet. This is based on 5 observation sites.

UPPER CAPE FEAR AQUIFER

The Upper Cape Fear aquifer is made up primarily of the upper part of the Cape Fear Formation of Cretaceous age, which in the Central Coastal Plain consists of alternating layers of gray to red colored, fine to coarse grained sand and gray to red clay. Gravel beds are also common, and provide a high degree of permeability to the aquifer where present. Sediments of the Cape Fear Formation are interpreted to be nonmarine in origin on the basis of a lack of marine fossils and the prevalence of accessory iron oxide minerals. Sediments become interbedded with thin limestone beds in the downdip portion of the study area, in Jones, Onslow and Craven Counties, indicating the juxtapositioning of marine and nonmarine sediments. Sands in the aquifer are lenticular in nature as indicated by well to well geophysical log correlations over short distances, and are quite variable in thickness, ranging from a few feet to 50 feet. As in the case of the Black Creek, sand bodies are well connected hydraulically, as evidenced by the widespread lateral transmission of drawdown effects in the study area.

The Upper Cape Fear aquifer dips to the southeast at a rate of 21.5 feet per mile in the western counties of the study region, increasing to 27 feet per mile in the east, according to a contour map of its elevation (plate 46). The aquifer thickens from west to east, ranging from 0 where it pinches out along a line running through central Wilson and northwestern Wayne Counties, to a maximum of 355 feet in Craven County. The aquifer ranges between 33 and 84 per cent in permeable material, with an average value of 65 per cent according to an isopach map (plate 47). A map of net thickness of permeable material (plate 48) indicates that it ranges between 22 and 247 feet, with an average value of 93 feet. Highest thicknesses of permeable sediments are found in the easternmost counties of the study area according to the map.

Along with the Black Creek, the Upper Cape Fear aquifer in the Central Coastal Plain has been subjected to increasing pumping stress since about the year1900, when cones of depression began to form. Year 1900 withdrawals of approximately 120,000 gallons per day (Winner and Lyke, 1986) from the Cretaceous aquifer system have spiraled to a present 116 million gallons per day (NC Division of Water Resources, 1999) Based on a 1999 synoptic survey by the NC Division of Water Resources, a potentiometric surface map was constructed for the Upper Cape Fear aquifer. Water levels were taken from NCDENR monitoring stations as well as many private and municipal well fields. Evident on the potentiometric surface map are a series of coalescing cones of depression centered in eastern Wayne/western Lenoir, eastern Lenoir, and central Pitt Counties. In some well fields, such as the city of Kinston and Greenville, many wells are screened in both the Black Creek and Upper Cape Fear aquifers. Therefore, it is impossible to quantify the amount of water being pumped from individual aquifers. The continued, rapid growth of the cones of depression in the Upper Cape Fear since 1980 are indicated by total drawdown data in table 4. Water levels in the Upper Cape Fear in western Lenoir and eastern Wayne County have declined to a point at which dewatering may occur in the next few years due to combined pumping effects from many public and private water systems. The water level in the Upper Cape Fear at the NCDENR Saulston station in western Wayne County (plate 11) has declined to within a few feet of the top of the aquifer.

Most recharge to the Upper Cape Fear aquifer occurs where it is close to the surface and covered exclusively by Quaternary, or both Yorktown and Quaternary age sediments, although this constitutes only a few counties in the northwestern part of the study area. Recharge rates are minimal where the aquifer is deeply buried and confined. As in the case of the Black Creek, a high degree of confinement, low recharge rates, and good hydraulic connection between sand bodies has allowed for the widespread development of cones of depression in the Upper Cape Fear aquifer.

Transmissivity values for the Upper Cape Fear aquifer range between 24.7 and 437.5 square feet per day as determined from aquifer test analyses at two NC-DENR monitoring station sites (table 2). Yields from this aquifer range from 10 to 300 gpm with specific capacities between .6 to .94 gpm per foot of drawdown.

The fresh water/saltwater transition zone in the Upper Cape Fear aquifer trends along a sinuous north to south path extending from central Martin County through eastern Pitt, western Beaufort, northern Craven, northern Jones, western Onslow, southern Duplin, and northern Pender Counties (plate 46). The interface is defined both by chloride measurements taken from selected intervals as depicted on a series of regional hydrogeologic cross sections (plates 2, 3, 5-10, 12, 14, 16-18), and time domain electromagnetic profiles (plates 19-23). TDEM profiles suggest the presence of the fresh water- salt water interface in the Upper Cape Fear aquifer where resistivity measurements are consistently 10 ohm-meters or less. Similar values can however, occur in the fresh water portion of the aquifer in areas where clay percentages are high, or where thick clay layers are present. Values of greater than 10 ohm-meters observed down gradient of the interface are interpreted to result from sands with lower than average effective porosity, which causes a decrease in electrical conductivity.

The sinuous profile of the interface is caused by variations in transmissivity, recharge rates, and possibly by the configuration of the Atlantic coastline and tidal influenced sounds during the time of deposition of Upper Cape Fear sediments. The distance between 250 ppm chloride isochlors varies between 3 and 17 miles along the extent of the interface through the Central Coastal Plain.

Along the toe of the fresh water wedge in the Upper Cape Fear aquifer, the overlying Black Creek aquifer contains salt water, as depicted on regional cross sections (plates 6, and 8-10). A well drilled in this zone will encounter salt water in the lower part of the Black Creek, and then fresh water again in the Upper Cape Fear.

East of the intersection of the 250 ppm chloride interface with the top of the aquifer, the Upper Cape Fear contains nothing but salt water that increases in concentration toward the Atlantic coastline.

LOWER CAPE FEAR CONFINING UNIT

The Cape Fear Formation is divided into two distinct aquifers, upper and lower, on the basis of persistent head differences observed at NCDENR monitoring stations across the study area. This was initially recognized and described by Winner and Coble (1989). The two aquifers are divided by the Lower Cape Fear confining unit, which consists of a series of clay and silt beds with lesser amounts of sand and sand interbeds that have regional continuity across the eastern study area. The unit pinches out against the basement surface along a line indicated on plate 49.

The unit dips to the southeast at a rate of 22 feet per mile in the western counties, increasing to 37 feet per mile in southern Craven, eastern Jones and eastern Onslow Counties according to a map of its elevation (plate 49). As displayed by an isopach map of its total thickness (plate 50), the unit maintains an average thickness of 43 feet across the study area, with a maximum accumulation of 120 feet found in Edgecombe County in a Crisp Water Association well. Head differences in screen zones above and below the unit range between 27 and 76 feet. Head differences have been maximized due to the lack of pumping from the Lower Cape Fear and heavy pumping from the Upper Cape Fear aquifer.

LOWER CAPE FEAR AQUIFER

The Lower Cape Fear aquifer is comprised of the lower part of the Cape Fear Formation of Cretaceous age, and consists of alternating beds of nonmarine sand, gravel and clay of similar color and character to the Upper Cape Fear aquifer. As in the case of the Upper Cape Fear, sediments become interbedded with thin limestone beds in the downdip portion of the study area, in Jones, Onslow, Beaufort and Craven Counties, indicating the juxtapositioning of marine and nonmarine sediments. This unit is everywhere overlain by the Upper Cape Fear aquifer and is present only in the eastern half of the study region. It pinches out against the basement surface along a line indicated in plate 51. The base of this aquifer is defined as the top of the basement surface.

The Lower Cape Fear aquifer dips to the southeast at a rate of 19 feet per mile where present in the western part of the study area, increasing to 37 feet per mile downdip, in the area of Craven, Jones, and Onslow Counties (plate 51). As indicated by 18 well penetrations, the aquifer is wedge shaped in profile, thickening from west to east. It averages 157 feet in thickness, and achieves a maximum thickness of 441 feet in the Carolina Petroleum Co., Charles Bryan No. 1 well in Craven County.

A map of percentage of permeable material in the Lower Cape Fear aquifer (plate 52) indicates an average of 59 per cent, with a range of 24 to 83 per cent. The aquifer averages 102 feet of net permeable material, with a range of 26 to 295 feet. As indicated by a contour map of net thickness of permeable material (plate 53), the net thickness increases prominently from west to east in accordance with the increase in total thickness of the aquifer.

Since the Lower Cape Fear aquifer pinches out against the basement surface in the central part of the study area (plate 51), it is everywhere overlain by significant thicknesses of sediment, and thus is recharged at a lower rate than the Black Creek and Upper Cape Fear aquifers.

Hydrograph data to evaluate the Lower Cape Fear aquifer is available from 4 NCDENR monitoring stations in the study area, and is presented on regional cross sections (plates 4, 6, and 15). Long term declines of 2 feet per year are noted at the NCDENR Cove City Station in Craven County, 1.5 feet per year at the NCDENR Bethel Station in Pitt County, 1 foot per year at the NCDENR Gardner Chicod Station in Pitt County, and 1.5 foot per year at the NCDENR Beaver Creek Station in Jones County. Inasmuch as the Lower Cape Fear aquifer sees minimal to no usage in the study area, it is apparent that drawdown in this aquifer is caused by induced leakage from pumping in the Upper Cape Fear and Black Creek aquifers. Synoptic water level data was available on only four wells, thus available data would not allow enough detail for preparation of a meaningful potentiometric surface map for this aquifer.

The fresh water/salt water transition zone in the Lower Cape Fear aquifer trends along a winding path from north to south extending through eastern Edgecombe, central Pitt, eastern Lenoir, western Jones, and western Onslow Counties (plate 51). The interface is defined by chloride measurements taken from selected intervals as depicted on a series of regional hydrogeologic cross sections (plates 1 through 18), and by TDEM soundings.

CONCLUSIONS

Heavy withdrawals of ground water from the Black Creek and Upper Cape Fear aquifers, and to a limited extent, the Peedee aquifer, have been causing a steady, inexorable decline in water levels since the early 1900s in the Central Coastal Plain of North Carolina. Pumping rates from these aquifers have increased through the past century to a present estimated total of 116 million gallons per day. Hydrographs from observation wells in the North Carolina monitoring network indicate decline rates in the potentiometric surfaces of up to 5.6 feet per year (table 3), with much higher rates of decline occurring within pumping centers.

In order to define the extent of this problem, a hydrogeologic framework study of the North Carolina Central Coastal Plain has been carried out in order to provide an up-to-date interpretation of the region that incorporates much additional data made available in recent years. The study was accomplished by correlation and interpretation of borehole geophysical and lithologic logs, water level and chloride measurements taken from observation wells, aquifer test data, and time domain electromagnetic soundings. Additional information has been made available from new wells being added to the North Carolina ground water monitoring network by the Division of Water Resources, and by new public and private water system wells. The study has been conducted concurrently with the development of new capacity use regulations for the Central Coastal Plain, and is intended to provide a basis for decision making in regard to implementation of the proposed rules. The study will also serve as a guide to those who desire to conduct more detailed water resource investigations in particular areas of the region, and will hopefully provide for efficient use of the aquifer system.

The hydrogeologic system in the study region, from basement to land surface, consists of eight regionally significant aquifers and the intervening confining units that separate them. Included are the surficial, Yorktown, Castle Hayne, Beaufort, Peedee, Black Creek, Upper and Lower Cape Fear aquifers. Each aquifer was mapped and described in as much detail as available data would allow in order to define them in terms of regional elevation, thickness and lateral distribution, hydraulic properties, relationship to stratigraphic units, ground water movement, and chloride distribution. The approximate positions of the 250 and 1,000 parts per million chloride interfaces were plotted for each aquifer on cross sections and elevation maps prepared for the study.

In order to determine the latest position of the potentiometric surfaces of the Peedee, Black Creek, and Upper Cape Fear aquifers, the North Carolina Division of Water Resources conducted a synoptic survey of water levels in October, 1999. Static water levels were taken from wells in the North Carolina ground water monitoring station network, and from numerous public and private water supply wells. Static water level data from the synoptic survey was used to construct potentiometric surface maps of the aquifers as shown in plates 55-57. The potentiometric surface of the Black Creek aquifer depicts a series of coalescing cones of depression with major centers in Onslow, Lenoir and Pitt Counties. Cones of depression formed as a result of concentrated pumping from municipal, industrial, private and agricultural supply wells. Ground water levels in the Black Creek aquifer have dropped below the top of the aquifer in part of the Kinston well field, as shown in plate 56, and within a few feet of the top of the aquifer in much of western Lenoir, and parts of eastern Wayne Counties. The potentiometric surface of the Upper Cape Fear Aquifer (plate 57) depicts a series of coalescing cones of depression with major centers in eastern Wayne, Lenoir, and Pitt Counties. Ground water levels in the Upper Cape Fear aquifer have possibly dropped below the top of the aquifer over localized areas in western Lenoir and eastern Wayne Counties. A drop in the potentiometric surface to a level below the top of a confined aquifer results in a condition called dewatering. Dewatering produces compaction and loss of pore space in an aquifer, as a consequence of the reduction in hydraulic support of the weight of overburden sediments. Permanent reduction of the yield and storage ability of the aquifer are a result. If pumping is allowed to continue on its present course, dewatering will become widespread in the Black Creek and Upper Cape Fear aquifers.

It is evident by the results of this study that a ground water management strategy is needed in the Central Coastal Plain in order to halt ground water level declines and preserve the aquifers as sources of water supply for future generations.

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