Groundwater Quality within the Surficial Aquifer and first confined aquifer in six counties of the Southern Coastal Plain

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Division of Water Quality
Groundwater Section

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PURPOSE AND OBJECTIVES

The Southern Coastal Plain Ground Water Advisory Council (SCPGWAC) is a coalition of local government representatives from six counties (Hoke, Scotland, Robeson, Columbus, Bladen and Sampson) with a goal of becoming informed of groundwater issues related to both availability and quality. The North Carolina Department of Environment and Natural Resources, Division of Water Quality, Groundwater Section (GWS) has assisted the SCPGWAC with determining several key elements of their overall objective. In most areas of the Coastal Plain of North Carolina, groundwater is being removed from the deep confined aquifers at rates that exceed natural recharge. The SCPGWAC is evaluating water sources for future use that have not historically been used by public water systems. As time passes, utilization of shallow groundwater will be an option many utilities may need to exercise.

The Groundwater Section's primary objectives for this study are to:

- Describe the occurrence and distribution of groundwater within the Surficial Aquifer and the first confined or semi-confined aquifer (below the Surficial Aquifer);
- Obtain ambient groundwater quality information for both mentioned aquifers;
- Provide information of known groundwater contamination incidents;
- Provide information of land uses that have potential to impact the groundwater quality; and
- Provide groundwater protection recommendations for use by local governments.

STUDY AREA DESCRIPTION

Location

For the purpose of continuity, the study area encompasses seven counties within the Coastal Plain province in southeastern North Carolina. Those counties are Hoke, Scotland, Robeson, Columbus, Bladen, Sampson, and Cumberland (Figure 1). The Coastal Plain is an area characterized by flat to moderately rolling landscapes in the eastern 1/3 of the state.

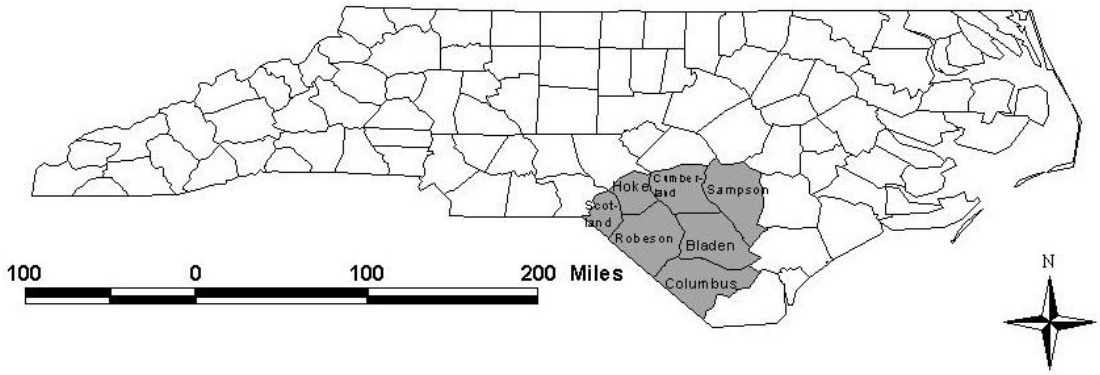


Figure 1: The counties used for this study, Hoke, Scotland, Robeson, Columbus, Bladen, Sampson, and Cumberland are in the shaded area.

Geology

The Coastal Plain is generally divided into two regions known as (1) the Tidewater region, and (2) the Inner Coastal Plain region (Winner and Coble, 1996). The study area is located mostly within the Inner Coastal Plain region (Figure 2).

The Inner Coastal Plain is characterized by land surface altitudes that range from about 50 feet in the east to over 700 feet above sea level along the western boundary (Winner and Coble, 1996). The northwestern portion of the study area contains a unique subdivision of the Inner Coastal Plain, known as the Sand Hills (Stuckey, 1965). Scotland, Hoke, Cumberland and a small section of Bladen counties contain some area of the Sand Hills subdivision. Figure 2 shows the distribution of the Inner Coastal Plain and the Sand Hills subdivision.

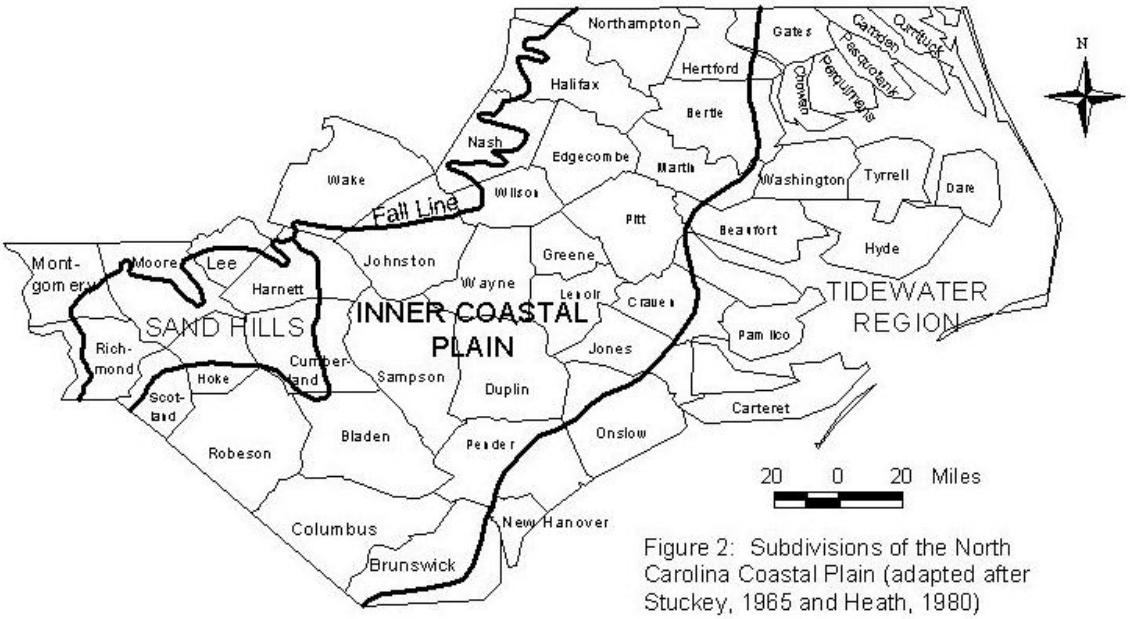


Figure 2: Subdivisions of the North Carolina Coastal Plain (adapted after Stuckey, 1965 and Heath, 1980)

Sediments that comprise the Coastal Plain are primarily stratified sequences of clays, sand, gravel, fossil shell layers and limestone, some of which form hard beds. The sediments that dip and thicken to the east-southeast, were deposited on crystalline bedrock in a marine environment (near and off-shore) during transgressions and regressions of sea level (Figure 3). The section shown in figure 3 is what we would expect to find in the subsurface from west to east.

Hydrogeology

Within the Coastal Plain, groundwater is stored in unconfined and confined to semi-confined aquifers. An aquifer is a rock (consolidated or unconsolidated sediments) unit that will yield an economical quantity of water to wells and springs. The unconfined aquifer is the first encountered below land surface and is not capped by a low permeability zone (confining unit). It has several very important functions. It is the zone that provides recharge to the deeper confined aquifers. Also, the unconfined aquifer is

the primary zone that provides much of the base flow to streams and rivers (discharge). Lastly the unconfined aquifer is the zone where many pollutants breakdown and are attenuated, keeping the environment and public health protected. Within the Coastal Plain, the unconfined aquifer is named the Surficial Aquifer (Figure 3).

Confined aquifers are water producing zones that are overlain by a significant layer of low permeability sediment (confining unit), which naturally limits the amount of water entering and leaving the water bearing zone. A series of confined to semi-confined aquifers underlies the unconfined aquifer throughout most of the study area (Figure 3). The aquifers are named according to the stratigraphic units. In some areas, a confining unit does not cap the first productive aquifer (encountered below the Surficial Aquifer). In such an instance, the aquifers are separated into two distinct units based on their lithology. As depicted in figure 3, the number and thickness of aquifers underlying the study area increases from west to east. The depth to bedrock at the Scotland-Richmond County line is 200-250 feet, where the unconfined aquifer and just one confined aquifer are identified (Figure 4). At the Columbus-Brunswick County line where the depth to bedrock is about 1,200 feet, in addition to the unconfined aquifer, there are at least 4 different confined aquifers (Figure 5).

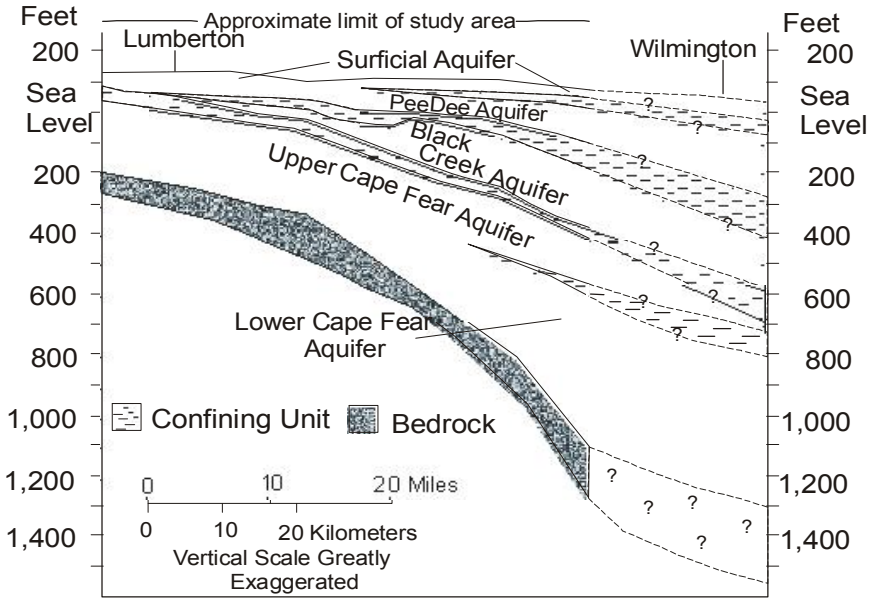


Figure 3: Generalized cross section of aquifers underlying the southern Coastal Plain study area (Scotland through Columbus Counties) of North Carolina (modified after Smith and others, 1996).

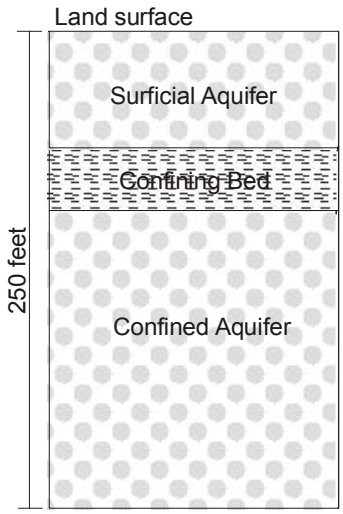


Figure 4: At the Scotland-Richmond County line, only the Surficial Aquifer and one confined aquifer are encountered below land surface.

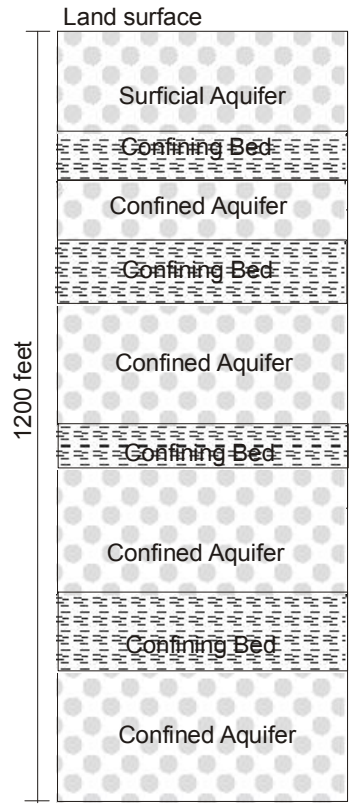


Figure 5: At the Columbus-Brunswick County line, four confined aquifers are identified below the Surficial Aquifer.

The southern Coastal Plain groundwater system is recharged mostly by precipitation. Precipitation falls to the ground surface and takes one of three paths. Most of the water (60-70%) will be utilized within the soil zone by a process known as evapotranspiration. This is simply the loss of water by evaporation from the soil and transpiration from plants. Only about 10% is transported directly to the streams and rivers by over land flow. The remaining 20-30% moves through the soil zone and recharges the aquifer system. Figure 6 illustrates this concept by using an average annual water budget of 50 inches of rainfall for the Coastal Plain. This conceptual model assumes groundwater is not being withdrawn by wells and that the amount of water entering the system is equal to the amount leaving the system (in equilibrium).

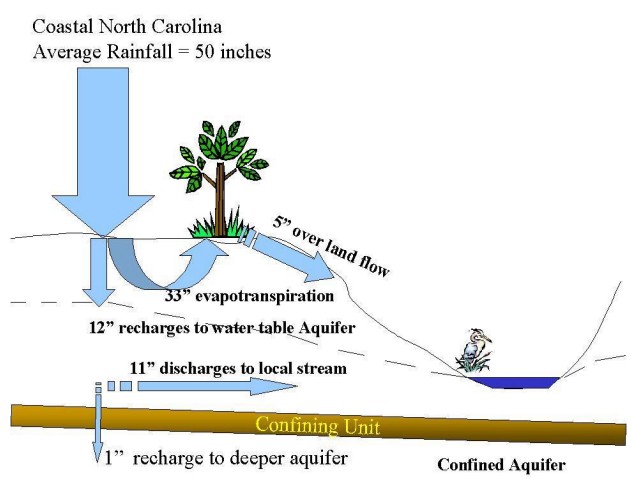


Figure 6. Example water budget for the Coastal Plain of North Carolina

The average rainfall amount was derived from a map of statewide annual average precipitation, which is based on historical data (Figure 7). The average precipitation for the study area ranges from 37.5-55 inches per year.

It has been estimated for northeast North Carolina that about 60-70% of the water that flows through stream and river channels originates as groundwater (Wilder, et al., 1978). This process is known as groundwater discharge. Continuous groundwater discharge is the reason our streams and rivers continue to flow during periods of little or no rainfall. The unconfined aquifer acts as an underground reservoir slowly releasing water to supply the base flow for streams, and also to the deeper confined aquifers below.

The time interval between recharge and discharge in the unconfined and semi-confined aquifer system can be anywhere from days to hundreds or thousands of years. This retention time not only supports stable surface water stream flow, it also allows time for contaminants to break down or be retained by the aquifer matrix. These natural contaminant transformations have been the focus of many scientific studies. However, some types and locations of contamination are too much of a threat to public health and the environment to allow the aquifer system to remediate itself. When this occurs, those responsible are required by state regulations to seek alternative remediation strategies. The delicate balance between groundwater quality and land uses that alter that quality is difficult to maintain.

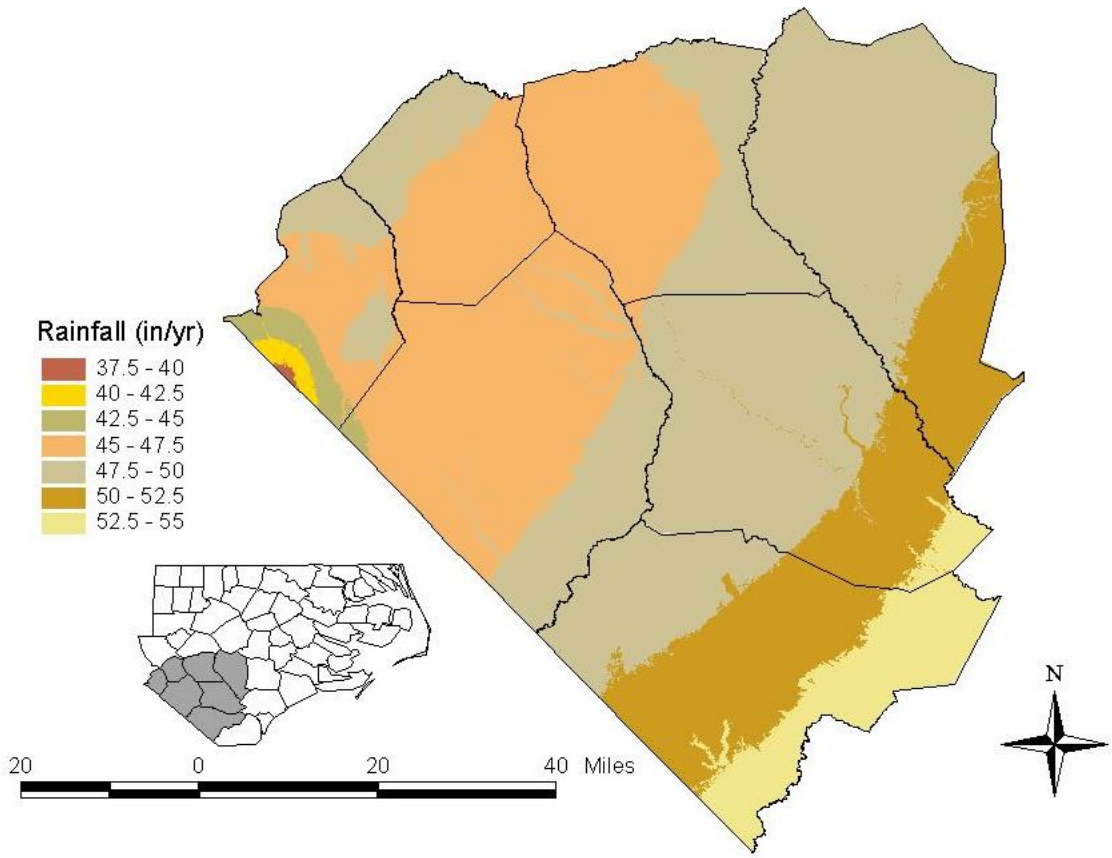
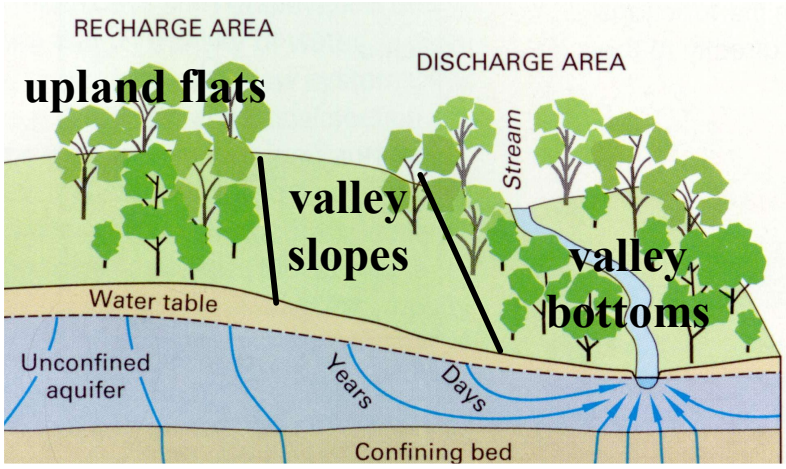


Figure 7. Map of average annual precipitation in North Carolina.

To better understand groundwater recharge and discharge, the terrain of the Coastal Plain can be divided into three regions. The wet flat uplands (upland flats) are areas such as Green Swamp, Colly Swamp or the Bladen Lakes Area, which are poorly drained (Figure 8). These areas are zones of recharge as the movement of groundwater is primarily vertical downward away from the recharging wetlands (Heath, 1997). In

these areas, man made contaminants will impact both the Surficial Aquifer and any unconfined primary aquifer beneath. Because the unsaturated zone above the water table is fairly thin or nonexistent in these areas, there is little beneficial degradation of contaminants and wastewater introduced into these areas.



The dry flat uplands and sloping uplands (valley slopes) of the area are situated on the margins of the main recharge areas (Figure 8). In these areas there is some recharge to the Surficial and shallowest confined aquifer, however much rainfall on these areas is lost to evapotranspiration (Heath, 1997).

Figure 8: Groundwater flow paths in zones of recharge and discharge.

Groundwater in these areas is moving with more of a horizontal than vertical component. The impact of releases of contaminants or wastewater in these areas affects mostly the upper portion of the Surficial Aquifer. In these areas, the unsaturated zone above the water table imposes beneficial degradation of waste and contamination moving toward the water table.

The streams and flood plain areas (valley bottoms) of the region are areas where groundwater is discharging or moving toward the land surface (Heath, 1997). As a result, contaminants and wastes introduced to these areas remain close to or on the land surface. However, in these areas, wastes or contaminants transported in groundwater as a result of activities in recharge areas returns to the land surface to be discharged into creeks and streams.

On figure 6, note that out of 50 inches of precipitation, only one inch recharges the deeper confined aquifers. This is not to say that one inch of recharge occurs within the confined aquifers everywhere across the coastal plain, but it is an estimated average that illustrates the limited quantity of water and the large amount of time that deep aquifer recharge requires (Harden, et al., 2003). Recent studies in the central Coastal Plain indicate that one inch of recharge to the deeper aquifers within the Coastal Plain may be an over estimate.

The confined aquifers within the Coastal Plain have historically been very popular choices for public water systems, municipalities, industries and agriculture to tap because of their high yield and excellent water quality. The NC Division of Water Resources has shown in hydrographs for the Cretaceous Aquifer system that water levels in Bladen County have been declining since the 1970's (DWR, 2002). If all water users in a region rely on the same source, withdrawing water at rates that exceed recharge, the water supply will eventually be depleted.

For the purpose of illustration, if one inch of recharge per year reaches the confined aquifer that a hypothetical municipality is drawing water from, the recharge is equal to 27,154 gallons of water for every acre of land area. This acre-volume of water would only supply one average household with water for 2.47 months. To put it another way,

each household would require a lot equal to 4.86 acres to balance annual recharge and withdraw. If withdrawal exceeds recharge, depletion of the aquifer gradually occurs. Very few towns or municipalities have the minimum lot size needed to meet these criteria. This example does not consider groundwater used for commercial and industrial use.

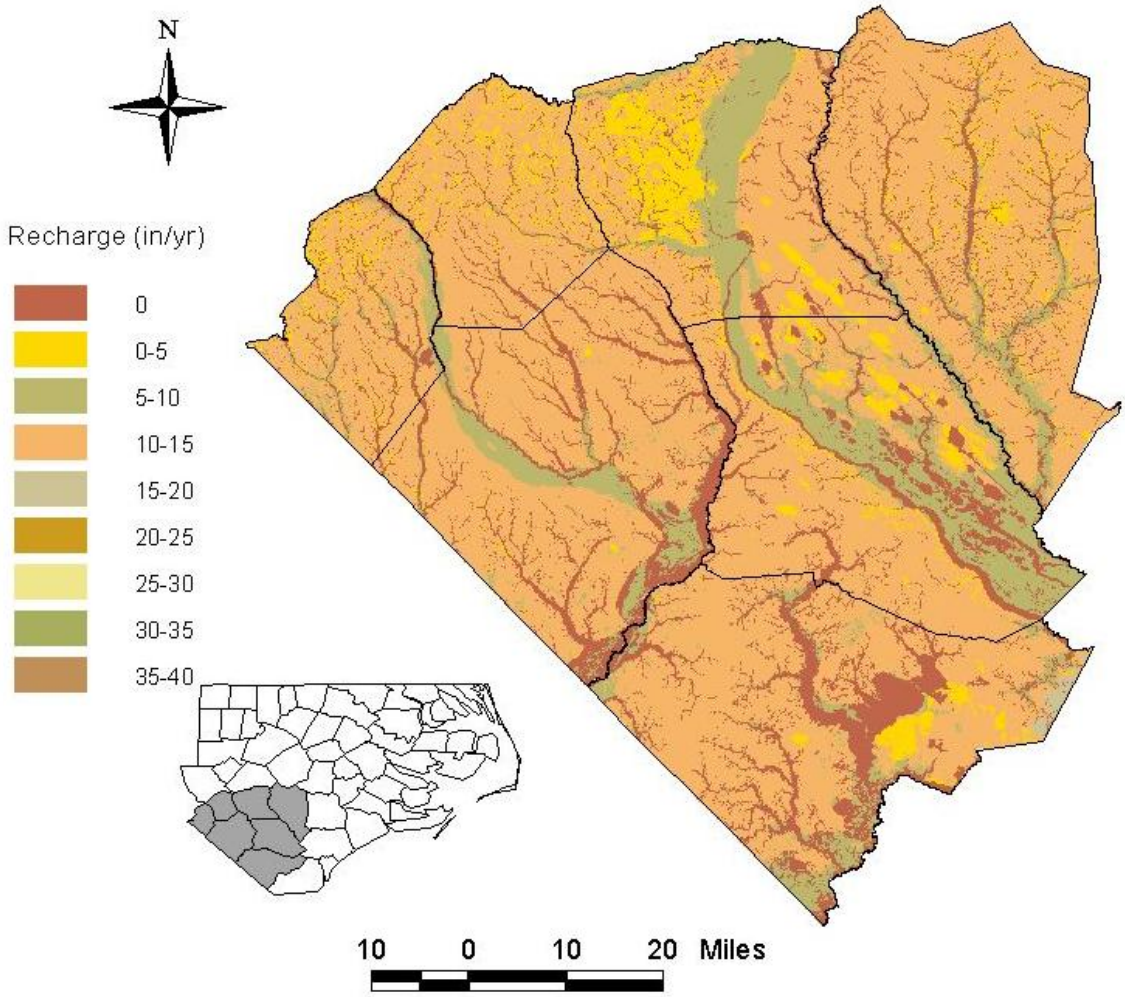


Figure 9: Recharge (inches/year) of the Surficial Aquifer based on soil type.

The unconfined aquifer receives an average of 12 inches of recharge per year (Figure 9). One inch is estimated to continue its downward migration into the confined aquifers below, with 11 inches remaining, slowly discharging to local streams. If the unconfined aquifer were to be utilized for the municipality's water supply, this annual amount of water available for use is 11 times greater than the recharge received by the confined aquifer.

In parts of the Coastal Plain, the deeper confined aquifers are over-used. Exceeding the safe yield (Heath, et al., 2003) has created a need for alternative water supplies and is the reason why increasing demand may be placed on the shallow confined and semi-confined aquifers. Because of the water demand, water quality protection and increased utilization of groundwater derived from the shallow unconfined and semi-confined aquifers will become more important into the future.

Research Site Details

Within the described study area, 17 research sites were evaluated for determining the groundwater quality and the characteristics of the near surface aquifers (Figure 10). Each county contains a minimum of 2 sites that are incorporated into this study. Figure 10 shows the location of each well site. Each site is described in detail and grouped according to county.

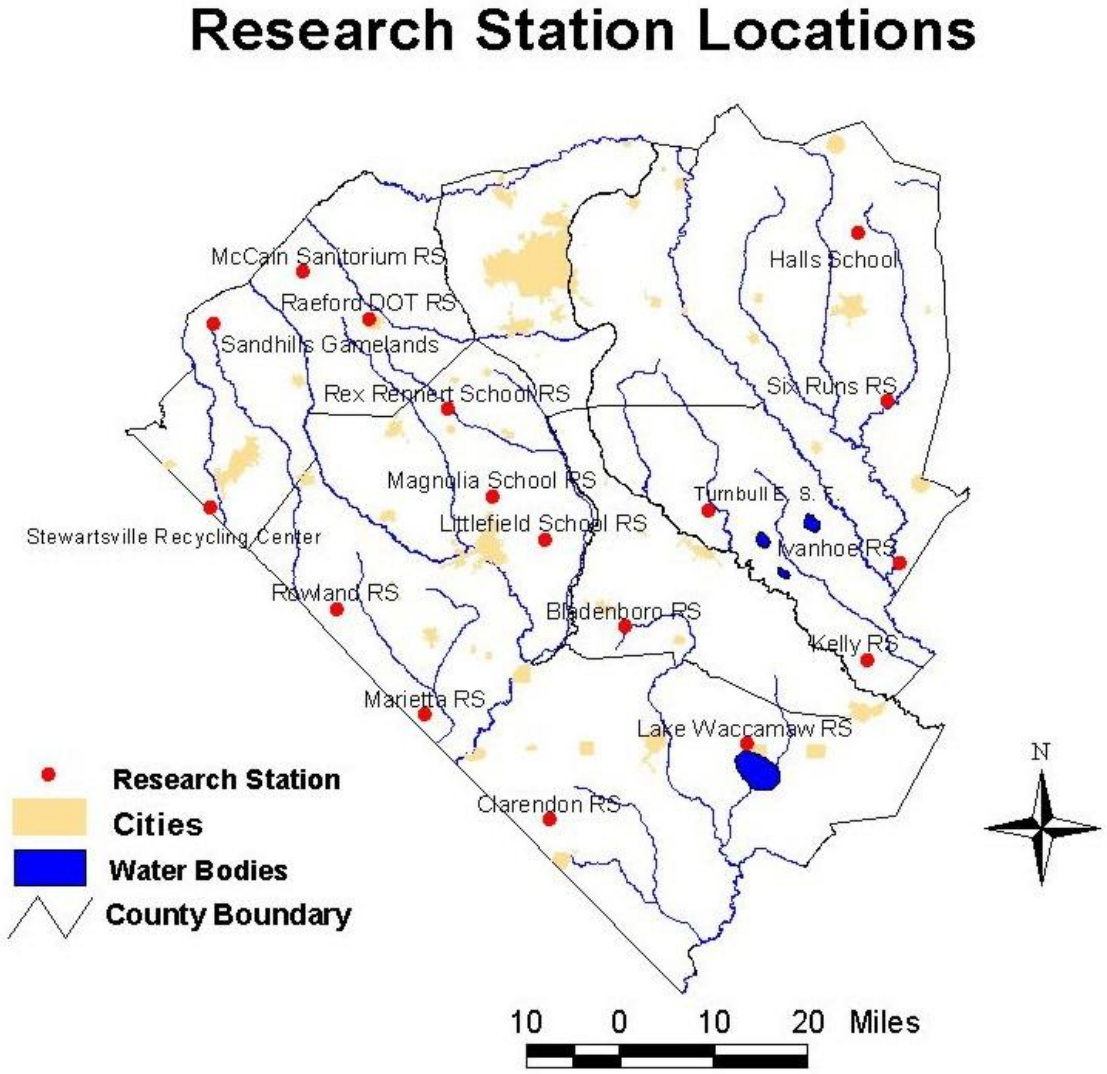


Figure 10: The location of each research station location is depicted on the map.

Scotland County Sites

Jordan Creek Sand Hills Game Land Site

The Jordan Creek Sand Hills Game Land research site is located in the north west part of Scotland County three miles south of the town of Hoffman. It is at an elevation of approximately 433 feet above mean sea level. Bedrock is encountered approximately 370 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 23 to 33 feet below land surface (U50 s5). The

lower zone extends from 99 to 124 feet below land surface (U50s6). Land use around this site consists of forestry and wildlife game management. A wildlife food plot, where various seed and browse crops are planted to enhance wildlife populations and health, is adjacent to well number U50s5.

Stewartsville Recycling Center Site
The Stewartville Recycling Center research site is located in the south central part of Scotland County, 0.46 miles from the state line along Highway 401. It is at an elevation of approximately 193 feet above mean sea level. Bedrock is encountered approximately 370 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 23 to 33 below land surface (X50s1). The lower zone extends from 80 to 90 feet below land surface (X50s2). Land use around this site consists of a mixture of forestry, residential and a controlled access solid waste collection station, which is located directly adjacent to both of study wells.

Hoke County Sites

McCain Sanitorium Site
The McCain Sanitorium research site is located in the north west part of Hoke County, 9 miles north west of Raeford off Highway 211. It is at an elevation of approximately 350 feet above mean sea level. Bedrock is encountered approximately 300 feet below land surface. At this study site, groundwater quality from one zone was evaluated. This zone extends from 82 to 92 feet below land surface (T48i2). The land use around this site is forestry. During the study period, the timber around the well location was harvested and reseeded with long leaf pine seedlings.

Raeford DOT
The Raeford DOT research site is located in the central part of Hoke County, in Raeford just north of the Burlington Industries Plant. It is at an elevation of approximately 280 feet above mean sea level. Bedrock is encountered approximately 270 feet below land surface. At this study site groundwater quality from two zones was evaluated. The upper zone extends from 33 to 43 feet below land surface (U46e7). The lower zone extends from 62 to 101 feet below land surface (U46e6). Land use around this site consists of a mixture of residential and industrial. Directly adjacent to the site, is a State owned DOT facility that contains equipment garages and an underground fuel storage tank system.

Robeson County Sites

Marietta School Site
The Marietta School research site is located in the southern part of Robeson County, near the NC-SC state line, along SR 2277. It is at an elevation of approximately 92 feet above mean seal level. Bedrock is encountered approximately 450 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 30 to 40 feet below land surface (BB45m6). The lower zone extends from 107 to 112 feet below land surface (BB45m5). Land use around this site consists of a mixture of residential and agricultural uses. The wells are situated on the playground of a closed school.

Rowland School Site
The Rowland Elementary School research site is located in the western part of Robeson County, near the NC-SC state line along Highway 301. It is at an elevation of 142 feet

above mean sea level. Bedrock is encountered approximately 375 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 31 to 41 feet below land surface (Z47m5). The lower zone extends from 73 to 78 feet below land surface (Z47m4). Land use around this site consists of a mixture of residential and commercial uses. The wells are situated between the school playground and a rail line that parallels Highway 301.

Magnolia School Site

The Magnolia School research site is located in the northern part of Robeson County, 6.5 miles south of St. Pauls, along Highway 301. It is at an elevation of approximately 146 feet above mean sea level. Bedrock is encountered at approximately 380 feet below land surface. Groundwater quality from two zones was evaluated at this study site. The upper zone extends from 21 to 31 feet below land surface (X44k4). The lower zone extends from 144 to 154 feet below land surface (X44k6). Land use around this site consists of a mixture of residential and agricultural uses. The wells are situated on the edge of the school property between athletic fields of the school and a newly developed park that was previously an active farm field.

Rex Rennert

The Rex Rennert research site is located in the northern part of Robeson County, about 7 miles north east of Red Springs along Rennert Road. It is at an elevation of 185 feet above mean sea level. Bedrock is encountered approximately 350 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 20 to 30 feet below land surface (V45u7). The lower zone extends from 65 to 90 feet below land surface (V45u3). Land use around this site consists of a mixture of residential and agricultural uses. The wells are situated on the down slope position near the edge of the school property. Also a row crop field under active cultivation exists adjacent to well V45u3.

Littlefield

The location of the Littlefield Site is in the east part of Robeson County in the Littlefield community along Highway 41. It is at an elevation of 140 feet above mean sea level. Bedrock is encountered at approximately 465 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 10 to 20 feet below land surface (Y42f12). The lower zone extends from 140 to 145 feet below land surface (Y42f11). Land use around this site consists of a mixture of residential, agricultural and commercial uses. The wells are situated on the edge of the school property. Adjacent to the wells are playground areas and a large subsurface septic system drain field that serves the school.

Bladen County Sites

Bladenboro

The Bladenboro research site is located in the west central part of Bladen County, south of Highway 211 and between Bladenboro and Abbottsburg. It is at an elevation of 106 feet above mean sea level. Bedrock is encountered approximately 570 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 25 to 35 feet below land surface (Z41u1). The lower zone extends from 100 to 110 feet below land surface (Z41u4). Land use around this site consists of a mixture of agriculture and forestry. The wells are situated in an area that has recently been harvested. Also a row crop field under active cultivation exists about 100 feet away, across the highway.

Turnbull Educational State Forest
The Turnbull Educational State Forest research site is located in the central part of Bladen County, about 3 miles north of Elizabethtown along Sweet Home Church Road. It is at an elevation of 64 feet above mean sea level. Bedrock is encountered approximately 495 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 23 to 33 feet below land surface (X38y1). The lower zone extends from 215 to 235 feet below land surface (X38y2). Land use around this site consists of forestry. The wells are situated at the end of an old airplane runway that is no longer used. The runway is surrounded by state forestland containing various types of managed forest plots.

Kelly
The Kelly research site is located in the southeastern part of Bladen County, near the Kelly community along Light Wood Knot Road. It is at an elevation of 28 feet above mean sea level. Bedrock is encountered approximately 680 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 10 to 14 feet below land surface (AA35n1). The lower zone extends from 74 to 84 feet below land surface (AA35n3). Land use around this site consists of a mixture of residential uses, agriculture and forestry. The wells are situated on property occupied by an old school that is now being used as a remote educational facility operated by Bladen Technical College.

Sampson County Sites

Halls School
The Halls School research site is located in the north central part of Sampson County, in the Keener community along Highway 701. It is at an elevation of 177 feet above mean sea level. Bedrock is encountered approximately 400 feet below land surface. At this study site, groundwater quality from one zone was evaluated. This zone extends from 19 to 29 feet below land surface (S35q5). Land use around this site consists of a mixture of residential uses, agriculture and forestry. The well is along the edge of a former school property just a few feet from a field under active row crop cultivation.

Six Runs
The Six Runs research site is located in the south central part of Sampson County, about 9 miles south of Clinton along Highway 421. It is at an elevation of 65 feet above mean sea level. Bedrock is encountered approximately 433 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 13 to 23 feet below land surface (V35u9). The lower zone extends from 63 to 82 feet below land surface (V35u5). Land use around this site consists of forestry. The wells are situated in the edge of a wooded area adjacent to a state DOT Rest Area.

Ivanhoe
The Ivanhoe research site is located in the southern part of Sampson County, near the intersection of Ivanhoe Road and Eddie L. Jones Road. It is at an elevation of 25 feet above mean sea level. Bedrock is encountered approximately 580 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 28 to 33 feet below land surface (Y34p3). The lower zone extends from 181 to 220 feet below land surface (Y34p2). Land use around this site consists of a mixture of residential use, agriculture, and forestry. The wells are situated along an access road to a state maintained boat launch ramp.

Columbus County Sites

Lake Waccamaw
The Lake Waccamaw research site is located in the central part of Columbus County, north of the town limits of Lake Waccamaw between Highways 74-76 and 214. It is at an elevation of 63 feet above mean sea level. Bedrock is encountered approximately 678 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 41 to 51 feet below land surface (CC38b5). The lower zone extends from 112 to 122 feet below land surface (CC38b6). Land use around this site consists of a mixture of residential, commercial, agricultural uses and forestry. The wells are situated inside an area used as a pasture for horses and cattle.

Clarendon
The Clarendon research site is located in the western part of Columbus County, north of Tabor City along Sidney Road. It is at an elevation of 100 feet above mean sea level. Bedrock is encountered approximately 880 feet below land surface. At this study site, groundwater quality from two zones was evaluated. The upper zone extends from 41 to 51 feet below land surface (DD42n1). The lower zone extends from 238 to 248 feet below land surface (DD42n4). Land use around this site consists of forestry. The wells are situated on the edge of an area used for production of southern yellow pine trees with an access road and drainage ditch approximately 40 feet to the east.

ANALYTICAL RESULTS

Groundwater from 32 wells screened in the Surficial and shallowest confined aquifers was analyzed for 41 parameters for four consecutive quarters. Historical data are included when available. Only those constituents detected or of primary concern will be discussed, including hardness, total organic carbon (TOC), total dissolved solids (TDS), nitrate, iron, manganese, lead, aluminum, bicarbonate, calcium and zinc.

Both Piper and Stiff diagrams are presented in Appendix 1 and Appendix 2, respectively, which depict groundwater geochemistry of the samples collected. The trilinear Piper diagram shows anion and cation groups based on a percentage of the sample (Driscoll, 1986). The points plotted within the diamond are grouped to show the relative water composition (Appendix 1). This analysis is used to group water samples with similar geochemistry. The Stiff diagram is a pattern analysis, which is also used to group water of similar geochemistry over a large geographical area (Appendix 2) (Driscoll, 1986).

Based on the analysis of Piper (Appendix 1) and Stiff diagrams (Appendix 2), groundwater quality data indicate there are four types of groundwater (Type A-D). The types range from calcium bicarbonate (Type A) to sodium chloride (Type B) (Figure 11). Type C is primarily a sodium chloride type with varying concentrations of bicarbonate (Appendix 1). Type D has variable sodium chloride and bicarbonate.

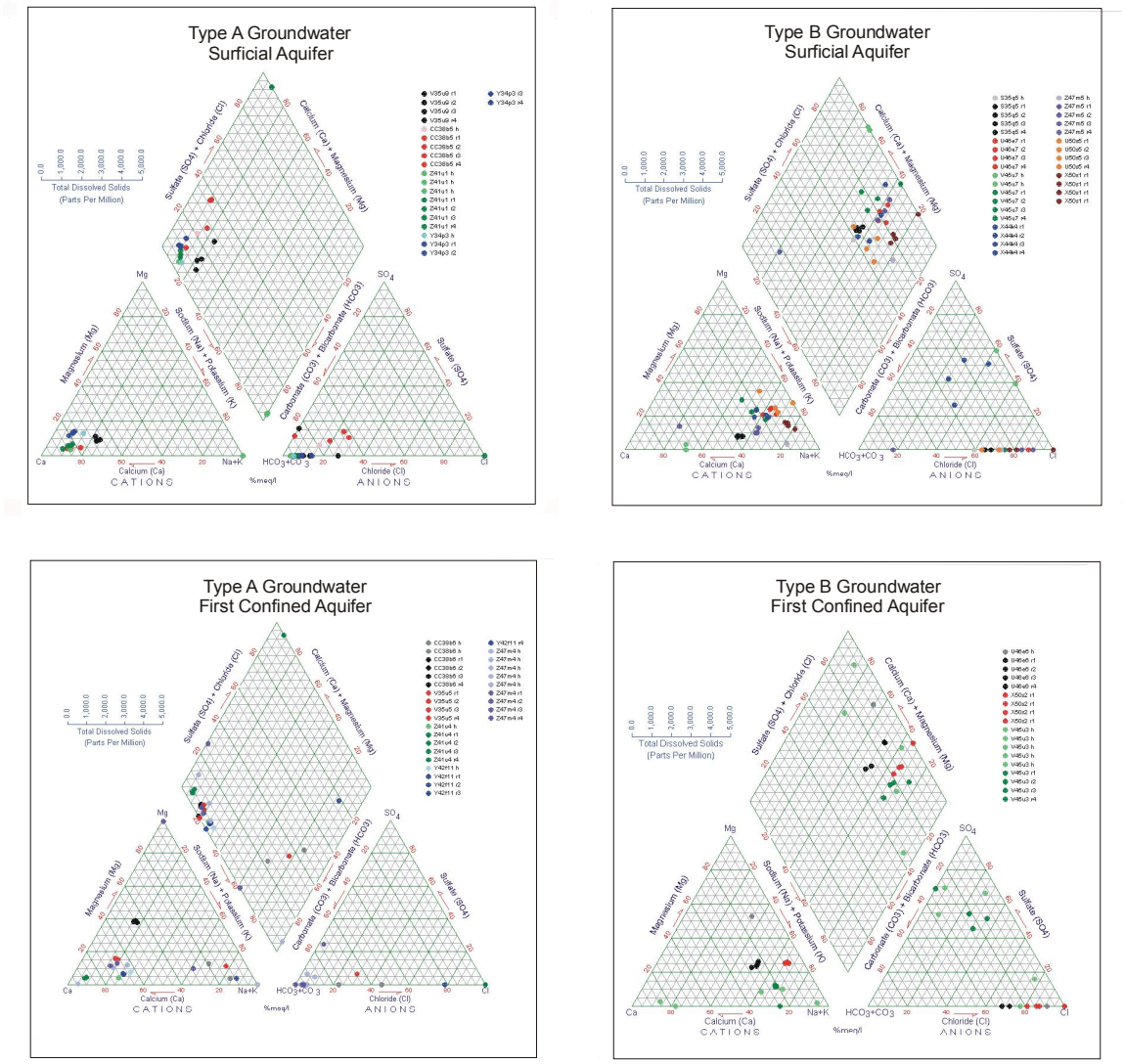


Figure 11: Piper diagrams of groundwater Types A and B from the Surficial Aquifer and the first confined aquifer. Groundwater types range from calcium bicarbonate to sodium chloride. The diagram produced for each groundwater type is presented in Appendix 1.

Surficial Aquifer

Fifteen wells were used to determine groundwater characteristics of the Surficial Aquifer. Overall, groundwater in the Surficial Aquifer has a high iron, manganese, aluminum, and bicarbonate signature (Appendix 3). Within the Surficial Aquifer, Type A groundwater is identified in wells screened in the Waccamaw, Black Creek and Cape Fear Formations (Figure 12). Wells that produce Type B groundwater are screened in the Black Creek and Middendorf Formations (Figure 12).

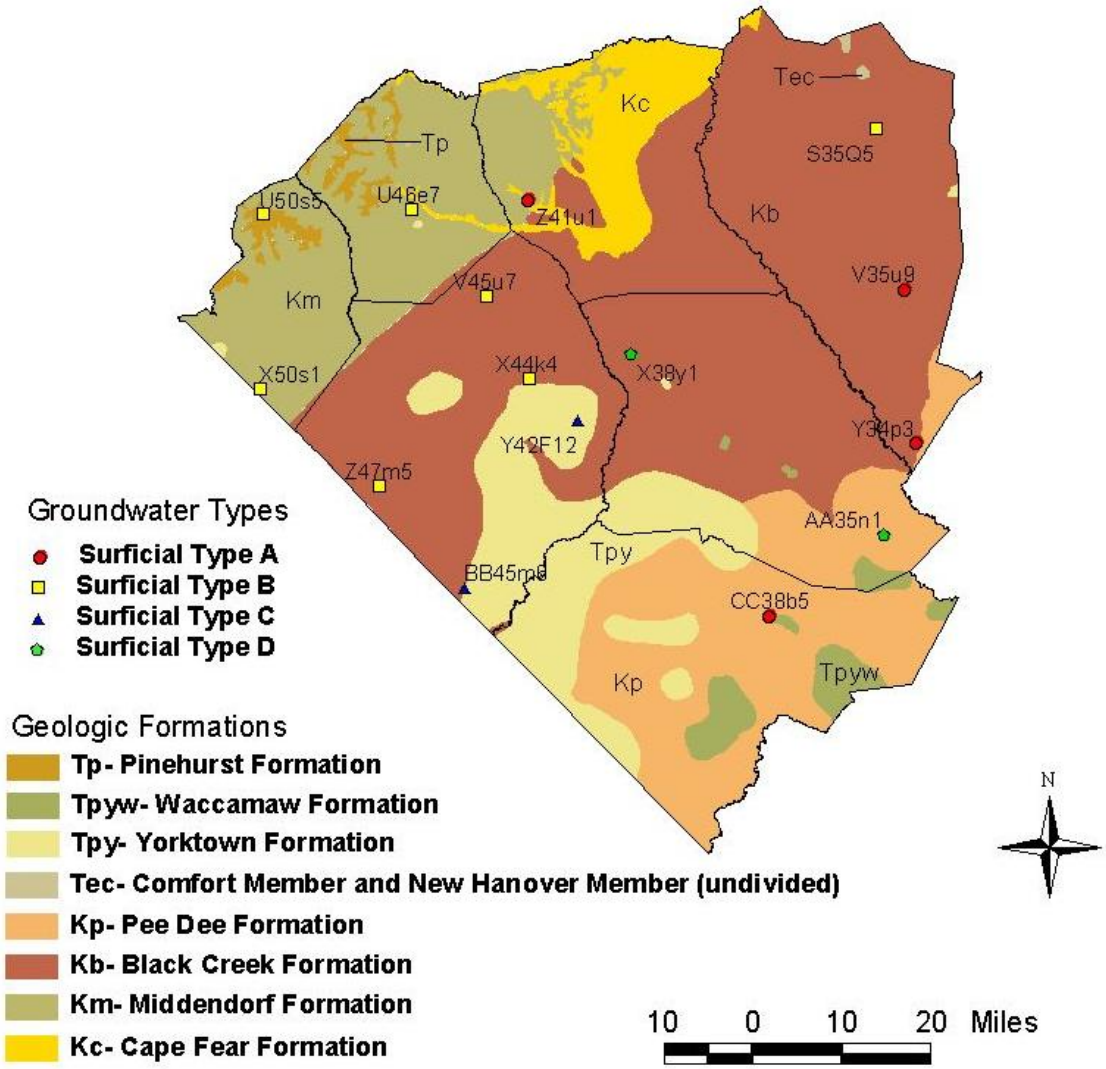


Figure 12: The research station locations screened in the Surficial Aquifer are shown on a geologic map of the study area and indicated according to the groundwater type that is produced. The colored units of the geologic map indicate the rock or sediment formation at the ground surface.

Over the one-year sampling period, 4 wells (Z41u1, CC38b5, Y42f12, and Y34p3) consistently produced groundwater with a TDS content, but not at values that exceed the North Carolina (15A NCAC 2L) Groundwater Standards (Appendix 3). Groundwater with a TOC content above the State's action level of 10 parts per million (ppm) was detected in well X38y1 during the first and fourth sampling events. Nitrate was detected through the four sampling quarters above Groundwater Standards in only one well used in the study (Y42f12). Iron was detected at concentrations as high as 83 times the Groundwater Standard of 300 parts per billion (ppb) (well Z41u1). Only three wells produced moderately (60-120 ppm) to very (180+ ppm) hard water. The mean hardness is 46 ppm in the Surficial Aquifer.

Shallow Confined Aquifers

Seventeen wells used in this study, are screened in the shallowest confined aquifer, which are within the Pee Dee (5 wells), Black Creek (8 wells), or Upper Cape Fear (4 wells) Aquifers. Groundwater analyzed from the Pee Dee Aquifer generally has high iron, magnesium, TDS, calcium, and bicarbonate. Two wells produced groundwater with

consistently high (above Groundwater Standards) manganese signatures (DD42n1, Z41u4).

Only three of the eight wells screened in the Black Creek Aquifer consistently produced groundwater with high iron (Y42f11, X44k6, and V45u3). Each of the four wells screened in the Upper Cape Fear Aquifer and three wells screened in the Pee Dee Aquifer produced groundwater with a high iron signature. Only two wells screened in the shallow confined aquifers produced moderately hard water through most sampling quarters. The mean hardness for the first confined zone is 62 ppm.

Groundwater Contamination

Contamination within the shallow aquifer system already exists within the Southern Coastal Plain study area. Based on a query of the Groundwater Section's Pollution Incident Database, 95 contamination sites were identified. These include discharges related to surface spills and underground leaks not associated with underground storage tanks (UST's). There are approximately 640 additional sites where releases from UST's have been reported. This incident list should not be considered comprehensive. Parties identified as responsible for the contamination are required by the State to remediate the soil and/or groundwater to specific standards.

Also, a study was completed by several collaborators to evaluate the potential source of nitrate contamination of the Surficial Aquifer within the Keener area of Sampson County (LAW, 1997). The contamination was identified during a statewide private well screening program sponsored by the Governor's Office in 1996. The study concluded that the contamination was the result of several different sources, including septic systems, fertilizer, and naturally occurring soil nitrogen. It was also noted that there appears to be a direct relationship between contamination and well construction standards and depth. As demand on the shallow aquifer system increases, care must be taken to prevent contamination of groundwater that may be needed as a drinking water supply.

INTERPRETATIONS

Groundwater quality varies by aquifer and geographic location. Within the Surficial Aquifer and shallow confined aquifers, groundwater ranges from calcium bicarbonate to sodium chloride. The calcium and bicarbonate is most likely the result of dissolution of natural shell material. Overall, water in the Surficial Aquifer and shallow confined aquifer is soft to slightly hard. Groundwater in the first confined zone (62 ppm) has a higher mean hardness value than the Surficial Aquifer (46 ppm). For each of the four research stations that produced Surficial groundwater with a high TDS content, the corresponding well screened in the shallow confined aquifer also produced groundwater with a high total dissolved solid content. Due to the limited extent of this study, the source of the TDS is unknown, but may be the result of land use activities. The elevated concentration in the confined aquifers may be the result of well construction and/or condition. One quarterly sample taken from well X38y2 returned a hardness concentration of 530 ppm, skewing the mean hardness for that zone. The pesticide parameter, 4-nitrophenol, was detected at a low concentration during the first of four sampling events. The isolated occurrence is most likely due to sampling technique or lab error.

CONCLUSIONS

This study is limited in its extent. However, some conclusions and recommendations

can be drawn based on the data collected (note: complete data set and GIS maps submitted in electronic form to SCPGWAC; geochemical diagrams and a partial data set are provided in the appendices). In most cases the Surficial Aquifer of the study area has not been extensively developed for public utility or industrial water supply systems. This is because of the limited yield and poorer water quality, which requires more treatment. A notable exception to this is found in certain areas of the Sand Hills. Also, because water in the Surficial Aquifer is unconfined, the level of water below the land surface is free to fluctuate depending upon stream flow or recharge from rain. Because of this fluctuation, the quantity of water that can be drawn from the unconfined aquifer changes throughout the year. Very little published information exists about the composition or quality of the shallower groundwater units of the study area.

In some areas, the shallow aquifers are the only economical source of groundwater supply because deeper confined aquifers reportedly contain elevated chloride. Because of limitations of available water and anticipated restriction on usage of deeper aquifers in the planning area, the quantity of water available in the Surficial Aquifer and the first confined aquifer may, in the future, be given consideration as an important source of recoverable water.

RECOMMENDATIONS

- Land use planning should consider soil permeability and groundwater recharge rates when siting potential pollution sources.
- Although any of the three terrains described in this report may be selected for a shallow well location, areas located near any of the following activities should be carefully considered or avoided:
    - Areas of known groundwater contamination resulting from industrial or commercial releases of chemicals
    - Proximity to onsite domestic waste systems
    - Areas where there is or will be land spreading of municipal and/or industrial waste
    - Areas where there are lagoon or spray fields used for the handling of animal waste
    - Sanitary landfills and other solid waste disposal sites
    - Quarries and borrow pits
- County well construction ordinances should be developed and employed to promote proper well construction standards and prevent contamination in the well or water supply zone(s).
- Develop a program to provide assistance for properly abandoning unused and/or improperly constructed wells.
- Continue to monitor groundwater quality by use of a comprehensive monitoring network.
- Research the effects of land use and growth.
- Properly locate and maintain septic systems.
- To adequately protect/preserve groundwater quality, an aquifer sensitivity evaluation should be conducted.
- Further groundwater quality investigations should be conducted to adequately characterize the shallow groundwater system. Additional research stations should be added to the established network and monitored over a period of time. The underlying geology at each station should also be evaluated to identify any depositional environment and groundwater signature correlations.

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APPENDIX 1

Available on CD. Please contact Michelle Rollins at 919-715-6697.

APPENDIX 2

Available on CD. Please contact Michelle Rollins at 919-715-6697.

APPENDIX 3

Available on CD. Please contact Michelle Rollins at 919-715-6697.