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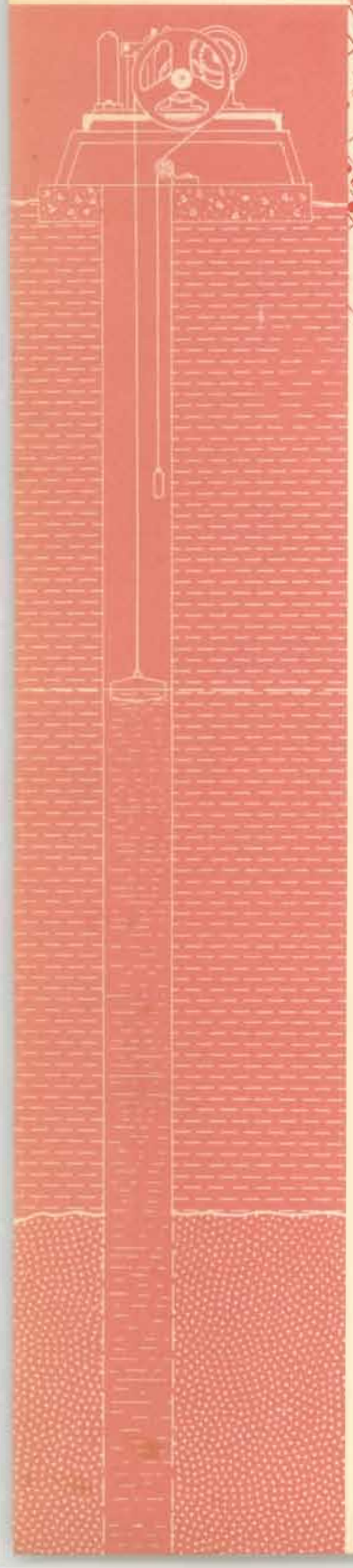
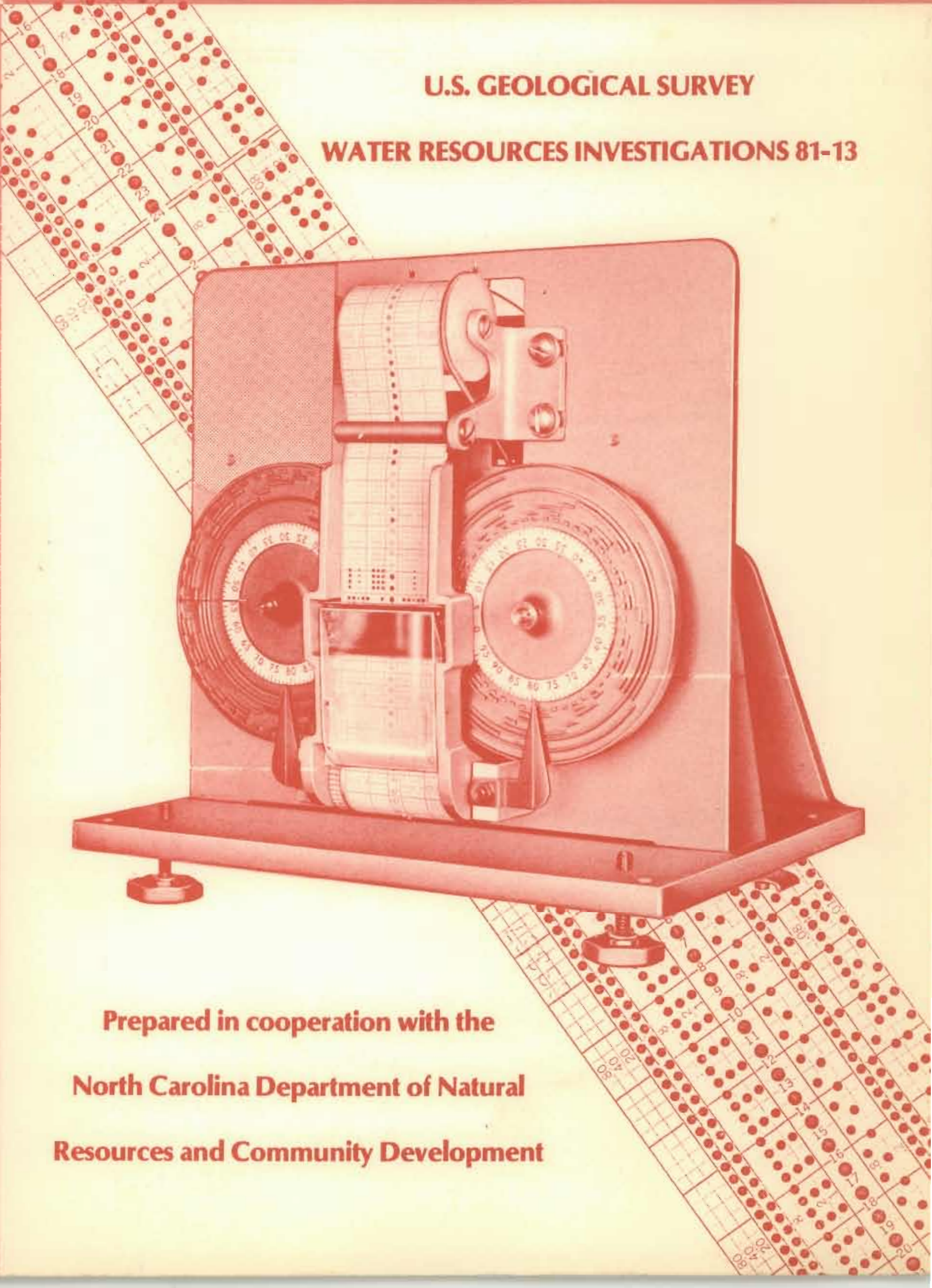
AN OBSERVATION-WELL NETWORK CONCEPT AS APPLIED TO NORTH CAROLINA





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A statewide observation-well program is proposed for North Carolina based on four networks of observation wells with different but clearly-defined objectives. These are referred to as the (1) climatic-effects network, (2) terrane-effects network, (3) local-effects network, and (4) areal-effects network.

The characteristics of each network are related to natural and manmade stresses in aquifers, and the areas and hydrogeologic units in North Carolina where these networks are needed are identified.

Formats for collection, processing, and publication of data from these networks are suggested.

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Resources and Community Development

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March 1981

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AN OBSERVATION-WELL NETWORK CONCEPT AS APPLIED TO NORTH CAROLINA

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ABSTRACT

A statewide observation-well program is proposed for North Carolina based on four networks of observation wells with different but clearly-defined objectives. These are referred to as the (1) climatic-effects network, (2) terrane-effects network, (3) local-effects network, and (4) areal-effects network.

The characteristics of each network are related to natural and manmade stresses in aquifers, and the areas and hydrogeologic units in North Carolina where these networks are needed are identified.

Formats for collection, processing, and publication of data from these networks are suggested.

INTRODUCTION

Purpose and Scope

This report is an outgrowth of a review of the observation-well networks operated by the U.S. Geological Survey and the North Carolina Department of Natural Resources and Community Development (NRCD) undertaken by the Survey at the request of Harry M. Peek, Chief of the Groundwater Section of NRCD. During the review, records of over 650 observation wells were examined to determine which of the wells should be retained for water-level measurements. The results and details of this examination are available in U.S. Geological Survey Open-File Report 81-544 entitled "Proposed Observation-Well Networks and Ground-Water Level Program for North Carolina," (Winner, 1981).

The purpose of this report is to show how a statewide observation-well program based on a network concept adapted from a paper by Heath (1976) may be used to develop an effective ground-water level monitoring program for North Carolina. Heath (1976) emphasized the importance of (1) setting objectives for each observation well related to the types of stresses--natural and manmade--occurring in aquifers and (2) establishing networks or groups of observation wells needed to measure these stresses. In addition to monitoring by objectives, an observation-well program organized into networks lends itself to periodic reviews, which reveal those wells no longer fulfilling their network function, as well as those areas where additional network coverage is needed.

It should be emphasized that the observation wells comprising a statewide network as proposed here are not the only wells for which water-level data might be needed. Some special-purpose observation wells that provide data for short-term areal and site-specific investigations and for special requests are also part of a ground-water observation-well program. However, such special-purpose wells are not included in the network concept because the records are usually short term and of only local value.

At the time of the network review, there were two existing observation-well networks in North Carolina--one of about 50 wells operated by the Survey, and the other of about 600 wells operated by NRCD. Although not considered in the review, it is obvious that where dual networks are in operation, it is necessary to carefully coordinate data-collection activities and data-processing procedures to assure comparable quality of basic data. This report outlines the important features to be considered in maintaining an observation-well network, and presents a format for the timely publication of ground-water level data.

Acknowledgments

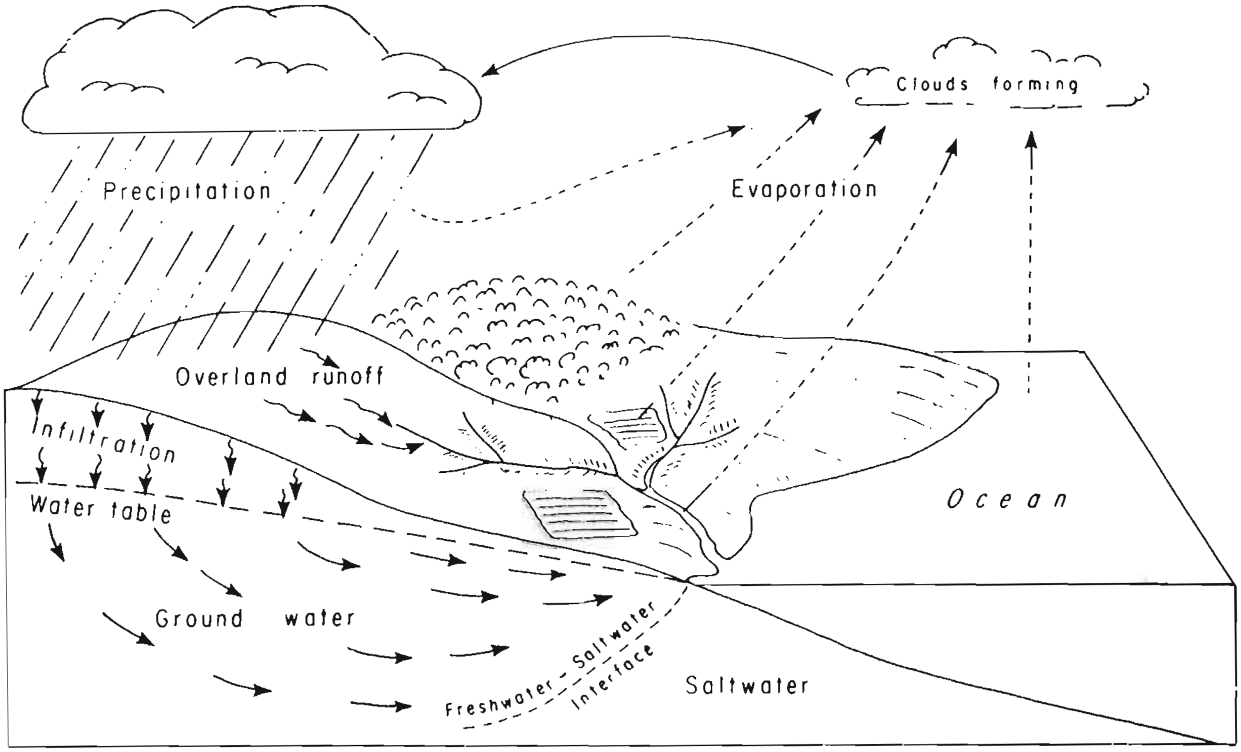
This report was prepared in cooperation with the North Carolina Department of Natural Resources and Community Development. As originally prepared, this report was part of an initial manuscript that included the basic parts of this report plus a description of the methodology of well-records review and recommendations to retain specific wells in a North Carolina observation-well program. The initial manuscript was reviewed by H. M. Peek, P. F. Nelson, L. L. Layman, and L. A. Register of NRCD, and in response to their recommendation the manuscript was divided into two reports, this report and a report containing specific recommendations for wells in the observation-well program.

Colleague review for this report was provided by R. W. Coble and R. C. Heath of the Survey. Kay E. Harris and Catherine Harrington typed the manuscript, and John R. Teel, Jr. drafted the illustrations and prepared the cover artwork.

GROUND-WATER SYSTEMS AND WATER-LEVEL FLUCTUATIONS

In arriving at a rationale for measuring ground-water levels it is first necessary to understand the role of ground water in the hydrologic cycle and the forces acting on ground-water systems to cause water-level fluctuations. This section serves to review briefly the occurrence of ground water, and to set the stage for the development of a system to monitor ground-water levels in North Carolina.

The large amount of water stored underground makes it an important part of the freshwater component of the hydrologic cycle, which is the term used to refer to the constant movement of water above, on, and below the Earth's surface (fig. 1). Although the hydrologic cycle has neither a beginning nor an end, it is convenient to discuss its principal features by starting with evaporation from exposed surfaces such as vegetation, land surface, lakes, streams, and from the ocean. This moisture forms clouds which, under favorable conditions, return the water to the land surface in the form of precipitation. Precipitation occurs in several forms, including rain, snow, sleet, and hail, but we will consider only rain in this discussion.



FROM HEATH, 1980, PAGE 6.

Figure 1.--The hydrologic cycle.

The first rain wets vegetation and other surfaces and then begins to infiltrate into the ground. The water that infiltrates replaces soil moisture; after deficiencies in soil moisture are satisfied, additional infiltration moves downward across the unsaturated zone to the saturated zone and the water table. (See fig. 1.) All the rain will infiltrate into the soil until the infiltration capacity of the soil is reached. Rainfall exceeding the infiltration capacity of the soil becomes overland runoff and moves downhill to streams.

Water in the saturated zone is called ground water, and the infiltrating water that reaches the saturated zone constitutes ground-water recharge. Ground water moves downward and laterally through the porous earth materials to sites of ground-water discharge such as springs on hillsides or seeps in the bottoms of streams, lakes, or beneath the ocean. Water reaching these surface-water bodies is evaporated again and, by this process, perpetuates the hydrologic cycle.

From the standpoint of ground-water occurrence, all rocks underlying the Earth's surface are classified as either aquifers or confining beds; and the aquifers and confining beds underlying an area comprise the ground-water system of that area.

An aquifer is a rock unit, or body of earth material, that will yield water in a usable quantity to a well or spring. A confining bed is a rock unit that restricts the movement of ground water either into or out of adjacent aquifers.

Ground water occurs in aquifers under either of two different conditions. First, where water only partly fills an aquifer, the top of the saturated zone is free to rise and fall, the ground water is said to be unconfined, and such aquifers are referred to as unconfined aquifers. Second, where water completely fills an aquifer that is overlain by a confining bed, the water in the aquifer is said to be confined. Such aquifers are referred to as confined aquifers.

Wells open to unconfined aquifers are referred to as water-table wells. The water level in these wells indicates the position of the water table in the surrounding aquifer--that is, the level in the surrounding aquifer at which the ground water is at atmospheric pressure. Wells drilled into confined aquifers are referred to as artesian wells. The water level in artesian wells is under some pressure greater than atmospheric and stands at some height above the top of the aquifer (but not necessarily above the land surface) and is called the potentiometric surface of the aquifer.

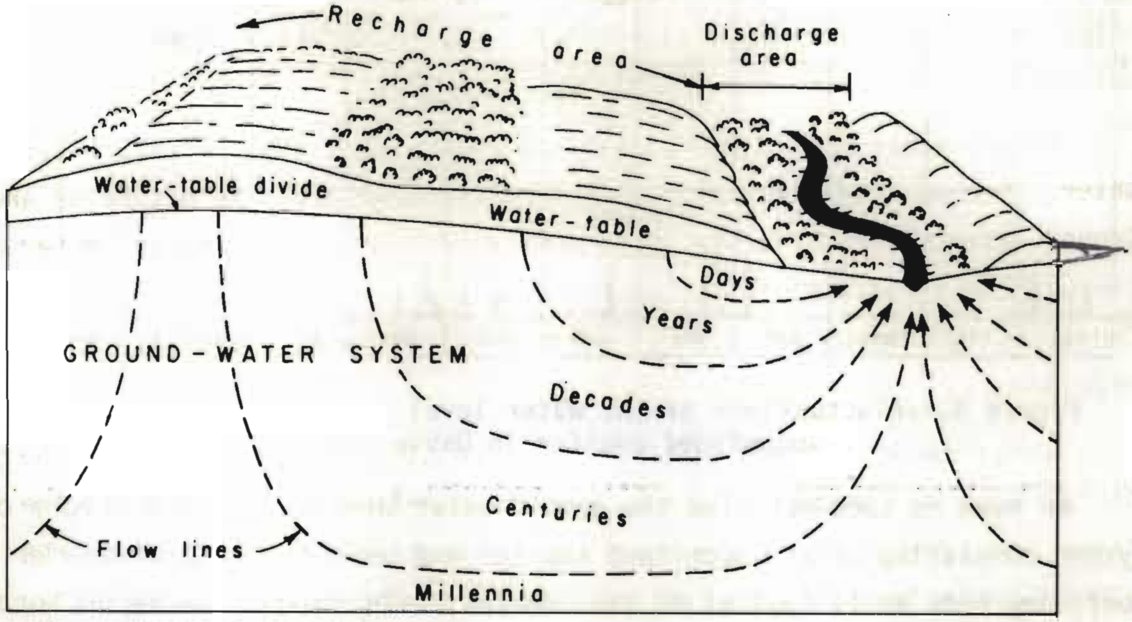
Ground-water systems serve two hydraulic functions. First, they store water. Second, they transmit water from recharge areas to discharge areas. Ground-water systems store a tremendous amount of water, and yet water moves through the systems at a slow rate, usually a few feet per day at the most. Thus, most ground-water systems are more effective as reservoirs than as pipelines.

Ground-water storage is constantly changing. It increases by the process of recharge that occurs naturally by precipitation infiltrating to the saturated zone, and decreases as a result of naturally occurring discharge through springs or by seeping into streams, lakes, or the ocean. Considerable natural discharge also takes place by evaporating directly from the saturated zone where the water table is near land surface, and by transpiration from plants where their roots reach to the saturated zone. Man also causes artificial ground-water discharge by withdrawing water through wells.

Water levels in wells rise in response to recharge and increasing storage in the aquifers they tap, and decline in response to discharge and decreasing storage. Thus, by measuring water levels in wells, hydrologists can determine changes in storage and the response of the aquifers to natural and man-made stresses.

Response to Natural Stress

In the previous discussion of the hydrologic cycle, a generalized picture of how the ground-water system operates was presented. We need to look at this part of the cycle in more detail. Rainfall enters the ground-water system in recharge areas, moves through the system, and leaves it in discharge areas. The time required for ground water to move from recharge areas to discharge areas can range from days to thousands of years. (See fig. 2.) The water moves through the system in response to hydraulic gradients and as dictated by the hydraulic conductivities of the aquifers and confining beds. It should be noted here that ground water will continue to discharge from the system in discharge areas, even though no recharge is taking place, as long as the hydraulic head in any part of the system is higher than it is in the discharge area.



FROM HEATH, 1980, PAGE 14.

Figure 2.--Movement of water through the ground-water system.

In the example shown in figure 2, the discharge area is a stream valley. As long as ground water continues to discharge to the stream, streamflow (base flow) will be maintained by ground water even though rain may not have fallen for a long period of time. Base flow is maintained at the expense of ground-water storage, and during an extended dry period the storage may be reduced greatly--the result of which will be a thinning of the zone of saturation as indicated by a declining water table.

The status of ground-water storage can be detected and monitored by measuring the changes in the position of the water level in wells. The hydrograph of a water-table well in Davie County, N.C. (fig. 3) is an example of a water-level record that shows seasonal changes in ground-water storage. The ground-water reservoir receives considerable recharge during the rainy winter months when evaporation is also at a minimum rate and plants are dormant. Recharge in excess of discharge is shown by the rises in the water level indicating that storage is increasing. In late spring, summer, and early fall, evaporation and transpiration capture most of the potential ground-water recharge, and ground-water storage decreases as indicated by a falling water level. This decrease represents ground water that was released from storage to maintain streamflow during the dry period.

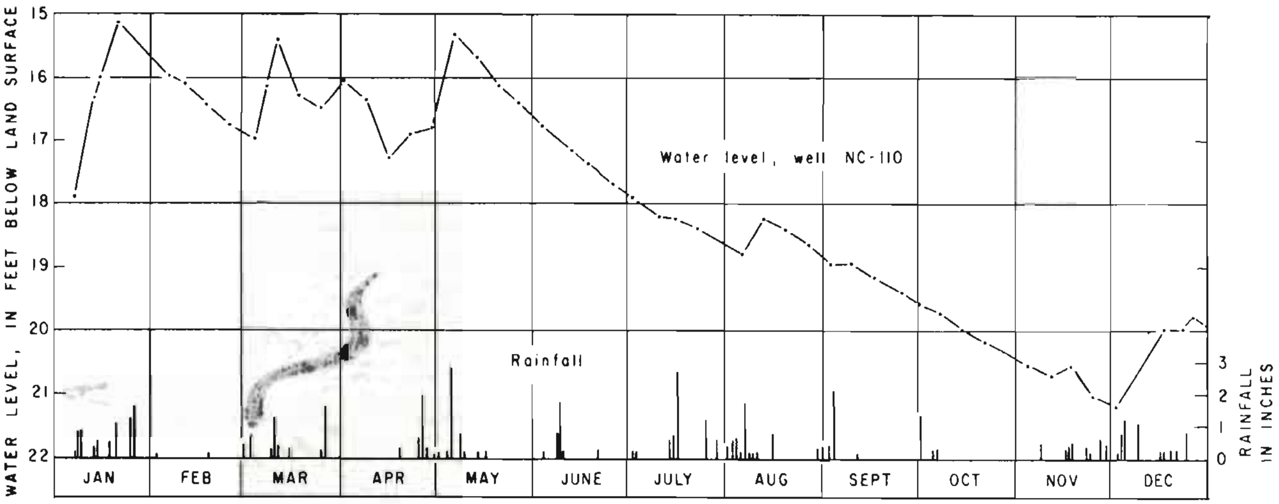


Figure 3.--Fluctuations of the water level in well NC-110 tapping an unconfined aquifer in Davie County.

We need to consider also the ground-water movement through a more complex system consisting of an unconfined aquifer and several confined aquifers and confining beds as is typical of the Coastal Plain aquifer system in North Carolina. Figure 4 shows the movement of ground-water from the recharge areas to the discharge area as modified by several confining beds, which separate the aquifers.

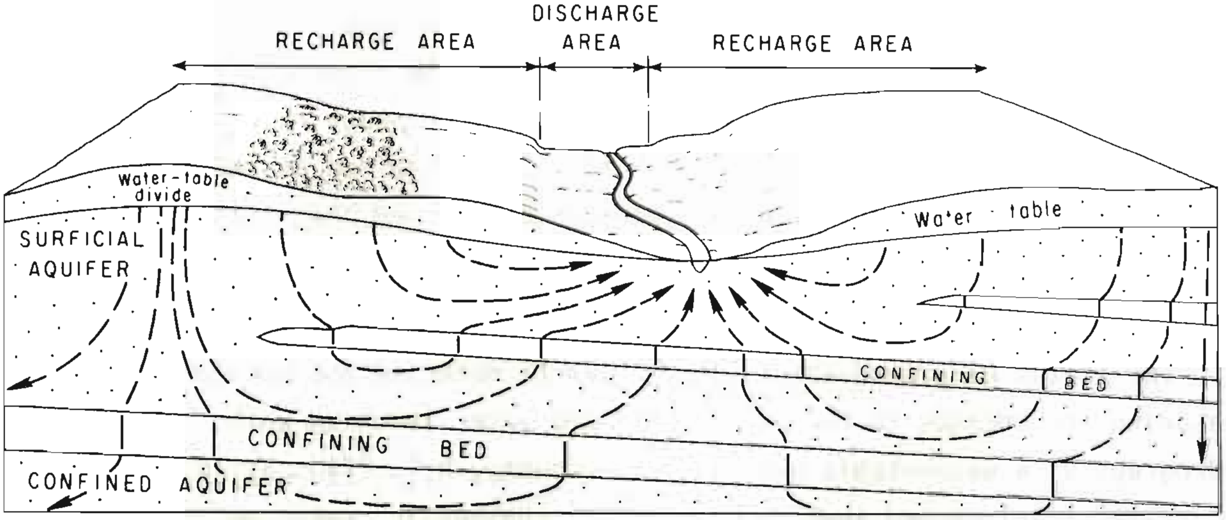
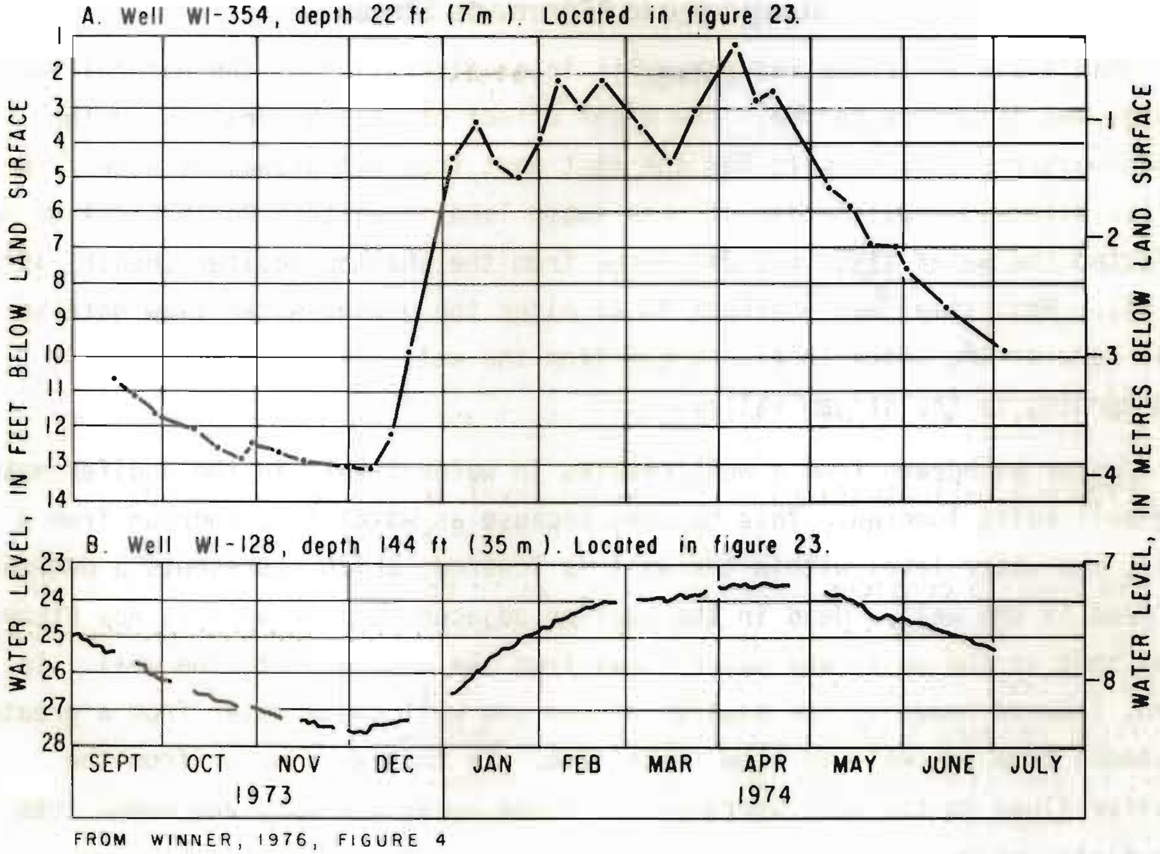


Figure 4.--Movement of water through a ground-water system of unconfined and confined aquifers--a typical Coastal Plain situation.

Although ground water can move from one aquifer to another, the movement is restricted by the confining beds.

An example of this restriction to flow between aquifers can be seen in the water-level responses of two wells located about 200 feet apart in eastern Wilson County, N.C. (fig. 5). The hydrograph of the water-table well (fig. 5A)



FROM WINNER, 1976, FIGURE 4

Figure 5.--Comparative fluctuations in (A) the water table of an unconfined aquifer and (B) the potentiometric surface of a confined aquifer.

reveals the same kind of response to climatic conditions as does the hydrograph of the Davie County well (fig. 3). During the winter months, recharge from rainfall and decreased evapotranspiration provided more water to the ground-water reservoir than was discharged from it, thus water levels rose because storage was increased. During the growing season, discharge exceeded recharge and ground-water storage decreased as indicated by the declining water level. The water level in the confined aquifer, which is separated from the unconfined aquifer by one or more confining beds, responds similarly to seasonal recharge and discharge (fig. 5B). However, the water-level rise was much slower and amounted to only about a third of that in the unconfined aquifer. The differences in depth to water level below land surface in the wells is the same as the difference in head in each aquifer. The head in the unconfined aquifer is from 14 to 22 feet higher than the head in the confined aquifer. Thus, the ground water is moving from the unconfined aquifer to the confined aquifer. These wells then are in a location similar to one of the recharge areas shown on figure 4.

Response to Manmade Stress

Man's use of ground water results in an alteration of the natural recharge and discharge regime. The major effect of this alteration on the ground-water system results for the most part from withdrawal of water from wells, although canalization of some swamp land in eastern North Carolina has affected the water table and discharge from the shallow aquifer (Heath, 1975, p. 64). Basically, man's effect is to alter the ground-water flow path so that some of the water is discharged from the well rather than all of it discharging in the stream valley.

Water withdrawn from a well results in water levels in the aquifer near the well being lowered. This happens because as water is withdrawn from a well, the water level within the well is lowered, which represents a decrease in head in the well. Head in the aquifer adjacent to the well is now higher than that in the well, and water flows from the aquifer into the well. In turn, lowered heads in the aquifer around the well cause water from a greater distance from the well to flow to it also. In this way, water from the aquifer flows to the well where it is picked up by the pump and moved into the distribution system.

The decrease in head at and around a pumping well takes the general form of a cone of depression. In an unconfined aquifer, the cone is represented by a dewatering of the aquifer; in a confined aquifer, it is represented by a lowering of the potentiometric surface. The longer a well is pumped, the deeper and more widespread the cone will be. If two or more pumping wells are close enough together, their cones may overlap. The effect of one cone on another is additive. This effect is known as well interference, which has been explained by Heath (1980) along with discussions of the cone of depression and sources of water derived from wells.

The lowering of water levels as a result of pumping becomes a concern of water users and regulatory agencies when well interference becomes great enough to cause conflicts between ground-water users. This lowering begins as water is removed from storage in the vicinity of each pumping well and a cone of depression is formed. The cone expands outward until the rate of withdrawal is balanced by a reduction in natural discharge from the aquifer or by an increase in recharge to the aquifer. If withdrawals from one or several closely spaced wells are not balanced by a decrease in natural discharge or an increase in recharge, water will continue to be drawn from storage and the cone will continue to spread until natural discharge, such as to streams, is stopped in the vicinity of the wells. Recharge may then be increased by water induced to move into the producing aquifer from the streams. Additional water may also be induced to move from adjacent aquifers through the confining beds (vertical leakage) to the producing aquifer.

The drawdown of ground-water levels resulting from withdrawals can be detected by observation wells. Examples of observation well hydrographs indicating pumping effects are shown in figures 6 and 7. Figure 6 shows water levels in well NC-14 which is located near public-supply and industrial wells in Washington, N.C. The influence of a weekly pumping cycle is evident, and the larger water-level rises during extended nonpumping periods (Christmas and Fourth of July) are obvious.

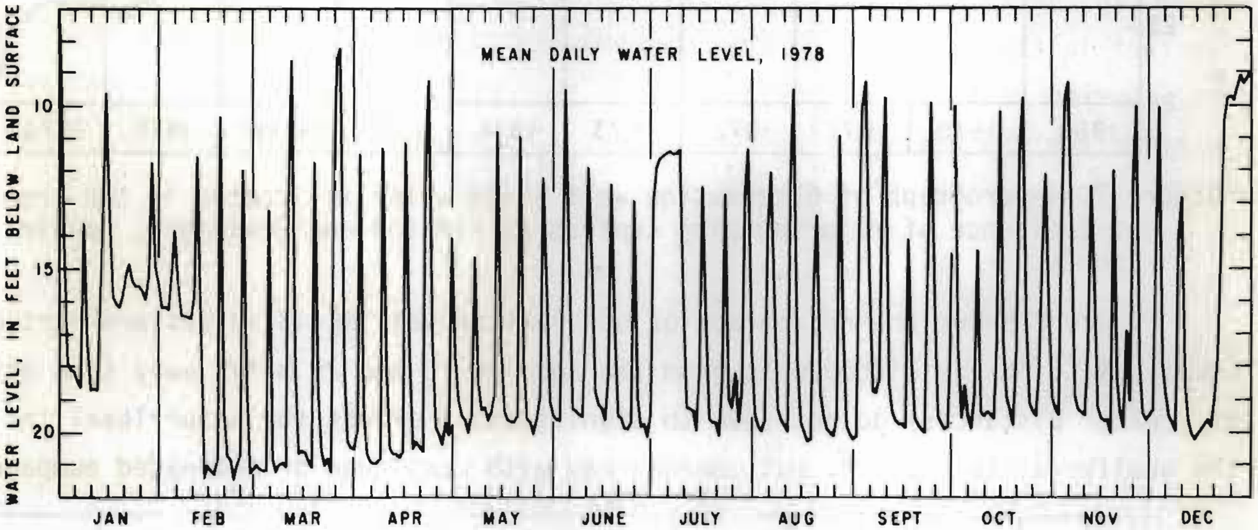


Figure 6.--Hydrograph of observation well NC-14 which is located near municipal and industrial wells in Washington, Beaufort County.

Evidence of the large cone of depression caused by pumping in the Kinston-Graingers area in Lenoir County, N.C. is shown by the gradual decline in water level in well NC-16 over several years (fig. 7). This well is about 25 miles from the centers of pumpage, and the water-level record indicates that the discharge has not yet been balanced by a reduction in natural discharge or an increase in recharge.

Water levels in areally extensive, heavily-pumped aquifers far removed from pumping centers may show fluctuations in response to the cumulative effects of all withdrawals from the aquifer. Evidence for such areal effects may be seen in a hydrograph as a progressive decline in the seasonal high and low water level, or else the areal effects may be so slight as to be effectively masked by climatic effects, requiring considerable skill to interpret effects of pumping.

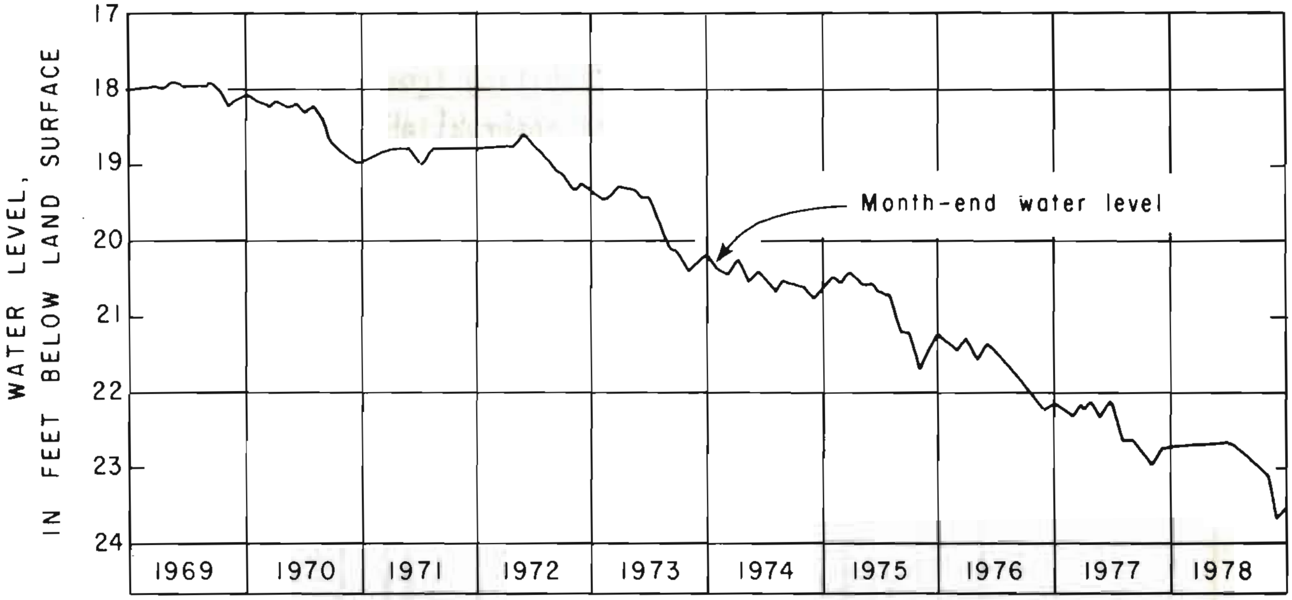


Figure 7.--Hydrograph of observation well NC-16 which is located in the area of influence of major pumping centers at Kinston and Graingers, Lenoir County.

Figure 8 shows the hydrograph of observation well NC-43 in western Martin County, N.C. Large withdrawals from the aquifer 10 and 25 miles away (and others at greater distances) do not seem to significantly affect the water level in the aquifer at this point, but someday may with continued or increased pumpage.

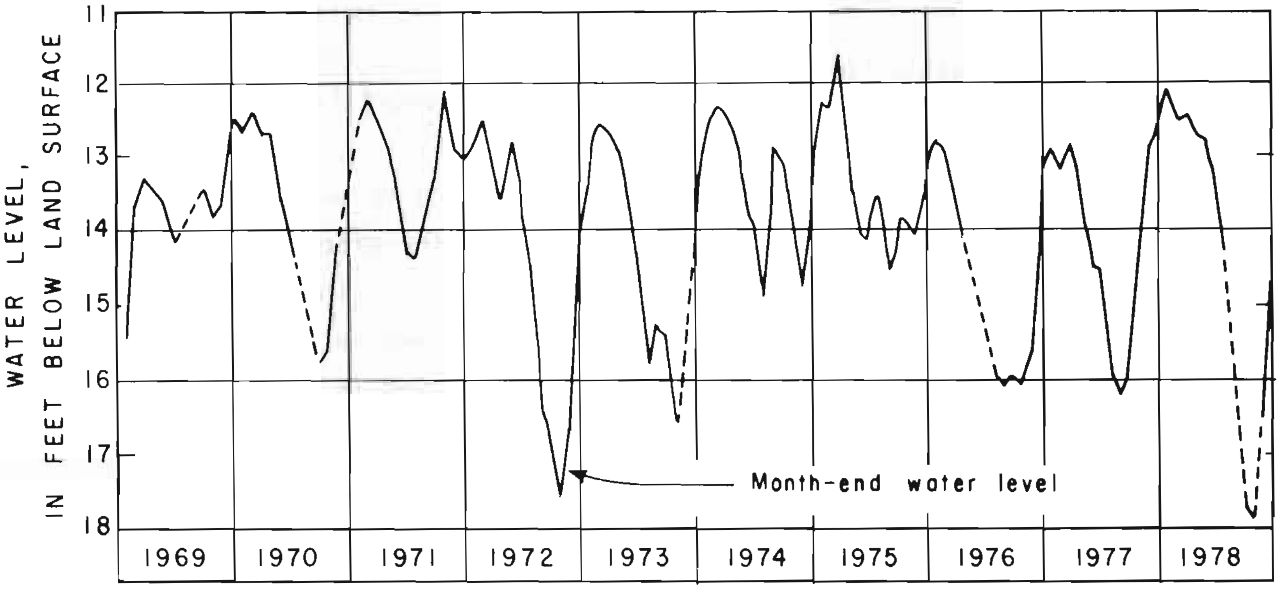


Figure 8.--Hydrograph of observation well NC-43 in Martin County which is outside the immediate area of influence of centers of large withdrawals.

NETWORK CONCEPT FOR OBSERVATION WELLS

The key to an effective observation-well program is to use wells in which water levels respond to the particular stresses--natural or manmade--you want to study or monitor. In 1976, Heath introduced an observation-well network concept which defined specific objectives of ground-water level monitoring and urged the selection of wells that furnish water-level records to meet those objectives. The Geological Survey's observation-well program in North Carolina is based on these concepts, which are outlined in the following sections, and summarized in table 1.

Table 1.--Summary of Observation-Well Networks

Networks		Objectives	Products
This report	Heath, 1976		
To monitor natural stresses			
Climatic effects	Baseline A	To define effects of climate on ground-water storage.	Hydrographs showing natural changes in storage.
Terrane effects	Baseline B	To define the effects of climate on ground-water storage as modified by topography and geology.	Hydrographs showing natural changes in storage as modified by topography and geology.
To monitor manmade stresses			
Local effects	Water management	To define effects of stresses on recharge and discharge conditions. To define hydraulic characteristics of aquifers. To assess degree of confinement.	Maps of cones of depression. Hydrographs showing changes in water levels with time. Graphs of water levels versus pumping rates.
Areal effects	Hydrologic	To determine status of storage. To define regional continuity of aquifers.	Regional water-level maps. Maps showing net change in water levels or storage over a selected period.

Monitoring Natural Stresses

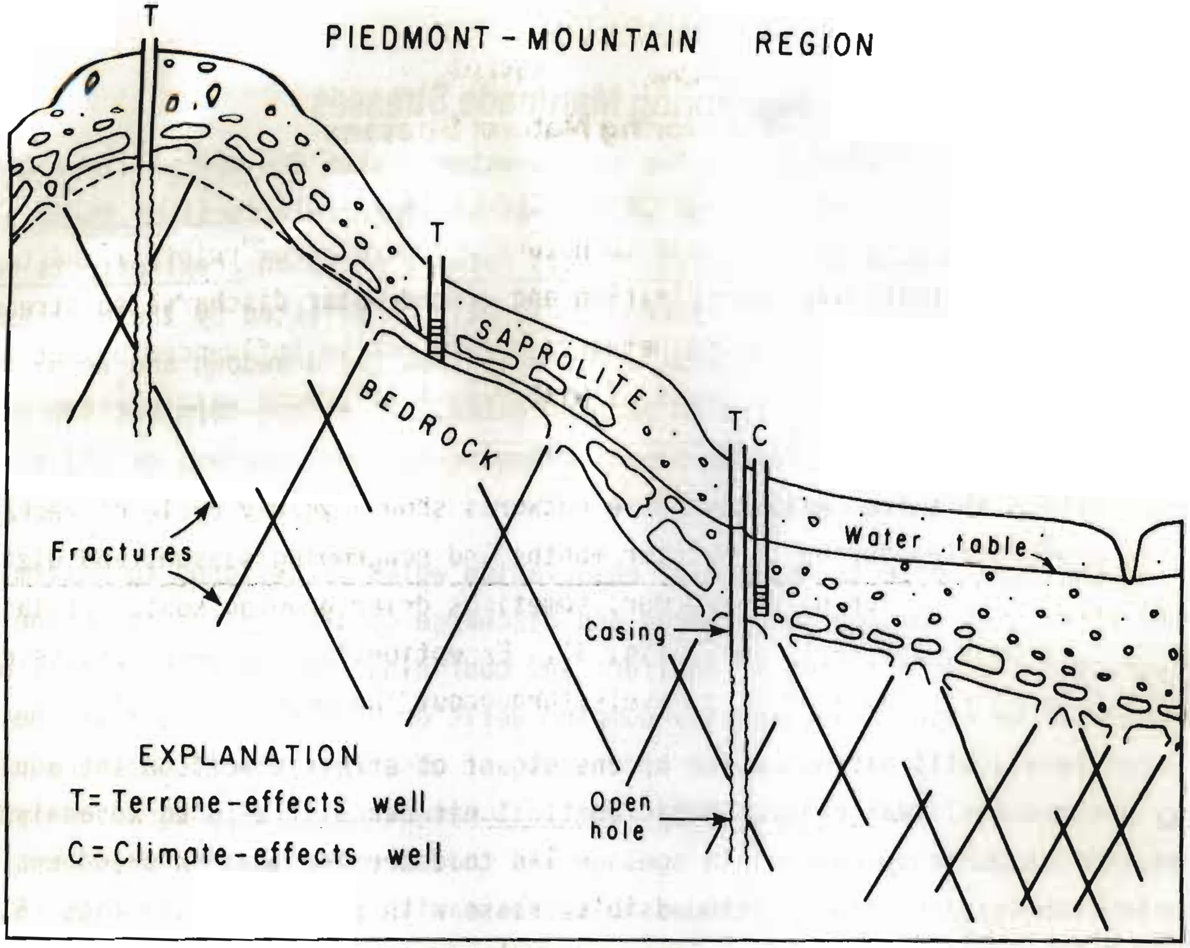
Water levels in wells that are assigned to a climatic-effects network or a terrane-effects network respond to natural recharge from rainfall and to discharge from both evapotranspiration and ground-water discharge to streams. Water levels monitored in these networks should not be influenced by man and should be remote from the effects of withdrawals of ground water by pumping or other artificial stresses.

Hydrographs from wells in these networks show a yearly cycle of recharge that predominates during the winter months and nongrowing season, and discharge that predominates during the warmer, sometimes drier growing season of late spring, summer, and early fall (fig. 3). Exceptionally dry years are revealed by predominately falling water levels throughout the year.

The climatic-effects network consists of observation wells open to the unconfined surficial hydrogeologic unit. Their purpose is to show the effect of climate on ground-water storage. Wells that are included in this statewide network should be, insofar as possible, similar in construction, depth to water level, topographic location, and geologic situation in order to identify and correlate the effects of climate on ground-water levels.

The terrane-effects network is also statewide in scope. Water-level observations in wells of the terrane-effects network are used specifically to define the added effects of topography and geology on ground-water storage in response to climatic changes (fig. 9). Some of the wells in this network should be near wells of the climatic-effects network, but in different topographic locations and (or) open to deeper aquifers.

Water-level data from both the climate-effects and the terrane-effects networks are essential for the interpretation of data collected from observation wells that monitor manmade stresses in the ground-water system. Climatic, topographic, and geologic factors that influence fluctuations in ground-water storage must be accounted for in order to determine the effects of manmade stress.



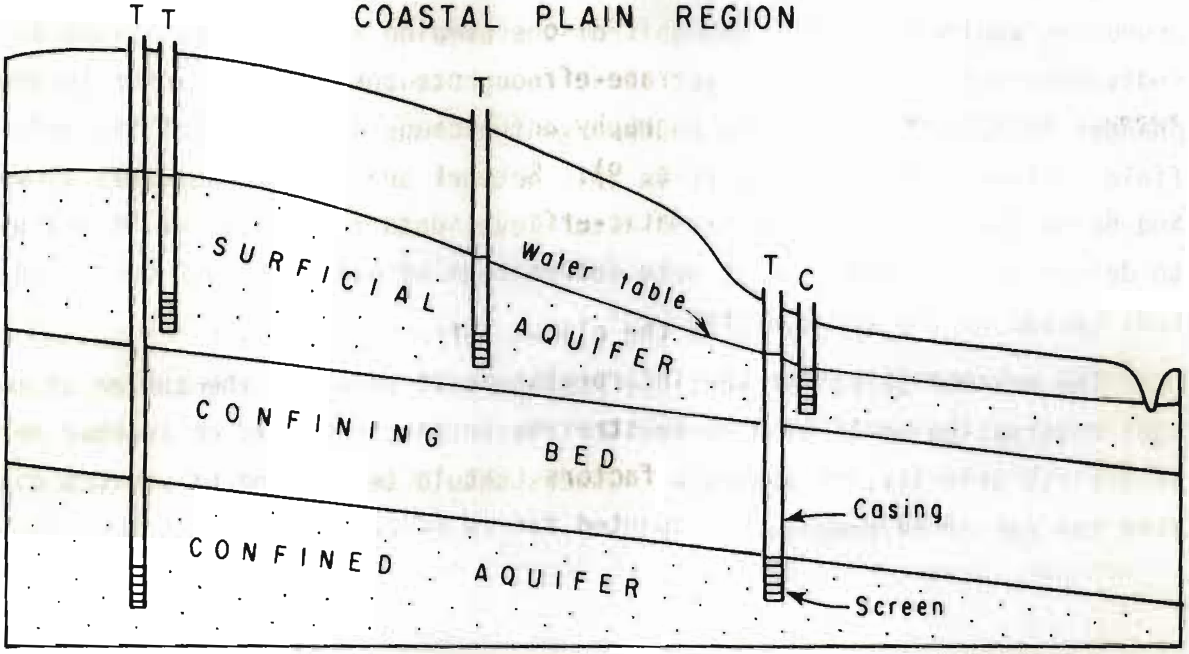


Figure 9.--Placement of terrane-effects observation wells to define the influence of topography and geology on ground-water levels.

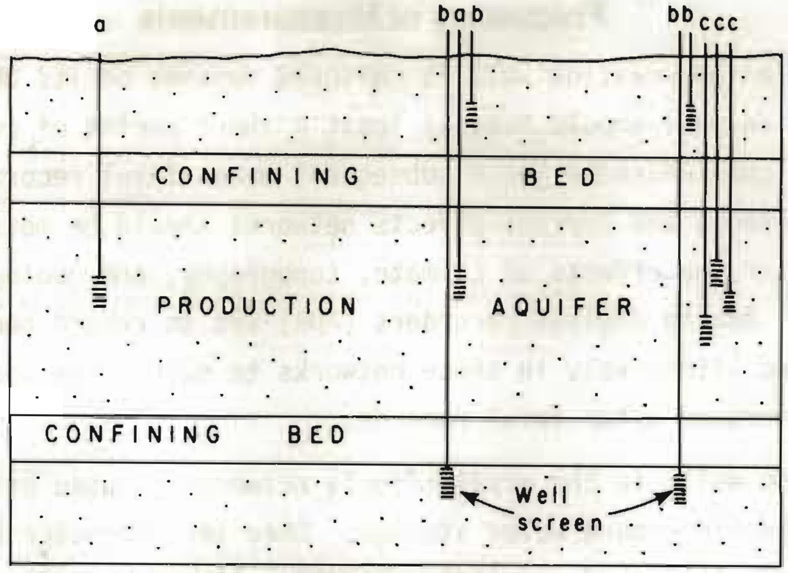
Monitoring Manmade Stresses

Major manmade stresses on the ground-water system are due to large withdrawals by pumping. Observation wells that monitor the effects of these stresses belong to either a <u>local-effects network</u> or to an <u>areal-effects network</u>, and are placed in each hydrogeologic unit so affected by these stresses. Water levels in these observation wells will show (1) drawdown and recovery cycles in response to changes in pumping rates, (2) a long-term decline or recovery trend superimposed on annual climatic-response cycles, or (3) a combination of these features.

The local effects network of observation wells is designed to determine the effects of pumpage on recharge and discharge conditions and to define the hydraulic characteristics of aquifers and confining beds. Wells in this network will be near large-capacity pumping wells or well fields so that their water levels will be indicative of the amount of stress placed on the aquifer by withdrawals. Water-level data from this network will be used to analyze aquifer response to changes in pumpage and to determine whether drawdowns have stabilized or have continued to increase with pumpage. (See figs. 6, 7, and 8.)

One set of wells in the local-effects network needs to be open to the producing aquifer, but far enough from the pumping wells so that response to individual wells is minimal, yet close enough to the pumping center to show changes in pumping regime and to observe the composite effect of the well field. Other observation wells in this network are open to aquifers above and below the producing aquifer. Water-level data from these wells are used to determine the magnitude of vertical leakage of water through confining beds caused by the pumpage (fig. 10).

The maximum potential vertical leakage will occur at the center of pumpage; observation wells used to monitor these effects should be located here as a first priority, if possible. Others should be located at various distances from the center of pumpage.



FROM HEATH, 1976, FIGURE 4.

Figure 10.--Idealized local-effects network observation wells: (a) wells open to the production aquifer some distance from the center of pumping, and (b) wells open to overlying and underlying aquifers to observe vertical leakage effects. Production wells are labeled (c).

The objectives of the areal-effects network are to determine the status of storage or change in storage in all or a large part of an aquifer, and to determine the aquifer's areal extent. Aquifers best observed through this network are those of considerable areal extent that have been heavily developed by large withdrawals, or are being developed. The observation wells of this network, ideally, are randomly but evenly distributed over the area to be mapped, but are not located near major pumping centers, or near other possible well interference.

The status of storage and the areal effect of stresses can be satisfactorily observed by making periodic measurements (once or twice a year) in all the wells in the network within a short period of time (a few days at most). The change in storage between times of water-level measurements can be determined by comparing water-level maps prepared at different times. An example of this procedure is given by Peek and Nelson (1975, figs. 3, 4, and 7) in their analysis of the drawdown of the potentiometric surface of the Castle Hayne aquifer between 1965 and 1973.

Frequency of Measurements

How often an observation well is measured depends on its objective, but every observation well should have at least a short period of continuous graphic record upon which to judge subsequent water-level record. Wells in the climatic-effects and terrane-effects networks should be measured continuously to monitor the effects of climate, topography, and geology on ground-water storage. Analog digital recorders (ADR) set to record hourly measurements also can be used effectively in these networks to supply the added convenience of computer-processed water-level records.

Observation wells in the areal-effects network are used primarily to determine changes in ground-water storage. Once the character of water-level fluctuations is established, periodic measurements once a year or no more than monthly generally meet the network objective. Wells whose water-level record shows weekly fluctuations less than about 0.1 foot, or shows seasonal fluctuation of less than 1 foot need not be measured more frequently than annually.

It is desirable to equip one areal-effects network well in each hydrogeologic unit with an ADR. This would serve (1) as a reference or calibration standard for the other wells in this network that are measured annually, and (2) as an interpretive link to climatic-effects network water-level records. In the event of a seemingly anomalous measurement in any given well, the continuous record from the reference well could be an interpretive aid.

Local-effects network observation wells should be monitored continuously with graphic or digital recorders to determine the water-level effects caused by withdrawals. In some instances the water-level fluctuations in the observation well may be so large and irregular because of the influence of nearby pumping wells that the analysis of the hydrograph is very difficult. Observation wells in this situation should be avoided, but when this is impractical, a hi-lo recorder should be installed so that daily, weekly, or monthly highest and lowest water-level readings can be obtained. Plots of these data reduces the well interference "noise" and produces a more easily interpreted hydrograph.

At the perimeter of the cone of influence periodic measurements made no less frequently than monthly should produce sufficient data to fulfill the local-effects network objective.

AN OBSERVATION-WELL NETWORK FOR NORTH CAROLINA

This section describes how the network concept of observation wells may be applied to monitor North Carolina's ground-water levels. Using the basic framework of hydrogeologic units, the several networks are related to climatic, geologic, and topographic differences within the State, and to major centers of ground-water pumpage both in the State and in neighboring Virginia and South Carolina.

Hydrogeologic Units

One of the major tasks in designing a statewide observation-well network is to define the aquifers and hydrogeologic units in order to make the network comprehensible and manageable. Geologic differences in the Piedmont-mountain and Coastal Plain areas of the State are the basis for separate discussions of the hydrogeologic units in these two areas. The Piedmont-mountain area is underlain by fractured rock aquifers and the Coastal Plain area is underlain by aquifers consisting of layers of unconsolidated rocks and porous limestone. The near-surface material covering both the Piedmont-mountain and Coastal Plain areas can be treated as one hydrogeologic unit, called the surficial hydrogeologic unit.

Surficial Hydrogeologic Unit

The surficial hydrogeologic unit of the Coastal Plain is composed of unconsolidated sedimentary deposits consisting of sand, clay, and shell beds. They occur at least as a veneer over the entire area, ranging in thickness from a few feet to as much as 150 feet in the extreme eastern part of the State at Manteo.

Water occurs under unconfined conditions in the surficial hydrogeologic unit of the Coastal Plain almost everywhere, commonly being confined only in the deeper parts where this unit is very thick in the eastern part of the Coastal Plain. Where the unit is thin or missing, the water table can occur in older Coastal Plain sediments such as those of the Yorktown hydrogeologic unit and others. The unconfined parts of these units are considered part of the surficial hydrogeologic unit.

The surficial hydrogeologic unit in most of the Piedmont and mountains consists of saprolite, which is a weathering product of the underlying igneous and metamorphic bedrock. It occurs as a residuum on the bedrock and consists of loose granular material such as sandy clay, clay, and rock fragments. It ranges in thickness from zero to only a few feet in areas where bedrock crops out to more than 100 feet in some major river valleys. The valley floors of many major Piedmont and mountain streams are also underlain by alluvium which consists of stream deposited sand, clay, and gravel. Alluvium is part of the surficial unit.

Coastal Plains Hydrogeologic Units

The Coastal Plain deposits, which cover nearly the eastern one-half of the State, consist of a wedge-shaped body of sedimentary rock. The deposits range in thickness from a feather edge at the western boundary of the Coastal Plain to 10,000 feet at Cape Hatteras. These sedimentary rocks form a complex system of aquifers and confining beds.

The Coastal Plain hydrogeologic units are based on established geologic formations and, thus, are groups of rock layers having similar or recognizable lithologic characteristics and, for the most part, layers which were deposited during the same geologic time. Each hydrogeologic unit may have more than one aquifer layer, such as sand or limestone, or confining bed at any one place; however, the units have been chosen so that each has considerable hydrologic continuity, or at least, similarity among the aquifer layers within the unit.

Hydrogeologic units are named for either the single geologic formation which makes up the entire unit, or the most prominent formation in the group of formations that compose the unit.

The sedimentary rocks underlying the Coastal Plain surficial hydrogeologic unit, which was described previously, have been grouped into five major units. These are described in table 2. The areas in which the units occur beneath the surficial hydrogeologic unit are shown in figure 11. The relationships of the older units (Cape Fear is the oldest) being overlapped in part by the younger units and covered by the surficial unit is shown by the cross sections (fig. 12).

TABLE 2.--HYDROGEOLOGIC UNITS IN THE COASTAL PLAIN

HYDROGEOLOGIC UNIT	COMPOSITION	ROCK UNITS AND GEOLOGIC AGE	REMARKS
YORKTOWN	CLAY, MARL, SAND, AND SHELL BEDS.	YORKTOWN FORMATION AND PUNGO RIVER FORMATION. EARLY MIOCENE TO PLIOCENE IN AGE.	
CASTLE HAYNE	LIMESTONE, CALCAREOUS SAND, AND CALCAREOUS CLAY.	CASTLE HAYNE LIMESTONE OF MIDDLE EOCENE AGE AND YOUNGER, OVERLYING LIMESTONE BEDS OF OLIGOCENE AGE.	SOURCE OF LARGE GROUND-WATER SUPPLIES. HYDRAULIC CONTACT WITH SOME BEDS OF THE UPPER PART OF THE PEEDEE FORMATION IN BRUNSWICK AND NEW HANOVER COUNTIES.
BEAUFORT	SAND, CLAY, AND POSSIBLY SOME CALCAREOUS BEDS.	BEAUFORT FORMATION OF PALEOCENE AGE AND POSSIBLY OVERLYING BEDS OF EARLY EOCENE AGE.	UNIT EXPOSED OR SUBCROPS BENEATH SURFICIAL MATERIALS IN A FEW SMALL AREAS. NOT SHOWN ON ACCOMPANYING AREAL-EXTENT MAP. PRESENT MOSTLY BENEATH YORKTOWN AND CASTLE HAYNE UNITS.
PEEDEE-BLACK CREEK.	SAND AND CLAY.	PEEDEE FORMATION AND BLACK CREEK FORMATION. LATE CRETACEOUS AGE.	MAJOR SAND AQUIFER OF THE COASTAL PLAIN. PEEDEE GENERALLY CONTAINS MORE SAND THAN THE BLACK CREEK.
CAPE FEAR	SAND AND CLAY.	1/MIDDENDORF AND CAPE FEAR FORMATIONS OF LATE CRETACEOUS AGE AND OLDER UNNAMED CRETACEOUS UNITS.	MIDDENDORF FORMATION IS THE UPDIP AGE EQUIVALENT OF THE BLACK CREEK FORMATION. HOWEVER, MIDDENDORF IS HYDROLOGICALLY PART OF THE CAPE FEAR UNIT.

1/SEE SOHL (1976) FOR A DISCUSSION OF THE NAME CAPE FEAR FORMATION.

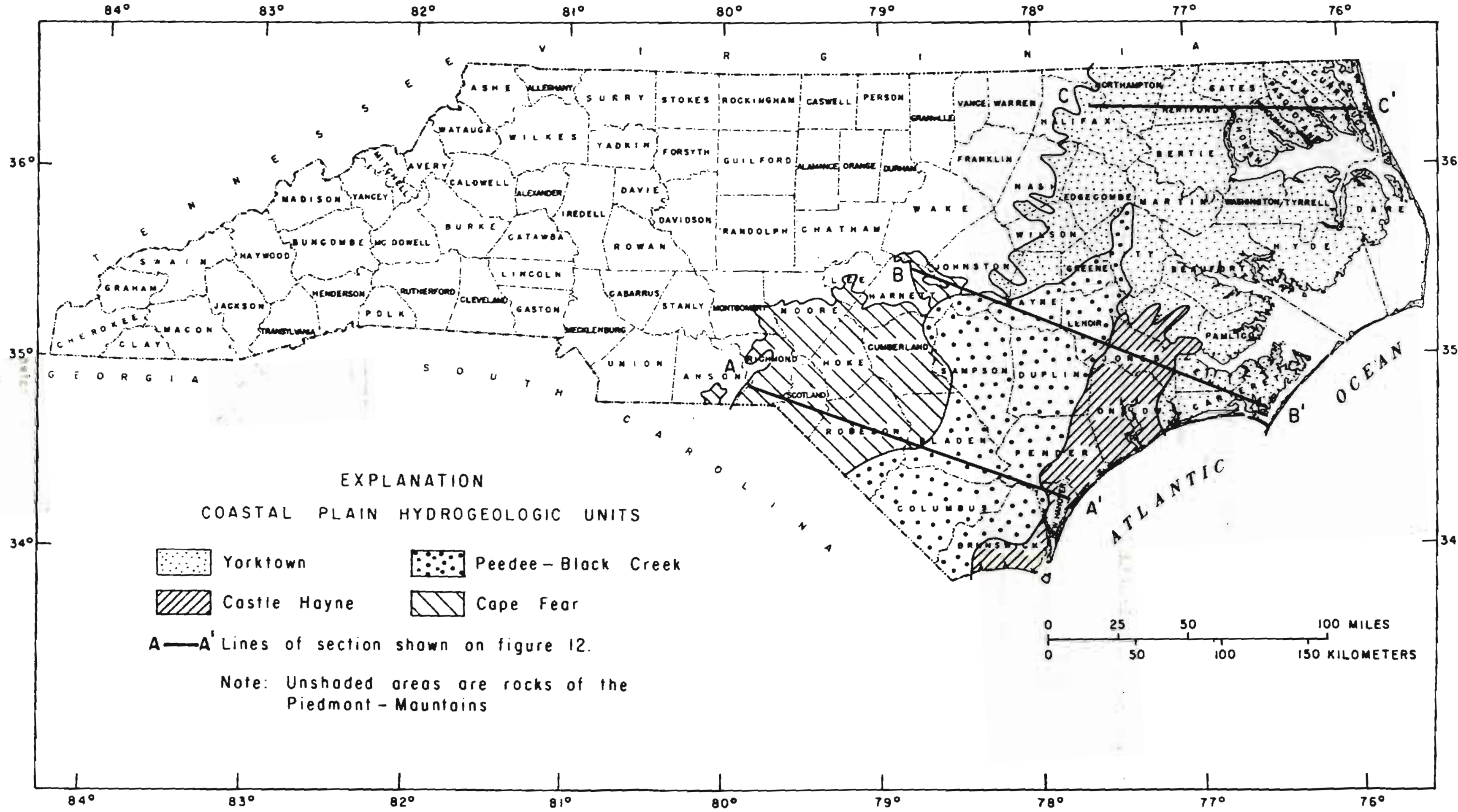
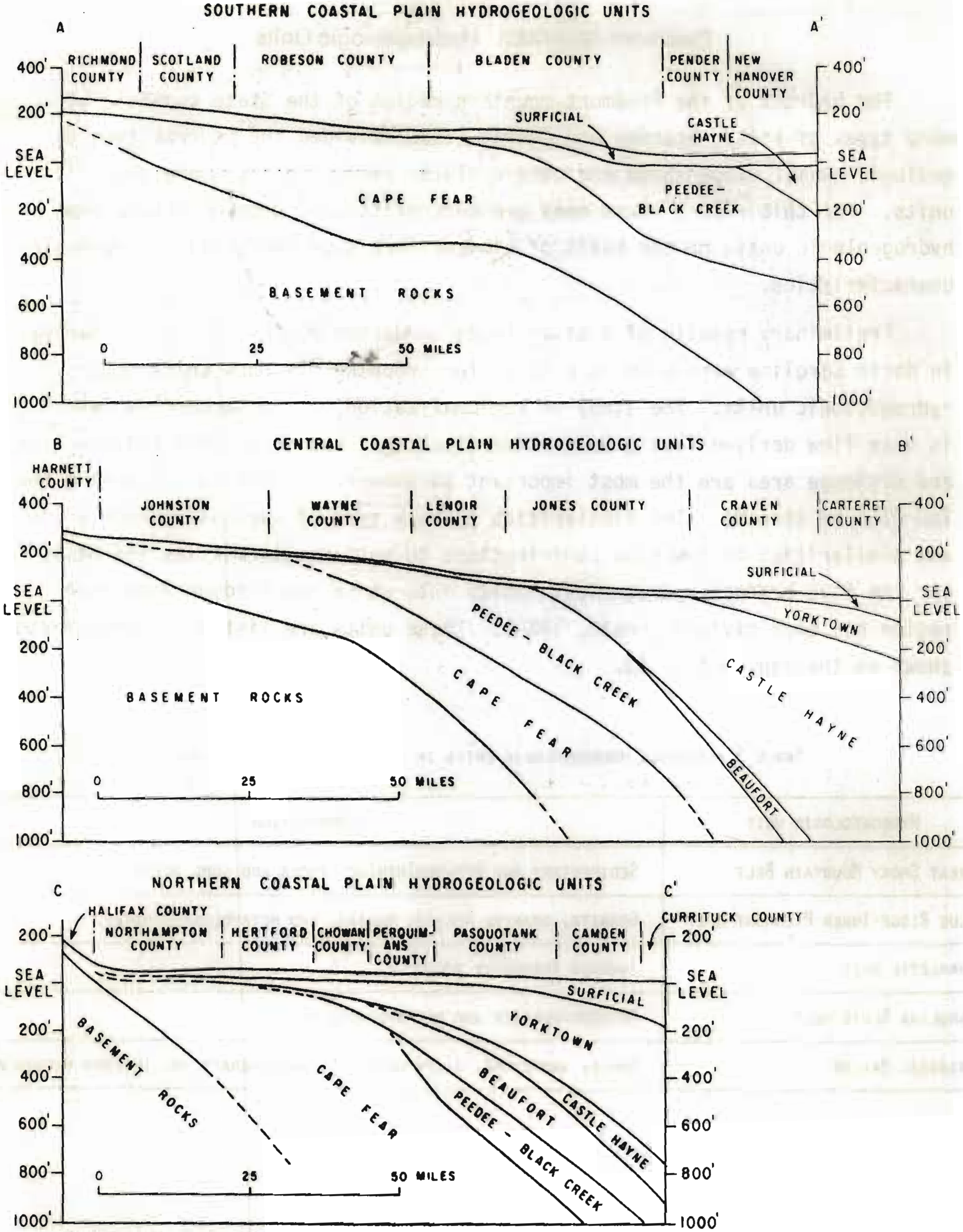


Figure 11.--Areal extent of the outcrop areas of the Coastal Plain hydrogeologic units.



Vertical scale greatly exaggerated.
Sea level is National Geodetic Vertical Datum of 1929.
Sections modified from Brown and others, 1972, and located in figure 11.

Figure 12.--Generalized sections of hydrogeologic units in the Coastal Plain of North Carolina.

Piedmont-Mountain Hydrogeologic Units

The bedrock of the Piedmont-mountain region of the State consists of many types of rock. Stuckey and Conrad (1958) divided the bedrock into 48 geologic units. Espenshade and others (1975) recognize even more geologic units. For this report these many geologic units were grouped into a few hydrogeologic units on the basis of similar rock type and similar hydrologic characteristics.

Preliminary results of a study being conducted by the Geological Survey in North Carolina were used as a basis for grouping the rock units into hydrogeologic units. The study on regionalization of low streamflow (which is base flow derived from ground-water discharge) has shown that bedrock type and drainage area are the most important parameters related to estimating the low flow of streams. The similarities in rock type of various bedrock units and similarities in low-flow contributions to surface streams was the basis for the five bedrock hydrogeologic units into which the Piedmont-mountain region has been divided (Heath, 1980). These units are listed in table 3 and shown on the map in fig. 13.

TABLE 3.--BEDROCK HYDROGEOLOGIC UNITS IN THE PIEDMONT AND MOUNTAINS

HYDROGEOLOGIC UNIT	COMPOSITION
GREAT SMOKY MOUNTAIN BELT	SEDIMENTARY AND METASEDIMENTARY ROCKS AND SOME SCHIST.
BLUE RIDGE-INNER PIEDMONT BELT	GRANITE, GRANITE GNEISS, SCHIST, AND METAVOLCANIC ROCKS.
CHARLOTTE BELT	IGNEOUS INTRUSIVE ROCKS.
CAROLINA SLATE BELT	METASEDIMENTARY AND METAVOLCANIC ROCKS.
TRIASSIC BASINS	SHALE, SANDSTONE, SILTSTONE, AND CONGLOMERATE AND IGNEOUS INTRUSIVES.

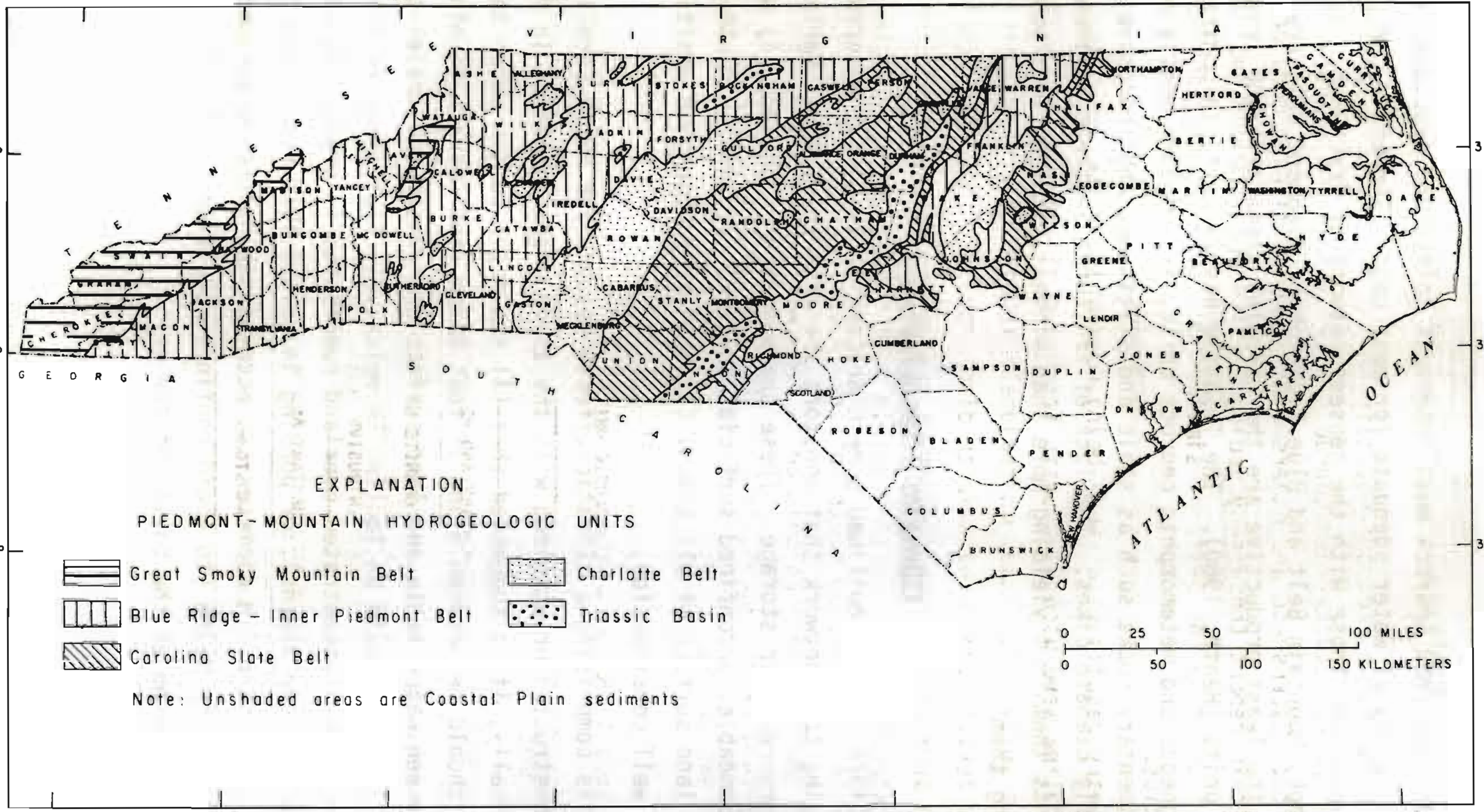


Figure 13.--Areal extent of the bedrock hydrogeologic units in the Piedmont-mountain region.

Wells drilled into bedrock must intersect joints and fractures in order to produce a supply of water adequate for most uses. Therefore, the most productive units are those with the densest network of fractures. Rocks of the Great Smoky Mountain Belt and Blue Ridge-Inner Piedmont Belt are the most productive; the least productive are the Carolina Slate Belt and Triassic Basins rock units (Heath, 1980). The Triassic Basins unit, in contrast to the other igneous and metamorphic bedrock units, is composed mostly of fine-grained sedimentary rocks such as shale and siltstone, and intrusive igneous rocks, chiefly diabase dikes. The lack of fractures in these sedimentary rocks prevents them from yielding more than minimal supplies to almost all wells tapping them.

Climatic-Effects Network

Heath (1976, p. 77) outlined some characteristics of all observation wells belonging to a network that monitors the effects of areal variation in climate on ground-water storage. These characteristics include (1) wells open to a permeable, unconfined surficial aquifer; (2) similar depth to water table below land surface at all sites; (3) similar topographic positions; and (4) similar well construction.

The wells comprising a climatic-effects network for North Carolina should be constructed or acquired with the above characteristics in mind. More specifically, it is suggested that (1) the depth to the water table in these wells should be between 5 and 15 feet below land surface to minimize distance between water table and land surface and consequent travel-time of recharge; (2) wells should be located in relatively flat areas at sites that are not affected by concentrated overland runoff (as in draws), by stream flooding (as in flood plains), or ponding in upland flat areas; and (3) wells should be 4 to 6 inches in diameter (to accommodate recording devices) and no more than 20 feet in depth (to avoid confined conditions) with at least 5 feet of screen placed at the bottom of the well.

Because the analysis of the water-level record will be made in conjunction with precipitation data collected by the National Weather Service of the National Oceanic and Atmospheric Administration, it is proposed that the climatic-effects network consist of one well in each of the eight National Weather Service divisions (fig. 14). Specific well sites for this network are not recommended here, but should be the result of a specific study for this purpose. In addition to using the above criteria and characteristics, it may be feasible to locate some climatic-effects wells with respect to the availability of streamflow data-collection sites in order to study the water budget and relationships between ground water and surface water.

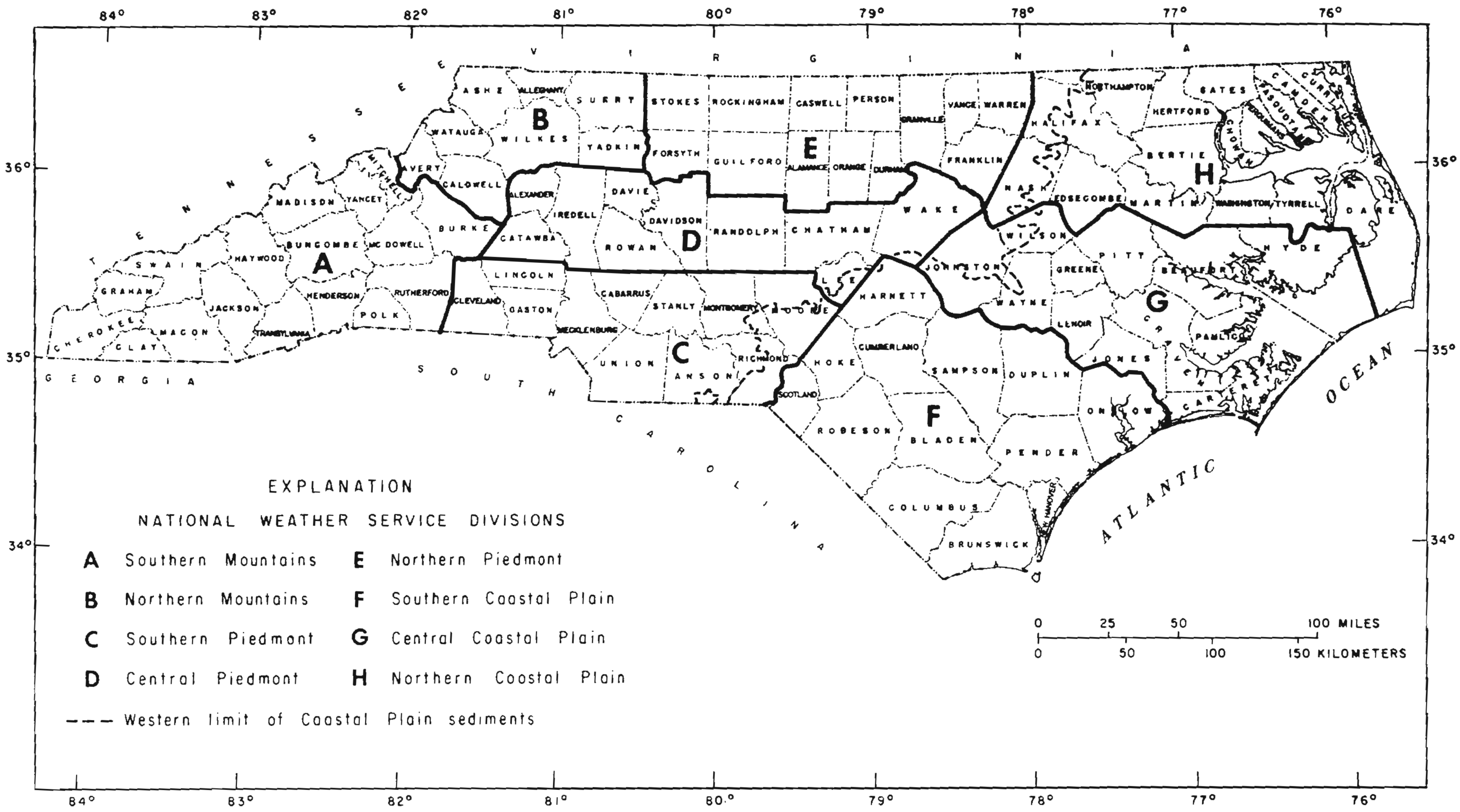


Figure 14.--National Weather Service divisions of North Carolina.

Terrane-Effects Network

The purpose of observation wells in this network is to define the added effects of geology and topography on the ground-water levels monitored by the climatic-effects wells. In North Carolina a terrane-effects network would consist of at least eight wells, one each at the site of a climatic-effects well, but in a deeper aquifer (same topography, but different geology)--plus other wells near the site or elsewhere in the Weather Service Division related to varying topography and geology.

Considering the combinations of selected topographic and geologic settings shown in figure 9 and the areas covered by the various hydrogeologic units in each Weather Service Division in the State (table 4), over 40 observation wells for this network could be selected in the Piedmont-mountain area and about 16 in the Coastal Plain.

TABLE 4.--PERCENTAGE OF EACH WEATHER SERVICE DIVISION COVERED BY VARIOUS HYDROGEOLOGIC UNITS IN NORTH CAROLINA

HYDROGEOLOGIC UNIT	NATIONAL WEATHER SERVICE DIVISIONS							
	SOUTHERN MOUNTAINS	NORTHERN MOUNTAINS	SOUTHERN PIEDMONT	CENTRAL PIEDMONT	NORTHERN PIEDMONT	CENTRAL COASTAL PLAIN	NORTHERN COASTAL PLAIN	SOUTHERN COASTAL PLAIN
GREAT SMOKY MOUNTAINS BELT	27	3	-	-	-	-	-	-
BLUE RIDGE-INNER PIEDMONT BELT	68	92	15	25	37	-	-	-
CHARLOTTE BELT	5	5	21	38	27	-	-	-
CAROLINA SLATE BELT	-	-	41	30	27	5	5	3
TRIASSIC BASINS	-	-	10	7	9	-	-	-
COASTAL PLAIN (UNDIFFERENTIATED)	-	-	13	-	-	95	95	97

-, UNIT NOT PRESENT OR INSIGNIFICANT.

The selection of specific sites for the terrane-effects wells should be made in conjunction with the study and selection of those sites for the climatic-effects wells. Each proposed site should be carefully evaluated to determine the appropriate terrane-effects conditions to be monitored. Wells in this network should be constructed similarly to the climatic-effects wells in that they should be 4 to 6 inches in diameter and should have at least 5 feet of screen or open hole at the bottom of the well.

Local-Effects Network

Observation wells that are to be chosen for this network will monitor the effects of pumpage from each hydrologic unit. In North Carolina the largest amounts of ground-water pumpage are from Coastal Plain hydrogeologic units; only a few significant centers are in the Piedmont-mountain area. This section presents an overall picture of the significant ground-water pumpage from each hydrogeologic unit as known at this time (1980), and outlines where first efforts should go in establishing a local-effects network.

Surficial Hydrogeologic Unit

The only known significant withdrawals from this unit occurs at Manteo in Dare County (fig. 15), where pumpage averages more than 0.1 Mgal/d (million gallons per day). An observation well should monitor the ground-water level near the center of this pumpage in order to establish a trend.

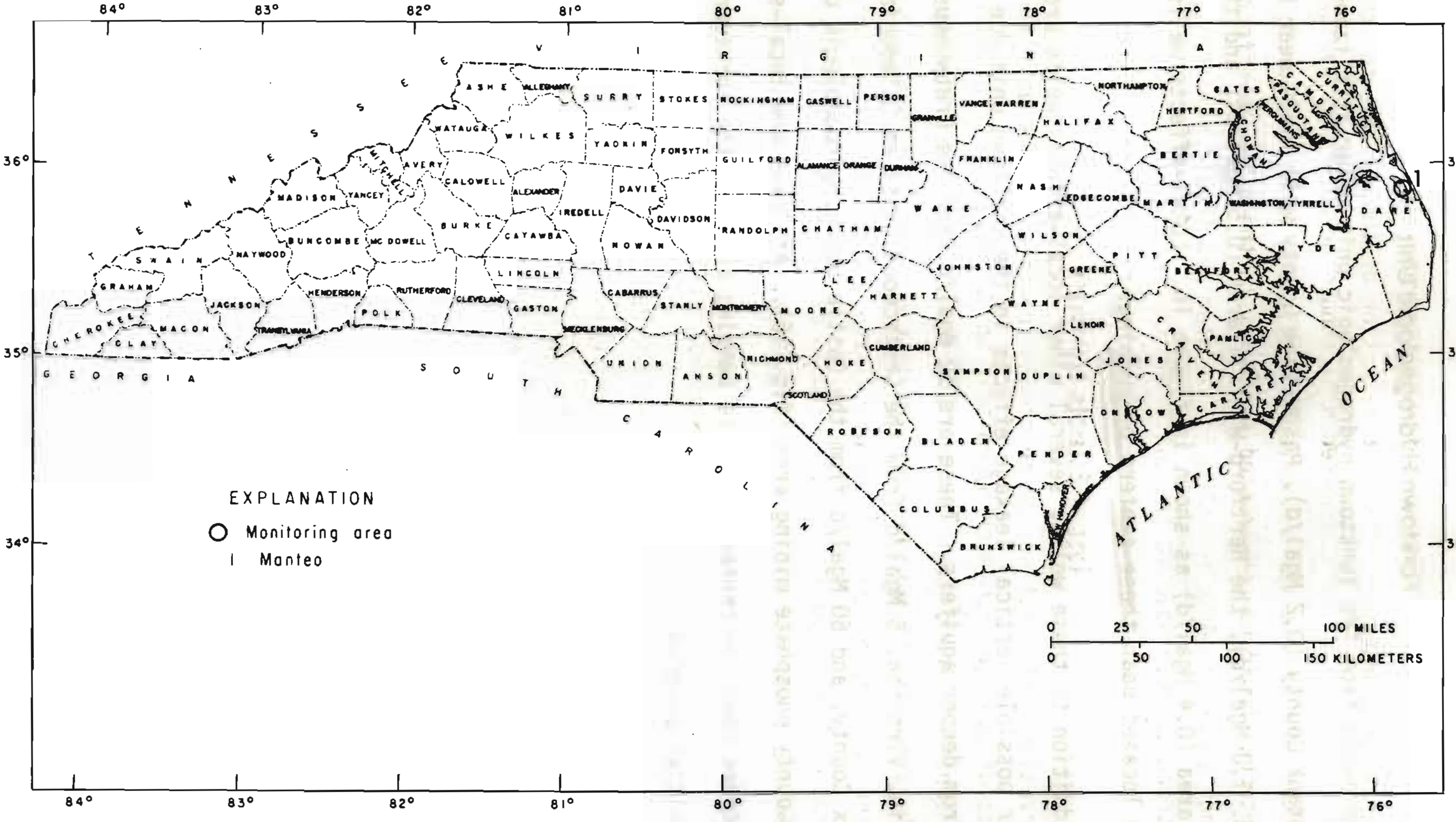


Figure 15.--Local-effects network monitoring area in the Surficial hydrogeologic unit.

Yorktown Hydrogeologic Unit

Withdrawals from the Yorktown hydrogeologic unit occur at Elizabeth City in Pasquotank County (0.2 Mgal/d), Pasquotank County well field near Elizabeth City (est. 1.0 Mgal/d), the Hertford-Winfall area (0.5 Mgal/d), and the Belhaven area (0.4 Mgal/d) as shown in figure 16. Local-effects wells should be located near these centers of pumping.

In addition to these wells, several other local-effects wells are needed to monitor possible vertical leakage effects in the Yorktown unit due to pumpage from deeper aquifers. These are 30 Mgal/d from the Cretaceous units at Franklin, Virginia, 5 Mgal/d from the Cretaceous units at Caledonia Prison in Halifax County, and 60 Mgal/d from the Castle Hayne hydrogeologic unit in Beaufort County phosphate mining area (fig. 16). At least one local-effects well is needed near the centers of these pumping areas in the Yorktown unit for the initial program.

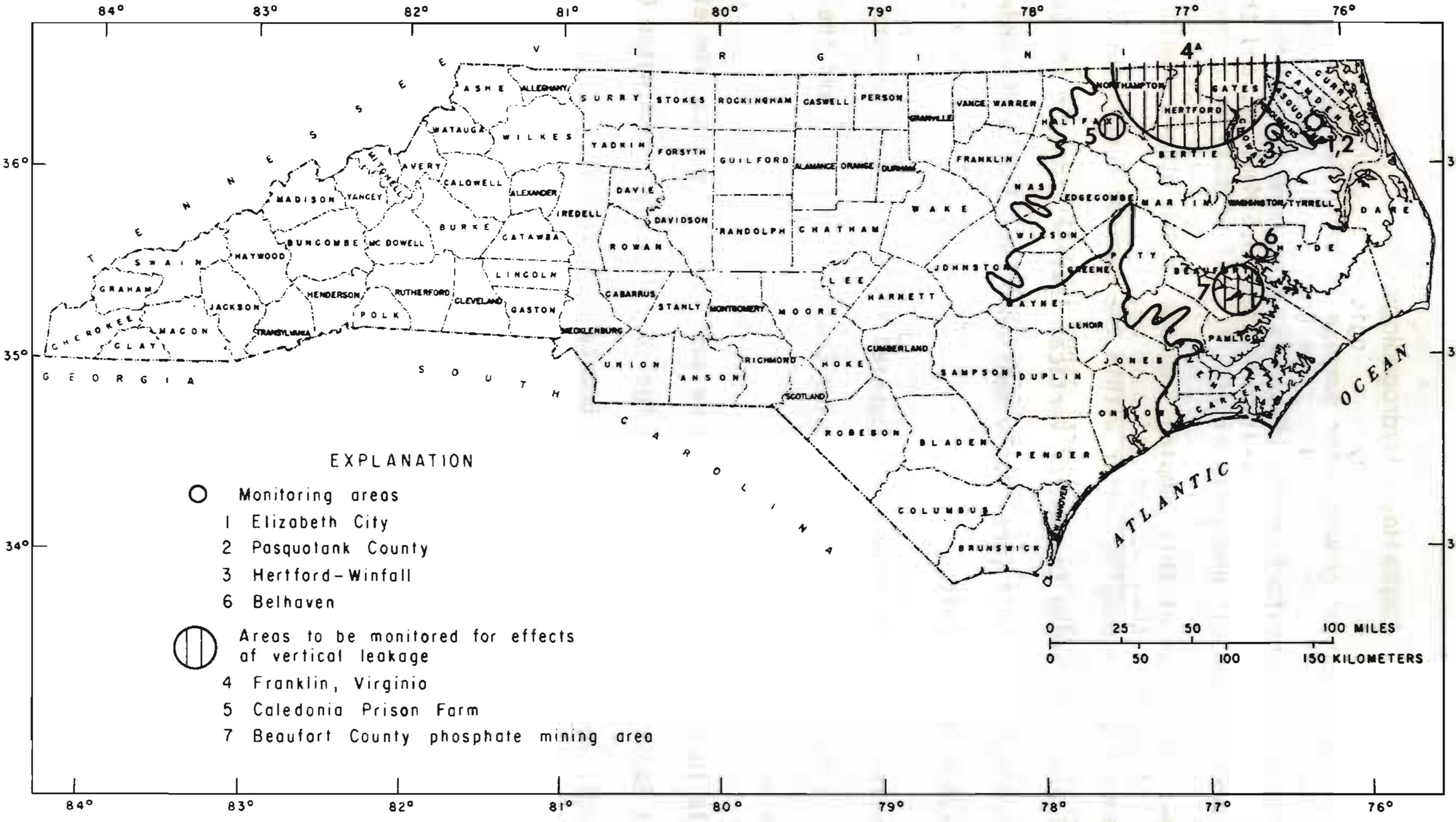


Figure 16.--Local-effects network monitoring areas in the Yorktown hydrogeologic unit.

Castle Hayne Hydrogeologic Unit

The largest amount of ground-water pumpage in North Carolina is from the Castle Hayne unit in Beaufort County (fig. 17) where more than 60 Mgal/d is pumped to dewater open-pit phosphate mines. A local-effects well should be located near the center of this pumping, and one or two others should be at some distance from the pumping center within the cone of depression. Observation wells are also needed to monitor vertical leakage: one in the overlying Yorktown hydrogeologic unit (previously mentioned) and one in the underlying Beaufort hydrogeologic unit.

A similar monitoring scheme is suggested for the pumping centers at Camp Lejeune (3.5 Mgal/d), northern New Hanover County (3 Mgal/d), and the Cherry Point-Havelock area (3 Mgal/d).

Single local-effects wells should be sufficient to monitor the effects of pumping at Edenton, Chowan County (0.6 Mgal/d), Plymouth, Washington County (1.5 Mgal/d), and Washington, Beaufort County (1.6 Mgal/d).

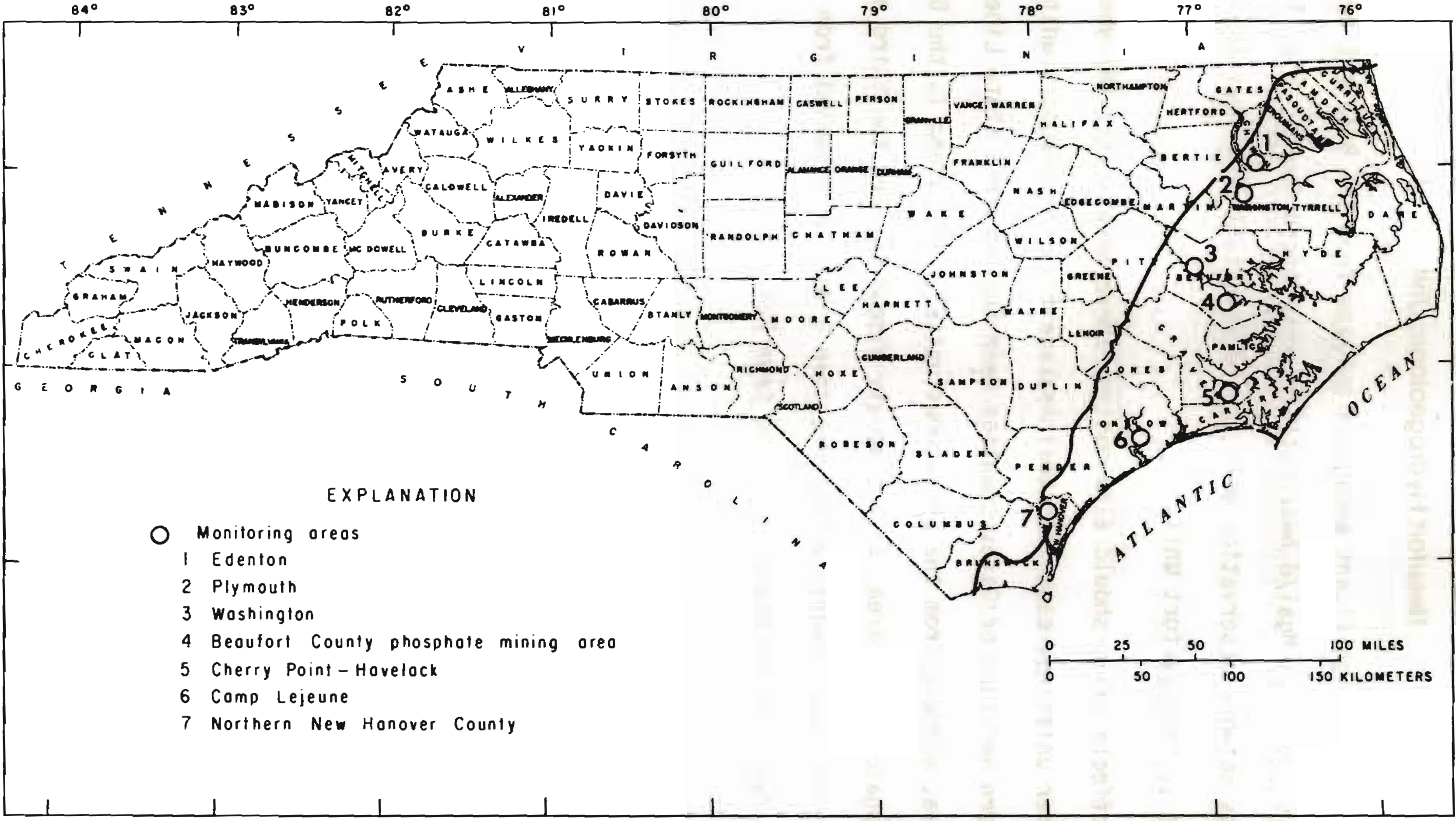


Figure 17.--Local-effects network monitoring areas in the Castle Hayne hydrogeologic unit.

Beaufort Hydrogeologic Unit

The only known significant amount of pumpage from the Beaufort hydrogeologic unit is about 0.1 Mgal/d near Cofield in Hertford County (fig. 18). A local-effects network observation well should be established near the center of this pumpage in the Beaufort unit.

Local-effects wells should also monitor three areas (fig. 18) where pumpage from other units may cause vertical leakage from the Beaufort unit. One area is in northern Hertford or Gates Counties near the Virginia State Line (Franklin, Virginia, pumpage from the Cretaceous units), the second is the Beaufort County phosphate mining area, as previously discussed, and the third area is at Cove City in Craven County where more than 3 Mgal/d is pumped from Cretaceous aquifers (Peedee-Black Creek and Cape Fear units).

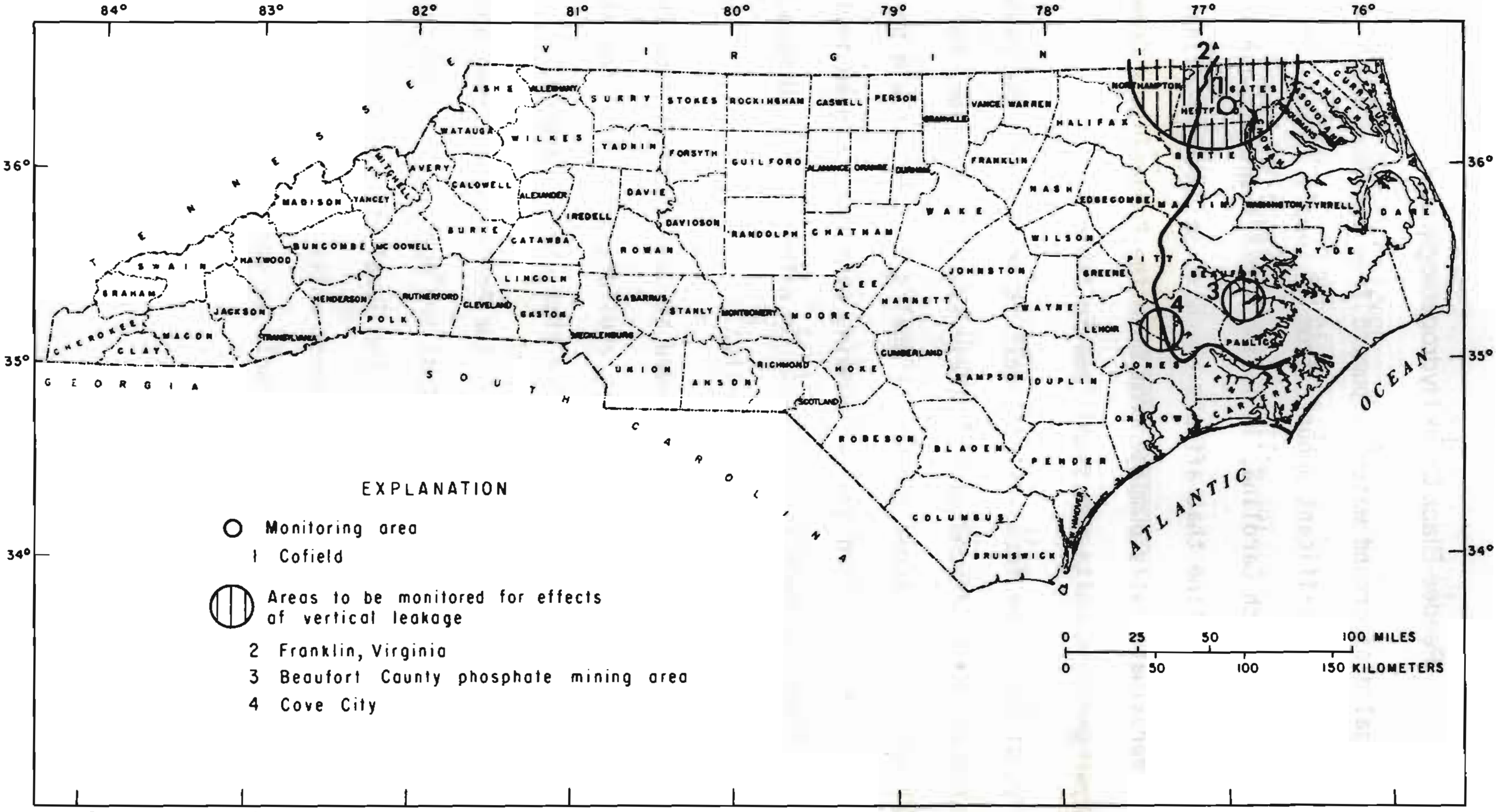


Figure 18.--Local-effects network monitoring areas in the Beaufort hydrogeologic unit.

Peedee-Black Creek Hydrogeologic Unit

About 24 Mgal/d of ground water is pumped from the Peedee-Black Creek hydrogeologic unit in significant amounts from 24 supply systems throughout the Coastal Plain of North Carolina, including significant pumpage in South Carolina near the State line that affects the unit in North Carolina. The systems and approximate daily pumpage from both the Peedee-Black Creek and the Cape Fear hydrogeologic units are summarized in table 5.

Ideally, at least one local-effects well is needed near the centers of the cones of depressions around each of these systems. However, for an initial network each of the larger systems (1 Mgal/d or more) should be monitored, but only a few selected smaller pumping centers should be included in the network at first to gauge their effects on water levels. Others can be added as warranted by later network analysis.

Local-effects wells will also be needed at some distance from the center of pumpage and in overlying and underlying aquifers to monitor the effects of pumping at those systems that withdraw more than about 3 Mgal/d.

In addition to these withdrawals from the Peedee-Black Creek unit, 16 systems pump about 22 Mgal/d from wells that are open to both the Peedee-Black Creek and the Cape Fear units (table 5). The local-effects network will need to include observation wells in each of these units at each pumping center where pumpage exceeds about 1 Mgal/d, as well as vertical-leakage monitor wells in overlying units.

Table 5.--Significant ground-water pumpage from Cretaceous aquifers in North Carolina and near the State line in bordering States

Supply location	Hydrogeologic unit	Approximate pumpage (Mgal/d)
Franklin, Virginia	Cape Fear	35
Myrtle Beach area, South Carolina*	Peedee-Black Creek	5
Kinston area, Lenoir County*	Cape Fear and Peedee-Black Creek	4.9
Wallace, Duplin County	Peedee-Black Creek	4.4
Cove City, Craven County	Cape Fear and Peedee-Black Creek	3.1
Graingers, Lenoir County	do.	3.0
Clinton, Sampson County	Cape Fear	2.8
Lumberton, Robeson County	Cape Fear and Peedee-Black Creek	2.8
Lumber Bridge, Robeson County	do.	2.7
Fayetteville area, Cumberland County*	Cape Fear	2.6
Bolivia, Brunswick County	Peedee-Black Creek	2.5
Greenville, Pitt County	do.	2.0
Laurenburg, Scotland County	Cape Fear	2.0
Rose Hill, Duplin County	Peedee-Black Creek	2.0
Jacksonville, Onslow County	do.	1.9
Farmville, Pitt County	Cape Fear and Peedee-Black Creek	1.6
Raeford, Hoke County	Cape Fear	1.3
Goldsboro, Wayne County	do.	1.3
Hamilton, Martin County	do.	1.2
Maxton, Robeson County*	Cape Fear and Peedee-Black Creek	1.2
Mt. Olive, Wayne County	Peedee-Black Creek	1.2
Loris-Conway, South Carolina*	do.	1.0
Williamston, Martin County	Cape Fear	.9
Elliott, Sampson County	do.	.8
Spring Lake, Cumberland County	do.	.6
Red Springs, Robeson County	Cape Fear and Peedee-Black Creek	.6
Robersonville, Martin County	Cape Fear	.6
Lewiston, Bertie County	do.	.6
Kenansville, Duplin County	do.	.5
Chadbourn, Columbus County	Peedee-Black Creek	.5
Ahoskie, Hertford County	do.	.5
La Grange, Lenoir County	do.	.5
Elizabethtown, Bladen County	Cape Fear and Peedee-Black Creek	.4
Ayden, Pitt County	do.	.4
Scotland Neck, Halifax County	Cape Fear	.4
Pinehurst, Moore County	do.	.4
Snow Hill, Greene County	do.	.4
Hope Mills, Cumberland County	do.	.4
Murfreesboro, Hertford County	do.	.4
Fairmont, Robeson County	Cape Fear and Peedee-Black Creek	.3
Aberdeen, Moore County	Cape Fear	.3
St. Pauls, Robeson County	Cape Fear and Peedee-Black Creek	.3
Caledonia Prison, Halifax County	Cape Fear	.3
Northern Lenoir County*	Peedee-Black Creek	.3
Pembroke, Robeson County	do.	.3
Warsaw, Duplin County	do.	.3
Salemburg, Sampson County	Cape Fear and Peedee-Black Creek	.2
Roseboro, Sampson County	do.	.2

*More than one water-supply system included.

TABLE 5.--SIGNIFICANT GROUND-WATER PUMPAGE FROM CRETACEOUS AQUIFERS IN NORTH CAROLINA AND NEAR THE STATE LINE IN BORDERING STATES--CONTINUED

SUPPLY LOCATION	HYDROGEOLOGIC UNIT	APPROXIMATE PUMPAGE (MGAL/D)
BLADENBORO, BLADEN COUNTY	CAPE FEAR AND PEEDEE-BLACK CREEK	0.2
BURGAW, PENDER COUNTY	PEEDEE-BLACK CREEK	.2
WHITEVILLE, COLUMBUS COUNTY	DO.	.2
ROWLAND, ROBESON COUNTY	CAPE FEAR AND PEEDEE-BLACK CREEK	.2
TABOR CITY, COLUMBUS COUNTY	PEEDEE-BLACK CREEK	.2
WINTERVILLE, PITT COUNTY	DO.	.2
GRIFTON, PITT COUNTY	DO.	.2
BETHEL, PITT COUNTY	DO.	.2
SOUTHPORT AREA, BRUNSWICK COUNTY	DO.	.2
WINDSOR, BERTIE COUNTY	DO.	.2
PINETOPS, EDGECOMBE COUNTY	CAPE FEAR	.1
WINTON, HERTFORD COUNTY	DO.	.1
CONWAY, NORTHAMPTON COUNTY	DO.	.1
RICH SQUARE, NORTHAMPTON COUNTY	DO.	.1
STANTONSBURG-SARATOGA, WILSON COUNTY*	DO.	.1
WHITE LAKE, BLADEN COUNTY	PEEDEE-BLACK CREEK	.1
FAISON, DUPLIN COUNTY	CAPE FEAR	.1
RICHLAND, ONSLOW COUNTY	PEEDEE-BLACK CREEK	.1
GIBSON, SCOTLAND COUNTY	CAPE FEAR	.1

*MORE THAN ONE WATER-SUPPLY SYSTEM INCLUDED.

Cape Fear Hydrogeologic Unit

Table 5 summarizes the significant pumpage from both Cretaceous hydrogeologic units. The 35 Mgal/d pumped at Franklin, Virginia, is the largest single source of withdrawals from the Cape Fear hydrogeologic unit that affects water levels in North Carolina. At least two local-effects wells in North Carolina should be established, one near the State line and another farther away near the periphery of the cone of depression. Several vertical-leakage monitor wells should also be added to the local-effects network.

A total of nearly 19 Mgal/d is pumped from 26 other supplies open to this unit. The largest of these pumping centers should be monitored by a local-effects network well in this unit, and vertical leakage should be monitored in overlying units where pumpage exceeds about 1 Mgal/d. Local-effects wells should be established at pumping centers that withdraw ground water from both Cretaceous hydrogeologic units (Peedee-Black Creek and Cape Fear units) as previously discussed.

Great Smoky Mountain Belt Hydrogeologic Unit

Most of the ground-water pumpage from the Great Smoky Mountain Belt hydrogeologic unit in North Carolina is summarized in table 6. The extent of drawdown effects from this pumpage is too limited in this fractured-rock aquifer to warrant monitoring, thus, no local-effects wells are needed for this unit at this time.

TABLE 6.--GROUND-WATER PUMPAGE FROM THE GREAT SMOKY MOUNTAIN BELT HYDROGEOLOGIC UNIT

SUPPLY LOCATION	APPROXIMATE PUMPAGE (MGAL/D)
SOCO AREA, JACKSON COUNTY	0.40
NEWLAND, AVERY COUNTY	.10
BANNER ELK, AVERY COUNTY*	<.10 (EST.)
CROSSNORE, AVERY COUNTY	.06
LINVILLE AREA, AVERY COUNTY	<.05 (EST.)
MARBLE, CHEROKEE COUNTY	.03
PINEOLA AREA, AVERY COUNTY	<.005 (EST.)
FOSCOE AREA, WATAUGA COUNTY	.003
HOT SPRINGS AREA, MADISON COUNTY	.003

*MORE THAN ONE WATER-SUPPLY SYSTEM INCLUDED.

Blue Ridge-Inner Piedmont Belt Hydrogeologic Unit

The public, commercial, and industrial water supplies that use ground water from the fractured rocks of the Blue Ridge-Inner Piedmont Belt hydrogeologic unit are estimated to pump nearly 15 Mgal/d from this source. The known major sources of this pumpage are listed in table 7.

Table 7.--Ground-water pumpage from the Blue Ridge-Inner Piedmont Belt hydrogeologic unit

Supply location	Approximate pumpage (Mgal/d)
Old Fort, McDowell County	4.0
Earl Station, Cleveland County	2.0
Fallston, Cleveland County	1.5
North Wilkesboro, Wilkes County*	.82
Boone, Watauga County	.52
Statesville, Iredell County*	.38
Fuquay-Varina, Wake County	.33
Baptist Conference Center, Buncombe County	.30
Troutmans, Iredell County	.26
Harmony area, Iredell County*	.26
Dobson, Surry County	<.25 (est.)
Marion area, McDowell County	<.25 (est.)
Lenoir, Caldwell County	.24
Oak Hill, Burke County	.20
Icard, Burke County	.20
Yadkinville, Yadkin County	.20
Lincolnton, Lincoln County	.20
Morganton-Valdese area, Burke County	.20
Marshall, Madison County	.18
Hayesville, Clay County	.16
Sparta, Alleghany County	.16
Barton, Caldwell County	.15
Boiling Springs, Cleveland County	.15
Rural Hall, Forsyth County	.15
West Jefferson, Ashe County	.13
Booneville, Yadkin County	.13
Lake Lure, Rutherford County*	.12
Stubbs, Cleveland County	.10
Wilkesboro, Wilkes County*	.10
Moravian Falls, Wilkes County	0.10
Kittrell, Vance County	.10
Littleton, Halifax County	.10
Bessemer City, Gaston County	.10
Kings Mountain area, Cleveland County*	<.10 (est.)
Pilot Mountain, Surry County	<.10 (est.)
Cashiers, Jackson County	<.10 (est.)
Etowah, Henderson County	.08
Walkertown area, Forsyth County	.07
Brevard, Transylvania County	.07
Alexander Mills, Rutherford County	.06
Jefferson, Ashe County	.05
Dillsboro, Jackson County	.05
Barnardsville, Buncombe County	<.05 (est.)
Fletcher area, Henderson County*	<.05 (est.)
Columbus, Polk County	<.05 (est.)
Bent Creek Subdivision, Buncombe County	.04
Turnersburg, Iredell County	.04
East Bend, Yadkin County	.04
Mt. Airy, Surry County	.04
Bakersville, Mitchell County	.04
Elk Park, Avery County	.03
Bostic, Rutherford County	.03
Roaring River, Wilkes County	.03
Lansing, Ashe County	.007
Golden Valley, Rutherford County	.005
Webster, Jackson County	.005
Blevens Creek area, Avery County	.003

*More than one water-supply system included.

Water levels near the centers of pumping at three of these supply locations should be monitored for the initial local-effects network. These are at: (1) Old Fort, McDowell County; (2) Fallston, Cleveland County; and (3) Earl Station, Cleveland County, and are located in figure 19.

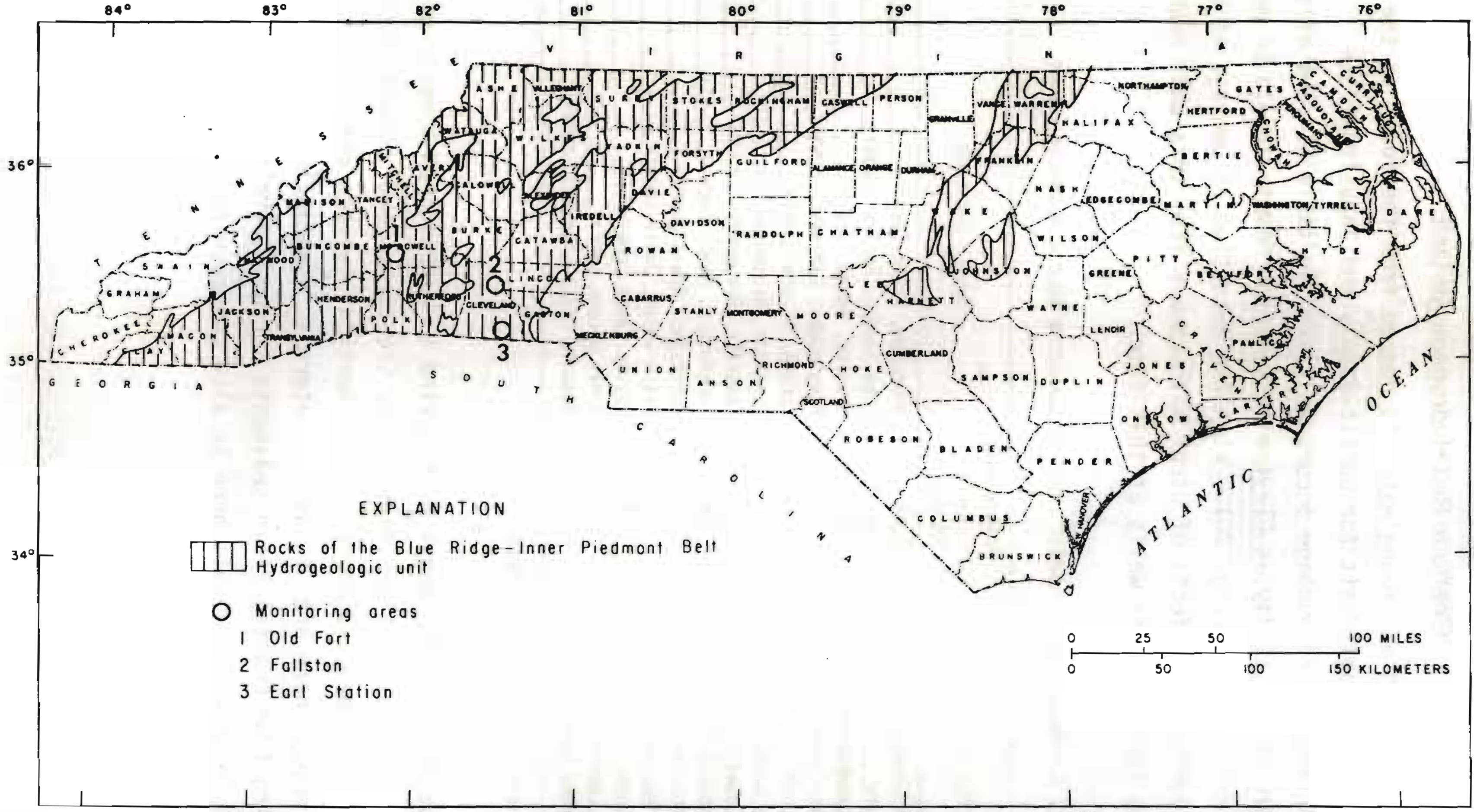


Figure 19.--Local-effects network monitoring areas in the Blue Ridge-Inner Piedmont Belt hydrogeologic unit.

Charlotte Belt Hydrogeologic Unit

About 3.5 Mgal/d of ground water is pumped from the rocks of the Charlotte Belt hydrogeologic unit for public-supply and industrial use. The known places where this pumpage occurs is listed in table 8. The effects of pumping about 0.45 Mgal/day at Clayton in Johnston County should be monitored by a local-effects well (fig. 20). With the exception of pumpage at Lucama in Wilson County, the effects of other withdrawals from this unit need not be monitored by local-effects wells at this time.

TABLE 8.--GROUND-WATER PUMPAGE FROM THE CHARLOTTE BELT HYDROGEOLOGIC UNIT

SUPPLY LOCATION	APPROXIMATE PUMPAGE (MGAL/D)	SUPPLY LOCATION	APPROXIMATE PUMPAGE (MGAL/D)
CLAYTON, JOHNSTON COUNTY	0.45	WOODLEAF, ROWAN COUNTY	0.10
GARNER, WAKE COUNTY	.40	HIGH SHOALS, GASTON COUNTY	.08
TAYLORSVILLE, ALEXANDER COUNTY	<.30 (EST.)	SPENCER, ROWAN COUNTY*	.08
CHINA GROVE, ROWAN COUNTY*	.27	HARRISBURG, CABARRUS COUNTY*	.07
LOWELL, GASTON COUNTY	.20	LUCAMA, WILSON COUNTY	.06
CONCORD, CABARRUS COUNTY	.19	ELM CITY, WILSON COUNTY	.06
ROCKWELL, ROWAN COUNTY	.18	CAROLEEN, RUTHERFORD COUNTY*	.05
HIDDENITE, ALEXANDER COUNTY	.16	LILESVILLE, ANSON COUNTY	.04
MCADENVILLE, GASTON COUNTY	.15	CLEVELAND, ROWAN COUNTY	.04
CHARLOTTE AREA, MECKLENBURG COUNTY*	.15	SMITH GROVE, DAVIE COUNTY	.03
NORLINA, WARREN COUNTY	.15	FAITH, ROWAN COUNTY	.02
SALISBURY, ROWAN COUNTY	.14	SIMS, WILSON COUNTY	.02
GREENSBORO, GUILFORD COUNTY	.14	ROBERTA MILL, CABARRUS COUNTY	.01

*MORE THAN ONE WATER-SUPPLY SYSTEM INCLUDED.

At Lucama (fig. 20), about 0.06 Mgal/d is pumped from a small patch of Charlotte Belt rocks that are overlain by Cretaceous and younger aquifers of the Coastal Plain area (Winner, 1976). Vertical leakage effects close to the center of pumpage here are of special interest, especially in regard to recharge moving from Coastal Plain sediments through saprolite and into the bedrock. A local-effects well here is also recommended.

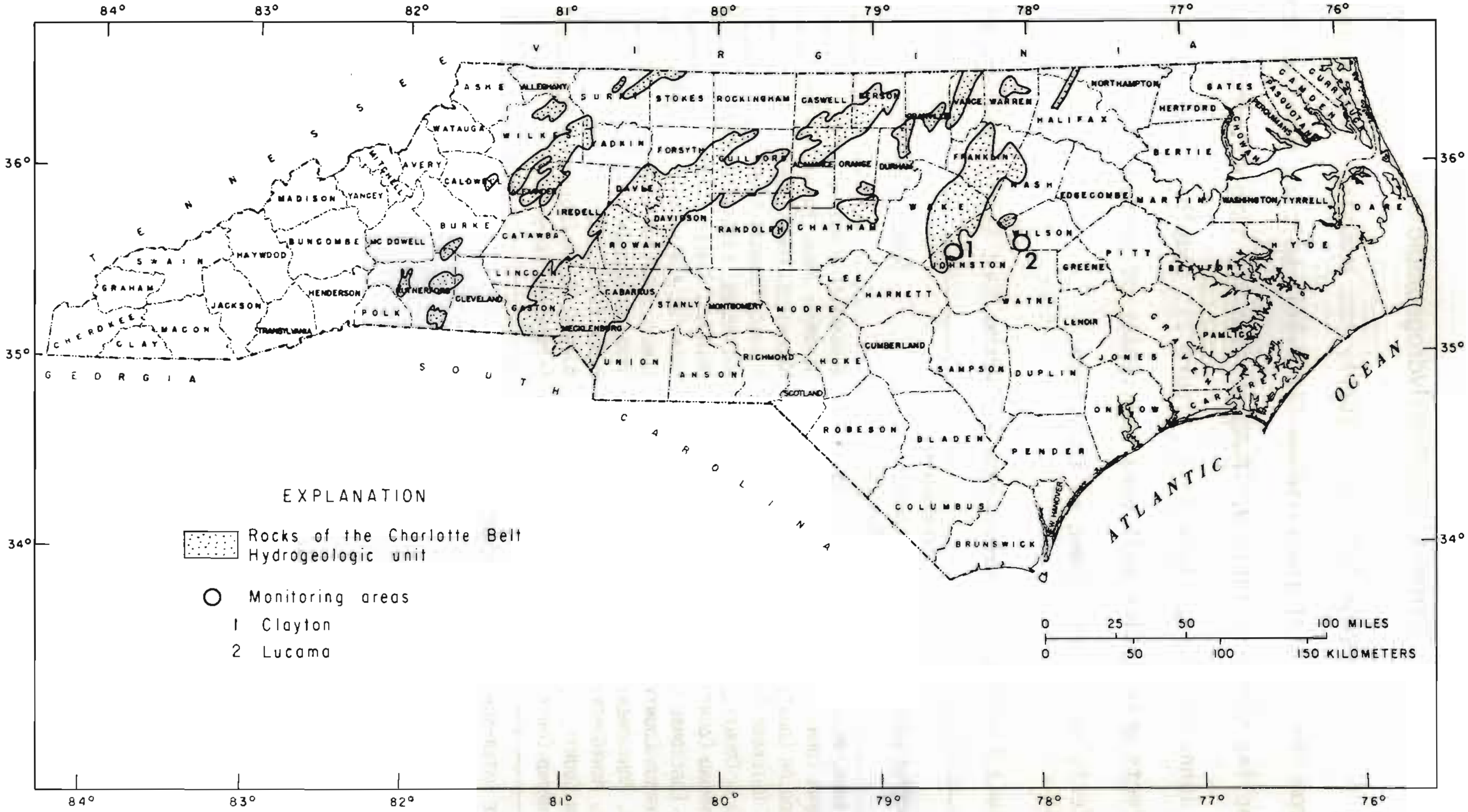


Figure 20.--Local-effects network monitoring areas in the Charlotte Belt hydrogeologic unit.

Carolina Slate Belt Hydrogeologic Unit

Ground-water pumpage for public supply and industrial use is nearly 5 Mgal/d from the rocks of the Carolina Slate Belt unit as reported for the 24 water supplies shown in table 9. Pumpage from the largest single source at Selma in Johnston County, located in figure 21, should be monitored by a local-effects observation well near the center of pumpage there. No other local-effects wells are needed at this time.

TABLE 9.--GROUND-WATER PUMPAGE FROM THE CAROLINA SLATE BELT HYDROGEOLOGIC UNIT

SUPPLY LOCATION	APPROXIMATE PUMPAGE (MGAL/D)	SUPPLY LOCATION	APPROXIMATE PUMPAGE (MGAL/D)
SPRING HOPE AREA, NASH COUNTY*_______	0.48	ALBEMARLE, STANLY COUNTY*_____________	0.17
SELMA, JOHNSTON COUNTY_______________	.40	SEAGROVE AREA, RANDOLPH COUNTY________	.17
LIBERTY, RANDOLPH COUNTY_____________	.34	NASHVILLE, NASH COUNTY_______________	.17
GIBSONVILLE, GUILFORD COUNTY_________	.30	ANGIER, HARNETT COUNTY_______________	.15
GOLD ROCK, NASH COUNTY_______________	.30	WHITAKERS, EDGECOMBE COUNTY__________	.15
CORDOVA, RICHMOND COUNTY_____________	.28	OAKBORO, STANLY COUNTY*______________	.14
ROCKY MOUNT, EDGECOMBE COUNTY________	.28	ELON COLLEGE, ALAMANCE COUNTY_________	.12
LONGHURST, PERSON COUNTY*____________	.27	KENLY, JOHNSTON COUNTY_______________	.10
PEE DEE AREA, MONTGOMERY COUNTY*_____	.24	STAR, MONTGOMERY COUNTY______________	.08
WOODRUN AREA, MONTGOMERY COUNTY*_____	.20	BLACK CREEK, WILSON COUNTY____________	.06
WAXHAW, UNION COUNTY_________________	.20	MONROE, UNION COUNTY_________________	.05
ELLERBE, RICHMOND COUNTY_____________	.18	FAIRFIELD, UNION COUNTY______________	.02

*MORE THAN ONE WATER-SUPPLY SYSTEM INCLUDED.

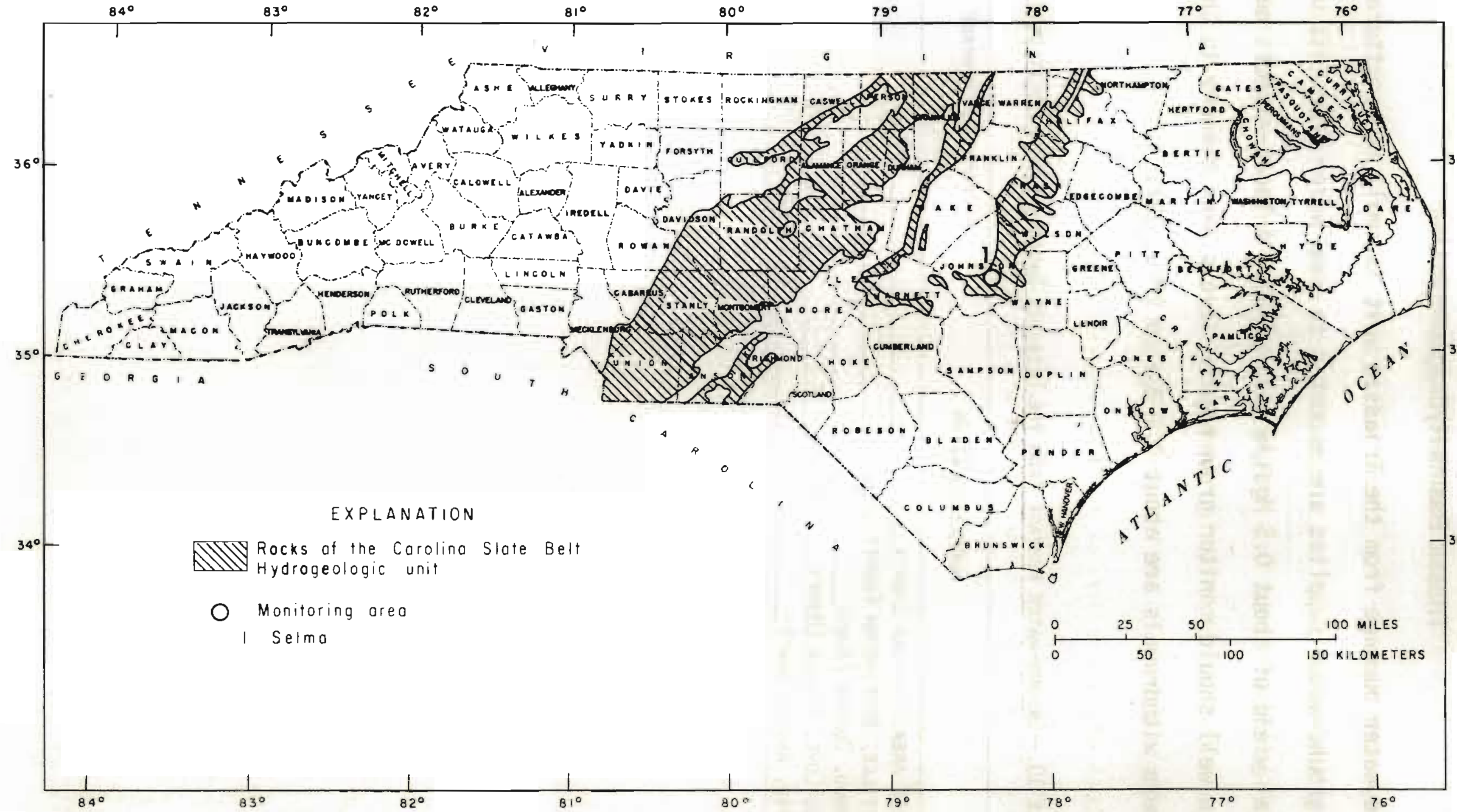


Figure 21.--Local-effects network monitoring area in the Carolina Slate Belt hydrogeologic unit.

Triassic Basins Hydrogeologic Unit

Ground-water pumpage from the Triassic unit is small and scattered. Only five ground-water supplies are reported to pump water from this unit, with a total yield of about 0.5 Mgal/d (table 10). A local-effects network observation well should monitor ground-water levels near Moncure in Chatham County, where withdrawals are about 0.2 Mgal/d (fig. 22).

TABLE 10.--GROUND-WATER PUMPAGE FROM THE TRIASSIC BASINS HYDROGEOLOGIC UNIT

SUPPLY LOCATION	APPROXIMATE PUMPAGE (MGAL/D)
MONCURE AREA, CHATHAM COUNTY	0.20
STONEVILLE, ROCKINGHAM COUNTY	.13
PARKWOOD, DURHAM COUNTY	.10
WALNUT COVE, STOKES COUNTY	.06
POLKTON, ANSON COUNTY	.04

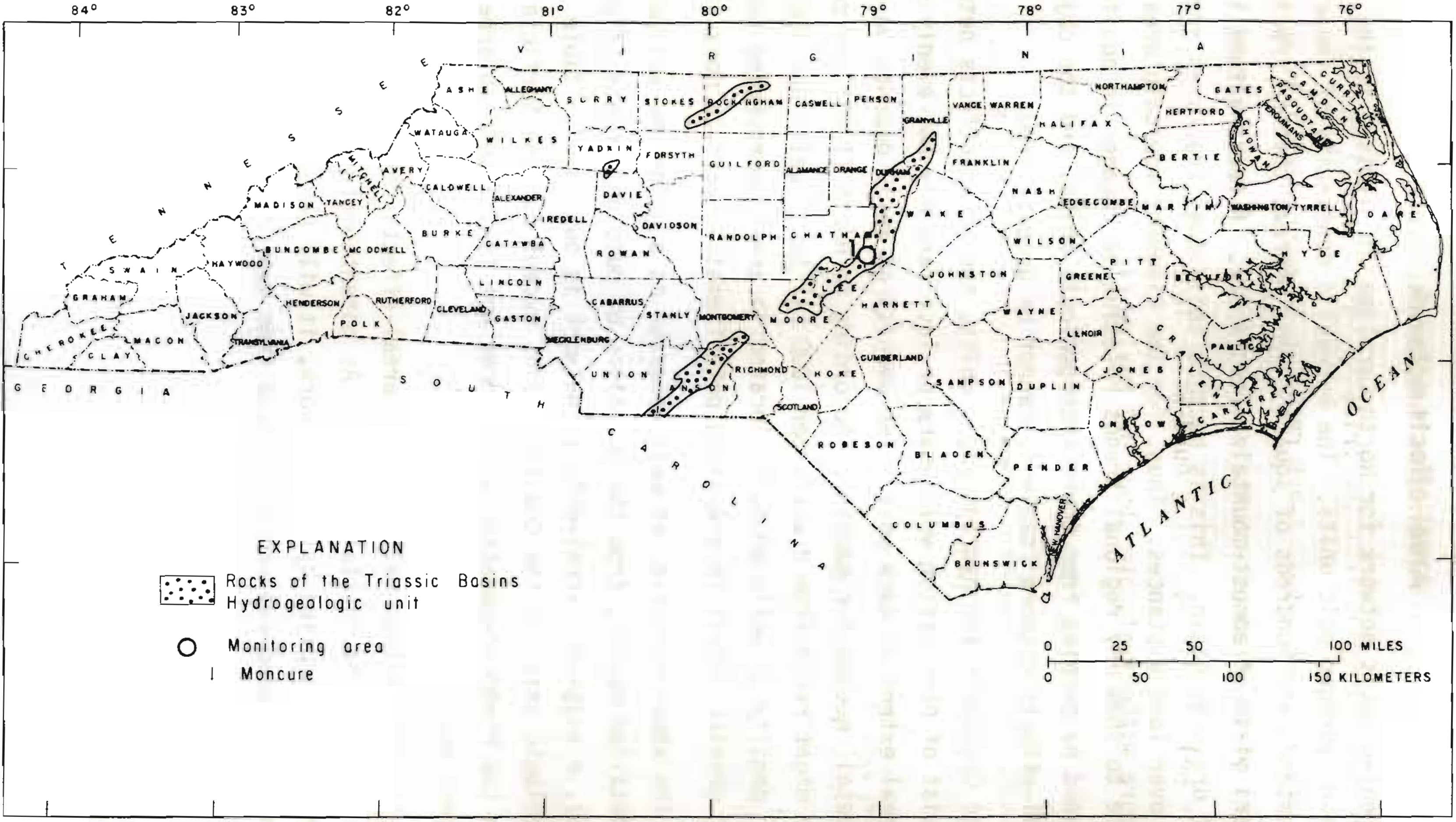


Figure 22.--Local-effects network monitoring area in the Triassic Basins hydrogeologic unit.

Areal-effects network

The areal-effects network for North Carolina is limited to the Coastal Plain hydrogeologic units. The hydraulic continuity of these units can extend over hundreds of square miles, whereas that of fractured rock aquifers of the Piedmont-mountain area rarely, if ever, extend into an adjacent drainage basin. This is because individual fractures are not continuous over long distances. Thus, for the Piedmont-mountain area, it is not possible to show any regional trends relative to changes in aquifer storage caused by pumping from these hydrogeologic units, and the objectives of the areal-effects network (table 1) cannot be accomplished.

For the Coastal Plain hydrogeologic units, the areal-effects network should consist of observation wells more or less randomly but evenly spaced over the areal extent of each unit. The density of wells depends on the amount of detail needed for mapping. According to Heath (1976) the density of coverage might range from 2 wells per 1000 mi^2 to 10 wells per 1000 mi^2. The greater density of wells would be located in areas surrounding pumping centers for greater detail in preparing potentiometric-surface maps.

Using the above densities of well coverage as a guide and estimating areas for detailed mapping from the locations of pumping centers (figs. 15-18 and table 5), a suggested areal-effects network is outlined in table 11 for the hydrogeologic units of the Coastal Plain, except for the Surficial unit, which, like the Piedmont-mountain units, does not lend itself to areal-effects objectives.

About 170 observation wells for the areal-effects network would be a reasonable goal for the initial network. As potentiometric surface maps are prepared from data supplied by this network, it will be evident that some wells may not be needed and can be dropped from the network.

TABLE 11.--SUMMARY OF AREAL-EFFECTS NETWORK OBSERVATION WELLS

HYDROGEOLOGIC UNIT	AREAL EXTENT (MI^2)	MINIMUM NUMBER OF WELLS FOR AREAL COVERAGE (2/1000 MI^2)[1/]	ESTIMATED AREA FOR DETAILED MAPPING (MI^2)	MAXIMUM NUMBER OF WELLS FOR DETAILED MAPPING (10/1000 MI^2)	TOTAL AREAL-EFFECTS WELLS
YORKTOWN	10,400	21	100	1	22
CASTLE HAYNE	9,100	16	1000	10	26
BEAUFORT	7,800	16	10	0	16
PEEDEE-BLACK CREEK	15,400	29	1000	10	39
CAPE FEAR	22,200	39	2800	28	67
TOTAL	------	--	----	--	170

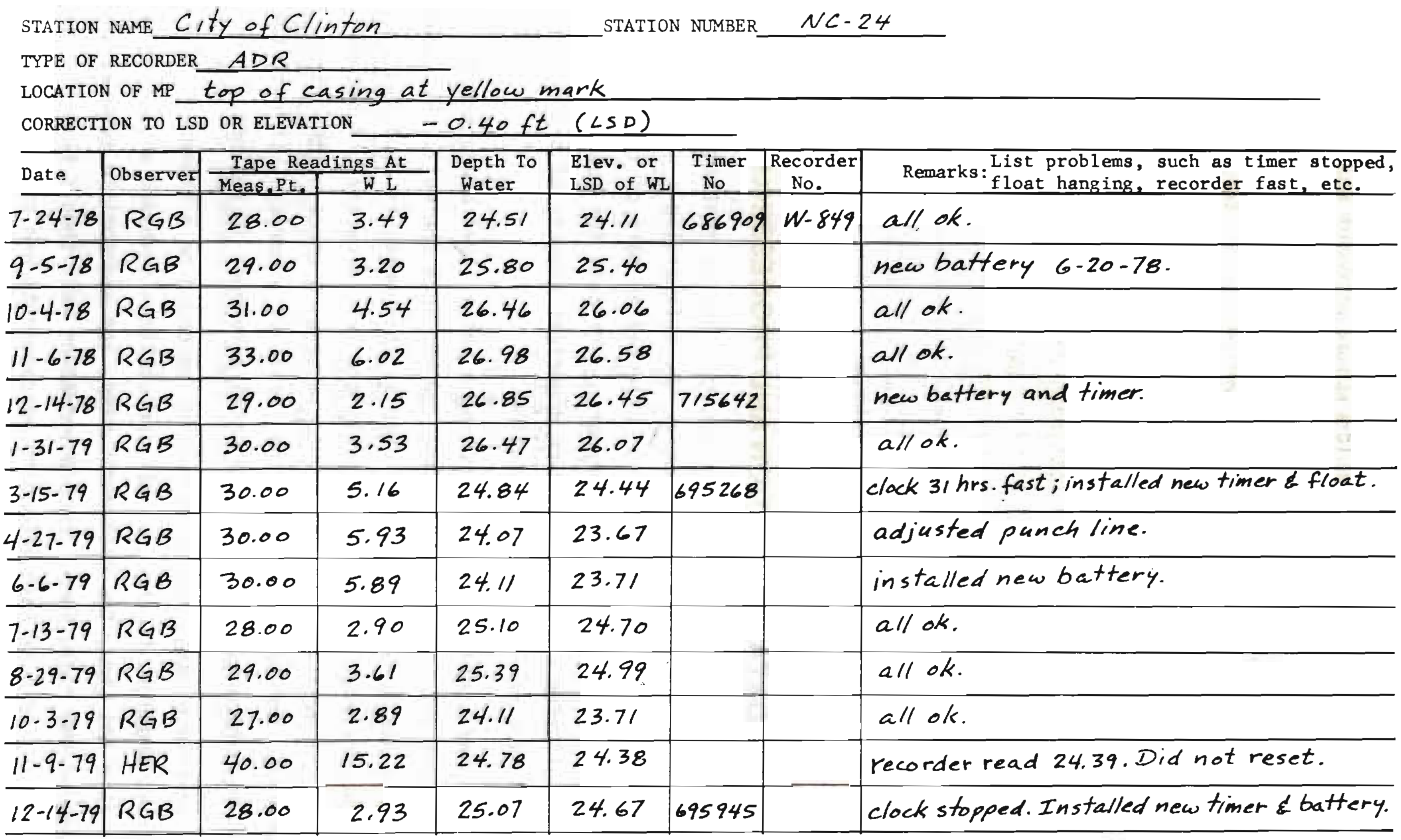
[1/] DETERMINED BY EXCLUDING ESTIMATED AREA FOR DETAILED MAPPING.

DATA COLLECTION AND PROCESSING

Standardized procedures are necessary in order to meet the objectives of the ground-water observation-well network. By maintaining a complete, accurate, and orderly file of data related to and collected as part of the network program, the work of processing and preparing the data for publication is made less complicated. Some of the more important aspects of data collection and processing are reviewed in this section.

The accepted standard method of making a water-level measurement in a well is by means of a chalked steel tape lowered into the well. Reproducible accuracy for a stable water level measured by this means is 0.01 foot; other methods of water-level measurement usually are less accurate. A second measurement is always made immediately to serve as a check on the first. The two measurements should agree within the limits of accuracy. If not, then additional measurements should be made until agreement is reached.

All water-level measurements should be recorded on a standard field form, such as shown in figure 23. All computations involved with each measurement, the date and time, the observer's name, and appropriate remarks should be recorded on the field form. Each observation well should have its own series of field forms so that preceding measurements and notes are available for consultation in the field.



STATION NAME City of Clinton STATION NUMBER NC-24

TYPE OF RECORDER ADR

LOCATION OF MP top of casing at yellow mark

CORRECTION TO LSD OR ELEVATION -0.40 ft (LSD)

Date	Observer	Tape Readings At		Depth To Water	Elev. or LSD of WL	Timer No	Recorder No.	Remarks: List problems, such as timer stopped, float hanging, recorder fast, etc.
		Meas. Pt.	W L					
7-24-78	RGB	28.00	3.49	24.51	24.11	686909	W-849	all ok.
9-5-78	RGB	29.00	3.20	25.80	25.40			new battery 6-20-78.
10-4-78	RGB	31.00	4.54	26.46	26.06			all ok.
11-6-78	RGB	33.00	6.02	26.98	26.58			all ok.
12-14-78	RGB	29.00	2.15	26.85	26.45	715642		new battery and timer.
1-31-79	RGB	30.00	3.53	26.47	26.07			all ok.
3-15-79	RGB	30.00	5.16	24.84	24.44	695268		clock 31 hrs. fast; installed new timer & float.
4-27-79	RGB	30.00	5.93	24.07	23.67			adjusted punch line.
6-6-79	RGB	30.00	5.89	24.11	23.71			installed new battery.
7-13-79	RGB	28.00	2.90	25.10	24.70			all ok.
8-29-79	RGB	29.00	3.61	25.39	24.99			all ok.
10-3-79	RGB	27.00	2.89	24.11	23.71			all ok.
11-9-79	HER	40.00	15.22	24.78	24.38			recorder read 24.39. Did not reset.
12-14-79	RGB	28.00	2.93	25.07	24.67	695945		clock stopped. Installed new timer & battery.

Figure 23.--A completed form showing field water-level measurements.

Data processing begins in the field with a series of checking procedures designed to insure the accuracy of the data collected. The additional water-level measurement mentioned above is the first step. If a recording device is installed on the well, a check is made to see that it is operating properly and that time and water-level readings of the instrument are in agreement with beginning and ending measurements.

The graphic chart from a recorder is scanned in the field to spot obvious problems such as clock failure or float hang-ups. Many times these problems can be corrected without further loss of record. A more detailed analysis of the chart is made back in the office when the data are transcribed to the office forms. ADR (analog digital recorder) tapes are inspected in the field to see that the correct number of days have elapsed since the last visit, and to see that the punched holes are evenly spaced.

In the office the tape is again inspected and the appropriate time and gage-height corrections are determined before the tape is processed. All computations associated with the field measurements are once again checked as the measurements are transcribed to the office forms, and the computer-produced print-out record from an ADR tape is scanned for repetitive or abnormally high or low water levels. When the data are determined to be correct and acceptable, the tapedown measurements, graphic charts, and ADR tapes and printouts become public record and are stored in the data file.

It should be the responsibility of the field office that collects the water-level data to maintain a current file of accurate information for each of their observation wells. The file should consist of:

1. A station file folder containing physical, geographic, geologic and ownership information about the observation well
2. A water-level-data file containing the compilation of the measurements
3. An original data file containing field measurements, graphic charts, and ADR tapes
4. Hydrographs

Maintenance of the water-level data file on a current basis should provide timely water-level data ready for publication.

DATA PUBLICATION

The timely availability of the results of the observation-well program to the public and particularly to officials and scientists who need these data for water-management decisions and hydrologic studies is the objective of this program. The practice of maintaining accurate data-collection and processing procedures which result in current, but unpublished, water-level data available for public use is one way to meet this objective. However, the most effective method of disseminating these data and making their availability known to those who need them is by publishing data reports. The purpose of this section is to describe a publication format for the data obtained from an observation-well network, such as described in the preceding pages.

An annual publication similar to one recently prepared by the Geological Survey (U.S. Geolological Survey, 1978) in cooperation with State and local agencies in Georgia is proposed for North Carolina. In that report, water-level data are presented in graphs and maps with brief explanatory text. This is a break from tradition where water-levels generally have been published in tabular form. To compliment the ground-water network concept as proposed in this report, it seems appropriate and useful to present hydrographs, water-level contour maps, water-level change maps, and brief statements about the status of ground-water storage in each of the hydrogeologic units. This is especially significant for those areas affected by large ground-water withdrawals.

The illustrations should include a location map of each hydrogeologic unit and the observation wells in it. Hydrographs should be used to show the ground-water conditions in each unit--both the current annual hydrograph and a longer-term hydrograph such as a decade, if data are available. Figure 24 is an example. Potentiometric surface maps for each major cone of depression should be presented and, when desirable, a water-level change map. Several of the maps presented by Peek and Nelson (1975) and North Carolina Groundwater Section (1976) are excellent examples.

Other miscellaneous illustrations should be included such as: (1) maps showing rates of water-level decline, (2) graphs relating ground-water level decline and pumpage, (3) graphs relating ground-water levels and rainfall, and (4) graphs relating ground-water levels and base flow of nearby streams.

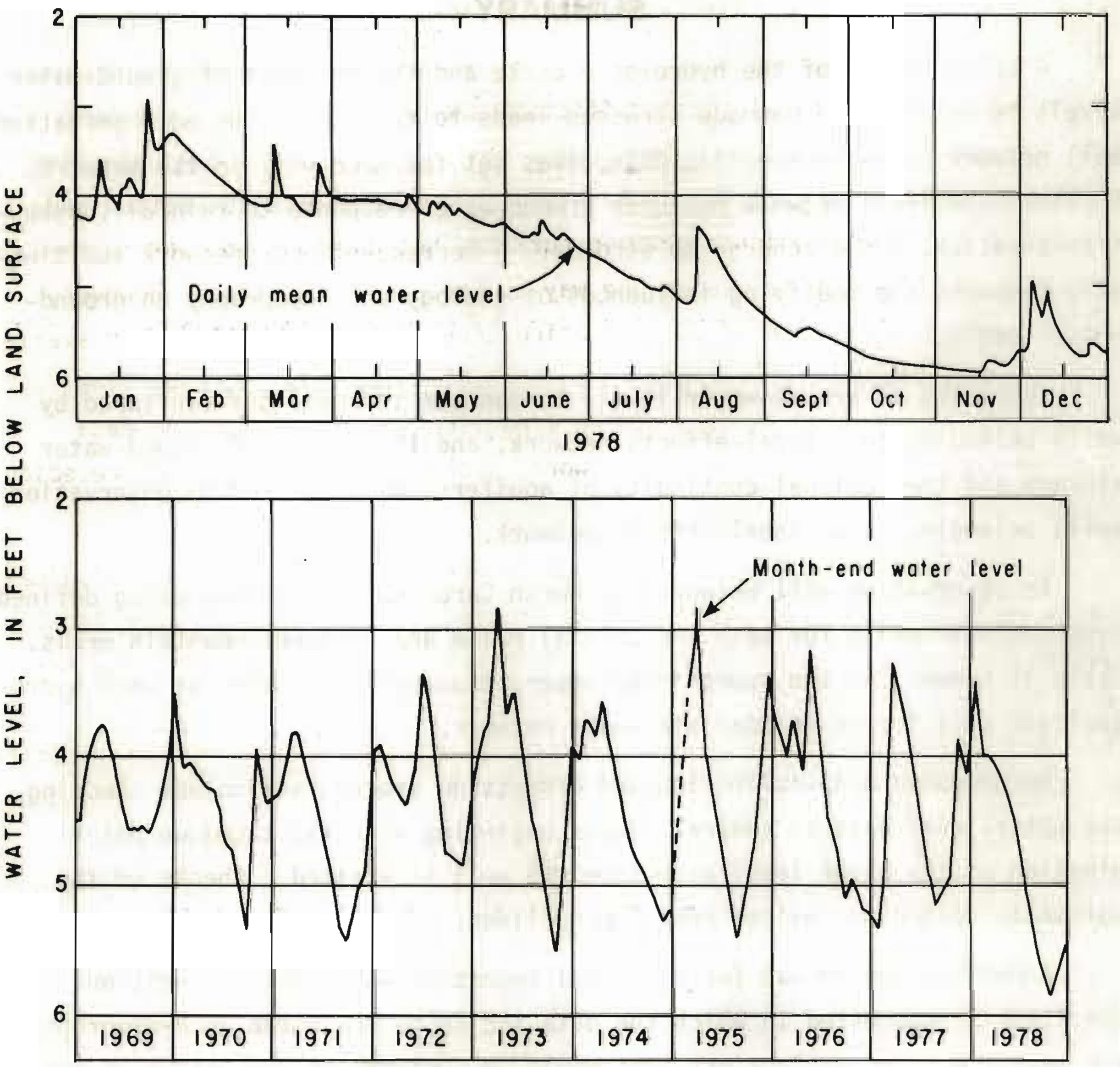


Figure 24.--Examples of short-term and long-term water-level fluctuations in well NC-40 in Haywood County.

This annual publication would also be a good medium to present other hydrologic information related to ground-water levels. Drought conditions that are monitored by special observation wells, or local dewatering problems are examples that could be presented.

For those users of water-level data who require the actual measurements, data from the observation-well files would be available upon request.

SUMMARY

A brief review of the hydrologic cycle and the response of ground-water levels to natural and manmade stresses leads to the concept of an observation-well network based on specific objectives set for each well in the network. A climatic-effects network measures ground-water response to rainfall, evapotranspiration, and discharge to streams. A terrane-effects network additionally measures the modifying influences of geology and topography on ground-water levels.

Responses of ground-water levels to manmade stresses are monitored by wells belonging to a local-effects network, and the status of ground-water storage and the regional continuity of aquifers are monitored by observation wells belonging to an areal-effects network.

An observation-well network for North Carolina is outlined using defined hydrogeologic units for both the Coastal Plain and Piedmont-mountain areas. Table 12 summarizes the approximate observation-well coverage for each hydrogeologic unit for an initial statewide network.

Recommended data-collection and processing procedures include checking the water-level data at several stages beginning with the tapedown determination of the water level each time the well is visited. Checks of the automatic recording devices are also outlined.

A publication format for an annual report of water-level conditions in the State is suggested in which the data are to be presented in hydrographs and maps. A brief explanatory text would be included on the status of ground-water conditions in each hydrogeologic unit.

TABLE 12.--APPROXIMATE NUMBERS OF WELLS FOR THE INITIAL OBSERVATION-WELL NETWORKS IN NORTH CAROLINA

HYDROGEOLOGIC UNIT	CLIMATE-EFFECTS NETWORK	TERRANE-EFFECTS NETWORK	LOCAL-EFFECTS NETWORK	AREAL-EFFECTS NETWORK
SURFICIAL	8	16*	1	-
YORKTOWN	-	-	6	22
CASTLE HAYNE	-	-	9	26
BEAUFORT	-	-	4	16
PEEDEE-BLACK CREEK	-	-	15**	39
CAPE FEAR	-	-	14**	67
GREAT SMOKY MOUNTAIN BELT	-	3	0	-
BLUE RIDGE-INNER PIEDMONT BELT	-	15	3	-
CHARLOTTE BELT	-	9	2	-
CAROLINA SLATE BELT	-	9	1	-
TRIASSIC BASINS	-	6	1	-

-, DOES NOT APPLY TO THIS UNIT.

*, INCLUDES THOSE WELLS THAT MAY BE OPEN TO OTHER COASTAL PLAIN HYDROGEOLOGIC UNITS.

**, DOES NOT INCLUDE VERTICAL-LEAKAGE MONITOR WELLS.

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METRIC CONVERSION FACTORS

The inch-pound system of units is used in this report. For readers who prefer the International System of Units (SI), the conversion factors for the terms in this report are listed below:

Multiply inch-pound unit	By	To obtain SI unit
	Length	
inches (in)	25.4	millimeters (mm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
square miles (mi^2)	2.590	square kilometers (km^2)
	Flow	
gallons per day (gal/d)	0.044	cubic meters per second (m^3/s)

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