AN APPRAISAL OF THE GROUNDWATER RESOURCES OF THE UPPER CAPE FEAR RIVER BASIN NORTH CAROLINA

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AN APPRAISAL OF THE GROUND-WATER RESOURCES OF THE UPPER CAPE FEAR RIVER BASIN, NORTH CAROLINA

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INTRODUCTION

This report has been jointly prepared by the U.S. Geological Survey and the Division of Ground Water of the North Carolina Department of Natural and Economic Resources as a contribution to the interagency study of the water resources of the upper Cape Fear River basin. The report describes the occurrence, availability, chemical quality, and cost of development of the ground-water resources in the basin.

The authors wish to acknowledge the cooperation of Heater Well Company, Inc., McCall Brothers, Inc., and Bainbridge and Dance, Inc., in supplying estimates of well-drilling costs in the basin.

PURPOSE AND SCOPE

An adequate and dependable supply of good-quality water is a prime requisite to economic development of an area. The decision to use ground water or surface water as a source of supply should not be made until both sources are compared in terms of quantity, dependability, quality, and costs.

The purpose of this report is to supply information pertaining to the feasibility of using ground water as a source of supply in the upper Cape Fear River basin. Within the scope of this report, an appraisal of the ground-water resources can be made by discussing, in general terms, the following basic questions:

1. Where can ground-water supplies be developed?

2. What quantity of ground water can be developed per unit area?

3. What is the cost of developing ground-water supplies in the basin?

4. What is the chemical quality of the ground water in the basin?

GENERAL ASPECTS

The upper part of the Cape Fear River basin, as discussed in this report, comprises about 3,400 square miles drained by the Haw and Deep Rivers and a short segment of the Cape Fear down to Lillington. This area is located in the central part of the State. Except for small interstream areas near Lillington, which are underlain by Coastal Plain sediments, all of the upper part of the basin lies entirely within the Piedmont physiographic province. The basin encompasses all or parts of 13 counties, as shown in figure 1.

The upland surface of the basin generally slopes towards the east or southeast and is characterized by gently rolling hills and elongated ridges. The ridges generally trend northeast to southwest, forming narrow stream valleys in between. The major streams generally flow towards the southeast and are contained in the wider valleys except where they cross the more resistant ridges. Land-surface altitudes range from about 150 feet above mean sea level in the Cape Fear River valley at Lillington to an extreme of 1,033 feet in southwest Alamance County.

On the basis of the 1970 census, it is estimated that slightly more than 600,000 people live in the upper part of the Cape Fear River basin. The water needs of the area are met either from surface-water sources or from ground water. Data on the population supplied by each of these sources are not available for the basin area but are available or can be readily estimated for each of the 13 counties which lie entirely or partly in the upper part of the basin (Jackson, 1972, and Jackson, 1973). Table 1 is a list of the counties showing total population, and the population served with ground water and surface water. The population using ground water ranges from about 92 percent in Caswell County to about 23 percent in Guilford County. For the 13 counties as a whole, 42 percent of the population use ground water. This usage is principally in rural areas and in the smaller towns.

Table 1.-- Population supplied with water from surface-water and ground-water sources in the counties lying entirely or partly in the upper Cape Fear River basin.

County	Population in 1970	Population served with Ground water	Population served with Surface water	Percent using ground water
Alamance	96,362	46,562	49,800	48
Chatham	29,554	21,854	7,700	74
Caswell	19,055	17,555	1,500	92
Durham	132,681	32,681	100,000	25
Guilford	288,590	66,293	222,297	23
Harnett	49,667	34,017	15,650	68
Lee	30,467	17,967	12,500	59
Montgomery	19,267	13,767	5,500	71
Moore	39,048	27,468	11,580	70
Orange	57,707	24,207	33,500	42
Randolph	76,358	53,858	22,500	71
Rockingham	72,402	31,702	40,700	44
Wake	228,453	91,653	136,800	40
Totals	1,139,611	479,584	660,027	42

GROUND-WATER RESOURCES

Occurrence of Ground Water

The source of all water in the upper part of the Cape Fear River basin is precipitation, about 45 inches each year. Most of the precipitation runs overland to streams and is classed as "surface runoff." Another large part is returned to the atmosphere through evaporation and by transpiration of plants. Ten to 15 percent of the total amount percolates to the water table and becomes ground water. Beneath the water table, ground water is stored in and is transmitted through the openings in the rocks to points of discharge, such as wells and streams.

The rocks underlying the basin generally occur in two distinct zones. The uppermost zone is formed by weathering of the underlying bedrock. The residual material formed by weathering is referred to as saprolite. It usually consists of clay with lesser amounts of sand and large rock fragments. The thickness of saprolite in the upper Cape Fear River basin ranges from a few feet or less near rock outcrops to somewhat more than 100 feet. The average thickness on most hills and ridges is 30 feet.

Saprolite that has been eroded from the hills and transported to the stream valleys to form the flood plains is called alluvium, which may range in composition from clay to boulders. Its thickness is generally less than 20 feet.

The saprolite in the basin is underlain by unweathered bedrock. It consists of several different types of rock, most of which have similar hydrologic properties. The different rock types will be discussed in another section of this report.

The saprolite and fractured parts of the bedrock form the ground-water reservoir of the basin. The quantity of water that can be stored or transmitted by the saprolite-bedrock reservoir is dependent on the size, shape, and abundance of their contained openings. In the saprolite, ground water occurs in the pore spaces between particles. In bedrock, water occurs in the sheetlike openings developed along fractures in the rock.

The bedrock has been subjected to great stresses during its long geologic history and comprises a complex reservoir system. The degree of fracturing of the rocks resulting from these stresses varies greatly from place to place, ranging from very small, widely spaced fractures to zones of intensely broken rocks that are tens or hundreds of feet wide. Generally, bedrock fractures are only fractions of an inch in size and spaced a few inches to several feet apart. As a rule, the fractures decrease in number and size with depth. Data show that zones of significant fracturing extend to depths of more than 800 feet. The range of depth and degree of fracturing is not adequately known and considerable exploratory drilling will be necessary to ascertain the structure of the reservoir system.

One of the basic concepts of ground-water hydrology is that aquifers function both as a reservoir to store water and as a pipeline to transmit water. The quantity of water that can be stored depends on the porosity of the aquifer material. The ability to transmit water depends on the permeability and thickness of the aquifer material. The porosity usually is between 20 and 50 percent in saprolite whereas the porosity of bedrock is generally a fraction of 1 percent. The permeability of both materials generally is between 1 and 100 gpd (gallons per day) per square foot. Obviously, the water in storage in a unit volume of saprolite is many times greater than in an equal volume of bedrock. However, the thickness of the water-bearing zone in bedrock is generally several times greater than the thickness of the saturated part of the saprolite. In most cases it is useful to consider that the saprolite functions as the reservoir and that the bedrock functions as the pipeline.

Geologic Units

The occurrence of ground water in the upper Cape Fear River basin is influenced to a large extent by the local geology. The type and structure of the rocks have a strong influence on such factors as topography and the thickness of the saprolite.

The upper part of the basin is underlain by at least nine types of rock as shown in figure 2. However, because the hydrologic properties of several of these rock types are similar, the nine types are grouped in this report into four major rock units according to these properties. The groups are identified as the igneous and metamorphic unit, the metavolcanic unit, the Triassic unit, and the sedimentary unit.

The rocks included in the igneous and metamorphic unit are predominantly coarse-grained biotite granite, medium-grained diorite, and gneisses and schists. Rocks of this unit occur in all parts of the basin but are most predominant in the northwestern part. This is the most productive water-bearing unit in the upper part of the basin.

The metavolcanic unit is composed principally of tuffs, breccias, phyllites, and argillites. It underlies the central part of the area and a relatively smaller area north and west of Lillington. The size and degree of interconnection of fractures in this unit are less than in the igneous and metamorphic unit. Also the saprolite in the area underlain by this unit usually contains more clay than the saprolite of the other units. As a result the water-bearing characteristics of the metavolcanic unit are not as favorable as those of the igneous and metamorphic rock unit.

The Triassic unit is composed principally of sedimentary rocks such as sandstone, siltstone, shale, and conglomerate. These rocks were deposited in a northeastward-trending trough or basin. The basin is 10 to 12 miles wide and extends through the southeastern part of the area. Because of the nature of deposition, the beds are lenticular in most places, and the lithology may differ considerably within short distances both vertically and laterally. The variable lithology and generally low permeability of the Triassic deposits makes this the least favorable unit for the development of ground-water supplies in the basin.

Along the southeastern boundary of the upper Cape Fear basin, a thin mantle of unconsolidated sand and clay overlies the older rock units. In this report, the sand and clay are called the sedimentary unit. It represents an extension of Coastal Plain deposits into the upper part of the basin and, although it is not important as an aquifer, its presence has a marked influence on the water-yielding characteristics of the underlying rocks.

GROUND-WATER SUPPLIES

Where Ground-Water Supplies Can Be Developed

Ground-water supplies can be developed in all parts of the upper Cape Fear River basin. However, in many places the ground-water situation is such that, because of quantity or quality problems, the development of large supplies is not feasible.

LeGrand (1967) has shown that the yield of wells in the Piedmont region, which includes the upper Cape Fear River basin, is related to the topography at the well site and to the thickness of the saprolite. The highest-yielding wells are almost invariably located in topographically low areas, such as draws and stream valleys. The lowest-yielding wells are generally located near the tops of hills and ridges.

The differences in yield in different topographic situations apparently reflect the composite effect of several factors. Chief among these is the number and size of fractures in the bedrock. Valleys are believed to be located where fractures are most abundant, whereas the hills and ridges suggest the presence of relatively massive (unfractured) rock. Another factor is the tendency of the ground water to move toward valleys from the adjoining ridges, so that more water is available to pumping wells in valleys. A third factor, and one of the most important, is the infiltration of water from streams into the fractured rock when ground-water levels are lowered by pumping.

The thickness of saprolite is important because, as noted earlier, the saprolite functions as a reservoir. When fractured-rock wells are pumped, water slowly seeps downward from the saprolite into the fractures in the rock. Thus, the thicker the saprolite the larger the volume of water available for withdrawal. From what was said in the preceding paragraph about stream infiltration in valley areas, it is apparent that the thickness of saprolite is of greatest significance to the yield of wells in upland areas. In uplands underlain by 25 to 50 feet of saprolite, the sustained yield of wells may be double that of wells in uplands underlain by only 5 to 10 feet of saprolite.

Quantity of Available Ground Water

During extended dry periods the flow of streams in the basin is sustained by ground water discharging from the adjacent aquifers. The volume of ground water discharged to streams is an indication of the amount of water available for development from the ground-water reservoir.

Comprehensive quantitative studies of the amount of ground water available for development in the upper part of the Cape Fear River basin have not been made. However, based on studies in similar areas, it is estimated that the streamflow equaled or exceeded 70 percent of the time is a reliable indicator of the amount of ground water available.

Figure 3 shows areas of approximately-equal ground-water discharge, based on the flow of streams equaled or exceeded 70 percent of the time. The area encompassed by each coincides with the areas underlain by the three principal hydrologic units and represents the average rate of ground-water discharge to streams, in millions of gallons per day per square mile of basin area. The values were determined from U. S. Geological Survey streamflow records for stream basins of 100 square miles or less in the Piedmont section of the State.

The quantity of ground water available for development ranges from about 0.26 mgd (million gallons per day) per square mile for the igneous and metamorphic unit to about 0.06 mgd per square mile for the Triassic unit. The quantity available from the metavolcanic unit is intermediate between these, or 0.13 mgd per square mile.

Figure 3 shows the quantities of ground water available in terms of unit areas; in this case, in terms of square miles. These average quantities depend primarily on the nature of the underlying bedrock. However, the development of ground water is accomplished with wells, and, as noted above, the yield of wells depends not only on the nature of the rock but also on the topographic situation and thickness of saprolite. Analysis of data on the depth to bedrock at several hundred wells in the area indicates that the thickness of saprolite is quite consistent. With the exception of the Triassic unit, it ranges from about 25 feet in valleys to about 50 feet in upland areas. In the Triassic unit the saprolite is thinner, ranging from a thickness of only a few feet near rock outcrops to a maximum of about 25 feet. Thus in considering the yield of wells in the upper Cape Fear River basin, the thickness of saprolite can be largely ignored and primary attention devoted to the type of rock and topographic situation.

The yield of wells in the upper Cape Fear River basin ranges widely - from essentially dry holes to a yield of more than 200 gpm (gallons per minute). Most of the wells drilled in the area are for home and farm needs, which are adequately met by as little as 2 to 3 gpm. Therefore, from the standpoint of this report, which is concerned with water for municipal, industrial, and other large needs, emphasis was on analysis of the data from the more productive wells. These are the wells that have been located with great care at the most favorable sites and have been drilled and developed to obtain the maximum amount of water. Such wells are located as near perennial streams as possible and, when drilled in uplands, are located in draws and other topographically low areas.

The available data on the yield of existing wells in the upper Cape Fear River basin are summarized in figure 4 in terms of the number of wells needed to produce 1 mgd. The area is divided into five zones on the basis of topography and type of rock. For example, the areas in which the highest yielding wells can be constructed consist of narrow bands on each side of the largest streams, such as the Haw River and its principal tributaries and segments of the Rocky and Deep Rivers. In these areas the yield of the most productive wells averages about 100 gpm, and only 7 wells are required to yield 1 mgd. These highest-yield areas and the smaller tributary streams in all except the area underlain by the Triassic unit, are bordered by zones in which the maximum sustained yield of wells averages about 75 gpm, and 1 mgd can be obtained from 10 wells.

The lowest-yielding wells are those drilled in the upland areas underlain by the Triassic unit. The maximum sustained yield of these wells is only about 25 gpm, and at least 28 wells are needed to obtain 1 mgd. The yield of well fields in uplands is derived from local recharge and thus cannot exceed the total yield per square mile shown on figure 3. In order to avoid significant interference between pumping wells, it is recommended that wells in uplands be spaced evenly over the areas indicated in figure 3. In the valleys the yield of wells is derived both from local recharge and from stream infiltration. The spacing of wells in these areas depends on the distance of the wells from the perennial streams and the nature of the alluvium between the stream channels and the bedrock. In the most favorable areas the spacing may be as close as 500 feet.

Cost of Ground Water

In order to determine the cost of developing a ground-water supply in different parts of the basin, it is necessary to determine the cost of well construction, land for well sites, pumping tests, pump installation, and other items. The physical characteristics of the wells needed to obtain the yields shown on figure 4 are listed in table 2. These characteristics are based on those of existing large-yielding wells in the area. The maximum sustained yields are assumed to be maintained at a steady rate 24 hours a day, 365 days a year.

Well depth was chosen to be 250 feet in all geologic units in the basin. A diameter of 6 inches was chosen for all wells because it is adequate to accommodate the largest pump needed. The lengths of well casing were selected as 40 feet in the lower topographic areas and 50 feet in the upland areas. For each well, a submersible pump was selected to produce the anticipated yield against a total dynamic head of 300 feet. It was also estimated that 50 percent of the wells would yield less than the estimated quantities of water and thereby would be considered as test wells. In other words, to assure that the estimated costs will be conservative, we assumed that two wells would have to be drilled to obtain one successful well. Allowances for the costs of drilling the test wells were made in estimating the costs of well-field construction.

The initial construction costs of a well or well field includes real estate, well drilling (includes casing and development), pump and column, pumping tests, automatic controls and wiring, and a 15-percent allowance for contingencies and engineering costs. As explained below, costs of transmission lines are not included. These costs are based on data supplied early in 1971 by well-drilling contractors and pump companies. (See table 3.)

Table 2.--Physical characteristics of hypothetical wells

Geologic Unit	Physiography	Well Depth (feet)	Well Diam. (inches)	Casing Length (feet)	Water Levels (feet below surface)		Pump horse-power	Maximum Sustained Yield (gpm)
					Static	Pumping		
Igneous and Metamorphic	Upland	250	6	50	30	175	5	50
	Stream Valley	250	6	40	10	150	10	100
Metavolcanic	Upland	250	6	50	30	175	5	45
	Stream Valley	250	6	40	10	150	7.5	75
Triassic	Upland	250	6	50	30	175	3	25
	Stream Valley	250	6	40	5	150	5	45

Table 3.-- Estimated costs of hypothetical wells and ground water in the upper Cape Fear River basin

Geologic Unit	Maximum Sustained Yield (GPM)	INITIAL COSTS									ANNUAL COSTS				UNIT COSTS	
		Real Estate	Test Well	Production Well	72-Hour Pumping Test	Pump and Column	Automatic Controls and Wiring	Contingencies and Engineering	Total Initial Cost Per Well	Total Initial Costs Per MGD of Design Yield	Annual Payment to Retire Initial Cost	Annual Power Cost	Annual Maintenance Cost	Total Annual Cost Per Well	Annual Cost Per 1000 Gal.	Annual Cost Per MGD
Igneous and Metamorphic	50	$1000	$1400	$1400	$1300	$ 860	$800	$1015	$7775	$108,900	$600	$ 675	$390	$1665	$0.064	$23,300
	100	1000	1400	1400	1300	1350	800	1090	8240	57,680	630	1055	410	2095	.040	14,600
Metavolcanic	45	1000	1400	1400	1300	860	800	1015	7775	124,400	600	675	390	1665	.070	25,600
	75	1000	1400	1400	1300	1225	800	1070	8195	81,950	630	740	410	1780	.045	17,800
Triassic	25	1000	775	775	1300	750	800	810	6230	174,440	480	400	310	1190	.086	33.400
	45	1000	775	775	1300	860	800	825	6335	101,360	485	675	315	1475	.062	22,600

The annual costs of operating a well or well field include annual payments to retire the initial costs, annual power costs, and an allowance for maintenance. The amount of the annual payment was computed by amortizing the initial costs at 4-1/2 percent over a 20-year period by the capital-recovery method of cost accounting. The annual power costs are based on estimated power consumption and cost-rates given in the commercial small-general-service schedule GIH furnished by the Carolina Power and Light Company. The allowance for the cost of annual maintenance was estimated at 5 percent of the initial cost of equipment.

The cost of pumping water from the wells was computed by adding the costs of construction, operation, and maintenance. The total annual cost of producing the water was divided by the quantity of water produced to arrive at the cost of water in dollars per 1,000 gallons and the annual cost per million gallons per day.

It is important to note that these costs include costs of delivering water at the well head only. In other words, the costs of header pipelines to interconnect the different wells in a well field and the cost of pipelines to deliver the water to the point of use are not included. The reason for this is obvious because the cost of header pipelines depends on the layout and spacing of the supply wells in a field, the number of wells, and their expected yields. The cost of the pipeline to deliver the water depends on the distance of the well field from the expected point of use and the amount of water needed. Estimates of these costs are beyond the scope of this report.

As a rough guideline for a preliminary comparison of potential sources of water supply, the cost was estimated for developing a well field capable of supplying one million gallons per day in two topographic situations in each major geologic unit. To arrive at this cost for a particular area, the yield of one well in that area was divided into one million gallons to determine the number of wells needed. The initial cost of the well field was then computed by multiplying the cost of one well by the number of wells needed.

Figure 5 is a map of the basin showing the estimated range in costs, in different areas of developing a well field that will produce 1 million gallons of water each day.

CHEMICAL QUALITY OF GROUND WATER

Developers of an area need to know the chemical quality of ground water. Industries and municipalities must supply water that meets established quality standards. If the natural quality of the available water is not satisfactory, it must be treated to adjust the quality to the user's requirements.

In the upper part of the Cape Fear River basin, the ground water generally is of good quality and suitable for most industrial and municipal uses with little or no treatment. Locally, excessive concentrations of iron, hardness, and chloride are known to occur. These conditions seem to be more prevalent in the Triassic unit than in the other two rock units. The average iron concentrations in ground water from the three rock units are 0.03 mg/l (milligrams per liter) in the metavolcanic rocks, 0.02 mg/l in the igneous and metamorphic rocks, and 0.2 mg/l in the Triassic rocks. These and other chemical constituents and characteristics are shown in table 4.

The total hardness of the ground water ranges from moderately hard to very hard with averages being about 113 mg/l in the metavolcanic rocks, 138 mg/l in the igneous and metamorphic rocks, and 86 mg/l in the Triassic rocks. Other constituents analyzed are in the acceptable ranges for most ground-water uses.

GROUND-WATER PROBLEMS

The upper part of the Cape Fear River basin has a large amount of water stored beneath the ground surface, and at present there is no general shortage of water. The known water-supply problems are localized and are not considered to be critical. The existing problems are related to development and management of the water resources such as determining the local availability of water, regulating the use to prevent overdevelopment, removal of objectionable minerals, and protection from pollution.

Because of the fairly wide range in the geologic and hydrologic conditions in the basin, adequate ground-water supplies are not always available at sites most convenient to the user, and locating the best sites at which to develop a supply requires expert advice. Existing reports form a basis for more detailed investigations in prospective areas of development, but, at this time, no detailed studies have been made in the basin.

Overdevelopment

There is no known large-scale overdevelopment of the ground-water resources in the upper part of the Cape Fear River basin. This does not mean that overdevelopment has not occurred in local situations. In these cases, the problem is either improper well location or pumping rates in excess of the aquifer potential for a specific site. It is apparent that there are some industries and towns that are in unfavorable areas for

Table 4.--Ranges of chemical constituents in ground water in the upper Cape Fear River basin

Geologic Unit	Igneous-Metamorphic Unit			Metavolcanic Unit			Triassic Unit			U.S. Public Health Service Recommended Limits (mg/l)
Range in concentration (mg/l)	Low	Avg.	High	Low	Avg.	High	Low	Avg.	High	
Silica (SiO_2)	22	33	35	16	31	49	2.3	28	40	--
Iron (Fe)	.00	.03	5.00	.02	.02	1.20	.09	.20	3.80	0.30
Calcium (Ca)	1.1	22	67	1.9	18	388	.8	25.0	154	--
Magnesium (Mg)	.4	8.0	30	.7	6.4	89	.6	5.3	34	125
Sodium (Na)	2.3	11.1	32	.2	12.2	119	7.7	44	188	--
Potassium (K)	.1	.5	4.1	.1	.3	19	.1	.6	4.8	--
Bicarbonate (HCO_3)	14.0	73	291	11	110	412	9	146	313	--
Sulfate (SO_4)	.4	8.7	34	.8	3.4	22	.1	3.3	24	250
Chloride (Cl)	1.0	12.5	5.9	.2	7.0	750	3.0	13.7	384	250
Fluoride (F)	.0	.1	.2	.0	.1	.4	.0	.15	.6	1.5
Nitrate (NO_3)	.0	4.1	75	.0	.9	21	.0	.4	6.8	45
Total Hardness	5.0	138	422	20	113	480	4	86	524	--
Dissolved Solids	61	150	252	54	153	673	32	137	936	500
Color	2	2	3	2	3	15	2	3	10	15
pH	6.1	6.6	6.8	6.1	7.0	8.0	7.2	7.2	7.6	--

ground-water development, and after spending thousands of dollars in drilling wells they still do not have an adequate supply of water. However, the ground-water resources of the basin are adequate to meet demands many times larger than those presently being met. To minimize future problems, development of ground-water supplies for industries and municipalities should be carefully designed and managed by qualified professional personnel.

Pollution

Even though ground water is better protected from pollution than surface water, there are many places where pollutants are known to have found their way into the aquifers. With increased development of an area, there comes an increasing potential for pollution of the ground-water resource. Sanitary land fills are becoming more numerous and in each case provide almost direct connection between the refuse and the water table. Sewage, fertilizers, and industrial wastes are common agents of stream pollution, and, if unchecked, they may preclude the development of potentially large ground-water supplies from some of the stream valleys in the basin.

CONCLUSIONS

Large amounts of water are stored in the rocks underlying the upper part of the Cape Fear River basin. Dependable ground-water supplies can be developed from these rocks in all parts of the basin if the hydrologic conditions are properly evaluated and the wells and well fields are designed accordingly.

The chemical quality of the ground water in the basin is generally suitable for most uses. However, excessive concentrations of iron, hardness, and chloride occur in some local areas. Where necessary, the objectionable constituents can be effectively and economically reduced or removed by treatment of the water.

It is not within the scope of this report to provide exact data for development of water supplies at specific sites. However, with the available data, it is possible to predict, within acceptable limits, the general hydrologic conditions over a sizable area. Even in similar geologic and topographic situations, the hydrologic conditions can differ greatly within a short distance. For this reason, it is rarely possible to predict accurately the conditions at a specific site prior to actual on-site testing.

The different geologic, hydrologic, and economic conditions that had to be considered in appraising the ground-water resources of the basin make it necessary that certain generalized assumptions be made in estimating the costs of development. On these assumptions were based the estimated costs of construction and operation of hypothetical wells. These estimates are valid only for a comparison with estimates of costs of developing a supply from surface-water sources or from the different geologic units in the basin. Because of these assumptions, the estimates given are neither appropriate nor intended for use in detailed planning of a specific system. Planning and design of specific systems require geologic and hydrologic data from the actual project site and also the services of consulting ground-water hydrologists and qualified well-drilling contractors.

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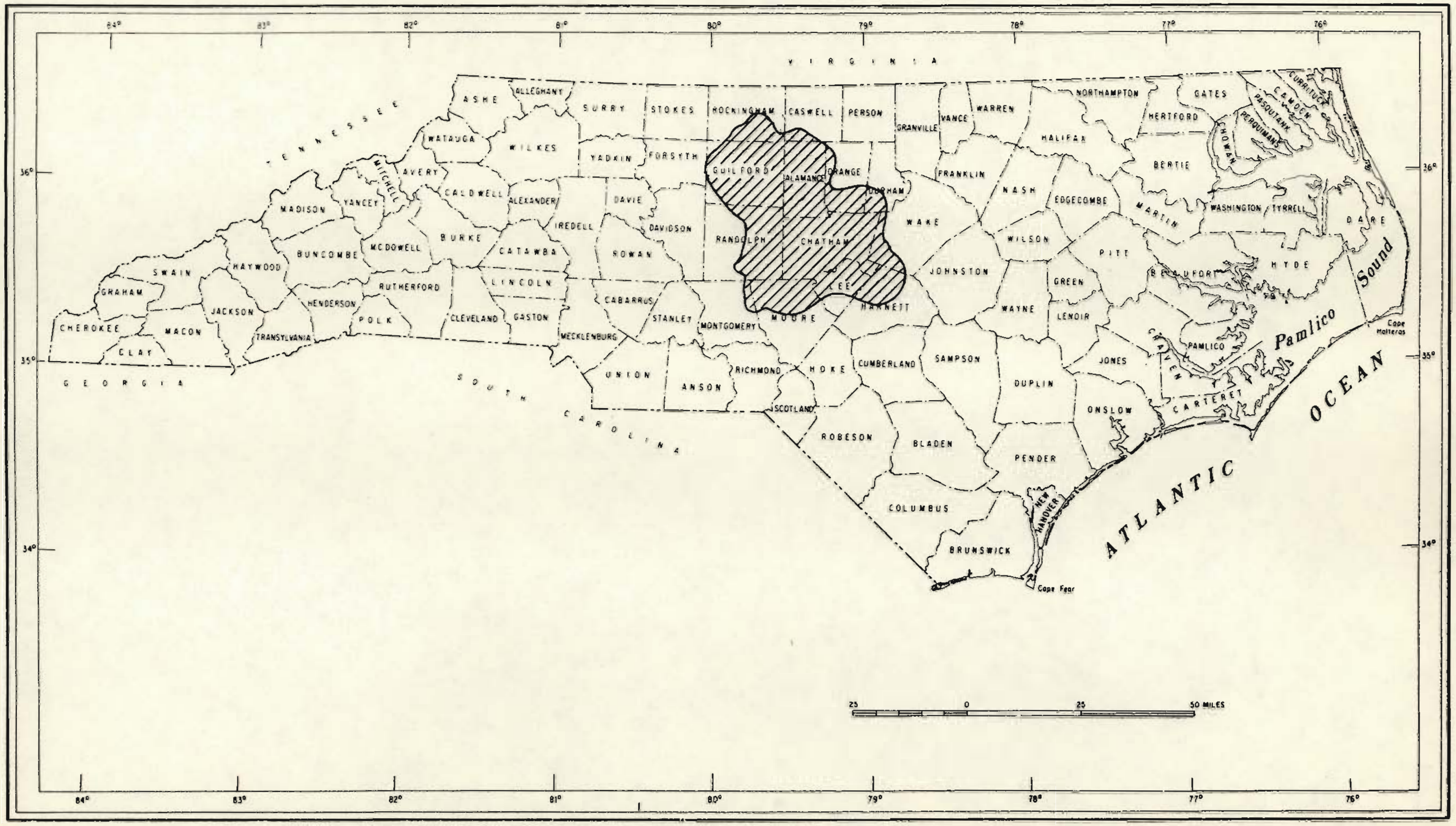
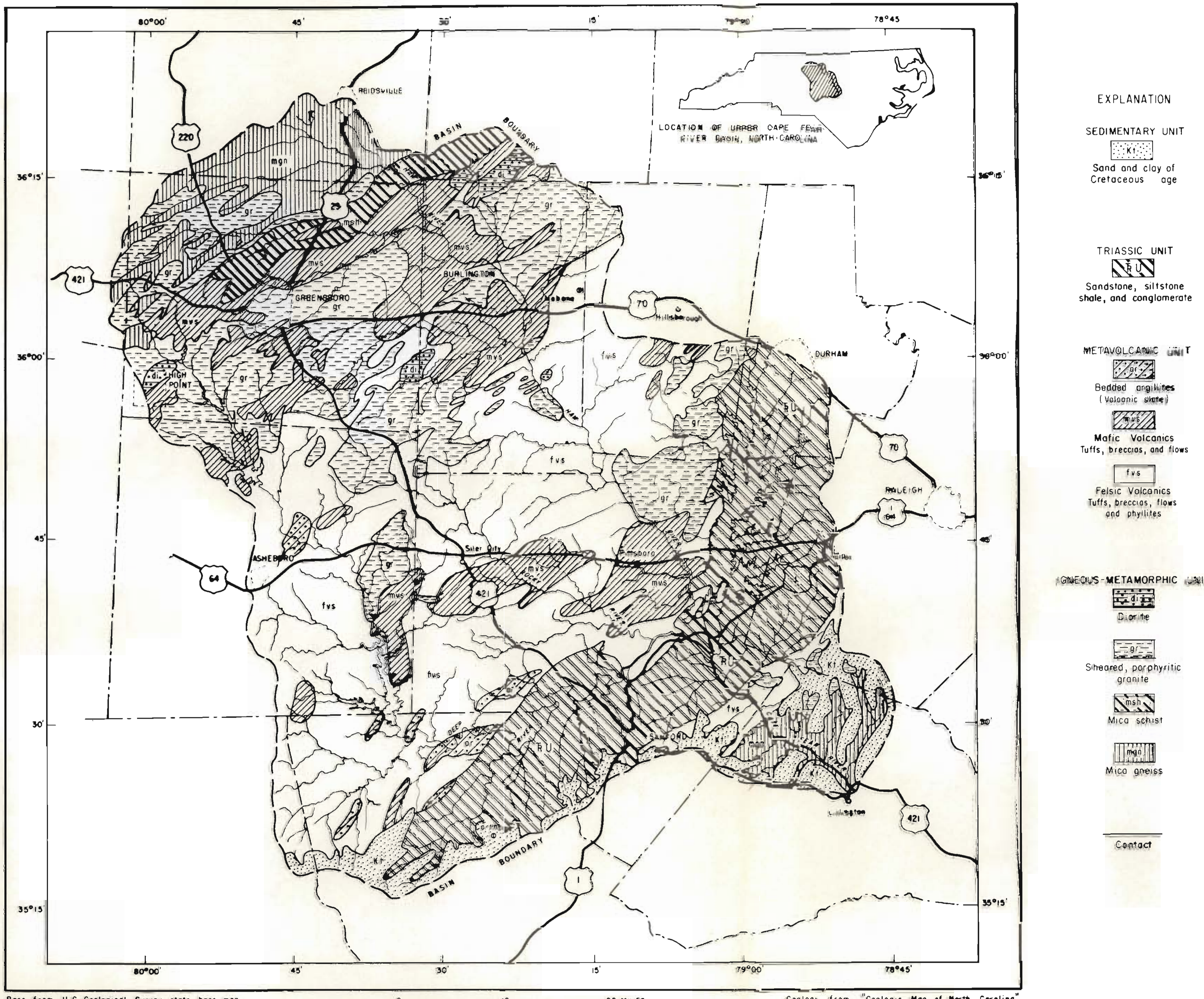


Figure 1. Map of North Carolina showing the location of the upper part of the Cape Fear River basin.



Base from U.S. Geological Survey state base map of North Carolina. Scale 1:500,000

Geology from "Geologic Map of North Carolina" N.C. Division of Mineral Resources

Figure 2. Geology of the upper Cape Fear River basin.

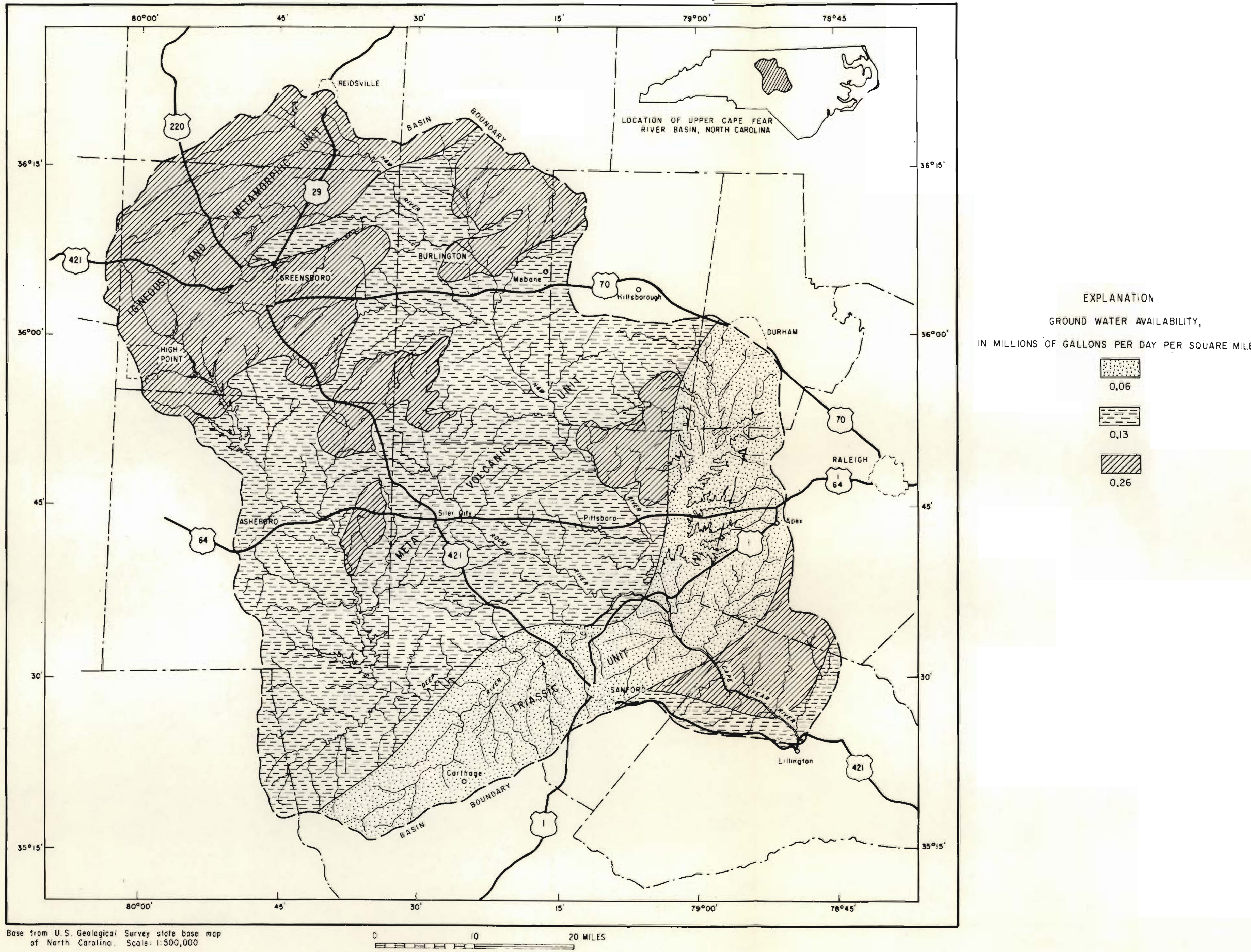
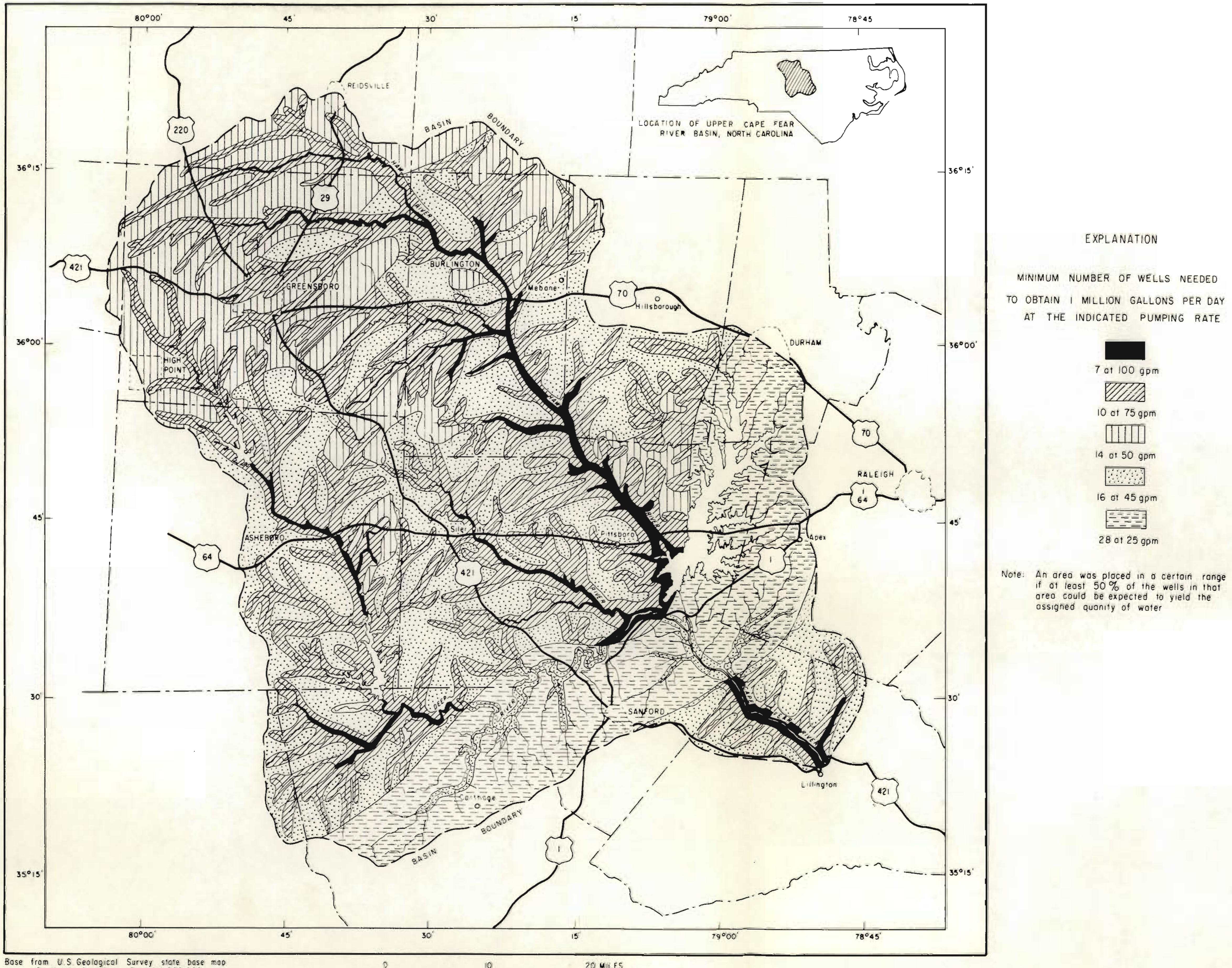


Figure 3. Approximate quantities of ground water available for withdrawal.



Base from U.S. Geological Survey state base map of North Carolina. Scale 1:500,000

Figure 4. Maximum sustained yields in different geologic and topographic situations.

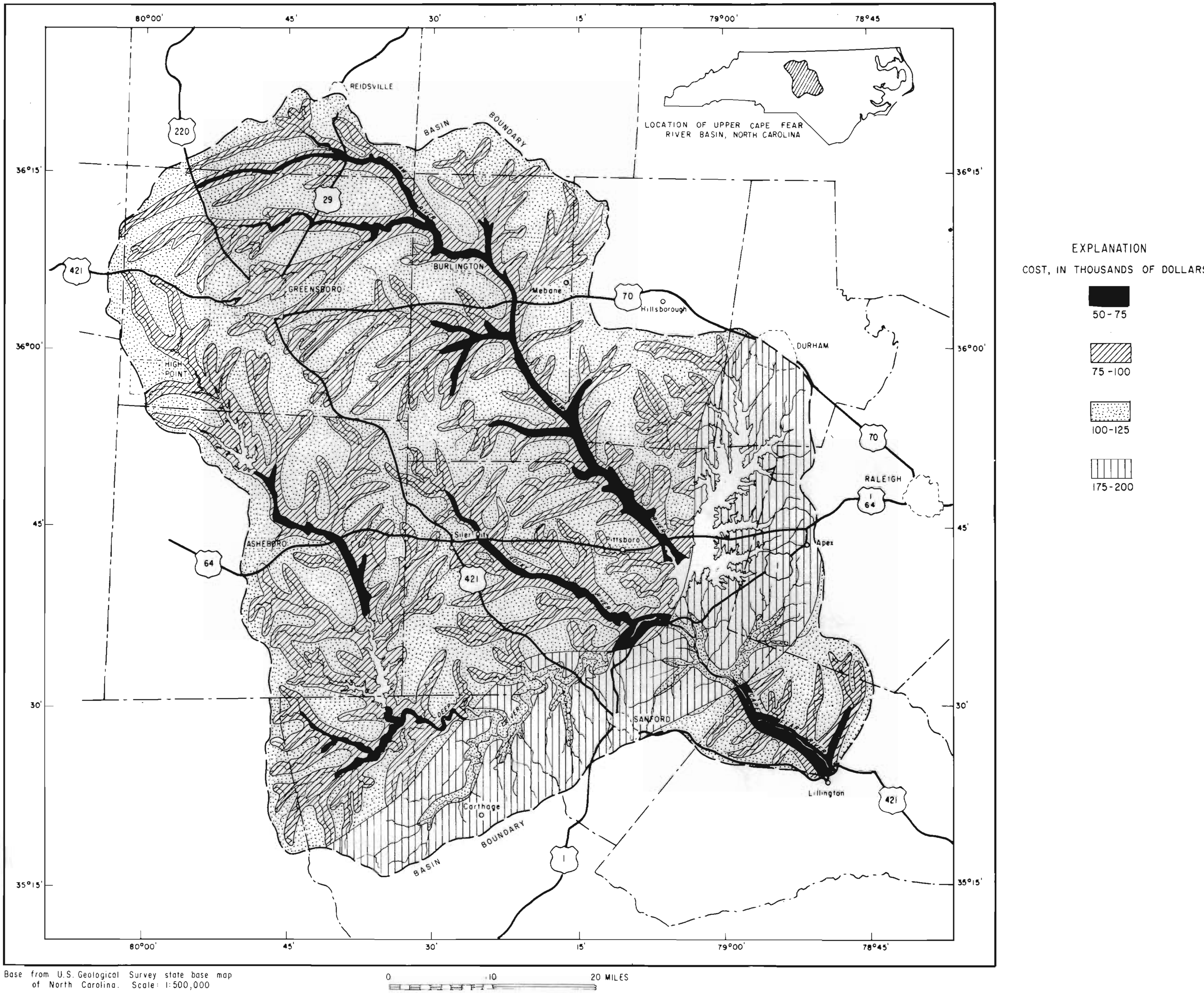


Figure 5. Initial cost of a well field to produce one million gallons per day.