

DEVELOPMENT OF GROUND-WATER SUPPLIES

When a well is pumped, the water level in the well is lowered and a cone of depression forms in the water table or piezometric surface around the point of withdrawal. The size and shape of the cone depend upon the pumping rate, the length of the pumping period, the aquifer's ability to store and transmit water, and the location and type of geohydrologic boundaries within the zone of influence of the well.

During the initial period of pumping, discharge is balanced by water taken from storage within the aquifer close to the well.

As pumping continues, a larger percentage of water is taken from

storage at greater distances from the well. The amount of water

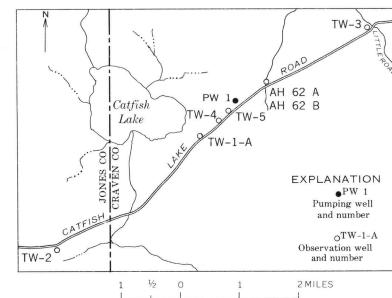
that is released from, or taken into, storage per unit surface area of the aquifer in response to a unit change in head, is expressed as the "coefficient of storage." The larger the coefficient of storage, the smaller the water-level decline required to obtain the amount of water being pumped. The shape of the cone of depression is influenced by the aquifer's ability to transmit water. The coefficient of "transmissibility" is defined as the quantity of water in gallons per day that will flow through a one-foot wide vertical section of the aquifer under a hydraulic gradient of one foot per foot. With other factors remaining constant, the lower the transmissibility, the steeper will be the gradient of the cone of depression and the greater will be the drawdown in the well. The drawdown of water levels within the cone of depression is directly proportional to the pumping rate. Drawdown generally diminishes logarithmically with distance from the well. With continued pumping, the cone of depression grows in size and depth at a diminishing rate until hydraulic gradients are established sufficient to reduce natural discharge or to induce enough recharge to balance the amount of water being pumped. When this occurs, the cone is said to be stabilized. Where pump-

ing wells are near streams or lakes that are hydraulically connected to the aquifer, stabilization may occur after a few hours of pumping. In other parts of the same aquifer, stabilization may not occur even after several years of pumping.

In areas of heavy pumping, the cones of depression may be quite extensive and may overlap cones from neighboring centers of pumping. When this happens, the drawdown effects are combined. This results in reduced well yield and increased costs of pumping.

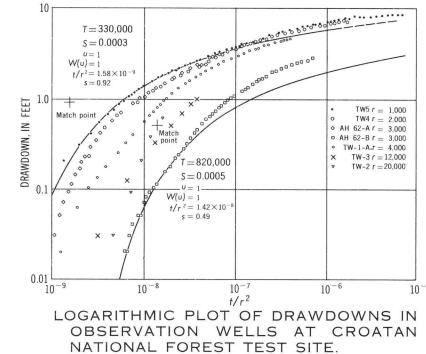
Aquifer tests.—Several pumping tests were made in Craven

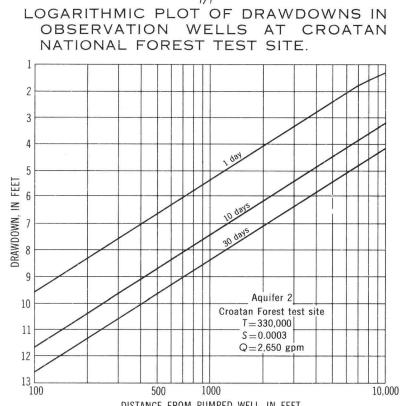
County to determine the hydraulic properties of the aquifers; this is essential in designing wells and well fields. To illustrate methods of analysis, the results of two pumping tests that were analyzed by the Theis nonequilibrium formula (Ferris and others, 1962, p. 92-98) are utilized. The nonequilibrium formula assumes that (1) the aquifer is homogeneous and isotropic; (2) the aquifer is infinite in areal extent; (3) the coefficient of storage is constant; and (4) water is released from storage instantaneously with a decline in water level. Although in Craven County none of these conditions is completely fulfilled, useful results are obtained from aquifer tests. In May 1966 the firm of Leggette, Brashears, and Graham made an aquifer test in aquifer 2 in the Croatan National Forest (see map of pumping test site). The pumped well (PW-1) has a 16-inch casing and is screened and gravel-packed from 100 to 130 feet and from 165 to 235 feet. The observation wells are either 4 inches or 6 inches in diameter and are screened at intervals corresponding to well PW-1 except well 62-B which is screened from 41 to 44 feet in aquifer 1. Well PW-1 was pumped at 2,650 gpm for about 6-1/2 days and water levels were measured in PW-1 and 7 observation wells.



MAP OF PUMPING TEST SITE IN THE CROATAN NATIONAL FOREST.

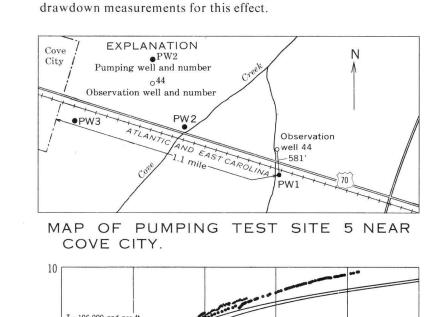
Analysis of the data from the pumping test indicates that the aquifer is not homogeneous and isotropic as transmissibility is different in different directions from the pumped well. Also the response of water levels in well AH-62B (see logarithmic plot of drawdowns) indicates that aquifer 1 and aquifer 2 are hydraulically connected and that during the pumping test leakage from aquifer 1 was recharging aquifer 2. The coefficient of transmissibility determined in TW-5 is 330,000 gpd per ft and the coefficient of storage is 0.0003. The graphs showing computed drawdowns were constructed (using the coefficients determined in TW-5) to illustrate the effects of pumping in aquifer 2 in the vicinity of the test site in Croatan National Forest. Although the effects of lateral changes in transmissibility and the long-term effects of leakage between aquifers are not reflected in the graphs, the graphs will be useful in estimating drawdown of water level. If other factors are constant, drawdown is directly proportional to well discharge rate. Inter-aquifer leakage will decrease the amount of drawdown and will tend to limit the spread of the cone of depression.

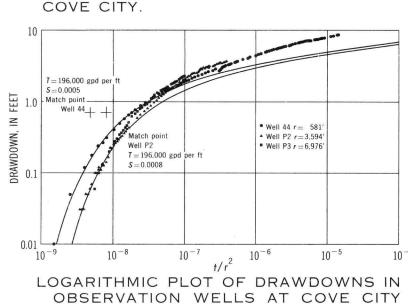




DISTANCE FROM PUMPED WELL, IN FEET GRAPH SHOWING COMPUTED DRAWDOWNS FOR WELLS PENETRATING AQUIFER 2 AT THE CROATAN NATIONAL FOREST TEST SITE. Another pumping test was made in June 1968 by the U.S. Geological Survey for the city of New Bern. The test site is about 1.1 miles east of Cove City along U.S. Highway 70 and is shown on the map below. Wells PW-1, PW-2, and PW-3 are about 3,500 feet apart and have casing diameters of 20 inches reduced to 10 inches and are gravel-packed to 34 inches at each screen. Each well has 11 screens totaling 100 feet in length which are set in the most permeable zones of aquifers 7 and 8. Well 44 is 581 feet from well PW-1. It is 2 inches in diameter and has three 10-foot screens spaced through the same aquifers. Well PW-1 was pumped for 4.8 days at 1,200 gpm, and drawdown in it was measured at 35.97 feet at the end of the test. Drawdowns in wells PW-2, PW-3, and 44 were plotted and matched with the Theis type curve as is shown in the logarithmic plot of drawdowns. Using the data plot for well 44, and analyzing with the nonequilibrium formula, the coefficients of transmissibility and storage for aquifers 7 and 8 combined were computed to be about 200,000 gpd per ft and 0.0005 respectively. During the test the water levels in the observation wells were probably recovering slightly from previous pumping. The rate

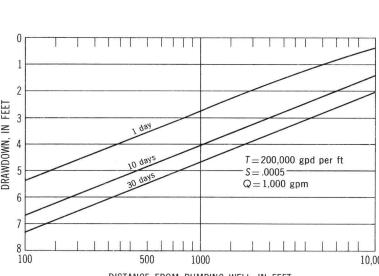
of recovery is uncertain, and no attempt was made to correct the





TEST SITE.

Note, as shown on the logarithmic plot of drawdowns, that after about 10 minutes of pumping at 1,200 gpm, the data plot deviates above the type curve. This indicates the presence of hydraulic boundaries in the aquifers. The boundary effects probably are due to lateral variations in permeabilities of the aquifers. An accurate computation of the distance to the boundaries could not be made because of the uncertainties involved in correcting the drawdown measurements. The convergence of the data plots near the end of the test indicates, that after several hours of pumping, the two aquifers began to respond more as a unit. It is conceivable that after prolonged pumping, the aquifers would respond as one unit, and the data plots for each well would coincide. The graphs of computed drawdowns show the drawdowns at distances from 100 feet to 10,000 feet from a well pumping 1,000 gpm from aquifers 7 and 8 for periods of 1 day, 10 days, and 30 days in the vicinity of the test site. For the purposes of computation, the effects of hydraulic boundaries and possible leakage have been ignored. However, it is believed that actual drawdowns would be very nearly those shown, and the graphs will be useful in estimating drawdown of water levels in the well field.



GRAPH SHOWING COMPUTED DRAW-DOWNS FOR WELLS PENETRATING AQUIFERS 7 AND 8 AT THE COVE CITY TEST SITE.

Continuous measurements of water levels in well 44 at the Cove City site have been made since May 1965, and the mean monthly water levels are shown in the hydrographs on sheet 1. It will be noted that, as of November 1967, water levels in the well had progressively declined about four feet. This effect probably is caused by heavy pumping from aquifers 4-8 about 15 miles away in Lenoir County. Available data are insufficient to indicate the level at which drawdowns caused by this pumping will stabilize in the Cove City area. Whatever the amount, it must be added to the drawdown caused by pumping in the well field at Cove City where pumping is scheduled to begin on June 22, 1968. There is sufficient available drawdown at the Cove City well field to tolerate considerable interference from other points of pumping. However, the present interference makes it advisable to consider greater spacing between wells and also to consider locating future wells in a southwesterly direction from the exist-

DEVELOPMENT OF A HYPOTHETICAL GROUND-WATER SUPPLY Conditions affecting the development of ground-water supplies in Craven County vary from one part of the county to another. The principal map on this sheet was prepared in an effort to summarize these conditions in a concise and yet readily usable manner. The map of the county shown in the figure is divided into squares 2 miles on a side (the area of each square being 4 square miles). The information shown for the upper left corner of each square includes the altitude of the land surface, depths to the top and bottom of each aguifer, and symbols related to the chemical quality of the water. The table of typical hydraulic properties included with the map shows data needed to estimate the yields of 2-inch and 36inch wells in aquifers 2-8. In addition, the aquifer composition is briefly described, and the names of the geologic formations, in which the aguifers occur, are shown. The use of the map may be illustrated with the following ex-

amples of the steps involved in determining the depth and well size for a hypothetical water supply:

Step 1.—Determine or estimate the quantity of water needed and the quality requirements for the water.

The quantity of water needed at any site ranges from a gallon per minute or less for a domestic or livestock supply up to several thousand gallons per minute for municipal, industrial, or irrigation supplies. The quality of the water that is acceptable depends on the intended use. For example, water intended for

domestic or municipal use should contain less than 0.3 mg/l of

iron and less than 250 mg/l of chloride (quality-of-water table—sheet 1).

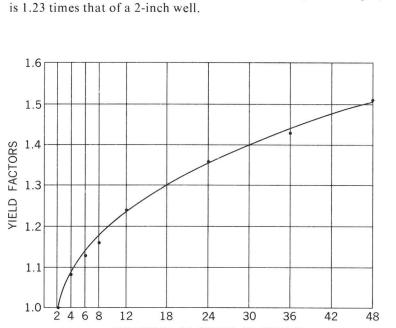
Step 2.—Locate the proposed well site on the map, and refer to the nearest intersection of the grid lines.

If the well location falls near the center of a grid square, the aquifer information may be interpolated from the surrounding points.

Step 3.—Determine from the chemical quality notation for each aquifer which aquifers underlying the site contain water of the desired quality.

The chemical quality of the ground water is described on sheet 1. The source and significance of the principal chemical constituents and characteristics are also described. The water from one or more aquifers in the northern and northwestern parts of the county is suitable for most uses. In the central and southern parts of the county the water from all aquifers, with the possible exception of aquifer 1 in some areas, would need to be treated for municipal and most industrial uses.

Step 4.—Determine the yield of the aquifers underlying the site. The yield obtainable at any site depends on (1) the hydraulic characteristics of the aquifers, (2) the diameter of the well, (3) the drawdown of water level at the pumping well, (4) the length of the "open-hole" section of the well, and (5) the number of aquifers penetrated by the well. Information needed to evaluate each of these factors is contained on this sheet. The steps required in this evaluation and the principal factors involved are described in the following paragraphs: The hydraulic characteristics of the aquifers are shown in the table on the map. From the standpoint of evaluating the yield of a well, the specific-capacity data in the fifth and sixth columns are the most important. The specific capacity values in the table show the amount of water in gallons per minute that can be obtained from each aquifer for each foot of drawdown in the water level. Column 5 shows the specific capacity of wells 2 inches in diameter, and column 6 shows the same data for wells 36 inches in diameter. The specific-capacity data assumes that the entire thickness of each aquifer is producing water and that the wells are fully developed. (See the following discussions of partial penetration multiple-aquifer wells.) The diameter of a well is one of the first factors that must be considered in evaluating the yield. The larger the diameter of a well the larger its yield, all other factors being the same. The differences in yield of wells of different diameters are shown in the graph below. The yield of 2-inch wells has been assigned a factor 1. The yield factors for wells larger than 2 inches are, therefore, larger than 1. The yield of a 12-inch well, for example,



DIAMETER OF WELLS, IN INCHES

GRAPH SHOWING YIELD OF WELLS OF

VARIOUS DIAMETERS AS COMPARED

TO THAT OF A 2-INCH WELL.

The drawdown of water level at the pumping well depends on the type of pump installed and the depth to the top of the aquifer below the static water level. All water pumps work on either one of two principles. So-called "shallow-well" pumps lower pressure at the pump and atmospheric pressure forces water up the column. These pumps generally cannot produce a drawdown of more than about 25 feet below the pump. So-called "deepwell" pumps, on the other hand, "push" water from the well and can produce a drawdown of almost any amount. Pumps of this type are generally available only for wells 2 inches in diameter and larger. Thus, shallow-well type pumps may be installed on wells of any diameter and are almost invariably installed on wells 2 inches in diameter and smaller. On wells equipped with deep-well pumps, it is feasible to draw water levels down to the top of the aquifer supplying the well. Actually, drawdowns greater than this are possible but not

The amount of drawdown available is the distance between the static water level and the top of the aguifer. Drawdown of water level below the top of the aquifer is feasible but not desirable. The depth to the static water level for aquifer 2 can be determined at each grid intersection on the map by subtracting the altitude of the piezometric surface shown on the piezometric map on sheet 1 from the altitude of land surface at the grid intersection. The use of the three factors discussed so far—that is, specific capacity, well diameter, and drawdown—in predicting well yields can now be illustrated with an example. For this purpose, data for aquifer 5 in the Fort Barnwell area will be used. The specific capacity of a 2-inch well in this aquifer is 1.3 gpm per ft and the static water level is estimated to be 5 feet below land surface. Therefore, the yield of a 2-inch well equipped with a shallow-well pump (limited to a pumping level about 25 ft below the pump) is calculated as follows: (pumping level — depth to static water level) × specific capacity = yield $(25 - 5) \times 1.3 = 20 \times 1.3 = 26$ gpm In view of the estimates used in calculating the yield, it is probable that the yield of an actual well would be more than 20 gpm and less than 30 gpm. To calculate the maximum yield that could be obtained from a well 12 inches in diameter drawing from aquifer 5 at Fort

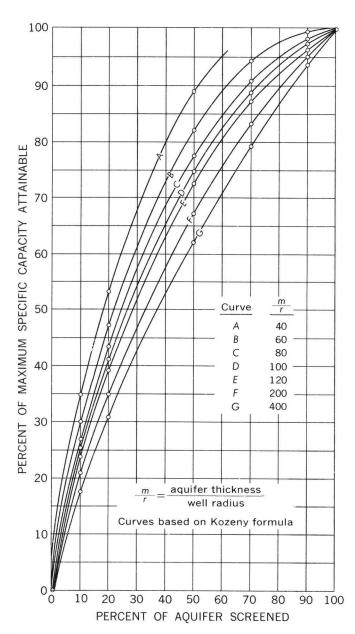
Barnwell, proceed as follows:
(a) Specific capacity of 2-inch well × yield factor of 12-inch well = specific capacity of 12-inch well.
1.3 × 1.23 = 1.6 gpm per ft of drawdown.
(b) Depth to top of aquifer 5 — depth to static water level = available drawdown.

280 feet — 5 feet = 275 feet.

(c) Available drawdown × specific capacity = yield 275 × 1.6 = 440 gpm.

Again, in view of the estimates involved in the calculations, the yield of an actual well would probably be more than 350 gpm and less than 500 gpm.

The discussion to this point has assumed that the pumping wells are open to the entire thickness of the aquifer supplying the water. This assumption is valid for very few wells in Craven County. Wells penetrating some parts of aquifer 2 and any part of all other aquifers must be screened. However, because of the high cost of screens usually less than half of an aquifer is screened. Such wells are said to "partially penetrate" the aquifer. The graph below provides data that can be used in estimating the effect of "partial penetration."



GRAPH SHOWING RELATIONSHIP OF PARTIAL PENETRATION AND ATTAINABLE SPECIFIC CAPACITY FOR WELLS IN HOMOGENEOUS ARTESIAN AQUIFERS.

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Returning to the example, suppose the 12-inch well in aquifer 5 at Fort Barnwell were finished with a screen 8 feet long rather than being screened through the entire 40 feet of the aguifer present at the site. In this case only 20 percent of the aquifer would be screened. The preceding graph contains 7 curves, and the next step is to determine which curve to use. This is done by finding the ratio of aquifer thickness (m) to radius (r). The aquifer thickness is 40 feet and the well radius is 0.5 or half a foot. Forty divided by 0.5 is 80. Therefore, curve C on the graph is used. Following the line representing 20 percent of the aquifer screened, vertically to the point where it crosses the C line, it is determined from the scale on the left side that the specific capacity is only about 43 percent of that of a well finished with 40 feet of screen. Therefore, the specific capacity is reduced from 1.6 gpm per ft to about 0.7 gpm per ft. Using this value, the yield of the well is found to be only about 190 gpm (275 \times 0.7) instead of 440 gpm. Where large quantities of water are needed it is common practice to screen each producing well in more than one aquifer. In such wells the specific capacity is the sum of the specific capacities of the aquifers screened reduced for partial penetra-

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