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GROUND-WATER AVAILABILITY IN SOUTHERN NEW CASTLE COUNTY, DELAWARE

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INTRODUCTION

Purpose and Scope

The purposes of the study described in this report are (1) to determine the total amount of fresh ground water (chloride content less than 150 milligrams/liter) available in New Castle County south of the Chesapeake and Delaware Canal, and (2) to map the geographic distribution of available fresh ground water on the basis of areas delineated by one minute of latitude and one minute of longitude (such areas measure essentially one square mile). The investigation has been based solely on data available in various publications and in the files of the Delaware and United States Geological Surveys.

The scope of the study excluded consideration of the manner in which ground water can best be developed in the area. However, during the investigation it became apparent that some thought had to be devoted to this matter, because the spacing and yield of wells (1) play an important role in inducing recharge, and (2) determine water availability from those aquifers whose hydraulic characteristics, rather than recharge, are the limiting factor. This subject will be further discussed in the section on Water Availability.

The topics of water use and of ground-water quality are outside the scope of this report. However, it should be noted that polluted ground water (amount unknown) must be subtracted from the total ground-water availability as described in this report.

Large amounts of surface water will probably not be developed in southern New Castle County due to the lack

of streams with adequate flows and of favorable geologic conditions for the construction of impoundments.

Acknowledgments

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REVIEW OF AVAILABLE DATA

The study area is completely covered by U. S. Geological Survey 7.5-minute topographic maps and by geologic maps published by the Delaware Geological Survey (Pickett, 1970; Pickett and Spoljaric, 1971; Pickett and Benson, 1977). A considerable number of drillers logs and geophysical logs are available in the files and publications of the Delaware Geological Survey and the Water Resources Center of the University of Delaware. These data are adequate to determine the areal extents, thicknesses, depths, and lithologies of the aquifers. The water-table elevation was mapped for the entire Coastal Plain of the State under a program involving the Delaware Division of Highways, the U. S. Geological Survey, and the Delaware Geological Survey. The data are published in the U. S. Geological Survey Hydrologic Atlas Series.

Data concerning hydraulic coefficients of aquifers obtained from pump tests are insufficient to accurately determine their regional variations. Where information on the saturated thickness and the transmissivity of an aquifer was available, hydraulic conductivity was determined. The average hydraulic conductivity was assumed to be constant

for the aquifer throughout its areal extent. Because transmissivity is the product of hydraulic conductivity and saturated thickness, the regional variation of transmissivity was then related to saturated thickness. This method of determining regional variations in transmissivity is considered reasonable when applied to aquifers that are essentially homogeneous in their grain size distribution, i.e., the aquifers of the Magothy Formation and the Rancocas Group, and, largely, the sands of the Columbia Formation. It is considered less satisfactory when applied to the aquifers in the Potomac Formation, which are lithologically more variable.

The number of chloride analyses available is too small to fix the locations of the 150 mg/l isochlors of the aquifers in the Magothy and Potomac formations with precision, but the locations shown in Figure 2, page 9, are thought to be correct within one or two miles.

ASSUMPTIONS MADE IN DETERMINING WATER AVAILABILITY

(a) It is assumed that maximum water withdrawal from any aquifer occurring in the study area shall not exceed available recharge.

(b) Water availability is frequently influenced by factors other than recharge, e.g., by unfavorable hydraulic properties of aquifers, limited available drawdown, and well efficiency. Such factors bear on well spacing, mutual interference of cones of depression, and depth of dynamic water levels, which, in turn, are related to the practical or economic feasibility of ground-water development. For the purposes of this study, it is assumed that the development of ground water from the artesian aquifers is practical only when a production of at least 100 gallons per minute (gpm) (continuous) can be achieved with a drawdown not exceeding 300 feet in any production well. Well efficiency is assumed to be 100 percent although this is seldom achieved in actual practice.

(c) Because ground-water development from the water-table aquifer is generally more economical in terms of well construction and pumping costs than that from the deeper artesian aquifers, it is assumed that wells producing 20 gpm (continuous) or more are a practical possibility.

(d) Throughout the study area small ground-water supplies (a few gallons per minute) for individual residences can be developed. These supplies have not been included in the water availability figures presented in this report. Thus, this study is focused on the availability of ground water for those users that require relatively large supplies: municipal water systems, industry, and irrigation. Limitations on the availability of water for these purposes are the limitations commonly recognized as having economic impact by constraining development.

(e) In calculating water availability it has been assumed that wells will be efficiently constructed and maintained.

(f) Water availability figures do not take into account present water use in the study area (which is assumed to be zero). However, as recharge of the aquifers of the Potomac Formation is influenced by pumpage north of the Chesapeake and Delaware Canal, water use in the latter area had to be considered.

(g) Ground-water availability figures do not reflect the possible deleterious effects of ground-water contamination caused by landfills and other sources of pollution.

GROUND-WATER AVAILABILITY

General Statement

Ground water occurs in the sands of the Potomac, Magothy, and marine Upper Cretaceous formations, the Rancocas Group composed of the Hornerstown and Vincentown formations, and the Columbia Formation. The geographic distribution of these units is shown in the geologic map and their vertical distribution in the cross-section (Figure 1).

Aquifers in the Potomac Formation

The Potomac Formation consists of a number of clay and water-bearing sand beds, which form essentially one hydrologic unit, although locally two or more aquifers within the formation may have somewhat different heads. This unit is informally called the Potomac aquifer (Woodruff, 1979).

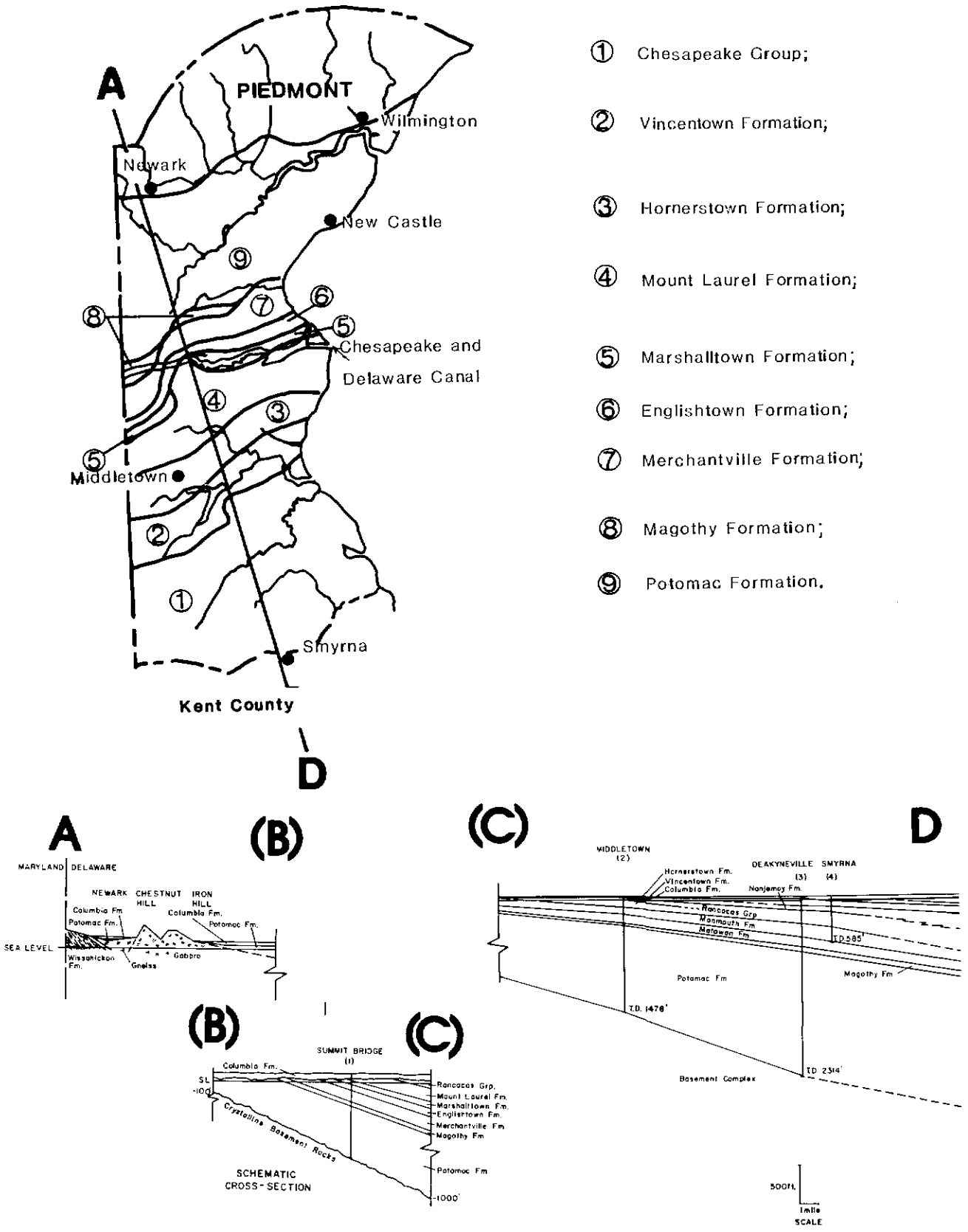

Figure 1. Geologic map and cross-section of New Castle County (Pickett, 1976).

Recharge of this aquifer occurs in the outcrop/subcrop area of the formation, which, in New Castle County, is located north of the Chesapeake and Delaware Canal, and by vertical leakage. The recharge area potentially affecting the County south of the Canal is less than 100 square miles (sq. mi). Recharge would be about 20 million gallons per day (mgd), assuming that 40 percent of the recharge area is sandy, and that recharge is 0.5 mgd/sq. mi. Considering that ground-water use from the Potomac aquifer and hydraulically connected Columbia sediments north of the Canal is at least that amount, it is likely that little recharge to the Potomac reaches the area south of the Canal.

If ground-water withdrawal in the study area would increase, some recharge from the outcrop/subcrop in the western part of the County and adjacent Maryland may be induced. But most of the area of potential use of the Potomac aquifer south of the Canal is at a considerable distance from the outcrop/subcrop. In view of the low velocity of ground-water flow, recharge originating in the outcrop/subcrop would not become available until after some decades of pumping. Consequently, if a large quantity of ground water were to be developed from the Potomac in the study area, and particularly in its central or southern part, most of the water would initially come from storage. However, with the establishment of large cones of depression in the potentiometric surface of the Potomac aquifer due to pumping, large head differences would be created between the Potomac and the overlying aquifer(s), leading to induced recharge by vertical leakage.

Unfortunately, vertical leakage is difficult to quantify. Walton (1965) expressed the rate of recharge by leakage through an aquitard under pumping conditions as follows.

$$\frac{Q_c}{A_c} = 2.8 \times 10^7 \times \frac{P'}{m'} \Delta h$$

where $\frac{Q_c}{A_c}$ = recharge rate in gallons per day (gpd)/sq. mi.

Q_c = vertical leakage through deposits, in gpd.

A_c = recharge area within which vertical leakage is being diverted to a pumping center, in sq. mi.

P' = coefficient of permeability of deposits in gpd/square foot.

m' = saturated thickness of deposits, in feet.

Δh = difference between the head in the aquifer and in the source bed, located above deposits through which leakage occurs, in feet.

The above equation indicates that recharge due to vertical leakage depends on lowering the head of the Potomac aquifer over as large an area as possible. This can be accomplished by pumping many wells at modest rates rather than one or two wells at high rates.

Vertical permeabilities vary greatly. Eight values pertaining to the marine Upper Cretaceous sediments range from 5.1×10^{-7} gpd/ft^2 (silty clay, Merchantville Formation) to 1.6 gpd/ft^2 (silty fine sand). The average figure, excluding that of the silty fine sand, is 1.78×10^{-1} gpd/ft^2. Figures for the Potomac Formation north of the Canal have an average of 3×10^{-1} gpd/ft^2 (Martin and Denver, 1982) and the average of four values for the Potomac Formation given by Sundstrom and Pickett (1971) is 1.35×10^{-3} gpd/ft^2. For the purposes of this study, the average vertical permeability of the aquitard(s) overlying the Potomac is considered to be between 10^{-2} and 5×10^{-3} gpd/ft^2. Although these figures are somewhat lower than the average of the figures quoted earlier, it is expected that the sediments south of the Canal are more compact and somewhat less permeable than those farther north. On the other hand, the figures of 10^{-2} and 5×10^{-3} gpd/ft^2 are higher than those of the aquitard overlying the Piney Point Formation in the Dover area (about 5×10^{-4} gpd/ft^2; Leahy, 1976), but the Miocene clays occurring in that area may be much less permeable than most of the sediments overlying the Potomac in southern New Castle County.

Sundstrom and Pickett (1971, p. 90) show drawdown curves for the upper and lower zones of the Potomac aquifer. The drawdown curve for the upper zone indicates an average drawdown of 25 feet over an area of about 310 square miles. Assuming an average water level in the water-table aquifer of 15 feet above the static water level in the Potomac, the average head difference would be 40 feet. Assuming also, for the sake of simplicity, that there is one aquitard between the Potomac and the water-table aquifer with a vertical permeability of 5×10^{-3} gpd/ft^2 and an average thickness fo 200 feet, recharge by leakage could be 8.7 mgd. Obviously, leakage induced by pumping 520 gpm (Sundstrom and Pickett's figure) or 0.7488 mgd cannot induce 8.7 mgd of

recharge if vertical permeability was 5 x 10^{-3} gpd/ft^2.

Although potentiometric surfaces respond rapidly to pumping, water movement does not. The velocity of ground-water movement depends on hydraulic gradient, hydraulic conductivity, and porosity. It is usually in the order of a few inches or a few feet per day. Thus, recharge water from a few miles away takes several years to reach a well. Therefore, inducing vertical leakage efficiently and soon after pumping begins requires fairly closely spaced wells.

Apart from recharge, there are practical restraints on ground-water withdrawal. Assuming that pumping water levels should not be below 300 feet, that transmissivity (T) = 12,000 gpd/ft, and storativity (S) = 6 x 10^{-5}, sixteen wells producing 300 gpm each, evenly spaced about 13,000 feet apart in the area between the Chesapeake and Delaware Canal and the fresh-water/salt-water interface (see Fig. 2) would be feasible. They would produce a total of 6.9 mgd, a figure of the same magnitude as that of potential recharge by vertical leakage. Assuming that the hydraulic properties of the Potomac aquifer do not vary significantly within the study area (an assumption that had to be made in view of a lack of pump test data), water availability would be 0.055 mgd for each one-minute quadrangle underlain by the Potomac Formation.

The cones of depression in the potentiometric surface which would result from pumping several millions of gallons per day would spread well beyond the boundaries of the study area into Maryland and New Jersey. Consequently, significant ground-water withdrawals in neighboring areas would, in time, diminish the amount of recharge by leakage available to the study area and negatively effect the amount of ground water available in southern New Castle County.

Aquifer in the Magothy Formation

The Magothy Formation contains a water-bearing sand, informally called the Magothy aquifer. Its outcrop/subcrop south of the Chesapeake and Delaware Canal is small; therefore, recharge from the subcrop in Delaware is probably limited to about one million gallons per day. However, the subcrop in northern New Castle County and adjacent Maryland is considerably larger and could contribute recharge if the potentiometric surface of the Magothy aquifer were lowered by substantial water withdrawals. Vertical leakage will

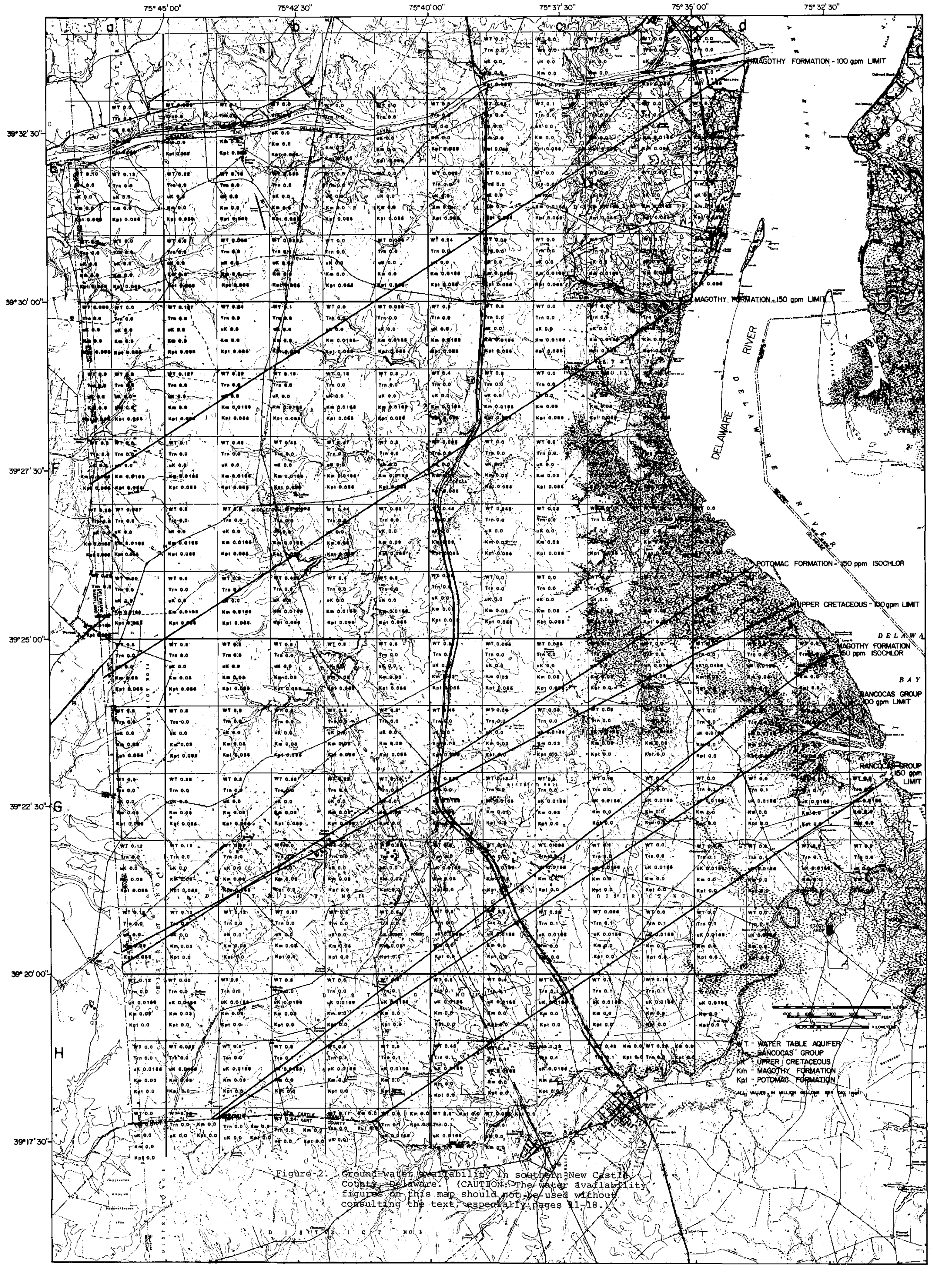

Figure 2. Ground-water availability in southern New Castle County, Delaware. (CAUTION: The water availability figures on this map should not be used without consulting the text, especially pages 11-18.)

also be an important source of recharge when the potentiometric surface is lowered. Where the aquifer is overlain by marine Upper Cretaceous sediments or the Rancocas Group, vertical permeability is probably 5 x 10^{-3} gpd/ft^2 or somewhat higher. Where Miocene clays are present, it will perhaps be an order of magnitude lower.

With transmissivity (T) = 4,000 gpd/ft, and a storativity (S) = 6 x 10^{-5} (Rima et al., 1964), the Magothy aquifer could produce, from fifteen evenly spaced wells, about 3 million gallons per day; it is expected that sufficient recharge will be available. In the area adjacent to the line showing the northern limit of development of the Magothy aquifer, (Fig. 2), wells producing 100 gpm can be constructed, resulting in a yield of 0.0165 mgd per quadrangle; farther south 150 gpm can be produced, giving a yield of 0.03 mgd per quadrangle. On the average, water availability in a one-minute quadrangle would be about 0.026 mgd. Drawdowns of up to 295 feet can be expected.

Aquifer in the Marine Upper Cretaceous Sediments

This aquifer is informally called the Englishtown-Mount Laurel aquifer, and is considered to be one hydrologic unit. Its outcrop/subcrop area is large (about 40 square miles) and potential recharge is considerably greater than the quantity of ground water that can be developed from it because withdrawals are limited by the hydraulic properties of the rocks. Where the aquifer forms one hydrologic unit with the Columbia Formation it is considered to be part of the water-table aquifer.

In view of the low transmissivity (T = 1,800 gpd/ft) and small available drawdown in the northern part of the study area (50 feet), large-capacity wells are not possible. Wells producing 100 gpm are feasible in the area south of Townsend and seven or eight evenly-spaced wells would produce 1 mgd (total), or approximately 0.0156 mgd per one-minute quadrangle. The cumulative drawdowns in some production wells will reach about 250 feet.

Aquifer in the Rancocas Group

This aquifer is informally called the Rancocas aquifer and includes the Vincentown and part of the Hornerstown formations. Its outcrop/subcrop in New Castle County is about

41 square miles, which can potentially provide at least 20 mgd of recharge. Where the Rancocas forms one hydrologic unit with the Columbia, it is part of the water-table aquifer. Only the artesian portion of the Rancocas is here considered.

In view of the hydraulic properties of the aquifer (T is about 18,000 gpd/ft, S = 2 x 10^{-4}) and the available drawdown, which ranges from about 50 feet near Blackbird to approximately 150 feet near the border with Kent County, the artesian part of the aquifer should be capable of producing 3 mgd from 15 wells, evenly spaced in the southern part of the study area (about 30 square miles). Thus, water availability in each one-minute quadrangle in that area is 0.1 mgd. Drawdowns of up to 85 feet are anticipated.

Water-Table Aquifer

The water-table aquifer consists of the deposits of the Columbia Formation and those portions of the Magothy, Englishtown-Mount Laurel, and Rancocas aquifers that are directly hydraulically connected with the Columbia deposits. The saturated thickness of the water-table aquifer is shown in Figure 3 and the saturated thickness of the Columbia Formation is shown in Figure 4.

Recharge of the water-table aquifer is provided by local precipitation. Although recharge varies from year to year (depending on the amount of precipitation), and also varies somewhat regionally - it is affected by soil conditions and slope - it has been demonstrated (Rasmussen and Andreasen, 1958; Johnston, 1973) that average recharge is about 0.65 mgd/sq. mi in the non-urban areas of the Delmarva Peninsula. Where urbanization takes place, there is a tendency toward reduced recharge. For the purposes of the present study the conservative figure of 0.5 mgd/sq. mi has been adopted. The amount of 0.5 mgd/sq. mi has also been used by Baker and others (1966) as the amount of recharge to Coastal Plain sediments. As long-term water availability is limited by the amount of recharge, no one-minute quadrangle has a ground-water availability from the water-table aquifer exceeding 0.5 mgd. If more than 0.5 mgd would be developed, it would be at the expense of water availability in adjacent quadrangles, and/or diminished ground-water runoff to streams.

Water availability in each quadrangle was computed on the basis of the following parameters:

(a) The saturated thickness of the Columbia sediments and that of the underlying aquifer, where the latter is in hydraulic contact with the Columbia.

(b) An average hydraulic conductivity of the Columbia sediments of 90 ft/day (Johnston, 1973), and of the Englishtown-Mount Laurel and Rancocas aquifers of 2.6 and 20 ft/day, respectively. Transmissivities in each quadrangle were calculated from the data on saturated thickness and hydraulic conductivity.

In quadrangles adjacent to the Canal and to estuaries containing saline water, dynamic water levels should not be allowed to fall below mean sea level in order to avoid saline water encroachment. In such areas drawdowns, and therefore water availability, are limited.

Potential water withdrawals were determined on the basis of calculated transmissivities, a storativity of 0.15 for the Columbia deposits, and 0.1 for the older aquifers, and available drawdown (assuming a suitable length of well screen and a maximum dynamic water level 2 to 5 feet above the top of the screen); the Theis non-equilibrium formula was used, assuming 365 days of pumping. Depending upon the hydraulic characteristics of the water-table aquifer, available ground water may be developed by one to nine producing wells per quadrangle. Quadrangles unable to support a well producing 20 gpm (continuous) from the water-table aquifer were considered non-productive (except for water availability from one of the artesian aquifers).

Most ground water that can be developed from the water-table aquifer will be derived from the Columbia deposits because they have a greater hydraulic conductivity than the other aquifers in the area. The Magothy is a water-table aquifer in a very small area only, and cannot contribute much ground water for that reason. The Englishtown-Mount Laurel aquifer has very low hydraulic conductivity and can produce only a negligible quantity of water where it is unconfined. Only the Rancocas aquifer can be a major source of ground water where it forms a hydraulic unit with the Columbia. In fact, the greatest potential productivity of the water-table aquifer occurs where unconfined Rancocas underlies paleochannels of the Columbia Formation.

The total quantity of ground water that could be developed from wells producing 20 gpm and more is about 36.1 mgd in 204 quadrangles, an average of 0.177 mgd per quadrangle. No ground

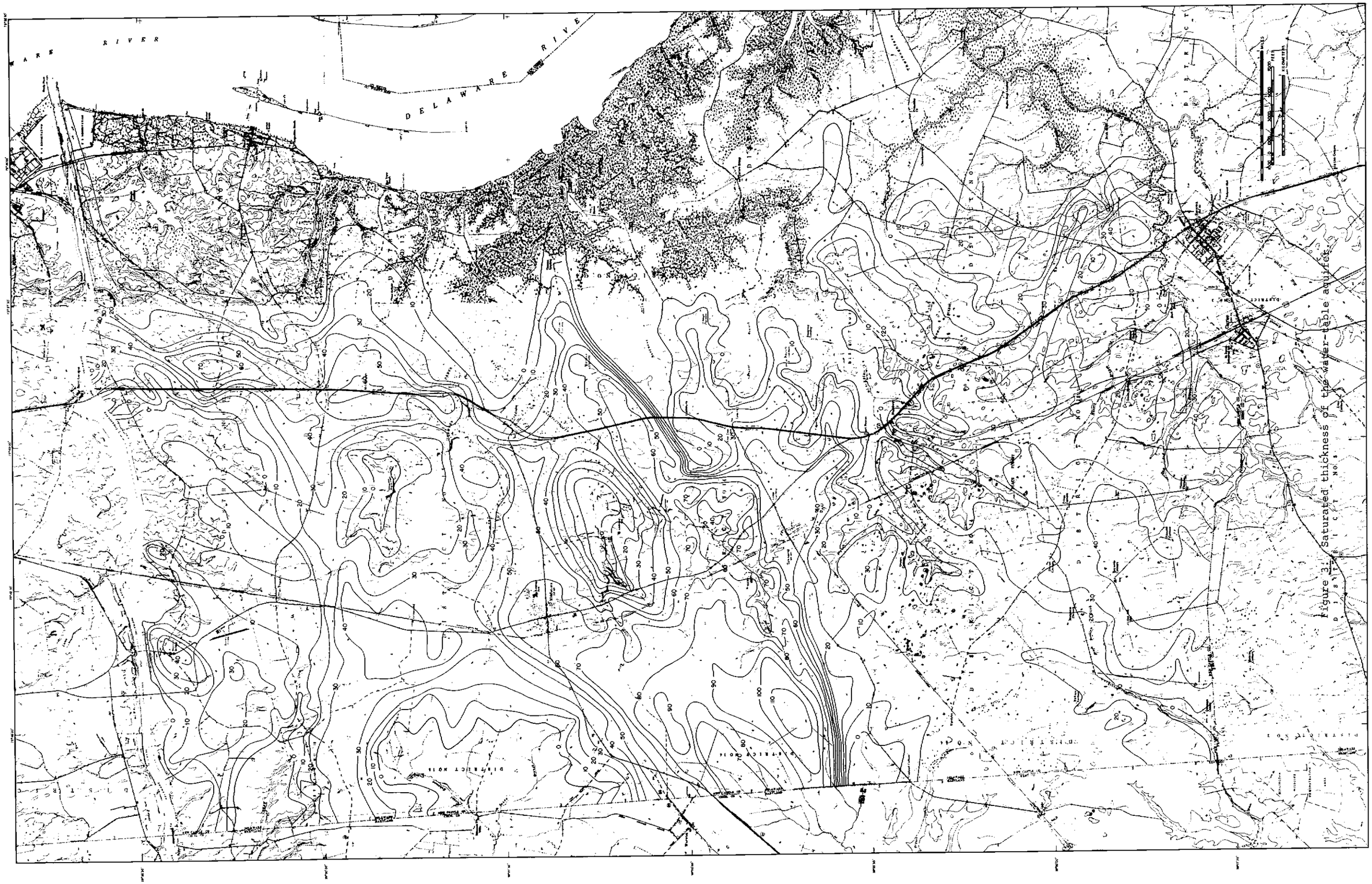

Figure 3.—Saturated thickness of the water-table aquifer.

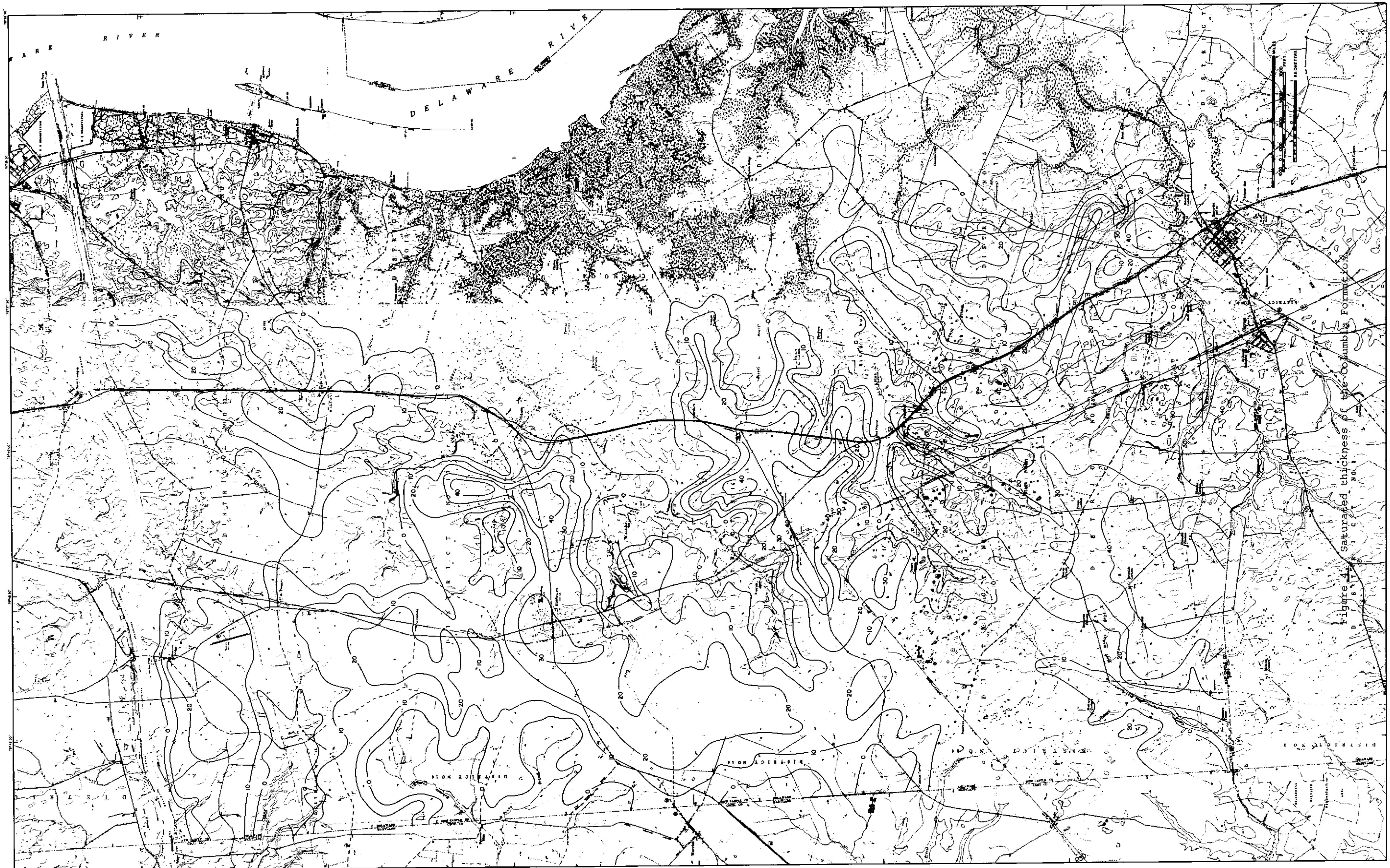

Figure 4. Saturated thickness of the Columbia Formation.

water development is projected in 75 quadrangles; 38 quadrangles can produce 0.5 mgd each (see Fig. 2).

The water-table aquifer is potentially the most prolific aquifer in the study area. But in order to develop it, numerous wells would be required. In fact, its full development (36.1 mgd) is very unlikely. But even if only about one-half of the quadrangles capable of producing 0.5 mgd would be fully utilized, 10 mgd would become available, a larger quantity than can be obtained from the other aquifers in the study area.

Interrelationship of Aquifers

The water availability from each of the five aquifers present in the study area has been discussed separately, as if there were no relationship between them. But, because the major potential source of recharge of some aquifers, particularly of the Potomac and Magothy, is vertical downward leakage from the water-table aquifer through aquitards, it is necessary to view the saturated sediments in southern New Castle County as one hydrologic system, whose productivity will depend on the efficiency of its development and total amount of recharge.

Recharge in the study area is estimated to be about 80 to 90 mgd; this figure is based on the area of 160 to 180 sq. mi (omitting low marshy areas draining to estuaries) and a recharge rate of 0.5 mgd/sq. mi. Total potential ground-water production from the five aquifers is 50 mgd; this would be about 60 percent of recharge, a high but not impossible figure. But producing 36.1 mgd from the water-table aquifer would lower the water table in most of the study area, thereby diminishing the head difference between the confined and unconfined aquifers, and causing a smaller rate of vertical downward leakage. On the other hand, if production from the water-table aquifer was limited by, say 10 mgd, its effect on vertical leakage would be much smaller. This relationship between aquifers should be kept in mind when planning ground-water development.

GEOGRAPHIC DISTRIBUTION OF GROUND-WATER AVAILABILITY

The geographic distribution of ground-water availability for each aquifer per one-minute quadrangle is shown in Figure 2.

The factors influencing the distribution are:

(1) saturated thickness and hydraulic conductivity of the aquifers;

(2) available drawdown;

(3) the number of aquifers available for development;

(4) distance from bodies of saline water.

Saturated thickness is particularly important in the case of the water-table aquifer; where Columbia sediments directly overlie the Rancocas, saturated thickness and good hydraulic conductivity combine to form a prolific aquifer. Thus, the subcrop of the Rancocas is generally a high-productivity area. Moreover, in the same area three other aquifers occur (Potomac, Magothy, Englishtown-Mount Laurel), each capable of enhancing ground-water availability.

Available drawdown is a crucial factor in the development of the artesian aquifers. It increases with distance from their outcrops or subcrops. In general, therefore, the yield of wells in the artesian aquifers increases in a southeasterly direction. In the northernmost part of the study area, near the Chesapeake and Delaware Canal, water availability is limited because of little available drawdown in the Magothy and Englishtown-Mount Laurel aquifers, and the small saturated thickness of the water-table aquifer. In the southernmost area, water availability is limited by the presence of only three aquifers containing fresh water (water-table, Rancocas, and Englishtown-Mount Laurel); the Magothy and Potomac aquifers contain water having more than 150 mg/l chloride.

SUMMARY AND CONCLUSIONS

(a) The five aquifers occurring in the study area are units of one hydrologic system.

(b) The water-table aquifer is the most productive aquifer in the study area; if there were no constraints of any sort other than those described in the section on Assumptions, it could produce about 36 mgd, not taking into account numerous small supplies for individual residences.

(c) The Potomac aquifer is expected to yield about 6.9 mgd, but its productivity depends, in the long run, on recharge by vertical leakage, which is hard to quantify accurately, and is also influenced by the degree of development of aquifers above it.

(d) Both the Magothy and the Rancocas aquifers are expected to yield about 3 mgd.

(e) The Englishtown-Mount Laurel aquifer is of minor importance owing to its poor hydraulic properties; it is expected to be capable of producing about 1 mgd.

(f) Total ground-water production from all sources is estimated to be 50 mgd.

(g) In general, the greatest water availability is in those quadrangles having a thick water-table aquifer as well as four artesian aquifers containing fresh water. A region is which such favorable conditions occur is the subcrop area of the Rancocas aquifer.

(h) It should be understood that the quantities of ground water that can be developed depend not only on available recharge, but also on well spacing and the yield of individual wells. In general, more water can be developed by drilling numerous low-yield wells than a few high-yield ones.

(i) In accordance with the terms of the contract under which this study was made, some important factors influencing water availability are not dealt with in this report: existing water use, chemical quality of ground water, ground-water pollution, well spacing, and well construction. These factors are both of a technical and an economic nature, and may present significant constraints on future large-scale ground-water development.

(j) The quantities of ground water that can be developed from the various aquifers in each one-minute quadrangle shown in Figure 2 should not be interpreted rigidly, because available data are insufficient to permit the precision suggested by the figures. Moreover, ground-water development in one quadrangle will greatly affect that in adjacent ones, particularly in the case of artesian aquifers, and it will do so in a short time. In a longer time scale, leakage between aquifers due to pumping will affect the productivity of every aquifer present beneath the quadrangle. Thus the figures

presented in Figure 2 should be considered only in terms of very general guidelines.

RECOMMENDATIONS

It is recommended that:

(a) Criteria be developed for optimum well spacing for different aquifers and those areas which appear to offer the best potential for future ground-water development.

(b) Identify and study the hydrologic characteristics of those areas where ground-water pollution from landfills or septic systems may occur.

(c) Identify the chemical quality of ground water in areas of greatest water availability.

(d) More data be developed on aquifer characteristics through carefully controlled and supervised pumping tests. Lack of such data was a major hindrance to this study.

REFERENCES

Baker, W. W. and others, 1966, Evaluation of the water resources of Delaware: Delaware Geological Survey Rept. of Invest. No. 8, 47 p.

Johnston, R. H., 1973, Hydrology of the Columbia (Pleistocene) deposits of Delaware: an appraisal of a regional water-table aquifer: Delaware Geological Survey Bull. No. 14, 79 p.

Leahy, P. P., 1976, Hydraulic characteristics of the Piney Point aquifer and overlying confining beds near Dover, Delaware: Delaware Geological Survey Rept. of Invest. No. 26, 24 p.

Martin, M. and Denver, J., 1982, Hydrologic data for the Potomac Formation in New Castle County, Delaware: U. S. Geological Survey Open File Report 81-916, 147 p.

Pickett, T. E., 1970, Geology of the Chesapeake and Delaware Canal area, Delaware: Delaware Geological Survey Geologic Map Series, No. 1.

Pickett, T. E., 1976, Generalized geologic map of Delaware (revised): Delaware Geological Survey Special Publication.

Pickett, T. E. and Spoljaric, N., 1971, Geology of the Middletown-Odessa area, Delaware: Delaware Geological Survey Geologic Map Series, No. 2.

Pickett, T. E. and Benson, R. N., 1977, Geology of the Smyrna-Clayton area, Delaware: Delaware Geological Survey Geologic Map Series, No. 5.

Rasmussen, W. C. and Andreasen, G. E., 1958, Hydrologic budget of the Beaverdam Creek basin, Maryland: U. S. Geological Survey Water-Supply Paper 1756, 54 p.

Rima, D. R., Coskery, O. J., Anderson, P. W., 1964, Groundwater resources of southern New Castle County, Delaware: Delaware Geological Survey Bull. No. 11, 54 p.

Spoljaric, N. and Jordan, R. R., 1966, Generalized geologic map of Delaware: Delaware Geological Survey Special Publication.

Sundstrom, R. W. and Pickett, T. E., 1971, The availability of ground water in New Castle County, Delaware: Univ. of Delaware Water Resources Center, Newark, Delaware, 156 p.

Walton, W. C., 1965, Ground water resources evaluation: McGraw-Hill Book Company, New York, 664 p.

Woodruff, K. D., 1979, Geohydrology of the Newark area, Delaware: Delaware Geological Survey Hydrologic Map Series No. 2.