Department of Natural Resources

MARYLAND GEOLOGICAL SURVEY

Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 24

AVAILABILITY OF FRESH GROUND WATER IN NORTHEASTERN WORCESTER COUNTY, MARYLAND:

WITH SPECIAL EMPHASIS ON THE OCEAN CITY AREA

by

James M. Weigle

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Prepared in cooperation with the Geological Survey
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AVAILABILITY OF FRESH GROUND WATER IN NORTHEASTERN WORCESTER COUNTY, MARYLAND: WITH SPECIAL EMPHASIS ON THE OCEAN CITY AREA

by

James M. Weigle

ABSTRACT

Fresh ground water in northeastern Worcester County is restricted to a block of sediments about 450 feet thick between the land surface and the top of the St. Marys Formation. The water is available in the Pleistocene aquifer under water-table and semi-confined conditions and in the Pocomoke and Manokin aquifers under confined conditions.

In the northern part of the area the Ocean City aquifer occurs between the Pocomoke and Manokin aquifers. Near Ocean City the Manokin and Ocean City aquifers are separated so poorly, hydraulically, that they function as a single hydrologic unit. As of June 1972, the entire public supply at Ocean City was obtained from wells in the Ocean City aquifer. The Manokin aquifer was virtually untapped there or elsewhere in northeastern Worcester County.

The Ocean City-Manokin aquifer system is potentially very productive. Its transmissivity averages about 10,000 ft^2/day (feet squared per day) and may exceed 20,000 ft^2/day in the northwestern part of the area. Beneath Ocean City, the transmissivity of the Ocean City-Manokin aquifer system averages about 14,000 ft^2/day, or twice the value previously assumed for the Ocean City aquifer. Transmissivity of the Pleistocene and Pocomoke aquifers, by comparison, averages, respectively, 5,000 and 4,000 ft^2/day in the area studied.

Potential short-term ground-water yields from the Ocean City-Manokin aquifer system (maintainable for several hours at a time) are estimated generally to exceed 1,000 gpm (gallons per minute), and may exceed 12,000 gpm in the northern part of the area. Yields from the Pleistocene and Pocomoke aquifers are estimated to range generally from 500 to 2,000 gpm each.

A cone of depression in the Ocean City-Manokin potentiometric surface results from ground-water withdrawals at Ocean City which averaged 3.04 million gallons per day in 1971. It changes cyclically in size and shape, principally in response to seasonal changes in the rate of withdrawal. In summer the cone attains a diameter of 12 miles or more; and in mid-summer of 1971, for example, the potentiometric surface was inferred to be below sea level approximately 3 miles offshore from Ocean City.

In autumn and early winter the cone recovers because of greatly reduced withdrawals. The rate of recovery is related principally to the amount and temporal distribution of nearby precipitation, which affects the Ocean City-Manokin water levels relatively quickly. More water is withdrawn from the Ocean City-Manokin aquifer system at Ocean City than is available from underflow in that system, yet the water levels in the Ocean City-Manokin system showed a net *rise*, indicating an *increase* in storage during the period of study (1970-72). This suggests that there is considerable recharge to the Ocean City-Manokin system by vertical leakage from the water-table deposits, probably on the nearby mainland.

Interaquifer leakage is important in northeastern Worcester County. At Ocean City, water not only from the Ocean City-Manokin system, but from the overlying units as well could probably be drained by long-continued large-scale withdrawals from the Ocean City-Manokin system.

In 1971, 1.1 billion gallons of water was pumped from the Ocean City-Manokin aquifer system. It is estimated that several times that rate of withdrawal could be sustained by the Ocean City-Manokin system indefinitely if the entire thickness of the aquifer were utilized effectively. However, there is a possibility of salt-water encroachment.

No evidence of contemporary salt-water intrusion was found in either the Ocean City-Manokin

aquifer system or the Pocomoke aquifer at Ocean City or elsewhere in the area. Nevertheless, salty water from the adjacent ocean and bays or underlying salty aquifers could contaminate the Ocean City-Manokin system at Ocean City by vertical leakage to the extent permitted by the permeabilities of the intervening beds.

Salty water in the Manokin itself may be a more serious threat to the Ocean City water supply, especially if the salt-water/fresh-water interface in the aquifer is near shore. Water from seaward of the interface can move rather freely toward the well fields in response to head differences in the Manokin because under those circumstances lateral movement within the aquifer predominates.

The salt-water/fresh-water interface in the Manokin lies offshore from Ocean City, probably approximately parallel to the coastline although its proximity to shore is unknown at this time. If, by test drilling or by monitoring outpost observation wells the salt-water front in the Manokin is discovered to be dangerously close to the Ocean City well fields, the effects of the salt water on the public supply could be postponed by drilling new wells west of the present well fields.

INTRODUCTION

This report summarizes the results of a water-resources investigation in northeastern Worcester County, Maryland, during 1969-71, by the U. S. Geological Survey in cooperation with the Maryland Geological Survey. Northeastern Worcester County, as used in this report, is an area about 240 square miles in extent that is bordered on the north by Delaware and on the east by the Atlantic Ocean (fig. 1).

Increasing water demands related to population growth, especially in the Ocean City area, have raised questions as to the productive limits of present ground-water resources and the potential effects of increased withdrawals on the chemical quality of water from those sources. This study was undertaken to answer those questions and to suggest alternate sources of ground water for the communities concerned. It was concerned chiefly with the availability and quality of ground water and the geologic framework within which the water occurs.

Water levels were measured periodically in about a dozen observation wells during the life of the project by R. P. Jett, of the Maryland Geological Survey. Supplemental chemical-quality data, especially iron and chloride content, were obtained from numerous ground-water samples collected by S. W. McKenzie in 1971.

Most of the wells and test holes referred to in this report or used in preparing the maps are described by Rasmussen and Slaughter (1955) or by Lucas (1972). A few additional wells and test holes are described in the appendix of this report.

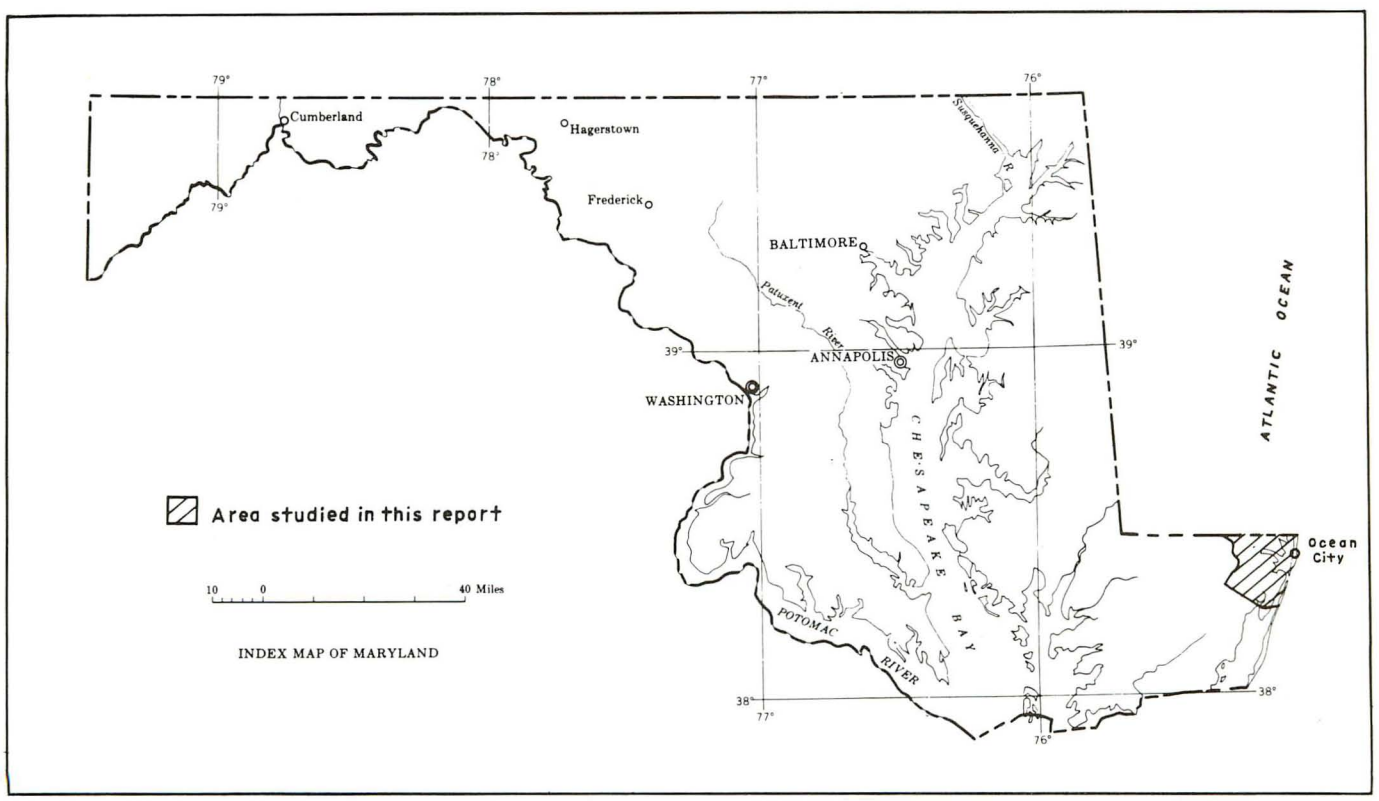


Figure 1.—Map showing location of northeastern Worcester County.

OTHER INVESTIGATIONS

Rasmussen and Slaughter prepared a comprehensive report (1955) of ground-water resources in Somerset, Wicomico, and Worcester Counties. Subsequently, Slaughter (1962) prepared a brief report on water supplies at Ocean City, and adjacent Fenwick Island in Delaware, that includes a discussion of potential productivity of the aquifers at Ocean City and the danger of salt-water contamination. During 1967-68, E. F. Hollyday conducted a test-drilling program and collected basic hydrologic data at Assateague Island National Seashore in Maryland and Virginia; some of the information gained there is pertinent to this study. A 1,200-foot test hole drilled at the north end of Ocean City was described by I. H. Kantrowitz (1969). In that report, determination of the base of fresh ground water in the test hole was discussed and the possible occurence of an unused fresh-water aquifer below the Manokin was considered. The present investigation relied heavily upon ground-water data collected recently for Worcester County (Lucas, 1972).

Concurrent with the study in northeastern Worcester County, the U. S. Geological Survey investigated the hydrology of the entire Delmarva Peninsula (Cushing, Kantrowitz, and Taylor, 1973). The reader is referred to the results of that study for a regional view of the hydrology.

ACKNOWLEDGEMENTS

The author is indebted to the Worcester County Roads Board; to the Assateague State Park Headquarters (Park Service, Maryland Department of Natural Resources); and to individual land owners, for the cooperation that made possible collection of data by test drilling and associated means. Thanks are expressed to the many well owners and well drillers who provided much of the background information for this report. Appreciation is expressed to the Ocean City Engineer and Water Department for their cooperation, interest, and patience during this investigation.

Thanks and appreciation are expressed to D. B. Duane, M. E. Field, and E. P. Meisburger of the Coastal Research Laboratory, U. S. Army Corps of Engineers for their cooperation and efforts toward coordinating the field-work phase of their concurrent investigation of offshore sand deposits with the geologic field-work phase of this investigation. Thanks and appreciation are due also to E. B. Cushing, I. H. Kantrowitz, and K. R. Taylor for their comments and suggestions during the study. The advice and assistance rendered by H. J. Hansen, Geologist, Maryland Geological Survey, are gratefully acknowledged.

The cover photograph is a view of Ocean City looking south from 18th Street. It was taken in 1964 by the Baltimore District of the U. S. Army Corps of Engineers.

GEOLOGIC SETTING

Northeastern Worcester County is underlain by a southeastward-thickening wedge of unconsolidated sediments. Individual geologic formations that comprise the sediments subcrop northwestward under the Pleistocene deposits (a mantle of sand, gravel, and fine materials) and occur at successively greater depths to the southeast (fig. 2).

The age, lithology, thickness, and water-bearing characteristics of the geologic units summarized in Table 1 are described in detail by Rasmussen and Slaughter (1955).

In this report, attention is focused on the Pleistocene, Pocomoke, Ocean City, and Manokin aquifers (Table 1), which are the fresh-water aquifers in northeastern Worcester County.

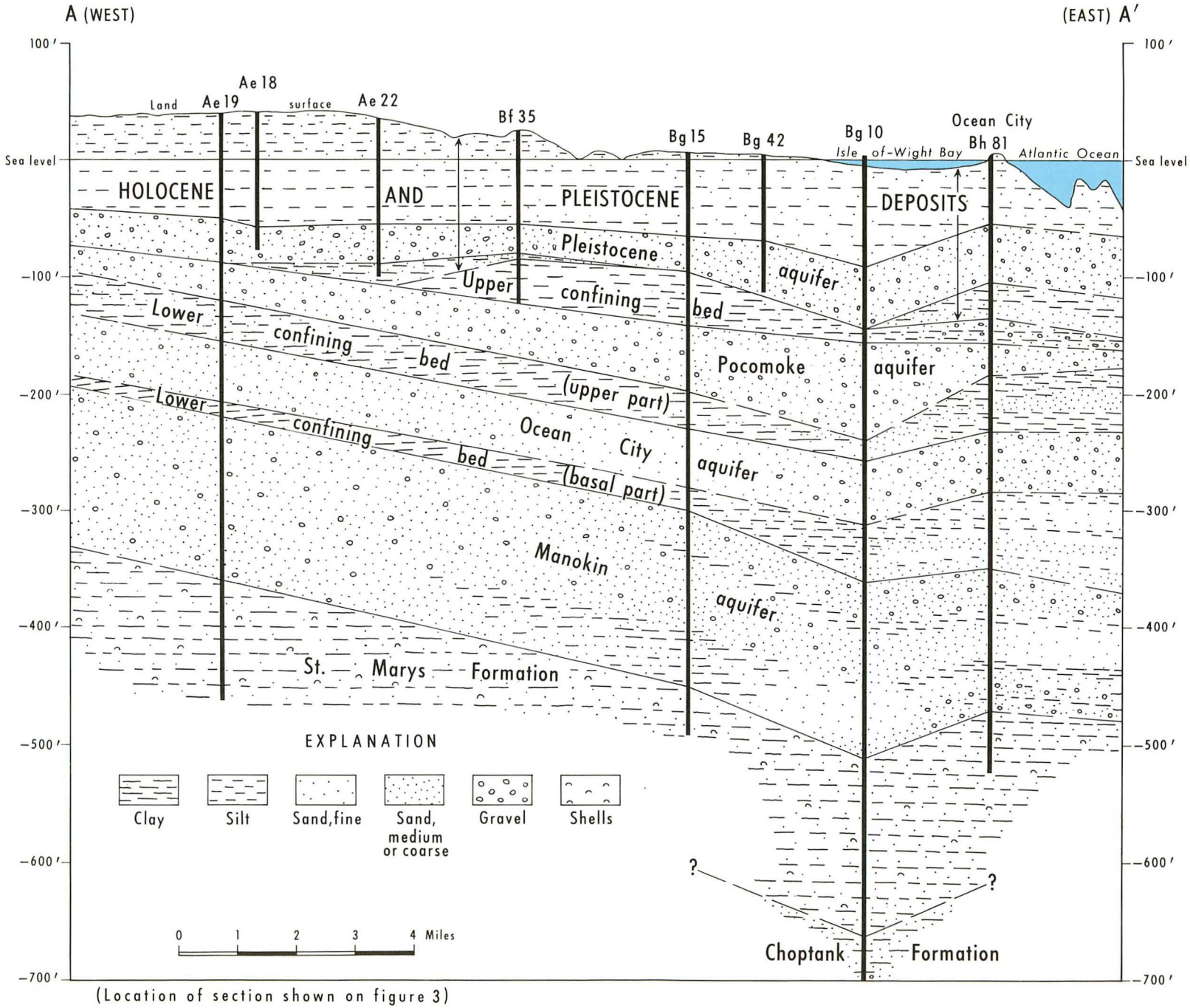
HOLOCENE DEPOSITS

The Holocene deposits are from 0 to 40 feet thick but approximate only 5 feet in average thickness.. They include soil, alluvial and windblown sand and silt, and peat. The Holocene deposits overlie the Pleistocene deposits disconformably.

PLEISTOCENE DEPOSITS

The Pleistocene deposits generally thicken eastward; but their thickness and basal contact are very irregular, owing to erosion of the underlying Miocene surface before Pleistocene deposition.

During the Pleistocene Epoch the sea level fluctuated widely in response to repeated advance and retreat of the glaciers. The stratigraphically com-



(Location of section shown on figure 3)

Figure 2.—Generalized geologic section trending east-southeastward across northeastern Worcester County.

Table 1.—Geologic units in northeastern Worcester County and their geohydrologic characteristics.

System	Series	Group	Geologic unit	Thickness (feet)	Hydrologic unit(s)	Lithologic character	Water-bearing characteristics and hydrology 2/
Quaternary	Holocene	—	Holocene deposits	0 - 40 average 5	—	Soil, alluvial sand and silt, dune sand, and peat. Disconformable base.	Commonly unsaturated, but permits water to percolate downward to underlying units. Possibly provides water locally for a few wells near the coast.
Quaternary	Pleistocene	—	Upper Pleistocene deposits	90 - 180	—	Lenticular deposits of sand, silt, clay, and peat. Some beds of coarse sand and fine gravel. Tan; some gray, and blue.	Functions as a partial confining bed. Generally capable of yielding supplies of water sufficient for household needs, but water "irony" locally. Susceptible to local salt-water contamination near coast.
Quaternary	Pleistocene	—	Beaverdam Sand	90 - 180	Pleistocene aquifer	In lower half of Pleistocene deposits. Lensoidal or rudely stratified deposits of medium-to-very-coarse sand and gravel. Color generally tan, green brown, white, or gray. Near coast, the bottom 10 or 20 feet is stratified blue clay and gray sand. Aquifer is 25 - 80 feet thick.	Important aquifer having a potential for large short-term yields (fig. 17). Water "irony" locally (fig. 15). Susceptible locally to salt-water contamination near coast. Water occurs under water-table conditions generally, but is semi-confined or confined in much of the area.
Quaternary(?)	Pleistocene(?)		Pleistocene (?) deposits	0 - 20			
Tertiary	Miocene	Chesapeake	Yorktown (?) Formation 3/	0 - 50	Upper confining bed	Lenticular silts, clays, and fine sands. Green-blue silt and fine gray sand most common, but occasionally includes blue-green pebbly clay.	Confining bed, providing partial hydraulic separation of the Pleistocene and Pocomoke aquifers. Pinches out in extreme northwestern part of area, and absent locally elsewhere. Effectiveness as a confining bed is good to poor.
Tertiary	Miocene	Chesapeake	Yorktown (?) Formation 3/	0 - 80	Pocomoke aquifer	Sand, gray or tan-gray; coarse and pebbly generally, but locally fine.	Important aquifer generally 30 to 60 feet thick, but absent under northern Ocean City. Where present, generally has a potential for large short-term yields. Potential yields (fig. 18) and transmissivity (fig. 14) greatest from Newark to Isle-of-Wight Bay; less to northwest, southeast, and northeast. Water confined except in extreme northwestern part of area.
Tertiary	Miocene	Chesapeake	Yorktown (?) Formation 3/	15 - 85	Lower confining bed	Blue and gray clayey silt and sand; some peat. Some beds of shell and calcite and/or limestone in top and bottom parts. Middle generally sandy; bottom part sandy in much of area; material in upper part (15 - 20 feet thick) fine.	Leaky confining layer. In much of the area only the upper part (15 - 20 feet thick) persists as a confining layer and the middle and lower parts are an aquifer (the Ocean City aquifer).
Tertiary	Miocene	Chesapeake	Yorktown (?) Formation 3/	15 - 85	Ocean City aquifer	Coarse gray sand, fine gravel.	Important aquifer at Ocean City; provided the entire public supply in 1972. Hydraulically connected with Manokin.
Tertiary	Miocene	Chesapeake	Yorktown (?) Formation 3/	140 - 240	Manokin aquifer	Fine to very coarse gray sand, and some lignite or peat. Some silty sand and clay, especially in middle part of aquifer, toward southeast. Occasional beds of shell and/or "rock".	Very important artesian aquifer. The Ocean City-Manokin aquifer system has a potential for large to very large short-term yields (fig. 19) except in the southeastern part of the area, where the potential is for moderate to large yields. Transmissivities of the Ocean City-Manokin aquifer system increase north-northwestward, and range from about 1,000 to more than 20,000 feet squared per day (fig. 8). At the coast, the Manokin may be susceptible to salt-water invasion in response to large-scale ground-water withdrawals there.
Tertiary	Miocene	Chesapeake	St. Marys Formation	160 - 190	Confining layer	Gray fossiliferous clay, silt, fine sand, and silty and sandy clay.	Confines the base of the Manokin aquifer, preventing or retarding movement of salt water from the Choptank Formation to the Manokin. Probably saturated with brackish or salty water. Generally unproductive of water in this area.
Tertiary	Miocene	Chesapeake	Choptank Formation	130 - 240	Aquifer	Gray fine sand. Thin beds of shell and calcite or limestone.	The aquifer could yield supplies of water at least sufficient for domestic needs, but the water is salty.
Tertiary	Miocene	Chesapeake	Choptank Formation	130 - 240	Confining layer	Green or brown clay and fine sand. Thin beds of shell and calcite or limestone.	
Tertiary	Miocene	Chesapeake	Calvert Formation	430 - 680	Aquifers and confining layers	Gray sand and diatomaceous silt and clay. Shell beds.	The aquifers could probably yield individual supplies of water measurable in hundreds of gallons per minute, but the water is salty.

1/ The nomenclature is that of the Maryland Geological Survey and does not necessarily agree with that of the U. S. Geological Survey.

2/ "Moderate" indicates yields of 100-300 gpm; "large", 300-1000 gpm; "very large", more than 1000 gpm. Short-term yields are maintainable for several hours at a time with longer intervening periods of no pumping, and assume optimum conditions of well construction and spacing (see text for discussion of short-term potential yields).

3/ Recent work suggests the Yorktown may be absent from this area.

plex Pleistocene deposits are the net result of cycles of erosion and deposition. Within the deposits, therefore, are numerous discontinuous and non-parallel erosional surfaces.

The upper Pleistocene deposits are primarily of barrier, back-barrier and foreshelf origin. They are chiefly lenticular deposits of fine to medium sand, silt, clay, and peat, but some beds of coarse sand and fine gravel are included. Tan and gray predominate as colors, but some of the clays are blue or brown. The base of these deposits is disconformable; the back-barrier lagoonal deposits of fine-grained materials are as much as 70 feet thick locally.

The lower Pleistocene deposits (in large part the Beaverdam Sand of Rasmussen and Slaughter, 1955) are of coarser materials. Generally, the deposits are lensoidal or rudely stratified deposits of medium to very coarse sand and gravel, typical of proglacial outwash deposits. The color is generally tan-gray, but may be green, brown, or white. Near the coast, the bottom 10 or 20 feet of the deposits is stratified estuarine or marine blue or gray clay and well-sorted fine or medium gray clay.

Beds of marine or estuarine blue and gray clay and silt and fine gray sand in the Pleistocene deposits increase in number and thickness toward the east. The marine or estuarine beds are interfingered with the fluvial and proglacial outwash deposits, recording sea-level changes that occurred during the Pleistocene Epoch.

The Berlin scarp, a prominent physiographic feature, traverses the middle of the area as shown in figure 3. The feature extends generally northeastward from Newark to Berlin and thence northward into Delaware. The face of the scarp slopes gently eastward, descending from 35 or 40 feet to 10 or 15 feet above sea level. It was formed by erosion in the Pleistocene and was partly buried by subsequent deposition, the entire process affecting only the upper part of the Pleistocene deposits.

The Berlin scarp is a geographic reference or landmark, but is also of hydrologic significance. In some places where stream valleys notch the face of the scarp, the water table in the Pleistocene deposits is lowered below the potentiometric surface of the underlying Pocomoke aquifer, locally reversing the head relations between the two aquifers (see section on Pocomoke potentiometric surface).

In attempting to establish definite age relationships and reference surfaces within the Pleistocene deposits, the utility of palynological and carbon-14 analysis was explored. The results, useful in this study, will also be helpful in the event of future major development of the Pleistocene deposits as a large-scale source of water.

Ten samples of clay and peat collected during this study were analyzed by Grace Brush of Johns Hopkins University for pollen and spore content (table 3, in appendix). The deepest sample, stratigraphically, was obtained from 140 feet below sea level at test hole Wor-Cg 63, on the mainland shore northwest of Assateague State Park (fig. 3). That sample was sticky blue clay from interbedded blue and gray clay and uniform blue-gray sand, approximately 22 feet below typical Pleistocene deposits of coarse sand and gravel. In that sample the presence of spruce, in particular, indicates a climate cooler than the present. Also, the sphagnum moss (and possibly yew) point to a cooler, moist climate. Altogether, the evidence indicates a Pleistocene climate, rather than the more tropical climate commonly attributed to the Miocene. The results of all the analyses were more suggestive of Pleistocene than Miocene climatic environments (oral communs., Grace Brush, 1971 and 1972). These results suggest that at least the upper 20 feet of the so-called Miocene deposits in northeastern Worcester County may be Pleistocene in age.

Peat occurs at several horizons in the Pleistocene deposits. In one horizon (here referred to as the 30-foot peat horizon), peaty materials occur discontinuously but persistently beneath parts of Assateague Island, Sinepuxent Bay, Lower Sinepuxent Neck, and Ocean City, and help locally to identify the horizon. The 30-foot peat horizon lies in generally fine materials within the Pleistocene deposits, above the Beaverdam Sand or Pleistocene aquifer, and dips southeastward at about 5 feet per mile. The lateral limits of the associated peat are not known.

To correlate parts of the peat horizon across an area of no data, two peat samples, one from 32 feet below sea level at test hole Wor-Dg 13 (Assateague State Park) and one from 27 feet below sea level at test hole Wor-Bh 83 (Ocean City) were submitted, respectively, through J. P. Owens (U. S. Geological Survey) and D. B. Duane (U. S. Army Corps of Engineers) for age determination by carbon-14 analysis. The age of the sample from beneath Assateague State Park was determined by Meyer Rubin (U. S. Geological

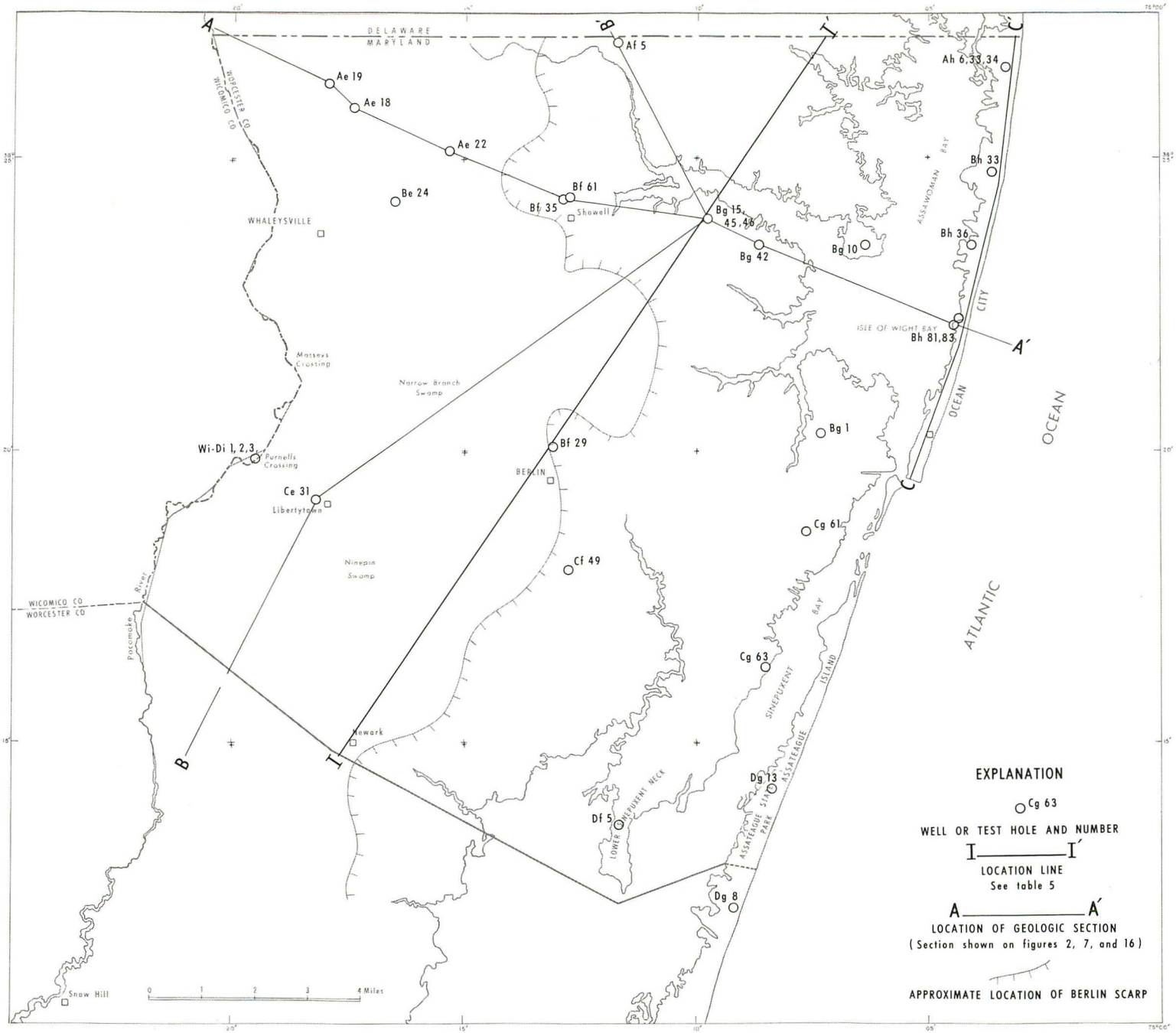


Figure 3.—Map showing locations of key wells, test holes, and data-collection sites referred to in this report.

Survey) to be about 31,000 years (oral comun. J. P. Owens, 6/1/71); that of the sample from beneath Ocean City was determined by a commercial laboratory to be more than 27,000 years and less than 40,000 years, with an uncorrected direct reading of 33,000 years (oral commun. D. B. Duane, 6/29/72). On the basis of those analyses the 30-foot peat horizon therefore is probably of late Pleistocene age beneath Assateague Island and Ocean City.

Additional tests were performed on selected materials (predominantly Pleistocene in age) collected during the investigation, to aid in correlating sediments and to gain insight into their genesis. The results of X-ray-diffraction and size-grade analyses were obtained too late for effective interpretation and presentation in this report but are on file at the Parkville, Maryland office of the U. S. Geological Survey and are available there for public inspection. The results of heavy-mineral analyses appear in table 6.

MIOCENE DEPOSITS

The Miocene deposits generally dip and thicken southeastward in northeastern Worcester County, and strike northeasterly (somewhat more easterly than the trend of the shoreline). The deposits are of marine origin, although toward the top of the deposits there are increasingly common indications of an estuarine or coastal depositional environment.

Fresh water is restricted to the upper part of the Miocene deposits.

Upper Miocene Deposits

Yorktown (?) Formation: Upper Miocene deposits in this area, which may be the Yorktown (?) Formation, include strandline deposits of relatively coarse sands alternating with lagoonal, estuarine, or nearshore deposits of clay, silt, and fine sand, indicating a mobile shoreline.

In general, the material composing the basal part of the deposits grades upward from fine to coarse sand, suggesting a regressive shoreline and a change from the earlier marine or offshore depositional environment.

The hydrologic units in the upper Miocene deposits are described by Rasmussen and Slaughter (1955). Two important fresh-water artesian aquifers are included: the Manokin and the Pocomoke (Table 1). They are discussed in the section on aquifers.

Middle and Lower Miocene Deposits

These deposits are of marine, offshore and continental-shelf origin. The deposits are saturated with brackish or salty water.

St. Marys Formation: The St. Marys Formation is a well-defined geologic unit from 160 to 190 feet thick, easily recognizable on a gamma-radiation log. The formation is massive, changes little throughout its thickness, and is characteristically fossiliferous gray clay, silt, fine sand, and silty and sandy clay.

Choptank Formation: In northeastern Worcester County the Choptank Formation is composed of two parts. The upper part consists of gray, fine sand and thin beds of shell and brown calcite and black limestone. The lower part consists of green or brown clay and fine sand, and thin beds of shell and calcite or limestone.

Calvert Formation: The Calvert Formation is made up of stratified gray sand and diatomaceous silt and clay, and contains shell beds.

RELATION TO OFFSHORE STRUCTURE

A sonic (sound-velocity) log of the 527 feet of sediments penetrated in well Wor-Bh 81 near the shore was obtained for comparison with electric and gamma-radiation logs of the same well and to aid in correlating results of onshore test drilling with results of contemporary or subsequent offshore acoustical profiling. The geophysical and lithologic logs of well Wor-Bh 81 are shown in figure 4. Acoustical or sonic logging is discussed in depth by Guyod and Shane (1969).

The results of onshore test-drilling in northeastern Worcester County were compared with results of recent nearby offshore acoustical profiling by the U. S. Army Corps of Engineers, through the courtesy and cooperation of D. B. Duane of that agency, and structural trends beneath the area were tentatively extrapolated seaward on that basis. Relative parallelism and continuity of acoustically reflective surfaces suggest that the general dip of the bedding planes in the uppermost 300 feet of materials under the mainland continues at least 5 miles offshore with little change.

Acoustical profiles of the uppermost 200 to 300 feet of sediments in the area between 2 and 4 miles offshore and parallel to the coast were scanned for evidence of faults or deep paleochannels extending seaward from the mainland, but no evidence of either type of feature was noted.

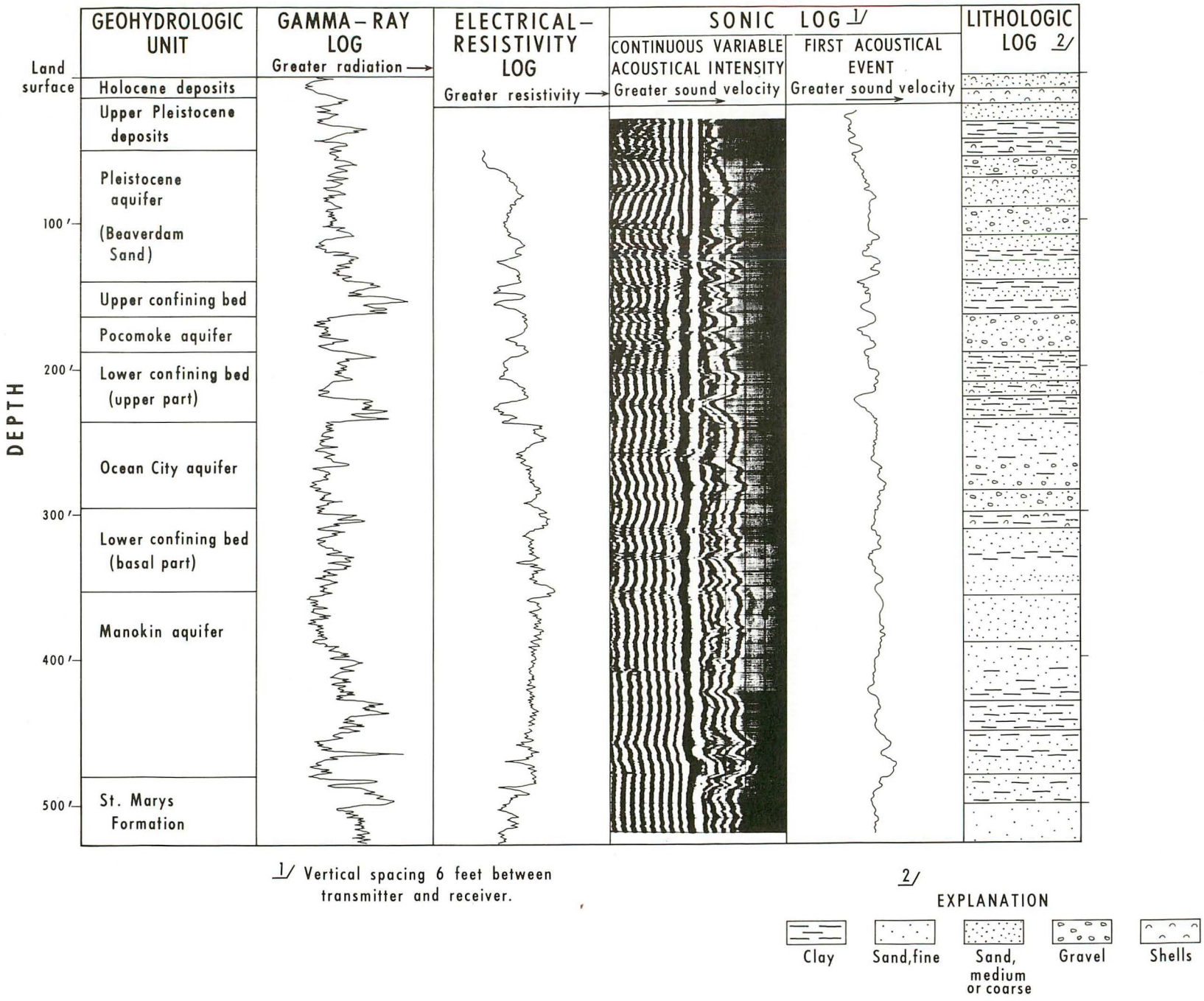


Figure 4.—Sonic log of sediments in well Wor-Bh 81, compared with gamma-ray, resistivity, and lithologic logs at same site.

GROUND-WATER HYDROLOGY

Water occurs in all the geologic units in northeastern Worcester County, but it can be withdrawn in significant quantity only where the materials in the units are permeable enough to permit water to move fairly freely. Such units are termed "water-bearing" and are referred to as "aquifers". By contrast, some geologic units are made up predominantly of silt or clay, and are relatively impermeable. These units impede the movement of water, and are termed "confining beds" or "confining layers".

Ground water occurs under both unconfined (water-table) and confined (artesian) conditions.

HYDROLOGIC UNITS

Most hydrologic units correspond to geologic units, but some do not. Aquifers and confining layers may transgress the boundaries of stratigraphic units through facies changes in the stratigraphic units. Furthermore, several hydrologic units may occur within an individual stratigraphic unit.

Maps of the tops of the Pocomoke and Manokin aquifers and a map of the base of the Quaternary deposits are presented by Cushing, Kantrowitz, and Taylor (1973). Maps of a similar nature were presented also by Rasmussen and Slaughter (1955).

Holocene Deposits

The Holocene deposits are as much as 40 feet thick, but generally are less than 10 feet thick. The deposits consist chiefly of sand, but contain some silt, clay, and more or less decomposed plant remains. Commonly the Holocene deposits are unsaturated, but permit water to percolate downward to underlying units.

Pleistocene Aquifer

The Pleistocene aquifer (principally the Beaverdam Sand) occurs in the lower part of the Pleistocene deposits, occupying an average of perhaps one-third to one-half their total thickness. The aquifer is generally from 25 to 50 feet thick in the area studied, but thickens toward the northeast and is from 60 to 80 feet thick beneath Ocean City.

Water in the Pleistocene aquifer occurs mostly under water-table conditions. However, in many places (especially in the vicinity of the coast) strata of fine materials in the upper part of the Pleistocene deposits confine or partly confine the water in the Pleistocene aquifer.

Recharge to the Pleistocene aquifer is predominantly by direct infiltration and downward percolation of rainfall and snowmelt. Within the saturated zone below the water table the water moves laterally in response to gravity, generally parallel to the water-table gradient (fig. 9), that is generally in the direction of the land-surface slope. Discharge from the Pleistocene aquifer is chiefly by evapotranspiration and by discharge to the Pocomoke River and its tributaries and to other streams, to widespread swamps, and at the shores or beneath the bay and ocean. The Pleistocene aquifer also contributes some water to the underlying Pocomoke aquifer (see section on water-table and potentiometric surfaces).

The Pleistocene aquifer provides water for by far the greatest number of domestic wells in northeastern Worcester County. The aquifer also provides public-supply water for Berlin, Maryland, and the Ocean Pines residential development area about 4 miles northeast of Berlin. Assuming optimum conditions of well construction, the Pleistocene aquifer is generally capable of producing from moderate to very large supplies of water (500 to 2,000 gpm) in northeastern Worcester County. In the northwestern part of the area, however, the Pleistocene aquifer is thinner or absent, and there the potential supplies from the aquifer correspondingly range between 500 and 0 gpm (see section on ground-water yields).

Knowledge of the transmissivity of an aquifer is basic to determining the amount of water that can be transmitted by the aquifer (assuming that amount is available for transmittal). The transmissivity (T) is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman, 1972). In this report the unit width of the aquifer is 1 foot, and transmissivity is expressed in feet squared per day (ft^2/day).

Maps showing transmissivity distribution and

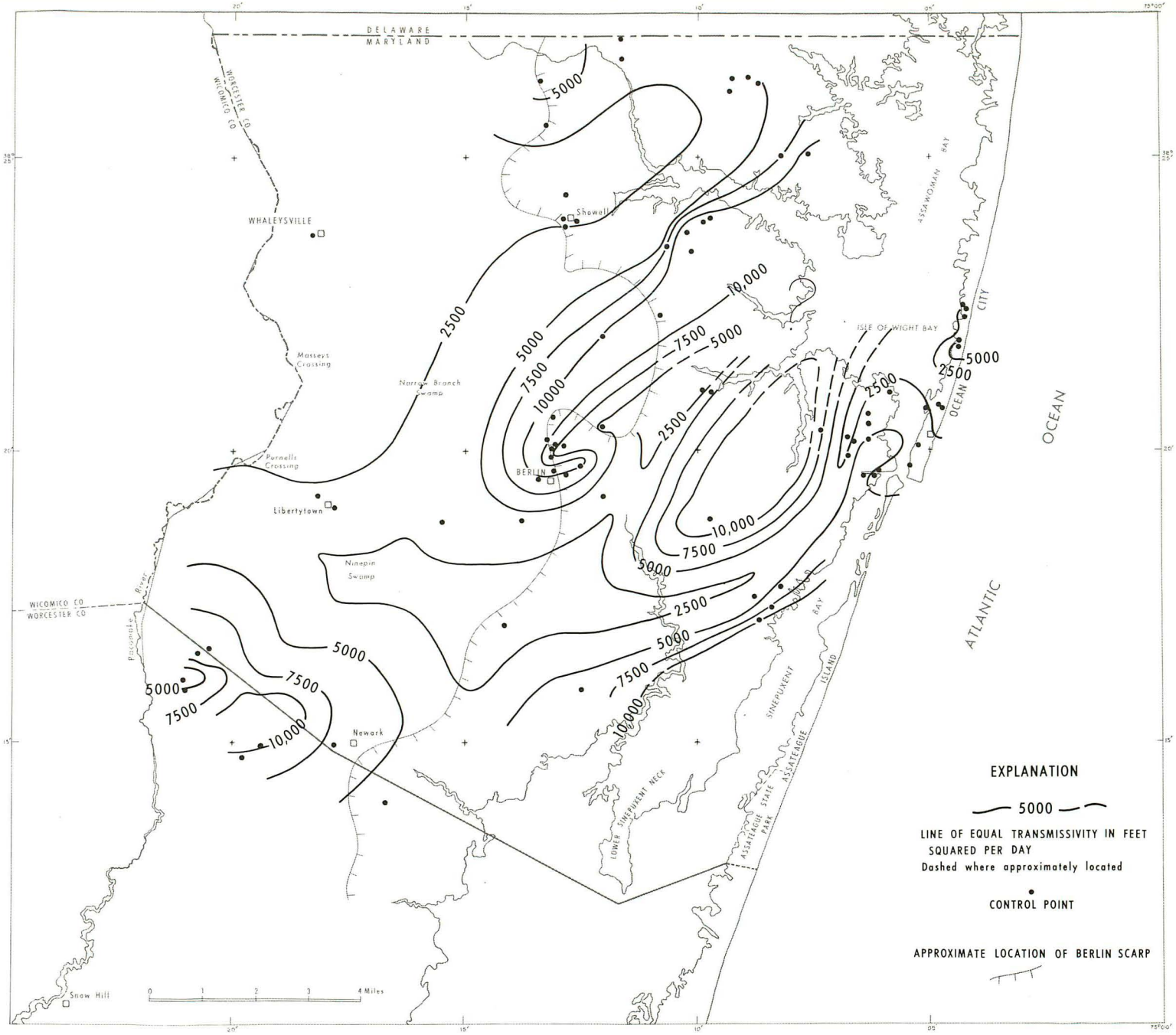


Figure 5.—Map showing transmissivity of the Pleistocene aquifer.

trends accompany the discussions of the major aquifers. The transmissivity values used in constructing the maps are based almost entirely on specific capacities adjusted for complete penetration of the aquifer; geophysical and lithologic logs; plus a few aquifer tests referred to in Rasmussen and Slaughter (1955) or in the sections on the Ocean City and Manokin aquifers in this report.

The distribution of transmissivity in the Pleistocene aquifer in northeastern Worcester County is shown in figure 5. As can be seen on the map, the transmissivity pattern is complex. Transmissivities are estimated to average about 5,000 ft^2/day, but they range from less than 2,500 ft^2/day to more than 10,000 ft^2/day in relatively short distances. The variability is related to differences in aquifer thickness and permeability of material in the aquifer. That is, in the areas of high transmissivity east and northeast of Berlin and west of Newark, greater thickness of the aquifer is combined optimally with greater permeability of materials in the aquifer.

In general, the Pleistocene aquifer comprises only one-half to one-third of the total thickness of the Pleistocene deposits, although the aquifer is the most productive part of the deposits. Therefore the transmissivity of the Pleistocene aquifer (as shown in figure 5) is less than the transmissivity of the Pleistocene deposits.

Upper Confining Bed

The upper confining bed (referred to as the upper aquiclude by Rasmussen and Slaughter, 1955), separates the Pocomoke and Pleistocene aquifers. The bed averages from 15 to 20 feet in thickness, but pinches out in the extreme northwestern part of the area and is absent locally elsewhere; for example, it is absent just north of Berlin, at well Wor-Bf 29. Where the upper confining bed is absent the Pleistocene deposits rest directly on the Pocomoke aquifer, and water can move freely from one unit to the other.

The upper confining bed is comprised of lenticular silts, clays, and fine sands. Blue-green silt and fine gray sand are most common, but blue-green pebbly clay occasionally is included. The effectiveness of the confining bed ranges from good to poor.

Pocomoke Aquifer

In northeastern Worcester County, the Pocomoke aquifer is composed of gray or tan-gray sand, generally coarse and pebbly but locally fine.

The Pocomoke is an important aquifer. It is thickest (about 80 feet) near Berlin, but generally is from 40 to 60 feet thick. The aquifer pinches out under northern Ocean City and is partly beveled off in the extreme northwestern part of the area studied. Ground water in the Pocomoke aquifer is confined except in the northwestern part of the area and locally elsewhere (for example, in the vicinity of well Wor-Bf 29, just north of Berlin), where the upper confining bed is absent.

Where the Pocomoke aquifer is present it is generally capable of producing moderate to very large (500 to 2,000 gpm) supplies of water, assuming optimum conditions of well construction (see section on ground-water yields). The aquifer provides water for some domestic, farm, and commercial wells, especially in the western part of the area where the Pleistocene aquifer is relatively thin and in the Bishop area where the Pleistocene aquifer includes much fine, nonproductive material. The Pocomoke aquifer provides water for the community of Newark, Maryland, and formerly supplied most of the water for Ocean City.

Transmissivity of the Pocomoke aquifer in northeastern Worcester County, as shown on figure 6, ranges from less than 2,000 ft^2/day in the northwestern, northeastern and southeastern corners of the area to more than 6,000 ft^2/day near Newark, and averages about 4,000 ft^2/day. Above-average values occur in a belt about 6 miles wide extending northeastward from Newark to Isle of Wight Bay, near Ocean City; this belt corresponds generally with the area of maximum thickness of the aquifer in northeastern Worcester County.

Recharge enters the Pocomoke aquifer by direct percolation from the overlying Pleistocene deposits where the upper confining bed is absent or relatively ineffective as a confining layer (see section on water-table, and potentiometric maps). Recharge by lateral movement, or underflow within the aquifer, occurs to some extent throughout the area but is a dominant factor only to the east of the Berlin Scarp, where the head in the Pocomoke normally exceeds that in the Pleistocene aquifer.

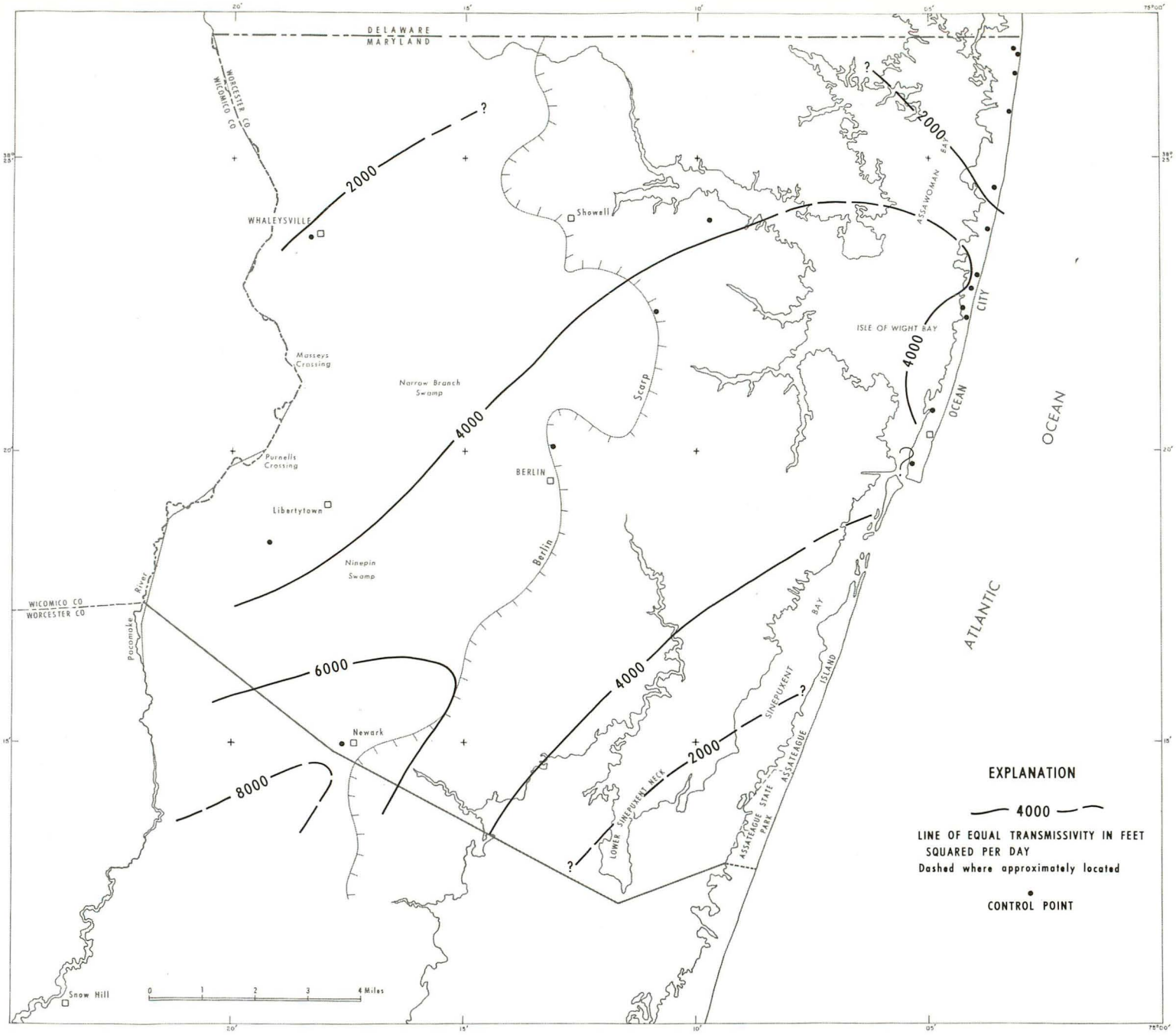


Figure 6.—Map showing transmissivity of the Pocomoke aquifer.

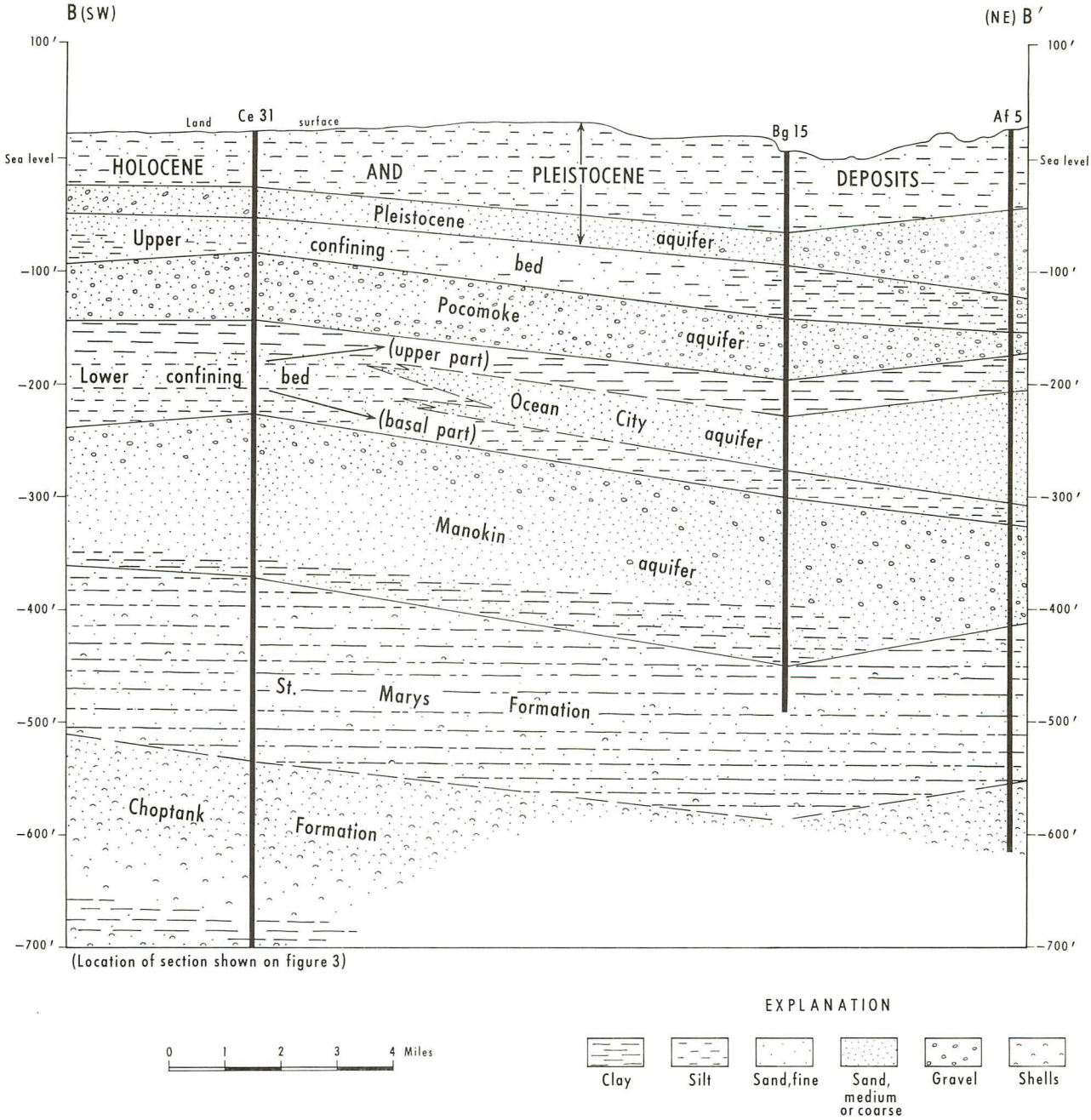


Figure 7.—Generalized geologic section trending northeastward across northeastern Worcester County.

Water in the Pocomoke aquifer moves generally eastward from its dominant area of recharge, and in the eastern part of the area it discharges upward into the Pleistocene aquifer through the upward confining bed. The upward flow is greater where the confining bed is thinner or more permeable. Some water travels southward in the Pocomoke aquifer and discharges into the Pleistocene deposits in the Pocomoke River valley from Massey's Crossing southward.

Lower Confining Bed

At Snow Hill, 8 miles southwest of Newark (fig. 3) the lower confining bed is a distinct, relatively homogeneous unit of clay and silt, and the contact with the underlying Manokin aquifer is well defined. Under most of northeastern Worcester County however, where the middle of the lower confining bed is a sand unit (fig. 7) and where in some places the basal part of the lower confining bed is sandy, there has been some confusion as to the top of the Manokin. Depending on what is considered to be the base of the lower confining bed, the "Manokin" may include either one or two aquifers and the top of the "Manokin" may be mapped at altitudes that disagree by 60 feet in part of the area and by as much as 120 feet elsewhere.

In northeastern Worcester County the lower confining bed is made up of blue, blue-green and gray clayey silt and sand. Some beds of peat, shell, and calcite and/or limestone occur in the top and bottom parts of the unit. The middle part is sandy in general, and the bottom part is sandy in much of the area. The material in the upper part is mostly fine sand, silt, and clay throughout the area.

The lower confining bed is a leaky confining layer which hydraulically separates the Pocomoke and Manokin aquifers and is probably characterized by substantial leakage in a large part of the area. The confining bed ranges from 15 feet to more than 100 feet in thickness, but in much of the area only the upper part (15 to 20 feet thick) persists as a confining layer. The middle part and, to a lesser extent the lower part functions as an aquifer and may be the upper part of the Manokin aquifer.

Stratigraphically, however, the basal part of the lower confining bed can be traced and identified under most of the area in spite of its facies changes. In this report, the sandy middle part of the lower confining bed is considered to be a separate aquifer named the Ocean City aquifer (fig. 7).

Ocean City Aquifer

The Ocean City aquifer occurs within the lower confining bed beneath approximately the northern two-thirds of the area of investigation. The aquifer is composed chiefly of gray sand that becomes coarser and more permeable northward. Generally the aquifer is also thicker and more productive in that direction. It is separated from the Manokin by the basal part of the lower confining bed, but is hydraulically connected by leakage through that semi-confining layer. Beneath Ocean City this aquifer consists primarily of coarse gray sand and fine gravel, and some shells. The aquifer lies between approximately 240 and 300 feet below sea level at well Wor-Bh 81.

During the period of this investigation and several prior years, the Ocean City aquifer supplied all the water for the public supply at Ocean City.

The transmissivity of the Ocean City aquifer is 3,500 ft^2/day near the southern end of Ocean City, based on an aquifer test at well Wor-Bh 1 (Rasmussen and Slaughter, 1955). The transmissivity is about 5,500 ft^2/day midway to the Delaware State line, based on a 27-hour aquifer test in 1968 at well Wor-Bh 35 and two observation wells. Both tests were of the Ocean City aquifer, then referred to as the Manokin aquifer.

A transmissivity of 8,000 ft^2/day was reported for the Manokin aquifer at well Oj32-12, at Bethany Beach, Delaware, 6 miles north of the Delaware-Maryland line (Sundstrom and Pickett 1969). Projection of the vertical limits of the Ocean City aquifer northward into Delaware suggests the Manokin aquifer referred to at well Oj32-12 in Delaware and the Ocean City aquifer in Maryland are the same unit.

The tests indicate that the transmissivity of the Ocean City aquifer increases northward beneath Ocean City, from approximately 3,000 ft^2/day near the inlet at the southern end of Ocean City to 5,000 ft^2/day about halfway from there to the Delaware-Maryland line; and to approximately 7,000 ft^2/day near the Delaware line, if well Oj32-12 taps the Ocean City aquifer. Geophysical logs and results of test drilling suggest that the transmissivity of this aquifer changes little west-northwestward (section A-A′, fig. 2), but decreases southwestward to where the aquifer pinches out (section B-B′, fig. 7). The combined transmissivities of the Ocean City and Manokin aquifers are shown in figure 8.

Manokin Aquifer

The Manokin is potentially a very important artesian aquifer in northeastern Worcester County. However, it was an untapped source of water at Ocean City prior to 1972, when two public-supply wells, Wor-Ah 33 and 34, were con-

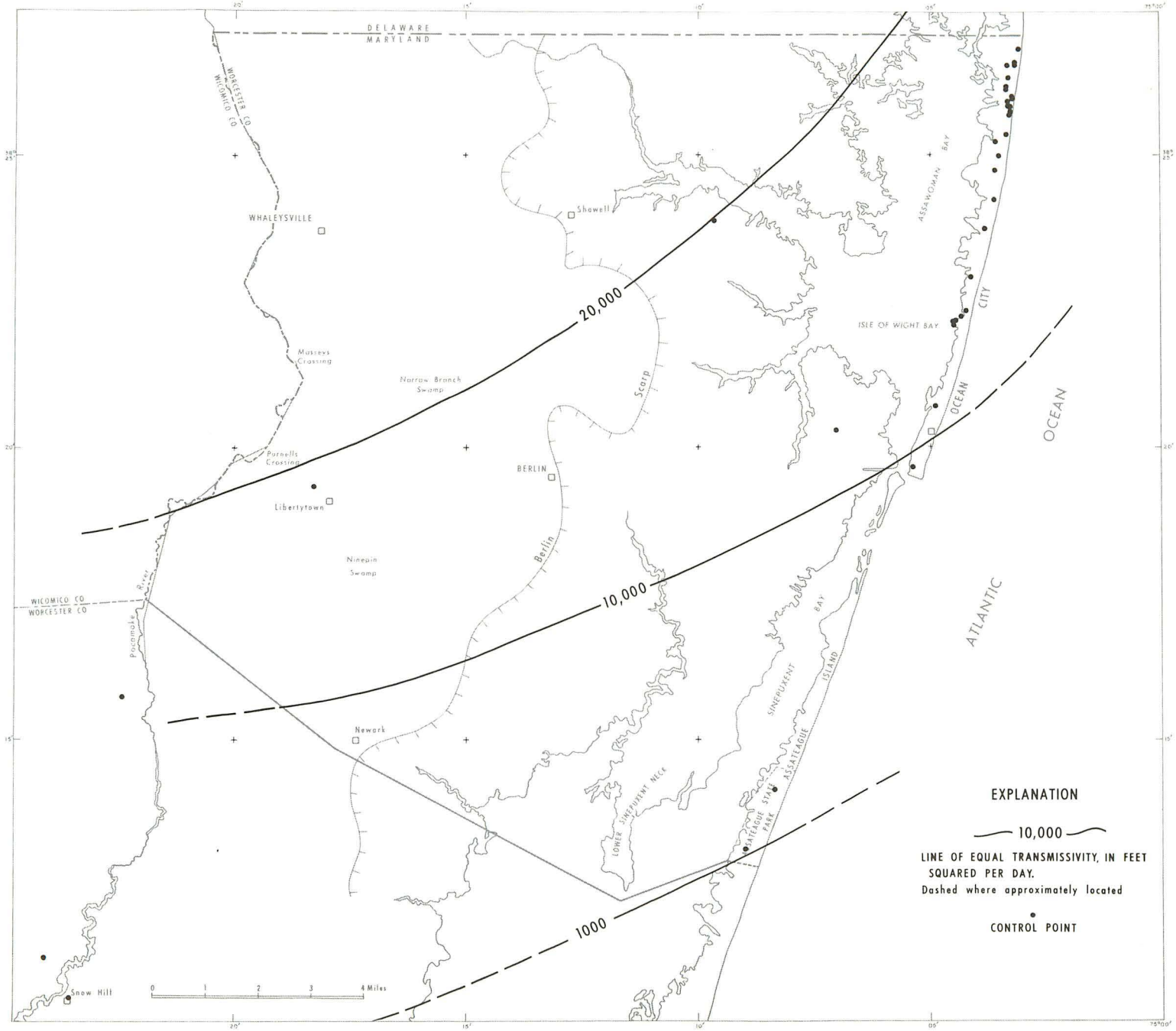


Figure 8.—Map showing transmissivity of the Ocean City-Manokin aquifer system.

structed in the Manokin aquifer at the north end of Ocean City.

The Manokin aquifer is confined above by the lower confining bed associated with the Pocomoke aquifer, and below by the St. Marys Formation. The Manokin occurs between 350 and 475 feet below sea level at well Wor-Bh 81, in Ocean City.

In northeastern Worcester County the Manokin aquifer consists primarily of fine to very coarse gray sand, although beds of peat or lignite occur locally in the sand. The productive, sandy part of the aquifer is generally thickest in the northern and northwestern parts of the area. Southward and southeastward, however, silty sand and clay, and beds of shells and shell fragments partly cemented by calcium carbonate occur in the middle of the aquifer, reducing the thickness of the productive part of the aquifer. In the vicinity of Assateague State Park, the permeable sands occur in two sections 30 or 40 feet thick near the top and bottom of the aquifer, and the middle part of the aquifer is nonproductive.

At Ocean City (and elsewhere, to a lesser degree) the Manokin and Ocean City aquifers are hydraulically connected across the basal part of the lower confining bed and function as one hydrologic unit. Near Whaleysville (Test hole Wor-Ae 19), hydraulic connection is in question because there the basal part of the lower confining bed appears to be less sandy and the Ocean City aquifer perhaps should be considered as a hydrologic unit separate from the Manokin. Nevertheless, for the purpose of describing yields and transmissivities in this report the Ocean City and Manokin aquifers are considered as the Ocean City-Manokin aquifer system.

Under optimum conditions of well construction, the Ocean City-Manokin aquifer system is capable of yielding very large supplies of water (several thousand gallons per minute) in most of the area and perhaps 1,000 gpm in the southeastern part of the area (see section on ground-water yields).

The transmissivities of the Manokin and Ocean City aquifers are combined in figure 8, as noted previously. At Ocean City, the transmissivity of the Manokin aquifer comprises about two-thirds of the transmissivity of the Ocean City-Manokin aquifer system, and elsewhere it comprises between two-thirds and the total transmissivity.

Most of the Manokin transmissivity values used in constructing the map in figure 8 were based on specific capacities (well discharge per unit of drawdown in the well, during pumping tests) and on lithologic and geophysical logs. Transmissivity values previously reported for the Manokin at Ocean City applied to the Ocean City aquifer instead.

In 1972, individual aquifer tests were made at wells Wor-Ah 33 and 34, about 400 feet apart in northern Ocean City. The wells are screened respectively 104 and 100 feet in the Manokin aquifer. During the tests water levels were measured in observation wells as well as in the production wells. The test at well Wor-Ah 33, pumped at 800 gpm for 20 hours, indicated a transmissivity of 14,000 ft^2/day. The test at well 34, pumped at 815 gpm for 20 hours, indicated a transmissivity of 14,800 ft^2/day.

The transmissivity of the Ocean City-Manokin aquifer system increases north-northwestward from approximately 1,000 ft^2/day in the southeastern corner of the project area to approximately 20,000 ft^2/day 11 miles to the north-northwest in the Berlin-Showell-Libertytown area (fig. 8). The increase is due partly to the presence of the Ocean City aquifer in the northern one-half or two-thirds of the area and partly to increase in permeability of the materials in the Ocean City and Manokin aquifers, respectively, toward the north and northwest.

The Manokin aquifer is recharged directly from overlying saturated sand and gravel of Pleistocene age along a belt several miles wide traversing the Delmarva peninsula (Rasmussen and Slaughter, 1955; Boggess and Heidel, 1968; and Sundstrom and Pickett, 1969). From the subcrop belt, located 20 to 50 miles northwest of Ocean City, ground water moves generally east-southeastward beneath northeastern Worcester County toward the ocean. Low base flow of streams in the western part of the Manokin subcrop belt in Delaware suggests recharge from the Pleistocene deposits to the Manokin aquifer (R. H. Johnston, written commun., 1973). Additional recharge probably occurs by vertical leakage from the Pocomoke aquifer through the leaky lower confining bed in the western and northern parts of the study area, and elsewhere to the north and west where the head in the Pocomoke is greater than that in the Manokin (see figs. 10 and 11, and section on water-table and potentiometric surfaces).

Water probably discharges upward from the Ocean City-Manokin aquifer system to the Pocomoke aquifer beneath the easternmost 3 to 4 miles of northeastern Worcester County and some miles

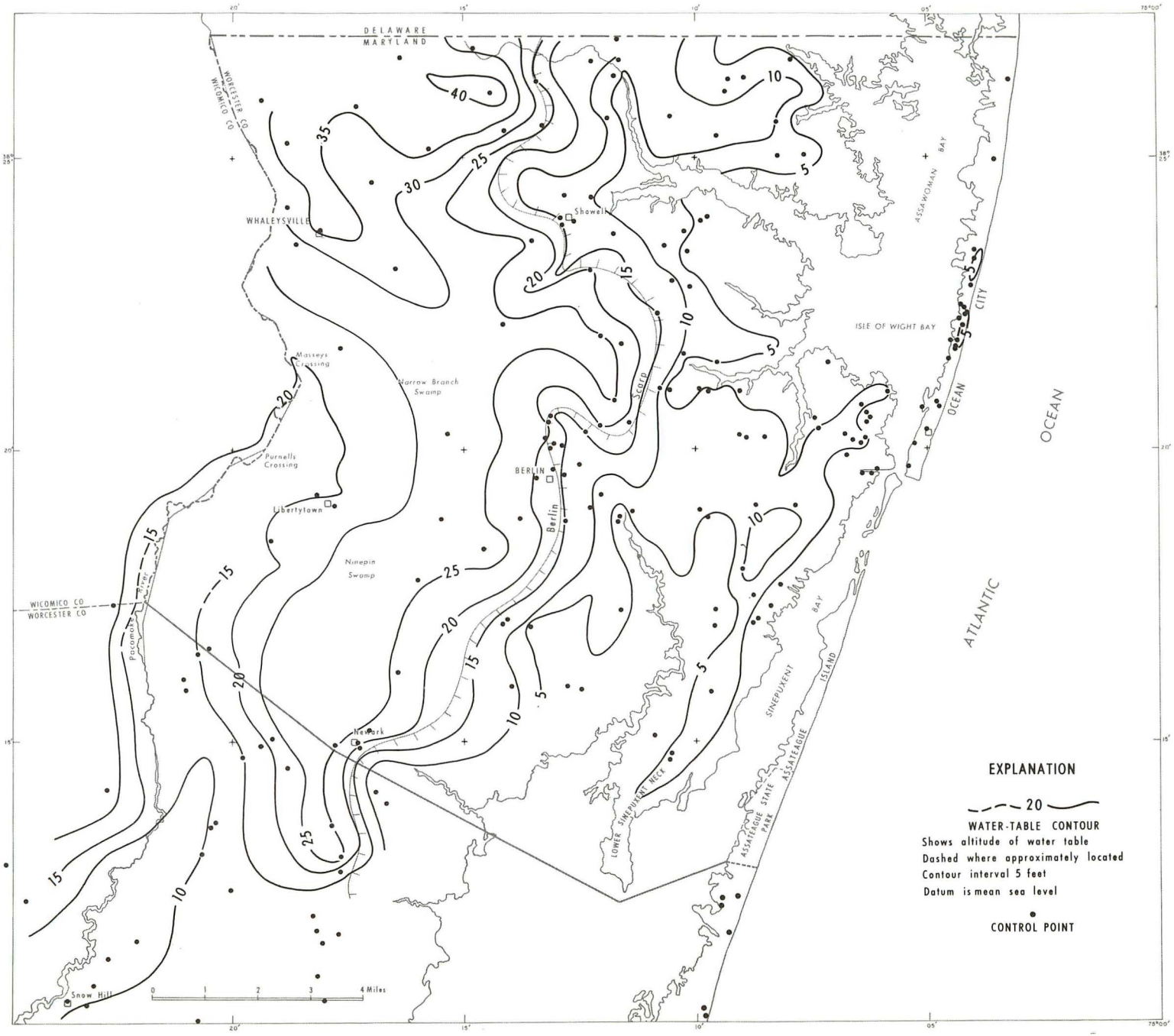


Figure 9.—Map showing water table in the Pleistocene deposits.

offshore, through permeable places in the lower confining bed except where (and when) withdrawal from the Ocean City-Manokin system beneath Ocean City, for example, depresses the Ocean City-Manokin potentiometric surface below the potentiometric surface of the Pocomoke.

It is assumed that the southeasterly trend toward gradual increase in content of fine materials in the Manokin continues seaward from Ocean City, and that there are no abrupt structural or lithologic changes in the upper Miocene deposits within 5 or 10 miles of shore. On the basis of those assumptions, it is tentatively concluded that, seaward, the lateral movement of water toward the east and southeast in the Manokin is increasingly retarded. Also, smaller head differences between the Manokin and the overlying confined aquifers offshore probably reduce the tendency for upward leakage from the Manokin offshore.

St. Marys Formation

The St. Marys Formation is from 160 to 190 feet thick in northeastern Worcester County. It is an effective confining layer at the base of the Manokin aquifer, and prevents or very much retards the movement of salt water from the underlying Choptank Formation into the Manokin aquifer. The St. Marys formation is probably saturated with brackish or salty water throughout this area, and is generally unproductive.

Choptank Formation

In northeastern Worcester County the Choptank Formation includes a salt-water aquifer in its upper part, capable of producing at least moderate (several hundred gallons per minute) supplies of water; and a confining layer in its lower part. The total thickness ranges from 130 to 240 feet.

Calvert Formation

The Calvert Formation is from 430 to 680 feet thick in northeastern Worcester County. The formation consists of alternating aquifers and confining layers. The aquifers could probably produce moderate to large (500 gpm or more) supplies of water, but the water is salty.

RELATION OF WATER-TABLE AND ARTESIAN HEADS TO GROUND-WATER MOVEMENT

Patterns of ground-water movement in northeastern Worcester County may be determined by comparing the water-table map for the unconfined aquifer (Pleistocene deposits) and the potentiometric-surface maps of the Pocomoke and Manokin artesian aquifers.

The water table is the top of the saturated zone, which occurs in the Pleistocene deposits in northeastern Worcester County, and the water-table map shows its position. Each of the potentiometric-surface maps shows the position of an imaginary surface that is determined by the levels to which water will rise in wells penetrating a specific confined aquifer.

The maps show lateral direction of ground-water movement within the individual aquifers. Comparison of the maps shows head differences between the aquifers and therefore indicates the direction of vertical movement between the aquifers. However, the *amount* of vertical leakage between aquifers depends on the vertical hydraulic conductivity of the confining beds in addition to the head differences. In the following sections, head differences plus lithology and thickness of confining beds are considered in determining patterns of ground-water movement.

The gradients of the water table and the potentiometric surfaces are generally east-southeastward. In the Pleistocene deposits the average gradient of the water table is much steeper than that of the potentiometric surfaces of the Pocomoke and Manokin aquifers. The steeper gradient, and comparable or greater permeability of the materials in the Pleistocene aquifer indicate that lateral movement of water is more rapid in the Pleistocene aquifer than in the Pocomoke and Manokin aquifers.

Water Table

The Pleistocene aquifer is essentially unconfined, and large withdrawals therefore cause relatively small changes in water level (see also section on ground-water storage).

The water table in northeastern Worcester County (fig. 9) is generally shallow, and is at land surface in swamp areas. Beneath Ocean City the

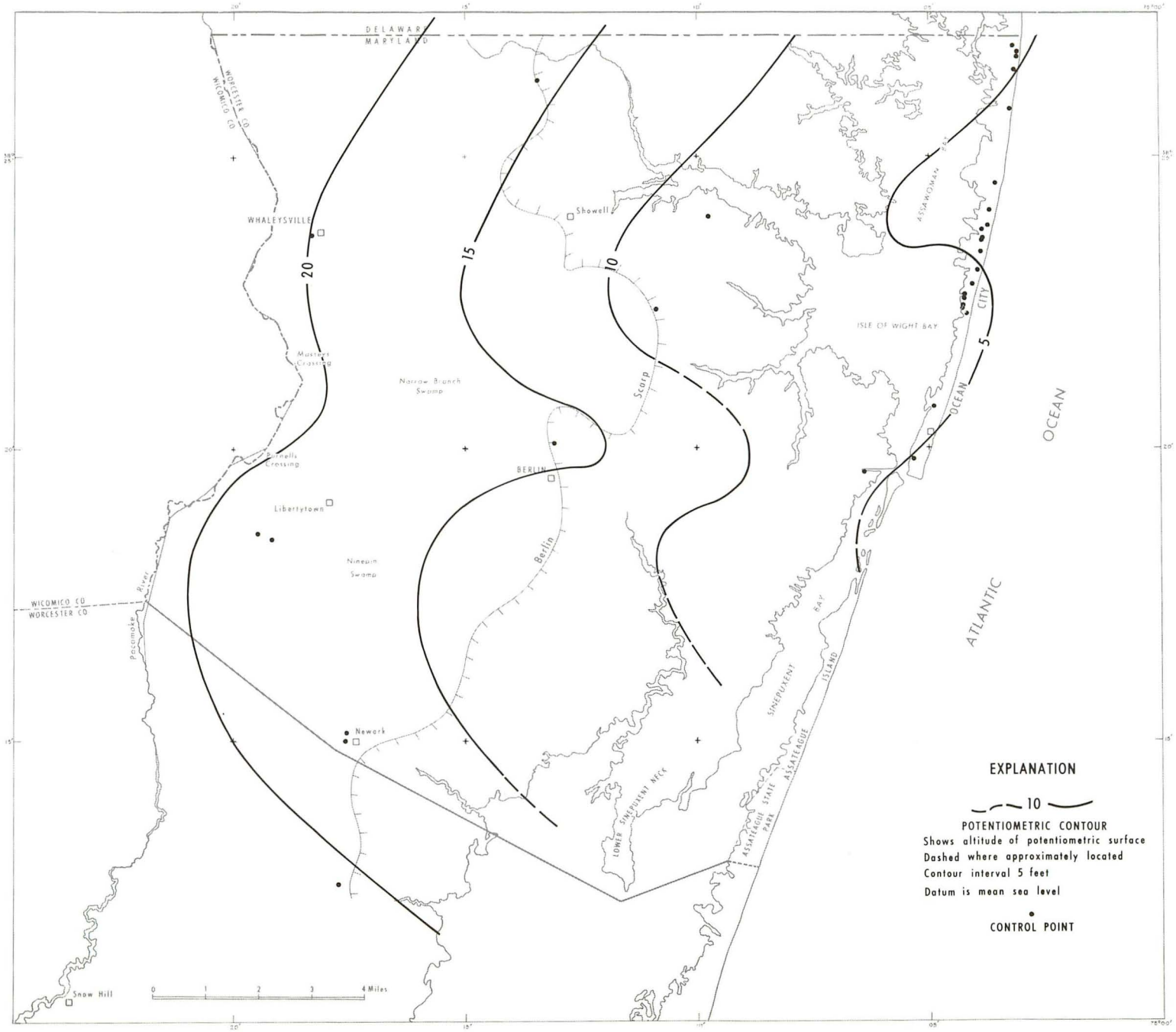


Figure 10.—Map showing potentiometric surface of the Pocomoke aquifer.

water table is generally less than 5 feet above sea level. In general the water table follows the contour of the land surface, and slopes gradually from about 40 feet above mean sea level in the northwest to near sea level along the coast. The water table is complex in shape compared with the potentiometric surfaces of the Pocomoke and Manokin aquifers, because the Pleistocene deposits receive recharge throughout the area and are constantly discharging at many places.

Pocomoke Potentiometric Surface

The potentiometric surface of the Pocomoke aquifer (fig. 10) slopes generally eastward at approximately 1¼ feet per mile, although in the northeastern part of the area the gradient is somewhat flatter.

The ridgelike feature trending eastward across the middle of the potentiometric surface may owe its existence to a local "window", or to a valley which at one time cut through the upper confining bed and into the Pocomoke aquifer and was later filled with Pleistocene deposits. The prominent eastward kick in the 15-foot contour in figure 10 represents a build-up of head in the Pocomoke aquifer near Well Wor-Bf 29, in the vicinity of the "window" or buried valley. Because the upper confining bed is absent there, the permeable materials of the Pleistocene aquifer rest directly on those of the Pocomoke, permitting water from the Pleistocene aquifer to move directly into the Pocomoke aquifer and to equalize the head in the two units.

The existence of a small trough in the corresponding part of the water-table map (fig. 9) also suggests movement of water downward from the Pleistocene aquifer. The trough may result partly from local ground-water seepage to streams, but is largely due to leakage of water downward to the Pocomoke aquifer through the "window" in the upper confining bed.

Whether the "window" from the Pleistocene to the Pocomoke is local, or is part of a buried channel cut down through the upper confining bed, can be determined by test drilling or possibly by seismic or resistivity surveys.

West of the Berlin Scarp the water table in the Pleistocene deposits in northeastern Worcester County (except for the Pocomoke River valley south of Masseys Crossing) is generally higher than the potentiometric surface of the Pocomoke aquifer. Consequently, in that area water must move downward from the Pleistocene deposits, through the leaky upper confining bed to the underlying Pocomoke aquifer. The Pocomoke aquifer probably receives much of its recharge there.

East of the Berlin Scarp, head conditions normally are reversed and considerable water from the Pocomoke probably leaks upward through the upper confining bed and into the Pleistocene deposits.

Areas of probable discharge from the Pocomoke to the Pleistocene also occur along the foot of the Berlin Scarp at Newark and east of Showell.

Water probably discharges upward from the Pocomoke aquifer into the Pleistocene deposits along the Pocomoke River valley from Masseys Crossing southward beyond the limits of the area. The head relationships favor such leakage in that area. Also, chemical analysis of a water sample (Test Hole Wi-Di 3) collected from the Pleistocene deposits at Purnell's Crossing indicated characteristics more similar to those of water from the Pocomoke aquifer than from the Pleistocene deposits. This conclusion is based on comparison of the analysis with the maps of chemical quality of ground water in the principal aquifers as presented by Cushing, Kantrowitz, and Taylor (1973).

The map of the potentiometric surface of the Pocomoke aquifer (fig. 10) is based primarily on water-level measurements made between 1960 and 1966. The few available recent measurements indicate little change in the potentiometric surface in general. However, no recent measurements of water levels in the Pocomoke aquifer are available for the Ocean City area, and any effects the recent large-scale seasonal withdrawals of water from the Ocean City aquifer may have had on the potentiometric surface of the Pocomoke aquifer are not known. Nevertheless, consideration of head relations between the Pocomoke and Ocean City-Manokin and the leakiness of the intervening confining bed suggests that the potentiometric surface of the Pocomoke aquifer is depressed seasonally due to vertical leakage from the Pocomoke to the Ocean City-Manokin aquifer system.

Ocean City-Manokin Potentiometric Surface

The potentiometric surface of the Ocean City-Manokin aquifer system (fig. 11) slopes east-southeastward about 1 foot per mile in northeastern Worcester County; the average gradient ranges from 0.85 foot per mile in the northern part to 1.13 feet per mile in the southern part.

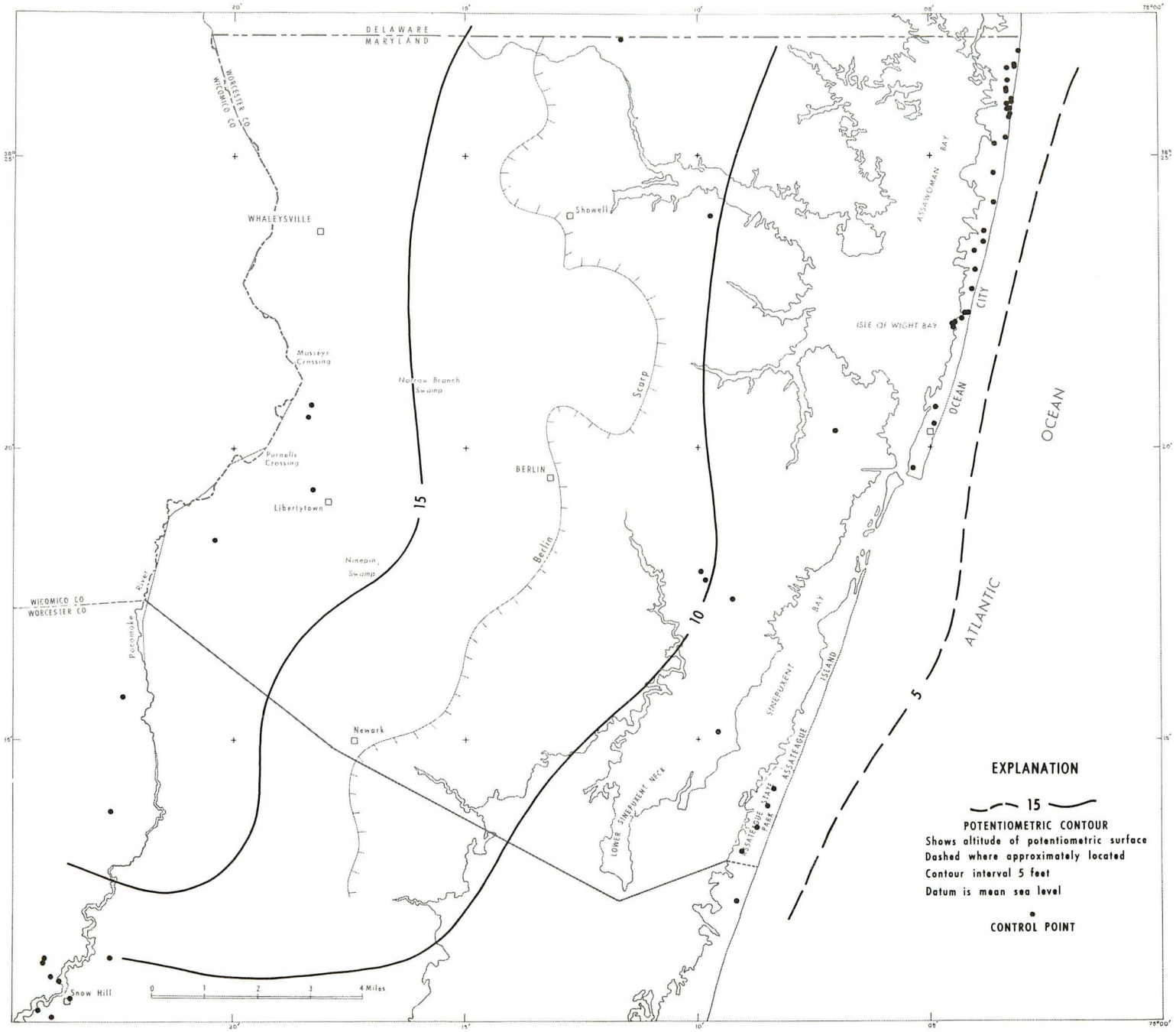


Figure 11.—Map showing potentiometric surface of the Ocean City-Manokin aquifer system before large-scale withdrawals were initiated at Ocean City.

In the western part of the area the artesian head in the Manokin is several feet lower than it is in the Pocomoke, and some recharge to the Manokin probably occurs there by vertical leakage from the Pocomoke aquifer. In the eastern part of the area the head formerly was several feet higher in the Manokin than in the Pocomoke, but since the development of the Ocean City-Manokin system as a source of water at Ocean City, head conditions there have reversed, and the head in the Manokin is much lower than it is in the Pocomoke. In summer the hydraulic head in the Manokin may be as much as 25 feet below the head in the Pocomoke. Consequently, the Manokin may be the seasonal recipient of considerable vertical leakage from the Pocomoke. If it is, then the Pocomoke potentiometric surface may be depressed compensatively during the summers. Unfortunately, no recent summer water-level measurements for the Pocomoke in the Ocean City area are available with which to test that possibility.

The effects of large-scale seasonal withdrawals of water from the Ocean City-Manokin aquifer system at Ocean City and of much smaller withdrawals from the Manokin in the vicinity of Assateague State Park, 7 miles south of Ocean City Inlet, are shown on a map that compares the potentiometric surface in summer and winter (fig. 12). As can be seen on the map, a cone of depression is centered around Ocean City during the summer with seasonal head declines as great as 20 feet. The effects of summer pumping extend several miles eastward and westward from Ocean City. If the potentiometric surface is depressed below sea level to a distance of 3 miles offshore, as assumed in constructing figure 12, it follows that shoreward movement of water occurs in the Manokin at least that far offshore during the summer months.

The partial recovery of the Ocean City-Manokin potentiometric surface at Ocean City between August 1971 and January 1972 (fig. 12) is shown in detail in the hydrographs of the observation wells in fig. 13.

CHANGES IN GROUND-WATER STORAGE

Fluctuations in the water table or potentiometric surface (fig. 13) indicate changes in ground-water storage resulting from changes in the balance between recharge and discharge. The discharge may be entirely by natural causes, or it may be increased by pumping water from the aquifer. Thus hydrographs, or graphs of water-level fluctuations, can be used to study not only short- or long-term effects of precipitation and long-term seasonal effects of evaporation and transpiration but also the response of water levels to large-scale changes in the rate of ground-water withdrawal. By knowing the rate and duration of pumping, the area and magnitude of influence and the time of response can also be studied.

In the area of investigation, the water table fluctuates in an annual cycle, generally rising during the autumn and winter and declining in late spring and summer. The annual water-table rise normally begins in late summer or autumn, but may be interrupted briefly in winter when the ground is frozen and when potential recharge is temporarily withheld as snow at the land surface.

The water table declines through the growing season. During that time some water is lost by direct evapotranspiration from the water table, in addition to ground-water discharge to streams. At the same time, recharge is reduced due to interception of precipitation by evapotranspiration. Hence, ground-water storage decreases through the growing season even though precipitation continues at about the same average monthly rate during that period.

Hydrographs of potentiometric-surface fluctuations in observation wells in the Ocean City-Manokin aquifer system in northeastern Worcester County (fig. 13) show a seasonal pattern of fluctuation very similar to that of the water table in the Pleistocene deposits. It might be argued that the similarity is due to the fact that maximum withdrawals from the Ocean City-Manokin system by pumping and from the Pleistocene by evapotranspiration occur at the same time; that is, during the summer. However, the similarity is apparent even where the observation wells are at considerable distances from the centers of withdrawal from the Ocean City-Manokin aquifer system (the Ocean City well fields).

It is possible that the similarity results at least in part from the changes in load on the Ocean City-Manokin aquifer system that accompany seasonal changes in saturated thickness of the Pleistocene deposits. The potentiometric surface of the Ocean City-Manokin system rises or falls with compression or relaxation of the skeletal structure of the aquifer. In this connection, note the effects of tidal loading on the potentiometric surface of the Ocean City-Manokin aquifer system

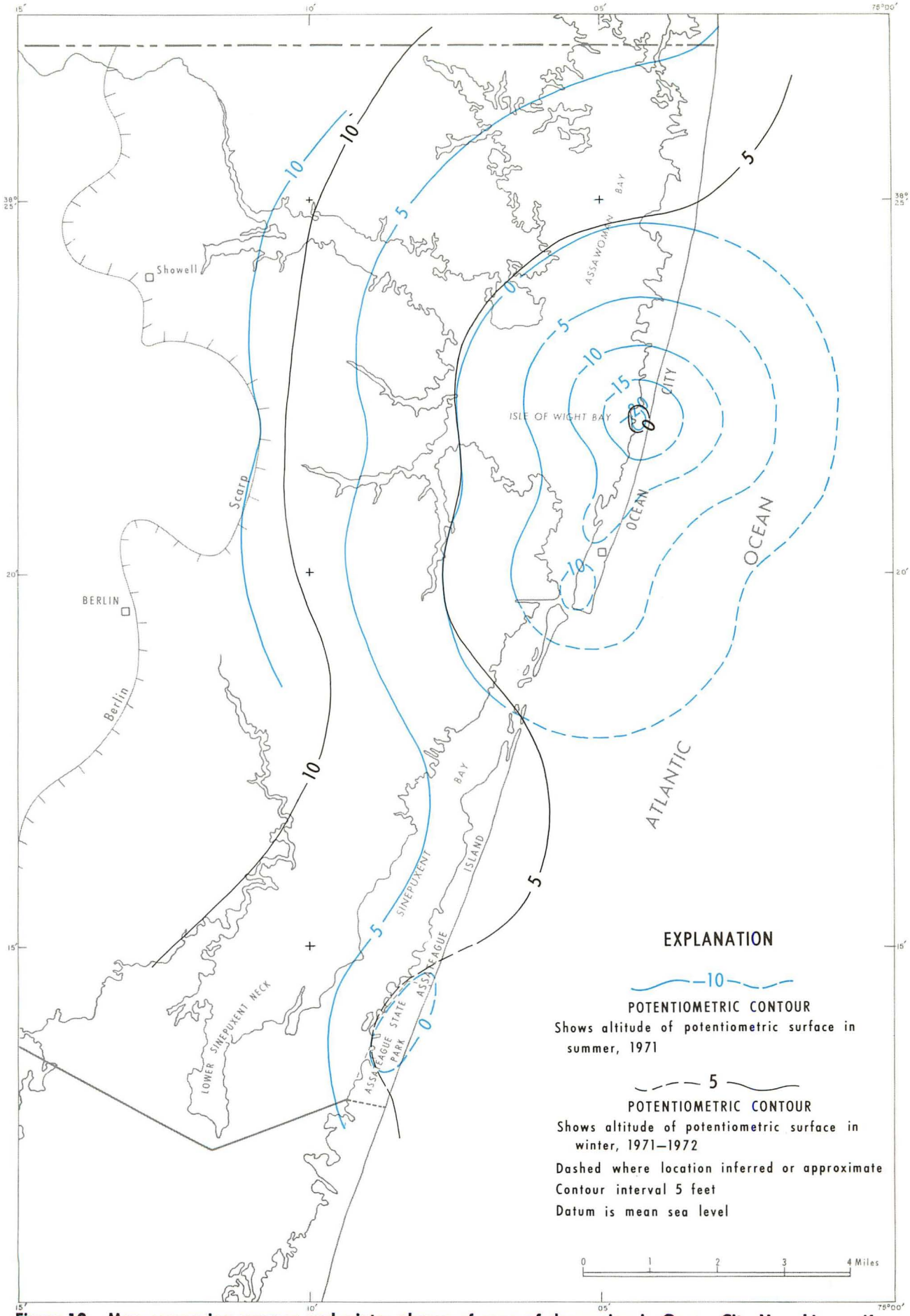


Figure 12.—Map comparing summer and winter phases of cone of depression in Ocean City-Manokin aquifer system.

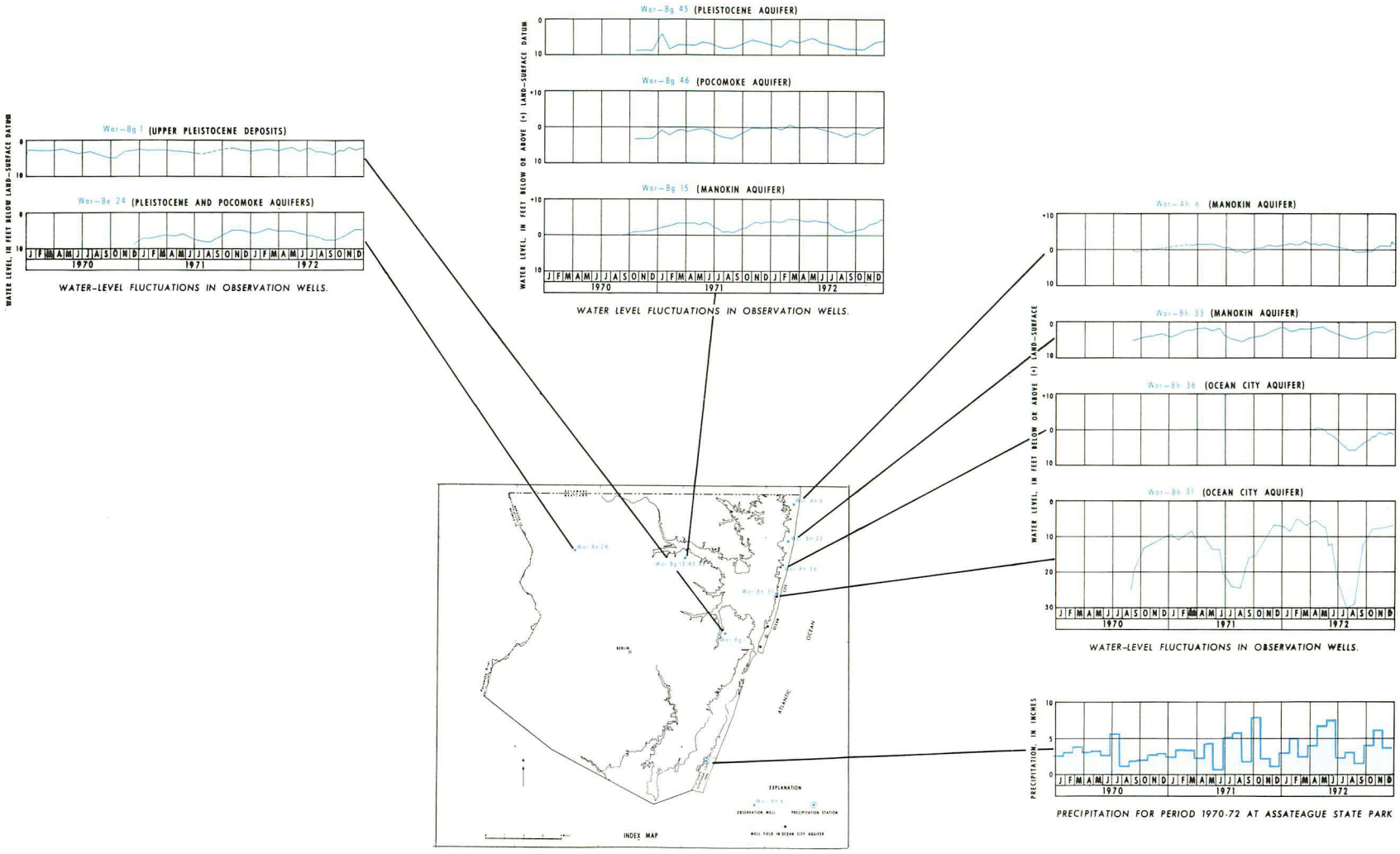


Figure 13.—Hydrographs of observation wells in northeastern Worcester County, Maryland

(fig. 14). The potentiometric surface of the Ocean City-Manokin aquifer system at Ocean City fluctuates throughout a range of from 1 to 1½ feet in response to normal tidal changes; inland, the fluctuations are smaller.

The Pleistocene and Ocean City-Manokin aquifers are hydraulically connected to some degree, even though the Pocomoke aquifer and two confining layers intervene between them. Changes in the water-table elevation represent changes in either the recharge head or discharge head controlling the entire system, and the Ocean City-Manokin head must follow the changes to some extent. For that reason hydraulic connection is another possible reason for the similarity in hydrographs. All these explanations may apply to this situation.

Hydrographs of observation wells were compared in determining the seasonal changes in extent and shape, and the seasonal recovery of the cone of depression developed in the Ocean City-Manokin aquifer system in the vicinity of Ocean City in response to changes in the rate of withdrawal of water there for public supply. The effects of seasonal increase and decrease in withdrawal are obvious in the hydrographs of observation well Wor-Bh 31 (at the edge of the northernmost well field in operation at the time of the investigation) and are decreasingly evident at wells Wor-Bh 36, Bh 33, and Ah 6, successively farther north-northeastward from the center of pumping. The hydrographs for observation wells Ah 6, 5 miles to the north-northeast; and Bg 15, 5½ miles to the northwest, are very similar to one another.

Short-term, detailed hydrographs (not shown) also were constructed from records of continuous water-level recorders in order to establish water-level trends and to isolate the effects of tidal fluctuations on the water levels in the Ocean City-Manokin system, as a step in conducting and interpreting the results of aquifer tests at the sites of wells Wor-Ah 22 and 23, and Bh 81 at Ocean City.

Year-long graphs of water-level fluctuations in the Pocomoke potentiometric surface at one or more locations at or near Ocean City would be of considerable value in determining the effectiveness of the Ocean City-Manokin cone of depression in inducing downward leakage from the Pocomoke aquifer to the Ocean City-Manokin aquifer system.

CHEMICAL QUALITY OF GROUND WATER

The chemical quality of water in the Manokin, Ocean City, Pocomoke, and Pleistocene aquifers in northeastern Worcester County generally is acceptable for most uses.

Measured temperatures of ground-water in northeastern Worcester County range from 11 to 22 degrees Celsius (52 to 71½ degrees Fahrenheit), and increase with depth. About 80 miles to the west in southern Maryland, ground-water temperatures at 100 feet below sea level are about 15 degrees Celsius (59 degrees Fahrenheit), and increase at a rate of about ⅘ degree Celsius (1½ degrees Fahrenheit) for each additional 100 feet of depth to at least 700 feet below sea level (Weigle, Webb, and Gardner; 1970).

Thirty samples of ground-water were collected and analyzed during the investigation. The results of those and earlier analyses are shown in Table 4.

The ranges in standard use by the U. S. Geological Survey for classifying hardness of water are:

Hardness range (mg/l of $CaCO_3$)	*Description*
0 - 60	Soft
61 - 120	Moderately hard
121 - 180	Hard
More than 180	Very hard

The analyses in Table 4 indicate the water in the Pleistocene aquifer is soft to moderately hard (hard locally, near the ocean). As a whole the water from this aquifer is slightly acidic; that is, the median pH of the 18 samples that were tested is 6.85 as compared with a neutral pH of 7.0. The chloride content of 32 samples averaged 19 mg/l (milligrams per liter), ranging from 3 to 66 mg/l. The chloride content is much higher than average

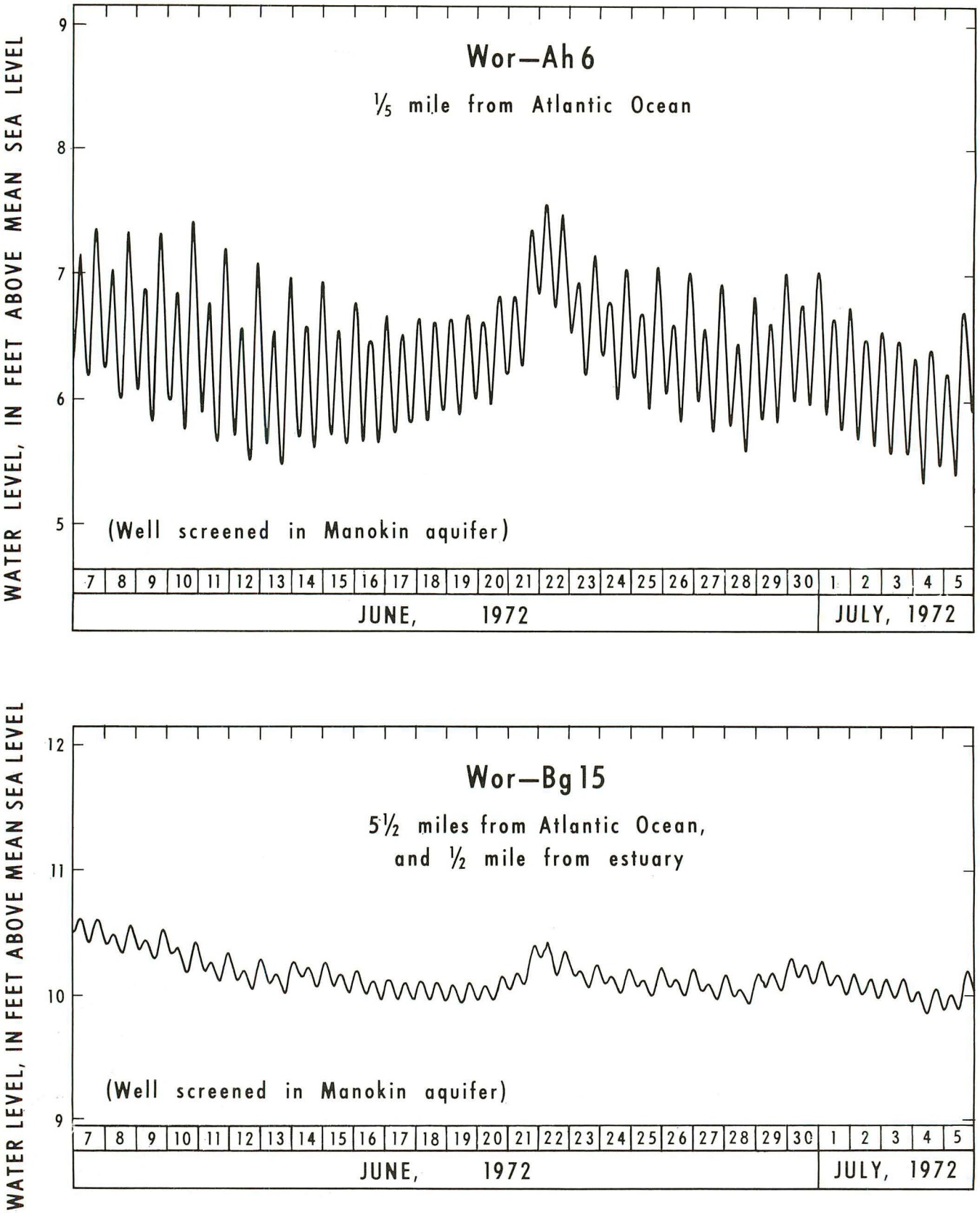


Figure 14.—Hydrographs of two wells showing effects of tidal loading on the potentiometric surface of the Ocean City-Manokin aquifer system.

locally, near the ocean and tidal marshes.

The water in the Pocomoke aquifer is slightly alkaline (the median pH of the 5 samples that were analyzed is 7.3), and the water is soft to moderately hard (hard locally, near the ocean). The chloride content of 5 samples averaged 15 mg/l, ranging from 12 to 20 mg/l.

Water in the Ocean City and Manokin aquifers, based on 8 analyses, is moderately hard to hard and is slightly alkaline (the median pH is 7.5), possibly more alkaline with depth. The chloride content is somewhat higher than in the upper aquifers; it averaged 33 mg/l and ranged from 7.5 to 59 mg/l. An additional sample, from between 464 and 474 feet deep in the base of the Manokin at well Wor-Ah 6 in Ocean City and presumably close to the base of fresh water, contained 296 mg/l chloride. In that sample concentrations of not only chloride but calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, fluoride, and dissolved solids were higher; and hardness, specific conductance, and alkalinity were greater, than in water from the Ocean City aquifer and the main part of the Manokin aquifer.

The chemical quality of ground water in Somerset, Wicomico, and Worcester Counties was described and discussed comprehensively by Rasmussen and Slaughter (1955). In the present investigation emphasis is placed on iron content and on chloride content as it relates to salty water, because they are considered to be the most critical of the chemical-quality factors in northeastern Worcester County.

IRON

Objectionably high concentration of iron (more than 0.3 mg/l) in ground water is a widespread problem in northeastern Worcester County. None of the aquifers offers a general escape from the problem. The average concentrations and ranges in the various aquifers are similar: for the Pleistocene (33 samples) an average of 4.5 mg/l and range of 0.02 to 25 mg/l; for the Pocomoke (5 samples) an average of 3.7 mg/l and range of 0.58 to 13.0 mg/l; and for the Ocean City-Manokin system (9 samples) an average of 4.1 mg/l and range of 0.02 to 13.0 mg/l.

Water containing iron concentrations greater than 0.3 mg/l, although not harmful to health, is considered undesirable because of the tendency to stain plumbing fixtures, cooking ware, and clothing washed in the water. Some form of treatment is generally desirable for water where iron-content exceeds 0.3 mg/l, if domestic use is planned.

The Pleistocene aquifer is the most readily accessible and most commonly used source for domestic water supplies in northeastern Worcester County. However, knowledge of the concentration of iron in water to be found in the Pleistocene aquifer at specific sites is, at best, meagre prior to drilling. For that reason, the areas in northeastern Worcester County where undesirable concentrations of iron are most likely to occur in water in the Pleistocene aquifer are shown on the map in figure 15. The map is based on chemical analyses shown in Table 4 (this report), and on qualitative reports of iron content included in Table 40, Rasmussen and Slaughter (1955).

Attempts to correlate the concentration of iron in water, with depth in the Pleistocene aquifer or with surface-drainage conditions, produced inconclusive results.

Available analyses were not sufficient to permit construction of iron-distribution maps for the other aquifers. However, it is unlikely (though possible) that unacceptably high concentrations of iron (more than 0.3 mg/l) occur in all three aquifers at identical sites.

SALTY WATER

Water containing more than 250 mg/l chloride tastes salty to most people; and the greater the concentration, the saltier the taste. In this report, a concentration of more than 250 mg/l signifies salty water, as opposed to fresh water.

In northwestern Worcester County water from 50 feet below land surface down to the base of the Manokin is fresh with few exceptions, and ground water above 50 feet is fresh in most of the area.

Pleistocene Aquifer

Salty water in the Pleistocene aquifer is limited to areas near the ocean or tidal marshes. There, salty water is probably common (although not general) in the leaky confining bed occurring in the uppermost few tens of feet of sediments, but in the Pleistocene aquifer (at depths greater than 40 to 50 feet) its occurrence is localized.

Salty water occurs in the Pleistocene aquifer beneath Ocean City in two areas — about ⅔ of a mile and 6 or 7 miles south of the Delaware line. On the section shown in figure 16 the northern area is about 0.8 mile wide and lies between 45

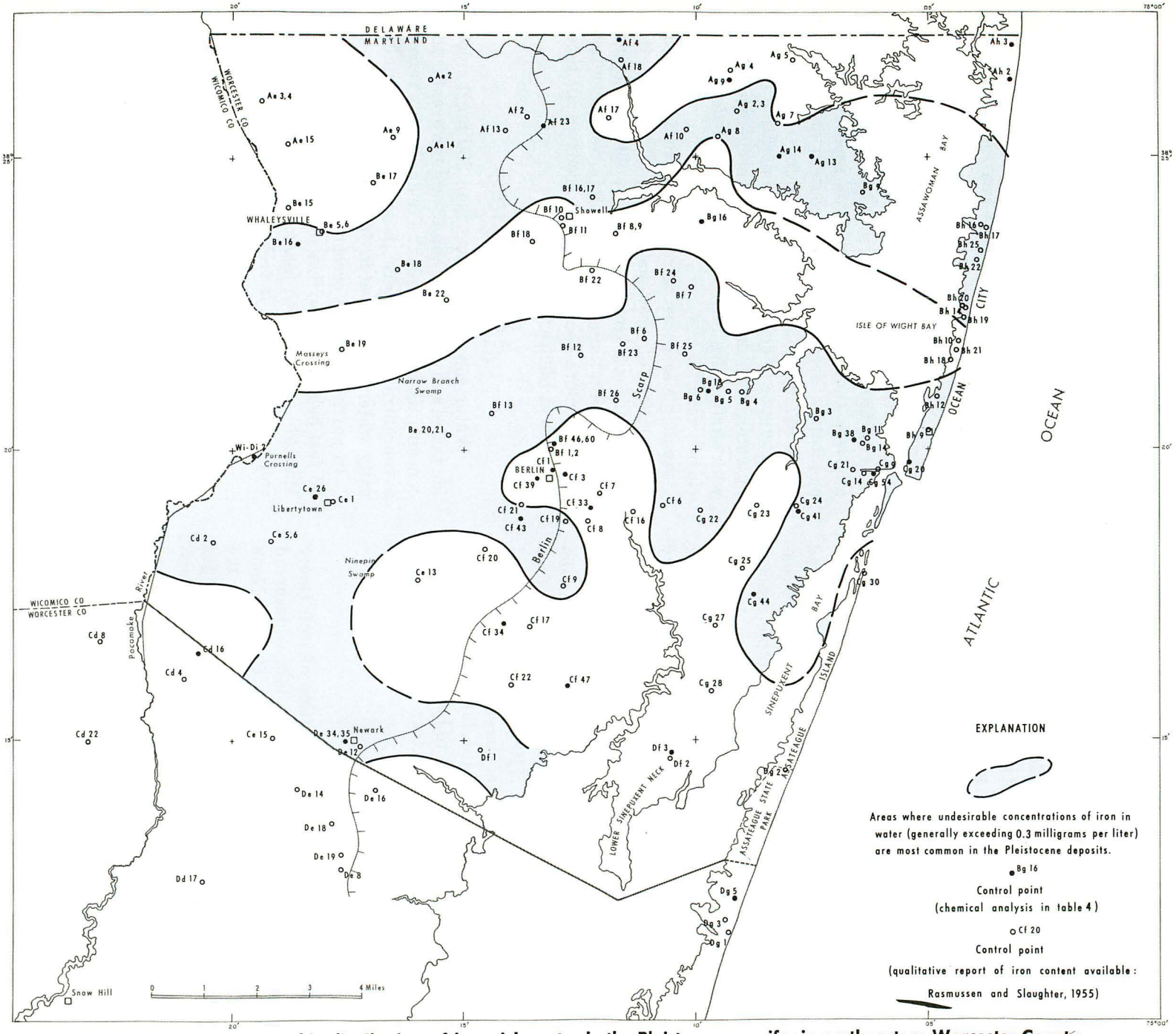


Figure 15.—Map showing geographic distribution of iron-rich water in the Pleistocene aquifer in northeastern Worcester County.

and 120 feet below sea level; the southern area is about 1.6 miles wide and lies between 30 and 120 feet below sea level.

The east-west extent of those bodies of salty ground water and their origin, persistence, and stability are not known. However, salty tasting water was obtained from a sample of saturated sand augered from between 90 and 95 feet below sea level, in test hole Wor-Bg 42, 4 miles west of the southern area, across and about ½ mile from Assawoman Bay.

Water reported to have tasted slightly salty was obtained from samples of saturated sand augered from depths of 16 to 26 feet and 56 to 61 feet below sea level 2 miles southeast of Berlin in test hole Wor-Cf 49.

Water at depths of 50 feet or more in the Pleistocene aquifer generally is reasonably well sealed off from nearby surface sources of salty water. The two instances of salty ground water in the Pleistocene aquifer in Ocean City, noted above, probably resulted when sea water entered through "windows" of permeable material in the 40 to 50-foot thick blanket of generally fine materials above the Pleistocene aquifer, under or adjacent to the ocean or bay. Unsuspected "windows" may occur elsewhere, along or beneath the bays or along the eastern shore of Assateague Island, originating as old gravel-filled channels in the fine materials or perhaps as reworked and winnowed deposits on the Atlantic side of the island.

Figure 9 shows the 5-foot contour on the water table near the coast. A 3-foot head of fresh water is sufficient to keep sea water down to a depth of 120 feet, which is approximately the depth of the base of the Pleistocene aquifer there. If salt water occurs in the Pleistocene aquifer offshore, then, the 3 to 5-foot fresh-water head at the coast probably supplies force sufficient to keep the salt water from beneath the land surface in the Pleistocene aquifer. However, if large-scale withdrawals of water from that aquifer reduce the 3 to 5 foot head at the coast, sea-water intrusion may result.

Normally, recharge from the land surface and lateral movement of fresh ground-water tend to preclude or eliminate salt water from the Pleistocene aquifer beneath the land areas. However, large-scale withdrawals of water from the Pleistocene aquifer near the ocean or tidal marshes may reverse the head relationships locally and encourage salt water to enter the aquifer through thin or leaky parts of the overlying "seal," or to move laterally shoreward from salty parts of the aquifer offshore.

Pocomoke Aquifer

There is no known instance of salty water in the Pocomoke aquifer in northeastern Worcester County. It is assumed that the salt-water/fresh-water interface is farther offshore in the Pocomoke than it is in the Manokin.

Although the Pocomoke is free of salt water in northeastern Worcester County, to the best of available information, it is probably susceptible to contamination by salt water indirectly through the Pleistocene aquifer in areas near salt water where: (1) the normally intervening upper confining bed is absent or inefficient as a confining layer and, (2) the overlying Pleistocene aquifer is poorly sealed off from nearby or adjacent salt water.

Ocean City-Manokin Aquifer System

The lower limit of fresh water in the sediments of northeastern Worcester County is approximately at the contact between the Manokin aquifer and the St. Marys Formation. This conclusion is based on chemical analyses of water samples from wells Wor-Ah 6 and Dg 8; and interpretation of electrical-resistivity logs at Wor-Ae 19, Ah 6, Bh 81, Ce 28, and Dg 8, all of which penetrated the entire thickness of the fresh ground-water zone.

Salty water occurs in the bottom few feet of the Manokin aquifer under northern Ocean City, but the salty zone apparently thins southward beneath Ocean City and is absent from the Manokin in the western part of the area. If salty water is present at all in the Manokin beneath the southeastern corner of the area, it probably is restricted to the basal 10 feet or less of the aquifer.

The Ocean City-Manokin aquifer system may be susceptible to contamination by salt water indirectly through the Pleistocene and Pocomoke aquifers in areas near salt water where: (1) the head in the Ocean City-Manokin system is depressed sufficiently below that in the Pocomoke and, (2) both the upper and lower confining beds of the Pocomoke are absent or are inefficient as confining layers, and (3) the Pleistocene aquifer is poorly sealed off from adjacent or nearby salt water. That is, some salt water may enter the Ocean City-Manokin system through the Pleistocene and Pocomoke aquifers in the northeastern part of the area during summer, when the cone of depression centered at Ocean City expands radially beneath Assawoman and Isle of Wight Bays and the ocean.

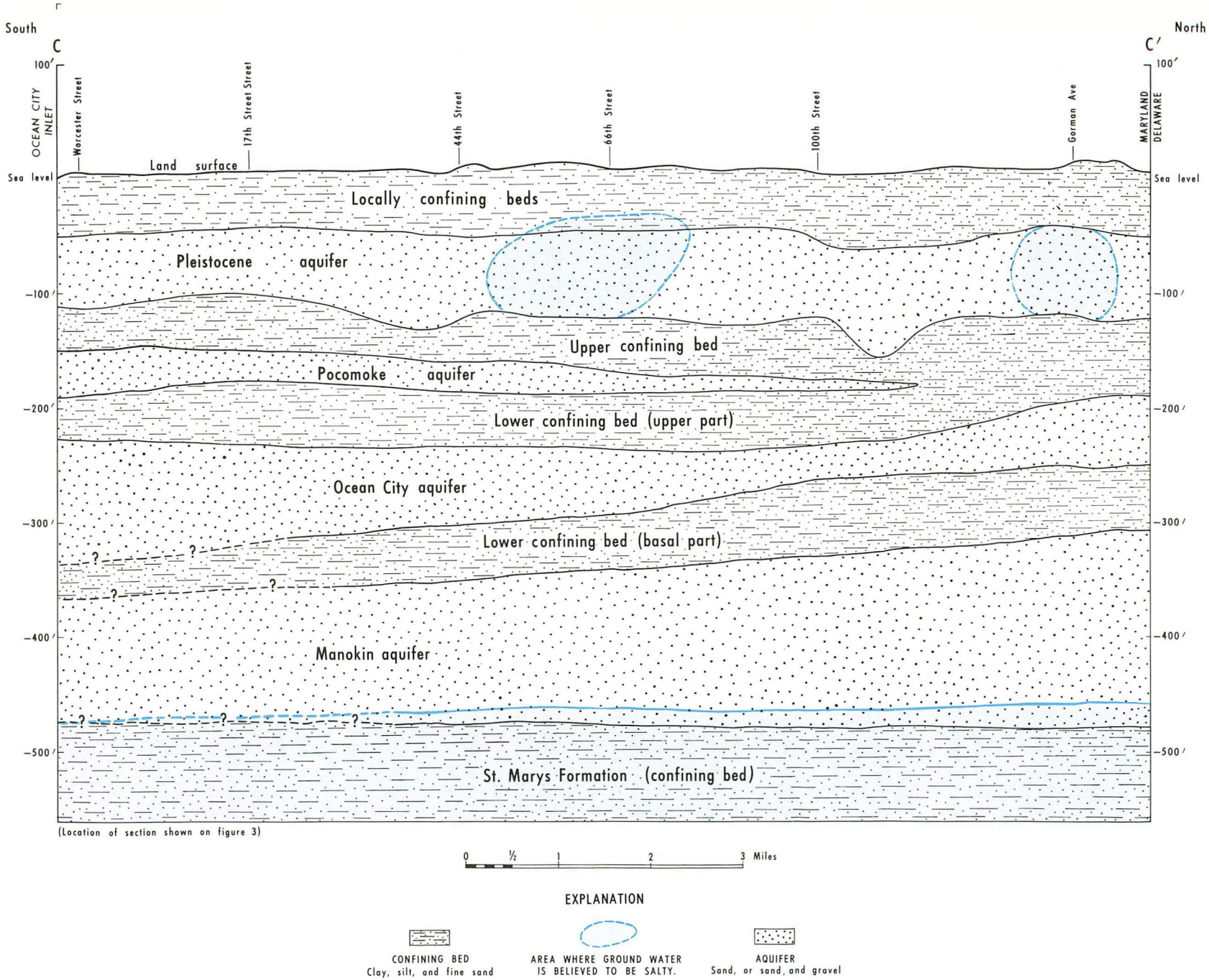


Figure 16.—Generalized section showing aquifers, confining beds, and vertical distribution of salty ground water beneath Ocean City.

Figure 12 shows an elliptical area about 6 miles wide and 8 miles long in which the potentiometric surface of the Ocean City-Manokin system is drawn down below sea level, or 5 to 25 feet below the potentiometric surface of the Pocomoke, permitting vertical leakage from the Pocomoke down through the lower confining bed — particularly where the bed is thin or permeable. Such leakage may induce compensatory vertical leakage from the Pleistocene aquifer down through permeable places in the upper confining bed, thence into the Pocomoke where it is available for vertical leakage into the Ocean City-Manokin system. Thus, the cone of depression formed in the Ocean City-Manokin potentiometric surface may eventually cause a reduction in head in the Pleistocene aquifer, which in turn may induce overlying or adjacent salty water to enter the Pleistocene aquifer through relatively permeable parts of the seal at its top.

In summary, the seasonal cone of depression produced by pumping from the Ocean City-Manokin system may produce head reductions in the overlying aquifers and confining beds, providing the mechanism for movement of salty water from the ocean and bays down into the Ocean-City-Manokin aquifer system.

Salty water may also enter the Manokin aquifer from the underlying St. Marys Formation. Assuming the St. Marys Formation is saturated with salty water (as the aquifers beneath it are), the contribution to the Manokin could be regional, wherever the head in the Manokin were to be lowered sufficiently.

However, the St. Marys Formation is about 160 feet thick in northeastern Worcester County, and its materials are consistently fine (silt, fine sand, and clay). The formation is a poor prospect for yielding water, or for transmitting water upward from the lower aquifers. Thus even in the event of very large-scale withdrawals of water from the Manokin and corresponding head reductions in the Manokin, the quantity of water contributable by the St. Marys Formation probably would be so small relative to the quantities of water obtainable from the Manokin and the overlying aquifers that its effect on the overall chemical quality of water from the Manokin would be negligible.

A source of salt-water contamination, potentially very important to Ocean City, lies within the Manokin itself. Somewhere offshore from Ocean City and Assateague Island, the entire thickness of the Manokin aquifer is occupied by salt-water. How far offshore the interface between the fresh water and salt water lies is not known, but its proximity is of critical concern to those responsible for the future of Ocean City water supplies. That aspect is discussed further in the section on Ocean City.

Salt-water Interface: The salty water in the fine materials at the base of the Manokin aquifer beneath Ocean City may be the toe of the fresh-water/salt-water interface in the Manokin; that is, the thin edge of an eastward-thickening wedge of salt water. However, the toe of the salt-water wedge may be farther offshore. The slightly salty nature of the water in the basal 10 or 20 feet of the Manokin may be residual from much earlier salty water, not yet completely flushed from the fine, poorly permeable materials by subsequent movement of fresh water seaward through the Manokin. Or, the salty water may have leaked upward from the underlying St. Marys Formation. If either of the latter explanations is true, salty water in the fine materials at the base of the Manokin aquifer may persist seaward for miles before the toe of the salt-water interface is encountered stratigraphically higher, in the more permeable part of the aquifer.

If fresh water and static sea water meet at a sharp interface within an aquifer the fresh-water head at points along the interface must be related to the depth of the interface below sea level, according to the equations given by Hubbert (1940, p. 868-869). Applied to conditions in the Manokin aquifer at Ocean City, these relations indicate that the fresh-water head at the base of the aquifer should have been about 12 feet above sea level prior to pumping if the salty water at the base of the aquifer actually represented the toe of a static sea-water wedge. The average prepumping head in the Ocean City-Manokin system in this area was 6 or 7 feet, and it is possible that the head at the base of the aquifer was as much as 12 feet. However, this evidence is not sufficient to indicate conclusively that the salty water actually does represent the toe of a sea-water wedge. The assumptions inherent in Hubbert's analysis may not actually have been satisfied; for example the sea water may not have been static prior to pumping, and the transition from fresh water to salt water in the aquifer was probably gradual, rather than sharp. Thus it is not possible to say with certainty whether or not the salty water at the base of the Manokin actually represents the toe of a sea-water wedge.

AVAILABILITY OF WATER

Fresh water in northeastern Worcester County is available from precipitation, from streams, and as ground water occurring under water-table and confined conditions.

About 130 mgd is estimated to be available from streamflow, but the streams are sluggish, subject to contamination, and limited in their accessibility. Furthermore, streamflow fluctuates greatly, and the local topography generally does not lend itself to large-scale impoundment of water by damming.

It is estimated that about 90 mgd (representing the average quantity of ground water discharging to the streams) is available under water-table conditions in shallow surficial deposits, predominantly of Pleistocene age.

Deposits of Pleistocene age, generally less than 130 feet thick, supply most of the domestic needs of the mainland. Locally, however, especially in the western part of the area, the Pleistocene deposits are thinner and less permeable, and the available drawdown generally is not sufficient to support large yields. Also, in some places, surface contamination and salt-water encroachment are potential hazards. Nevertheless, in most of the mainland area it is probably feasible to develop large to very large supplies (500 to 2,000 gpm) of fresh water from these deposits, particularly where their saturated thicknesses are greatest or where wells are located near streams with high base flow.

Underflow in the deeper artesian aquifers is less than it is in the shallow deposits, but the amount of water in storage is much greater in the deeper aquifers. Although the annual replenishment of water to the artesian aquifers is small, the large available drawdown, dependability, and relative freedom from contamination favor dependence upon those aquifers as sources of water.

GROUND-WATER YIELDS

Yields, as discussed in this report are (1) short-term, (2) long-term, or (3) indefinitely sustainable. Short-term yields are those maintainable for several hours at a time, with longer intervening periods of no pumping. Long-term yields are those maintainable for a number of years, assuming withdrawal chiefly from storage and a gradually declining head. Indefinitely sustainable yields are those maintainable indefinitely, assuming withdrawal is dependent only on normal and induced perennial ground-water underflow and vertical leakage.

SHORT-TERM POTENTIAL YIELDS

Short-term yields are of significance primarily to those who wish to obtain water on an intermittent rather than a sustained basis, and who plan to withdraw ground water during only a small fraction of the total time.

The yield maps indicate potential short-term yields from wells tapping the Pleistocene, Pocomoke, and Manokin aquifers. These yields are not the theoretically attainable upper limits. Rather, all but the greatest yields could generally be obtained from wells 6 inches or more in diameter (subject to mechanical limitations of modern pumps) if the wells were screened, gravel-packed, properly developed, and penetrated the total effective part of the aquifer. The method of determining the yields is outlined by Weigle, Webb, and Gardner (1970).

The yields indicated on the maps do not allow for possible interference from adjacent wells, or for slow cumulative drawdown effects during extended periods of pumping. Both factors can and do become important locally, and pose problems where withdrawals are sustained. The yields indicated are additive at any given point. That is, at a site where the potential short-term yields from the Pocomoke and Manokin aquifers are 300 gpm from each aquifer, the total for wells screened in both aquifers is 600 gpm.

The maps are based on well specific-capacities adjusted upward for complete penetration of the effective aquifer thickness and for utilization of available drawdown. Most of the specific capacities used in the study are based on pumping-test data submitted by well drillers. The potential yields indicated on the maps may be conservative

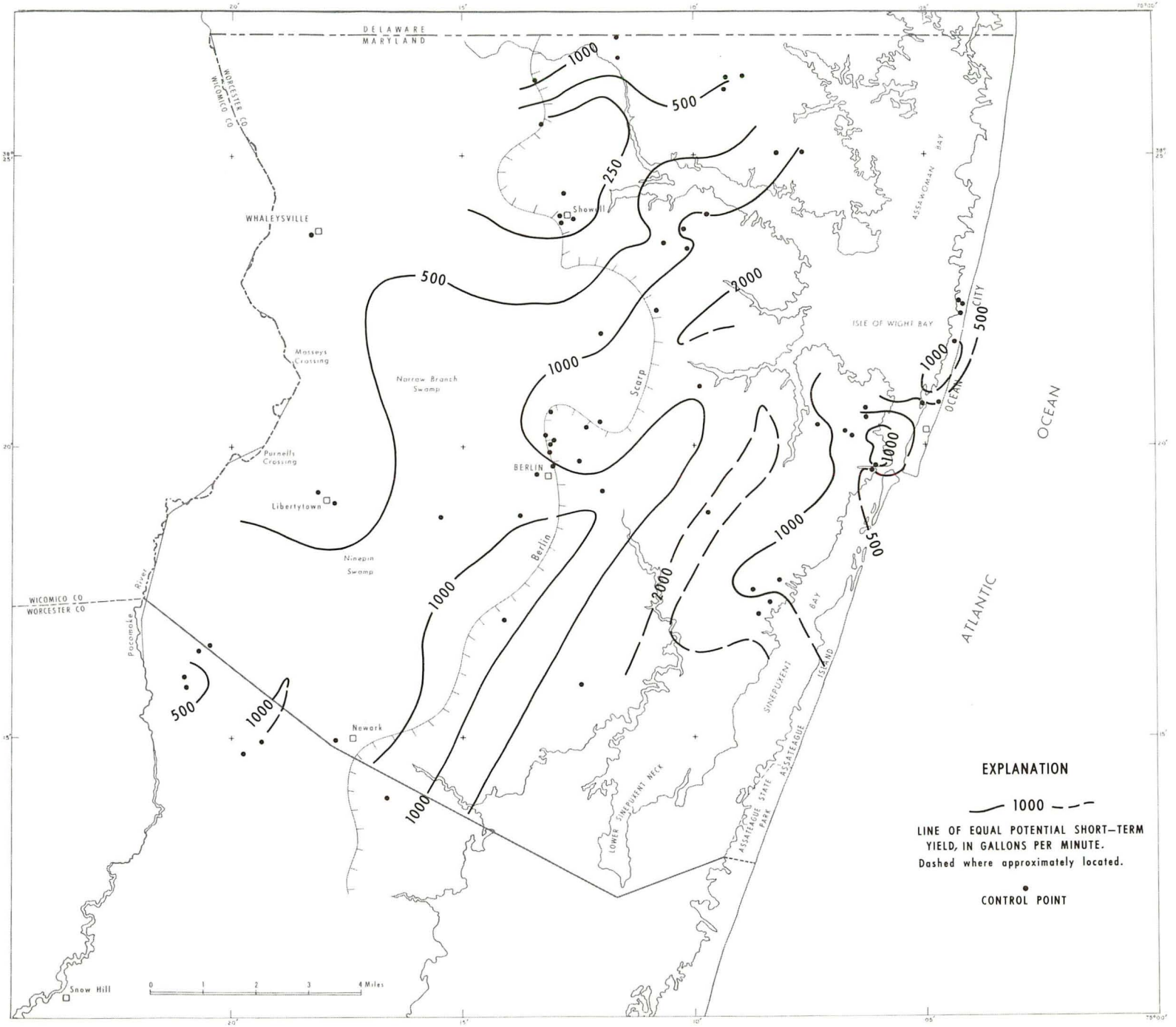


Figure 17.—Map of potential short-term yields available from the Pleistocene aquifer.

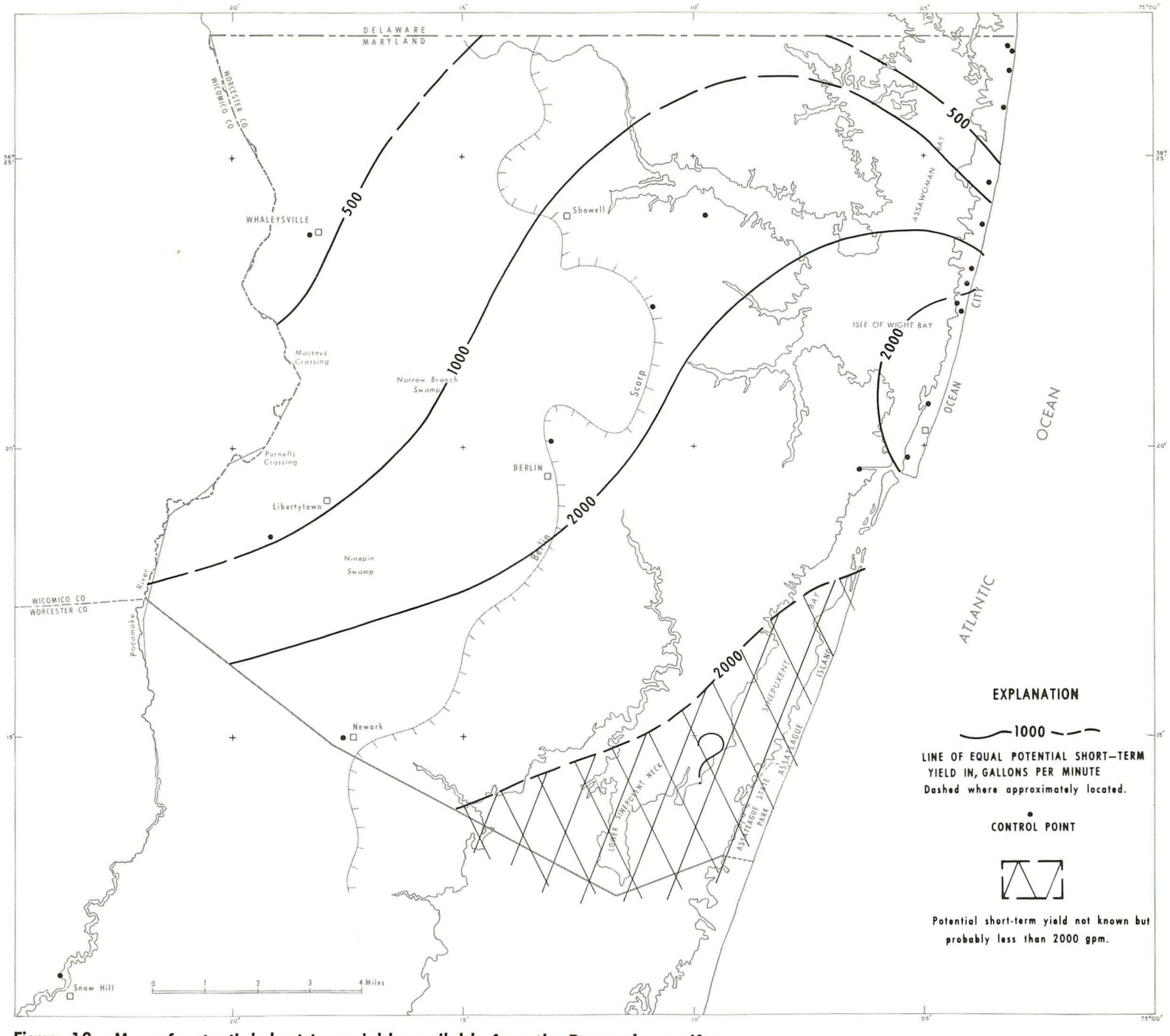


Figure 18.—Map of potential short-term yields available from the Pocomoke aquifer.

in some areas because only three fourths of the drawdown available to the tops of the aquifers was used in computing the potential yields from the adjusted specific capacities. This was done to allow for decreases in well efficiency and specific capacity resulting from increased yield, for the variation in available drawdown caused by differences in land-surface elevation and the dip of the aquifer, and for the probably imprecise nature of some reported data.

The potential short-term yields computed for the Pleistocene aquifer are more conservative than those computed for the other aquifers. Only that part of the Pleistocene deposits more than 50 feet below land surface was considered in the calculations; the deposits in the uppermost 50 feet were disregarded because of their generally lower productivity and greater susceptibility to contamination from the land surface. The values for available drawdown and effective aquifer thickness were somewhat minimized thereby, and this was reflected in the values computed for the potential short-term yields.

Pleistocene Aquifer

In most of the area the potential short-term yields from wells tapping the Pleistocene aquifer are greater than 500 gpm (fig. 17); in the eastern half, they are greater than 1,000 gpm and locally exceed 2,000 gpm.

In the northwestern part of the area the Pleistocene deposits are thinner and an increasing proportion of the total thickness of the Pleistocene deposits is composed of back-bar, lagoonal deposits of fine-grained materials. There, the potential yields from the Pleistocene aquifer are less than 500 gpm generally and less than 250 gpm locally. Near Whaleysville, the Pocomoke aquifer occurs at depths where the Pleistocene aquifer normally is found.

Pocomoke Aquifer

The Pocomoke aquifer does not occur beneath northern Ocean City. Elsewhere, the potential short-term yields of wells tapping the aquifer increase southeastward from about 500 gpm in the northwestern part of the area (fig. 18) to more than 2,000 gpm in a belt about 4 miles wide south of Berlin, extending from Newark northeastward to the Isle-of-Wight Bay. Southeast of that belt the potential yields are not known, but are probably less than 2,000 gpm and decrease southeastward.

Ocean City-Manokin Aquifer System

Potential short-term yields greater than 1,000 gpm are available from wells in the Ocean City-Manokin aquifer system everywhere in northeastern Worcester County except possibly in the extreme southeastern part (on Assateague Island and the southern tip of Lower Sinepuxent Neck) (fig. 19). Yields greater than 12,000 gpm may be available in the northern part of the area. The larger yields are available, but obviously could be obtained only from very large-diameter wells (more than 1 foot and perhaps several feet in diameter) or from well fields, because of pump limitations.

The calculated potential short-term yields from the Ocean City-Manokin system at Ocean City are somewhat erratic. Locally, potential yields are relatively low, but larger yields are generally available nearby. In the southernmost 2½ miles of Ocean City, potential yields are mostly less than 8,000 gpm; in the northernmost 6 miles, they are greater than 8,000 gpm. Probably, the variability in yields is related to the fact that materials in the Ocean City aquifer are finer beneath parts (especially the southern end) of Ocean City than they are to the west, and to variability in effectiveness of hydraulic connection between the component layers of the Ocean City-Manokin system.

LONG-TERM POTENTIAL YIELDS

The maps of potential short-term yields, discussed above, do not take into account the possible effects of nearby wells that might tap the same aquifer. If wells were to be pumped for extended periods, local cones of depression would develop in the potentiometric surfaces of the corresponding aquifers, and would expand if pumping were maintained. In time (depending on their proximity) the cones of depression would merge, and the drawdown effect would then be compounded, with resulting decrease in yields. Therefore, for long-term yields well spacing is a critical factor.

Long-term yields from wells are affected also by ground-water underflow within the aquifers, proximity of permeability barriers, and vertical leakage. Underflow is discussed under "Indefinitely Sustainable Yields". The presence of perme-

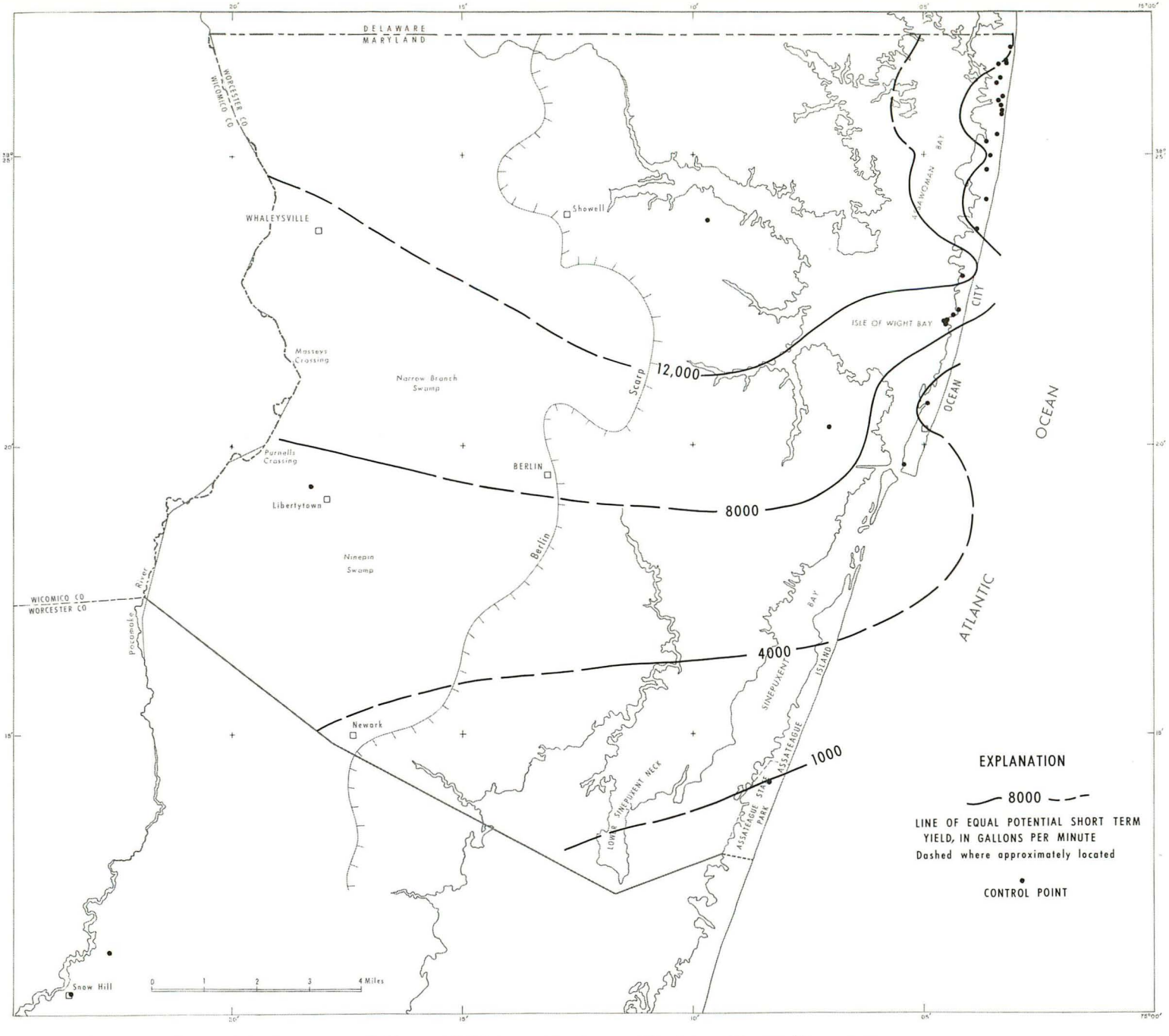


Figure 19.—Map of potential short-term yields available from the Ocean City-Manokin aquifer system.

ability barriers is not well known. The extent of vertical leakage in northeastern Worcester County is probably large, and potentially very large.

Results of aquifer tests at wells Wor-Ah 33 and 34 in Ocean City, in which water was withdrawn from the Manokin at 1.1 mgd for 20 hours, suggest that the relative importance of vertical leakage during the tests was small. However, hydrographs (fig. 13) of observation wells throughout the area suggest vertical leakage in the Ocean City area becomes important in a matter of months or less when 4 to 5 mgd of water are withdrawn continuously from the Manokin.

The quantities of water induced by vertical leakage from other aquifers and by lateral flow within the aquifer increase as drawdown produced by withdrawal from the Ocean City-Manokin system increases. Similar effects probably would result from large-scale withdrawals from the Pocomoke aquifer.

As the cone of depression in the Manokin expands and deepens, increased head differences cause an increased leakage from the confining beds. Also, as the cone widens it embraces more "pipes" or "windows" (areas where the confining beds are absent, or are thinner or sandier and therefore less effective as hydraulic barriers) that permit greater leakage from the overlying Pocomoke aquifer through the intervening confining beds. Presumably the consequent withdrawal of water from the Pocomoke aquifer by vertical leakage results in a cone or cones of depression in the Pocomoke, similarly inducing localized vertical leakage to the Pocomoke from the overlying Pleistocene aquifer through the intervening confining beds. Ultimately, large-scale long-term withdrawal of ground water from the Manokin probably would reduce streamflow somewhat by capturing some recharge that normally would be rejected as surface runoff and evapotranspiration.

Evaluation of the individual factors involved and determination of potential long-term ground-water yields; and prediction of the composite, multistage cone of depression that probably would result from long-term large-scale withdrawal of ground water from the Manokin in northeastern Worcester County, are beyond the scope of this report. Analysis by analog or digital model, however, might lend itself well to such a study.

INDEFINITELY SUSTAINABLE YIELDS

Indefinitely sustainable yields involve no net reduction in ground-water storage as they depend on utilization of the natural discharge from aquifers (underflow from artesian aquifers, and discharge to streams or by evapotranspiration from water-table aquifers).

The ground-water underflow in the artesian fresh-water aquifers at line I-I′ (fig. 3) was estimated using a modification of the Darcy equation as follows:

$$Q = T\,I\,L$$

where: Q = ground-water discharge, in cubic feet per day.

T = transmissivity, in feet squared per day.

I = hydraulic gradient, in feet per mile.

L = length, in miles, of the vertical section through which the flow occurs.

The appropriate transmissivities are shown in figures 6 and 8; and the hydraulic gradients can be computed from the slopes of the water table and potentiometric surfaces (fig. 9, 10, and 11). Line I-I′ (fig. 3) is 17 miles long. In this computation vertical leakage to or from the aquifer is neglected (unrealistically).

By use of the modified Darcy equation, underflow in the Pocomoke and Ocean City-Manokin aquifers across line I-I′ is estimated to be respectively 1.5 and 2.0 mgd — a total of 3.5 mgd (table 5). That much water could be withdrawn along line I-I′ without affecting the volume of water in storage, because the underflow is not destined to remain there even under natural conditions. However, if that underflow were withdrawn there it could not be withdrawn elsewhere in the area.

This method of analysis is not applicable to the Pleistocene aquifer. Natural discharge from water-table aquifers is to streams and by evapotranspiration; only a very small part is underflow.

It is estimated that the average quantity of ground water discharging to streams in northeastern Worcester County is about 90 mgd as indicated by base-flow data for Maryland and Delaware and by the local terrain and surficial geology. That is, at least that much water is available from the Pleistocene aquifer without reduction of storage.

The estimated 90+ mgd perennial yield from the Pleistocene aquifer is many times greater than the total underflow or perennial yield from the

artesian fresh-water aquifers (table 5). Probably the total fresh ground water available on an indefinitely sustainable basis in northeastern Worcester County exceeds 100 mgd.

If the potentiometric surfaces of the Manokin and Pocomoke aquifers were drawn down everywhere to the tops of the respective units (see maps of tops of aquifers in Rasmussen and Slaughter, 1955; and Cushing, Kantrowitz, and Taylor, 1973) by withdrawal of water through many closely spaced wells, the hydraulic gradients would be increased and the total potential underflow might be increased, but it would be at the expense of encouraging landward movement of salt-water in the aquifers.

However, the situation at Ocean City (see below) shows that underflow is not necessarily the whole story. The predicted yields may be much greater when other factors, such as vertical leakage of captured streamflow and water normally lost by evapotranspiration, are considered.

Indefinitely sustainable yields represent the total quantities available perennially from *all* sources except from storage.

Table 5.—Computation and summary of underflow in artesian fresh-water aquifers beneath line I-I′ (location on fig. 3) in central northeastern Worcester County, Maryland.

Aquifer	(ft^2 per day) T	×	(ft. per mile) I	×	(miles) L	=	(cfd · 10^6) Q	(gpd · 10^6)
Pocomoke	4,800	×	2.4	×	17	=	.199	(1.5)
Ocean City-Manokin	18,000	×	.9	×	17	=	.266	(2.0)
Total							.465	(3.5)

OCEAN CITY

SOURCES OF FRESH WATER

In the Ocean City area the uppermost aquifer is the Beaverdam Sand, which in this part of the area is synonymous with the Pleistocene aquifer. The aquifer is composed of sand and gravel, and is a discrete hydrologic unit whose top locally is about 50 feet below sea level and whose base is undulatory, ranging between approximately 90 and 130 feet below sea level.

The upper Pleistocene deposits that overlie the Beaverdam Sand contain much stratified fine material, including silt, clay, fine sand, and peat. Those materials partly confine and protect the Beaverdam against infiltration or leakage from above. Unfortunately, the protection is incomplete; in some places the Beaverdam is susceptible to contamination from land-surface sources or by sea water. Ocean City discontinued use of the Beaverdam as a source of public supply in 1927, because of contamination.

Salty or brackish water reportedly occurs in the Pleistocene aquifer beneath two parts of Ocean City (fig. 16, and section on salty water). Possibly that water is residual from a time when sea level was higher. Possibly local abandoned and unplugged wells have offered routes for the salt water to move from the sea to the aquifer during periods of high water. More likely, the protective effect of the overlying materials is weak locally and permitted sea water to enter the aquifer during periods of storm waves or very high tide. The salty or brackish water may be flushed out slowly by fresh ground water originating from above as precipitation or moving laterally from beneath the mainland, but the flushing effect may be nullified by repeated injections of sea water.

Below the Pleistocene aquifer and more-or-less separated hydraulically from it by the upper confining bed, is the Pocomoke aquifer. This aquifer occurs between approximately 155 and 185 feet below sea level at Ocean City, but pinches out beneath the north end. The Pocomoke aquifer was

a source of public-supply water for Ocean City until sometime in the 1960's when the more prolific "Manokin" aquifer became the exclusive source.

The "Manokin" aquifer, which in recent years has supplied all the water for the Ocean City public supply, is not the Manokin aquifer proper: it is the Ocean City aquifer, referred to previously as the Manokin aquifer (Rasmussen and Slaughter, 1955) and the upper Manokin aquifer. Beneath Ocean City, the Ocean City aquifer occurs from about 240 to 300 feet below sea level, in the lower confining bed between the Pocomoke and Manokin aquifers.

The basal part of the lower confining bed is so leaky under much of the area, and especially under Ocean City, that the Ocean City aquifer is hydraulically connected with the underlying Manokin aquifer proper. In the following discussion therefore, the Ocean City aquifer, the Manokin aquifer proper, and the intervening basal part of the lower confining bed are referred to as a hydrologic unit: the Ocean City-Manokin aquifer system.

This aquifer system is by far the most productive source of ground water at Ocean City. The aquifer system is about 250 feet thick there, and is composed of an upper and a lower part separated by a relatively nonproductive but hydraulically conductive layer of fine sand and silt about 40 feet thick.

The Ocean City-Manokin aquifer system is confined below by the St. Marys Formation; and it is confined above, and separated from the overlying Pocomoke aquifer, by the leaky lower confining bed of the Pocomoke aquifer. The confinement at the top and the separation from the Pocomoke are imperfect, because of variation in thickness and lithology of the lower confining bed of the Pocomoke.

Locally the Ocean City-Manokin aquifer system may be hydraulically connected with the overlying Pocomoke, directly or indirectly. Analysis of geophysical and descriptive logs of some of the wells and test holes suggests a general, albeit sluggish hydraulic conductivity between the two. In fact, the imperfect nature of the confining layers separating the aquifers at Ocean City suggests a slow, indirect hydraulic interconnection among all three (or four) aquifers; the Pleistocene, Pocomoke, and Ocean City-Manokin.

Below the bottom of the Manokin aquifer at Ocean City the ground water is salty. This effectively limits the sources of potable ground water at Ocean City to those aquifers discussed above, and the maximum depth of wells for public supply to between 450 and 480 feet.

AVAILABILITY FROM PRESENT SOURCE

As of 1971, the entire public supply for Ocean City was derived from the Ocean City aquifer. That aquifer, connected hydraulically with the Manokin proper, probably is also connected hydraulically (although less efficiently) with the Pocomoke aquifer and quite possibly with the Pleistocene aquifer. Considerable vertical leakage is received by the Ocean City-Manokin system from the overlying aquifers, especially during periods when the system is subjected to hydraulic stress by large-scale withdrawals. On a long-term basis (in excess of a year or two) the amount of water available from the Manokin aquifer beneath Ocean City probably includes all the water in the overlying aquifers as well as the water in the Manokin itself.

The perennial seaward underflow in the Ocean City-Manokin aquifer system beneath Ocean City under non-pumping conditions was about 0.85 mgd assuming an average transmissivity of 14,000 feet squared per day (105,000 gallons per day per foot), a hydraulic gradient of 0.9 foot per mile, and a cross-sectional length of 9 miles. The 0.85 mgd was previously discharged offshore, probably by vertical leakage.

Effect Of Present Withdrawals

Since the 1960's when the Ocean City aquifer became the exclusive source of public supply at Ocean City, discharge by pumping from that aquifer has exceeded and reduced the natural offshore discharge from the Ocean City-Manokin aquifer system. In 1971 the withdrawal from all municipal wells and the Convention Hall wells at Ocean City averaged 3.04 mgd, or more than three times the amount of water that is estimated to have flowed beneath Ocean City and discharged naturally offshore.

Obviously, underflow did not supply all the water withdrawn from the Ocean City aquifer at Ocean City during 1971. Furthermore, although some of the water was withdrawn from storage the deficit was more than made up in a few months near the end of the year. Only about one third of the recharge can be attributed to underflow; the

other two thirds was derived primarily from leakage.

Withdrawal of large quantities of water (1.466 X 10^8 cubic feet, or 1.1 billion gallons in 1971) from the Ocean City aquifer at Ocean City has produced the cone of depression in the Ocean City-Manokin potentiometric surface shown in figure 12. The withdrawals vary seasonally; by far the greater part occurs during the warmer months, and the cone of depression varies accordingly.

During the winter the cone diminishes considerably in size (see comparison of summer and winter potentiometric surfaces in fig. 12, and hydrographs of observation wells in fig. 13). The period of water-level measurements is too short to show conclusively if the Ocean City-Manokin potentiometric surface in the Ocean City area recovers to about the same position each winter. There may be a slow, long-term expansion of the cone of depression, on which the seasonal changes in size and shape are superposed. However, based on consideration of water-level records collected during this study residual drawdown effects of the summer withdrawals at Ocean City do not appear to be increasing.

The hydrographs of Ocean City-Manokin observation wells Wor-Ah 6, Bg 15, Bh 33, Bh 36 and Bh 31 (fig. 13), although short, show that at those sites the cone recovered to higher levels during the winter of 1971-72 than during the preceding winter even though more water was withdrawn from the Ocean City aquifer in 1971 than in 1970. In other words, the water levels show there was a net *gain* in storage despite greater withdrawals.

The recharge required for the cone to recover to its winter condition is probably local, originating in precipitation on northeastern Worcester County and provided mostly by leakage from the Pocomoke and Pleistocene aquifers. The Ocean City-Manokin potentiometric surface suggests this by recovery proportionate to volume of precipitation.

Probably most of the leakage to the Ocean City-Manokin aquifer system occurs vertically through the Pocomoke aquifer and intervening confining beds from the Pleistocene (water-table) deposits on the mainland. Some of the leakage occurs west of the Berlin scarp where the heads in the Pleistocene, Pocomoke, and Ocean City-Manokin aquifers are successively lower. Some, however, occurs within the area of the Ocean City-Manokin cone of depression. Within the area of that cone, leakage to the Ocean City-Manokin aquifer system from the overlying Pocomoke and Pleistocene aquifers implies an obvious danger of salt-water intrusion, because in most of the area of the cone the Pleistocene aquifer is overlain by salt water (see section below on salt-water intrusion).

It is concluded tentatively that the winter and summer phases of the cone of depression resulting from withdrawal of water from the Ocean City-Manokin aquifer system at Ocean City have "stabilized" at approximately the positions shown in figure 12, and that continued withdrawal on the present scale would not materially affect the potentiometric surface further or deplete ground-water reserves in that aquifer system.

Effects Of Future Increased Withdrawals

The recent history of northeastern Worcester County and the overall population and geographic relations strongly suggest that summer (and possibly year-around) population and water consumption at Ocean City will continue to increase, and that new communities on the neighboring mainland will also seek to develop water supplies from the Ocean City-Manokin aquifer system.

Because of the importance of vertical leakage in that area, the quantity of water available from the Ocean City-Manokin aquifer system on a permanant basis probably would equal the total underflow available there in all the fresh-water aquifers; plus all recharge that could be induced into those aquifers from local precipitation. If the annual withdrawal exceeds that total some of the water must come from storage.

In some areas the volume of ground water available from storage can be added on a prorated basis to the quantity available perennially, to arrive at an estimate of the total yield available over a given number of years. This assumes the head declines steadily, and all the available water in storage is withdrawn by the end of the period. In the Ocean City area, however, salt-water intrusion probably would become a problem long before the potentiometric surface was drawn down to the top of the Ocean City-Manokin aquifer system. The quantity of fresh water stored beneath Ocean City can be estimated, but only an unknown fraction of the quantity is available for withdrawal.

Based on hydrographs (fig. 13) and comparison of summer and winter phases of the cone of depression at Ocean City (fig. 12), it is estimated that several times (perhaps 10 times) the present annual withdrawal of water could be accommodated by the Ocean City-Manokin aquifer system at Ocean City on a permanent or almost permanent basis. This assumes the cone has attained a fluctuating "stability" in response to the present seasonal withdrawals from the Ocean City aquifer, which are replaced largely by vertical leakage from the Pocomoke and Pleistocene aquifers. Also, it is assumed that a considerable expansion of the cone of depression associated with greatly increased withdrawals would induce sufficient additional vertical recharge from those same aquifers (under a much larger area) to replace all or most of the water withdrawn from the Ocean City-Manokin system. However, that expansion of the cone, and the additional leakage induced from the Pleistocene and Pocomoke aquifers would increase the chances for salt-water intrusion through the Pleistocene deposits (see below). How much salt water would enter the Ocean City-Manokin system and how dilute it would be, we do not know at this stage of knowledge.

Salt-Water Intrusion

Yield is only one of two important factors limiting the quantity of fresh ground water that can be withdrawn from beneath Ocean City. Another critical factor is the likelihood of salt-water intrusion in response to ground-water withdrawal.

Salty water lies at the surface both east and west of Ocean City, in the ocean and in Assawoman Bay. Beneath Ocean City salty water also occurs in the aquifers below the Manokin; in the bottom few feet of the Manokin; and locally in the Pleistocene aquifer beneath the upper Pleistocene deposits of finer materials. In addition, salty water may occur in the Pleistocene aquifer beneath Assawoman Bay and the ocean adjacent to Ocean City. Salty water from any of those sources might invade the Manokin aquifer, provided increased withdrawals produced sufficient head differences; the *amount* of leakage would depend upon the head differences and the vertical permeabilities of the intervening confining layers. The vertical permeabilities are known only in a qualitative or relative way.

Because most of the area of the cone of depression is overlain by salt water, contamination of the Ocean City-Manokin aquifer system by salt water through vertical leakage poses a very real threat. However, that danger is reduced somewhat by several factors:

(1) The bottoms of the bays and estuaries are generally mucky or silty, based on shallow test borings by the U. S. Army Corps of Engineers and on bridge borings by the Maryland State Roads Commission. Thus the entry of bay and estuarine water into the Pleistocene deposits is impeded, to the proportionate advantage of recharge to the Pleistocene deposits by precipitation on the mainland within the area of the cone of depression.

(2) The cone is seasonal, and within most of its maximum extent the corresponding potentiometric surface is above sea level more than half of the year. Consequently, salt or brackish water that enters the Pleistocene deposits beneath the bays and estuaries may be confined to the upper part of those deposits, moving downward and upward seasonally in response to changing heads.

(3) Although the leakage is assumed to be vertical, the vertical paths may be offset within the various hydrologic units. That is, surface infiltration to the Pleistocene deposits may occur several miles from where leakage occurs from the Pleistocene to the Pocomoke and from the Pocomoke to the Ocean City-Manokin system. Clarification of that picture requires seasonal water-level data for the Pleistocene and Pocomoke aquifers. Meanwhile, no evidence of increased saltiness of water in any of the aquifers has been observed during this study.

Salty water occurs locally in the Pleistocene aquifer beneath Ocean City (fig. 16), but it is not known to occur in that aquifer beneath the mainland. Salty water may occur in the Pleistocene aquifer beneath Assawoman Bay, although to some extent the fine materials in the upper Pleistocene deposits probably shield the aquifer

from the water in the bay. Salt water almost certainly occurs in the Pleistocene aquifer seaward from Ocean City.

In spite of considerable increase in the number of wells and in withdrawal of water from the Pleistocene aquifer during the last several years from public-supply and domestic wells within a mile of Assawoman Bay and associated estuaries, no new reports of salty water from that aquifer have been noted. Nevertheless, it is possible that salty water occurs in the Pleistocene aquifer beneath the bay and in the future it may appear in wells tapping that aquifer near the bay or estuaries. If salty water does occur there it provides a potential source of contamination for the Ocean City-Manokin aquifer system through leakage. Seaward from Ocean City, however, salt water in the Pleistocene aquifer is more definitely a potential source of contamination for the Ocean City-Manokin aquifer system through leakage.

In order for salty water in the aquifers *below* the Manokin to invade the Manokin, the water must leak upward through the 160 feet or more of clay, silt, and fine sand that comprise the St. Marys Formation. The upward movement would be extremely slow, even in the presence of a large head differential.

Water in the St. Marys Formation itself is probably salty; but it, too, could move upward into the Manokin only very slowly because of the low permeability of the materials comprising the St. Marys Formation.

Somewhat salty water in the fine material comprising the basal 10 or 20 feet of the Manokin aquifer beneath Ocean City may have leaked upward from the underlying St. Marys Formation; or it may be residual from salt water that occupied more of the Manokin aquifer during a time of higher sea levels. In neither case does serious contamination of the Manokin aquifer by salty water from below appear likely.

Possibly, the somewhat salty water in the basal few feet of the Manokin is the toe of a wedge of salt water in the Manokin, thickening eastward from Ocean City. Salt water in the wedge can move laterally shoreward with relative freedom in response to changes in head, regardless of vertical permeability. Salt water in the Manokin east of Ocean City may therefore be the most important source of salt-water contamination of the Manokin at Ocean City, depending on its closeness to Ocean City. For that reason the salt-water front in the Manokin is discussed in more detail below, and is speculated upon.

Significance of Salt-water Interface: Somewhere offshore from Ocean City the entire thickness of the Manokin aquifer is occupied by salt water. The salt-water front probably trends approximately northeastward, more-or-less parallel to the shoreline at Ocean City (see section on chemical quality), but its distance offshore is unknown. If the salt-water wedge in the Manokin is at the shore, appearing in well Wor-Ah 6 near the north end of Ocean City and thickening eastward from there, large-scale withdrawal of water from the Manokin at Ocean City may induce salty water to move into that part of the Manokin beneath Ocean City and into wells tapping the aquifer. Under those circumstances the chloride content of the water from wells Wor-Ah 33 and Ah 34, drilled near Ah 6 early in 1972 and screened deep in the Manokin, should increase steadily soon after large-scale withdrawals begin there. Such an occurrence would signal at least a local limit to development of the lower part of the Manokin as a source of fresh water in Ocean City.

However, if the toe of the wedge in the permeable part of the Manokin is several miles offshore it would require so much time for the first salt water behind the interface to reach the wells at Ocean City that its arrival there probably would be irrelevant. The farther offshore the interface occurs, the less the likelihood of contamination from that source of salt water (and the greater the relative importance of other sources of salt-water contamination).

Precise knowledge of the position of the interface is essential for evaluating the likelihood and imminence of contamination of the Manokin aquifer beneath Ocean City by salt water from behind the interface. A horizontal difference of only several thousand feet could mean a difference of many years in the time required for salt water from behind the interface to arrive at the Ocean City well fields.

Analysis of head distribution and water-density differences suggests the interface is near (possibly at) Ocean City; however, its position cannot be pinpointed using the data currently available. A direct approach to determining the position would be to test drill at the beach and offshore from Ocean City, logging the holes geophysically to determine if the top of the salty water in the basal part of the Manokin is higher to the east. If the salt-water front proved to be near shore, subsequent conversion of the shoreward test holes to

"outpost" monitoring wells might then provide a warning system for approach of the front.

Provided the interface is not already at Ocean City, its movement shoreward toward the centers of withdrawal probably will be slow. Before the salt water from beyond the interface can arrive at the Ocean City wells, the intervening fresh water in the Manokin must be removed by withdrawal from the wells. The quantity of water that must be removed is approximately 0.2 times the volume of material (conservatively assuming 20 percent average porosity) included in the most permeable part (about 150 feet thick) of the Ocean City-Manokin aquifer system and extending radially in all directions from the wells a distance equal to that between the wells and the interface.

In 1971, 1.466×10^8 cubic feet (1.1 billion gallons) of water was withdrawn from the Ocean City-Manokin aquifer system at Ocean City. If the future rate of withdrawal were five times as great, for example, the figures would be 7.330×10^8 cubic feet (5.5 billion gallons) per year, averaging 15 million gallons per day.

If the withdrawal at the increased rate were supplied equally from a large number of wells evenly spaced in linear fashion the length of Ocean City, the volume of water withdrawn annually would be equivalent to that contained in a prism 150 feet high, 40,000 feet long, (the length of Ocean City) and about 610 feet wide. Because the water would be withdrawn both landward and seaward of the line of wells, 610 ÷ 2 or 305 feet would be the theoretical annual shoreward movement of the salt-water interface under the conditions outlined above.

In practice, however, the development of the well-distribution system at Ocean City may continue along present lines, with groups of wells about 1½ miles apart culminating in a total of six or seven well fields. If the withdrawal at the increased rate were shared equally among six equally spaced well fields, the theoretical rate of shoreward movement of the salt-water interface would be closer to 1,100 feet per year.

Conditions have been greatly simplified in this brief discussion of the movement of the salt-water interface. For example, although only the one source of contamination by salt water is considered, the other sources described previously are potentially functional regardless of the shoreward position or rate of movement of the interface in the Manokin.

Also, some parts of the interface may move faster than others, arriving at the well fields ahead of the main part of the interface. However, the salt water initially arriving at the wells would be greatly diluted by fresh water moving to the well fields from inland. Furthermore, the material in the part of the aquifer considered is generally of fairly uniform permeability and the interface probably will move more or less as a unit.

Finally, this calculation assumes the fresh water to be taken from aquifer storage only. No allowance is made for vertical leakage and underflow, both of which contribute water for withdrawal and thereby reduce the rate of shoreward movement of the interface.

ALTERNATIVE SOURCES

Alternative sources of ground water at Ocean City are strictly limited, but within those limits there is some flexibility.

The Pleistocene aquifer was formerly utilized as a source of public supply at Ocean City, but is locally susceptible to salt-water contamination.

The Pocomoke aquifer also was formerly utilized as a source of public supply at Ocean City. Currently it probably provides recharge to the Ocean City-Manokin aquifer system because of the seasonally decreased head in the Manokin.

The Ocean City aquifer has by no means been developed to its fullest potential. Should its development reach that stage, the logical alternative or supplemental source would be the Manokin aquifer proper.

Sometimes overlooked, are the large quantities of water withdrawn from the Ocean City aquifer at Convention Hall in Ocean City and discharged nearby into Assawoman Bay after use in air conditioning and in heating the Hall. That water (approximately 300 million gallons per year and equal to 37 percent of the Ocean City public-supply requirements for 1971) is potentially available for recharge to the Ocean City-Manokin aquifer system or for use as part of the Ocean City water supply.

Although salt water occurs in the Manokin east of Ocean City, fortunately it is absent to the west in that aquifer. Therefore, if test drilling or increasing chloride concentration in water from individual wells indicates the interface is dangerously close to the well fields, the threat can be countered by drilling new wells in the Manokin

beneath the westernmost parts of Ocean City or even farther west (on artificial islands, for example, or on the Isle-of-Wight).

Arrival of the salt-water interface at the source of Ocean City's public supply could thus be postponed by a period dependent upon the number and distribution of wells, as indicated previously in the section on salt-water intrusion. That is, arrival of the salt water could be delayed by distributing the withdrawals among equally spaced well fields west of the interface, or for a longer period by distributing the withdrawals among a large number of wells spaced equally and linearly west of the interface.

CONCLUSIONS

Fresh ground water in northeastern Worcester County is restricted to a block of sediments about 450 feet thick. The top of the block is the land surface, and the base is at or a few feet above the contact between the St. Marys Formation and the overlying Manokin aquifer. Within that block water is available under water-table and semiconfined conditions in the Pleistocene aquifer, and under confined conditions in the Pocomoke, Ocean City, and Manokin aquifers.

Water from all four aquifers is generally of a chemical quality acceptable for most purposes, but commonly contains iron in concentrations sufficient to make some treatment desirable before the water is used.

The Ocean City aquifer occurs in the northeastern part of the area. Hydraulic separation between it and the Manokin is poor, and the two aquifers function as a hydrologic unit near Ocean City. The Ocean City public supply of water (as of 1972) was obtained from the Ocean City aquifer, rather than the Manokin.

The Manokin aquifer is potentially very productive, and is virtually untapped (1972) in northeastern Worcester County. The transmissivity of the Ocean City-Manokin aquifer system averages about 10,000 ft^2/day, ranging from 1000 in the southeastern part of the area to more than 20,000 in the northwestern part, and averages about 14,000 ft^2/day at Ocean City. Transmissivity of the Pleistocene and Pocomoke aquifers is somewhat less, averaging respectively about 5,000 and 4,000 ft^2/day in the area of study.

In 1971, 1.466×10^8 cubic feet of water was pumped from the Ocean City aquifer. It is estimated that several times that rate of withdrawal could be accommodated by the Ocean City-Manokin system on a long-term basis if the entire aquifer thickness were utilized.

A cone of depression in the Ocean City-Manokin potentiometric surface at Ocean City fluctuates in size in response to seasonal changes in rates of withdrawal. In mid-summer it attains its maximum extent (12 miles or more in diameter), extending beneath adjacent parts of the back bays and Atlantic Ocean. The cone almost completely dissipates in autumn and early winter, principally in response to greatly reduced withdrawals at Ocean City. Based on 2½ years of record, a seasonally fluctuating equilibrium apparently has been reached between withdrawal and recharge.

Interaquifer leakage is important in northeastern Worcester County. In the vicinity of Ocean City, especially, the effectiveness of the confining layers between the Manokin and the Pleistocene aquifer is inconsistent or poor. In the Ocean City area, long-continued large-scale withdrawals from the Manokin proper probably would drain water from the overlying units as well; this would increase the likelihood of salt-water intrusion from below, and especially from the surface.

No evidence of increasing saltiness of ground water was found at Ocean City or elsewhere in the area of investigation. However, the Ocean City-Manokin aquifer system at Ocean City is exposed to the danger of salt-water intrusion from several sources: from the nearby ocean and back bays, at the surface; from the basal few feet of the Manokin; from the aquifers below the Manokin; and locally from the Pleistocene aquifer. The danger of salt-water intrusion from any of these sources becomes greater with increased head differences, such as accompany expanding and deepening cones of depression.

Another potential source of intrusion — perhaps the most significant — is the salt water in the Manokin offshore from Ocean City. The salt-

water/fresh-water interface in the Manokin probably lies approximately parallel to the coastline. If it is in close proximity it could be a very real threat to the Ocean City water supply. Its position can possibly be determined by test drilling, and subsequent conversion of the test holes to "outpost" monitoring wells can provide a warning system for approach of the salt-water front.

SELECTED REFERENCES

BACK, WILLIAM, *1966, Hydrochemical facies and ground-water flow patterns in the Atlantic Coastal Plain: U. S. Geol. Survey Prof. Paper 498-A, 42 p.*

BIGGS, R. B., *1970, Assateague ecological studies, final report; pt. 1, Environmental information: Univ. of Maryland Nat. Resources Inst. Contr. no. 446, 426 p.*

BOGGESS, D. H. and HEIDEL, S. G., *1968, Water resources of the Salisbury area, Maryland: Maryland Geol. Survey Rept. Inv. 3, 69 p.*

COOPER, H. H., KOHOUT, F. A., HENRY, H. R., and GLOVER, R. E., *1964, Sea water in coastal aquifers: U. S. Geol. Survey Water-Supply Paper 1613-C, p. C1-C84.*

CUSHING, E. M., KANTROWITZ, I. H., and TAYLOR, K. R., *1973, Water resources of the Delmarva Peninsula: U. S. Geol. Survey Prof. Paper 822, 58 p.*

GUYOD, HUBERT, and SHANE, L. E., *1969, Geophysical well logging: Houston, Hubert Guyod, p. 44-232.*

HANSEN, H. J., *1972, A user's guide for the artesian aquifers of the Maryland coastal plain; pt. 1, Introductory definitions and examples, 86 p.; pt. 2, Aquifer characteristics, 123 p.; Maryland Geol. Survey.*

HUBBERT, M. K., *1940, The theory of ground-water motion: Jour. Geology v. 48, no. 8, pt. 1, 785-944.*

——, *1953, Entrapment of petroleum under hydrodynamic conditions: Am. Assoc. Petroleum Geologists Bull., v. 37, no. 8, p. 1954-2026.*

JOHNSTON, R. H., *1971, Base flow as an indicator of aquifer characteristics on the coastal plain of Delaware: U. S. Geol. Survey Prof. Paper 750-D, p. D212-D215.*

——, *1974, Hydrology of the Columbia (Pleistocene) deposits of Delaware: Delaware Geol. Survey Bull. No. 14.*

KANTROWITZ, I. H., *1969, Preliminary results of an exploratory water well drilled at Ocean City, Maryland: U. S. Geol. Survey open-file report, 19 p.*

KRAFT, J. C., *1971, Sedimentary environment, facies patterns and geologic history of a Holocene marine transgression: Geol. Soc. America Bull., v. 82, no 8, p. 2131-2158.*

LOHMAN, S. W., *1972, Ground-water hydraulics: U. S. Geol. Survey Prof. Paper 708, p. 30-34*

LOHMAN, S. W., and OTHERS, *1972, Definitions of selected ground-water terms — revisions and conceptual refinements: U. S. Geol. Survey Water-Supply Paper 1988, 70 p.*

LUCAS, R. L., *1972, Worcester County ground-water information: well records, pumpage, chemical quality data, and selected well logs; Maryland Geol. Survey Basic Data Rept. No. 6, 90 p.*

MILLER, J. C., *1971, Ground-water geology of the Delaware Atlantic seashore: Delaware Geol. Survey Rept. of Investigations No. 17, 33 p.*

RASMUSSEN, W. C. and ANDREASEN, G. E., *1959, Hydrologic budget of the Beaverdam Creek basin, Maryland: U. S. Geol. Survey Water-Supply Paper 1472, 106 p.*

RASMUSSEN, W. C., and SLAUGHTER, T. H., *1955, The ground-water resources,* in *The water resources of Somerset, Wicomico, and Worcester Counties: Maryland Dept. of Geology, Mines and Water Resources*[1] *Bull. 16, 533 p.*

SLAUGHTER, T. H., *1962, Beach-area water supplies between Ocean City, Maryland and Rehoboth Beach, Delaware: U. S. Geol. Survey Water-Supply Paper 1619-T, 9 p.*

SUNDSTROM, R. W., and PICKETT, T. E., *1969, The availability of ground water in eastern Sussex County, Delaware: Univ. of Delaware Water Resources Center rept., 136 p.*

UPSON, J. E., *1966, Relationship of fresh and salty ground water in the northern Atlantic Coastal Plain of the United States: U. S. Geol. Survey Prof. Paper 550-C, p. C-235 - C-243.*

U. S. GEOLOGICAL SURVEY, *Surface Water Records, pt. 1 of Water Resources Data for Maryland and Delaware: Published yearly from 1961 to 1970.*

WEIGLE, J. M., WEBB, W. E., and GARDNER, R. A., *1970, Water resources of southern Maryland: U. S. Geol. Survey Hydrol. Inv. Atlas HA-365.*

[1] The name of this agency was changed to the Maryland Geological Survey in June 1964.

APPENDIX

Table 2.—Descriptions of pertinent wells and test holes not published elsewhere.

Well number: Wi- indicates location in Wicomico County; and Wor-, in Worcester County. Locations are shown in Figure 3.

Well number	State permit number	Owner or name	Driller	Date completed	Altitude of land surface (feet)	Method of construction	Depth of well (feet)	Diameter of well (inches)	Depth of bottom of casing or top of screen (feet below land surface)	Total screen length (feet)	Principle waterbearing unit	Water level (measured)		Use	Type of pump	Yield				Specific capacity (gpm/foot of drawdown)	Remarks	Well number
												Feet above (+) land surface	Date			Gallons per minute (gpm)	Duration of test (hrs)	Drawdown (feet)	Date			
Wi-Di 1	—	———	U. S. Geological Survey	10/19/71	18	A	130	5	-	-	Poc	-	-	T	N	-	-	-	-	-	Lg.	Wi-Di 1
Wi-Di 2	—	———	do.	10/27/71	18	A	29½	5	-	-	Pleist	-	-	T	N	-	-	-	-	-	Pollen analysis of clay sample (Table 3).	Wi-Di 2
Wi-Di 3	—	———	do.	10/27/71	18	A	29½	5	-	-	Pleist	Flow	10/21/71	T	N	3	1	-	10/21/71	-	Water flowed up through drill-stem. A. Temp. 13½ deg. C. (56½ deg. F.)	Wi-Di 3
Wor-Ah 33	W0720062	Ocean City	Shannahan Artesian Well Co.	4/22/72	5	Dr	450	18-12	346	104	Mk	+0.53	4/26/72	PS	T	800	20	18.6	3/30-31/72	43.0	Transmissivity = 14,000 ft^2/day. Test pumped 1400 gpm with present pump.	Wor-Ah 33
Wor-Ah 34	W0720059	Ocean City	Shannahan Artesian Well Co.	5/1/72	5	Dr	450	18-12	350	100	Mk	+0.44	4/26/72	N	N	815	20	17.1	4/26-27/72	47.4	Transmissivity = 14,800 ft^2/day. Temp. 16 deg. C. (61 deg. F).	Wor-Ah 34
Wor-Ce 31	—	William Molnar	Delmarva Drilling Co.	6/14/72	25	Dr	1040	9	-	-	-	-	-	T	N	-	-	-	-	-	Lg.	Wor-Ce 31

Method of construction
A Power augered
Dr Hydraulic rotary

Principal water-bearing unit
Mk Manokin aquifer
Pleist Pleistocene aquifer
Poc Pocomoke aquifer

Use
N Not used
PS Public supply
T Exploratory test hole

Type of pump
N None
T Turbine

Remarks
A Chemical analysis in table 4
Lg Geophysical log available

Table 3.—Palynological analyses of selected samples of material from northeastern Worcester County, Maryland.

(All samples obtained by power augering during this investigation. All analyses made by Grace Brush.)

Site: Wi-Di 2 (Purnells Crossing)
Depth below land surface: 25′-26′
Altitude of land surface (sea-level datum): 18′±
Material analyzed: clay, "black", stiff

	Percent
Picea (spruce)	21.3
Pinus (pine)	44.5
Taxus (yew)	—
Acer (maple)	—
Alnus (alder)	—
Betula (birch)	1.3
Carya (hickory)	5.8
Castanea (chestnut)	0.6
Cornus (dogwood)	0.6
Corylus (hazelnut)	1.3
Fagus (beech)	1.3
Fraxinus (ash)	0.6
Ilex (holly)	1.9
Juglans (walnut)	0.6
Quercus (oak)	8.3
Salix (willow)	—
Tilia (linden)	—
Ulmus (elm)	—
Ambrosia (ragwood)	3.2
Campanula (bellflower)	—
Chenopodiaceae (pigweed)	3.2
Cyperaceae (sedges)	—
Ericaceae (heath)	—
Gramineae (grasses)	—
Nuphar (a genus of water lily)	—
Nymphea (water lily)	—
Plantago (plantain)	—
Rosaceae	—
Rubus (bramble)	—
Typha (cat-tail)	—
Umbelliferae	—
Viola (violet type)	—
Lycopodium (club moss)	—
Pteridophytes (ferns)	1.9
Selaginella	—
Sphagnum (sphagnum moss)	1.3
Unidentified	1.9
Total	99.6

Site: Wor-Ae 22 (3 mi. NE of Whaleysville)
Depth below land surface: 54′-59′
Altitude of land surface (sea-level datum): 35′±
Material analyzed: clay, dark gray and brown

	Percent
Picea (spruce)	—
Pinus (pine)	23.0
Taxus (yew)	—
Acer (maple)	1.9
Alnus (alder)	0.6
Betula (birch)	8.3
Carya (hickory)	12.7
Castanea (chestnut)	—
Cornus (dogwood)	—
Corylus (hazelnut)	—
Fagus (beech)	1.9
Fraxinus (ash)	8.3
Ilex (holly)	1.3
Juglans (walnut)	0.6
Quercus (oak)	15.3
Salix (willow)	2.5
Tilia (linden)	0.6
Ulmus (elm)	—
Ambrosia (ragweed)	1.3
Campanula (bellflower)	—
Chenopodiaceae (pigweed)	1.3
Cyperaceae (sedges)	3.1
Ericaceae (blueberry)	7.0
Gramineae (grasses)	0.6
Nuphar (a genus of water lily)	—
Nymphea (water lily)	1.3
Plantago (plantain)	—
Rosaceae	—
Rubus (bramble)	1.3
Typha (cat-tail)	1.9
Umbelliferae	—
Viola (violet type)	—
Lycopodium (club moss)	1.9
Pteridophytes (ferns)	3.1
Selaginella	—
Sphagnum (sphagnum moss)	—
Unidentified	—
Total	99.8

Table 3.—Palynological analyses of selected samples of material from northeastern Worcester County, Maryland—Continued.

Site: Wor-Ae 22 (3 mi. NE of Whaleysville)
Depth below land surface: 125′-127′
Altitude of land surface (sea-level datum): 35′±
Material analyzed: clay, dark-gray and leather-brown

	Percent
Picea (spruce)	14.4
Pinus (pine)	41.1
Taxus (yew)	—
Acer (maple)	—
Alnus (alder)	0.9
Betula (birch)	0.5
Carya (hickory)	1.4
Castanea (chestnut)	—
Cornus (dogwood)	—
Corylus (hazelnut)	1.4
Fagus (beech)	0.9
Fraxinus (ash)	2.4
Ilex (holly)	—
Juglans (walnut)	0.5
Quercus (oak)	19.6
Salix (willow)	1.9
Tilia (linden)	—
Ulmus (elm)	—
Ambrosia (ragweed)	1.9
Campanula (bellflower)	—
Chenopodiaceae (pigweed)	1.9
Cyperaceae (sedges)	2.9
Ericaceae (heath)	—
Gramineae (grasses)	1.9
Nuphar (a genus of water lily)	—
Nymphea (water lily)	0.5
Plantago (plantain)	—
Rosaceae	—
Rubus (bramble)	—
Typha (cat-tail)	0.5
Umbelliferae	—
Viola (violet type)	—
Lycopodium (club moss)	0.5
Pteridophytes (ferns)	1.0
Selaginella	0.9
Sphagnum (sphagnum moss)	—
Unidentified	2.9
Total	99.9

Site: Wor-Bf 61 (approx. ½ mi. N. of Showell)
Depth below land surface: 125′
Altitude of land surface (sea-level datum): 25′±
Material analyzed: clay, dark-gray, stiff

	Percent
Picea (spruce)	—
Pinus (pine)	10.8
Taxus (yew)	—
Acer (maple)	—
Alnus (alder)	2.7
Betula (birch)	8.1
Carya (hickory)	8.1
Castanea (chestnut)	—
Cornus (dogwood)	—
Corylus (hazelnut)	—
Fagus (beech)	5.4
Fraxinus (ash)	2.7
Ilex (holly)	—
Juglans (walnut)	—
Quercus (oak)	16.2
Salix (willow)	2.7
Tilia (linden)	—
Ulmus (elm)	—
Ambrosia (ragweed)	5.4
Campanula (bellflower)	2.7
Chenopodiaceae (pigweed)	—
Cyperaceae (sedges)	5.4
Ericaceae (heath)	—
Gramineae (grasses)	—
Nuphar (a genus of water lily)	—
Nymphea (water lily)	—
Plantago (plantain)	—
Rosaceae	—
Rubus (bramble)	—
Typha (cat-tail)	—
Umbelliferae	—
Viola (violet type)	—
Lycopodium (club moss)	2.7
Pteridophytes (ferns)	5.4
Selaginella	—
Sphagnum (sphagnum moss)	—
Unidentified	21.6
Total	99.9

Table 3.—Palynological analyses of selected samples of material from northeastern Worcester County, Maryland—Continued.

Site: Wor-Bh 83 (Ocean City)
Depth below land surface: 32′-33′
Altitude of land surface (sea-level datum): 5′±
Material analyzed: peat

	Percent
Picea (spruce)	—
Pinus (pine)	39.1
Taxus (yew)	—
Acer (maple)	—
Alnus (alder)	0.9
Betula (birch)	5.4
Carya (hickory)	—
Castanea (chestnut)	—
Cornus (dogwood)	—
Corylus (hazelnut)	—
Fagus (beech)	3.6
Fraxinus (ash)	—
Ilex (holly)	—
Juglans (walnut)	—
Quercus (oak)	3.6
Salix (willow)	—
Tilia (linden)	—
Ulmus (elm)	—
Ambrosia (ragweed)	0.9
Campanula (bellflower)	—
Chenopodiaceae (pigweed)	—
Cyperaceae (sedges)	—
Ericaceae (heath)	—
Gramineae (grasses)	0.9
Nuphar (a genus of water lily)	1.8
Nymphea (water lily)	—
Plantago (plantain)	—
Rosaceae (?)	0.9
Rubus (bramble)	—
Typha (cat-tail)	1.8
Umbelliferae (parsley)	1.8
Viola (violet type)	—
Lycopodium (club moss)	1.8
Pteridophytes (ferns)	18.2
Selaginella	0.9
Sphagnum (sphagnum moss)	14.5
Unidentified	3.6
Total	99.7

Site: Wor-Bh 83 (Ocean City)
Depth below land surface: 36′-38½′
Altitude of land surface (sea-level datum): 5′±
Material analyzed: clay, dark-gray, stiff

	Present
Picea (spruce)	8.8
Pinus (pine)	83.1
Taxus (yew)	—
Acer (maple)	—
Alnus (alder)	—
Betula (birch)	—
Carya (hickory)	—
Castanea (chestnut)	—
Cornus (dogwood)	—
Corylus (hazelnut)	—
Fagus (beech)	—
Fraxinus (ash)	—
Ilex (holly)	0.7
Juglans (walnut)	0.7
Quercus (oak)	0.7 (?)
Salix (willow)	—
Tilia (linden)	—
Ulmus (elm)	—
Ambrosia (ragweed)	2.9
Campanula (bellflower)	—
Chenopodiaceae (pigweed)	—
Cyperaceae (sedges)	—
Ericaceae (heath)	—
Gramineae (grasses)	—
Nuphar (a genus of water lily)	—
Nymphea (water lily)	—
Plantago (plantain)	—
Rosaceae	—
Rubus (bramble)	—
Typha (cat-tail)	—
Umbelliferae	—
Viola (violet type)	—
Lycopodium (club moss)	—
Pteridophytes (ferns)	1.4
Selaginella	0.7
Sphagnum (sphagnum moss)	—
Unidentified	0.7
Total	99.7

Table 3.—Palynological analyses of selected samples of material from northeastern Worcester County, Maryland—Continued.

Site: Wor-Cg 61 (3 mi. SW of Ocean City)
Depth below land surface: 10′-14′
Altitude of land surface (sea-level datum): 10′±
Material analyzed: clay

	Percent
Picea (spruce)	31.1
Pinus (pine)	33.4
Taxus (yew) (?)	13.8
Acer (maple)	—
Alnus (alder)	2.2
Betula (birch)	3.0
Carya (hickory)	—
Castanea (chestnut)	2.2
Cornus (dogwood)	—
Corylus (hazelnut)	—
Fagus (beech)	—
Fraxinus (ash)	—
Ilex (holly)	—
Juglans (walnut)	—
Quercus (oak)	0.5
Salix (willow)	0.2
Tilia (linden)	—
Ulmus (elm)	1.6
Ambrosia (ragweed)	2.2
Campanula (bellflower)	—
Chenopodiaceae (pigweed)	—
Cyperaceae (sedges)	—
Ericaceae (heath)	0.2
Gramineae (grasses)	1.3
Nuphar (a genus of water lily)	—
Nymphea (water lily)	—
Plantago (plantain)	—
Rosaceae	—
Rubus (bramble)	—
Typha (cat-tail)	—
Umbelliferae	—
Viola (violet type)	—
Lycopodium (club moss)	2.2
Pteridophytes (ferns)	1.3
Selaginella	—
Sphagnum (sphagnum moss)	4.6
Unidentified	—
Total	99.8

Site: Wor-Cg 63 (mainland, 2 mi. N. of Assateague State Park)
Depth below land surface: 139′-144′
Altitude of land surface (sea-level datum): 5′±
Material analyzed: clay

	Percent
Picea (spruce)	28.1
Pinus (pine)	49.0
Taxus (yew) (?)	0.3
Acer (maple)	—
Alnus (alder)	1.0
Betula (birch)	1.9
Carya (hickory) (?)	2.3
Castanea (chestnut)	—
Cornus (dogwood)	—
Corylus (hazelnut)	—
Fagus (beech)	0.3
Fraxinus (ash)	0.3
Ilex (holly) (?)	0.3
Juglans (walnut)	—
Quercus (oak)	3.3
Salix (willow)	—
Tilia (linden)	—
Ulmus (elm)	—
Ambrosia (ragweed)	0.3
Campanula (bellflower)	—
Chenopodiaceae (pigweed)	—
Cyperaceae (sedges)	—
Ericaceae (heath)	—
Gramineae (grasses)	2.3
Nuphar (a genus of water lily)	—
Nymphea (water lily)	—
Plantago (plantain)	—
Rosaceae	—
Rubus (bramble)	—
Typha (cat-tail)	—
Umbelliferae	—
Viola (violet type)	0.3
Lycopodium (club moss)	1.0
Pteridophytes (ferns)	5.3
Selaginella	—
Sphagnum (sphagnum moss)	3.6
Unidentified	—
Total	99.7

Table 3.—Palynological analyses of selected samples of material from northeastern Worcester County, Maryland—Continued.

Site: Wor-Df 5 (Lower Sinepuxent Neck)
Depth below land surface: 115′-117′
Altitude of land surface (sea-level datum): 5′±
Material analyzed: clay, blue-gray, stiff

	Percent
Picea (spruce)	—
Pinus (pine)	18.6
Taxus (yew)	—
Acer (maple)	—
Alnus (alder)	—
Betula (birch)	—
Carya (hickory)	—
Castanea (chestnut)	—
Cornus (dogwood)	—
Corylus (hazelnut)	—
Fagus (beech)	7.0
Fraxinus (ash)	2.3
Ilex (holly)	4.7
Juglans (walnut)	—
Quercus (oak)	16.3
Salix (willow)	9.4
Tilia (linden)	—
Ulmus (elm)	—
Ambrosia (ragweed)	2.3
Campanula (bellflower)	—
Chenopodiaceae (pigweed)	—
Cyperaceae (sedges)	—
Ericaceae (blueberry)	7.0
Gramineae (grasses)	2.3
Nuphar (a genus of water lily)	—
Nymphea (water lily)	4.7
Plantago (plantain)	—
Rosaceae	2.3
Rubus (bramble)	—
Typha (cat-tail)	—
Umbelliferae	—
Viola (violet type)	—
Lycopodium (club moss)	4.7
Pteridophytes (ferns)	2.3
Selaginella	—
Sphagnum (sphagnum moss)	2.3
Unidentified	14.0
Total	100.2

Site: Wor-Dg 13 (Assateague State Park)
Depth below land surface: 38′-39′
Altitude of land surface (sea-level datum): 4′±
Material analyzed: peat

	Percent
Picea (spruce)	—
Pinus (pine)	23.2
Taxus (yew) (?)	1.6
Acer (maple)	—
Alnus (alder)	13.3
Betula (birch)	7.9
Carya (hickory)	—
Castanea (chestnut)	0.8
Cornus (dogwood)	—
Corylus (hazelnut)	—
Fagus (beech)	—
Fraxinus (ash)	—
Ilex (holly)	0.4
Juglans (walnut)	—
Quercus (oak)	1.6
Salix (willow)	1.2
Tilia (linden)	—
Ulmus (elm)	0.4
Ambrosia (ragweed)	2.1
Campanula (bellflower)	—
Chenopodiaceae (pigweed)	0.4
Cyperaceae (sedges)	—
Ericaceae (heath)	1.2
Gramineae (grasses)	0.8
Nuphar (a genus of water lily)	—
Nymphea (water lily)	0.4
Plantago (plantain)	2.1
Rosaceae	—
Rubus (bramble)	—
Typha (cat-tail)	0.8
Umbelliferae	1.6
Viola (violet type)	—
Lycopodium (club moss)	2.4
Pteridophytes (ferns)	17.4
Selaginella	—
Sphagnum (sphagnum moss)	20.0
Unidentified	—
Total	99.6

Table 4.—Chemical analyses of ground water from northeastern Worcester County, Maryland (adapted from Lucas, 1972).

(Chemical constituents in milligrams per liter)

U.S.G.S. well number	Aquifer	Date of collection	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (P as PO_4)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
Wor-Af 4	PLEISTOCENE	11-05-52	-	33	9.5	0.05	4.5	0.4	8	1.0	26	1.4	9.1	0.0	0.5	0.0	73	13	0	71	6.4	5
Af 23	PLEISTOCENE	12-22-71	14.0	47	5.2	.10	-	-	8.7	1.5	102	.2	9.8	.1	1.1	-	170	86	3	214	6.8	-
Ag 9	PLEISTOCENE	12-22-71	12	14	.04	.00	-	-	9.0	1.8	8	.2	13	.0	3.0	-	43	8	2	72	6.4	-
Ag 13	PLEISTOCENE	12-22-71	12.2	-	11	-	-	-	-	-	-	-	17	-	.0	-	-	35	-	142	-	-
Ag 14	PLEISTOCENE	12-22-71	11.0	-	25	-	-	-	-	-	-	-	13	-	.1	-	-	73	-	222	-	-
Ah 2	PLEISTOCENE	08-31-53	-	-	.02	-	-	-	32		13	14	55	-	1.1	-	-	34	23	249	6.5	-
Ah 3	PLEISTOCENE	08-31-53	-	-	.23	-	-	-	28		141	1.2	66	-	.9	-	-	149	33	436	7.3	-
Ah 6	MANOKIN (363'-373')	07-29-69	21	33	12	.18	24	5.8	24	3.8	110	0.0	35	.1	.7	-	191	84	0	297	6.4	-
Ah 6	MANOKIN (363'-373')	07-25-69	17	32	13	.18	28	5.9	23	4.0	128	0.0	30	.1	.8	-	203	95	0	298	7.0	15
Ah 6	MANOKIN (464'-474')	07-24-69	22	58	.81	.05	42	15	228	13	296 1/	7.2	296	.3	.5	-	801	167	0	1430	8.4	5
Ah 6	CHOPTANK	07-14-69	-	51	2.1	.04	100	98	1690	65	584 2/	149	2710	.8	3.3	-	5240	653	141	8900	8.4	3
Be 16	PLEISTOCENE	11-04-52	-	-	1.5	-	-	-	-	-	6	71	31	-	22	-	-	52	47	332	5.4	5
Bf 46	PLEISTOCENE	12-21-71	14.4	-	.02	-	-	-	-	-	-	-	14	-	9.7	-	-	23	-	118	-	-
Bf 60	PLEISTOCENE	12-21-71	14.2	-	.02	-	-	-	-	-	-	-	11	-	1.6	-	-	18	-	86	-	-
Bg 10	CALVERT (?)	01-06-54	-	-	17	-	100	89	-	-	606	-	2550	-	.8	-	-	615	119	8240	7.5	-
Bg 16	PLEISTOCENE	12-22-71	12.8	25	.03	.00	-	-	10	1.3	20	1.8	12	.0	1.0	-	61	14	0	79	6.3	-
Bg 18	PLEISTOCENE	12-21-71	14.5	-	5.3	-	-	-	-	-	-	-	7.8	-	0	-	-	17	-	84	-	-
Bg 38	PLEISTOCENE	12-21-71	15.2	40	6.5	.15	-	-	9.9	1.2	70	.0	11	.2	.7	-	127	48	0	162	7.1	-
Bh 1	OCEAN CITY	12-12-51	-	24	2.9	.0	37	16	27	12	226	2.0	30	.1	.1	.1	260	158	-	434	7.2	5
Bh 8	POCOMOKE	12-17-51	-	28	1.3	.0	29	14	36	10	229	.1	20	.1	.7	.0	260	130	-	413	7.8	10
Bh 81	OCEAN CITY	06-16-71	-	30	4.8	.12	15	13	44	11	136	8.0	59	.2	.7	-	248	91	0	407	7.4	35
Cd 16	PLEISTOCENE	12-20-71	14.6	-	.05	-	-	-	-	-	-	-	21	-	69	-	-	82	-	289	-	-
Ce 2	POCOMOKE	08-31-53	-	-	2.4	-	-	-	31		123	1.2	12	-	1.2	-	-	52	0	241	6.8	-
Ce 21	POCOMOKE	12-20-71	15	34	13	.07	-	-	22	5.6	128	.0	14	.2	.7	-	166	76	0	262	7.0	-
Ce 26	PLEISTOCENE	12-20-71	13.8	45	12	.09	-	-	18	2.1	82	.0	21	.2	.3	-	148	57	0	212	7.2	-

1/ 6.0 mg/l carbonate.
2/ 20 mg/l carbonate.

Table 4.—Chemical analyses of ground water from northeastern Worcester County, Maryland—Continued.

(Chemical constituents in milligrams per liter)

U.S.G.S. well number	Aquifer	Date of collection	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (P as PO_4)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color
																		Calcium, magnesium	Noncarbonate			
Wor-Cf 3	PLEISTOCENE	11-04-52	-	21	.09	0.02	5.2	1.7	13	2.1	15	6.4	15	0.0	0.2	0.0	93	20	8	122	6.1	3
Cf 3	PLEISTOCENE	12-21-71	14.5	-	.13	-	-	-	-	-	-	-	14	-	18	-	-	25	-	128	-	-
Cf 33	PLEISTOCENE	12-21-71	14.2	-	.02	-	-	-	-	-	-	-	13	-	7.4	-	-	18	-	94	-	-
Cf 34	PLEISTOCENE	12-21-71	-	19	.07	.00	-	-	11	1.3	10	.2	8.6	.0	26	-	76	18	10	105	6.5	-
Cf 39	PLEISTOCENE	12-27-71	13.0	-	.09	-	-	-	-	-	-	-	39	-	5.7	-	-	17	-	187	-	-
Cf 43	PLEISTOCENE	12-22-71	-	-	4.1	-	-	-	-	-	-	-	18	-	.1	-	-	14	-	105	-	-
Cf 47	PLEISTOCENE	12-21-71	14.8	-	.02	-	-	-	-	-	-	-	9.0	-	.3	-	-	12	-	76	-	-
Cg 5	POCOMOKE	01-04-52	-	32	1.3	.0	18	8.3	39	9.2	183	.8	16	.2	.1	.2	214	79	-	325	7.3	28
Cg 6	OCEAN CITY	01-11-52	-	-	1.4	-	-	-	-	-	220	1.0	26	.2	.2	-	-	140	-	414	7.6	-
Cg 20	PLEISTOCENE	01-11-52	-	37	3.0	.01	23	5.2	12	1.4	103	1.2	14	.2	.1	.1	154	79	-	214	7.5	26
Cg 20	PLEISTOCENE	12-21-71	15.0	-	1.6	-	-	-	-	-	-	-	15	-	1.0	-	-	70	-	347	-	-
Cg 35	OCEAN CITY	12-20-71	14.5	29	2.0	.05	-	-	23	8.7	200	.0	7.5	.2	.1	-	215	124	0	353	7.9	-
Cg 41	PLEISTOCENE	12-20-71	12.3	40	6.7	.19	-	-	11	.9	71	.0	3	.1	2.1	-	127	49	9	159	6.9	-
Cg 44	PLEISTOCENE	12-20-71	13.4	40	6.9	.20	-	-	11	1.0	70	.4	11	.1	.7	-	118	52	0	159	7.1	-
Cg 54	PLEISTOCENE	12-21-71	13.2	-	8.1	-	-	-	-	-	-	-	12	-	.6	-	-	74	-	192	-	-
Dd 10	MANOKIN	05-27-52	-	17	.07	.02	16	5.6	113	6.4	303	2.5	52	.1	.6	1.1	381	63	0	612	7.9	2
De 33	POCOMOKE	07-20-71	15	40	.58	.00	10	5.6	32	7.2	131	2.2	14	.2	.9	-	169	48	0	248	7.7	20
De 34	PLEISTOCENE	12-21-71	15	41	5.6	.14	-	-	17	1.5	45	24	18	.2	.1	-	147	46	9	198	7.0	-
De 35	PLEISTOCENE	12-21-71	-	-	11	-	-	-	-	-	-	-	17	-	.0	-	-	76	-	321	-	-
Df 3	PLEISTOCENE	10-05-67	14	29	2.1	.08	32	9.5	25	3.8	194	.2	12	.2	1.3	-	205	118	0	323	7.7	-
Df 3	PLEISTOCENE	12-22-71	13.6	-	2.3	-	-	-	-	-	-	-	11	-	.1	-	-	116	-	353	-	-
Dg 5	PLEISTOCENE	09-10-53	16	-	.27	-	-	-	96		290	1.2	60	-	.2	-	-	115	0	614	7.4	0
Dg 10	MANOKIN	12-20-71	15.4	16	.02	.02	-	-	49	10	258	.4	21	.1	1.1	-	260	134	0	472	8.2	-
Wi-Di 3 1/	PLEISTOCENE	10-27-71	13.5	-	7.8	.03	-	-	8.5	1.5	58	-	8.7	-	-	-	12	41	0	125	7.7	-

1/ Location in Wicomico County, Maryland.

Table 6.—Heavy-mineral analyses of selected samples of material from northeastern Worcester County, Maryland.

(Statistical counts of heavy mineral grains, expresed as percentages of total heavy minerals in each sample. All analyses made by U. S. Geological Survey.)

Site: Wor-Be 30
Depth below land-surface: 19-24 ft.
Altitude of land-surface (sea-level datum) : 30 ft.
Material analyzed: fine brown sand; Pleistocene (back-bar lagoonal) deposits

Heavy minerals are 2.7 percent of sample.

	Percent
Hornblende	50
Epidote	7
Magnetite	5
Collophane	4
Apatite	3
Tourmaline	3
Tremolite	3
Diopside	3
Chlorite	2
Augite	2
Limonite	2
Leucoxene	2
Muscovite	2
Biotite	2
Garnet	1
Zoisite	1
Enstatite	<1
Zircon	<1
Sphene	<1
Sillimanite	<1
Unknown	7

Site: Wor-Bg 42
Depth below land-surface: 119-124 ft.
Altitude of land-surface (sea-level datum) : 4 ft.
Material analyzed: tan coarse sand; Pleistocene, estuarine and fluvial (Beaverdam)

Heavy materials are 1.6 percent of sample.

	Percent
Hornblende	30
Magnetite	24
Epidote	9
Leucoxene	6
Apatite	5
Diopside	4
Garnet	3
Augite	2
Tourmaline	2
Staurolite	2
Biotite	1
Zircon	1
Chlorite	1
Zoisite	1
Tremolite	1
Collophane	<1
Limonite	<1
Muscovite	<1
Monazite	<1
Rutile	<1
Unknown	5

Site: Wor-Bh 81
Depth below land-surface: 90-97 ft.
Altitude of land-surface (sea-level datum) : 5 ft.
Material analyzed: gray coarse sand, fine gravel; Pleistocene (Beaverdam)

Heavy materials are 1.0 percent of sample.

	Percent
Apatite	31
Magnetite	26
Hornblende	6
Garnet	6
Pyrite	6
Epidote	4
Leucoxene	3
Tremolite	3
Staurolite	3
Biotite	2
Diopside	2
Limonite	2
Chromite (?)	1
Olivine	<1
Unknown	2

NOTE: Insufficient grain population on slide for a meaningful count (repeated traverses necessary).

Table 6.—Heavy-mineral analyses of selected samples of material from northeastern Worcester County, Maryland—Continued.

Site: Wor-Bh 81
Depth below land-surface: 143-147 ft.
Altitude of land-surface (sea-level datum): 5 ft.
Material analyzed: clay and gravelly sand; upper aquiclude.

Heavy minerals are 4.4 percent of sample.

	Percent
Magnetite	40
Hornblende	12
Collophane	8
Limonite	6
Zircon	5
Pyrite	4
Garnet	4
Leucoxene	3
Apatite	3
Staurolite	3
Epidote	3
Diopside	2
Olivine	1
Augite	<1
Sillimanite	<1
Zoisite	<1
Tourmaline	<1
Tremolite	<1
Unknown	3

Site: Wor-Bh 81
Depth below land-surface: 180-190 ft.
Altitude of land-surface (sea-level datum): 5 ft.
Material analyzed: tan fine sand; Pocomoke aquifer

Heavy minerals are 2.5 percent of sample.

	Percent
Magnetite	30
Hornblende	15
Collophane	12
Pyrite	6
Limonite	5
Leucoxene	5
Garnet	3
Apatite	3
Zircon	2
Epidote	2
Tourmaline	2
Diopside	2
Hypersthene	1
Monazite	1
Augite	1
Muscovite	1
Sphene	<1
Sillimanite	<1
Staurolite	<1
Chlorite	<1
Zoisite	<1
Unknown	5

Site: Wor-Bh 81
Depth below land-surface: 285-290 ft.
Altitude of land-surface (sea-level datum): 5 ft.
Material analyzed: gray sand; Ocean City aquifer (upper Manokin)

Heavy minerals are .24 percent of sample.

	Percent
Magnetite	44
Pyrite	12
Hornblende	12
Leucoxene	8
Limonite	7
Apatite	5
Garnet	3
Zircon	2
Staurolite	1
Collophane	1
Hypersthene	<1
Olivine	<1
Sillimanite	<1
Diopside	<1
Unknown	5

Table 6.—Heavy-mineral analyses of selected samples of material from northeastern Worcester County, Maryland—Continued.

Site: Wor-Bh 81
Depth below land-surface: 325-330 ft.
Altitude of land-surface (sea-level datum): 5 ft.
Material analyzed: gray sand; lower part of lower aquiclude.

Heavy minerals are 1.6 percent of sample.

	Percent
Magnetite	31
Hornblende	14
Limonite	10
Leucoxene	7
Apatite	7
Pyrite	6
Collophane	4
Diopside	3
Garnet	3
Staurolite	2
Olivine	1
Epidote	1
Chlorite	1
Glauconite	<1
Muscovite	<1
Sillimanite	<1
Tremolite	<1
Kyanite	<1
Tourmaline	<1
Unknown	4

Site: Wor-Bh 81
Depth below land-surface: 465-470 ft.
Altitude of land-surface (sea-level datum): 5 ft.
Material analyzed: gray sand and fine gravel; Manokin aquifer, proper

Heavy minerals are 1.6 percent of sample.

	Percent
Magnetite	33
Hornblende	11
Limonite	9
Apatite	8
Leucoxene	8
Epidote	5
Pyrite	3
Garnet	3
Enstatite	2
Tremolite	2
Staurolite	2
Diopside	2
Chlorite	1
Kyanite	1
Hypersthene	1
Muscovite	1
Tourmaline	1
Biotite	<1
Monazite	<1
Zoisite	<1
Sillimanite	<1
Zircon	<1
Unknown	6

Site: Wor-Ce 25
Depth below land-surface: 38-43 ft.
Altitude of land-surface (sea-level datum): 35 ft.
Material analyzed: tan clayey sand; upper Pleistocene deposits

Heavy minerals are 1.5 percent of sample.

	Percent
Magnetite	57
Apatite	14
Leucoxene	5
Epidote	5
Hornblende	4
Diopside	3
Xenotime	3
Staurolite	1
Tourmaline	1
Augite	<1
Chlorite	<1
Garnet	<1
Andalusite (?)	<1
Kyanite	<1
Zircon	<1
Topaz (?)	<1
Limonite	<1
Unknown	3

Table 6.—Heavy-mineral analyses of selected samples of material from northeastern Worcester County, Maryland—Continued.

Site: Wor-Ce 25
Depth below land-surface: 89-94 ft.
Altitude of land-surface (sea-level datum) : 35 ft.
Material analyzed: pebbly gray sand; Pleistocene (Beaverdam)

Heavy minerals are 1.3 percent of sample.

	Percent
Magnetite	78
Leucoxene	5
Zircon	2
Diopside	2
Garnet	2
Epidote	2
Apatite	1
Limonite	1
Hornblende	1
Monazite	1
Tourmaline	<1
Sillimanite	<1
Tremolite	<1
Olivine (?)	<1
Unknown	1

Site: Wor-Ce 25
Depth below land-surface: 109-114 ft.
Altitude of land-surface (sea-level datum) : 35 ft.
Material analyzed: Fine gray sand; basal Pleistocene deposits or upper aquiclude

Heavy minerals are 1.1 percent of sample.

	Percent
Magnetite	50
Leucoxene	9
Muscovite	9
Apatite	8
Epidote	3
Diopside	2
Limonite	2
Zircon	2
Hornblende	1
Tremolite	1
Garnet	1
Staurolite	1
Monazite	1
Sillimanite	1
Biotite	<1
Chlorite	<1
Collophane	<1
Zoisite	<1
Tourmaline	<1
Kyanite	<1
Glauconite (?)	<1
Unknown	5

Site: Wor-Cf 48
Depth below land-surface: 94-99 ft.
Altitude of land-surface (sea-level datum) : 3 ft.
Material analyzed: gray coarse sand and fine gravel; Pleistocene (Beaverdam).

Heavy minerals are 1.1 percent of sample.

	Percent
Magnetite	53
Hornblende	11
Epidote	7
Leucoxene	4
Garnet	3
Diopside	3
Zircon	2
Staurolite	2
Tremolite	1
Biotite	<1
Monazite	<1
Zoisite	<1
Enstatite	<1
Pyrite	<1
Apatite	<1
Sphene	<1
Tourmaline	<1
Limonite	<1
Sillimanite	<1
Unknown	6

Table 6.—Heavy-mineral analyses of selected samples of material from northeastern Worcester County, Maryland—Continued.

Site: Wor-Cg 61
Depth below land-surface: 107-110 ft.
Altitude of land-surface (sea-level datum): 10 ft.
Material analyzed: dark gray sandy clay; Pleistocene deposits (lower; estuarine)

Heavy minerals are .6 percent of sample.

	Percent
Magnetite	51
Collophane	12
Epidote	6
Pyrite	6
Hornblende	5
Leucoxene	4
Garnet	4
Diopside	3
Monazite	2
Staurolite	1
Zircon	1
Tourmaline	1
Kyanite	1
Limonite	1
Apatite	1
Chlorite	<1
Sillimanite	<1
Zoisite (?)	<1
Unknown	3

Site: Wor-Cg 63
Depth below land-surface: 140-144 ft.
Altitude of land-surface (sea-level datum): 5 ft.
Material analyzed: fine brown sand, dark gray clay; Pleistocene deposits(lower; marine or estuarine)

Heavy minerals are 4.3 percent of sample.

	Percent
Hornblende	39
Apatite	9
Epidote	8
Garnet	6
Collophane	5
Magnetite	5
Chlorite	3
Augite	3
Diopside	2
Biotite	2
Leucoxene	2
Muscovite	1
Glauconite	1
Sillimanite	1
Tourmaline	1
Pyrite	<1
Zircon	<1
Monazite	<1
Zoisite	<1
Staurolite	<1
Kyanite	<1
Unknown	9

Site: Wor-Bg 47
Depth below land-surface: 35-36 ft.
Altitude of land-surface (sea-level datum): 5½ ft.
Material analyzed: light-gray sand; Pleistocene deposits (upper)

Heavy minerals are 1.1 percent of sample.

	Percent
Magnetite	48
Hornblende	9
Leucoxene	8
Epidote	7
Limonite	5
Augite	3
Zircon	3
Diopside	2
Garnet	2
Zoisite	1
Staurolite	1
Apatite	1
Unknown	9

Table 6.—Heavy-mineral analyses of selected samples of material from northeastern Worcester County, Maryland—Continued.

Site: Wor-Bg 47
Depth below land-surface: 60-61 ft.
Altitude of land-surface (sea-level datum): 5½ ft.
Material analyzed: coarse green sand; Pleistocene (Beaverdam)

Heavy minerals are 1.2 percent of sample.

	Percent
Magnetite	51
Hornblende	16
Epidote	7
Leucoxene	6
Apatite	4
Zircon	3
Enstatite	2
Garnet	2
Pyrite	<1
Augite	<1
Limonite	<1
Strontianite	<1
Tourmaline	<1
Limonite	<1
Actinolite	<1
Sillimanite	<1
Unknown	6

Table 7.—Conversion from English units to International System (SI) units.

Multiply English units	By	To obtain SI units
	Length	
inches (in)	25.4	millimeters (mm)
	.0254	meters (m)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
square miles (mi^2)	2.590	square kilometers (km^2)
	Volume	
gallons (gal)	3.785	*liters (l)
	3.785	cubic decimeters (dm^3)
	3.785×10^{-3}	cubic meters (m^3)
million gallons (10^6 gal)	3785	cubic meters (m^3)
	3.785×10^{-3}	cubic hectometers (hm^3)
cubic feet (ft^3)	28.32	cubic decimeters (dm^3)
	.02832	cubic meters (m^3)
	Flow	
gallons per minute (gpm)	.06309	liters per second (l/s)
	.06309	cubic decimeters per second (dm^3/s)
	6.309×10^{-5}	cubic meters per second (m^3/s)
million gallons per day (mgd)	43.81	cubic decimeters per second (dm^3/s)
	.04381	cubic meters per second (m^3/s)

*The unit liter is accepted for use with the International System (SI). See NBS Special Bulletin 330, p. 13, 1972 edition.

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