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HYDROLOGY, GEOLOGY, AND MINERAL RESOURCES OF THE COASTAL ZONE OF DELAWARE

Delaware Coastal Zone Management Program

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Hydrology, Geology and Mineral Resources of the Coastal Zone of Delaware

by

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INTRODUCTION

PURPOSE AND SCOPE OF THE REPORT

The Delaware State Planning Office is charged with the responsibility to develop a coastal zone management program for the State's coastal regions. The geological and hydrological framework of the coastal regions is an essential component for the accomplishment of this important goal.

To this end, the State Planning Office contracted with the University of Delaware for a "state of the art" report on Delaware's geology, hydrology and mineral resources. This assignment was a logical extension of previous work by the University of Delaware Water Resources Center and the Delaware Geological Survey. Over the past decade, the team of Sundstrom and Pickett has produced a series of publications on the hydrology and geology of Delaware that, when combined with the work of the U. S. Geological Survey, the Delaware Geological Survey and the Delaware Department of Natural Resources and Environmental Control, constitute the definitive works on the subject of this report. All this information is either summarized or referenced in this present study and, therefore, this report truly represents the state of the art on the geology, hydrology and mineral resources of Delaware as of 1975.

Our hope is that this study will prove to be the valuable tool for the effective management of Delaware's coastal lands and waters.

PERSONNEL AND ACKNOWLEDGMENTS

This report describing the hydrology, geology, and mineral resources in the Coastal region of Delaware for planning purposes has been formulated and prepared principally by R. W. Sundstrom, Senior Hydrologist and consultant to the Water Resources Center; Dr. Thomas E. Pickett, Senior Geologist, Delaware Geological Survey; and Dr. Robert D. Varrin, Director, Water Resources Center, University of Delaware. The authors have had very able assistance in their study and preparation of this report by many people. Dr. Pickett has been ably assisted in preparing the geology section of this report by Mr. James Demarest. Mr. Demarest also helped Mr. Sundstrom in preparing water-altitude maps and saturated thickness maps of the water table in Kent County. Dr. Pickett and Mr. Sundstrom both had the able assistance of Ms. Michelle Mayrath and Ms. Katherine Roxlo in drafting several of the illustrations presented in this report. A rather detailed inventory of the water used in Delaware in 1974 was done by Mr. Frederick Robertson with assistance by Ms. Roxlo. The results of Mr. Robertson's inventory are recorded in tables in the hydrology section of this report. The final drafting on many of the figures was done by the State Planning Office staff and their efforts are appreciated.

All three authors have had the excellent assistance of Mrs. Terri Reutter, clerk typist, and Mrs. Beverly Grunkemeyer, staff assistant, of the Water Resources Center in composing, compiling and getting the report ready for publication.

The authors have had excellent cooperation with the Delaware State Planning Office, the Delaware Geological Survey, and the Delaware Department of Natural Resources and Environmental Control, the University of Delaware's Cooperative Extension Service and the Agricultural Agents in Delaware's three counties, city and industrial officials and many others who assisted by furnishing data and other material.

WELL-NUMBERING SYSTEM

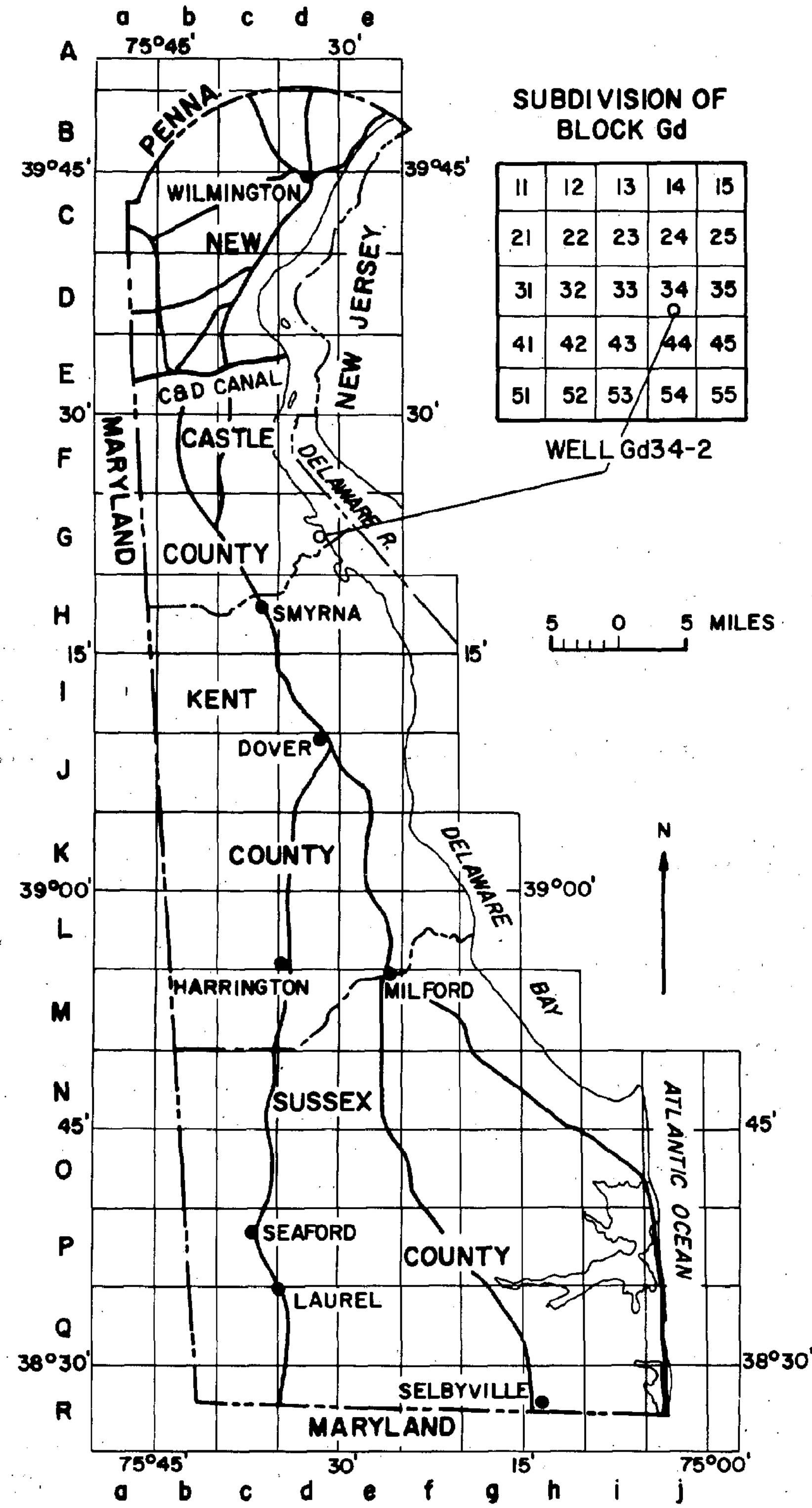
For the purpose of numbering wells in Delaware, the State is divided into 5-minute quadrangles of latitude and longitude. The quadrangles are lettered north to south with capital letters, and west to east with lower case letters. Each 5-minute quadrangle is further subdivided into 25 1-minute blocks which are numbered from north to south in series of 10 from 10 to 50 and are numbered from west to east in units from 1 to 5 (see Figure 1). Wells within these 1-minute blocks are assigned serial numbers as they are scheduled. Thus, the identity of a well is established by prefixing the serial number with an upper and lower case letter followed by two numbers to designate the 5-minute and 1-minute blocks, respectively, in which the well is located. For example, well number Gd34-2 is the second well to be scheduled in the 1-minute block which has the coordinates Gd-34. The wells listed in many of the tables of this report can be approximately located on the map in Figure 1 by applying the well number coordinates of the well listed in the tables to the coordinates of the map. Exact locations of the well can be found on maps in the files of the Delaware Geological Survey.

DEFINITIONS OF TERMS

Acre-foot - The volume of water required to cover 1 acre to a depth of 1 foot (43,560 cubic feet) or 325,851 gallons.

Aquifer - A body of either consolidated or unconsolidated rock material that contains sufficient saturated permeable material to conduct ground water and to yield economically significant quantities of ground water to wells and springs.

Artesian Aquifer - Artesian (confined) water occurs where an aquifer is overlain by earth material of lower permeability (such as clay) that confines the water under pressure greater than atmospheric. The water level in an artesian well will rise above the top of the aquifer even without pumping.



FROM RIMA, ET. AL., 1964

FIGURE I. MAP SHOWING THE COORDINATES FOR THE WELL-NUMBERING SYSTEM.

Available Drawdown - The lowering of the water table or piezometric surface caused by pumping (or artesian flow). In most instances, it is the difference, in feet, between the static level and the pumping level.

Barrier Boundary Effect - The result of a hydrologic boundary of restricted permeability which affects the radial growth of the cone of depression of a pumping well. This occurs after an elapsed pumping time. Because of this, the drawdown data of pumping tests are abnormal and the transmissivity value obtained is less than the true transmissivity.

Clay - A rock or mineral fragment or a detrital particle of any composition (often a crystalline fragment of a clay mineral, having a diameter less than 1/256 mm., 4 microns, 0.00016 inches, or 8 phi units).

Coastal Plain - A low, generally broad but sometimes narrow plain that has its margin on the shore of a large body of water and its strata either horizontal or very gently sloping toward the water.

Coefficient of Storage, or Storativity - The volume of water an aquifer releases from or takes into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface.

Concretion - A hard, compact, rounded and normally subspherical mass of mineral material of a composition different from that of the earth material in which it is found and from which it is sharply separated.

Cone of Depression - Depression of the water table or piezometric surface surrounding a discharging well, more or less the shape of an inverted cone.

Confining Bed - One which, because of its position and its impermeability or low permeability relative to that of the aquifer, keeps the water in the aquifer under artesian pressure.

Contamination - An impairment of the quality of the water by sewage (high nitrate content), industrial waste (such as oil-field brines from improperly cased or plugged wells), or intraformational leakage from overlying or underlying strata that contain undesirable water (Glen Rose Formation), to a degree which creates an actual hazard to public health.

Continental Shelf - A part of the continental margin that is between the shoreline and the continental slope (usually about 200 m. maximum depth).

Discharge - Rate of flow at a given instant in terms of volume per unit of time.

Earthquake - A sudden motion or trembling in the earth caused by the abrupt release of slowly accumulated strain (associated with faulting and/or volcanic activity).

Electric Log - A geophysical record of the uncased part of a well or borehole, obtained by lowering and raising an electrode on a wire line and making in-situ measurements (continuously recorded at the surface) of the electrical properties of the geologic formations encountered at various depths.

Evapotranspiration - Water withdrawn by evaporation from a land area, a water surface, moist soil, or the water table, and the water consumed by transpiration of plants.

Fall Zone - An imaginary narrow zone connecting the waterfalls on several successive and nearly parallel rivers, marking the points where these rivers make a sudden descent from the upland to the lowland, as at the boundary between the Piedmont Province and the Coastal Plain.

Fault - A surface or zone of rock fracture along which there has been displacement, from a few centimeters to a few kilometers in scale.

Formation - The basic or fundamental rock-stratigraphic unit in the local classification of rocks, consisting of a body of rock characterized by some degree of internal lithologic homogeneity or distinctive lithologic feature, and by mappability at the Earth's surface, or traceability in the subsurface.

Fossil - Any remains, traces, or imprints of a plant or animal that has been preserved by natural processes in the Earth's crust since some past geologic time; any evidence of past life.

Geology - The study of the planet Earth.

Group - A major rock-stratigraphic unit next higher in rank than the formation, consisting wholly of two or more (commonly two to five) continuous or associated formations having significant lithologic features in common.

Head, or Hydrostatic Pressure - The pressure exerted by the water at any given point in a body of water at rest reported in pounds per square inch or in feet of water. That of ground water is generally due to the weight of water at higher levels in the same zone of saturation.

Hydraulic Conductivity - The rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot.

Hydraulic Gradient - The slope of the water table or piezometric surface, usually given in feet per mile.

Hydrology - The science that deals with continental water, its properties, circulation, and distribution on and under the Earth's surface and in the atmosphere from the moment of its precipitation until it is returned to the atmosphere through evapotranspiration or is discharged into the ocean.

Intrusion - The process of emplacement of molten rocks into existing rocks.

Isopach - A line drawn on a map through points of equal thickness of a designated stratigraphic unit or group of stratigraphic units.

Lignite - A brownish-black coal that is intermediate in coalification between peat and subbituminous coal.

Lithology - The description of rocks, especially sedimentary clastics, and especially in hand specimen and in outcrop on the basis of color, structure, mineralogy, and grain type.

Marine Sediments - Sediments which were deposited in a marine environment by marine processes.

Marsh - A water-saturated, poorly-drained area, intermittently or permanently water-covered, having aquatic and grasslike vegetation, and essentially without peat accumulation.

Milligrams Per Liter (mg/l) - One milligram per liter represents 1 milligram of solute in 1 liter of solution. As commonly measured and used, one milligram per liter is numerically equivalent to one part per million (1 milligram of solute in 1 kilogram of solution).

Mineral - A naturally-formed chemical element or compound having a definite chemical composition and usually a characteristic crystal form.

Non-Marine Sediment - Sediment which was deposited in an environment not associated with marine waters, i.e. fluvial, brackish, lacustrine, eolian, etc.

Outcrop - That part of a geologic formation or structure that appears at the surface of the Earth.

Permeability - The property or capacity of a porous rock, sediment, or soil for transmitting a fluid without impairment of the structure of the medium; a measurement of the relative ease of fluid flow under unequal pressure.

Piedmont - Lying or formed at the base of a mountain range; in the U.S., the Piedmont is a plateau extending from New Jersey to Alabama and lying east of the Appalachian Mountains.

Piezometric Surface - An imaginary surface that everywhere coincides with the static level of the water in the aquifer. The surface to which the water from a given aquifer will rise under its full head.

Pyrite - A common, pale-bronze or brass-yellow mineral; FeS_2.

Recharge - The process by which water is absorbed and is added to the zone of saturation. Also used to designate the quantity of water that is added to the zone of saturation, usually given in acre-feet per year or in million gallons per day.

Rejected Recharge - The natural discharge of ground water in the recharge area of an aquifer by springs, seeps, and evapotranspiration, which occurs when the rate of recharge exceeds the rate of transmission in the aquifer.

Runoff - The water which flows on the surface is called the runoff, though this term is used to include also the water which returns to the surface after a greater or less underground passage.

Safe Yield - The rate at which water can be withdrawn from an aquifer for human use without depleting the quantity or quality of the supply to such an extent that withdrawal at this rate will become no longer economically feasible. The practical rate of withdrawing water from an underground reservoir perennially for human use.

Salt-Water Intrusion - The phenomenon occurring when a body of salt water, because of its greater density, invades a body of fresh water. It can occur either in surface or ground-water bodies. The balance between the two, in static situations, is expressed by the Ghyben-Herzberg formula.

Sand - A rock fragment or detrital particle smaller than a granule and larger than a coarse silt grain, having a diameter in the range of 1/16 to 2 mm. (62-200 microns, or 0.0025 - 0.08 inches, or 4 to 1 phi units, or the lower limits of visibility for a single grain to the size of the head of a small wooden match).

Silt - A rock fragment or detrital particle smaller than sand and larger than clay, having a diameter in the range of 1/256 to 1/16 mm. (4-62 microns, or 0.00016 - 0.0025 inches, or 8 to 4 phi units).

Specific Capacity - The rate of yield of a well per unit of drawdown, usually expressed as gallons per minute per foot of drawdown. If the yield is 250 gallons per minute and the drawdown is 10 feet, the specific capacity is 25 gallons per minute per foot.

Specific Yield - The quantity of water that an aquifer will yield by gravity if it is first saturated and then allowed to drain; the ratio expressed in percentage of the volume of water drained to volume of the aquifer that is drained.

Static Water Level - The water level in an unpumped or nonflowing well measured in feet above or below the land surface or sea-level datum.

Stratigraphic Correlation - The process by which stratigraphic units in two or more separate areas are demonstrated or determined to be laterally similar in character or mutually correspondent in stratigraphic position, as based on geologic age, lithologic characteristics, fossil content, or any other property of the strata.

Strike - The direction or trend that a structural surface takes as it intersects the horizontal.

Structure - Said of or pertaining to features that are the result of crustal folding or faulting.

Subcrop - An occurrence of strata in contact with the undersurface of an overlying stratigraphic unit.

Subsurface - The zone below the surface whose geologic features, principally stratigraphic and structural, are interpreted on the basis of drill records and various kinds of geophysical evidence.

Surface Water - The water which rests or flows on the surface of the earth lithosphere.

Transmissivity - The number of gallons of water that will move in one day through a vertical strip of the aquifer one foot wide extending the vertical thickness of the aquifer when the hydraulic gradient is one foot per foot. It is the product of the hydraulic conductivity and the saturated thickness of the aquifer.

Unconformity - A substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession, such as an interruption in the continuity of a depositional sequence of sedimentary rocks.

Variegated - Said of a sediment or sedimentary rock showing variations of colors or tints in irregular spots, streaks, blotches, stripes, or reticulated patterns.

Water Level - Depth to water, in feet below the land surface, where the water occurs under water-table conditions (or depth to the top of the zone of saturation). Under artesian conditions the water level is a measure of the pressure on the aquifer, and the water level may be at, below, or above the land surface.

Water-Table Aquifer - An aquifer in which the water is unconfined; the upper surface of the zone of saturation is under atmospheric pressure only and the water is free to rise or fall in response to the changes in the volume of water in storage. A well penetrating an aquifer under water table conditions becomes filled with water to the level of the water table.

Yield of a Well - The rate of discharge, commonly expressed as gallons per minute, gallons per day, or gallons per hour.

GEOLOGY

GEOLOGY FOR PLANNING PURPOSES

Geology as a Constraint

The geologic framework is the means by which current earth processes are controlled by past geologic processes. Man's input into this system adds another determinative factor to the present and future dynamics of the system. To better understand and manage our environment we must first understand the constraints within which we must work as determined by the geologic conditions.

The geologic framework of an area is the most important factor in determining: drainage patterns; location, quality and quantity of water in the subsurface; stability of the ground for construction uses; location, quality and quantity of mineral resources. There are no earth processes or conditions which are not controlled or greatly affected by geologic constraints.

It is also important to understand the basic differences between the geologic constraints and man's input into the system. Man's policies, and therefore his input into the system, can be changed and therefore man's effect on the system can be controlled and predicted. In contrast, geologic conditions are not changeable or manageable except on a very small scale with large inputs of energy.

Geology as a Predictor

By studying the geologic processes that formed our present environment, we not only can predict future environments, but we can also understand the processes involved in producing them. Therefore, changes man makes in these processes can also be taken into account when predicting future environmental conditions. For example, understanding the geologic framework of aquifers enables us to identify recharge areas and areas of vulnerability of the aquifer. We will then be able to predict quantitatively what changes, if any, man's activities will have on water quality and quantity. Similarly, study of the geology of an area allows us to determine, in general, soil quality, stability of the ground, erosional hazards, etc., in areas without actually doing costly tests and studies on location in the area of interest. We can also predict the lateral extent of conditions by projection of the geologic situation under which these conditions exist, i.e., topography, surface lithology, subsurface lithology and structure, geologic history, and present earth processes as determined by geologic history.

GENERAL GEOLOGIC HISTORY OF DELAWARE

The Piedmont

Delaware lies within two regional geologic provinces: the Appalachian Piedmont and the Atlantic Coastal Plain (Figure 2). The northernmost part of the State lies in the Piedmont. This area is characterized by very old crystalline rocks which slope generally southeasterly under all of Delaware. The minerology of these rocks is very complex because they consist of sedimentary and igneous rocks which have been intensely metamorphosed throughout the area during the building of an ancient mountain range which has now been eroded.

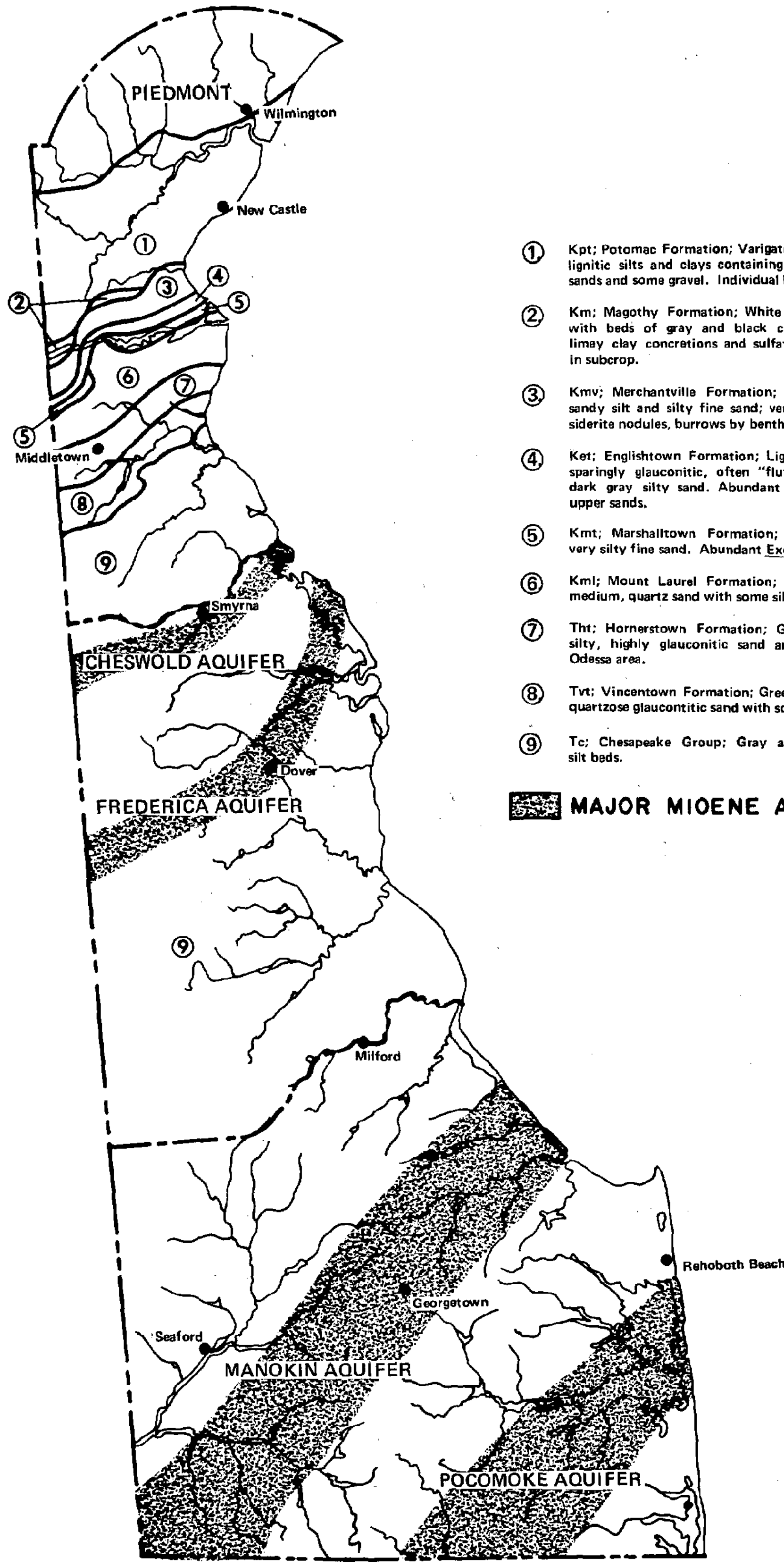
The Coastal Plain

South of the Fall Zone, the Piedmont-type rocks are covered by a thick wedge of unconsolidated and semiconsolidated sedimentary rocks. This region is the Coastal Plain Province (Figure 3). In the southeastern part of Delaware, these sediments reach a thickness of about 8,000 feet, and although they are covered by water farther east, they continue out to the edge of the continental shelf with a maximum thickness of about 8 to 10 miles. All these sediments are much younger than any of those found in the Piedmont by over 300 million years except for those found in the Bryn Mawr Formation north of Wilmington, which are much younger than the Piedmont rocks but have an unknown age. The Coastal Plain sediments have been divided into units, each of which is called a formation (at times formations are put together and called groups) whose lithology is distinctly different from the sediments above and below it (Table 1).

The oldest sediments in the Coastal Plain, which were deposited by streams on the subsurface extension of the Piedmont, are at the base of the Potomac Formation and are about 120 million years old. This unit is the most extensive sedimentary formation in Delaware. It consists of color-banded clays with interbedded sands which eroded off the ancestral Appalachian Mountains to the northwest. During the deposition of the Potomac Formation a gradual tilting down to the east allowed about 4,000 feet of sediment to accumulate. Above this the Magothy Formation was deposited after a period of erosion or nondeposition (an unconformity) which represents the encroachment of the sea over most of Delaware. The Magothy Formation is very distinct with its white sands and black lignite. The presence of lignite suggests that this unit represents a transitional environment from stream deposits to marine, much like that found in a delta or marsh.

Above the Magothy are marine formations of Cretaceous through Eocene age. The units deposited during this time, from oldest to youngest, are as follows: Merchantville Formation, Englishtown Formation, Marshalltown Formation, Mt. Laurel Formation, Rancocas Group, Nanjemoy Formation, Pamunkey Formation (unit A), Piney Point Formation.

FIGURE 2
A GEOLOGIC MAP OF DELAWARE



① Kpt; Potomac Formation; Varigated red, gray, purple, yellow and white, frequently lignitic silts and clays containing interbedded white, gray, and rust-brown quartz sands and some gravel. Individual beds usually laterally restricted.

② Km; Magothy Formation; White and buff, frequently sugary, clean quartz sand with beds of gray and black clayey silt containing much lignite, pyrite-filled limey clay concretions and sulfate blooms. Formation discontinuous along strike in subcrop.

③ Kmv; Merchantville Formation; Dark gray to dark blue, micaceous, glauconitic sandy silt and silty fine sand; very sticky when wet. Placenticeras placenta, small siderite nodules, burrows by benthic organisms.

④ Ket; Englishtown Formation; Light gray and rust brown, well sorted, micaceous, sparingly glauconitic, often "fluffy", fine sand with thin interbedded layers of dark gray silty sand. Abundant nodulose burrows of Callianassa, particularly in upper sands.

⑤ Kmt; Marshalltown Formation; Dark greenish-gray, massive, highly glauconitic very silty fine sand. Abundant Exogyra ponderosa.

⑥ Kml; Mount Laurel Formation; Gray, green and red-brown, glauconitic, fine to medium, quartz sand with some silt.

⑦ Tht; Hornerstown Formation; Green, gray and reddish-brown, fine to medium silty, highly glauconitic sand and sandy silt. Red sands are found locally in Odessa area.

⑧ Tvt; Vincentown Formation; Green, gray and reddish-brown, fine to coarse, highly quartzose glaucontitic sand with some silt.

⑨ Tc; Chesapeake Group; Gray and bluish-gray silt, with some fine sand and silt beds.

MAJOR MIOENE AQUIFER

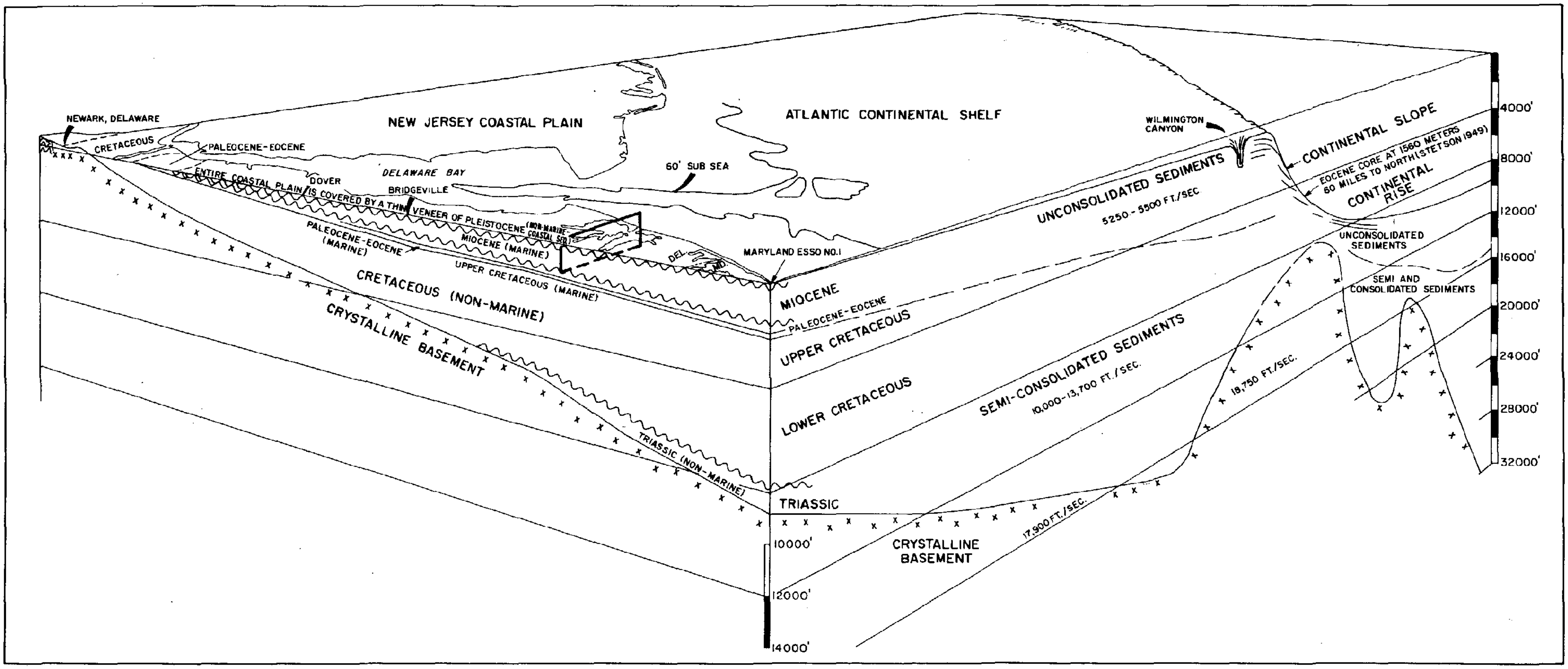


FIGURE 3. GEOLOGIC CROSS-SECTION SHOWING GROUND-WATER AQUIFERS OF DELAWARE.

System	Series	New Jersey Group	New Jersey	Delaware Group	Delaware	Delaware (downdip)	Maryland Group	Maryland	Maryland (other)
Quaternary	Pleistocene		Cape May Fm.		Omar Fm.	Columbia Grp.	Columbia Grp.	Walston Fm.	Lowland Deposits
			Pensauken Fm.		Columbia Fm.				
			Bridgeton Fm.		Beaverdam Fm.			Salisbury Fm.	
Tertiary	Pliocene (?)		Beacon Hill Gravel		Bryn Mawr Fm.			Upland Gravels	
	Miocene		Cohansey Fm.		Chesapeake Group		Chesapeake Grp.	Yorktown Fm.	
								St. Marys Fm.	
								Choptank Fm.	
			Kirkwood Fm.					Calvert Fm.	
	Oligocene								
	Eocene		Piney Point Fm.		Piney Point Fm.			Piney Point	Chickahominy Fm.
			Shark River Fm.						
			Manasquan Fm.		Nanjemoy Fm.		Pamunkey Grp.	Nanjemoy Fm.	
			Vincentown Fm.		Vincentown Fm.			Marlboro Clay	
	?								
	Paleocene	Rancocas Grp.	Hornerstown Fm.	Rancocas Grp.	Hornerstown Fm.	Pamunkey Fm. (downdip)		Brightseat Fm.	
Cretaceous	Upper Cretaceous	Monmouth Grp.	Tinton Fm.			Monmouth Fm. (downdip)			
			Redbank Fm.						
			Navesink Fm.						
			Mt. Laurel Fm.		Mt. Laurel Fm.			Monmouth Fm.	
		Matawan Grp.	Wenonah Fm.	Matawan Grp.		Matawan Fm. (downdip)			
			Marshalltown Fm.		Marshalltown Fm.				
			Englishtown Fm.		Englishtown Fm.				
			Woodbury Clay		Merchantville Fm.			Matawan Fm.	
			Merchantville Fm.						
			Magothy Fm.		Magothy Fm.			Magothy Fm.	
			Raritan Fm.				Potomac Grp.	Patapsco Fm.	
	Lower Cretaceous		Potomac Fm. ?		Potomac Fm.			Arundel Fm.	
								Patuxent Fm.	

Table 1. Correlation Chart of the Coastal Plain Units in New Jersey, Delaware and Maryland

Above this is an unconformity which represents a gap in the sedimentary record during which no sediments have been preserved (Oligocene age). Later, the sea again covered most of Delaware and deposited the Chesapeake Group (Miocene age). This group consists of interbedded silts and sands and reaches a maximum thickness of over 1,000 feet in southern Delaware. Many of the sandy layers contain important supplies of water for municipal and industrial use. From oldest to youngest, these units are as follows: the Cheswold, Frederica, Manokin, and Pocomoke aquifers.

The repeated advance and retreat of continental glaciers during the past one to two million years (Pleistocene age) caused drastic changes in relative sea level and the configuration of streams draining from the glaciers. The Columbia Group and Formation, which covers most of the surface of Delaware up to the Fall Zone, generally consists of channel deposits from meltwater runoff and marine deposits. The Columbia supplies most of the water used in the state as well as most of the sands and gravel for construction. Many of the stream and channel gravels have been reworked in southern Delaware by the sea during a higher-than-present sea level stand.

This is, briefly, the history of the geologic framework which provides the constraints within which man must plan his activities. It is also important to realize that the processes of erosion, deposition, and sea level change are operating at present, slowly transforming the surface expression of this geologic framework.

DESCRIPTIONS OF AQUIFERS

The maps of the stratigraphic formations of Delaware's Coastal Plain are based on the most recent data available to the Delaware Geological Survey. These maps are continually changed as more data are accumulated and must, therefore, be considered incomplete. Although their reliability exceeds previous maps, which were based on less data, they still must be used with caution.

The maps are indicators of the general structure of the formations and therefore should only be used in a general way. If a contour or isopach is more than a few miles from a data point, its exact positioning becomes more artistic than geologic. The maps indicate the scarcity of data in some areas.

The Potomac Formation

The Potomac Formation, which overlies the crystalline rocks of the basement, consists of variegated silts and clays. These are red, gray, purple, yellow and white and contain some lignite. There are many beds of sand which are white, gray, or rust-brown, predominantly quartz, with some gravel, and which are usually laterally restrictive (Pickett, 1970a).

Between the Fall Zone and just north of the Chesapeake and Delaware Canal, the Potomac Formation (Figure 4) subcrops immediately below the surficial Columbia Formation, and reaches a maximum thickness of about 600 feet. South of this area the Potomac is overlain by other sedimentary formations and dips toward the south. In southern New Castle County the top of the Potomac reaches a depth of 650 feet below sea level and the formation is 1,700 feet thick. Because of extreme depth and because of salt-water contamination, it is not presently useful as an aquifer in Kent and Sussex Counties.

The Magothy Formation

The Magothy Formation (Figure 5) represents a transition from the non-marine fluvial depositional environment of the underlying Potomac Formation to the marine depositional environment of the overlying formations. It is a white and buff, often sugary, clean quartz sand with occasional beds of gray and black clayey silt which contains much lignite, pyrite-filled concretions and sulfate blooms (Pickett, 1970a). Because of its clean sandy nature and consistent thickness of a few tens of feet, the Magothy Formation produces a distinctive "kick" on electric logs of wells; therefore, it is one of the most easily recognizable units in the Coastal Plain.

There is a trough-ridge system running nearly perpendicular to strike near the subcrop area, which accounts for its apparent discontinuity along strike. The cause of these structures is as yet unknown, although they may be associated with differential erosion of the Potomac before deposition of the Magothy.

The Magothy Formation, like the Potomac Formation, is too deep and salty to be useful as an aquifer in Kent and Sussex Counties.

The Monmouth Formation

The Monmouth Formation (synonymous with Mount Laurel Formation at the Chesapeake and Delaware Canal) consists of gray to greenish red-brown glauconitic, fine to medium sand with some silt (Pickett, 1970a). It was deposited under shallow marine conditions. The non-salty portion of the Monmouth is found from the Chesapeake and Delaware Canal to approximately Dover where it is located about 700 feet below sea level (Figure 6).

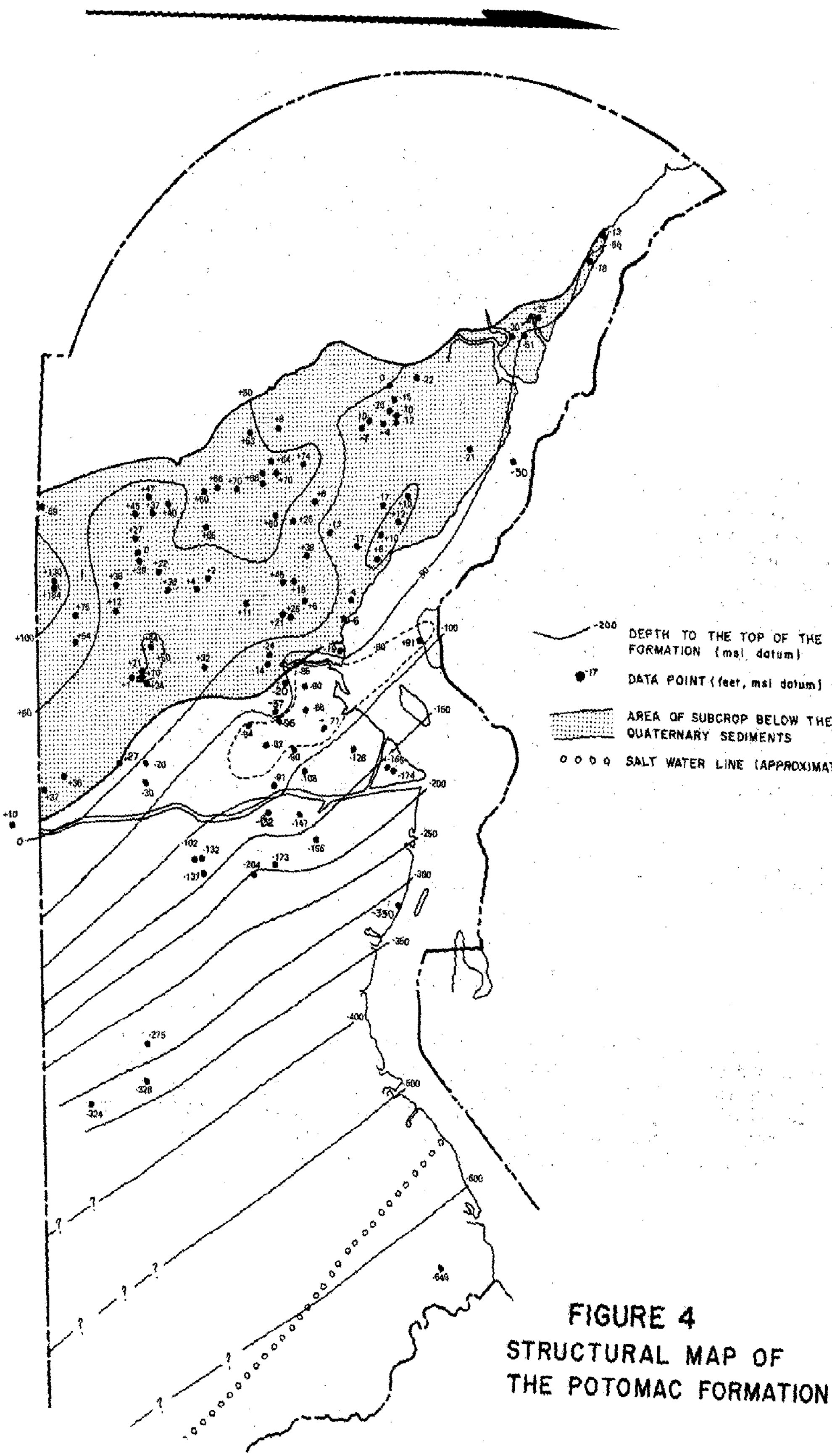


FIGURE 4
STRUCTURAL MAP OF THE POTOMAC FORMATION

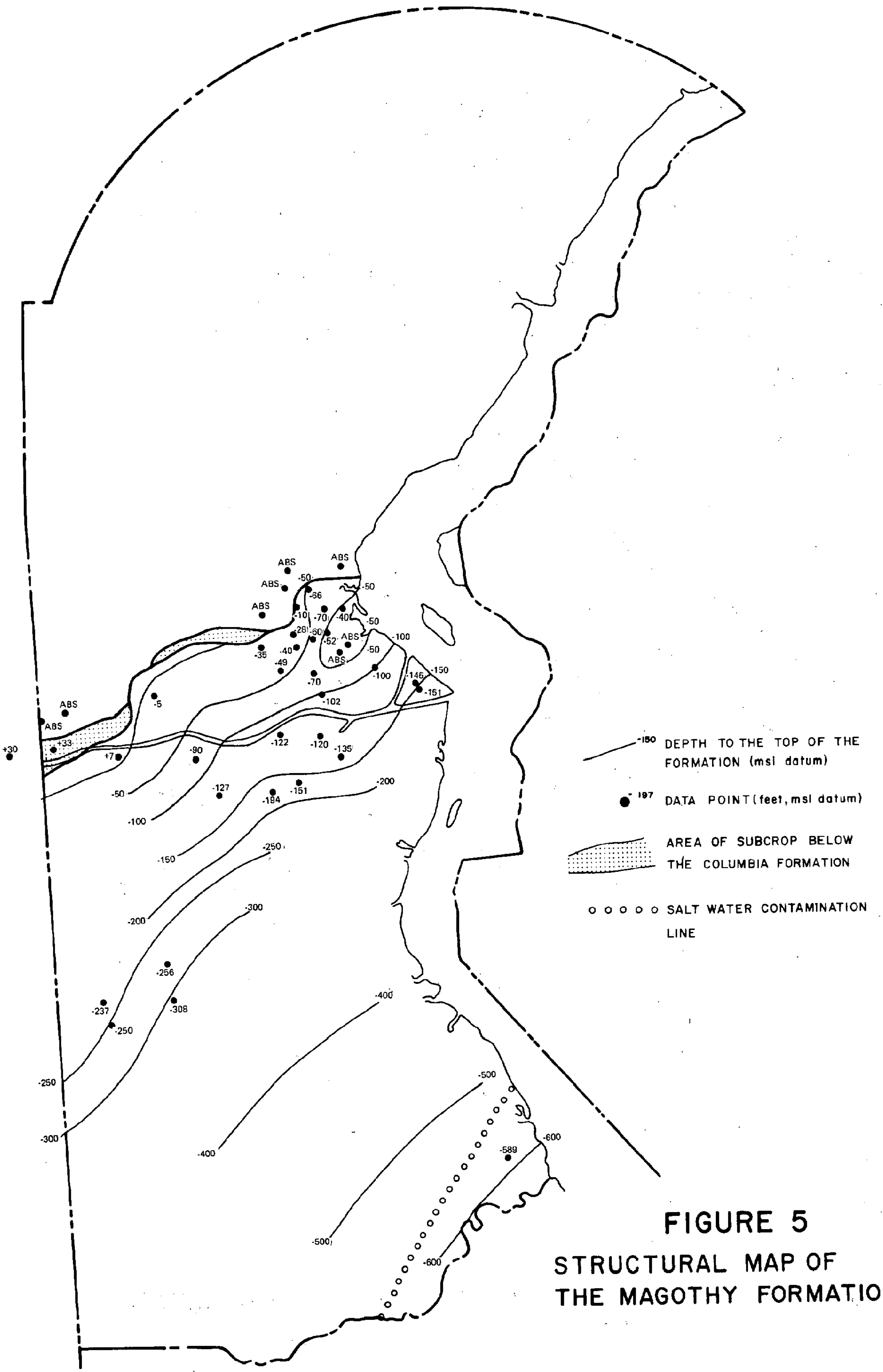


FIGURE 5
STRUCTURAL MAP OF THE MAGOTHY FORMATION

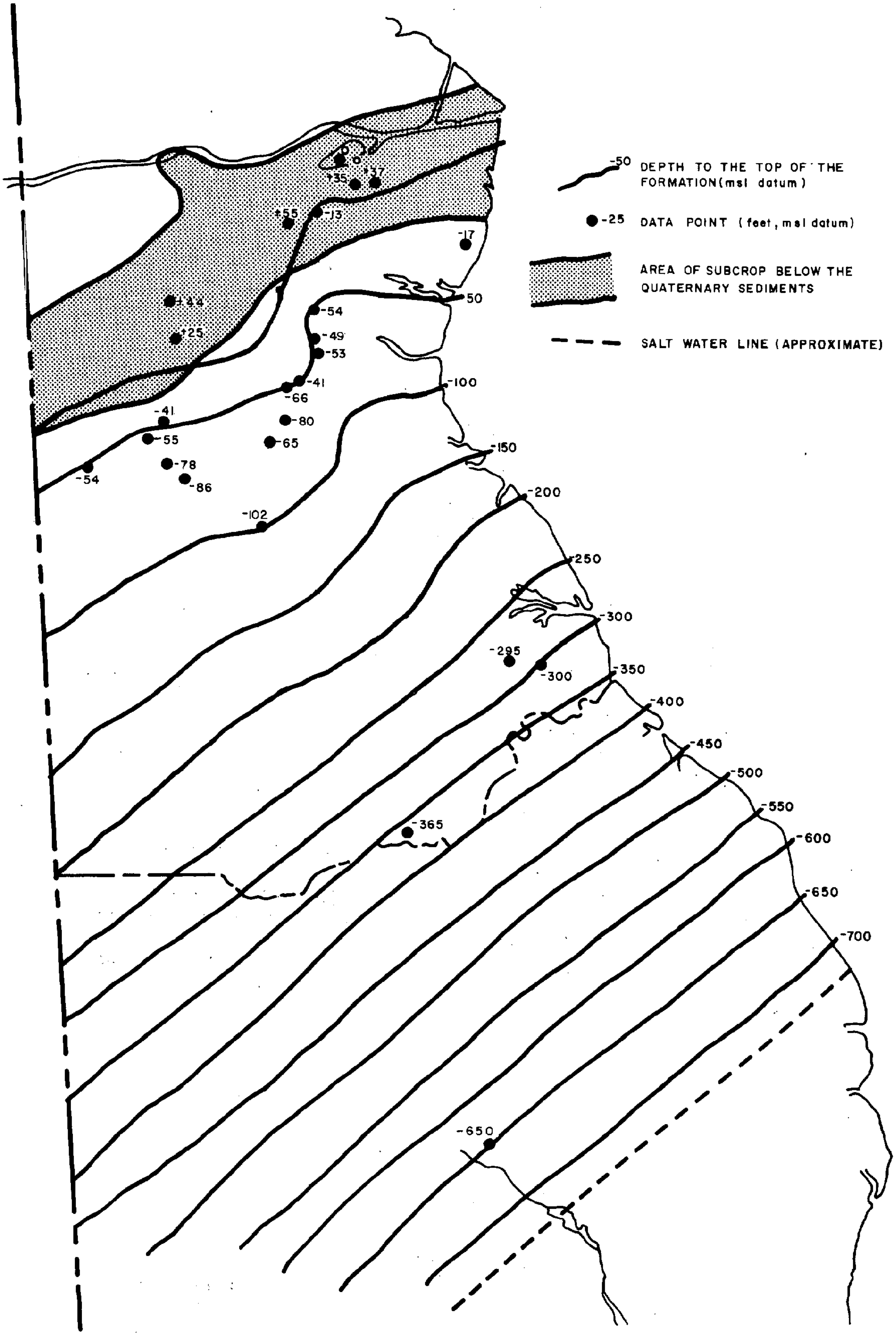


FIGURE 6 STRUCTURAL MAP OF THE MONMOUTH GROUP

The Rancocas Group

The Rancocas Group consists of two formations, the Hornerstown and the Vincentown. These are differentiated by the relatively coarser component found in the younger Vincentown. The Rancocas Group is green, gray and reddish-brown, highly glauconitic sand with some silt (Pickett and Spoljaric, 1971). The subcrop area begins about three to four miles south of the Chesapeake and Delaware Canal and underlies the entire Middletown-Odessa area (Figure 7). The group pinches out in the subsurface in the Cheswold area. Its maximum thickness is about 300 feet.

The Piney Point Formation

The Piney Point Formation in Kent County is a green, medium to fine grained, glauconitic sand of the Eocene Epoch (Jordan, 1962a). In Sussex County (Greenwood test well) it is a greenish-gray to bluish-gray, silty, sparingly to moderately glauconitic, very fine to coarse sand (Talley, 1975). The Piney Point is found in the area between Kent County and the rest of southern Delaware (Figure 8). It nowhere comes near the surface. It is thickest and sandiest in Dover and adjacent area south. In most of Sussex County it is too salty to be useful as an aquifer (Cushing, et al, 1973).

The Chesapeake Group

The Miocene Chesapeake Group consists of gray and bluish-gray silts, with some sands (Pickett and Spoljaric, 1971). It contains four major aquifers (sands) and some minor aquifers, and thus has been only partially differentiated in Delaware. The major aquifers are the Cheswold (oldest), Frederica, Manokin, and Pocomoke (youngest) aquifers (Figures 9 and 10). These sands may have been deposited along ancient shorelines. The Cheswold is located from the Smyrna area into northern Sussex County. The Frederica extends from Dover to northern Sussex County. The discrepancy of overlapping Cheswold and Frederica aquifers shown in Figure 9 may be explained by the presence of the "Federalsburg aquifer." Cushing, et al (1973) mapped this sand between the Cheswold and Frederica; whereas in Figure 9 it is included within the Cheswold. The Manokin is confined to Sussex County, and the Pocomoke to southern Sussex County.

Cushing, et al (1973) extend the Manokin into Kent County. Miller (1971) mapped the Manokin and Pocomoke, with the best available information, in greater detail than is present in Figure 10.

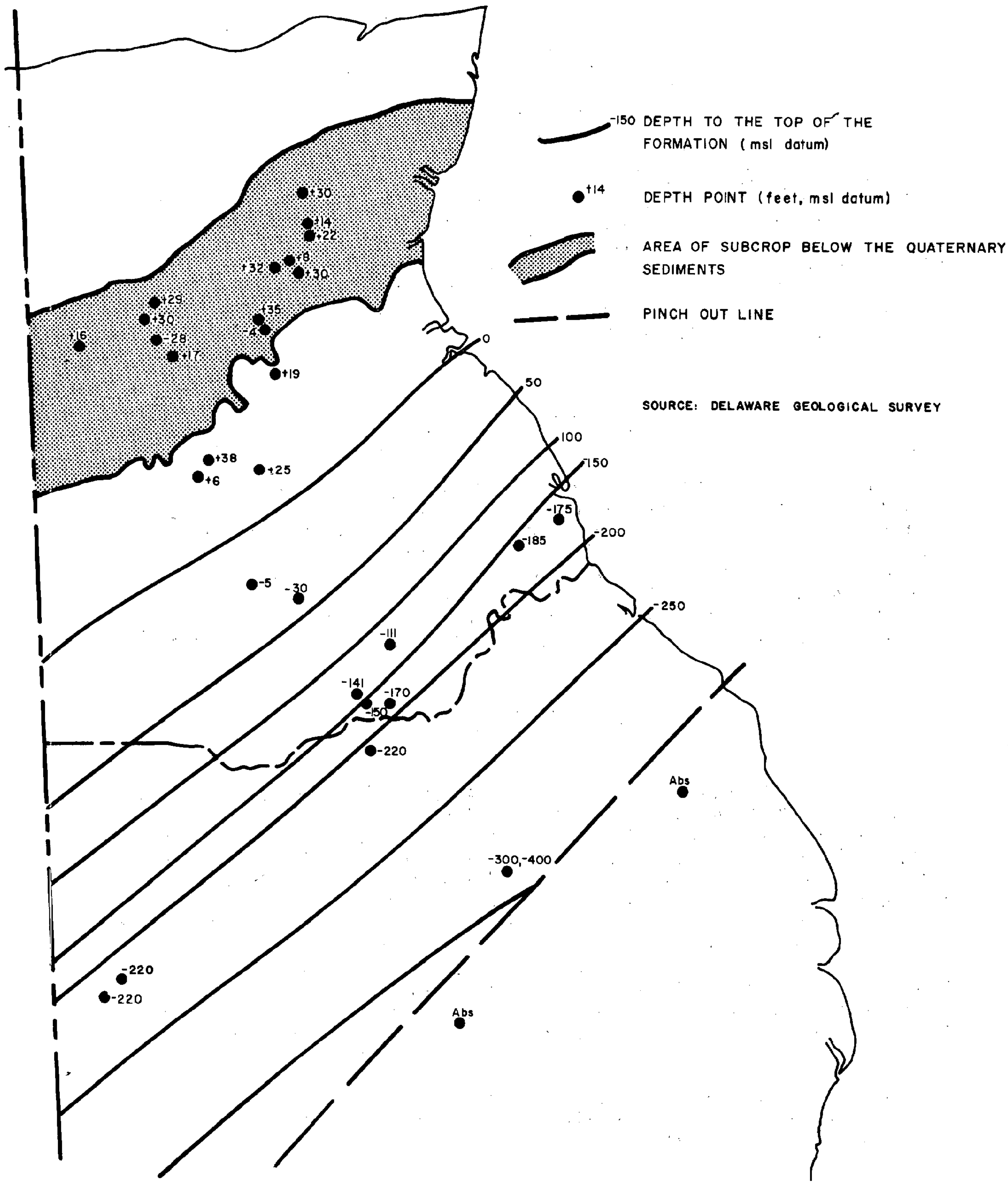


FIGURE 7 STRUCTURAL MAP OF THE RANCOCAS GROUP

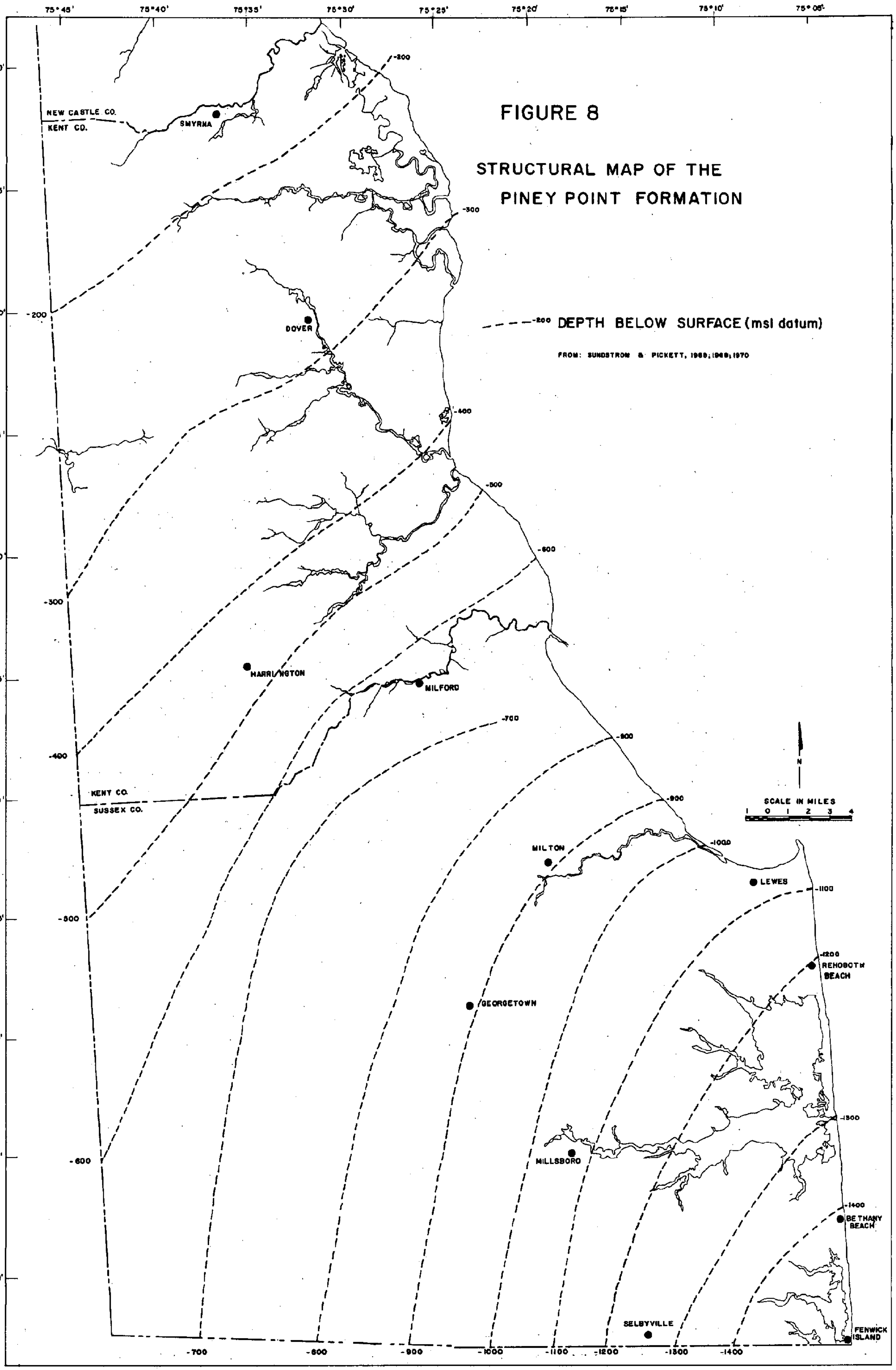


FIGURE 8
STRUCTURAL MAP OF THE
PINEY POINT FORMATION
-200 DEPTH BELOW SURFACE (msl datum)
FROM: SUNDSTROM & PICKETT, 1968; 1969; 1970
NEW CASTLE CO.
KENT CO.
SMYRNA
DOVER
HARRINGTON
MILFORD
KENT CO.
SUSSEX CO.
MILTON
LEWES
REHOBOTH BEACH
GEORGETOWN
MILLSBORO
BETHANY BEACH
SELBYVILLE
FENWICK ISLAND
SCALE IN MILES
N

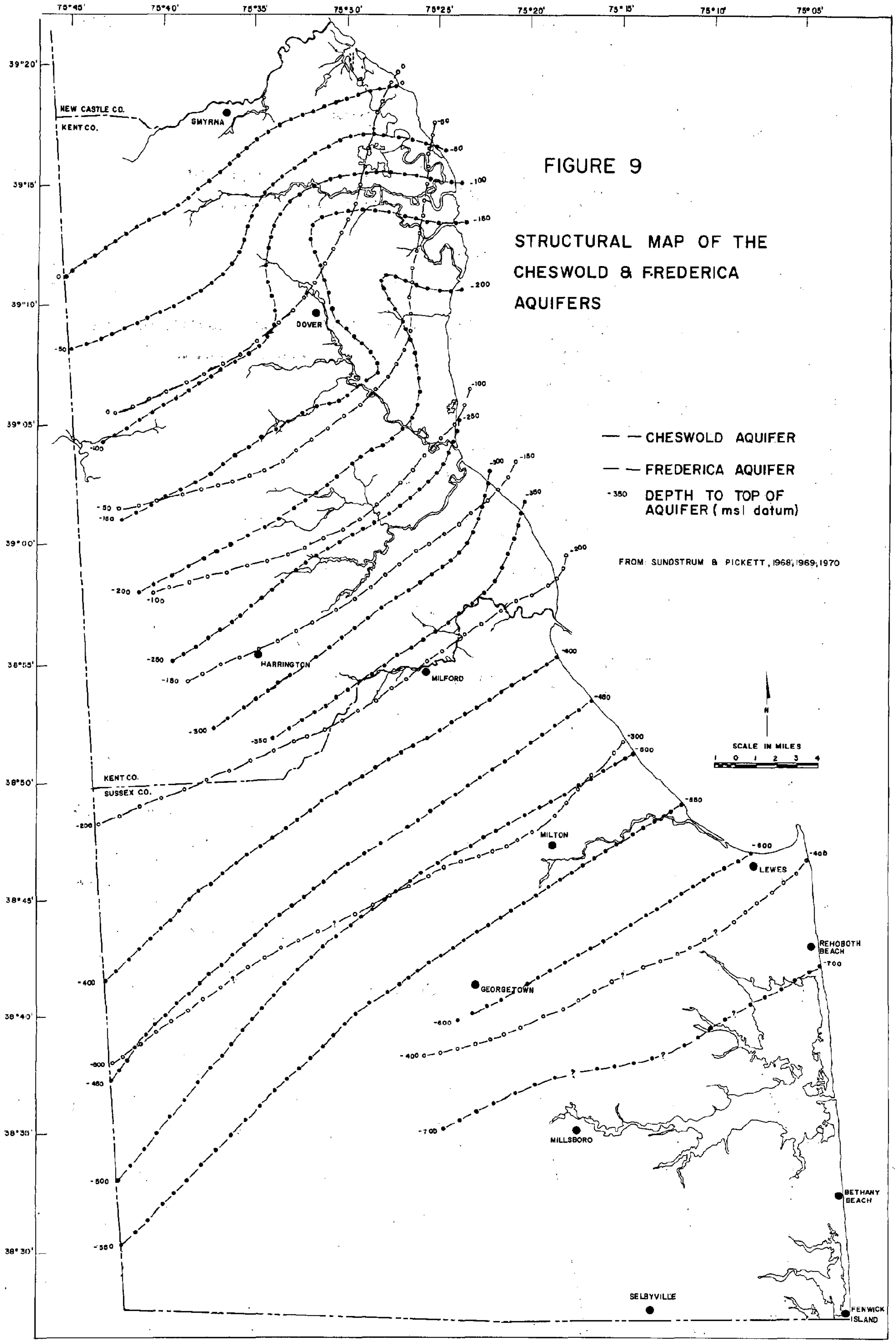
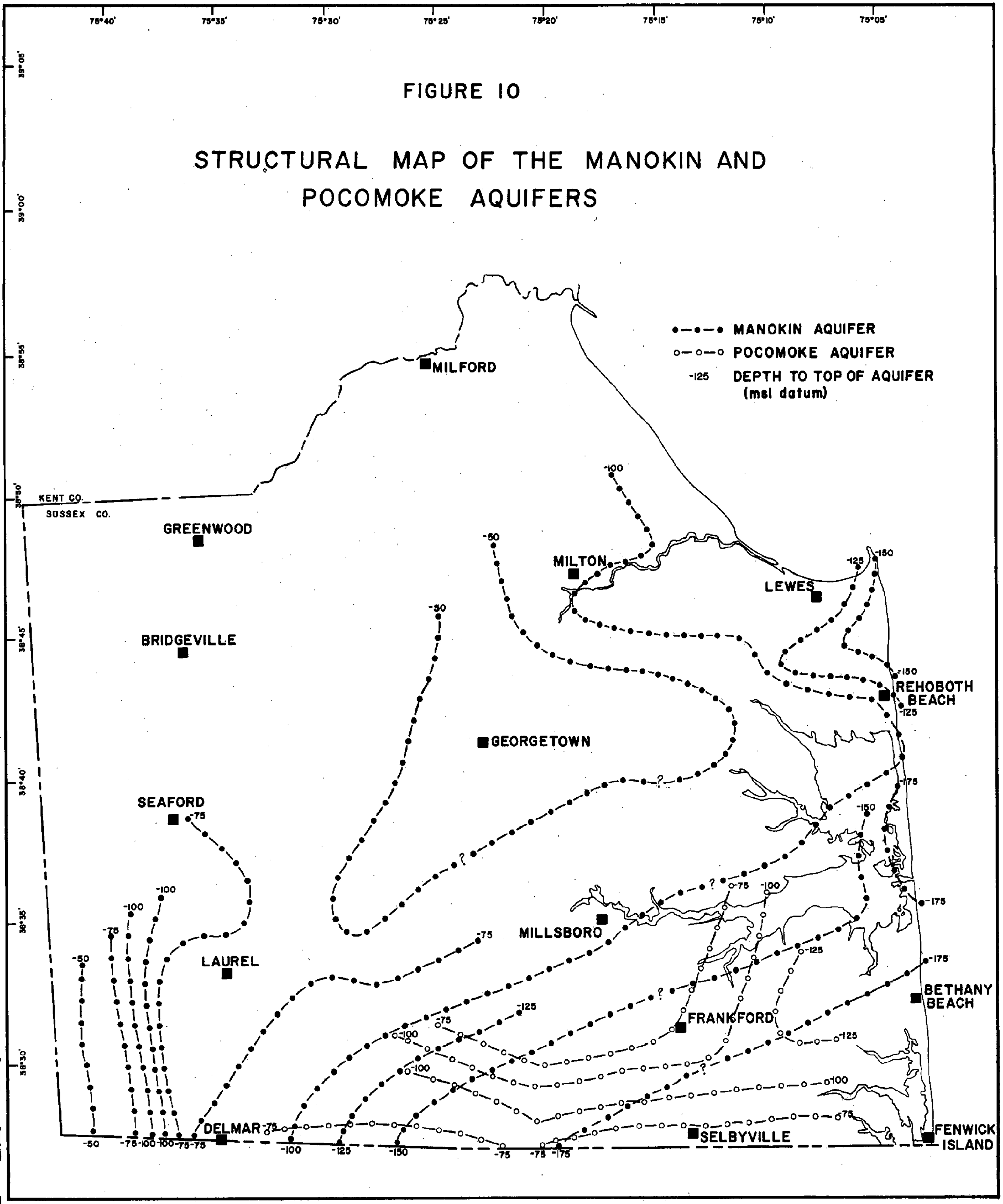


FIGURE 9
STRUCTURAL MAP OF THE CHESWOLD & FREDERICA AQUIFERS
CHESWOLD AQUIFER
FREDERICA AQUIFER
-350 DEPTH TO TOP OF AQUIFER (msl datum)
FROM: SUNDSTRUM & PICKETT, 1968, 1969, 1970
SCALE IN MILES
NEW CASTLE CO.
KENT CO.
SUSSEX CO.
SMYRNA
DOVER
HARRINGTON
MILFORD
MILTON
LEWES
REHOBOTH BEACH
GEORGETOWN
MILLSBORO
BETHANY BEACH
SELBYVILLE
FENWICK ISLAND

FIGURE 10

STRUCTURAL MAP OF THE MANOKIN AND POCOMOKE AQUIFERS



The Pleistocene Aquifer

The topmost sediments in much of the Delaware Coastal Plain are presumed to be Pleistocene in age and consist mostly of medium to very coarse sand and gravel, generally of a yellow-orange to tan-brown color. These are termed the Columbia Formation. They were deposited in channel-fill and associated river environments, and, in the southern part of Kent County and in Sussex County, they are marine in origin. There is also some reworking of the older sediments by Pleistocene marine processes (Jordan, 1964).

Figure 11 indicates the approximate thicknesses of these surficial deposits. It is the thickness of the saturated sands and therefore includes some areas of pre-Pleistocene sand subcrop. Because the largely sandy Columbia Formation (Pleistocene?) is in some places underlain by older sediments which are also very sandy and often unfossiliferous, it is very difficult to differentiate Columbia from Miocene or possibly Pliocene age sediments. It is therefore difficult to map the Columbia Formation. Figure 11, a sand thickness map, is presumed to be mostly of Pleistocene Columbia sediments.

MINERAL RESOURCES OF DELAWARE

Sand and Gravel

Sand and gravel are the most important mineral resources in Delaware. The State Division of Highways, the largest consumer of sand and gravel, has adopted strict regulations controlling the quality required for concrete, road beds, and fill (Standard Specifications, 1974, Delaware Division of Highways). The location of coarse pockets in the Columbia Formation appears to be random and therefore difficult to predict. In general the pockets are located by accident, then tested and evaluated by the Highway people. Figure 11 is a rough guide to the thickness of sand or gravel (undifferentiated) which could be utilized. However, specific on-site investigations are needed before evaluating a given location. Figure 12, the mineral resources map, is an attempt to summarize the available data on sand, gravel and other resources.

There are several variables which must be assessed before the value of a gravel pocket can be calculated. The important ones are as follows:

1. Variability in grain size (sorting);
2. The average grain size;
3. The amount of coarse material in the pocket;
4. Cost per ton paid to the owner.

Each of these criteria must be evaluated before deciding which gravel pocket should be used. For example, if the sand in a borrow pit is not very well sorted, but is very close to the construction site, it may be more economical

FIGURE IIA

THICKNESS OF THE PLEISTOCENE AQUIFER

(NEW CASTLE COUNTY)

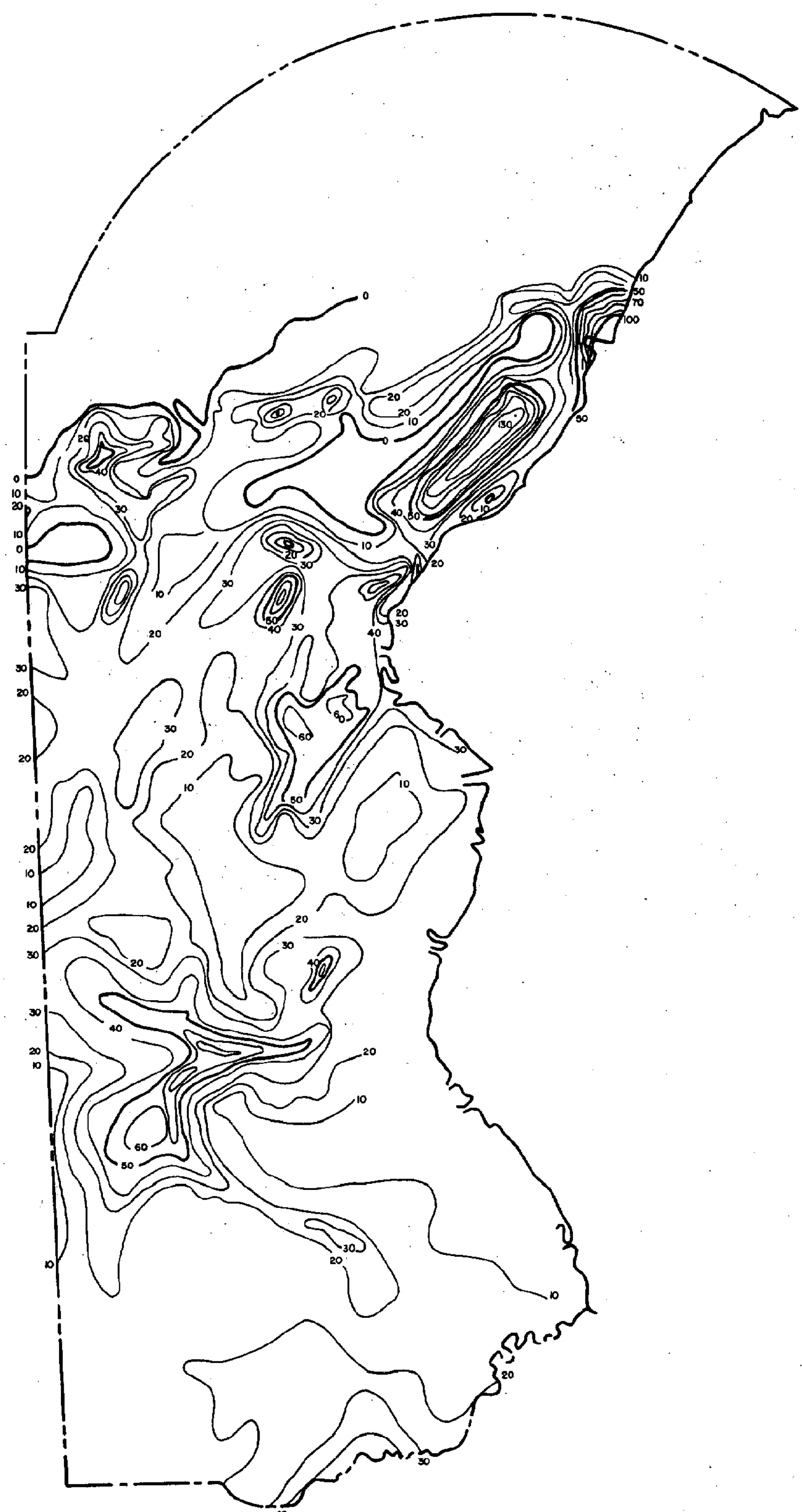


FIGURE 11B

THICKNESS OF THE PLEISTOCENE AQUIFER

(KENT COUNTY)

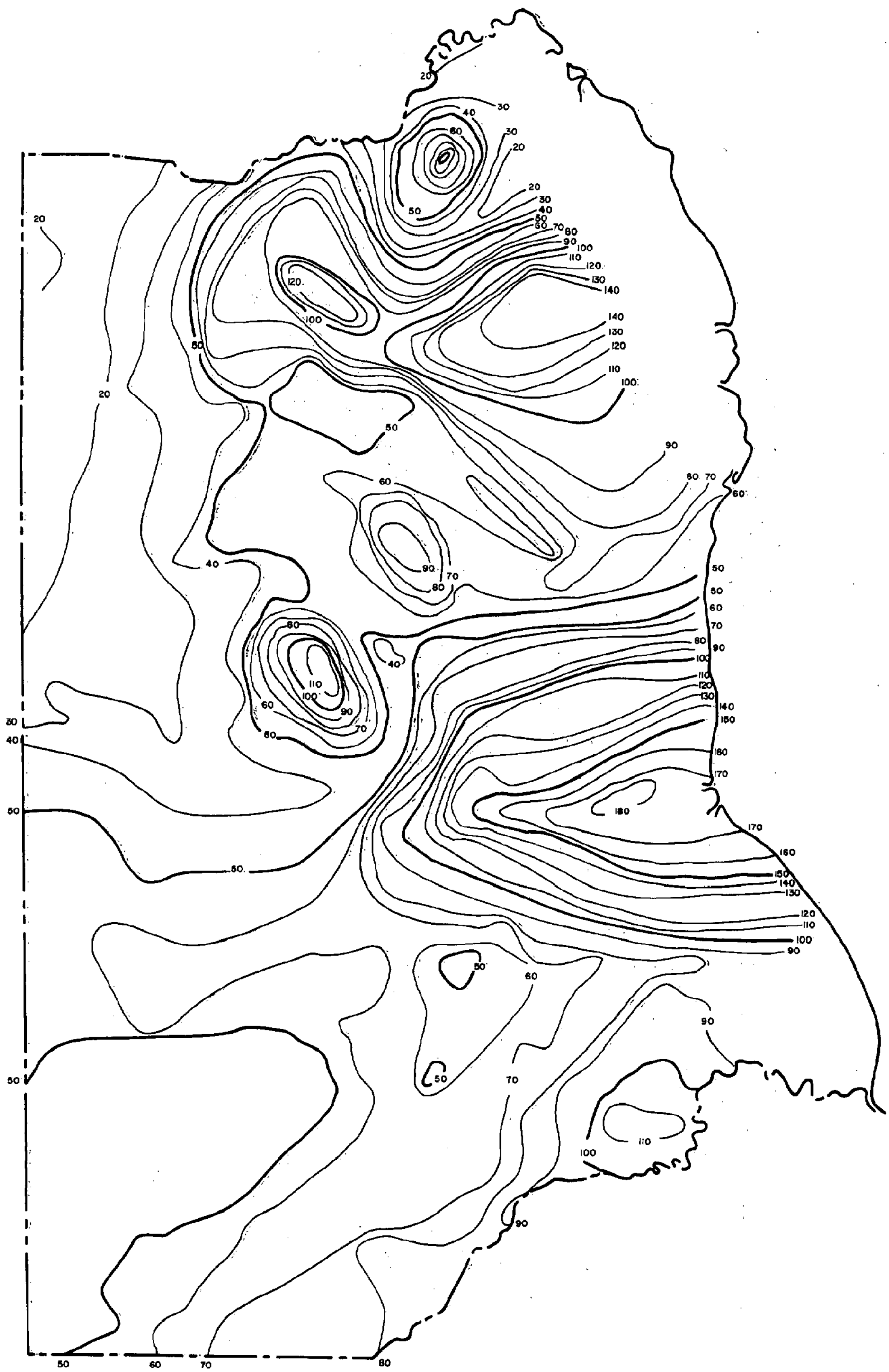
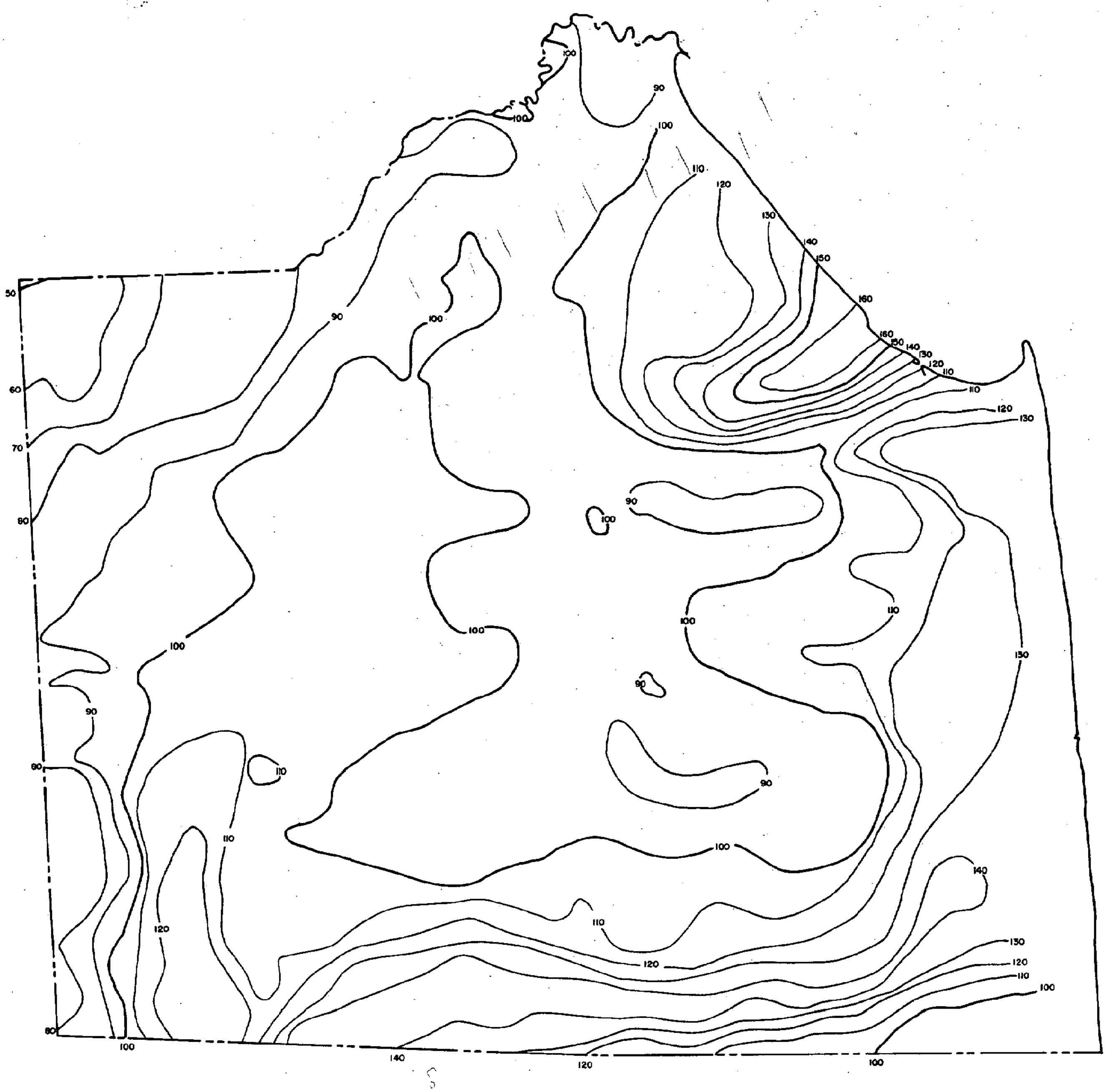
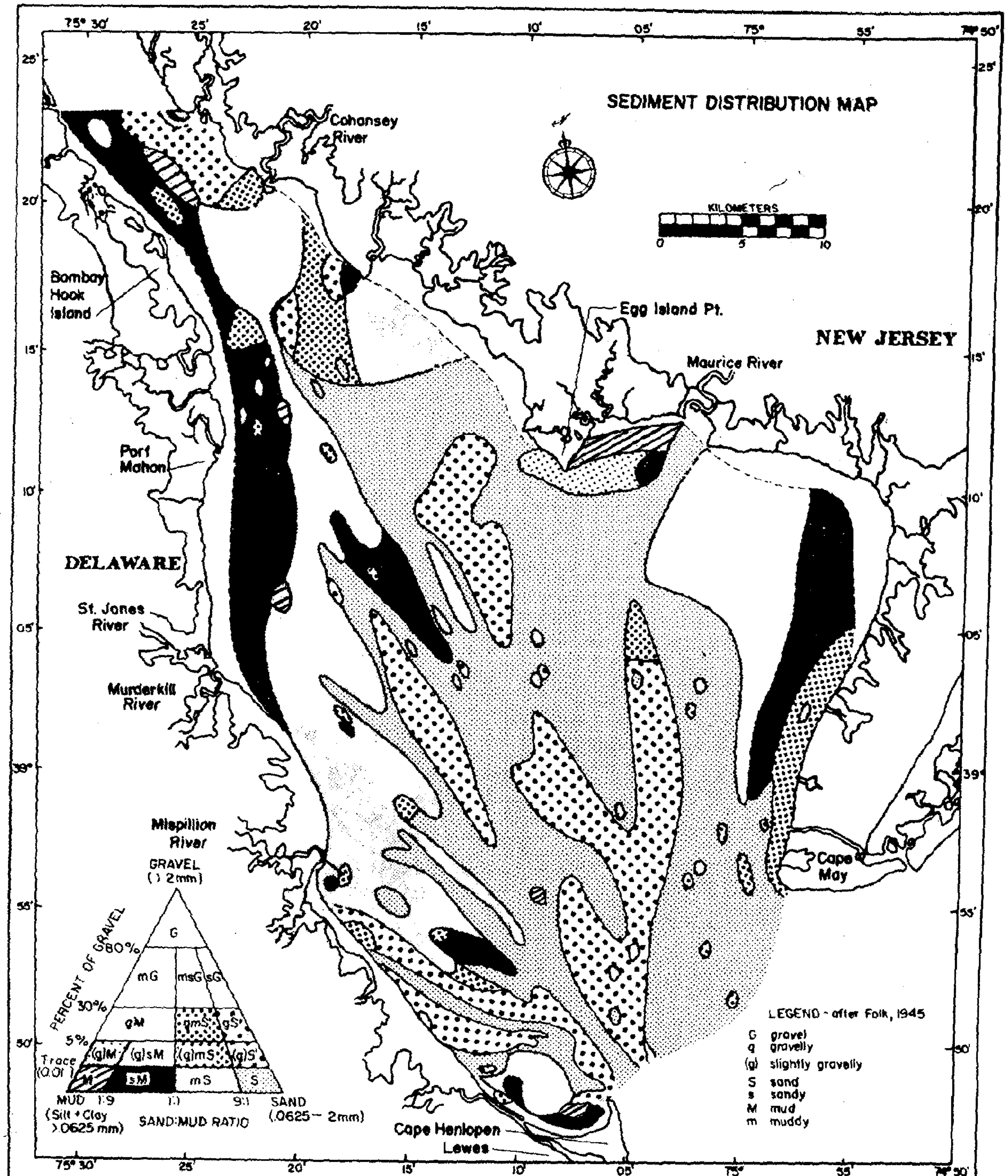


FIGURE IIC

THICKNESS OF THE PLEISTOCENE AQUIFER

(SUSSEX COUNTY)





SEDIMENT DISTRIBUTION MAP
KILOMETERS
0 5 10
NEW JERSEY
DELAWARE
Cohansey River
Bombay Hook Island
Egg Island Pt.
Maurice River
Port Mahon
St. Jones River
Murderkill River
Mispillion River
Cape May
Cape Henlopen
Lewes
75° 30'
25'
20'
15'
10'
05'
75°
55'
74° 50'
39°
GRAVEL (> 2mm)
PERCENT OF GRAVEL
80%
30%
5%
Trace (0.01)
G
mG
msG
sG
gM
gmS
gS
(g)M
(g)sM
(g)mS
(g)S
M
sM
mS
S
MUD (Silt + Clay > .0625 mm)
1:9
1:1
9:1
SAND (.0625 – 2mm)
SAND:MUD RATIO
LEGEND - after Folk, 1945
G gravel
g gravelly
(g) slightly gravelly
S sand
s sandy
M mud
m muddy

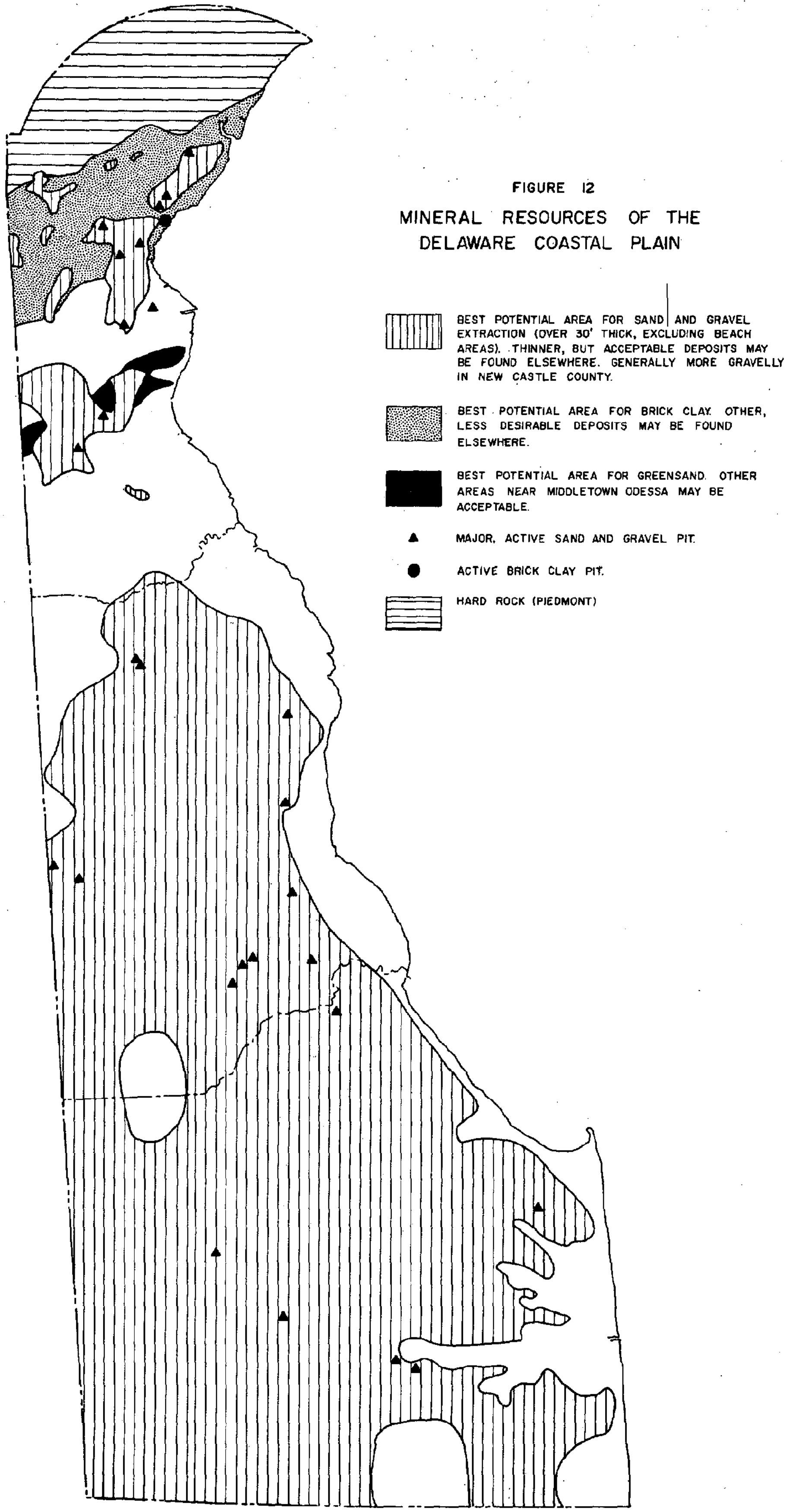


FIGURE 12

MINERAL RESOURCES OF THE DELAWARE COASTAL PLAIN to wash the gravel to remove the fine material, rather than transport higher quality gravel from farther away.

In 1973 Delaware produced 3,408,000 tons of sand and gravel, valued at $3,678,000 (U. S. Bureau of Mines Yearbook, 1973). Figures for 1974 are expected to be roughly the same.

Much sand and gravel is imported from adjacent states. Stone is no longer quarried in Delaware.

Clay

There is at present only one commercial producer of clay in Delaware. The clay is used for the manufacture of bricks. In the past there were more brick plants; however, it now seems to be more economical to import bricks from Maryland. Clay production in Delaware in 1973 was about 15,000 tons, with a value of about $9,000 (U. S. Bureau of Mines Yearbook, 1973).

The Delaware Geological Survey has cooperated with the U. S. Bureau of Mines for several years to test clays. Figure 13 shows the location of 48 clay samples analyzed under this program (Pickett, 1970). Table 2 summarizes the results of the analyses, showing which samples are promising for various clay products and which have only marginal potential use.

The data show that clays for brickmaking are common (the Potomac Formation is best). Marsh sediments are somewhat promising for lightweight aggregate (used for pre-cast concrete products). Preliminary research also indicates that spoils obtained by maintenance dredging of harbors in the Delaware River may be promising for lightweight aggregates. If power for roasting the material is available, a severe ecologic problem of how and where to dispose of dredge spoils may be solved.

Glauconite, a clay mineral, has potential use in wastewater treatment. Preliminary tests show that glauconite ("greensand") has the ability to remove heavy metals from industrial wastewater (Spoljaric and Crawford, 1975).

In the past, greensand has been used as a water softener and as a fertilizer. It still has limited use as a water softener, but, because of the long time necessary for it to release nutrients (potash), glauconite is not used as a fertilizer at the present time.

The Rancocas Group, which subcrops in the Middletown-Odessa area, contains from 95 percent (along Drawyers Creek near Odessa) to 50 percent glauconite by weight. The greensands are also most accessible in these areas, outcropping along many of the streams (Spoljaric, personal communication) [see Figure 12]. Other formations have concentrations of 5 to 90 percent glauconite by weight. The Delaware Geological Survey is presently researching the potential of greensands as a wastewater filtering agent. If these results are positive, industrial wastes, landfill effluents and many other wastes may be filtered of heavy metal contaminants.

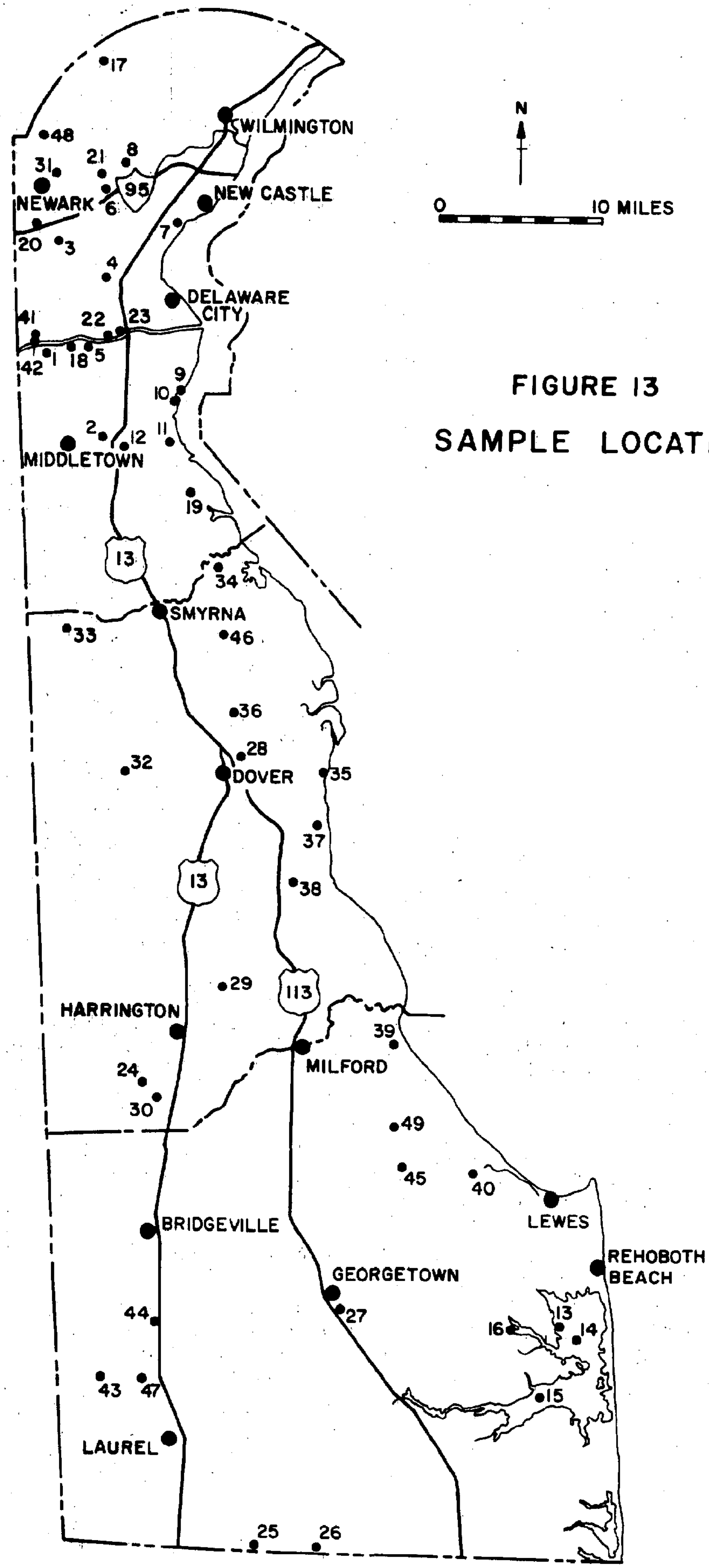


FIGURE 13

SAMPLE LOCATIONS

Table 2.

Summary of Clay Data
(Sample Numbers)

Brick		Lightweight Aggregate		Glazed Tile	Sewer Pipe	Stoneware
Promising	Marginal	Promising	Marginal	Promising	Promising	Promising
6	3	11	9	1	21	41
8	4	35	10	30	41	42
19	5		16		46	43
21	7		23		47	46
30	17		24			47
31	18		38			
33			39			
34						
37						
43						
44						
47						

From: Pickett, 1970.

Potential Mineral Resources

Potential mineral resources, not currently utilized, include: garnets for abrasives, kaolin for fine china, serpentinite and gabbro for building stone, feldspar for ceramics (all in the Piedmont). In the Coastal Plain, potential mineral resources are: iron ore (at Iron Hill and bog iron ore in Sussex County); heavy minerals, such as those containing titanium (mostly in Sussex County); glass sands (mostly in Sussex County); and the possibility of phosphate deposits. There are no known economic deposits of these commodities, but industrial interest has been displayed at various times and the geologic conditions do not preclude their occurrence in Delaware in economically feasible amounts.

The mineral resources of Delaware have been discussed with an historic perspective by Pickett (1973).

Very little is known about the occurrence of mineral resources offshore Delaware. We know that sand for possible use as aggregate exists in state waters just east of Cape Henlopen (Hen and Chickens Shoal). Elongate bars of sand occur in Delaware Bay (see Figure 12). Phosphate and manganese nodules have been found in the Atlantic Continental Shelf, but next to nothing is known of their distribution off Delaware. The Delaware Geological Survey is devoting much time attempting to evaluate the hydrocarbon potential. Clearly, we need to assess the possibilities of all offshore mineral resources using new data.

GEOLOGIC PROBLEMS

Geologic Hazards

Delaware has relatively few geologic hazards as compared to many other states. However, the hazards which do exist can be severe. There are three major geologic hazards prevalent in Delaware: floods, faulting (and associated earthquakes), and slumping caused by structural instability.

The map of geologic hazards (Figure 14) provided with this section is only meant to identify in a general way the areas which are threatened by certain geologic conditions. This map cannot be used for site specific problems, but should be useful for identifying general areas of possible geologic problems.

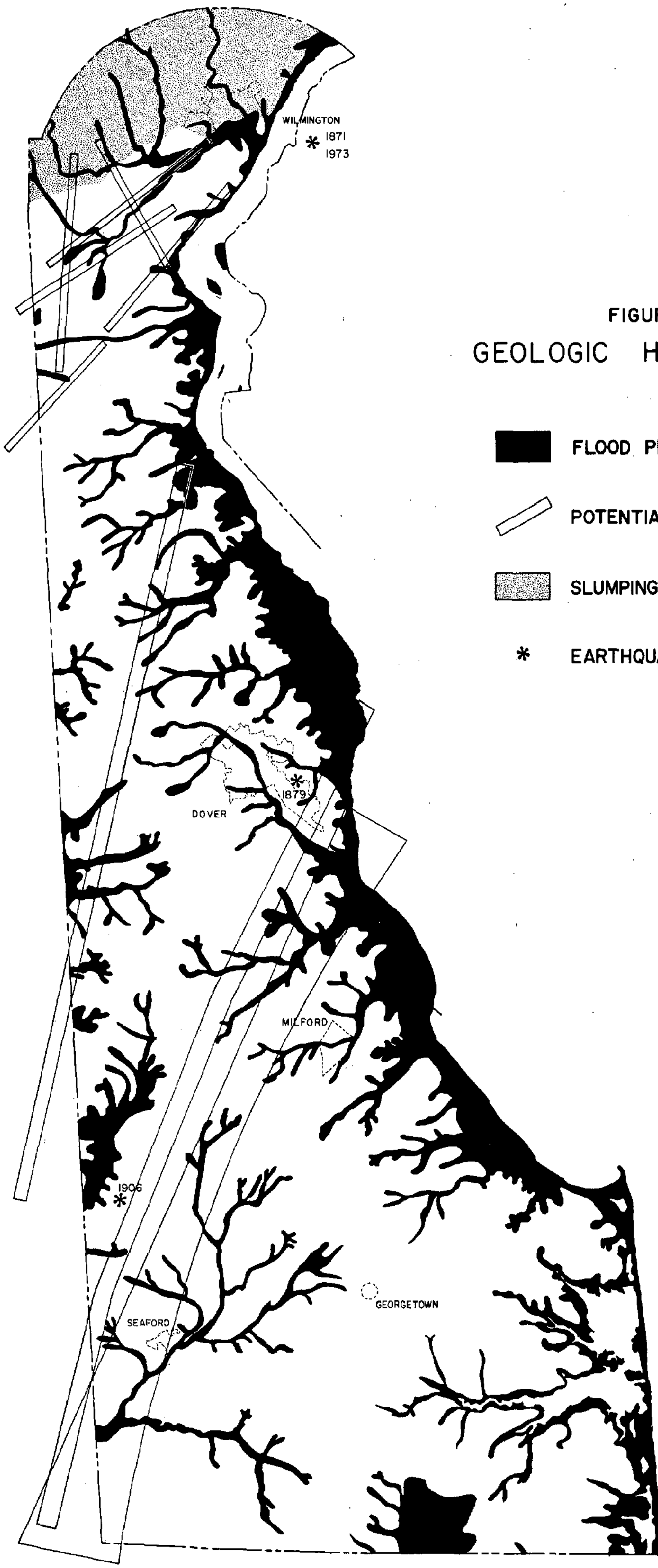


FIGURE 14

GEOLOGIC HAZARDS MAP

FLOOD PRONE AREAS

POTENTIAL FAULT ZONE

SLUMPING HAZARD

* EARTHQUAKE EPICENTERS

Flood Prone Areas

Because of the low relief of the Coastal Plain of Delaware, most of the rivers in this area are prone to flooding. There are many factors, such as stream gradient, depth to water table, upstream drainage area, amount and duration of rainfall, base level of streams, topography of the stream valley, and the ability of the ground to absorb water, which affect the flooding of an area. The designated "flood prone areas" were determined by the U. S. Geological Survey (1974) using tidal data, high water marks from previous floods, and topography. As a result, their maps only indicate the potential for flooding. In detail, their lines may be considerably in error, depending on the extent to which the previously-mentioned factors pertain to the local area.

These areas may be changed significantly as a result of man's activities as well. For example, changes in elevation of a site by filling could affect the potential for flooding of both that site and adjacent areas. Highways, housing, denudation, storm sewers, parking lots and increased surface slope all contribute to increased runoff, and therefore increase the hazard of flooding, especially in urban areas. Areas with extremely high water tables also are relatively more prone to flooding, since very little water can be absorbed into the ground. Also, as the water table fluctuates with total rainfall, weather conditions over a several-month period prior to a heavy rain affect the likelihood of flooding.

All of these factors must be evaluated for proposed land use areas in order to protect both the potential owner and the taxpayers, who often end up paying the bill for damages.

Faulting

The hazards map (Figure 14) has several zones designated as potential faulting areas. They have been tentatively identified using lineations on photos, evidence from seismic surveys, and analysis of subsurface geologic data (Spoljaric, 1975). The areas delineated are very generalized and tentative. There is enough evidence to warrant further research into the possibility of faulting. Active faults have <u>not</u> been identified in these areas; in fact, <u>no</u> active faults have as yet been located anywhere in Delaware, although there are earthquakes on record originating in the state (Jordan, et al, 1972). The importance of potential earthquakes and faulting increases with the size of the project being considered. Nuclear power plants, dams, pipelines and other major projects can be endangered by this particular type of hazard.

Slumping

Slumping represents a real and identifiable geological hazard in most of the Piedmont Province of northern Delaware. The surface slopes much more steeply in this area than in the rest of the state. As a result, unconsolidated alluvium or soil on steep gradients, mainly along rivers or streams, can move downslope, or slump. This can be triggered by excavation, rainfall, earthquake (including even minor tremors), stream erosion, or surface loading by buildings. It is extremely important to evaluate this hazard before any projects, even those on a small scale, are begun. In some cases this will require extensive geologic study of the area in order to understand the structural stability at present, and also to evaluate how geologic and human processes will change the structural stability of the overburden.

There is a similar hazard in the Coastal Plain, although the process is not technically considered slumping. This is the settling and compaction of sediments. Again, it is not only very important to examine the structural stability and engineering characteristics of the sediments, it is also important to understand how, for example, a lowering water table or stream erosion will affect this stability.

Resource Use Conflict

Several potential conflicts between users of resources, developers, zoning officials, ecologists, and others is foreseen.

The previously mentioned potential use of wetlands sediment to produce lightweight aggregate may precipitate a confrontation between industry and those who wish to preserve the wetlands.

Because of land values, zoning regulations, and possible other economic factors, much aggregate and bricks are now imported into Delaware. The specific reasons for this are not known to geologists, because the resources exist. Further problems for those desiring to produce aggregate in Delaware may be forthcoming if new construction and road building come associated with coastal zone development. If large support facilities for offshore drilling are built in Delaware, the necessary aggregate may be unavailable or scarce.

If heavy minerals, glass sand, or other potential mineral resources discussed previously are developed in Sussex County, the potential for conflict with those wishing to do otherwise with the land is probable. This should be recognized in planning for the long term in the Coastal Zone.

There may be a demand for greensand extraction in the Middletown-Odessa area, with associated land use conflicts, if current research indicates the economic feasibility of its use in wastewater treatment.

Lack of Geologic Knowledge

In the preparation of maps for this report, the lack of deep subsurface data was quite evident. No drill holes through the Coastal Plain sediments to basement crystalline rocks have ever been drilled in Kent or Sussex County. Consequently, structural contour lines for most geologic units below the Miocene sediments have to be interpolated at a distance from Salisbury or other areas in Maryland. This makes the maps less accurate; and therefore, evaluations of water resources, possible hydrocarbons, other mineral resources, and possible deep-seated faults are less definite.

A lesser problem is a lack of information from shallow drill holes, mostly in Kent and Sussex Counties. More data is needed for accurate delineation of shallow geologic formations.

Our knowledge of the specific geology of earthquakes, flooding and earth slumps and other geologic hazards is increasing all the time, but is still insufficient. Research should detail more of the specific role Delaware's geology plays in these processes. These processes should also be monitored. A seismic station is in operation at the University of Delaware, and plans are made for a seismic net throughout the state to help pinpoint earthquake epicenters. The Delaware Geological Survey cooperates with the National Weather Service and others to monitor flooding in the state's streams and is interested in the specific geologic parameters and conditions which could lead to accurate flooding forecasts.

RECOMMENDATIONS

It is recommended that deep drilling to the basement rocks for geologic information be funded. This will provide information for resource evaluation, basic geology, and possible fault delineation. More shallow holes should be drilled, particularly in Kent and Sussex Counties. Drilling should be accompanied by seismic investigations of the subsurface. Also, deep geologic structures for gas storage may be found.

Geologic hazards should be thoroughly investigated in Delaware, and our knowledge of them should be an important factor in planning for the use of the Coastal Zone.

Environmental geologic quadrangle maps of selected impact areas should be made. This requires new data (drill holes) and might start with the Lewes and Big Stone Beach areas. In conjunction with the detailed geologic maps, the proposed cooperative topographic mapping program with the U. S. Geological Survey should be funded so that accurate base maps are available to all those involved in land use and geology.

Possible resource use conflicts should be recognized in planning for the Coastal Zone. It is further recommended that a geologic-economic study be made of the sand and gravel industry in Delaware to determine the specific reasons why aggregate has to be imported in large quantities from Maryland and is not produced here.

The railroad lines in Delaware should be repaired so that, among other commodities, sand and gravel and possible other mineral resources can be efficiently moved to where they are needed.

Potential sand, gravel, and other mineral deposits should be investigated in Delaware Bay and offshore. This requires new data because practically nothing is known about subaqueous mineral resources in this area.

It is suggested for coastal policy that the geologic limitations of the Coastal Zone be fully recognized in the planning process, and as little as possible be done by man to interfere with geologic processes.

It is recommended that the State of Delaware review all legislation it has concerning the regulation of mineral extraction in the Coastal Zone. There are existing regulations for oil and gas, but apparently none for sand, gravel, clay, greensand, or other mineral resources. An exception to this may be some regulations dealing with worker safety and others on pollution of the air or water. As the demand for minerals increases with possible oil-related activities, there may be a need for mineral legislation.

Although coastal erosion has been discussed well in the Coastal Zone management report of Kraft, et al, 1975, it should be re-emphasized that it should be the policy of the State of Delaware to recognize and plan around the fact that sea level is now rising. Thus, ultimately coastal erosion is inevitable within the foreseeable geologic future. Efforts at controlling coastal erosion must be ongoing and stopgap measures at best.

HYDROLOGY

BACKGROUND

Hydrology of the waters of Delaware received state-wide attention in 1967 when the University of Delaware, in cooperation and sponsorship with other State agencies, began a series of studies to appraise, define and evaluate the water resources of Delaware (Sundstrom, Pickett and others, 1967, 1968, 1969, 1970, and 1971). In 1972 the College of Marine Studies, University of Delaware, published a very comprehensive report on the coastal zone of Delaware giving the findings of the Governor's Task Force on Marine and Coastal Affairs. In 1973 the United States Geological Survey issued Professional Paper 882 entitled "Water Resources of the Delmarva Peninsula" (Cushing, Kantrowitz and Taylor, 1973). These reports and those listed in the bibliography of this paper constitute the basis of the maps and discussions pertaining to the hydrology of the waters of Delaware. The maps and discussion herein are made primarily for regional or state-wide water planning purposes in the coastal area. The hydrology of the surface and ground waters of the Piedmont Plateau are discussed in detail in a report on the availability of water in New Castle County (Sundstrom and Pickett, 1971). The Piedmont Plateau area is not a part of this report. This report concerns primarily the mapping and discussion of hydrology of the surface water of the Coastal Plain and the 12 ground-water aquifers of the Coastal Plain of Delaware.

HYDROLOGY FOR PLANNING PURPOSES

A properly planned and developed aquifer or ground-water reservoir is one that will supply the need for acceptable quality water within the safe limits of development of the aquifer without seriously affecting the other useful and sometimes necessary functions of the aquifer. Independent and co-dependent factors such as the geology, hydrology, water quality (chemical and bacterial), engineering, economics, well construction and development, and ecology are involved in the planning, development and management of ground-water reservoirs.

In the Coastal Zone of Delaware, the geology and hydrology of 12 aquifers (ground-water reservoirs) are discussed at length in this report. Eleven of the 12 aquifers are artesian in character except in the outcrop or subcrop areas. In the outcrop or subcrop area, the aquifers receive most of their recharge from precipitation penetrating to the aquifer from the water falling only on the outcrops or subcrops. The aquifer that is not artesian in character is the Pleistocene or Quaternary aquifer in which the precipitation percolates directly downward to the water table. The subcrops of the artesian aquifers underlying the Quaternary are also a part of the water-table aquifer. The water-table aquifer receives recharge by downward percolation of precipitation over the entire area of the aquifer, whereas the artesian aquifers receive most of their recharge supply only from the outcrop or subcrop area. In a broad perspective, the water-table aquifer can be considered a storage reservoir receiving direct downward percolation of precipitation to be released later as evapotranspiration, fairweather flow to streams, recharge to the artesian ground-water aquifers and water supply to wells and springs. In the same perspective the artesian aquifer can be considered primarily as a conduit, conveying water from the outcrop or subcrop area to discharge points (wells and springs) under pressure. The hydrologic characteristics of the aquifers determine the extent to which an aquifer can be developed and the best methods for withdrawing water from it.

Land development involving impervious cover of the surface will have a direct effect at the place of development on the downward percolation of precipitation for recharge to the water-table aquifer. In areas supplied by artesian aquifers this situation would not prevail except in the close proximity of the recharge area of the aquifer. For example, in Dover where the water is obtained primarily from wells drawing from the Cheswold and Piney Point artesian aquifers, impervious cover from land development in Dover would be several miles away from the major recharge area of the artesian aquifers supplying the water to Dover. Dover lies in an area where the withdrawals from the Cheswold and Piney Point artesian aquifers are approaching or exceeding recharge. The problem, however, lies in the transmissive properties of the aquifers in moving water from the recharge area to the wells in Dover. These problems are discussed in considerable detail in Sundstrom and Pickett, 1968, and the current report.

New Castle County "corridor" is a part of the water-short area of metropolitan northern Delaware north of the Chesapeake and Delaware Canal and is in part of a subdivision of the water-short area of northern Delaware as a whole. In recent years, the U.S. Army Corps of Engineers; the Delaware River Basin Commission; Whitman, Requardt and Associates for New Castle County; and others have brought into focus the need for developing the Brandywine, White Clay Creek or bringing water into the area from the Susquehanna River or other sources. In any event, the northern Delaware area north of the Chesapeake and Delaware Canal needs more water than appears to be available from the ground-water aquifers under it. The eastern half of the New Castle County "corridor" is shown in the area where present withdrawals are approaching or exceeding recharge or in the area of possible salt-water encroachment as mapped by the U.S. Geological Survey, 1974, and shown in Figure 15.

The hydrology of the surface and ground-water resources for planning purposes is given in mapped areas and tables of the applied hydrology as it pertains to the availability and use or potential use of water. In using the maps, tables and discussions, it is important to remember that both surface and ground water have the same source or origin; namely, the precipitation that falls on the respective drainage areas which, in most cases, are common to both ground-water recharge and surface water runoff. Much of the fairweather flow of the streams is ground-water discharge to them. The hydrology of each of the ground-water aquifers is discussed or mapped to give graphically the location and depth of the aquifer; the developed and undeveloped parts of the aquifer; the hydrologic potential of the aquifer; the available water from the aquifer; the limits of development; and the salt-water problems.

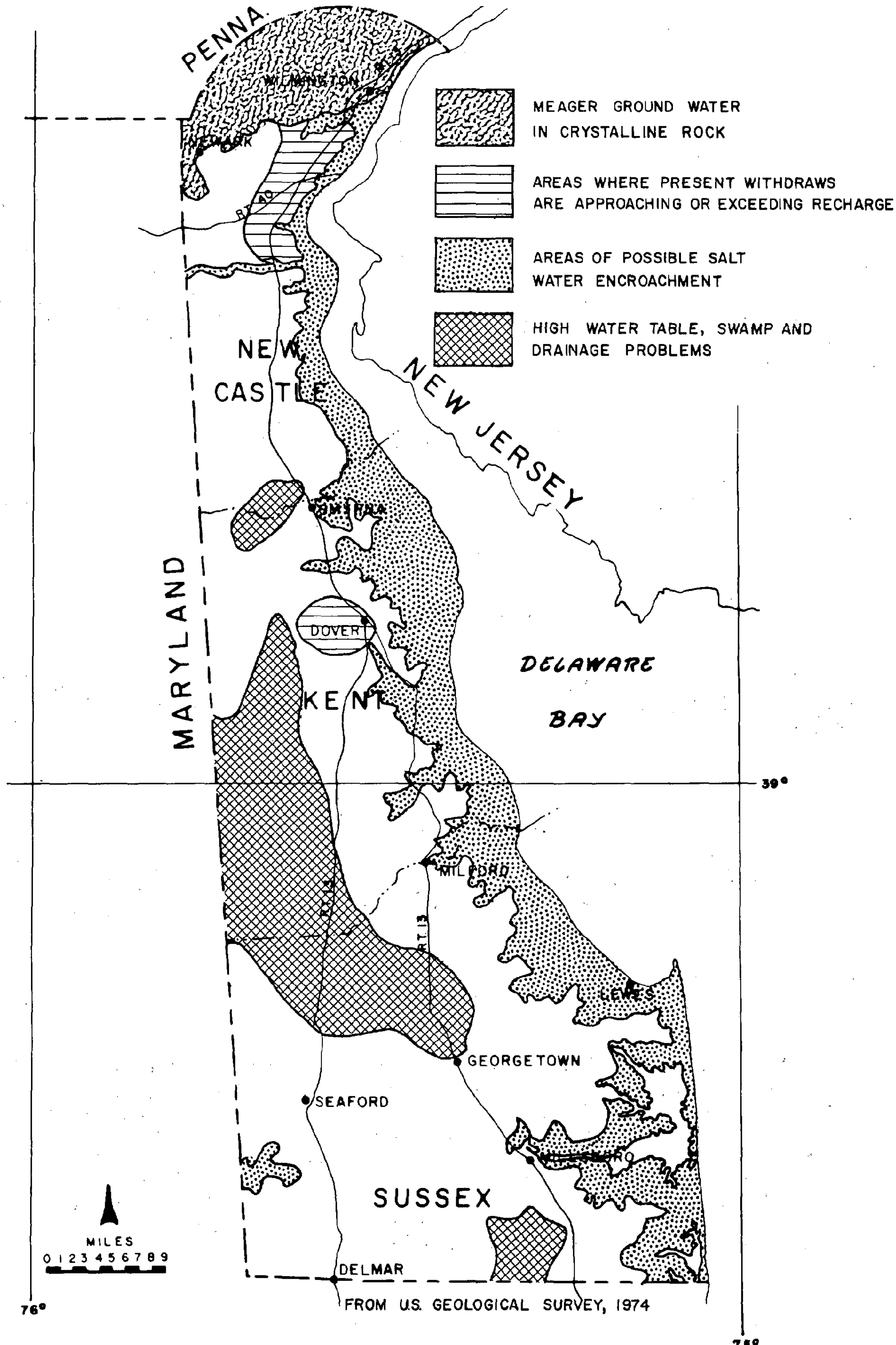


FIGURE 15: WATER PROBLEM MAP OF DELAWARE

THE USE OF WATER

The average daily use of water in Delaware from 1953-56 through 1974 is given in Table 3. Table 3 gives the municipal use including institutional and military uses, industrial, irrigation, rural and other uses for the periods 1953-56, 1966 and 1974. Noteworthy statistics from Table 3 show that (1) the use of ground water for municipal, military and institutional purposes has almost tripled in the two decades, 1953-1974; (2) the use of surface water for the same purposes has almost doubled in the two-decade period; and (3) the overall use of water in the State has increased about 1.6 times in the period.

The Use of Water in New Castle County

The average daily use of water in New Castle County for municipal, industrial, irrigation and rural purposes from 1954 through 1974 is given in Table 4.

The Use of Water in Kent County

The average daily use of water in Kent County for municipal, industrial, military, institutional, irrigation, rural and other purposes from 1953 through 1974 is given in Table 5.

The Use of Water in Sussex County

The average daily use of water in Sussex County for municipal, industrial, irrigation, and rural purposes from 1957 through 1974 is given in Table 6.

THE AVAILABILITY OF SURFACE WATER

The quantities of water available within the drainage basins of the Delaware River system in Delaware and within the Coastal Basins of Delaware are fairly well known. For many years the United States Geological Survey has measured the daily flow of the Delaware River and many of its tributaries. Likewise, the U. S. Geological Survey has also measured the flow of streams of Delaware draining to Chesapeake Bay and the Atlantic Ocean. Figure 16 shows the streams and stream measuring stations in Delaware. Table 7 gives a summary of the U. S. Geological Survey streamflow data for the Delaware River Estuary, the Piedmont Plateau and Atlantic Coastal Plain streams draining to

Table 3

Average Daily Use of Water in Delaware for Municipal, Industrial, Irrigation and Rural Purposes in 1953-57, 1966, and 1974

Type of Use	Ground Water MGD	Surface Water MGD	Total MGD	Remarks
		1953-57		
Municipal, Institutional and Military	11.0	24.0	35.0	1/ 2/
Industrial	16.7	30.0	46.7	1/
Irrigation	1.7	.6	2.3	1/
Rural	5.4	--	5.4	1/
Other	--	--	--	---
TOTAL	34.8 (38.9%)	54.6 (61.1%)	89.4	
		1966		
Municipal, Institutional and Military	24.5	40.3	64.8	2/ 3/
Industrial	20.7	40.0	60.7	2/ 4/ 5/
Irrigation	9.2	1.2	10.4	4/
Rural	11.4	--	11.4	4/
Other	.3	--	.3	7/
TOTAL	66.1 (44.8%)	81.5 (55.2%)	147.6	
		1974		
Municipal, Institutional and Military	29.4	45.0	74.4	6/
Industrial	23.6	10.3	33.9	6/
Irrigation	12.1	1.8	13.9	6/
Rural	13.1	--	13.1	6/
Other	2.5	--	2.5	6/
TOTAL	80.7 (58.6%)	57.1 (41.4%)	137.8	

Source of data:

1/ Marine and Rasmussen, 1955
2/ Parker and others, 1964
3/ Whitman, Requardt and Associates, 1967
4/ Stuart W. McKenzie, 1967
5/ Sundstrom et al, 1967
6/ Frederick N. Robertson, 1975
7/ Estimated
MGD Million Gallons a Day

Table 4

Average Daily Use of Ground Water and Surface Water
In New Castle County for
Municipal, Industrial, Irrigation and Rural Purposes in
1954, 1966 and 1974

Type of Use		Ground Water MGD	Surface Water MGD	Total MGD	Remarks
		1954			
Municipal		4.5	24.0	28.5	1/ 2/
Industrial		2.8	30.0	32.8	6/
Irrigation		0.6	0.6	1.2	
Rural		1.1	--	1.1	
	TOTAL	9.0 (14.2%)	54.6 (85.8%)	63.6	
		1966			
Municipal		10.2	40.3	50.5	3/
Industrial		4.6	40.0	44.6	2/4/5/ 7/
Irrigation		1.0	1.2	2.2	4/
Rural		2.0	--	2.0	8/
	TOTAL	17.8 (17.9%)	81.5 (82.1%)	99.3	
		1974			
Municipal		15.2	45.0	60.2	9/
Industrial		7.7	10.3	18.0	9/
Irrigation		0.3	1.3	1.6	9/
Rural		2.2	--	2.2	9/
Other		2.5	--	2.5	9/
	TOTAL	27.9 (33.0%)	56.6 (67.0%)	84.5	

Source of data:

1/ Marine and Rasmussen, 1955
2/ Parker and others, 1964
3/ Whitman, Requardt and Associates, 1967
4/ Stuart W. McKenzie, 1967
5/ Sundstrom et al, 1967
6/ Does not include more than 200 MGD of surface water used for cooling and mostly returned to stream
7/ Does not include more than 600 MGD of surface water used for cooling and mostly returned to stream
8/ Estimated
9/ Frederick N. Robertson, 1975
MGD Million Gallons a Day

Table 5

Average Daily Use of Water in Kent County for Municipal, Industrial, Irrigation and Rural Purposes in 1953, 1966, and 1974

Type of Use	Ground Water MGD	Surface Water MGD	Total MGD	Remarks
		1953		
Municipal, Institutional and Military	2.8	--	2.8	1/
Industrial	2.5	--	2.5	1/
Irrigation	.7	--	.7	1/
Rural	1.1	--	1.1	1/
Other	---	--	---	
TOTAL	7.1 (100%)		7.1	
		1966		
Municipal, Institutional and Military	7.6	--	7.6	2/
Industrial	4.5	--	4.5	2/
Irrigation	2.2	--	2.2	2/
Rural	3.4	--	3.4	2/
Other	0.3	--	0.3	2/
TOTAL	18.0 (100%)		18.0	
		1974		
Municipal, Institutional and Military	7.7	--	7.7	3/
Industrial	4.0	--	4.0	3/
Irrigation	6.6	--	6.6	3/
Rural	4.0	--	4.0	3/
Other	---	--	---	
TOTAL	22.3 (100%)		22.3	

Source of data:

1/ 1953 data - Bulletin 4, Delaware Geological Survey

2/ 1966 data - Delaware Water and Air Resources Commission and this study. Consumption for rural, domestic and livestock use estimated on bases of census of rural population, livestock and poultry on the average water requirement for each in each category.

3/ 1975 data - Delaware Water Use Inventory for 1974, Frederick N. Robertson, Water Resources Center, University of Delaware.

Table 6

Average Daily Use of Water in Sussex County for
Municipal, Industrial, Irrigation and Rural Purposes in
1957, 1966, and 1974

Type of Use	Ground Water MGD	Surface Water MGD	Total MGD	Remarks
		1957		
Municipal, Institutional and Military	3.7	--	3.7	1/
Industrial	11.4	--	11.4	1/
Irrigation	0.4	--	0.4	1/
Rural	3.2	--	3.2	1/
TOTAL	18.7 (100%)		18.7	
		1966		
Municipal, Institutional and Military	6.7	--	6.7	2/
Industrial	11.6	--	11.6	2/
Irrigation	6.0	--	6.0	2/
Rural	6.0	--	6.0	2/
TOTAL	30.3 (100%)		30.3	
		1974		
Municipal, Institutional and Military	6.5	--	6.5	3/
Industrial	11.9	--	11.9	3/
Irrigation	5.2	.5	5.7	3/
Rural	6.9	--	6.9	3/
TOTAL	30.5 (98%)	.5 (2%)	31.0	

Source of data:

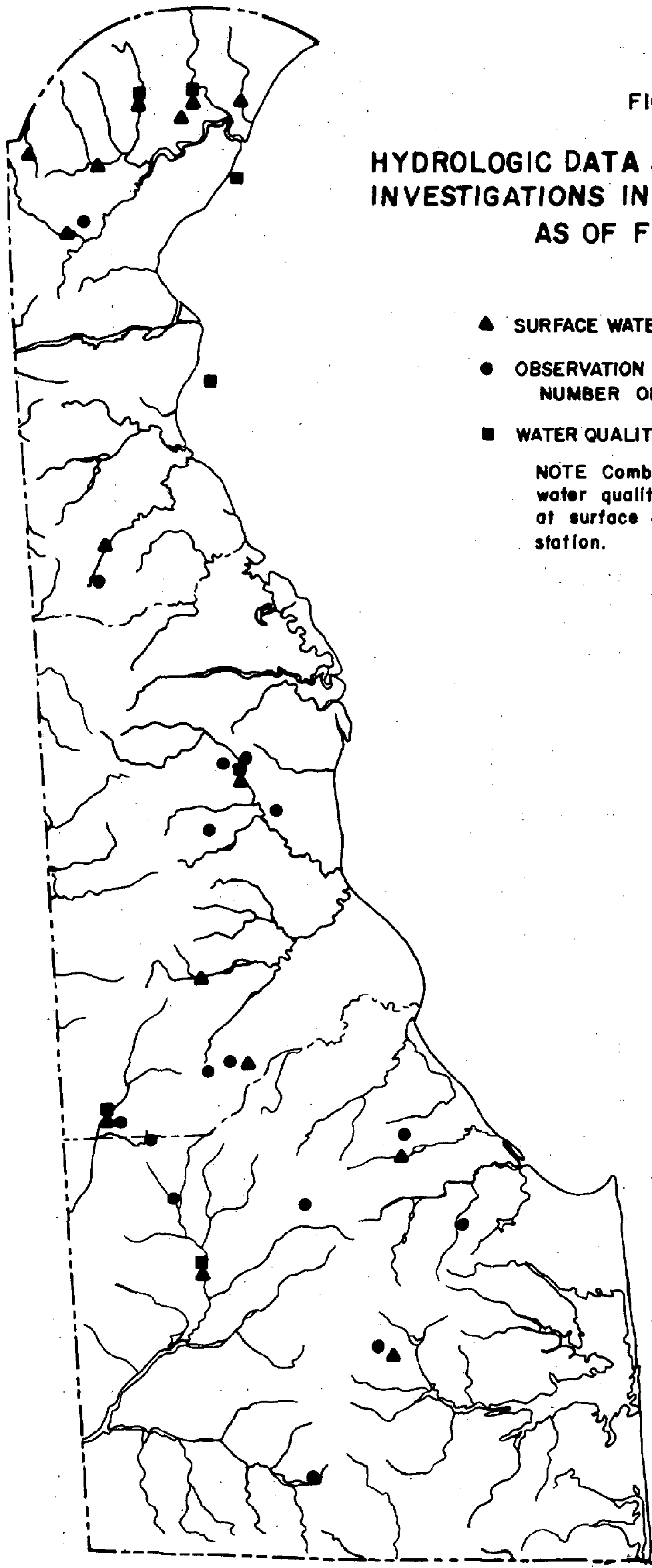
1/ Delaware Geological Survey, Bulletin 8

2/ Inventory of the Use of Water in Delaware, Stuart W. McKenzie, Hydrologist, Water Resources Center, University of Delaware

3/ Delaware Water Use Inventory for 1974, Frederick N. Robertson, Water Resources Center, University of Delaware

FIGURE 16

HYDROLOGIC DATA STATION ACTIVITIES AND INVESTIGATIONS IN PROGRESS IN DELAWARE AS OF FEBRUARY 1974



▲ SURFACE WATER STATION

● OBSERVATION WELL (FIGURE INDICATES NUMBER OF WELLS IN SMALL AREA)

■ WATER QUALITY STATION

NOTE Combined sybols indicate water quality data also collected at surface and (or) ground water station.

Table 7. Summary of U. S. Geological Survey Streamflow Data for Streams in Delaware

Stream	Location	Drainage Area (sq miles)	Yrs. of Record 1/	Average Discharge (CFS) 2/	Maximum Discharge (CFS)	Minimum Discharge (CFS)	Average Discharge Per Square Mile (CFS)	Remarks
Delaware River Estuary								
Delaware River	Trenton, N.J.	6,780	56	11,930	329,000	1,220	1.76	
Piedmont Plateau Streams								
Shellpot Creek	Wilmington	7.46	26	9.34	6,850	0.10	1.25	Records good
White Clay Creek	Nr. Newark	87.8	32	110	9,080	4.7	1.25	Same
White Clay Creek	Abv. Newark	66.7	17	76.7	10,200	4.6	1.15	Same
Red Clay Creek	Nr. Wooddale	47.0	29	61.7	4,780	4.5	1.31	Same
Little Mill Creek	Elsmere	6.7	9	9.59	3,960	0.10	1.43	Same
Brandywine Creek	Chadds Ford, PA	287	52	381	23,800	42	1.33	Same
Brandywine Creek	Wilmington	314	26	451	29,000	56	1.44	Same
Coastal Plains Streams								
Christina River	Cooches Bridge	20.5	29	25.8	3,320	0.20	1.26	Records good
Blackbird Creek	Blackbird	3.85	16	4.47	712	0	1.16	Records fair
St. Jones River	Dover	31.9	14	33.3	1,900	0		Records good
Murderkill River	Nr. Felton	13.6	14	18.3	2,090	0.80		Same
Beaver Dam	Houston	2.83	14	3.57	176	0.20		Same
Sowbridge Branch	Nr. Milton	7.08	16	9.93	134	0.47		Same
Stockley Branch	Stockley	5.24	29	6.98	132	0.13		Same
Nanticoke River	Nr. Bridgeville	75.4	29	91.6	2,360	6.3		Records fair
Marshyhope Creek	Nr. Adamsville	7.10	22	8.66	792	0		Records good

1/ As of 1972.

2/ (CFS) Cubic feet per second. One CFS equals 646,323 gallons a day.

the Delaware Estuary and Bay and Delaware Coastal Plain streams draining to the Atlantic Ocean and Chesapeake Bay.

The Delaware River Estuary receives from the river proper at Trenton, New Jersey, on the average nearly 12,000 cubic feet of water per second or 7.7 billion gallons a day (Table 7). As the estuary progresses downstream to the Delaware state line, Keighton (1966) states that the flow at Marcus Hook is 1.43 times as great as it is at Trenton. This indicates that the Delaware Estuary receives on the average about 17,000 cubic feet per second or about 11 billion gallons a day of inflow before it reaches Delaware. Below the Pennsylvania-Delaware state line, the estuary and bay of the Delaware receive from their tributaries on the average an additional inflow of about 1,700 cubic feet per second or 1.1 billion gallons a day before the Delaware River system discharges to the ocean. The average daily discharge of the estuary and bay increases about 6,700 cubic feet per second from the beginning of the estuary at Trenton to the Atlantic Ocean.

Streams heading in the Piedmont Plateau in Pennsylvania and draining Piedmont Plateau areas in Pennsylvania and northern Delaware furnish the bulk of the water used for municipal and self-served industrial purposes, exclusive of cooling water. The streams providing most of the water are the Brandywine, Red Clay and White Clay Creeks. See Figure 3 for location of streams in the report area that are quantitatively measured.

The Brandywine Creek at Wilmington drains 314 square miles in Pennsylvania and Delaware; and at Chadds Ford, Pennsylvania, 287 square miles in Pennsylvania. At Wilmington the Brandywine has an average flow of 436 cubic feet per second or 282 million gallons a day. The low flow of 56 cubic feet per second is about 36 million gallons a day. Wilmington, which uses the Brandywine for public supply, has protected its supply during the periods of low flow and attendant poor water quality in the Brandywine by developing the 2.3 billion gallon Edgar M. Hoopes Reservoir in the Red Clay Creek watershed. The Hoopes Reservoir is filled by pumping water from the Brandywine to the reservoir when the supply of water is ample. The reservoir is seldom used because of lack of water in the Brandywine. It is more often used because of poor quality Brandywine water during low flow.

Red Clay Creek drains an area of about 53 square miles at the point where it joins White Clay Creek. Streamflow records of 47 square miles of the drainage basin are summarized in Table 7. For the 47 square miles, the average discharge is 60.3 cubic feet per second or about 39 million gallons a day. The low flow of the stream is only 4.5 cubic feet per second or 2.9 million gallons a day. Without storage, the available water during dry periods is small. Water was taken at the confluence of Red Clay and White Clay Creeks for an average public and industrial supply of about 13 million gallons a day in 1966.

White Clay Creek drains an area of about 104 square miles at its confluence with Red Clay Creek. Streamflow data for 88 square miles of the drainage are summarized in Table 7. For the 88 square miles the average discharge is 104 cubic feet per second or about 67 million gallons a day. The minimum discharge is 4.7 cubic feet per second or only 3 million gallons a day. Studies have been made by the U. S. Army Corps of Engineers (1960) and the Delaware River Basin Commission to increase the available supply from White Clay Creek by storage to augment the present available supplies in Red Clay Creek and the Christina River during low flow periods and to increase the flow of White Clay Creek. The available supply of the three streams, thus, would be increased to a combined minimum total of 80 million gallons a day.

Part of the Christina River heads in and drains part of the Piedmont Plateau, but the major part of its drainage is in the Coastal Plain. The river above its estuary at Smalleys Pond drains 46 square miles of which 20.5 square miles of the drainage above Cooches Bridge has been measured and is summarized in Table 7. The discharge at Smalleys Pond is about 2.24 times that at Cooches Bridge. Thus, for the 46 square miles of drainage the average discharge is about 57 cubic feet per second or about 36.8 million gallons a day. The minimum flow is 0.45 cubic feet per second or only 290,000 gallons a day. Engineering studies have shown that the available supply can be assured to 9 million gallons a day with increased storage above Smalleys Pond.

South of the Christina River many small rivers and creeks drain to the Delaware River system and to the Atlantic Ocean and Chesapeake Bay. The streams supply water for a large number of small ponds and shallow lakes which are, in many instances, used for fishing, swimming, rural water supply, and irrigation. The topography is flat, the slope of the stream beds is also flat, and the drainage areas of the streams are small. No sites are available to develop deep or large storage lakes. The streams south of the Christina River are, therefore, unimportant as sources of large supplies of water from storage reservoirs. Without adequate storage, the streams are unimportant because of the low flow during dry weather. Table 7 shows the low flow of seven Coastal Plain streams to range from 0.0 to 1.3 cubic feet per second. The average discharge of the seven streams is 1.22 cubic feet per second per square mile. Studies of the relation of surface water to ground water in Sussex County reveal that the discharge of the streams is about 80 percent ground-water drainage and only 20 percent overland runoff (Sundstrom, 1970). A detailed analysis of the surface-water yield and low flow frequencies is given in the report by Cushing, Kantrowitz and Taylor, 1973, pages 11 through 37.

GENERAL GROUND-WATER HYDROLOGY 1/

Hydrologic Cycle

The hydrologic cycle is the sum total of processes and movements of the earth's moisture from the sea, through the atmosphere, to the land, and eventually, with numerable delays en route, back to the sea. Many courses that

1/ Taken from Texas Water Development Board Report 195 (November 1975) with some modification.

the water may take to complete the hydrologic cycle are illustrated on Figure 17. Water occurring in the study region is derived, for the most part, from water vapor carried inland from the Gulf of Mexico.

Source and Occurrence

The primary source of ground water in the study region is the infiltration of precipitation, either directly as recharge or indirectly as seepage from streamflow. A large percentage of precipitation is evaporated back to the atmosphere directly or is consumed by plants and returned to the atmosphere by transpiration. A large portion also becomes surface runoff because it moves rapidly over land surfaces which are steep or impermeable. If the rain is intense, surface runoff increases because the time available for absorption is inadequate even in sandy areas. A portion of the rainfall will percolate downward under the force of gravity to the zone of saturation where all the rock voids contain water. The upper surface of the zone of saturation is the water table. Water percolating down may be intercepted by a local impermeable layer of rock above the zone of saturation, thus forming a saturation zone above the main water table known as a perched water table. Two characteristics of fundamental importance in the zone of saturation are porosity, or the amount of the interstices, voids, or open space contained in the rock; and permeability, which is the ability of the porous material to transmit water. Fine-grained sediments, such as clay and silt, generally have high porosity; however, because of their small voids they have little or no permeability and consequently do not readily transmit water. Sand and gravel are usually porous and permeable, the degree depending upon the size, shape, sorting, and amount of cementation of the grains. In limestone or igneous rocks, or in tightly cemented or compacted rocks, porosity and permeability are controlled to some degree by the occurrence and extent of joints, crevices, and solution cavities. For a formation to be an aquifer, it must be porous, permeable, water-bearing, and yield water in usable quantities.

Water in an aquifer is either under water-table or artesian conditions. In the outcrop area, ground water generally occurs under water-table, or unconfined conditions; it is under atmospheric pressure and will rise or fall in response to changes in the volume of water stored. In a well penetrating an unconfined aquifer, water will rise to the level of the water table. The hydraulic gradient in an unconfined aquifer coincides with the slope of the water table which corresponds to the general slope of the land surface.

Downdip from the outcrop or recharge area, ground water within an aquifer occurs under artesian or confined conditions as a result of being overlain by relatively impermeable beds which confine the water under a pressure greater than atmospheric. In a well penetrating an artesian aquifer, water will rise above the confining bed and, if the pressure head is large enough to cause the water in the well to rise above the land surface, the well will flow. The level or surface to which water will rise in an artesian well is called the piezometric surface. The hydraulic gradient of an artesian aquifer is the slope of the piezometric surface.

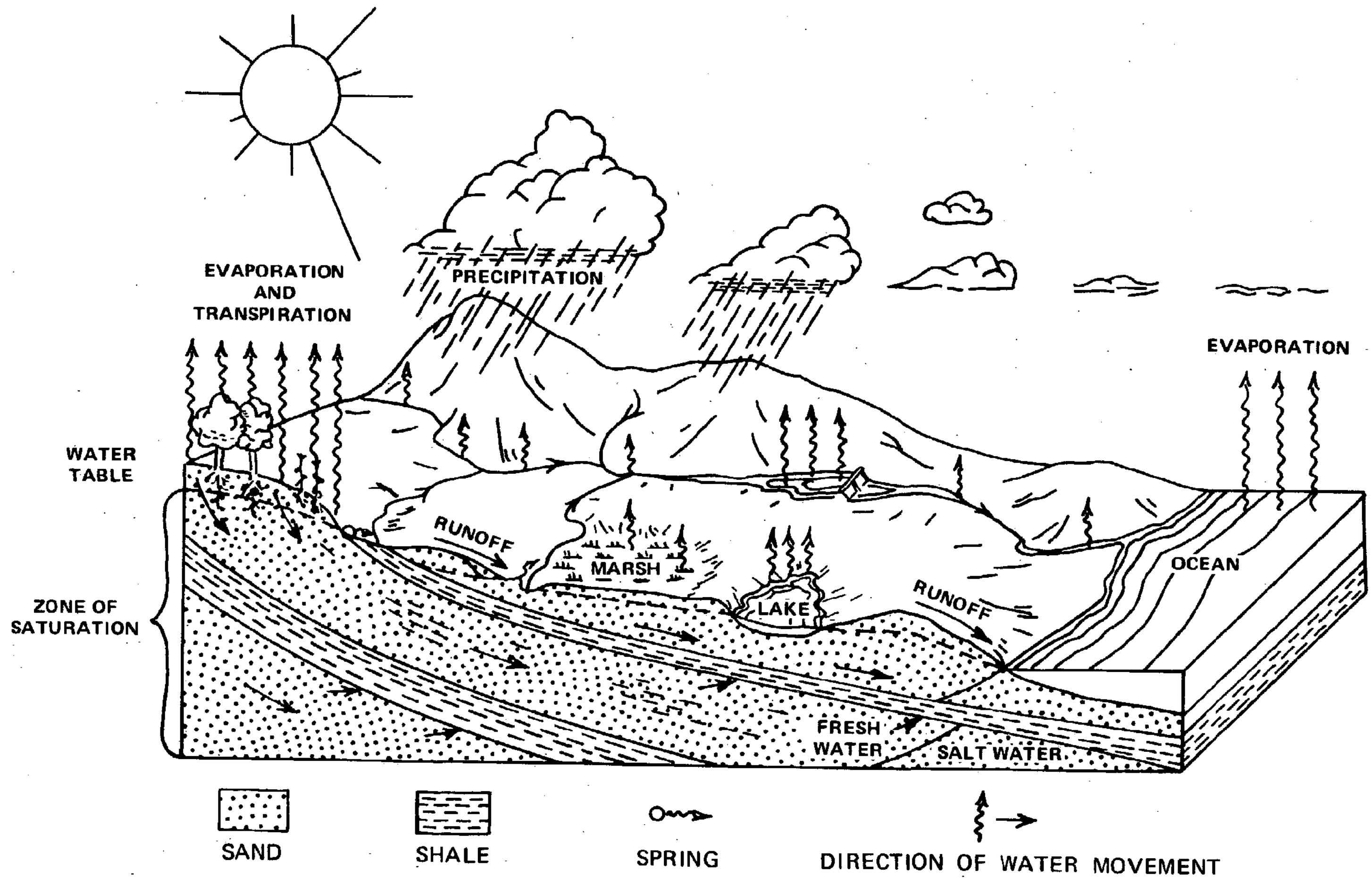


FIGURE 17

THE HYDROLOGIC CYCLE

Recharge, Movement, and Discharge

Recharge is the process by which water is added to an aquifer and may result from either natural or artificial processes. Precipitation on the outcrop of an aquifer is generally the most significant natural source of recharge; however, water may enter from surface streams and lakes on the outcrop and possibly through intraformational leakage. Artificial recharge is the process of replenishing ground water in an aquifer and may be accomplished by (1) injection wells, and (2) infiltration of storm-water runoff, irrigation water or properly treated industrial waste water and sewage. The amount of recharge must be considered in determining the amount of water which can be safely developed from an aquifer, because it must balance the discharge over a long period of time or the water in storage in the aquifer will eventually be depleted. Factors which influence the amount of recharge received by an aquifer in its outcrop area are the amount and frequency of precipitation, rate of evaporation, types and condition of soil cover, topography, type and amount of vegetation, and the extent of the outcrop area. In addition, the ability of the aquifer to accept recharge and transmit it to areas of discharge influences the amount of recharge it will eventually receive. Recharge is generally greater during winter months when plant growth and well use are at a minimum and evaporation rates are low.

Ground water moves in response to the hydraulic gradient from areas of recharge to areas of discharge, or from points of higher hydraulic head to points of lower hydraulic head. Ground water under artesian conditions generally moves in the direction of the aquifer's regional dip, while movement of ground water under water-table conditions is closely related to the slope of the land surface. However, in areas of large and extensive withdrawals, ground water moves from all directions toward the areas of pumpage or lowered pressure. The rate of movement of ground water is directly related to the porosity and permeability of the aquifer. In most sands and gravels, the rate of movement ranges from tenths of a foot to several feet per day, while in cavernous limestone, water flows in subterranean channels and may have velocities comparable to surface streams.

Discharge is a process by which water is removed from an aquifer and may be either natural or artificial. Natural discharge includes springs, seepage to streams, lakes, and marshes which intersect the water table, transpiration by vegetation, evaporation through the soil where the water table is close to the land surface, and intraformational leakage as a result of differences in head. Since ground water moves in response to gravity, its natural discharge from an aquifer is always at a lower elevation than that of the recharge area. Ground water is artificially discharged from flowing and pumped water wells, and by drainage ditches, gravel pits, and other forms of excavation that intersect the water table.

CHEMICAL QUALITY OF GROUND WATER AS RELATED TO USE 1/

General Chemical Quality of Ground Water

All ground water contains minerals carried in solution, the type and concentration of which depend upon the environment, movement, and source of the ground water. Precipitation is relatively free of minerals until it comes in contact with the various constituents which make up the soils and component rocks of the aquifer; then, as a result of the solvent power of water, minerals are dissolved and carried into solution as the water passes through the aquifer. The concentration depends upon the solubility of the minerals present, the length of time the water is in contact with the rocks, and the amount of dissolved carbon dioxide in the water. In addition, concentrations of dissolved minerals in ground water generally increase with depth and especially increase where circulation has been restricted due to faulting or zones of lower permeability. Restricted circulation retards the flushing action of fresh water moving through the aquifers, causing the water to become highly mineralized. In addition to natural mineralization, man can adversely alter the chemical quality of ground water by permitting highly mineralized water to enter fresh water strata through inadequately constructed wells, by seepage from brine disposal pits used in disposing of highly mineralized water produced with oil, and by disposal of animal wastes, sewage, or various industrial waste into fresh water strata or into aquifer recharge areas.

The principal chemical constituents found in ground water are calcium, magnesium, sodium, potassium, iron, silica, bicarbonate, carbonate, sulfate, chloride, and minor amounts of manganese, nitrate, fluoride, and boron. Concentrations of these ions or chemical constituents are commonly reported in milligrams per liter (mg/l). Milligrams per liter are the preferred metric system units and may be considered equal to parts per million at concentrations less than about 7,000 mg/l. At higher concentrations the units are not directly interchangeable, as conversion must take into account the greater differences in density of saline waters. The source, significance, the range of mineral constituents and properties of natural waters for the various aquifers in the study region are given in Table 8. Chemical analyses of water from selected wells in the study region are given for the various aquifers discussed in this report.

Water Quality Considerations for Public Supply, Domestic and Livestock Use

The Delaware State Department of Health (1971) has established standards of drinking water to apply to all public water suppliers in the state. The

1/ Taken from Texas Water Development Board Report 195 (November 1975) with some modification.

Table 8.

Source and Significance of Dissolved-Mineral Constituents and Properties of Water

CONSTITUENT OR PROPERTY	SOURCE OR CAUSE	SIGNIFICANCE
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 mg/l. High concentrations, as much as 100 mg/l, generally occur in highly alkaline water.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment.	On exposure to air, iron in ground water oxidizes to reddish-brown precipitate. More than about 0.3 mg/l stain laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. U.S. Public Health Service (1962) drinking water standards state that iron should not exceed 0.3 mg/l. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Calcium (Ca) and Magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quanitites in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.
Sodium (Na) and Potassium (K)	Dissolved from practically all rocks and soils. Found also in oil-field brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium content may limit the use of water for irrigation.
Bicarbonate (HCO_3) and Carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon-dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. U.S. Public Health Service (1962) drinking water standards recommend that the sulfate content should not exceed 250 mg/l.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in oil-field brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. U.S. Public Health Service (1962) drinking water standards recommend that the chloride content should not exceed 250 mg/l.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual (Maier, 1950, p. 1120-1132.)
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest pollution. U.S. Public Health Service (1962) drinking water standards suggest a limit of 45 mg/l. Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding (Maxcy, 1950, p. 271). Nitrate shown to be helpful in reducing inter-crystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.

Table 8 cont.

SOURCE OR CAUSE	CONSTITUENT OR PROPERTY	SIGNIFICANCE
Boron (B)	A minor constituent of rocks and of natural waters.	An excessive boron content will make water unsuitable for irrigation. Wilcox (1955, p. 11) indicated that a boron concentration of as much as 1.0 mg/l is permissible for irrigating sensitive crops; as much as 2.0 mg/l for semitolerant crops; and as much as 3.0 mg/l for tolerant crops. Crops sensitive to boron include most deciduous fruit and nut trees and navy beans; semitolerant crops include most small grains, potatoes and some other vegetables, and cotton; and tolerant crops include alfalfa, most root vegetables, and the date palm.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils.	U.S. Public Health Service (1962) drinking water standards recommend that waters containing more than 500 mg/l dissolved solids not be used if other less mineralized supplies are available. For many purposes the dissolved-solids content is a major limitation on the use of water. A general classification of water based on dissolved-solids content, in mg/l, is as follows (Winslow and Kister, 1956, p. 5): Waters containing less than 1,000 mg/l of dissolved solids are considered fresh; 1,000 to 3,000 mg/l, slightly saline; 3,000 to 10,000 mg/l, moderately saline; 10,000 to 35,000 mg/l, very saline; and more than 35,000 mg/l, brine.
Hardness at $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All of the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called non-carbonate hardness. Waters of hardness up to 60 mg/l are considered soft; 61 to 120 mg/l, moderately hard; 121 to 180 mg/l, hard; more than 180 mg/l, very hard.
Percent Sodium (% Na)	Sodium in water.	A ratio (using milliquivalents per liter) of the sodium ions to the total sodium, calcium, and magnesium ions. A sodium percentage exceeding 50 percent is a warning of a sodium hazard. Continued irrigation with this type of water will impair the tilth and permeability of the soil.
Specific conductance (micromhos at 25°C)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.
Hydrogen ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.
Sodium-adsorption ratio (SAR)	Sodium in water.	A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil (U.S. Salinity Laboratory Staff, 1954, p. 72, 156). Defined by the following equation: $SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$, where Na^+, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter (me/l) of the respective ions.

standards are designed to protect the public and may be used to evaluate public and domestic water supplies. Some of these standards, in milligrams per liter, are as follows:

Substance	Maximum Concentration Recommended (mg/l)
Chloride (Cl)	200.0
Iron (Fe)	0.3
Manganese (Mn)	0.05
Nitrogen (N) (Nitrate plus Nitrite)	10.0
Sulfate (SO_4)	100.0
Total dissolved solids	500.0

In areas where the nitrate concent of water is excessive, a potential danger exists. Concentrations of nitrate in excess of 45 mg/l in water used for infant feeding have been related to the incidence of infant cyanosis (methemoglobinemia or "blue baby" disease), a reduction of the oxygen content in the blood constituting a form of asphyxia (Maxcy, 1950, p. 271). Since nitrates are considered to be the final oxidation product of nitrogenous material, their presence in concentrations of more than a few milligrams per liter may indicate present or past contamination by sewage or other organic matter (Lohr and Love, 1954, p. 10). Excessive concentrations of iron and manganese in water cause reddish-brown or dark gray precipitates that stain clothes and plumbing fixtures. Water having a chloride content exceeding 250 mg/l may have a salty taste, and sulfate in excess of 250 mg/l may produce a laxative effect.

The hardness in water is caused principally by the concentration of calcium and magnesium. Excessive hardness of water causes an increase in soap consumption and encrustation and formation of scale in hot water heaters, water pipes, and cooking utensils. The hardness of water becomes objectionable when it exceeds 100 mg/l (Hem, 1959, p. 147). A commonly accepted classification of water hardness is shown in the following table:

Hardness Range (mg/l)	Classification	Usability
60 or less	Soft	Suitable for many uses without further softening
61 to 120	Moderately hard	Usable except in some industrial applications

Hardness Range (mg/l)	Classification	Usability
121 to 180	Hard	Softening required by some industries
More than 180	Very hard	Softening desirable for most purposes

The total dissolved solids content is a major limiting factor in the use of water. The following general classification of water is based on dissolved solids (Winslow and Kister, 1956, p. 5).

Description	Dissolved Solids Content (mg/l)
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

Quality limits for livestock are variable. The limits of tolerance depend principally on the kind of animal and, according to Heller (1933, p. 22), the total amount of soluble salts in the drinking water, more so than the kind of salt, is the important factor. According to Hem (1959, p. 241), a high proportion of sodium or magnesium and sulfate in highly mineralized waters would make them very undesirable for livestock use. Heller also suggests that as a safety rule 15,000 mg/l dissolved solids content should be considered the upper limit for most of the more common livestock animals. According to Hem (1959, p. 241), the California State Water Pollution Control Board (1952) quotes other investigators who have found concentrations as high as 15,000 mg/l to be safe for limited periods but not for continuous use. In a publication (1950) relating to practices in Western Australia, the officers of the Department of Agriculture of that state quote the following upper limits for dissolved solids concentration in livestock water (Hem, 1959, p. 241).

Animal	Dissolved Solids (mg/l)
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle (Dairy)	7,150
Cattle (Beef)	10,000
Adult Sheep	12,900

Water Quality Considerations for Irrigation Use

The chemical composition of ground water is important in determining its usefulness for irrigation in that it should not adversely affect the productivity of the land. The extent to which chemical quality limits the suitability of ground water for irrigation depends on the nature, composition, and drainage of the soil and subsoil; the amounts of water used and methods of application; the kinds of crops grown; and the climate of the region, including the amounts and distribution of rainfall.

The most important characteristics in determining the quality of ground water for irrigation, according to the U.S. Salinity Laboratory Staff (1954, p. 69) are (1) total concentration of soluble salts; (2) relative proportion of sodium to other cations; and (3) concentration of boron or other elements that may be toxic.

High concentrations of dissolved salts in irrigation water may cause a buildup of salts in the soil solution and may make the soil saline. Increased salinity of the soil may drastically reduce crop yields by decreasing the ability of the plants to take up water and essential plant nutrients from the soil solution. The tendency of irrigation water to cause a high buildup of salts in the soil is called the salinity hazard of the water. The specific conductance of the water is used as an index of the salinity hazard.

High concentrations of sodium relative to the concentrations of calcium and magnesium in irrigation water may adversely affect soil structure. Cations in the soil solution become fixed on the surface of the soil particles; calcium and magnesium tend to flocculate the particles, whereas sodium tends to deflocculate the colloidal soil particles. Consequently, soils may become plastic, movement of water through the soil can be restricted, drainage problems can develop, and cultivation can be rendered difficult. This adverse effect on soil structure caused by high sodium concentrations in an irrigation water is called the sodium hazard. An index used for predicting the sodium hazard is the sodium-adsorption ratio (SAR), which is defined by the equation given in Table 8.

Water Quality Considerations for Industrial Use

The chemical quality of water suitable for industry is not necessarily referenced to potability and may or may not be acceptable for human consumption. The tolerance in chemical quality of water for industrial use differs widely for different industries and different processes. Suggested water-quality tolerances for a number of industries are presented in Table 9 (American Water Works Association, 1950, p. 66-67). Water used by industry may be classified into three principal categories: cooling water, boiler water and process water.

TABLE 9.

WATER QUALITY TOLERANCES FOR INDUSTRIAL APPLICATIONS[1]

[Allowable Limits in Milligrams Per Liter Except as Indicated]

INDUSTRY	TURBIDITY	COLOR	COLOR + O_2 CONSUMED	DISSOLVED OXYGEN (ml/l)	ODOR	HARDNESS	ALKALINITY (AS $CaCO_3$)	pH	TOTAL SOLIDS	Ca	Fe	Mn	Fe + Mn	Al_2O_3	SiO_2	Cu	F	CO_3	HCO_3	OH	$CaSO_4$	Na_2SO_4 TO Na_2SO_3 RATIO	GENERAL[2]
Air Conditioning[3]	—	—	—	—	—	—	—	—	—	—	0.5	0.5	0.5	—	—	—	—	—	—	—	—	—	A,B
Baking	10	10	—	—	—	(4)	—	—	—	—	.2	.2	.2	—	—	—	—	—	—	—	—	—	C
Boiler feed:																							
0-150 psi	20	80	100	2	—	75	—	8.0+	3,000-1,000	—	—	—	—	5	40	—	—	200	50	50	—	1 to 1	—
150-250 psi	10	40	50	.2	—	40	—	8.5+	2,500-500	—	—	—	—	.5	20	—	—	100	30	40	—	2 to 1	—
250 psi and up	5	5	10	0	—	8	—	9.0+	1,500-100	—	—	—	—	.05	5	—	—	40	5	30	—	3 to 1	—
Brewing:[5]																							
Light	10	—	—	—	Low	—	75	6.5-7.0	500	100-200	.1	.1	.1	—	—	—	1	—	—	—	100-200	—	C,D
Dark	10	—	—	—	Low	—	150	7.0→	1,000	200-500	.1	.1	.1	—	—	—	1	—	—	—	200-500	—	C,D
Canning:																							
Legumes	10	—	—	—	Low	25-75	—	—	—	—	.2	.2	.2	—	—	—	—	—	—	—	—	—	C
General	10	—	—	—	Low	—	—	—	—	—	.2	.2	.2	—	—	—	1	—	—	—	—	—	C
Carbonated beverages[6]	2	10	10	—	0	250	50	—	850	—	.2	.2	.3	—	—	—	.2	—	—	—	—	—	C
Confectionery	—	—	—	—	Low	—	—	(7)	100	—	.2	.2	.2	—	—	—	—	—	—	—	—	—	—
Cooling[8]	50	—	—	—	—	50	—	—	—	—	.5	.5	.5	—	—	—	—	—	—	—	—	—	A,B
Food, general	10	—	—	—	Low	—	—	—	—	—	.2	.2	.2	—	—	—	—	—	—	—	—	—	C
Ice (raw water)[9]	1-5	5	—	—	—	—	30-50	—	300	—	.2	.2	.2	—	10	—	—	—	—	—	—	—	C
Laundering	—	—	—	—	—	50	—	—	—	—	.2	.2	.2	—	—	—	—	—	—	—	—	—	—
Plastics, clear, undercolored	2	2	—	—	—	—	—	—	200	—	.02	.02	.02	—	—	—	—	—	—	—	—	—	—
Paper and pulp:[10]																							
Groundwood	50	20	—	—	—	180	—	—	—	—	1.0	.5	1.0	—	—	—	—	—	—	—	—	—	A
Kraft pulp	25	15	—	—	—	100	—	—	300	—	.2	.1	.2	—	—	—	—	—	—	—	—	—	—
Soda and sulfite	15	10	—	—	—	100	—	—	200	—	.1	.05	.1	—	—	—	—	—	—	—	—	—	—
Light paper, HL-Grade	5	5	—	—	—	50	—	—	200	—	.1	.05	.1	—	—	—	—	—	—	—	—	—	B
Rayon (viscose) pulp:																							
Production	5	5	—	—	—	8	50	—	100	—	.05	.03	.05	<8.0	<25	<5	—	—	—	—	—	—	—
Manufacture	.3	—	—	—	—	55	—	7.8-8.3	—	—	.0	.0	.0	—	—	—	—	—	—	—	—	—	—
Tanning[11]	20	10-100	—	—	—	50-135	135	8.0	—	—	.2	.2	.2	—	—	—	—	—	—	—	—	—	—
Textiles:																							
General	5	20	—	—	—	20	—	—	—	—	.25	.25	—	—	—	—	—	—	—	—	—	—	—
Dyeing[12]	5	5-20	—	—	—	20	—	—	—	—	.25	.25	.25	—	—	—	—	—	—	—	—	—	—
Wool scouring[13]	—	70	—	—	—	20	—	—	—	—	1.0	1.0	1.0	—	—	—	—	—	—	—	—	—	—
Cotton bandage[13]	5	5	—	—	Low	20	—	—	—	—	.2	.2	.2	—	—	—	—	—	—	—	—	—	—

1 American Water Works Association, 1950.
2 A—No corrosiveness; B—No slime formation; C—Conformance to Federal drinking water standards necessary; D-NaCl, 275 mg/l.
3 Waters with algae and hydrogen sulfide odors are most unsuitable for air conditioning.
4 Some hardness desirable.
5 Water for distilling must meet the same general requirements as for brewing (gin and spirits mashing water of light-beer quality; whiskey mashing water of dark-beer quality).
6 Clear, odorless, sterile water for syrup and carbonization. Water consistent in character. Most high quality filtered municipal water not satisfactory for beverages.
7 Hard candy requires pH of 7.0 or greater, as low value favors inversion of sucrose, causing sticky product.
8 Control of corrosiveness is necessary as is also control of organisms, such as sulfur and iron bacteria, which tend to form slimes.
9 Ca $(HCO_3)_2$ particularly troublesome. Mg $(HCO_3)_2$ tends to greenish color. CO_2 assists to prevent cracking. Sulfates and chlorides of Ca, Mg, Na should each be less than 300 mg/l (white butts).
10 Uniformity of composition and temperature desirable. Iron objectionable as cellulose adsorbs iron from dilute solutions. Manganese very objectionable, clogs pipelines and is oxidized to permanganates by chlorine, causing reddish color.
11 Excessive iron, manganese, or turbidity creates spots and discoloration in tanning of hides and leather goods.
12 Constant composition; residual alumina 0.5 mg/l.
13 Calcium, magnesium, iron, manganese, suspended matter, and soluable organic matter may be objectionable.

Cooling water usually is selected on the basis of temperature and chemical quality since any characteristic which may adversely affect the heat exchange surface is undesirable. Chemical substances such as calcium, magnesium, aluminum, iron, and silica may cause the formation of scale. Excessive hardness is objectionable because it contributes to the formation of scale in steam boilers, pipes, water heaters, radiators, and various other equipment where water is heated, evaporated, or treated with alkaline materials. The accumulation of scale increases costs for fuel, labor, repairs and replacement, and lowers the quality of many products. Some calcium hardness may be desirable because calcium carbonate sometimes forms protective coatings on pipes and other equipment and reduces corrosion. A high concentration of dissolved solids in a water may be closely associated with its corrosive properties, especially if chloride, calcium, magnesium chloride, sodium chloride in the presence of magnesium, acids, and oxygen and carbon dioxide are among the substances. Water that contains a high concentration of magnesium chloride may be highly corrosive because the hydrolysis of this salt yields hydrochloric acid.

Water used for boilers generally must meet rigid chemical-quality standards, especially in high-pressure boilers where the problems of encrustation and corrosion are greatly intensified. Iron oxides in boiler water may cause priming and foaming and magnesium chloride to break down and form hydrochloric acid. In addition, magnesium, calcium, and silica in most waters cause scale, and in the case of silica, the tendency for forming scale intensifies with increased boiler pressure. Suggested water-quality tolerances for boiler water (Moore, 1940, p. 263), in milligrams per liter for various pressures in pounds per square inch (psi), are as follows:

Constituent or Property	0-150 psi	150-250 psi	250-400 psi	Over 400 psi
Turbidity	20	10	5	1
Color	80	40	5	2
Oxygen consumed	15	10	4	3
Dissolved oxygen*	1.4	.14	.0	.0
Hydrogen sulfide (H_2S)	5**	3**	0	0
Total hardness as $CaCO_3$	80	40	10	2
Sulfate-carbonate ratio (Na_2SO_4:Na_2CO_3)	1:1	2:1	3:1	3:1
Aluminum oxide (Al_2O_3)	5	.5	.05	.01
Silica (SiO_2)	40	20	5	1
Bicarbonate (HCO_3)*	50	30	5	0
Carbonate (CO_3)	200	100	40	20
Hydroxide (OH)	50	40	30	15
Total dissolved solids***	3,000-500	2,500-500	1,500-100	50
pH value (minimum)	8.0	8.4	9.0	9.6

* Limits applicable only to water entering boiler, not to original water supply.

** Except when odor in live steam would be objectionable.

*** Depends on design of boiler.

Some treatment of boiler water may be needed, and it may be better to appraise the water source from the viewpoint of suitability for treatment rather than for direct use of raw water.

Process water is that water which is incorporated into or comes in contact with final manufactured products and is subject to a wide range of quality standards, usually rigidly controlled since they involve physical, chemical, and biological factors. In textile manufacturing, water used must generally be low in dissolved-solids content and free of iron and manganese which cause staining. The paper industry, especially where high-grade paper is made, requires water in which all heavy metals are either absent or in small concentrations, and water approaching the quality of distilled water is required for the manufacture of pharmaceuticals. Water free of iron, manganese, and organic substances is generally required by many beverage industries. Unlike cooling and boiler water, much of the process water is consumed or undergoes a change in quality in the manufacturing process and generally is not available for reuse.

THE AVAILABILITY OF GROUND WATER

Ground water is available in the Coastal Plain of Delaware from 12 aquifers of which 11 (except for their subcrop area beneath the Quaternary deposits) are artesian in character and one, the Quaternary and subcrop deposits of the artesian aquifers, is a water-table reservoir. The 12 ground-water aquifers are: (1) the upper sand zone of the Potomac Formation; (2) the lower sand zone of the Potomac Formation; (3) the Magothy aquifer; (4) the sand of the Englishtown-Mount Laurel Formations; (5) the Rancocas aquifer; (6) the Piney Point aquifer; (7) the Cheswold aquifer; (8) the Federalsburg aquifer; (9) the Frederica aquifer; (10) the Manokin aquifer; (11) the Pocomoke aquifer; and (12) the Quaternary aquifer, also called the Pleistocene and Columbia aquifer.

The Potomac Aquifers

The nonmarine Potomac Formation in Delaware contains upper and lower sandy zones which vary considerably in thickness and water-transmitting properties. About 170 square miles of the artesian part of the Potomac Formation in Delaware were studied by Sundstrom and others, 1967. Their report describes the complexity of the geology and hydrology. The report should be studied in detail to understand the complexities of both the geology and hydrology of the two Potomac Formation aquifers.

Location of the Potomac Formation

The outcrop or subcrop of the Potomac Formation is shown in Figure 2. The structural map of the basement of the crystalline rocks on which the Potomac Formation lies is shown in Figure 4. The position of the Potomac Formation in a generalized cross-section of Delaware is shown in Figure 3. A map of the thickness of the Potomac Formation is shown in Figure 5. A structural map of the top of the Potomac Formation is shown in Figure 6.

Development of the Potomac Aquifers

The Potomac aquifers are completely developed so far as large wells are concerned in the area where development equals or exceeds the available recharge as shown on the water problem map in Figure 15. The area of the Potomac aquifers developed to date is shown in Figure 18.

Undeveloped Areas and Potential Use of the Potomac Aquifers

The area of potential use of the Potomac aquifers is shown in Figure 18. Downdip from the area of potential use, the aquifers are believed to contain saline water.

Hydrologic Potential of the Potomac Aquifers

The hydrologic potential of the Potomac aquifers is small in terms of supplying large quantities of water to wells. In the upper Potomac aquifer in the artesian part of the aquifer the transmissivity, storage and available drawdown were so low that only one well yielding 750,000 gallons a day was developed in the 5,000 acre tract of the Tidewater (now Getty) Oil Company; whereas, the company was able to develop more than four million gallons a day in the same tract from the lower artesian aquifer of the Potomac. The reason for the greater production lies primarily in the larger available drawdown in the wells of the lower artesian aquifer. Based on the 12-year pumpage record of the tidewater well field and the observed decline in water levels elsewhere in the two Potomac aquifers, two rating curves (Figure A1) were developed to give the effect of pumping on the upper and lower aquifers away from the Tidewater (Getty) well field. By applying these curves to five selected centers of pumping, Sundstrom and others, 1967, demonstrate the effects of 15 selected patterns of development along the Chesapeake and Delaware Canal. These are given in Table B1. Table B1 indicates that five million gallons a day might be developed from a well field similar to the Getty well field

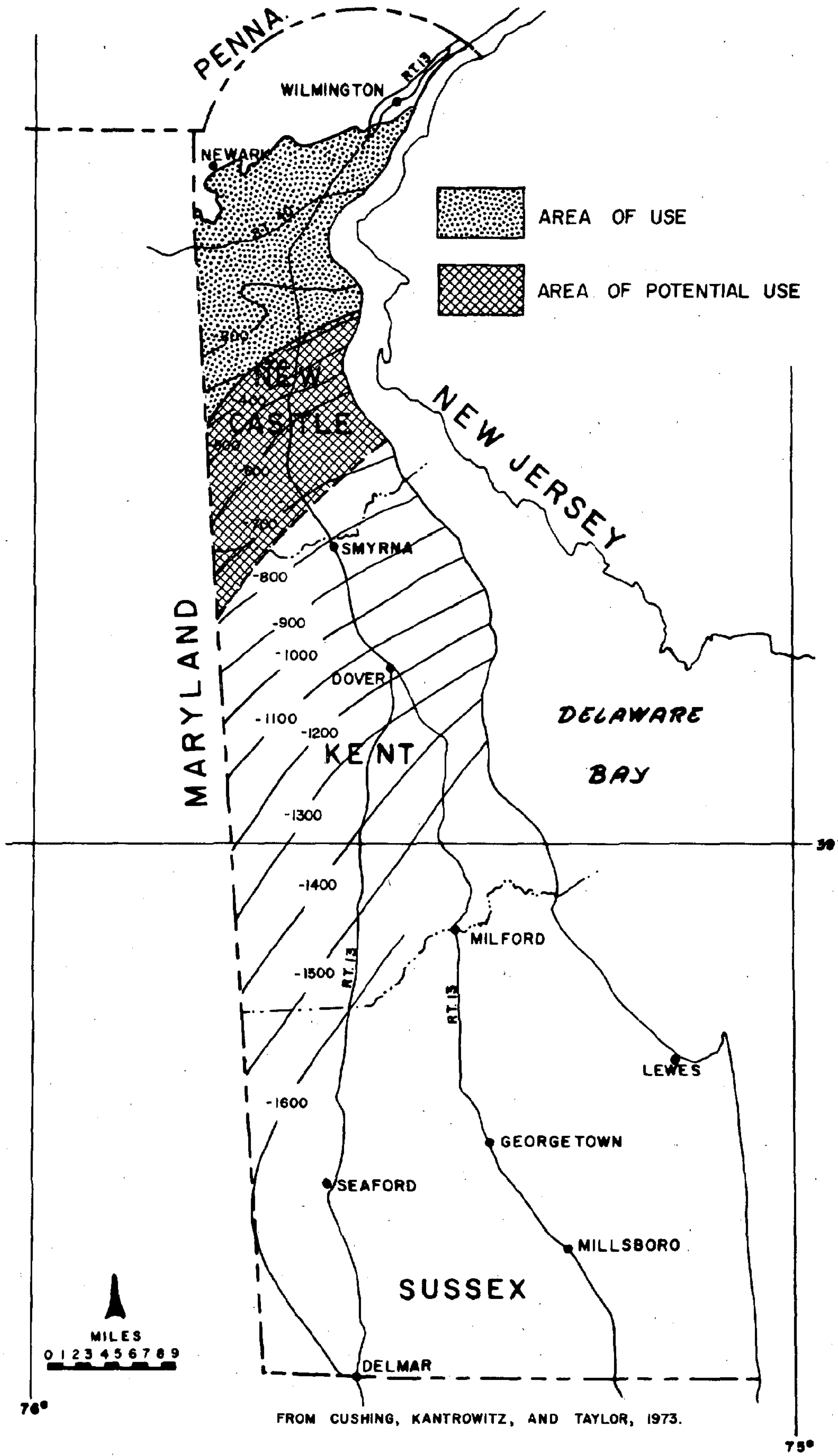


FIGURE 18 CONFIGURATION OF THE TOP AND AREAS OF USE AND OF POTENTIAL USE OF THE NONMARINE CRETACEOUS AQUIFER.

located in the extreme western part of the canal area in Delaware. This amount of development would be predicated on the assumption that no new substantial amounts of pumping would take place in the canal area in Delaware or adjoining Maryland from the Potomac aquifer. The centers of pumping tested in the 1967 study by Sundstrom and others are shown in Figure A2. The location of wells in the Potomac aquifer used for well data is given in Figure A3. Data on water levels, well data, and screen settings are given in Table B2. Specific capacities of wells and test wells in the Potomac aquifers are given in Table B3. Coefficients of transmissivity and storage determined from pumping tests of Potomac aquifer wells are given in Table B4.

Available Water from the Potomac Aquifers

Figure 17 shows that the present development of the outcrop-subcrop area has reached or exceeded the available recharge in the eastern half of the area. The amount of development permissible in the western half of the subcrop area is not known, but is probably small in terms of supplies to wells of medium to large capacities. In the western part of the canal area studied by Sundstrom and others, 1967, there still remains a capacity of about five million gallons a day provided the well field is properly planned and developed and provided no other development takes place adjacent to the well field either in Delaware or Maryland. South of the Chesapeake and Delaware Canal, between the canal and the position of the fresh-salt water interface in the Potomac Formation, some additional water, perhaps three or four million gallons a day, may be developed from the Potomac aquifers.

Limits in Development of the Potomac Aquifers

The known development and hydrology of the Potomac aquifers indicate that the limits of additional development of the aquifers is about eight or nine million gallons a day with proper use of the aquifers.

Quality of Water in the Potomac Aquifers

The quality of ground water and areas of potential saline water intrusion in the Potomac aquifers are shown in Figure 19. The chemical constituents in ground water in the Potomac aquifers (concentration of constituents in milligrams per liter) are given in Table 10.

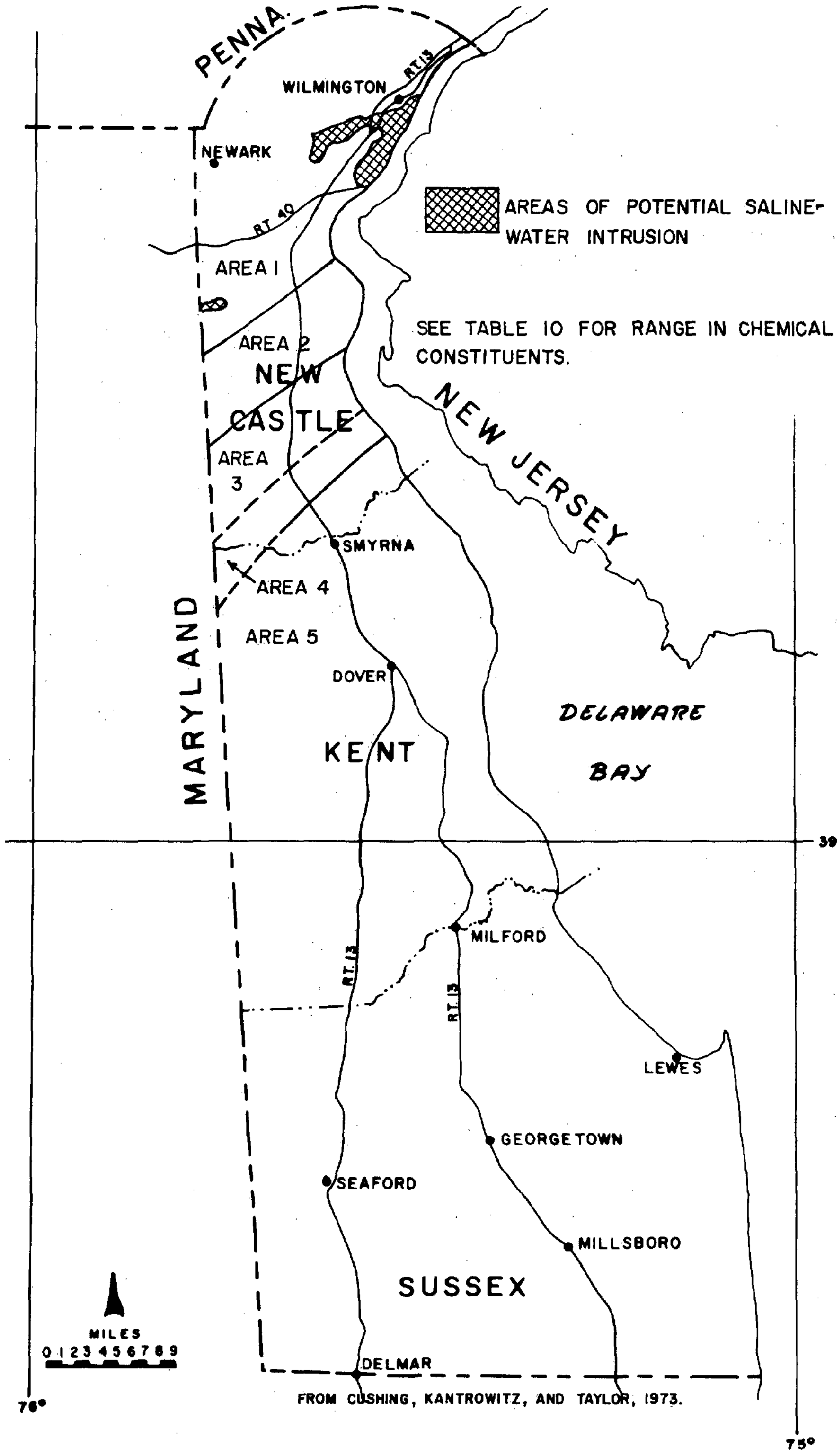


FIGURE 19 AREAS OF SIMILAR CHEMICAL QUALITY OF GROUND WATER AND AREAS OF POTENTIAL SALINE-WATER INTRUSION IN THE POTOMAC AQUIFER.

Table 10.

Quality of Ground Water and Area of Potential Saline-Water Intrusion in the Nonmarine Cretaceous Aquifer, as Shown in Figure 19.

Chemical constituents in ground water in the nonmarine Cretaceous aquifer (concentration of constituents in milligrams per liter)

Area	1	2	3	4	5
Dissolved solids*	<100	100-250	250-500	500-1000	>1000
Hardness	5-60	2-50	<10	<15	15-60
Sodium	2-14	14-70	70-200	200-340	>300
Bicarbonate	6-80	80-180	180-450	450-750	---
Sulfate	<1-25	3-25	20-40	20-60	---
Chloride	2-15	2-20	2-10	5-200	>200
Fluoride	0.0-0.3	0.1-0.6	0.6-3.0	1.0-4.0	---
Nitrate	<1-24	<1.6	<1.5	<1.3	---
Silica	3-10	10-15	10-15	10-15	---
Iron and manganese	0-10	0.1-0.6	0.01-0.35	0.04-0.4	---
pH	5.6-7.0	7.0-8.0	8.0-8.6	8.2-8.9	---

*Dissolved solids x 1.60 = specific conductance (Micromhos at 25°C)
From Cushing, Kantrowitz and Taylor, 1973.

Salt-Water Problems in the Potomac Aquifers

Although salt-water problems have not occurred in the part of the Potomac aquifers yielding fresh water, salt-water problems could occur as shown on the map in Figure 19. This area is in the subcrop area where the water levels in wells adjacent to the wetlands of the Delaware Estuary have been drawn down below sea level. To date no problem has developed from this situation, but a problem may occur later if the water levels in wells continue to be pumped down below sea level. There is also a danger of salt-water problems along the western part of the Chesapeake and Delaware Canal where the sands of the Magothy aquifer are in direct contact with the upper Potomac aquifer and the Magothy sands outcrop in the Canal which contains salt water.

Unknown Hydrology of the Potomac Aquifers

Much of the hydrology of the very complex aquifers of the Potomac Formation has been studied. The irregular occurrence of the sands still leave some doubt about the total available water, especially in the western part of the canal area where development has been limited. In the fresh-salt water interface area in the Potomac aquifers, data are still too meager for exact delineation of the interface.

The Magothy Aquifer

The hydrology of the Magothy aquifer in and near its subcrop in Delaware is closely associated with the upper aquifer zone of the Potomac Formation. The marine sediments that compose the Magothy aquifer rest directly on the nonmarine sediments of the upper Potomac Formation. Where the sands of the Magothy aquifer lie on sand of the Potomac, hydraulic continuity exists between the two aquifers. As the aquifers become deeper downdip, marine clay sediments thicken and probably separate the two aquifers to some extent. The Magothy aquifer and the upper sands of the Potomac probably should be considered a single aquifer in hydrologic treatment.

The original water levels in the Magothy were influenced by the hydraulic association with the water levels in the upper Potomac. In the subcrop area the altitude of the water levels in the overlying Pleistocene sediments controlled the altitude of the water levels in the nonartesian part of the Magothy aquifer. They also controlled the artesian pressure on both the Potomac and Magothy aquifers where they are confined. Measured artesian pressures in the Potomac aquifer zones suggest that by similarity the original artesian pressure in the Magothy aquifer, where it is confined, ranged from about 15 to 20 feet above sea level.

Location of the Magothy Aquifer

The subcrop of the Magothy aquifer occupies two small areas as shown in Figure 2. The configuration of the top of the aquifer to a depth 1,400 feet below sea level is shown in Figure 20. A structural map of the Magothy Formation above the fresh-salt water interface is shown in Figure 5.

Development of the Magothy Aquifer

The Magothy aquifer is developed in two areas shown in Figure 20. Pumping from the Magothy-Potomac upper zone south of the Chesapeake and Delaware Canal has been on a small scale. In 1959, the total pumpage mostly from the upper Potomac was reported (Rima and others, 1964) to be only 80,000 gallons a day for all purposes.

Undeveloped Areas and Potential Use of the Magothy Aquifer

The potential undeveloped area of the Magothy aquifer is shown in Figure 20.

Hydrologic Potential and Available Water from the Magothy Aquifer

The hydraulic coefficients that control the water-yielding properties of the Magothy aquifer are not sufficiently known for a good appraisal of the aquifer. Geologic evidence indicates the aquifer is of a leaky nature in the updip part and becomes more confined downdip. The more leaky part of the aquifer lies on and is hydrologically connected in places to the upper zone of the Potomac. Based on one pumping test at Middletown, the transmissivity of the Magothy is 4,000 gallons per day per foot as compared to an average transmissivity in 11 wells in the upper Potomac of 5,900 gallons per day per foot in the Chesapeake and Delaware Canal area (Sundstrom and others, 1967). The canal area comprises an area of about 170 square miles. The area of the Magothy from the beginning of the subcrop to the fresh-salt water interface is also about the same size. The available drawdowns in the upper Potomac aquifer and in the Magothy are similar in range of depths. Assuming that the transmissivity of 4,000 gallons for the Magothy is representative of all the aquifer, then a comparison with the average transmissivity of the upper Potomac zone indicates that the Potomac upper aquifer will yield about one and one-half times as much water as the Magothy. Sundstrom and others (1967) tested 15 patterns of development at five hypothetical centers of pumping stretched across the canal area and assumed that the upper Potomac aquifer would be

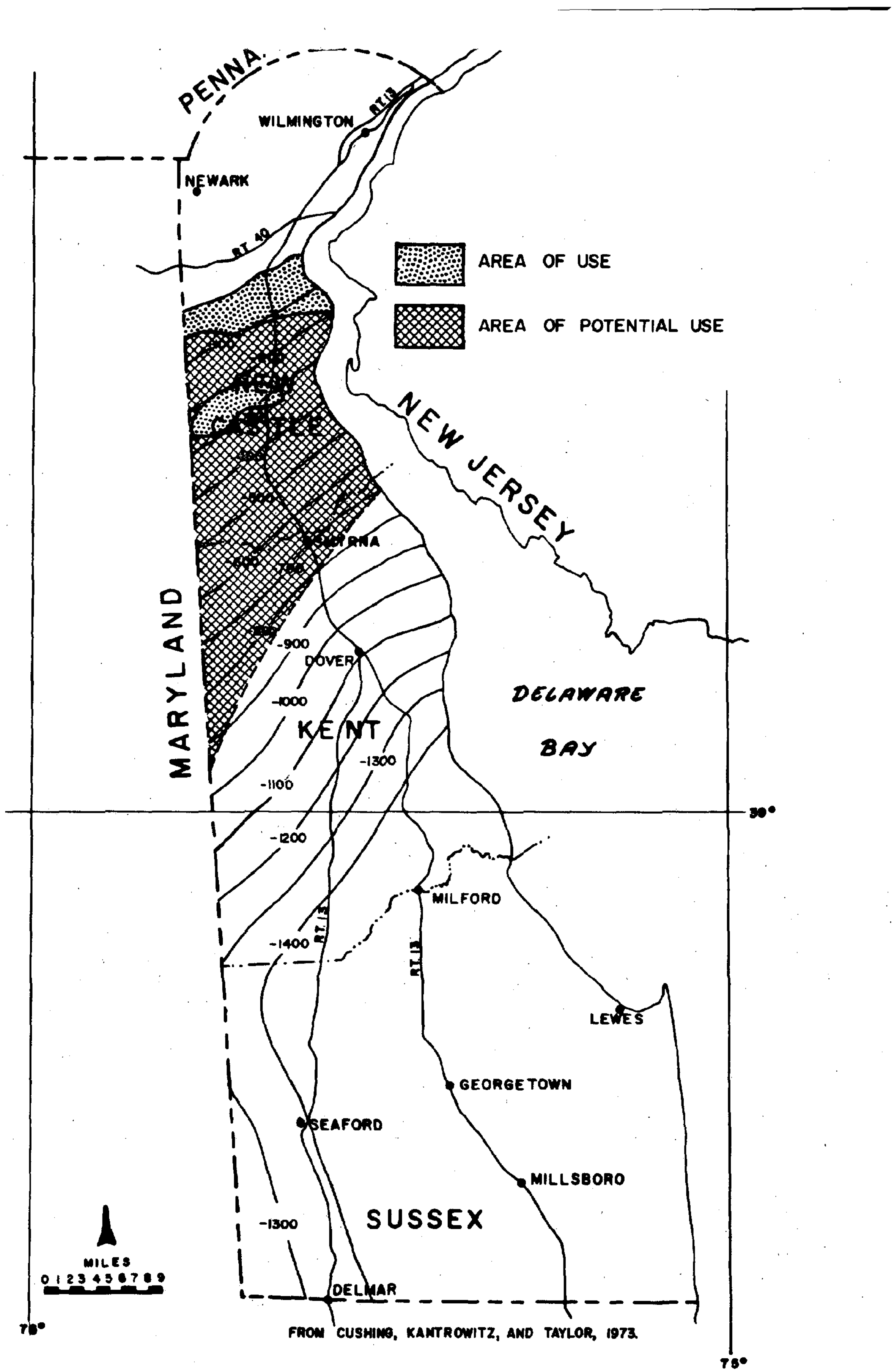


FIGURE 20 CONFIGURATION OF THE TOP AND AREAS OF USE AND OF POTENTIAL USE OF THE MAGOTHY AQUIFER.

pumped at the five centers from one or more wells at rates ranging in total from 0.0 to 1.75 million gallons a day. Of the 15 patterns tested that were feasible, the maximum rate of pumpage from the upper Potomac aquifer in the canal area was 4.7 million gallons a day from the five centers. The 4.7 million gallons a day in the canal area would indicate 3.1 million gallons a day from Magothy from a similar hypothetical analysis of the Magothy laid out in the same direction across the county and centering in the vicinity of Middletown. The production well yields would probably range from 250 to 300 gallons a minute. The area as a whole is not favorable for centers of large development of water. For smaller supplies (wells yielding 10 to 50 gallons a minute), the Magothy north of the fresh-salt water interface is a good source of water.

Quality of Water in the Magothy Aquifer

Areas of similar chemical quality of ground water and areas of potential salt-water intrusion into the Magothy aquifer are shown in Figure 21. For detailed discussions of the danger of salt-water intrusion into the Magothy and upper Potomac aquifers, see Sundstrom and others, 1967; Sundstrom and Pickett, 1971; and Cushing, Kantrowitz and Taylor, 1973. The chemical constituents of the ground water from the Magothy for areas shown on Figure 21 is given in Table 11.

The Englishtown and Mount Laurel Aquifers

Location of the Englishtown and Mount Laurel Aquifers

The subcrops of the Englishtown-Mount Laurel aquifers also sandwich in the Marshalltown Formation, which interconnects the two aquifers, but is of little value as an aquifer itself. The subcrops of the three formations are shown in Figure 2.

Hydrology of the Englishtown and Mount Laurel Aquifers

The Englishtown aquifer and the Mount Laurel aquifer are minor aquifers of fair to poor water-yielding properties which are unimportant in terms of large individual supplies of water, but are of considerable importance from the Chesapeake and Delaware Canal southward past Middletown for rural inhabitants. The two aquifers are separated by the Marshalltown Formation which, according to Pickett (1970a), consists of dark greenish gray, massive, glauconitic, very silty fine sand. The entire unit, including the Englishtown

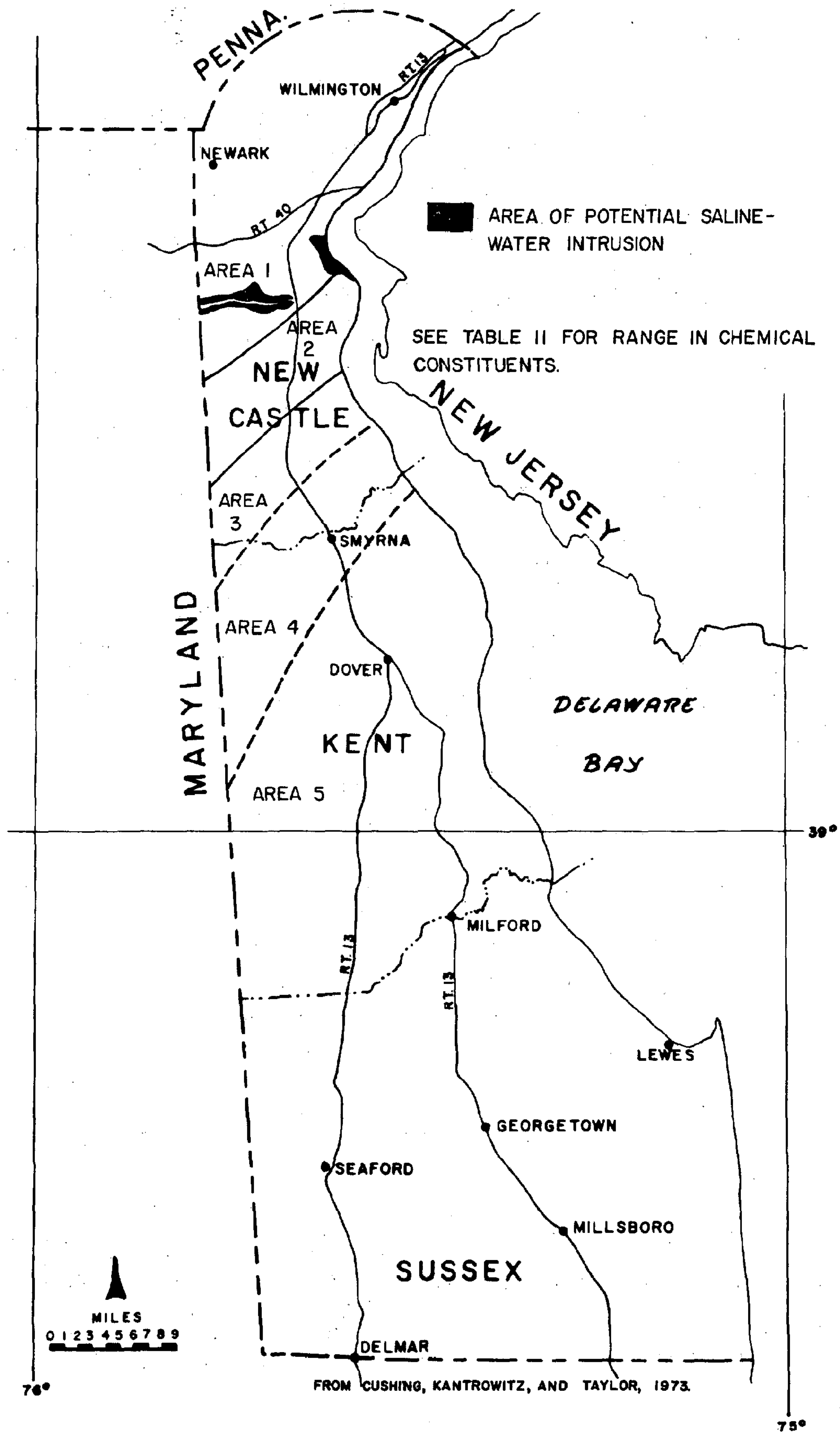


FIGURE 21 AREAS OF SIMILAR CHEMICAL QUALITY OF GROUND WATER AND AREAS OF POTENTIAL SALINE-WATER INTRUSION IN THE MAGOTHY AQUIFER.

Table 11.

Quality of Ground Water and Area of Potential Saline-Water Intrusion in the Magothy Aquifer, as shown in Figure 21

Chemical constituents in ground water in the Magothy aquifer (concentration of constituents in milligrams per liter)

Area	1	2	3	4	5
Dissolved solids*	<100	100-250	250-500	500-1000	>1000
Hardness	4-70	4-70	<20	---	<20
Sodium	3-12	12-95	>95	---	>400
Bicarbonate	5-100	100-250	>250	---	>900
Sulfate	1-12	9-15	>10	---	>60
Chloride	1-3	2-5	<10	---	>50
Fluoride	0.1-0.3	0.2-1.1	>1.0	---	>5.0
Nitrate	0-1	0-2	<2	---	<2
Silica	3-16	6-15	>10	---	>10
Iron and manganese	2.0-24	0.03-4.4	<1	---	<1
pH	6.1-7.5	6.8-8.2	>7.0	---	>8.0

*Dissolved solids x 1.60 = specific conductance (Micromhos at 25°C)
From Cushing, Kantrowitz and Taylor, 1973.

and Mount Laurel aquifers, may be considered as one hydrologic unit, although the Marshalltown probably contributes little to the available water from the entire section.

The pumpage in 1959 was reported, by Rima and others (1964), to be on the average of 460,000 gallons a day from the Englishtown-Mount Laurel aquifers. Of this amount, rural water supplies used 290,000 gallons a day; the town of Middletown used 120,000 gallons a day; and vegetable processing industries used 50,000 gallons a day. Some increase in pumpage probably has taken place since 1959, but it is believed that the increase is not large because of the minor increase in rural development since 1959.

The specific capacities of 25 wells in the Englishtown-Mount Laurel aquifers are reported by Rima. Of the 25 wells, only two have specific capacities above two gallons a minute per foot of drawdown. The specific capacities of 16 wells range between one and two gallons a minute per foot of drawdown and the remaining seven wells have specific capacities of less than one gallon a minute per foot of drawdown. The yield of the 25 wells ranged from 10 to 123 gallons a minute. Only five wells yielded 60 or more gallons a minute.

The most reliable value of transmissivity of the aquifers was determined from a pumping test at Middletown in 1961. Rima reports the transmissivity to be 1,800 gallons per day per foot and the coefficient of storage to be 0.00025. The transmissivity of the aquifers is generally very low.

Availability of Water from the Englishtown and Mount Laurel Aquifers

The availability of water in large quantities for individual supplies from the Englishtown-Mount Laurel aquifers is impracticable because the water-yielding properties of the aquifers are only fair to poor. To develop a supply of a million gallons a day would require, under favorable conditions, 10 to 15 costly and dispersed wells. On the other hand, the aquifers are important for rural supplies and small users of water in the area south of the Chesapeake and Delaware Canal southward past Middletown. Small users of water could probably withdraw a combined total of two to five million gallons throughout the area.

The Rancocas Aquifer

Location of the Rancocas Aquifer

The subcrop of the Rancocas aquifer is shown in Figure 2. The subcrop and structure of the top of the formation is shown in Figure 7. The configuration of the top and areas of use and of potential use of the Rancocas aquifer are given in Figure 22 and Table B5.

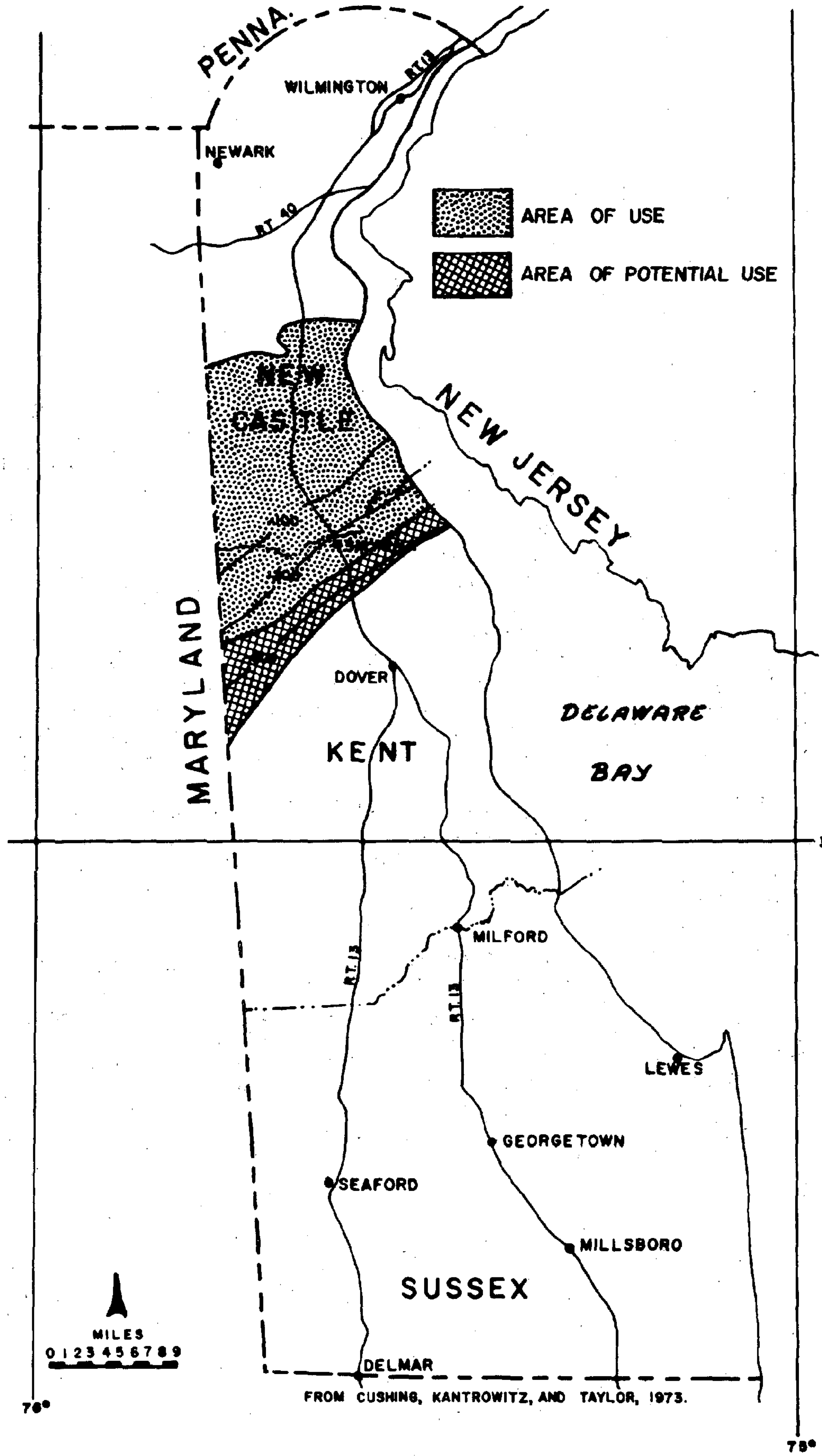


FIGURE 22 CONFIGURATION OF THE TOP AND AREAS OF USE AND OF POTENTIAL USE OF THE RANCOCAS AQUIFER.

Developed and Undeveloped Areas of the Rancocas Aquifer

The areas of use and potential use of the Rancocas aquifer are shown in Figure 22.

Hydrology of the Rancocas Aquifer

The Rancocas aquifer supplies more than 25 percent of the ground water used in New Castle County south of the Chesapeake and Delaware Canal (Rima and others, 1964). The aquifer is used for public supply at Middletown and Townsend, for supply at the Delaware State Correctional Institution near Smyrna, for industrial and commercial establishments and for much of the rural area. The Rancocas aquifer is available in the southern third of New Castle County and subcrops in the Middletown-Odessa area (see Figure 2). Water in the aquifer occurs under both water-table and artesian conditions.

The water levels in the subcrop of the Rancocas aquifer are close to those in the overlying Pleistocene water-table aquifer, discussed later. The artesian pressure is also influenced by the altitude of the water table in the subcrop. Early water-level measurements of artesian pressure in the Rancocas at Clayton, about a half-mile south of the New Castle-Kent County line, indicate that the original artesian pressure was about 25 feet above sea level.

The specific capacities of 25 wells in the Rancocas aquifer are reported by Rima and others (1964). The specific capacities ranged from 0.7 to 6.5 and averaged 2.3 gallons a minute per foot of drawdown. Sundstrom and Pickett (1968) reported specific capacities in five wells in the Rancocas aquifer in New Castle and Kent Counties as shown in Table B7.

The transmissivity of the Rancocas aquifer has been computed from pumping tests made by A. C. Schultes and Sons Well Drilling Company in three wells at the Delaware Correctional Institution about two miles north of Smyrna. The transmissivity ranges from 14,000 to 19,200 gallons per day per foot. The four determinations of transmissivity are given in Table B8. The graphic plot of pumping-test data and computation of the coefficients of transmissivity and storage in Delaware State Correctional Institutional well (Gc54-2) are given in Figure A4. The time-distance-drawdown graphs, based on the coefficients of transmissivity and storage obtained from the pumping test in well Gc54-2, are given in Figure A5.

Coefficients of storage in the Rancocas aquifer vary widely. In the subcrop area the coefficient of storage approaches the specific yield of the aquifer which may be 5 to 15 percent. In the southern part of the county, the aquifer is tightly confined and the coefficients of storage shown in Table B7 range from 0.00019 to 0.00028.

The subcrop area of the Rancocas, shown in Figure 2, is a recharge area and can be treated analytically as a recharge boundary or line source of water for the artesian part of the aquifer. Some recharge to the artesian aquifer also occurs from vertical leakage through the overlying confining beds in the extreme southern part of the county. Downdip from extreme southern New Castle County, hydraulic boundary conditions are unknown. The Rancocas loses its identity as a formation in Kent County. The relation of pumpage in the Wheatley well to water level changes in the town of Clayton well indicates there is little, if any, barrier boundary effect discernable (Sundstrom and Pickett, 1968).

The available drawdown in the subcrop area of the Rancocas is equal to the thickness of the aquifer plus the overlying saturated portion of the water-table aquifer of the Pleistocene. In the water-table part of the aquifer, it would be impracticable to use all of the available drawdown because of the diminishing yield of the well as the aquifer becomes unwatered. In the artesian part of the aquifer, the available drawdown is the distance to the top of the aquifer as shown in Figure 13 plus the altitude of the artesian pressure above sea level. The range in available drawdown in the artesian part of the aquifer is from about 50 to 250 feet, with the greatest available drawdown in the extreme southern part of the county. In the subcrop area of the Rancocas the water-table aquifer is discussed in conjunction with the overlying water-table aquifer of the Pleistocene.

Availability of Water from the Rancocas Aquifer

The Rancocas aquifer is an important source of small supplies of water throughout the area in which the aquifer exists in southern New Castle County. It is important as a source of water to wells yielding 300 or more gallons a minute in the artesian part of the aquifer only in the area east and northeast of Smyrna. The limited capacity of wells is attributed largely to the low specific capacity of wells and to the limited available drawdown. Some evidence is available at Clayton (Wheatley well) and at the Delaware Correctional Institution well, Gc54-2, that specific capacities in the Rancocas wells might be improved considerably by using more screen, large well-type construction and better development of wells. If specific capacities of wells could be improved, much more water could be obtained with the limited available drawdown that exists.

In appraising the availability of water from the Rancocas in Kent County, Sundstrom (1968) points out that the ultimate amount of water available from the aquifer depends upon the plan for total development. He demonstrated the feasibility of a line of seven wells, 5,000 feet apart, pumping 300 to 350 gallons a minute and yielding a total of 3.3 million gallons a day (Table B9). If the more favorable specific capacities of the Wheatley well (4.6 gallons a minute per foot of drawdown) and of the Delaware Correctional Institution well (3.4 gallons a minute per foot of drawdown) could be developed at all hypothetical wells, then it would be possible to readjust the pumpage slightly and develop about six million gallons a day from a string of wells pumping from the deeper part of the Rancocas aquifer across part of Kent and New Castle Counties. The ultimate yield of the Rancocas aquifer in the two counties is predicated on proper spacing and rate of pumping. If wells yielding 300 or more gallons a minute are used, the six million gallons a day indicated is probably the maximum rate for the aquifer in the two counties. If smaller wells are used, more water can be obtained.

Quality of Water in the Rancocas Aquifer

The areas of similar chemical quality of ground water and area of potential salt-water intrusion in the Rancocas aquifer are shown in Figure 23. The chemical constituents in ground water in the Rancocas aquifer in milligrams per liter are given in Table 12.

Salt-Water Problems in the Rancocas Aquifer

The Delaware Bay extends 48 miles from the Atlantic Ocean to Liston Point, Delaware. The estuary of the river then continues upstream 86 more miles to Trenton, New Jersey. Above Trenton, the river ceases to be tidal. At the beginning of the estuary at Trenton, the stream contains fresh water and the river's estuary remains relatively uncontaminated by salt water for many miles downstream from Trenton. At Memorial Bridge near Wilmington during periods of low river flow and high tide from the bay, chlorides are often above 1,000 parts per million and on occasions reach 1,700 or more parts per million. Downstream from Memorial Bridge about twelve and one-half miles at Reedy Island Jetty, Delaware, and about nine and one-half miles above the beginning of Kent County, the chlorides during similar periods will reach more than 6,000 parts per million. During these periods of high chloride, the low for the day may be no more than 2,000 parts per million below the daily high. All of Kent County is bounded on the east by the middle and lower part of the Delaware Bay, wherein the lower part of the chloride concentration approaches that of the ocean.

The Rancocas aquifer outcrops in New Castle County adjacent to the Delaware River Estuary from a point opposite Reedy Island southward to the mouth of Blackbird Creek, an airline distance of about seven miles (see Rima, et al, 1964). These outcrop extremities lie 5 to 10 miles north of Kent County. In discussing the possibility of brackish water encroachment from the estuary to the fresh-water aquifers in southern New Castle County, Rima, et al, 1964, have this to say:

> "At the time of this investigation in 1962, no evidence was found of the encroachment of brackish water into fresh-water aquifers in southern New Castle County from either the Delaware estuary or the Chesapeake and Delaware Canal. Nonetheless, the

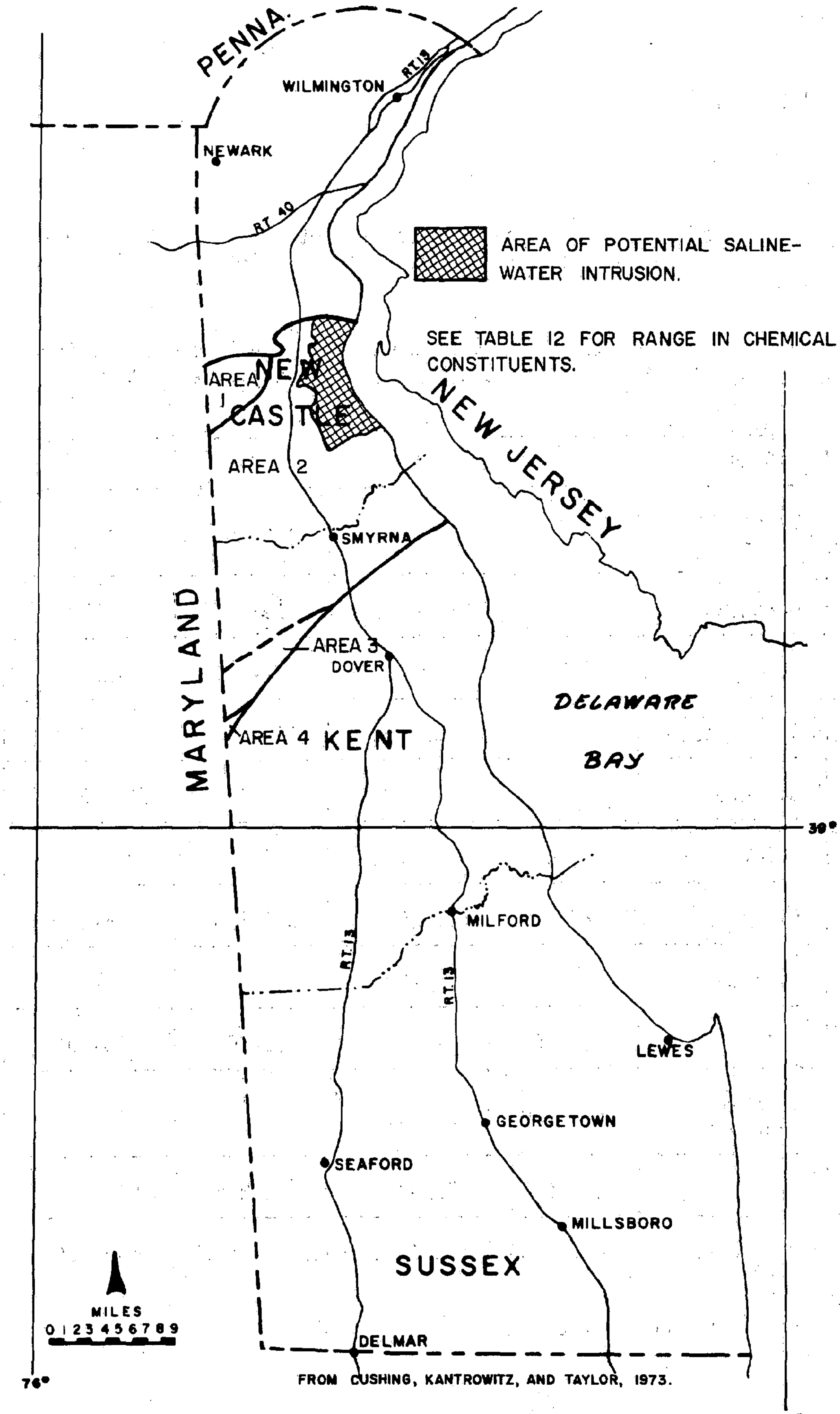


FIGURE 23 AREAS OF SIMILAR CHEMICAL QUALITY OF GROUND WATER AND AREA OF POTENTIAL SALINE-WATER INTRUSION IN THE RANCOCAS AQUIFER.

Table 12.

Quality of Ground Water and Area of Potential Saline-Water Intrusion in the Rancocas Aquifer, as Shown in Figure 23

Chemical constituents in ground water in the Rancocas aquifer (concentration of constituents in milligrams per liter)

Area	1	2	3	4
Dissolved solids*	<100	100-250	250-500	>500
Hardness	<50	50-155	30-170	<30
Sodium	<10	2-70	40-150	>200
Bicarbonate	<50	50-200	200-500	>500
Sulfate	0-20	0-15	0-12	10-15
Chloride	<10	<10	4-55	<15
Fluoride	<0.3	0.1-0.9	0.2-2.0	3.5-4.2
Nitrate	0.1-12	0.1-30	<2	<1
Silica	10-25	10-40	10-20	10-20
Iron and manganese	0.1-3.0	0.1-6.0	<0.5	<0.5
pH	5.6-6.8	7.2-7.9	7.8-8.5	8.1-8.4

*Dissolved solids x 1.55 = specific conductance (Micromhos at 25°C)

From Cushing, Kantrowitz and Taylor, 1973.

presence of bodies of brackish water along the northern and eastern borders of the area should be considered as potential threats to the future development of aquifers in southern New Castle County.

"The most likely places for encroachment to occur are near the suboutcrops of the principal aquifers beneath the Delaware estuary and the Chesapeake and Delaware Canal. The suboutcrops beneath the canal are covered by not more than a few feet of silt of low permeability. The suboutcrops beneath the estuary, however, are somewhat better insulated from the brackish water by the presence of thick alluvial muds, which line the channel of the estuary. As these muds are considerably less permeable than the aquifers, some protection from encroachment is afforded the adjacent aquifers. Nevertheless, movement of water from the estuary into the fresh-water aquifers will occur if the natural hydraulic gradient is reversed by pumping from the aquifer. Consequently, much care should be exercised in developing large ground-water supplies close to the estuary."

A well to the Rancocas aquifer about two miles north of Smyrna yields water of only one part per million of chloride. The well is owned by the Delaware Correctional Institution and was drilled in 1967. However, three wells east (Woodland Beach) and southeast of Smyrna yield and are reported to yield brackish water. These wells are reported to be drilled to a depth of about 270 feet and only cased to a depth of 170 feet. The wells have been reported to draw water from the Rancocas. Considering the depth of the casing and the position of the Rancocas, it appears doubtful that the wells obtain water from the Rancocas.

Most of the Rancocas aquifer available for development in Kent County lies west and southwest of Smyrna and is 10 to 22 miles remote from the nearest point the Rancocas outcrops or passes under the valley fill of the Delaware Estuary. The remote position of the estuary from the most usable part of the aquifer in Kent County precludes any problem of salt-water contamination in the Rancocas aquifer in the county.

The Piney Point Aquifer

Location of the Piney Point Aquifer

A structural map of the Piney Point Formation is shown in Figure 8. The Piney Point aquifer in Delaware is a segment of an extensive hydrologic unit that has continuity from the Atlantic Coast between the Atlantic City area and Cape May and extends southwesterly, veering more to the south as progression goes southwestward and southward to the other known extremity of the aquifer in Virginia. Thus, the aquifer is known to extend from the Atlantic Coast in

New Jersey, through parts of Kent and Sussex Counties, Delaware, across the eastern shore of parts of Maryland to the Potomac River in the vicinity of Piney Point, where the aquifer gets its name, and beyond into Northcumberland and Westmoreland Counties, Virginia (Otton and Heidel, 1966). The aquifer is unusual in that it has no outcrop. E. G. Otton (1955) in discussing the Piney Point, reveals that the Piney Point has not been recognized in surface exposure and has not been known to lie above an altitude of 75 to 80 feet below sea level. In Kent County the top of the Piney Point ceases about 200 feet below sea level.

Areas of Development and Potential Development of the Piney Point Aquifer

Configuration of the top and areas of use and of potential use of the Piney Point aquifer are shown in Figure 24.

Hydrology of the Piney Point Aquifer

The ground-water hydrology of the Piney Point aquifer has been reported and analyzed in considerable detail, especially as the hydrology applies to the Dover area, by Sundstrom and Pickett, 1968. The original artesian pressure in the Piney Point aquifer is not precisely known. The annual report of the New Jersey State Geologist for 1899 reports a well to the Piney Point aquifer in Kent County, Delaware, at the mouth of the Mahon River. The well was drilled in 1897 and the water rose 16 feet above tide or about 20 feet above sea level. A test well drilled to the Piney Point at Milford in 1938 is reported by Marine and Rasmussen, 1955, to have had artesian pressure 17 feet above mean sea level.

The specific capacities of 12 wells drawing water from the Piney Point are given in Table B10. The specific capacities range from 0.3 to 14.6 gallons a minute per foot of drawdown. Two of the specific capacities listed are less than unity and represent one well that is near the downdip extremity of the aquifer at Milford. Eliminating these two observations of specific capacity, the remaining 10 wells have specific capacities ranging from 2.7 to 14.6 and averaging 6.6 gallons a minute per foot of drawdown. Specific capacities averaging as low as 6.6 indicate only moderate water-yielding properties of the aquifer. The relatively low specific capacities also make necessary high pumping lifts to pump substantial quantities of water. Low specific capacities also affect the allowable rate of pumping. Assuming that a well has been properly designed, properly constructed and properly developed, the specific capacities give clues not only to the amount of water that can be developed from the well, but also to the hydrology of the ground-water reservoir from which the well obtains water. If a well meets all of the criteria of good design, construction and development and is highly efficient when pumped, then there is a definite relation of well diameter, specific capacity

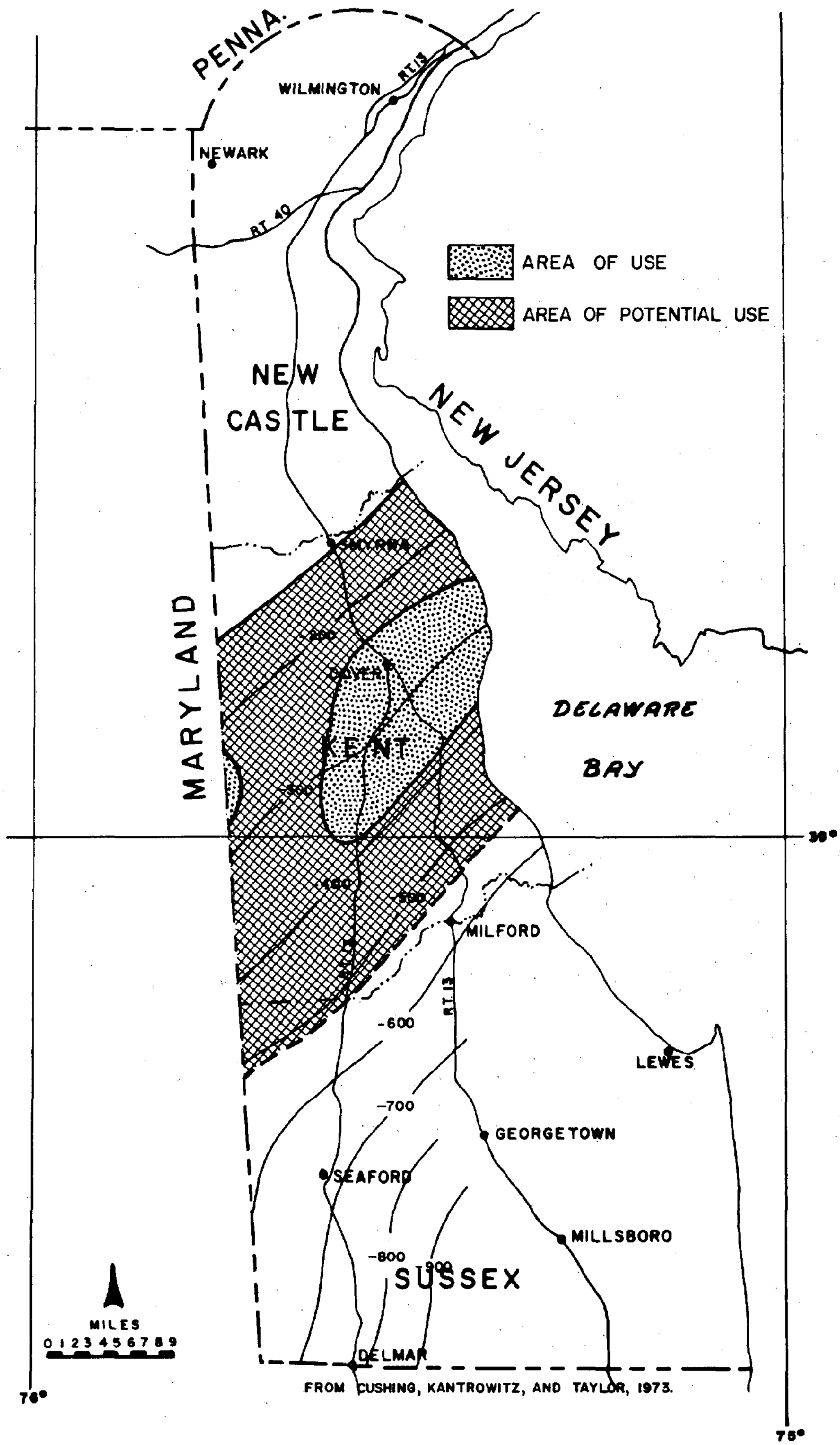


FIGURE 24 CONFIGURATION OF THE TOP AND AREAS OF USE AND OF POTENTIAL USE OF THE PINEY POINT AQUIFER.

of the well and the coefficients of transmissivity and storage in the aquifer. This relationship has been illustrated graphically by Meyer (1963) and is shown in Figure A6.

The transmissive properties of the Piney Point aquifer have been computed from pumping tests in wells in Kent County made by the Layne-New York Company, Shannahan Artesian Well Company, A. C. Schultes and Sons Drilling Company and R. D. Varrin, Director of the Water Resources Center of the University of Delaware. One pumping test made in a well to the Piney Point in Cambridge, Maryland, by R. H. Brown and T. H. Slaughter is included in this report. The coefficients of transmissivity determined by 13 computations from pumping test data from eight wells ranged from 6,000 to 41,000 gallons a day per foot in Kent County and from 42,500 to 47,500 gallons a day per foot in the well at Cambridge, Maryland. Non-leaky drawdown curves for six Piney Point wells are given in Sundstrom and Pickett, 1968. In the thicker part of the Piney Point aquifer (see thickness map, Figure 6 in the 1968 report), extending from Port Mahon almost true southwest to the state line, five wells, zero to three and one-half miles off this line, and extending a distance 10 miles southwestward from the Dover Air Force Base, have coefficients of transmissivity ranging from 21,000 to 39,000 gallons a day per foot. The average of the five coefficients of transmissivity is 31,800 gallons a day per foot. The low coefficients of transmissivity were found in two wells about five miles updip and the third about three miles updip from the thick axis of the aquifer. Coefficients of transmissivity determined from pumping tests are given in Tables B11 and B12.

Two coefficients of storage for the Piney Point aquifer are available. One at the Dover Air Force Base was computed from a pumping test in which the water levels in well Je32-4 were observed while well Je32-5 was pumping. The other coefficient of storage was determined at Cambridge, Maryland, in well DorCe4 while well DorCe2 was pumping. The two locations are about 50 miles apart, but the two determinations are almost identical. At the Dover Air Force Base, R. D. Varrin determined the coefficient of storage to be 0.0003. R. H. Brown and T. H. Slaughter of the U. S. Geological Survey determined the coefficient of storage at Cambridge to be 0.00036. The coefficient of storage for the Piney Point used in this report is 0.0003. The low coefficient indicates a relatively non-leaky type artesian reservoir.

Sundstrom and Pickett, 1968, devote much discussion to the determination of the aquifer coefficients and the relation of the computed coefficients to the actual drawdowns that have been observed. The entire hydrology section of the 1968 report should be studied as a supplement to this report.

Available Water from the Piney Point Aquifer

The quantity of water available from the Piney Point aquifer in Kent County is controlled by the geologic and hydraulic characteristics of the aquifer and also by the location of the downdip extremity by the fresh-salt water interface in the aquifer. The data available from the wells drilled into the Piney Point show the aquifer has fairly good water-yielding properties near and in the thickest part of the aquifer and poor water-yielding properties toward each flank of the aquifer. The axis of the best part of the aquifer would extend in an almost true north-east-southwest line across Kent County passing through the Dover Air Force Base well Je32-5. The distance across Kent County on this line is about 21 miles. Several patterns of hypothetical wells in lines varying from one to three were laid out and tested for feasibility and to ascertain the probable yield of the Piney Point aquifer. Two feasible patterns of hypothetical wells, the allowable rate of pumping from each well, and the computed drawdown in each well are given in Tables 18 and 19 in the report by Sundstrom and Pickett (1968).

In the hypothetical plan given in Table 18, the pumpage would be limited to 500 and 600 gallons a minute from the 22 wells, and the combined yield would be 17 million gallons a day. The aquifer is approaching full development in parts of the Dover and Dover Air Force Base area.

Quality of Water in the Piney Point Aquifer

Areas of similar chemical quality of ground water in the Piney Point aquifer are given in Figure 25. The chemical constituents in ground water in the Piney Point aquifer in milligrams per liter are given in Table 13.

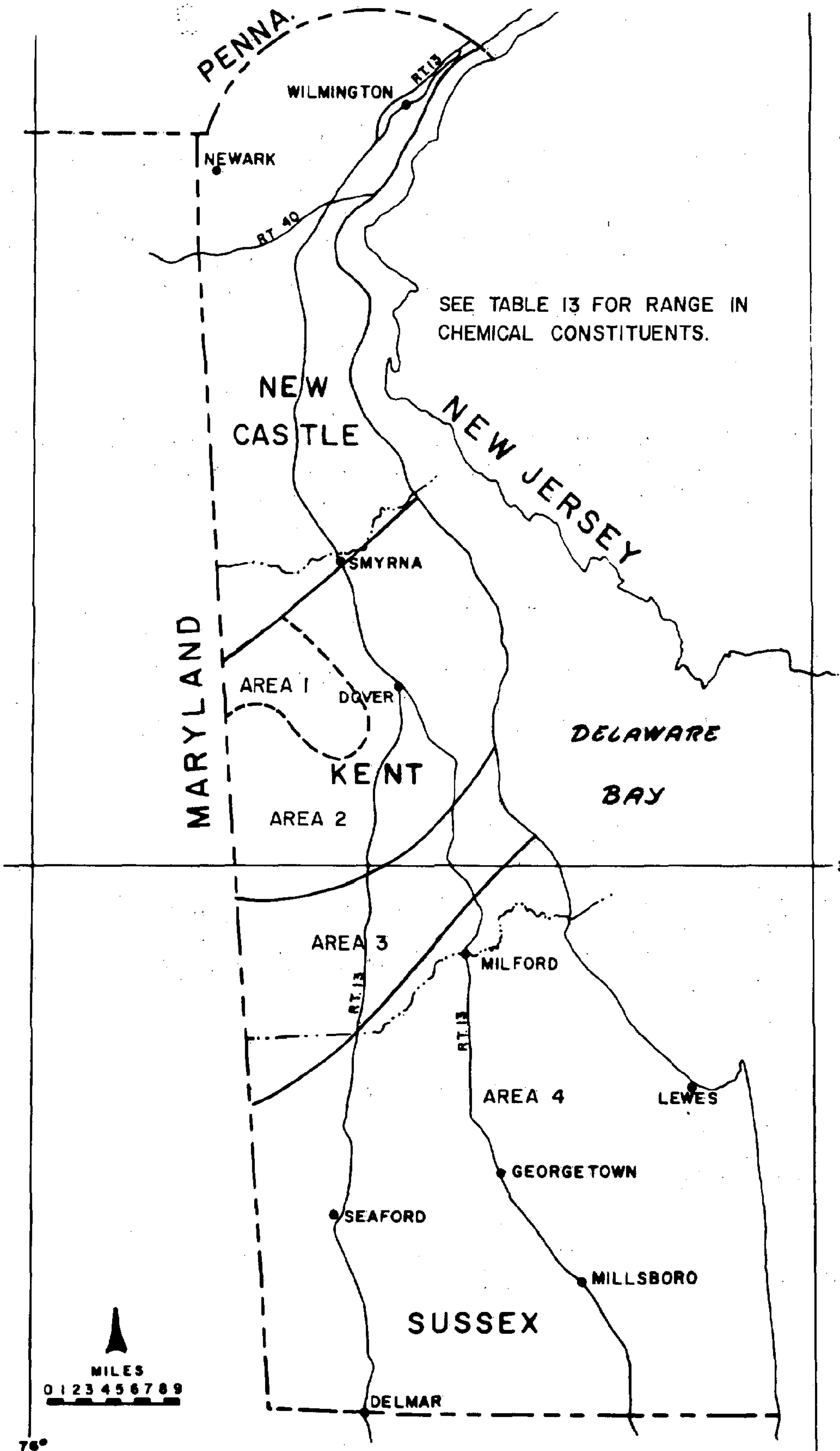
Salt-Water Problems in the Piney Point Aquifer

There are no known or anticipated salt-water problems in the Piney Point aquifer in Delaware. The aquifer lies about 200 feet beneath Delaware Bay. The aquifer becomes less transmissive downdip before the fresh-salt water interface is encountered.

The Cheswold Aquifer

Location of the Cheswold Aquifer

The subcrop area of the Cheswold in Delaware is shown in Figure 2. The configuration on the top of the Cheswold is shown in Figure 26.



FROM CUSHING, KANTROWITZ, AND TAYLOR, 1973

FIGURE 25 AREAS OF SIMILAR CHEMICAL QUALITY OF GROUND WATER IN THE PINEY POINT AQUIFER.

Table 13.

Quality of Ground Water in the Piney Point Aquifer,
as Shown in Figure 25

Chemical constituents in ground water in the Piney Point aquifer (concentration of constituents in milligrams per liter)

Area	1	2	3	4
Dissolved solids*	200-250	250-500	500-1000	>1000
Hardness	90-200	20-90	15-45	>30
Sodium	4-30	30-190	190-500	>500
Bicarbonate	170-250	200-500	400-800	>600
Sulfate	3-15	3-20	7-100	>100
Chloride	1-7	1-25	3-200	>200
Fluoride	<0.4	0.4-1.6	1.4-2.3	0.7-2.0
Nitrate	<2	<2	<2	<3
Silica	45-60	10-45	15-30	10-45
Iron and manganese	0.1-1.5	0.0-0.4	0.0-0.5	>1.0
pH	7.7-7.9	7.9-8.6	7.8-8.5	7.8-8.9

*In area 1, dissolved solids x 1.40 = specific conductance (Micromhos at 25°C)
In areas 2, 3, and 4, dissolved solids x 1.55 = specific conductance

From Cushing, Kantrowitz and Taylor, 1973.

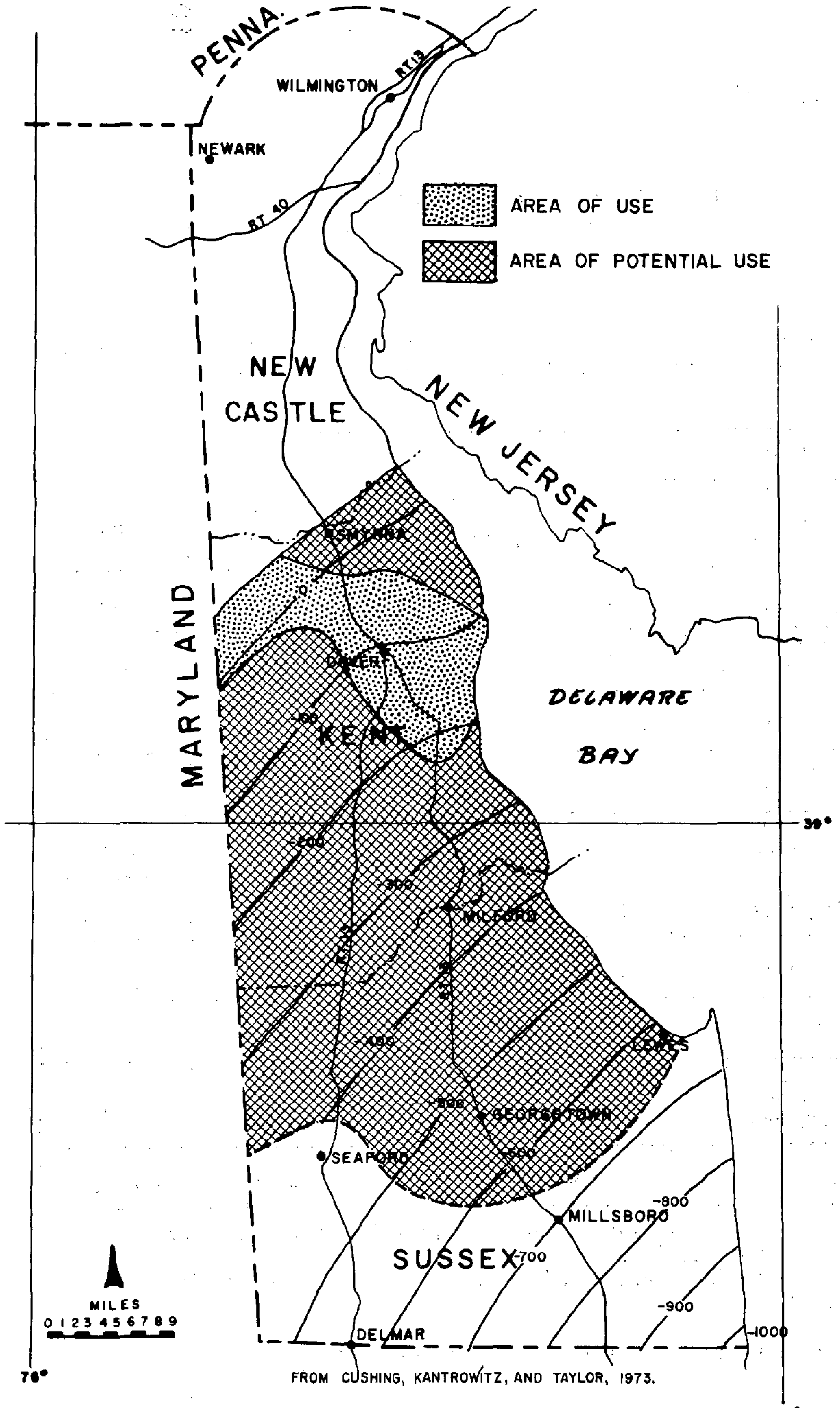


FIGURE 26 CONFIGURATION OF THE TOP AND AREAS OF USE AND OF POTENTIAL USE OF THE CHESWOLD AQUIFER.

Development of the Cheswold Aquifer

The area in which the Cheswold aquifer has been developed is shown in Figure 26. Sundstrom (1968) reports that the Cheswold aquifer was producing 30 percent of all of the ground water used in Kent County and most of the water was used in the Dover-Dover Air Force Base area. The Cheswold is a good aquifer in the Dover area and is developed to its capacity. Elsewhere northwest, west and south of the area, the Cheswold aquifer is only fair to poor in water-yielding properties.

Undeveloped Areas of the Cheswold Aquifer

The undeveloped areas of the Cheswold aquifer are shown in Figure 26. As noted above, much of these areas are underlain by a Cheswold aquifer of poor water-yielding potential, but useful for local rural and domestic supply.

Hydrology of the Cheswold Aquifer

According to a report by Woolman, State Geologist of New Jersey, 1899, the original artesian pressure in the first well drilled to the Cheswold aquifer in Dover was 12 feet above sea level in 1893. Prior to 1893, Woolman reports that Dover obtained its water supply from a four-inch well that terminated in a sand a few feet above the sands to which the new well was drilled. The static water level reported is eight feet less than the original static water level reported for the Piney Point.

Pumpage from the Cheswold aquifer has been continuous for 75 years or more at a rate that has grown from a flowing well of 36 gallons a minute in 1893 to a complex of pumped wells that now produce an average of more than five million gallons a day in the county. The one hundredfold increase in the rate of pumping has caused the artesian pressure to decline sharply. The artesian pressure has been observed daily in all of the wells at the Dover Air Force Base, weekly in the City of Dover wells, and in an unused well about midway between Dover and the Air Force Base. The record shows that the average high water level for July, 1965, was 97 feet below land surface or 67 feet below mean sea level at unused well Jd52-1 and is the recorded monthly low for the period of record. The average pumpage of the City of Dover and the Air Force Base totaled 4,600,000 gallons daily for the month of June of the same year.

The specific capacities of 14 wells drawing water from the Cheswold aquifer are given in Table B10. The specific capacities range from 0.9 to 25.4 gallons a minute per foot of drawdown. The average specific capacity of the 14 wells is 11.2 gallons a minute per foot of drawdown. Only four of the 14 wells for which specific capacities have been determined are located outside the Dover-Dover Air Force Base area. The specific capacities of the four wells range from 0.9 to 7.6 and average 4.7 gallons a minute per foot of drawdown. Most of the wells to the Cheswold aquifer to the northwest, west and south of the Dover-Dover Air Force Base area are believed to have low specific capacities, evidenced by their moderate to low yield.

The transmissive properties of the Cheswold aquifer have been computed from pumping tests made by Jack R. Woods, Superintendent of Public Works, City of Dover; Shannahan Artesian Well Company; and R. W. Sundstrom of the Water Resources Center, University of Delaware. The coefficients of transmissivity determined by seven computations from pumping test data from six wells ranged from 11,200 to 32,800 gallons a day per foot. The average coefficient of transmissivity is 18,300 gallons a day per foot.

Two coefficients of storage for the Cheswold aquifer have been computed from pumping tests conducted by the Shannahan Artesian Well Company and by R. W. Sundstrom in two wells. Both wells are owned by the City of Dover, one at the East Dover Elementary School and one at the Danner Farm well site. The coefficients of storage in both wells indicate artesian conditions. The coefficient of storage at the East Dover Elementary School is 20 times higher than that at the Danner Farm well, although both are low. The coefficient of storage at the East Dover Elementary School is 0.0062 and at the Danner Farm test well 0.00031.

The outcrop of the Cheswold aquifer in the northern part of Kent County is sufficiently close to the pumping in the Dover-Dover Air Force Base area so that its favorable recharge image effect on the pumping levels in the wells is substantial and must be taken into account in computing the mutual interference between wells. Likewise, in any other part of the northern half of the county the recharge boundary effect will be favorable to the computed drawdowns.

The transmissive properties of the Cheswold vary greatly from place to place. Northwest, west and south of the Dover-Dover Air Force Base area, the water-yielding properties of the Cheswold are not conducive to large yielding wells. No wells in this area are known to yield more than 300 gallons a minute, some are in the 100 to 200 gallons a minute range, many are in the 100 gallons a minute or less range, and in some localities, the Cheswold does not yield a satisfactory supply. Although the Cheswold has poor water-yielding properties in such places, it is believed that the continuity of the aquifer is such that no barrier boundaries of substantial magnitude exist.

The available drawdown at the time pumping began in the Cheswold aquifer ranged from no drawdown at 12 feet above sea level in the northwestern part of the county in the outcrop area to about 360 feet below sea level downdip at Milford. At Dover and at Milford the development of the Cheswold has been so intensive that the pumpage during peak demands in 1965, 1966 and 1967 has caused the drawdown to reach the top of the aquifer in four of the seven wells of the City of Dover and in one well in Milford. Table B13 lists the lowest pumping levels and the dates they occurred in the City of Dover wells along with the remaining available drawdown. The low drawdowns occurred during periods when the pumpage in the Dover area from the Cheswold aquifer averaged about 6,500,000 gallons daily. Additional draft on the Cheswold will necessitate adjustment in the rate of pumping of some of the Dover City wells.

Available Water from the Aquifer and Limits of Development

Sundstrom and Pickett (1968) wrote about the City of Dover wells to the Cheswold aquifer as follows:

> "The available drawdown in the Cheswold aquifer has been exceeded in four of the seven City of Dover wells during periods of heavy draft of about 6,500,000 gallons a day in 1965, 1966 and 1967. Without readjustment of the rate of pumping in the over-pumped wells, it appears that additional draft cannot be made on the Cheswold and still supply the peak demand at Dover. On the other hand, with readjustment of the pumpage from some of the city wells, it might be possible to maintain pumping operations at the present average daily pumpage of about 5,500,000 gallons daily and allow a planned distribution of pumpage in other parts of the county to about eight million gallons daily from the Cheswold aquifer. The present maximum rate of pumping in the Dover area of 6,500,000 gallons daily and the excessive drawdown in four of the city wells does not allow additional draft from the Cheswold without altering the rate of pumping from at least four of the city wells."

Michael Apgar of the Delaware Department of Natural Resources and Environmental Control reports that this has already been done (personal communication).

Quality of Water in the Cheswold Aquifer

Areas of similar chemical quality of ground water and the area of potential salt-water intrusion into the Cheswold aquifer are shown in Figure 27. The chemical constituents in the ground water in the Cheswold aquifer in milligrams per liter are given in Table 14.

Salt-Water Problems in the Cheswold Aquifer

Salt-water problems may arise in the subcrop area of the Cheswold aquifer where the subcrop and overlying Quaternary deposits are in contact with the

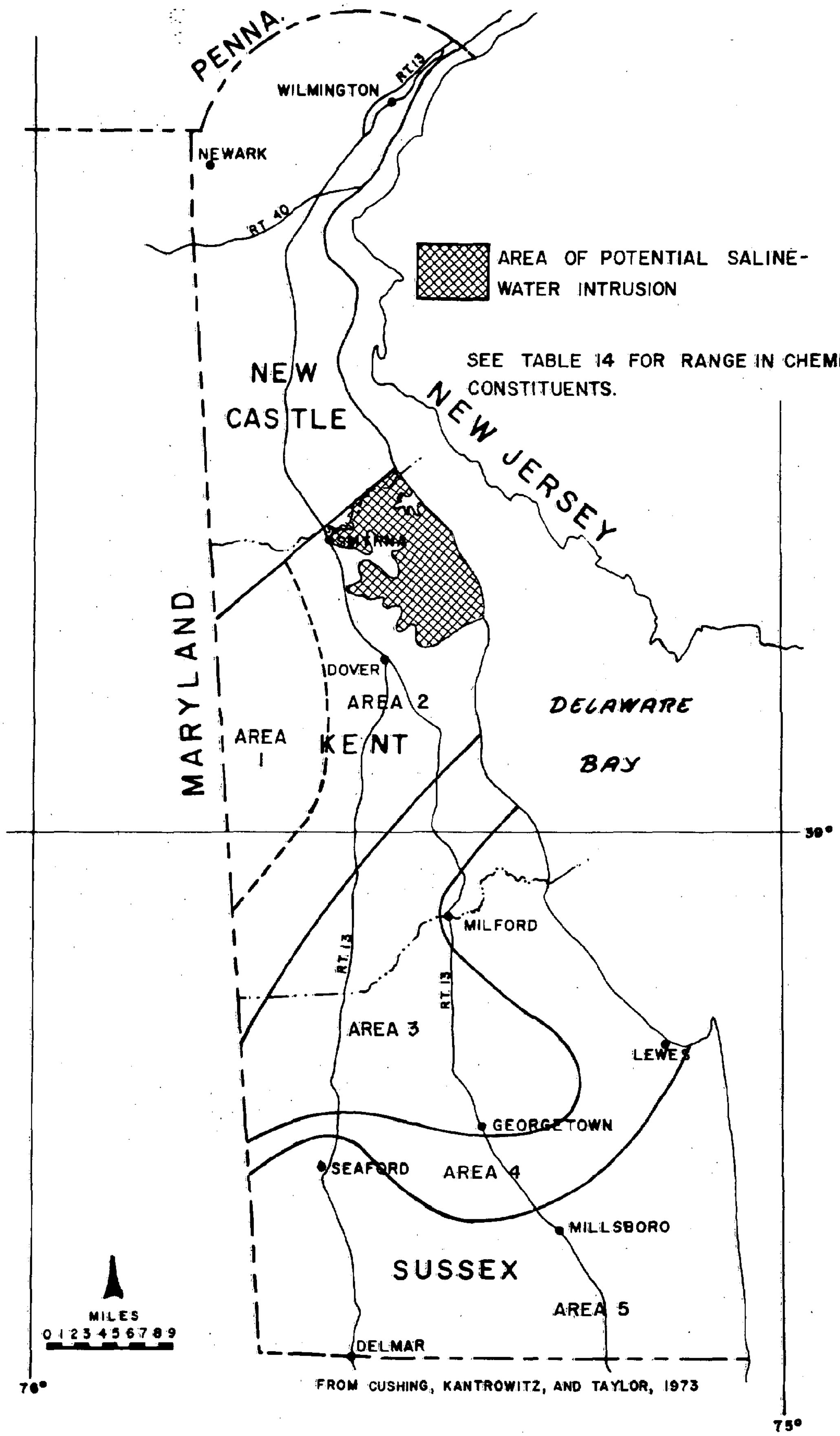


FIGURE 27 AREAS OF SIMILAR CHEMICAL QUALITY OF GROUND WATER AND AREA OF POTENTIAL SALINE-WATER INTRUSION IN THE CHESWOLD AQUIFER.

Table 14.

Quality of Ground Water and Area of Potential Saline-Water Intrusion in the Cheswold Aquifer, as Shown in Figure 27

Chemical constituents in ground water in the Cheswold aquifer (concentration of constituents in milligrams per liter)

Area	1	2	3	4	5
Dissolved solids*	<100	100-250	250-500	500-1000	>1000
Hardness	<75	75-100	20-100	<40	---
Sodium	<5	5-30	30-150	150-200	>200
Bicarbonate	<50	50-200	200-400	>400	>450
Sulfate	---	5-20	2-10	>10	---
Chloride	---	1-5	2-10	10-100	>100
Fluoride	---	0-0.5	0.2-0.5	>0.3	---
Nitrate	---	0-8	<1	<1	<1
Silica	---	30-60	50-60	50-60	---
Iron and manganese	---	0.02-0.6	0.15-0.75	---	---
pH	---	7.0-8.3	7.0-8.5	>8.5	---

*In areas 1, 2, and 3, dissolved solids x 1.36 = specific conductance (Micromhos at 25°C)
In areas 4 and 5, dissolved solids x 1.59 = specific conductance

From Cushing, Kantrowitz and Taylor, 1973.

marshland containing tidal salty water. The area needs considerably more observation and study to define positively the conditions of and prospects of salt-water encroachment in and from the subcrop area.

The Federalsburg Aquifer

In 1969, Sundstrom wrote on the hydrology of the Miocene aquifer above the Cheswold, which was recognized in electric logs of wells at Dover and Milford, Delaware. Cushing, et al, (1973) observed the hydrology of the aquifer in nearby Federalsburg, Maryland, and named the aquifer the Federalsburg in U. S. Geological Survey Professional Paper 822.

Location of the Federalsburg Aquifer

The configuration of the top of the Federalsburg aquifer is shown in Figure 28, as defined by Cushing, et al, (1973).

Development of the Federalsburg Aquifer

The Federalsburg aquifer has been developed in the Dover and Milford areas in Delaware. The areas of development are shown in Figure 28.

Undeveloped Areas of the Federalsburg Aquifer

The undeveloped area of the Federalsburg aquifer in Delaware is shown in Figure 28.

Hydrology of the Federalsburg Aquifer

A Miocene aquifer above the Cheswold is shown on the electric log of Me15-29. The electric log shows the aquifer from a depth of 276 feet to 358 feet with intervening clayey sections. The sands total about 62 feet in thickness with the best half of the sand sections at the top between depths of 276 and 314 feet. The aquifer appears to be separated from the Cheswold in test well Me15-29 by a dense clay 20 feet thick lying 420 to 440 feet below the surface and by a clay of lesser density (more sandy) 10 feet thick lying

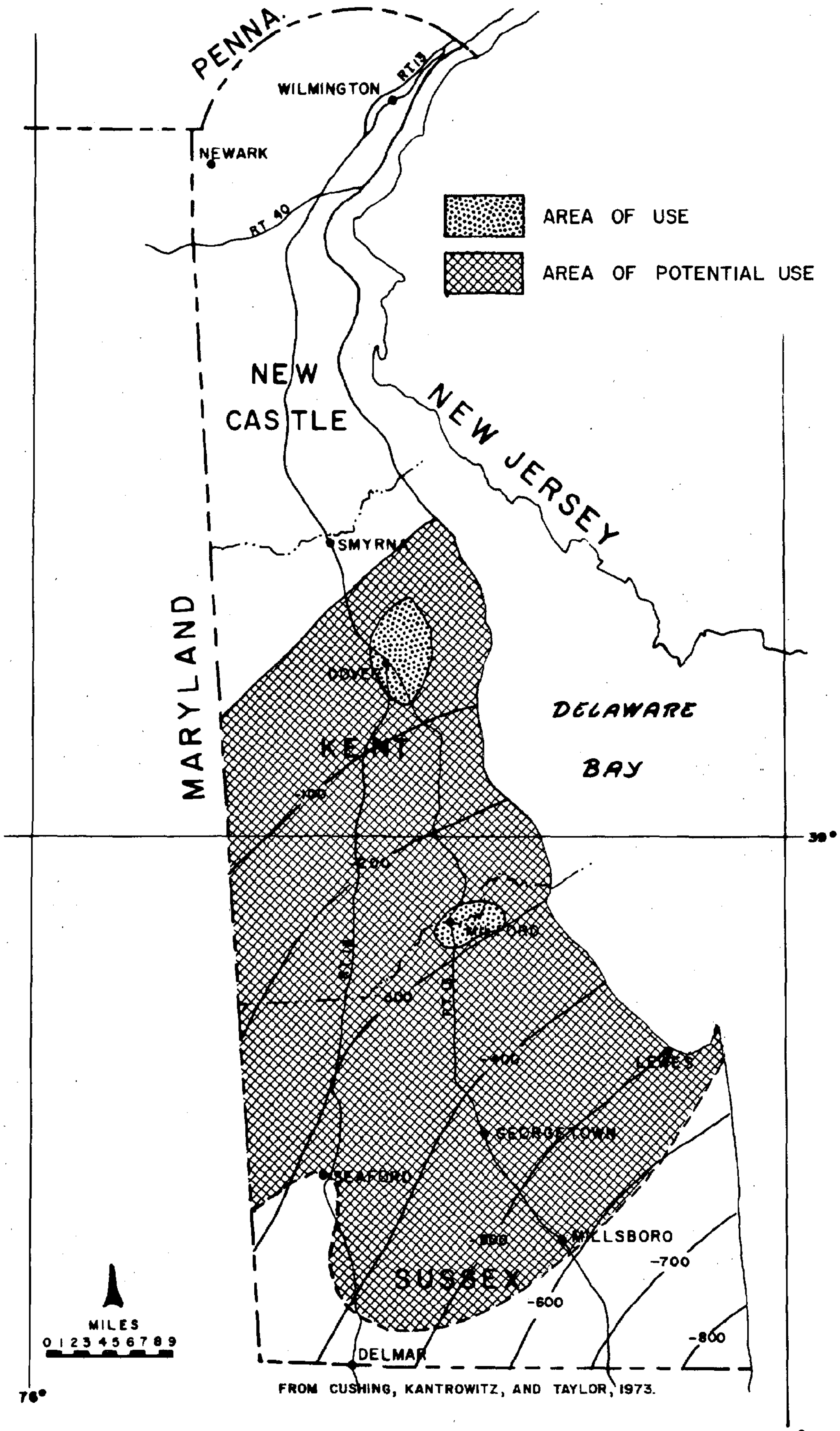


FIGURE 28 CONFIGURATION OF THE TOP AND AREAS OF USE AND OF POTENTIAL USE OF THE FEDERALSBURG AQUIFER.

between 466 to 476 feet below the surface. The aquifer is separated from the overlying Frederica aquifer by 46 feet of clay 228 to 274 feet below the surface. The electric log of test well Og31-1 at Gravel Hill about 15 miles south-southeast of Me15-29 suggests the continuity of the aquifer from Milford and places it 518 to 586 feet below the land surface.

The original artesian pressure in the Miocene aquifer between the Cheswold and Frederica aquifers is unknown. It probably was about the same as that in the Cheswold aquifer, which has been estimated to have been between 16 and 20 feet above mean sea level. In August 1952, the Layne-New York Company recorded the static water level in city well Le55-5 as 17 feet below land surface or about three feet above sea level. This measurement was made before an eight-hour acceptance test and is believed to be low because of pumpage for well development before the acceptance test took place. Darton (1896) reports the artesian pressure in a Frederica aquifer well at Milford 14 feet above sea level. It is possible that the measurement was taken after the well had flowed for a short period of time. Meager data on the fresh-salt water interface in the Miocene aquifers below and including the Frederica aquifer suggest the original artesian pressure was equal to or slightly greater than 18 feet above mean sea level, but less than 20 feet above mean sea level.

The first pumpage of any magnitude began in 1952 when the City of Milford began using well Le55-5 in Kent County north of the Kent-Sussex County line. The well was initially tested at 500 gallons a minute. During the year of 1955, the average daily pumpage amounted to 248,000 gallons. In 1956 the average increased to 312,000 gallons a day. For the four-year period, 1958 through 1961, the pumpage averaged 260,000 gallons a day. The present rate of pumping is estimated at about 300 gallons a minute or about 400,000 gallons a day.

Water-level measurements have not been made to determine the decline in artesian pressure in the aquifer. The theoretical decline that should take place at any time after pumping began at any place on the piezometric surface can be computed by using the time-distance-drawdown graphs referred to later in this section.

The specific capacity of well Le55-5 at Milford was computed from an eight-hour test on August 26, 1953. The specific capacity of the well was four gallons a minute per foot of drawdown at the end of the test. Both major sand sections were screened in the well and the well was gravel packed throughout the aquifer. It is believed that the specific capacity probably represents a maximum for the aquifer. The well is about nine times more productive than a test well at the Torsch Canning Company, where only the upper section of the aquifer is believed to have been tested. The Torsch test well yielded only 55 gallons a minute. Another test in the Milford area reports 100 gallons a minute with a drawdown of 77 feet indicating a specific capacity of 1.3 gallons a minute per foot of drawdown. No tests of the specific capacity of the aquifer are known outside of the Milford area.

Specific capacities of wells in Sussex County and the surrounding area are given in Tables B14 and B15. The tables show that wells drawing water from the water-table aquifer of the Pleistocene or the Pleistocene and subcropping Miocene sands have the higher specific capacities. Of the 42 wells listed, three wells had specific capacities of 40 or more gallons a minute per foot of drawdown, one well had a specific capacity of 34.5 gallons a minute per foot of drawdown, six wells ranged between 30 and 20 gallons per minute per foot of drawdown. All wells except one (10.6 gpm/ft) that had specific capacities of more than 10 gallons a minute per foot of drawdown obtained water from the water-table aquifer. The 20 wells listed in Table B14 of low specific capacity, with three exceptions, draw water from the artesian aquifers of Miocene and Eocene age. The three exceptions are believed to be poorly constructed wells in the Pleistocene. The 17 wells, except two, drawing water from the artesian aquifers, had specific capacities of less than five gallons a minute per foot of drawdown.

The specific capacity of a well not only controls the amount of water that can be developed from a well, but also affects the amount of power required to pump a given quantity of water. Wells with very low specific capacities are therefore costly to pump. The overall evaluation of the aquifers based on specific capacities clearly demonstrates that the water-bearing properties of the Pleistocene and subcropping Miocene are good to excellent, whereas, the specific capacities of the wells in the artesian aquifers show the water-bearing properties to range from very poor to only fair, except in the Manokin aquifer when the water-bearing properties are usually good.

Pumping Tests to Determine Transmissivity and Coefficients of Storage

Pumping tests made in areas surrounding western Sussex County have been used to determine the coefficients of transmissivity and storage in the artesian and water-table aquifers of western Sussex County. The coefficients of transmissivity and storage coupled with other hydraulic characteristics of the aquifers have been used to appraise the available water from the artesian aquifers. The water-table aquifer of the Pleistocene and the Pleistocene and subcropping Miocene sands have been appraised by other methods of applied hydrology, and are partially supported by the results of pumping tests. The coefficients of transmissivity and storage determined from pumping tests in Sussex County and surrounding area are given in Table B16. Some of the computations of transmissivity and storage were computed from pumping tests made for purposes of acceptance of the well, and in some instances, lack the refinement desired. On the whole, it is believed that the data given for transmissivity and coefficients of storage in Table B16 are in the right order of magnitude and serve reasonably well for quantitative computations that follow in later sections of this report.

The transmissivity of the aquifer has been computed from the pumping test made in well Le55-5 by the Layne-New York Company on March 30, 1962. The graphic plot of the pumping test data and the computation of the coefficient of transmissivity are given in Figure A7. The results of the computation give a low transmissivity of 9,400 gallons per day per foot. The low transmissivity indicated an aquifer of only fair to low water-yielding properties. Based on examination of the electric logs and on inspection of the drill cuttings, the transmissivity and permeability are also low at wells Me15-29 and Og31-1.

The coefficient of storage of the aquifer has not been determined from a pumping test. The electric log of test well Me15-29 shows that the aquifer is tightly confined by dense clay above the aquifer and possibly less tightly confined by clays below the aquifer. For the purpose of computing time-distance-drawdown relation, a coefficient of storage of 0.0003 has been assumed (Figure A8).

The available drawdown in the aquifer ranges from 270 feet in well Me15-29 in the northwestern part of the area to the depth of the aquifer before the fresh-salt water interface is reached. The available drawdown probably ranges from 270 to 600 or more feet below sea level. More than half of the aquifer in Sussex County probably contains fresh water. This part of the aquifer underlies the northern, northwestern and western parts of the county.

Available Water from the Federalsburg Aquifer

On a basis of long-term pumping, the yield of wells will be less than 300 gallons a minute, and many may be as low as 100 gallons a minute or less. In downdip areas, where the pumping lift can be much greater, yields may increase. The time-distance-drawdown relation of the effect of pumping is given in Figure A8. The graph shows large drawdown in the area of the pumped well, but only 18 feet at a distance less than two miles from the pumped well, after a long period of pumping. The aquifer may support a large number of small, costly wells. The ultimate yield of the aquifer is estimated to be less than five million gallons a day.

Quality of Water in the Federalsburg Aquifer

Areas of similar chemical quality of ground water in the Federalsburg aquifer are shown in Figure 29. Chemical constituents in the ground water in the Federalsburg aquifer in milligram equivalents per liter are given in Table 15.

Salt-Water Problems in the Federalsburg Aquifer

The area of potential salt-water intrusion in the subcrop area beneath the wetlands adjacent to Delaware Bay is shown in Figure 29.

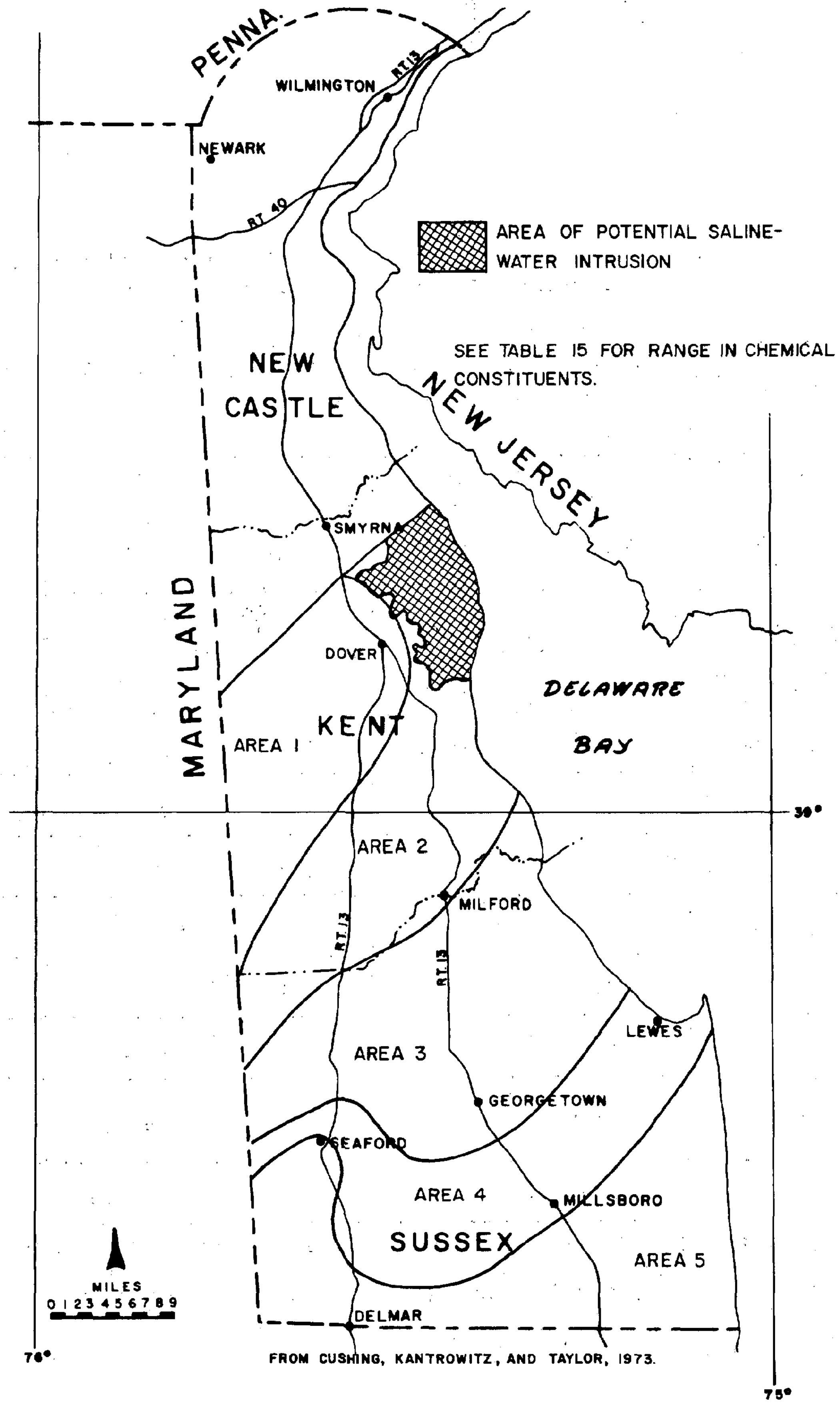


FIGURE 29 AREAS OF SIMILAR CHEMICAL QUALITY OF GROUND WATER AND AREA OF POTENTIAL SALINE-WATER INTRUSION IN THE FEDERALSBURG AQUIFER.

Table 15.

Quality of Ground Water and Area of Potential Saline-Water Intrusion in the Federalsburg Aquifer, as Shown in Figure 29

Chemical constituents in ground water in the Federalsburg aquifer (concentration of constituents in milligrams per liter)

Area	1	2	3	4	5
Dissolved solids*	<100	100-250	250-500	500-1000	>1000
Hardness	<5	5-170	100-150	50-100	<50->200
Sodium	<7	6-25	25-200	300-350	>350
Bicarbonate	<55	55-225	225-450	450-750	>750
Sulfate	10-20	2-10	4-25	25-150	>150
Chloride	<5	<5	2-50	50-150	>150
Fluoride	<0.3	0.2-0.5	0.2-0.7	0.7-1.0	>1.0
Nitrate	0.5-51	<1.0	<1.0	<1.0	<1.0
Silica	<15	15-60	50-60	50-60	50-60
Iron and manganese	0.05-0.8	0.05-2.4	0.02-0.4	0.04-3.0	>3.0
pH	4.6-7.0	7.0-8.5	7.5-8.0	8.0-8.5	>8.5

*In areas 1, 2, and 3, dissolved solids x 1.35 = specific conductance (Micromhos at 25°C)
In areas 4 and 5, dissolved solids x 1.55 = specific conductance

From Cushing, Kantrowitz and Taylor, 1973.

The Frederica Aquifer

Location of the Frederica Aquifer

The configuration of the top of the Frederica aquifer is shown in Figure 30. The aquifer is available for development in the southern two-thirds of Kent County and all of Sussex County except the southeast corner.

Development of the Frederica Aquifer

The areas of use of the Frederica aquifer are shown by Cushing and others (1973) in Figure 30. Sundstrom and Pickett, 1968 and 1969, wrote:

> "The Frederica aquifer is of importance in Kent County and in the northern part of Sussex County. Sundstrom (1968) grouped the Frederica and overlying Miocene sands together and reported that in Kent County the amount of pumpage from the aquifers was about 2,600,000 gallons daily. He also reported that peak demands reached 1,500,000 gallons daily from the two aquifers in the City of Milford. The report stated that these rates of pumping in Milford probably can go no higher without rearranging rates and locations of pumping. In the northern part of eastern Sussex County, other industrial wells add to the draft on the Frederica aquifer and draw from it to the limit during the heavy summer canning, vegetable and poultry processing season. The Frederica aquifer has been used in the Milford area for a long period of time. Darton (1905) of the U. S. Geological Survey reports that in 1898 he received a letter from a City official of Milford who said: 'The depth of our well is 228 feet, ten-inch diameter. We can pump from the well 250 gallons a minute. Temperature 58°F. Water rises 4 feet above the surface.' This well may be the first well to the Frederica aquifer in Milford and is at the same location at which the City of Milford is pumping water from the Frederica today."

Undeveloped Areas of the Frederica Aquifer

The Frederica aquifer has not been developed in about three-fifths of the area it occupies in Delaware. The potential area of use is shown by Cushing, et al, (1973) in Figure 30.

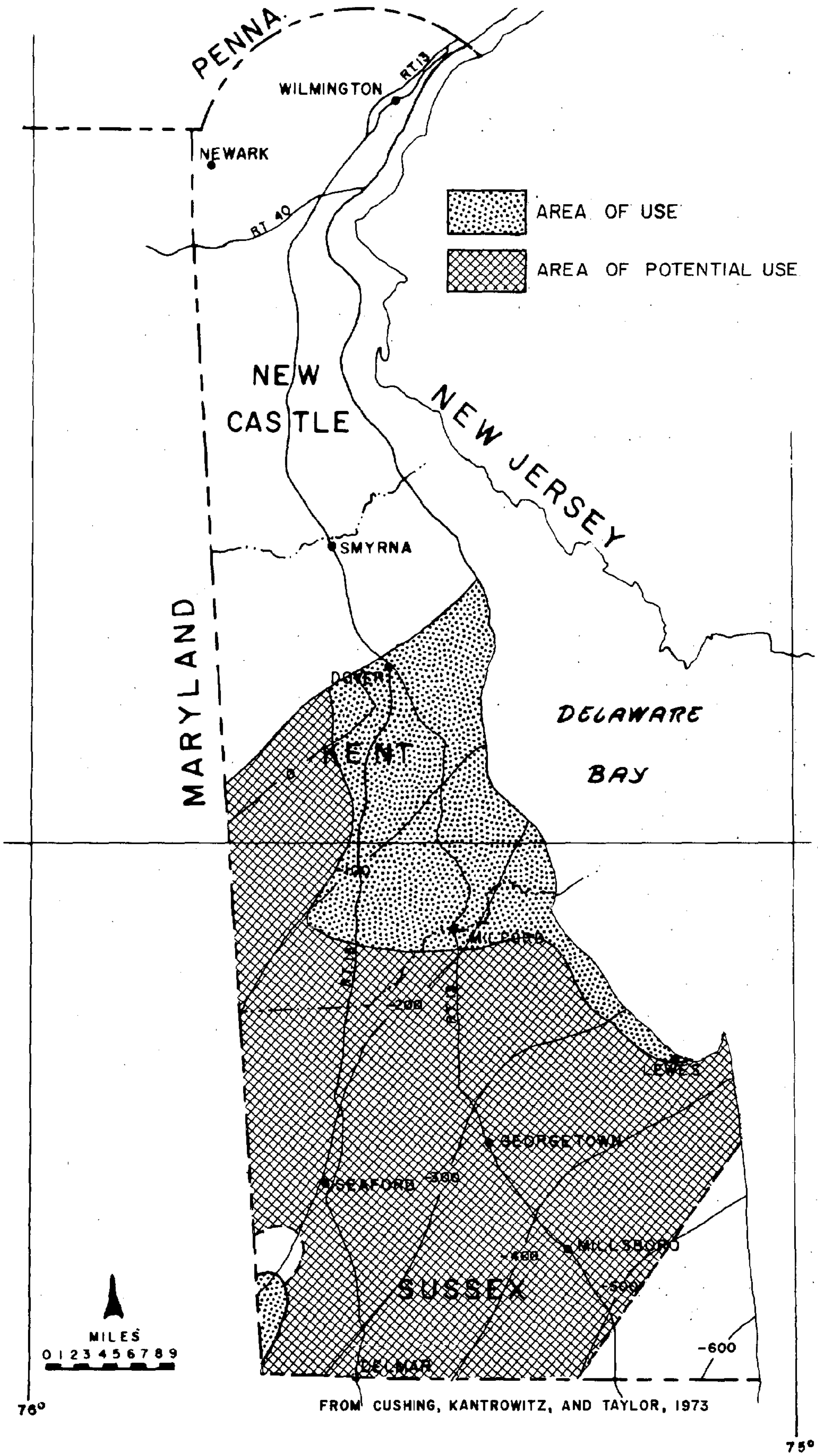


FIGURE 30 CONFIGURATION OF THE TOP AND AREAS OF USE AND OF POTENTIAL USE OF THE FREDERICA AQUIFER.

Hydrology of the Frederica Aquifer

The average daily consumption from the Frederica and younger aquifers of the Miocene is about 2,600,000 gallons. The Frederica and younger Miocene aquifers supply about 14.5 percent of the ground water produced in Kent County in 1966. The Frederica aquifer is developed from the central part of the county southward to the county line. The Frederica and overlying Miocene sands supply the towns of Felton, Frederica, Harrington and Milford. These aquifers also supply several food processing and poultry industries. The City of Milford is the largest user where peak demands have reached 1,500,000 gallons daily and probably can go no higher without rearranging rates and loci of pumping.

Pumpage from the Frederica aquifer in the Milford area is estimated to be over a million gallons a day. The City of Milford pumps an average of about 50,000 gallons daily from wells 1 and 2 at the downtown water plant. Industries processing vegetables, poultry and canning food products use water from the Frederica on a variable seasonal basis. The pumpage is about five percent of the ground water used in eastern Sussex County.

The decline in water levels in the Frederica has been great because of the low coefficient of storage, the low transmissivity of the aquifer, the relatively low specific capacity of wells and the concentration of pumping in one locality. Decline in static level of over 100 feet has been noted in a Milford well. This large decline, however, is believed to be due, in part, to the drawdown caused by the pumping of other wells. Records of water-level fluctuations are inadequate to relate correctly with withdrawal to the decline in artesian pressure on an observed basis.

Two determinations of specific capacity of wells in the Frederica aquifer range from 4.3 to 5.6 gallons a minute per foot of drawdown. No determinations of specific capacity in the Frederica downdip from Milford are available. The examination of the electric log of the test well at Gravel Hill (Og31-1) suggests that the water-yielding properties of the Frederica are considerably less than at Milford. At Milford the specific capacities are moderately low. Approximately 25 feet of drawdown is required to produce 100 gallons a minute.

At Harrington in Kent County, about eight miles west of Milford, Sundstrom (1968) computed the transmissivity of the Frederica to be 12,300 gallons per day per foot (Figure A9). The transmissivity of the Frederica aquifer has not been determined in the report area. It is believed that the transmissivity at Milford is in the same range as the transmissivity at Harrington. Downdip from Milford the transmissivity is believed to decrease.

Coefficients of storage have not been determined in the Frederica aquifer. The aquifer appears to be tightly confined by dense clays and probably has coefficients of storage similar to the Cheswold aquifer. The coefficient of storage of the Cheswold is about 0.0003 and this figure has been used for the Frederica aquifer.

No significant hydraulic boundaries in the aquifer have been identified. The aquifer subcrop in northern Kent County is about 23 miles north of the report area and is too remote to act effectively as a recharge boundary for pumpage at Milford. Tne transmissive properties diminish in the downdip direction from the northwestern boundary, although this decline is so gradual that it probably should not be simulated as a barrier boundary.

The available drawdown in the Frederica aquifer below the original artesian pressure is about 190 feet at Milford and probably reaches about 600 feet in the southern extremity of the area. The time-distance-drawdown relation based on an assumed storage coefficient and a coefficient of transmissivity determined at Harrington are given in Figure A10. Declines in the artesian pressure caused by heavy pumping in Milford limit further development locally. Outside of Milford very little pumping has taken place from the Frederica.

Quantity of Water Available from the Frederica Aquifer and Limits of Development

The quantity of water available from the Frederica aquifer is not large. This is demonstrated by placing a hypothetical line of 11 wells across the aquifer south of Milford and computing the drawdowns caused by pumping each well.

The computations were made by applying the Theis non-leaky nonequilibrium equation to determine the time-distance-drawdown relation caused by pumping each well. The computations show that in less than 30 years (10,000 days) the allowable drawdown will be reached or nearly reached with pumping rates of only 200 to 250 gallons a minute. The combined yield of all 11 wells is only 3,600,000 gallons a day.

It may be assumed that the yield of the wells would be more several miles downdip where the allowable drawdown is greater. This assumption, however, is probably not true, for there is evidence from test wells at Lewes and Gravel Hill that this advantage may be cancelled by the poorer water-yielding properties of the Frederica downdip. A well to the Frederica at Gravel Hill drilled in 1962 is reported by Paul White, the driller, to have yielded on test 30 gallons a minute. The Frederica will supply water to wells of small yield over the northern part of the area, and will probably yield 10 or more million gallons a day to small wells properly spaced. The cost of drilling the wells and producing water from them will be high. The development of the aquifer with wells yielding 100 gallons a minute or more will probably not produce much more than three and a half million gallons a day.

Quality of Water in the Frederica Aquifer

Areas of similar chemical quality of ground water from the Frederica aquifer are shown in Figure 31. The chemical constituents in the ground water in the Frederica aquifer are given in milligrams per liter in Table 16.

Salt-Water Problems in the Frederica Aquifer

The area of potential salt-water intrusion in the subcrop area is shown in Figure 31. The position of the fresh-salt water interface is unknown. By applying the Ghyben-Herzberg principle (1889,1901) to the original artesian pressure of the Frederica, the fresh-salt water contact should be 600 or more feet below sea level. On this basis, the Frederica should contain fresh water throughout most of the report area. Slaughter (1962) reports a well at Bishopville, Maryland, less than a mile south of the area, contained salt water at 640 feet.

The Manokin Aquifer

Location of the Manokin Aquifer

The subcrop of the Manokin aquifer and the configuration on the top of the aquifer are given in Figures 2 and 32. In the subcrop area, the Manokin is overlain by the Quaternary deposits and in much of the area is a part of the water-table aquifer of the Quaternary.

Development of the Manokin Aquifer

The areas of use of the Manokin are shown in Figure 32. In the subcrop area some wells that are considered to have the Quaternary deposits as their source of water may also draw water from the Manokin.

Undeveloped Areas of the Manokin Aquifer

The areas of potential use of the Manokin aquifer are shown in Figure 32 from Cushing, et al, 1973.

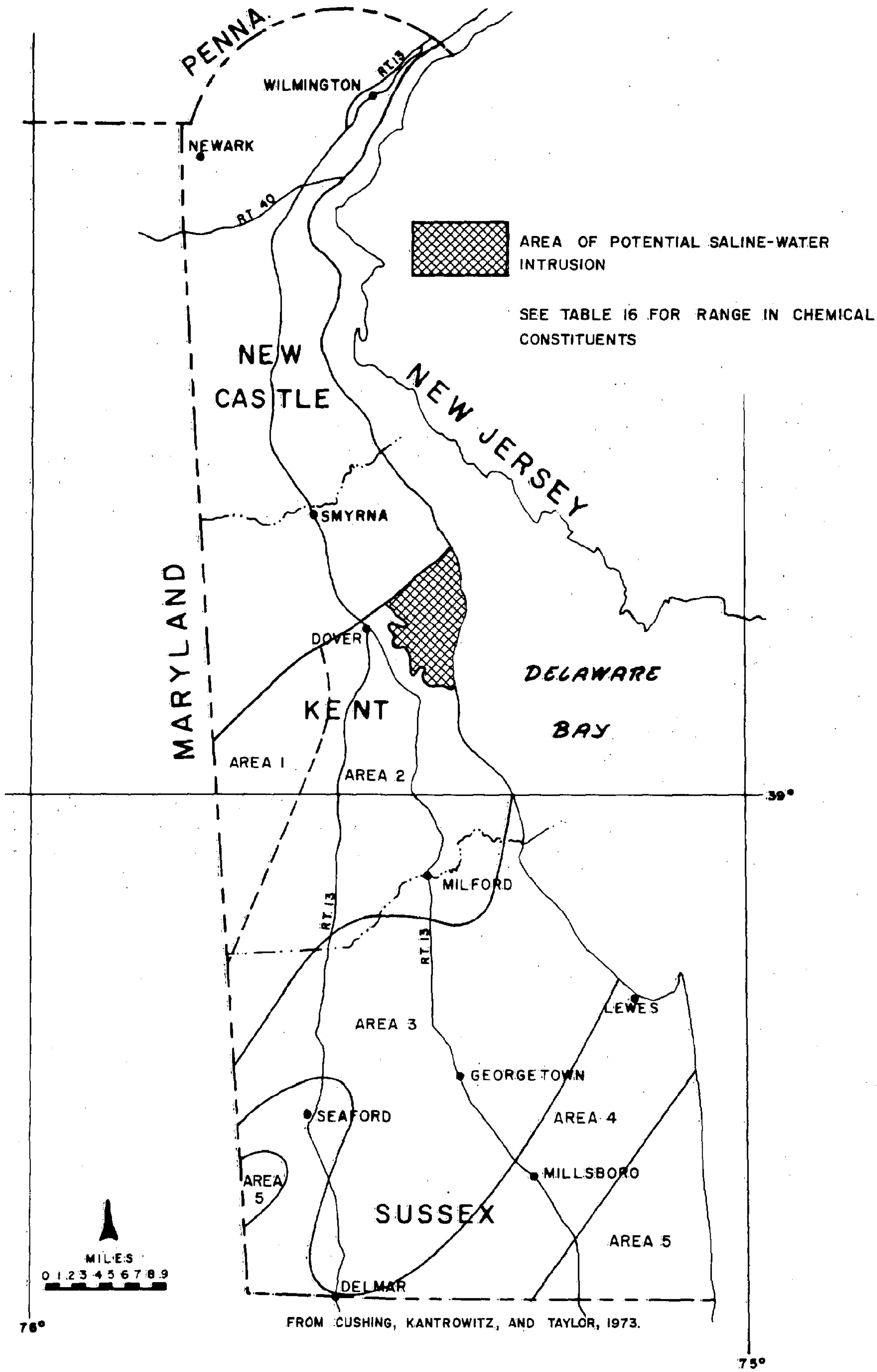


FIGURE 31 AREAS OF SIMILAR CHEMICAL QUALITY OF GROUND WATER AND AREA OF POTENTIAL SALINE-WATER INTRUSION IN THE FREDERICA AQUIFER.

Table 16.

Quality of Ground Water and Area of Potential Saline-Water Intrusion in the Frederica Aquifer, as Shown in Figure 31

Chemical constituents in ground water in the Frederica Aquifer (concentration of constituents in milligrams per liter)

Area	1	2	3	4	5
Dissolved solids*	<100	100-250	250-500	500-1000	>1000
Hardness	<5	5-200	50-70	20-50	<20->500
Sodium	<10	4-50	50-150	150-300	>300
Bicarbonate	<50	50-250	250-350	350-500	>500
Sulfate	---	2-10	5-15	15-100	>100
Chloride	---	2-10	2-50	50-150	>150
Fluoride	---	0.1-0.3	---	---	0.8-1.0
Nitrate	---	<1	<1	1.0-1.2	1.0-3.0
Silica	---	30-60	50-60	50-60	50-60
Iron and manganese	---	0.01-0.4	<0.3	<0.3	0.2-2.0
pH	---	7.5-8.0	>8.0	>8.0	>8.0

*Dissolved solids x 1.55 = specific conductance (Micromhos at 25°C)

From Cushing, Kantrowitz and Taylor, 1973.

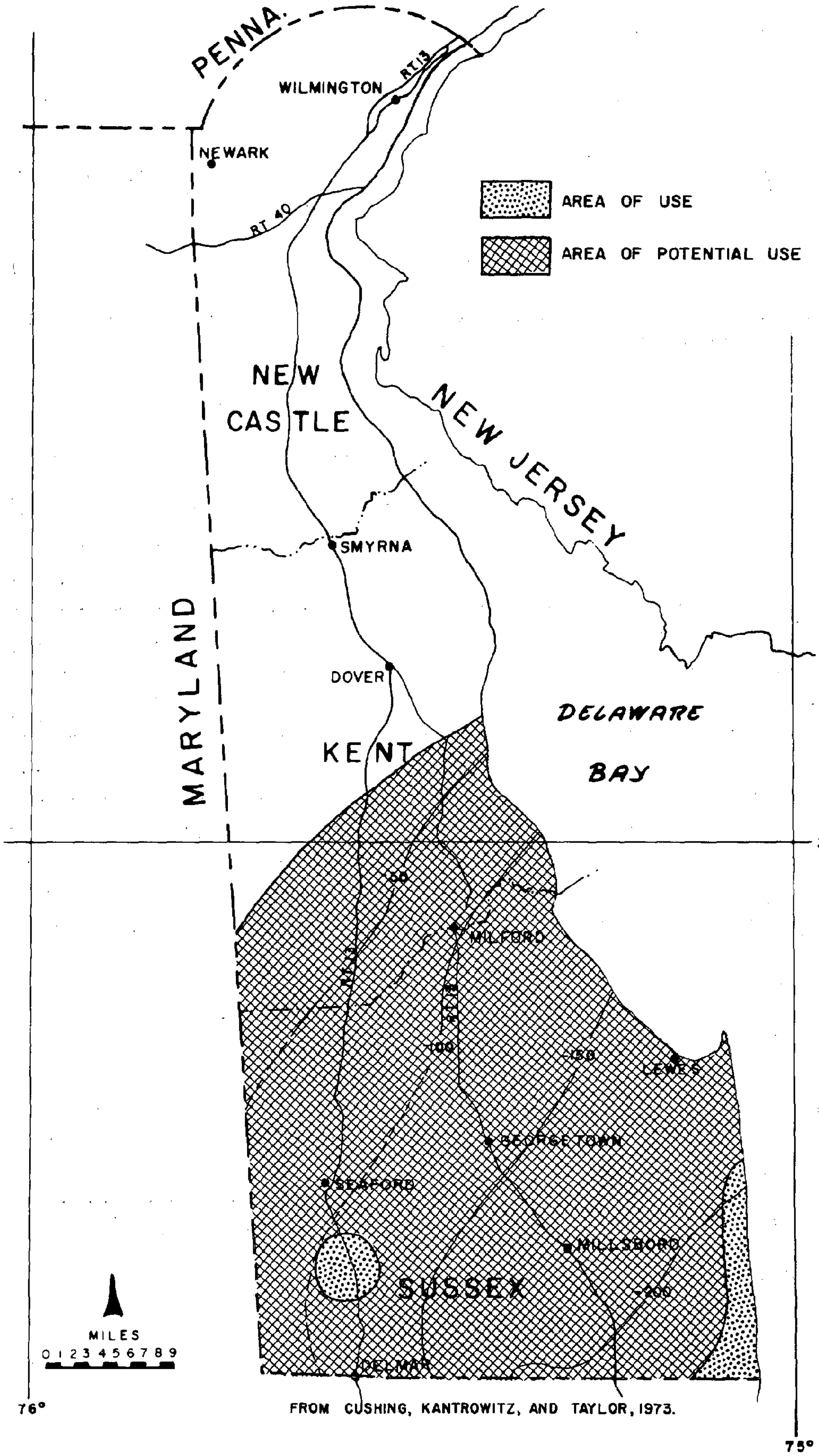


FIGURE 32 CONFIGURATION OF THE TOP AND AREAS OF USE AND OF POTENTIAL USE OF THE MANOKIN AQUIFER.

Hydrology of the Manokin Aquifer

The hydrology of the Manokin aquifer has been studied in two parts by Sundstrom and Pickett, 1969 and 1970. In the eastern part of Sussex County, the subcrop of the Manokin occupies an area of about 75 square miles and in the western part about 125 square miles. Thus, the Manokin becomes an integral part of the overlying Quaternary aquifer over an area of about 200 square miles in Delaware. Downdip from the subcrop, the Manokin begins to become confined by overlying silts and clays and becomes artesian in water-yielding properties. The water levels in the Manokin in the subcrop area are the same as those in the overlying Quaternary deposits and range from sea level to about 48 feet above sea level. In the artesian part, the artesian pressure at Selbyville was reported 23.3 feet above sea level in 1957.

The specific capacities of 10 wells pumping water from the Manokin, or Manokin and Pleistocene, range from 10 to 49 and average 23.4 gallons a minute per foot of drawdown. Eight of the 10 wells yield 500 or more gallons a minute and two wells yield more than 1,000 gallons a minute. The maximum yield is 1,200 gallons a minute. The high specific capacities, coupled with the high yield of wells, indicate that the Manokin aquifer has good to excellent water-bearing properties.

The transmissivity of the Manokin artesian aquifer has been computed from pumping tests at Bethany Beach in Sussex County, near Salisbury, Maryland and at Snow Hill, Maryland. The coefficient of transmissivity at Bethany Beach is 60,000 gallons a day per foot, computed from a pumping test conducted by the Middletown Drilling Company. Near Salisbury and at Snow Hill, pumping tests by the U. S. Geological Survey gave transmissivities of 40,000 gallons a day per foot at both places. The graphic plot of the pumping-test data and computation of the coefficient of transmissivity at the Bethany Beach well Qj32-12 are shown in Figure A11. The time-distance-drawdown graphs, based on the transmissivity at well Qj32-12 and an assumed coefficient of storage and rate of pumping, are given in Figure A12. The electric log of well Pf23-2 (Figure A13) south of Georgetown indicates that the water-bearing properties of the Manokin are probably better at well Pf23-2 than they are at Bethany Beach; therefore, the higher transmissivity at Bethany Beach appears to be more applicable than the lower transmissivities determined in Maryland.

The coefficient of storage has not been determined in the report area. In the subcrop area of the aquifer the effective specific yield is probably about 0.15 and in the same order of magnitude as the overlying Pleistocene sediments. In the artesian part of the Manokin the coefficient of storage is low, probably in the order of 0.0005 or less. Gill (1962) reports the determination of 26 coefficients of storage from aquifer tests in the Cohansey sand (Manokin?) in Cape May County, New Jersey, ranging from 0.0027 to 0.0012. The New Jersey coefficients may suggest some vertical leakage to the aquifer. In computing the time-distance-drawdown graphs in Figure A12 a coefficient of storage of 0.0005 was used.

The Manokin aquifer does not reach sufficient depth in the report area to encounter the interface between fresh and salt water. The interface occurs several miles downdip from the southern boundary of the report area and in the coastal outcrop area several miles east and southeast.

The hydraulic boundary that is important to the artesian part of the Manokin aquifer is the favorable recharge boundary of the subcrop. The subcrop is so close to the artesian part that the favorable effect of recharge from the subcrop will be substantial throughout the artesian portion. In using the time-distance-drawdown curves in Figure A12 to estimate the effect of pumping in the artesian area, favorable corrections of drawdown will have to be computed, based on the position of pumping and the recharge effect for that position. The recharge corrections can be computed by applying the image well theory described by Ferris, et al, (1962). In the downdip direction, or elsewhere in the Manokin, no barrier boundaries are believed to exist close to the report area.

The available drawdown in the Manokin in the subcrop area includes the thickness of the Manokin aquifer plus the saturated thickness of the overlying Pleistocene. The saturated thickness of both aquifers ranges from about 90 to about 200 feet. In the artesian part of the Manokin, the available drawdown ranges from about 100 to 225 feet.

Quantity of Water Available from the Manokin Aquifer

The quantity of water available from the Manokin is considered in two parts. The first part is the amount available in the 200 square miles of subcrop shown in Figure 2. The second part is the amount from that area of the Manokin which is confined and under artesian pressure. The amount of water available from the 200 square mile subcrop area is included in the available water from the Quaternary water-table aquifer discussed later. The available water from the artesian part of the aquifer is estimated to be 40 to 50 million gallons a day.

Quality of Water in the Manokin Aquifer

Areas of similar chemical quality of ground water in the Manokin aquifer are shown in Figure 33. Chemical constituents in ground water in the Manokin aquifer in milligram equivalents per liter are given in Table 17.

Salt-Water Problems in the Manokin Aquifer

Potential saline intrusions into the subcrop area of the Manokin are shown in Figure 33. The interface of fresh-salt water in the artesian part of the aquifer is probably too far downdip in the aquifer to be a problem in Delaware.

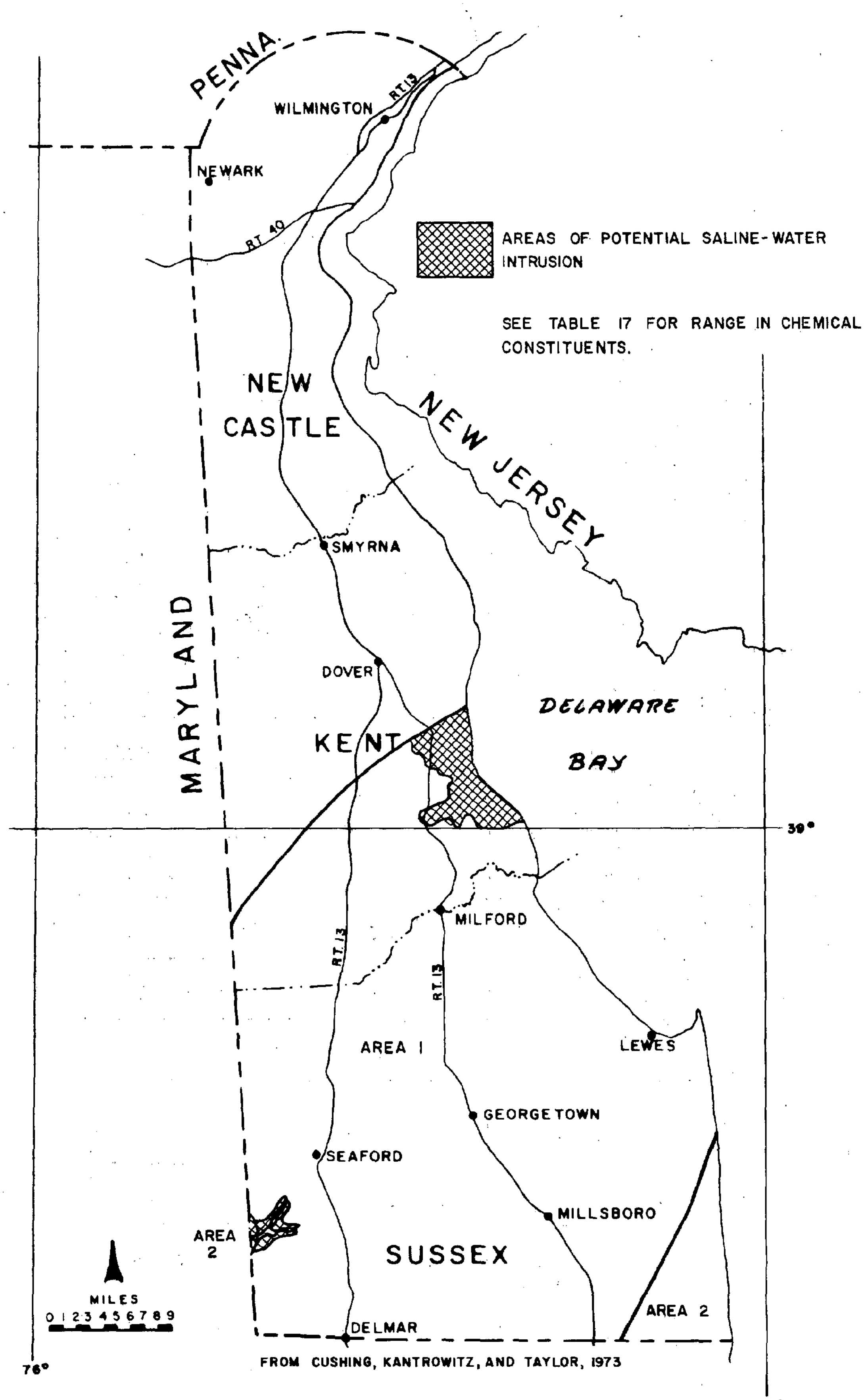


FIGURE 33 AREAS OF SIMILAR CHEMICAL QUALITY OF GROUND WATER AND AREAS OF POTENTIAL SALINE-WATER INTRUSION IN THE MANOKIN AQUIFER.

Table 17.

Quality of Ground Water and Area of Potential Saline-Water Intrusion in the Manokin Aquifer, as Shown in Figure 33

Chemical constituents in ground water in the Manokin aquifer (concentration of constituents in milligrams per liter)

Area	1	2
Dissolved solids*	<150	150-250
Hardness	5-60	60-150
Sodium	5-20	20-55
Bicarbonate	3-125	100-225
Sulfate	0-23	0-7
Chloride	<10	10-60
Fluoride	0.0-0.2	0.0-0.3
Nitrate	0.0-6.0	0.1-3.5
Silica	20-40	15-45
Iron and manganese	0.3-5.0	0.06-12.0
pH	6.0-6.8	6.4-8.0

*Dissolved solids x 1.68 = specific conductance (Micromhos at 25°C)

From Cushing, Kantrowitz and Taylor, 1973.

The Pocomoke Aquifer

Location of the Pocomoke Aquifer

The configuration of the top of the Pocomoke aquifer is shown in Figures 2 and 34. The aquifer lies directly beneath the Quaternary water-table aquifer. Throughout the area occupied by the Pocomoke aquifer in Delaware, the water-table aquifer of the Quaternary (Pleistocene) and the Pocomoke are common to each other.

Development of the Pocomoke Aquifer

The areas of use of the Pocomoke are shown in Figure 34. In some places the deeper water table of the Pocomoke is preferred because of the better quality of water contained in it.

Undeveloped Areas of the Pocomoke Aquifer

The undeveloped area of the Pocomoke in Delaware is shown in Figure 34.

Hydrology of the Pocomoke Aquifer

The hydrology of the aquifer is discussed later in this report as a part of the water-table aquifer of the Quaternary (Pleistocene).

Quality of Water in the Pocomoke Aquifer

Areas of similar quality of ground water in the Pocomoke aquifer are shown in Figure 35. Chemical constituents in the ground water in the Pocomoke in milligram equivalents per liter are given in Table 18.

Salt-Water Problems in the Pocomoke Aquifer

The area of potential salt-water intrusion into the Pocomoke aquifer in Delaware is shown in Figure 35.

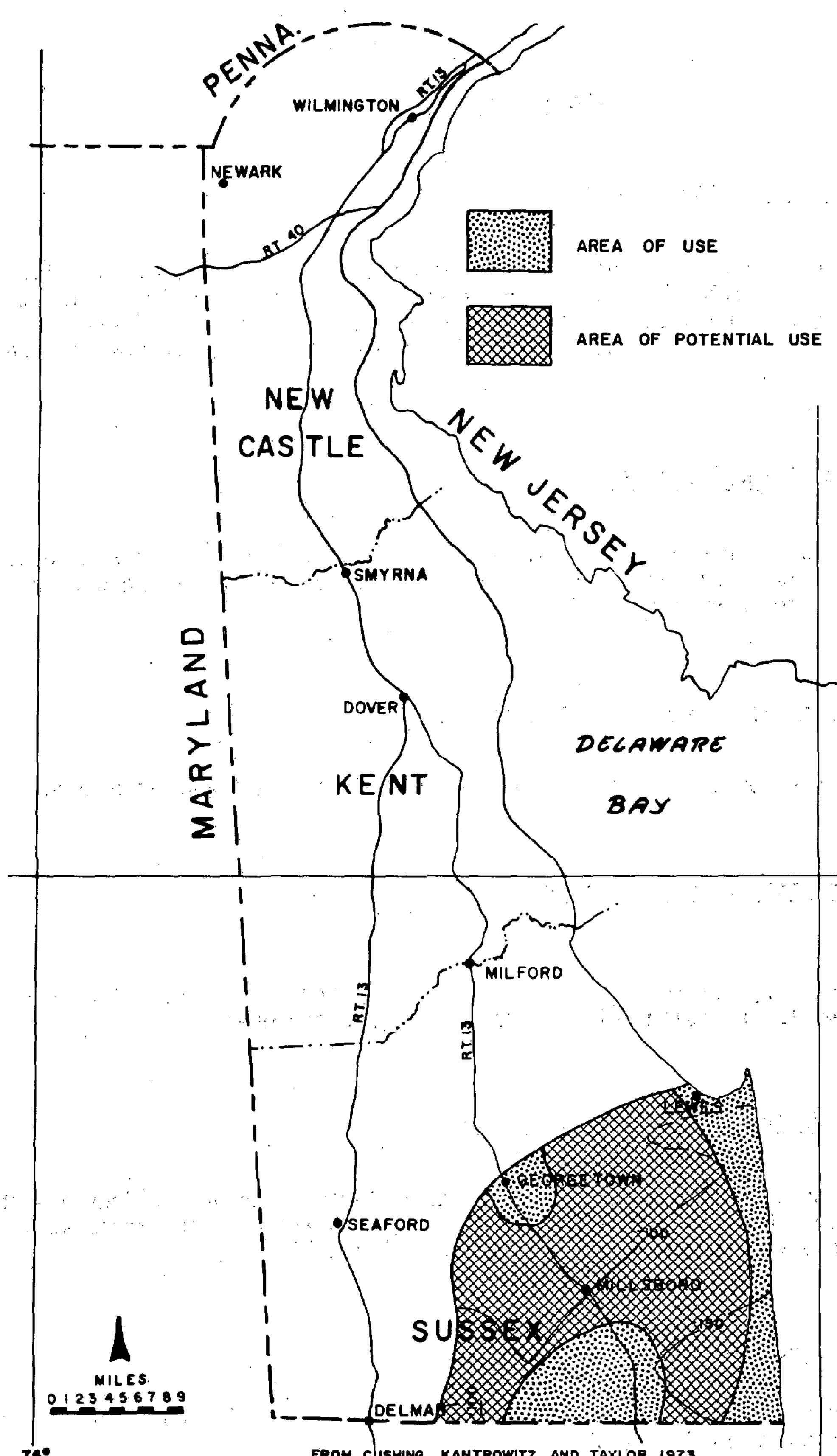


FIGURE 34 CONFIGURATION OF THE TOP AND AREAS OF USE AND OF POTENTIAL USE OF THE POCOMOKE AQUIFER.

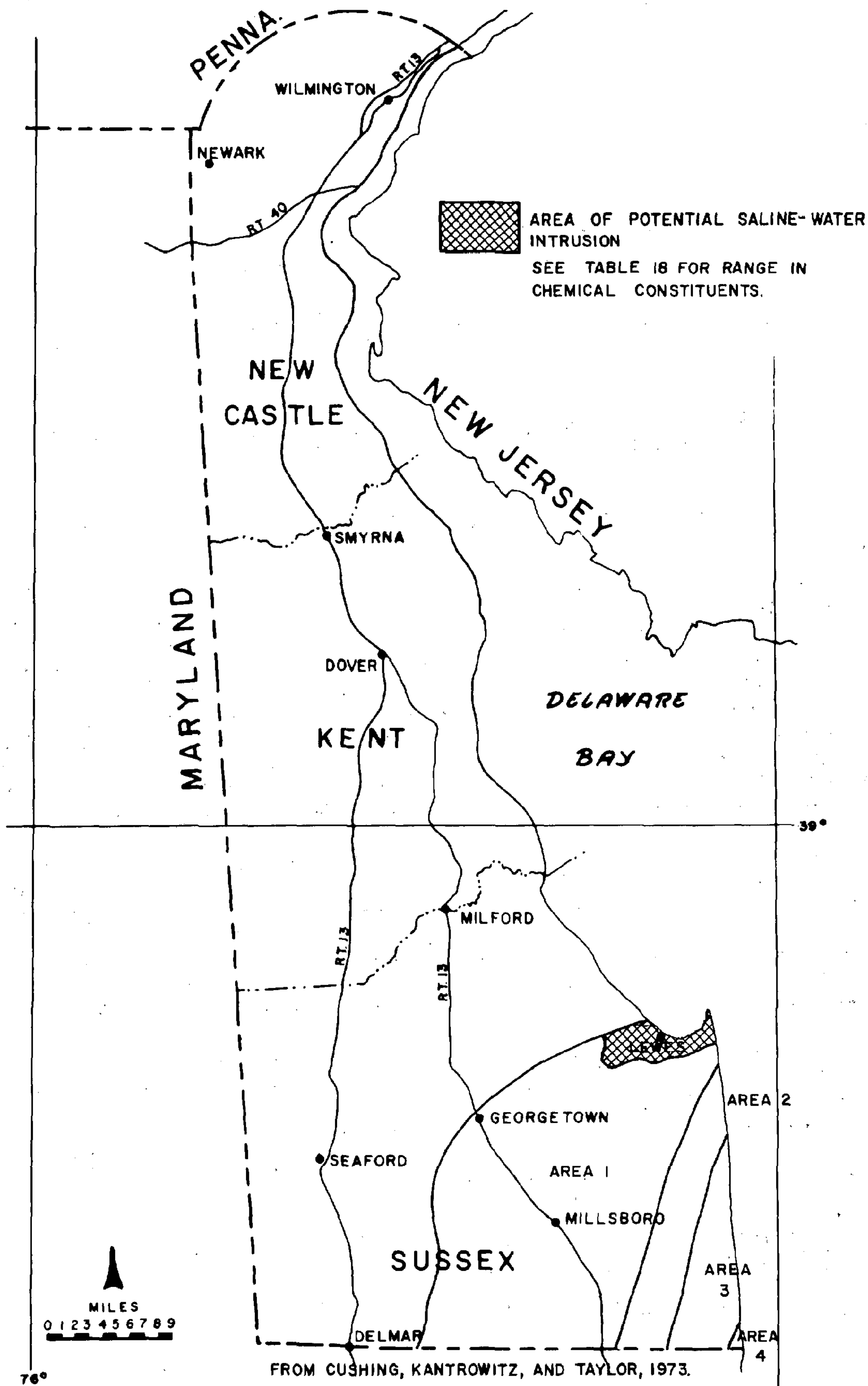


FIGURE 35 AREAS OF SIMILAR CHEMICAL QUALITY OF GROUND WATER AND AREA OF POTENTIAL SALINE-WATER INTRUSION IN THE POCOMOKE AQUIFER.

Table 18.

Quality of Ground Water and Area of Potential Saline-Water Intrusion in the Pocomoke Aquifer, as Shown in Figure 35

Chemical constituents in ground water in the Pocomoke aquifer (concentration of constituents in milligrams per liter)

Area	1	2	3	4
Dissolved solids*	<100	100-150	250-500	500-1,000
Hardness	<25	25-50	50-200	50-200
Sodium	<10	10-25	35-175	175-350
Bicarbonate	<25	25-125	180-430	190-440
Sulfate	1-17	---	<1-6	<1-30
Chloride	3-15	5-15	20-100	100-450
Fluoride	0.0-0.3	---	0.2-0.5	---
Nitrate	0.0-29	---	0.2-4.1	---
Silica	20-40	---	15-30	<15
Iron and Manganese	0.0-20	---	0.3-3.0	0.0-2.0
pH	5.6-7.1	---	7.3-8.4	---

*Dissolved solids x 1.53 = specific conductance (Micromhos at 25°C)

From Cushing, Kantrowitz and Taylor, 1973.

The Quaternary Water-Table Aquifer

Availability of Water from the Water-Table Aquifer in the Coastal Plain in New Castle County

The available water from the water-table aquifer in the Coastal Plain of New Castle County is small in terms of an adequate supply to large-capacity wells of 500 or more gallons a minute each. This is especially true north of the Chesapeake and Delaware Canal. Although the water-table aquifer where the Pleistocene sediments contain 10 or more feet of saturated material covers 182 square miles, the thickness of saturation of 40 feet or more needed to assure large-capacity wells occupies only 11 square miles, of which eight are south of the Chesapeake and Delaware Canal. The Pleistocene water-table aquifer probably will supply large-capacity wells in these isolated areas in amounts equal to the available recharge which would amount to about three million gallons a day north of the canal and about eight million gallons a day on the south side of the canal in the Middletown-Odessa and Smyrna areas. The total available supply to large-capacity wells in the county is about 11 million gallons a day.

The Pleistocene aquifer is an important source of water to small wells over the entire area of 182 square miles where it has 10 or more feet of saturated thickness. Although the Pleistocene aquifer is a poor source of large supplies of water in the county, it has importance in maintaining the base flow of streams, in furnishing plant life moisture, in maintaining a reservoir of recharge water for the artesian aquifers, and in maintaining the hydraulic gradient that halts the ingress of salt water along the Delaware Estuary and Bay.

The prospects of supplementing the water supply of New Castle County by the use of artificial recharge to the ground-water reservoir of the Pleistocene aquifer is brought into focus in the report by Sundstrom (1971). Whether or not such recharge is practicable and feasible can be told only after required research and study are made.

Availability of Water from the Quaternary and Miocene Outcrop Water-Table Aquifers in Kent County

The Pleistocene deposits cover about 88 percent of the land area in Kent County and almost everywhere small to moderate supplies for rural and domestic purposes can be obtained, although the aquifer may be only a few feet thick. In other parts of the county, where the Pleistocene aquifer is thicker, and in many instances underlain by Miocene outcrop or near outcrop sands, the total aquifer thickness has been observed to reach a thickness of 178 feet and yields of 1,000 gallons a minute are reported.

In appraising the availability of water from the Pleistocene and Miocene outcrop aquifers, it must be kept in mind that any development of the water-table aquifers is related and will have an effect on the fairweather discharge to the streams. If the low flow stream discharge can be neglected, then the Pleistocene and underlying Miocene outcrop aquifers probably could be pumped at a rate of 100 million gallons daily or more without seriously depleting the reservoir. If such a high rate of withdrawal is undertaken, there might be an associated problem of salt-water encroachment close to sources of salt water unless proper planning and pumping rates are maintained. The problem is discussed in the report by Sundstrom and Pickett, 1968.

Hydrology of the Pleistocene and Subcropping Miocene Water-Table Aquifer in Sussex County

The Pleistocene and, in some localities, subcropping Miocene sands form a water-table aquifer that supplies water to wells in all of Sussex County. The aquifer provides approximately 90 percent of the ground water pumped in the area. The water-table aquifer not only supplies water to municipalities, industries, irrigators, and the rural area; but also provides (1) a reservoir of water available to the artesian aquifers as a continual source of recharge; (2) a supply of water furnishing the fairweather flow of the streams; and (3) a supply of water that maintains the hydraulic gradient that prevents ingress of the salt water into the ground-water reservoirs from Delaware Bay, the Atlantic Ocean, the tidal estuaries and the tidal marshlands in part of the coastal area. In some of the coastal area, the altitude of the water-table is not adequate to protect the deeper sections of the water-table aquifer. The many functions of the water-table aquifer make it necessary to give consideration to each of the functions the aquifer is now providing and integrate into these functions the effect of new and further development of the aquifer. If new development is done wisely, the aquifer can supply large quantities of additional water without seriously harming its contribution to the fairweather flow of the streams or its role in protecting against salt-water encroachment. In fact, there are many thousands of acres where the water table is too high, and withdrawal of ground water would help alleviate swampy conditions and excess evaporation and would induce more recharge to replace water pumped.

Estimated Thickness of Saturation in the Water-Table Aquifer

The thickness of saturation in the water-table aquifer in the Pleistocene in Sussex County has been computed and is illustrated in Figure 36. The thickness of the saturated portion of the Pleistocene has been determined from the altitude of the water-table aquifer in 467 wells and the base of the Pleistocene, as shown in Figure 36. Records of wells giving the land surface, the altitude of the water-table, the depth of penetration in the water-table aquifer below sea level, the depth of the base of the Pleistocene and in some wells and the known thickness of the water-table aquifer is given in Table B18. The thickness of saturation in the Manokin has been estimated from its thickness

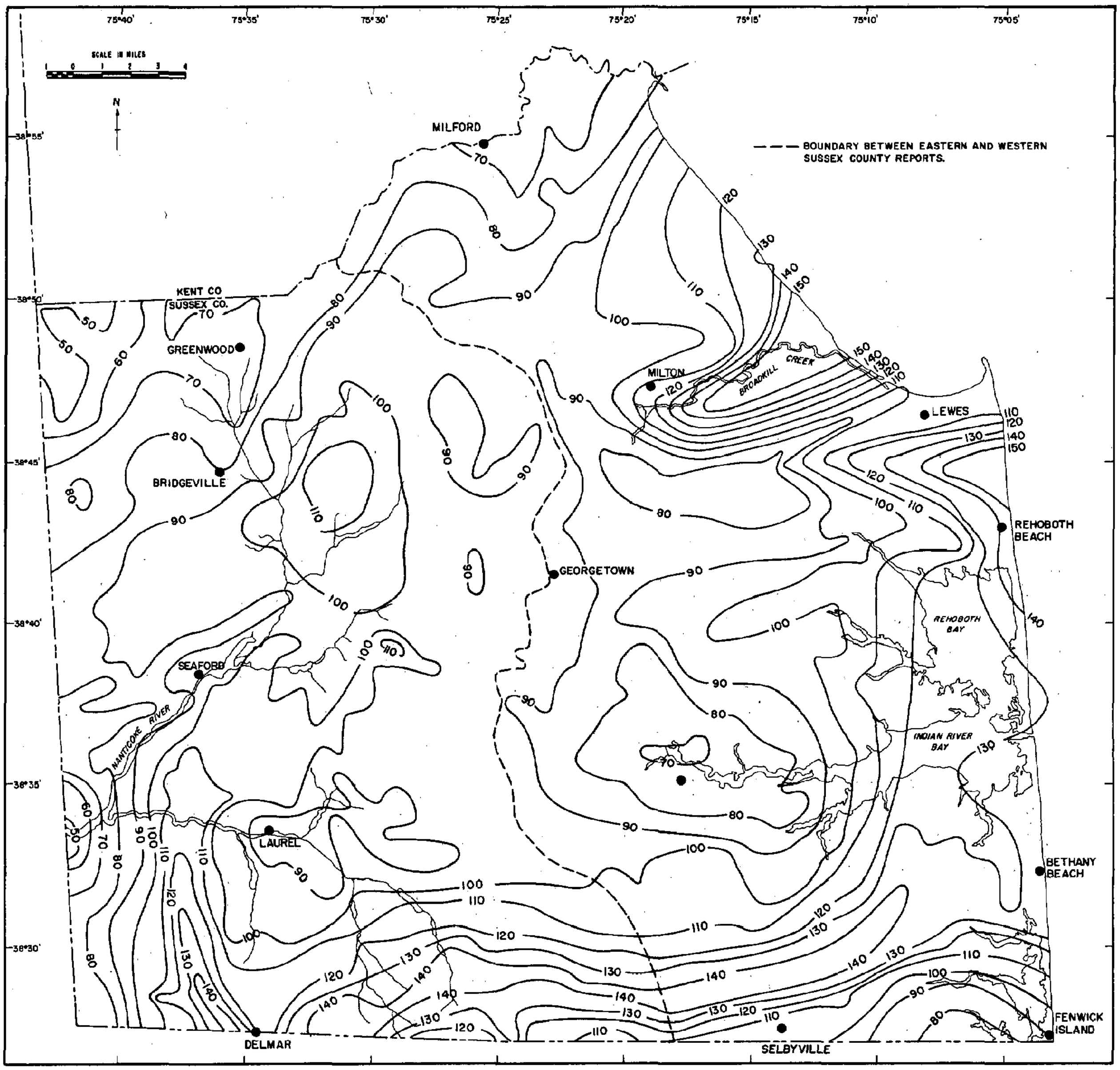


FIGURE 36. MAP SHOWING THE SATURATED THICKNESS OF THE WATER-TABLE AQUIFER IN THE PLEISTOCENE DEPOSITS IN SUSSEX COUNTY.

in the eight wells that penetrate the aquifer. The average thickness of the Manokin in the eight wells is 45 feet, and this thickness is previously used in the computations of water in the Manokin subcrop. Three wells that penetrate the Pocomoke subcrop have thicknesses of water-bearing sand that average 30 feet. This average is used in the later computations of available water from the Pocomoke subcrop.

No estimate of the thickness of other subcropping Miocene sands was possible because of lack of data. The other subcrops, while adding to the total supply of the water-table ground-water reservoir, are unknown, but are believed to be minor when considering the aquifer as a whole. The altitude of the water table in the Pleistocene is known with much more accuracy than is the position of the base of the Pleistocene. For this reason, the thickness of the water-table aquifer, including the Manokin subcrop, ranges from 41 to 194 feet.

Estimated Volume of Saturation in the Water-Table Aquifer

The volume of saturated material in the water-table aquifers of the Pleistocene, the Manokin subcrop and the Pocomoke subcrop has been computed. In computing the volume of saturated material, the volume of saturated material above and below sea level was first computed. The report area was subdivided into 5-minute grids of latitude and longitude, as shown in Figure 1. The area within each grid in acres was determined. The average thickness of saturation above sea level was determined from the altitudes of the water levels of wells within the grid. The volume of saturation in each grid in acre-feet is the product of the area of the grid in acres multiplied by the average thickness of saturation in feet. The results of these computations for the volume of saturation in the Pleistocene above and below sea level are given in Table B19. In determining the thickness of saturation below sea level, the base of the Columbia Group (Pleistocene) is shown in Figure 11. The sum of the altitude above sea level, taken from the average altitude of the water level and the depth to the base of the Columbia Group, equals the total thickness of the saturated portion of the Pleistocene at concurrent points of measurement. The thickness of saturation in the Pleistocene is shown in Figure 36. The saturated subcrops of the Manokin and Pocomoke both are below sea level. The volumes of saturated material in both aquifers have been computed by the product of the area in acres of the aquifers multiplied by their thickness in feet.

The Pleistocene aquifer contains about 22 million acre-feet of saturated material above sea level, and about 40 million acre-feet of saturated material below sea level, totaling 62 million acre feet. The volume of saturated material in the subcrop of the Manokin is estimated to be 4,500,000 acre-feet. The volume of saturated material in the subcrop of the Pocomoke is only 1,900,000 acre feet.

The total volume of saturated material in the water-table aquifer of the Pleistocene and subcropping Manokin and Pocomoke aquifers is about 68 million acre-feet, or more than 20 cubic miles.

Effective Yield of the Water-Table Aquifer

The sands and gravels that form the water-table aquifer will yield only a part of the water contained in storage when the aquifer is pumped or drained by natural ground-water flow to a stream, spring or lake. Many water-table aquifers, similar to that of Sussex County, have effective specific yields to wells or natural drainage of 11 to 19 percent of the volume of the aquifer unwatered. In Sussex and Kent Counties, two wells tapping the water-table aquifer were observed and the declines during the extreme drought period from June to October, 1968, were analyzed for effective yield. Likewise, the rises during the extreme wet period from July 21 to August 20, 1969, when 13.27 inches of rain fell at Georgetown, were analyzed for effective recharge to the aquifer. Figure A14 shows graphically the fluctuation in the two wells from March 1967 to December 1969. The effect of drought that extends over a long period of time, generally, is subject to analysis with better results because during the prolonged drought little or no recharge is taking place over the area under study. In making recharge analyses during periods of heavy precipitation the amount of rainfall often varies widely from place to place, and the water levels observed at one place may not be precisely correct in magnitude to correlate with precipitation that was measured elsewhere.

The period of drainage analyzed extends from water-level measurements made in wells Md22-1 and Qe44-1 on June 6, 1968, to the measurements made in the wells on October 4, 1968. During this period the precipitation at Georgetown was deficient by 9.76 inches and at no time, except July 4, 1968, did more than an inch of precipitation fall. The rainfall on July 4 was 1.35 inches. No rainfall during the period is believed to be adequate to affect the decline of the water table. The water table declined 5.8 feet in well Md22-1 and 5.0 feet in well Qe44-1 between June 6, 1968, and October 4, 1968. The gravity drainage or specific yield in terms of deficiency in precipitation to total decline in well Md22-1 is equal to $9.76/5.8 \times 12 = 14.0$ percent and in well Qe44-1 is equal to $9.76/5.0 \times 12 = 16.2$ percent. The figures of 14.0 and 16.2 percent represent a ratio of the deficiency in rainfall to the decline in water level and approaches the true drainage or specific yield value. The average of these two values is 15.1 percent. Sundstrom (Sundstrom and Pickett, 1968) in discussing the effective specific yield of the water-table aquifer in Kent County, used 15 percent for his quantitative computation of the aquifer. The same figure is used for Sussex County.

The period of recharge to the aquifer analyzed extends from water-level measurements made in wells Md22-1 and Qe44-1 on July 23, 1969, to a measurement made in well Md22-1 on September 11, 1969, and by an estimated water level in well Qe44-1 on September 11, 1969, by extending the rate or rise observed from July 23 to August 28 onward to September 11, 1969. The rise in water level for the above period, July 23 to September 11, 1969, was 5.7 feet in well Md22-1 and 5.1 feet in well Qe44-1. During the period July 19 to August 21, 1969, a period of 34 days, 13.27 inches of rain fell at Georgetown. Based on an average annual rainfall of 46.75 inches of rain at Georgetown, the 13.27 inches of rain in a 34-day period represents an excess over average precipitation of 8.91 inches. The excess precipitation, when related to the rise in water levels in in wells Md22-1 and Qe44-1, shows that excess precipitation in depth is equal to 14.6 percent of the rise in water level in well Qe44-1 and 13 percent of the rise in water level in well Md22-1.

Meyer and Bennett (1955) show graphically the water-level fluctuations in a well at the nearby Salisbury, Maryland, airport in response to precipitation that occurred from May 13 to 18, 1948. The graph is of value in quantitative analysis of the Pleistocene water-table aquifer in reflecting the relationship of water added to the aquifer to the volume of material saturated. During the five-day period 5.80 inches of rain caused the water level to rise to 48.12 inches. The volume of water precipitated on the surface above the aquifer amounted to a little more than 12 percent of the volume of the aquifer saturated. In the early part of the five-day period 2.31 inches of precipitation fell, causing a rise in the water table of 16.2 inches. During this period, the volume of water from rainfall is more than 14 percent of the volume of material saturated. The figure of 14 percent is nearly representative of the effective specific yield and approaches closely the figure of 15 percent used by Sundstrom and Pickett in the Kent County, Delaware, study (1968) and in the Sussex County studies (1969 and 1970).

The Water-Table Aquifer and Its Relation to Streamflow

The water-table aquifer of the Pleistocene supplies nearly all of the fairweather flow of the streams. When the stage of the aquifer is high, the discharge from it is high. When the water level in the aquifer diminishes, its discharge also declines. Precipitation or lack of precipitation causes the aquifer to fluctuate considerably, often in short periods of time. Figure A15 shows the composite fluctuation in 13 water-table wells in Delaware over a period of more than 11 years. Examples of the relation of the stage of the ground-water reservoir to the flow of streams can be demonstrated by the fluctuations in wells Md22-1 and Qe44-1, shown in Figure A14 and the relation of the fluctuation of stage of the water table to the discharge of the Nanticoke River near Bridgeville, Delaware, and to the discharge of the Pocomoke River across the state line near Willards, Maryland. In June, 1968, the water level in well Md22-1 measured 6.6 feet below land surface. As the drought continued, the water level in well Md22-1 was measured 9.9 feet below land surface and in well Qe44-1 was measured 11.6 feet below land surface. The average daily discharge of the Pocomoke River for the same period was 49.2 cubic feet per second. In September 1968, the drought had decreased the average monthly flow of the Nanticoke to 34.2 cubic feet per second. The relation of ground-water stage to the average monthly discharge of the two rivers is summarized in Table B20 (Sundstrom and Pickett, 1970). Table B20 shows that the average daily discharge for the Nanticoke dropped from 46.9 million gallons a day to 22.1 million gallons a day, representing a decrease in discharge of 24.8 million gallons a day in the four-month period. The average daily discharge of the Pocomoke dropped from 31.8 million gallons a day to three million gallons a day in the four-month period. During the drought period, the flow of both streams was mostly water-fed by the water-table aquifer.

In a three-year study of the Pleistocene water-table aquifer in the Salisbury area of Maryland, a few miles south of western Sussex County, Rasmussen and Andreasen (1959) found very close relation between the stage of the water table and the base flow of Beaverdam Creek. The relation is shown in Figure A16. Similar studies now in progress by the U. S. Geological Survey and the Delaware Geological Survey will soon define the relation of the stage of the water level in Pleistocene wells with the stage of the Nanticoke and other Delaware streams in more detail. The studies are important in defining the ground-water contribution and the overland runoff to the streams.

Specific Capacities of Wells in the Water-Table Aquifer

Specific capacities have been determined in 72 wells in the water-table aquifer. In 28 of these wells the specific capacity ranges from 2.2 to 10.0 gallons a minute per foot of drawdown. All of the wells having a specific capacity below 10 are smaller-diameter wells, generally used for rural water supply. The low specific capacities of these wells are not representative of the specific capacities that would be obtained from larger-diameter and better-constructed wells at the same location. The 44 wells that have higher specific capacities, ranging from 10.0 to 49.0 gallons a minute per foot of drawdown, are more representative of the better-developed wells in the area. The specific capacities of the better wells are better indicators of the true water-yielding properties of the aquifer. Of the 44 wells that have specific capacities over 10 gallons a minute per foot of drawdown, 29 wells range from 10 to 20 gallons a minute per foot of drawdown, nine wells range from 20 to 30 gallons a minute per foot of drawdown, two wells range from 30 to 40 gallons a minute per foot of drawdown, and four wells have specific capacities above 40 gallons a minute per foot of drawdown. The average specific capacity of the 44 wells is 27.3 gallons a minute per foot of drawdown. The specific capacity of individual wells is given in the report by Sundstrom and Pickett (1969) and in the Table B16.

Transmissivity of the Water-Table Aquifer

The transmissivity of the water-table aquifer has been determined from pumping tests conducted at Lewes and Rehoboth Beach by the U. S. Geological Survey during the course of ground-water studies at the two cities. Seven pumping tests, five at Lewes and two at Rehoboth Beach, give coefficients of transmissivity ranging from 45,000 to 135,000 gallons a day per foot. The average of the seven determinations is 88,000 gallons a day per foot. One coefficient of transmissivity was determined at Laurel by permeability determinations made from samples collected in a place while digging a well by hand. The transmissivity was later determined by multiplying the average permeability by the thickness of the aquifer. The computed transmissivity at Laurel is 114,000 gallons a day per foot. For purposes of quantitative study and analyses in this report, a transmissivity of 100,000 gallons a day per foot has been used. Transmissivities determined from individual tests have been reported by Sundstrom and Pickett (1969).

The time-distance-drawdown graph in Figure A17 demonstrates the effect of pumping a well at a rate of 1,000 gallons a minute on the water levels in the water-table aquifer after pumping continually for 100 and 1,000 days at distances ranging from 10 to 25,000 feet. Figure A17 is based on the assumption that no recharge takes place during the period of pumping and that the aquifer is not affected by gravity drainage. For the 100-day pumping period, no recharge from rainfall would be unusual and for the 1,000-day period would be impossible, according to rainfall records. Figure A15 shows the effect of recharge from rainfall and drought on the water level in the water-table aquifer. Figure A15 clearly demonstrates by fluctuations in the water level in 1951-52 and in 1957-58 that the effect of rainfall and drought on the water level in a few months is greater than the effect of pumping a well continuously for 100 days on the water level in the water-table aquifer 1,000 feet from the pumped well. Figure A17 also demonstrates that during the 100 days of continuous pumping, the effect of pumping on the water table would only reach less than a mile, and that beyond 1,000 feet from the pumped well the effect would be less than four feet. The graphs in Figure A17 have been computed using a coefficient of transmissivity of 100,000 gallons a day per foot and a specific yield, or coefficient of storage, of 0.15.

Table B17 gives the yield and specific capacity of large-diameter wells tapping the Quaternary deposits and estimated transmissivity of the aquifer from Richard H. Johnston (1974).

Coefficients of Storage in the Water-Table Aquifer

Coefficients of storage have been determined from observations in three wells during pumping tests to determine aquifer coefficients. All of the determined values are too low. The true coefficient of storage probably approaches the effective specific yield of the aquifer. Earlier discussion in this report indicates that the effective specific yield is in the order of 0.15. In nearby Salisbury, Maryland, Rasmussen and Slaughter (1957) report a coefficient of storage for the aquifer of 0.15. The figure is in harmony with the effective specific yield determined in this study from the fluctuation of water levels in wells Md22-1 and Qe44-1. The figure of 0.15 was used for the effective specific yield in appraising the water-table aquifer in Kent and Sussex Counties (Sundstrom and Pickett, 1968 and 1969) and is the figure used herein.

Recharge to the Water-Table Aquifer

Recharge to the water-table aquifer is a substantial part of the precipitation that falls on the surface of Sussex County. The average amount of precipitation is 46.55 inches annually. On an average daily basis, the precipitation is equal to slightly more than two billion gallons a day for the report area or about 2,200,000 gallons a day per square mile. Barksdale and others (1958) estimated 20 to 21 inches of the annual rainfall was available to recharge the outcrop and subcrop of the Raritan aquifer in Delaware. The same amount or slightly more should be available to recharge the water-table aquifer in Sussex County. In the Salisbury area of Maryland, Rasmussen and Andreasen (1959) report recharge to the water-table aquifer of 42.63 inches over a two-year period. In Sussex County, an average annual recharge of 21 inches seems reasonable. If this estimate is reasonable, then the average annual recharge to the area as a whole is about 950 million gallons daily, or one million gallons per day per square mile. The recharge is adequate to keep much of the aquifer brimful as shown in Figure 37, and in several areas swamps are general. Pumpage in parts of the aquifer might lower the water table and induce considerably more recharge. The stage of the aquifer is illustrated in Figures 38 and 39.

Discharge of the Water-Table Aquifer

Discharge from the water-table aquifer is a continuous process. It provides the fairweather flow of the streams, the ground water that is used in Sussex County, the recharge to the underlying artesian aquifers and a part of the evaporation directly to the atmosphere, and a part of the transpiration of trees and plants growing in the area. The discharge of the water-table aquifer to the fairweather flow of the streams is quantitatively the most important.

Many hydrologists have studied the relation of ground-water discharge to the total discharge of streams. Two important studies of this relation have been made in the nearby Beaverdam Creek watershed just south of the report area in Maryland. Rasmussen and Andreasen (1959) made a two-year study and found that nearly 26 percent of the rainfall that fell on the watershed reached Beaverdam Creek as ground-water discharge. Meyer and Bennett (1955) analyzed 14 years of streamflow records and reported the average daily discharge of the stream as 764,000 gallons a day per square mile, of which 602,000 gallons a day per square mile was ground-water discharge. For the purpose of this study, Meyer's and Bennett's figure for ground-water discharge has been used because the precipitation during the two-year study of Rasmussen and Andreasen was 5.64 inches annually less than normal.

The discharge of the Nanticoke River over a period of 24 years has averaged 776,000 gallons a day per square mile. The Nanticoke average discharge per square mile is almost identical with that reported by Meyer and Bennett. Using the same proportion for ground-water discharge as Meyer and Bennett used, the ground-water discharge of the Nanticoke River near Bridgeville was 611,000 gallons a day per square mile. Based on this analysis and applying it to Sussex County as a whole, the gravity drainage of ground water received by streams amounts to about 580 million gallons a day, or about 61 percent of the recharge to the aquifer. The overland or flood runoff to streams that does not enter the ground-water reservoir averages only 157 million gallons a day.

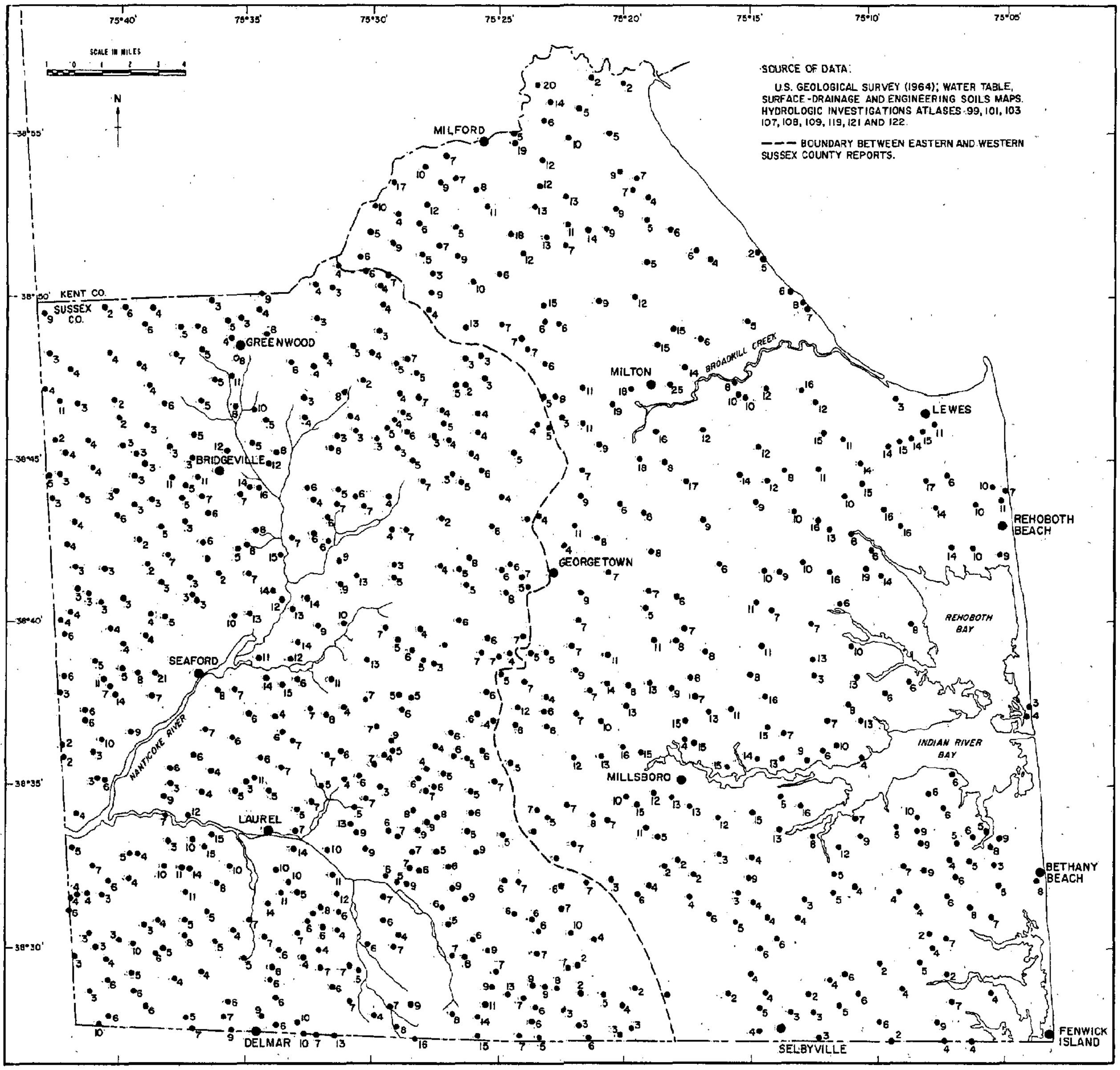


FIGURE 37. MAP SHOWING DEPTH TO WATER IN FEET BELOW LAND SURFACE IN THE WATER-TABLE AQUIFER IN SUSSEX COUNTY.

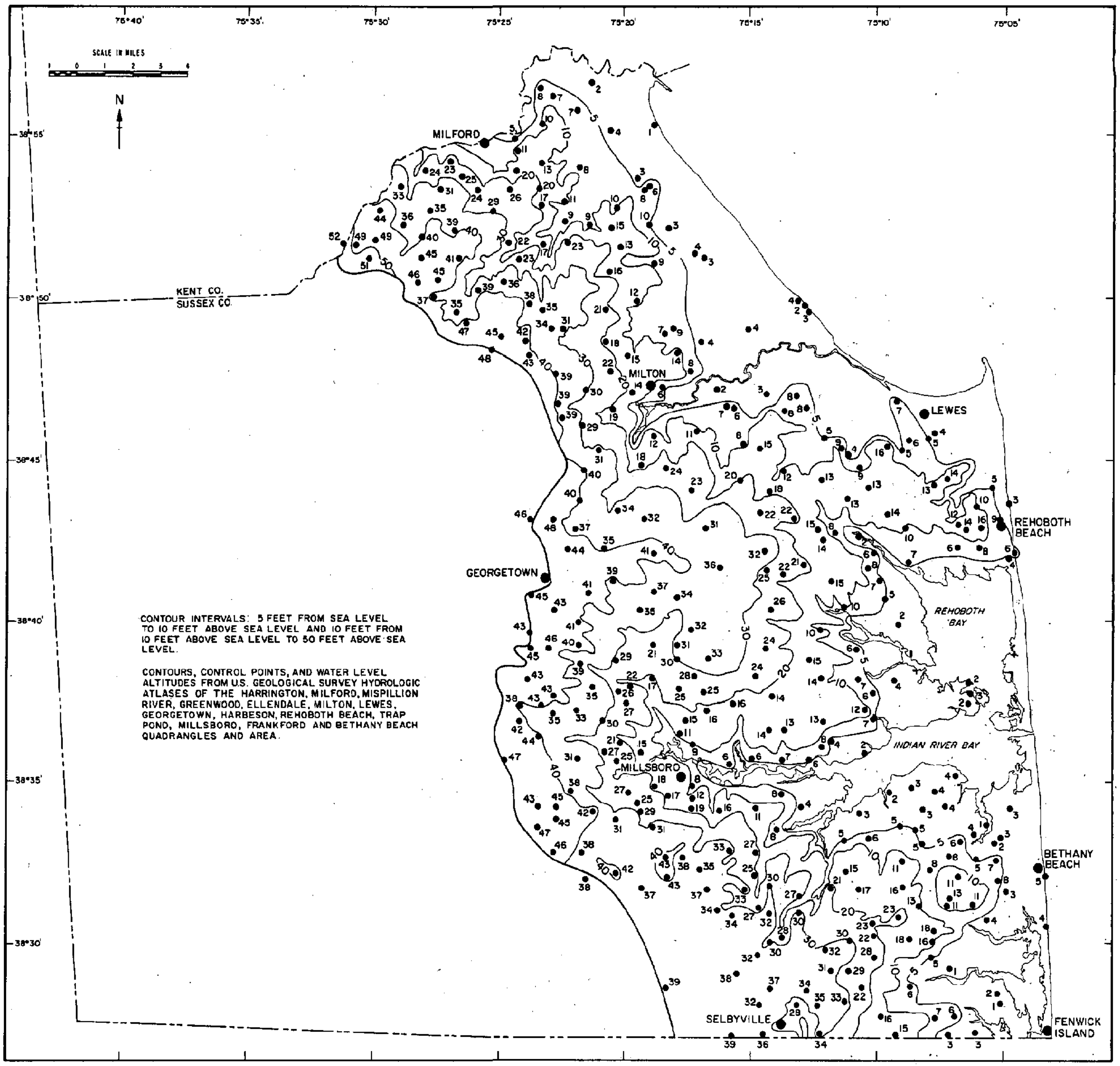


FIGURE 38. MAP OF EASTERN SUSSEX COUNTY SHOWING THE ALTITUDE OF THE WATER TABLE IN THE WATER-TABLE AQUIFIER OF THE PLEISTOCENE AND SUBCROPPING MIOCENE SANDS.

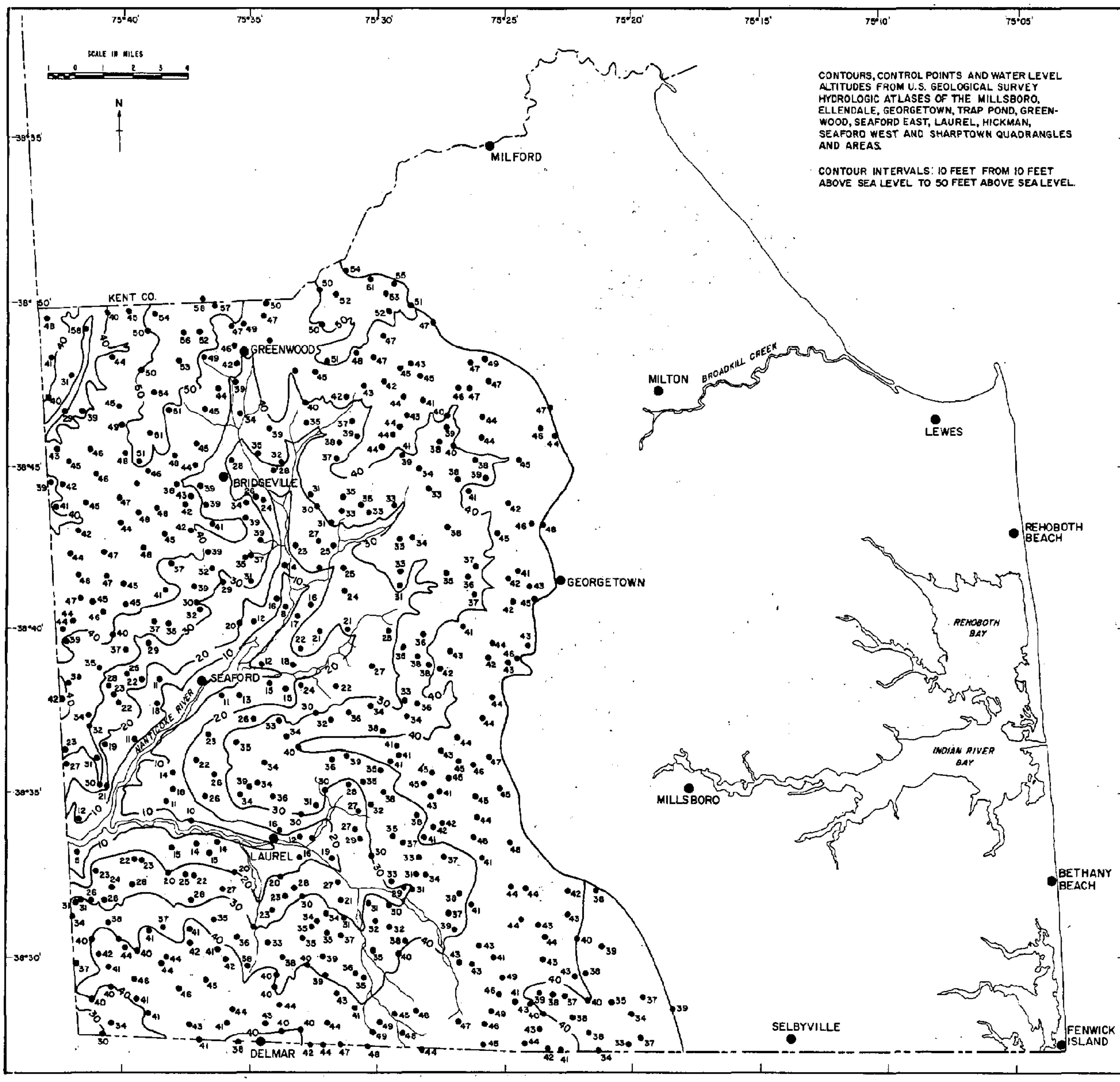


FIGURE 39. MAP SHOWING CONTOURS ON THE ALTITUDE OF THE WATER TABLE IN WESTERN SUSSEX COUNTY.

Availability of Water from the Water-Table Aquifer in Eastern Sussex County

Pleistocene deposits cover or underlie the entire area of eastern Sussex County. The water-table aquifer formed by the Pleistocene and subcropping Manokin and Pocomoke sands ranges from 70 to 150 feet in thickness and provides moderate to large supplies of water to wells. In appraising the availability of water from the aquifer, it must be kept in mind that the aquifer is not only a source of water to wells, but it also provides the fairweather flow of the streams in the area, provides the hydraulic gradient that protects the aquifer from the ingress of salt water, provides recharge to the artesian aquifers, and provides more than 90 percent of all of the ground water used. The nearly 18 million gallons a day that are now used show little or no effect on the aquifer. The effect of departures from normal precipitation is estimated 10 to 20 times greater than the effect of pumping.

All of the water-table aquifer coefficients are favorable for large development of ground water throughout most of the area. Development of large supplies are feasible, except where limited by the salt-water problems or by the need for maintaining fairweather flow of streams. It is evident that by proper and planned development more than 100 million gallons a day can be developed from the water-table aquifer without seriously harming the other useful functions of the aquifer.

Availability of Water from the Water-Table Aquifer in Western Sussex County

The amount of ground water available from the water-table aquifer of the Pleistocene and subcropping Miocene sands is large and exceeds 100 million gallons daily. To assess the yield of the aquifer more closely, many hydrologic facts concerning the aquifer must be kept in mind, and in developing plans to use the aquifer these hydrologic facts must be weighed and applied in deciding the best and proper use of the aquifer. For example, if the ground-water contribution to streamflow were disregarded, Sundstrom and Pickett (1970) show that the gravity drainage amounting to 280 million gallons a day, plus salvaged evaporation, could be used to boost the yield of the aquifer to wells past 300 million gallons daily. Such development might be very beneficial to agricultural pursuits and at the same time would be detrimental to the water supply, recreational facilities and sanitary aspects of the streams.

Some of the hydrologic factors that affect the water-table aquifer discussed in this report are: (1) on the average, slightly more than one billion gallons of water fall in the report area daily; (2) of the water that precipitates on the area, about 460 million gallons a day are available for recharge; (3) about 280 million gallons a day reach the streams as gravity drainage or ground-water discharge; (4) about 12 million gallons daily are pumped from wells; (5) an unknown small amount moves downdip in subcropping artesian ground-water reservoirs; and (6) the remainder of the recharge is dissipated by evapotranspiration or change in the volume of storage within the aquifer.

In considering the precipitation that falls on the area, these observations are apparent: (1) wet periods and droughts can make the water table fluctuate five to seven feet in a period of a few months (Figures A14 and A15); (2) drought periods have reduced the ground-water discharge to many small streams to zero, and in the Nanticoke at Bridgeville, the ground-water discharge to the river has been observed as low as 6.3 cubic feet per second, representing a ground-water flow to the river of only about 37 gallons a minute for each square mile of drainage area; (3) precipitation that falls on the area exceeds the recharge to the ground-water reservoir by an average of more than 640 million gallons a day with much of the water falling in areas where the water-table aquifer is brimful and in areas of swamps where the surface is covered with water at the time precipitation falls; (4) precipitation that falls on the area exceeds the overland surface runoff to streams by about 924 million gallons a day.

In considering recharge to the water-table aquifer, these observations are apparent: (1) of the estimated average 460 million gallons daily available to recharge the aquifer, about 12 million gallons a day are removed from the aquifer by pumps, and about 280 million gallons a day are fed to the streams by gravity drainage; (2) the remaining 168 million gallons are largely paid out from the ground-water reservoir by evapotranspiration. Presently, the recharge to the aquifer is taking place under natural conditions. The aquifer could probably be developed to take more induced recharge by lowering the water table in some areas where it is close to the surface. This is possible in both intake and discharge areas. The streamflow would be affected in discharge areas; swamps would be affected in the intake areas.

A study of 24 years of streamflow data on the Nanticoke River near Bridgeville indicates that, on the average, the discharge of the river is 776,000 gallons a day per square mile of drainage area of which 79 percent of the discharge is computed to be from ground-water gravity drainage. The Nanticoke records further show that during three months of drought in July, August and September 1957, the flow of the river only amounted to 207,000 gallons a day per square mile of drainage area, or about 143 gallons a minute per square mile.

On September 29, 1943, the discharge of the river declined to 54,000 gallons a day per square mile, or less than 40 gallons a minute per square mile. The records show that storage is needed to supplement the ground-water discharge in order to maintain the flow during prolonged drought.

Under prudent planning, development and management, the combined supply of ground and surface water supplying the streamflow in the area can be reasonably stabilized so that the ground-water supply can be increased tenfold over the present usage or to about 120 million gallons a day. In accomplishing the increased ground-water withdrawal, water lost to evapotranspiration in the high water table and swampy areas should be salvaged as much as possible to minimize the effect on the fairweather flow of the streams. Base flow of the streams can be supplemented by pumped ground water during extreme drought periods if necessary.

Quality of Water from the Quaternary Aquifer

Tables 19 and 20 show that the water from the Quaternary aquifer is generally of good quality except for the high iron and manganese content of samples of water from some of the wells. The low hydrogen ion concentration in the water from many of the wells indicates that the water is acid in character. Consideration must be given to treatment of the water in several areas to make it suitable for some uses. Areas of similar chemical quality of ground water and areas of potential salt-water intrusion into the Quaternary aquifer are shown in Figure 40.

Table 19.

Quality of Ground Water and Potential Saline-Water Intrusion in the Quaternary Aquifer, as Shown in Figure 40

Chemical constituents in ground water in the Quaternary aquifer (concentration of constituents in milligrams per liter)

Area	1	2
Dissolved solids*	<100	100-250
Hardness	<35	35-150
Sodium	2-20	12-70
Bicarbonate	5-40	10-140
Chloride	5-20	10-70
Fluoride	<0.2	<0.2
Silica	10-30	15-40
Iron and manganese	0.02-21	0.02-17
pH	5.4-7.0	5.8-7.5

*In area 1, dissolved solids x 1.20 = specific conductance (Micromhos at 25°C)
In area 2 dissolved solids x 1.45 = specific conductance

From Cushing, Kantrowitz and Taylor, 1973.

Table 20.

Chemical Constituents in Water from 19 Wells
Tapping the Columbia Deposits

(Chemical Constituents in Milligrams Per Liter)

Constituent of Chemical Property	Minimum	Maximum	Average
Silica (SiO_2)	9.8	25	16
Iron (Fe)	.00	2.1	.33
Calcium (Ca)	1.6	17	7.6
Magnesium (Mg)	0.4	13	5.2
Sodium and Potassium (Na + K)	3.7	40	15
Bicarbonate (HCO_3)	4	38	17
Sulfate (SO_4)	0.4	40	13
Chloride (Cl)	4	86	21
Nitrate (NO_3)	0	36	13
Dissolved Solids	50	235	113
Hardness (as $CaCO_3$):			
Calcium, Magnesium	5	93	39
Noncarbonate	0	64	18
pH	5.4	7.5	6.1

From R. H. Johnston, 1974.

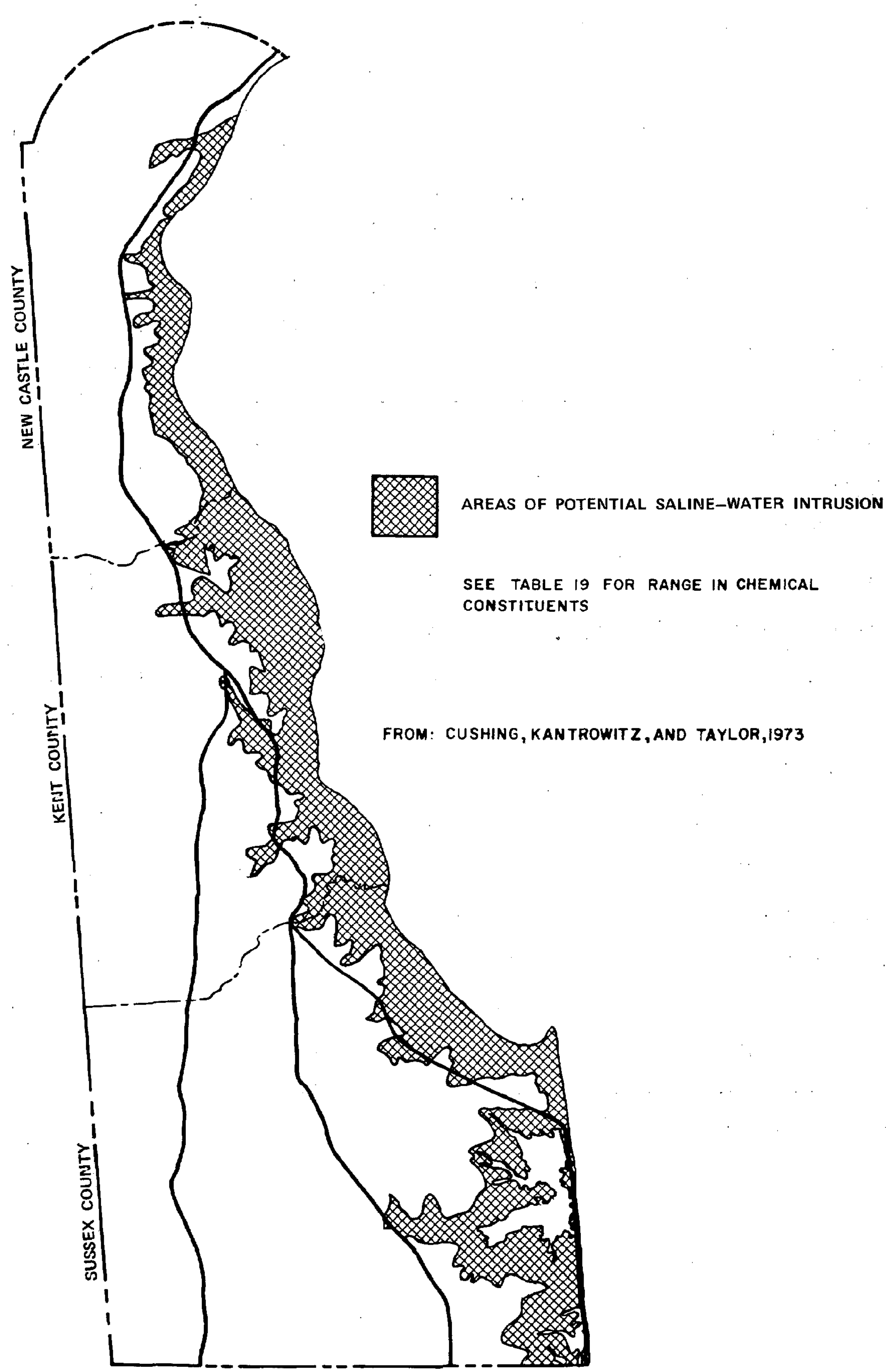


FIGURE 40–AREAS OF SIMILAR CHEMICAL QUALITY OF GROUND WATER & AREAS OF POTENTIAL SALINE-WATER INTRUSION IN THE QUATERNARY AQUIFER.

WATER RESOURCES PROBLEMS

THE SALT-WATER PROBLEM

This section of the report discusses the probability of salt-water problems in the aquifers of eastern Sussex County. The Atlantic Ocean, the Delaware Bay, the four inland bays (Rehoboth, Indian River, Little Assawoman, and Assawoman) and the tidal estuaries draining to these bays all contain highly mineralized water. The Atlantic Ocean is in direct contact with the water-table aquifer from Cape Henlopen to the southern end of the area near Fenwick Island. The inland bays, whose outlets are to the ocean and the tidal estuaries discharging into the bays, all overlie the Pleistocene water-table aquifer. In most places the aquifer is discharging fresh water into the inland bays and tidal estuaries. The subcrops of some of the artesian aquifers extend as far as northern Kent County so that they are crossed by Delaware Bay as much as 40 miles upstream from the mouth of the bay.

The Delaware Bay, with its mouth in direct contact with the Atlantic Ocean, extends 48 miles upstream to the beginning of the Delaware River Estuary at Liston Point, Delaware. The estuary of the river then continues upstream 86 more miles to Trenton, New Jersey. Above Trenton, the river ceases to be tidal and the river proper begins. At the beginning of the estuary at Trenton, the stream contains fresh water and the river's estuary remains relatively uncontaminated by salt water for many miles downstream from Trenton. At Memorial Bridge near Wilmington during periods of low river flow and high tide from the Bay, chlorides are often above 1,000 parts per million and on occasions reach 1,700 or more parts per million. Downstream from Memorial Bridge about 12.5 miles at Reedy Island Jetty, Delaware, and about 9.5 miles above the New Castle-Kent County boundary line, the chlorides during similar periods will reach more than 6,000 parts per million. During these periods of high chloride, the low for the day may not decline more than 2,000 parts per million from the high for the day. About two-fifths of eastern Sussex County is bounded on the northeast by the lower part of Delaware Bay, where the chloride concentration of the Bay approaches that of the Atlantic Ocean. The subcrops of the lower Miocene artesian aquifers are of sufficient distance upstream to be crossed by the middle section of the bay.

The Piney Point Aquifer Crossed by Delaware Bay

The Piney Point aquifer lies at depths of 200 feet or more below sea level where it is crossed by Delaware Bay. The Cheswold, Frederica and minor Miocene aquifers containing fresh water lie above the Piney Point and are also crossed in subcrop by the Delaware Bay in northern Kent County. No evidence of contamination from the Bay has been found in the overlying Cheswold or Frederica aquifers in the subcrop area in Kent County. The confining clays and overlying sands of the Cheswold and Frederica containing fresh water preclude salt-water contamination in the Piney Point.

The Interface Between Fresh and Salt Water in the Piney Point Aquifer

The interface between fresh and salt water is believed to be close to the Kent-Sussex County boundary line. A test well drilled to the Piney Point at Milford in 1968 obtained water that contained 540 parts per million of chloride. This amount of chloride in relation to the depth of the aquifer and the original artesian pressure lends evidence that the fresh-salt water interface is nearby. The chloride content, although not sufficiently high to make the water unusable for some purposes, is more than twice as high as recommended for public consumption on public carriers by the U. S. Public Health Service. If the chlorides found in the water in the test well are an indicator of the proximity of the interface, then the water should increase considerably in salinity a few miles downdip.

The Cheswold Aquifer Crossed by the Delaware Bay

In considering the salt-water problem in Kent County in 1968, Sundstrom wrote the following about the outcrop of the Cheswold:

> "The outcrop of the Cheswold aquifer extends across the northern part of Kent County. In the extreme northeastern part of the County, the Cheswold outcrop is about two miles wide where it is crossed by the Delaware Bay. The problem of the possibility of salt-water leakage from the estuary of the Delaware to the outcrops of the ground-water aquifers crossed by the estuary was given considerable study during an earlier investigation in 1967 of the availability of ground water from the Potomac Formation to the north in New Castle County. No evidence of contamination of the Potomac Formation by the estuary was found, and Dr. R. R. Jordan of the Delaware Geological Survey reports a Delaware Research Foundation study in progress in which he was of the belief that the nature of the sediments in the bed of the estuary that protected the Potomac were such that they formed a protective seal of the bottom of the estuary downstream past the southern New Castle County line.
>
> "Dr. Jordan has continued his study of the Delaware Estuary and Bay sediments and presented his findings in a paper presented at the Northeastern Section Meeting of the Geological Society of America in Washington, D.C., February 17, 1968. The paper is entitled: 'Suspended and Bottom Sediments in the Delaware Estuary.' Jordan's

study reveals that in the Bay 10 to 11 miles southeast of Woodland Beach, Delaware, a transition from fine to coarser sediments begins and that the sediments get progressively coarser to the mouth of the Bay where sand predominates. The Bay crosses the outcrop of the Cheswold aquifer about 9 to 12 miles above the transition zone of the fine to coarser sediments in the Bay as described by Jordan. The outcrop of the Cheswold is overlain by fine Bay bottom sediments, and the distance to the coarser sediments affords protective cover to the outcrop of the aquifer. Protection from salt-water intrusion is further provided by the high water table in the Cheswold outcrop and overlying Pleistocene. (See the Smyrna Hydrologic Atlas of the U. S. Geological Survey.) Pumping has been in progress from the Cheswold for more than 75 years with no reports of intrusion into the aquifer anywhere in the County."

The Interface Between Fresh and Salt Water in the Cheswold Aquifer

The position of the interface in the Cheswold is unknown. The aquifer yields fresh water at Milford and at Gravel Hill near Georgetown. In 1968, A.C. Schultes and Sons drilled test well Me15-29 at Milford and sampled the water from sands in the Cheswold from 370 to 430 feet below land surface. The analysis of this sample showed nine parts per million of chloride. In 1969, Paul White Drilling Company drilled test well Og31-1 and obtained a sample of water from the Cheswold. The United States Geological Survey analyzed the water and found 10 parts per million of chloride. This suggests that the Cheswold aquifer probably contains fresh water to a depth considerably below 600 feet below sea level. The test of the Cheswold near Georgetown and an early test near Lewes indicated that the Cheswold was not a promising aquifer in terms of yield to wells. Dr. Pickett in Figure 9 of this report indicates that the Cheswold probably pinches out at a depth of about 700 feet below sea level. On this basis a fresh-salt water interface in the Cheswold does not exist in the report area.

The Frederica Aquifer Crossed by the Delaware Bay

The Frederica aquifer subcrops beneath the Pleistocene sediments in northern Kent County. In 1968, Sundstrom in studying the salt-water problem in Kent County wrote about the Frederica aquifer crossed by the Delaware Bay as follows:

"The outcrop of the Frederica aquifer is crossed by the Delaware Bay five to seven miles upstream from the transition zone from fine to coarser sediments and is about four miles closer to the zone than the outcrop of the Cheswold aquifer. The Frederica outcrop is not only protected by the fine sediments in the bottom of the Bay, but it is also protected by the high water table in the outcrop and overlying Pleistocene and by the clay cover downdip that forms the confining beds of the Frederica artesian aquifer. No evidence of salt-water contamination of the Frederica was found and it is believed that the aquifer is safe from salt-water encroachment."

The Interface Between Fresh and Salt Water in the Frederica Aquifer

The Frederica contains fresh water at Milford, Lewes, Cape Henlopen and Gravel Hill near Georgetown. At Cape Henlopen and Gravel Hill the Frederica is reported to yield only 15 to 30 gallons a minute. The drill cuttings at Gravel Hill were inspected and indicated a poor-yielding aquifer. Dr. Pickett indicates in Figure 9 that the Frederica aquifer probably pinches out at a depth of about 400 feet below sea level. A fresh-salt water interface in the Frederica aquifer probably does not exist in the report area.

Minor Artesian Aquifers in the Miocene Above the Frederica Crossed by the Delaware Bay

Shallow artesian aquifers above the Frederica are found in the southern part of Kent County. These aquifers and perhaps others exist in the northern part of eastern Sussex County. Concerning the salt-water problem where these aquifers are crossed by the Delaware Bay, Sundstrom (1968) wrote:

> "Shallow artesian aquifers above the Frederica aquifer are found in the southern part of the county. Two of these aquifers are used in the vicinity of Milford and perhaps elsewhere in the southern part of the county. Little is known about the areal extent of the reservoirs away from Milford. The outcrops of the aquifers, if they exist, probably lie south of the transition zone between the fine and coarser sediments and would probably be more susceptible to salt-water intrusion if the protective hydraulic gradient of the Pleistocene over their subcrop were lowered below sea level. There is no evidence of salt-water contamination of the shallow Miocene artesian aquifers."

The Delaware Geological Survey reports the log of a well, Mh41-1, at Shorts Beach on Delaware Bay. The log records brackish water in Pleistocene sediments 36 to 50 feet below the surface, and in Miocene sands 138 to 150 feet below the surface. The surface altitude at the well is five feet. The drillers log of the well shows only sand sections between Pleistocene and Miocene sediments; thus the Miocene sands appear to be in direct contact with

Pleistocene sands. Contamination might be accounted for by either low water-table altitude or by hurricane flooding or by both.

The Subcrop of the Manokin Aquifer and the Relation to Salt Water of the Atlantic Ocean and to the Salt Water of the Inland Bays and Estuaries

The subcrop of the Manokin aquifer with the overlying Pleistocene removed is shown in Figure 2. In this illustration, Dr. Pickett shows the Manokin subcrop removed by erosion along the Delaware Bay during Pleistocene time except for a narrow tongue of the subcrop reaching the Bay near the outlet of the Broadkill River. The Broadkill River, containing saline water, crosses Pleistocene sediments over much of the eastern central part of the subcrop. In both the area of the tongue and in the area crossed by the Broadkill, the altitude of the water table is not adequate to protect some parts of the aquifer from salt water. The low altitudes below the five foot contour line are shown in Figure 38 and demonstrate some of the danger points. The depth to fresh or salt water in most of the water-table aquifer is established by the altitude of the water table and by the ratio of the densities of the fresh water in the aquifer to the salt water in contact with the fresh water.

The Interface Between Fresh and Salt Water in the Manokin Aquifer

In the subcrop where the fresh water head has been more than four feet above sea level and the surface has not been periodically flooded with salt water from hurricane storms, there seems to be little danger of the presence of salt water in the aquifer. The base of the subcrop Manokin reaches a maximum depth of about 150 feet below sea level. Where the fresh water head is less than four feet above sea level or where salt water floods from storms have occurred, there is a good possibility of salt water in the subcrop. Based on the altitude of water levels in the aquifer, it is believed that the closest source of salt water is at the subcrop near Delaware Bay or the estuary of the Broadkill River. The Delaware Bay area is the most likely source of contamination. In the artesian part of the Manokin aquifer, the artesian head is adequate to protect the aquifer.

The Subcrop of the Pocomoke Aquifer and Its Relation to Salt Water of the Atlantic Ocean and Salt Water of the Bays

The Pocomoke subcrop lies beneath the Pleistocene water-table aquifer. Dr. Pickett shows the position of the subcrop in Figure 2. The eastern boundary of the subcrop is shown four to eight miles inland from the Atlantic

Ocean and is overlain by salt water only in the northern part by Indian River Bay and by a small branch of Little Assawoman Bay in the eastern part. The contact, of course, is separated by the Pleistocene aquifer which overlies the Pocomoke. The Pleistocene sediments are in direct contact to the east with the ocean and the inland bays. Indian River Bay contains highly mineralized water. Dr. John C. Kraft, Chairman of the Geology Department, University of Delaware, determined the salinity content of the bay in two sections through the tide cycle. The lower section, which represents the midsection of the bay proper, shows water containing 28,000 to 30,000 parts per million of salinity. The upper section shows water containing 6,000 to 11,000 parts per million of salinity through the tide cycle in the upper part of the bay. Dr. Kraft's observations were made July 17 and 20, 1967, and are given in Figure A18.

Most of the Pocomoke subcrop and overlying Pleistocene aquifer are protected from salt-water intrusion by adequate head of fresh water in the water-table aquifer. However, some of the area lies beneath a water table less than four feet above sea level. In the areas of low water table the same discussion given to the Manokin applies to the Pocomoke except that the Pocomoke, as shown in Figure 2, is more remote from the ocean than the Manokin is from the Delaware Bay. The areas of low head in the water-table aquifers of the Manokin, Pocomoke and Pleistocene are shown in Figure 38. The illustration also shows the thickness of the Pleistocene aquifer above the Manokin and Pocomoke. The total thickness of Manokin and Pocomoke subcrops combined with that of the Pleistocene aquifer is generally less than 160 feet in thickness.

The Quaternary and Subcropping Miocene Water-Table Aquifer Adjacent to Delaware Bay, the Atlantic Ocean, the Inland Bays and Stream Estuaries

Most, if not all, of the salt-water problems in the water-table aquifer of the Pleistocene and subcropping Miocene sands will occur in the area shown in Figure 38 where the altitude of the water table is five feet above sea level or less. More than 20 percent of the report area is bounded by the five foot contour. In this area there are a few localities in which fresh water cannot be obtained from the water-table aquifer. This is true at some localities on the barrier beach in the southern part of the area. Some of the salt water in the aquifer probably has never been replaced by fresh water because of the lack of fresh-water head to displace the salt water. Figure 38 shows several locations where the fresh-water head is only one, two, or three feet above sea level. Sundstrom and Pickett's report of 1969 lists 69 wells in the water-table aquifer in which the water level has been measured three feet or less above sea level. In these areas of very low water-table altitude and close proximity to salt water, the possibility of contamination must be considered, although it is believed that most of the wells of small yield that are now producing fresh water will continue to produce fresh water. In areas of low water-table altitude where pumping has been heavy, trouble can be expected and has been encountered, especially at Lewes and Rehoboth Beach. Problems at both places have been alleviated by moving away from the area of contamination and to an area of higher fresh-water head in the aquifer.

The water-table aquifer, where the water table is five feet or less, is estimated to contain more than 300 billion cubic feet of material saturated with fresh water. Only about three percent of it lies above sea level. Salt-water problems can occur at many places in the area. In some places where the aquifer contains only salt water there is no remedy, except to go elsewhere for water. In most of the area, pumping of small quantities of water probably will not present a problem. Where heavy continuous pumping is contemplated, the wells should be developed in areas where the water-table head is 10 feet or more above sea level.

GROUND-WATER CONTAMINATION

Man-made ground-water contamination problems are many. Examples of such contamination can be cited; but it is believed that no overall study of the damages has ever been made. New Castle County has done a very large amount of work to determine the cause and cure of the Llangollen landfill leachate problem. The results of these studies have been documented for the Department of Public Works, New Castle County, by Roy F. Weston and Associates, 1972 and 1974; by R. W. Sundstrom, 1974; and by the Delaware Department of Natural Resources and Environmental Control. Delaware has many more landfill projects; but the effect of contamination from leachate, if any, is unknown for most of them.

Dredging along the Chesapeake and Delaware Canal is thought to be responsible for high chlorides in shallow wells in the vicinity of the dredging spill. This contamination may be of short duration over a term of a few years because of the natural hydraulic gradient back toward the canal.

Fertilizers (chemical and animal, especially chicken) pose problems of added nitrates to the water-table ground-water reservoir. However, an allowable concentration of 45 parts per million in the ground water is seldom exceeded.

Salt-water intrusion has taken place in the water-table aquifer along the coast in eastern Sussex County. Bethany Beach, Rehoboth Beach and Lewes all have had their problems. Large-capacity wells were developed in areas where the fresh-water head was less than 10 feet above sea level and when heavy pumping started, the pumping levels were lowered many feet below sea level. Encroachment took place in accordance to the relation of fresh water to salt water as described in Appendix C of this report. Lewes and Rehoboth Beach took care of their problem by moving their production wells to an area where the altitude of the water table was higher.

The magnitude of the effect of contamination of ground-water reservoirs from cesspools and septic tanks is unknown.

POTENTIAL PROBLEM AREAS

The New Castle County "corridor", when considered in terms of the "corridor" itself and in terms of the requirements of New Castle County, lies in a water-short area where there is not enough available ground water within the corridor to supply the area. It has been pointed out that under present conditions of development about five million gallons a day might be produced in a 5,000 acre area at the western end of the Chesapeake and Delaware Canal in Delaware. If pumpage should be developed in an adjoining area of Maryland, the overall pumpage would be reduced in Delaware by the pumpage in adjoining development in Maryland.

In the Lewes area development should be upgradient from the 10-foot contour shown on the water table. In upgradient areas adjacent to the 10-foot water-table contour, pumpage probably should be limited to 500,000 gallons a day per square mile and farther upgradient beyond the first mile to 750,000 gallons a day per square mile.

In the Dover area, Dover and the Air Force Base can still develop the Piney Point in its deepest and best section in a southwesterly direction to the Maryland state line, see Sundstrom and Pickett, 1968. Dover could also find favorable supplies in the Quaternary deposits in parts of southern and western Kent County.

AREAS OF NEEDED RESEARCH AND STUDY CONCERNING THE PROSPECTS OF USING ARTIFICIAL RECHARGE OR OTHER NEW SOURCES OF WATER

Comprehensive research and study of the prospects of using artificial recharge as a supplement to the water supply of New Castle County is needed. Such research and study must establish, without a doubt, whether or not the development of supplemental water supply from artificial recharge is a feasible and practicable development from the economic, environmental, engineering, hydrologic, geologic, sanitary and public welfare consideration. Among many problems that must be resolved are:

1. Is there available water, over and above present and future requirements, from the Brandywine, Red Clay and White Clay Creeks and the Christina River for supplying artificial recharge? If there is a substantial amount of water from these sources, can these sources fulfill the feasibility and practicability requirements for development? Are there better methods of using the water?

2. Can flood waters be stored from the Brandywine, Red Clay and White Clay Creeks for artificial recharge? Are detention reservoir sites available and feasible for storing the needed water? Are there better methods of holding and using the flood waters?

3. Can urban storm runoff through storm sewers be effectively captured and used for artificial recharge? Would the amount of water captured be significant in the total water requirement needs? Would such development meet feasibility and practicality requirements?

4. Can the proper treatment of 70 or more million gallons a day of effluent from municipalities and industries provide a supply of water that meets all requirements for water supply be used for artificial recharge? If this is possible, is this the best way to use the water?

5. Are ground-water reservoirs of adequate capacity and hydraulic properties available for receiving and paying out to pumps the artificial recharge water?

6. Are artificial recharge waters compatible with the native ground water?

7. What method of inducing the recharge water to the aquifer should be employed? What part of the induced recharge can be recovered?

8. Can the proper treatment of the large supply of effluent water allow the direct recycling of the water without going through the artificial recharge process? If not, can a part of it be used for industrial or agricultural purposes?

Problems such as the above must have adequate research, study and integration into the overall water supply problems of New Castle County before the prospects of artificial recharge can become a significant part of the county water supply. In the overall evaluation of water supply and problems of water supply, New Castle County north of the Chesapeake and Delaware Canal is in direct need of a new source or sources of water (see Figures 17 and 41).

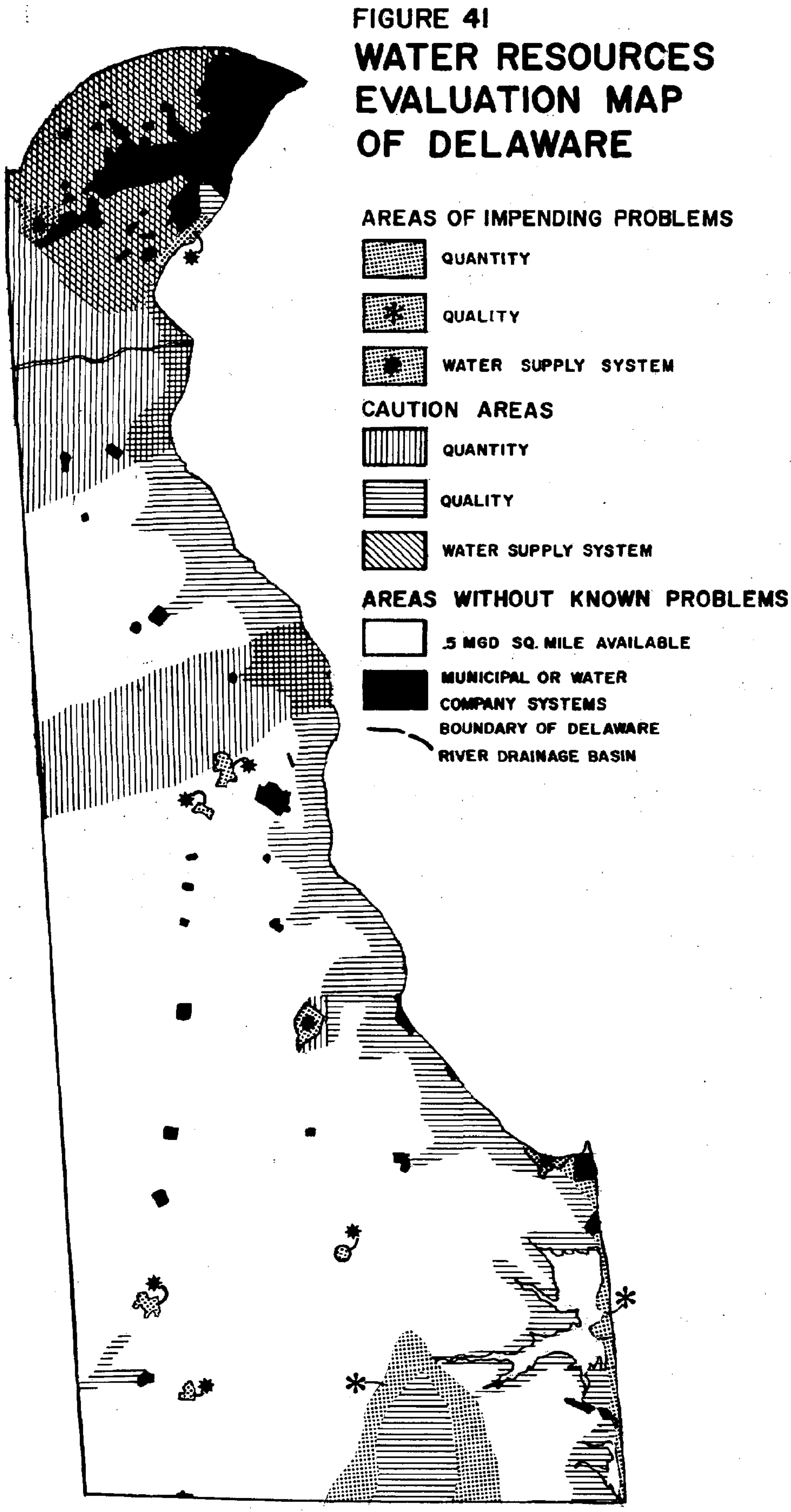


FIGURE 41
WATER RESOURCES EVALUATION MAP OF DELAWARE
AREAS OF IMPENDING PROBLEMS
QUANTITY
QUALITY
WATER SUPPLY SYSTEM
CAUTION AREAS
QUANTITY
QUALITY
WATER SUPPLY SYSTEM
AREAS WITHOUT KNOWN PROBLEMS
.5 MGD SQ. MILE AVAILABLE
MUNICIPAL OR WATER COMPANY SYSTEMS
BOUNDARY OF DELAWARE RIVER DRAINAGE BASIN

SUMMARY AND CONCLUSIONS

NEW CASTLE COUNTY

New Castle County encompasses portions of two geological provinces whose ground-water reservoirs vary widely in water-yielding properties. In northern New Castle County, the Appalachian Piedmont Province occupies about 113 square miles. The remainder of the county lies in the Atlantic Coastal Plain Province. The ground-water reservoirs in the Piedmont are contained in very old rocks of igneous or metamorphic origin. The aquifers of the Coastal Plain are in sedimentary material.

The ground-water reservoirs of the Piedmont provide about 67 percent of the flow of the Brandywine, Red Clay and White Clay Creeks and more than 30 percent of the flow of the Christina River. The amount of water contributed to the streams from the ground-water reservoirs of the Piedmont amounts to an average of 500,000 gallons a day per square mile of drainage. The ground-water reservoirs of the Piedmont on the whole are very poor providers of water to wells except in the Cockeysville Marble. Water occurs in fractures in the rock and wells must be located such that they intercept fracture concentrations or the yields will be very low. The yields of 103 randomly located wells (Sundstrom and Pickett, 1971) average 15.6 gallons a minute. Of the 103 wells, 83 had yields less than average. Only six wells yield more than 50 gallons a minute. A number of wells are known that yield considerably more water than those listed by Sundstrom and Pickett (1971). The Artesian Water Company has six wells in the Cockeysville Marble which have a maximum capacity of greater than 3.5 million gallons a day and are supplying the Artesian Water Company an average of 1.6 million gallons a day. Artesian presently has an allocation from the Department of Natural Resources and Environmental Control to pump up to 3.0 million gallons a day and withdraw an annual average of 1.9 million gallons a day. Extensive monitoring of precipitation, streamflow, well withdrawals and water levels are required to assess whether this allocation represents a sustainable yield for the aquifer and to determine the impact on existing well owners and streamflow. The City of Newark has completed several wells in the Wissahickon schist whose initial capacities range from 100 to 200 gallons a minute. Weighing all data presented in the New Castle County report, it appears probable that the development of ground water from wells yielding 75 or more gallons a minute from the granodiorite, gabbro and schists which comprise 98 percent of the Piedmont area, will not produce more than an average of five million gallons a day. The Cockeysville Marble probably will yield an average of two million gallons a day to large wells if solution channels can be found. The Piedmont aquifers, although poor in water-yielding properties to large wells, are very important to the large rural area of the Piedmont where individual supplies of a few gallons a minute will suffice. The Piedmont aquifers are of great importance to the base flow of the Brandywine, Red Clay and White Clay Creeks and the Christina River which contribute substantially to the water supply of northern New Castle County.

The ground-water reservoirs of the Potomac Formation consist of sands in two hydrologic zones in the Potomac Formation. The Potomac is a formation in which clays are more dominant than sands. In the outcrop and subcrops of the two aquifer zones, the sands of the Potomac are mantled in places by sands of the Pleistocene age so that, in places, sands of the Potomac and Pleistocene form a single water-table aquifer. The Potomac sands in outcrop or subcrop are estimated to cover about 60 square miles. Although the available recharge to the area amounts to about a million gallons a day per square mile, and under most favorable conditions could be pumped by wells, it is believed that the saturated thickness and low water-yielding properties of the aquifer in many places will cut the large-scale development of the outcrop or subcrop of the aquifer to about a third of its total areal extent, or to an available supply of about 20 to 25 million gallons a day. Of the available supply, 11 million gallons a day are now developed leaving 9 to 14 million gallons a day for future use. In the Chesapeake and Delaware Canal area, study has indicated the maximum amount of water from the artesian part of the Potomac aquifers to be about 11 million gallons a day, of which 4 million gallons per day have been developed. The canal study covers about 170 square miles extending six miles on each side of the canal in Delaware. There may be two to four million gallons a day available south of the area studied and north of the interface between the fresh and salt water in the aquifers. In all, about 18 to 25 million gallons a day are believed to be available from the Potomac outcrop-subcrop area and the artesian aquifers of the Potomac.

The available water from the Magothy aquifer is difficult to determine because of lack of the hydraulic coefficients required to determine the water-yielding properties of the aquifer. At Middletown the transmissivity of the aquifer is 4,000 gallons a day per foot of drawdown. If the Middletown test is representative of the aquifer as a whole, the water-yielding properties are about two-thirds that of the upper Potomac aquifer in the canal area. Using the hydraulic data of the upper Potomac aquifer in the Chesapeake and Delaware Canal area and applying it to the Magothy with proper adjustments, it appears that about three million gallons a day are available from the Magothy from properly spaced wells ranging in yield from 250 to 300 gallons a minute. For smaller supplies (wells yielding 10 to 50 gallons a minute), the Magothy, over an area of about 170 square miles north of the fresh-salt water interface in the aquifer, is a good to fair source of supply for rural water.

The availability of water in large quantities for large supplies is impracticable from the Englishtown-Mount Laurel aquifers because of the low water-yielding properties of the aquifers. At Middletown the transmissivity of the aquifers is only 1,800 gallons a day per foot, or less than half of the transmissivity of the Magothy aquifer. The aquifer is of value only to those who need small supplies for individual use.

The Rancocas is an important source of water in small quantities throughout the area in which the aquifer exists in southern New Castle County. The Rancocas aquifer is important as a source of water to wells yielding 300 or more gallons a minute in the area east and northeast of Smyrna in New Castle County. This is also true in a southwesterly direction from Smyrna in Kent County. The ultimate yield of the Rancocas aquifer in the deeper part in the two counties probably will not exceed six or seven million gallons a day to wells properly spaced yielding 300 or more gallons a minute. A larger total supply can be developed from wells yielding smaller amounts of water.

The available water from the water-table aquifer in the Coastal Plain of New Castle County is small in terms of an adequate supply to large-capacity wells of 500 or more gallons a minute each. This is especially true north of the Chesapeake and Delaware Canal. Although the water-table aquifer, where Pleistocene deposits contain 10 or more feet of saturated material, covers 182 square miles, the thickness of saturation of 40 feet or more needed to assure large-capacity wells occupies only 11 square miles, of which 8 are south of the Chesapeake and Delaware Canal. The Pleistocene water-table aquifer probably will supply large-capacity wells in these isolated areas in amounts equal to the available recharge, which would amount to about three million gallons a day north of the canal and about eight million gallons a day on the south side of the canal in the Middletown-Odessa and Smyrna areas. The total available supply to large-capacity wells in New Castle County is about 11 million gallons a day.

The Pleistocene is an important source of water to small wells over the entire area of 182 square miles where the Pleistocene has 10 or more feet of saturated thickness. Although the Pleistocene is a poor source of large supplies of water in the county, it has importance in maintaining the base flow of streams, in furnishing plant life moisture, in maintaining a reservoir of recharge water for the artesian aquifers, and in maintaining the hydraulic gradient that halts the ingress of salt water along the Delaware Estuary and Bay.

The prospects of supplementing the water supply of New Castle County by the use of artificial recharge to the ground-water reservoir of the Pleistocene is brought into focus in the New Castle County report (Sundstrom and Pickett, 1971). Whether or not such recharge is practicable and feasible can be told only after required research and study are made.

KENT COUNTY

The four major artesian aquifers of Kent County are the Rancocas, Piney Point, Cheswold and Frederica. The major water-table aquifer is found in the Pleistocene deposits that cover most of the surface of Kent County and in the underlying outcrop and near outcrop sands of the Miocene. Minor artesian aquifers are found in the Miocene deposits in the southern part of the county above and below the Frederica aquifer.

In Kent County the Rancocas aquifer is available for development in the extreme northern and northwestern parts. The aquifer will supply water to wells generally in amounts ranging from 50 gallons a minute in the extreme northwestern part of the county to as much as 600 gallons a minute near the downdip extremity of the aquifer at Clayton. The hydraulic properties of the aquifer have been determined and applied to assess the quantity of water available from the aquifer. Sundstrom and Pickett (1968) demonstrate that the ultimate yield under planned development does not exceed four million gallons a day in Kent County. The aquifer, because of its low specific capacity, coefficient of transmissivity, coefficient of storage and limited available drawdown is classified as fair to poor as a source of moderate quantities ranging from 200 to 600 gallons a minute.

The Piney Point aquifer is available for its maximum development along the axis of its thickest section which lies in a northeast-southwest direction from Port Mahon through the Dover Air Force Base well Je32-5 and beyond across Kent County, a distance of 21 miles. Two hypothetical plans for developing the aquifer have been presented in the Kent County report (Sundstrom and Pickett, 1968). The first plan shows that if 22 wells were used producing 500 to 600 gallons a minute, the aquifer would produce about 17 million gallons a day. The second plan demonstrates the use of 11 wells pumping 800 to 1,000 gallons a minute, which would produce about 14 million gallons a day. Both plans appear to be feasible and represent about the maximum amount of water that can be obtained with the given rates of pumping in the two hypothetical plans. Both plans take advantage of the thickest section of the aquifer. There is good evidence presented in the report, however not conclusive, that the water-yielding properties of the Piney Point deteriorate rapidly both updip and downdip from the thick section of the aquifer and in Kent County at a distance of about 12 miles in each direction the Piney Point ceases to be an aquifer of importance.

Except in the northern part, the Cheswold aquifer is available in much of Kent County. It is a highly-developed aquifer in the Dover-Dover Air Force Base area where peak pumpage from it reaches an average of about 6,500,000 gallons a day. Evidence is presented that this rate of pumping is about the maximum from the aquifer without readjustment of pumping rates in some of the wells in Dover. With adjustments, the total withdrawal from the Cheswold can be increased to eight million gallons daily. The Cheswold aquifer is rated good in the Dover-Dover Air Force Base area, but elsewhere ranges from fair to poor.

The Frederica aquifer is available in the southern part of the county. The hydraulic properties, as defined by the specific capacity, coefficient of transmissivity, coefficient of storage and available drawdown, are relatively low and for these reasons the aquifer is classified as only a fair water producer. Few wells produce over 300 gallons a minute from the artesian part of the aquifer and most of the wells produce much less. The maximum production of the Frederica, under planned control of spacing and yield, is about five million gallons a day.

Minor artesian aquifers above and below the Frederica exist in the southern part of Kent County and are developed in the Milford area. The transmissive properties of the aquifers have been tested and found to be low. The areal extent of the aquifers is not known and the available drawdown in them is small. It is estimated that the aquifers will not produce more than one million gallons a day.

Pleistocene age sediments cover about 88 percent of Kent County. In many places subcropping sands of Miocene age underlie the Pleistocene sediments to form a combined water-table aquifer. The aquifer furnishes meager to copious supplies of water to several hundred wells in the rural area of Kent County. Based on the saturated thickness of the water-bearing material in 161 wells, the water-table aquifer contains about 280 million cubic feet of water. The water in this reservoir is the recharge to the underlying artesian aquifers in their outcrop section; with the discharge from the aquifer that provides the fairweather flow of the streams; with the discharge from the aquifer that is yielded to evapotranspiration; with the hydraulic gradient that prevents the ingress of salt water in the Delaware Bay area; and with the supply to many hundred rural and city wells in Kent County. All of these functions of the aquifer pose related problems that require consideration in the ultimate and wise use of the aquifer. Under proper development, it is evident that a minimum of 100 million gallons daily can be developed without destroying the other useful functions of the aquifer.

Salt-water contamination from the Delaware Bay and associated tidal estuaries and marshland adjoining the bay appears to be a problem only to the development of ground water in the Pleistocene and underlying Miocene water-table aquifer adjacent to the salt water. The water-table aquifer is now discharging water to the bay and is protected by the high hydraulic gradient in the aquifer. The gradient could be reversed by pumping too close and too heavily near the source of salt water. If this should happen, salt water would start to move into the fresh water aquifer.

The Kent County report (Sundstrom and Pickett, 1968) concludes that there are about 34 million gallons daily available in the county from the artesian reservoirs and more than 100 million gallons daily available in the county from the water-table aquifer of the Pleistocene and subcropping Miocene sands. These available quantities are predicated on the proper development of the entire aquifers in the county.

EASTERN SUSSEX COUNTY

Sundstrom and Pickett (1969) summarize and give the following conclusions about their study of eastern Sussex County:

The availability of ground water from the aquifers yielding potable water in eastern Sussex County has been determined or estimated by methods of applied ground-water hydrology. The report discusses and appraises the availability of ground water from seven artesian aquifers and one water-table aquifer. The artesian aquifers are the Piney Point, the minor Miocene aquifer below the Cheswold, the Cheswold, the Federalsburg, the Frederica and the minor Miocene aquifers above the Frederica and the Manokin. The water-table aquifer is composed of sediments of Pleistocene age and subcropping Manokin and Pocomoke aquifers of Miocene age.

The Piney Point aquifer is available in the extreme northern part of the area in a strip less than four miles wide, bordering the northern boundary. Based on analysis of water from the aquifer, Milford is close to the fresh-salt water interface. The transmissive properties of the aquifer are extremely low. The extremely low transmissivity and the extremely low specific capacity of the Milford well indicate yields less than 30 gallons a minute. Wells will be costly to drill and pump. Total development of ground water in eastern Sussex County by many small wells will produce not more than one-half million gallons a day. For these reasons, the aquifer is not recommended for development.

A minor Miocene aquifer below the Cheswold is available in the extreme north and northwestern parts of eastern Sussex County in a strip 6 to 12 miles wide. Downdip from this strip the aquifer is believed to contain salt water. Low specific capacity of wells coupled with low transmissivity of the aquifer preclude the development of wells with yields over 200 gallons a minute. The low aquifer coefficients and low specific capacities of wells indicate the costs of producing water from the aquifer will be high. The aquifer may support a large number of small wells, but the total production from them is not likely to exceed three million gallons a day.

The Cheswold aquifer is available in the northern half of eastern Sussex County. It is encountered at a depth of 365 feet below sea level at Milford and about 600 feet below sea level at Lewes and Georgetown. It is believed that the aquifer disappears at a depth of about 700 feet below sea level in the vicinity of Rehoboth Beach and north of Millsboro. The aquifer is estimated to have a low transmissivity of about 6,000 gallons a day per foot at Milford. The transmissivity is believed to diminish in a downdip direction to an extremely low figure. Wells at Milford and near Georgetown have extremely low specific capacities. The unfavorable water-yielding properties of the aquifer indicate costly development. Generally, the quantity of water available from each well will not exceed 100 gallons a minute in the northern part or 30 gallons a minute in the southern part of the aquifer. The aquifer as a whole is unlikely to be developed. If developed, the production of 50 or more small wells is estimated at about 3,500,000 gallons a day.

The Federalsburg aquifer is available in the northern part of eastern Sussex County. At Milford the aquifer is reached at 270 feet below sea level. At Gravel Hill, about four miles northeast of Georgetown, the top of the aquifer is 520 feet below sea level. Elsewhere little is known about the depth or areal extent of the aquifer. The aquifer may be available in the northern and northwestern parts of the area. The yield of wells in the northern part of the area is generally expected to be less than 300 gallons a minute. Most of the wells may yield as little or less than 100 gallons a minute. If the aquifer is extensive, the estimated production will be less than five million gallons daily.

The Frederica aquifer is available over the northern part of eastern Sussex County. The aquifer is developed to capacity in Milford. Away from Milford, in the northern part of the area, wells yielding up to 250 gallons a minute may be developed. The meager data available in the central part of the report area indicate wells of only low capacity (50 gallons a minute or less) are obtainable. In the northern half of the report area, the aquifer may supply 3,500,000 gallons a day to many small wells.

The minor Miocene aquifer above the Frederica is used in the Milford area and is believed to supply water at Slaughter Beach. The aquifer may extend over more than the northern half of eastern Sussex County. In Milford the transmissive properties of the aquifer are slightly less than the underlying Frederica. Two city wells at Milford yield about 250 gallons a minute each. Downdip the water-yielding properties of the aquifer are believed to diminish progressively. If the aquifer is extensive in eastern Sussex County, it may yield a total of four to six million gallons a day to many small wells.

The Manokin aquifer subcrops beneath Pleistocene sediments in an area of about 75 square miles in the southern part of eastern Sussex County. The southern and thickest part of the subcrop extends from the mouth of the Broadkill River on Delaware Bay to the vicinity of Georgetown on the western boundary of the area. The thickness of the subcrop ranges from 0 to 40 feet. It is estimated that the subcrop contains about 144,000 acre-feet (47 billion gallons) of water available to wells. The water in the subcrop is not under artesian pressure. The subcrop, therefore, is part of the water-table aquifer of the overlying Pleistocene aquifer discussed later in this summary. The artesian part of the aquifer extends downdip from the southern extremity of the subcrop and is available for development to the southern boundary of the area. The artesian part of the aquifer has good to very good water-yielding properties. At Bethany Beach the transmissivity is 60,000 gallons a day per foot. It is estimated 20 to 30 million gallons a day can be developed from the artesian part of the aquifer.

The Pocomoke aquifer occupies an area of about 90 square miles in the southern part of eastern Sussex County. The Pocomoke aquifer subcrops beneath the Pleistocene in its entirety. The water in the aquifer is not under artesian pressure. The aquifer is therefore hydraulically a part of the overlying Pleistocene aquifer. The Pocomoke part of the water-table aquifer contains about 200,000 acre-feet (65 billion gallons) of water available to wells.

The water-table aquifer of Pleistocene age is available throughout eastern Sussex County. In about 75 square miles the subcrop of the Manokin of the Miocene is part of and contributes to the overlying water-table aquifer. In about 90 square miles the subcrop of the Pocomoke of the Miocene is a part of and contributes to the water-table aquifer. The saturated material of the water-table aquifer in volume is equal to 10 cubic miles and holds about three cubic miles of fresh water. The water contained in the aquifer is adequate to cover the surface of the report area to a depth of 30 feet. The aquifer receives on the average about 490,000,000 gallons a day of recharge from precipitation, most of which is rejected. The rejected recharge is about equally distributed between fairweather flow of streams and evapotranspiration. In about 20 percent of the area the water table in the aquifer is five feet or less above sea level. Salt-water contamination is a problem in parts of this area and other parts of the area may be vulnerable to salt-water problems in the future. The water-table aquifer not only supplies more than 90 percent of the ground water used in eastern Sussex County, but also supplies the water for fairweather flow of the streams, water that evaporates from the land and stream surfaces, water that transpires from the trees and plants, and water that recharges the artesian aquifers in their subcrops. Predicated on proper planning, development and use, the aquifer can supply more than 100 million gallons a day without seriously harming the other useful functions of the aquifer.

The salt-water problems of the subcrops of the artesian aquifers, of the fresh-salt water interface in the artesian aquifers and of the water-table aquifer have been given consideration in the eastern Sussex County report. The Atlantic Ocean, the Delaware Bay, the four inland bays (Rehoboth, Indian River, Assawoman and Little Assawoman) and the tidal estuaries draining to these bays all contain highly mineralized water. Some of these bodies of water cross the subcrops of the artesian aquifer. In some places the major salt-water problems of the area occur in the water-table aquifer where the water table is five feet or less above sea level. Major problems have occurred in the past at Lewes and Rehoboth Beach. Both cities solved their problem by moving their well fields. In a few localities the hydrology applied in relating the low altitude of the water table to the thickness of the aquifer indicates that the aquifer has always contained salt water and the only solution is to seek water elsewhere. Where such areas exist there is evidence that fresh-water supplies can be found within a distance of a few miles or less.

The conclusions concerning the eight aquifers studied in eastern Sussex County are:

(1) the extremely poor water-yielding properties of the Piney Point coupled with the apparent close proximity of the fresh-salt water interface preclude the development of the aquifer;

(2) the poor water-yielding properties of the minor Miocene aquifer below the Cheswold preclude development of wells of more than 200 to 300 gallons a minute, and the total available water from the aquifer from many small wells is not likely to exceed three million gallons a day;

(3) the unfavorable water-yielding properties of the Cheswold indicate that it will be costly to develop. Most of the wells are estimated to produce at a rate less than 100 gallons a minute and the total available water does not exceed 3,500,000 gallons a day;

(4) The fair water-yielding properties of the Federalsburg aquifer above the Cheswold in the northern part of the area indicates wells of 100 to 300 gallons a minute. The southern part of the aquifer will probably yield less than 100 gallons a minute to wells. The aquifer is estimated to have an available supply of not more than five million gallons a day to many small wells;

(5) the fair to poor water-yielding properties of the Frederica indicate wells of 50 to 250 gallons a minute. The aquifer is totally developed at Milford. It is estimated the available water from the aquifer in the northern part of the area may be 3,500,000 gallons a day;

(6) the fair water-yielding properties of the minor Miocene aquifer above the Frederica produces 250 gallons a minute from each of two wells at Milford. Downdip the yields probably would diminish to less than 100 gallons a minute. If the aquifer is extensive, many small wells might produce as much as six million gallons a day from the aquifer;

(7) the good water-yielding properties of the artesian part of the Manokin aquifer indicate that it will yield water to wells up to 500 gallons a minute in some places, and the available water from the aquifer is estimated to be 20 million to 30 million gallons a day;

(8) the water-table aquifer consisting of the Pleistocene deposits and subcrops of the Manokin and Pocomoke are available for development throughout the eastern Sussex County area, except in a small part of the area where the salt-water problem precludes development. The very favorable water-yielding properties and available recharge of the water-table aquifer make the aquifer available for large supplies of water in most of the area. Available recharge to the aquifer averages about 490 million gallons daily. The aquifer not only supplies more than 90 percent of the ground water used, but it also furnishes the hydraulic head that protects most of the aquifer from the intrusion of salt water; the fairweather flow of the streams; the recharge to the artesian aquifers; and the water that is discharged by evapotranspiration. It is evident that the aquifer can supply more than 100 million gallons daily to wells without seriously hindering the other useful functions of the aquifer, provided the development is properly planned and the pumping properly distributed.

WESTERN SUSSEX COUNTY

In summarizing and giving conclusions of their study of the availability of water in western Sussex County, Sundstrom and Pickett (1970) wrote:

The geology and hydrology of seven artesian ground-water reservoirs and one water-table aquifer in western Sussex County have been carefully studied. From these studies, methods of ground-water hydrology have been applied to compute or estimate the amount of ground water available from each of the aquifers. The study reveals that the water-table aquifer of the Pleistocene, Manokin and Pocomoke is by far the most prolific source of ground water in the area and can be developed throughout the area. Under prudent planning, development and management, the aquifer is capable of producing more than 120 million gallons a day. By lowering the water table by pumpage in the swampy areas, more recharge might be effected and the amount of water available in western Sussex County might reach 140 million gallons daily or more. Pumpage at this rate will probably affect to some extent the fairweather flow of ground water to streams; but, if properly planned, the effect will not be serious because much of the water will be derived from the surface swamps and shallow ground water that is normally lost to evapotranspiration. The water-yielding properties of the water-table aquifer are good to excellent over the entire area. The aquifer should supply wells of proper construction and pumping facilities with supplies of water ranging from about 400 to 1,200 gallons a minute.

Of the seven artesian aquifers studied, only the Manokin artesian aquifer of the Miocene has good to excellent water-yielding properties. The Manokin occurs under both water-table and artesian conditions. In its water-table area, it is a subcrop of the Pleistocene water-table aquifer. The artesian part of the Manokin begins at the southeastern edge of the subcrop and extends under about 77 square miles of overlying Miocene clay. The artesian Manokin aquifer has a probable transmissivity of about 60,000 gallons per day per foot and probably can be developed to yield about 20 million gallons a day.

The minor Miocene aquifers above the Frederica, the Frederica aquifer, the Federalsburg aquifer, the Cheswold aquifer, and the minor Miocene aquifer below the Cheswold are all of Miocene age and have not been developed in western Sussex County. Tests indicate that the aquifers are of very low transmissivity, and wells will have a very low specific capacity. Because of the very low water-yielding properties of the aquifers, it is very doubtful that the aquifers will be developed to any extent. If they are developed, it is doubtful that the five Miocene aquifers could produce more than 25 to 30 million gallons a day and the yield of the wells would probably range from less than 50 gallons a minute to about 200 gallons a minute.

The Piney Point aquifer is believed to contain fresh water only in the extreme northwestern part of western Sussex County. No well produced water from the Piney Point. Based on surrounding data, the transmissivity of the Piney Point is probably less than 10,000 gallons a day per foot and the small area in the northwestern part of western Sussex County where the water may be fresh will probably produce only three to four million gallons a day if developed.

The only salt-water problems in the report area are in the interface area between fresh and salt water in the Piney Point and the minor Miocene aquifer below the Cheswold. The Cheswold, the Federalsburg and the Frederica lose their identity as aquifers before they reach the fresh-salt water interface.

The Nanticoke River is tidal at Seaford and contains fresh water under present hydrologic conditions. If the fresh ground-water discharge were eliminated all of the way to the Chesapeake Bay, a salt-water problem of a local nature might occur in the shallow water-table aquifer near the tidal part of the river.

Finally, in western Sussex County it is concluded:

(1) the use of ground water from the water-table aquifer can be expanded tenfold over the present use of the aquifer or to 120 million gallons a day;

(2) the undeveloped artesian part of the Manokin aquifer is a potential source of about 20 million gallons a day;

(3) the development of the deeper artesian aquifers below the Manokin is not likely, because of the poor water-yielding properties of the aquifers;

(4) no potential salt-water problems are anticipated;

(5) research may lead to additional water supply in the swampy areas by lowering the water table by pumpage to recover recharge water lost by evaporation; and

(6) the maximum use of ground water is predicated on proper planning, development and management of the aquifers.

Much of the discussion in this report leads to management recommendations, policies and controls to assure adequate water supply of good quality. This has been the concern of the Department of Natural Resources and Environmental Control and the Board of Health for many years. Many of these conclusions have been discussed with the above departments and the recommendations included in the report of the Governor's Task Force on Marine and Coastal Affairs entitled "The Coastal Zone of Delaware, 1972." Legislation may be needed in several areas of water resources development and management.

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APPENDICES

APPENDIX A: SUPPLEMENTAL ILLUSTRATIONS

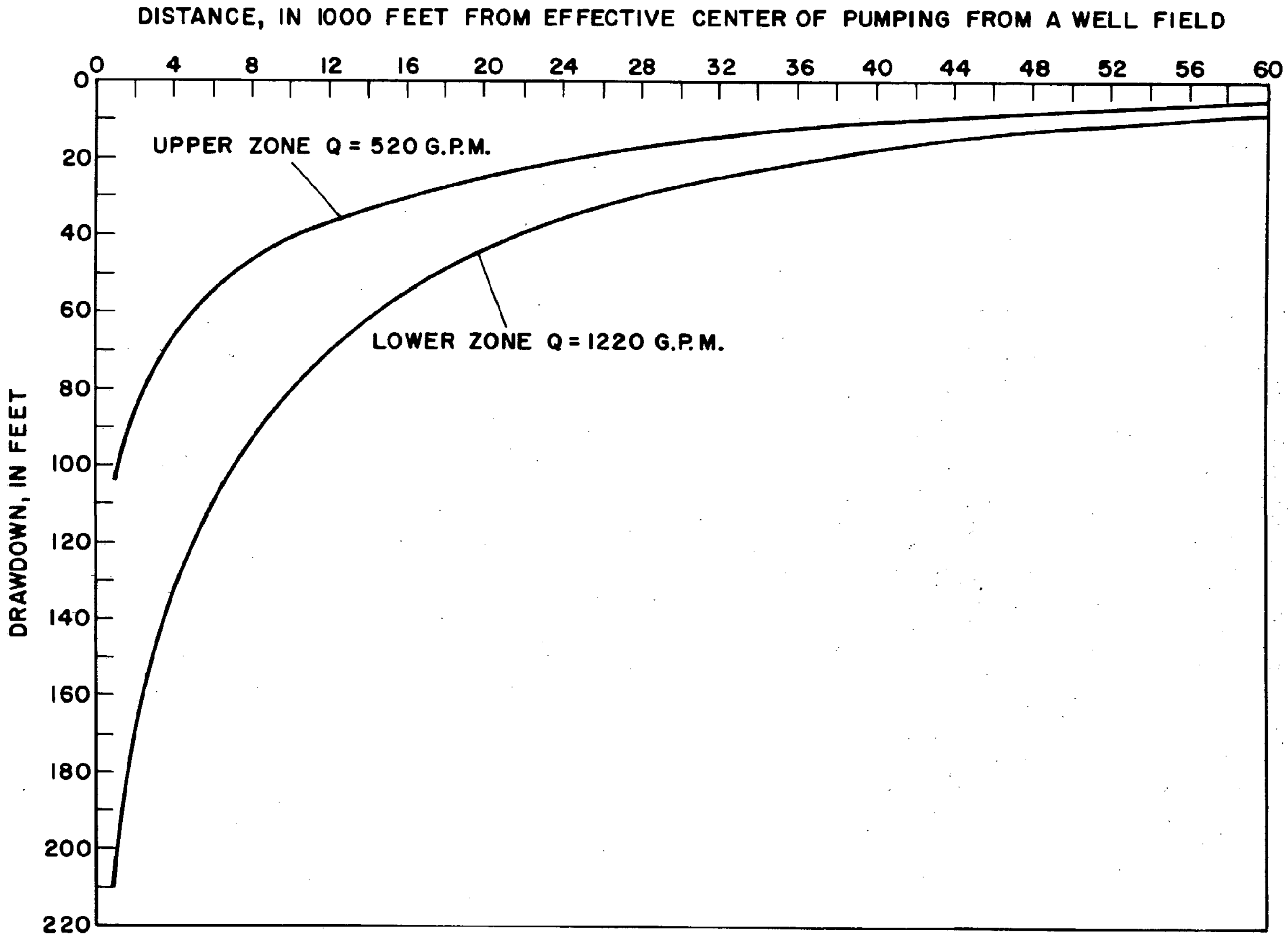


FIGURE A1 . DRAWDOWN CURVES FOR UPPER AND LOWER POTOMAC AQUIFERS.

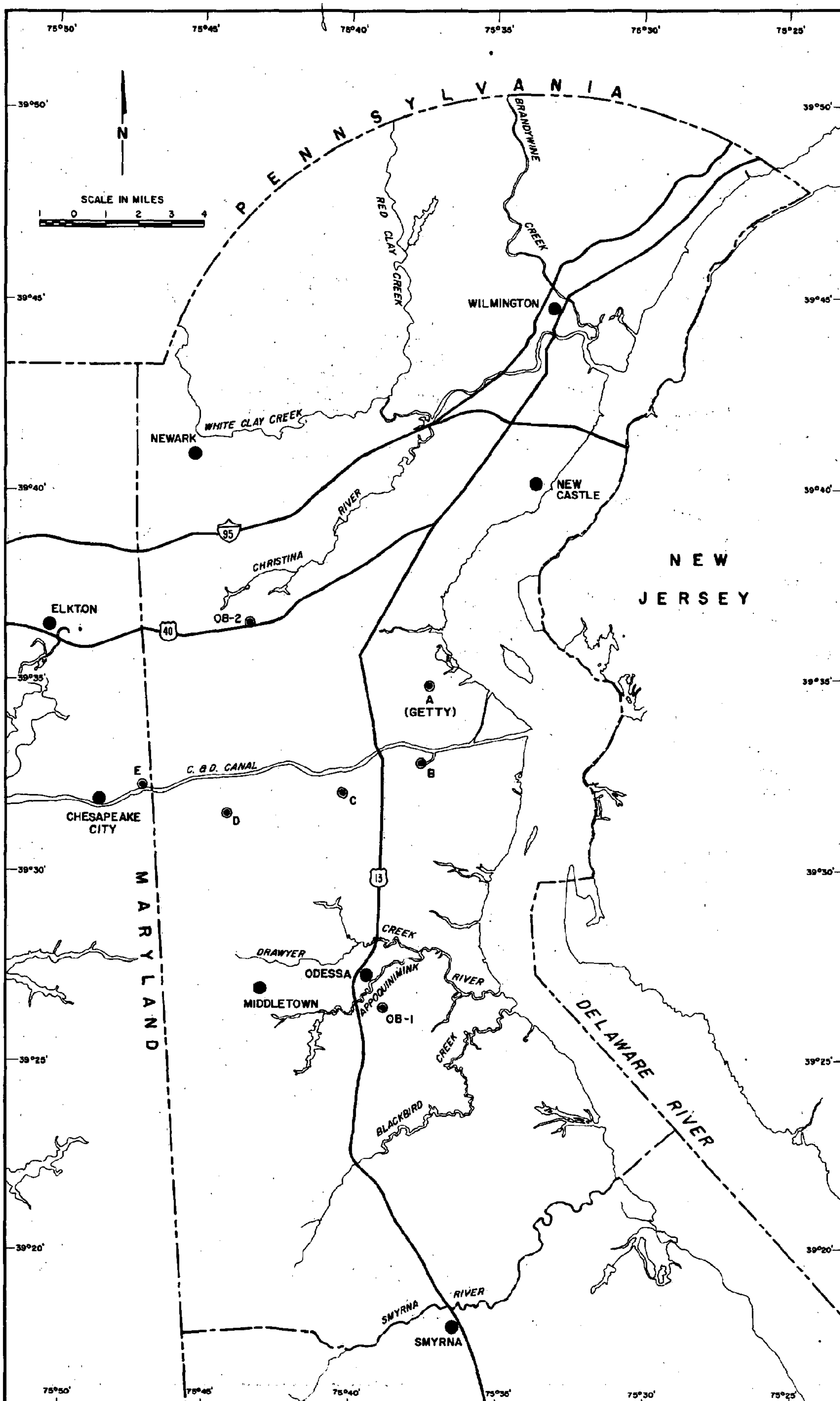


FIGURE A2. LOCATION OF HYPOTHETICAL CENTERS OF PUMPING FOR TESTING DRAWDOWNS IN THE CANAL AREA.

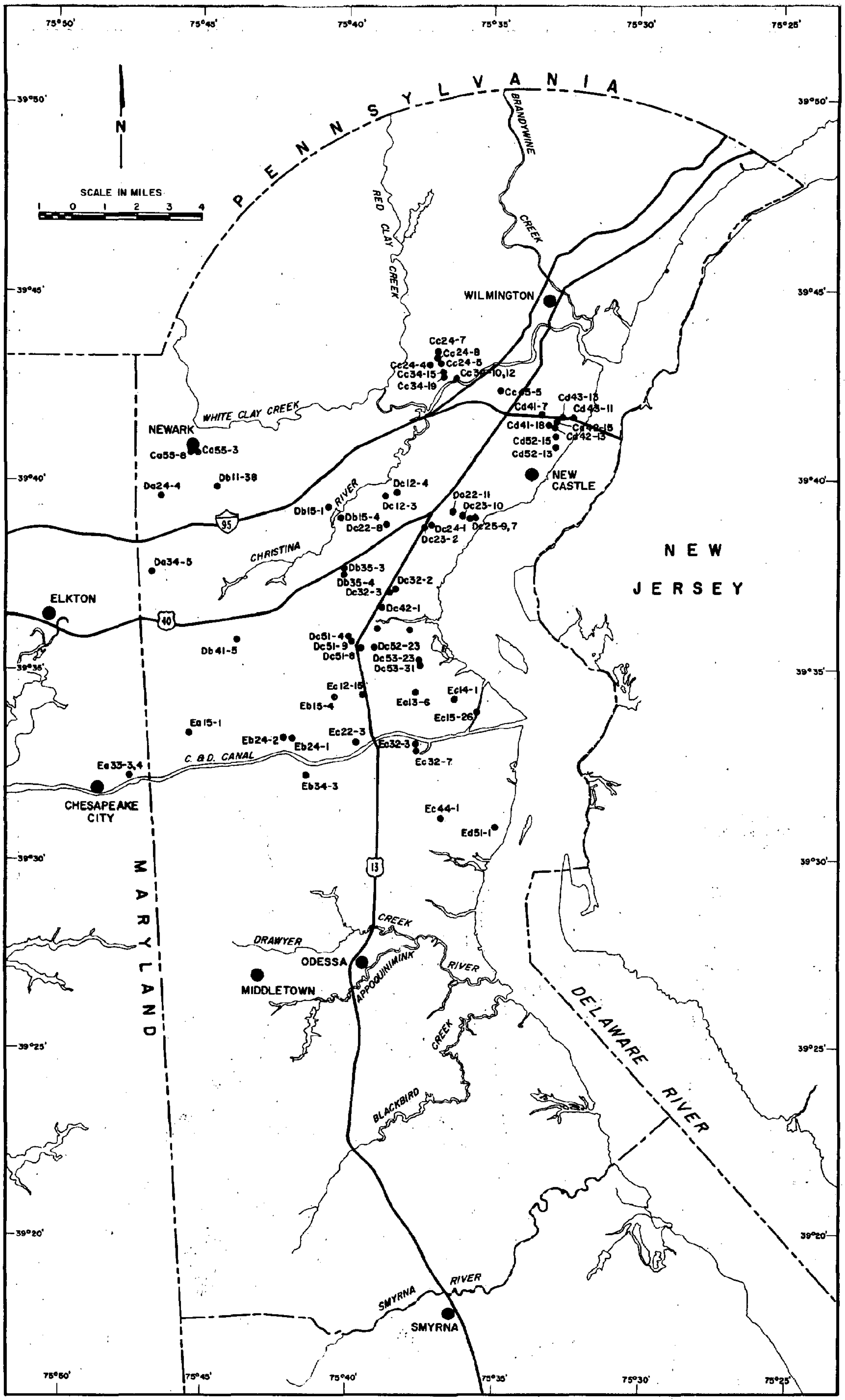


FIGURE A3. MAP SHOWING LOCATION OF SELECTED WELLS IN THE POTOMAC FORMATION.

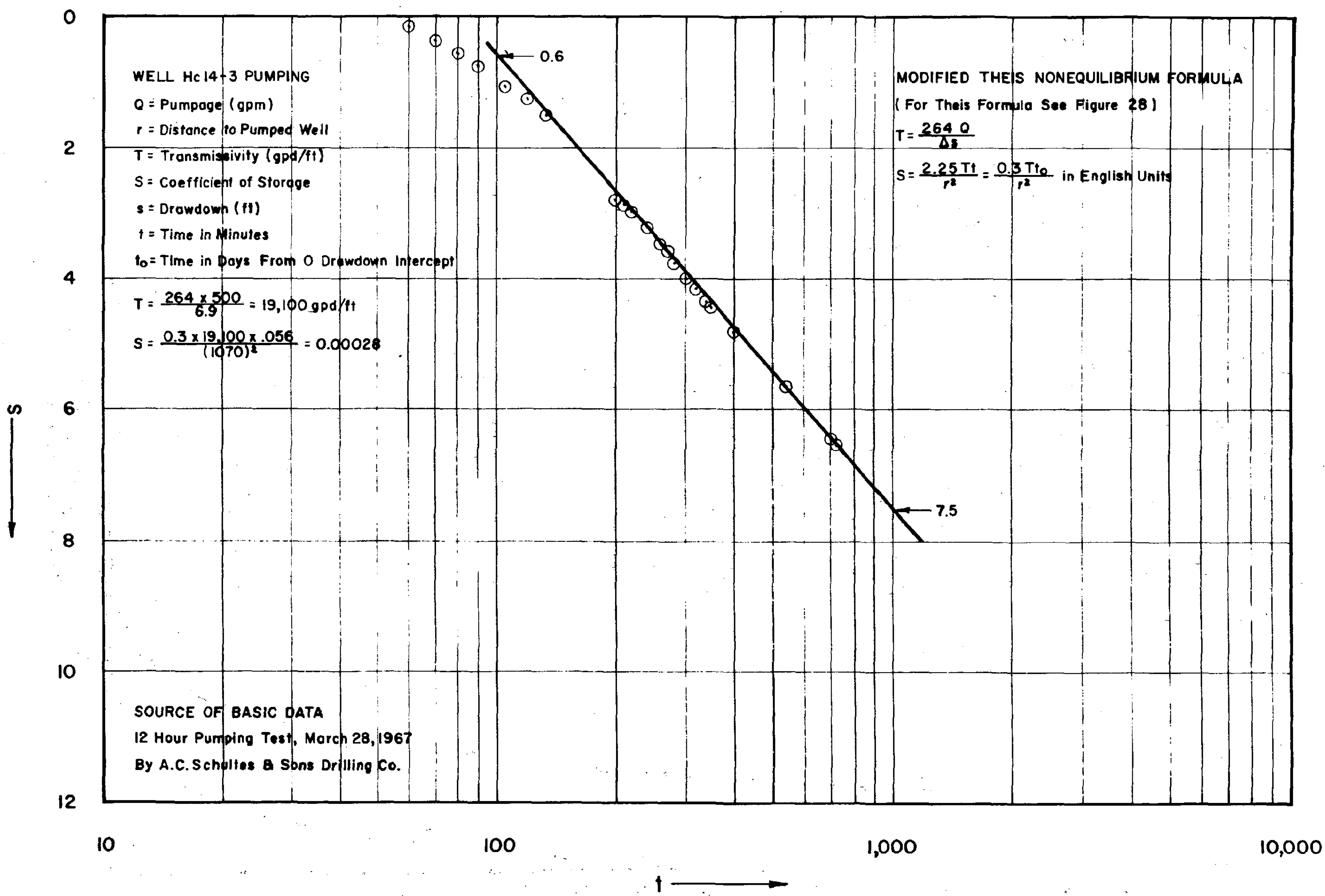


FIGURE A4. GRAPHIC PLOT OF PUMPING TEST DATA AND COMPUTATION OF THE COEFFICIENTS OF TRANSMISSIVITY AND STORAGE IN DELAWARE STATE CORRECTIONAL INSTITUTION WELL (Gc54-2) IN THE RANCOCAS AQUIFER.

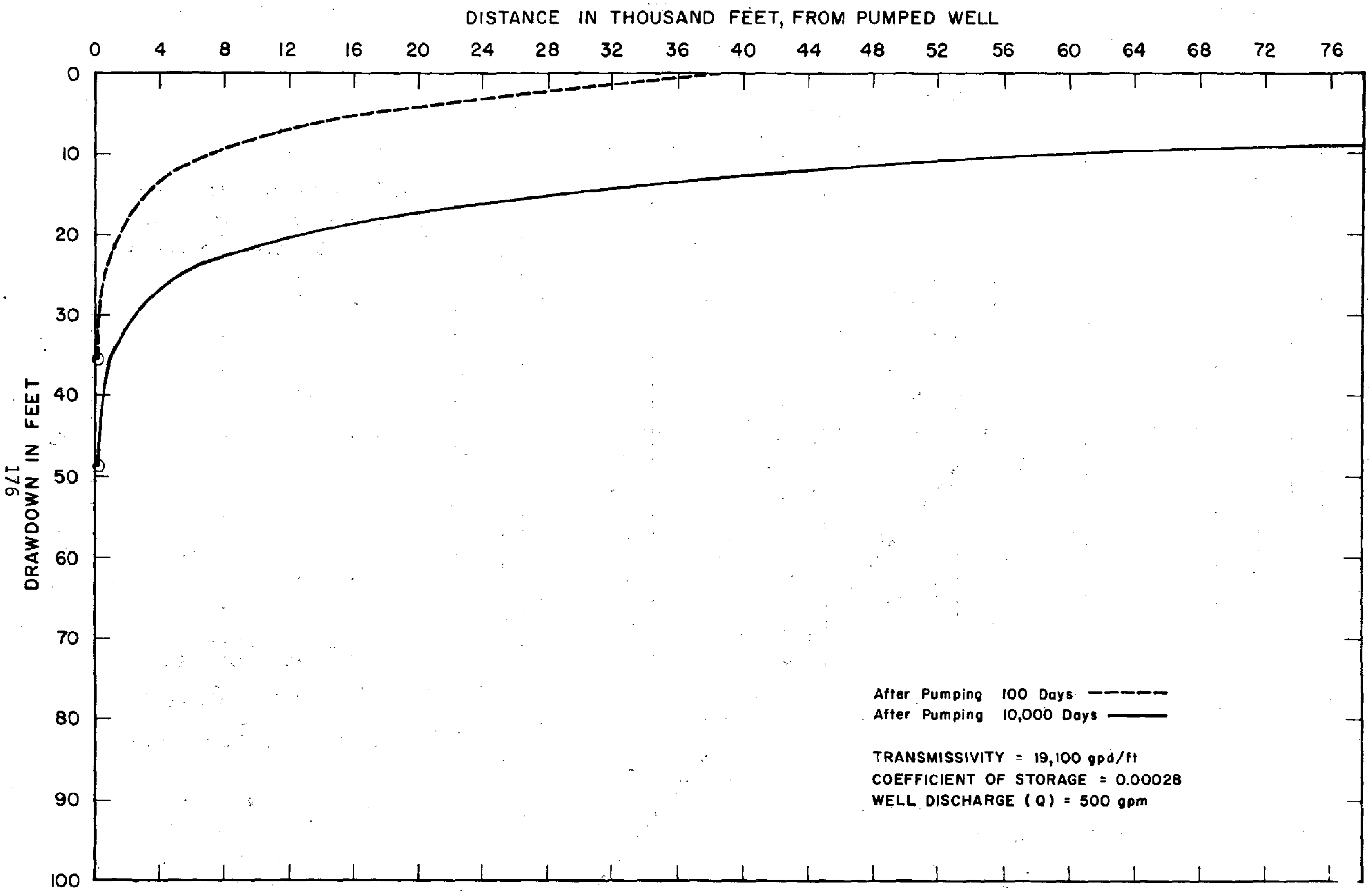


FIGURE A5. NONLEAKY ARTESIAN DRAWDOWN CURVES FOR DELAWARE STATE CORRECTIONAL INSTITUTION WELL Gc54-2

Based on Theis Nonequilibrium Equation

RANCOCAS AQUIFER

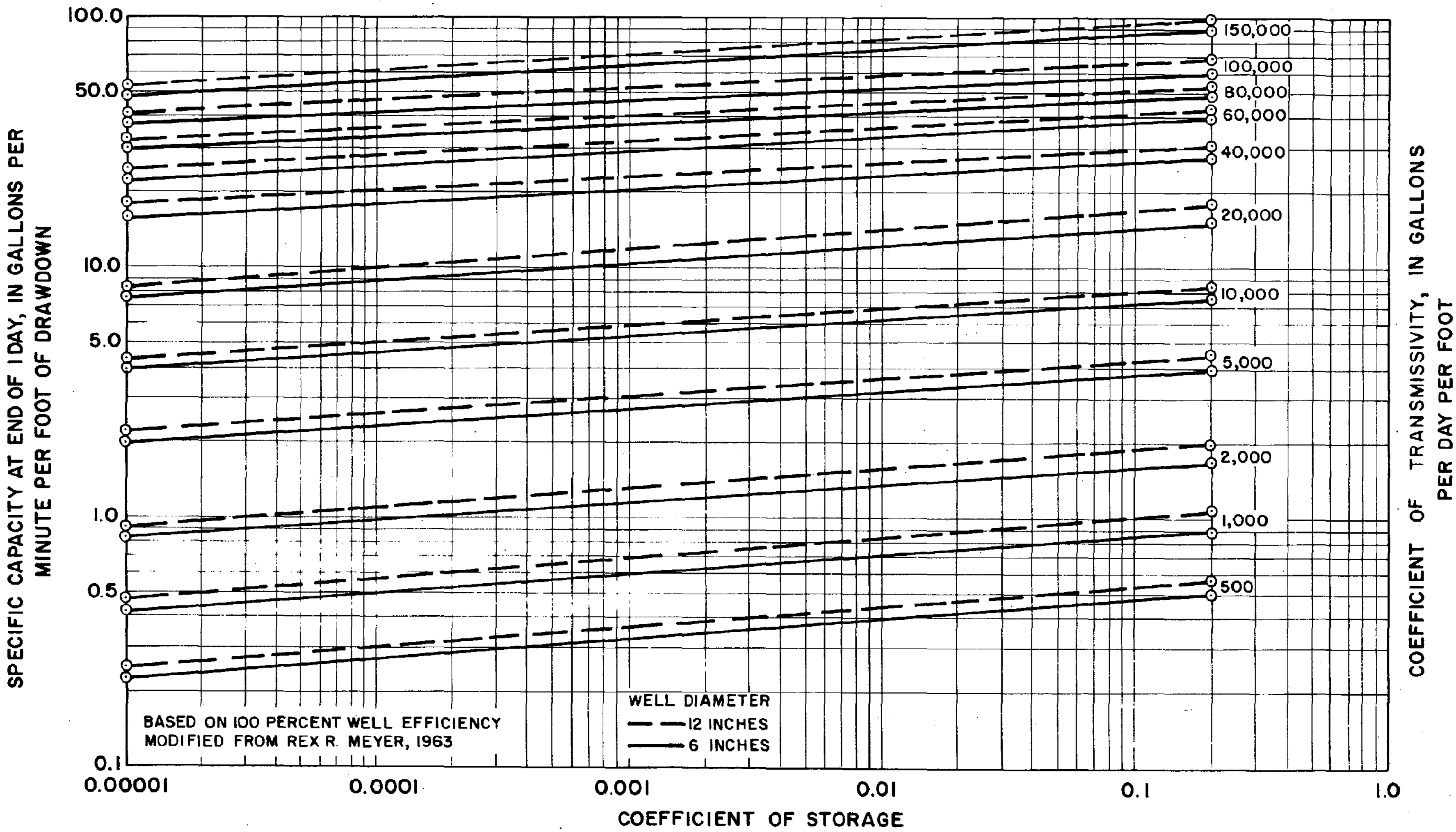
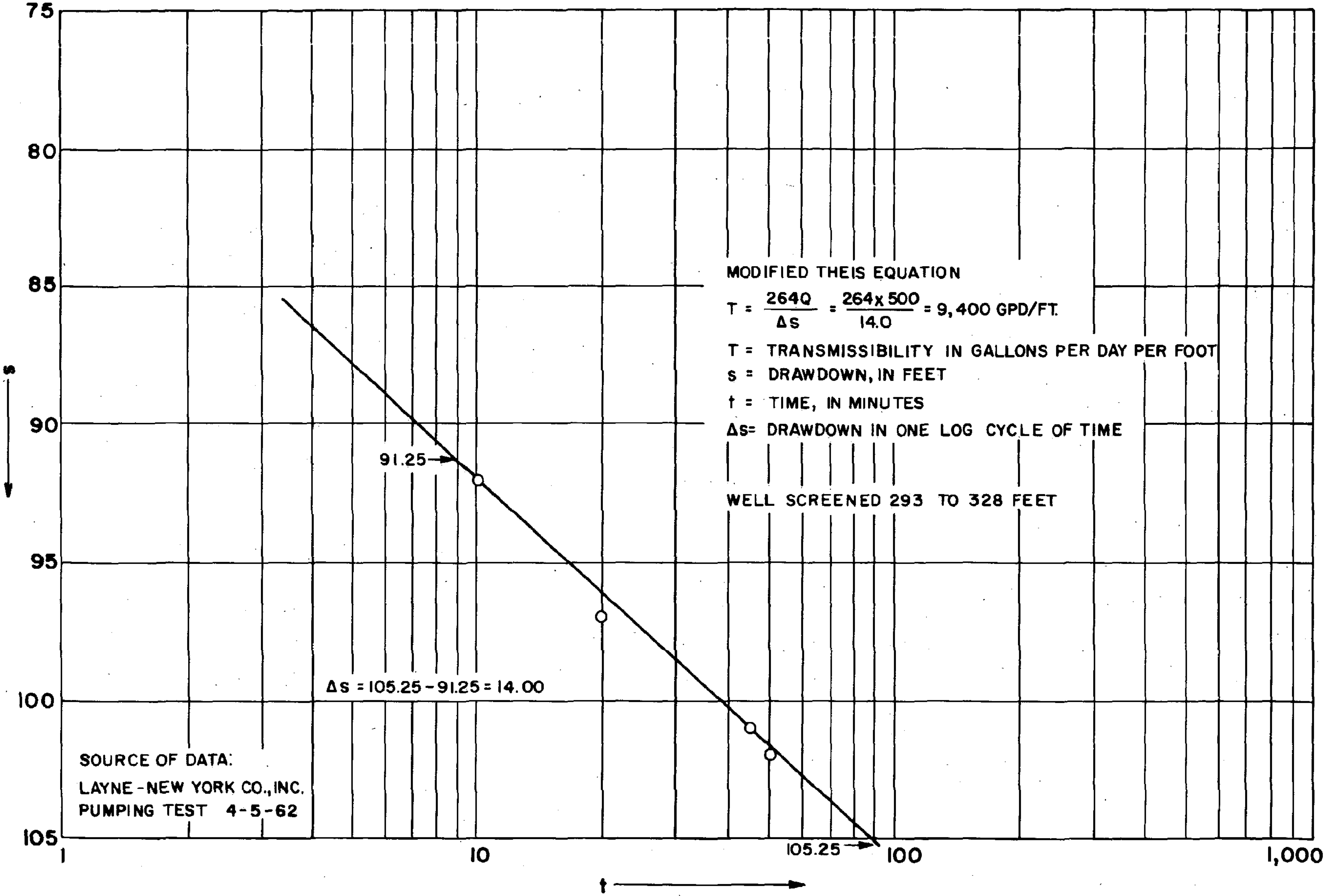


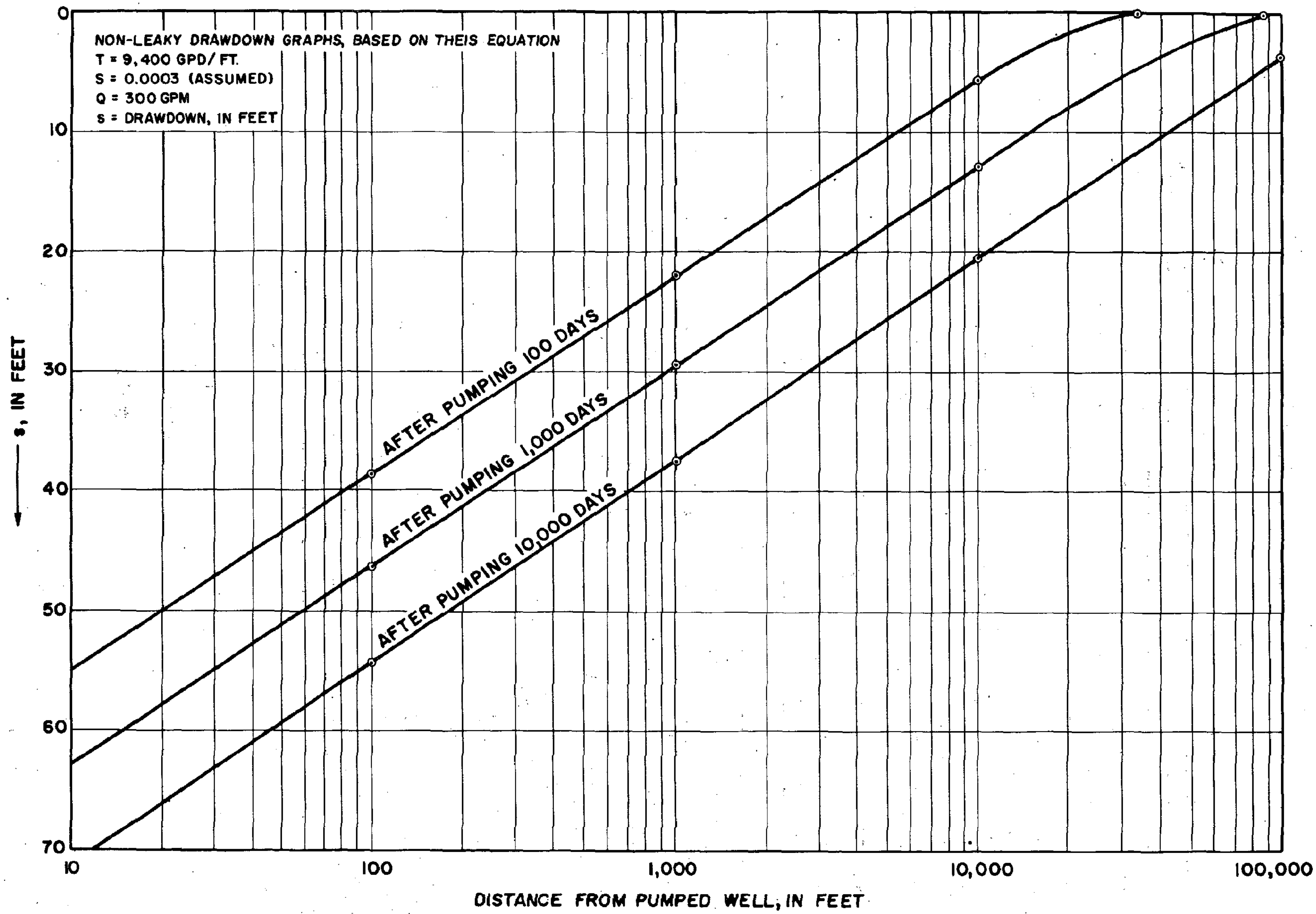
FIGURE A6. RELATION OF WELL DIAMETER, SPECIFIC CAPACITY, TRANSMISSIVITY AND COEFFICIENT OF STORAGE.



CITY OF MILFORD WELL 5 (Le 55-5)

THE FEDERALSBURG AQUIFER

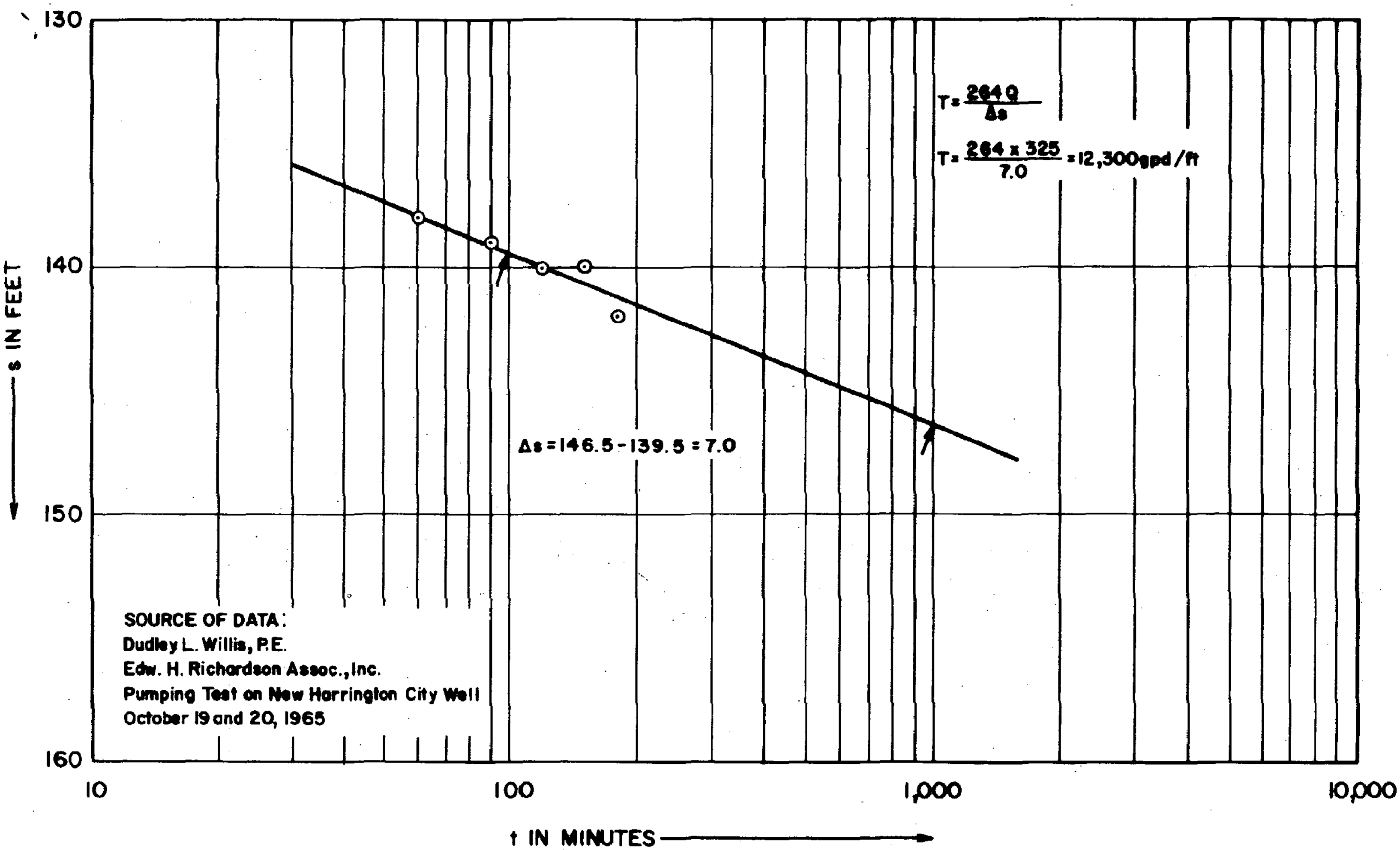
FIGURE A7. GRAPHIC PLOT OF PUMPING TEST DATA AND COMPUTATION OF COEFFICIENT OF TRANSMISSIVITY IN CITY OF MILFORD WELL 5 (Le 55-5) IN THE FEDERALSBURG AQUIFER.



CITY OF MILFORD WELL 5 (Le55-5)

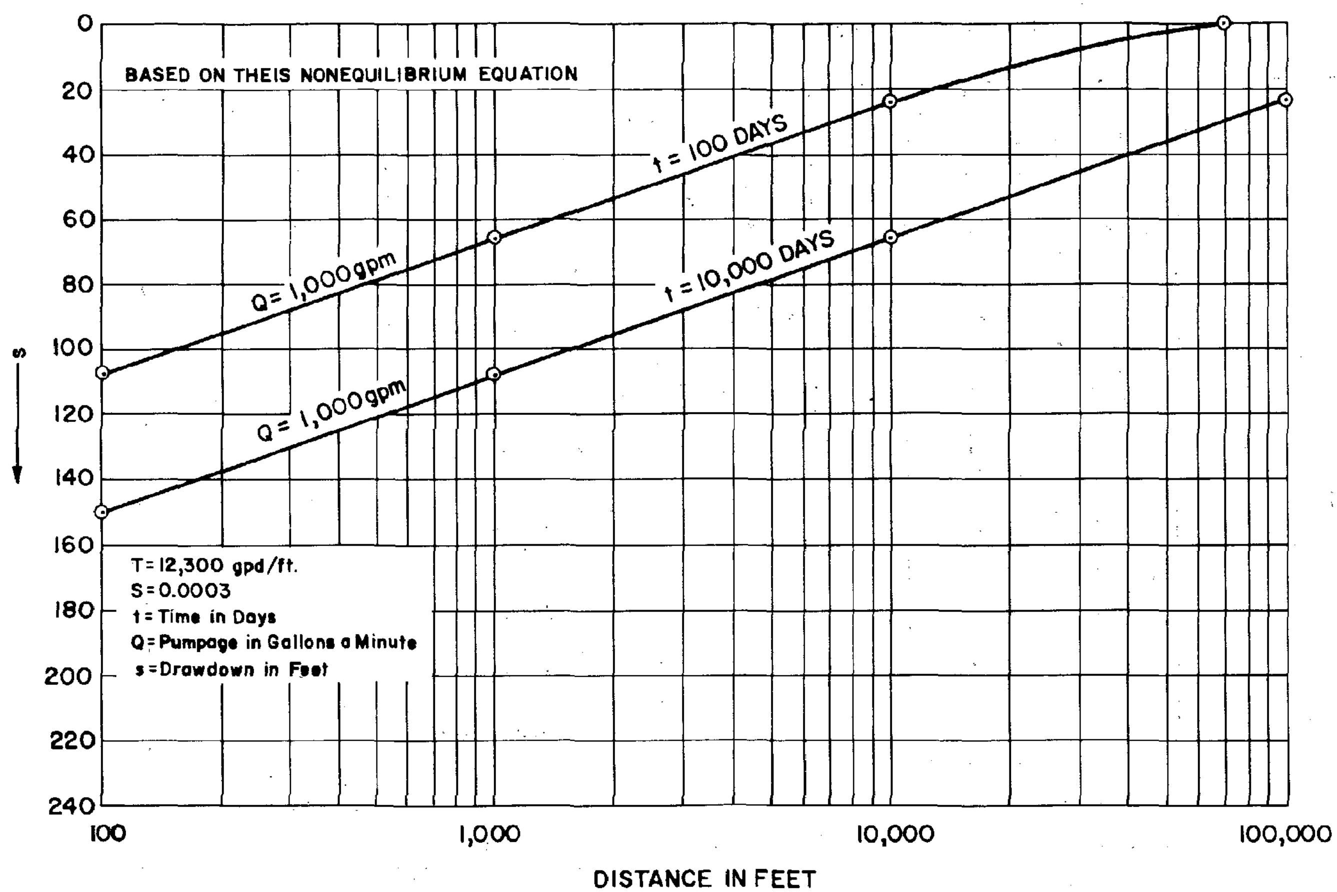
THE FEDERALSBURG AQUIFER

FIGURE A8. NONLEAKY DRAWDOWN GRAPHS FOR THE CITY OF MILFORD WELL 5(Le55-5), BASED ON THEIS EQUATION.



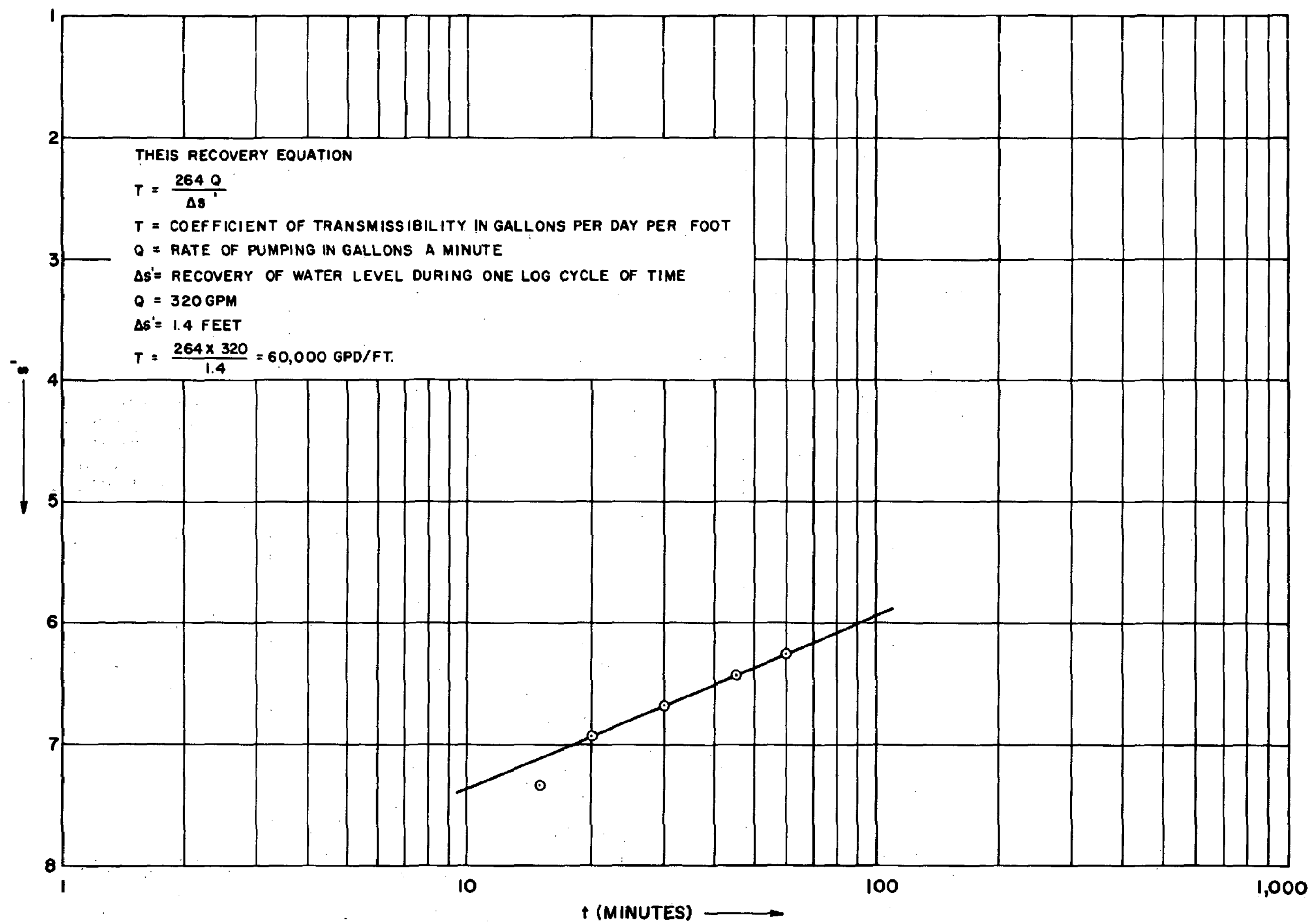
CITY OF HARRINGTON WELL (Ld51-8) *FREDERICA AQUIFER*

FIGURE A9. GRAPHIC PLOT OF PUMPING TEST DATA AND COMPUTATION OF THE COEFFICIENT OF TRANSMISSIVITY IN THE CITY OF HARRINGTON WELL (Ld51-8) IN THE FREDERICA AQUIFER.



NONLEAKY DRAWDOWN GRAPH HARRINGTON WELL Ld51-8 *FREDERICA AQUIFER*

FIGURE A10. NONLEAKY DRAWDOWN GRAPHS FOR THE CITY OF HARRINGTON WELL (Ld 51-8) IN THE FREDERICA AQUIFIER, BASED ON THEIS EQUATION.



BETHANY BEACH WELL Qj 32-12

MANOKIN AQUIFER

FIGURE A11. GRAPHIC PLOT OF PUMPING TEST DATA AND COMPUTATION OF COEFFICIENT OF TRANSMISSINITY IN TOWN OF BETHANY BEACH WELL (QJ32-12) IN THE MANOKIN AQUIFIER.

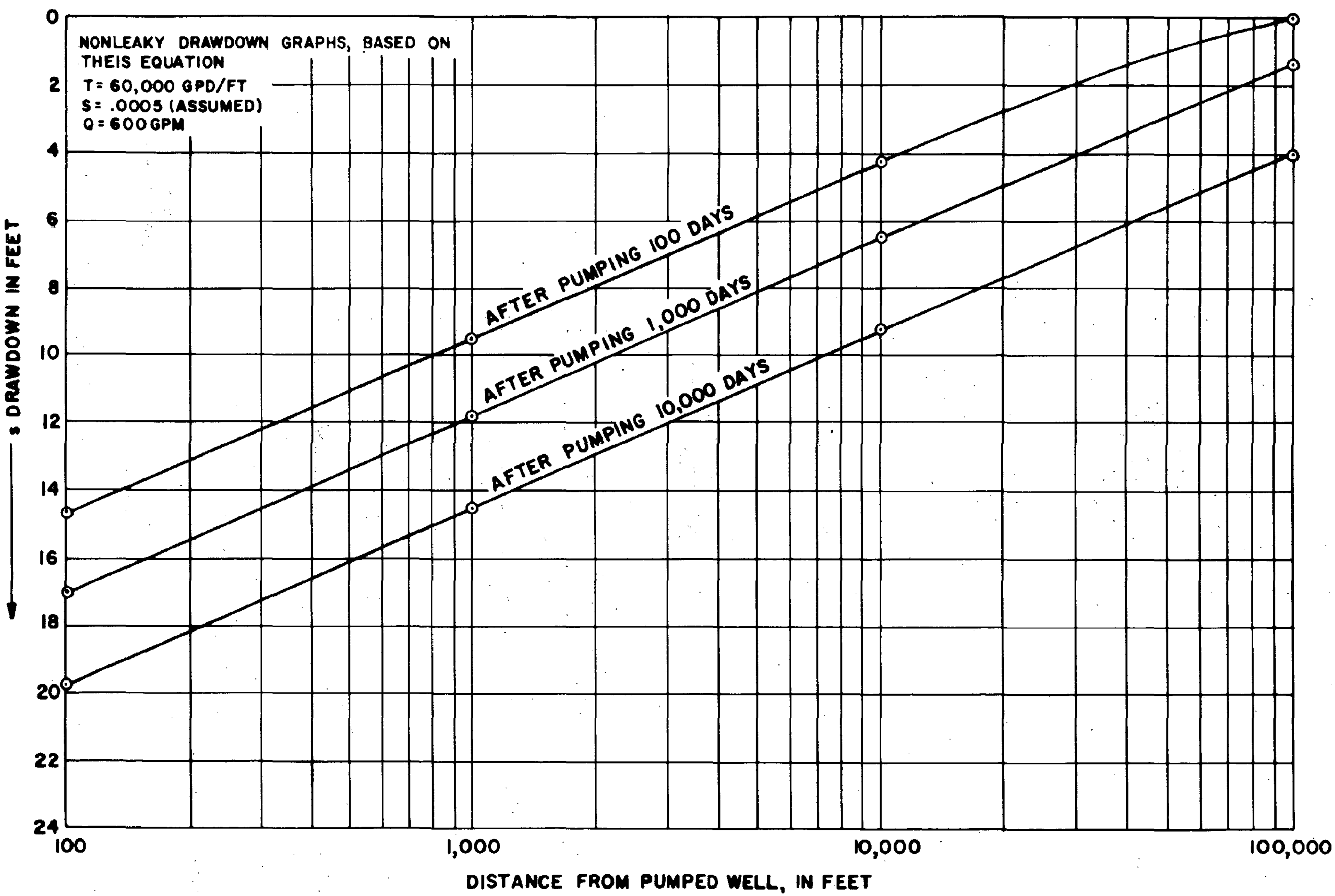


FIGURE A12. NONLEAKY DRAWDOWN GRAPHS FOR THE TOWN OF BETHANY BEACH WELL (Qj 32-12) IN THE MANOKIN AQUIFIER, BASED ON THEIS EQUATION.

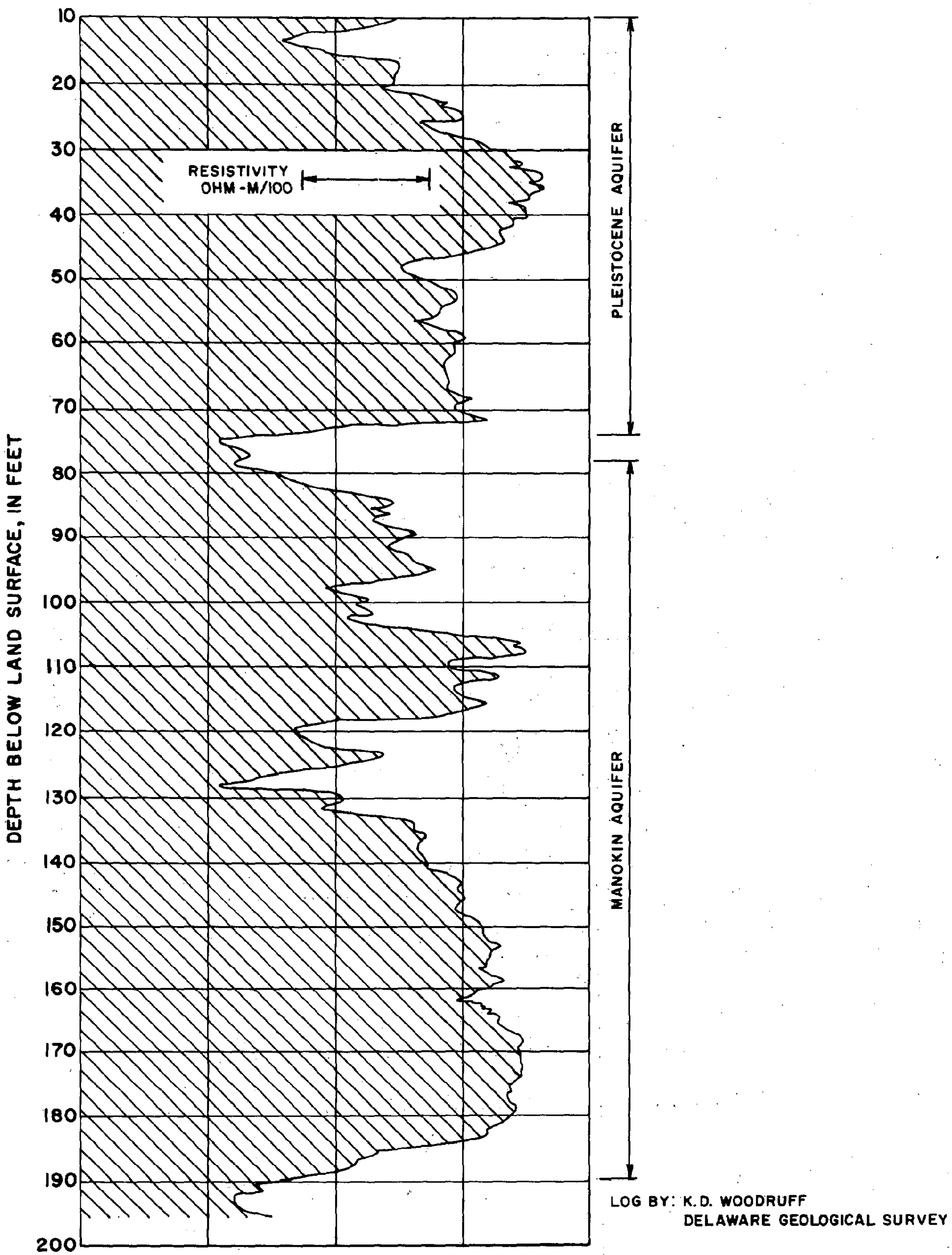


FIGURE A13. ELECTRICAL RESISTIVITY LOG OF WELL (PF23-2) OWNED BY H. KRUGER, INC.

FIGURE A14. GRAPH SHOWING DEPTH TO WATER IN WELLS (MD 22-1 AND QE 44-1) IN THE WATER TABLE AQUIFER IN KENT AND SUSSEX COUNTIES FROM MARCH 1967 TO DECEMBER 1969.

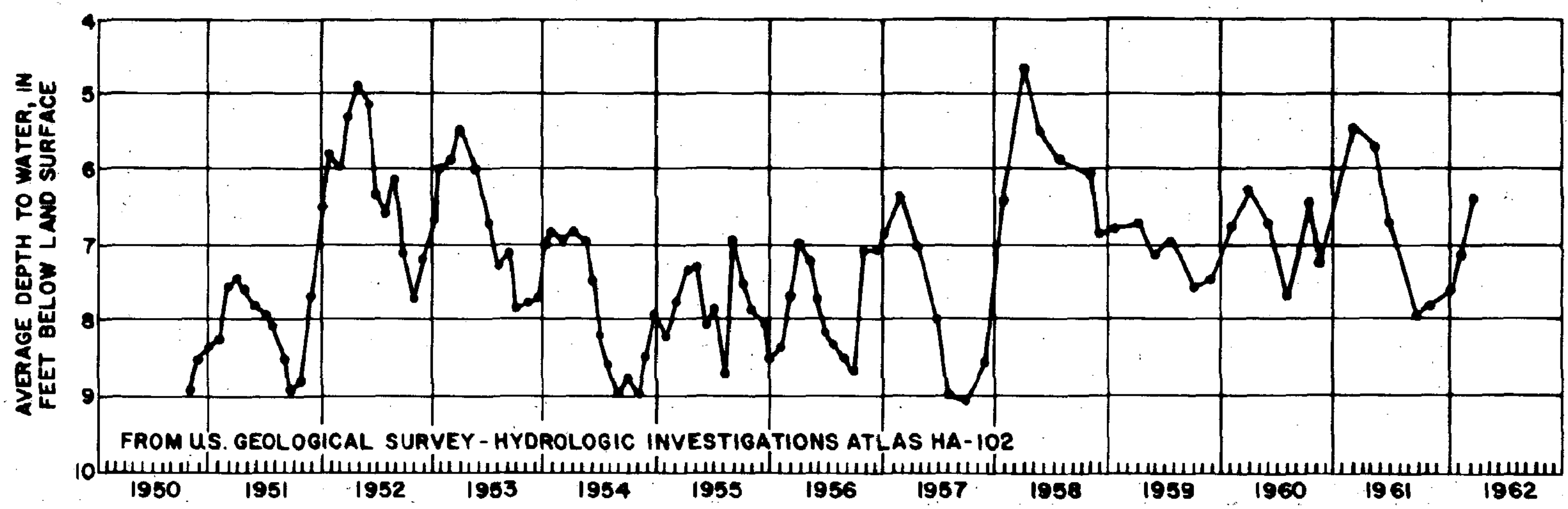


FIGURE A15. COMPOSITE FLUCTUATION OF WATER LEVELS IN 13 WELLS IN THE WATER-TABLE AQUIFER OF THE PLEISTOCENE IN DELAWARE.

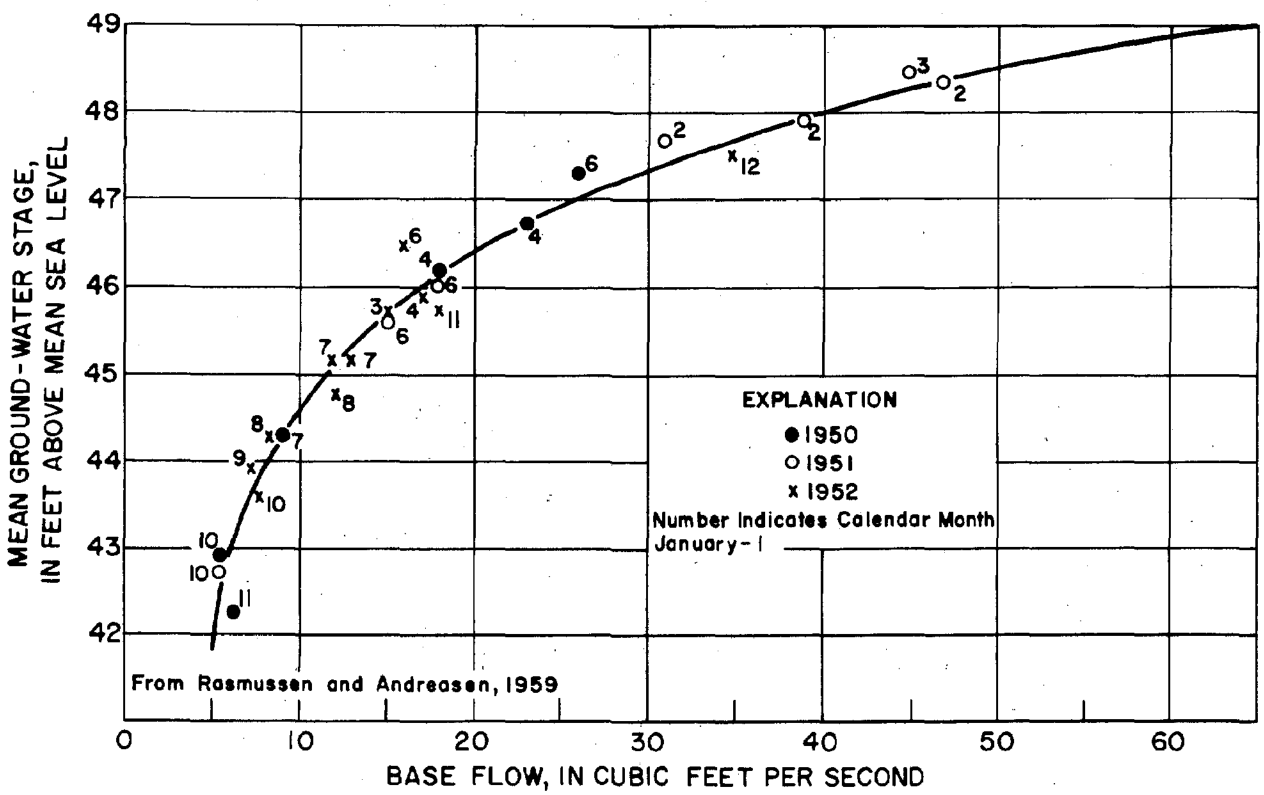


FIGURE A16. RELATION OF THE ALTITUDE OF THE WATER TABLE IN A WELL IN THE WATER TABLE AQUIFIER TO THE BASEFLOW OF BEAVERDAM CREEK.

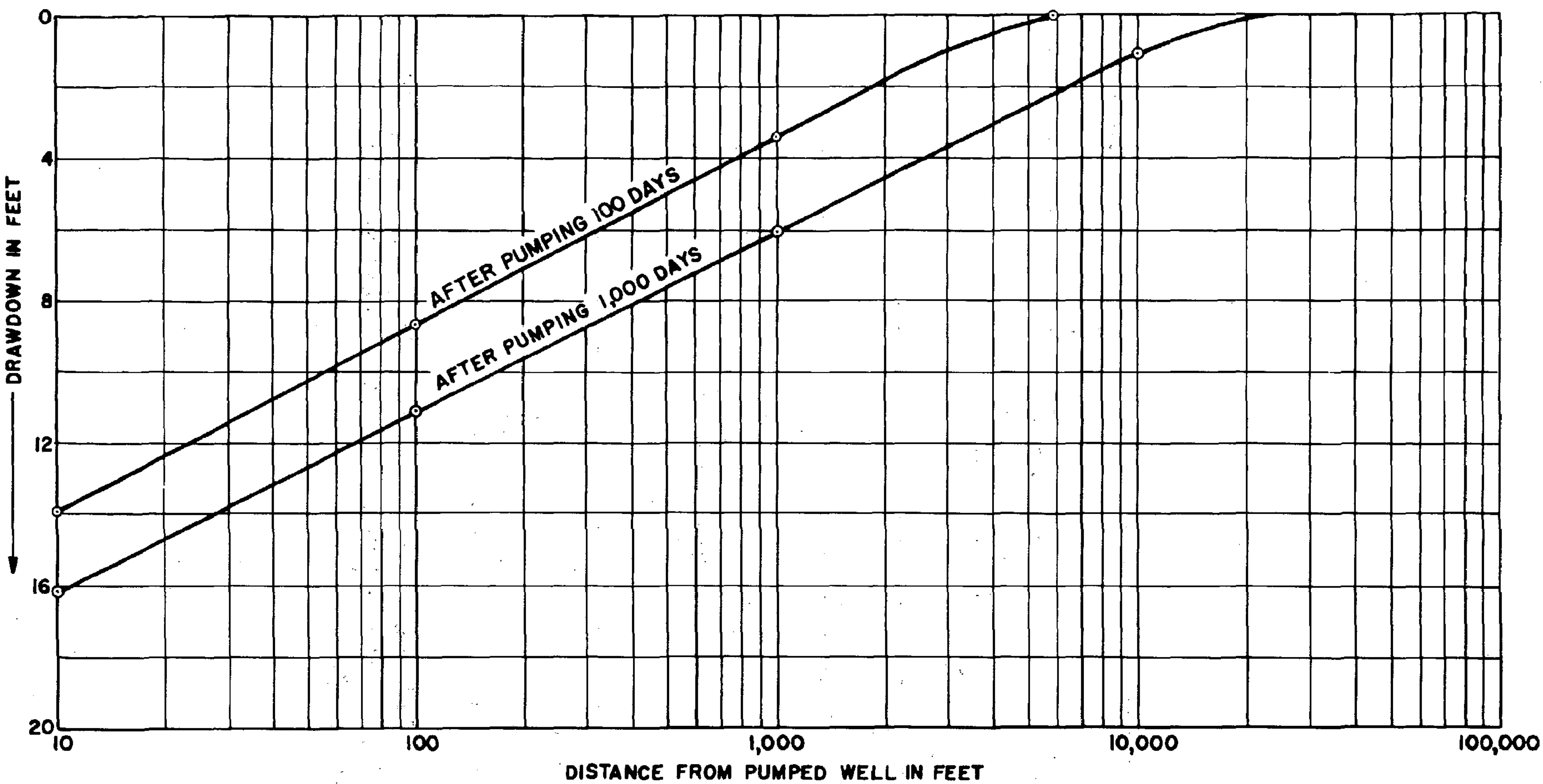
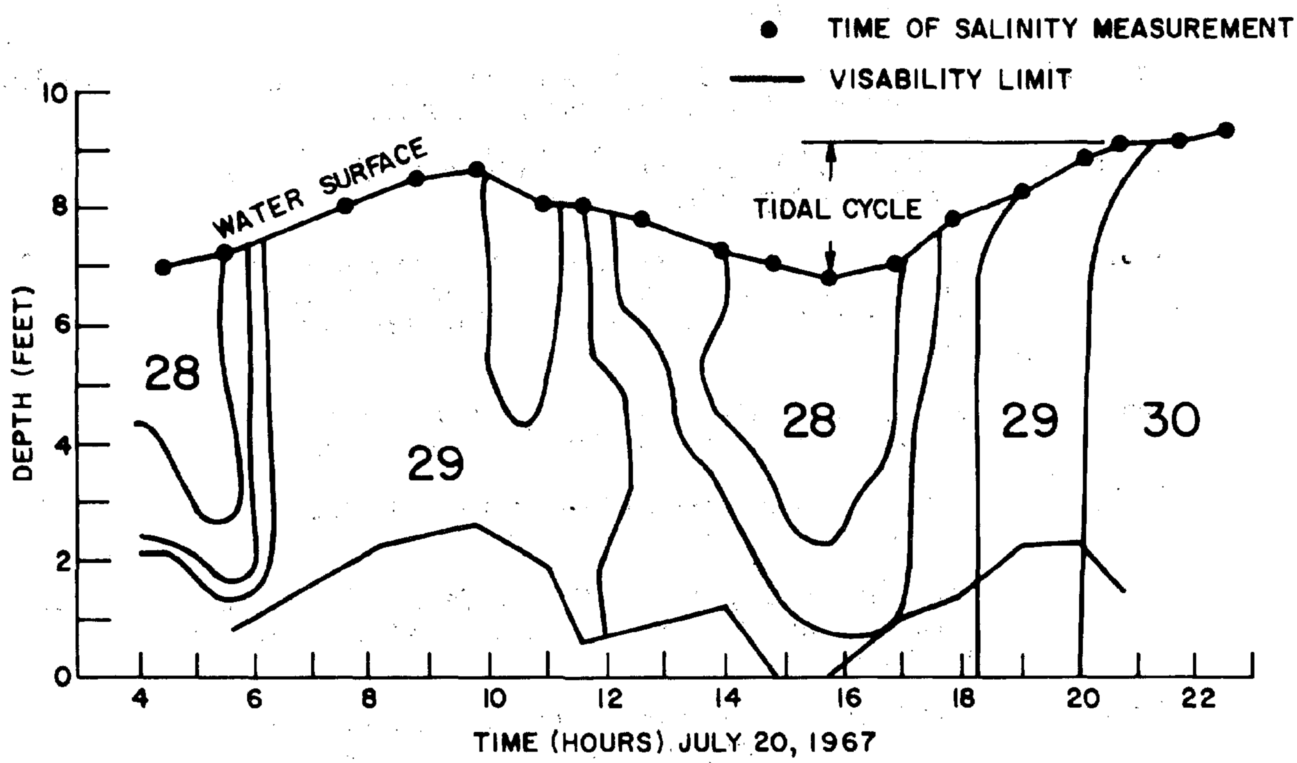
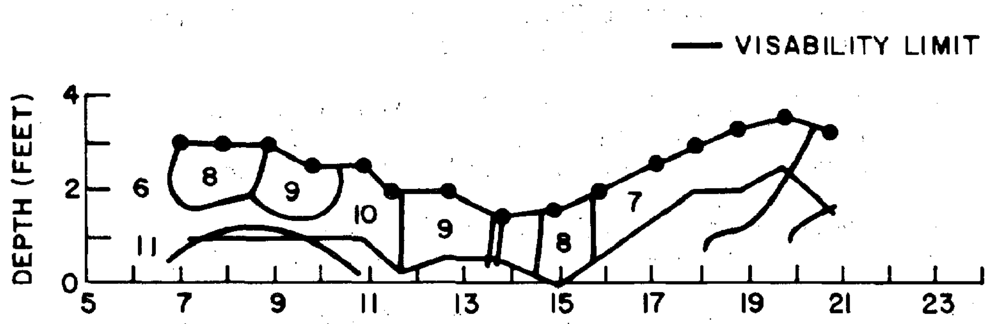


FIGURE A17. NONLEAKY DRAWDOWN GRAPH FOR A WELL AFTER PUMPING 100 DAYS AND 1000 DAYS AT A RATE OF 1000 GALLONS A MINUTE FROM AN AQUIFER HAVING A TRANSMISSIVITY OF 100,000 GALLONS PER DAY PER FOOT AND A COEFFICIENT OF STORAGE OF 0.15, BASED ON THE THEIS EQUATION.

SECTION A- MID-EAST INDIAN RIVER BAY
SALINITY VARIATION
(PARTS PER THOUSAND)



SECTION B - NEAR WESTERN TIDAL LIMIT -INDIAN RIVER
SALINITY
(PARTS PER THOUSAND)



AFTER JOHN C. KRAFT, 1968

FIGURE A18. SALINITY CROSS SECTIONS OF INDIAN RIVER.

APPENDIX B: SUPPLEMENTAL TABLES

Table B1.

Selected Patterns of Development
along the Canal and their Effects

Pattern Number	Total Pumping Rate at Selected Well Field Site (mgd)					Total Development (mgd)	Drawdown at Observation Point in Selected Well Field Site (feet)									
	Well Field Site						A		B		C		D		E	
	A	B	C	D	E		L	U	L	U	L	U	L	U	L	U
1	2.5	1.7	1.8	2.5	2.5	11.0	189	100	197	104	208	113	213	114	183	95
2	2.5	1.8	2.2	3.5	0	10.0	191	101	204	107	219	118	197	103	-	-
3	2.5	2.0	3.5	0	0	8.0	186	98	207	108	197	102	-	-	-	-
4	2.5	4.0	0	0	0	6.5	185	94	197	98	-	-	-	-	-	-
5	2.5	0	5.0	0	0	7.5	157	84	-	-	203	102	-	-	-	-
6	2.5	0	0	5.0	0	7.5	125	66	-	-	-	-	187	93	-	-
7	2.5	0	0	0	5.2	7.7	112	57	-	-	-	-	-	-	186	91
8	4.1	0.9	0.9	1.25	1.25	8.4	190	97	171	91	147	82	131	72	110	57
9	4.1	0.9	1.1	1.8	0	7.9	191	97	174	92	152	85	123	67	-	-
10	4.1	1.0	1.75	0	0	6.85	188	96	176	92	140	76	-	-	-	-
11	4.1	2.0	0	0	0	6.1	187	93	171	87	-	-	-	-	-	-
12	4.1	0	4.0	0	0	8.1	195	101	-	-	194	100	-	-	-	-
13	4.1	0	0	4.7	0	8.8	175	90	-	-	-	-	190	96	-	-
14	4.1	0	0	0	5.0	9.1	164	82	-	-	-	-	-	-	189	93
15	0	0	0	0	3.0	3.0	17	10	17	10	30	17	70	38	-	-

L = Lower Zone of the Potomac Formation

U = Upper Zone of the Potomac Formation

Table B2.

Records of Wells Drawing Water from the
Potomac Formation in New Castle County, Delaware

Delaware Geological Survey Well Number	Local Well Number	Depth in Feet	Screened	Water Level Ft ± Mean Sea Level	Date of Measurement	Altitude of Ground Surface in Feet
Ca55-3		64.5		80	2-29-52	109
Ca55-8		42		81	7-12-53	105
Cc24-5	Artesian Water Company #17	160		-12	3-22-50	75
Cs24-7	Artesian Water Company #20	163		0	3-24-50	76
Cc24-8		140		-22	3-24-50	70
Cc34-15		112		8	12-7-53	23.3
Cc45-5		302	278-288	-14	7-51	65
Cd41-7		200	189+	0	7-55	65
Cd41-18		80		43	3-18-61	69
Cd42-13		73		19	11-53	40
Cd43-11		88		-21	4-16-52	13.2
Cd52-13		132	116-134	5	8-20-52	12
Cd52-15		73		19	11-53	40
Db11-38		192		52	3-12-64	75±
Db15-1		136		27	1951	30
Dc51-9	Getty #R4	340	252-270, 286-312	21	11-30-55	40.3
Dc53-7	Getty #12	657	534-539	16	9-20-54	54.9
Dc53-23	Getty #5C	710	538-543	8	9-16-54	32.2
Dc53-31	Getty #5A	613	400-406, 201-207	12	7-19-54	32.0
Ea15-1		55		62	11-27-53	65
Ea33-1	Goodrich TW #2	427	390-410	2	11-18-66	60
Ea33-2	Goodrich Obs #1	431	408-418	0	11-18-66	60
Ea33-3	Goodrich Obs #2	431	398-408	2	11-18-66	60
Ea33-4	Goodrich TW #1	695	580-585, 598-608	2	9-30-66	60

Table B2 Continued

Delaware Geological Survey Well Number	Local Well Number	Depth in Feet	Screened	Water Level Ft ± Mean Sea Level	Date of Measurement	Altitude of Ground Surface in Feet
Eb15-2	Getty #8	636	240-245	26	10-13-54	65.5
Eb15-4	Getty #P3	556	510-541	14	10-25-55	69.5
Eb24-1		208		9+	10-19-43	60+
Eb24-2		177		21	8-52	45
Eb34-3		845	442-462	-2	4-20-67	58.2
Ec11-2	Getty #7	565+	560-565	+19.64	1955	41.5
Ec12-15	Getty #3B	734	340-345	10	9-19-54	57.5
Ec12-20	Getty #P9	558	525-558	-14	4-56	13±
Ec13-6	Getty #16	705	523-563, 581-592	4	1-5-55	35.5
Ec14-1	Getty #13	757	678-685	6	9-20-54	4.4
Ec15-26		701	631-636, 675-695	-44±	4-12-61	10±
Ec22-3		261-	235-260	13	2-16-53	10
Ec32-3	Union Carbide TW #2 (Site 1)	420	318-328, 338-348		1966	
Ec32-7	Union Carbide TW #1 (Site 1)	752	586-596	-33	1966-67	11.15
Ec44-1		350		6	3-50	25
Ed51-1		473	447-473	6	1-20-56	11

Table B3. Specific Capacities of Wells and Test Wells in the Chesapeake and Delaware Canal Area

Well	Owners Number	Owner	Specific Capacity gpm/ft.	Time Pumped	Bottom of Screen feet	Hydrologic Zone	Reported by
Eb15-4	P-3	Getty Oil Company	1.7	24 Hrs.	541	Lower Potomac	Delaware Geological Survey
Dc51-7	P-4	do	1.7	24 Hrs.	544	do	do
Dc41-4	P-5A	do	2.3	24 Hrs.	539	do	do
Dc42-6	P-6A	do	1.5	24 Hrs.	698	do	do
Ec12-20	P-9	do	5.4	24 Hrs.	588	do	do
Ec14-7	P-10	do	4.4	24 Hrs.	702	do	do
Dc52-24	P-15	do	3.5	60 days	333	Upper Potomac	do
Ec13-6	P-16	do	2.1	24 Hrs.	592	Lower Potomac	do
Ec32-3	TW-2	Union Carbide Corporation	6.0	24 Hrs.	348	Upper Potomac	Geraghty and Miller
Ec32-7	TW-1	do	0.9	8 Hrs.	595	Lower Potomac	do
Eb34-3	*TW-1*	*Canal Realty Co.*	*1.0*	*24 Hrs.*	*462*	*Upper? Potomac*	do
Ea33-1	TW-1	B.F.Goodrich	1.5	Several Hours	608	Lower Potomac	do
Ea33-2	TW-2	do	7.0	24 Hrs.	427	do	do

Remarks: Production wells are indicated in owner's number column by the prefix "P".
Test wells are indicated in the owner's number column by the prefix "TW".
The sand screened in Canal Realty Co. well TW-1 is in the clayey zone just below the upper hydrologic zone (Sundstrom et al., 1967).

Table B4. Coefficients of Transmissivity and Storage Determined from Pumping Tests of Wells in the Potomac Formation in the Chesapeake and Delaware Canal Area

Date	Well	Hydrologic Zone	Owner	Pumping Test Conducted by	Data Analyzed by	Coefficient of Storage	Effective Coefficient of Transmissivity gpd/ft.	Remarks
1-24 to 2-10-55	16 (Ec13-6)	Lower Potomac Zone	Tidewater Oil Company (Now Getty Oil Co.)	Leggette and Brashears	Leggette and Brashears		5,500	Source of data: Report by Leggette and Brashears to Tidewater Oil Co. on "Potential Ground-Water Supply at Delaware City, Delaware" p. 45
do	5C (Dc53-23)	do	do	do	do	0.00019	4,700	do
do	1C (Dc52-31)	do	do	do	do	0.00017	5,400	do
do	6 (Ec12-3)	do	do	do	do	0.00011	9,600	do
do	3 (Ec12-2)	do	do	do	do	0.0003	6,400	do
do	13 (Ec14-1)	do	do	do	do	0.00028	11,500	do

Table B4 Continued

Date	Well	Hydro-logic Zone	Owner	Pumping Test Conducted by	Data Analyzed by	Coefficient of Storage	Effective Coefficient of Trans-missivity gpd/ft.	Remarks
do	5C,1C, 6,3,13	do	do	do	do	0.00021	7,500	Average of above 5 wells
10-12, 13,1955	5A (Dc53-31)	do	do	Tidewater Oil Company	Tidewater Oil Co.		5,900	
11-8 to 12-28-55	6 (Ec12-3)	do	do	do	do		8,500 to 6,000	
do	13 (Ec14-1)	do	do	do	do		9,300	
Dec. 1954	15 (Dc52-24)	Upper Potomac Zone	do	Leggette and Brashears	Leggette and Brashears		4,500	Pumped well. Source of data same as for Well #16 above
do	1-D (Dc52-32)	do	do	do	do	0.00017	4,100	
do	14-A (Dc53-6)	do	do	do	do	0.0005	7,100	
do	3-B (Ec12-15)	do	do	do	do	0.00006	4,700	
do	5-B (Dc53-32)	do	do	do	do	0.00025	7,200	

Table B4 Continued

Date	Well	Hydrologic Zone	Owner	Pumping Test Conducted by	Analyzed by	Coefficient of Storage	Effective Coefficient of Transmissivity gpd/ft.	Remarks
9-29-55	1-H (Dc52-6)	do	do	Tidewater Oil Company	Tidewater Oil Co.		6,100	
do	3-B (Ec12-15)	do	do	do	do		7,500	
do	9 (Ec51-3)	do	do	do	do		4,800	
Oct. 1966	TW-2 (Ec32-3)	do	Union Carbide Company	Geraghty and Miller	R. W. Sundstrom		6,100	Basic data furnished by Geraghty and Miller
do	OB-1 (Ec32-4)	do	do	do	do		6,500	do
do	OB-2 (Ec32-5)	do	do	do	do		6,500	do
Nov. 1966	BFG OB-1 (Maryland)	Lower Potomac Zone	B. F. Goodrich Company	do	do		12,300	do
do	BFG OB-2 (Maryland)	do	do	do	do		12,300	do

Remarks: Numbers in parenthesis are assigned by Delaware Geological Survey.

Table B5.

Static Water Levels and Pumpage Data in the Town of Clayton Well Drawing from the Rancocas Aquifer

Date	Static Water Level Below Pump Base in Feet	Altitude of Static Water Level Above MSL	Yield GPM	Discharge Pressure LBS	Remarks
1954	31	14	350		410 ft. Total dynamic head
Apr. 1964	98	-53			
July 1965	123	-78	255	63	Pumping level 200 ft.
do			318	0	Pumping level below 205 ft.
June 1967	103	-58	335	10	Pumping level 205 ft.

Source of data: Shannahan Artesian Well Company

Table B6.

Early Artesian Pressure Data in Wells to the Rancocas Aquifer in the Clayton Area

Well	Date	Owner	Depth to Water in Feet	Altitude of Measuring Point	Altitude of Artesian Pressure in Feet
Hc32-16	April 1943	W. L. Wheatley	14	40	26
Ib32-1	Oct. 21, 1949	Marvel Everett	40	65	25
Hc32-2	Mar. 27, 1950	Town of Clayton	22	45	23

Table B7.

Specific Capacities of Wells and Test Wells in the Rancocas Aquifer in New Castle and Kent Counties, Delaware

Well	Owners Number	Owner	Aquifer	Specific Capacity GPM/Ft.	Time Pumped	Depth of Well in Feet
Hc14-3	2	State of Delaware	Rancocas	3.4	12 hrs.	271
Gc54-3	1	do	do	1.1	12 hrs.	250
Hc32-2		Town of Clayton	do	1.8		272
Hc32-16	4	W. L. Wheatley	do	4.6		260
Ib32-1		Marvel Everett	do	1.4		296

Table B8.

Coefficients of Transmissivity and Storage Determined from Pumping Tests of Wells in the Rancocas aquifer in New Castle County

Date	Well	Aquifer	Owner	Pumping Test Conducted by	Data Analyzed by	Coefficient of Storage	Coefficient of Trans-missivity GPD/FT.	Remarks
3-28-67	Gc54-2	Rancocas	State of Delaware	A.C. Schultes and Sons	R.W. Sundstrom	0.00028	19,100	Well He14-3 Pumping
3-28-67	Gc54-3	do	do	do	do	0.00027	19,200	do
4-10-67	Gc54-2	do	do	do	do	0.00022	14,000	Well Gc54-3 Pumping
4-10-67	Hc14-3	do	do	do	do	0.00019	16,800	Well Gc54-3 Pumping

Table B9.

Example of Computed Drawdowns Caused
by Pumping Seven Hypothetical Wells in the
Rancocas Aquifer, 5,000 Feet apart, from Clayton
Southwestward toward the State Line in Kent County

Well	1	2	3	4	5	6	7
Rate of Pumpage GPM	350	350	300	300	300	350	350
Drawdown effect, in feet, Well 1	140	17	15	13	12	11	10
Drawdown effect, in feet, Well 2	17	140	17	15	13	12	11
Drawdown effect, in feet, Well 3	13	15	120	15	13	12	10
Drawdown effect, in feet, Well 4	12	13	15	120	15	13	12
Drawdown effect, in feet, Well 5	10	12	13	15	120	15	13
Drawdown effect, in feet, Well 6	11	12	13	15	17	140	17
Drawdown effect, in feet, Well 7	10	11	12	13	15	17	140
Pumping Level, in feet, (10,000 days)	213	220	205	206	205	220	213

Allowable drawdown	220	feet
Distance between wells	5,000	feet
Time	10,000	days
Transmissivity	16,800	gpd/ft.
Coefficient of storage	0.00019	
Specific Capacity	2.5	gpm/ft.

Table B10.

Specific Capacities of Wells and Test Wells
in Kent County, Delaware, and Surrounding Area

Well	Owners Number	Owner	Aquifer	Specific Capacity GPM/Ft.	Time Pumped	Depth of Well in Feet	Source of Data
Hc14-3	2	State of Delaware	Rancocas	3.4	12 hrs.	271	Pumping test by A. C. Schultes & Sons 3-28-67
Gc54-3	1	do	do	1.1	12 hrs.	250	do - 4-10-67
Hc32-2		Town of Clayton	do	1.8		272	Pumping test by Shannahan Artesian Well Co. 6-21-67 and using original static of 1950
Hc32-16	4	W. L. Wheatley	do	4.6		260	Plant Engineer, W. L. Wheatley, 1955
Ib32-1		Marvel Everett	do	1.4		296	Ennis Bros. Drillers Completion Report 10-21-49
He52-2	1	National Wildlife Refuge	Piney Point	0.9	4 hrs.	262	Delaware Geological Survey
If11-1	5	do	do	3.6	Flowed	312	do
Id53-3	McKee Run 6	City of Dover	do	2.7	14 days	372	Layne-New York Co. Test 5-8-63
Id53-2	do 7	do	do	3.6	10 hrs.	379	do - 4-4-62
Jd14-12	Division Street Test Well	do	do	6.1	5 hrs.	423	Shannahan Artesian Well Co. 10-19-61

Table B10 Continued

Well	Owners Number	Owner	Aquifer	Specific Capacity GPM/Ft.	Time Pumped	Depth of Well in Feet	Source of Data
Jd25-3	Danner Farm #10	City of Dover	Piney Point	14.6		484	Shannahan Artesian Well Co.
Jd23-1	Crossgates	do	do	4.7	24 hrs.	435	Shannahan Artesian Well Co.
Je32-5	D	U. S. Air Force Dover Air Force Base	do	9.6 to 5.6	4 years	575	Daily observations by personnel of Air Force Base
Kd13-1		Kent County Vocational and Technical School	do	5.9			Shannahan Artesian Well Co. Pumping Test 6-15-65
Kd51-5	3	Swift & Co.	do	4.9	7-1/2 hrs.	583	Layne-New York Co. 7-6-60
Kd11-8	2	Green Giant Co.	do	10.8	12 hrs.	490	A. C. Schultes & Sons 3-11-59
Me15-29	Piney Point Test Well	City of Milford	do	0.3	3 hrs.	788	A. C. Schultes & Sons 2-20-68
Id31-18	7	International Latex Co.	Cheswold	0.9	Several hrs.	163	Delmarva Drilling Co. Test 7-3-57
Id31-2	8	do	Cheswold, Upper Miocene and Pleistocene	3.4	do	160	do

Table B10 Continued

Well	Owners Number	Owner	Aquifer	Specific Capacity GPM/Ft.	Time Pumped	Depth of Well in Feet	Source of Data
Jd14-2	Power Plant #1	City of Dover	Cheswold	7.9	Several hrs.	228	Shannahan Artesian Well Co. Pumping test 12-2-66
Jd14-1	Division Street #2	do	do	5.5	38 hrs.	210	do - 2-17-64
Jd24-1	Dover Street #3	do	do	12.0	24 hrs.	222	City of Dover
Jd14-6	Water Street #4	do	do	16.7	1-1/2 hrs.	221	Shannahan Artesian Well Co. 1-4-61
Jd15-2	Bayard Ave. #5	do	do	25.4		224	do Pumping test 11-23-67
Jd15-4	East Dover #8	do	do	16.6	576 hrs.	229	City of Dover - 1966 Pumpage and Water Level Records
Jd25-2	Danner Farm #9	do	do	6.2	641 hrs.	222	do
Je32-3	Well A	Dover Air Force Base	do	11.2 to 5.9	5 years (inter-mittently)	268	Dover Air Force Base - 1966 Pumpage and Water Level Records Joseph W. White, Chief Engineer
Je31-1	Well B	do	do	21.6 to 17.2	do	232	do
Je31-2	Well C	do	do	15.7 to 13.6	7 days	233	do
Jd35-2		C. Zimmerman	do	6.9	24 hrs.	213	Delaware Geological Survey-Bulletin 4

Table B10Continued

Well	Owners Number	Owner	Aquifer	Specific Capacity GPM/Ft.	Time Pumped	Depth of Well in Feet	Source of Data
Jd43-2		Towns of Camden and Wyoming	Cheswold	7.9	24 hrs.	237	Delaware Geological Survey - Bulletin 4
Ld51-1	1	Town of Harrington	Frederica	9.6		234	Test Report by M. Pentz 3-14-63
Ld51-2	2	do	do	10.6		234	Well Completion Report M. Pentz 12-8-58
Le45-1		Scarborough's Hatchery	do	3.0		223	Delaware Geological Survey - Bulletin 4
Le55-5	5	City of Milford	Miocene above the Frederica	6.4	2 hrs.		
Le54-3	8	do	do	5.2	6 hrs.		
Hc55-1		W. Gibe	Pleistocene	52.4	5 hrs.	121	Delaware Geological Survey - Bulletin 4
Mf11-6	7	City of Milford	do	24.6	24 hrs.	68.5	

Table B11.

Coefficients of Transmissivity and Storage Determined from Pumping Tests of Wells in Kent County, Delaware, and Surrounding Area

Date	Well	Aquifer	Owner	Pumping Test Conducted by	Data Analyzed by	Coefficient of Storage	Coefficient of Transmissivity GPD/Ft.	Remarks
3-28-67	Gc54-2	Rancocas	State of Delaware	A.C.Schultes & Sons	R. W. Sundstrom	0.00028	19,100	Well He14-3 Pumping - Data from Del. Geological Survey well in New Castle County near county line
3-28-67	Gc54-3	do	do	do	do	0.00027	19,200	do
4-10-67	Gc54-2	do	do	do	do	0.00022	14,000	Well Gc54-3 Pumping
4-10-67	Hc14-3	do	do	do	do	0.00019	16,800	Well Gc54-3 Pumping
4-4-62	McKee Run 6 (Id53-2)	Piney Point	City of Dover	Layne-New York Co.	do		6,000	Data from City of Dover
4-4-62	McKee Run 7 (Id53-3)	do	do	do	do		8,500	do
10-19-61	Division St Test Well (Jd14-12)	do	do	Shannahan Artesian Well Co.	do		28,000	do
8-2-65	Crossgates 11 (Jd23-1)	do	do	do	do		21,000	do First 2-1/2 hrs. of test

Table B11 Continued

Date	Well	Aquifer	Owner	Pumping Test Conducted by	Analyzed by	Coefficient of Storage	Coefficient of Trans-missivity GPD/Ft.	Remarks
8-2-65	Crossgates 11 (Jd23-1)	Piney Point	City of Dover	Shannahan Artesian Well Co.	R. W. Sundstrom		9,900	Data from City of Dover - Last 2-1/2 hrs. of test
do	do	do	do	do	do		9,000	Recovery test
7-24-63	Je32-4	do	U.S. Air Force	R. D. Varrin	R. D. Varrin	0.0003	32,000	Well Je32-5 Pumping
do	do	do	do	do	do		41,000	Recovery
do	do	do	do	do	R. W. Sundstrom	0.00027	39,000	Using first 36 minutes and last 15 hrs. of drawdown curve
3-11-59	Kd11-8	do	Green Giant Co.	A. C. Schultes & Sons	do		33,200	Data from A. C. Schultes & Sons
7-6-60	Kd51-5	do	Swift & Co.	Layne-New York Co.	do		38,000	Data from Swift & Co.
7-23-51	DorCe4 Cambridge Md.	do	City of Cambridge Md.	R. H. Brown and T. H. Slaughter	Brown and Slaughter	0.00036	47,500	Drawdown test-Data from Bed 18 Maryland Dept of Geology Mines & Water Resources

Table B11 Continued

Date	Well	Aquifer	Owner	Pumping Test Conducted by	Data Analyzed by	Coefficient of Storage	Coefficient of Trans-missivity GPD/Ft.	Remarks
7-23-51	DorCe4 (Cambridge, Md.)	Piney Point	City of Cambridge Md.	R.H. Brown and T.H. Slaughter	Brown and Slaughter	0.00038	42,500	Recovery test
2-19-68	(Me15-29)	Piney Point	City of Milford	A. C. Schultes and Sons	R. W. Sundstrom		200	
3-1-68	Milford Test Well (Me15-29B)	Miocene below Ches-wold	City of Milford	A. C. Schultes and Sons	A. C. Schultes and Sons		3,180	Drawdown in Miocene sands from 480 to 540 feet below land surface
1-2-64	Division Street 2 (Jd14-1)	Ches-wold	City of Dover	J. R. Woods	R. W. Sundstrom		32,800	Data from City of Dover
2-17-64	Bayard Ave. 5 (Jd15-2)	do	do	Shannahan Artesian Well Co.	do		23,500	do
12-30-63	E. Dover El. School (Jd15-4)	do	do	do	do		19,000	do
12-30-63	E. Dover El. School Test Well (Jd15-6)	do	do	do	do	0.0062	16,300	Jd15-4 Pumped
3-25-68	DannerFarm Test Well (Jd25-5)	do	do	R.Sundstrom, E. M.Cushing, and S.W.McKenzie	do	0.00031	11,200	Jd25-4 Pumped

Table B11 Continued

Date	Well	Aquifer	Owner	Pumping Test Conducted by	Data Analyzed by	Coefficient of Storage	Coefficient of Trans-missivity GPD/Ft.	Remarks
3-26-68	DannerFarm Test Well (Jd25-5)	Ches-wold	City of Dover	R.Sundstrom, E. M.Cushing, and S.W.McKenzie	R. W. Sundstrom		13,600	Recovery
3-26-68	DannerFarm Well 9 (Jd25-4)	do	do	do	do		11,800	do
10-19-65	Harrington (Ld51-8)	Fred-erica	City of Harring-ton	Alexander Pump Co.	do		12,300	First 3 hrs. of drawdown test
7-25-67	City Well 8 (Le54-3)	Miocene sands above the Frederica	City of Milford	Shannahan Artesian Well Co.	do		10,900	Drawdown test Data from City of Milford
3-30-62	City Well 5 (Le55-5)	do	do	Layne-New York Co.	do		11,000	do

Table B12

Coefficients of Transmissivity and Storage Determined from Pumping Tests of Wells in Eastern Sussex County, Delaware, and Surrounding Area

Date	Well	Aquifer	Owner	Pumping Test Conducted by	Data Analyzed by	Coefficient of Storage	Coefficient of Trans-missivity GPD/Ft.	Remarks
3-1-68	Me15-29B	Miocene below Cheswold	Milford	A.C. Schultes and Sons	R. W. Sundstrom		3,500	Screened 480 to 540 feet.
3-30-62	Le55-5	Miocene above Cheswold	do	Layne-New York Co.	do		9,400	Screened 293 to 328 feet.
10-19-65	Ld51-8	Frederica	Harring-ton	Alexander Pump Co.	do		12,300	
7-25-67	Le54-3	Miocene above Frederica	Milford	A.C. Schultes and Sons, Inc	do		10,900	
6-9-67	Le54-1	do	do	do	do	.0066	10,700	
6-67	Qj32-12	Manokin	Bethany Beach	Middletown Drilling Co.	do		60,000	
12-51	WorBh-1	do	Ocean City, Maryland	G. E. Andreasen	G. E. Andreasen	.00001	26,500	Dept. of Geol. Mines and Water Res. Bul. 16
10-3-47	WorDd 8	do	Snow Hill, Maryland	Rex R. Meyer	Rex Meyer		40,000	do

Table B12 Continued

Date	Well	Aquifer	Owner	Pumping Test Conducted by	Data Analyzed by	Coefficient of Storage	Coefficient of Transmissivity GPD/Ft.	Remarks
12-51	WorBh 6,7,8	Pocomoke	Ocean City, Maryland	G. E. Andreasen	G. E. Andreasen	.00012	10,000	Dept. of Geol. Mines and Water Res. Bul. 16
1-52	WorCg 5	do	do	do	do	.00014	14,000	do
12-23-54	Ni3 Obs 3	Pleistocene	Lewes	US Geological Survey	W. C. Rasmussen	.0147	84,000	Leaky non-artesian aquifer.
12-23-54	Ni47 Obs 7	do	do	do	do		106,000	do
do	Ni48 Obs 8	do	do	do	do		87,000	do
do	Ni36 TW 1	do	do	do	do		135,000	do
do	Ni37 TW 2	do	do	do	do		102,000	do
5-11-44	Oi24-1	do	Rehoboth Beach	do	P. B. Smoor	.006	58,000	do Well 2 pumping.
1-21-52	Oi34-1	do	do	Shannahan Artesian Well Co.	do		45,000	do Recovery pumped well.
1925	Qd21-2	do	Laurel	Permeability Determinations	US Geol. Survey		114,000	Average permeability between depths of 21 and 80 feet times thickness.

Table B13

Lowest Pumping Levels and Available Drawdown
in the City of Dover Wells to the Cheswold Aquifer

Well	Lowest Pumping Level in Feet	Date	Depth to Top of Aquifer in Feet	Depth to Top of Screen in Feet	Available Drawdown		Remarks
					To Top of Aquifer in Feet	To Top of Screen in Feet	
Power Plant 1 (Jd14-2)	154	6-21-67	141	181	Below	27	Source of data:
Division St. 2 (Jd14-1)	181	7-28-65 and 11-17-65	175	195	Below	14	Weekly measurements made by the City of
Dover St. 3 (Jd24-1)	172	9-14-66	175	197	3	25	Dover. Pumping levels are below
Water St. 4 (Jd14-6)	172	6-23-65 and 9-14-66	169	189	Below	17	land surface datum at the well.
Bayard St. 5 (Jd15-2)	157	10-6-65	193	193	36	36	
E.Dover El.S.8 (Jd15-4)	174	8-30-67	188	188	14	14	
Danner Farm 9 (Jd25-2)	183	7-7-65 and 8-30-67	175	175	Below	Below	

Table B14

Specific Capacities of Wells in Eastern Sussex County, Delaware, and Surrounding Area

Well	Owner	Aquifer	Specific Capacity GPM/Ft.	Period of Pumping Hours	Depth of Well in Feet	Source of Data
Me15-29	City of Milford	Piney Point	0.24	3	795	A. C. Schultes & Sons, Inc. Pumping Test 2-20-68
Me15-298	do	Miocene below Cheswold	0.90	4	540	do--3-1-68
Le55-5	do	Federalsburg	4.0	8	328	Layne-New York Co. 8-26-53
Me15-3	do	Frederica	5.6	12	242	Delaware Geological Survey
Me15-5	Schine-Milford Theater	do	4.3		225	do
Le54-2	City of Milford	Miocene above Frederica	5.4	2.5	165	A. C. Schultes & Sons, Inc. Pumping Test 6-9-67
Le54-3	do	do	3.4	6	165	do---7-25-67
Qj22-3	Sussex Shores Water Co.	Manokin	9.5	8	186	Delaware Water and Air Resources Commission
Qj22-4	do	do	3.0	8	186	do
Qj32-12	Bethany Beach	do	17.3	2	230	Delaware Geological Survey
Qj32-12	do	do	18.7	2	230	Delaware Water and Air Resources Commission

Table B14 Continued

Well	Owner	Aquifer	Specific Capacity GPM/Ft.	Period of Pumping Hours	Depth of Well in Feet	Source of Data
Rh32-6	Town of Selbyville	Manokin	10.0		185	Delaware Geological Survey-Bulletin 8
Qh51-12	Hipro Associates	Pleistocene-Pocomoke	14.5		121	do
Me21-1	Diamond State Nurseries	Pleistocene	15.0		63	Delaware Geological Survey
Mf11-6	City of Milford	do	24.6	48	68	Shannahan Artesian Well Co.
Mf23-3	Roland Sharp	do	2.2		84	Delaware Geological Survey
Mg43-1	Carlton Clifton	do	3.2		119	do
Mg51-1	Carlton Clifton	do	16.7		62	Delaware Geological Survey-Bulletin 4
Nf34-2	Clyde Betts & Sons	do	2.7	4	91	Delaware Water and Air Resources Commission
Nh42-1	B. White	do	5.7		68	Delaware Geological Survey-Bulletin 4
Ni42-8	City of Lewes	do	16.0		64	do
Ni51-6	do	do	11.4		162	do
Ni52-1	Diamond State Poultry Co.	do	20.0		94	do
Ni51-13	F. Thorpe	do	3.5		87	do

Table B14 Continued

Well	Owner	Aquifer	Specific Capacity GPM/Ft.	Period of Pumping Hours	Depth of Well in Feet	Source of Data
Ni51-14	J. W. Webb	Pleistocene	2.5		87	Delaware Geological Survey-Bulletin 4
Nj51-1	Fort Miles	do	10.5		85	do
Of42-16	Water and Supply Co.	Pleistocene-Manokin	17.8		116	do
Of42-23	Towsend Canning Co.	do	34.5		110	do
Of43-2	Swift & Co.	do	44.2		110	do
Og32-1	H. G. Graves	Pleistocene	2.8		88	do
Og23-3	Paramount Poultry	do	7.8		79	do
Oh11-2	M. G. Vaughn	do	8.8		84	Delaware Geological Survey
Oi12-1	Charles Nelson, Jr.	do	2.5	8	69	do
Oi24-1	Rehoboth Beach	do	3.8	8	102	do
Oi25-1	A. P. Richardson	do	12.0		118	do
Oi34-1	J. Wolfe	do	10.0		104	Delaware Geological Survey Bulletin 4
Oi35-18	Harry R. Watson	do	16.0		112	Delaware Geological Survey

Table B14 Continued

Well	Owner	Aquifer	Specific Capacity GPM/Ft.	Period of Pumping Hours	Depth of Well in Feet	Source of Data
Oj41-9	James Pierce	Pleistocene	5.6		98	Delaware Geological Survey
Oj41-26	Francis Denmead	do	5.5		110	do
Oj41-10	E. Kline	do	2.6		100	Delaware Geological Survey-Bulletin 4
Oj41-13	J. Rawlins	do	3.8		107	do
Oj41-16	T. B. O'Toole	do	6.6		111	do
Oj41-18	C. Riggs	do	4.0		105	do
Oj41-30	Francis Denmead	do	5.5		110	do
Oj41-31	Anderson-Stokes	do	5.0	10	120	Delaware Water and Air Resources Commission
Pg53-10	Norman Rogers	do	4.1	2	80	do
Pg54-1	Millsboro Poultry Co.	do	12.5		105	Delaware Geological Survey-Bulletin 4
Ph51-1	Delaware Power and Light	do	10.0		71	do
Pi13-1	James Travis	do	4.6		70	Delaware Water and Air Resources Commission
Pi33-1	S. H. Showell	do	12.5	1.5	60	do

Table B14 Continued

Well	Owner	Aquifer	Specific Capacity GPM/Ft.	Period of Pumping Hours	Depth of Well in Feet	Source of Data
Qg13-3	National Cash Register	Pleistocene	13.0	4	90	Delaware Water and Air Resources Commission
Qh11-1	Delmarva Poultry Co.	do	15.4		111	Delaware Geological Survey
Qh51-10	Eagle Poultry Co.	do	24.0		105	do
Qh51-11	do	do	14.6		122	do
Qj32-7	Sussex Shores Water Co.	do	3.0	4	71	do
Qj42-2	Thomas Throop	do	0.6	4	160	Delaware Water and Air Resources Commission
Rg35-1	E. S. McCabe and Son	do	14.2	8	118	Delaware Geological Survey
Rh32-9	Town of Selbyville	do	9.0	12	125	do
Rj32-18	Conn Scott Inc.	do	2.4	4	68	Delaware Water and Air Resources Commission

TABLE B15

Specific Capacities of Wells in Western Sussex County Delaware, and Surrounding Area

Well	Owner	Aquifer	Specific Capacity (gpm/ft)	Period of Pumping (hours)	Yield of well (gpm)	Depth of well (feet)	Source of Data
Me15-29	City of Milford	Piney Point	0.24	3	46	795	A. C. Schultes & Sons, Inc., Pumping Test 2-20-68
Care Dd-TW2	Town of Denton, Md.	do	4.9	3	250	440	Delmarva Drilling Co. Pumping Test 5-20-69
Care Dc-67	Caroline Poultry Farms	do	1.8	72	160	470	Rasmussen and Slaughter 1957
Care Dc-122	do	do	0.2		25	490	do
Me15-29 B	City of Milford	Miocene below Cheswold	0.9	4	46	540	A. C. Schultes & Sons, Inc., Pumping Test 3-1-68
Le55-5	City of Milford	Federalsburg	4.0	8	480	328	Delaware Geological Survey
Me15-13	do	Frederica	5.6	12	373	242	do
Me15-5	Schine-Milford Theater	do	4.3		400	225	do
Ld51-1	Town of Harrington	do	9.6		200	234	M. Pentz. Pumping Test 3-14-63

TABLE B15. Continued

Well	Owner	Aquifer	Specific Capacity (gpm/ft)	Period of Pumping (hours)	Yield of well (gpm)	Depth of well (feet)	Source of Data
Ld51-2	do	do	10.6		200	234	M. Pentz. Pumping Test 12-8-58
Care Ee-1	L. B. Case	Miocene above Frederica	5.6	10	50	170	Rasmussen and Slaughter, 1957
Le54-2	City of Milford	do	5.4	6	210	165	A. C. Schultes & Sons, Inc. Pumping Test 7-25-67
Le54-3	do	do	3.4	6	280	165	A. C. Schultes & Sons, Inc. Pumping Test 6-9-67
Pb13-1	Phillips Canning Co.	do	1.6			303	Delaware Geological Survey
Care Fd-6	Caroline Poultry Farms	do	4.0	8	200	304	Rasmussen and Slaughter, 1955
Care Fd-7	do	do	4.0	8	200	306	do
Rh32-6	Town of Selbyville	Manokin	10		100	185	Delaware Geological Survey
Rh32-2	do	Manokin-Pocomoke			500	110	do
Of42-23	Townsend Canning Company	Manokin-Pleistocene	34.5		1,005	110	do

TABLE B15 Continued

Well	Owner	Aquifer	Specific Capacity (gpm/ft)	Period of Pumping (hours)	Yield of well (gpm)	Depth of well (feet)	Source of Data
Of43-2	Swift & Company	do	44.2		575	110	Delaware Geological Survey
Pe23-2	University of Delaware	do	12.4		80	84	do
Pf23-2	H. Kruger, Inc.	do	28.6	3	1,200	180	Delmarva Drilling Co.
Qc14-5	Coleman Wheatley	do	49.0		831	96	Delaware Geological Survey
Qd21-2	Town of Laurel	do	12.9		500	91	do
Qd21-3	do	do	12.9		540	91	do
Qd21-4	do	do	12.8		730	94	do
Qd21-5	do	do	16.7		700	103	do
Qh41-1	Delmarva Poultry Company	Pocomoke-Pleistocene	14.4	12	400	111	do
Qh51-9	do	do	4.4		120	98	do
Qh51-10	do	do	24.0		240	105	do
Qh51-11	Hipro Associates	do	14.5		240	121	do
Rg35-1	E. S. McCabe & Son	do	14.1		220	118	do

TABLE B15 Continued

Well	Owner	Aquifer	Specific Capacity (gpm/ft)	Period of Pumping (hours)	Yield of well (gpm)	Depth of well (feet)	Source of Data
Nc25-2	Town of Green-wood	Pleistocene or Pleisto-cene and subcropping Miocene	13		690	61	do
Pc23-3	Town of Sea-ford	do	27.6		800	95	do
Pc23-4	E. I. DuPont & Company, Inc.	do	20.3		650	100	do
Pc24-8	Town of Sea-ford	do	15.5		420	68	do
Pc33-9	E. I. DuPont & Company, Inc.	do	23.7		640	83	do
Pc33-10	do	do	24.0		600	78	do
Pc44-4	Ralph Givens	do	40.0		300	109	do
Pd21-1	Dr. D. L. Bice	do	6.0		60	92	do
Pe23-2	University of Delaware	do	12.3		80	84	do
Pe23-5	do	do	6.7		100	115	do
Rd31-8	Town of Delmar	do	10.0		290	126	do

Table B16.

Coefficients of Transmissivity and Storage Determined from Pumping Tests of Wells in Sussex County, Delaware and Surrounding Area

Date	Well	Aquifer	Owner	Pumping Test Conducted by	Data Analyzed by	Coefficient of Storage	Coefficient of Transmissivity GPD/Ft.	Remarks
2-19-68	Me15-29	Piney Point	Milford	A. C. Schultes	R. W. Sundstrom		200	Test well. 65 feet of screen
7-6-60	Kd51-5	do	Swift and Company	Layne-New York Company	do		38,000	Data from Swift and Co.
5-20-69	Care DdTW1	do	Denton, Md.	Delmarva Drilling Company	do	0.00042	11,900	Data from Delmarva Drilling Company
3-1-68	Me15-29 B	Miocene below Cheswold	Milford	A. C. Schultes and Sons, Inc.	do		3,500	A. C. Schultes and Sons, Inc. Pumping Test 3-1-68
3-9-56	Tal-Bf-73	do	Esskay Packing Company Cordova, Md.	Rasmussen and Slaughter	Rasmussen and Slaughter	0.0001	1,300	Data from Rasmussen and Slaughter, 1957
1-16-56	Tal-Ce 2,6,7 and 8	Cheswold	Easton Utilities Comm.	do	do	0.0001	3,500	Data from Rasmussen and Slaughter, 1957 Wells in Easton, Maryland

Table B16 Continued

Date	Well	Aquifer	Owner	Pumping Test Conducted by	Data Analyzed by	Coefficient of Storage	Coefficient of Transmissivity GPD/Ft.	Remarks
3-30-62	Le55-5	Miocene above Cheswold	Milford	Layne-New York Company	R. W. Sundstrom		9,400	Screened 293 to 328 feet.
10-19-65	Ld51-8	Fred-erica	Har-rington	Alexander Pump Company	do		12,300	
7-18-52	Cas-De -57	do	-	D. H. Boggess	D. H. Boggess	0.003	6,000	Data from Ras-mussen and Slaughter,1957
7-25-67	Le54-3	Miocene above Frederica	Milford	A. C. Schultes and Sons, Inc.	R. W. Sundstrom		10,900	
6-9-67	Le54-1	do	do	do	do	0.006	10,700	
6-7-67	Qj32-12	Manokin	Bethany Beach	Middletown Drilling Company	do		60,000	
-	-	do	Mardel Bypro-ducts	U. S. Geol. Survey		0.0003	40,000	Data from Otton and Heidel,1966 Wells a few miles west of Salisbury, Md.

Table B16 Continued

Date	Well	Aquifer	Owner	Pumping Test Conducted by	Data Analyzed by	Coefficient of Storage	Coefficient of Transmissivity GPD/Ft	Remarks
10-3-47	Wor Dd -8	do	Snow Hill, Md.	Rex R. Meyer	R. R. Meyer		40,000	Data from Rasmussen and Slaughter, 1955
12- -51	Wor Bh 6,7,8	Pocomoke	Ocean City, Md.	G. E. Andreasen	G. E. Andreasen	0.0001	10,000	do
1- -52	Wor Cg -5	do	do	do	do	0.001	14,000	do
1925	Od21-2	Pleistocene	Laurel	Permeability Determinations	U.S. Geol. Survey		114,000	Average permeability between depths of 21 and 80 feet multiplied by thickness in feet
4-6-50	Care Fd-2	do	Federalsburg, Md.	Brown and Brookhart	Brown and Brookhart		170,000	Data from Rasmussen and Slaughter, 1957
3-6-56	Dor Bg-33	do	U.S.G.S. State of Maryland	U.S.G.S.	U.S.G.S.		150,000	do
--	Wi Ce 1 to 13	do	Salisbury, Md.	do	do	0.15	100,000	do

Table B17

Yield and Specific Capacity of Large-Diameter Wells Tapping the Columbia (Pleistocene) Deposits and Estimated Transmissivity of the Aquifer

Well Number	Owner	Depth (feet)	Diameter (inches)	Screened Interval (feet)	Yield (gpm)	Specific Capacity (gpm/ft)	Estimated Transmissivity	
							gal/day/ft	ft^2/day
Cd 42-13	Artesian Water Co.	73	17	49 - 73	570	38	60,000	8,000
Cd 43-6	Atlas Chemical Industries, Inc.	71	26	52 - 67	600	27	40,000	5,300
Cd 51-1	Artesian Water Co.	47	17	24 - 47	350	10	18,000	2,400
Db 31-19	E.I. duPont Co.	65	10	53 - 65	100	8	14,000	1,900
Db 31-35	E.I. duPont Co.	80	8	70 - 80	500	11	9,000	1,200
Dc 53-5	Getty Oil Co.	90	8	70 - 90	525	48	72,000	9,600
Eb 55-4	Baker Brothers	40	17	16 - 40	600	19	30,000	4,000
Eb 55-5	Warren Baker	45	17	17 - 45	450	24	36,000	4,800
Fb 23-6	Fred Wicks	71	8	30 - 70	100	8.3	12,000	1,600
Fb 34-16	University of Delaware	74	8	54 - 74	110	3.5	33,000	4,500
Fb 51-4	George & Sam Brooks	44	17	24 - 44	520	19	29,000	4,000
Fb 51-5	George & Sam Brooks	44	17	16 - 44	620	20	30,000	4,000
Fb 51-6	Norman & Sam Brooks	54	17	---	300	12	19,000	2,500
Fb 53-7	Chris Wicks	80	17	21 - 80	580	9	14,000	1,900
Ga 15-4	Gerald Zeh	63	17	30 - 60	1,120	51	76,000	10,000
Hc 32-5	City Products Corp.	56	10	43 - 56	325	20	36,000	4,800
Hc 32-12	W.L. Wheatley, Inc.	77	12	---	780	14	25,000	3,300
Hc 34-3	City of Smyrna	100	10	70 - 100	550	30	54,000	7,200
Hc 34-22	City of Smyrna	96	12	55 - 85	1,100	54	120,000	16,000
Hc 43-3	George Wicks	115	10	---	1,020	82	150,000	20,000
Hc 44-3	George Wicks	133	12	75 - 132	1,050	88	160,000	21,000
Hc 55-1	Walter Gibe	120	10	90 - 120	1,000	52	93,000	12,000

(See Figure 1 for approximate location of wells)

Table B17 Continued

Well Number	Owner	Depth (feet)	Diameter (inches)	Screened Interval (feet)	Yield (gpm)	Specific Capacity (gpm/ft)	Estimated Transmissivity	
							gal/day/ft	ft^2/day
Ic 32-4	Frank Johnson	48	12	---	350?	5	9,000	1,200
Id 24-4	Philip Cartanza	157	17	25 - 157	1,050	20	30,000	4,000
Ie 31-1	Joseph Zimmerman	94	17	16 - 94	940	19	28,000	3,700
Ie 43-2	Philip Cartanza	106	17	16 - 103	1,400	50	75,000	10,000
Ie 53-2	Alfred Bilbrough	114	17	21 - 113	700	54	82,000	11,000
Ie 53-3	Alfred Bilbrough	72	17	36 - 72	750	17	25,000	3,300
Ie 53-4	Alfred Bilbrough	70	17	13 - 69	720	21	32,000	4,200
Jc 34-1	Joseph Wild	97	17	20 - 96	900	17	25,000	3,300
Jd 12-2	Eugene Gagan	104	17	40 - 96	1,300	22	33,000	4,400
Jd 21-2	Papen Farms	96	17	40 - 96	760	17	23,000	3,100
Jd 41-1	Libby, McNeil & Libby, Inc.	125	10	87 - 109	400	9	15,000	2,000
Jd 54-1	Joseph Jackweiez	118	17	26 - 118	1,260	21	38,000	5,100
Je 12-2	Jacob Zimmerman	72	10	---	600	16	24,000	3,200
Je 13-1	Alfred Bilbrough	70	17	18 - 66	780	21	31,000	4,200
Kd 24-2	Joseph Kowalski	134	13	38 - 134	1,050	21	31,000	4,200
Ke 12-2	Kenneth Bergold	146	17	30 - 74; 122 - 146	1,600	44	67,000	9,000
Ld 33-1	Walter Winkler	64	17	20 - 56; 60 - 64	1,400	39	60,000	8,000
Le 22-2	Charles West	73	8	13 - 73	400	11	17,000	2,300
Le 23-3	Charles West	74	13	22 - 74	380	9	14,000	1,900
Le 51-2	Floyd Blessing	105	17	---	1,200	64	96,000	13,000
Md 15-8	Libby, McNeil & Libby, Inc.	67	10	41 - 67	280+	22	40,000	5,300
Md 24-3	U.S. Geological Survey - DE Geological Survey	80	8	70 - 80	300+	10	165,000	22,000

Table B17 Continued

Well Number	Owner	Depth (feet)	Diameter (inches)	Screened Interval (feet)	Yield (gpm)	Specific Capacity (gpm/ft)	Estimated Transmissivity gal/day/ft	ft^2/day
Md 54-2	John Annet	82	17	30 - 82	1,180	53	80,000	11,000
Me 24-5	City of Milford	80	8	---	400	18	26,000	3,500
Me 24-6	City of Milford	69	12	39 - 59	520	29	42,000	5,600
Me 33-3	Donald Calhoun	74	17	38 - 70	700	30	45,000	6,000
Me 54-5	Delmarva Nursery	90	8	58 - 90	500	20	30,000+	4,000+
Mf 11-6	City of Milford	67	--	---	220	25	44,000	5,900
Mf 21-1	Diamond State Nurseries	63	8	---	180	15	27,000	3,600
Mf 22-4	Brown Thawley	131	17	44 - 106	1,400	80	120,000	16,000
Mg 42-13	Draper Foods, Inc.	89	8	69 - 89	150+	35	50,000	6,700
Nc 25-19	Bramble Canning Co.	84	--	---	1,300	24	36,000	4,800
Nc 53-3	O.A. Newton & Sons	100	12	---	1,080	22	33,000	4,400
Nd 33-1	J. Howard Lyons	92	17	---	1,200	30	45,000	6,000
Ng 12-1	Carlton Clifton	61	6	---	300	17	31,000	4,100
Ng 31-1	Willard Workman	122	17	---	900	74	110,000	15,000
Ng 41-2	Willard Workman	112	17	---	1,080	32	48,000	6,400
Ng 42-1	Town of Milton	68	6	---	200	31	56,000+	7,500+
Ng 42-15	Draper Canning Co.	--	13	---	1,300	65	100,000	13,000
Ng 42-16	Draper Canning Co.	84	13	---	1,020	49	73,000	10,000
Ng 55-4	U.S. Geological Survey-DE Geological Survey	70	8	60 - 70	200+	7	104,000	14,000
Ni 31-3	Lewes Dairy	60	8	---	100+	14	25,000	3,300
Ni 51-16	Town of Lewes	97	10	---	480	16		
Ni 51-17	Town of Lewes	157	10	---	500	11		
Ni 51-18	Town of Lewes	89	10	---	400	11	110,000	15,000
Ni 51-19	Town of Lewes	151	10	---	975	--		
Ni 51-20	Town of Lewes	146	10	---	900	26		

Table B17 Continued

Well Number	Owner	Depth (feet)	Diameter (inches)	Screened Interval (feet)	Yield (gpm)	Specific Capacity (gpm/ft)	Estimated Transmissivity	
							gal/day/ft	ft^2/day
Ni 52-1	Diamond State Poultry Co.	94	8	---	100	20	36,000	4,800
Oc 14-4	H.P. Cannon & Son, Inc.	109	8	---	600	21	38,000	5,100
Oc 14-5	H.P. Cannon & Son, Inc.	116	10	---	800	21	38,000	5,100
Oc 14-6	H.P. Cannon & Son, Inc.	98	8	---	500	15	27,000	3,600
Oc 24-1	H.P. Cannon & Son, Inc.	106	17	---	700	55	83,000	11,000
Of 42-23	Townsend, Inc.	105	16	---	950	27	41,000	5,500
Of 43-2	Swift & Co.	110	10	---	575	44	66,000	9,000
Og 23-1	Paramount Poultry Co.	64	6	---	150	4	7,000+	1,000+
Og 23-3	Paramount Poultry Co.	78	8	---	340	8	13,000+	1,700+
Oi 24-1	Town of Rehoboth	102	12	73 - 102	380	6	55,000	7,300
Oi 34-1	Town of Rehoboth	131	12	69 - 131 (Multiple)	720	23		
Pb 35-2	Ralph O'Day	89	17	33 - 89	920	42	63,000	8,400
Pc 23-3	City of Seaford	95	10	---	800	28	50,000	6,700
Pc 33-5	E.I. duPont Co.	98	10	---	540	12	21,000	2,800
Pc 33-9	E.I. duPont Co.	83	10	---	640	24	43,000	5,700
Pc 33-10	E.I. duPont Co.	78	10	---	600	24	43,000	5,700
Pc 33-11	E.I. duPont Co.	101	10	---	620	13	23,000	3,000
Pc 44-4	Ralph Givens	109	17	65 - 109	300+	40	60,000	8,000
Pc 54-1	Fred O'Neal	100	17	16 - 100	900	65	100,000	13,000
Pd 53-1	Emory Spicer	164	17	44 - 160	950	38	57,000	7,600
Pf 23-2	H. Kruger, Inc.	180	17	40 - 180	1,200	29	51,000	6,800
Pg 53-8	Town of Millsboro	83	8	---	250	9	14,000	1,900
Pg 53-9	Town of Millsboro	84	8	---	180	7	11,000	1,500
Pg 54-1	Millsboro Poultry Co.	105	8	---	400	12.5	19,000	2,500
Qb 44-5	Howard Rider	111	17	---	1,070	40	60,000	8,000
Qc 14-5	Coleman Wheatley	98	17	---	830	49	74,000	10,000

Table B17 Continued

Well Number	Owner	Depth (feet)	Diameter (inches)	Screened Interval (feet)	Yield (gpm)	Specific Capacity (gpm/ft)	Estimated Transmissivity	
							gal/day/ft	ft^2/day
Qc 14-6	Coleman Wheatley	90	17	---	550	32	48,000	6,400
Qc 24-6	Emory Spicer	121	17	---	1,400	107	160,000	21,000
Qc 34-1	Paul Spear	86	17	78 - 86	1,300	36	54,000	7,200
Qh 51-7	Town of Frankford	100	8	80 - 100	100+	22.5	36,000	4,800
Qh 51-10	Delmarva Poultry Co.	105	8	---	240	24	38,000	5,100
Qh 51-14	Town of Frankford	101	8	80 - 101	350+	40	64,000	8,500
Rd 31-11	Town of Delmar	139	8	---	---	18.4	33,000?	4,400
Rh 32-9	Town of Selbyville	125	8	105 - 125	300	9	16,000	2,100

From Richard H. Johnston, 1973.

Table B18

Records of Wells in Western Sussex County Giving the Altitude of the Land Surface, the Altitude of the Water Table, the Depth of Penetration in the Water-Table Aquifer below Sea Level, the Depth to the Base of the Pleistocene below Sea Level in Some Wells and the Known Thickness of the Water-Table Aquifer at Each Well

Well	Altitude of Surface in feet	Altitude of Water Table in feet	Depth of Penetration Below Sea Level in feet	Depth of Base of Pleistocene below sea level in feet	Known Thickness of Water-Table Aquifer in feet
Nc25-1	50	45	21	21	66
Nd41-1	45	31	46		77
Ne14-1	50	47	39		86
Ne34-2	49	41	44		85
Ne54-1	45	35	49		84
Ob33-1	48	43	32		75
Oc14-8	45	29	74		103
Oc35-2	45	31	39		70
Od23-1	43	30	133	84	163
Od24-1	36	33	127		160
Od32-1	25	11	89		100
Od42-2	30	15	69		84
Oe15-1	47	40	47		87

Table B18 Continued

Well	Altitude of Surface in feet	Altitude of Water Table in feet	Depth of Penetration Below Sea Level in feet	Depth of Base of Pleistocene below sea level in feet	Known Thickness of Water-Table Aquifer in feet
Of31-1	47	43	47		90
Of42-16	55	47	65		112
Pb13-1	46	39	44	44	83
Pc13-5	33	28	69		97
Pc23-10	29	19	87	87	106
Pc25-9	16	9	90		99
Pc32-6	17	10	78	78	88
Pc33-17	7	3	88		91
Pc45-1	43	35	56		91
Pc55-1	39	29	69	69	98
Pd21-4	30	20	79	79	99
Pe15-1	50	47	45		92
Pe23-5	50	40	62	62	102
Pe32-1	40	26	54		80
Pe33-1	42	36	52		88
Pf23-2	45	39	145	31	184

Table B18 Continued

Well	Altitude of Surface in feet	Altitude of Water Table in feet	Depth of Penetration Below Sea Level in feet	Depth of Base of Pleistocene below sea level in feet	Known Thickness of Water-Table Aquifer in feet
Qc13-3	4	3	116	103	119
Qc24-6	24	12	97		109
Qd21-5	25	5	77	77	82
Qd31-1	32	20	62		82
Qd51-1	41	33	42		75
Qe42-2	40	36	104	75	140
Rb25-2	44	39	41		80
Rc22-2	50	41	60		101
Rd21-1	50	45	54		99
Rd31-8	40	37	120		157
Rf21-3	52	37	94	94	131
Rf24-5	46	33	67		100
Rf32-4	50	40	73	49	113
Rg22-1	40	37	120		157

TABLE B19

Estimated Area and Volume of Saturated Material above and below Sea Level in the Water-Table Aquifer in the Pleistocene in each 5 Minute Grid of Latitude and Longitude of Western Sussex County

Grid (see Figure 1)	Area in Acres	Thickness of Saturation Above Sea Level in feet	Volume of Saturation Above Sea Level in Acre-feet	Thickness of Saturation Below Sea Level in feet	Volume of Saturated Material Below Sea Level in Acre-feet	Total Volume of Saturated Material in Acre-feet
Md	1,809	52	94,068	50	90,450	184,518
Me	580	55	31,900	50	29,000	60,900
Nb	10,381	39	404,859	50	519,050	923,909
Nc	16,682	50	834,100	50	834,100	1,668,200
Nd	16,682	46	767,372	50	834,100	1,601,472
Ne	13,708	43	589,444	50	685,400	1,274,844
Nf	4,042	46	185,932	50	202,100	388,032
Ob	9,268	43	398,524	52	481,936	880,460
Oc	16,682	46	767,372	52	867,464	1,634,836
Od	16,682	27	450,414	100	1,668,200	2,118,614
Oe	16,682	38	633,916	86	1,434,652	2,068,568
Of	6,117	45	275,265	73	446,541	721,806

TABLE B19- Continued

Grid (see Figure 1)	Area in Acres	Thickness of Saturation Above Sea Level in feet	Volume of Saturation Above Sea Level in Acre-feet	Thickness of Saturation Below Sea Level in feet	Volume of Saturated Material Below Sea Level in Acre-feet	Total Volume of Saturated Material in Acre-feet
Pb	7,970	30	239,100	44	350,680	589,780
Pc	16,682	25	417,050	75	1,251,150	1,668,200
Pd	16,682	27	450,414	62	1,034,284	1,484,698
Pe	16,682	42	700,644	62	1,034,284	1,734,928
Pf	1,293	43	55,599	70	90,510	146,109
Qb	6,673	20	133,460	45	300,285	433,745
Qc	16,682	27	450,414	75	1,251,150	1,701,564
Qd	16,682	30	500,460	66	1,101,012	1,601,472
Qe	16,682	40	667,280	60	1,000,920	1,668,200
Qf	6,117	42	256,914	40	244,680	501,594
Qg	287	38	10,906	50	14,350	25,256
Rb	2,844	39	110,916	60	170,640	281,556
Rc	8,414	40	336,560	60	504,840	841,400
Rd	8,994	39	350,766	70	629,580	980,346
Re	9,574	40	382,960	80	765,920	1,148,880

TABLE B19 - Continued

Grid (see Figure 1)	Area in Acres	Thickness of Saturation Above Sea Level in feet	Volume of Saturation Above Sea Level in Acre-feet	Thickness of Saturation Below Sea Level in feet	Volume of Saturated Material Below Sea Level in Acre-feet	Total Volume of Saturated Material in Acre-feet
Rf	9,864	40	394,560	90	887,760	1,282,320
Rg	2,959	40	118,360	120	355,080	473,440
Totals			11,009,529		19,080,118	30,089,647

Table B20.

The Relation of Ground-Water Stage to the Average Monthly
Discharge of the Nanticoke and Pocomoke Rivers
During Drought Recession
June to October 1968

Month	Water Level (feet below land surface)		Average Monthly Discharge (cubic feet per second)	
	Well Md22-1	Well Qe44-1	Nanticoke R.	Pocomoke R.
June, 1968	4.1	6.6	72.5	49.2
September, 1968			34.2	4.6
October, 1968	9.9	11.6		
Decline	5.8	5.0	38.3	44.6

Drainage area of Nanticoke River 75.4 square miles
Drainage area of Pocomoke River 60.5 square miles
One cubic foot per second equals 646,323 gallons a day

APPENDIX C: GHYBEN-HERZBERG PRINCIPLE

During the course of an extensive field and office study of the salt-water problem in the Atlantic City region by Barksdale and Sundstrom (1936), their report states in part:

"The problem of obtaining fresh water from sands that are exposed for a part of their extent to the waters of the ocean has been studied in many parts of the world. The earliest scientific work on this problem was done in Europe, where the basic principles were first pointed out in 1887 by Badon Ghyben, a Dutch captain of engineers, and in 1900 by Herzberg, who appears to have had no knowledge of the earlier work. The basic principles that govern the relation of salt water to fresh water in a water-bearing sand have now been fairly well established.

"At the contact between the fresh and salt waters the zone of diffusion is surprisingly narrow. In Holland, Pennink found a range of salinity from 100 to 15,000 parts per million of chloride in distances varying from 60 to 100 feet. In the present investigation ranges from 800 to 8,000 parts per million and from 1,900 to 7,300 parts per million were observed in four feet of depth.

"Salt water is heavier than fresh water and tends to fill the lower parts of a formation. The fresh water in the sand floats on the salt water much as ice floats on water, with most of its volume submerged. The position of the contact is determined by the head of the fresh water above mean sea level and by the relative specific gravities of the two waters. This is the principle developed by Badon Ghyben and Herzberg.

"This theory is illustrated in Figure 33, A and B (Figure C1 in this report). Figure 33A shows a simple U-type with both ends open to the air. The two legs of the tube are filled with two liquids of different specific gravities. The liquids in the tube will come to rest in such a way that the pressure at the bottom of one leg is exactly equal to and balanced by that at the bottom of the other leg. The surface of the lighter liquid will, therefore, necessarily stand higher than that of the heavier liquid. Furthermore, as the heavier liquid fills the lower part of the tube in both legs up to the level of the contact between the liquids, the pressure at this level is equal in both legs, and the heights of the two columns of liquid above the level of the contact are inversely proportional to the specific gravities of the liquid.

"In a small island or narrow peninsula composed entirely of permeable sand and surrounded by sea water, this same balance of pressure occurs between sea water and the lighter fresh water.

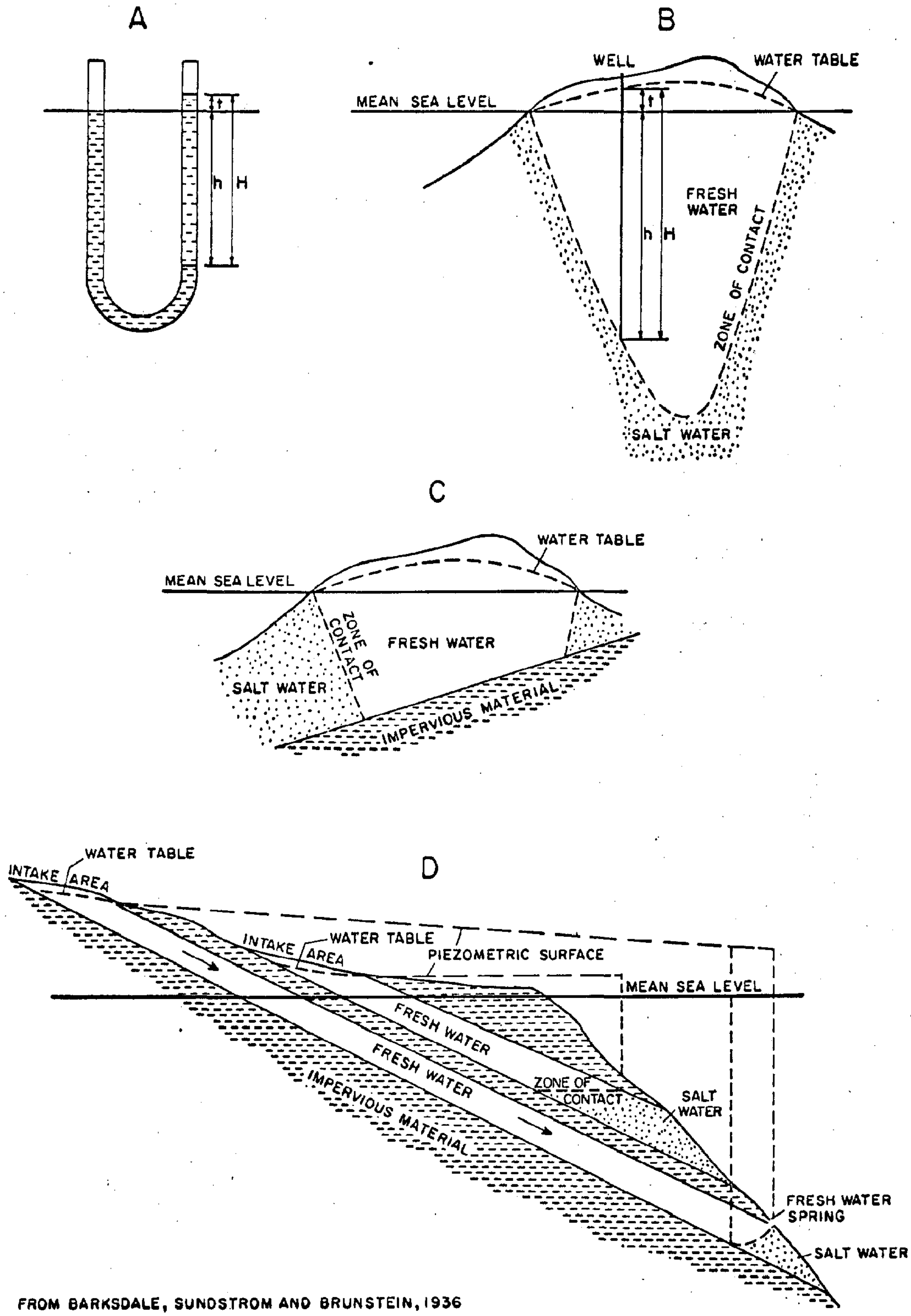


Figure C1. Relation between fresh and salt water in water-bearing sands when not disturbed by pumping.

Figure 33B represents a cross-section of such an island and shows that the salt water not only fills the sand around the island, but also extends entirely under it below the lens-shaped body of fresh water. In such an island the resistance of the sand to the flow of water causes the fresh water from rainfall to build up a head above sea level sufficient to cause it to flow out into the ocean at the shores of the island. It also prevents the mixing of the salt and fresh waters in the sand below sea level by wave action. As the sand is permeable in all directions, the fresh-water head will cause a downward flow of fresh water until it fills the sand to a depth at which its head is balanced by the head of the salt water. When equilibrium has thus been reached, the depth of the fresh water below sea level at any point on the island will be proportional to the fresh-water head above sea level at that point, and the ratio between the depth and head of the fresh water will depend upon the relation between the specific gravities of the fresh and salt waters.

"The following explanation of the relation between salt water and fresh water under a small sand island is applicable both to Figure 33A and Figure 33B:

Let H = total thickness of fresh water;

h = depth of fresh water below sea level;

t = height of fresh water above mean sea level;

Then $H = h + t$.

"But the column of fresh water H must be balanced by a column of salt water h in order to maintain equilibrium. Therefore, if g is the specific gravity of sea water and the specific gravity of fresh ground water is assumed to be 1,

$$H = h + t = hg$$

whence $$h = \frac{t}{g - 1}$$

in any case $g-1$ will be the difference in specific gravity between fresh water and the salt water.

"If it is assumed that the specific gravity of sea water is 1.025, which is about an average figure, then $h = 40t$. In other words, for every foot that the fresh water stands above sea level, it extends 40 feet below sea level. This ratio is so extreme that it is not practicable to show it in the various parts of Figure 33. For convenience, therefore, the first three parts of this figure have been drawn with a ratio of 1 to 10 between the head and depth of the fresh water. This would be the true condition if the specific gravity of the sea water were 1.100 instead of about

1.025. The fourth part of this figure is drawn with a ratio of 1 to 5 between the head and depth of the fresh water and represents an imaginary specific gravity of sea water of 1.200. The general relation between fresh and salt water shown by these diagrams is not affected in the least by this assumption of a specific gravity of sea water greater than the range that occurs in nature. The specific gravity of sea water varies from place to place, so that the figure of 1.025 used in the example above is only an approximate average.

"In nature a body of land composed entirely of permeable material to any great depth is rare. The occurrence of beds or layers of impermeable material does not change the basic principles just discussed, but it does modify their application. If the island shown in Figure 33B were underlain by clay or bedrock that reached a level above the bottom of the fresh-water body, conditions such as those shown in Figure 33C would occur. Along the coast the position of the contact would be determined by the head of the fresh water, just as in an island composed entirely of sand, but under the center of the island fresh water would extend all the way down to the impermeable layer and would not be in direct contact with salt water.

"The modification of conditions by impermeable formations is even more marked on the coasts of larger bodies of land, where water-bearing sands may lie under and between as well as above layers of impermeable material and may slope upward to remote intake areas well above sea level. Along such a coast the conditions in a permeable sand underlain by impermeable material would be similar to those in the sand island underlain by impermeable material, except that the fresh water would be in contact with salt water only on the side exposed to the ocean.

"Figure 33D shows two conditions which occur in water-bearing sands confined between layers of impermeable material. This diagram differs essentially from the others in that it shows the conditions that occur when the fresh water in the sand is under artesian head rather than under water-table conditions. In the upper sand in this diagram the salt water and fresh water are in balance, just as in the preceding examples. Salt water fills the lower part of this sand, and fresh water fills the upper part of it. The position of the contact is determined by the head of the fresh water, which in turn is determined by the elevation of the intake area. The similarity between the conditions in this sand and those in the U-tube in Figure 33 is easily apparent.

"In an artesian sand the water is prevented from rising to the surface by the overlying impermeable bed. It is under a head that would cause it to rise in a well to a level above the bottom of the confining bed. The imaginary surface that would pass through the surface of the water in a well drilled to the sand at any point throughout its extent is called the "piezometric surface." The piezometric surface is therefore a pressure-indicating surface, and its elevation at any point indicates the head on the water in the sand at that point. At the intake area of the sand it merges into the water table which, though not imaginary, might be considered a part of the piezometric surface. In a section such as Figure 33D the line representing the piezometric surface is the hydraulic gradient of the water in the sand along the section. As there is no flow in the upper sand in this figure, the line representing the piezometric surface is level and extends from the intake area toward the ocean as far as the fresh water extends in the sand.

"In the lower sand in Figure 33D the head of the fresh water is sufficient to cause a flow of fresh water into the ocean below sea level, forming a suboceanic fresh-water spring. The fresh water fills the water-bearing formation down to the bottom edge of the overlying impermeable layer and far enough below this level to permit the water to flow out into the ocean. Here again, the salt water fills the lowest part of the formation, but as the pressure in the main body of fresh water is greater than that in the salt water at the outlet, the salt water has been reduced below the pressure of the salt water by the resistance of the sand of its movement. The line representing the piezometric surface for this sand slopes gently downward from the intake area to the point where the thickness of the sand carrying fresh water is reduced by the intrusion of salt water. From that point to the point of discharge the slope increases.

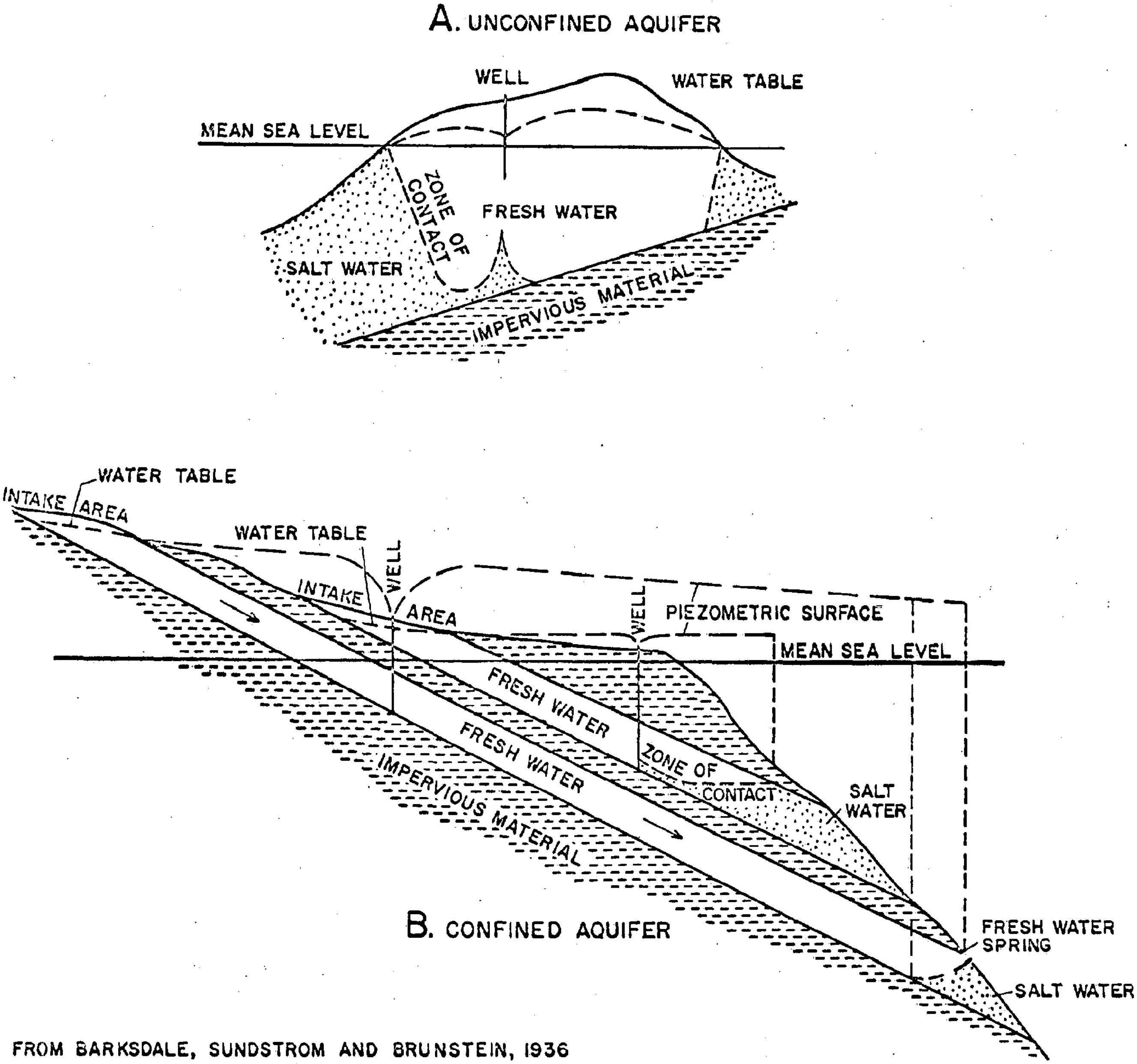
"If the basic principles that govern the relation between fresh and salt waters in water-bearing sands are kept in mind, it is usually possible to develop a continuous supply of fresh water from sands that are exposed for a part of their extent to salt water. The amount of water that can be taken from such a supply without drawing in salt water will, however, depend on the methods used to develop the supply, on local conditions, and especially on the amount of fresh water available for recharging the sand.

"Any general lowering of the head of the fresh water in a sand exposed for a part of its extent to the waters of the ocean will permit the salt water to advance farther inland and occupy more of the sand. The lowering may be caused by natural conditions, such as a dry year or a series of dry years, but lowering due to such causes is not likely to have any serious consequences, unless it occurs in conjunction with artificial withdrawal of water from the sand. This is usually accomplished through wells, either by pumping or by the natural flow from artesian sands. Pumping water from a water-bearing sand lowers the head of the water in it materially in the immediate vicinity of the point of pumping and, to a decreasing extent, for a considerable distance away. If this lowering of head or "cone of depression" occurs above or extends beyond the zone of contact, it will disturb the balance between fresh and salt water and permit the salt water to move up through the formation toward the well. The radius and depth of the cone of influence increase as the rate of pumping from the well is increased. It might, therefore, be possible to take a small amount of fresh water from a well in a water-bearing sand exposed to salt-water contamination without drawing in salt water, whereas if the same well were pumped at a higher rate the salt water would enter it.

"The specific gravity of sea water varies slightly from place to place and sometimes at different depths at the same place, but it is never much greater than that of fresh water. For the purpose of this report the specific gravity of fresh water may be considered to be 1.000. In the summer of 1913, Begelow (1915) found that the specific gravity of the water off the Atlantic coast of the northern United States at different places and at different depths ranged from 1.019 to 1.028.

"Owing to the very small difference between the specific gravity of fresh water and that of salt water, a slight change in the head of the fresh water produces a very considerable change in the position of the zone of contact. If a water-bearing sand is exposed to sea water having a specific gravity of 1.025, the level of the fresh water in it must be maintained at 2.5 feet above mean sea level if the zone of contact is to be held at a depth of 100 feet below sea level. A fresh-water head of five feet above mean sea level would be sufficient to hold back the sea water to a depth of 200 feet below sea level. Similarly, if the fresh-water head in such a sand were lowered only 2.5 feet, it would permit the salt water to rise 100 feet. If the fresh-water head in the sand were lowered to sea level, the salt water would rise to sea level. In a gently sloping confined sand, such as the upper sand in Figure 34B (Figure C2 in this report), a vertical rise of 100 feet might represent a movement of the salt water several miles inland.

"The mere fact that a well or well field in a sand containing both salt water and fresh water yields fresh water when it is first pumped is no assurance that it will not eventually yield salt water. The adjustment of the position of the zone of contact to the lowering of the fresh-water head caused by pumping would not be instantaneous, but the upward movement of the salt water would begin as soon as the fresh-water head above the zone of contact was lowered. The salt water would continue to move upward until equilibrium was again established or until it entered the well. The rate of movement of the salt water would be goverened by the rate of pumpage from the well, because it would be necessary to remove, by pumping, the fresh water between the original position of the zone of contact and the position that it would occupy when equilibrium had again been established. If the well were situated in a



FROM BARKSDALE, SUNDSTROM AND BRUNSTEIN, 1936

Figure C2. Effect of pumping water from wells in sands exposed to salt-water contamination.

uniform sand and if the lowering of head were enough to draw salt water into it eventually, a considerable part of the fresh water between the well and the zone of contact would have to be pumped out before salt water could enter the well. Usually this would require a considerable period of time."

More recently, the effect of the dynamics of flow, as controlled by the vertical and horizontal permeabilities, on the position of the interface of the fresh-salt water in coastal areas has been presented by Hubbert (1940); Henry (1964); DeWiest (1965); Rumer and Shiau (1968); and others. Their treatment of the interface tends to move it to allow for discharge of the aquifer which is not considered in the earlier application of the Ghyben-Herzberg principle. In the fresh-salt water interface relations of the Pleistocene water-table aquifer most of the recharge water is being discharged in the upper reaches of the aquifer as fairweather flow of the streams and by evapotranspiration. In many instances where evidence of the fresh-salt water contact is available from electric logs or from water samples the original Ghyben-Herzberg principle is sufficiently reliable for practical use a short distance inland.