STATE OF DELAWARE

DELAWARE GEOLOGICAL SURVEY

REPORT OF INVESTIGATIONS NO. 13

THE OCCURRENCE OF SALINE GROUND WATER IN DELAWARE AQUIFERS

By

K. D. Woodruff

Newark, Delaware

August, 1969

THE OCCURRENCE OF SALINE GROUND WATER IN DELAWARE AQUIFERS

By

K. D. WOODRUFF

Hydrologist, Delaware Geological Survey

August, 1969

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Cont.)

TABLES

THE OCCURRENCE OF SALINE GROUND WATER IN DELAWARE AQUIFERS

ABSTRACT

The location of the fresh-salt-water-boundary in the deeper aquifers of Delaware is related mainly to head values. Near coastal areas, dynamic conditions may prevail that affect the interface position within shallow aquifers open to the sea.

Holocene and Columbia sands which form Delaware's shallow water-table aquifers contain brackish water in scattered coastal areas while brackish water in the artesian aquifers is found at various depths. Water from Chesapeake Group sediments (Miocene) is fresh in Kent County but is salty in poorly defined areas of Sussex County. The interface in the Piney Point Formation (Eocene) lies just north of Milford and extends in a northeast-southwesterly direction across the State. Brackish water exists in the Magothy and Potomac formations of Cretaceous age a few miles south of Middletown.

Heavy pumping near sources of brackish water should be avoided for the present. Proper location of monitoring wells is necessary for detection of future chloride movement.

INTRODUCTION

Ground water is one of Delaware's most important natural resources. All of Kent and Sussex Counties (excepting some irrigation from streams) and about 55 per cent of the population of New Castle County depend on ground water to supply their daily water needs. The State has many water-bearing formations but in some areas the use of these aquifers is limited by the nearness of two major types of salt-water sources: (1) large surface bodies of saline water including the Delaware and Chesapeake bays and the Atlantic Ocean; and (2) saline water presently existing within certain aquifers. The exact reason for the occurrence of high chloride water within aquifers some distance from the ocean is not always known. In formations deposited under marine conditions sea water may have been trapped within the sediments at the time of deposition or, in some cases, salt water may have entered due to higher sea-level stands during the geologic past. It is improbable that there is a direct hydraulic connection with the ocean to artesian aquifers under inland areas even though such aquifers may now contain saline water. Lithologic changes within a single formation and the presence of overlying silts or clays usually impede or modify ground-water flow.

Increasing population and water use have caused some concern about the possibility of salt-water encroachment. Such fears are not entirely unfounded because improper management of the State's ground-water resources could indeed lead to encroachment under certain conditions.

This study (1) evaluates existing data and chemical analyses pertinent to the salt-water problem, (2) points out those areas where further data are needed, and (3) recommends or reaffirms those areas where ground-water development should be limited because of potential salt-water problems.

Previous Work

In 1958 Barksdale and others discussed the theoretical position and possible movement of water in Cretaceous aquifers under and adjacent to the lower Delaware River. Their postulated fresh-salt water interface positions appear today to be essentially correct, at least for Delaware. Rasmussen and others (1958) studied the chloride concentrations in aquifers along the Chesapeake and Delaware Canal. Three monitoring wells were installed in an attempt to determine the effect of deepening and widening the Canal. It was tentatively concluded that such construction would increase the opportunity for recharge from the Canal to then unaffected aquifers by a small, but unknown, amount.

More recently, Back (1966) and Upson (1966) have separately considered the problem for the northern Atlantic Coastal Plain of the United States. Recent drilling has indicated that in Delaware the location of their postulated fresh-salt water interface for Cretaceous aquifers is basically valid.

Acknowledgements

Analyses included in this report were made by a number of agencies. Most analyses before about 1962 were made by or under the direction of the U. S. Geological Survey either independently or in cooperation with the Delaware Geological Survey. After that date analyses have been made by private consulting laboratories, various industries, the Delaware Water and Air Resources Commission, and the Delaware Geological Survey.

Dr. John C. Kraft of the Department of Geology, University of Delaware, provided correlations on parts of the cross section of Delaware (Figure 2). Dr. Robert R. Jordan, Mr. Nenad Spoljaric, and Dr. Thomas Pickett of the Delaware Geological Survey were especially

helpful in discussions of stratigraphic problems. Dr. J. J. Groot, Mr. Ray Sundstrom and Dr. Robert D. Varrin of the University of Delaware reviewed the manuscript and offered many helpful suggestions.

SALINITY DETERMINATIONS, RANGES, AND COLLECTION OF DATA

Salinity of water is usually expressed in terms of the chloride ion content, the chloride being initially in the form of sodium chloride. Titration, or reacting, with a measured amount of silver nitrate is the standard laboratory procedure for determining the exact amount of chloride in a water sample. Other analytical methods do exist and selection of technique depends on the materials available, personal preference, and accuracy desired. Chloride concentration is usually expressed as parts per million (ppm), i.e., parts by weight of chloride in one million parts of water. Lately, efforts have been made to standardize analytical results and to express all concentrations in milligrams per liter, another measure of weight. For most practical purposes milligrams per liter is equal to parts per million.

Sea water has a chloride content of about 18,000 ppm. Actual chloride ion concentrations in Delaware aquifers that have undergone salt-water intrusion or have residual chlorides do not appear to be as high as that of sea water except in one or two cases. The highest concentration found in any aquifer to date is about 17,000 ppm of chloride. However, as will be discussed below, this is not a typical occurrence, and more commonly two or three thousand ppm of chloride is maximum.

Fresh water in Delaware and most of the eastern United States is usually considered to be water with a chloride content under 250 ppm. This is the highest limit of concentration recommended by the U. S. Public Health Service. Few people can taste a concentration of 250 ppm as the taste threshold for most individuals seems to be around 500 to 600 ppm. Indeed, in some western portions of the country water with 500 ppm chloride is locally considered to be fresh.

Water for industrial and irrigation use often requires low chlorides. Certain industrial processes cannot tolerate even a few ppm and Rima et al (1964) state that any concentration over 100 ppm is toxic to most plants.

Chlorides in Delaware's tidal surface waters vary considerably and consequently affect the water use. In Delaware Bay, for example, chlorides may range from a few hundred parts per million at Delaware

Memorial Bridge to essentially sea water concentrations in the central portion of the Bay. Tidal fluctuations exist as far north as Trenton, New Jersey and during periods of low fresh-water inflow the 50 ppm chloride line may extend up river into the Philadelphia area. The salinity in smaller ungated, tidal streams also varies greatly, depending on tide and fresh-water run-off. During high run-off periods water in these streams is fresh while at other times the chlorides at the same points may reach as high as 6500 parts per million. This points out the need for careful management of the shallow ground-water aquifers which contribute the bulk of fresh-water inflow to Delaware's surface streams in the Coastal Plain.

Chemical analyses and ground-water levels used in this report were obtained mainly from Delaware Geological Survey files and from existing publications. Some additional field data were recently collected by the Delaware Survey and the Delaware Water and Air Resources Commission. A few chemical analyses were not used because of questionable field procedure or disagreement with duplicate samples. Except for those analyses made by the Delaware Geological Survey, the sampling procedure was not always known. Factors such as the pumping time before sampling and the depth of the water sample may have effected some results. Because of the variable nature of local water supply problems, available data are not uniformly distributed within the State. In those areas where a great deal of information exists it was not considered necessary to list all available analyses, especially where chlorides are known to be due to waste discharges.

Well locations in this report are numbered according to the Delaware Geological Survey's well numbering system. In this system, the State is divided into 5-minute blocks of latitude and longitude with each block being designated by a combination of one upper case and one lower case letter. These two letters constitute the first part of the well number.

Each 5-minute block is further subdivided into 25 one-minute blocks, each one-minute block bearing a two digit number according to its location in the 5-minute block. This number follows the two letters in the first part of the code. The last part of the code is a sequential number which indicates the order in which the well information was "scheduled" or entered into the well files. The location of each well is plotted on a series of master grid maps and retained permanently.

RELATIONSHIP OF GROUND-WATER LEVELS TO FRESH-WATER INTERFACE

The boundary between fresh and salt water in an aquifer, or water-bearing stratum, can be sharp or can be a mixed or diffused wedge-shaped zone of varying height and width. The exact shape of the interface depends on a number of factors including permeability and aquifer thickness. In monitoring any movement of the interface it is important to locate the diffused zone or the edge of the interface rather precisely to be sure of detecting any actual movement. In general, under static conditions in the deeper aquifers the interface will occur where the head or weight of fresh water balances or equals the weight of underlying salt water. A larger volume of fresh water than salt water is required for this balance because of the greater density of salt water. Also, some loss of fresh-water head may occur in a long flow path. More precisely, salt water would theoretically be found about 41 feet below sea level per foot of fresh water above sea level according to the Ghyben-Herzberg Principle. Mathematically this can be stated as:

$$h = (d-1)H \tag{1}$$

where:
h=height of fresh water above sea level
d=density of salt water
H=total depth of fresh water below sea level

Taking the density of sea water as about 1.024 and the fresh water head as 1 foot then equation (1) becomes:

$$H = \frac{h}{d-1} = \frac{1}{1.024-1} \tag{2}$$

$$H = 41 \text{ feet}$$

Water levels in artesian aquifers can, therefore, be a general guide to the depth at which the interface can be expected. The chloride concentration at the interface would not usually be the same as that of the adjacent salt or brackish water body, but would be of some lower value due to mixing occuring at the interface. Such mixing apparently occurs to some degree even under essentially static conditions.

In shallow aquifers near coastal areas open to the sea, other factors may modify the interface position. Experimental work by Cahill (1967) indicates that a cyclic flow exists on the salt-water side of an interface depending on tidal amplitude and the amount of fresh water inflow. Salt water may thus be continually moving landward only to be swept seaward again under the influence of a lateral fresh water head. This had been suggested earlier by a number of workers including Cooper and others (1946).

OCCURRENCE OF SALT WATER IN AQUIFERS

Holocene Aquifers

Along coastal areas the size and pattern of land forms is constantly changing. The process may be due to the gradual work of wind, currents, and waves, or may be extremely sudden such as occurred in Delaware during the devastating storm of 1962. In any case, newly formed shoreline features may have salt water trapped within their sediments. Also, the nearness of such features to salt water provides opportunity for hydraulic connection with the ocean. In Sussex County, Delaware, there are many instances of high chlorides in what are mainly Holocene deposits. At Indian River Inlet, a chloride content of 17,150 ppm was recorded at about 11 feet in test hole Pj42-11 (see Figure 6 for location). At 40 feet chlorides were also high, about 14,600 ppm. Approximately two and one-half miles north of Indian River Inlet, in hole Pj21-3, the chloride content of water squeezed from core samples varied from 650 ppm to a high of about 6900 ppm depending on depth. Chlorides in test holes Pj22-1 and Pj22-2, both due west of Pj21-3, also show similar variations in salinity with depth.

Table 1 is based on an unpublished report by Peter B. Smoor, hydrologist, formerly with the Delaware Geological Survey, and shows the results of chloride analyses made on water samples squeezed from cores, including data from the test holes mentioned above. The cores were taken in a series of test holes located from Indian River Inlet north to Cape Henlopen. The possibility exists that some of these test holes may penetrate both Holocene and older, Columbia, deposits. South of Dewey Beach, Columbia, rather than Holocene sediments, are known to outcrop both inland and along beach areas (J. C. Kraft, personal communication). However, in this case, the difference is not significant from a hydrologic standpoint as both units are water-table aquifers. Probably no large scale pumping would be feasible from any shallow wells in this area and in most instances there is no guarantee that even small yield domestic wells will tap fresh water. However, there are scattered coastal areas where small amounts of fresh water are skimmed off the top of underlying salt water by wells as shallow as ten feet.

Inland, known sediments of Holocene age are not extensive or thick enough to be seriously considered as water-supply sources.

Columbia Aquifers

Throughout most of Delaware sediments that were either derived directly from glacial melt-water or were otherwise deposited during the Pleistocene (glacial) Period mantle the surface and overlie older sediments. These rocks are referred to as the Columbia Formation in the northern part of the State and the Columbia Group in Sussex County where more than one formation of Pleistocene age exists (Jordan, 1962). In New Castle County, the Columbia Formation is generally thin, having an average thickness of about 30 feet except in paleochannels where the maximum known thickness is about 105 feet. The Columbia thickens to the south and in Sussex County the maximum thickness exceeds 150 feet. Much vertical recharge to deeper aquifers probably takes place through the Columbia Formation. Hundreds of shallow domestic wells and many irrigation wells tap Columbia sands and in northern Delaware some high-yielding industrial wells are located in Columbia paleochannels. In Kent and Sussex Counties many municipal wells also are screened in the Columbia.

The data reveal a few incidents of abnormally high chlorides in known Columbia aquifers. Three such cases - New Castle, Lewes, and Rehoboth Beach have been known for some time and have been discussed by Marine and Rasmussen (1955). Lewes has alleviated its problem by drilling new wells farther inland with resultant lowering of chlorides in the older wells nearer Delaware Bay, indicating that a reversal of the intrusion took place. Getty Oil Company reported another instance of brackish water from well Ec13-11 (see Figure 4). Chlorides in this well were as high as 360 ppm during August, 1966. This is probably indicative of general lateral migration of salt water in the Delaware City area. Pumpage from this well, which taps a Columbia channel, has been curtailed. In all cases contamination was induced from nearby surface bodies of saline or brackish water.

Recently, high chlorides occurred in well Ec23-6 (see Figure 4) located at the Gunning-Bedford School just north of the Chesapeake and Delaware Canal. In August, 1967, a high iron content and unusual tastes were reported in water from this well. However, no analyses were made until January, 1968 when over 800 ppm chloride were found. The well penetrates at least 80 feet of Columbia material and analysis of electric logs made in recent test holes shows the high chloride water to exist from about 70-100 feet below land surface. The apparent immediate source of chloride appears to be the dredging spoil area on the north bank of the Chesapeake and Delaware Canal, 1000 to 1500 feet south of the well. Very probably the high chlorides will eventually be flushed from the area but there is no indication as to how long this might take.

TABLE I

Chloride analyses of water from core samples of Holocene Age. (See Figure 6 for location of holes)

Test Hole No.	Depth of Core (below land surface)	ppm Chlorides	Test Hole No.	Depth of Core (below land surface)	ppm Chlorides
Ni25-1	40.0-42.5	12,375	Oj51-3	32.5-35.0	11,280
	45.0-47.5	10,100		35.0-37.5	12,950
	52.5-55.0	12,725			
			Pj21-2	5.0- 7.5	300
Ni35-3	2.5- 5.0	57		7.5-10.0	150
	7.5-10.0	133			
	12.5-15.0	130	Pj21-3	5.0- 7.5	700
	17.5-20.0	47		7.5-10.0	650
	22.5-25.0	34		12.5-15.0	900
	25.0-27.5	43		15.0-17.5	3,000
	27.5-30.0	85		27.5-30.0	7,050
	30.0-32.5	45		32.5-35.0	6,930
	35.0-37.5	119		37.5-40.0	5,120
	37.5-40.0	285		45.0-47.5	735
	47.5-50.0	4,040			
	52.5-55.0	4,960	Pj22-1	12.5-15.0	200
	70.0-72.5	3,400		15.0-17.5	475
	72.5-75.0	4,755		17.5-20.0	1,550
	75.0-77.5	2,905		27.5-30.0	4,550
	80.0-82.5	2,720			
	82.5-84.0	530	Pj22-2	7.5-10.0	5,025
	85.0-87.5	2,535		10.0-12.5	2,475
				12.5-15.0	1,950
Nj51-2	5.0- 7.5	11,400		15.0-17.5	2,630
				25.0-27.5	5,670
Oj51-1	17.5-20.0	6,000		30.0-32.5	8,000
	42.5-45.0	2,403			
	57.5-60.0	900	Pj42-11	10.0-12.5	17,150
				17.5-20.0	13,250
Oj51-2	7.5-10.0	1,500		20.0-22.5	16,450
				27.5-30.0	14,000
Oj51-3	7.5-10.0	6,450		37.5-40.0	14,620
	12.5-15.0	4,000			
	15.0-17.5	5,590			

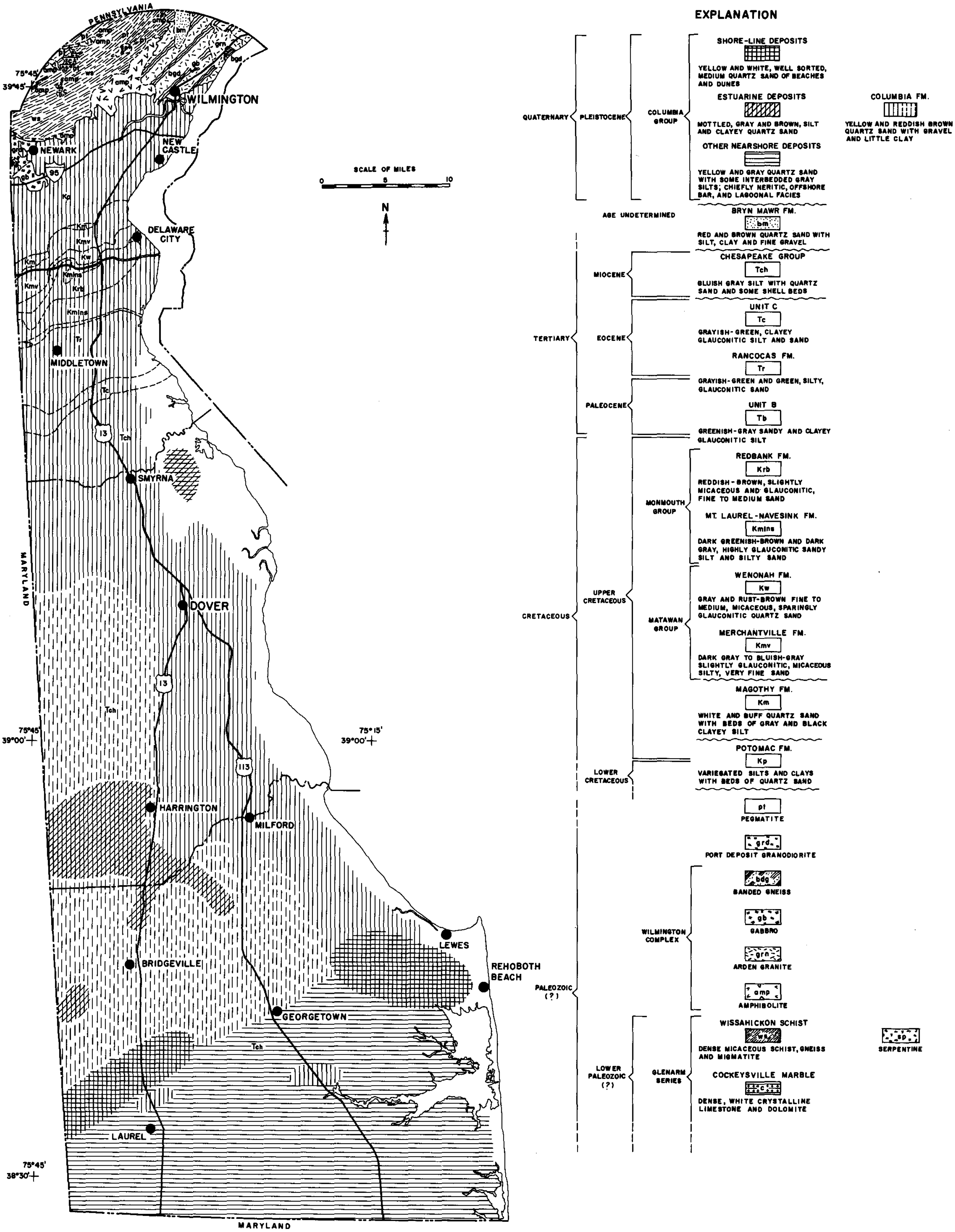

Figure 1. Generalized geologic map of Delaware (after Spoljaric and Jordan, 1966).

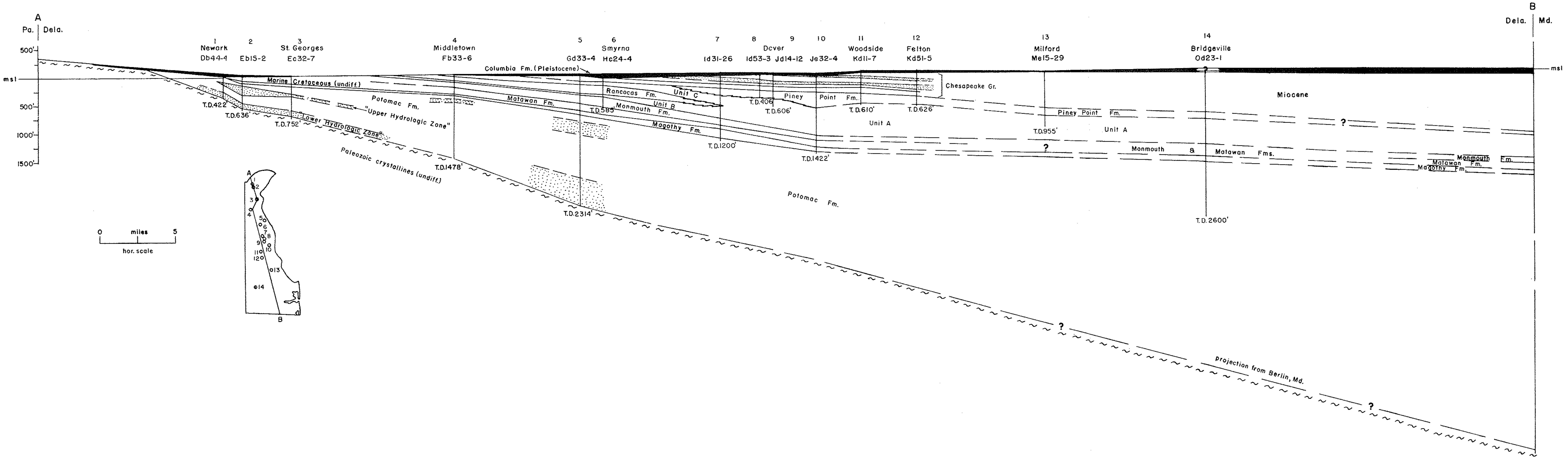

Figure 2. Geologic cross section of Delaware (Modified after Jordan, 1962).

Most of the natural flow of water within the Columbia is toward existing surface streams and water bodies. As long as local pumping does not reverse the gradient, lowered stream flows and salt-water intrusion will not be a problem. The exact amount of pumpage necessary to do this depends on the individual situation and few areas in the State have been evaluated in this regard. Trained personnel, basic data, and time have so far been insufficient to permit much detailed study. In coastal areas some fresh water can usually be found in the upper part of the Columbia, especially north of Lewes, although there are some exceptions. Baker et al. (1966) reported salt-water contamination in the shallow Columbia sands at Slaughter Beach. Also, as mentioned above, the high chloride content of water from test holes south of Dewey Beach could be at least partly from the Columbia. Salt-water can usually be expected in the deeper Columbia in southern Delaware coastal areas. Although hydraulic connection with the ocean is probably the main reason for high chlorides, upward vertical leakage from the underlying Chesapeake Group could account for higher than normal chlorides in some Columbia wells near the coast.

Chesapeake Group

Miocene age sediments crop out in southern New Castle County and thicken towards the southeast as shown in Figures 1 and 2. Throughout Maryland and Delaware they are known collectively as the Chesapeake Group. Generally, south of about Dover, at least two distinct sands within the Chesapeake Group can be recognized, and are known informally as the Frederica (upper) and Cheswold (lower) aquifers. These aquifers are an extremely important source of water for central and southern Kent County. In areas of present pumping, natural chlorides are low and no evidence can be found of induced abnormally high chlorides. Water analyses from a recently drilled well at Milford (Me15-29) show the chloride content of water from the Cheswold (?) aquifer to be 64 ppm. There is no reason to believe that there would be any danger of salt-water intrusion considering the locations of present and potential heavy pumping areas in central Delaware.

In Sussex County the situation is somewhat different. Inland, the Frederica and Cheswold aquifers are thought to be fresh in the northern and western part of the county although there are few data available. Data are especially meager for the southern inland portion of Sussex County due to the lack of wells drilled to the Chesapeake Group. At Slaughter Beach, Baker et al. (1966) reported fresh water in wells tapping the Frederica and Cheswold aquifers at depths of 240 to 300 feet. At Prime Hook Beach local drillers report fresh water at about 300 feet but salt water at shallower depths. This is believed to be substantiated by electric logs from the area. However, the Cheswold and Frederica aquifers apparently contain brackish water in most central and southern Sussex County coastal areas. Water from well Pj11-1 (see Figure 6 for location) near Dewey Beach reportedly contained 1200 ppm chlorides at 300 feet and also at 530 feet. Water from well Nh13-1, drilled in 1940 at Broadkill Beach, reportedly was high in chlorides at 380 feet although the evidence is poor. However, the theoretical interface or 300 ppm isochlor line at this depth according to Back (1966), apparently based on water levels is several miles south of Broadkill Beach. In general, the fresh-salt-water interface appears to cut across the southeast corner of Delaware somewhere near Rehoboth Beach and extends in a southwesterly direction. At present, the exact position of this line is not known with certainty.

In Sussex County two additional sands, younger and thus higher in the stratigraphic section than the Frederica and Cheswold, have been recognized and are called the Pocomoke and Manokin aquifers. It is not everywhere possible to distinguish these individual sand layers but this classification has proven quite helpful in dealing with stratigraphic problems of a general nature. Usually water in the Pocomoke and Manokin aquifers is low in chlorides. Data for well Oj22-1, which taps the Manokin at Sussex Shores, shows brackish water at 80 feet but fresh water at about 178 feet. Approximately 50 feet of clay or sandy clay is present between the two strata, the upper of which is probably of Pleistocene age. The electric log of a well at Bethany Beach, Oj32-10, also seems to indicate fresh water from about 185 feet to 215 feet, but brackish water occurs in sands shallower than 185 feet. Two analyses, first reported by Rasmussen and others (1960), are evidence of local, apparently natural, intrusion in the Manokin aquifer near Lewes due to the nearness of Delaware Bay and the Lewes-Rehoboth Canal.

Paleocene-Eocene Aquifers

The major Paleocene-Eocene aquifers in Delaware are the Rancocas and the Piney Point formations, the Piney Point being slightly younger than the Rancocas Formation. As can be seen on Figure 2, the Rancocas outcrops in south-central New Castle County and dips in a southeasterly direction beneath younger sediments. South of Smyrna the Rancocas appears to grade into a silt called Unit C (Jordan, 1962) and interfingers laterally into another silt named Unit A. The electric log of a deep well (Id31-26) drilled north of Dover and south of Cheswold shows about 10 feet of Rancocas sand and only a short distance to the south of this well the Rancocas disappears entirely.

Very few reliable chemical analyses exist for water from the Paleocene-Eocene sediments, particularly the Rancocas Formation.

Data from one well, Hd44-1, drilled in 1957 about four miles southeast of Smyrna, shows the water to have a chloride content of over 900 ppm. Correlation by Kraft et al. (1966) on the basis of electric logs indicates that the bottom of the well is in Unit C, a short distance above the top of the Rancocas, although Unit C is not usually water-bearing. The analyses on this well are thought to be entirely reliable as two commercial laboratories are in reasonable agreement on the chloride content. Furthermore, the static water level within the aquifer was only two to three feet above sea level at time of drilling and according to the Ghyben-Herzberg principle at least five feet of fresh-water head would be needed to maintain a fresh-water aquifer at this location and depth (see Table 2). It is quite possible that the high chlorides are residual, due to incomplete flushing of ancient sea water. However, pumping from the Rancocas in the Clayton area, recorded in the period from 1943 to 1966, could also lower the levels near Smyrna as shown by calculations which used a transmissibility of 16,800 gallons per day per foot and a storage coefficient of .00019 (aquifer coefficients from Sundstrom et al. 1968).

Data from well He12-1, drilled to the Paleocene (Rancocas?) in 1946 at Woodland Beach indicates the water is brackish and not suitable for drinking. Unfortunately, no actual analyses were made available. As shown in Table 2, the static level was four feet above sea level and, theoretically, should be slightly greater than four feet to prevent salt-water encroachment.

Based on available information, it appears then that salt-water exists in at least part of the Rancocas Formation and possibly in Unit C also. A brackish-water line apparently extends from Woodland Beach on Delaware Bay in a southeasterly direction, passing about two to three miles south of Smyrna. Farther to the north, the level in well Fb33-3, drilled in 1930 to the Rancocas Formation at Middletown was over 44 feet above sea level, more than enough to inhibit salt-water intrusion at this location. Little or no control exists other than the wells mentioned above and it is presently not possible to extend the line farther southwest with confidence. Moreover, it is possible that part of the chloride content reported in these cases could be residual. Also, other unpublished work by Kraft indicates rapid lateral facies changes within the Rancocas. Thus it becomes extremely difficult in northern Kent County to determine the cause or the possibility of salt water within the Rancocas and the Eocene age sediments in general.

The Piney Point Formation, the other major aquifer in the Paleocene and Eocene series does not crop out in Delaware but underlies the Chesapeake Group in the Dover area. To the north it grades into Unit A of Jordan (1962) and is absent, as an aquifer at least, a mile or two south of Cheswold. However, there is electric log evidence that the Piney Point as a geologic unit is found north of Dover but has become finer grained. The thickest section of Piney Point found in Delaware so far is at Dover Air Force Base. To the south and westward into Maryland the Piney Point thins and loses its identity in southern Sussex County (see Figure 2). The Piney Point Formation is one of the more important water producers in central Delaware, yielding as high as 1100 to 1200 gallons per minute at the Dover Air Force Base and about 600 gallons per minute in central Dover. Farther to the south as the formation becomes finer grained the yield drops off considerably. At Milford, Delaware a maximum yield of only 65 gpm was obtained in a partially developed test well (Me15-29) drilled in January, 1968 and pump test results showed a very low transmissibility.

Piney Point water in areas of present pumping is low in chlorides. One of the earlier reports on Piney Point water quality was from wells He45-1 and He45-2 drilled at Bombay Hook in 1938 and 1940 respectively. These wells were reported to flow above ground surface at the time of drilling and the water was reported to be fresh. A driller's report also exists for another Piney Point (?) well, Hd52-2 drilled in 1953 a little less than two miles southeast of well Hd44-1 (see Figure 5). The water quality was reported to be good although no actual analyses were made. The static level in Hd52-2 was measured as nine feet below sea level at the time of drilling. Normally, high chlorides would be expected under such conditions in a Delaware aquifer.

The static level at the time of drilling in well Je32-4 (Dover Air Force Base), which is screened both at the top and bottom of the Piney Point and produced fresh water, was also lower than might theoretically be expected (see Table 2). The stratigraphy of the Piney Point and the overlying and adjacent formations probably play a role in keeping the aquifer fresh in Kent County.

The Piney Point undoubtedly contains brackish or salty water to the south. Prior to the drilling of a Piney Point well at Milford (Me15-29) there was some question as to the exact location of the interface in that area. Two screens were installed in the Milford well in an attempt to locate more exactly the depth of the interface. One screen was placed from 640' to 700' (land surface datum), near the top of the aquifer, and one near the bottom of the Piney Point from 780' to 785'. A series of water quality samples were taken and samples for both zones contained about 537 ppm chloride. The static level was one foot above sea level in February, 1968 while according to the Ghyben-Herzberg principle a fresh-water head of at least 18 feet above sea level should be needed to maintain a fresh-water aquifer at this location. On this basis, the interface is probably at least a mile or two north of Milford. On Figure 3, the postulated interface extends in a northeast-southwest direction across Delaware and consequently passes just north of Milford and thence beneath the southwest corner of Delaware. Some questionable further support for the existence of salt-water in the Piney Point is provided by data from an 1080 foot well drilled in 1898 at Lewes. Correlation by Rasmussen and others (1960) indicated that the well penetrated Eocene sediments and water from the interval 1064 to 1080 (Piney Point?) reportedly was saline. The stratigraphic correlation however is in some doubt (Jordan, personal communication) and no trace of the well can be found today.

Table 2 - Theoretical water-levels required in selected wells to maintain a fresh-water aquifer at given depths.

Well no.	Formation or aquifer screened and screen setting (feet below msl)	Depth to bottom of aquifer (feet below msl)	Static level at time of drilling and date (feet above msl)		Theoretical level required to maintain fresh-water aquifer (feet above msl)	Chlorides ppm
Gd33-4(a)	Magothy (screen setting 607-639)	658	5	5/61	15.6	270
Gd33-4(b)	Monmouth (376-409)	458	3.4	5/61	10.9	8
Hd44-1	Eocene (190-250)	250 (bottom of screen)*	3	5/57	6.0	922
He12-1	Rancocas (open at 219)	219 (bottom of well)*	4	1946	5.1	reported brackish
Id31-26	Magothy	1034	1	6/66	24.8	946
Je32-4	Piney Point (337-367, 531-541)	569	5.7	4/57	13.1	6
Me15-29	Piney Point (633-793, 773-778)	798	1	1/68	18.1	537

*Depth to bottom of aquifer not known.

Marine Cretaceous Aquifers

The marine Cretaceous sediments in Delaware include the Monmouth and Matawan groups. The younger Monmouth Group has been divided in the outcrop area into the Redbank Formation and the underlying Mt. Laurel-Navesink Formation; the Matawan Group includes the Wenonah and Merchantville formations. However, downdip all four of these formations lose their identity and the terms Monmouth and Matawan are lowered to formation status.

In general, the marine Cretaceous sediments are silts and very fine sands and therefore are not high-yielding aquifers. Some water-bearing sands do occur, but, they are generally very thin. Chlorides are low from the Monmouth sediments in central New Castle County and, in view of the light withdrawals, there is no immediate reason to expect any occurrence of high chlorides in areas of present pumping. However, head values for the Monmouth Formation in well Gd33-4(a) on Thoroughfare Neck, in southeastern New Castle County indicate that this well location is probably close to an interface. Table 2 shows the calculated head value necessary to theoretically limit salt water intrusion at this point. In the vicinity of the Chesapeake and Delaware Canal ground-water discharge appears to be towards the Canal, thus limiting intrusion from this source (Rasmussen et al., 1958).

Magothy Formation

The Magothy is recognized as a transitional unit between younger marine units and the older non-marine Potomac Formation. The Magothy Formation crops out in the Chesapeake and Delaware Canal near Chesapeake City, and generally dips to the southeast. Magothy sands form an important aquifer in northern Delaware and, except for some local thinning, generally persist beneath the entire State south of the outcrop area. Several analyses confirm the presence of brackish water in the Magothy south of a northeast-southwest trending line passing about five miles south of Middletown. Water from well Gd33-4(b) near Deakyneville, in southern New Castle County contains about 300 ppm chloride and farther south, water from the Magothy well Id31-26, located between Dover and Cheswold, contains over 1000 ppm chloride. These analyses are in good agreement with the theoretical interfaces proposed by Upson (1966) and by Back (1966).

The presently fresh-water bearing portions of the aquifer lie adjacent to surface salt or brackish-water sources in New Castle County and thus careful management of the aquifer is necessary. These sources are (1) the Chesapeake and Delaware Canal, (2) Delaware Bay to the east and (3) possibly, the Chesapeake Bay to the west. At present, where the Magothy underlies the Canal, the fresh water gradient within the Magothy appears to be towards the Canal

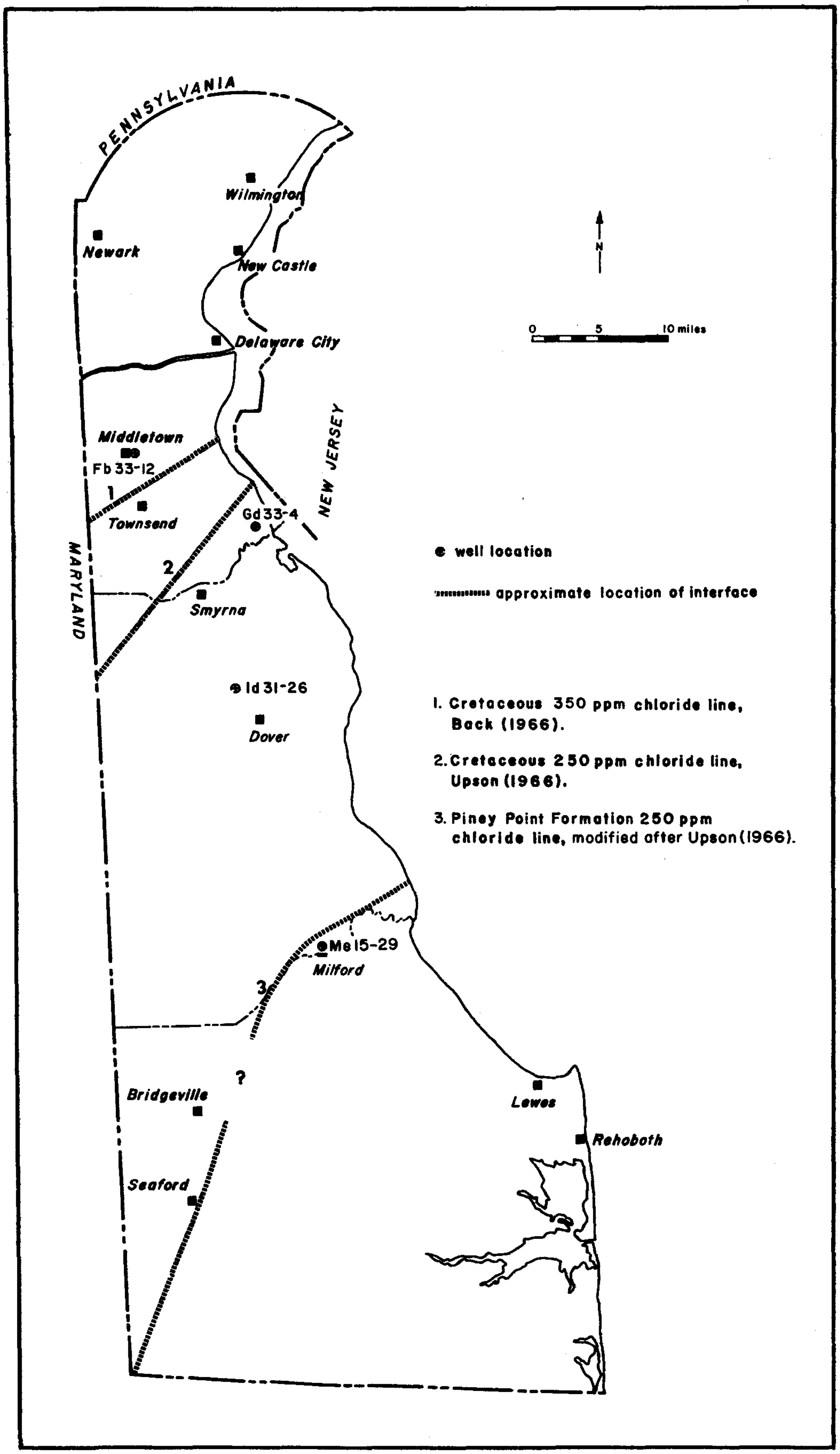

Figure 3. Map of fresh-salt-water interface positions according to Upson, 1966 and Back, 1966 showing key well locations.

(Rasmussen et at., 1958) and salt-water intrusion would not occur unless future pumping reversed the gradient. Beneath Delaware Bay the situation is somewhat more complicated with regard to both the stratigraphy and ground-water movement. Apparently fine-grained Holocene sediments overlie the Bay floor from at least Delaware Memorial Bridge south to about Port Mahon (Jordan et al., 1962). In addition, the Merchantville Formation, younger than the Magothy, may overlap the Magothy in a northerly direction (Spoljaric, personal communication) and help prevent direct connection with the Bay. This is not known with any certainty, however, and much work remains to be done on the stratigraphy beneath Delaware Bay. Ground-water flow directions along and under Delaware Bay south of New Castle are probably towards the Bay. Farther to the northeast in the Philadelphia-Camden area, local pumping has reversed this gradient toward the centers of pumping (Barksdale and others, 1958). No actual cases of intrusion into the Magothy due to pumping have been reported in southeastern New Castle County and in general, pumping from the Magothy in the Delaware Bay area is light.

The possibility of intrusion from Chesapeake Bay appears to be less of a problem than the other two sources mentioned above although an interface probably exists in the Chesapeake Bay area (Back, 1966). Sundstrom et al. (1967) believe that pumpage from the older Potomac Formation in the western end of the Chesapeake and Delaware Canal would have little effect on this interface and the same should also generally hold true for the Magothy.

Potomac Formation

The Potomac either outcrops or lies directly beneath a cover of Columbia sediments over about 95-100 square miles in New Castle County. It is the chief water-producing formation of northern Delaware with the possible exception of Columbia paleochannels. The stratigraphy and basic hydrology have been rather extensively covered in other reports, especially by Sundstrom et al., (1967), and thus will not be treated here in detail. Sands within the Potomac Formation, like those of the Magothy, are geographically close to large brackish surface water bodies. In the Chesapeake and Delaware Canal area, flow does not appear to be toward the Canal, as in shallower aquifers, but rather is toward centers of pumping. In this case, the center of the main cone of depression is in the Delaware City area at the eastern end of the Canal. Thick intervening clays apparently exclude at least local recharge to the Potomac from surface water sources and salt water intrusion is not generally thought to be an immediate threat. Sundstrom et al., (1967) has given considerable attention to this problem and reference should be made to this paper for detailed explanations.

Over-all, the possibility of declining water levels are in themselves thought to be more of a problem than salt-water intrusion.

Water from the Potomac at some point downdip undoubtedly contains high chlorides. The theoretical fresh-salt-water interface appears to occur at about the same position as that for the Magothy (see Figure 3). Geophysical logs from well Gd33-4, which penetrated Potomac sediments, indicate the presence of high chlorides and tend to confirm the 250 ppm chloride line postulated by Upson (1966) and the 350 ppm line of Back (1966). In addition, Rima and others (1964) place the fresh-salt-water interface (chloride value not specified) in nearly the same position as did Upson (1966) but apparently somewhat south of the 350 ppm line proposed by Back (1966). The electric log of the deep well at the Dover Air Force Base (Je32-4) likewise may indicate the presence of chlorides in the upper part of the Potomac. Only a single point resistivity log is quite tenuous. The interface apparently bends north quite sharply on the New Jersey side of Delaware Estuary, reflecting pumping in that area. It should be noted that the interface position in Delaware as shown on Map I-514-B of the map series "Engineering Geology of the Northeast Corridor, Washington, D. C. to Boston, Massachusetts: Coastal Plain and Surficial Deposits (1967)" is inconsistent with present data.

PUMPING LIMITATIONS

Two general situations exist where large ground-water withdrawals should be controlled to prevent salt-water intrusion. These are (1) at or just on the fresh-water side of the interface in artesian aquifers, and (2) in the water-table or shallow aquifers immediately adjacent to salt or brackish water bodies. In Delaware's artesian aquifers however, the fresh-salt water boundary does not always appear to be well-defined but rather seems to be a broad, diffused zone that may extend for several miles. Chlorides in such a zone are generally only a few hundred parts per million and seem to change very little along the dip of any particular formation. Data from both the Magothy and Piney Point formations in particular indicate the existence of such zones. Possibly, those Delaware aquifers formed under marine conditions at least are still in the process of being flushed by fresh water and the chlorides now present are remnants of ancient sea water. Moreover, dynamic conditions may prevail in shallow water-table aquifers of Pleistocene or Holocene age opening to the sea and cautious use of the Ghyben-Herzberg is necessary in all cases.

Specifically, additional large amounts of water should not be pumped from the Potomac and Magothy formations in a zone across the State bounded by Townsend on the north and Smyrna on the south, at least until the movement of water within the formations can be monitored and the exact nature of the interface defined. The same should hold true for the Piney Point Formation in an area bounded by a northeast-southwest line two to three miles north of Milford and by a line passing through Milford on the south. However, some limited planned withdrawals could probably be made relatively close to these arbitrary boundaries with proper monitoring.

In most Atlantic Shore areas north of Cape Henlopen fresh water could probably continue to be skimmed off the top by small withdrawals without undesireable results, especially if the withdrawals were seasonal.

However, any specific coastal area should be studied as an entity in itself. The ground-water flow patterns in the water table and shallow aquifers are known to some degree but the detailed picture is rather complex and any fresh-salt-water interface in these shallow aquifers could probably be affected in a number of ways. Detailed stratigraphic knowledge of shallow sediments may become important when considering dredging projects, especially in Sussex County. As long as fresh-water heads are high the danger of encroachment is minimal. Unrestricted dredging in salt-water areas might initiate intrusion in certain cases. Thus in considering any large scale ground-water projects, or even a number of small ones, it becomes important to know fresh-water heads and to predict the exact flow patterns.

Increased pumping from the shallow Columbia Formation near New Castle should be done cautiously and with adaquate monitoring due to the nearness of Delaware Bay and the possibility of resultant intrusion. However, this would not apply to areas just west of the city and east of U.S. Route 13 where a Columbia paleochannel offers excellent yield possibilities with no apparent salt-water problems.

Finally, the possibilities of pumping from the Rancocas two to three miles south of Middletown should be viewed with caution. Theoretically, an interface should occur somewhere in this area and a limited amount of field data does indicate the presence of brackish water although the exact source of this water is not known.

RECOMMENDATIONS FOR FURTHER STUDY

Four specific lines of investigations are recommended upon review of the existing data:

(1) Determine the nature and position of the fresh-salt-water interface in the Piney Point Formation in Delaware. The yield of the formation is generally high and further development is quite certain. In northern Sussex County and southern Kent County the exact position of the interface is critical from a water-supply planning viewpoint. At least one deep well to the Piney Point one to three miles north of Milford would be required as a minimum to locate and subsequently

monitor the interface. If increased development of the area took place, one or more wells could be added on a northeast-southwest line across the State. Chlorides should be monitored at least once a year and water levels several times a year. Considering the high cost of well installations, one well, if correctly located, would probably be adequate for many years, if no additional heavy pumping of the Piney Point occurred. Actually, the interface would move extremely slowly, if at all, and probably is not moving any perceptible amount at present.

(2) Refine the generally known data on chloride distribution in the Magothy and Potomac formations. Such refinement is important from the standpoint of development for southern New Castle and northern Kent counties. The Magothy and Potomac formations, with the exception of Columbia channels, are generally the only reliable producers of large amounts of water in the area. The Rancocas will yield, in places, as high as 500 gpm to properly developed wells, but more often the maximum yield is about 250-300 gpm. Again, one well to each formation just north of Townsend would provide much-needed control in this area. Water-level measurements and quality data should be taken on the same basis as outlined for the Piney Point well. Because of the several sand zones or hydrogeologic units within the Potomac there may be more than one interface depending on head relationships between these sandy zones. This is illustrated by two recently drilled wells (Ec32-3 and Ec32-7) near St. George's screened in separate sands within the Potomac and having a head differential between the two sandy zones of about 30 feet. Figure 2 partially differentiates two of these Potomac zones.

(3) Investigate the reported high chlorides in the Rancocas Formation in northern Kent County as suggested by analyses from well Hd44-1 and well He44-1. To confirm the initial analyses would be a relatively easy matter but, to determine the position of any salt-water interface by conventional drilling would be more expensive. Nevertheless, the presence of chlorides should be actually confirmed by at least one hole. Water-level measurements should also be made in wells tapping the Rancocas in order to define flow directions. The stratigraphic situation in the Rancocas is complicated somewhat by a facies change downdip where the Rancocas sands apparently grade or interfinger laterally into Unit A, an aquitard. No reliable water level data or chloride analyses exist for Unit A because of its non-water yielding nature. Although this general area southeast of Smyrna is only lightly pumped at present, the water supply possibilities should be accurately defined as part of future planning.

(4) Fresh-salt-water boundary positions in the Columbia sands along coastal areas need to be determined, specifically for pumping areas near New Castle, Delaware City, Lewes, Rehoboth Beach, Bethany Beach and Fenwick Island. Each locality in itself is probably

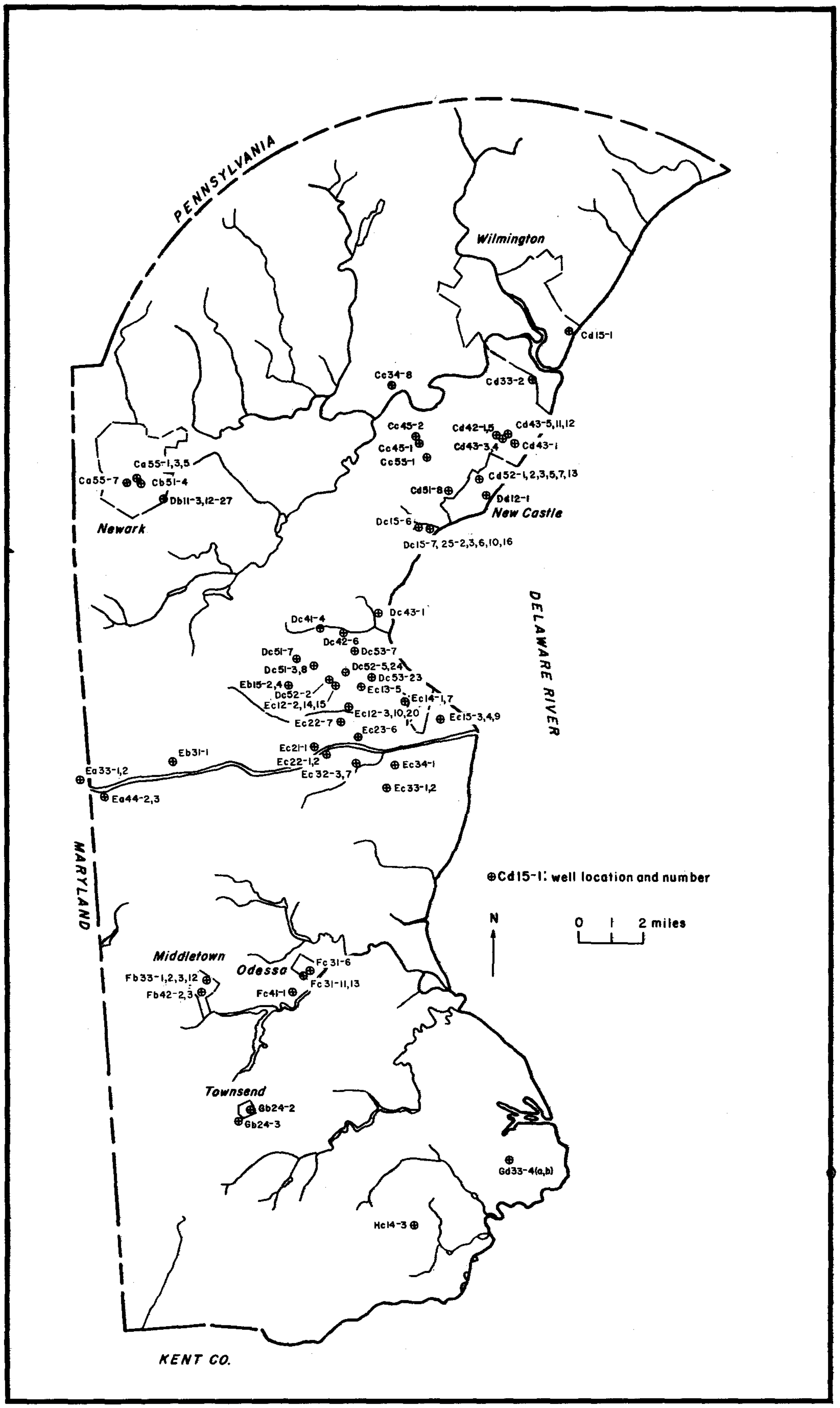

Figure 4. Well locations for which chloride analyses are available in New Castle County, Delaware.

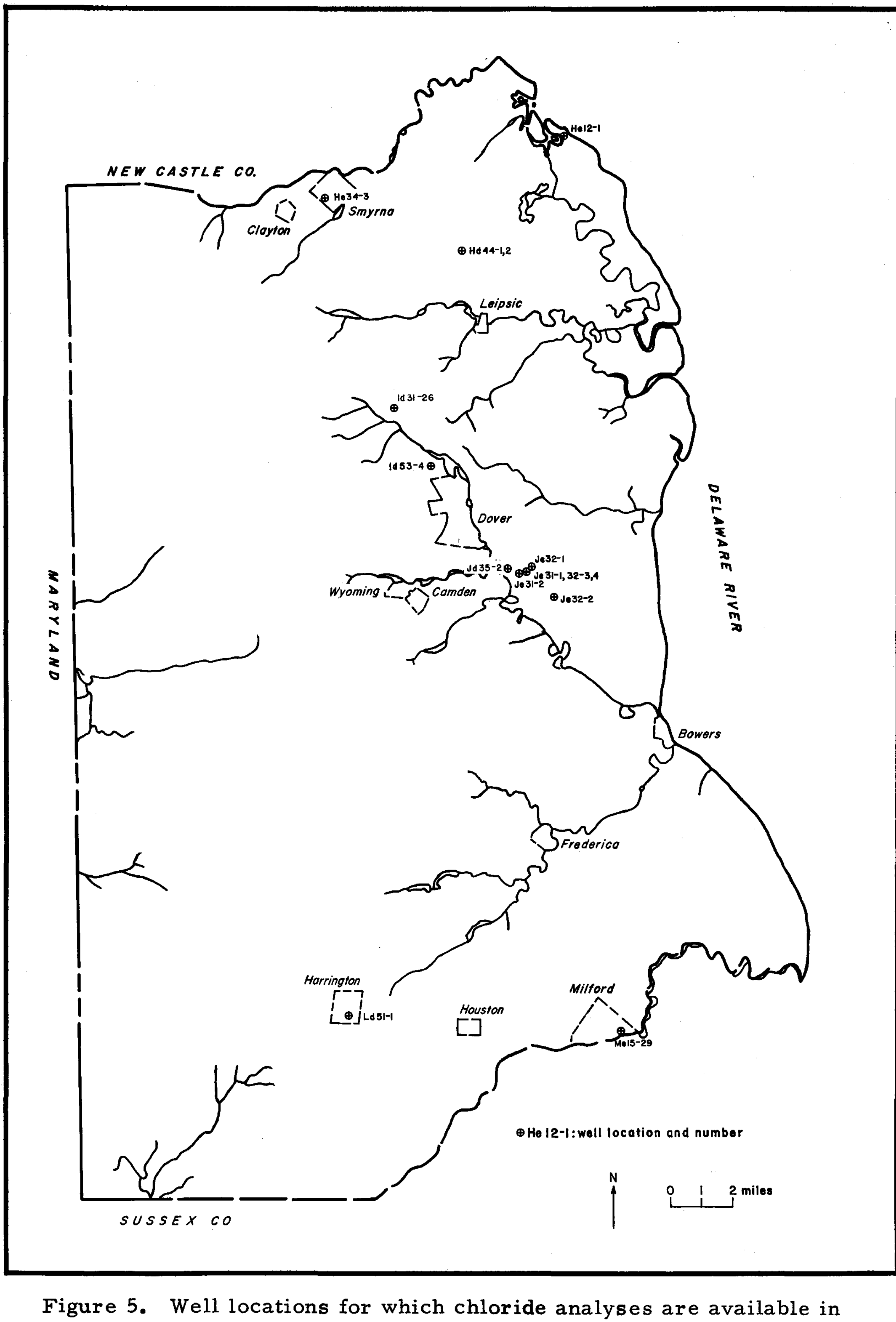

Figure 5. Well locations for which chloride analyses are available in Kent County, Delaware.

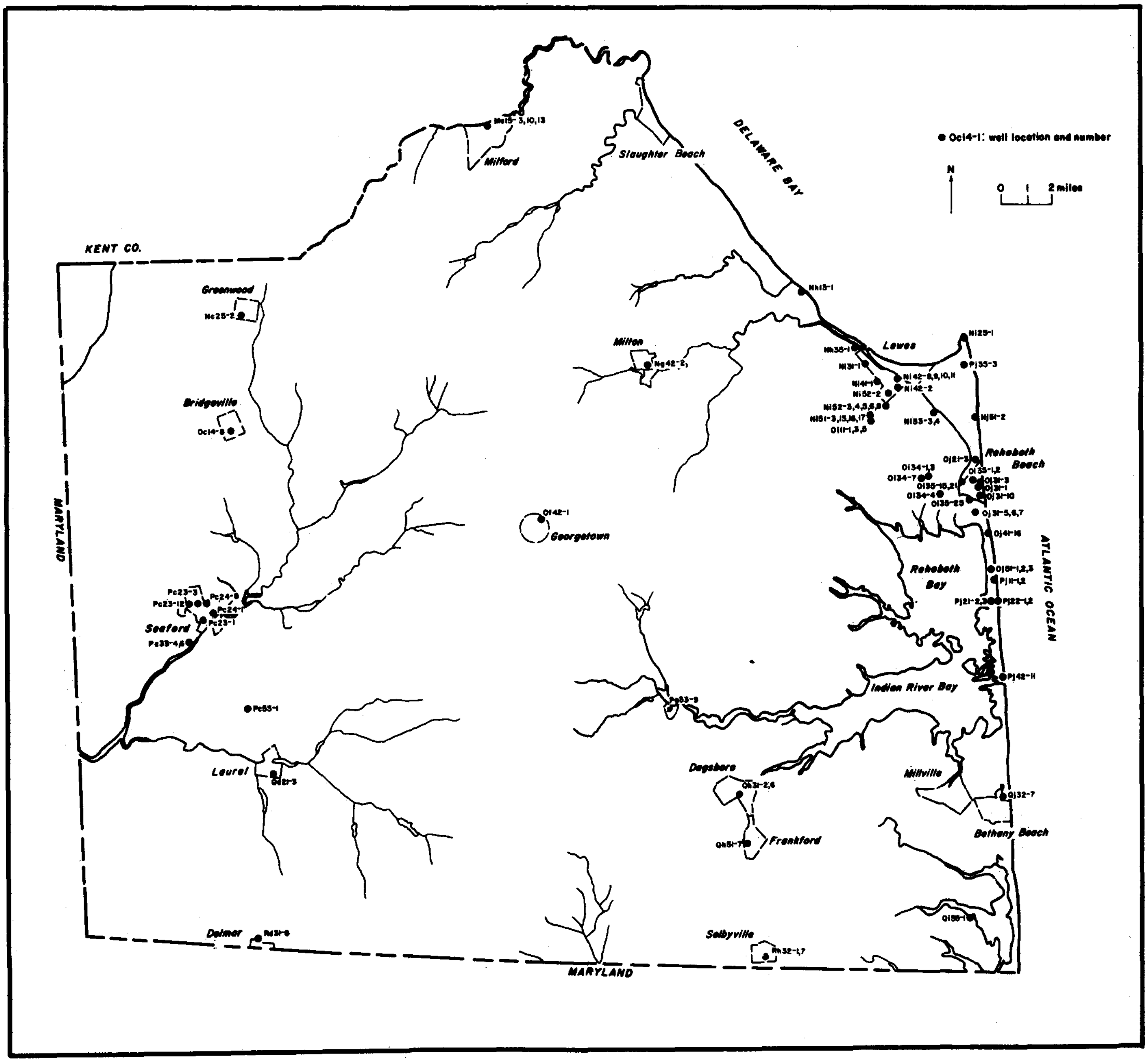

Figure 6. Well locations for which chloride analyses are available in Sussex County, Delaware.

a considerable project and may involve rather complex head relationships. There does not appear to be any immediate danger of drastically changing existing boundaries. However, continued growth and development of these areas dictate that we understand what is happening or what might happen within the shallow aquifers.

SUMMARY

Brackish water is present in nearly all of Delaware's aquifers. The exact depth and location of the salt-water interface varies with each aquifer and is dependent mainly on fresh-water heads, centers of pumping, and lithology. The interface positions for the artesian Potomac and Magothy Formations are fairly well known but the interface positions for younger formations are not adequately defined at present.

Salt-water intrusion in water-table aquifers underlying coastal areas is spotty. The fresh-water heads of the Columbia sands which make up the water-table aquifers are lowest near the ocean, and intrusion would be expected to occur naturally in some areas. Further development of the Columbia Formation throughout the State should be done cautiously as these sands provide most of the recharge to deeper aquifers and sustain base flow to tidal surface streams.

Monitoring of salt-water movement is generally inadequate but not critical at present from the standpoint of water use. Further monitoring will be needed in the future as ground-water development increases. Most heavy centers of ground-water pumping are not in an immediate danger of salt-water intrusion but proper management and control of pumping is essential.

Table 3 - Chloride Analyses of water from Delaware Wells
na - not available

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Ca55-1	City of Newark	76	na	Potomac	4/26/51	12
Ca55-3	City of Newark	64	na	Potomac	4/26/51	12
Ca55-5	City of Newark	63	na	Potomac	4/26/51	16
"	" " "	"	"	"	12/18/51	"
Ca55-7	Phillips Packing	79	na	Potomac	9/22/53	9.0
Cb51-2	City of Newark	62	na	Potomac	4/26/51	12
Cc34-8	Town of Newport	71	na	Potomac	9/20/55	13
Composite Cc54-1, Cc45-2, Cc55-1	New Castle Co.	197, 159, 221	na	Potomac	1/11/51	3.4
	" " "	" " "	"	"	1/21/54	5.0
Cc45-1	New Castle Co.	197	187-197	Potomac	9/3/57	5.3
Cc55-1	New Castle Co.	221	211-221	Potomac	4/3/57	2.5
Cc55-1	" " "	"	na	"	9/3/57	5.0
Cd15-1	Ludlow Mfg.	98	na	Potomac	6/ /53	15.7
Cd15-1	" "	"	"	"	6/28/55	35
Cd33-2	Cork Insulation Co.	120	na	Potomac	1/18/54	515
Cd33-2	" " "	"	"	"	6/28/55	218
Cd33-2	" " "	"	"	"	4/18/57	174
Cd42-1	Collins Park Water Co.	72	60-72	Potomac	1/18/54	25

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Cd42-5	Collins Park Water Co.	113	108-113	Potomac	1/18/54	7
Cd43-1	Atlas Chemical	52	36-51	Columbia	6/28/55	14
Cd43-3	Atlas Chemical	117	92-112	Potomac	1/4/50	7.1
	" "	"	"	"	8/60	158
Cd43-4	Atlas Chemical	110	94-104	Potomac	6/29/49	14
Cd43-5	Atlas Chemical	94	70-90	Potomac	1/4/50	28
Cd43-11	Atlas Chemical	88	75-85	Columbia	8/10/51	10.7
Cd43-11	" "	"	"	"	6/28/55	38
Cd43-11	" "	"	"	"	4/18/57	30
Cd43-12	Delaware State Highway Dept.	52	44-49	Potomac	7/22/52	15
Cd51-8	Town of New Castle	150	65-82	Potomac	5/5/67	9
Cd52-1	Town of New Castle	24	open (?)	Columbia	4/26/51	12
Cd52-1	" " "	"	"	"	5/5/67	92
Cd52-2	Town of New Castle	24	open (?)	Columbia	4/26/51	9.8

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Cd52-3	Town of New Castle	24	open (?)	Columbia	4/23/31	27
Cd52-3	" " "	"	"	"	1/1/48	98
Cd52-3	" " "	"	"	"	1/1/49	98
Cd52-3	" " "	"	"	"	1/1/50	98
Cd52-3	" " "	"	"	"	1/1/51	119
Cd52-3	" " "	"	"	"	1/1/52	185
Cd52-3	" " "	"	"	"	1/1/53	184
Cd52-3	" " "	"	"	"	10/53	190
Cd52-3	" " "	"	"	"	12/17/53	233
Cd52-3	" " "	"	"	"	5/5/67	92
Cd52-5	Town of New Castle	24	na	Columbia	6/28/55	210
Cd52-5	" " "	"	"	"	4/18/57	267
Cd52-7	Town of New Castle	15	na	Columbia	5/5/67	50
Cd52-3	Town of New Castle	130	na	Potomac	10/28/55	2.4
Db11-3	W. C. Waples	247	open from 182'	Crystalline basement	9/22/53	12
Db12-27	City of Newark	79	33-43, 52-67, 72-79	Columbia	10/13/56	7.0
Dc15-6	Avisun Corp.	625		Potomac	5/4/67	12
Dc15-7	Avisun Corp.	606	513-518, 543-548	Potomac	5/4/67	9

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Dc25-2	Delaware Rayon	199	121-153	Potomac	2/16/37	2
Dc25-2	" "	"	"	"	8/11/48	4
Dc25-2	" "	"	"	"	8/20/51	2
Dc25-2	" "	"	"	"	6/8/55	4
Dc25-2	" "	"	"	"	6/29/55	5
Dc25-3	Delaware Rayon	400-500	at bottom slotted 200'	Potomac	2/16/37	4
Dc25-3	" "	"	"	"	8/11/48	6
Dc25-3	" "	"	"	"	8/20/51	4
Dc25-6	Delaware Rayon	190			2/16/37	8
Dc25-10	Delaware Rayon	162		Potomac	8/15/51	4
Dc25-16	Avisun Corp.	664	525-530, 552-557	Potomac	5/4/67	9
Dc41-4	Getty Oil Co.		366-396, 519-539	Potomac	10/12/55	4.5
					5/4/67	8
Dc42-6	Getty Oil Co.		602-626, 639-659, 668-698	Potomac		10.0
					5/4/67	9
Dc43-1	Getty Oil Co.	151		Potomac	6/8/55	3.5
Dc43-1	" " "	"		"	7/6/55	3.5
Dc51-3	Getty Oil Co.				3/11/66	11
					4/7/66	21

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Dc51-7	Getty Oil Co.	566	416-439, 454-474, 534-544	Potomac	10/6/55	19.0
Dc51-7	" " "	"	"	"	10/7/55	19.0
Dc51-7	" " "	"	"	"	5/4/67	17
Dc51-8	Getty Oil Co.	255	229-255	Potomac	3/7/56	2.0
Dc52-2	Getty Oil Co.	815	476-481	Potomac	7/12/54	6.5
Dc52-5	Getty Oil Co.		73-85	Columbia	10/5/54	7.0
Dc52-5	" " "		"	"	10/8/54	5.5
Dc52-24	Getty Oil Co.		302-333	Potomac	12/9/54	4.0
Dc52-24	" " "		"	"	12/12/54	4.0
Dc52-24	" " "		"	"	12/15/54	4.0
Dc52-24	" " "		"	"	3/11/66	5
Dc52-24	" " "		"	"	1/6/67	1
Dc53-7	Getty Oil Co.	785	534-539	Potomac	10/1/54	12.0
Dc53-23	Getty Oil Co.	712	538-543	Potomac	8/25/54	4.0
Dd12-1	Town of New Castle	36		Potomac	4/22/44	46
Ea33-1(Md.)	B. F. Goodrich	695	580-608	Potomac	9/30/66	1.0
Ea33-2(Md.)	B. F. Goodrich	427	390-410	Potomac	11/20/66	1.0

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Ea44-2	Corps. of Engrs.	144	122-132	Potomac	1/5/56	2.0
Ea44-2	" " "	"	"	"	2/21/56	2.5
Ea44-2	" " "	"	"	"	7/2/56	3.0
Ea44-2	" " "	"	"	"	9/18/56	4.5
Ea44-2	" " "	"	"	"	9/16/57	1.5
Ea44-2	" " "	"	"	"	12/29/61	1.5
Ea44-3	Corps. of Engrs.	153	117-145	Potomac	1/14/56	2.0
Ea44-3	" " "	"	"	"	2/21/56	5.0
Ea44-3	" " "	"	"	"	7/2/56	4.5
Ea44-3	" " "	"	"	"	9/18/56	3.3
Ea44-3	" " "	"	"	"	9/16/57	4.0
Eb15-2	Getty Oil Co.	245	240-245	Potomac	1/5/56	5.0
Eb15-2	" " "	"	"	"	12/6/55	2.5
Eb15-4	Getty Oil Co.		510-541	Potomac	10/21/55	10.0
Eb15-4	" " "		"	"	5/4/67	12.0
Eb31-1	Corps. of Engrs.		94-103	Magothy	12/15/55	2.8
Eb31-1	" " "		"	"	2/21/56	1.5
Eb31-1	" " "		"	"	5/17/56	2.1
Eb31-1	" " "		"	"	7/2/56	3.0
Eb31-1	" " "		"	"	10/4/56	3.4
Eb31-1	" " "		"	"	9/16/57	2.5

Also see Delaware Geological Survey Report of Investigations No. 3 for additional analyses from wells along Chesapeake and Delaware Canal.

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Ec12-2	Getty Oil Co.	608	549-553	Potomac	4/7/66	9
Ec12-2	" " "	"	"	"	1/6/67	7
Ec12-3	Getty Oil Co.	828	548-553	Potomac	11/1/54	11.0
Ec12-3	" " "	"	"	"	1/6/67	3
Ec12-10	Getty Oil Co.	43	29-39	Columbia	3/15/55	8.5
Ec12-10	" " "	"	"	"	3/16/55	9.5
Ec12-14	Getty Oil Co.	605	114-157	Potomac	8/9/54	3.0
Ec12-15	Getty Oil Co.	734	585-590(?)	Potomac	9/2/54	11.5
Ec12-20	Getty Oil Co.	574	525-558	Potomac	5/4/67	13
Ec13-5	Getty Oil Co.	694	543-547	Potomac	1/6/67	2
Ec13-6	Getty Oil Co.	726	524-566	Potomac	1/31/55	8.5
Ec13-6	" " "	"	581-592	"	1/26/55	8.0
Ec13-6	" " "	"	523-563, 581-592	"	1/24/55	9.0
Ec13-6	" " "	"	"	"	2/10/55	9.0
Ec13-6	" " "	"	"	"	6/3/66	4
Ec13-6	" " "	"	"	"	1/6/67	4
Ec13-11	Getty Oil Co.	127	97-127	Columbia	8/23/66	360
Ec13-11	" " "	"	"	"	8/25/66	315
Ec14-1	Getty Oil Co.	685	678-685	Potomac	10/8/54	43.0

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Ec14-7	Getty Oil Co.	764	642-668, 692-702	Potomac	5/9/67	21
Ec15-3	Gov. Bacon Health Center	178	157-177	Magothy	6/29/55	19
					4/18/57	5.0
Ec15-4	Gov. Bacon Health Center	176	158-176	Magothy	9/22/53	15
Ec15-9	Gov. Bacon Health Center	22	open	Columbia	6/28/55	22
					4/18/57	20
Ec21-1	Gam Estates	35	open	Columbia	12/16/53	34
Ec21-1	" "	"	"	"	12/18/61	44
Ec21-1	R. White	30	open	Columbia	2/16/53	25
Ec21-1	" "	"	"	"	11/1/60	38
Ec22-2		35	open	Columbia	11/1/60	44
Ec22-7	E. W. Wilson	45	open	Columbia(?)	11/1/60	7.0
Ec23-6	Gunning Bedford School	104	94-104	Redbank(?)	1/10/68	864
				Columbia(?)	2/5/68	854
Ec32-3	Union Carbide Corp.	420	318-348	Potomac	10/14/66	7.0
Ec32-7	Union Carbide Corp.	752	586-596	Potomac	8/30/66	10
Ec33-1	F. Pyle	95	open	Mt. Laurel Nevesink(?)	2/16/53	28

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Ec33-2	F. Pyle	95	open	Mt. Laurel Nevesink(?)	11/1/60	7.0
Ec34-1	S. E. Poole	40	open(?)	Columbia	11/1/60	34
Fb33-1	Town of Middletown	425	na	Magothy	9/19/60	1.8
Fb33-1	"	"	"	"	11/1/60	8.0
Fb33-2	Town of Middletown	525	na	Magothy	9/19/60	6
Fb33-3	Town of Middletown	100	74-90	Rancocas	9/19/60	12(?)
Fb33-3	" " "	"	"	"	4/15/57	6.2
Fb33-3	" " "	"	"	"	11/1/60	7.5
Fb33-12	Town of Middletown	na	na	Magothy	1/16/62	1.4
Fb42-2	Town of Middletown	206	open from 134'	Monmouth Group	9/7/60	2.1
Fb42-3	Town of Middletown	206	open from 132'	Monmouth Group	10/17/61	2.6
Fc31-6	H. Davis	164	open from 130'	Monmouth-Matawan Groups	8/20/54	10
Fc31-11	Cantwell Water Co.	168	open from 98'	Monmouth-Matawan Groups	11/1/60	14

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Fc31-13		203	open from 164'(?)	Matawan Group	11/1/60	2.0
Fc41-1	E. Roberts	113	open from 78'	Rancocas & Monmouth Group	8/20/54	3.5
Gb24-2	Village of Townsend	190	na	Wenonah(?)	11/1/60	1.5
Gb24-3	Bellmont Limestone	180	na	Wenonah(?)	11/1/60	4.0
Gd33-4a	Shell Oil Co.	427	394-427	Monmouth	5/1/61	8.0
Gd33-4a	" " "	"	"	"	12/6/66	17
Gd33-4b	Shell Oil Co.	660	625-657	Magothy	5/1/61	270
Gd33-4b	" " "	"	"	"	12/6/66	308
Hc14-3	State of Dela.	273	na	Rancocas	3/28/67	1
Hc34-3	Town of Smyrna	100	80-95	Columbia Group	7/24/52	17.8
Hd44-1	W. E. Cornelius	271	210-270	Eocene	5/15/57	922
Hd44-2	W. E. Cornelius	50	na	Chesapeake Group	7/2/57	30

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Id31-26	International Latex	1200	1132-1147	Magothy	6/21/66	946
					6/23/66	1098
					6/12/67	1050
Id53-4	City of Dover	530	301-370	Piney Point	10/10/60	7.0
Jd35-2	Dover A.F.B.	213	190-210	Cheswold	1/1/43	2.2
Je31-1	Dover A.F.B.	270	185-195 ?	Cheswold	3/4/48	2.8
Je31-1	" "	"	"	"	4/11/61	3.7
Je31-1	" "	"	"	"	4/25/62	3.6
Je31-2	Dover A.F.B.	233	na	Cheswold	3/11/57	2.3
					3/4/58	2.4
					4/11/61	2.8
Je32-1	Dover A.F.B.	220	208-231		4/24/62	2.4
Je32-1	" "	"	"		11/4/42	2.9
Je32-1	" "	"	"		5/27/47	18
Je32-2	Dover A.F.B.	259	220-240	Cheswold	5/27/47	16
Je32-3	Dover A.F.B.	252	216-236 ?	Cheswold	3/4/58	2.8
Je32-3	" "	"	"	"	4/11/61	3.2
Je32-3	" "	"	"	"	4/29/62	2.8
Je32-4	Dover A.F.B.	1422	361-391, 555-566	Piney Point	4/17/57	6.2
Ld51-1	Town of Harrington	240	open	Frederica	10/27/51	2.9

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	pmm Chlorides
Me15-3	City of Milford	242	220-236	Frederica	4/13/31	2.5
Me15-3	" " "	"	"	"	2/20/56	1.5
Me15-10	City of Milford	224	open from 200?	Frederica	4/13/31	2.5
Me15-13	City of Milford	242	220-236	Frederica	12/18/51	3.4
Me15-13	" " "	"	"	"	6/18/54	2.4
Me15-29	City of Milford	867	640-700, 780-785	Piney Point	2/16/68 2/20/68	537 541
Nc25-2		61	41-61	Columbia	2/16/56	9.5
Ng42-2	Town of Milton	68	na	Columbia	2/17/56	6.5
Nh35-1		62	na	Manokin	11/4/53	6300
Ni25-1	See Table I, Page 8.					
Ni35-3	See Table I, Page 8.					
Ni41-1	Town of Lewes	110	80	Columbia	12/28/43	19
Ni41-1	" " "	"	"	"	2/13/44	18.0
Ni41-1	" " "	"	"	"	3/44	20.2
Ni41-1	" " "	"	"	"	8/26/47	13.0
Ni42-2	Town of Lewes	60-65	na	Columbia	6/16/44	18
Ni42-2	" " "	"	"	"	9/22/44	18
Ni42-2	" " "	"	"	"	10/5/45	17

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Ni42-8	Town of Lewes	64	na	Columbia	3/10/44	422
Ni42-8	" " "	"	"	"	4/8/44	452
Ni42-8	" " "	"	"	"	6/16/44	660
Ni42-8	" " "	"	"	"	9/44	1190
Ni42-8	" " "	"	"	"	12/5/44	1040
Ni42-8	" " "	"	"	"	1/45	1280
Ni42-8	" " "	"	"	"	2/23/45	738
Ni42-8	" " "	"	"	"	10/5/45	605
Ni42-8	" " "	"	"	"	11/3/53	
Ni42-9	Town of Lewes	60-65	na	Columbia	6/16/44	25
Ni42-9	" " "	"	"	"	9/22/44	72
Ni42-9	" " "	"	"	"	12/5/44	147
Ni42-9	" " "	"	"	"	1/22/45	139
Ni42-9	" " "	"	"	"	10/5/45	184
Ni42-10	Town of Lewes	64	na	Columbia	4/8/44	29
Ni42-10	" " "	"	"	"	6/16/44	28
Ni42-10	" " "	"	"	"	2/23/45	26
Ni42-10	" " "	"	"	"	10/5/45	31
Ni42-11	Town of Lewes	shallow, exact depth unknown	na	Columbia	5/44	855
Ni42-11	" " "	"	"	"	6/6/44	825
Ni42-11	" " "	"	"	"	9/22/44	1400
Ni42-11	" " "	"	"	"	12/5/44	1420
Ni42-11	" " "	"	"	"	2/23/45	1170
Ni42-11	" " "	"	"	"	10/5/45	1060
Ni51-3	Town of Lewes	84	64-84	Columbia	1944	16

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Ni51-15	Ralph Martin	30	Drive Point	Columbia	5/16/44	37
Ni51-16	Town of Lewes	97	78-96	Columbia	2/23/56	15
Ni51-17	Town of Lewes	162	130-162	Columbia	10/4/45	10
Ni51-17	" " "	"	"	"	2/23/56	9
Ni52-2	Henlopen Poultry	80	na	Columbia	5/15/44	13
Ni52-3	V. L. Dennis	Shallow, exact depth unknown	Drive Point	Columbia	5/16/44	14
Ni52-4	F. C. Marshall	65	Drive Point	Columbia	5/16/44	11
Ni52-5	E. H. Maull	65	Drive Point	Columbia	5/16/44	15
Ni52-6	L. Mitchell	80	Drive Point	Columbia	5/16/44	12
Ni52-8	O. Warrington	72	Drive Point	Columbia	5/15/44	12
Ni53-3	U.S. Government	147(?)	na	Columbia	3/1/44	15
Ni53-3	" "	"	"	"	9/22/44	13
Ni53-3	" "	"	"	"	10/24/44	13
Ni53-3	" "	"	"	"	10/25/44	13
Ni53-3	" "	"	"	"	10/31/44	12
Ni53-3	" "	"	"	"	8/26/47	19
Ni53-3	" "	"	"	"	9/28/49	12
Ni53-4	U.S. Government	103	na	Columbia	9/22/44	12
Nj51-2	See Table I, Page 8.					

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Oc14-8	Town of Bridgeville	119	100-119	Columbia	2/16/56	11
Of42-1	Water & Supply Co. of Georgetown	128(?)	120-128(?)	Columbia	2/13/56	38
Oi11-1	C. Baker	80	Drive Point	Columbia	5/16/44	18
Oi11-3	W. Murray	Shallow, exact depth unknown	Drive Point	Columbia	5/16/44	11
Oi11-5	W. Carpenter	90	Drive Point	Columbia	5/15/44	11
Oi34-1	Town of Rehoboth	131	69-138 (4 screens)	Columbia	2/13/56	14
Oi34-3	Town of Rehoboth	116	102-112	Columbia	1956 ?	15
Oi34-4	J. Boyd	35	Drive Point	Columbia	5/12/44	15
Oi34-7	Town of Rehoboth	125 (?)	na	Columbia	1964	20
Oi35-1	Town of Rehoboth	110 (?)	na	Columbia	12/19/44	13
Oi35-2		110	na	Columbia	12/15/44	13
Oi35-15	Atlantic Ice Mfg. Co.	136	na	Columbia	9/22/44	16
Oi35-21	State of Delaware	128	na	Columbia	2/20/46	28
Oi35-25	R. Hall	28	Drive Point	Columbia	1952 ?	17.1

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Oj21-3	R. Dodge	93	Drive Point	Columbia	7/1/44	720
Oj21-3	" "	"	"	"	9/1/44	860
Oj21-3	" "	"	"	"	8/1/45	910
Oj21-3	" "	"	"	"	4/51	70
Oj31-1	Town of Rehoboth	110	na	Columbia	1931	18
Oj31-1	" " "	"	"	"	1938	36
Oj31-1	" " "	"	"	"	1944	86
Oj31-1	" " "	"	"	"	1953	95
Oj31-3	Blue Hen Theater	136	na	Columbia	9/1/44	910
Oj31-3	" " "	"	"	"	6/20/45	655
Oj31-3	" " "	"	"	"	8/1/45	910
Oj31-5	L. Miller	113	106-112	Columbia	1951 ?	15
Oj31-6	L. Miller	38	32-38	Columbia	1951 ?	22
Oj31-7	R. Lingenfelter	27	Drive Point	Columbia	1950	23.9
Oj31-10	J. Hemmerick	25	Drive Point	Columbia	5/52	39.3
Oj41-16					3/10/44	21
Oj51-1	See Table I Page 8.					
Oj51-2	See Table I Page 8.					
Oj51-3	See Table I Page 8.					

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Pc23-1	Town of Seaford	87	53-86	Columbia	10/9/53	11
Pc23-3	Town of Seaford	95	65-95	Columbia	2/27/53	12.0
Pc23-3	" " "	"	"	"	10/9/53	6
Pc23-3	" " "	"	"	"	2/21/56	4
Pc23-12	Town of Seaford	115	70-98	Columbia	1/60	31
Pc24-1	Town of Seaford	80	na	Columbia	10/9/53	10
Pc24-8	Town of Seaford	90	48-68	Columbia	10/9/53	14
Pc33-4	DuPont Company	87	67-87 (?)	Columbia	3/7/45	7.5
Pc33-6	DuPont Company	76	56-76 (?)	Columbia	3/7/45	8.4
Pc55-1	Heckman Products	114	97-108	Manokin	7/51	7
Pg53-9	Village of Millsboro	84	72-85	Columbia	2/14/56	9
Pj11-1	State of Delaware	536	500+	Miocene	7/59	1200
Pj11-2	State of Delaware	267	103-107	Miocene	7/28/59	2972
Pj21-2	See Table I, Page 8.					
Pj21-3	See Table I, Page 8.					
Pj22-1	See Table I, Page 8.					
Pj22-2	See Table I, Page 8.					

Well No.	Owner	Total Depth In Feet	Depth Screened (land surface datum)	Geologic Unit Screened	Date of Sample	ppm Chlorides
Pj42-11	See Table I, Page 8.					
Qd21-3	Town of Laurel	91	Multiple	Columbia	2/21/56	6.5
Qh31-2, 6	Atlantic Ice Co.	16, 16	Drive Point	Columbia	2/14/56	40
Qh51-7	Village of Frankford	102	na	Columbia	2/14/56	14
Qi55-1	Delaware Police Chief's Association	117	na	Columbia	8/23/53	16
Qj32-7	W. D. Short	71	61-69	Columbia	9/14/54	58
Rd31-8	Town of Delmar	126	115-125	Columbia	2/14/56	12
Rh32-1	Town of Selbyville	95	85-95	Columbia	11/24/52	10.6
Rh32-7	Town of Selbyville	495	na	Columbia	4/5/65	28

SELECTED BIBLIOGRAPHY

Back, W., 1966, Hydrochemical Facies and Ground-Water Flow Patterns in the Atlantic Coastal Plain: U.S. Geol. Survey Prof. Paper 498-A, 42 p.

Barksdale, H. C., Greenman, D. W., Lang, S. M., Hilton, G. S., and Outlaw, D. E., 1958, Ground-Water Resources in the Tri-State Region Adjacent to the Lower Delaware River: Special Report 13, State of New Jersey Dept. of Conservation and Economic Development, 190 p.

Cahill, J. M., 1967, Hydraulic Sand-Model Study of the Cyclic Flow of Salt Water in a Coastal Aquifer: U.S. Geol. Survey Prof. Paper 575-B, p. B240-B244.

Cooper, H. H., Kohout, F. A., Henry, H. R. and Glover, R. E., 1964, Sea Water in Coastal Aquifers: U.S. Geol. Survey Water Supply Paper 1613-C, 84 p.

- 1967, Engineering Geology of the Northeast Corridor, Washington, D. C. to Boston, Massachusetts: Coastal Plain and Surficial Deposits; U.S. Geol. Survey Miscellaneous Geological Investigations Map I-514-B.

Gill, H. E., 1962, Ground-Water Resources of Cape May County, N.J., Salt Water Invasion of Principal Aquifers: State of New Jersey, Dept. of Conservation and Economic Development, Div. of Water Policy and Supply, Special Report 18, 171 p.

Jordan, R. R., 1962, Stratigraphy of the Sedimentary Rocks of Delaware: Delaware Geol. Survey Bull. 9, 51 p.

Jordan, R. R., and Groot, J. J., 1962, Some observations on the Sediments of the Delaware River South of Wilmington: Delaware Geol. Survey Report of Investigations No. 6, 12 p.

Kraft, J. C., and Maisano, M. D., 1968, Geologic Cross-Section of Delaware Showing Stratigraphic Correlations, Aquifer Distribution and Geologic Setting Within the Atlantic Coastal Plain - Continental Shelf Geosyncline: A Contribution of the University of Delaware Water Resources Center.

Marine, I. W., Rasmussen, W. C., 1955, Preliminary Report on the Geology and Ground-Water Resources of Delaware: Delaware Geol. Survey Bull. 4, 336 p.

Rasmussen, W. C., Groot, J. J., and Beamer, N. H., 1958, Well for the Observation of Chloride and Water Levels in Aquifers that Cross the Chesapeake and Delaware Canal; Delaware Geol. Survey Report of Investigations No. 3, 22 p.

Rasmussen, W. C., Groot, J. J., and Depman, A. J., 1958, High-Capacity Test Well Developed at the Air Force Base, Dover, Delaware: Delaware Geol. Survey Report of Investigations No. 2, 36 p.

Rasmussen, W. C., Wilkens, R. S., and Beall, R. M., 1960, Water Resources of Sussex County, Delaware: Delaware Geol. Survey Bull. 8, 228 p.

Rima, D. R., Coskery, O. J., Anderson, P. W., 1964, Ground-Water Resources of Southern New Castle County, Delaware: Delaware Geol. Survey Bull. No. 11, 54 p.

Spoljaric, N., and Jordan, R. R., 1966, Generalized Geologic Map of Delaware.

Sundstrom, R. W. and Others, 1967, The Availability of Ground-Water from the Potomac Formation in the Chesapeake and Delaware Canal Area, Delaware: University of Delaware, Water Resources Center Publication, 95 p.

Sundstrom, R. W., and Pickett, T. E., 1968, The Availability of Ground Water in Kent County, Delaware with Special Reference to Dover Area: University of Delaware Water Resources Center Publication, 123 p.

Upson, J. E., 1966, Relationships of Fresh and Salty Ground Water in the Northern Atlantic Coastal Plain of the United States: U.S. Geol. Survey Prof. Paper 550-C, p. C235-C243.