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AVAILABILITY OF GROUND WATER IN CHARLES COUNTY, MARYLAND

By Turbit H. Slaughter and E. G. Otton
with a section on the
CHEMICAL CHARACTER OF THE WATER
By Charles P. Laughlin

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AVAILABILITY OF GROUND WATER IN CHARLES COUNTY, MARYLAND

BY

T. H. SLAUGHTER AND E. G. OTTON

ABSTRACT

This report is an appraisal of the ground-water resources of an important segment of the Maryland Coastal Plain. Its purpose is to guide engineers, planning agencies, and local residents concerned with the development and planning of ground-water supplies.

Charles County covers an area of 457 square miles and is bounded on the west and south by the Potomac River, on the north by Prince Georges County, and on the east by the Patuxent River and St. Marys County.

The area is in the temperate, humid climatic belt of the eastern United States. On the average it receives about 46 inches of precipitation. The average annual temperature is about 56°F. The population of the county was about 35,600 in 1960.

The estimated use of ground water during 1962 was about 3.8 mgd (million gallons per day). The largest single user of ground water was the U. S. Naval Propellant Plant at Indian Head.

The county is underlain by a wedge-shaped mass of sedimentary strata ranging in thickness from 600 to 2,000 feet. Several important aquifers are present throughout the county; based on rough estimates, these aquifers may be capable of yielding at least 55 mgd (million gallons per day) of water to properly spaced drilled and dug wells.

An appraisal of the ground water available from five separate areas of anticipated future economic and population growth indicates that about 3 mgd of ground water can be obtained in the area of lowest potential to about 16 mgd in the area of greatest potential. However, proper management of the ground-water resource will be necessary for optimum development to take place. The Waldorf area in the north-central part of the county appears to be most favorable for the development of large additional supplies.

The chemical quality of the ground water is satisfactory for most uses, although, locally, treatment for iron removal may be required.

INTRODUCTION

Purpose and Methods of Investigation

In response to concern about increasing demands for water, the Charles County Commissioners requested that a detailed investigation be made of the

availability of ground water in an effort to meet the water requirements of a rapidly growing population and for water supplies for agricultural and industrial expansion in the county.

The U. S. Geological Survey and the Maryland Geological Survey (formerly the Maryland Department of Geology, Mines and Water Resources) cooperated in making the investigation. This work is part of a series of cooperative water-resources studies that have been undertaken by the respective Federal and State agencies covering a period of nearly 25 years.

Prior to this study the knowledge about ground water was primarily based on data from two earlier studies of the ground-water resources of Charles County (Overbeck, 1948 and Otton, 1955), and from unpublished reports of the U. S. Geological Survey.

In the course of this investigation, 320 wells were inventoried. Of these, 54 wells were surveyed for elevation above sea level using levels and aneroid barometers. Static water levels were measured in 105 wells. Nineteen test holes averaging 43 feet in depth were power augered to determine the lithology of the surficial deposits at selected sites.

To collect streamflow data, for a hydrologic study of the basins, two recording stream-gaging stations were operated, one on the North Piney Branch and the other on the South Piney Branch.

Seventeen observation wells were established in the North Piney Branch basin and 11 in the South Piney Branch basin. These wells were used in the hydrologic budget analysis.

Well cuttings from 87 wells were used in the study of the subsurface geology. Nine outcrop samples from cliffs along the Potomac River were tested in the laboratory for specific gravity, dry-unit weight, specific retention, porosity, and specific yield.

Twenty aquifer tests were conducted to determine the coefficients of transmissibility and storage of the aquifers. Thirteen aquifer tests of the recovery type were conducted on flowing wells. Aquifer tests were also conducted at Dahlgren and Quantico in Virginia to obtain aquifer coefficients pertinent to the Charles County study. Temperature logs were made on eight wells to ascertain the temperature gradient and the position of water-bearing sands. Twenty-five water samples were analyzed to determine the chemical character of water in the principal aquifers. To determine the seasonal range of chloride content of the tidal water of the county, salinity measurements were made at a few sites along the Potomac River and its estuaries. To estimate the ground-water component of runoff, streamflow measurements were made of several streams.

Records of wells and springs, chemical analyses of water, and selected logs of deep wells have been published by the Maryland Geological Survey as *Water Resources Basic Data Report No. 2* (1966). These data, covering primarily the period 1942–63, form the major source of such information used in the prepara-

tion of this report. Other basic geologic and hydrologic data for Charles County are on file in the district water-resources office in Towson, Maryland. These data were assembled and studied to obtain an understanding of the nature of the aquifers and aquicludes and an understanding of the geohydrology of the area.

Figure 1 shows the location of basic sources of chronohydrologic information in the county; these sources are—weather stations, stream-gaging stations, observation wells, and tide gages.

ACKNOWLEDGMENTS

The authors express appreciation to the residents of Charles County and to personnel of Government agencies, military installations, and industrial plants in the area for their cooperation and assistance. In addition to providing finan-

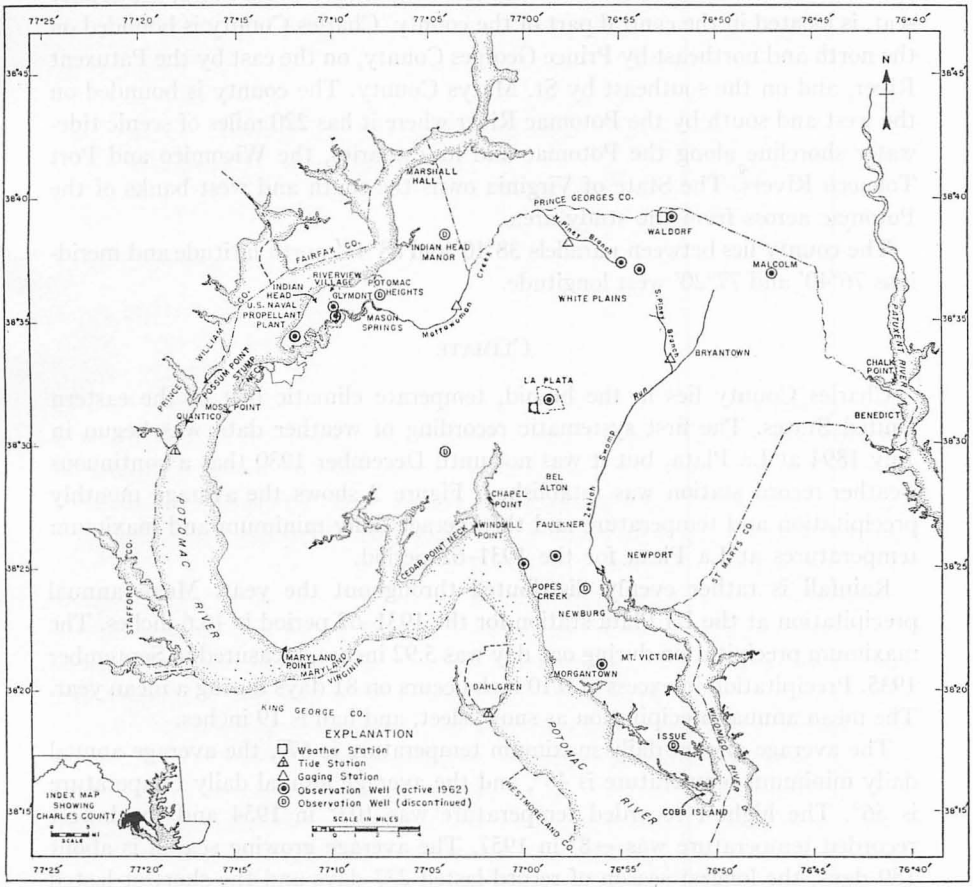


FIGURE 1. Map showing the location of basic sources of hydrologic data.

cial support the Commissioners of Charles County provided work and storage space. Officials of the U. S. Naval Propellant Plant at Indian Head assisted in aquifer tests conducted at the plant. Personnel of Charles County Sanitary Commission aided in conducting aquifer tests at Waldorf. Captain Francis L. Busey, U. S. Navy, Retired, obtained permission to conduct aquifer tests at Government installations at Dahlgren and at Quantico, Va. Officials at the U. S. Army Signal Station at La Plata, Md., permitted use of a well for water-level observation purposes. This investigation was carried out under the immediate supervision of E. G. Otton of the U. S. Geological Survey.

LOCATION AND EXTENT OF AREA

Charles County covers an area of 457 square miles within the region known as Southern Maryland, which includes the five counties lying west of Chesapeake Bay and south of Baltimore and Washington, D. C. La Plata, the county seat, is located in the central part of the county. Charles County is bounded on the north and northeast by Prince Georges County, on the east by the Patuxent River, and on the southeast by St. Marys County. The county is bounded on the west and south by the Potomac River where it has 220 miles of scenic tidewater shoreline along the Potomac and its estuaries, the Wicomico and Port Tobacco Rivers. The State of Virginia owns the south and west banks of the Potomac across from the study area.

The county lies between parallels 38°10′ and 38°43′ north latitude and meridians 76°40′ and 77°20′ west longitude.

CLIMATE

Charles County lies in the humid, temperate climatic belt of the eastern United States. The first systematic recording of weather data was begun in July 1894 at La Plata, but it was not until December 1930 that a continuous weather-record station was established. Figure 2 shows the average monthly precipitation and temperature and the average daily minimum and maximum temperatures at La Plata for the 1931–62 period.

Rainfall is rather evenly distributed throughout the year. Mean annual precipitation at the La Plata station for the 1931–62 period is 46.6 inches. The maximum precipitation during one day was 5.92 inches, measured in September 1935. Precipitation in excess of 0.10 inch occurs on 81 days during a mean year. The mean annual precipitation as snow, sleet, and hail is 19 inches.

The average annual daily maximum temperature is 67°, the average annual daily minimum temperature is 45°, and the average annual daily temperature is 56°. The highest recorded temperature was 103° in 1954 and the lowest recorded temperature was −8° in 1957. The average growing season is about 189 days, the longest season of record lasted 237 days and the shortest lasted 165 days.

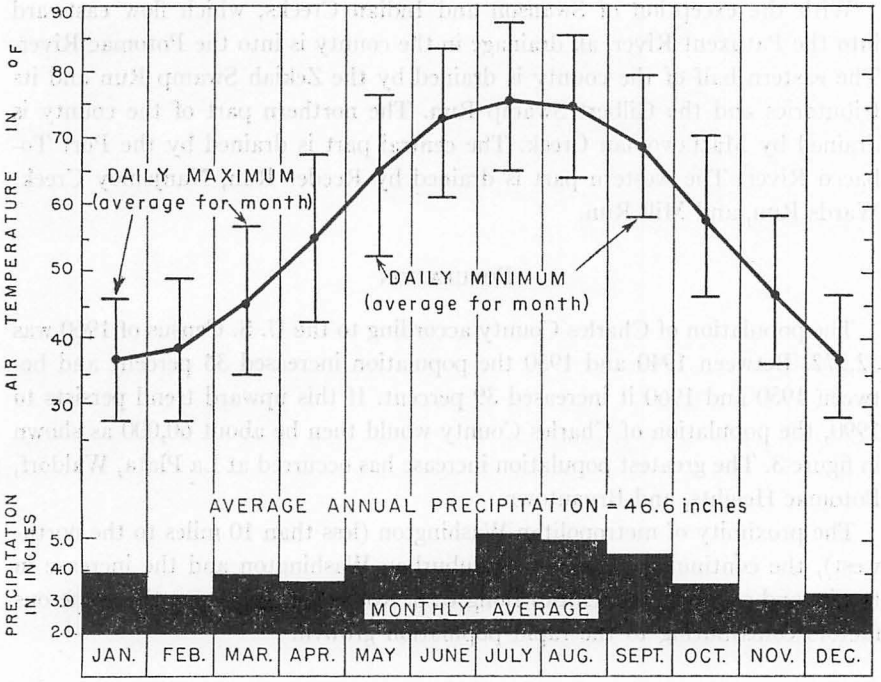


FIGURE 2. Graphs showing monthly air temperatures and precipitation at La Plata for period 1931–62.

SURFACE FEATURES

Charles County lies entirely within the Coastal Plain physiographic province. The western boundary of the county is 6 to 8 miles east of the edge of the Piedmont province in Virginia. A plateau of rather uniform altitude forms a rough triangle in the north-central part of the county centered in the area along U. S. Route 301 between White Plains and Waldorf. This upland plateau is not deeply entrenched by stream valleys, but the land gently slopes west, south, and east and is incised by the major streams of the county, the larger of which flow south.

About two-thirds of the county lies at an altitude of 100 feet or more. Along some parts of the Potomac and Wicomico River shorelines there is definite evidence of terracing with a rather abrupt slope change occurring at the 40-foot contour line. Uniformly elevated terraces below the 40-foot contour are located in the Marshall Hall, Stump Neck, and Moss Point areas, and at Maryland Point extending northeast to the Port Tobacco River. A terrace also occurs at Mt. Victoria extending to the northwest along the Wicomico River shoreline. These broad flat areas (altitude 25–40 feet) may be parts of the Talbot terrace of late Pleistocene age.

With the exception of Swanson and Indian Creeks, which flow eastward into the Patuxent River, all drainage in the county is into the Potomac River. The eastern half of the county is drained by the Zekiah Swamp Run and its tributaries and the Gilbert Swamp Run. The northern part of the county is drained by Mattawoman Creek. The central part is drained by the Port Tobacco River. The western part is drained by Reeder Run, Nanjemoy Creek, Wards Run, and Mill Run.

POPULATION

The population of Charles County according to the U. S. Census of 1960 was 32,572. Between 1940 and 1950 the population increased 33 percent and between 1950 and 1960 it increased 39 percent. If this upward trend persists to 1990, the population of Charles County would then be about 60,000 as shown in figure 3. The greatest population increase has occurred at La Plata, Waldorf, Potomac Heights, and Bryantown.

The proximity of metropolitan Washington (less than 10 miles to the northwest), the continuing expansion of suburban Washington and the increase in tourist and commercial facilities along U. S. Route 301 are among the numerous factors contributing to the rapid population growth.

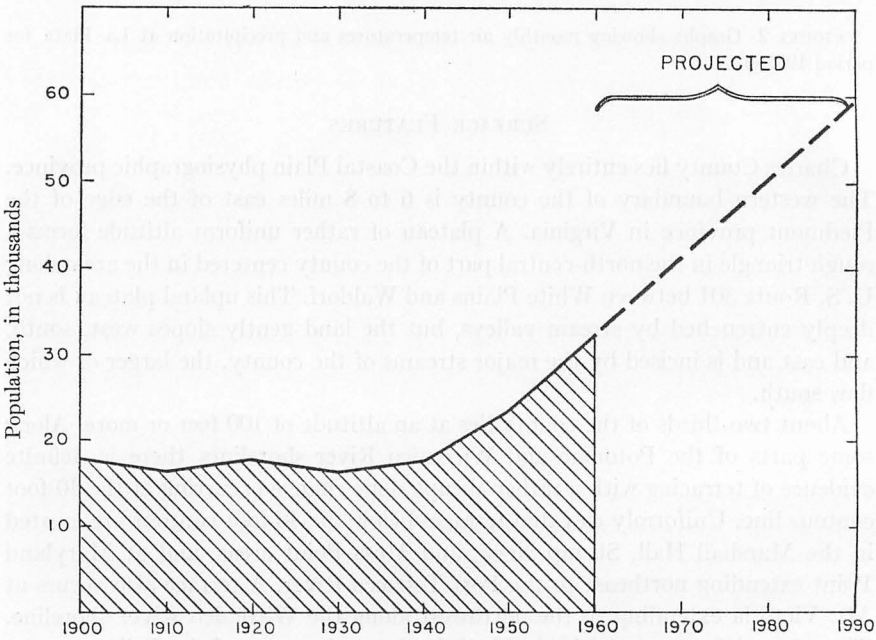


FIGURE 3. Graph showing population trends since 1900.

WATER USE

In 1962 use of ground water for all purposes in Charles County totaled an estimated 3.8 mgd (million gallons per day), table 1. This amount does not include water from flowing wells as much of this water flows to waste. The U. S. Naval Propellant Plant at Indian Head is the largest user of ground water in the county. During 1964 public supplies accounted for only 14 percent of the total ground-water usage, although an increase in this category is anticipated. Tourist facilities along U. S. Route 301 accounted for a substantial proportion of ground water classified as commercial and industrial use. Private water supplies accounted for only about 3 percent of the total ground water used in the county. Figure 4 shows the location of centers of pumpage in Charles County and adjacent areas during 1962.

As a result of the enactment of the Maryland Water Well law in 1945 the number of permit wells drilled in the county increased from 12 in 1945 to 66 in 1963. This increase in drilling activity during this period is an index to general population growth and economic activity in the area. It also provides a rough estimate of the increased use of ground water during the period.

Although there have been more than 50 farm ponds constructed since 1950 in Charles County, there is a record of only one well being drilled specifically for water to fill such a pond. The use of water from wells as a source of replenishment to farm ponds may increase in the future.

WELL NUMBERING SYSTEM

The system of numbering water wells in use by the Maryland Geological Survey groups all wells outside of Baltimore City by counties. A two-letter

TABLE 1

USE OF GROUND WATER IN CHARLES COUNTY IN 1962

Type of Use	Average Quantity Used (gpd)	Percent of Total
Public Supply:		
Town of Indian Head	100,000	2.6
Potomac Heights	200,000	5.2
La Plata	110,000	2.9
Waldorf	118,000	3.1
Privately owned community supply	130,000	3.4
Military:		
U. S. Naval Propellant Plant at Indian Head	1,600,000	42.0
Stump Neck section of Propellant Plant	30,000	.8
Miscellaneous military installations	20,000	.5
Commercial and industrial	500,000	13.1
Domestic and farm	1,000,000	26.4
Total ground water	3,808,000	100.0

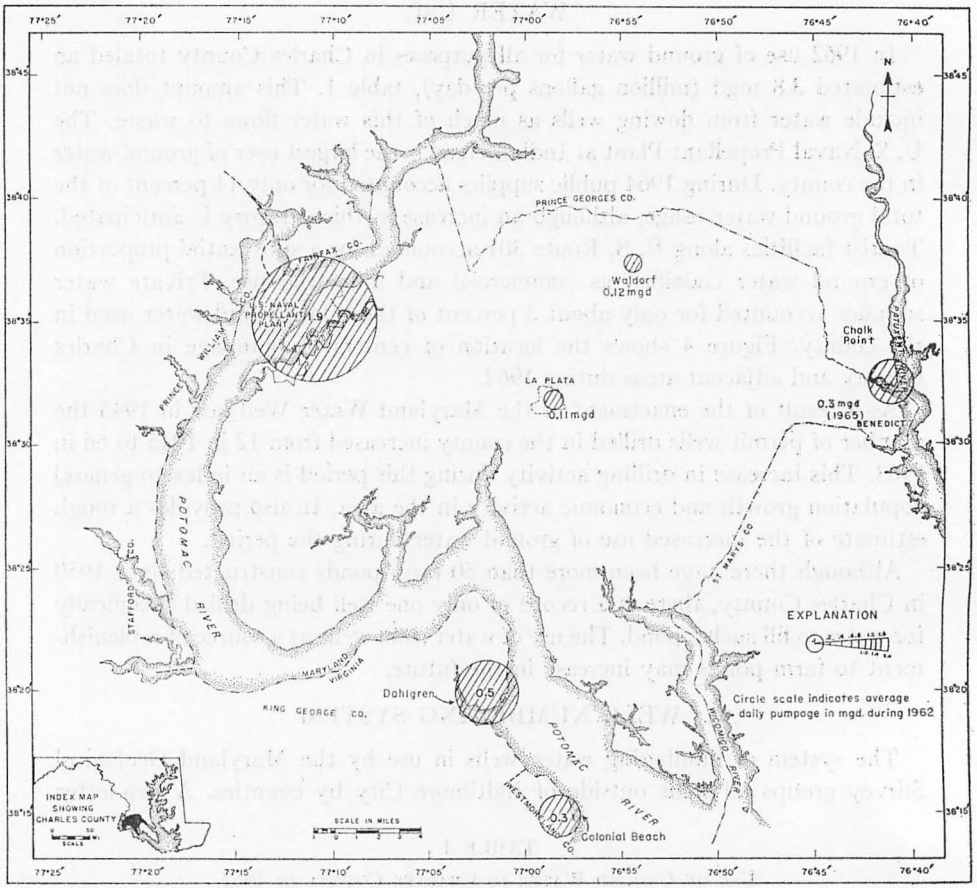


FIGURE 4. Map showing magnitude and distribution of ground-water pumpage in Charles County and adjacent areas in 1962.

symbol, derived from the county name is used as a prefix for each well number. In this report the prefix Ch is used for wells in Charles County and PG for those in Prince Georges County. Each county is divided into 5-minute quadrangles, based on latitude and longitude. Each quadrangle from north to south is designated by uppercase letters and from west to east by lowercase letters. The wells are numbered in each 5-minute quadrangle in the order in which they were inventoried. For example, Ch-Bf 1 is the first well inventoried in the Bf quadrangle which is in the north-central part of Charles County.

A few wells used in this report are located in Virginia; these wells are given arbitrary numbers which may not correspond with the numbers used by the appropriate agency in that State.

GEOLOGY

The rocks beneath Charles County, which is entirely within the Atlantic Coastal Plain, are composed of gravel, sand, silt, and clay. These materials were transported by streams from the Appalachian and Piedmont region west and north of the county and deposited in the form of alluvial fans, deltas, and as estuarine and marine mud and silt layers. The deposits are chiefly of Cretaceous, Tertiary, and Quaternary age resting on dense, hard, crystalline metamorphic and igneous rocks of Precambrian or Cambrian age. The altitude of the crystalline rocks along the western boundary of the county near Indian Head is about 600 feet below sea level, but at Benedict, at the extreme eastern boundary of the county, the altitude of the bedrock is estimated to be about 2,000 feet below sea level (fig. 5).

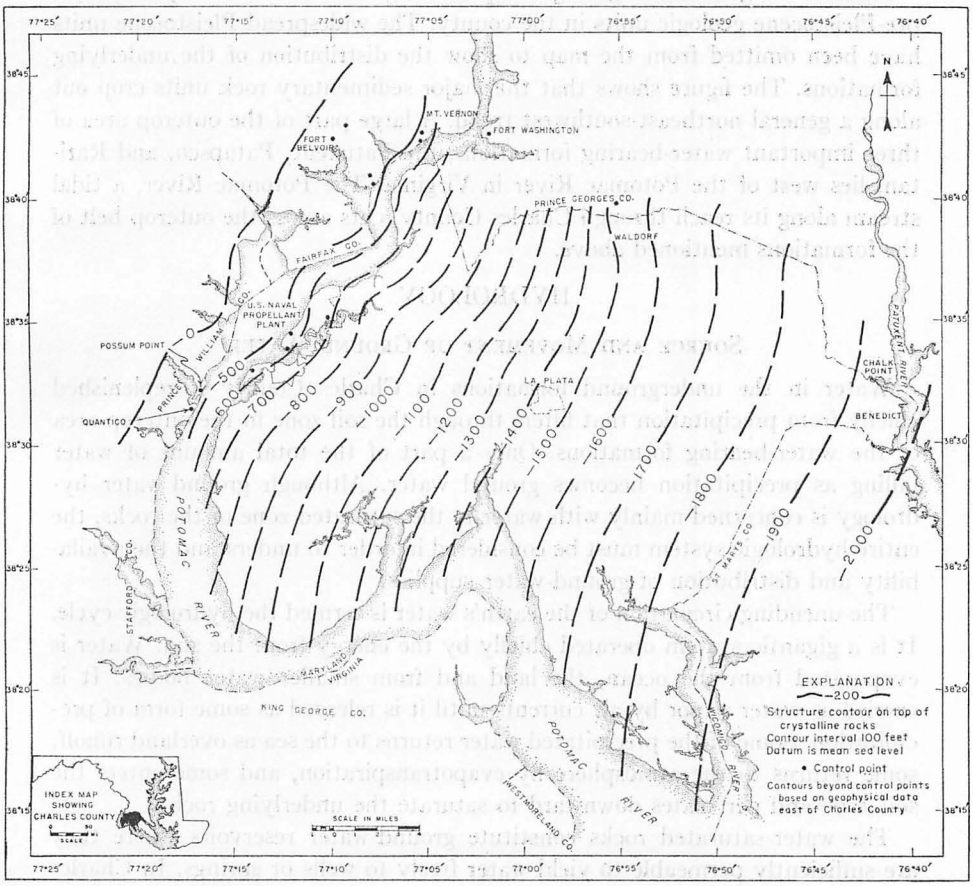


FIGURE 5. Map showing contours on top of the crystalline rocks.

The stratified Coastal Plain sediments strike northeast and dip to the southeast. The sediments thicken in a southeasterly direction so that they appear to be wedge shaped.

The sands and gravels are porous and permeable and contain large quantities of water in storage. Such sands are generally capable of yielding some water to wells. The silts and clays also contain interstitial water, but yield it slowly or not at all. The name, age, thickness, and water-bearing properties of the geologic units are summarized in table 2.

The entire mass of unconsolidated sediments range in geologic age from Early Cretaceous to Quaternary. Rocks of Triassic age may underlie parts of Charles County, although their presence to date (1967) has not been established. However, to the north in neighboring Prince Georges County, deep test holes have confirmed the existence of strata of Triassic age.

Figure 6 is a generalized geologic map showing the area covered by the major pre-Pleistocene geologic units in the county. The widespread Pleistocene units have been omitted from the map to show the distribution of the underlying formations. The figure shows that the major sedimentary rock units crop out along a general northeast-southwest trend. A large part of the outcrop area of three important water-bearing formations, the Patuxent, Patapsco, and Raritan, lies west of the Potomac River in Virginia. The Potomac River, a tidal stream along its reach through Charles County, cuts across the outcrop belt of the formations mentioned above.

HYDROLOGY

SOURCE AND MOVEMENT OF GROUND WATER

Water in the underground formations in Charles County is replenished chiefly from precipitation that filters through the soil zone in the outcrop area of the water-bearing formations. Only a part of the total amount of water falling as precipitation becomes ground water. Although ground-water hydrology is concerned mainly with water in the saturated zone of the rocks, the entire hydrologic system must be considered in order to understand the availability and distribution of ground-water supplies.

The unending circulation of the earth's water is termed the hydrologic cycle. It is a gigantic system operated chiefly by the energy from the sun. Water is evaporated from the ocean, the land and from smaller water bodies. It is carried as water vapor by air currents until it is released as some form of precipitation. Some of the precipitated water returns to the sea as overland runoff, some returns to the atmosphere by evapotranspiration, and some enters the soil zone and percolates downward to saturate the underlying rocks.

The water-saturated rocks constitute ground-water reservoirs where they are sufficiently permeable to yield water freely to wells or springs. In Charles County the stratified sands and gravels are the major ground-water reservoirs or aquifers. Other types of sediments, such as silts and clays, also become

saturated with water, but as they do not yield this water freely to wells or springs they are not considered to be aquifers. Most of the water in the stratified deposits occupies interstices or voids between the rock grains. Within the uppermost 1,000 feet of the deposits, water may constitute 25 to 40 percent by volume of their total volume.

Much of the water in storage in the rocks is moving slowly through them from one place to another in response to differences in hydraulic head. During dry weather periods the flow of the streams is maintained by the water in the ground seeping into stream channels which incise the surficial rocks.

Aquifers are the underground reservoirs that store and yield ground water in economically usable quantities. Water-saturated beds that yield it very slowly or not at all are called aquicludes or "aquatards".

Aquifers perform three principal functions: They act as filters at their intake areas which commonly includes their outcrop areas—this is their filter-plant function; they transmit water from their intake area to the point of withdrawal —this may be termed their pipe-line function; and they store water—this is their reservoir function. Many formations have a relatively large capacity to store water, but their pipeline, or conduit function is so limited that they cannot transmit water to wells at sufficiently rapid rates to be useful as productive aquifers. Some of the quantitative estimates of water availability presented in this report are based on the concept of the aquifers functioning chiefly as conduits.

The water-table aquifers that overlie the entire county are recharged or replenished chiefly by direct precipitation. The artesian aquifers are recharged where they crop out in areas principally west of the Potomac River in Fairfax, Prince William and Stafford Counties, Va. These aquifers also receive some water from vertical leakage downward or upward from imperfect confining layers.

The quantity of ground water that can be stored within an aquifer is dependent upon the volume of material and its porosity. The rate of movement of ground water through an aquifer is determined by the permeability of the aquifer and the head or pressure difference between points of flow.

Movement of ground water in the unconfined water-table aquifers is controlled in part by the configuration of the land surface (relief) and by the permeability of the deposits. In Charles County the general direction of ground-water movement in the water-table aquifers is toward the south and west from the central upland area. Ground water moves from the central upland to the low-lying areas along the major stream valleys. Ground water occurs at points of emergence in low places as seeps, swamps, springs and maintains the flow of streams during periods of no overland runoff.

The movement of ground water in the artesian aquifers is controlled by the regional geologic structure, the hydraulic gradients, and by differences in permeability. The direction of artesian ground water movement is from points

TABLE 2

AGE, THICKNESS, AND WATER-BEARING PROPERTIES OF GEOLOGIC UNITS IN CHARLES COUNTY

System	Series	Group	Geologic Unit	Average Thickness (feet)	Physical Character	Water-bearing Properties
Quaternary	Recent and Pleistocene	Columbia	Lowland deposits (0–40 ft. above sea level)	0–25+	Tan to orange, fine sand, silt and clay mixtures irregularly bedded.	Yields limited quantities of ground water to large-diameter dug or bored wells; has yielded 200 gpm to caisson-type wells.
Quaternary and Tertiary(?)	Pleistocene and Pliocene(?)		Upland deposits (40+ ft. above sea level)	0–30+	Tan to orange, fine to medium sand, silt and clay mixtures, some granule and gravel beds.	Yields as much as 25 gpm to large-diameter dug or bored wells.
Tertiary	Miocene	Chesapeake	Choptank	0–30+	Light-olive fine sand, silt, and clay.	Not water bearing in this county.
			Calvert	0–150+	Olive to pale-brown diatomaceous clay and sandy clay with abundant megafossils.	Not water bearing in this county.
	Eocene	Pamunkey	Nanjemoy	70–200+ (clay member at base averages 30 ft.)	Gray, green to black, fine sand with layers of silt, clay, glauconite, and shells.	Not water bearing in this county.
			Aquia Greensand	80–150	Light to dark-olive glauconite with interbedded very fine sand, silt, and clay. Sands are salt and pepper in appearance.	Principal water-bearing formation in southeastern Charles County. Its potential in the eastern part of the county is untested; yields as much as 200 gpm in favorable locations.
	Paleocene		Brightseat	0–30+	Gray to dark-gray silty, sandy clay.	Not known to be an aquifer in the county

Cretaceous	Upper Cretaceous	Monmouth and Matawan	0–60	Gray to gray-black fine sand, silt and clay.	Not considered as important water-bearing formations.
		Magothy	0–70	Buff-to-gray medium sand, of salt-and-pepper appearance. Some very coarse sands are at the base of the formation.	An important water-bearing formation in northeastern part of the county; yields as much as 450 gpm to wells.
		Raritan and Patapsco	100–300+	Chiefly brown and red clay and sandy clay; some clays are tough and waxy. Interbedded yellow and white sands are fine-to-medium grained.	Principal water-bearing formation in western half of the county. Wells to these formations are commonly screened in more than one sand; wells yield as much as 560 gpm.
		Arundel Clay	Not positively identified as a mappable unit in Charles County.	Where identified north of Charles County, the formation is principally a vari-colored clay.	Not generally a water-bearing formation.
	Lower Cretaceous	Patuxent	350–800+	Gray, brown, light-green to deep-red, sandy, silty clays with interbedded sands.	One of the principal aquifers in western Charles County where wells yield as much as 385 gpm. It is untested in the eastern part.
Precambrian		Crystalline rocks	Unknown	Granite, gabbro, quartz diorite, schist, rhyolite, greenstone, and quartzite.	Does not yield water to wells in the county.

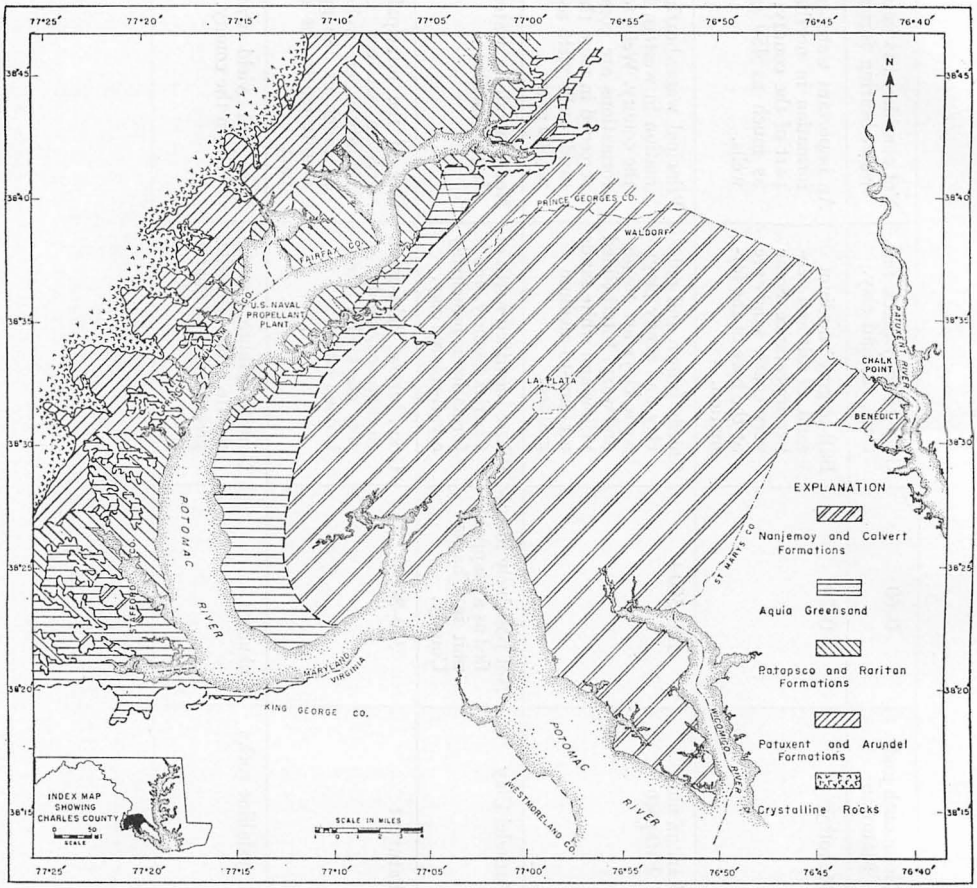


FIGURE 6. Map showing generalized geology of Charles County and adjacent areas.

of high to points of low head. Nearly continuous withdrawal of ground water by means of wells since the early part of this century by the Naval Propellant Plant at Indian Head has created a cone of depression which is such an area of low artesian head.

The hydrologic budget may be expressed quantitatively by an equation which accounts for the water gained and lost during selected periods. The hydrologic equation or budget is balanced by equating precipitation as water gained, to runoff and evapotranspiration as water lost, plus any water stored in reservoirs or as ground-water storage in aquifers. The elements of the hydrologic budget may be expressed by the equation:

$$P = R + ET + \Delta S$$

in which:

P is precipitation

R is surface and ground-water runoff
ET is evapotranspiration
ΔS comprises the change in storage (usually a small segment of the equation for the surface or ground-water reservoirs. This change results in a gain or loss of water during any particular period of time, but over a long period under normal conditions it tends to balance out.)

A detailed study of the hydrologic budget of the Beaverdam Creek basin in Wicomico County, Maryland (Rasmussen and Andreasen, 1959, p. 98) showed the hydrologic budget components to be as follows, in percent of precipitation:

Total runoff	36
Total evapotranspiration	61
Basin storage change (2-years)	3
Total	100

As Charles County is an area where similar geohydrologic and climatic contitions prevail, the above values may be applied to obtain a rough estimate of the quantities of water involved in the hydrologic budget. Based on an average annual precipitation rate of 46 inches per year the budget equation is, in inches of water:

$$P = R + ET + S$$

$$46 = 16.5 + 28 + 1.5$$

Of course, the change in storage, S, varies from one time period to another, but over a long period of time it should average out to essentially zero. Thus, the right-hand term in the equation could be omitted and the quantity distributed between the other two terms.

Rasmussen and Andreasen additionally estimated that ground-water drainage, or discharge, in their area of investigation was about 26 percent of the precipitation, or about 11 inches of water per year. They further determined that ground-water recharge was about 51 percent, or slightly more than 22 inches per year. Eleven of the 22 inches of recharge they determined to be lost as ground-water evapotranspiration.

Rates of ground-water recharge to most of the aquifers in Charles County are not available, but the rates are probably somewhat less than those estimated for the Beaverdam Creek basin. Because of the greater topographic relief of Charles County, and the more clayey nature of the soils, in comparison with the Beaverdam Creek basin, probably somewhat less than 50 percent of the precipitation effectively recharges the ground-water reservoirs. Because of the differences in geology and topography between the two areas ground-water evapotranspiration is probably less in Charles County than in the Beaverdam Creek basin.

FACTORS GOVERNING THE AVAILABILITY OF GROUND WATER

Ground water, a perennially replenishable natural resource, is available nearly everywhere throughout Charles County. It is available in a few places from springs, but in most localities it can be obtained only from drilled or dug wells. Several water-bearing formations occur throughout the area; these may be tapped by wells ranging in depth from 10 feet or less to drilled wells greater than 1,000 feet deep.

Several factors such as frequency and amount of precipitation, infiltration capacity of the soils, permeability of the aquifers, and hydraulic heads and gradients in them govern the availability of water from aquifers. Enormous volumes of water are in storage in the Coastal Plain sediments beneath the area. Reliable quantitative estimates of the total amount of stored water are not available, but probably are on the order of hundreds of millions of gallons for each square mile. Much of this stored water, however, is not readily available for withdrawal as much of it occurs in strata which are too fine grained or impermeable to yield the water to wells or springs.

PRECIPITATION AND INFILTRATION CAPACITY

The rate at which an aquifer can be recharged depends chiefly on the amount of water available from precipitation and on the infiltration capacity of the soils. On the average each square mile of area in Charles County receives about 800 million gallons of water per year (46 inches x 17.4 million gallons). Of this amount it is estimated that between 240 and 320 million gallons (between 30 and 40 percent) infiltrates to the ground-water reservoirs. This amounts to between 660,000 and 880,000 gallons per day per square mile. The distribution of ground-water recharge is variable, both with regard to time and place.

Some of this water is returned to the atmosphere by evapotranspiration from the surficial deposits and never shows up as ground-water runoff to the streams.

Over a long period of time a measure of the quantity of water that is in slow transient storage, in the zone of saturation, can be obtained by measuring the base (or dry-weather) flow of streams. Examination of the published analyses of stream flow data (Darling, 1962) for four small drainage basins in southern Maryland show that the base flow (95 percent duration) ranges from 80,000 gallons per day per square mile (gpd/sq. mi.) to 335,000 gpd/sq. mi. The basins used in this analysis are the South River basin, the North River, Chaptico Creek, and the St. Marys River.

Analyses of the hydrologic budgets of two small drainage basins in central Charles County, covering a 2-year period show that ground-water runoff, or effective recharge, amounted to 16 and 17 percent of the precipitation for each basin, respectively. On the basis of an average annual precipitation of 46 inches per year the ground-water runoff (effective recharge) amounts to about 350,000 gpd/sq. mi. for one of the basins and about 373,000 gpd/sq. mi. for the other basin. These rates do not represent total ground-water recharge as some of the

water recharged or infiltrated to the aquifers is lost as ground-water evapotranspiration. This matter is elaborated further in a subsequent section of the report describing the hydrologic budgets of the basins.

PERMEABILITY, TRANSMISSIBILITY, AND STORAGE

Hydraulic permeability is the ability of a material to transmit water. The *coefficient of permeability* (P_f) is defined as 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 at the prevailing temperatures. Coefficients of permeability of natural earth materials cover an extreme range, but for most of the aquifers in Charles County they range from a few hundred to a few thousand gallons per square foot per day.

Typical permeability coefficients of natural earth materials are given in the following table (adapted from an unpublished report by A. I. Johnson of the U. S. Geological Survey, 1964):

Material	*Coefficient of Permeability (gpd/sq. ft. at 60° F)*
Clay	0.001–1
Silt	1–10
Very fine sand	10–100
Fine sand	100–1,000
Medium sand	1,000–4,500
Coarse sand	4,500–8,000
Gravel	8,000–40,000

The *coefficient of transmissibility* (T) is the rate of flow of water in gallons per day through a vertical section of the aquifer 1 foot wide extending the full saturated thickness of the aquifer under a hydraulic gradient of 1 foot per foot. The thickness of the aquifer is commonly designated by the symbol (m). Thus, the coefficient of transmissibility may be written as:

$$T = P_f M$$

Coefficients of transmissibility range widely, as both permeability and thickness are involved in the definition of the term. In the Coastal Plain of Maryland the transmissibility of most aquifers commonly falls within the range of 100 to 300,000 gallons per day per foot (gpd/ft).

The *coefficient of storage* (S) is the volume of water released or taken into storage per unit surface area of the aquifer, per unit change in the component of hydraulic head normal to that surface. It is dimensionless.

The quantity of water yielded by gravity drainage from saturated water-bearing material is termed the *specific yield* and is expressed as a percent of the total volume of material drained. No time factor is included in the definition of specific yield. Many experiments have shown that draining of saturated materials is most rapid at the outset, decreases with time and may continue for

months or even years. Where water-table conditions exist in aquifers, the coefficient of storage is approximately equivalent to the specific yield.

Very large quantities of ground water are in storage in the sand and gravel deposits underlying Charles County. Based on an average porosity of about 25 percent, rough estimates indicate that about 2.8 trillion (2.8×10^{12}) gallons are in storage within the 457 square mile area comprising the county. About 80 percent of this quantity (2.2×10^{12}) gallons is stored in the water-bearing sediments of the Cretaceous system.

However, much of this water is in fine sand and clayey sand layers of low permeability such that the water cannot be efficiently recovered by means of wells. Thus, only a small part of the stored water may be economically withdrawn for use on the basis of present technology. Probably to withdraw even a fraction of the vast quantity in storage would require a large investment in wells, pumps and collecting lines. Extraction of water from the deeper aquifers would ultimately result in relatively high expenditures for power required to lift the water from great depths. Therefore the estimate of the total stored water is of limited practical significance as its recovery would be governed largely by economic factors.

The coefficients of permeability, transmissibility, and storage may be obtained from aquifer tests, laboratory analyses of earth materials, from analyses of ground-water level fluctuations and streamflow data, and by approximate means, from specific capacity data from wells.

Most of the transmissibility and storage coefficients used in this report were obtained from aquifer tests on pumping wells, commonly using one or more observation wells tapping the same aquifer. Procedures for analyzing aquifer-test data have been summarized by Ferris and others (1962). Such hydrologic coefficients are useful in predicting drawdowns (changes in hydrostatic pressures) to be expected in aquifers as a result of pumping wells.

HYDRAULIC HEAD AND MOVEMENT

The studies of Hagen (1839) and Poiseuille (1846) showed that the rate of flow of water is proportional to the hydraulic gradient, but Darcy (1856) was the first to apply this physical law to the flow of water percolating through sands. Darcy's law expresses the equation for flow in a water-bearing bed as:

$$Q = PIA$$

The terms in the equation are:

Q = the quantity of water discharged per unit time
P = the coefficient of permeability
I = the hydraulic gradient
A = the cross-sectional area through which the water percolates

Darcy's law is valid only for the movement of ground water under laminar flow conditions. Jacob (1950) has shown that the law may not be valid for the flow

of water in unsaturated sands, or in extremely fine-grained sediments such as clays where molecular binding forces may operate on the flow system.

For convenience in solving field problems involving ground-water flow and movement, Darcy's law may be expressed as:

$$Q = TIL$$

Where:

Q = discharge, in gallons per day
T = coefficient of transmissibility in gallons per day per foot
I = the hydraulic gradient in feet per mile
L = the length, in feet, of the cross-section of the aquifer through which flow occurs.

Figure 7, an idealized block diagram, illustrates the general geologic and hydrologic conditions that exist throughout the western part of Charles County. The terms involving spatial parameters in the modified Darcy equation are labeled on the figure. The diagram shows the general area of intake of water into a single aquifer which might be penetrated by deep wells in the county. Figure 7 may be regarded as a model of an idealized aquifer system. In practice the real situation differs from the idealized model because overlying and underlying strata are not perfect confining layers and vertical leakage occurs into and out of the aquifers. Such leakage may be significant where the so-called confining layers consist largely of silt or clayey sand. In general however the intake areas of the aquifers are filled with water and movement through them occurs both down slope and laterally to supply a component of ground-water discharge of streams incising their intake areas. Better under-

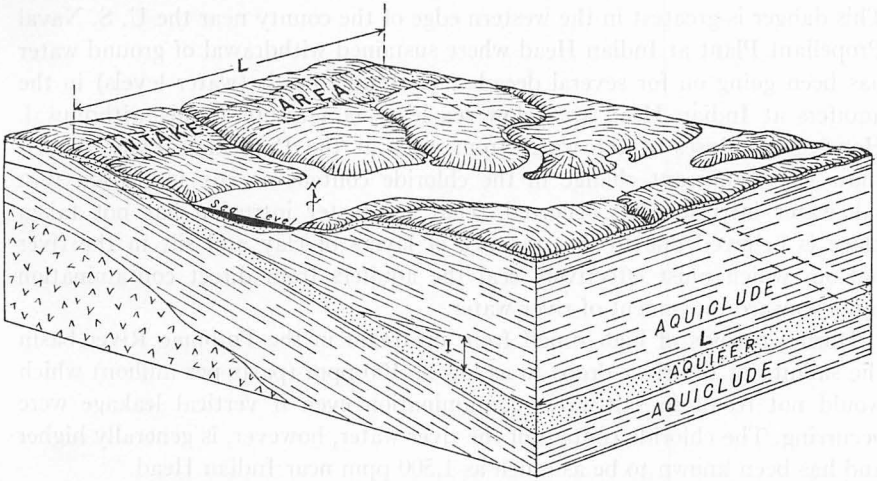


FIGURE 7. Idealized block diagram showing how an aquifer may function as a conduit to transmit water laterally from its area of intake.

standing of the movement of ground water in saturated materials can be had by the construction of piezometric maps, or maps showing the hydraulic head in an aquifer system.

SAFE YIELD

The "safe yield" of a ground-water reservoir was defined by Meinzer (1923, p. 55) as "the practicable rate of withdrawing water from an aquifer perennially for human use." Meinzer's original definition has been modified by others who state that the safe yield of an aquifer is generally considered as the quantity of water that can be withdrawn indefinitely without lowering the water levels to uneconomical limits and without impairing the quality of the water.

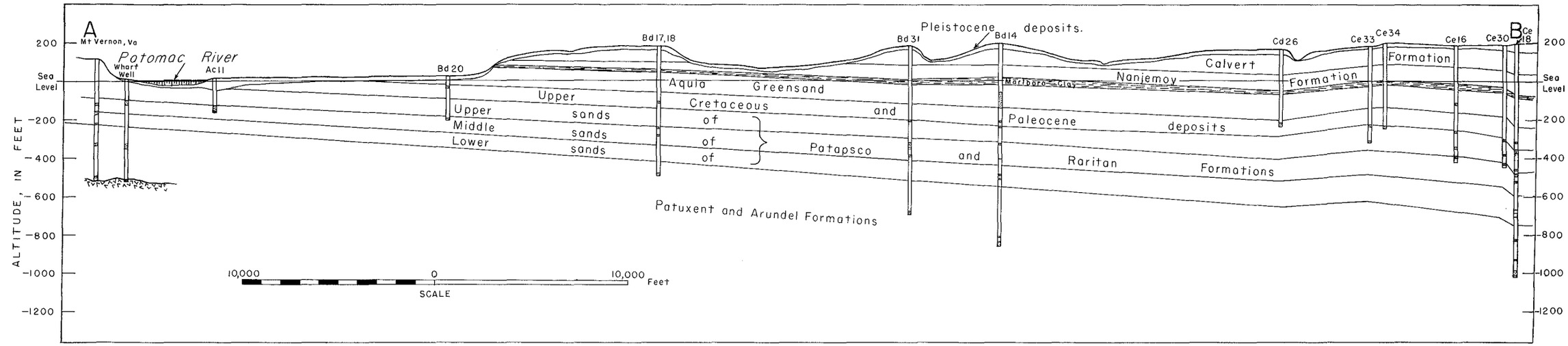
Because the concept of safe yield involves economic and human factors the term has come under criticism. In some instances it may be desirable or feasible to temporarily exceed the so-called safe yield of a ground-water reservoir, pending the development of an alternative source of supply. Nevertheless, the limiting factors determining the rates of withdrawal from a ground-water reservoir are the rates of recharge to it, the transmissibility of the aquifer and its susceptibility to contamination or pollution.

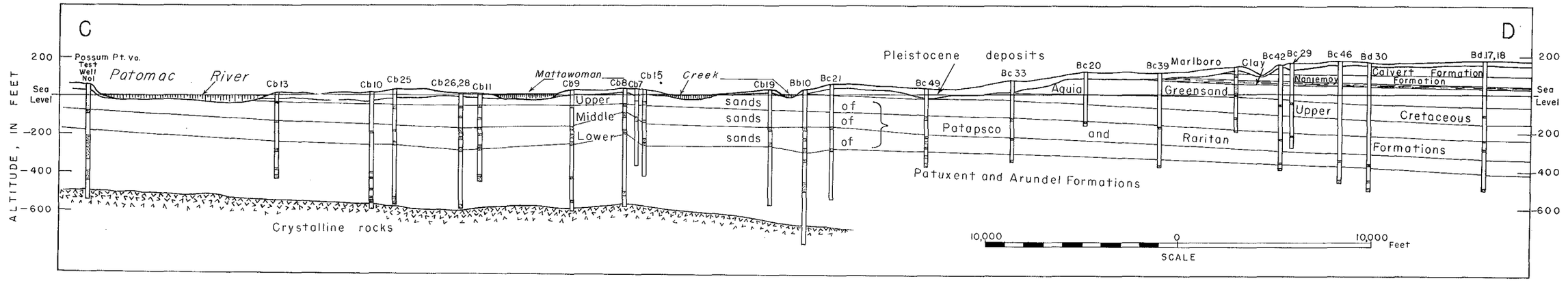
SALT-WATER INTRUSION

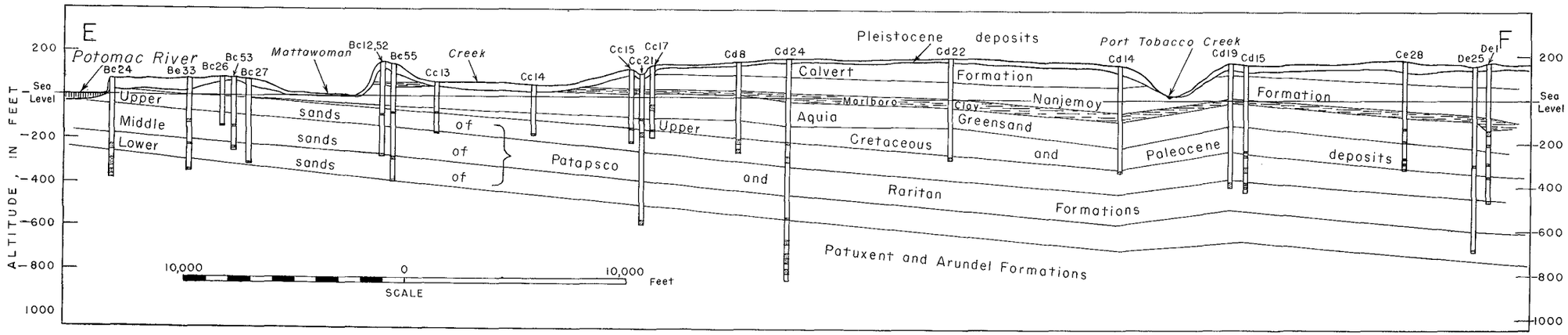
As far as is known all the water-bearing formations in Charles County contain fresh water. However, as the Potomac River, a tidal stream in the area, contains saline or brackish water the danger is ever present that excessive pumping of water from some of the aquifers extending beneath the Potomac could result in those aquifers becoming contaminated with brackish water. This danger is greatest in the western edge of the county near the U. S. Naval Propellant Plant at Indian Head where sustained withdrawal of ground water has been going on for several decades. Hydraulic heads (water levels) in the aquifers at Indian Head are below sea level as a result of this withdrawal. However, analyses of the water from wells at the Propellant Plant do not show any significant change in the chloride content or any indication that salt-water intrusion has occurred. That salt-water intrusion has not taken place is believed due to the presence of layers of clay and silt in the river bottom which must effectively seal the aquifers from direct contamination by downward movement of river water.

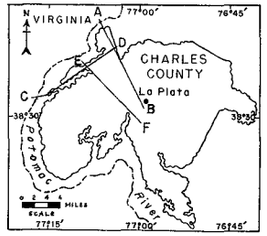
During periods of high runoff from upstream in the Potomac River basin the salinity of the river drops to as low as 100 ppm (parts per million) which would not result in salt-water contamination even if vertical leakage were occurring. The chloride content of the river water, however, is generally higher and has been known to be as much as 1,500 ppm near Indian Head.

One well at the Propellant Plant, located about 75 feet from the river bank, yielded water with a chloride content of 160 parts per million (ppm). This

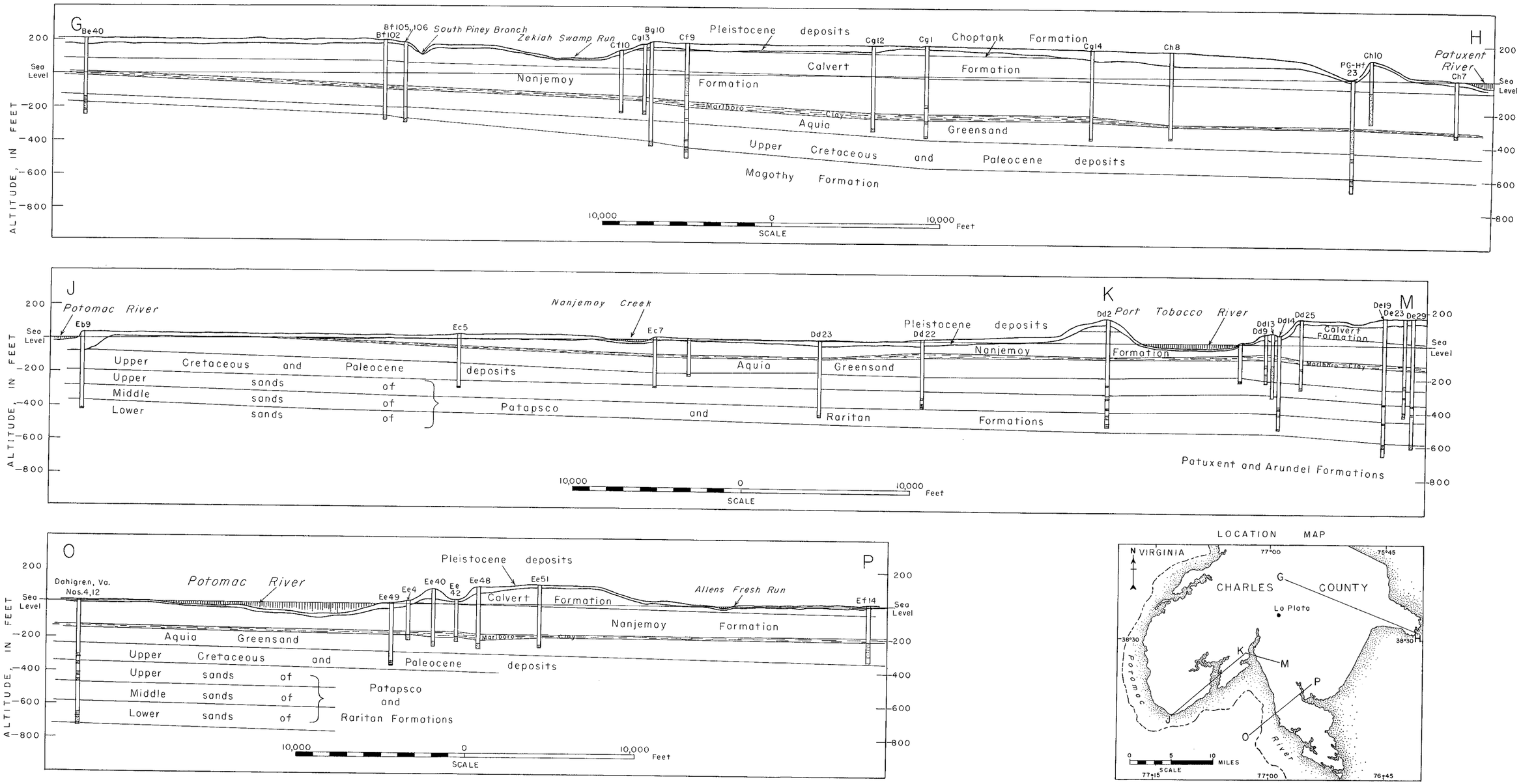








LOCATION MAP



9. Geologic sections G-H, J-K-M and O-P across Charles County.

well was screened in two sands, the uppermost of which is only about 45 feet below mean river level. The well is no longer (1963) in use.

In other tidewater sections of the county ground water levels indicate that the normal hydraulic gradients in the aquifers have not been reversed by pumping and the movement of ground water is toward the river. Ground water is thus discharging through the confining layers into the estuaries (the Potomac and its tributaries). In these areas the hydraulic head in the artesian aquifers has been sufficient to result in flowing fresh-water wells.

The water-bearing sands in the Patapsco and Raritan Formations are shown in figure 8 in approximate contact with the bed of the Potomac River east of Possum Point, Virginia.

Figure 9 shows three geologic sections across the southern and eastern sections of the county. Section J-K-M in the figure indicates that in the vicinity of the Port Tobacco River the Marlboro Clay Member of the Nanjemoy Formation may function as an effective confining layer to retard or prevent salt-water intrusion into the underlying Aquia Greensand and the deeper water-bearing formations.

In summary, it appears that the most likely mechanism which would result in salt-water intrusion into the fresh-water aquifers would be vertical leakage through corroded well casings in wells adjacent to estuaries. Movement of saline waters into the aquifers could occur where nearby pumping would reverse the normal hydraulic gradients in the aquifers. Proper sealing and plugging of leaking or abandoned wells would decrease the possibility of salt-water intrusion by this means.

AVAILABILITY OF GROUND WATER FROM GEOLOGIC UNITS

The major aquifers in Charles County are in the Patuxent, Patapsco, Raritan, and Magothy Formations of the Cretaceous System of rocks, the Aquia Greensand of the Eocene Series, and Pleistocene deposits.

In general, throughout the county all the major aquifers lying beneath the Pleistocene deposits are penetrated only by drilled wells. The surficial mantle of the deposits of Pleistocene age, however, are tapped by a number of dug or bored wells whose depths seldom exceed 40 feet. Most of these wells furnish only domestic water supplies. No large-capacity public-supply or commercial wells are known to have been constructed in the surficial deposits.

Geologic and geophysical logs of the strata penetrated by drilled wells show that water-bearing sands in the older and deeper formations are not continuous in their occurrence and distribution. This is true chiefly of sands in formations lying below the Magothy Formation.

At most localities in the county the aquifers are separated by layers of clay, silt, or silty sand with low permeability which function as confining layers.

In the preparation of maps showing the extent and position of the water-bearing formations it was not possible to accurately separate the Patuxent

and Arundel Formations and they are considered in this report as one unit, although in northern Prince Georges County the Arundel Clay has been mapped as a separate entity. It is considered to function as an aquiclude in areas where it can be recognized as a mappable unit.

For convenience in discussion the Patapsco and Raritan Formations are grouped together as one geologic unit, although three water-bearing horizons have been identified. These horizons have been designated as the lower, middle and upper zones. In some well logs one or two zones appear to be absent; this may be due to inaccurate logging or irregular distribution of the sands. It is believed that some degree of hydrologic connection exists between the equivalent zones in different localities.

PATUXENT AND ARUNDEL FORMATIONS

The Patuxent and Arundel Formations (undifferentiated) immediately overlie the crystalline rocks and contain the deepest aquifers in Charles County. The formations crop out west of the Potomac River in Virginia and extend northeast across Washington, D.C. to the Baltimore area. The section of the outcrop area pertinent to this report is about 30 miles long and 3 to 4 miles wide (fig. 10). In many places in Virginia the outcrop area lies beneath small tributaries of the Potomac River.

The Patuxent and Arundel Formations consist of clay, sandy clay, silt and sand; the sand layers contain gravel in places and in others mixtures of silt and fine sand. Otton (1955, p. 23) reported that in one well, at Indian Head, of a total thickness of 437 feet of strata penetrated, about 77 percent consisted of clay and related fine sediments. Logs of other wells at Indian Head indicate that the lithologic character of the unit varies horizontally and vertically within relatively short distances.

Contours drawn on the top of the Patuxent and Arundel Formations, based on a sea-level datum, are shown in figure 10. The geologic horizon used for control points on the figure is somewhat arbitrary, being designated as the top of the uppermost clay occurring immediately beneath the lowermost sand in the Patapsco Formation. This horizon may or may not be an exact equivalent to the top of the Arundel Clay as designated by earlier studies in northern Anne Arundel County and northeastern Prince Georges County. The top of the Patuxent and Arundel Formations as mapped dips to the southeast in Charles County at rates ranging from 30 to 50 feet per mile. The lesser rates of dip are in the central and eastern parts of the area.

Both the upper and lower surfaces of the combined formations are irregular. The basal surface is especially irregular due to pre-Cretaceous erosion of the surface of the underlying ancient crystalline rocks. In the Baltimore area, to the northeast, the buried erosion surface of the crystallines may locally have slopes as steep as 150 feet per mile. Thus, the thickness of the Patuxent and Arundel Formations as mapped may range widely within short distances.

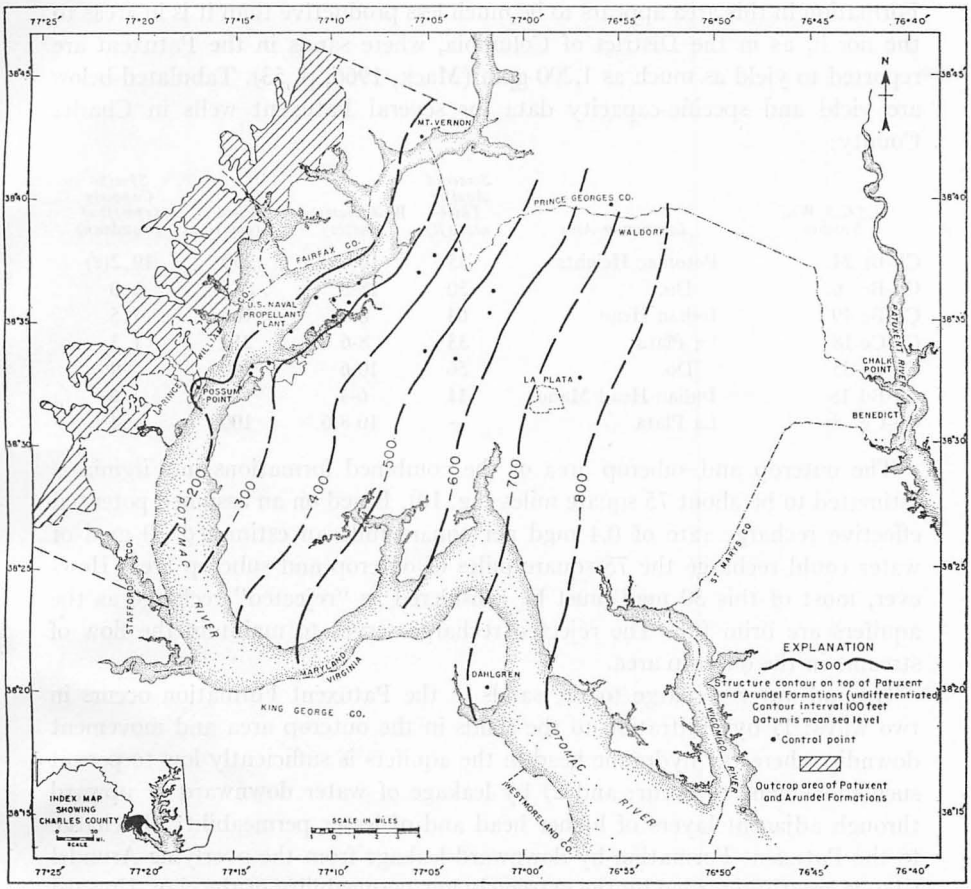


FIGURE 10. Map showing the outcrop area and altitude of the top of the Patuxent and Arundel Formations (undifferentiated).

Where data are available the thickness of the units ranges from 350 to 800 feet. The thickness is unknown east of La Plata.

YIELDS OF WELLS

The yields of wells screened in sands of the Patuxent Formation in Charles County range from less than 100 gpm to a maximum of 385 gpm. The most productive well, Ch-Bc 6, is at the town of Potomac Heights in the northwestern part of the county.

Specific capacities of wells range from less than 1.0 gpm per foot of drawdown to a questionable maximum of 19.2 gpm per foot. The average specific capacity of six of the most productive wells (exclusive of the anomalous value of 19.2) is approximately 1.8 gpm per foot of drawdown. In general, the Patuxent

Formation in this area appears to be much less productive than it is in areas to the north, as in the District of Columbia, where sands in the Patuxent are reported to yield as much as 1,200 gpm (Mack, 1966, p. 53). Tabulated below are yield and specific-capacity data for several Patuxent wells in Charles County:

U.S.G.S. Well Number	*Location or Area*	*Screened Aquifer Thickness (ft)*	*Well Diameter (inches)*	*Yield (gpm)*	*Specific Capacity (gpm/ft of Drawdown)*
Ch-Bc 24	Potomac Heights	35	10	250	19.2(?)
Ch-Bc 6	Do.	50	18-8	385	6.0
Ch-Bc 49	Indian Head	64	8	160	1.5
Ch-Ce 18	La Plata	33	8-6	210	1.3
Ch-Ce 35	Do.	56	10-6	240	.9
Ch-Bd 18	Indian Head Manor	11	6-4	63	.6
Ch-Ce 8	La Plata	—	10-8-6	100	.4

The outcrop and subcrop area of the combined formations in Virginia is estimated to be about 75 square miles (fig. 10). Based on an assumed potential effective recharge rate of 0.4 mgd per square mile an estimated 30 mgd of water could recharge the 75 square miles of outcrop and subcrop area. However, most of this 30 mgd must be considered as "rejected" recharge as the aquifers are brim full. The rejected recharge serves to maintain the flow of streams in the outcrop area.

Ground-water recharge to the sands in the Patuxent Formation occurs in two ways: 1) by infiltration to the sands in the outcrop area and movement downdip where the hydraulic head in the aquifers is sufficiently low to permit such movement to occur; and 2) by leakage of water downward or upward through adjacent layers of higher head and of lesser permeability. Recharge to the Patuxent Formation by downward leakage from the overlying Arundel Clay is greatly retarded by the extremely low permeability of the clay. Upward leakage from the crystalline bedrock is believed to be negligible because of the existence of a zone of buried saprolitic clay lying above the hard rock and the reported scarcity of fractures in the rocks where they lie deeply buried beneath Coastal Plain sediments.

CONDUIT FUNCTION OF THE AQUIFERS

Aquifer-test data obtained at Quantico, Va., and Potomac Heights, Md., show that the coefficients of transmissibility of the water-bearing sands in the Patuxent Formation range from 3,000 to 5,000 gpd per foot.

As is shown on figure 10 the undifferentiated Patuxent and Arundel Formations dip to the southeast beneath Charles County from their outcrop area in Virginia. It is assumed from well logs and cuttings that some degree of interconnection exists between individual sand layers. If this assumption is correct, then the sands may be considered to function as conduits capable of transmitting water downdip from their area of outcrop (or intake). As the quantity

of water moving through a given cross-section of the aquifer is proportional to the hydraulic gradient and the coefficient of transmissibility, the quantity of water capable of moving through the aquifer can be computed for any segment of it using the modified form of the Darcy equation $Q = TIL$ (see p. 19).

Based on differences in slope of the aquifers and on local variations in transmissibility, the Patuxent Formation has been divided into three segments across the county from north to south. The theoretical rates of flow through the segments are:

$Q = TIL$

Segment	*gpd/ft*		*ft/mile*		*miles*		*mgd*
A (northern):	$Q = 5,000$	×	43	×	10	=	2.1
B (central):	$Q = 5,000$	×	36	×	10	=	1.8
C (southern):	$Q = 3,000$	×	31	×	9	=	0.8
Total	Q					=	4.7

The above analysis, showing that a theoretical maximum flow of 4.7 mgd could occur through the sands in the Patuxent Formation across Charles County, is based on certain assumptions. These are: 1) The sands are hydraulically interconnected; 2) their transmissibility is relatively constant across any given segment of the aquifer; and 3) water levels in the deeper parts of the aquifer (eastern part of the county) can be lowered to a level sufficient to cause hydraulic gradients approximating those assumed in the analysis.

None of the three assumptions are completely fulfilled. Therefore, the quantity of 4.7 mgd which can be transmitted across a 29-mile wide strip of the aquifer is only an approximate theoretical limit. Lack of direct hydraulic connection of a deep-lying section of an aquifer with its area of outcrop would tend to isolate the deep aquifer from a source of recharge. This factor, plus the difficulty of lowering water levels in the aquifer to a position necessary to create the required hydraulic gradients, are both factors which tend to restrict the usefulness of the concept of an aquifer functioning as a conduit.

PATAPSCO AND RARITAN FORMATIONS

In Charles County the Patapsco and Raritan Formations have been grouped together as one geohydrologic unit because of the difficulties in readily separating them on the basis of their lithology as inferred from well logs. In many places in the area individual sands in the formations cannot be traced laterally for distances greater than a few miles, but study of logs across the county indicate that a regular sequence of position and thickness of the sands do exist. On this basis the sands have been arbitrarily designated as lower, middle and upper. Many wells in the area have been screened opposite two or more sands in the

Raritan and Patapsco; thus, the arbitrary classification of the sands serves a practical need in discussion of the hydrology of the formations.

As of the date of preparation of this report (1966) sands in the Patapsco and Raritan Formation constitute the major aquifer used in the county. Figure 6, showing the approximate area of outcrop and subcrop of the formations, indicates that they extend over about 140 square miles in both Virginia and Maryland. About 40 percent (56 square miles) of the outcrop area lies beneath the Potomac River and its tributaries. Much of the outcrop area underlying the river is covered by muds and silts of younger geologic origin.

Based on an assumed rate of potential ground-water recharge of 0.4 mgd per square mile the part of the outcrop area not covered by tidewater (84 square miles) is recharged by precipitation at an average rate of 34 mgd. Of course, that part of the outcrop area lying beneath the Potomac River is capable of receiving continuous recharge from the river to the extent that existing hydraulic gradients and the protective layer of silt and mud in the river bottom would permit such recharge to occur. However, except in the vicinity of the Naval Propellant Plant, where pumping has reversed the normal hydraulic gradients, the movement of water is from the aquifers into the Potomac River and its estuaries.

The Patapsco and Raritan Formations are believed to underlie all of Charles County but only a small part of their total thickness has been penetrated by wells in the eastern half of the county. Figures 11, 12, and 13 show the altitude, by means of contours.

The formations vary locally in color and texture. The strata are generally fine textured, consisting of mixtures of sand, silt and clay; the sands are commonly medium to fine grained. The clayey sediments are red brown to brown and the sands are tan, buff and gray. In the western part of the county the proportion of sandy material appears to be greater than in the eastern part.

The thickness of the formations ranges from about 200 feet in the western part of the county to 700 feet in the central part.

Figure 11 shows that the slope or dip of the top of the lower sands decreases from west to east across the county. South of La Plata the dip is about 25 feet per mile. The lower sands are the principal source of ground water in the Indian Head area and they probably are the greatest single source of ground water in the county.

Figure 12 shows some irregularities on the top of the middle sands, especially in the area between La Plata, Maryland, and Dahlgren, Virginia. A finger-shaped dome or "high" extends about 6 miles south of La Plata. This geologic structure, if correctly interpreted, probably has no significant effect on the hydrology of the aquifer, but does affect the depth to which wells must be

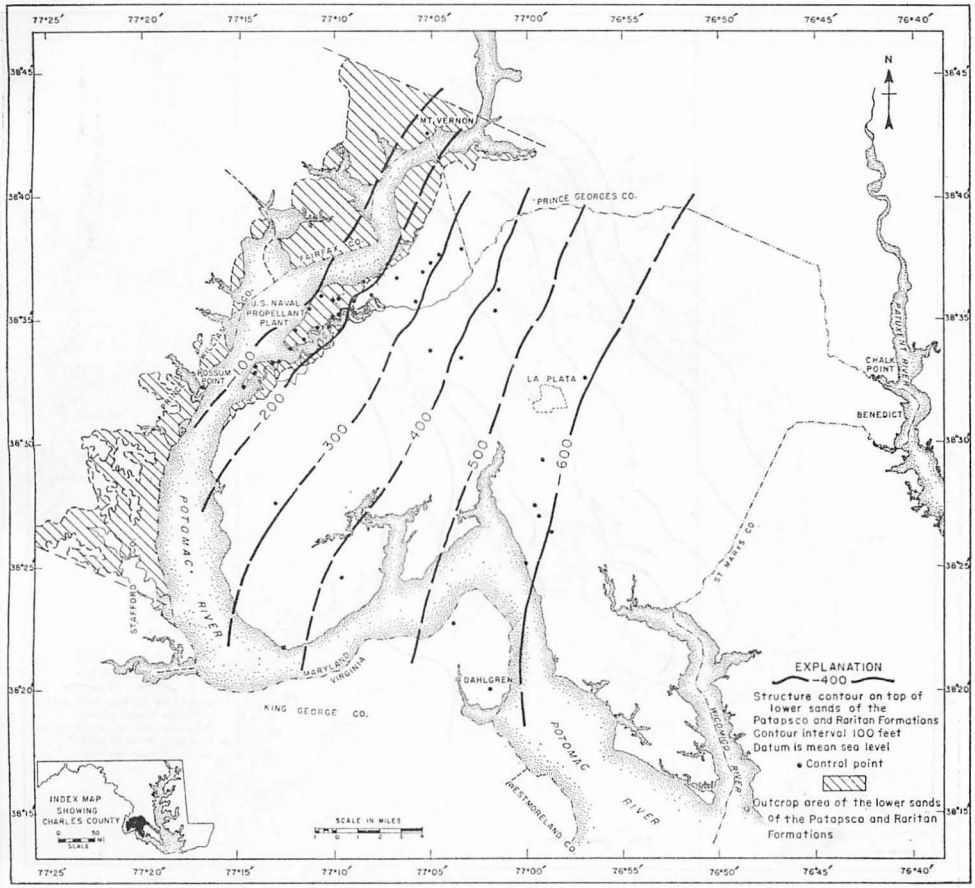


FIGURE 11. Map showing the outcrop area and altitude of the top of the lower sands in the Patapsco and Raritan Formations.

drilled to encounter it. The middle sands are tapped by several wells in the vicinity of Glymont, Indian Head Manor, Marshall Hall and in a few localities south of La Plata.

Figure 13 shows irregularities on the upper surface of the upper sands similar to those noted in figure 12. The upper sands have been tapped by wells mainly between Mason Springs and La Plata and near Bel Alton.

YIELDS OF WELLS

Yields of the most productive wells in the Patapsco and Raritan Formations range from 200 to about 560 gpm. The most productive well, Ch-Cb 8, is located at the Naval Propellant Plant along the west edge of the county; this

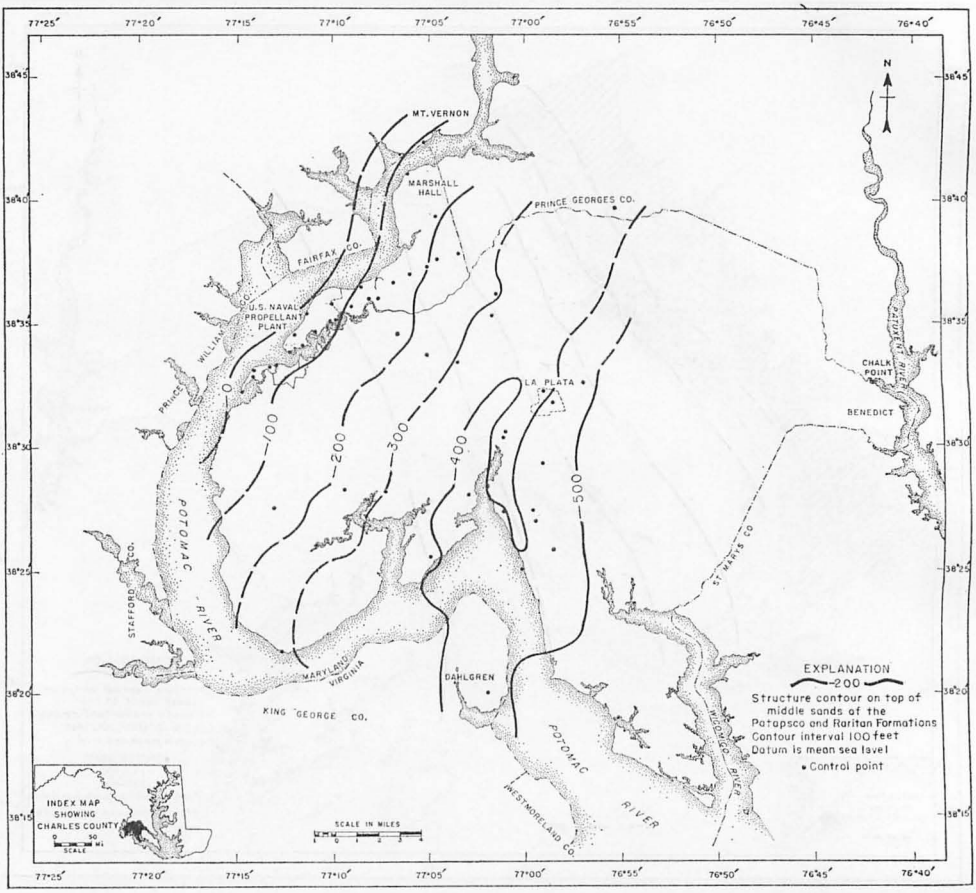


FIGURE 12. Map showing the altitude of the top of the middle sands of the Patapsco and Raritan Formations.

well had a specific capacity of 7.1 gpm per foot of drawdown when tested in 1953.

Well Va. 12, yielding 530 gpm from the Patapsco and Raritan Formations, was completed in 1962 at the Naval Proving Ground at Dahlgren, Va.; this well had a specific capacity of 3.3 gpm per foot of drawdown. It contains 56 feet of screen at a depth of 682 to 738 feet.

Wells Ch-Cb 8 and Va. 12 are the only wells in the area yielding more than 500 gpm from the Patapsco and Raritan Formations.

Specific capacities of nine of the most productive Patapsco and Raritan wells range from 2.2 to 7.1 gpm per foot of drawdown; the average specific capacity of the nine wells is 3.7 gpm per foot. The following tabulation lists the yield and specific capacity data for 10 of the most productive wells:

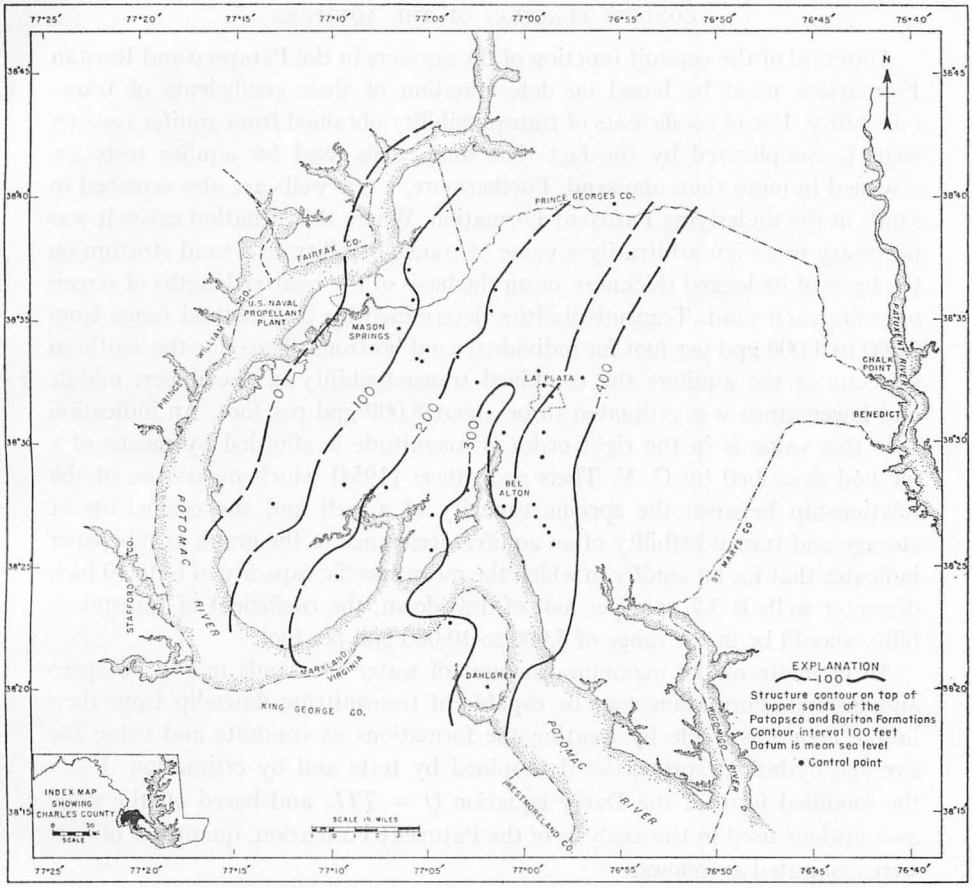


FIGURE 13. Map showing the altitude of the top of the upper sands of the Patapsco and Raritan Formations.

U.S.G.S. Well Number	*Location or Area*	*Screened Aquifer Thickness (ft)*	*Well Diameter (inches)*	*Yield (gpm)*	*Specific Capacity (gpm/ft of Drawdown)*
Ch-Cb 8	Naval Propellant Plant	34	12-10	559	7.1
Ch-Bb 12	Indian Head	29	10	220	4.0
Ch-Cb 19	Naval Propellant Plant	40	10-8	300	4.0
Ch-Bc 23	Do.	47	10-8	240	3.7
Ch-Cb 18	Do.	34	16-10	332	3.4
Va. 12	Dahlgren, Va.	56	10	530	3.3
Va. 10	Do.	66	10	370	2.7
Ch-Cb 7	Naval Propellant Plant	23	8	200	2.7
Ch-Cb 9	Do.	55	10-8	310	2.2
Ch-Bb 17	Do.	54	16-10	500	—

CONDUIT FUNCTION OF THE AQUIFERS

Appraisal of the conduit function of the aquifers in the Patapsco and Raritan Formations must be based on determination of their coefficients of transmissibility. Use of coefficients of transmissibility obtained from aquifer tests on wells is complicated by the fact that some wells used for aquifer tests are screened in more than one sand. Furthermore, a few wells are also screened in sands in the underlying Patuxent Formation. Where this situation exists it was necessary to assign arbitrarily a value of transmissibility to a sand stratum on the basis of its logged thickness, or on the basis of the relative lengths of screen opposite each sand. Transmissibilities determined by this method range from 2,000 to 4,000 gpd per foot for individual sand horizons. Thus, for the southern segment of the aquifers the combined transmissibility of the upper, middle and lower sands was estimated to be about 8,000 gpd per foot. An indication that this value is in the right order of magnitude is afforded by means of a method described by C. V. Theis and others (1954) which makes use of the relationship between the specific capacity of a well and the coefficients of storage and transmissibility of an aquifer. Reference to the graph in this paper indicates that for an aquifer in which the mean specific capacity of 6- to 10-inch diameter wells is 3.7 gpm per foot of drawdown, the coefficient of transmissibility should be in the range of 5,000 to 10,000 gpd per foot.

An estimate of the maximum amount of water the sands in the Patapsco and Raritan Formation may be capable of transmitting downdip from their intake area was made by treating the formations as conduits and using the average hydrologic properties determined by tests and by estimation. Using the modified form of the Darcy equation $Q = TIL$, and based on the same assumptions used in the analysis of the Patuxent Formation, quantities of flow were computed as follows:

$$Q = TIL$$

Segment	*gpd/ft*		*ft/mi*		*miles*		*mgd*	
A (northern part):	Q = 3,000	×	28	×	16	=	1.3	upper sand
	Q = 3,000	×	35	×	14	=	1.5	middle sand
B (southern part):	Q = 2,000	×	24	×	13	=	0.6	upper sand
	Q = 2,000	×	25	×	15	=	0.7	middle sand
	Q = 4,000	×	29	×	18	=	2.1	lower sand
Total	Q					=	6.2	

From the calculations above it appears that about 6 mgd of water could be transmitted downdip through a 30-mile wide strip of the aquifers in Charles County. It is doubtful if the hydraulic gradients required to conduct this quantity of water could be created by pumping wells, but nevertheless, the estimate of the quantity of 6 mgd affords a rough idea of the possible upper limit of transmission of water across the county through these aquifers.

MAGOTHY FORMATION

The Magothy Formation appears to be present only in the northeastern part of Charles County, although it is found in other areas to the north and east. Its approximate western and southern boundary is shown by a broken line in figure 14. The Magothy is used as an aquifer principally along U. S. 301 from White Plains northward to the county boundary where it supplies water to motels and other commercial establishments. Eastward from U. S. 301 it has not been commonly used as farm and domestic water needs have been met by wells tapping shallower aquifers. It is tapped by wells at the Potomac Electric Power Company (PEPCO) plant at Chalk Point in Prince Georges County a few miles north of the town of Benedict.

The Magothy Formation does not crop out at the surface in Charles County.

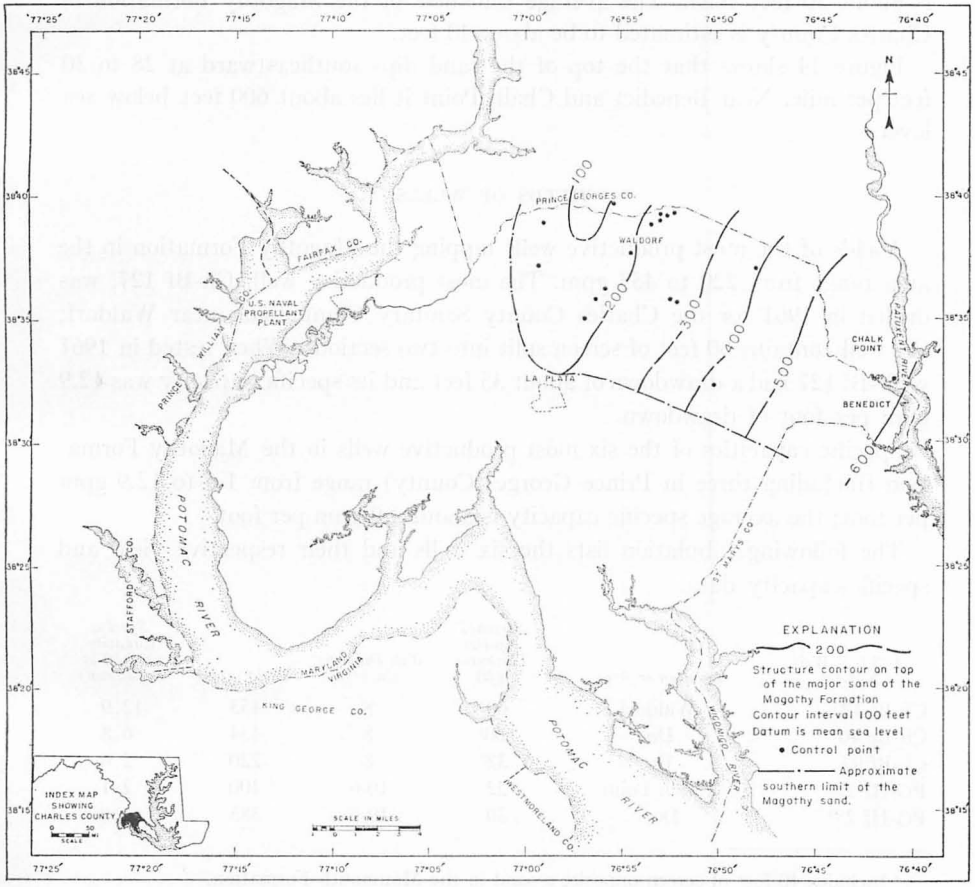


FIGURE 14. Map showing the altitude of the top of the major sand in the Magothy Formation and the approximate limit of its extent.

Its nearest area of exposure is about 3 miles southwest of Anacostia in the District of Columbia (Darton, 1951).

Lithologically, the Magothy Formation as found in the area of this report consists of medium to coarse-grained sand with some associated silty clay. The sand ranges in color from light gray to blue or pink. Some dark minerals (possibly hornblende and magnetite) and lignitic material give the sand a salt and pepper appearance. Logs of a few wells along U. S. 301 north of Waldorf show that a second water-bearing sand overlies the Magothy Formation separated from the Magothy sand by a layer of dark clay. This overlying sand may be part of the Matawan Formation. The intervening clay layer may thin or disappear in places as aquifer tests at some localities show that the two sands are hydrologically connected. Just north of Waldorf the sand in the Magothy Formation is about 70 feet thick, but it thins eastward and at Chalk Point it is about 30 feet thick. The average thickness of the Magothy Formation in Charles County is estimated to be about 40 feet.

Figure 14 shows that the top of the sand dips southeastward at 28 to 30 feet per mile. Near Benedict and Chalk Point it lies about 600 feet below sea level.

YIELDS OF WELLS

Yields of the most productive wells tapping the Magothy Formation in the area range from 220 to 453 gpm. The most productive well, Ch-Bf 127, was drilled in 1961 for the Charles County Sanitary Commission near Waldorf; the well contains 60 feet of screen split into two sections. When tested in 1961 well -Bf 127 had a drawdown of about 35 feet and its specific capacity was 12.9 gpm per foot of drawdown.

Specific capacities of the six most productive wells in the Magothy Formation (including three in Prince Georges County) range from 1.6 to 12.9 gpm per foot; the average specific capacity is about 4.9 gpm per foot.

The following tabulation lists the six wells and their respective yield and specific-capacity data:

U.S.G.S. Well Number	*Location or Area*	*Screened Aquifer Thickness (ft)*	*Well Diameter (inches)*	*Yield (gpm)*	*Specific Capacity (gpm/ft of Drawdown)*
Ch-Bf 127	Waldorf	60	8	453	12.9
Ch-Be 40	Do.	60[1]	8	434	6.8
Ch-Bf 97	Do.	32[2]	8	220	2.6
PG-Hf 27[3]	Chalk Point	22	10-6	400	2.1
PG-Hf 28[3]	Do.	30	10-6	385	1.6

[1] Includes 40 feet of screen opposite a sand in the Monmouth Formation.

[2] Includes 7 feet of screen opposite a sand in the Monmouth Formation.

[3] Data from Mack (1966, p. 74)

CONDUIT FUNCTION OF THE AQUIFER

Determination of the coefficients of transmissibility and permeability provide a means of evaluating the function of the Magothy Formation as a ground-water conduit. Aquifer tests, analyzed by means of the Theis equation, show a range in the coefficients of transmissibility and permeability as follows:

Locality	T (*gpd/ft*)	P_f (*gpd/ft*^{2})
Waldorf (north)	16,000	228
Waldorf (south)	11,000	275
Chalk Point	6,000	183
Average	11,000	229
Weighted average	10,000	208

The coefficients of transmissibility (T) determined for the Magothy Formation in Charles County are well below the range of 23,000 to 79,000 reported for the aquifer in the Annapolis area (Otton, 1955, p. 65). The higher transmissibilities in the Annapolis area are due in part to the greater thickness of the sands, which are about 90 feet thick.

The principal water-bearing sand in the Magothy Formation is overlain and underlain by silts and clays which serve as confining layers, although some vertical leakage of water must occur through these materials. For purposes of simplification the leakage may be neglected and the aquifer considered to function as a conduit capable of transmitting water downdip from its area of maximum altitude north of La Plata. The theoretical rate of flow across a 9-mile wide section of the aquifer, based on the modified Darcy equation, would be about 2.5 mgd:

$$Q = TIL$$

gpd/ft.	*ft/mi*	*miles*		*mgd*
$Q = 10{,}000$	28	9	=	2.5

Inasmuch as the formation does not have a surface outcrop area in the updip direction in Charles County it could only function as a conduit if the rate of recharge to it by vertical leakage in its subcrop area were sufficient to permit water to replenish that transmitted downdip. Thus, it is improbable that the aquifer could function as a simple conduit across Charles County. It is likely the recharge to it must come from areas of surface outcrop in Prince Georges County to the north and therefore some water removed from the aquifer in Charles County would be derived from beyond the limits of the county.

AQUIA GREENSAND

The Aquia Greensand (of Eocene age) underlies nearly all of Charles County except at the Naval Propellant Plant and in the vicinity of Marshall Hall in the extreme northwestern part of the county. The Aquia is an extensive geologic unit in Prince George and Westmoreland Counties, Va., and in Prince Georges,

Calvert, and St. Marys Counties, Md. Although the formation underlies nearly all of Charles County it does not yield ground water everywhere. It yields water to farm and domestic wells along both shores of the Port Tobacco River and generally eastward from this locality. It is tapped by many wells at Cobb Island and by some wells at Benedict and Malcolm. It has not generally yielded water to wells west of the valley of the Port Tobacco River or west of La Plata and Waldorf.

Figure 15 shows that the Aquia has an extensive subcrop area along the western edge of the county. The subcrop belt ranges in width from less than 1 mile to 3.5 miles. Along much of the belt it is overlain by deposits of Miocene and Pleistocene age. The Aquia is recharged chiefly by infiltration through the overlying deposits except where it crops out in irregular patches along the Virginia side of the Potomac River.

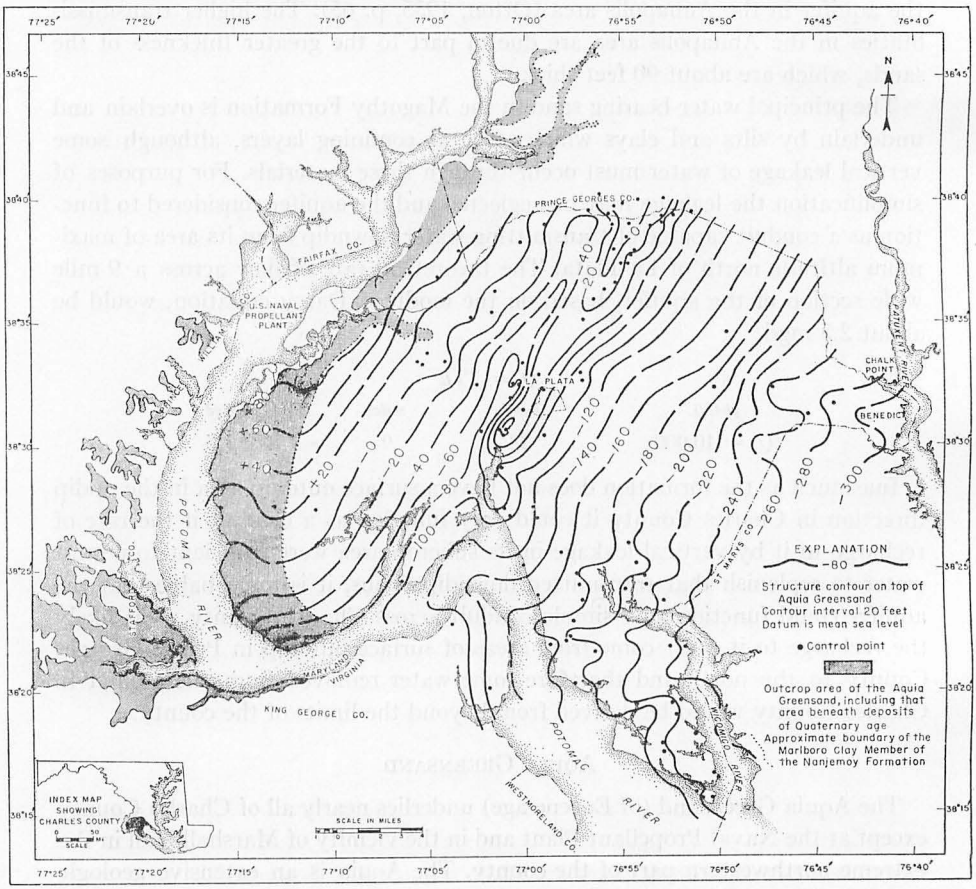


FIGURE 15. Map showing the outcrop area and altitude of the top of the Aquia Greensand.

The formation consists of glauconitic medium to fine-grained sand with some interbedded layers of sandy or silty clay. Its color is greenish to dark gray; it is fossiliferous in places and semi-indurated locally where shell layers are present. Individual water-bearing sands are scarce in the western part of the county and where present are usually less than 10 feet thick. In much of the western half of the county the formation is a poor aquifer.

The thickness of the Aquia Greensand in the area of this report ranges from 80 to 150 feet and averages about 110 feet. Its area of maximum thickness is north of Waldorf near the Prince Georges County boundary. At Chalk Point it is about 135 feet thick, and in the southeastern corner of the county it is about 100 feet thick.

Figure 15 shows that the upper surface of the greensand forms a central ridge, or anticline which extends both northward and southward from La Plata. This ridge may mark the approximate western limit of the area where the formation yields water freely to wells. East of the ridge the top of the greensand slopes at a rate of 18 to 20 feet per mile.

The Aquia Greensand is overlain by the Marlboro Clay Member of the Nanjemoy Formation which functions hydrologically as a confining layer creating artesian conditions in the eastern part of the area. The Aquia is underlain by the Brightseat Formation, which functions chiefly as an aquiclude.

YIELDS OF WELLS

Many small-diameter domestic wells tapping the Aquia Greensand penetrate only a small fraction of the total thickness of the formation. For this reason, they provide little information concerning the maximum yield of this formation.

Yields of the most productive wells range from 25 to 200 gpm. The best Aquia well in the county (Ch-Ef 14) is a 6-inch diameter irrigation well drilled near Newport for W. W. Bowling, Jr. The yield of this well provides a measure of the potential of the aquifer, at least in the Newport area. Many of the other Aquia wells yield less than 100 gpm because of their small diameter and the relatively short length of screen used. The following tabulation provides data on seven of the most productive wells in the county:

U.S.G.S. Well Number	*Location or Area*	*Screened Aquifer Thickness (ft)*	*Well Diameter (inches)*	*Yield (gpm)*	*Specific Capacity (gpm ft of Drawdown)*
Ch-Ef 14	Newport	33	6	200	—
Ch-Ee 52	Newburg	12	6	60	1.6
Ch-Ee 48	Do.	10	4	45	1.3
Ch-Ee 51	Do.	15	2½	25	1.2
Ch-Cg 13	Bryantown	15	6	60	.7
Ch-Ch 7	Benedict	15	4	40	.7
Ch-Cg 14	Hughesville	10	6	50	.6

CONDUIT FUNCTION OF THE AQUIFER

Data concerning the coefficients of transmissibility and permeability and information regarding the existing and possible hydraulic gradients are im-

portant in evaluating the function of the aquifer to transmit water. A piezometric map provides data concerning the direction of flow of water through an aquifer. Maps of this type are compiled from measured or reported water levels in wells tapping the aquifer.

Figure 16 is a piezometric map showing the altitude of water levels in the Aquia in the eastern part of the county. As the movement of ground water is normal to the direction of the contour lines it can be concluded from figure 16 that the water in the aquifer is moving to the south and east from the north-central part of the county. The hydraulic head in the greensand ranges from 4 to 22 feet above sea level along the north bank of the Potomac River southeastward from Port Tobacco. Most wells in this area flow freely when completed. One such well is located under the U. S. 301 bridge at Morgantown, and the water was reportedly used in the construction of the bridge.

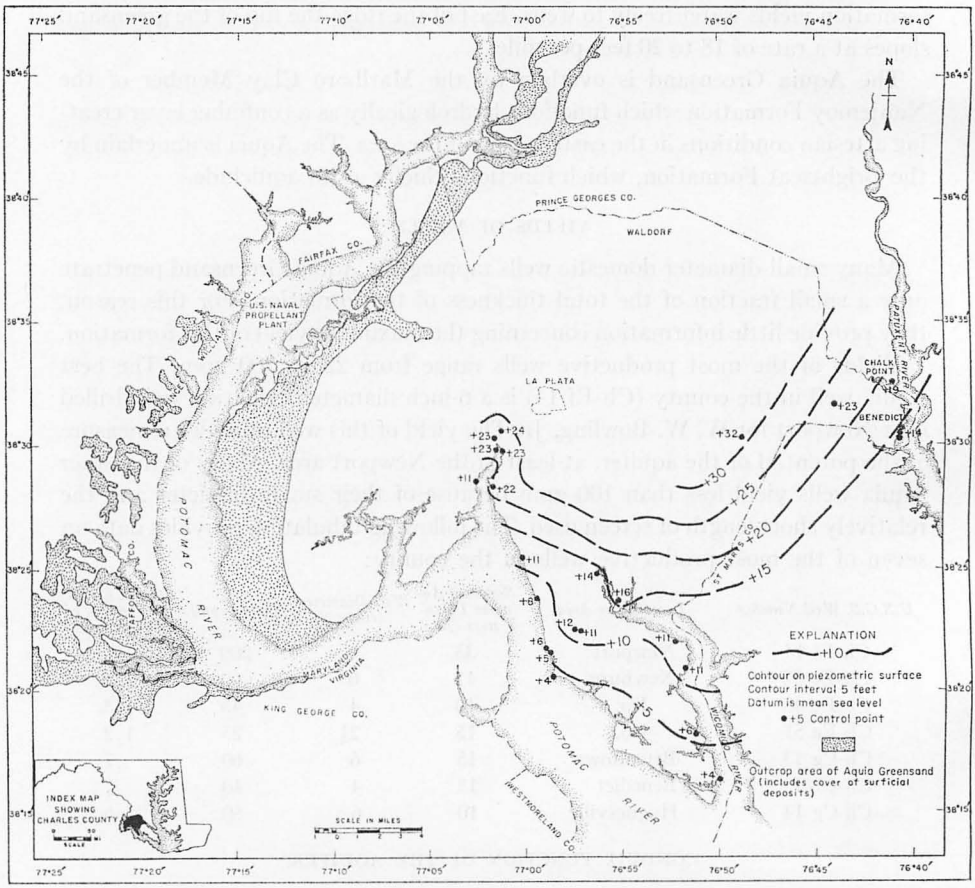


FIGURE 16. Map of the piezometric surface in the Aquia Greensand.

Based on the concept of the Aquia Greensand functioning as a conduit transmitting water downdip from near its intake area, the theoretical maximum rate of flow across a 22-mile wide section of the aquifer is about 1.6 mgd. The computations, based on the modified Darcy equation are:

$$Q = TIL$$

$$Q = \underset{gpd/ft}{5{,}000} \times \underset{ft/mi}{15} \times \underset{miles}{22} = \underset{mgd}{1.6}$$

The value of T used above is based on an aquifer test on irrigation well Ch-Ef 14 near Newport. Mack (1966, p. 46) reports that the transmissibility of the Aquia at Chalk Point is about 4,000 gpd/ft. Thus, his reported value of transmissibility is in the same range as the Newport value.

The idealized assumptions used in computing the quantity of 1.6 mgd which could be transmitted downdip through the aquifer are probably unrealistic, chiefly because of the difficulty in creating the required hydraulic gradient, and because some vertical leakage probably takes place from the overlying and underlying strata.

On the Virginia side of the Potomac River the Aquia Greensand may not be an aquifer. Geologic samples from a well drilled at Dahlgren, Va., show the formation to consist of silt, clay and fine sand.

NANJEMOY FORMATION

The Nanjemoy Formation (of Eocene age) overlies the Aquia Greensand, but in Charles County it does not appear to be an aquifer, although it yields water to many wells in adjacent counties to the south and east.

In Charles County the Nanjemoy consists of glauconitic sandy clay and silt. The base of the formation contains a distinctive clay member (Marlboro Clay) which is commonly red or brown in color. The Nanjemoy in this area is believed to function chiefly as an aquiclude, although wells tapping it in southern St. Marys County have yielded as much as 60 gpm (Otton, 1955, p. 84).

DEPOSITS OF PLIOCENE(?) AND PLEISTOCENE AGE

Deposits of gravel, sand, silt, and clay veneer nearly all the surface of Charles County. These materials (of Pliocene and Pleistocene age) average about 30 feet in thickness and were deposited on older strata of Tertiary and Cretaceous age.

These younger deposits have been arbitrarily divided into an upland and a lowland unit (Bennett and Meyer, 1952, p. 68 and Otton, 1955, p. 99–106). Upland deposits are here considered to be those lying higher than 40 feet above present sea level; lowland deposits are those lying below 40 feet and extending beneath the estuaries to depths of more than 100 feet below sea level. The lowland deposits contain beds of silt and clay of estuarine origin with distinctive Quaternary age fossils.

The upland deposits have been divided into two members, a lower reddish

orange silty sand and gravel, 10 to 50 feet thick, and an upper gravelly loam, as much as 25 feet thick, yellowish orange to yellowish brown in color.

The average thickness of the upland deposits is about 27 feet and only about 10 to 15 feet of this thickness commonly lies below the zone of saturation. Where the Pleistocene deposits have been sharply dissected by recent streams, drainage is relatively rapid and in these locales they do not constitute a usable aquifer as they are saturated only during infrequent periods of abundant ground-water recharge. However, where undissected, the Pleistocene deposits constitute an aquifer of limited importance. Their usefulness as a major source of water supply depends on their transmissibility and on their effective storage capacity, or specific yield. Specific yield under water-table conditions is approximately equivalent to the coefficient of storage.

As the deposits of Pliocene(?) and Pleistocene age are an important source of ground water for shallow farm and domestic wells in northern Charles County, 19 test holes were augered to determine the character of the aquifer. The auger holes averaged 43 feet deep and the deposits average about 27 feet in thickness. The maximum thicknesses occur primarily at altitudes above 80 feet.

Test holes drilled along Port Tobacco Creek, Zekiah Swamp Run, and Gilbert Swamp Run indicate that in these valleys Recent alluvium overlies deposits of Miocene or Eocene age. The absence of shallow permeable water-bearing sands and gravels in these stream valleys emphasizes the dependence on the deeper artesian aquifers as a source of ground water in the valleys. The test augering showed that the most favorable locality for the development of ground-water supplies from the surficial deposits is in the flat upland near Waldorf and White Plains.

Four test holes augered along the Potomac River between Maryland Point and Windmill Point show that the fine sand and clayey silt found in these localities to a depth of 15 feet do not constitute an aquifer.

YIELDS OF WELLS

Based on reported well yields, the lowland deposits appear to be the most productive of the materials of Pliocene(?) and Pleistocene age. A large-diameter collector-type well (-Ac 3) installed for the Navy Department near Marshall Hall reportedly yielded 250 gpm in 1942. This well was 68 feet deep and its caisson had a diameter of about 10 feet. The well penetrated about 58 feet of saturated material of relatively low permeability.

The yields of dug and bored wells tapping the upland deposits in the north central part of the county range from 1.5 to 15 gpm (gallons per minute), but only a few of the wells have been tested to determine their capacity. Furthermore, most of the dug wells are lined with concrete rings to their bottoms, and little or no water enters the well from the sides as well screens are not ordinarily used. Possibly if large-diameter well screens were used, the yields of individual wells could be increased.

CONDUIT FUNCTION OF THE AQUIFER

Because the deposits of Pliocene(?) and Pleistocene age form the surficial mantle throughout much of Charles County and as they are dissected by numerous streams, their hydrologic function as conduits is largely limited to transmitting stored ground water to maintain the flow of streams, and to recharge the underlying deposits of Miocene age through downward vertical leakage. However, locally, as in the Waldorf area where they are undissected throughout an area of several square miles, the permeability and thickness of the deposits is important in determining the rates at which shallow wells may supply ground water.

Relatively few data are available concerning the coefficients of transmissibility and storage of the Pleistocene deposits, but the few aquifer tests that have been made indicate that their coefficient of transmissibility is less than 500 gpd per ft. An aquifer test conducted on dug well (-Bf 129) at a laundry in Waldorf showed a coefficient of transmissibility ranging from 165 to 320 gpd/ft. A suggestion that such low values of transmissibility for the Pleistocene deposits may be prevalent throughout much of Charles County was obtained by use of a method of computing the transmissibility described by Ferris and others (1962, p. 131). This method, based on assumed steady-state hydrologic conditions, involves merely the measurement of water levels in a water-table aquifer and relating these data to the base flow of a nearby stream. The formula used is:

$$T = 0.0017W\left(\frac{ax}{h_0} - \frac{x^2}{2h_0}\right)$$

where:

T = coefficient of transmissibility, in gpd/ft

W = average rate of ground-water accretion, in inches per year (W may be estimated from the base flow of a nearby stream)

a = distance from the stream to the ground-water divide, in feet

x = distance from the stream to the observation well, in feet

h_o = mean elevation of the water table above mean stream level, in feet

Using this formula and applying it to three dug wells in the Piney Branch (south) basin, computed values of transmissibility are 150, 160, and 180 gpd/ft. These results show rather close agreement with the aquifer test data from wells at Waldorf.

HYDROLOGIC BUDGET FOR TWO SMALL DRAINAGE BASINS

In order to determine, at least approximately, the hydrologic coefficients and to establish a hydrologic budget for the deposits of Pliocene(?) and Pleistocene age two small stream basins draining only these deposits were studied using streamflow, water-level and precipitation data for them.

The basins selected for study and their location are shown on the bottom of

figure 17. By coincidence both streams used in the study are named Piney Branch. The northern of the two streams drains northwestward into Mattawoman Creek and the southern stream drains southeastward into Zekiah Swamp Run. Pertinent elements of the drainage basin analyses are listed below:

Piney Branch basin (north)

Drainage area: 5.7 square miles
Period of streamflow measurement: 12/21/60 to 9/17/62
No. of observation wells and period of measurement: 6 wells—1/61 to 9/62
Precipitation records used: Weather Bureau station at Waldorf Police Barrack

Piney Branch basin (south)

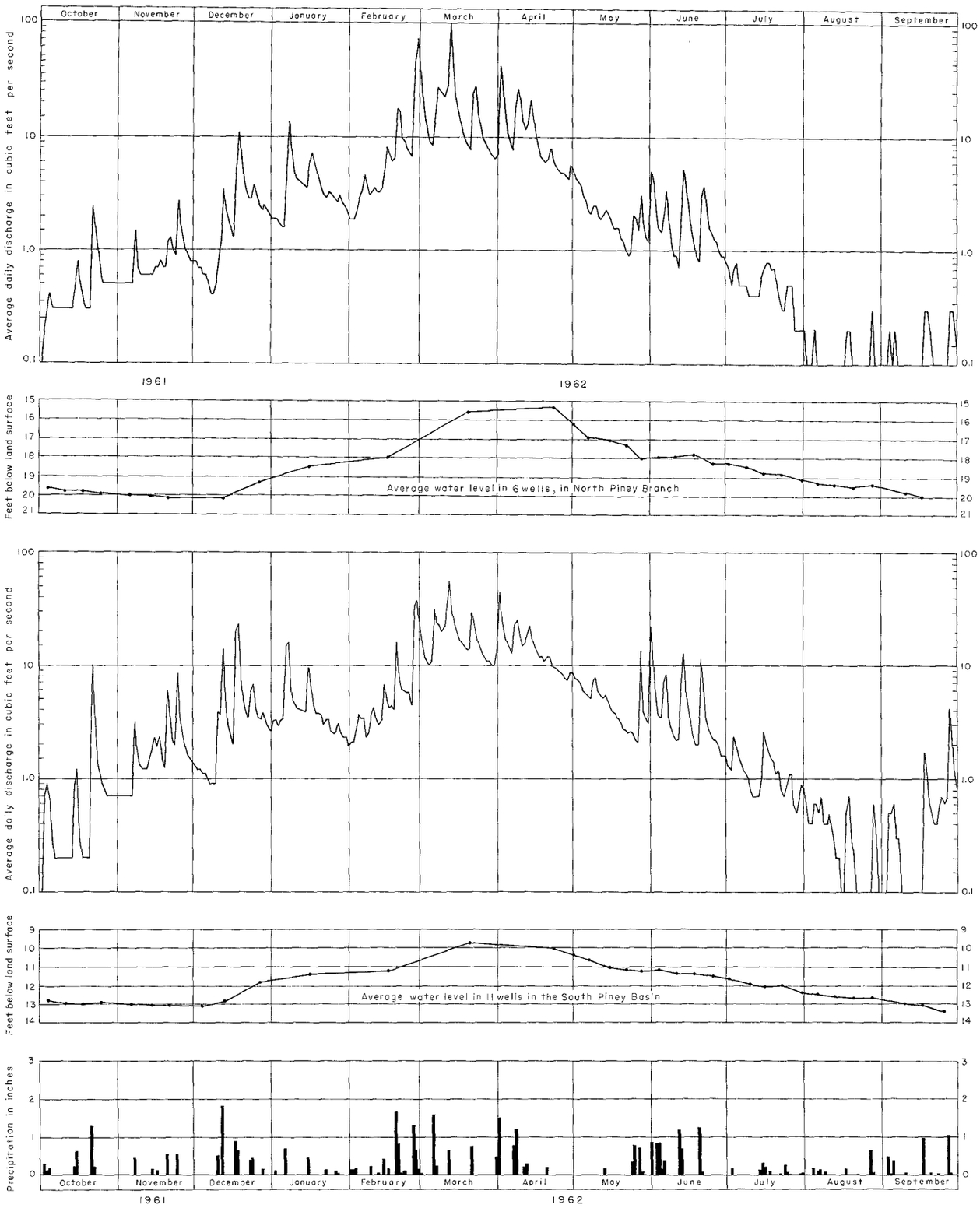
Drainage area: 6.7 square miles
Period of streamflow measurement: 12/6/60 to 12/2/62
No. of observation wells and period of measurement: 11 wells— 1/61 to 11/62
Precipitation records used: Weather Bureau station at Waldorf Police Barrack

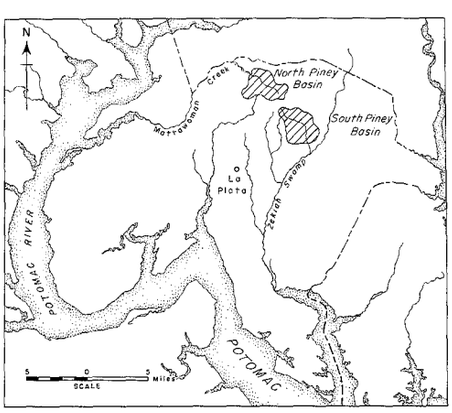
The hydrologic cycle may be expressed quantitatively by a budget equation, which is an accounting of the water gains and losses in an area (usually a drainage basin) for a selected period of time. The budget equation is:

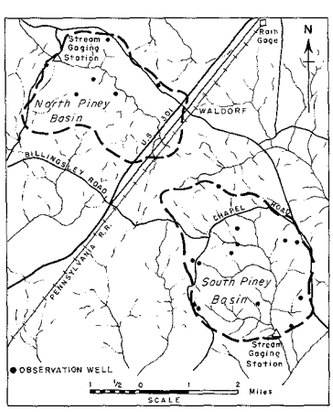
$$P = R + ET + \Delta S$$

For the Piney Branch basins (north and south) the terms P, R, and ΔS were measured and the ET was estimated. The methods and equations used to solve the hydrologic equation were similar to those used by Rasmussen and Andreasen (1959) to solve the hydrologic equation for the Beaverdam Creek basin in Wicomico County, Md. The results of the hydrologic budget determination for the three basins are shown in table 3. The values in the table show that the Piney Branch basins have a slightly lower proportion of total runoff and a higher proportion of total evapotranspiration than given for the Beaverdam Creek basin. The most significant difference in the comparative figures for the three basins is the substantially higher rate of ground-water recharge (51 percent) for Beaverdam Creek compared with the lower rate for the Piney Branch basins (about 30 percent). It is believed that this difference can be explained partly by the existence of highly permeable sands and gravels underlying Beaverdam Creek, by the difference in soil types, and by differences in topographic relief between the respective areas.

Based on an average rate of ground-water recharge of 30 percent (see table 3), about 13.8 inches of the 46 inches of precipitation falling on Charles County becomes ground-water recharge. This quantity amounts to about 660,000 gpd per square mile. Some of this water, about 12 percent of the 46 inches of pre-







17. Graphs showing precipitation, water levels, and stream discharge of Piney Branch basin (north) and Piney Branch basin (south), October 1961 to 1962.

TABLE 3

COMPARISON OF THE HYDROLOGIC BUDGETS, IN PERCENTAGE OF PRECIPITATION, OF THE PINEY BRANCH BASINS (NORTH AND SOUTH) AND BEAVERDAM CREEK BASIN

	Piney Branch (North)	Piney Branch (South)	Beaverdam Creek[a]
Total runoff	29.4	28.0	36.1
Total evapotranspiration	66.1	67.3	60.7
Basin storage	4.5	4.7	3.2
Total budget	100.0	100.0	100.0
Ground-water runoff (drainage)	16.0	17.0	25.9
Ground-water evapotranspiration	12.0	11.0	23.5
Ground-water storage (change)	1.9	2.2	2.1
Ground-water recharge (infiltration)	29.9	29.2	51.5
Percent of total runoff sustained by ground-water flow	54	61	72

[a] From Rasmussen and Andreasen (1959, p. 98).

cipitation, is returned to the atmosphere as ground-water evapotranspiration. This quantity amounts to about 260,000 gpd per square mile. Thus, subtracting 260,000 gallons from 660,000 gallons leaves about 400,000 gpd per square mile, on the average, for that part of the ground-water recharge which is available to sustain the flow of streams during dry weather periods or to replenish that withdrawn by means of pumping wells.

In order to obtain an approximate value of the water-table storage coefficient, or the *gravity yield*, of the deposits of Pliocene(?) and Pleistocene age the water level declines in several observation wells in the basins were averaged and compared with base flow of the streams during selected periods of no ground-water recharge. The method will give values of gravity yield somewhat below the probable true value as it fails to account for loss of ground water from the aquifer by means of evapotranspiration. Nevertheless, the analysis of the data gives a value for the storage coefficient of the deposits which appear to be in the right order of magnitude. The data are:

Piney Branch basin (north)
(period April–September 1962)

Base flow (cu ft/sec)	332
Base flow (inches/day/sq mi)	0.013
Base flow (gal/day/sq mi)	226,000
Coefficient of storage or gravity yield (in percent)	2

Piney Branch basin (south)
(period April–September 1962)

Base flow (cu ft/sec)	555
Base flow (inches/day/sq mi)	0.017
Base flow (gal/day/sq mi)	295,000
Coefficient of storage or gravity yield (in percent)	6

Table 4 summarizes the streamflow measurements during six selected periods of time when ground-water declines and base stream flow could be used to compute the approximate storage coefficient of the aquifer. The reason for the difference in the storage coefficients obtained from comparable data for the two small drainage basins is not readily apparent, but must be due chiefly to the more permeable nature of the sediments in the south basin in comparison with those of the north basin. Rasmussen and Andreasen (1959, p. 91) determined that the gravity yield of the sediments underlying the Beaverdam Creek basin was 11 percent.

TABLE 4

SUMMARY OF STREAM DISCHARGE AND DECLINE OF GROUND-WATER LEVELS FOR PERIODS OF BASE FLOW AND THE COMPUTED COEFFICIENTS OF STORAGE FOR THE DEPOSITS IN THE PINEY BRANCH BASINS

	Period of Measurement						
	Aug. 7–14, 1961	April 23–May 7, 1962	May 15–22, 1962	June 25–July 2, 1962	July 2–9, 1962	Aug. 6–13, 1962	Average April–Aug. 1962
Piney Branch basin (north), 6 observation wells							
Stream discharge (inches of water)	0.024	0.40	0.063	0.042	0.027	0.0049	—
Decline in ground-water level (inches)	2.9	17.1	2.8	2.5	2.3	1.4	—
Coefficient of storage (percent)	.008	.0209	.0225	.0205	.0117	.0035	0.016
Piney Branch basin (south), 11 observation wells							
Stream discharge (inches of water)	0.035	0.621	0.123	0.064	0.059	0.016	—
Decline in ground-water levels (inches)	3.1	6.7	.7	2.05	3.0	1.4	—
Coefficient of storage (percent)	.011	.0927	.1757	.0312	.0196	.0115	0.066
Average for both basins							0.0409

Determination of an approximate coefficient of storage for the surficial deposits is significant because during drought periods (or periods of no ground-water replenishment) the sustained yield of wells is dependent on the water available from storage. Based on a coefficient of storage of 0.06, each cubic foot of aquifer dewatered would yield 0.429 gallon. A single well pumping 50,000 gpd (35 gpm) would drain water from 116,000 cubic feet each day of pumping. Because of the limited thickness of saturated aquifer available, the sustained yield of wells may be expected to decline after relatively short periods of no ground-water replenishment.

It is estimated that of the total ground-water recharge of 400,000 gpd per square mile only about one-half of this quantity, or 200,000 gallons per day, can be feasibly withdrawn by means of wells. Thus, for the approximately 200 square miles of the county underlain by the upland deposits of Pleistocene age a total of about 40 mgd might be available for sustained withdrawal if it were economically feasible to construct the large number of wells and numerous pipelines necessary to pump and convey this quantity of water.

In spite of the fact that the deposits of Pleistocene age cannot be used as a source of large quantities of water at any particular place, they will continue to be an important, though dispersed, source of domestic and farm supplies throughout much of the rural areas of the county.

AVAILABILITY IN SELECTED AREAS

Charles County is principally agricultural and, therefore, at present except for seasonal localized needs for supplemental irrigation, has small requirements for water. Most of the water requirements are centered in the populated areas of Indian Head, La Plata, and Waldorf. In addition to these three localities, future population growth and commercial development is anticipated at Hughesville, Benedict, Morgantown, and Popes Creek.

For this reason, five sub-areas were selected for a detailed quantitative appraisal of their ground-water resources. These areas are shown in figure 18 and are designated by the names of the major town or towns in the area; they are: Indian Head-Glymont, Waldorf, La Plata, Popes Creek-Morgantown, and Hughesville-Benedict.

The size and shape of the areas shown in figure 18 were determined by geologic and hydrologic considerations and are not directly related to political or geographic boundaries. The reliability of the estimates of the quantities of ground water available in each of the areas is based on the geohydrologic data available in 1963. For some of the areas little is known of the thickness or character of the sedimentary strata below the depth of the deepest well and any productive aquifers that may be present in these strata cannot be included in the estimate of quantities of water available. For example, test drilling in the Hughesville-Benedict area has extended only to a depth of 675 feet, but geologic and geophysical data extrapolated from other areas indicate that perhaps at least 1,300

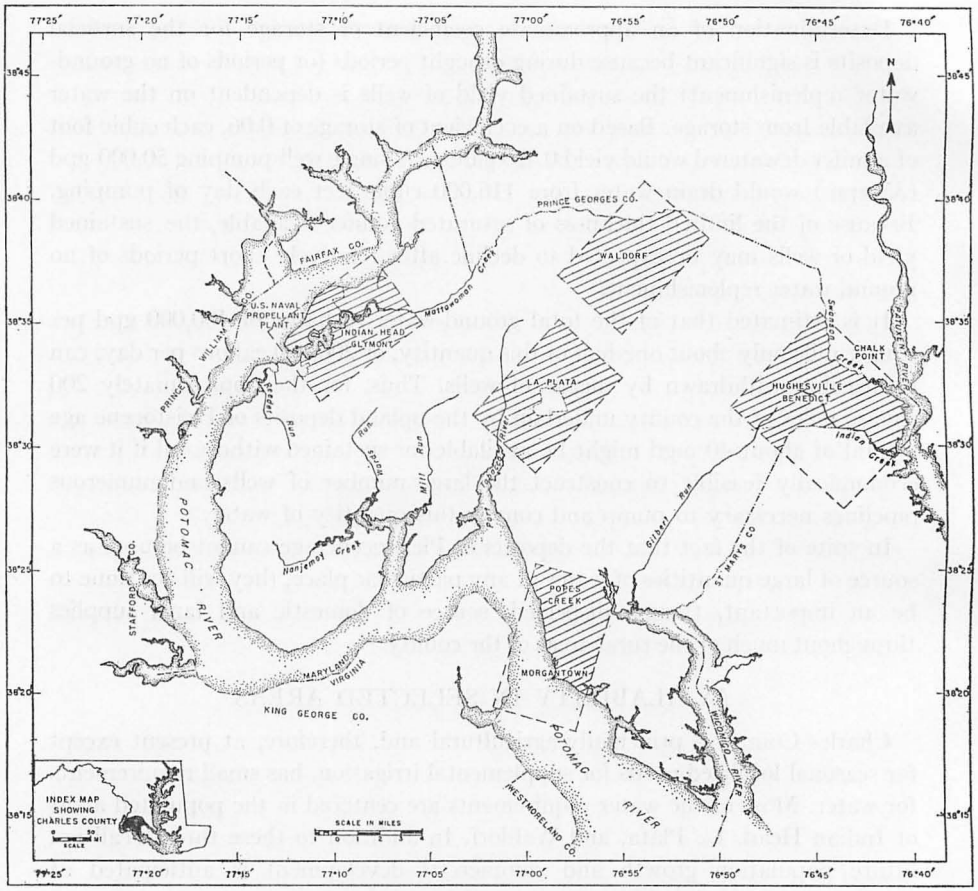


FIGURE 18. Map showing location of areas where detailed studies were made.

additional feet of underlying sediments are present which may contain important aquifers.

The quantitative estimates of water availability are also predicated on the water levels existing in the aquifers in 1963. The quantities will be less if and when water levels in the aquifers are drawn below those which prevailed in the reference year.

INDIAN HEAD-GLYMONT AREA

The Indian Head-Glymont area, in the northwestern part of the county, includes 24 square miles bordered on the northwest by the Potomac River. It consists of a rectangle 6 by 4 miles, oriented with its long axis parallel to the strike of the aquifers.

The area has the greatest population density in Charles County due pri-

marily to the existence of the U. S. Naval Propellant Plant (fig. 19). Since 1899 when the first production well was drilled at the plant ground-water pumpage has increased from an estimated 0.25 mgd to about 1.6 mgd in 1963. An additional 0.4 mgd was also pumped from public-supply wells at the towns of Indian Head and Potomac Heights in 1963.

The geohydrologic conditions in the area are complex because of the restricted continuity of the water-bearing sands and their variability in thickness and lithologic character. To achieve maximum yields many of the drilled wells have been screened opposite as many as four separate aquifers. Cross-sections made from geologic data obtained from well logs shows that the water-bearing sands occur along certain horizons with a fair degree of persistence.

The area is underlain by the Patuxent, Patapsco, Raritan, Aquia, and Nanjemoy Formations which are mantled by a thin cover of deposits of Pleistocene and Recent age. The crystalline rocks lie about 500 feet below sea level near the western corner of the area and are nearly 1,000 feet below sea level near the eastern corner.

The Patuxent and Arundel Formations (undifferentiated) yield water to wells mainly from sands in the upper part of the unit (section E–F in fig. 8). These sands occur in the Indian Head-Glymont area at altitudes ranging from −200 to about −400 feet below mean sea level. The absence of wells in the southwest part of the area indicate these sands may become less permeable.

Most of the ground water pumped from wells at the Propellant Plant is obtained from three water-bearing sands in the Patapsco and Raritan Formations. These aquifers, shown in geologic section E–F of figure 8, are designated lower, middle and upper sands.

WELLS AT THE NAVAL PROPELLANT PLANT

N. H. Darton described a well drilled at the U. S. Naval Powder Factory (former name of the Propellant Plant) on or about 1895 (1896, p. 134). The well, at an altitude of about 100 feet, was located between the Old Indian Head landing and the present Riverview Village. The depth of the well was 463½ feet and it contained 459 feet of 6-inch casing. The static water level was about 10 feet above river level and the well yielded about 11 gpm. The well log given by Darton indicates no water-bearing sands as deep as 456 feet. The sand at this depth is in the upper part of the Patuxent Formation. This well, which no longer exists, is probably the first well in the area to yield from the Patuxent.

The earliest known large-capacity well in the area was number Ch-Bb 1, drilled at the Propellant Plant in 1899, as one of the wells in Group 1 (fig. 19). This well was screened opposite the lower sands in the Patapsco and Raritan Formations and opposite a sand in the upper part of the Patuxent Formation. The initial static water level was reported to be 13 feet above sea level and the well yielded 104 gpm.

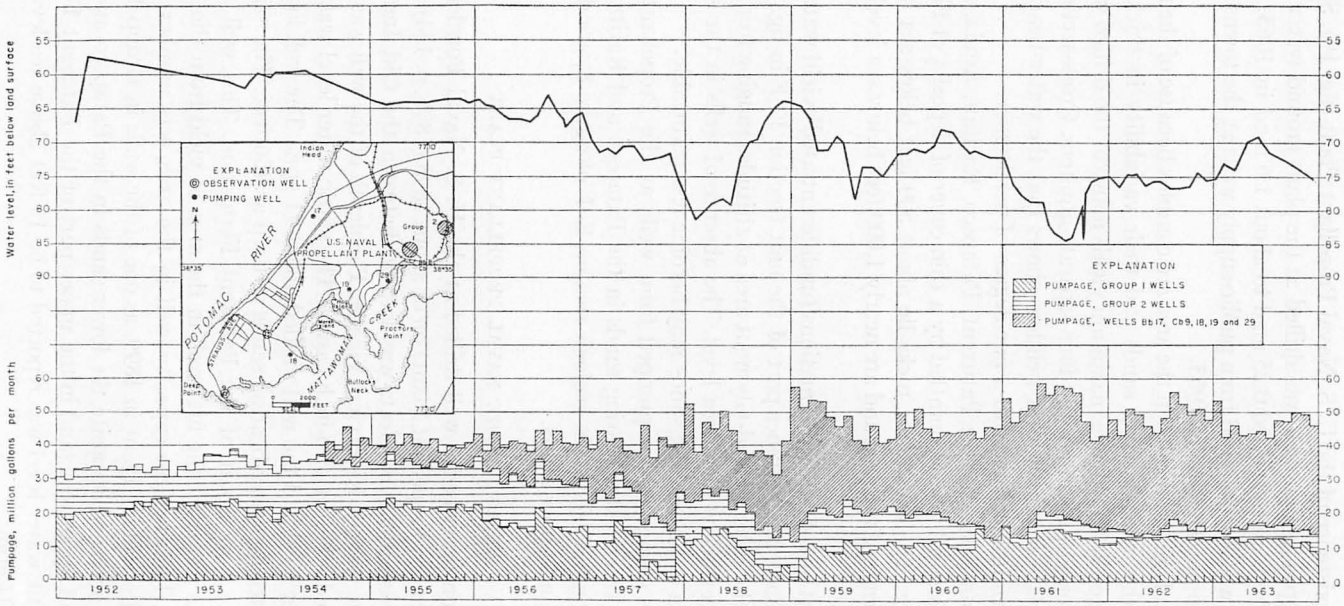


FIGURE 19. Graph showing the water level in observation well Ch-Cb 7 and the pumpage from wells at the Naval Propellant Plant.

By 1915 a total of nine wells had been drilled and by 1918 five additional wells were drilled as part of the wells in Group 2. The static levels in these wells were reported to be at or slightly above mean sea level. Data on the number and depth of the well screens in the Group 2 wells has been lost so the position of the water-bearing sands is not known.

By 1938 the Group 1 well field consisted of eight producing wells placed within a circle approximately 500 feet in diameter. An unpublished report by A. G. Fiedler and C. E. Jacob describes the results of extensive aquifer tests conducted on the wells in Groups 1 and 2 (1939). Based on information in their report, it is likely that some of the wells in Group 2 were sufficiently deep to be screened in the Patuxent Formation.

The wells in the Group 2 field were pumped intermittently from 1918 to 1940. It was not until after the latter date that the Group 2 wells were pumped almost continuously.

Accurate pumpage records at the Naval Propellant Plant were not kept until 1921, but Fiedler and Jacob (p. 12) estimated that from 1899 to 1921 the pumpage increased from 0.28 to 0.86 mgd. From 1921 to 1940 pumpage averaged about 0.70 mgd, chiefly from wells in Group 1. From 1940 to mid-1954 pumpage from both well groups averaged about 1.0 mgd. Between 1953 and 1956 five additional wells were drilled to increase the ground-water supply at the Propellant Plant. The first of these was placed in full time operation in August 1954. The five wells produce water only from the lower sands of the Patapsco and Raritan Formations. The location of the new wells is shown in figure 19 and they are numbered -Bb 17, -Cb 9, -Cb 18, -Cb 19, and -Cb 29. Between 1954 and 1963 the total pumpage from well Groups 1 and 2 declined from 1.1 to 0.5 mgd while the pumpage from the five newer wells rose from 0.08 to 1.1 mgd. This change in the pumping regime is shown in figure 19.

Wells -Bc 6 and -Bc 24 at Potomac Heights, immediately east of the Propellant Plant, produce water from sands in the Patuxent Formation. In 1962 pumpage from these wells was estimated to be about 0.2 mgd. Well -Bc 49 at nearby Woodland Village yielded about 0.015 mgd from the Patuxent Formation in 1962. The Woodland Village well is about 5,000 feet from the Group 2 wells and the Potomac Heights wells are about 10,000 feet from Group 2.

The total quantity of water produced from the sands in the Patuxent Formation in the Indian Head-Glymont area since 1899 can be only roughly estimated because of the problem of multiple-screening of the wells in several sands. However, based on proportionate screen lengths of individual wells, it is believed that about 40 percent of the total water pumped from 1899 to 1954 was derived from the Patuxent Formation. Because few wells in the area are screened only in the Patuxent it was not possible to compile a piezometric surface of the upper sands in the formation. However, water levels were measured in a few Patuxent wells along Md. Rt. 210. These wells and the measurements follow:

Well[4] Number	*Location or Owner*	*Distance from Center of Groups 1 and 2 (feet)*	*Water Level (in feet below msl.)*	*Date of Meas.*
-Bc 24	Potomac Heights	11,000	−39	5/12/61
-Bc 60	Glymont Crest	13,000	−21	10/25/62
-Bc 54	E. A. Jenkins	26,000	−9	10/30/61
-Bc 29	N. Indian Head Estates	30,000	−8	6/13/61
Group 1	Propellant Plant	—	−155	5/16/61
Group 2	Do.	—	−117	5/16/61

It appears from the above data that the pumping from the wells listed above and from other Patuxent wells in the area has undoubtedly created a significant cone of depression in the Patuxent Formation in the Indian Head-Glymont area.

The capacities of individual wells tapping sands in the Patuxent Formation in the area range from 12 to 360 gpm. Specific capacities of individual wells are as great as 2.5 gpm per foot of drawdown. The best well is -Bc 6 at Potomac Heights which yields 360 gpm. The well has about 50 feet of screen in it.

The hydrologic coefficients determined from aquifer tests conducted during this investigation and during 1938 by Fiedler and Jacob of the U. S. Geological Survey (1939) on wells in the Indian Head-Glymont area are summarized in table 5.

In general, the results of the computations of the coefficients of transmissibility of sands in the Patuxent Formation show a close agreement and the transmissibility of all the aquifers is moderately low.

To check the reliability of the computed values of the coefficients of transmissibility and storage an analysis was made of the theoretical drawdown to be expected in observation wells at points distant from the center of pumping. The theoretical drawdowns may then be compared with real drawdowns measured in the wells.

An analysis of this nature, based on pumping water from the Patuxent Formation since 1899, has the following elements and assumptions:

a) Pumping rate from the Patuxent Formation at the Naval Propellant Plant averaged 274,000 gpd (190 gpm) for the 63-year period 1899 to 1962. This pumping rate is estimated to be about 40 percent of the total rate from all artesian aquifers in the area.

b) Initial static water levels in the aquifer were about 10 feet above low-tide level as reported by N. H. Darton (1896), and that the initial static level was approximately the same throughout the Indian Head area.

c) That the conditions involved in the use of the Theis equation are applicable and that the coefficient of transmissibility of 5,000 gpd/ft and the coefficient of storage of 0.0004 are approximately correct.

d) That vertical leakage into or out of the aquifers is negligible and that the pumped water has been withdrawn from the designated aquifer.

[4] Location of wells shown in Maryland Geol. Survey Water Resources Basic Data Report 2 (1960).

TABLE 5

HYDROLOGIC COEFFICIENTS OF AQUIFERS IN THE INDIAN HEAD-GLYMONT AREA

Well Number[2]	Location	Coefficient of Transmissibility (T) (gpd/ft)	Coefficient of Storage (S)	Aquifer or Formation
Ch-Bc 6	Potomac Heights	5,000	0.004	Patuxent
Group 1 and 2	Propellant Plant	4,000[1]	0.0004	Patuxent and Patapsco
1	Quantico, Va.	3,900	—	Patuxent
3	Do.	3,300	—	Do.
Ch-Cb 7 and Ch-Cb 8	Propellant Plant	6,000	0.0002	Patapsco and Raritan

[1] Results for T and S may be low because of inadequate development and clogging of screens in old wells of Groups 1 and 2.

[2] Location of wells given in Maryland Geol. Survey Water Resources Basic Data Report 2 (1966).

Using well -Bc 24 at Potomac Heights and well -Bc 54 along Md. Rt. 210 as the observation wells, and based on pumping from well Groups 1 and 2 at the Naval Propellant Plant, the following compilation shows the theoretical decline in water levels during a 21-year period compared with the approximate measured decline:

Well Used in Drawdown Computations	*Distance from Center of Pumping (feet)*	*Theoretical Decline due to Pumping 274,000 gpd (feet)*	*Approximate Measured Decline During 63-yr. Period (feet)*	*Difference Theoretical vs. Measured Decline (feet)*
-Bc 24	11,000	54[5]	49[6]	5
-Bc 54	26,000	21	19[6]	2

The relatively close agreement between the theoretical and approximate measured decline in water levels in the aquifer may be fortuitous, but the analysis suggests that the coefficients used in the analysis are of the right order of magnitude.

If the drawdowns computed for wells -Bc 24 and -Bc 54 are approximately correct, then it appears possible that the cone of depression in the Patuxent Formation, resulting from the pumping at the Propellant Plant may extend westward across the Potomac River into Virginia to points at least 5 miles (26,000 feet) from the center of pumping at the Propellant Plant. Unfortunately, no observation wells are available on the Virginia side of the river to verify this conclusion.

Overlying the Patuxent Formation in the Indian Head-Glymont area are a group of aquifers designated in this report the lower sands of the Patapsco and Raritan Formations. Figure 11 shows that the upper surface of these sands dips

[5] Includes 26 feet of computed drawdown resulting from pumping of well -Bc 6 during period 1941–62; -Bc 6 is located 525 feet from well -Bc 24.

[6] Based on assumed original static level in the aquifer of +10 feet, mean sea level datum.

eastward across Charles County from an altitude of about 100 feet below mean sea level at the Propellant Plant to about 600 feet below sea level at La Plata. The gradient of the upper surface of the sands is about 40 to 50 feet per mile.

Until 1953 the major source of pumping from the lower sands was from the wells of Groups 1 and 2 at the Propellant Plant. After 1953 wells at the town of Indian Head and the newer wells at the Propellant Plant yielded water from this aquifer. It is estimated that by 1963 about 1.4 mgd was pumped from them at the Propellant Plant and an additional 0.1 mgd was pumped by the Indian Head wells.

Well -Cb 7, screened in a sand in this aquifer at a depth of 144 to 167 feet below the land surface, has been used as an observation well since 1952. The record of water levels in this well is shown in figure 19, which also shows by bar graphs the pumpage from well Groups 1 and 2 and the pumpage since 1954 from the newer wells -Bb 17, -Cb 9, -Cb 18, -Cb 19 and -Cb 29. In general, the trend in water levels shown in the figure appears to correlate with the pumping from the newer wells.

Some of the water-bearing sands below a depth of 200 feet in the Indian Head area may be hydrologically connected to a degree as is suggested by figure 20, a piezometric map of the lower sands in the Patapsco and Raritan Formations. Most of the water levels used in the preparation of figure 20 were measured during May 16 and 17, 1961; levels in a few wells were measured during July 1962. The figure shows that the cone of depression centers around well Groups 1 and 2 and that it extends nearly 7 miles in a northeast-southwest direction and about 4 miles in the northwest-southeast direction.

The piezometric map (fig 20) and the pumpage data shown graphically in figure 19 afford a means of determining if the cone of depression at the Naval Propellant Plant had reached equilibrium at the time of measurement of the water levels used in constructing the piezometric map (May 1962). The following form of the modified Darcy equation is used for this analysis:

$$Q = \frac{TIL_1 + L_2}{2}$$

where:

Q = discharge, in gallons per day
T = coefficient of transmissibility, in gpd per foot
I = the hydraulic gradient, in feet per mile
L_1 = length, in miles, of any limiting contour defining the cone of depression
L_2 = length, in miles, of an adjoining contour defining the cone of depression

For the lower sands of the Patapsco and Raritan Formations the terms used are:

T = 5,000 gpd per foot
I = 10 feet per mile
L_1 = 10.1 miles (the length of the -50 foot contour on figure 21)

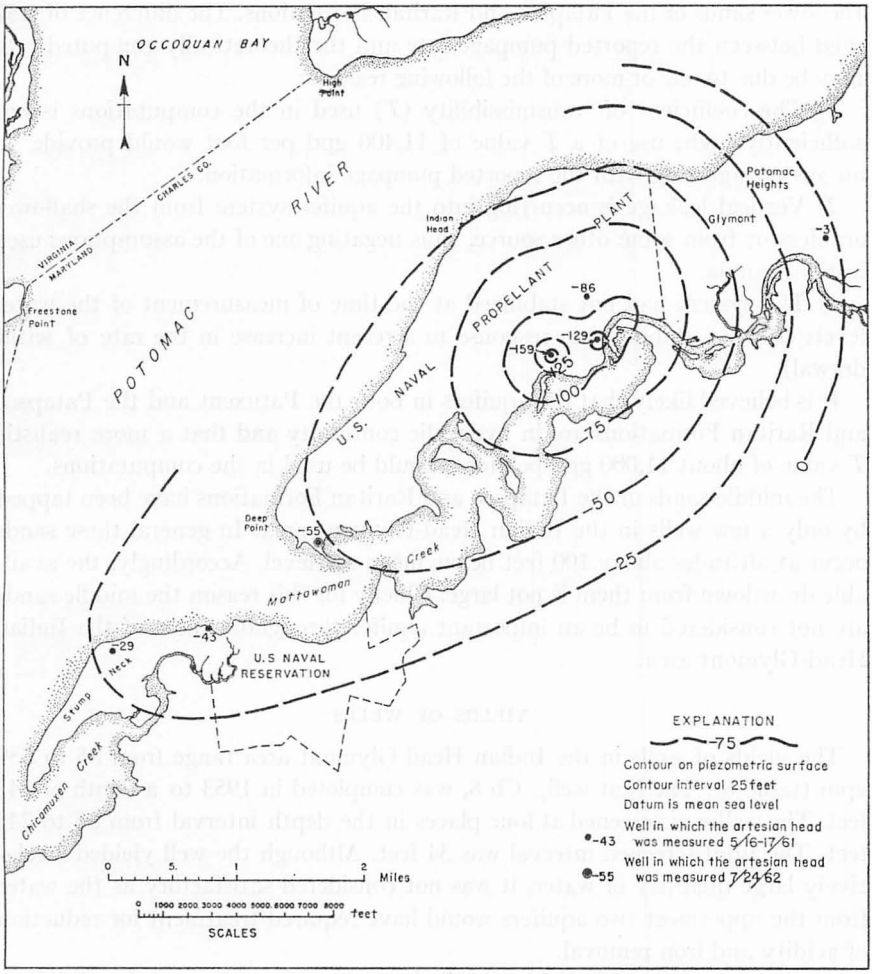


FIGURE 20. Map of the piezometric surface in the lower sands of the Patapsco and Raritan Formations at the Naval Propellant Plant during 1961–62.

L_2 = 8.4 miles (the length of the extrapolated -60 foot contour on figure 20) or:

$$5{,}000 \times 10 \times \frac{10.1 + 8.4}{2} = 0.46 \text{ mgd}$$

The quantity of 0.46 mgd determined from the computations is the theoretical rate of flow across the limiting contours to the center of pumping at the Propellant Plant. However, the pumpage graph (figure 19) indicates that during May 1962 the total pumpage from all wells at the plant was at the rate of about 1.48 mgd, of which 1.03 mgd was from the newer wells yielding water chiefly from

the lower sands of the Patapsco and Raritan Formations. The difference of 0.57 mgd between the reported pumpage rate and the theoretically computed rate may be due to one or more of the following reasons:

1) The coefficient of transmissibility (T) used in the computations is not sufficiently high; use of a T value of 11,400 gpd per foot would provide an an answer agreeing with the reported pumpage information.

2) Vertical leakage is occurring into the aquifer system from the shallower aquifers or from some other source, thus negating one of the assumptions used in the formula.

3) The system had not stabilized at the time of measurement of the water levels (that is, stabilized in response to a recent increase in the rate of withdrawal).

It is believed likely that the aquifers in both the Patuxent and the Patapsco and Raritan Formations are in hydraulic continuity and that a more realistic T value of about 11,000 gpd per foot should be used in the computations.

The middle sands of the Patapsco and Raritan Formations have been tapped by only a few wells in the Indian Head-Glymont area. In general these sands occur at altitudes above 100 feet below mean sea level. Accordingly, the available drawdown from them is not large. Chiefly for this reason the middle sands are not considered to be an important aquifer throughout most of the Indian Head-Glymont area.

YIELDS OF WELLS

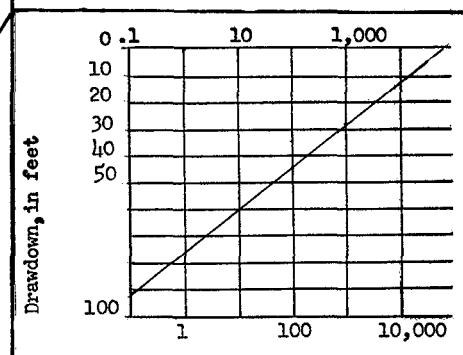
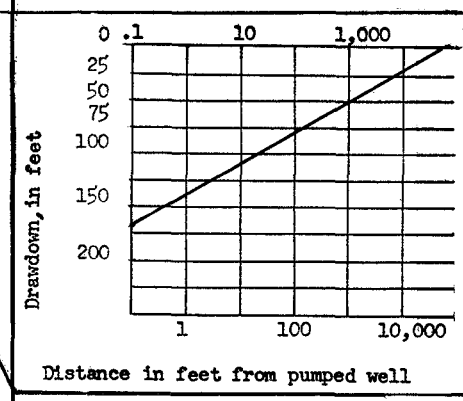
The yields of wells in the Indian Head-Glymont area range from 85 to 559 gpm (table 6). The best well, -Cb 8, was completed in 1953 to a depth of 242 feet. The well was screened at four places in the depth interval from 85 to 242 feet. The total screened interval was 34 feet. Although the well yielded a relatively large quantity of water, it was not considered satisfactory as the water from the uppermost two aquifers would have required treatment for reduction of acidity and iron removal.

Specific capacities of individual wells in the area range from 2.2 to 7.1 gpm per foot of drawdown. The maximum specific capacity was reported for well -Cb 8. The median specific capacity of nine of the most productive wells is 3.7 gpm per foot of drawdown.

QUANTITATIVE ESTIMATES

To estimate the quantity of ground water perennially available in the Indian Head-Glymont area a practical application can be made of the hydrologic coefficients (T and S) of the aquifers. The analysis assumes that a line of wells could be drilled parallel to the strike of the aquifers along the 6-mile extent of the arbitrarily designated area (fig. 18). The wells, or groups of wells, would be screened opposite the chief water-bearing sands and the spacing of these wells would be at reasonable distances so that when pumping simultaneously (from

INDIAN HEAD-GLYMONT

GEOHYDROLOGY				QUALITY OF WATER		QUANTITY OF WATER							
						Data Used in Computations							
						Aquifer Properties		Hypothetical Well Field					
Geologic Unit	Position relative to sea level (ft)	Composite geologic section	Aquifer or Aquiclude	No. of analyses	Range in chemical constituents and properties of ground water (in ppm except for pH)	Transmissibility (gpd/ft)	Storage coefficient (S)	Available drawdown (ft)	Number of wells	Spacing between wells (ft)	Pumping rate per well (gpm)	Distance - drawdown graph for 1,000 days of pumping	Estimated quantity of water available (mgd)
Pleistocene Deposits	Sea Level		Aquiclude										
Patapsco and Raritan Formations — Middle Sands			Aquiclude										
			Aquifer		Water reported to be irony and to have a "marshy" odor. Not considered as an Aquifer to be developed								
	-100		Aquiclude										
Patapsco and Raritan Formations — Lower Sands 1/	-200		Aquifer	5	Iron (Fe) 0.08 - 0.57								
			Aquiclude	5	Chloride (Cl) 6.5 -15.0								
			Aquifer	5	Hardness as $CaCo_3$ 3 - 6	5,000	.0004	150	7	5,280	150		1.5
			Aquiclude	5	pH								
			Aquifer										
	-300		Aquiclude	5	Iron (Fe) 0.0 - 1.3								
				5	Chloride (Cl) 3.3 - 7.0								
			Aquifer	5	Hardness as $CaCo_3$ 2.0 -22	5,000	.0004	300	7	5,280	275		2.8
				5	pH 7.3 - 7.6								
	-400												
Patuxent and Arundel Formations	-500		Aquiclude										
	-600												
Crystalline Rocks	-700		Aquiclude		1/Wells are multiple screened opposite the individual aquifers.								

21. Chart showing geologic, chemical, and hydrologic data used in estimating the availability and quality of water in the Indian Head-Glymont area.

the same aquifer) the resulting drawdown would be the limiting drawdown, or the drawdown which would cause the pumping level in the center well (or wells) to decline to the upper surface of the aquifer. A pumping period of 1,000 days was selected as it can be shown that by this time more than 90 percent of the total drawdown in the aquifers will have occurred. The analysis is based on the preparation of a distance-drawdown graph for each aquifer, the selection of a realistic rate of pumping (150 gpm for the lower sands of the Patapsco and Raritan Formations), and the computation of the mutual hydraulic interference of each well on other wells in the aquifer system. The computations of water-level decline are based on the use of the Theis equation and have been described by Ferris and others (1962). For example the self-drawdown in a single well tapping the lower sands of the Patapsco and Raritan Formations would be about 80 feet if the well were pumped at a rate of 150 gpm. To this must be added the drawdown of about 17 feet caused by each adjacent well located 1 mile distant; a well of the same capacity 2 miles distant would cause an additional drawdown of 11 feet; a well 3 miles distant would cause an additional drawdown of 9 feet and so on.

Figure 21 includes a composite geologic section of the Indian Head-Glymont area and presents the hydrologic and chemical quality data used in evaluating the ground-water resources. The figure shows the existence of two major aquifers in the area, the lower sands of the Patapsco and Raritan Formations and a sand in the Patuxent Formation. Data on the right side of figure 21 show that 7 wells spaced 1 mile apart and tapping the lower sands should yield about 1.5 mgd on a sustained basis. This quantity is shown on the right hand side of the figure. Each well would pump water at a rate of 150 gpm and computations show that the drawdown in the center well after 1,000 days of pumping would stabilize at about 154 feet below the initial non-pumping level.

A similar analysis for the sand in the Patuxent Formation shows that 7 wells, spaced 1 mile apart, should yield about 2.8 mgd while pumping at a rate of 275 gpm. Thus, the total sustained yield of wells tapping the two major water-bearing units in the area should be on the order of 4.3 mgd. The cone of influence resulting from withdrawal of this quantity of water might reasonably be expected to extend 3 to 5 miles beyond the Indian Head-Glymont area.

The above analysis is based on the assumption that no vertical leakage occurs into or out of the artesian aquifers, that the hydrologic coefficients are correct, and that the geohydrologic conditions in the aquifers are reasonably uniform. The reliability of the quantitative estimates is dependent on the degree and extent that the real conditions agree with the assumptions used in the analysis. One of the most likely sources of errors in the analysis is due to the existence of geohydrologic boundaries caused by lenticularity and irregular distribution of the sands in the formations of the Potomac Group. The Potomac Group consists of (ascending) the Patuxent, Arundel, and Patapsco Formations.

TABLE 6

DATA FOR HIGH-CAPACITY WELLS IN THE INDIAN HEAD—GLYMONT AREA

U.S.G.S. Well Number 7	Owner's Name or Designation	Owner's Number and Date Drilled	Altitude of Land Surface (feet)	Depth of Well (feet)	Casing Diameter (inches)	Depth of Screen Below Land Surface (feet)	Depth of Water Level Below Land Surface (feet)			Yield (gpm)	Specific Capacity (gpm/ft of Drawdown)	Well Status (1962)	Aquifer
							Static	Pumping	Date				
Ch-Bb 5	U. S. Naval Propellant Plant, Group 1	5 (1910)	42.8	395	8	271–281 320–332 381–391	—	—	3/—/61	85	—	In use	Patuxent, Patapsco and Raritan
Ch-Bb 6	Do.	6 (1915)	38.3	398	8	251–261 301–311 376–397	—	212	12/—/60	100	—	Do.	Do.
Ch-Bb 7	Do.	7 (1915)	38.9	419	8	255–265 308–317 377–399	—	240	12/—/60	95	—	Do.	Do.
Ch-Bb 8	Do.	8 (1915)	36.1	397	8	223–231 262–273 310–321 372–394	178	226	8/—/60	155	—	Do.	Do.
Ch-Bb 9	Do.	9 (1915)	32.1	390	8	185–195 235–245 284–294 355–376	—	246	8/—/60	110	—	Do.	Do.
Ch-Bb 12	Town of Indian Head	1 (1953)	95	515	10	238–245 248–260 288–298	149	203.5	12/10/53	220	4.0	Do.	Patapsco and Raritan
Ch-Bb 17	U. S. Naval Propellant Plant	23 (1957)	52.0	294	16 10	240–294	105	—	2/—/57	450	—	Do.	Do.

Ch-Bc 3	U. S. Naval Propellant Plant, Group 2	12 (1918)	18.7	390	8	—	—	251	12/—/60	115	—	Do.	Patuxent, Patapsco and Raritan
Ch-Bc 5	Do.	14 (1918)	39.2	430	8	—	—	234	12/—/60	130	—	In use	Patuxent, Patapsco and Raritan
Ch-Bc 23	Town of Indian Head	2 (1958)	65	311	16 10 8	229–250 262–270 280–292 305–311	141	206	4/15/58	240	3.7	Do.	Patapsco and Raritan
Ch-Cb 7	U. S. Naval Propellant Plant	19 (1952)	36	167	8	144–167	67	140	3/3/52	200	2.7	Not in use	Do.
Ch-Cb 8	Do.	16 (1953)	38	242	20 12 10	85–93 123–133 221–229 234–242	52	131	5/28/53	559	7.1	Do.	Do.
Ch-Cb 9	Do.	15 (1953)	24.3	280	16 10 8	191–206 230–234 240–244 268–280	52 81.6	192 —	6/30/53 7/24/62	310 206	2.2 —	In use	Do.
Ch-Cb 18	Do.	17 (1954)	30.5	295	16 10	261–295	77 125	210 221	4/20/54 10/—/60	350 332	2.6 3.4	Do.	Do.
Ch-Cb 19	Do.	18 (1954)	32	302	16 10 8	208–220 274–302	95 100	187 175	5/15/54 10/—/60	363 300	3.9 4.0	Do.	Do.
Ch-Cb 29	Do.	24 (1957)	12.4	286	10	228–239 269–286	100	—	1956	383	—	Do.	Do.

[1] Location of wells shown in Maryland Geol. Survey Water Resources Basic Data Report 2 (1966).

WALDORF AREA

The Waldorf area includes about 24 square miles in the north-central part of the county (fig. 18). It is on an upland flat which has an average altitude of about 200 feet. Ground water provides the only source of water in the area. During 1963 the average quantity of water supplied by wells of the Charles County Sanitary District was about 0.15 mgd and during 1964 this quantity increased to about 0.21 mgd. An additional 0.2 mgd was believed to have been supplied by private domestic and commercial wells in 1964. In summary, the total use of ground water in 1964 is estimated to have been slightly more than 0.4 mgd.

At Waldorf the altitude of the top of the crystalline rocks is estimated to be about 1,600 feet below sea level (fig. 5). Therefore, about 1,800 feet of sedimentary strata underlie the town.

Information regarding the deeper stratified sediments is based chiefly on the record of a test hole (PG-Gc 5) drilled by the Washington Gas Light at a site approximately 3 miles northwest of the center of Waldorf in Prince Georges County. The test hole penetrated the lower part of the Patuxent Formation to a depth of 1,527 feet below sea level.

Below are listed the approximate positions of a few of the sands penetrated by well PG-Gc 5:

Depth Interval in Feet below Sea Level	*Thickness (in feet)*	*Geologic Unit*
123–178	55	Magothy
257–286	29	Patapsco and Raritan
360–381	21	
479–536	57	
553–633	80	
722–759	37	Patuxent and Arundel
1246–1283	37	

In 1965 a test hole (Ch-Bf 131) was drilled about 0.7 mile south of Waldorf to a depth of 935 feet. The following is a tentative classification of the sands reported by the driller and confirmed by an electric log of the well.

Depth Interval, in Feet below Sea Level	*Thickness (in feet)*	*Geologic Unit*
179–295	116	Magothy
380–408	28	Patapsco and Raritan (upper sand)
692–720	28	Patapsco and Raritan (lower sand)

The Magothy Formation has been penetrated by several wells in the Waldorf area and was the chief aquifer in use at the time of preparation of this report. Tabulated below are the thicknesses of the water-bearing sands in the Magothy in the Waldorf area:

Well Number	*Depth Below Land Surface (in feet)*	*Aquifer Thickness (in feet)*
PG-Gc 1	315–390	75
Ch-Be 40	490–531	41
Bf 97	419–490	74
Bf 127	445–517	72
Bf 131	445–505	55
		63 (average)

The Monmouth (possibly the Matawan) Formation overlies the Magothy and in places, in the Waldorf area, yields water to drilled wells. However, the water-bearing sand in the Monmouth is thin and irregular in extent. Its thickness, as determined from well logs, ranges from 5 to 20 feet and averages about 10 feet. It is not considered to be an important source of ground water. Based on scanty information its coefficient of transmissibility is estimated at about 1,500 gpd/ft and its coefficient of storage at about 0.00001.

The hydrologic coefficients of the aquifers in the area can best be determined by means of aquifer tests using a pumping well and at least one or more observation wells. Where it is not feasible to run aquifer tests it is possible to approximate the coefficients of transmissibility and storage on the basis of the nature and thickness of the logged strata. Only a few reliable aquifer tests were available near Waldorf (Wells -Be 40 and -Bf 127 in the Magothy Formation) and estimates had to be made for the remaining aquifers in the area. These data are summarized in table 7.

The coefficients of transmissibility of the aquifers range from 1,500 gpd/ft (estimated) for the Monmouth Formation to about 16,000 gpd/ft for the Magothy Formation. The two values given for the Magothy Formation, 11,000 and 16,000 gpd/ft, are in general agreement with values reported by Mack (1966, p. 43) for the Magothy in southern Prince Georges County. Mack reports a value of transmissibility of 17,000 gdp/ft at the Boys Village of Mary-

TABLE 7

HYDROLOGIC COEFFICIENTS OF AQUIFERS IN THE WALDORF AREA

Well Number	Location	Coefficient of Transmissibility (*T*) (gpd/ft)	Coefficient of Storage (*S*)	Aquifer or Formation
Ch-Be 40	Waldorf (south)	1,500[1]	0.00001[1]	Monmouth
Ch-Be 40	Do.	13,500	.00007	Magothy
Ch-Bf 127	Waldorf (north)	16,000	.0002	Do.
Ch-Bf 131	South of Waldorf	4,000[1]	.0001[1]	Patapsco and Raritan (upper sand)
Ch-Bf 131	Do.	4,000[1]	.0001[1]	Patapsco and Raritan (lower sand)

[1] Estimated.

land and a value of 11,000 gpd/ft at the U. S. Naval Radio Station at Cheltenham.

YIELDS OF WELLS

The yields of moderate to high-capacity wells in the Waldorf area range from 60 to 453 gpm. All of the high-capacity wells are screened opposite the Magothy or the Magothy and Monmouth Formations. Well -Bf 127, drilled for the Charles County Sanitary District in 1961, is the most productive well in the area. This well, screened at depths of 452 to 485 feet and 490 to 517 feet, had a specific capacity of 12.9 gpm/ft of drawdown when tested in 1961. Table 8 lists the yields and construction data for eight high-capacity wells in the area.

The specific capacities of the wells shown in the table range from 0.8 to 12.9 gpm/ft of drawdown. Where wells in the Magothy Formation yield less than a few hundred gallons a minute it is probable that larger yields could be obtained by increasing the length and diameter of the screen, by more adequate well development, or by the use of a gravel envelope, where this feature is lacking in existing wells.

A number of homes and small commercial establishments in the area use shallow dug or bored wells ending in the deposits of Pleistocene age. These wells range in diameter up to 36 inches or more, but most of them are of small capacity. The best wells yield about 15 gpm and most of them yield less than 10 gpm. The small capacity of these wells is due partly to the limited available drawdown, which seldom exceeds 15 or 20 feet, and to the relatively low transmissibility of the Pleistocene deposits.

QUANTITATIVE ESTIMATES

In February 1962 the Charles County Sanitary District's north and south public-supply wells at Waldorf were placed in operation. The pumpage at both wells was metered during the period from February 1, 1962 through December 31, 1964. Tabulated below are the metered total withdrawals, in millions of gallons, for each well:

Year	*North Well (-Bf 127)*	*South Wel (-Be 40)*	*Total Both Wells*
1962 (11 mos.)	15,493,307	19,544,109	35,037,416
1963	30,693,481	25,191,968	55,885,449
1964	45,472,800	36,125,984	81,598,784
Total	91,659,588	80,862,061	172,521,649

The average daily rate of pumping for the 3-year period is 60 gpm for well -Bf 127 and 52 gpm for well -Be 40, or 112 gpm for both wells.

The data given above are useful in an analysis made to verify the reliability of the coefficients of transmissibility and storage determined from aquifer tests (table 7). Using the water-level measurements in two observation wells in the

TABLE 8

DATA FOR HIGH-CAPACITY WELLS IN THE WALDORF AREA

U.S.G.S. Well Number[1]	Owner's Name or Designation	Owner's Number and Date Drilled	Altitude of Land Surface (feet)	Depth of Well (feet)	Casing Diameter (inches)	Depth of Screen Below Land Surface (feet)	Depth of Water Level Below Land Surface (feet)			Yield (gpm)	Specific Capacity (gpm/ft of Draw-down)	Well Status (1962)	Aquifer
							Static	Pumping	Date				
Ch-Bf 93	Waldorf Motor Court	1 (1952)	205	480	6–5½	—	157	225	5/16/52	70	1.0	In use	Magothy
Ch-Bf 96	U. S. Army	1 (1956)	210	472	6	459–472	160	235	8/29/56	60	.8	Do.	Do.
Ch-Bf 97	301 Ranch	1 (1958)	220	602	8	370–378 430–435 457–465 470–482	170.4	254.4	4/23/58	220	2.6	Do.	Magothy and Monmouth
Ch-Bf 100	Stardust Motel	1 (1958)	205	508	8–5	471–477 481–494	180	280	8/29/58	123	1.2	Do.	Magothy
Ch-Bf 101	Martha Washington Motor Court	1 (1953)	210	477	6	423–438 449–465 465–475	172	250	3/27/53	94	1.2	Do.	Do.
Ch-Bf 123	Frontier Restaurant	1 (1953)	210	471	6	466–471	170	220	12/23/53	60	1.2	Do.	Do.
Ch-Bf 127	Charles County Sanitary District	1 (1961)	213	517	8	452–485 490–517	168	203	5/25/61	453	12.9	Do.	Do.
Ch-Be 40	Do.	2 (1961)	209	428	8	350–370 388–428	149	213	6/20/61	434	6.8	Do.	Magothy and Monmouth

[1] Location of wells shown in Maryland Geol. Survey Water Resources Basic Data Report 2 (1966).

Magothy Formation located some distance from pumping well -Bf 127, the following results were obtained, based on the average pumping rate of -Bf 127 and -Be 40 during the 3-year period:

Observation well number	*Distance from well -Be 40 (in feet)*	*Distance from well -Bf 127 (in feet)*	*Average Q, 2 wells pumping (in gpm)*	*Theoretical Drawdown (in feet)*	*Meas. Drawdown (in feet)*
Ch-Bf 128	15,000	10,500	94[7]	3.10	2.94
PG-Fd 40	36,700	14,260	94[7]	2.20	3.31

The agreement between the theoretical drawdowns, computed by means of the Theis equation, and the actual measured drawdowns is far from perfect but a few factors could not be handled in the analysis. Among these is the effect of pumping from other Magothy wells in the area. It is believed that this factor is mainly responsible for the difference of 1.11 feet between the theoretical and the observed drawdown in observation well PG-Fd 40. In general, the analysis indicates that the hydrologic coefficients are in the right order of magnitude.

Figure 22 presents geologic, hydrologic, and chemical data used to evaluate the ground-water resources of the Waldorf area. The left hand side of the figure, under the heading "Geohydrology" shows a composite geologic section of the area in which the aquifers and non-aquifers (aquicludes) are drawn to scale. The right hand side of the figure shows a distance-drawdown graph for each aquifer, based on computations using the Theis equation.

The estimated quantity of water obtainable from each aquifer is based on the assumption that a line of seven wells, spaced 1 mile apart and parallel to the strike of the formations, would pump at the rate indicated in the column under the heading "Hypothetical well field". The interference effect of each well on the others screened in the same aquifer was summarized in the analysis, and the limit of combined interference effect is assumed to be that drawdown which would cause the water level in the aquifer to decline to a position slightly above the top of the aquifer. Thus, a well having a radius of 0.5 foot and screened opposite the Magothy Formation, would have a self-drawdown of 100 feet at the end of 1,000 days of continuous pumping at a rate of 375 gpm. At the end of this period the water level in the middle well of the seven would have declined to an altitude of about −180 feet, or approximately to the top of the aquifer. The combined yield of all seven wells would, therefore, be at the rate shown in the right hand column of figure 22, or 3.8 mgd (7 × 375 gpm). A similar analysis was made for each major aquifer.

Two of the aquifers, the lower and upper sands of the Patapsco and Raritan Formations, are assumed to be of infinite extent, but the Magothy Formation is believed to have two pinchout boundaries, one about 4 miles northwest and another 4 miles southwest of the Waldorf area. Based on an analysis using

[7] Total average pumping rate from -Be 40 was 52 gpm, but only 34 gpm of this rate is attributed to the Magothy Formation.

WALDORF

GEOHYDROLOGY				QUALITY OF WATER		QUANTITY OF WATER — Data Used in Computations: Aquifer Properties		Hypothetical Well Field					
Geologic Unit	Position relative to sea level (ft)	Composite geologic section	Aquifer or Aquiclude	No. of analyses	Range in chemical constituents and properties of ground water (in ppm except for pH)	Transmissibility (gpd/ft)	Storage coefficient (S)	Available drawdown (ft)	Number of wells	Spacing between wells (ft)	Pumping rate per well (gpm)	Distance - drawdown graph for 1,000 days of pumping	Estimated quantity of water available (mgd)
Pleistocene Deposits	+200		Aquifer 1/	4	Iron (Fe) 0.02 - 0.59								
Calvert Formation			Aquiclude	4	Chloride (Cl) .2 -48 Hardness as $CaCo_3$ 12 -154 pH 6.0 - 6.8								
	+100												
Nanjemoy Formation			Aquiclude										
	Sea Level												
Aquia Greensand			Aquiclude										
	-100			1 1 1	Iron (Fe) 0.05 Chloride (Cl) 1.2 Hardness as $CaCo_3$ 172								
Monmouth(?) Formation			Aquifer	1	ph 8.0	1,500	.0001	220	7	5,280	60	Distance in feet from pumped well	0.60
			Aquiclude										
Magothy Formation	-200		Aquifer	9 9 9 9	Iron (Fe) 0.10 - 0.70 Chloride (Cl) .6 - 5.0 Hardness as $CaCo_3$ 41 -144 pH 7.4 - 7.9	15,000	.0001	260	7	5,280	375	Drawdown, in feet; Distance in feet from pumped well	3.3
Raritan Formation	-300		Aquiclude										
Patapsco and Raritan Formations — Upper Sands			Aquiclude										
	-400		Aquifer			4,000 2/	.0001 2/	360	7	5,280	215	Drawdown, in feet; Distance in feet from pumped well	2.4
			Aquiclude										
Patapsco and Raritan Formations — Middle Sands	-500		Aquiclude										
Patapsco and Raritan Formations — Lower Sands	-600		Aquiclude										
	-700		Aquifer			4,000 2/	.0001 2/	780	7	5,280	500	Drawdown in feet; Distance in feet from pumped well	5.0
Patuxent Formation	-800		Aquiclude										

1/ Omitted from estimate because of the limited supply available per individual well.

2/ Estimated value

22. Chart showing geologic, chemical, and hydrologic data used in estimating the availability and quality of water in the Waldorf area.

image wells to show the effect of the hydrologic boundaries (Ferris and others, 1962, p. 144) the distance-drawdown curve for the Magothy reflects the steepened drawdown curve resulting from the two boundaries.

The surficial deposits of Pleistocene age, which mantle the surface throughout the Waldorf area, constitute a ground-water reservoir of significance, although the yield from individual wells is small, as discussed in a previous section of the report (page 43). It is estimated that each square mile of the surficial deposits might yield about 0.2 mgd, or a total of 4.8 mgd for the 24-square mile area. About 13 wells of an average capacity of 10 gpm would be required per square mile to obtain the yield indicated. It is probably not economically feasible to develop a central water supply from this source because of the large number of wells required, but, nevertheless, these deposits are considered as a part of the total available ground-water supply.

The following summarizes these estimates:

Aquifer	*Theoretical Yield (mgd)*
Deposits of Pleistocene age	4.8
Monmouth Formation	.6
Magothy Formation	3.8
Patapsco and Raritan Formations	
Upper sand	2.4
Lower sand	5.0
Total	16.6

Thus, about 16 mgd is the theoretical limit of ground water which could be withdrawn from aquifers in the Waldorf area if the aquifers were to be pumped at rates close to their limit. The analysis on which the estimate is based does not take into account vertical leakage between aquifers and assumes an idealized configuration of the aquifers. Hydraulic interference resulting from pumping beyond the limits of the area would, of course, reduce the quantity available.

LA PLATA AREA

The La Plata area, as defined in this report, includes about 24 square miles in the central upland part of the county (fig. 18). La Plata is the county seat and is bisected by U. S. Route 301 and Maryland Route 6. In 1960 La Plata had a population of about 1,200.

In 1962 the town's water supply came from three drilled wells, 580, 598, and 637 feet deep. The wells were not metered and reliable figures of pumpage are not available, but during 1962 the estimated average ground water consumption was about 0.11 mgd. In 1964 a fourth well was drilled to a depth of 1,155 feet. This well was completed and added to the supply system.

The total thickness of sedimentary deposits underlying the La Plata area is estimated to be about 1,600 to 1,700 feet. Figure 5, a map of the altitude of

the top of the crystalline rocks, shows that the −1,400 and −1,500-foot contours pass immediately west and east of the town, respectively.

The La Plata area straddles a structural ridge or "high" as shown by the contours on figures 12, 13, and 15. This ridge is the southward extension of the same feature mapped in the Brandywine area of Prince Georges County. Figure 15, showing by contours the top of the Aquia Greensand, indicates that closure, or reversal of dip of the strata amounts to about 60 feet in the vicinity of La Plata. The anticline appears to flatten out or become less distinctive in the deeper strata as it is shown in figure 12 (map of the altitude of the middle sands of the Patapsco and Raritan Formations) mainly as a repetition of the −400-foot contour. The significance of this structural ridge with regard to the occurrence of ground water is not apparent, but its existence may possibly relate to permeability distribution in the aquifers.

Most of the information concerning the geology of the La Plata area is obtained from the record of well -Ce 35. This well is immediately south of the town limits between U. S. Route 301 and St. Marys Avenue at an altitude of about 165 feet. Below are the approximate positions of some of the geologic units penetrated by the well:

Depth Interval, in Feet below Sea Level	*Thickness (in feet)*	*Geologic Unit*
95–229	134	Aquia Greensand
403–440	37	Patapsco and Raritan Formations (middle sand)
893–949	56[8]	Patuxent(?) Formation (upper sand)

The Aquia Greensand, although more than 130 feet thick in the log of well -Ce 35, is not an aquifer in the La Plata area. However, it does yield water to domestic wells along the Port Tobacco River to the south.

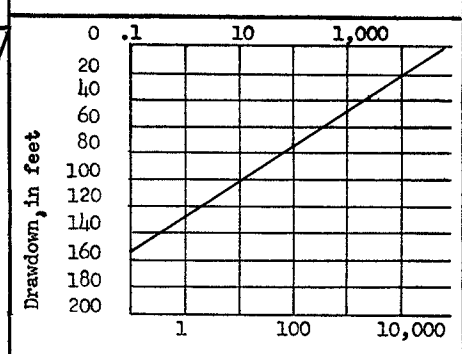
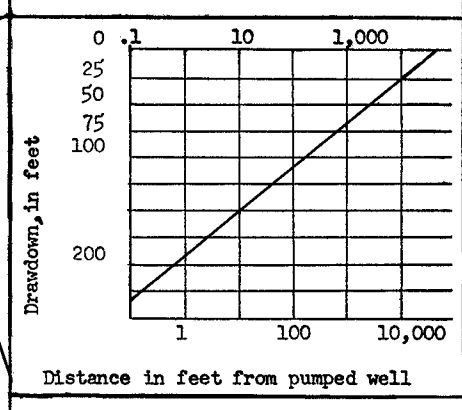
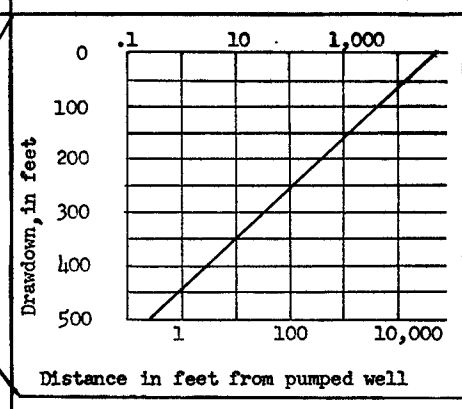
The Monmouth Formation is not considered to be a major aquifer at La Plata, although it has been tapped by well -Ce 6 at the Army Radio Receiving Station, about 2 miles northeast of La Plata. This well yields about 40 gpm and has 17 feet of screen at an altitude of −219 to −236 feet. No wells are known to produce from this aquifer south or west of the Receiving Station.

The Magothy Formation, an important aquifer in the Waldorf area, does not appear to be present at La Plata, although it may occur in a few wells immediately north of the town. If it is present to the north, it probably would be thin and incapable of producing more than domestic supplies of water.

The upper and middle sands of the Patapsco and Raritan Formations and an upper sand in the Patuxent Formation appear to be the most reliable source of ground water in the La Plata area. Well -Ce 30, drilled for the town of La Plata in 1959, was screened opposite five zones in the upper and middle sands of the Patapsco and Raritan Formations and yet the total screen length was

[8] Includes some streaks of gray silty clay.

LA PLATA

GEOHYDROLOGY				QUALITY OF WATER		QUANTITY OF WATER — Data Used in Computations							
						Aquifer Properties		Hypothetical Well Field					
Geologic Unit	Position relative to sea level (ft)	Composite geologic section	Aquifer or Aquiclude	No. of analyses	Range in chemical constituents and properties of ground water (in ppm except for pH)	Transmissibility (gpd/ft)	Storage coefficient (S)	Available drawdown (ft)	Number of wells	Spacing between wells (ft)	Pumping rate per well (gpm)	Distance - drawdown graph for 1,000 days of pumping	Estimated quantity of water available (mgd)
Pleistocene Deposits			Aquifer 1/	2	Iron (Fe) 0.07 - 2.4								
Calvert Formation	+100		Aquiclude	2 2 2	Chloride (Cl) 3.8 -41 Hardness as $CaCo_3$ 41 -75 pH 6.8 - 6.9								
Nanjemoy Formation	Sea Level		Aquiclude										
	-100												
Aquia Greensand			Aquiclude										
	-200												
Patapsco and Raritan Formations — Upper Sands 2/			Aquiclude										
	-300		Aquifer	2 2 2	Iron (Fe) 0.10 Chloride (Cl) .5 - 4.0 Hardness as $CaCo_3$ 8 -12	2,000 3/	.0001 3/	300	7	5,280	100		1.0
			Aquiclude	2	pH 5.8 - 7.9								
	-400		Aquifer										
Middle Sands			Aquiclude	2 2 2	Iron (Fe) 0.20 - 0.30 Chloride 3.5 Hardness as $CaCo_3$ 2.0 - 6.0	1,500	.0001	400	7	5,280	112		1.1
	-500			2	pH 7.0 - 7.2								
Lower Sands	-600		Aquiclude										
	-700												
Patuxent Formation	-800		Aquiclude										
			Aquifer 1/										
	-900		Aquiclude										
	-1,000		Aquifer	2 2 2	Iron (Fe) 0.3 - 1.2 Chloride (Cl) 2 - 4 Hardness as $CaCo_3$ 2 - 3	1,000	.0001 3/	900	7	5,280	175		1.8
			Aquiclude	2	pH 7.3 - 7.9								
	-1,200												

1/ Omitted from estimate because of the limited supply available per individual well.

2/ Wells are multiple screened opposite the individual aquifers.

3/ Estimated value.

23. Chart showing geologic, chemical, and hydrologic data used in estimating the availability and quality of water in the La Plata area.

only 36 feet. This well yielded only 200 gpm and had a specific capacity of 0.8 gpm/ft of drawdown, a relatively low value.

The Patuxent Formation, which yields water to well -Ce 35, is not much better than the Patapsco and Raritan Formations in terms of well productivity. Well -Ce 35 contains 56 feet of screen and yielded about 240 gpm when tested in 1964.

Water levels in the deeper artesian strata may be declining in the La Plata area. The static level in well -Ce 18, drilled to the Patuxent Formation at the Radio Receiving Station, was reported to be 7 feet above sea level in 1956 at the time of completion of the well. The static level in well -Ce 35, also drilled to the Patuxent Formation, was reported to be about 5 feet below sea level in 1964. If the initial static level in the two wells was at the same approximate altitude prior to drilling, then the difference of 12 feet would indicate a decline in the water level in the aquifer of 12 feet during the 8-year interval. The two wells are about 2½ miles apart.

No aquifer tests were run in the La Plata area, but the coefficients of transmissibility of the aquifers were estimated on the basis of lithologic character and thickness of the sands and from the reported specific capacities of wells. The upper sands of the Patapsco and Raritan Formations are estimated to have a transmissibility of about 2,000 gpd/ft, the middle sands about 1,500 gpd/ft, and the upper sand in the Patuxent Formation about 1,000 gpd/ft.

YIELDS OF WELLS

The yields of moderate to high-capacity wells in the La Plata area range from 40 to 240 gpm. The most productive well, Ch-Ce 35, drilled for the town of La Plata is screened opposite a sand in the upper part of the Patuxent Formation at an altitude of −893 to −949 feet. This well is 10 inches in diameter and had a specific capacity of 0.9 gpm/ft of drawdown when tested in January 1965. Another well Ch-Ce 18, screened opposite a sand at an altitude of −979 to −1,014 feet in the Patuxent yielded 210 gpm in 1956. Table 9 lists the yields and construction data for eight wells in the area.

Specific capacities of wells shown in table 9 range from 0.4 to 1.3 gpm/ft of drawdown. The measured specific capacity of 1.3 gpm/ft in well -Ce 18 was the highest of any well in the area. At the termination of the test on this well the pumping level was about 828 feet above the top of the well screen. Thus, substantial additional drawdown was available at the time of the original test.

From the data in table 9 it appears that wells yielding more than 240 gpm in the La Plata area must be considered exceptional. Possibly the yields of new wells could be increased by screening opposite all known aquifers and by more adequate well development.

QUANTITATIVE ESTIMATES

Figure 23 summarizes the geologic, chemical, and hydrologic data for the uppermost 1,200 feet of sedimentary strata in the La Plata area. The left-hand

TABLE 9

DATA FOR HIGH-CAPACITY WELLS IN THE LA PLATA AREA

U.S.G.S. Well Number[1]	Owner's Name or Designation	Owner's Number and Date Drilled	Altitude of Land Surface (feet)	Depth of Well (feet)	Casing Diameter (inches)	Depth of Screen below Land Surface (feet)	Depth of Water Level below Land Surface (feet)			Yield (gpm)	Specific Capacity (gpm/ft of Drawdown)	Well Status (1962)	Aquifer
							Static	Pumping	Date				
Ch-Ce 3	Town of La Plata	1 (1929)	186.0	580	10	—	160		1929	60		Not in use; obs. well	Patapsco-Raritan
Ch-Ce 4	Do.	2 (1936)	187.9	652	8 6	—	231.49	—	4/3/63		—	In use	Do.
Ch-Ce 8	Do.	3 (1947)	149.4	1,094	10 8 6	—	135	420	11/19/47	100	.4	Do.	Patuxent
Ch-Ce 16	Do.	4 (1950)	188.2	608	8 6	583–598	190 204.92 204.6	— — —	10/30/50 1960 5/1/63	60	—	Not in use; obs. well	Patapsco-Raritan
Ch-Ce 30	Do.	5 (1959)	190.6	637	16 10 6	493–502 519–525 569–578 618–625 632–637	170	414	6/1/59	200	.8	In use	Do.
Ch-Ce 35	Do.	6 (1964–65)	165	1,252	10 6	1058–1114	165	430	1/–/65	240	.9	—	Patuxent
Ch-Ce 6	U. S. Army	1 (1943)	196	432	8 6	415–432	148.8 —	— 260	7/26/61 9/9/57	40	—	In use	Monmouth
Ch-Ce 18	Do.	3 (1959)	197	1,219	8 6	1178–1211	190	348	11/17/58	210	1.3	Do.	Patuxent

[1] Location of wells shown in Maryland Geological Survey Water Resources Basic Data Report 2 (1966).

side of the figure shows a composite geologic section based on the logs of a few deep wells near La Plata. The geologic units, drawn to scale, are arbitrarily designated as aquifers or aquicludes, and on the right-hand side of the figure, under the heading "Quantity of Water" the aquifers are assigned coefficients of transmissibility and storage.

Based on the Theis equation and using realistic rates of pumping, distance-drawdown graphs were prepared for each aquifer. The graphs, on the right-hand side of the figure, show the predicted decline in water levels caused by one well pumping continuously for 1,000 days at the rate indicated.

The analysis made is based on the additional assumption that each aquifer will be tapped by a line of 7 wells spaced 1 mile apart and centered along a line parallel to the strike of the formations and in the central part of the rectangular 24-square mile area. The hydraulic interference of each well on the water level in the other 6 wells is summed and the limiting drawdown is assumed to be at the top of the aquifer in the middle well in the line of wells. Thus, the distance-drawdown graph for a single well pumping 175 gpm from a sand in the Patuxent Formation shows that the self drawdown (radius of 0.5 foot) will be about 470 feet and at a distance of 1 mile the pumping well will have lowered the water level in the aquifer about 100 feet. The combined yield of all seven wells tapping the same sand would be 1225 gpm, or 1.8 mgd. A similar analysis shows distance-drawdown graphs for the two other important aquifers in the La Plata area. The right hand column of figure 23 summarizes, in mgd, the combined yield of the well groups tapping the various aquifers.

The Pleistocene deposits, although considered to be an aquifer in the La Plata area, are not capable of yielding more than a few gallons a minute to individual wells, and as such are not included in the quantitative estimates.

The total quantity of 3.9 mgd believed to be available from the aquifers in the La Plata area is many times more than the quantity of 0.11 mgd reportedly pumped during 1962 from the municipal wells. The analysis used to determine the total available supply assumes that the aquifers are infinite in extent and that no vertical leakage occurs between aquifers. Since some of the sands at La Plata may be discontinuous and occur as isolated lenses, water levels may decline at more rapid rates than those predicted by the computations and hence the quantity of water available may be less than the 3.9 mgd estimated. If vertical leakage occurs, however, this would permit downward movement of water from the shallower strata to the deeper strata. Such leakage would cause the water-level decline in the aquifers to be less than predicted. In summary, the prospect of obtaining large additional supplies of ground water does not appear favorable in the La Plata area, and future large water requirements will have to be met from other sources.

POPES CREEK-MORGANTOWN AREA

The Popes Creek-Morgantown area, as designated in this report, includes about 24 square miles of land and water in the south-central part of the county

(fig. 18). The area extends across the Potomac River to include a small part of Virginia and it includes, in Maryland, the small towns of Newburg, Popes Creek, and Morgantown. The area is traversed by U. S. Route 301 and includes the Potomac River bridge. The Maryland part of the area is largely rural and had an estimated population in 1960 of about 1,000. Several motels, restaurants, and small commercial establishments are located along Route 301.

The area is entirely dependent on ground water for water supply and the 1962 use, based on the estimated population was about 100,000 gpd. An additional 500,000 gallons a day was pumped from deep wells at the Dahlgren Naval Proving Ground in Virginia.

The topography of the area is characterized by moderate relief with uplands dissected by small streams. The land surface altitude at Newburg is about 140 feet. A terrace of Pleistocene or Recent age underlies a few square miles of one in the vicinity of Morgantown; the upper edge of this terrace is about 40 feet above sea level.

The thickness of sedimentary deposits underlying the area ranges from about 1,700 to 1,900 feet, as shown on the contour map of the crystalline-rock surface (fig. 5). Several water-bearing sands appear to be present in the sediments and they occur at depths of from less than 100 to more than 600 feet. A precise determination of the top of the Patuxent Formation is not possible on the basis of existing information, but it is believed to occur between 750 and 850 feet below sea level.

Data concerning the character of the uppermost 759 feet of strata in the Popes Creek-Morgantown area are available from the driller's log of well Ch-De 32 drilled in 1963 for the American Telephone and Telegraph Co. at a site about 0.5 mile south of the crossroads town of Faulkner. The altitude of this well is approximately 155 feet. The geologic classification and the driller's description of strata encountered in the well is as follows:

Description	*Thickness (in feet)*	*Geologic Unit*
Clay, gray, and thin layers sand	22	Pleistocene deposits
Gravel, coarse, and sand, white		
Sand, silty, gray, fine and layers green clay	123	Calvert(?) Formation
Clay, dark green and thin layers of sand		
Clay, sandy, greenish, soft		
Clay, green, soft		
Rock	175	Nanjemoy Formation
Clay, muddy, black		
Clay, sandy, black, with thin layers clam shells		
Clay, silty, black, with thin layers clam shells		
Clay, black and gray, muddy, and thin layers sand		
Sand, silty, black, and clay		
Hardpan		
Sand, black, silty, and shells		

Description	*Thickness (in feet)*	*Geologic Unit*
Clay, dark gray, and shells		
Clay, mixed gray and red, and thin shell layers		
Shellrock	88	Aquia Greensand
Shellrock and sand, black, silty, mixed		
Clay, mixed green, gray and brown, and shell rock		
Clay, green and gray, sandy; thin layers of shell		
Clay, gray, silty, and shell in thin layers		
Clay, brown, gray and white, hard	351	Patapsco and Raritan Formations
Clay, as above, with streaks wood		
Clay, light green, sandy, and streaks of wood		
Clay, green and brown		
Clay, gray, soft		
Sand, medium gray and black (water); streaks white clay		
Clay, yellow, brown and green, hard		
Sand, black and white		
Clay, gray, hard		
Sand streaks, coarse, with wood and clay, gray		
Clay, red, white, yellow and gray, with wood		
Sand streaks and clay, white, red and yellow		
Sand, brown and black, with streaks white clay and wood		
Clay, mixed, very hard		
Clay, red and white, very hard		
Clay, yellow, brown and white, very hard		
Clay, mixed, hard, dry		

Information on the geology of the deeper strata is based primarily on the driller's logs of two deep wells at the U. S. Naval Proving Ground at Dahlgren, Va. The approximate thickness, depth intervals, and water-bearing geologic units penetrated in one of these wells (No. 12) follow:

Description	*Depth Interval, in Feet below Sea Level*	*Thickness (in feet)*	*Geologic Unit*
Gray sand	357–370	13	Raritan Formation
Sand	471–476	5	Patapsco and Raritan (upper sand)
Medium gray and white sand	663–722	59	Patapsco and Raritan (lower sand)

The deposits of Pleistocene and Recent age in the Popes Creek-Morgantown area, are not considered to be an important ground-water source except for shallow farm and domestic wells. However, these deposits have an important role in the geohydrology of the area as they extend beneath the Potomac River and fill the pre-Pleistocene river channel. They form an irregularly distributed mantle of silt, sand, gravel, and mud lying between the

brackish river water and the underlying Eocene and Cretaceous formations. Figure 24, compiled from borings made prior to the construction of the Potomac River bridge near Morgantown, shows the nature of the sub-river deposits at this place. It should be noted on the figure that at a point about 3,500 feet east of the Virginia shore the basal river gravels are nearly in contact with the Aquia Greensand, a fresh-water aquifer. However, the existence of a blanket of alluvial river mud, several feet thick, overlying the basal gravels and extending across most of the river channel probably serves as a confining layer. The presence of this layer would restrict the movement of brackish river water into the Aquia if heavy pumping from it were to create a cone of depression sufficiently large to induce downward vertical movement of water from the river.

The Aquia Greensand underlies all of the Popes Creek-Morgantown area, but is used primarily as a source of supply for domestic wells along the Potomac River and upper Wicomico River shores. The altitude of the top of the formation ranges from −140 to −200 feet below sea level. With the exception of well -Ef 14, an irrigation well located near Newport, no large-capacity wells tap the Aquia.

Figure 16, showing the piezometric surface of the Aquia Greensand, indicates that in the northern part of the area the hydraulic head is about 15 feet above sea level and near Morgantown the head is about 5 feet above sea level. As part of the field studies made in connection with this report measurements were made of the rate of discharge of 15 flowing wells in the area. The measurements showed that in 1962 the combined flow from the aquifer amounted to about 60,000 gpd, or about 22 million gallons a year. Most of this water flows to waste.

Aquifer tests run on flowing wells tapping the Aquia Greensand indicate an average coefficient of transmissibility of about 2,000 gpd/ft, but as most of the wells on which the tests were run are screened opposite only a segment of the aquifer, the value obtained is probably not representative of the entire aquifer thickness.

Using pumping wells and observation wells, where available, aquifer tests were made of the important aquifers in the area. These data, including three tests on the Aquia Greensand are summarized in table 10.

On the basis of the data in table 10, the weighted average coefficient of transmissibility of the Aquia Greensand is about 5,000 gpd/ft. This value is nearly the same as the value of 4,000 gpd/ft reported for extreme southern Prince Georges County by Mack (1966, p. 46).

The Magothy Formation is not known to occur in the Popes Creek-Morgantown area as it apparently wedges out a few miles to the north (fig. 14). The absence of the Magothy Formation has necessitated drilling to the Raritan and Patapsco Formations, in which the lower sand appears to be the thickest and most productive zone. The lower sand, at an altitude of 650 to 700 feet

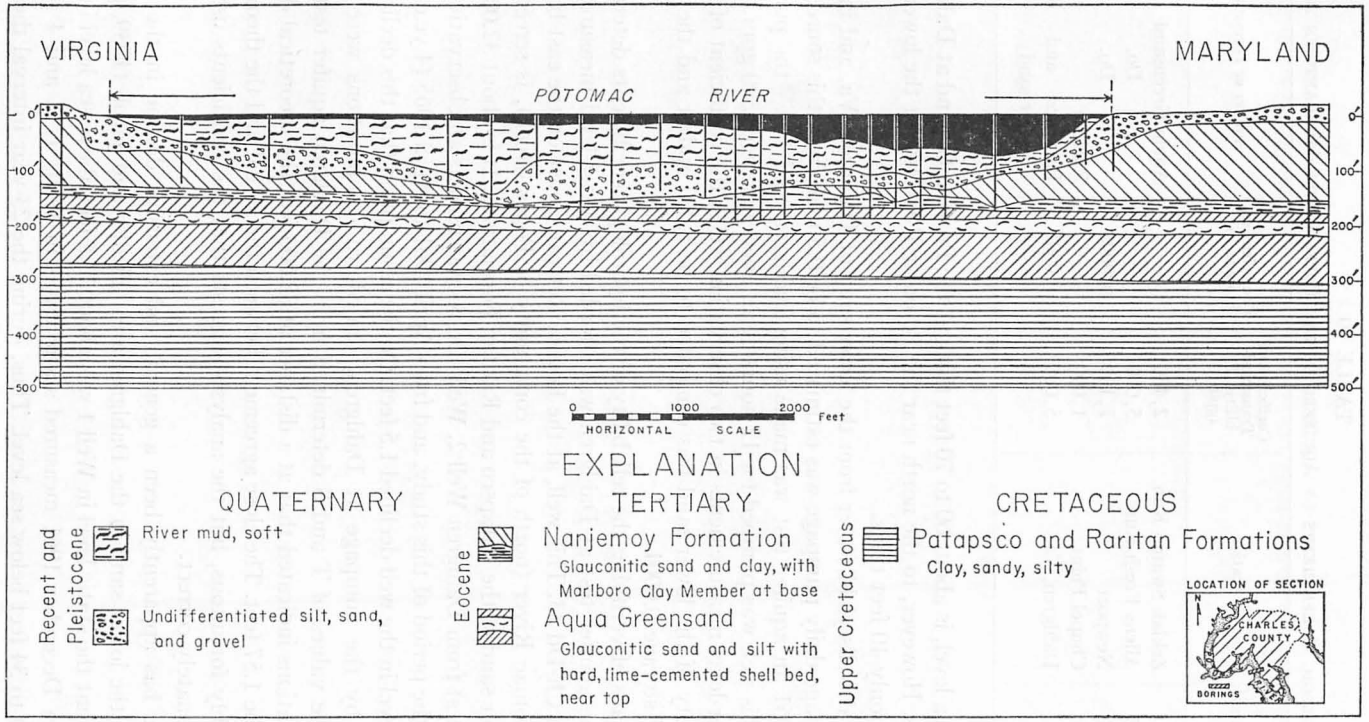


FIGURE 24. Geologic section at the Potomac River bridge on U. S. Route 301 near Morgantown.

TABLE 10

HYDROLOGIC COEFFICIENTS OF AQUIFERS IN THE POPES CREEK-MORGANTOWN AREA

Well Number	Location	Coefficient of Transmissibility (*T*) (gpd/ft)	Coefficient of Storage (*S*)	Aquifer or Formation
Ch-De 5	Zekiah Swamp Run	2,450	—	Aquia Greensand
Ch-Ee 63	Allens Fresh Run	5,000	—	Do.
Ch-Ef 14	Newport	7,100	0.0003	Do.
Ch-Dd 9	Chapel Point	1,000	—	Raritan
No. 10	Dahlgren, Va.	5,000	.0001	Patapsco and Raritan (lower sand)

below sea level, is about 60 to 70 feet thick at the Proving Ground at Dahlgren, Virginia. However, to the north near the Potomac River bridge the lower sand may be only 40 feet thick.

Several wells yield water from the lower sand at Dahlgren, Va. and in 1962 the average daily pumpage was estimated to be 0.5 mgd from this source.

In 1961 an aquifer test was made using Dahlgren well 10 as the pumping well. This well was pumped for 12 hours at an average rate of 390 gpm. Based on water-level measurements in two observation wells, the coefficient of transmissibility of the lower sand was computed to be 5,000 gpd/ft and the coefficient of storage 0.0001.

A means of verifying the reliability of the hydrologic coefficients determined from the aquifer test at Dahlgren was afforded by water-level measurements made in Ch-Dd 33. This well, at the Loyola Retreat House on the east bank of the Potomac River (north of the community of Popes Creek), is screened in the lower sand of the Patapsco and Raritan Formations. It is about 32,000 feet (6.1 miles) from Dahlgren Well 2. Well -Dd 33 was used as an observation well during the period of this study, and from April 1961 to April 1965 (4 years) the water level in the well declined 1.5 feet. On the assumption that this decline was caused by the pumpage at Dahlgren, drawdown computations were made using the values of T and S determined from the Dahlgren aquifer test. The computations indicated that at a distance of 32,000 feet the theoretical decline should be 1.57 feet. The close agreement between the actual and the theoretical is possibly fortuitous, but the analysis suggests that the coefficients used are approximately correct.

There has apparently been a general and extensive decline in the water level in the lower sand in the Dahlgren area. Fiedler and Jacob (1939, p. 18) report that the static level in Well 1 was about 13.5 feet above sea level in May 1938. In December 1961 measured static levels in Wells 1, 2, and 4 ranged from 30 to 34 feet below sea level. Thus, during the 23-year interval there has been a general lowering of water levels in the aquifer of at least 44 feet in the

Dahlgren area. The effect of this decline extends beneath the Potomac River into Charles County 6 to 8 miles from the center of pumpage at Dahlgren.

The development of large ground-water supplies from the lower sand in the Patapsco and Raritan Formations in the Popes Creek-Morgantown area, therefore, must be based on the understanding that there will be hydraulic interference by pumping from the aquifer at Dahlgren.

An aquifer test, based on water-level recovery measurements, was made on well Ch-Dd 9 located near the mouth of the Port Tobacco River. This well, 240 feet deep, is screened opposite a sand in the Raritan Formation. The transmissibility computed from the test was about 1,000 gpd per ft, a relatively low value. No storage coefficient could be obtained.

YIELDS OF WELLS

Yields of the most productive wells in the Popes Creek-Morgantown area range from 25 to 530 gpm. Table 11 lists the yields and construction data for 12 wells in the area. Specific capacities of these wells range from 0.2 to 3.3 gpm/ft.

Data in table 11 show that the three most productive wells are at the Dahlgren Proving Ground and are screened opposite aquifers in the Patapsco and Raritan Formations. None of the wells in Charles County for which data is shown in table 11, with the possible exception of -Ee 57, have been completed opposite the lower sand in the Patapsco and Raritan Formations, but there is reason to believe that the same aquifer, which is productive in Virginia, would be equally productive across the Potomac River in Maryland. Proof of this supposition must await future development of ground-water supplies from the aquifer.

Yields of wells ending in the Aquia Greensand (table 11) range from 25 to 200 gpm, but the best well is screened opposite 33 feet of the aquifer, which is from 90 to 100 feet thick. Based on well yields and specific capacities from nearby localities, the Aquia is believed capable of supplying wells having higher yields than the existing wells in the Popes Creek-Morgantown area. Using the hydrologic coefficients determined for the aquifer (table 10), it is possible to compute the maximum theoretical yield available from wells in the aquifer based on specified drawdown limits. The computations indicate that wells having 100 percent efficiency and an available drawdown of 180 feet should theoretically be capable of furnishing relatively large quantities of water. The formula used and the computations are:

$$Q = \frac{T}{114.6\ W(u)}\ s$$

$$Q = \frac{5{,}000}{114.6 \times 26.0}\ 180 = 302 \text{ gpm (theoretical maximum)}$$

TABLE 11

DATA ON HIGH-CAPACITY WELLS IN THE POPES CREEK-MORGANTOWN AREA

U.S.G.S. Well Number[1]	Owner's Name or Designation	Owner's Number and Date Drilled	Altitude of Land Surface (feet)	Depth of Well (feet)	Casing Diameter (inches)	Depth of Screen Below Land Surface (feet)	Depth of Water Level below Land Surface (feet)			Yield (gpm)	Specific Capacity (gpm/ft of Draw-down)	Well Status (1962)	Aquifer
							Static	Pump-ing	Date				
Ch-De 30	Never Never Land	1962	151.4	618	4								
					3	474–484	138.9	—	12/5/61			Not in	Patapsco-Raritan
					2	608–618	142	178	1/20/62	25	0.7	use	
Ch-Ee 8	Potomac Enterprises Inc.	—	3.5	218.8	$1\frac{1}{2}$	—	Flows +2.58	—	1/22/47	—	—	In use	Aquia Greensand
Ch-Ee 39	F. C. Pace	1947	60	310	6	300–310	30	—	6/21/47	40	—	Do.	Do.
Ch-Ee 44	Wallace E. Bowling	1948	50	293	$3\frac{1}{2}$								
					$2\frac{1}{2}$								
					$1\frac{1}{2}$	273–293	30	—	9/—/48	25	—	Do.	Do.
Ch-Ee 47	Wayside Elementary School	1951	115	523	6	518–523	115.04	230	7/—/51	70	.6	Do.	Raritan
Ch-Ee 48	Joseph H. Farrell	1959	102	365	4	355–365	110	145	3/27/59	45	1.3	Do.	Aquia Greensand
Ch-Ee 49	Aqualand	1959	8	369	6	345–355							
					4	364–369	9	225	6/15/59	54	.3	Do.	Raritan
Ch-Ee 51	Southern Maryland Oil Co.	1960	114.7	365	$2\frac{1}{2}$	350–365	125	146	8/24/60	25	1.2	Do.	Aquia Greensand
Ch-Ee 52	White House Motel	1953	145	365	6	353–365	125	162	5/28/53	60	1.6	Do.	Do.
Va. 4	U. S. Navy, Dahlgren, Va.	4 (1951)	15	780	6	695–735	34	—	12/19/61	250	—	Not in use	Patapsco-Raritan
Va. 10	Do.	10 (1959)	17	753	10	674–740	63	198	1959	370	2.7	In use	Do.
Va. 12	Do.	12 (1962)	15	745	10	682–738	48	205	1962	530	3.3	Do.	Do.

Ch-Ee 53	Thunderbird Motel	1953	140	505	6	499–505	130	250	5/15/53	45	0.4	In use	Raritan
Ch-Ee 54	Shell Oil Co.	1953	145	465	6	459–465	170	220	10/28/53	15	.3	Do.	Do.
Ch-Ee 56	A. H. Zimmerman	1960	145	504	4								
					2	493–503	130	153	12/10/60	16	.7	Do.	Do.
Ch-Ee 57	George Robertson	1960	3	550	4	314–319							
					2	370–375	Flows		8/—/60				
						540–545	0.0	—	7/18/61	—	—	Do.	Patapsco-Raritan
Ch-Ee 58	Atlee Rogers	1955	118	385	4	335–340							
						380–385	106	160	8/28/55	40	.7	Do.	Aquia Greensand
Ch-Ee 59	Thomas Lowery	1961	130.4	347	2½		120	145	4/10/61				
					2	327–347	117.79	—	4/13/61	5	.2	Do.	Do.
Ch-Ee 60	Leslie Drinks	1959	3	305	6	296–306	2	20	9/30/59	20	1.1	Do.	Raritan
Ch-Ef 14	Walter Bowling	1957	8	300	6	217–220	Flow-	—	12/18/57	200	—	Do.	Aquia Greensand
						229–244	ing						
						265–270							
						290–295							
						295–300							

[1] Location of wells shown in Maryland Geol. Survey Water Resources Basic Data Report 2 (1966).

where:

Q = well discharge, in gpm

T = transmissibility, in gpd/ft

s = average available drawdown in the aquifer, in feet

$W(u)$ = well-function of u, described by Ferris and others (1962, p. 93) and used in the Theis equation

However, as even the best wells are only 50 to 80 percent efficient, probably about 150 to 240 gpm is the maximum practical limit of yield per individual well.

QUANTITATIVE ESTIMATES

Figure 25 summarizes the geologic, chemical quality, and hydrologic data for the uppermost 900 feet of strata in the Popes Creek-Morgantown area. Six aquifer zones are shown in the composite geologic section on the left side of the figure. Only three of the six aquifers are believed to be capable of yielding significant quantities of water to wells; these are the Aquia Greensand, an upper sand in the Raritan Formation, and the lower sands of the Patapsco and Raritan Formations.

The figure shows that seven properly spaced wells, pumping at a rate of 100 gpm each, would yield about 1.0 mgd of water from the Aquia Greensand. The rate of 100 gpm per well used in the estimate is a conservative value well below the theoretical maximum yield described previously. The figure shows also that seven properly-spaced wells screened in the upper sand of the Raritan Formation, and pumping 60 gpm each, could be expected to yield a total of 0.5 mgd of water. This quantity is based on a limiting available drawdown of 300 feet in the aquifer. A similar analysis for the lower sands in the Patapsco and Raritan Formations indicates they should be capable of producing about 4.5 mgd.

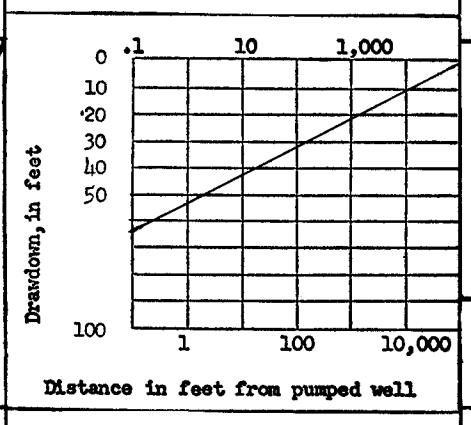
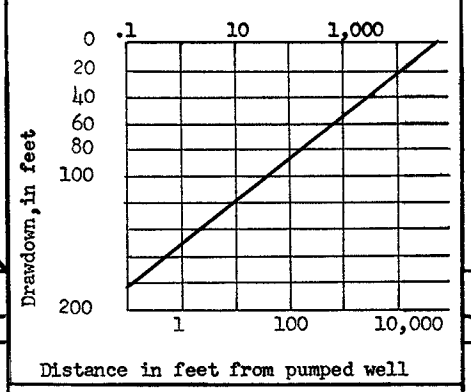
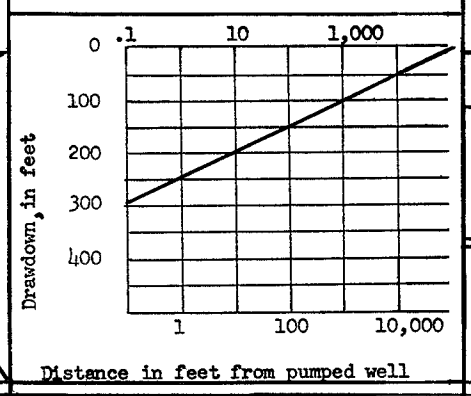
The following is a summary of the estimated yields of the aquifers in the Popes Creek-Morgantown area:

Aquifer	*Theoretical Yield (mgd)*
Aquia Greensand	1.0[9]
Raritan Formation	.5
Patapsco and Raritan Formations	
Lower sands	4.5
Total	6.0

The method of analysis used above is subject to the same limitations described in previous sections of this report. To be valid it must be assumed that the aquifers are infinite in extent, that the coefficients of transmissibility and

[9] The drawdown computations used to derive this quantity are based on an assumed aquifer boundary 1 mile west of the line of wells.

POPES CREEK-MORGANTOWN

GEOHYDROLOGY				QUALITY OF WATER		QUANTITY OF WATER							
						Data Used in Computations							
						Aquifer Properties		Hypothetical Well Field					
Geologic Unit	Position relative to sea level (ft)	Composite geologic section	Aquifer or Aquiclude	No. of analyses	Range in chemical constituents and properties of ground water (in ppm except for pH)	Transmissibility (gpd/ft)	Storage coefficient (S)	Available drawdown (ft)	Number of wells	Spacing between wells (ft)	Pumping rate per well (gpm)	Distance - drawdown graph for 1,000 days of pumping	Estimated quantity of water available (mgd)
Pleistocene Deposits			Aquifer	3/									
Calvert Formation	+100		Aquiclude	2 2 2 2	Iron (Fe) 0.74 - 1.4 Chloride (Cl) 4.0 - 6.2 Hardness as $CaCo_3$ 46 -52 pH 6.5 - 6.8								
Nanjemoy Formation	Sea Level -100		Aquiclude										
Aquia Greensand	-200		Aquiclude Aquifer Aquiclude	3 3 3 3	Iron (Fe) 0.01 - 8.2 Chloride (Cl) 1.3 - 2.2 Hardness as $CaCo_3$ 15 -21 pH 7.5 - 8.6	5,000	.0001	180	7	5,280	100		1.0
Raritan (?) Formation	-300		Aquiclude Aquifer Aquiclude	2 2 2 2	Iron (Fe) 0.11 - .34 Chloride (Cl) 2 - 3 Hardness as $CaCo_3$ 6 -20 pH	1,000 2/	.0001 2/	300	7	5,280	60		0.5
Patapsco and Raritan Formations: Upper Sands	-400		Aquiclude										
Patapsco and Raritan Formations: Middle Sands	-500		Aquiclude Aquifer	1/									
Patapsco and Raritan Formations: Middle Sands	-600		Aquiclude										
Patapsco and Raritan Formations: Lower Sands	-700		Aquifer Aquiclude	6 6 6 6	Iron (Fe) 0.00 - .84 Chloride (Cl) 1.6 - 7.7 Hardness as $CaCo_3$ 0 - 8 pH 7.7 - 8.3	5,000	.0001	600	7	5,280	450		4.5
Patuxent Formation	-800		Aquiclude Aquiclude Aquifer Aquiclude	1/									
	-1,000												

1/ May be absent in part of area; insufficient data available for quantitative estimate.

2/ Estimated value.

3/ Omitted from estimate because of the limited supply available per individual well.

25. Chart showing geologic, chemical, and hydrologic data used in estimating the availability and quality of water in the Popes Creek-Morgantown area.

storage do not change markedly within the area, and that vertical leakage does not occur in significant quantities into or out of the aquifers. It is likely that the greatest source of error in the analysis used, with regard to the sands in the Patapsco and Raritan Formations, may be caused by thinning or lensing of the water-bearing sands. Where a particular sand occurs as an isolated lense, surrounded by impermeable clay, drawdowns of the water level in the aquifer should be expected to occur much more rapidly than predicted, and the yield of wells tapping a sand under this circumstance will inevitably decrease.

In summary, probably several millions of gallons of water per day are available from the aquifers in the upper 900 feet of strata in the area.

HUGHESVILLE-BENEDICT AREA

The Hughesville-Benedict area as shown in figure 18, is about 6 miles wide and 7 miles long. The area, as designated, includes a small part of Prince Georges County and a somewhat larger part of St. Marys County. The area is mainly rural with a population estimated to be slightly more than 1,000. Much of the area is a dissected upland drained by eastward flowing tributaries of the Patuxent River. The town of Benedict is located along the river at the edge of an eastward-sloping terrace 0.5 to 1 mile wide. Hughesville is located to the west about 200 feet above sea level.

Except for the Potomac Electric Power Company plant at Chalk Point (Prince Georges County) which uses several million gallons of river water a day for cooling, ground water is the only source of water supply for the area. The electric plant also uses some ground water in their boiler system. In 1965 this ground water use amounted to about 0.3 mgd. Use of ground water for all purposes, exclusive of the PEPCO plant at Chalk Point, is estimated to be about 0.1 mgd.

At Benedict the depth to the top of the crystalline rocks is estimated to be about 2,000 feet (fig. 5). The deepest well in the area is PG-Hf 23, drilled in 1962 at Chalk Point; this well was drilled 675 feet deep, or through roughly one-third the total available thickness of sedimentary material.

The surficial deposits at Benedict consist of silt, clay, sand, and gravel of Recent and Pleistocene age. These materials extend beneath the Patuxent River to a depth of about 100 feet below sea level where they form a veneer upon Miocene and Eocene deposits. Details of the nature and extent of the subriver deposits are shown in figure 26 prepared from test bore holes made prior to the construction of the Patuxent River bridge, Maryland Route 231.

Data concerning the character and thickness of the uppermost 675 feet of Coastal Plain deposits in the Benedict area are available from the driller's log of well PG-Hf 23. This well, drilled by the Shannahan Artesian Well Company, was screened opposite a sand in the Magothy Formation. A geologic classification and the condensed driller's description of the strata follow:

Description	*Thickness (in feet)*	*Geologic Unit*
Sand and gravel, yellow brown	18	Pleistocene deposits
Clay, green; tough drilling	278	Calvert and Nanjemoy Formations
Clay, green, with shells		
Clay, sandy, dark green		
Clay, fatty, red (marl)		
Sand, dark green	171	Aquia Greensand
Sand, dark green; some clay		
Sand, green, crusty		
Rock (1 ft. thick)		
Sand dark green		
Sand dark green; shells abundant		
Clay, dark green, sandy		
Rock layer (1 ft. thick)		
Clay, hard	123	Monmouth and Matawan Formations[10]
Clay, sandy		
Clay, dark green; some gravel		
Clay, dark green, with hard layers		
Clay, as above; rock at 531 feet		
Clay, black, some wood		
Clay, light gray		
Sand, light gray and wood	33	Magothy Formation (sand)
Sand, gray, medium to coarse; streaks of clay abundant		
Sand, medium to coarse, light gray		
Clay, tough, red-brown	52	Raritan Formation
Clay, red and white		

Although a few dug and bored wells obtain water from the surficial deposits, the uppermost aquifer of importance in the area is the Aquia Greensand. The top of the Aquia ranges in altitude from 220 to 320 feet below sea level in the Hughesville-Benedict area (fig. 15). At Benedict it is about 170 feet thick and at Hughesville it is about 100 feet thick.

During the past 60 years about two dozen farm and domestic wells have been drilled to the Aquia Greensand in the vicinity of Benedict. Many of these wells have been flowing continuously since they were drilled, although during the past few years some of them have been equipped with shut-off valves.

Figure 16, discussed previously, shows the approximate contour of the piezometric surface in the Aquia Greensand, based mainly on water-level measurements during the period 1960-62. The altitude of the piezometric surface at Benedict as shown is 14 feet and at Chalk Point 19 feet above sea level. At Hughesville to the west, the piezometric surface rises to 32 feet above sea level.

Clark, Mathews and Berry (1918, p. 397) list a well (-Ch 13) drilled in 1908 to a depth of 345 feet. This well was reported to have had an initial static level of

[10] May include the Brightseat Formation.

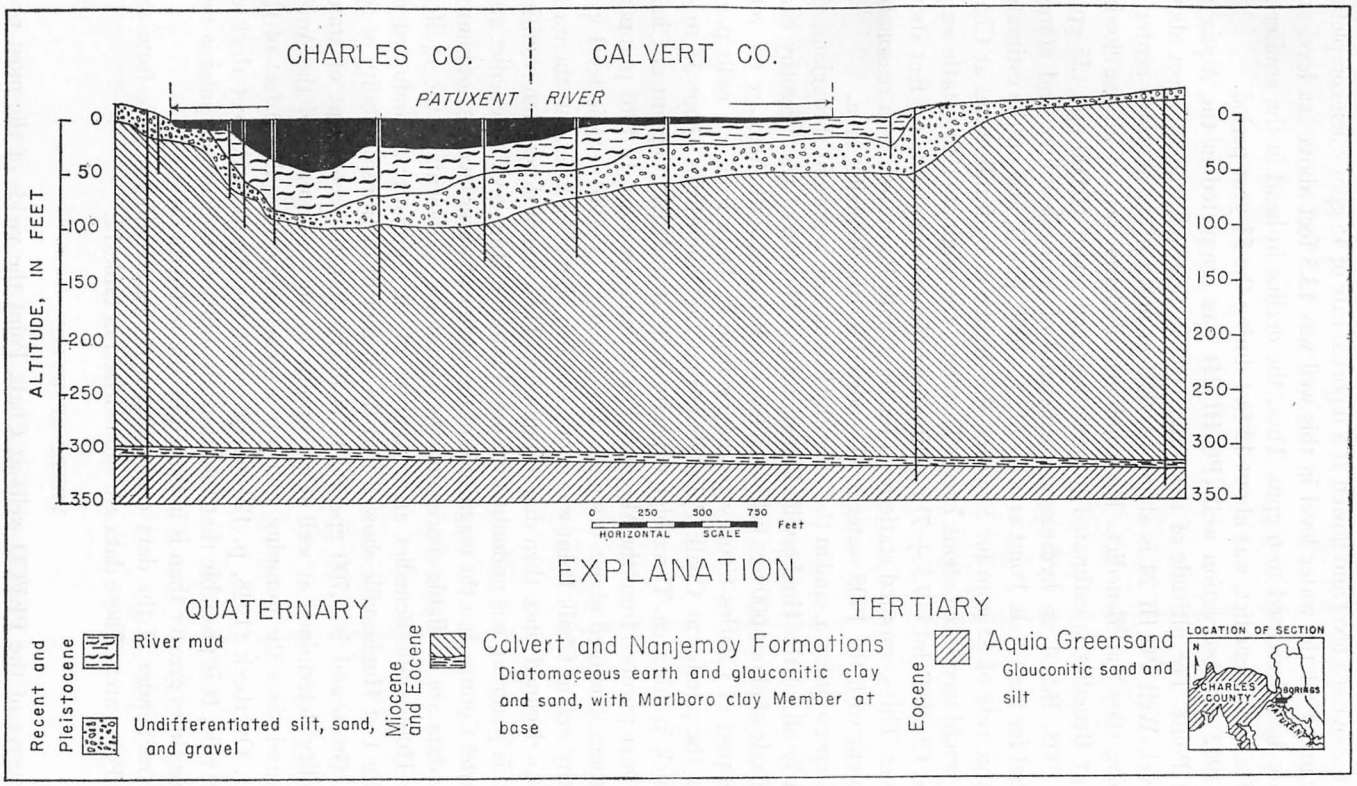


FIGURE 26. Geologic section across the Patuxent River at the bridge near Benedict.

25 feet above sea level and flowed at a reported rate of 45 gpm when completed. In August 1961 the water level in this well was 13.5 feet above sea level and the flow had decreased to 6 gpm. Thus, the decline in head in the aquifer at this site, near Benedict, was about 12 feet during the 53-year period.

In 1962 an observation well (PG-Hf 24) was completed in the Aquia at Chalk Point. The altitude of the water level in this well was 19.5 feet above sea level. Well PG-Hf 24 is about 12,000 feet north of an assumed center of pumping (flow) at Benedict. The combined discharge rate of all the flowing wells at Benedict is estimated to have averaged about 50,000 gpd (35 gpm) since 1908. Based on hydrologic coefficients of transmissibility and storage reported for the Chalk Point area by Mack (1966, p. 43), and on the estimated discharge rate of 35 gpm for 54 years, the decline in hydraulic head at Chalk Point would have been about 7 feet. Therefore, the original (1908) static water level at Chalk Point (19.5 + 7) is estimated to have been about 26.5 feet above sea level. This computed static head for the Chalk Point area is in reasonable agreement with the 1908 water level reported for the Benedict area.

A deeper aquifer, a sand in the Magothy Formation, is present throughout all, or nearly all, of the Hughesville-Benedict area. The top of the Magothy is at an altitude of about 600 feet below sea level at Benedict, but there are no wells in this part of Charles County producing from it. Data from the wells penetrating the aquifer at Chalk Point show that the Magothy is about 33 to 40 feet thick in this area. Three high-capacity wells at the PEPCO plant at Chalk Point have pumped from the Magothy Formation since 1963. In 1965 pumpage from them averaged about 0.3 mgd. The initial (May 1961) static level in a Magothy well at Chalk Point was about 12.7 feet above sea level, but the water level has declined since then due to pumping. The cone of depression resulting from this pumping has undoubtedly spread into the Hughesville-Benedict area of Charles County, but the magnitude of the decline of water levels is not known.

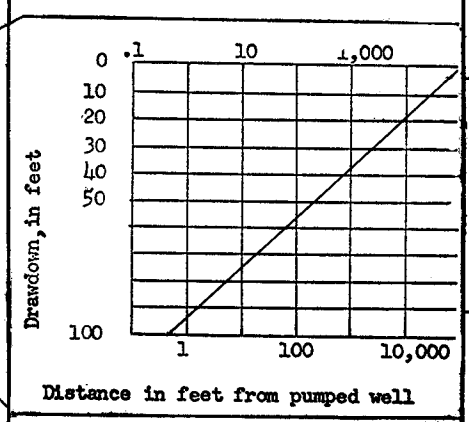
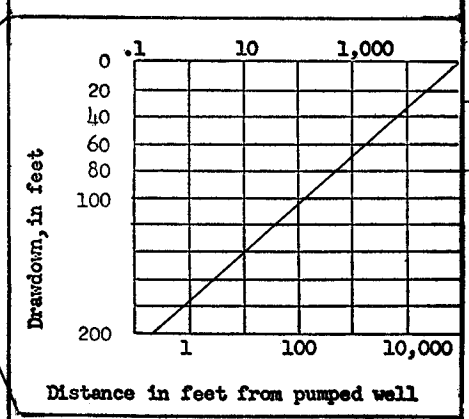
Few data are available concerning the hydrologic coefficients of the aquifers in the Hughesville-Benedict area. Analysis of an aquifer test conducted on well -Cg 1 at Hughesville showed that the coefficient of transmissibility of the Aquia Greensand is 6,700 gpd/ft. It is likely that the coefficient of transmissibility determined at well -Cg 1 applies to only a segment of the Aquia Greensand since the pumping well was screened opposite only 10 feet of the aquifer. Overbeck (1948, p. 124) reports that the Aquia is 83 feet thick at Hughesville. It is probable that the transmissibility of the entire aquifer is two or three times greater than is indicated by the test data on -Cg 1.

The remainder of the data concerning hydrologic coefficients are from the Chalk Point area. These data are summarized in table 12.

YIELDS OF WELLS

Exclusive of the PEPCO wells at Chalk Point the yields of the most productive wells in the Hughesville-Benedict area range from 25 to 60 gpm. These data are summarized in table 13.

HUGHESVILLE-BENEDICT

GEOHYDROLOGY				QUALITY OF WATER		QUANTITY OF WATER — Data Used in Computations: Aquifer Properties		Hypothetical Well Field					
Geologic Unit	Position relative to sea level (ft)	Composite geologic section	Aquifer or Aquiclude	No. of analyses	Range in chemical constituents and properties of ground water (in ppm except for pH)	Transmissibility (gpd/ft)	Storage coefficient (S)	Available drawdown (ft)	Number of wells	Spacing between wells (ft)	Pumping rate per well (gpm)	Distance - drawdown graph for 1,000 days of pumping	Estimated quantity of water available (mgd)
Pleistocene Deposits			Aquifer 1/	1	Iron (Fe) 0.12 Chloride (Cl) 5.5 Hardness as $CaCo_3$ 56 pH 6.6								
Calvert Formation	+100 Sea Level		Aquiclude										
Nanjemoy Formation	-100 -200		Aquiclude										
Aquia Greensand	-300 -400		Aquifer	5 5 5 5	Iron (Fe) 0.01 - 0.38 Chloride (Cl) .3 - 8.8 Hardness as $CaCo_3$ 95 - 126 pH 7.6 - 7.9	5,000	.0001	300	7	5,280	175		1.9
Upper Cretaceous and Eocene Deposits	-500		Aquiclude										
Magothy Formation	-600		Aquifer	4 4 4 4	Iron (Fe) 0.46 - 0.73 Chloride (Cl) .3 - 2.0 Hardness as $CaCo_3$ 87 - 125 pH 7.2 - 8.2	4,500	.00006	550	7	5,280	300		3.0
Raritan Formation	-700		Aquiclude										

1/ Omitted from estimate because of the limited supply available per individual well.

27. Chart showing geologic, chemical, and hydrologic data used in estimating the availability and quality of water in the Hughesville-Benedict area.

TABLE 12

HYDROLOGIC COEFFICIENTS OF AQUIFERS IN THE HUGHESVILLE-BENEDICT AREA

Well Number	Location	Coefficient of Transmissibility (T) (gpd/ft)	Coefficient of Storage (S)	Aquifer or Formation
PG-Hf 26-28	Chalk Point	4,500[1]	0.00006[2]	Magothy
PG-Hf 24	Do.	4,000	.0001	Aquia Greensand
Ch-Cg 1	Hughesville	6,700	—	Do.

[1] Average of 3 values reported by Mack (1966, p. 43).
[2] Average of 2 values reported by Mack.

Specific capacities of five wells shown in the table range from 0.4 to 0.7 gpm/ft, which are relatively low values. Nearly all the wells for which yield data are available are screened in the Aquia Greensand. Inasmuch as the most productive well, -Cf 13, is only 6 inches in diameter and is screened opposite only 15 feet of the aquifer it is likely that properly located larger-diameter gravel-walled wells could yield at least 200 to 300 gpm from the Aquia Greensand. It is probable that wells of relatively high capacity could also be obtained from the Magothy Formation, although this unit is untested in easternmost Charles County.

Although no wells have been completed to the Magothy Formation in this part of Charles County, it is possible to compute the theoretical maximum yield which could be obtained from the aquifer using data obtained from aquifer tests on nearby wells at Chalk Point. Using the hydrologic coefficients given by Mack (1966, p. 43) for the Magothy Formation, the computations are:
where:

T = 4,500 gpd/ft
S = 0.00006
r = 0.5 ft (well radius of 12-inch diameter well)
t = 14,400 minutes (10 days)
s = 550 ft (available drawdown)
$W(u)$ = as defined previously (20.62 for this problem)
$Q = [4{,}500/(114.6 \times 20.62)]\ 550 = 1{,}045$ gpm (theoretical maximum)

Thus, if wells having an assumed efficiency of about 70 percent were to be constructed, a maximum yield of about 730 gpm could be obtained. In May 1963 the most productive Magothy well (PG-Hf 28) at Chalk Point yielded about 421 gpm and had a specific capacity of 1.7 gpm/ft. Probably well -Hf 28 would yield at a higher rate if the radius of its well screen were larger and if all the available drawdown were to be utilized in pumping it.

QUANTITATIVE ESTIMATES

Figure 27 summarizes the geologic, chemical quality, and hydrologic data for the uppermost 675 feet of strata in the Hughesville-Benedict area. The

TABLE 13

DATA FOR HIGH-CAPACITY WELLS IN THE HUGHESVILLE-BENEDICT AREA

U.S.G.S. Well Number[1]	Owner's Name or Designation	Owner's Number and Date Drilled	Altitude of Land Surface (feet)	Depth of Well (feet)	Casing Diameter (inches)	Depth of Screen Below Land Surface (feet)	Depth of Water Level Above or Below Land Surface (feet)			Yield (gpm)	Specific Capacity (gpm/ft of Draw-down)	Well Status (1962)	Aquifer
							Static	Pump-ing	Date				
Ch-Cg 1	Southern Maryland Electric Co-op	1946	179	548	6	538–548	140.58	300	11/11/46	50	—	In use	Aquia Green-sand
Ch-Cg 12	Southern Maryland Public Works Camp	1955	174	510	6	498–510	140	195	7/6/55	25	0.5	Do.	Do.
Ch-Cg 13	David Hume	1957	175	410	6	395–410	140	225	9/25/47	60	.7	Do.	Do.
Ch-Cg 14	Prince Georges Co. Girl Scout Council	1956	165	541	6	531–541	160	250	6/15/56	50	.6	Do.	Do.
							152.72	—	9/28/60				
Ch-Ch 7	Benedict Pier	1959	6	344	4	329–344	Flows			40	.7	Do.	Do.
								55	4/30/59				
Ch-Ch 8	Charles Co. Animal Shelter	1960	155	525	6	515–525	150	210	12/23/60	25	.4	Do.	Do.
							132.90	—	3/16/61				
Ch-Ch 10	Ralph Brown	1955	115	380	$2\frac{1}{2}$	—	128	—	4/—/55	4	—	Do.	Nanjemoy
Ch-Ch 11	Harry Messick	1910	2	365	$1\frac{1}{2}$	—	Flows +11.75	—	8/8/61	—	—	Do.	Aquia Green-sand

[1] Location of wells shown in Maryland Geol. Survey Water Resources Basic Data Report 2 (1966).

composite geologic section on the left-hand side of the chart shows the idealized geologic column, based on well logs from Chalk Point. The geologic units in the column are designated as aquifers or aquicludes, and, for purposes of quantitative analysis, it is assumed that no vertical leakage occurs into or out of the aquifers. Only two primary aquifers are present within the explored depth; these are the Aquia Greensand and the Magothy Formation.

The left-hand side of figure 27 contains the data used to estimate the quantity of water available from each aquifer. Based on the values in the distance-drawdown graph, seven wells yielding 175 gpm each would be capable of furnishing about 1.9 mgd from the Aquia Greensand, providing the wells were spaced 1 mile apart across the 6-mile width of the area. The discharge rate used in the analysis, 175 gpm, is a conservative value somewhat arbitrarily selected.

The distance-drawdown graph for the Aquia Greensand was constructed on the basis of an assumed impermeable boundary that lies about 3 miles west of the Hughesville-Benedict area. The hydrologic effect of this boundary is to steepen the drawdown slope-line shown in the graph and to decrease the total quantity of water available.

The data in the right-hand column of figure 27 shows that seven wells in the Magothy Formation, spaced 1 mile apart and pumping at 300 gpm for 1,000 days, will yield about 3.0 mgd, based on a limiting available drawdown of 550 feet. The distance-drawdown graph for the Magothy Formation was also constructed on the assumption that an impermeable boundary condition exists 1 mile south of the border of the Hughesville-Benedict area (see fig. 14). As was true for the Aquia Greensand, the effect of the assumed hydrologic boundary is to steepen the slope of the distance-drawdown slope-line shown on the graph and to reduce by about 1.0 mgd the estimate of the total quantity of water available from the aquifer.

A summary of the estimated yields of aquifers in the Hughesville-Benedict area is:

Aquifer	*Theoretical Yield (mgd)*
Aquia Greensand	1.9
Magothy Formation	3.0
Total	4.9

The method of analysis described above is subject to the same limitations as set forth in earlier sections of this report. A possible source of error in the analysis may be due to the difficulty in determining accurately the hydrologic boundaries believed to exist in both the Aquia and Magothy Formations. No wells have been drilled to a depth sufficient to penetrate the Magothy immediately south of the Hughesville-Benedict area, although it has been determined with a fair degree of reliability that it is absent at La Plata and that it is a poor aquifer at Great Mills in St. Marys County.

The analysis used to derive the quantity of 4.9 mgd of ground water available does not take into account the interference effect on water levels in the Magothy aquifer resulting from the existing (1965) pumping at the PEPCO plant at Chalk Point. Preliminary calculations indicate that this pumping has lowered water levels in the aquifer a few tens of feet along the northern part of the area.

CHEMICAL CHARACTER OF THE WATER

BY

CHARLES P. LAUGHLIN

The water-quality investigation in Charles County was undertaken to determine the quality of water in the various aquifers as an aid in developing and utilizing the ground-water resources. The chemical character of ground water is determined chiefly by the minerals in the soil and rock in which it occurs and by the length of time in which it is in contact with them. Wide variations in the chemical character of ground water are possible.

Table 14 lists some of the more important chemical constituents in ground water and indicates their significance. The U. S. Public Health Service (1962) has established criteria for the chemical and physical character of public water supplies. Although drinking water ideally should not contain higher concentrations of chemical constituents than given in these standards, in actual practice in some areas where other water is not available, water containing much greater concentrations of some constituents and properties is used without ill effect. In Charles County, except for a few shallow wells in the Pleistocene deposits that may be high in iron, low in pH, or both, there are relatively few instances where chemical water treatment is necessary to obtain potable water.

OCCURRENCE OF PRINCIPAL CHEMICAL CONSTITUENTS

All values used in this report, except for pH, are expressed in parts per million by weight (ppm). One part per million is a unit weight for a constituent in a million unit weights of water.

Silica (SiO_2): The concentration, range, median value, and number of analyses for silica in the ground water from the aquifers are:

Aquifer	*Number of Samples*	*Range in Concentration (ppm)*	*Median (ppm)*
Deposits of Pleistocene age	14	3.8–62	6
Aquia Greensand	12	11–32	13
Magothy Formation	11	3.2–16	11
Patapsco and Raritan Formations	42	9.5–56	20
Patuxent Formation	7	33–45	37

The standards established by Public Health Service do not provide a maximum allowable concentration because in normal concentrations silica does not affect the potability of water. Water from the older wells at the Naval Propellant Plant cannot be used without treatment in the high-pressure boilers, because of the high concentration of silica (25–38 ppm) which would

TABLE 14

ELEMENTS AND SUBSTANCES COMMONLY FOUND IN GROUND WATER (FROM WALKER, 1956)

Constituent	Source	Significance
Silica (SiO_2)	Siliceous minerals present in essentially all formations.	Forms hard scale in pipes and boilers. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	The common iron-bearing minerals present in most formations.	Oxidizes to a reddish-brown sediment. More than about 0.3 ppm stains laundry and utensils reddish brown, is objectionable for food processing, beverages. Larger quantities impart taste and favor the growth of iron bacteria.
Manganese (Mn)	Manganese-bearing minerals.	Rarer than iron; in general has same objectionable features; brown to black stain.
Calcium (Ca) and magnesium (Mg)	Minerals that form limestone and dolomite and occur in some amount in almost all formations. Gypsum also a common source of calcium.	Cause most of the hardness and scale-forming properties of water; soap consuming.
Sodium (Na) and potassium (K)	Feldspars and other common minerals; ancient brines, sea water; industrial brines and sewage.	In large amounts, cause foaming in boilers, and other difficulties in certain specialized industrial water uses.
Bicarbonate (HCO_3) carbonate (CO_3)	Action of carbon dioxide in water on carbonate minerals.	In combination with calcium in magnesium forms carbonate hardness; decomposes on application of heat with attendant formation of scale and release of corrosive carbon dioxide gas.
Sulfate (SO_4)	Gypsum, iron sulfides, and other rarer minerals; common in waters from coal-mining operations and many industrial wastes.	Sulfates of calcium and magnesium form hard scale.
Chloride (Cl)	Found in small to large amounts in all soils and rocks; natural and artificial brines, sea water, sewage.	Objectionable for various specialized industrial uses of water.
Fluoride (F)	Various minerals of widespread occurrence, in minute amounts.	In water consumed by children about 1.5 ppm and more may cause mottling of the enamel of teeth, and as much as 1.5 ppm reduces incidence of tooth decay.
Nitrate (NO_3)	Decayed organic matter, sewage, nitrate fertilizers, nitrates in soil.	Values higher than the local average may suggest pollution. More than about 45 ppm NO_3 may cause methemoglobinemia (infant cynosis), which is sometimes fatal. (Waters of high nitrate content should not be used for baby feeding (Maxey, 1950).)

form a scale inside the boiler at pressures on the order of 500 pounds per square inch. However, the presence of silica does not affect the taste or odor of the water. The silica content of ground water in Charles County is not troublesome for most uses.

Aluminum (Al): Aluminum is chemically similar to ferric iron but is generally not present in as high concentrations as is iron. Concentrations of greater than 1 ppm are rare but may occur along with high concentrations of iron. The range of concentration of aluminum in 63 samples of ground water in Charles County is from 0.00 ppm to 0.7 ppm. Most values were 0.00 ppm.

Fluoride (F): The recommended optimum limit of naturally occurring fluoride in water does not exceed 1.2 ppm. Of 88 ground water analyses, eight show a fluoride content of more than 1.2 ppm. Seven of these analyses are of water from wells tapping sands in the Patapsco and Raritan Formations. One of the samples showing high fluoride content is from the deposits of Pleistocene age. Six of the analyses are from wells at the Naval Proving Ground at Dahlgren, Va. The range and median value for fluoride from each of the major aquifers is:

Aquifer	*Number of Samples*	*Range in Concentration (ppm)*	*Median (ppm)*
Deposits of Pleistocene age	15	0.0–1.4	0.1
Aquia Greensand	12	.0–.9	.3
Magothy Formation	12	.0–.5	.2
Patapsco and Raritan Formations	41	.0–2.1	.9
Patuxent Formation	8	.0–1.1	1.0

The fluoride content of ground water in this area appears to be greatest in the deeper artesian aquifers.

Iron (Fe): The recommended limit of concentration of iron is 0.3 ppm according to the Standards of the Public Health Service. About 40 percent of 94 samples of water from wells in Eocene and Cretaceous strata show an iron concentration higher than 0.3 ppm. Figure 28 shows the location of wells and iron content of water samples. Generally the iron content of ground water in the Eocene and Cretaceous formations decreases downdip (towards the southeast).

The range and median value for iron from each of the major aquifers is:

Aquifer	*Number of Samples*	*Range in Concentration (ppm)*	*Median (ppm)*
Deposits of Pleistocene age	21	0.02–2.4	0.43
Aquia Greensand	17	.00–3.0	.17
Magothy Formation	13	.10–1.1	.30
Patapsco and Raritan Formations	48	.00–12.0	.13
Patuxent Formation	13	.00–1.2	.30

The water sample showing a concentration of 12 ppm is from a well located at the Naval Propellant Plant. This well is screened in 5 different sands, the uppermost being at a depth of 85 to 93 feet. The iron content of 12 ppm suggests vertical leakage from an overlying marshy deposit that contains acidic

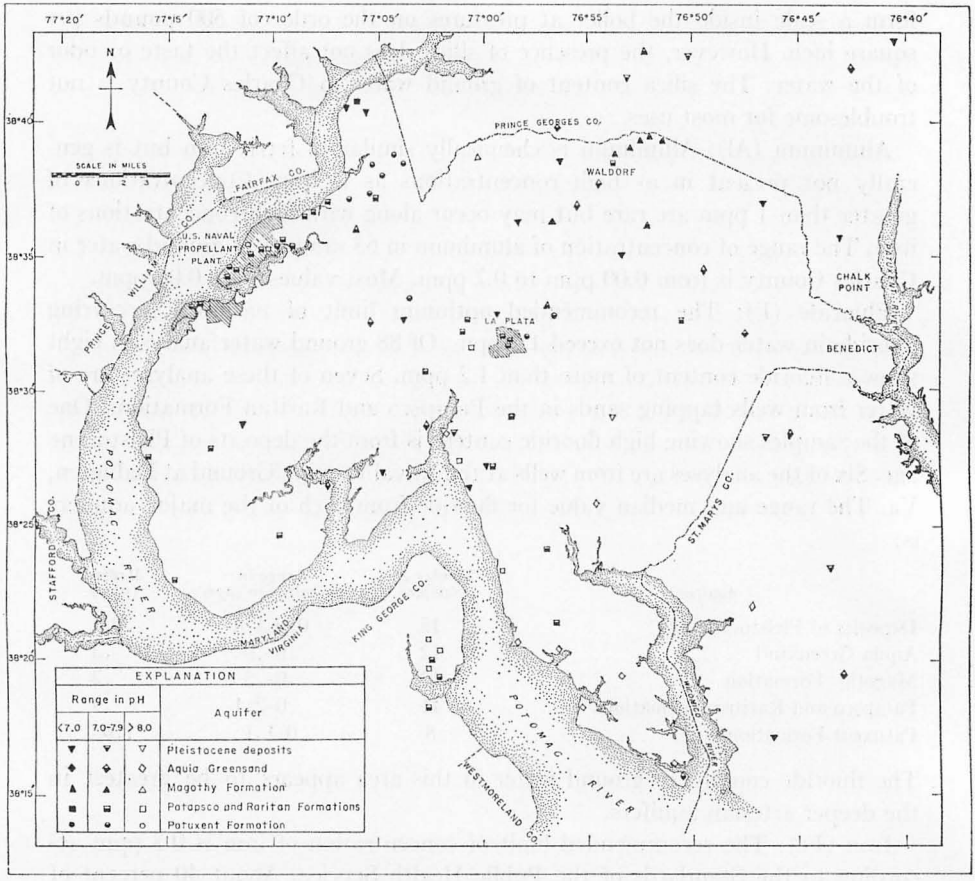


FIGURE 28. Map showing range in iron content in ground water in Charles County and adjacent areas.

water resulting in the solution of iron bearing minerals in the uppermost aquifer.

Manganese (Mn): According to the Public Health Service Standards the recommended limit of concentration of manganese is 0.05 ppm. Concentrations of greater than 0.01 ppm are apt to produce stains. In 91 determinations of manganese about 10 percent were above the recommended limit allowable. However, since manganese does affect its potability it does not appear to be a serious problem in the ground waters of Charles County. The range and median value for manganese from each of the major aquifers is:

Aquifer	*Number of Samples*	*Range in Concentration (ppm)*	*Median (ppm)*
Deposits of Pleistocene age	14	0.00–0.54	0.02
Aquia Greensand	12	.00–.03	.00
Magothy Formation	12	.00–.02	.00
Patapsco and Raritan Formations	46	.00–.17	.00
Patuxent Formation	7	.00–.05	.00

Chloride (Cl): On the basis of the same standards used for other constituents, the recommended limit of chloride concentration is 250 ppm. Of 114 analyses of ground water for chloride content, none exceeded 160 ppm. The range and median value for this constituent from each of the major aquifers is:

Aquifer	*Number of Samples*	*Range in Concentration (ppm)*	*Median (ppm)*
Deposits of Pleistocene age	21	0.2–48	7.2
Aquia Greensand	17	.5–17	2.0
Magothy Formation	13	1.0–20	3.0
Patapsco and Raritan Formations	50	.5–160	4.3
Patuxent Formation	13	1.6–13	4.0

In any tidewater area, such as Charles County, where brackish water may be in direct contact with some of the aquifers, salt-water intrusion to ground-water aquifers can occur. Such contamination can result from pumping an aquifer that is recharged through outcrops beneath a brackish-water estuary, or by means of vertical leakage through semi-permeable confining layers. Evidence suggesting possible salt-water intrusion in a shallow aquifer at the Naval Propellant Plant has been discussed in a previous section of this report (p. 20).

Higher than normal chloride content of ground water may occur because of sanitary pollution. Analyses of water from three wells in the shallow deposits of Pleistocene age at Issue and two wells at Waldorf, show a chloride content of more than 18 ppm, which is more than twice as high as the median chloride value for this aquifer. These wells also yielded water with a higher nitrate content than other water samples from the same aquifer, which suggest pollution of the water by septic-tank effluent has occurred.

Nitrate (NO_3): Using the same standards applied to other constituents, 45 ppm nitrate is a limit which should not be exceeded. Of 112 analyses of water for nitrate, only one from a well in the deposits of Pleistocene age, shows a concentration of more than 45 ppm. This well, on Cedar Point Neck, is in a barnyard near stock pens and is probably polluted.

Although nitrate content is usually low in water from wells tapping the artesian aquifers, water from shallow dug wells in inhabited areas may have a relatively high nitrate content. In Waldorf, before 1961, a large percentage of wells in the town were shallow dug wells ranging in depth from 12 to 25 feet. Apparent widespread pollution of the shallow ground water was one of the reasons for the creation of the Charles County Sanitary Commission and the subsequent drilling of deep public-supply wells at Waldorf.

The range and median value for nitrate for each of the major aquifers are:

Aquifer	*Number of Samples*	*Range in Concentration (ppm)*	*Median (ppm)*
Deposits of Pleistocene age	21	0.006–60	1.8
Aquia Greensand	17	.0–10	.4
Magothy Formation	13	.02– 0.8	.12
Patapsco and Raritan Formations	48	.0– 6.1	.08
Patuxent Formation	13	.00– .3	.08

Phosphate (PO_4): Because phosphate does not generally affect the potability of water, the Standards of the Public Health Service for drinking water do not have a maximum allowable concentration for this constituent. Although phosphate is necessary for plant growth, little data are available concerning the normal range of phosphate in ground water. Sixty-six samples of ground water in Charles County show a range in concentration from 0.00 to 9.9 ppm and a median value of 0.8 ppm.

Hardness (as $CaCO_3$): Degrees of hardness are recognized by the amount of soap needed to produce a good lather and by the amount of scale formed by heating the water. Below is a commonly used scale for classifying water according to hardness:

Hardness Range (Parts per Million of Calcium Carbonate)	*Description*
0– 60	Soft water
61–120	Moderately hard water
121–180	Hard water
more than-180	Very hard water

Below are the hardness determinations of 115 samples of ground water in Charles County, grouped by aquifers:

Aquifer	*Number of Samples*	*Range in Concentration (ppm)*	*Median (ppm)*
Deposits of Pleistocene age	21	9–403	46
Aquia Greensand	19	8–150	31
Magothy Formation	14	25–144	104
Patapsco and Raritan Formation	48	1–114	5
Patuxent Formation	13	2–22	8

Figure 29 shows areas of different classes of hardness of ground water. Otton (1955, p. 151) shows that water in the Aquia Greensand in Charles County increases in hardness towards the northeast. A similar increase appears to occur in the underlying Magothy Formation.

Of the 115 ground-water samples analyzed for hardness, about 75 percent are soft water and about 25 percent are moderately hard and hard water. However, water from only one well can be classified as hard (402 ppm hardness as $CaCO_3$); it is from a dug well in a tobacco field at Chapel Point. The hardness of this water may be due to the use of agricultural lime on the field.

Sulfate (SO_4): Based on the same standards used for the other constituents, the maximum recommended concentration of sulfate is 250 ppm. In 86 water samples there were no sulfate concentrations which approached the recommended limit. The range and median value for sulfate in water from each of the major aquifers is:

Aquifer	*Number of Samples*	*Range in Concentration (ppm)*	*Median (ppm)*
Deposits of Pleistocene age	14	0.2–112	6.0
Aquia Greensand	12	2.8–11	9.4
Magothy Formation	11	4.6–20	9.9
Patapsco and Raritan Formations	42	.2–20	11
Patuxent Formation	7	5.6–18	11

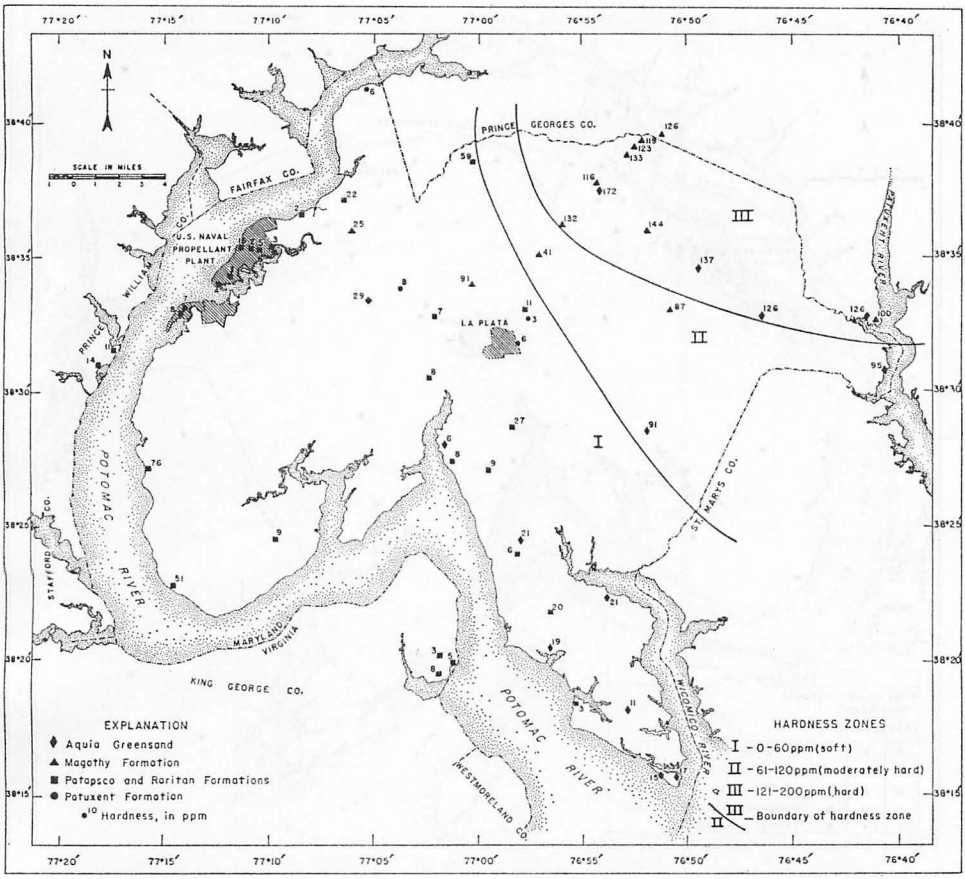


FIGURE 29. Map showing distribution of hardness of ground water in Charles County and adjacent areas.

Hydrogen-ion concentration (pH): The hydrogen-ion concentration or "pH" is the quantitative expression of the acidity or the alkalinity of water. Acid water has a pH less than 7.0 and alkaline water has a pH greater than 7.0. A low pH, common in ground water in some places in the Maryland Coastal Plain, can cause excessive corroding of water pipes. In combination with excessive amounts of iron a low pH may cause brown staining of fixtures, even clogging of pipes. Water with a low pH will frequently stain porcelain fixtures bluish-green when the water is supplied by copper pipes. Figure 30 shows the range of pH and the location wells used for pH determinations.

The range and median values of pH in 114 analyses are:

Aquifer	*Number of Samples*	*Range in pH*	*Median pH*
Deposits of Pleistocene age	21	4.1-7.2	6.3
Aquia Greensand	18	6.9-8.6	7.7

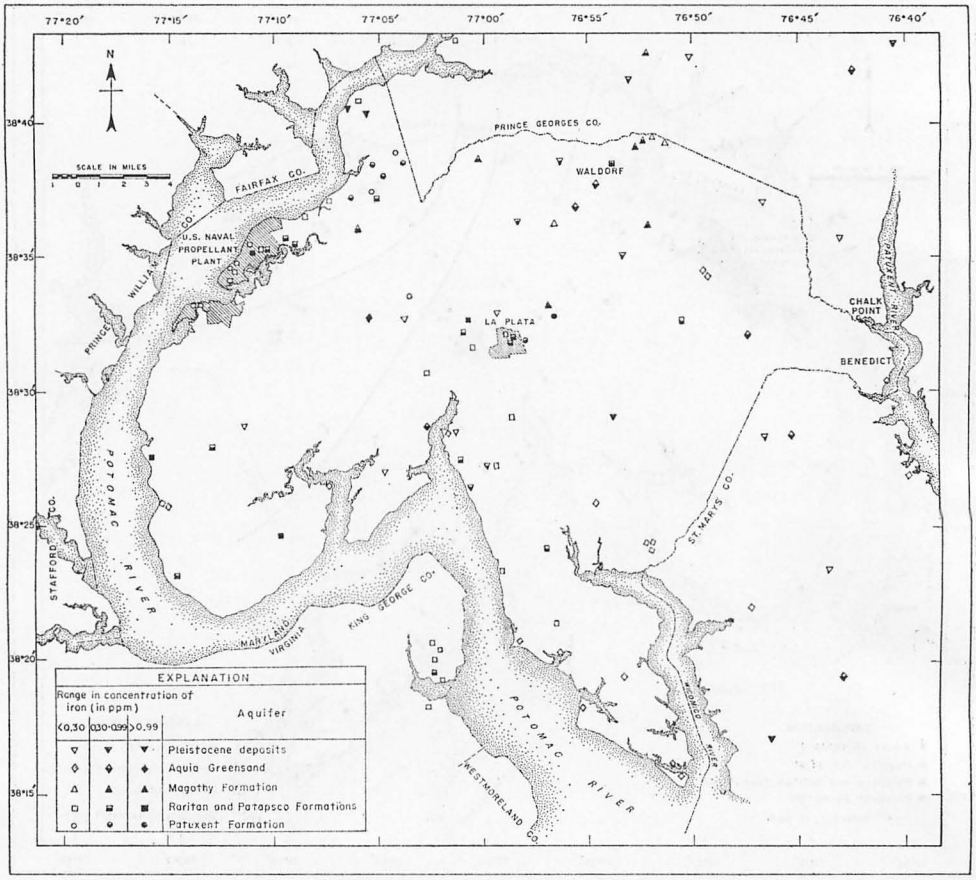


FIGURE 30. Map showing range in pH of ground water in Charles County and adjacent areas.

Magothy Formation	14	7.4–8.0	7.6
Patapsco and Raritan Formations	48	6.8–8.6	7.6
Patuxent Formation	13	6.4–7.9	7.5

CHLORIDE CONTENT OF SURFACE WATERS

During the period from August 1961 to August 1962 chloride analyses were made at 11 selected sites along the tidal streams bordering the county to obtain some idea of the salinity of these streams. This type of information is of importance in the ground-water study because the water-bearing sands that crop out underneath these streams are subject to possible contamination by brackish water. It is also desirable to have some idea of the salinity of

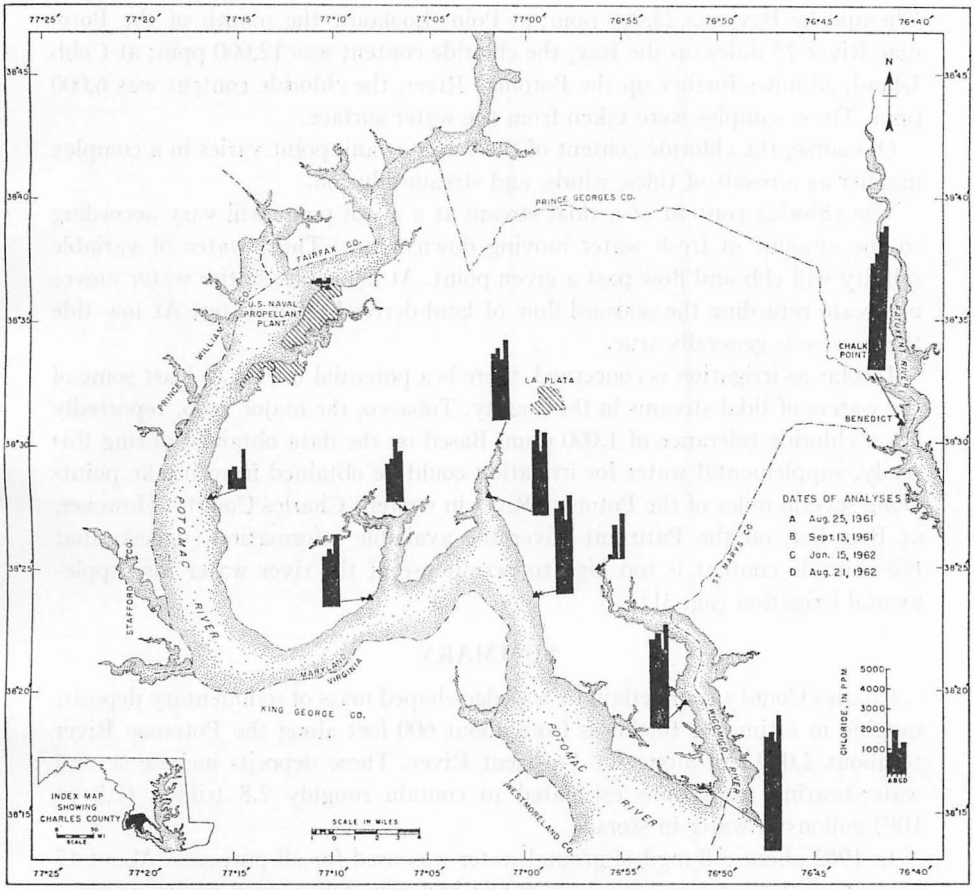


FIGURE 31. Map of Charles County showing tidewater sampling sites for chloride analyses.

these streams because of their potential use as a source of water for irrigation.

Figure 31 shows the location and graphical plotting of the chloride of water at the sites. Most samples were taken at the river bank near the water surface.

The three main rivers bordering the county are the Potomac, Patuxent, and the Wicomico. The Potomac forms the western and southern boundaries of the county and the Patuxent the extreme eastern boundary.

Tidal streams normally increase in chloride content downstream. On January 15, 1962, when the chloride content of the Potomac River at Neale Sound (mouth of Wicomico River) was 5,920 ppm, the chloride content at Indian Head, 52 miles upstream was only 20 ppm. Whaley and Hopkins report (1952) that in January 1951, the chloride content at the mouth of the

Chesapeake Bay was 25,000 ppm; at Point Lookout, the mouth of the Potomac River 75 miles up the Bay, the chloride content was 12,000 ppm; at Cobb Island, 35 miles further up the Potomac River, the chloride content was 6,000 ppm. These samples were taken from the water surface.

Of course, the chloride content of the water at any point varies in a complex manner as a result of tides, winds, and stream dilution.

The chloride content of a tidal stream at a given point will vary according to the amount of fresh water moving downstream. Thus, water of variable salinity will ebb and flow past a given point. At high tide, saltier water moves upstream retarding the seaward flow of land-derived fresh water. At low tide the reverse is generally true.

Insofar as irrigation is concerned, there is a potential use for at least some of the waters of tidal streams in the county. Tobacco, the major crop, reportedly has a chloride tolerance of 1,000 ppm. Based on the data obtained during this study, supplemental water for irrigation could be obtained from intake points along several miles of the Potomac River in western Charles County. However, at Benedict, on the Patuxent River the available information suggests that the chloride content is too high to permit use of the river water for supplemental irrigation (fig. 31).

SUMMARY

Charles County is underlain by a wedge-shaped mass of sedimentary deposits ranging in estimated thickness from about 600 feet along the Potomac River to about 2,000 feet along the Patuxent River. These deposits include several water-bearing formations estimated to contain roughly 2.8 trillion (2.8×10^{12}) gallons of water in storage.

In 1962 about 3.8 mgd of ground water was used for all purposes. About 17 percent of the total was used by public and privately-owned water systems, about 13 percent was used for commercial and industrial purposes, about 26 percent was for domestic and farm purposes, and about 43 percent by military installations.

Factors which govern the rates of withdrawal of water from the aquifers are their permeability, the opportunity for developing the hydraulic gradients necessary to cause water to move through the aquifers, and the rates of replenishment of the aquifers in their outcrop or recharge areas. Thus, the aquifers function as both storage reservoirs and conduits transmitting water from areas of recharge to points of discharge.

To obtain a crude estimate of the rate of flow of water through the aquifers, estimates were made of the coefficients of transmissibility of the aquifers and these were multiplied by their average downdip slope. The hydraulic gradients asumed in this analysis are those which would prevail if water levels at their lower end could be drawn down to the upper surface of the aquifer. These quantities are:

Formation or Aquifer	*Width (in miles)*	*Quantity (mgd)*
Deposits of Pliocene(?) and Pleistocene age	200[11]	40.0
Aquia Greensand	22	1.6
Magothy Formation	9	2.5
Patapsco and Raritan Formations (upper, middle, and lower sand)	29	6.2
Patuxent Formation	10±	4.7
Total	—	55.0

The quantity of 55 mgd of available ground water shown above is only an approximation. Of this total about 73 percent is water which could be recovered from the surficial deposits of Plicocene(?) and Pleistocene age only by a large number of dispersed small-capacity wells. Therefore, based on this method of analysis, only about 15 mgd is available from the artesian aquifers. Inasmuch as the conduit analysis does not take into account water recoverable from storage or that is available from adjacent areas the analysis gives a minimum or conservative value for the total availability.

Based on the method of analysis (well-interference method) used to estimate the availability of water in five separate areas of anticipated economic growth and development, it would appear that somewhat larger quantities of ground water are available. Quantities of ground water estimated to be available from all explored aquifers in the five areas are listed below:

Area	*Quantity available (mgd)*
Indian Head-Glymont	4.3
Waldorf	16.6
La Plata	3.9
Popes Creek-Morgantown	6.0
Hughesville-Benedict	4.9

Summation of the quantity available from each area adds up to a total of about 35 mgd, but to obtain this quantity of water in any area, as, for example, at Waldorf would require the development of widespread cones of influence which would extend beyond the boundary of Charles County. The net effect of the withdrawal of 11.8 mgd of water from the artesian aquifers in the Waldorf area would be to lower water levels in all contributing aquifers and to decrease the quantity of water available in adjoining parts of Prince Georges County and in the La Plata and Indian Head areas. Therefore, where the aquifers are extensive, the hydraulic effects of heavy pumping may be expected to ultimately extend beyond the arbitrary limits of the area. The problems caused by the interference of wells in the same aquifer in the various areas are resolved into a problem of priorities of use, or of water management.

Further analysis of the effects of mutual hydraulic interference among competing ground-water users will require the construction of analog or

[11] Available quantity determined on the basis of average rate of ground-water recharge/square mile; the value given for width is the areal extent of the aquifer.

mathematical models. Realistic development of models requires the continuing acquisition of geohydrologic data. Information needed consists of geologic logs, well construction records, ground-water pumpage, ground-water levels, aquifer tests, and other relevant facts.

The chemical quality of the ground water in Charles County is satisfactory for most uses, but, locally, treatment of pH and iron removal may be required. Pollution of shallow ground-water supplies may become increasingly critical as population growth in the area continues.

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