Water Resources of the Baltimore Area Maryland

By E. G. OTTON, R. O. R. MARTIN, and W. H. DURUM

WATER RESOURCES OF INDUSTRIAL AREAS

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WATER RESOURCES OF THE BALTIMORE AREA, MARYLAND

By E. G. OTTON, R. O. R. MARTIN, and W. H. DURUM

ABSTRACT

The available fresh-water supplies from all sources in the Baltimore area except the Susquehanna River total about 800 mgd (million gallons per day). In 1956, the fresh water used for all purposes was about 280 mgd, 22 percent of the available supply. Baltimore City used 198 mgd, or about 71 percent of the total water used in the area. The Susquehanna River is not included in these totals although it is a potential source of supply. Industries use, principally for cooling, 1,500 mgd of saline water from the lower Patapsco estuary.

Ground-water sources supply only about 5.5 mgd, or 2 percent, of the 248 mgd combined use of ground and surface water in the Piedmont subarea. In contrast, about 32 mgd of ground water and only 0.5 mgd of surface water is presently withdrawn in the Coastal Plain subarea. About 75 percent of the water used in the Coastal Plain subarea supplies industrial and commercial needs.

INTRODUCTION

The Baltimore area as here defined includes all Baltimore City, Baltimore and Harford Counties, eastern Howard County, and northern Anne Arundel County. Streams of special importance are Gunpowder Falls, Patapsco River, Magothy River, Severn River, the lower reaches of the Patuxent River, and the Susquehanna River at the east edge of the area.

The Baltimore area lies in two geologic and physiographic provinces, the Piedmont and the Coastal Plain, separated by a northeastward-trending line called the Fall Line or, more properly, the Fall Zone (fig. 1). The Fall Zone is roughly followed by the Baltimore and Ohio Railroad from Laurel in Prince Georges County to Aberdeen in Harford County. The Piedmont subarea lies north of the Fall Zone, and the Coastal Plain subarea lies to the south.

In general, the water resources of the Baltimore area are more than adequate to support its expanding population and economy. Most of

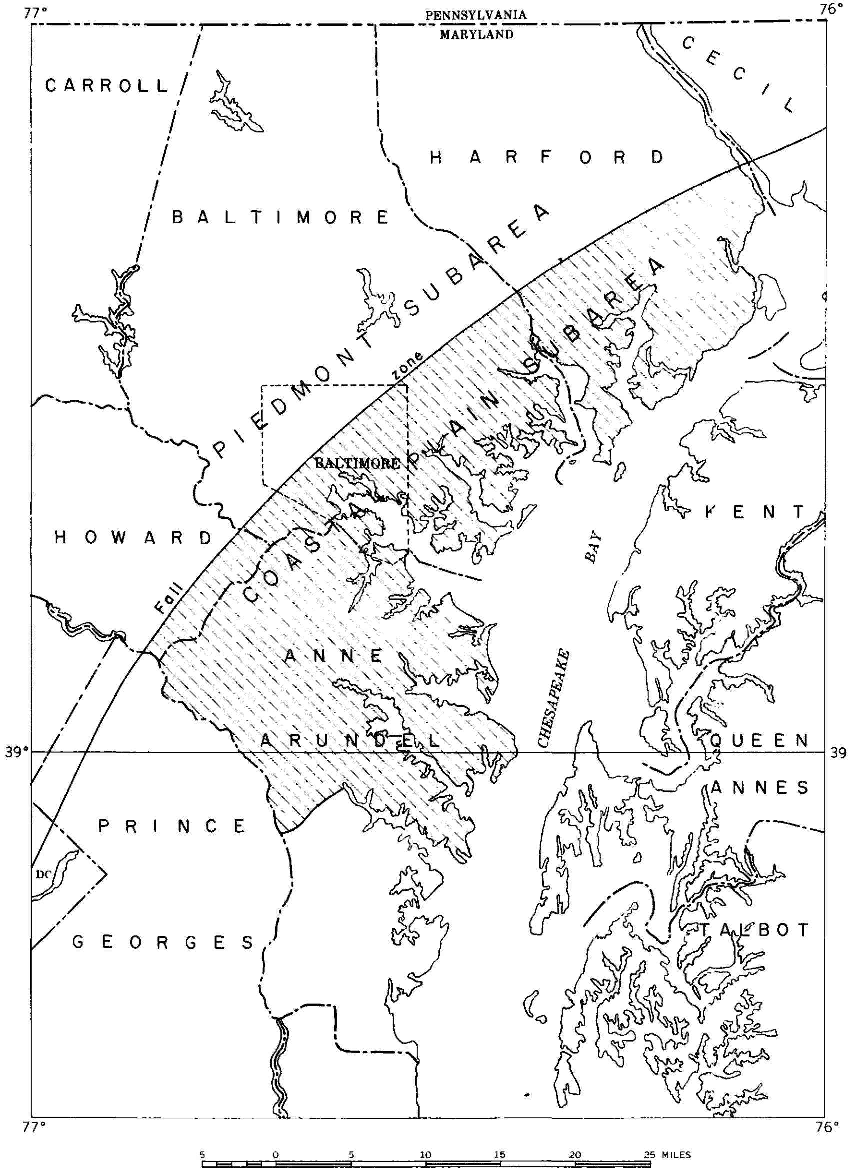


FIGURE 1.—Index map showing location of the Baltimore area, Maryland.

the flow, however, already has been pre-empted. The flow of the major streams is adequately maintained, even during severe drought, by release from storage. Some stream water is excessively turbid and may be too warm at times for some uses. The chief ground-water problem is the development of an adequate quantity of water that is of acceptable quality or that can be made so economically. In some places in the Baltimore area, where ground water is of poor chemical quality, the use of surface water is favored.

In the Piedmont subarea, ground-water supplies are sufficient only to supply the needs for domestic or some commercial use; the yields of individual wells range from less than 1 to more than 100 gpm (gallons per minute) but average only 12 gpm or 0.017 mgd (million gallons per day). Wells yielding 50 to 100 gpm are uncommon and those yielding more than 100 gpm are scarce. Ground water in the Piedmont subarea commonly occurs under water-table conditions in the uppermost 250 feet of the rocks, and most wells and springs yield water derived from local recharge. The chief aquifers are the crystalline rocks, including schist, gneiss, gabbro, granite, and marble in which much of the ground water is stored in the more permeable zone of decomposed rock that lies near the land surface. The chemical character of ground water in the Piedmont subarea is not uniform. The lowest concentrations of dissolved solids, which range from about 20 to 300 ppm (parts per million), are associated with water from schist and quartzite, and the highest are associated with water from serpentine and marble. The latter yield the hardest water also. Iron in water is a widespread problem.

Comparatively large supplies of ground water are available in the Coastal Plain subarea. Here the yields of individual wells for industrial and public supplies range from a few gallons per minute to as much as 1,000 gpm, or 1.44 mgd (million gallons per day), and average more than 200 gpm, or 0.288 mgd. The major aquifers are the sand and gravel of Cretaceous and Pleistocene ages. These units are separated from each other by relatively impervious confining layers of clay. Most of the ground water in the Coastal Plain occurs under artesian or semi-artesian conditions.

Poor water quality hinders development of additional fresh ground-water supplies in some parts of the Coastal Plain. The important aquifers yield water that generally contains as much as 1 ppm iron, is low in dissolved solids, is slightly acidic, and, therefore, is corrosive to pumping equipment.

The major aquifers have been contaminated with saline water from the Patapsco River and its tributaries as a result of heavy ground-water pumping in the Baltimore industrial area during the last 30 to 40 years. Locally the chloride content has exceeded 1,600 ppm.

Baltimore and its suburbs, Annapolis, Bel Air, and Laurel are the principal areas served by public water-supply systems. The Baltimore supply is the largest, and in 1954 served a population of more than 1,260,000 with water that is treated to meet rigid quality specifications.

A feature of the Baltimore sewerage system is that treated sewage effluent from its Back River plant is sold for industrial cooling water at Sparrows Point.

The increase in utilization of fresh surface water in the Baltimore area has been gradual, but by 1959 most surface-water sources were pre-empted. The storage of streamflow in three large reservoirs has greatly increase the efficiency of the water-supply system. Expansion to sources outside the area has been required because present demand is rapidly approaching the safe yield (with storage) of these supplies. This need is being met by development of diversion facilities from the Susquehanna River, which will insure an adequate supply for Baltimore at least until the year 2000.

Less populated outlying industrial and residential areas may find it feasible to develop some of the smaller but presently undeveloped streams, as nearly all streams in the area flow continually. Yields for streams in the Coastal Plain subarea exceed those for the Piedmont subarea. Large quantities of saline water, suitable for cooling, are available in the lower Patapsco estuary.

Surface water in the Piedmont subarea is generally low in dissolved solids, soft, slightly alkaline on the pH scale, and moderately low in dissolved iron and manganese. In the Coastal Plain the water in small streams is generally low in mineral content, soft, and acid; sulfate is a prominent constituent.

This report contains and evaluates basic information on the availability and use of water resources of the Baltimore area. This information will aid water planners, industrialists, planning officials of local governmental units, engineers, and hydrologists in the development of the area's water resources.

In addition to this report, detailed data on streamflow and ground-water levels in the area are published in the annual series of U.S. Geological Survey water-supply papers: Part 1B of "Surface Water Supply of the United States" and Part 2 of "Water Levels and Artesian Pressure in Observation Wells in the United States."

The principal water-resources studies in Maryland are cosponsored by the U.S. Geological Survey and the Maryland Department of Geology, Mines, and Water Resources. This cooperative program of studies has provided much of the basic information used to prepare this report. Several recent publications by the Maryland Department of Geology, Mines, and Water Resources, which were prepared in cooperation with the U.S. Geological Survey, contain information on the occurrence of ground water, the flow of streams, and the chemical character of both surface and ground water in the area. These publications are: Bulletin 3, "The Water Resources of Anne Arundel County, 1949"; Bulletin 4, "Geology and Ground-water Resources of the Baltimore area, 1952"; Bulletin 14, "The Water Resources of Howard and Montgomery Counties, 1954"; and Bulletin 17, "The Water Resources of Baltimore and Harford Counties, 1956."

The authors of this report have been aided greatly by the cooperation of the Director, Maryland Department of Geology, Mines, and Water Resources, by the officials of the Baltimore City Bureau of Water Supply, and by the Anne Arundel County Sanitary Commission. Information on the chemical character of the water has been provided also by the Maryland Department of Health and by the Maryland Water Pollution Control Commission. Precipitation data were obtained from published records of the U.S. Weather Bureau.

THE HYDROLOGIC CYCLE

The hydrologic cycle describes the movement of water from the sea, to the atmosphere, to the land masses, and back again to the sea. An understanding of the operation of the cycle aids in appraising and developing the water resources. This report describes the movement of water after the water falls upon the surface of the earth and before it reaches the sea.

The source of all fresh water is precipitation, which averages about 42 inches per year in the Baltimore area. Part of the precipitation enters the ground and the rest runs off in streams or evaporates. The water entering the ground percolates downward to the ground-water reservoir (zone of saturation) or is collected in the soil and returned to the atmosphere by evaporation or transpiration. The upper surface of the zone of saturation is called the water table, and the ground-water reservoir is called an aquifer if it is capable of yielding water to wells or springs at a usable rate. Where a stream channel cuts into a ground-water reservoir, ground water seeps into the stream channel and becomes the base or dry weather flow of the stream.

As the water percolates downward, some is used to wet the soil in the layer of unsaturated earth above the water table (zone of aeration), and the remainder recharges the ground-water reservoir. Soil moisture is depleted by evaporation or transpired by vegetation. Water returned to the atmosphere by evaporation and transpiration usually is considered together as evapotranspiration.

Recent studies of the Little Gunpowder Falls basin, whose drainage area is 36 square miles (Dingman and Ferguson, 1956, p. 48), show that during a 22-year period about 25 inches (about 60 percent) of the precipitation was returned to the atmosphere through evapotranspiration. The remaining 17 inches (40 percent) ran off in the streams—6 inches (14 percent) directly as overland flow and about 11 inches (11 inches) after temporary storage in the ground.

Over a period of time, ground-water discharge equals ground-water recharge in the Baltimore area. Some ground water is discharged through transpiration by deep-rooted vegetation or by evaporation from areas where the water table reaches or approaches the land surface, but the amount of water discharged in this process apparently is relatively small. Thus, the 11 inches of annual ground-water discharge in the Little Gunpowder Falls basin is approximately the measure of ground-water recharge in the Piedmont subarea.

LOW-FLOW ANALYSES

Gaging-station records are the principal basic data for the study of surface-water resources. The records collected in the Baltimore area are shown on the bar graph of figure 2 and their locations are shown on plate 1. Some of the 28 streamflow records in the area are short term. To improve the reliability of the low-flow analysis, the streamflow records in the area were correlated with long-term streamflow records outside the report area and adjusted to a 57-year base period, April 1896 to March 1953. Records for this period are available for Monocacy River near Frederick, Md., and Potomac River at Point of Rocks, Md. Records for Brandywine Creek at Chadds Ford, Pa., for the 42-year period 1912–53 also were used in developing the basic correlations. In making the low-flow analyses, the climatic year starting April 1 was used in order that the low-flow period of the summer and fall could be treated as a unit.

Water-supply engineers sometimes base their designs on the lowest flow known. This single event, however, is a poor basis for design without consideration of the frequency of its occurrence. Frequency of low-flow events is expressed in two ways in this report, by flow duration curves and by low-flow frequency curves.

The flow-duration curve (fig. 3) is a cumulative frequency curve that shows the percentage of time in which specified discharges were equaled or exceeded during a given period. If streamflow during the period on which the curve is based represents the long-term daily flow of the stream, the curve may be used as a probability curve to estimate the percentage of time a specified daily discharge will be equaled or exceeded in the future. A single flow-duration curve also shows the flow characteristics of a stream throughout the entire range in discharge. The slope of the curve indicates the magnitude of storage in the drainage basins. Thus, on unregulated streams, well-sustained or flat duration curves indicate large natural storage. The lower end of the duration curve reflects the effects of subbasin geology on streamflow. The daily flow-duration curves in figure 3 were compiled from

INDEX NO. (see pl. 1)	WATER YEARS ENDING SEPTEMBER 30 (Dates indicate limits of records)	DRAINAGE AREA IN SQUARE MILES	GAGING STATIONS
1	Oct. 1, 1926	94.4	Deer Creek at Rocks
2	Dec. 14, 1904–Mar. 31, 1909	141	Deer Creek near Churchville
3	July 7, 1950–Sept. 30, 1955	7.7	Bynum Run near Bel Air
4	June 3, 1944–Apr. 5, 1951 July 1, 1955	8.8	Bynum Run at Bel Air
5	June 24, 1944	52.9	Little Falls at Blue Mount
6	Sept. 17, 1947	2.27	Slade Run near Glyndon
7	Sept. 1, 1944	59.8	Western Run at Western Run
8	Dec. 15, 1904–Mar. 31, 1909	160	Gunpowder Falls at Glencoe
9	Jan. 1915	303	Gunpowder Falls at Lock Raven Dam[1]
10	Jan. 1883–Dec. 1914	304	Gunpowder Falls at Lock Raven Dam (former site)[1]
11	Sept. 29, 1949	314	Gunpowder Falls near Carney
12	Dec. 7, 1926	36.1	Little Gunpowder Falls at Laurel Brook
13	Dec. 13, 1904–Mar. 31, 1909	43	Little Gunpowder Falls near Bel Air
14	Sept. 22, 1945	56.6	North Branch Patapsco River at Cedarhurst
15	June 30, 1927 Dec. 31, 1953	91.0	North Branch Patapsco River near Reisterstown
16	Oct. 28, 1929	165	North Branch Patapsco River near Marriottsville
17	Aug. 18, 1948	64.4	South Branch Patapsco River at Henryton
18	Sept. 22, 1931	11.4	Piney Run near Sykesville
19	1897, 1898, 1902, 1903, 1906–8	260	Patapsco River at Woodstock
20	May 22, 1944	285	Patapsco River at Hollofield
21	May 11, 1944–Sept. 30, 1952	5.1	Sawmill Creek at Glen Burnie
22	Dec. 15, 1931	8.5	North River near Annapolis
23	Nov. 5, 1942–Sept. 30, 1952	6.92	Bacon Ridge Branch at Chesterfield
24	Oct. 1, 1944	133	Patuxent River near Laurel
25	Aug. 3, 1896–Aug. 10, 1898	137	Patuxent River at Laurel
26	May 3, 1932	38.0	Little Patuxent River at Guilford
27	Nov. 27, 1939	98.4	Little Patuxent River at Savage
28	July 1, 1948	11.6	Dorsey Run near Jessup (at Annapolis Junction)

Gaging stations: Nonrecording; Recording

[1] Monthly discharge records furnished by Baltimore Department of Public Works

FIGURE 2.—Streamflow records in the Baltimore area, Maryland.

records for several small streams in each basin. These curves indicate that the daily flow per square mile, equaled or exceeded 95 percent of the time, is highest for the Coastal Plain. In the four basins in the Piedmont province, yield per square mile decreases progressively towards the south. (See table on p. F8.)

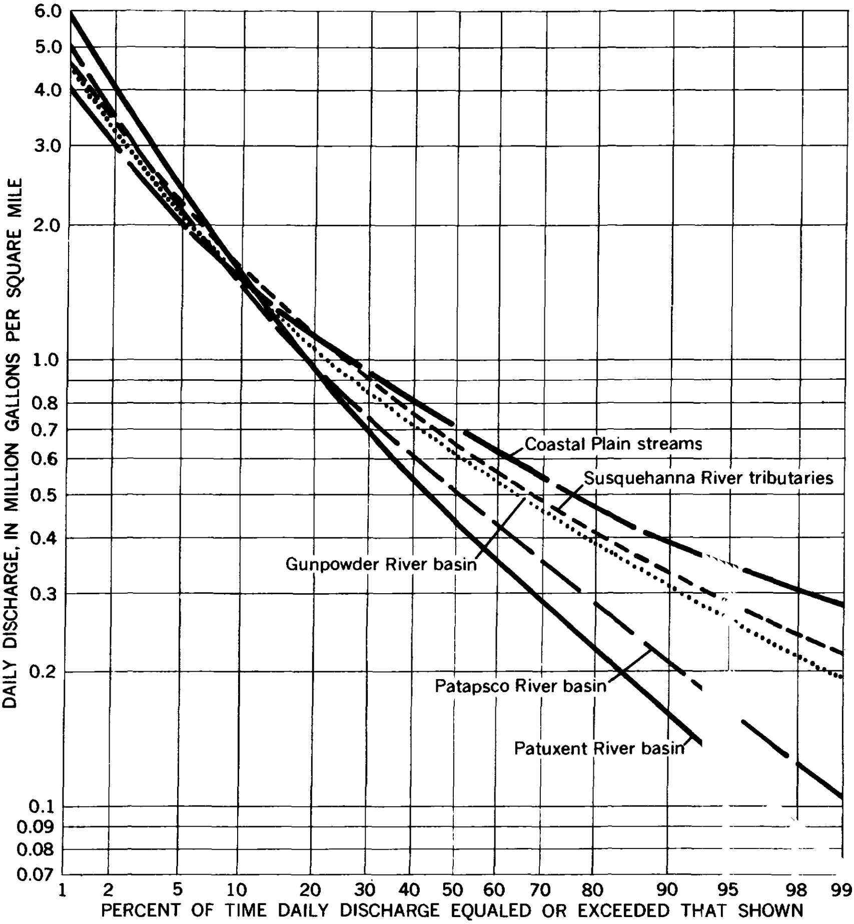


Figure 3.—Duration curves of daily flow in five basins in the Baltimore area, Maryland, 1896–1952.

Median duration of daily flow from major basins

[Adjusted to 57-year period 1896–1952 on basis of long-term streamflow records in adjacent areas]

Basin	Representative gaged discharge (mgd per sq mi) from major basins equaled or exceeded the percent of time indicated												
	1	2	5	10	20	30	50	70	80	90	95	98	99
Susquehanna River	4.62	3.39	2.22	1.60	1.12	0.904	0.656	0.485	0.411	0.335	0.286	0.243	0.220
Gunpowder River	4.56	3.27	2.10	1.50	1.06	.850	.615	.460	.390	.312	.263	.218	.195
Patapsco River	4.99	3.43	2.13	1.44	.964	.743	.516	.358	.286	.210	.163	.123	.104
Patuxent River	5.87	4.06	2.36	1.52	.962	.694	.434	.289	.227	.160	.122	.0904	.0754
Coastal Plain streams	4.02	3.00	2.01	1.49	1.12	.928	.712	.541	.463	.386	.346	.307	.284

The preparation and use of flow-duration curves is described by Searcy (1959). It is evident that a duration curve fails to disclose whether the lowest period of record occurred as successive days in one rare drought year or as isolated days over a succession of years. This serious shortcoming, or lack of information on the chronological sequence of flow, is overcome by low-flow frequency curves.

Low-flow frequency curves treat consecutive days as a period and show the average intervals between the recurrence of annual low flows of selected-length periods. (See fig. 10 for an example of a low-flow frequency curve.) The use of an average flow for a given period presupposes enough storage to regulate the flow during the period.

The need for storage becomes apparent when the natural flow of a stream cannot meet demands. The amount of storage that would have been required to meet a given demand during a particular period may be determined by a mass-curve analysis (Rippl, 1883). It is important to know the frequency that a given amount of storage will be needed, because the cost of providing the needed storage then can be weighed against the benefits.

The analyses of storage requirements in this report are indicated by storage-required frequency-mass curves and diagrams which differ from the one described by Rippl in that they represent the flow for various recurrence intervals rather than particular drought period. These diagrams generally do not deal with any particular drought, such as Rippl's do, but instead indicate the frequency at which a deficiency might recur, as well as the maximum allowable draft rates that are possible under variable conditions of storage and variable probabilities of recurrence. (See fig. 18 for an example of a storage-required frequency curve.) Losses due to evaporation or seepage are neglected. The amount of storage required should be increased by the amount of the losses.

WATER RESOURCES OF THE PIEDMONT SUBAREA

The sources of water in the Piedmont subarea are streams, wells, and springs. Man-made reservoirs regulate surface flow and supply Baltimore City. Although constituting about two-thirds of the area of this report, the Piedmont subarea contains only about half the population and much less than half of the industries. The subarea is largely rural and suburban.

In 1950 the population of Harford, Baltimore, and Howard Counties, and Baltimore City was 1,294,000, of which 700,000 to 800,000 live in the Piedmont subarea. About 70 percent of the land in Baltimore and Harford Counties is used for agriculture. The most important crops are corn, wheat, and vegetables. Dairy products and poultry are also produced in substantial quantities. Industry in the subarea is light and diversified, consisting of distilleries, metal fabricating plants, food processing, dye works, and several limestone, gabbro, marble, and flagstone quarries.

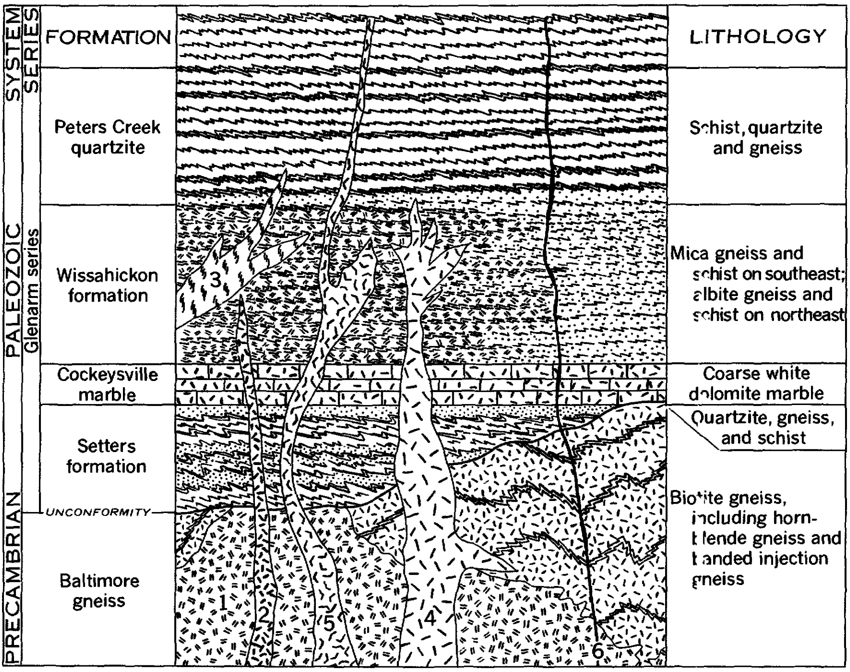
The principal uses of water in the area are for the public-supply of Baltimore City and its suburbs, for rural domestic supply, for hydroelectric power at Conowingo Dam, for air conditioning of industrial plants, and to a small extent for irrigation. The use of small streams for irrigation in the low-water season has increased, especially during critical droughts. Most of this water is consumed; therefore, this use depletes the supply appreciably, although the quantity of water is small in comparison to the amount withdrawn by industry.

CRYSTALLINE ROCKS

Ground water in the Piedmont subarea occurs chiefly under water-table conditions in pores and other openings in the weathered mantle, and in fractures in the hard, dense rock beneath the weathered zone.

The oldest rock in the Piedmont subarea, the Baltimore gneiss of Precambrian age, crops out along a belt 2 to 3 miles wide in central and southwest Baltimore City, near Granite in western Baltimore county, in the Towson-Ruxton area north of Baltimore, and in an extensive area near Phoenix and Monkton in north-central Baltimore County. (See pl. 2.) Gabbro and pyroxenite underlie much of the area between downtown Baltimore and the towns of Ilchester and Ellicott City along the Patapsco River. The Cockeysville marble of early Paleozoic(?) age crops out in an east-west belt in the Greenspring and Worthington valleys and more extensively in the Cockeysville-Texas area, where it is quarried at many places. Approximately one-third of the Piedmont subarea is underlain by the Wissahickon formation of early Paleozoic(?) age throughout an extensive area west of Chestnut Ridge, extending to the towns of Reisterstown, Arcadia, Parkton, and Gorsuch Mills.

The structure of the crystalline rocks of the Baltimore area is complex. The Baltimore gneiss is the central core in at least three dome-like structural features, one near Granite, another north of Pikesville, and the third in the Glencoe-Phoenix area. The surrounding younger metamorphic rocks dip steeply away from the central core of the domes. Throughout much of the area the highly metamorphosed schist, gneiss, and marble have dips ranging from 45° to 90° from the horizontal. Joint systems in the crystalline rocks also dip steeply and at least three of the systems trend at sharp angles to one another. The complex age relation of the igneous and metamorphic rocks in the Baltimore area are shown in figure 4.



EXPLANATION

(IGNEOUS ROCKS—NUMBERED IN ASCENDING ORDER FROM OLDEST TO YOUNGEST)

6. Diabase (Triassic)
5. Woodstock granite and associated pegmatites
4. Gunpowder granite
3. Gabbro and serpentine (peridotite and pyroxenite)
2. Port Deposit gneiss (granodiorite) and Relay quartz diorite of Knopf and Jonas (1929)
1. Hartley augen gneiss

Figure 4.—Columnar section showing complex age relationship of metamorphic and igneous rocks. From Knopf and Jonas (1929).

The total thickness of the metamorphic rocks in the area is not known, but it must be from more than 5,000 to 10,000 feet, if allowance is made for the repetition of beds due to repeated folding and crumpling. According to Knopf and Jonas (1929, p. 104), the total known thickness of the Wissahickon, Cockeysville, and Setters formations is 3,100 feet.

The crystalline rocks may be divided into a lower and an upper zone with respect to their physical character and permeability. The lower zone is the hard fresh rock commonly seen in quarries, and the upper zone is the weathered or rotted rock, which grades upward into the true soil zone. Most of the ground water available to wells in the Piedmont is stored in the weathered more permeable upper zone, although considerable ground water is stored in small crevices or fractures in the underlying hard rock.

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The average thickness of the weathered zone in the crystalline rocks is from 25 to 50 feet, but in some places the thickness may exceed 150 feet. The average depth of 809 wells in rock is 117 feet, but depths range from a few to nearly 1,800 feet. Dingman and Ferguson (1956, table 7, p. 34) have shown that in Baltimore and Harford Counties the average yield of water from wells in rock increases slightly with increasing depth to about 250 feet. Below this depth the rocks become harder and denser, and crevices and parting planes tend to disappear. Although the average yield of wells more than 250 feet deep is a little more than that of shallower wells, the yield per foot of hole is much less than that of the shallower wells. Nearly 70 percent of all wells in rock are completed at depths ranging from 50 to 150 feet. The average yield of these wells is 0.1 gpm per ft of well.

The yield of crystalline rock wells is governed in part by the topographic position of the well. Dingman and Ferguson (1956, p. 36) have shown that the best wells are in draws and valleys, and the poorest wells are on hilltops. The average yield of 109 valley wells is about 22 gpm, whereas the average yield of 300 hilltop wells is about 8 gpm, only slightly more than one-third that of the valley wells.

Marble is the best water-bearing rock in the Piedmont subarea. The yield of 55 wells ranges from less than 1 to 80 gpm and averages 19 gpm. The specific capacities average 1.0 gpm per ft of drawdown and range from less than 0.1 to as much as 13.3 gpm. (See p. F99 for definitions of terms used.) The coefficient of permeability determined from one aquifer test at Hydes is 325 gpd (gallons per day) per sq ft, and coefficients of transmissibility for two tests at Hydes and Harrisonville, were 3,000 and 35,000 gpd per ft. The coefficient of storage has not been measured.

The next most productive rock aquifers are granite, granodiorite, and quartzite. The yields of 129 wells in these rocks range from 1 to 135 gpm and average 13 gpm. Specific capacities of 34 wells range from less than 0.1 to 6.0 and average 0.5 gpm per ft of drawdown. Coefficients of transmissibility of the weathered granite range from 2,600 to 5,100 gpd per ft. A coefficient of storage of 0.05 was obtained in a test near Simpsonville; it probably indicates semiartesian conditions. A coefficient of transmissibility of 3,400 gpd per ft was obtained in a test of the quartzite near Butler.

The yields of 584 wells ending in the schist and gneiss range from less than 1 to 200 gpm and average 11 gpm. The depths of the wells range from 18 to 735 feet and average about 120 feet. Specific capacities of 101 schist wells average 0.7 gpm per ft of drawdown, and 49 gneiss wells average 0.4 gpm per ft drawdown.

Coefficients of permeability of the schist range from 50 to 130 gpd per sq ft. Coefficients of transmissibility from two aquifer tests of the schist were 3,000 to 10,000 gpd per ft. Coefficients of transmissibility of the gneiss range from 1,000 to 13,000 gpd per foot based on three aquifer tests. Field coefficients of permeability of the gneiss near Shawan range from 115 to 265 gpd per sq ft. These figures are representative chiefly of the shallow weathered part of the rock.

Gabbro and pyroxenite are the least productive of the crystalline rocks. The yields of 151 wells ending in these rocks range from 1 to 80 gpm and average 10 gpm. Specific capacities range from 0.1 to 2.8 and average 0.7 gpm per ft of drawdown. Coefficients of transmissibility and storage of the gabbro and pyroxenite have not been determined. The water-bearing properties of the crystalline rocks in the Piedmont are summarized in the table on page F14.

PROBLEMS OF WELL AND AQUIFER HYDRAULICS

The safe yield of the aquifers and reliable guides to well spacing were not computed, because the water-bearing zones of the crystalline rocks are irregular in shape and erratic in distribution. Aquifer tests in the crystalline rocks have shown that the yield of a well may decline substantially before the effective cone of depression has spread more than a few hundred feet. If wells are heavily pumped during long periods of no recharge, yields may decrease sharply, although the water level in wells a few thousand feet away may remain unaffected. Overdrafts might be expected in some places were large quantities of water are pumped. Overdrafts however, are unknown at the present time.

WATER-LEVEL FLUCTUATIONS

The water level in wells seldom remains constant but fluctuates continually in response to changes in the relative rates of recharge and discharge. In the Piedmont subarea, the principal changes in water levels are caused by replenishment from precipitation, discharge by springs and seeps, evapotranspiration, and pumping.

Periodic measurements of water levels in the area have been made since 1944. The fluctuations in water level in two wells are shown in figure 5. These wells are 48 and 114 feet deep and end in schist and gabbro, respectively. The water level in the 48-foot well near Slacks Corner, in Howard County, fluctuated 15 feet during the 9-year period 1947–55. The fluctuation in any single year was substantially less than that during the period of record. Fluctuation of the 114-foot well was 7½ feet during the 12-year period 1944–55.

Precipitation is more variable than other factors affecting water level flucuation; therefore, water levels decline during dry years and rise during wet years (fig. 6). The net change in the ground-water level in the area as a whole was only −0.09 foot during the 12 years of record. An additional slight downward trend in ground-water

Hydrologic properties of and depth of wells in crystalline rocks in the Baltimore area

Rock type	Character	Number of wells	Depth of wells (feet)		Yield of wells (gpm)			Specific capacities (gpm per ft)			Hydrologic coefficients [1]			
			Range	Average	Number of wells	Range	Average	Number of wells	Range	Average	Locality	Coefficient of transmissibility (gpd per ft)	Coefficient of permeability (gpd per ft)	Coefficient of storage
Igneous rocks														
Granite and granodiorite (Gunpowder granite and Woodstock granodiorite).	Medium-grained potassic granite containing biotite and muscovite. Medium- to coarse-grained light-gray granodiorite, with biotite and epidote.	19	18–210	109	27	1–53	13	20	0.1–6.0	0.6	Simpsonville [2]	2,600– 5,100	90–170	0.05
											Elkridge [3]	1,200	----------	----------
Gabbro and pyroxenite	Purplish-gray to dark-green massive hypersthene or hornblende gabbro; grades locally to meta-gabbro or gabbro-diorite.	150	29–450	75	151	1–80	10	39	.1–2.8	.7	----------	----------	----------	----------
Metamorphic rocks														
Schist (chiefly Wissahickon formation).	Consists of two facies, an albite-chlorite facies to the northwest and an oligoclase-mica facies to the southeast.	308	37–735	130	309	1–200	11	101	.1–10.0	0.7	Arcadia	3,000–10,000	50–160	0.002–.01
											do	6,000– 7,000	110–130	.02
Marble (Cockeysville marble).	White fine to coarse-grained completely crystalline dolomitic marble; frequently contains phlogopite or muscovite.	54	50–1,800	210	55	1–80	19	40	.1–13.3	1.0	Hydes	35,000	325	----------
											Harrisonville	3,000	----------	----------
Quartzite (Setters formation and Peters Creek quartzite).	Vitreous quartzite, feldspathic mica schist, and mica gneiss.	102	35–380	112	102	1–135	13	14	.1–1.0	.3	Butler	3,400	----------	----------
Gneiss (Baltimore and Port Deposit gneisses).	White or gray heavily bedded granitoid gneiss to thinly banded ribbon gneiss; contains intrusions of pink pegmatite and white granite.	176	18–480	105	176	1–110	11	49	.1–4.0	.4	Shawan	2,300– 5,300	115–265	----------
											Rising Sun [2]	13,[illegible]	[illegible]	.003
											Pikesville	13,[illegible]00	----------	----------
											Towson	1,000	----------	----------

[1] Applicable chiefly to the weathered parts of the rocks.
[2] Adjacent to the area of this report.
[3] Test in Relay quartz diorite of Knopf and Jonas (1929).

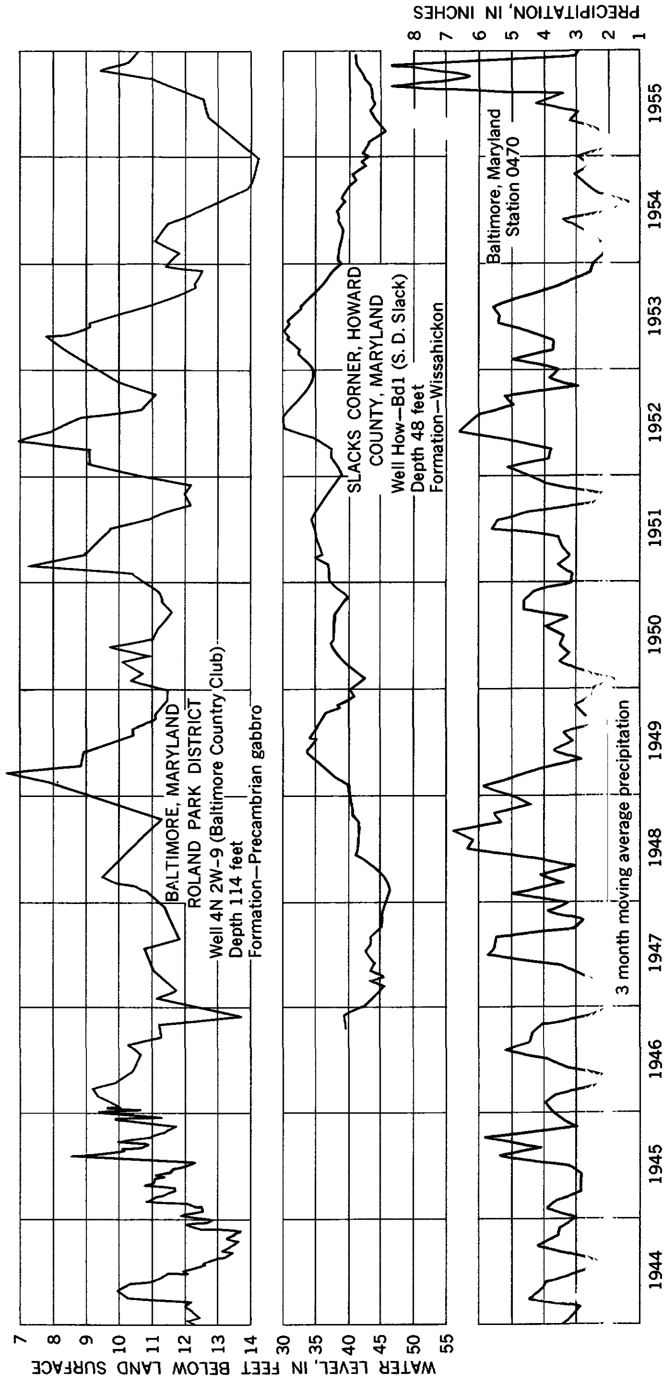

FIGURE 5.—Water level fluctuation in two wells and moving average precipitation in the Piedmont subarea.

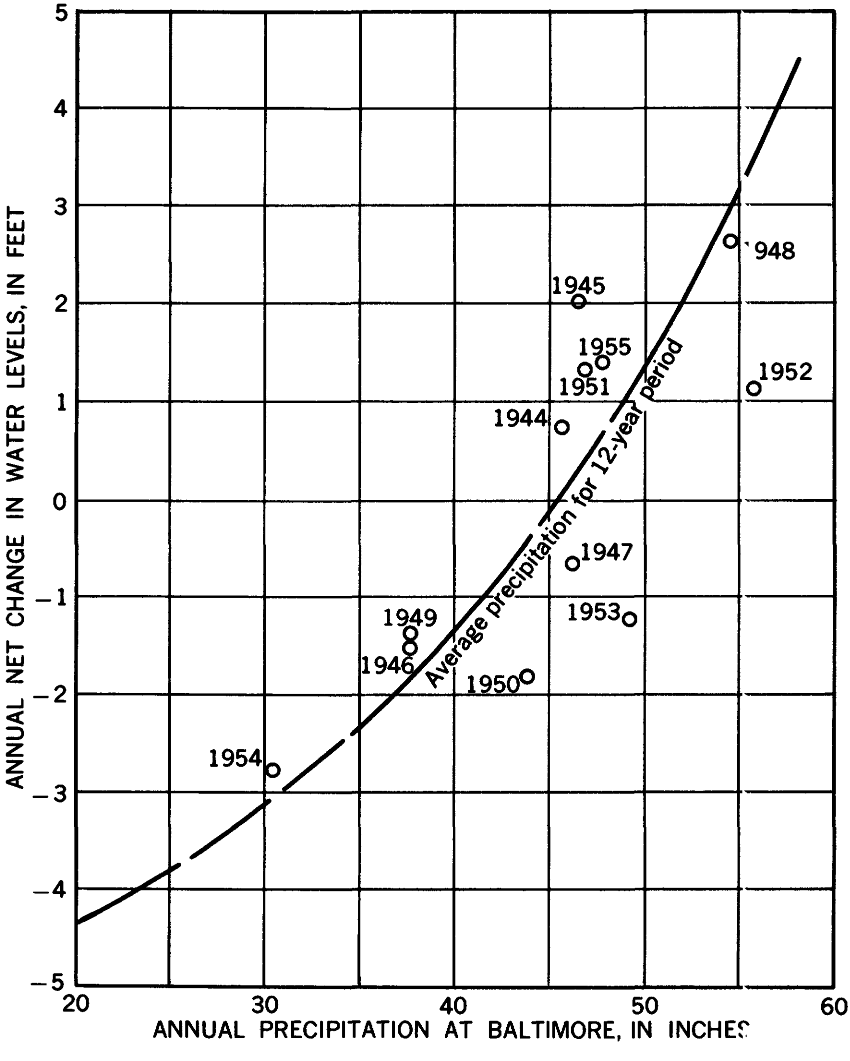

FIGURE 6.—Relation between annual net change in water levels and annual precipitation at Baltimore, Md.

levels may be expected if precipitation in coming years is normal or below normal, because the average precipitation for the 12 years was 45.2 inches, or 2.6 inches above the 84-year average. If precipitation is only 30 inches per year, the net annual decline in the water table will be about 3.1 feet (fig. 6). If precipitation is 55 inches per year (13 inches above normal), the net annual rise in the water table will be about 3.0 feet.

CHEMICAL QUALITY OF GROUND WATER

The chemical character of ground water is largely determined by the characteristics of the rock that the water comes in contact with and the length of contact. The permeable weathered rock mantle affects the chemical character of the water more than the unweathered rock, because most of the circulation is through the weathered rocks.

The chemical composition of the crystalline rocks in the Piedmont subarea is not uniform. The quartz veins are composed principally of silica, the marble is chiefly calcium carbonate, and the granite, gneiss, and schist include both silica and other minerals of simple and complex composition. Hence the chemical character of the ground water, too, is not uniform. The dissolved-solids content in 51 samples from wells in the crystalline rocks in Baltimore and Harford Counties ranged from 21 to 305 ppm and averaged 105 ppm (Dingman and Ferguson, 1956, p. 62). The lowest concentrations were in samples from schist and quartzite, and the highest were in samples from serpentine and marble.

Hardness, as indicated by 60 analyses, ranged from 6 to 246 ppm as $CaCO_3$ and averaged 59 ppm. Hard water is commonly associated with deposits of serpentine and marble. The average hardness of 7 samples from the marble was 133 ppm; 3 samples from the serpentine averaged 201 ppm.

The iron content of 60 samples ranged from 0.0 to 3.5 ppm, and 30 percent of the samples contained 0.3 ppm or more of iron.

The nitrate content of 58 samples ranged from 0.02 to 76 ppm and averaged 5.1 ppm (Dingman and Ferguson, 1956, p. 55–56). Probably the high nitrate content of some samples was caused by leakage of water from the surface downward alongside the well casings.

Water from the crystalline rocks is generally several times more mineralized than that from the sedimentary rocks of the Coastal Plain because many crystalline rocks contain more cacium carbonate. Silica is also prominent in water from the crystalline rocks, generally in concentrations of about 40 ppm. Analyses of 12 samples of water from the crystalline rocks are given in the upper table on page F18.

TEMPERATURE OF GROUND WATER

Ground water is in large demand for industrial cooling and air conditioning, because its temperature seldom fluctuates more than a few degrees during the year. In general, temperatures of ground-water at shallow depths average about the same as the mean annual air temperature. At depths below a few hundred feet, temperatures commonly rise at a rate dependent on the temperature gradient of the earth at a given place. This gradient is about 1° F. for each 50 to 100 feet of depth.

Chemical analysis of water from wells in Precambrian crystalline rocks

[Analytical results in parts per million except as indicated]

Location	Well depth (feet)	Date of collection	Temperature (° F)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)
West Elkridge	165	Apr. 26, 1944	------	------	1.0	------	------	------	------	112	7.9
Joppa	290	Aug. 9, 1944	------	------	8.0	------	------	------	------	144	12
Edgewood	166	Mar. 19, 1954	47	43	.68	20	7.2	5.9	1.9	114	0
Towson	133	July 8, 1955	------	------	------	------	------	13		86	0
Woodstock	248	Mar. 17, 1954	56	24	.04	22	8.2	7.5	3.5	81	0
Towson	160	July 18, 1955	------	------	.00	------	------	27		60	0
Catonsville	157	Mar. 18, 1955	56	42	.35	36	15	12	3.9	182	0
Southwest Baltimore	291	Mar. 18, 1954	57	45	1.3	40	7.8	18	3.3	159	0
North Baltimore	185	Mar. 18, 1954	56	42	1.5	19	8.0	5.9	4.2	105	0
Do	175	Feb. 10, 1954	------	49	1.0	63	32	8.1	.5	165	0
Northwest Baltimore	85	Aug. 3, 1954	------	------	.13	------	------	------	------	67	0
East Baltimore	80	Aug. 6, 1954	------	------	.17	------	------	------	------	156	0

Location	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Residue of dissolved solids on evaporation at 180° C	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25° C)	pH	Color
West Elkridge	20	5	------	0.1	----------	105	--------	------	200	8.5	------
Joppa	6	4	------	0	----------	123	--------	------	290	8.2	------
Edgewood	1.0	2.5	0	.1	[1] 140	81	0	9	180	7.3	25
Towson	3.8	3.0	------	.3	----------	50	0	------	146	6.7	5
Woodstock	33	7.0	0.1	.1	[2] 142	89	22	13	215	7.0	5
Towson	37	14	------	48	----------	88	39	------	320	6.6	2
Catonsville	12	17	.2	.2	219	152	3	9	341	7.5	7
Sonthwest Baltimore	30	15	.2	.1	[3] 250	133	3	16	344	7.2	28
North Baltimore	12	5.5	.1	.4	[4] 157	82	0	17	194	7.0	------
Do	155	8.0	.1	1.1	[5] 398	290	155	10	525	7.4	16
Northwest Baltimore	------	------	------	------	----------	82	27	------	251	6.6	------
East Baltimore	------	------	------	------	----------	60	0	------	321	8.1	------

[1] Lithium (Li), 0.3 ppm; manganese (Mn), 0.05 ppm.
[2] Lithium (Li), 0.5 ppm; manganese (Mn), 0.02 ppm.
[3] Lithium (Li), 0.7 ppm; manganese (Mn), 0.10 ppm.
[4] Lithium (Li), 0.5 ppm; manganese (Mn), 0.10 ppm.
[5] Aluminum (Al), 0.2 ppm; copper (Cu), 0.3 ppm; zinc (Zn), 0.000 ppm; lithium (Li), 0.2 ppm; phosphate (PO_4) 0.0 ppm; manganese 0.10 ppm.

Temperature measurement of ground water in the Piedmont ranged from 49.5° to 57° F and averaged 54° F. (See following table.) The profile of water temperatures in four wells in the Maryland Piedmont are shown in figure 7. All the wells contained a thin layer of warm

Temperature of ground water in the Piedmont subarea

Area	Number of measurements	Depth of wells (feet)	Temperature (°F): Range	Temperature (°F): Average
Howard and Montgomery Counties (after Dingman and Meyer, 1954)	20	40–203	51.5–55.5	54
Baltimore and Harford Counties (after Dingman and Ferguson, 1956)	19	60–440	49.5–57	54

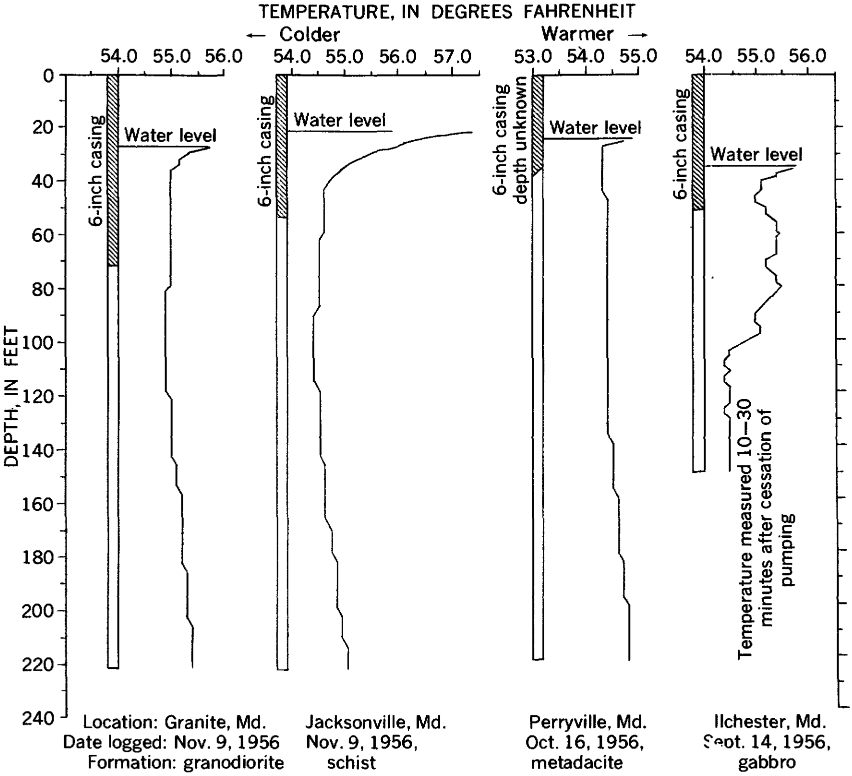

FIGURE 7.—Profile of water temperatures in four wells in the Maryland Piedmont subarea.

water near the water table. Three profiles show a geothermal gradient of approximately 1° F per 200 feet below a depth of 100 feet. This is only half the commonly observed gradient and probably is due to the relatively low thermal conductivity of the crystalline rocks.

USE OF GROUND WATER

The uses of ground water in the Piedmont subarea may be divided into three main categories; industrial and commercial, rural and suburban domestic, and irrigation. About 0.7 mgd is used by industry and commerce. About two-thirds of this quantity (0.45 mgd) is used by two large industries, and the remaining one-third by nine others.

By far the largest use of ground water is for domestic supply. On the basis of the population in 1955, an estimated 90,000 people in the Piedmont subarea depend on wells and springs for water. They withdraw about 4.5 mgd. Irrigation use amounts to about 0.3 mgd during the irrigation season, which lasts 50 to 100 days in the summer. Therefore, the total withdrawal of ground water in the Piedmont subarea is about 5.3 mgd.

SUSQUEHANNA RIVER

The Susquehanna River, the largest river in the area, has a drainage area of 27,570 square miles, of which about 1 percent (282 square miles) is in Maryland. It rises in New York and winds tortuously through Pennsylvania and into Maryland, where it has a wide slightly winding channel and several small tributaries. Gradients of the main river and the tributaries are moderately high; the main river drops about 1,100 feet in its 444-mile length.

DISCHARGE

Records of flow at Marietta (drainage area, 25,990 square miles) are published by the U.S. Geological Survey. The minimum daily flow of record at this gaging station is 892 mgd, or 1,380 cfs (cubic feet per second). Discharges less than 8,000 cfs are regulated by the York Haven powerplant. Safe Harbor, Holtwood, and Conowingo powerplants are downstream from the gaging station.

CHEMICAL QUALITY OF WATER

Water from the Susquehanna River in nontidal reaches appears to be chemically suitable for most uses; however, water from low flows is sometimes hard. (See following table.)

Chemical analyses, in parts per million, of water from the Susequehanna River

[Public supply for Havre de Grace, raw water; analyses by Maryland State Department of Health, except as noted]

Date of collection	At Conowingo Dam			At Havre de Grace		
	Jan. 17, 1952	Feb. 4, 1954	Nov. 21, 1957 [1]	Jan. 29, 1953	Apr. 25, 1956	Feb. 20, 1957
Silica		8.1		20		
Aluminum (Al)		1.3		2.2		
Iron (Fe)	0.6	.6	0.0	.4	0.2	0.4
Calcium (Ca)		16	42	5.6		
Magnesium (Mg)		3.3	13	.3		
Sodium (Na) and potassium (K)			18			
Bicarbonate (HCO_3)			69			
Sulfate (SO_4)		37	116	27		
Chloride (Cl)	5.8		13	6.8	8.7	7.8
Fluoride (F)				.2		
Nitrate (NO_3)	.2		2.8	.5	6.1	.3
Dissolved solids	114	116		132	103	100
Hardness as $CaCO_3$	56	53	158	15		
Noncarbonate hardness as $CaCO_3$			102			
pH	6.7	7.1	7.5	6.8	7.3	6.8

[1] At Shures Landing, one-quarter mile below dam; specific conductance, 391 micromhos; color, 0 units analysis by U.S. Geol. Survey.

At Havre de Grace, where the Susquehanna River is used as a source of public water supply, the chloride content ranged from 4.4 to 133 ppm from November 1946 to February 1957. The maximum observed chloride, 133 ppm, occurred on August 13, 1955, at the end of a prolonged drought.

WATER STORAGE

Conowingo Reservoir is used to generate hydroelectric power. It will also serve as a source of water for Baltimore City after 1965 through a pipeline which will divert 220 mgd, enough to supply Baltimore until the year 2000. The proposed diversion is only about one-fourth the minimum daily flow of 892 mgd (1,380 cfs). Details pertinent to Conowingo Reservoir are (Thomas and Harbeck, 1956):

Location:			
Latitude			39°40′
Longitude			76°10′
Date of completion			1928
Drainage area	sq mi		27, 098
Surface area	do		13. 4
	acres		8, 563
Volume of storage:			
Dead	million gal	45, 290	
Usable	do	[1] 55, 070	
Total	do	100, 360	
Storage ratio [2]	yr		0. 05
Elevation of spillway crest	ft above mean sea level		108. 5
Average pond level	do		104. 5

[1] Usable capacity at normal operating conditions is 23,050 million gal.
[2] See "Definitions of terms used," pages F99–F101.

WATER USE

The chief withdrawal use of water from the Susquehanna River in Maryland at the time of this investigation (1957) was approximately 0.4 mgd for the public water supply of the town of Havre de Grace. The water is taken from a tidal reach of the stream at the town and is treated. The treatment plant was constructed in 1955 and has a rated capacity of 2 mgd.

DEER CREEK

Deer Creek, a tributary of the Susquehanna River, drains an area of 170.7 square miles, of which about 25 square miles is in Pennsylvania and the remainder in Maryland. The topography of the basin is undulating to rolling, and the altitude of the highest point is about 1,050 feet, north of Stewartstown, Pa.

DISCHARGE

Streamflow records have been collected at Rocks (drainage area, 94.4 square miles) since October 1926. During the period 1927–55, the average flow was 80.1 mgd (124 cfs) or 0.846 mgd per square mile. The lowest daily flow was 8.4 mgd (13 cfs) on August 2, 1931, and the lowest average flow for a calendar month was 19.5 mgd (30.2 cfs) in October 1931 (Fig. 8). Flow at the gaging station was at least

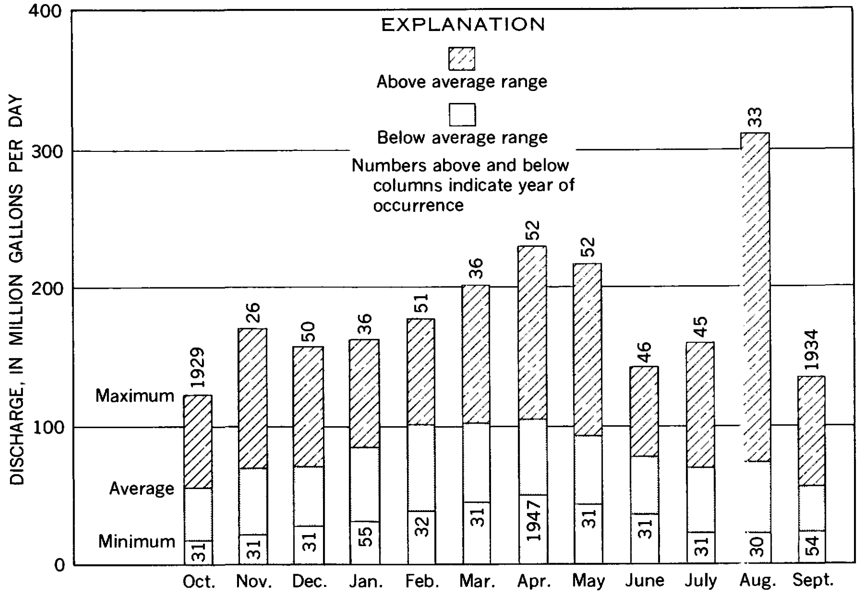

FIGURE 8.—Monthly flow of Deer Creek at Rocks, Md., 1927–55.

0.29 mgd per square mile, or 27.0 mgd, for 50 percent of the time (Fig. 9 and table 1).

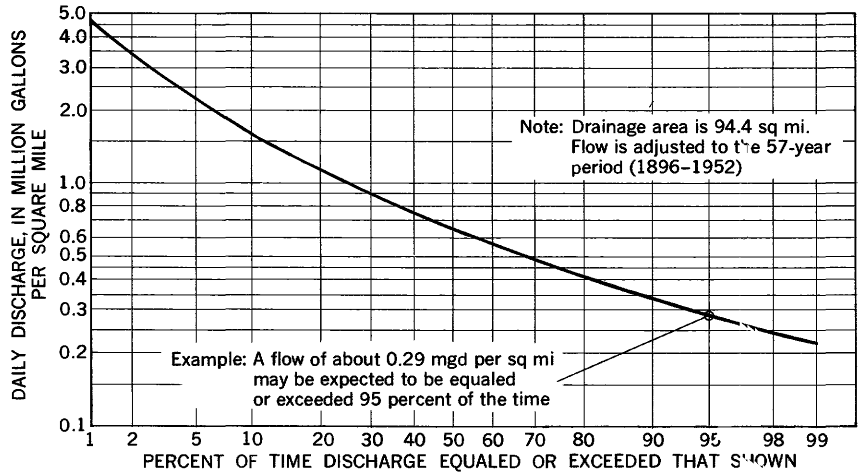

FIGURE 9.—Duration curve of daily flow, Deer Creek at Rocks, Md.

LOW-FLOW FREQUENCY

The average flow for 30 consecutive days at Rocks may be less than 0.25 mgd per sq mi at average 10-year intervals, or there is 1 chance in 10 that the flow will be less than 0.25 mgd per sq mi in a particular year. A flow of 0.25 mgd per sq mi amounts to 23.8 mgd at Rocks. Frequency of low flow of Deer Creek is given in figure 10 and table 2.

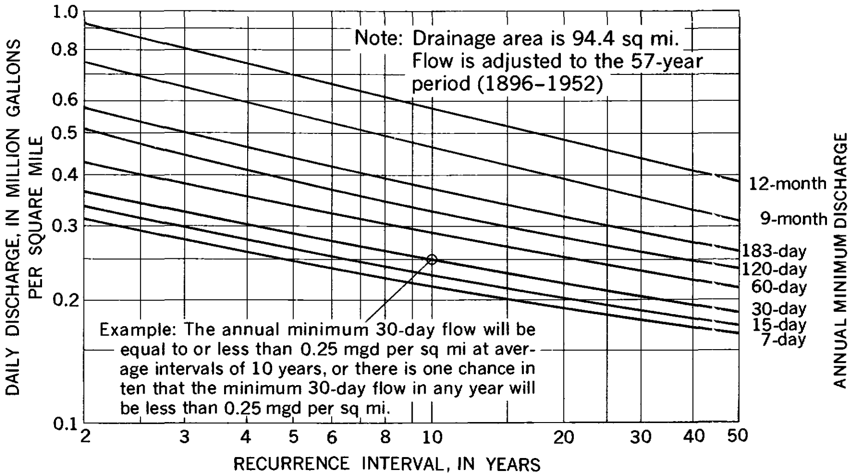

FIGURE 10.—Low-flow frequency curves, Deer Creek at Rocks, Md.

CHEMICAL QUALITY OF WATER

The water of Deer Creek at Rocks is of excellent chemical quality, as it is low in dissolved solids, hardness, and other principal constituents. No individual constituent is dominant. (See fig. 11 and table 3.) As with much of the other water in the area having low concentrations of dissolved solids, silica, calcium, and bicarbonate are slightly in excess of other constituents and dissolved iron is low.

Requardt and others (1953) reported that daily samples taken at the Chapel Hill water-plant intake (downstream from the Deer Creek gaging station) during the period June 1951 to April 1952 averaged as follows: Turbidity, 108 ppm; alkalinity as $CaCO_3$, 15 ppm; hardness as $CaCO_3$, 21 ppm; and pH, 7.0

If the alkalinity reported as $CaCO_3$ is recalculated to bicarbonate (by multiplying by 1.22), data for the latter three items agree well with the results reported in table 3. Turbidity is not reported in table 3.

FLOODS

The maximum flood of record on Deer Creek occurred August 23, 1933. The maximum flow on this day was about 13,600 cfs The crest gage height from flood marks was 17.7 feet (268.1 feet above mean sea level). A major flood also occurred on November 17, 1926, when the crest gage height was 15.45 feet (265.8 feet above mean sea level) and the flow was 9,080 cfs. A flood of at least 265.3 feet above mean sea level will occur at the gaging station at average intervals of 10

TABLE 1.—*Duration of daily flow of streams in the Baltimore area, Maryland*

[Adjusted to 57-year period 1896–1952 on basis of long-term streamflow records in adjacent areas]

No. on pl. 1	Gaging stations	Drainage area (sq mi)	Discharge (mgd) equaled or exceeded the percent of time indicated												
			1	2	5	10	20	30	50	70	80	90	95	98	99
	Susquehanna River basin														
1	Deer Creek at Rocks	94.4	436	320	210	151	106	85.3	61.9	45.8	38.8	31.6	27.0	22.9	20.8
	Gunpowder River basin														
6	Slade Run near Glyndon	2.27	9.10	6.54	4.13	2.88	2.02	1.62	1.16	0.860	0.724	0.568	0.470	0.388	0.343
5	Little Falls at Blue Mount	52.9	242	175	114	82.0	57.7	46.4	33.8	25.6	21.7	17.6	14.8	12.3	11.0
7	Western Run at Western Run	59.8	271	194	123	86.7	61.6	49.1	35.4	26.2	22.1	17.5	14.7	12.2	10.9
12	Little Gunpowder Falls at Laurel Brook.	36.1	186	130	80.1	56.3	39.0	31.3	23.0	17.0	14.2	11.0	8.92	7.11	6.21
	Patapsco River basin														
14	North Branch Patapsco River at Cedarhurst.	56.6	258	182	114	80.4	54.7	42.6	29.3	21.0	17.2	13.2	10.8	8.66	7.64
17	South Branch Patapsco River at Henryton.	64.4	323	222	138	93.4	61.2	45.5	30.4	19.9	15.4	10.8	7.99	5.80	4.77
18	Piney Run near Sykesville	11.4	56.9	39.1	24.3	16.4	11.0	8.47	5.88	4.08	3.26	2.39	1.86	1.40	1.19
	Patuxent River basin														
26	Little Patuxent River at Guilford	38.0	213	147	85.5	54.3	34.8	25.8	16.9	11.2	8.85	6.27	4.79	3.54	2.95
27	Little Patuxent River at Savage	98.4	553	382	221	141	89.8	67.2	43.8	29.1	22.9	16.2	12.3	9.18	7.63
28	Dorsey Run near Jessup	11.6	71.1	49.1	28.8	18.6	11.7	8.21	4.90	3.27	2.56	1.81	1.37	1.02	.847
	Coastal Plain States														
21	Sawmill Creek at Glen Burnie	5.1	15.3	12.3	9.23	7.34	5.87	5.06	4.32	3.80	3.55	3.23	2.98	2.73	2.59
22	North River near Annapolis	8.5	34.2	25.5	17.1	12.7	9.27	7.62	5.81	4.43	3.76	3.01	2.49	2.01	1.79
23	Bacon Ridge Branch at Chesterfield	6.92	28.6	21.5	14.4	10.6	7.75	6.42	4.93	3.74	3.20	2.67	2.39	2.12	1.97

TABLE 2.—*Magnitude and frequency of low streamflow at gaging stations in the Baltimore area, Maryland*

[Adjusted to 57-year period 1896–1952 on basis of long-term streamflow records in adjacent areas]

No. on pl. 1	Gaging station	Drainage area (sq. mi.)	Recurrence interval (years)	Discharge (mgd) below which flow remained continuous for length of minimum period indicated							
				7-day	15-day	30-day	60-day	120-day	183-day	9-month	12-month
1	Deer Creek at Rocks	94.4	2	30.1	32.0	35.2	41.4	49.4	55.6	71.1	87.9
			5	23.5	24.9	27.3	31.5	36.8	41.4	53.0	65.9
			10	20.6	21.8	23.8	27.4	31.0	34.9	43.9	54.9
			25	17.5	18.3	20.0	22.9	25.5	28.6	34.3	43.3
			50	15.5	16.2	17.5	20.2	22.6	24.6	29.1	36.2
5	Little Falls at Blue Mount	52.9	2	16.7	18.0	19.9	23.7	28.1	31.5	39.0	48.1
			5	12.3	13.2	14.7	17.5	20.7	23.3	29.5	36.6
			10	10.3	11.0	12.3	14.6	17.1	19.4	24.7	31.0
			25	8.41	8.94	10.0	11.8	13.9	15.6	19.8	24.9
			50	7.35	7.78	8.68	10.1	11.8	13.3	16.7	21.3
6	Slade Run near Glyndon	2.27	2	.533	.586	.665	.795	.938	1.06	1.31	1.62
			5	.372	.411	.465	.563	.679	.776	.983	1.23
			10	.302	.329	.375	.458	.561	.654	.826	1.04
			25	.234	.252	.291	.359	.445	.518	.672	.860
			50	.194	.209	.243	.297	.375	.438	.581	.742
7	Western Run at Western Run	59.8	2	16.7	18.3	20.5	24.4	29.1	32.5	40.1	49.8
			5	11.8	13.0	14.7	17.5	21.1	23.9	30.2	37.9
			10	9.69	10.6	12.0	14.3	17.5	20.0	25.4	32.2
			25	7.71	8.31	9.51	11.4	14.0	16.2	20.7	26.4
			50	6.46	7.00	8.01	9.63	12.0	13.9	17.9	23.0
12	Little Gunpowder Falls at Laurel Brook	36.1	2	10.3	11.5	13.1	15.9	19.0	21.5	26.7	33.0
			5	6.97	7.76	8.99	11.0	13.4	15.4	19.9	24.8
			10	5.56	6.10	7.11	8.84	10.7	12.4	16.2	20.7
			25	4.26	4.62	5.42	6.71	8.27	9.67	12.9	16.7
			50	3.55	3.86	4.51	5.56	6.97	8.19	10.9	14.4
14	North Branch Patapsco River at Cedarhurst	56.6	2	12.3	14.0	15.8	19.2	23.3	26.4	33.3	42.6
			5	8.49	9.45	10.8	13.1	16.4	18.7	24.5	31.3
			10	6.68	7.41	8.55	10.4	13.2	15.3	20.2	26.2
			25	5.07	5.59	6.51	7.92	10.3	12.2	16.4	21.2
			50	4.14	4.54	5.33	6.51	8.66	10.3	14.1	18.4
15	North Branch Patapsco River near Reisterstown.	91.0	2	20.0	22.5	25.7	30.9	37.5	42.5	53.6	68.5
			5	13.6	15.2	17.3	21.1	26.4	30.6	39.4	50.3
			10	10.7	12.0	13.7	16.7	21.3	24.8	32.6	42.1
			25	8.14	8.99	10.4	12.8	16.6	19.3	23.4	34.1
			50	6.72	7.30	8.53	10.5	14.0	16.7	22.6	29.7
16	North Branch Patapsco River near Marriottsville.[1]	165	2	36.3	40.8	46.5	55.9	68.0	77.1	97.4	124
			5	24.6	27.6	31.4	38.3	47.9	55.4	71.4	91.2
			10	19.5	21.8	24.8	30.4	38.8	45.0	59.1	76.2
			25	14.9	16.4	18.6	23.3	30.0	35.5	47.9	62.0
			50	12.2	13.4	15.4	19.0	25.2	30.2	40.8	54.0

See footnote at end of table.

TABLE 2.—*Magnitude and frequency of low streamflow at gaging stations in the Baltimore area, Maryland*—Continued

[Adjusted to 57-year period 1896–1952 on basis of long-term streamflow records in adjacent areas]

No. on pl. 1	Gaging station	Drainage area (sq. mi.)	Recurrence interval (years)	Discharge (mgd) below which flow remained continuous for length of minimum period indicated							
				7-day	15-day	30-day	60-day	120-day	183-day	9-month	12-month
17	South Branch Patapsco River at Henryton	64.4	2	9.79	11.4	13.5	17.5	22.6	26.4	35.0	46.4
			5	5.72	6.70	8.11	10.8	14.2	16.9	23.6	31.8
			10	4.14	4.83	5.88	7.86	10.5	13.0	18.7	24.9
			25	2.88	3.30	4.01	5.36	7.28	9.21	13.6	18.7
			50	2.25	2.57	3.10	4.01	5.59	7.21	10.9	15.3
18	Piney Run near Sykesville	11.4	2	2.20	2.51	2.92	3.67	4.51	5.22	6.71	8.66
			5	1.40	1.60	1.87	2.42	3.04	3.59	4.78	6.14
			10	1.05	1.20	1.43	1.84	2.36	2.83	3.88	4.99
			25	.756	.847	1.01	1.31	1.71	2.11	2.98	3.88
			50	.608	.671	.801	1.01	1.35	1.69	2.44	3.27
20	Patapsco River at Hollofield [1]	285	2	61.8	70.4	79.5	96.9	117	133	168	213
			5	42.2	47.3	54.2	66.1	83.2	94.9	123	158
			10	33.6	37.3	42.8	52.7	67.0	77.2	102	132
			25	25.4	28.1	32.5	40.2	51.9	60.7	82.7	107
			50	20.9	22.9	26.7	32.8	43.6	51.6	70.7	93.2
21	Sawmill Creek at Glen Burnie	5.1	2	3.10	3.23	3.39	3.63	3.88	4.10	4.52	5.10
			5	2.73	2.84	2.98	3.22	3.41	3.59	3.94	4.36
			10	2.53	2.62	2.75	2.97	3.19	3.33	3.67	4.00
			25	2.31	2.40	2.51	2.70	2.91	3.09	3.37	3.68
			50	2.15	2.22	2.33	2.51	2.71	2.89	3.21	3.50
22	North River near Annapolis	8.5	2	2.78	3.07	3.37	4.04	4.70	5.24	6.37	7.69
			5	2.03	2.22	2.49	2.97	3.50	3.98	4.90	5.95
			10	1.68	1.84	2.05	2.46	2.93	3.36	4.17	5.11
			25	1.34	1.47	1.64	1.94	2.34	2.70	3.41	4.24
			50	1.13	1.23	1.38	1.64	1.98	2.29	2.95	3.67
23	Bacon Ridge Branch at Chesterfield	6.92	2	2.57	2.75	2.97	3.41	3.93	4.39	5.30	6.4
			5	2.13	2.25	2.39	2.66	3.02	3.37	4.12	5.03
			10	1.91	2.00	2.13	2.35	2.65	2.93	3.50	4.30
			25	1.65	1.75	1.86	2.04	2.31	2.51	2.97	3.55
			50	1.50	1.57	1.70	1.87	2.09	2.29	2.64	3.12
26	Little Patuxent River at Guilford	38.0	2	5.70	6.38	7.68	9.88	12.5	14.8	20.2	26.5
			5	3.59	4.03	4.79	6.27	8.09	9.69	13.4	18.1
			10	2.75	3.08	3.63	4.75	6.16	7.37	10.3	14.3
			25	2.00	2.24	2.62	3.39	4.37	5.36	7.49	10.5
			50	1.62	1.78	2.09	2.69	3.36	4.18	5.93	8.40
27	Little Patuxent River at Savage	98.4	2	14.7	16.7	19.9	25.6	32.4	38.3	51.6	68.6
			5	9.31	10.4	12.4	16.2	20.9	25.1	34.4	46.9
			10	7.11	7.95	9.44	12.3	15.9	19.3	26.6	37.0
			25	5.19	5.75	6.79	8.79	11.3	13.7	19.4	27.3
			50	4.15	4.62	5.40	6.98	8.79	10.9	15.3	21.8
28	Dorsey Run near Jessup	11.6	2	1.65	1.84	2.24	2.82	3.65	4.34	6.08	8.47
			5	1.03	1.15	1.38	1.77	2.31	2.77	3.87	5.43
			10	.789	.879	1.04	1.36	1.74	2.12	2.97	4.16
			25	.570	.635	.751	.969	1.23	1.54	2.15	3.04
			50	.456	.503	.596	.763	.957	1.22	1.71	2.44

[1] Prior to regulation.

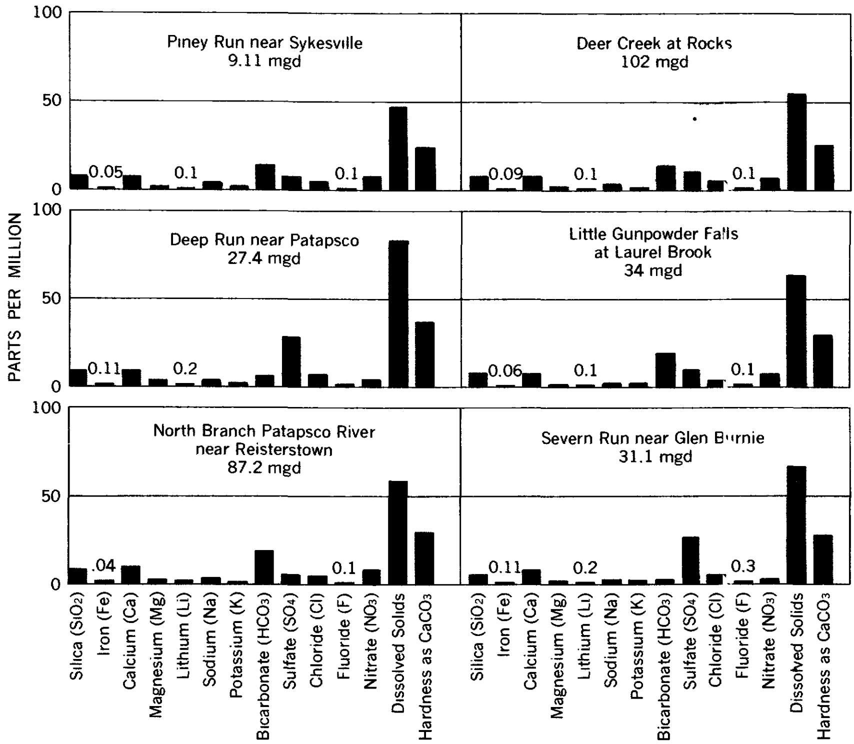

FIGURE 11.—Chemical and physical characteristics of water from selected streams.

years; there is 1 chance in 10 that a flood will exceed 265.3 feet in a particular year. (See fig. 12.)

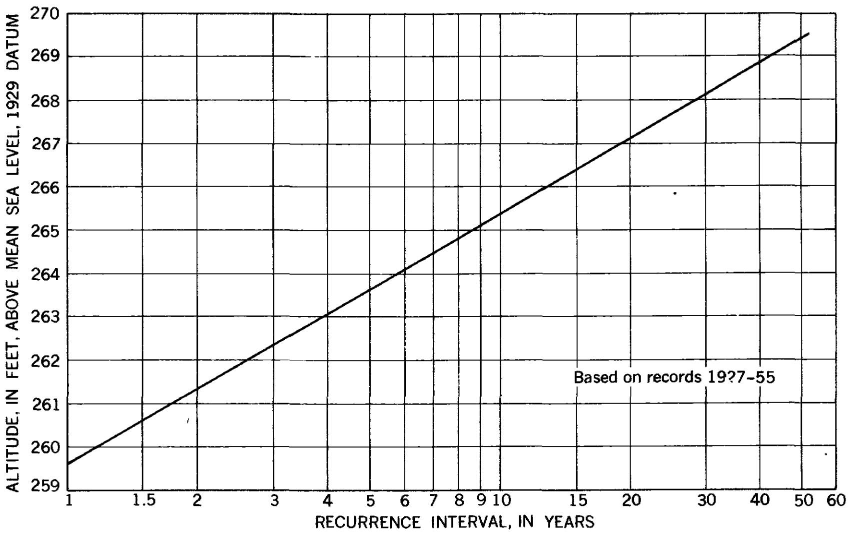

FIGURE 12.—Flood-stage frequency curve, Deer Creek at Rocks, Md.

TABLE 3.—*Chemical analyses of water from selected Piedmont streams*

[Analytical results in parts per million except as indicated]

Date of collection	Discharge (mgd)	Lithium (Li)	Manganese (Mn)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Residue of dissolved solids on evaporation at 180°C	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
Susquehanna River at Perry Point (U.S. Veterans' Hospital intake)																				
Aug. 10, 1953	------	------	------	2.9	0.01	33	12	12	12	64	86	9.0	0.4	1.8	195	132	79	307	7.2	4
Deer Creek at Rocks [1]																				
Dec. 13, 1954	30.6	0.1	0.00	8.8	.07	4.5	2.0	3.2	1.3	12	9.0	3.0	0.1	10	51	20	10	60.0	6.7	5
Mar. 7, 1955	102	.1	.00	6.5	.09	6.8	1.8	2.6	1.4	14	9.5	5.0	.1	6.2	53	25	13	74.8	6.8	20
Gunpowder Falls near Carney [2]																				
Feb. 11, 1952	2.68	------	0.00	8.6	0.00	13	3.5	2.6	1.6	48	8.5	3.2	0.2	3.2	68	47	8	113	7.8	------
Dec. 13, 1954	------	[3] 0.3	.00	8.7	.01	27	12	5.0	2.4	122	13	6.2	.2	9.5	157	117	17	247	7.7	15
Mar. 7, 1955	100	.3	.00	8.7	.06	18	6.5	3.9	2.6	68	15	6.0	.2	5.5	106	72	16	174	7.4	15
Little Gunpowder Falls at Laurel Brook [4]																				
Dec. 13, 1954	13.2	.1	0.00	12	.10	6.9	3.1	3.3	1.8	30	4.0	3.0	0.2	8.8	70	30	6	81.4	7.4	7
Mar. 7, 1955	33.7	.1	.00	8.8	.06	7.7	2.3	2.7	1.8	20	10	4.0	.1	6.8	63	29	12	87.7	6.9	7
North Branch Patapsco River near Reisterstown																				
Feb. 13, 1952	87.2	------	0.00	8.1	0.04	8.2	2.0	3.2	1.9	19	6.2	5.4	0.1	8.0	58	29	13	82.3	7.2	10

North Branch Patapsco River near Marriottsville [5]																				
Dec. 6, 1954	0.17	0.1	0.00	13	0.02	15	4.3	3.3	1.6	64	6.5	2.5	0.1	1.8	92	55	0	124	7.9	5
Mar. 8, 1955	.40	.2	.00	10	.23	9.2	3.8	2.8	2.1	36	13	3.0	.2	1.8	66	39	10	103	7.1	55
South Branch Patapsco River at Henryton [6]																				
Dec. 8, 1954	11.8	0.2	0.00	9.4	0.01	5.9	2.6	4.4	1.6	25	3.2	4.0	0.1	10	62	25	5	79.6	7.3	2
Mar. 8, 1955	65.9	.2	.01	7.1	.07	8.5	2.0	2.5	1.0	14	14	4.0	.1	7.2	54	30	18	77.9	7.0	7
Piney Run near Sykesville [7]																				
Dec. 8, 1954	2.11	0.0	0.00	9.4	0.02	6.6	2.2	2.6	1.1	22	2.8	2.7	0.1	10	58	26	8	66.0	7.2	5
Mar. 8, 1955	9.11	.1	.00	7.2	.05	6.8	1.5	2.4	.8	14	7.0	4.0	.1	6.5	47	23	12	70.2	6.9	4
Patapsco River at Hollofield [8]																				
Dec. 6, 1954	22.9	0.2	0.00	10	0.01	8.2	2.9	5.2	2.0	33	7.0	5.5	0.1	7.5	74	32	5	95.6	7.5	5
Mar. 8, 1955	117	.4	.00	8.4	.07	8.0	2.7	3.2	1.5	17	14	6.4	.0	7.5	67	31	17	88.1	6.8	8
Jones Falls near Rockland (above Lake Roland)																				
Dec. 17, 1954	6.42	0.0	0.00	9.9	0.02	21	7.8	3.4	1.4	88	8.2	4.0	0.1	6.2	113	84	13	176	7.9	5
Mar. 7, 1955	24.8	.2	.00	8.1	.07	19	6.5	2.8	1.8	70	16	5.0	.1	5.2	107	74	17	170	7.4	18

[1] Range in flow, .8 to 11,000 cfs.
[2] Range in flow, 1.7 to 7,000 cfs.
[3] Aluminum (Al), 0.00 ppm.
[4] Range in flow, 3.1 to 9,200.
[5] Range in flow, 0.2 to 19,500 cfs.
[6] Range in flow, 5.3 to 4,930 cfs.
[7] Range in flow, 0.4 to 2,100 cfs.
[8] Range in flow, 6.0 to 13,500 cfs.

The maximum flow per square mile recorded in Maryland was caused by a thundershower on a small unnamed tributary of Broad Creek at Pylesville, Harford County, on July 15, 1951. This small tributary of the Susquehanna River has a drainage area of less than 4 square miles. The maximum flow was at least 1,100 cfs per sq mi. Four persons from one family were swept to their deaths while attempting to ford the flooded highway 165.

WATER USE

Water is withdrawn at the Chapel Hill intake plant of the U.S. Army Aberdeen Proving Ground. Some water from Deer Creek may be used for supplemental irrigation during dry weather. The extent of this use is not known, but it is not considered large.

BUSH RIVER

Bush River is an estuary near the head of Chesapeake Bay which is fed by small streams draining about 140 square miles in Harford County.

DISCHARGE

Streamflow records are available for one tributary, Bynum Run at Bel Air, Md. The drainage area above this station is 8.8 square miles. The maximum daily flow at this station during the period of record, June 1944 through April 1951 and since July 1955, was 281 mgd (434 cfs), and the minimum daily flow was 0.39 mgd (0.6 cfs). The 6-year (1945–50) average flow was 6.66 mgd (10.3 cfs). A gaging station was operated at a point 0.5 mile upstream (drainage area, 7.7 square miles) from October 1950 to September 1955 and the records published as Bynum Run near Bel Air, Md.

Winters Run, another tributary of Bush River, drains an area of about 55 square miles above Van Bibber near State Highway 7. This stream has not been gaged. It has served as a source of water for the town of Bel Air since 1954 and as a source of part of the water for the Army Chemical Center at Edgewood, Md. Atkissor Reservoir, 1½ miles southwest of Emmorton, stores water for the Chemical Center.

CHEMICAL QUALITY OF WATER

Five partial analyses of water from the Bush River basin by the Maryland Water Pollution Control Commission indicate that the water was soft, moderately low in dissolved solids, and alkaline on the pH scale. (See following table.)

Partial chemical analyses of water from tributary streams in the Bush River basin

[Analyses by Maryland Water Pollution Control Commission; results in parts per million except for pH]

Sample	Location	Dissolved solids	Dissolved oxygen (O_2)	Alkalinity as $CaCO_3$	Hardness as $CaCO_3$	pH
1	Falling Branch at Hawkins Road	66		12	18	6.9
2	James Run at Harford Furnace	90	10	32	44	7.8
3	James Run at Quarry Road	90	9.2	24	46	8.1
4	Bynum Run at Heighe Road	106	9.8	42	56	7.9
5	Bynum Run at McPhail Road	102	9.3	34	50	8.0

GUNPOWDER RIVER

Gunpowder Falls (head of Gunpowder River) probably is the most important source of fresh water in the area; it provides three-fourths of the water supply for Baltimore City. Gunpowder Falls, including Little Gunpowder Falls (drainage area, 58.3 square miles), drains an area of 408 square miles, of which 11 square miles is in Pennsylvania. The topography ranges from rolling to rugged. The highest point in the basin is about 900 feet above mean sea level.

DISCHARGE

Streamflow records in the Gunpowder River basin have been collected at seven gaging stations, of which five were in operation when this report was prepared. (See pl. 1.)

The flow at four stations, Little Gunpowder Falls at Laurel Brook, Little Gunpowder Falls near Bel Air, Little Falls at Blue Mount, and Western Run at Western Run, is not affected by regulation and diversions. Data concerning these gage stations are given in table 4.

TABLE 4.—*Gaging-station data for Gunpowder River basin, Maryland*

No. on pl. 1	Gaging station	Drainage area (sq mi)	Elevation of gage (feet above mean sea level)	Period of record
12	Little Gunpowder Falls at Laurel Brook.	36.1	261.43	Dec. 1926 to Sept. 1955.
13	Little Gunpowder Falls near Bel Air.	43	200	Dec. 1904 to Mar. 1909.
8	Gunpowder Falls at Glencoe	160	250	Dec. 1904 to Mar. 1909.
11	Gunpowder Falls near Carney	314	135	Sept. 1949 to Sept. 1955.
5	Little Falls at Blue Mount	52.9	305	June 1944 to Sept. 1955
7	Western Run at Western Run	59.8	260	Sept. 1944 to Sept. 1955.
6	Slade Run near Glyndon	2.27	420	Sept. 1947 to Sept. 1955.

No. on pl. 1	Average flow				Minimum daily flow			Minimum monthly flow		
	Years	Cfs	Mgd	Mgd (per sq mi)	Cfs	Mgd	Date	Cfs	Mgd	Month and year
12	28	47.4	30.6	0.85	5.8	3.7	Aug. 1931	7.83	5.1	Oct. 1931
13	3	80.0	51.7	1.20	13	8.4	Sept. 25, 1908	32.3	20.9	Sept. 1908
8	3	259	167	1.04	71	45.9	July 19–21, 1908	10.4	67.2	Sept. 1906
11	6	[1]144	[1]93.1	([1])	[1]1.4	[1].90	Sept. 7, 8, 1954	[1]1.95	[1]1.26	Sept. 1954
5	11	71.5	46.2	.87	12	7.8	Aug. 3, 1953	19.6	12.7	Sept. 1954
7	11	75.6	48.9	.82	9.7	6.3	Aug. 3, 1955	19.0	12.0	Sept. 1954
6	8	2.63	1.70	.75	.4	.26	Several days in 1954 and 1955.	.64	.41	Sept. 1954

[1] Flow highly regulated, affected by storage and diversion.

The flow-duration curves of unregulated streams in the Gunpowder River basin are similar (fig. 13 and table 1). Little Falls has a slightly higher minimum flow than the other streams, and Slade Run has the lowest.

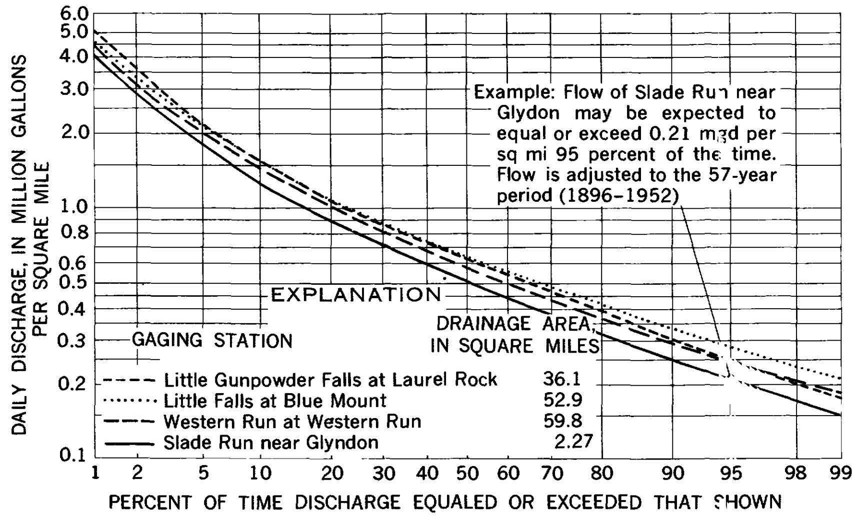

FIGURE 13.—Duration curves of daily flow of streams in the Gunpowder River basin, Maryland.

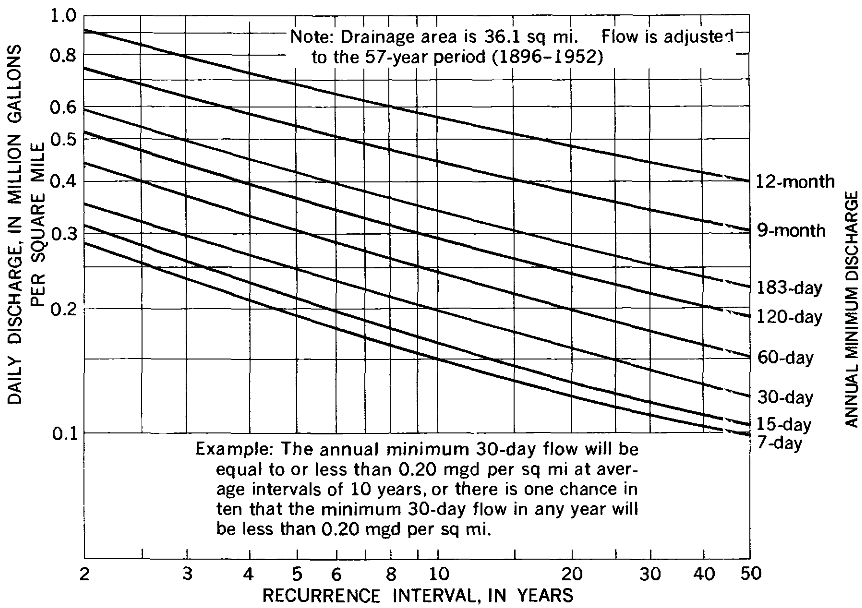

FIGURE 14.—Low-flow frequency curves, Little Gunpowder Falls at Laurel Brook, Md.

LOW-FLOW FREQUENCY

The low-flow frequency curves for Little Gunpowder Falls at Laurel Brook (fig. 14 and table 2) show that the annual minimum average flow for 30 consecutive days will be equal or less than 0.20 mgd per square mile (7.11 mgd at Laurel Brook) at average intervals of 10 years. Flows less than 0.20 mgd per square mile will not occur at regular 10-year intervals, but there is 1 chance in 10 that such flows will occur in a particular year.

There are some problems related to the low flow of streams, such as dilution of waste material, for which one must know the largest number of consecutive days in any year that the flow will be sufficient to meet the determined needs. Figure 15 and the following table give this type of information. The discharge is considered deficient when it is less than a specified amount. Suppose that 8 mgd is needed in the vicinity of Laurel Brook at a place where the drainage area of Little Gunpowder Falls is 40 square miles. This is 0.2 mgd per sq mi. How often will the flow be deficient for a given number of consecutive days? There is 1 chance in 5 that the flow will be less than 0.2 mgd per sq mi for 3 consecutive days, but 1 chance in 10 that the flow will be deficient for 12 consecutive days (fig. 15).

Magnitude and frequency of deficient streamflow

[Adjusted to 57-year period 1896–1952 on basis of long-term streamflow records in adjacent areas]

No. on pl. 1	Gaging station	Drainage area (sq mi)	Recurrence interval (years)	Discharge (mgd) below which flow remained continuous for length of minimum period indicated				
				1-day	7-day	15-day	30-day	60-day
1	Deer Creek at Rocks	94.4	2	27.3	34.3	40.0	48.4	75.6
			5	20.2	26.1	30.0	35.9	50.4
			10	16.7	22.3	25.5	30.4	40.7
			25	13.0	18.8	21.3	25.2	31.6
			50	11.0	17.5	19.7	22.7	27.2
12	Little Gunpowder Falls at Laurel Brook.	36.1	2	9.64	11.9	13.6	17.7	29.3
			5	6.46	8.16	9.57	12.3	18.7
			10	5.16	6.46	7.69	9.89	14.5
			25	3.90	4.80	5.85	7.62	10.8
			50	3.25	3.90	4.80	6.28	8.77
15	North Branch Patapsco River near Reisterstown.	91.0	2	17.5	22.7	26.2	34.9	62.1
			5	12.8	15.2	17.8	23.3	37.5
			10	9.46	11.9	14.2	18.6	28.3
			25	7.01	8.92	10.8	14.1	20.7
			50	5.64	7.28	9.01	11.7	16.7

CHEMICAL QUALITY OF WATER

Water in Gunpowder Falls is the composite of water from many small streams draining the Piedmont Plateau. In the eastern reaches of Gunpowder Falls, where the stream is deeply entrenched in the fresh rock, chemical solution is slow. However, in the upper reaches, soluble salts are removed by water flowing over or percolating through the soil-covered, decomposed, and disintegrated rocks.

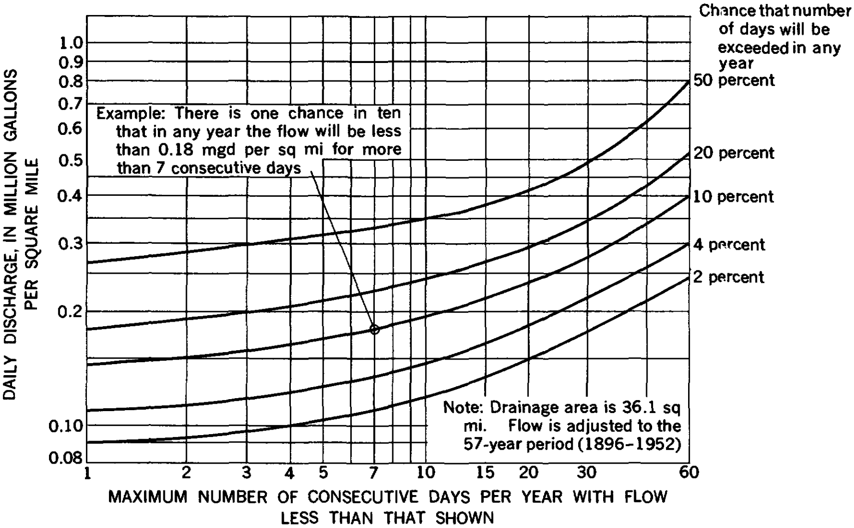

FIGURE 15.—Number of consecutive days of deficient discharge, Little Gunpowder Falls at Laurel Brook, Md.

The quantity of dissolved solids in water reaching Prettyboy Reservoir depends on the relative proportion of flow contributed by upstream tributaries. However, in Prettyboy Reservoir, as in any reservoir, the quality of the water entering the reservoir is modified by mixing and storage. Further mixing occurs downstream in Loch Raven Reservoir.

Some of the chemical characteristics of water from Gunpowder Falls at Carney, particularly dissolved solids and hardness, show appreciably more variation than for other streams sampled. The water is somewhat harder than the raw water at Montebello filter plant (tables 3 and 5).

The chemical quality of water from Little Gunpowder Falls at Laurel Brook, near the headwaters, is similar to that of Deer Creek to the east. This similarity is to be expected as these streams drain areas of similar topography and geology. The few data available indicate that calcium and bicarbonate are the principal constituents of the dissolved solids in the water. Undoubtedly, the excellent quality deteriorates somewhat in the more populated lower reaches of the stream, east of U.S. Highway 1.

Monthly and seasonal variations in the chemical constituents of raw water from Loch Raven Reservoir are slight, although the monthly composite samples to tend the mask diurnal variations (table 5). In general, the raw water is soft, slightly alkaline, and moderately low in iron and manganese; these constituents averaged 0.20 and 0.08 ppm in 1954.

TABLE 5.—*Selected chemical and physical characteristics of raw water from Gunpowder Falls, 1954* [1]

[Results in parts per million except as indicated]

	Temperature (° F)	Iron (Fe)	Manganese (Mn)	Hardness as $CaCO_3$	Carbon dioxide (CO_2)	Dissolved oxygen (percent saturated)	pH	Color
January	40	0.20	0.00	39	3.4	93	7.3	5
February	39	.18	.00	41	2.9	88	7.4	5
March	43	.16	.00	41	2.4	91	7.4	5
April	50	.23	.00	41	3.6	89	7.5	7
May	58	.20	.00	39	5.3	73	7.3	6
June	64	.17	.00	39	5.0	65	7.2	6
July	70	.10	.00	39	4.3	66	7.3	6
August	70	.17	.05	39	4.0	63	7.3	6
September	69	.34	.21	38	5.4	53	7.2	6
October	65	.29	.44	38	6.4	53	7.1	6
November	53	.19	.22	36	4.5	70	7.1	6
December	44	.20	.03	33	3.0	78	7.2	6
Average	[2] 55	.20	.08	39	4.2	74	7.3	6

[1] Analysis of water from Montebello filter plant by city of Baltimore Department of Public Works.
[2] Water temperature at filters ranged from 37° to 72° F.

Chemical character of raw and treated water from Gunpowder Falls at Loch Raven Reservoir for the 10-year period 1945–54 is shown in the following table. The average annual hardness of raw water ranged from 37 to 40 ppm, pH ranged from 7.0 to 7.3, and total iron ranged from 0.20 to 0.72 ppm. The total iron and manganese content of the raw water is reduced to negligible amounts by treatment, and hardness was increased about 10–15 ppm. Turbidity was reduced to 0.1 or 0.2 ppm, a negligible amount.

Selected chemical and physical characteristics of raw and treated water, Gunpowder Falls, 1945–54

[Results in parts per million except as indicated. Symbols: R. Raw water at Montebello filter plant; T. Treated water at Montebello filter plant. Analyses by city of Baltimore, Department of Public Works]

	Total iron (Fe)		Total manganese (Mn)		Fluoride (F)	Hardness as $CaCO_3$		Carbon dioxide (CO_2)	Dissolved oxygen (percent saturated)		pH		Turbidity	
	R	T	R	T	T	R	T	R	R	T	R	T	R	T
1945	0.45	0.02	0.14	0.00		38	50	5.4	74	77	7.1	7.9	6	0.07
1946	.72	.02	.17	.00		38	49	5.7	72	77	7.1	7.9	10	.1
1947	.27	.02	.12	.00		40	50	3.9	72	80	7.2	7.9	4	.2
1948	.37	.01	.15	.00		39	49	5.0	67	76	7.2	7.9	4	.1
1949	.32	.01	.14	.00		37	48	3.8	74	81	7.1	7.9	4	.1
1950	.26	.01	.11	.00		40	52	3.9	74	81	7.2	8.0	5	.1
1951	.51	.01	.12	.00		38	52	5.1	68	77	7.0	7.8	10	.1
1952	.45	.01	.06	.00	0.6	37	51	5.7	66	76	7.0	7.9	8	.1
1953	.21	.01	.07	.00	.93	37	51	4.7	71	81	7.1	7.9	6	.1
1954	.20	.01	.08	.00	.96	39	51	4.2	74	78	7.3	7.9	5	.1

TEMPERATURE

The only stream-temperature data available for the Gunpowder River basin are the monthly averages at the Montebello filter plant (table 5). The highest average temperature, 70° F, occurred in July and August, and the lowest, 39° F, occurred in February.

Water temperatures in the distribution system are somewhat higher (fig. 16). A maximum temperature of 82° F was reported for September 1953.

WATER STORAGE

Loch Raven Dam, operated by the Baltimore Bureau of Water Supply, controls the flow from nearly seven-eighths of the Gunpowder Falls drainage basin (exclusive of Little Gunpowder Falls). The combined storage capacity of Loch Raven and Prettyboy Reservoirs amounts to 56 percent of the average flow (Whitman, Requardt, and Associates, 1956, p. 21). Details of Prettyboy and Loch Raven Reservoirs are as follows:

Prettyboy Reservoir

Location:			
Latitude			39°47′
Longitude			76°42′
Date of completion			1933
Drainage area	sq mi		80
Surface area	sq mi		2.34
	acres		1,498
Volume of storage:			
Usable	million gal	19,640	
Total	do	19,870	
Storage ratio	yr		0.8
Elevation of spillway crest	ft above mean sea level		520
Elevation of dead storage pool	do		420

Loch Raven Reservoir

Location:			
Latitude			39°26′
Longitude			76°32′
Date of completion			1914, 1922
Drainage area	sq mi		303
Surface area	sq mi		3.74
	acres		2,391
Volume of storage:			
Dead	million gal	70	
Usable	do	23,630	
Total	do	23,700	
Storage ratio	yr		0.2
Elevation of spillway crest	ft above mean sea level		240
Elevation of dead storage pool	do		173.5

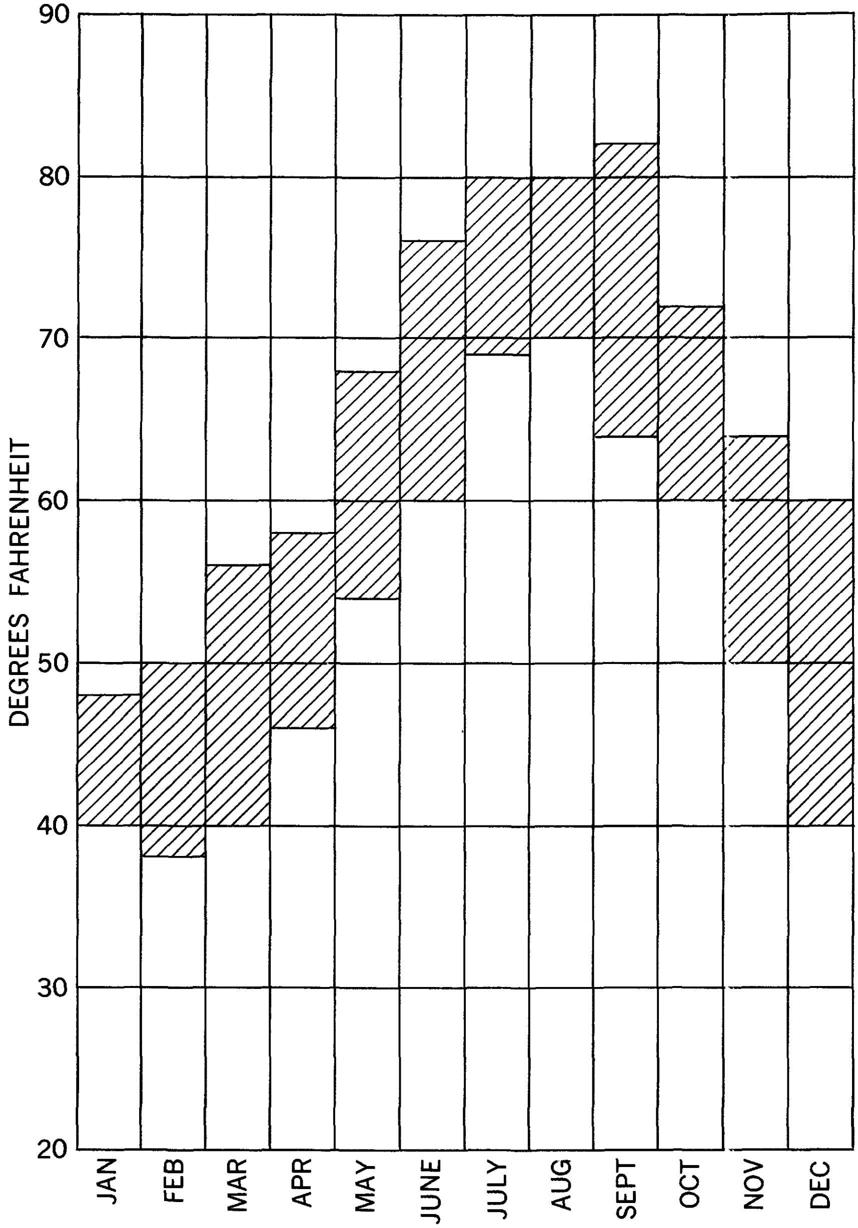

FIGURE 16.—Maximum and minimum temperatures of tap water at Baltimore, Md., in 1953, based on measurements at 44 stations in the distribution system, Baltimore City Bureau of Water Supply.

The water passing the dam is measured several miles downstream near Carney, Md. (station 11, pl. 1). The flow at this station for 6 years (1950–55) averaged 93.1 mgd (144 cfs), whereas the natural flow unaffected by diversion would have been 275 mgd, or 425 cfs. The minimum flow during the 6-year period was 1.8 mgd (1.2 cfs).

Streamflow records (table 4) are available for the gaging station on Gunpowder Falls at Glencoe (station 8, pl. 1) for the period December 1904 to March 1909, before the construction of Prettyboy Reservoir. This site is upstream from Loch Raven Dam and has a drainage area of 160 square miles. Other gaged streams flowing into Loch Raven Reservoir are Little Falls and Western Run, which drain 53.1 and 85.4 square miles, respectively, at their mouths. These two streams drain 46 percent of the area upstream from Loch Raven Dam.

The Baltimore Bureau of Water Supply has, since 1883, published in annual reports the computed flow into Loch Haven Reservoir. Only monthly discharge was published before 1937. This record was computed from flow over rated spillways, flow diverted through recording venturi tubes, and storage changes in reservoirs. No adjustment was made for evaporation from the Loch Raven Reservoir, built in 1881, and the Prettyboy Reservoir, built in 1933.

The annual mean discharge for each year, which is plotted by bar graphs in figure 17, indicates that streamflow for the 57-year base period, 1896 to 1952, averaged less than it did during the preceding 12 years, 1884 to 1895. This should not be interpreted to mean that streamflow for the base period was unusually low because U.S. Weather Bureau precipitation records for Baltimore show at least four periods between 1825 and 1884 in which the average precipitation for 3 consecutive years was less than that recorded during the 3 low years, 1929–31.

Storage requirements at Laurel Brook are given in figure 18. Thus storage of 3 million gallons per square mile will sustain a minimum 7-day flow greater than 0.265 mgd per sq mi for 14 years out of 15 on the average (smaller flows recur at intervals of 15 years on the average). The curves shown in figure 18 do not make an allowance for evaporation losses; therefore, additional storage must be provided to compensate for these losses.

FLOODS

Floods occurred in the Gunpowder River basin a few times between 1932 and 1957. One of these occurred during an exceptional storm on August 23, 1933, when 7.62 inches of rain fell. Floodmarks of Little Falls at Blue Mount for August 1933 were the highest recorded at that station. Other great storms occurred in August 1955 when two hurricanes passed across Baltimore. The maximum precipitation during the period August 10–19, 1955, was along a narrow zone extending southwestward from Baltimore to Washington. During Baltimore's

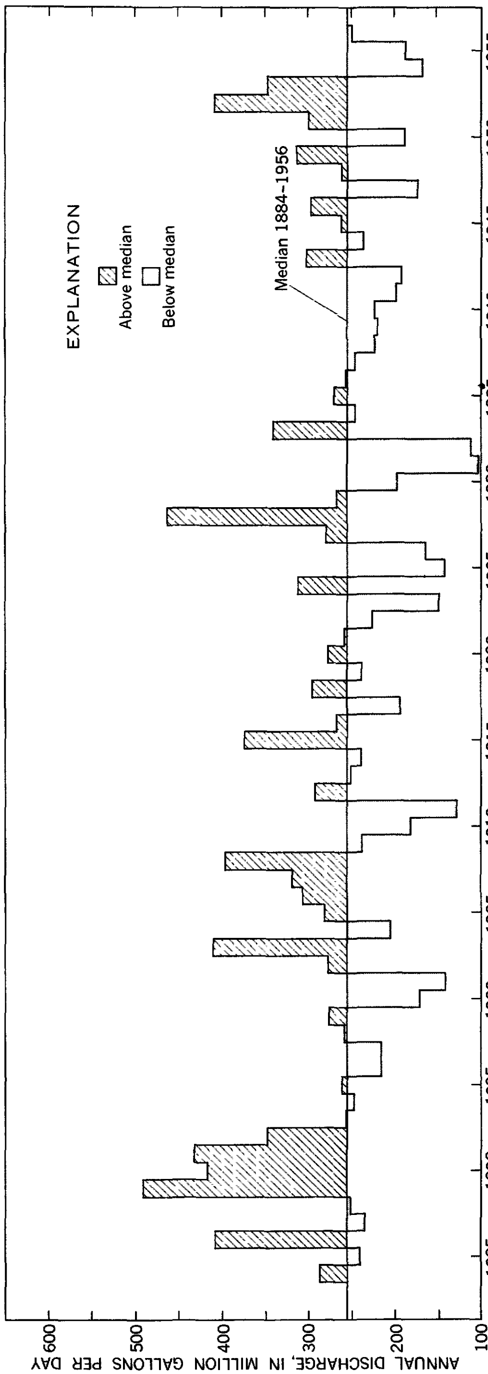

FIGURE 17.—Annual flow of Gunpowder Falls at Loch Raven Dam, 1884–1956, adjusted for diversion and storage.

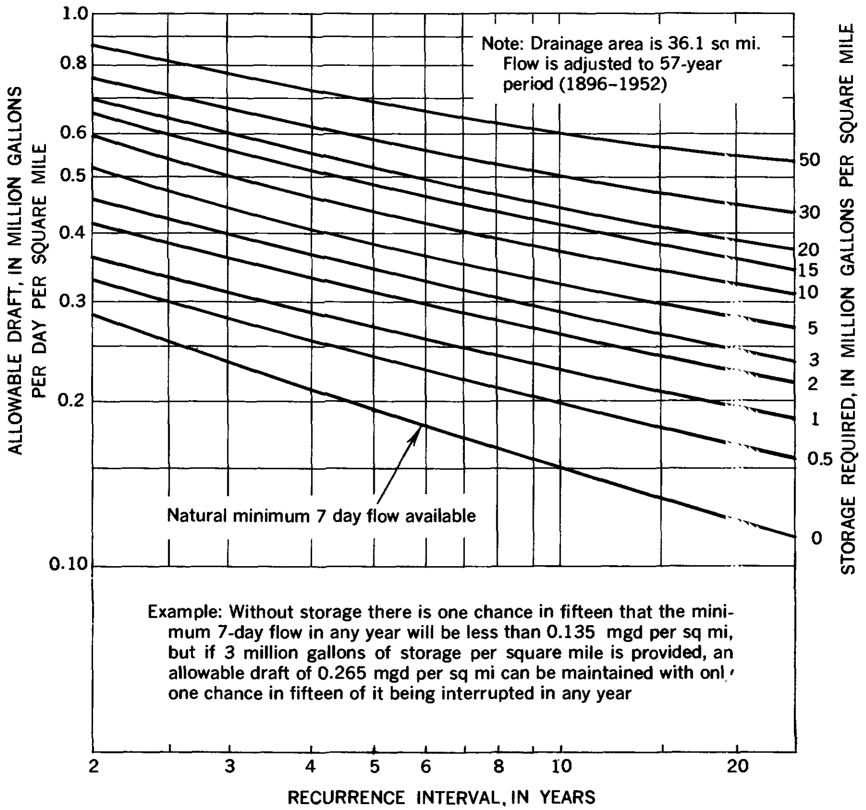

FIGURE 18.—Curves of stage required to sustain a given minimum 7-day flow with a specified recurrence interval, Little Gunpowder Falls at Laurel Brook, Md.

wettest month of record, August 1955, a total of 17.69 inches of precipitation was recorded by the U.S. Weather Bureau at its gage at the Baltimore Custom House. The fact that the maximum flood in the Gunpowder River basin did not occur in August 1955 (see table on p. F41) indicates, however, that the precipitation must have been concentrated in a relatively narrow band and might not have been as widespread as other less publicized storms. Recent storms above Gunpowder Falls near Carney have not caused major floods, as the peaks have been greatly reduced by upstream reservoirs.

Summary of floods in the Gunpowder River basin

No. on pl. 1	Gaging station	Drainage area (sq mi)	Period	Duration of record		Maximum recorded discharge			
				Complete water years	Months	Date	Cfs	Mgd	Gage height (feet)
12	Little Gunpowder Falls at Laurel Brook.	36.1	Dec. 1926 to Sept. 1955.	28	10	8-23-33	9,200	5,950	10.3
13	Little Gunpowder Falls near Bel Air.	43	Dec. 1904 to Mar. 1909.	4	4	2-26-08	[2] 1,600	[2] 1,030	
8	Gunpowder Falls at Glencoe.	160	Dec. 1904 to Mar. 1909.	4	4	2-26-08	[2] 5,530	[2] 3,570	
11	Gunpowder Falls near Carney.	314	Sept. 1949 to Sept. 1955.	6	1	7- 9-52	7,000	4,520	9.50
5	Little Falls at Blue Mount.	52.9	June 1944 to Sept. 1955.	11	4	9-10-50	5,730	3,700	[1] 11.93
7	Western Run at Western Run.	59.8	Sept. 1944 to Sept. 1955.	11	1	3-18-46	5,500	3,550	10.62
6	Slade Run near Glyndon.	2.27	Sept. 1947 to Sept. 1955.	8	1	9- 1-52	448	290	4.53

[1] August 1933 flood gage height estimated at about 14 ft.
[2] Average for the day.

WATER USE

The city of Baltimore, the chief user of water from the Gunpowder River basin, supplied approximately 1,330,000 persons in 1956 and used about 200 mgd from the Gunpowder and Patapsco reservoirs. (See tables on p. F42–F43.) The demand of raw water increased from 129 mgd in 1940 to 200 mgd in 1956; the per capita demand rose from 133 to 150 gpd during the same period. Consulting engineers (Geyer and Wolff, 1955) predict that by 1975 the raw water demand will be 333 mgd and the per capita demand 187 gpd. During 1956 approximately 85 percent of the city's water was obtained from the Gunpowder River basin. The total draft from that source (raw water used) during the year was 62,092 million gallons, equivalent to an average draft rate of 261 cfs, which was about 70 percent of the runoff above the Loch Raven Dam. The raw water used monthly during 1956 ranged from 48 to 142 percent of the computed streamflow.

Average delivery of filtered water to city of Baltimore, Md., 1939–56

[Adapted in part from Requardt and others, 1953]

Year	Filtered water delivered to city	Percent of usable storage
1939	120.17	0.27
1940	126.03	.29
1941	133.42	.30
1942	145.08	.33
1943	160.82	.37
1944	171.29	.39
1945	171.63	.40
1946	172.75	.40
1947	184.90	.42
1948	191.57	.44
1949	187.10	.43
1950	183.68	.42
1951	190.26	.44
1952	188.53	.43
1953	192.98	.45
1954	194.56	.45
1955	[1] 195.81	.23
1956	196.20	.23

[1] Usable storage increased from 43,266 million gallons to 85,388 million gallons with addition of Liberty Reservoir to the system after 1954.

Raw-water demand in relation to probable population supplied

[Adapted from Requardt and others, 1953]

Year	Total raw water demand	Estimated population supplied (millions)	Raw water demand per capita (gpd)
1940	129	0.97	133
1941	137	1.01	136
1942	149	1.13	132
1943	165	1.19	138
1944	176	1.16	152
1945	176	1.14	154
1946	177	1.14	155
1947	190	1.14	166
1948	195	1.16	169
1949	190	[1] 1.16	164
1950	187	[1] 1.16	161
1951	198	1.19	167
1952	197	1.21	163
1953	199	1.23	162
1954	199	1.26	158
1955	198	1.30	152
1956	200	1.33	150
1975 [2]	333	1.78	187
2000 [2]	461	2.27	203

[1] Adjusted to conform to 1950 census figures.
[2] Prediction for these years by consulting engineers Geyer and Wolf, 1953, (table 3-1).

Water use in millions of gallons, by the Baltimore Bureau of Water Supply from the Gunpowder Falls, 1956

Year and month	Raw water used	Storage change in reservoir	Bypassed at dam	Computed streamflow	Percent of streamflow used
January	3,106	+2,430	------------	5,576	56
February	5,700	+4,164	2,027	11,871	48
March	5,993	+3,264	2,057	11,314	53
April	5,668	+1,553	2,791	10,012	57
May	6,086	−32	1,385	7,439	82
June	5,535	−675	1,378	6,238	89
July	5,408	+441	4,695	10,544	51
August	5,686	−1,110	68	4,644	122
September	5,168	−1,541	------------	3,627	142
October	4,677	+397	------------	5,074	92
November	4,177	+2,147	------------	6,324	66
December	4,838	+241	1,253	6,332	76
Total	62,042	+11,279	15,654	88,975	70
Daily average:					
Million gallons	169	------------	43	243	70
Cubic feet per second	261	------------	66	376	70

PATAPSCO RIVER

The Patapsco River is the second largest stream in the Baltimore area. Its total drainage area above the point where it crosses U.S. Route 301 at Lansdowne is 359 square miles. The topography of the Patapsco River basin is largely rolling to undulating, but it is somewhat rugged in a few places, as in the vicinity of Ellicott City and Elkridge. The maximum elevation is about 1,100 feet in the vicinity of Snydersburg in eastern Carroll County. More than 90 percent of the Patapsco River basin overlies the crystalline rocks of the Piedmont province. Near its mouth, below Elkridge, the river becomes tidal, its valley widens, and its channel cuts through softer sedimentary rocks of Cretaceous and younger age.

DISCHARGE

Streamflow records are available from 7 gaging stations in the Patapsco River basin (see table on p. F44 and pl. 1), 2 of which have been discontinued. The static North Branch Patapsco River near Reisterstown was discontinued in December 1953, because it was affected by backwater from the recently built Liberty Dam; flow during the period of record was not affected by diversions or storage and thus is not representative of present flows. Of the 5 active stations, 3 are not affected by regulation or diversion and two are highly regulated.

The flows of North Branch Patapsco River at Cedarhurst, South Branch Patapsco River at Henryton, and Piney Run near Sykesville are unaffected by regulation and diversion. Flow-duration curves for these streams are given in figure 19. The flow from 285 square miles of the Patapsco River basin (nearly 80 percent) is measured at the Hollofield station. Duration curves of daily flow in figure 20 show

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Gaging-station data for the Patapsco River basin

No. on pl. 1	Gaging station	Drainage area (sq mi)	Elevation of gage feet above mean sea level	Period of record	Average flow			
					Years	Cfs	Mgd	Mgd per sq mi
14	North Branch Patapsco River at Cedarhurst.	56.6	425	Sept. 1945 to Sept. 1955.	10	71.5	46.2	0.82
15	North Branch Patapsco River near Reisterstown.	91.0	344.35	June 1927 to Dec. 1953.	26	103	66.6	.73
16	North Branch Patapsco River near Marriottsville.	165	269.78	Oct. 1929 to Sept. 1955.	26	[1] 180	[1] 116	.70
17	South Branch Patapsco River at Henryton.	64.4	289.15	Aug. 1948 to Sept. 1955.	7	78.6	50.9	.79
18	Piney Run near Sykesville.	11.4	450	Sept. 1931 to Sept. 1955.	24	12.8	8.27	.73
19	Patapsco River at Woodstock.	260	235	Aug. 1896 to Mar. 1909.	7	450	291	1.12
20	Patapsco River at Hollofield.	285	190	May 1944 to Sept. 1955.	11	[1] 340	[1] 220	.71

No. on pl. 1	Minimum daily flow			Minimum monthly flow		
	Cfs	Mgd	Date	Cfs	Mgd	Date
14	12	7.76	Aug. 2; Sept. 14, 1954	17.2	11.1	Sept. 1954
15	11	7.1	Aug. 9, 1931; Aug. 28, 29, 1932	17.6	11.2	Oct. 1941
16	[2] .2	[2] .13	Sept. and Oct. 1954	[2] .25	[2] .16	Sept. 1954
17	8.0	5.17	Oct. 14, 1954	12.2	7.9	Sept. 1954
18	1.2	.78	Sept. 1932	1.82	1.18	Sept. 1932
19	50	32.3	July and Aug. 1900; June to Sept. 1904	106	68.5	Sept. 1898
20	[1] 18	[1] 12	Sept. 14, 1954	[2] 24.2	[2] 15.6	Sept. 1954

[1] Includes adjustments for diversions since February 1953.
[2] Minimum flow regulated by Liberty Reservoir since July 22, 1954.

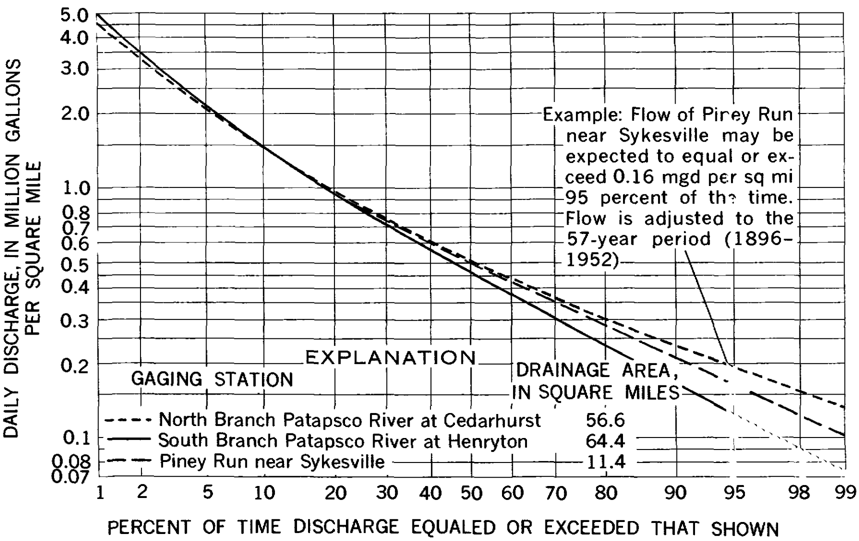

FIGURE 19.—Duration curves of daily flow for streams in the Patapsco River basin, Maryland.

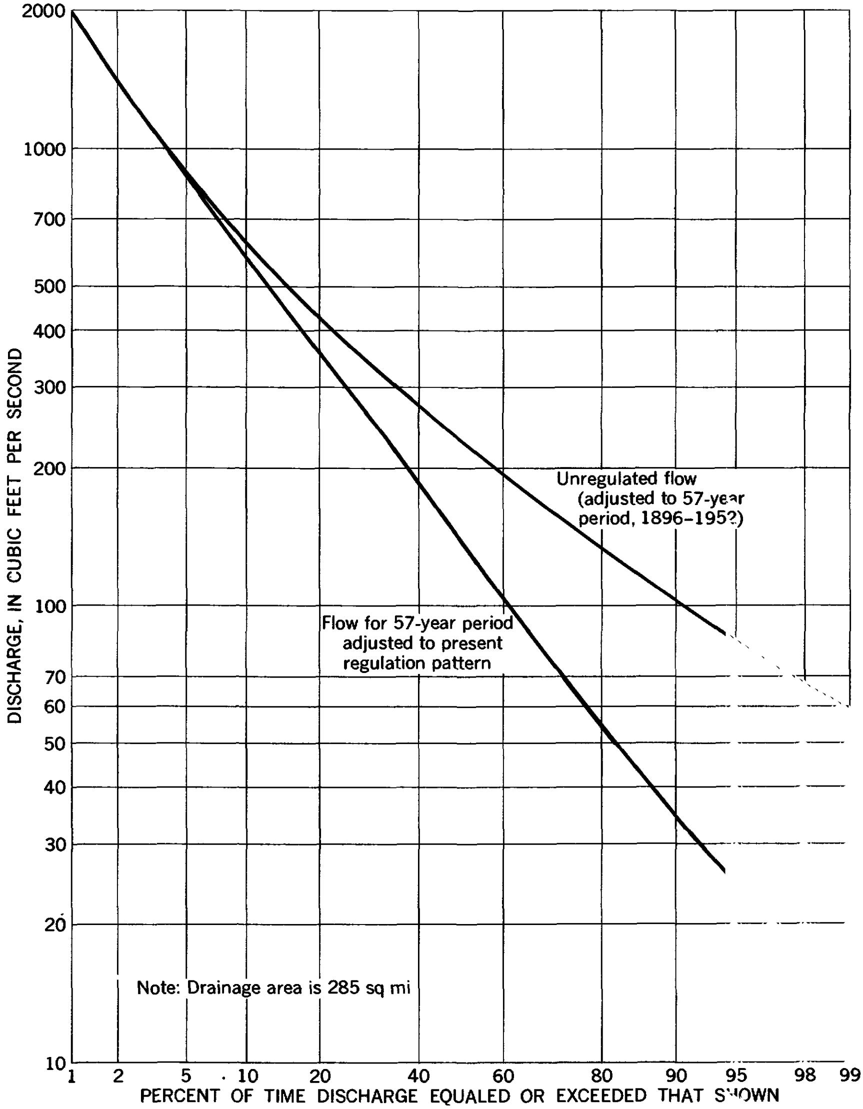

FIGURE 20.—Duration curves of daily flow, Patapsco River at Hollofield, Md.

the natural flow (upper curve), adjusted to the 57-year period 1896–1952 and the flow under the pattern of regulation during the period 1953–55, also adjusted to the 57-year base period. The area between the two curves represents the average amount of water, evaporated and diverted from Liberty Reservoir.

Low-flow frequency analyses for six stations in the Patapsco River basin are shown in table 2, and sample curves for one station have been plotted in figure 21.

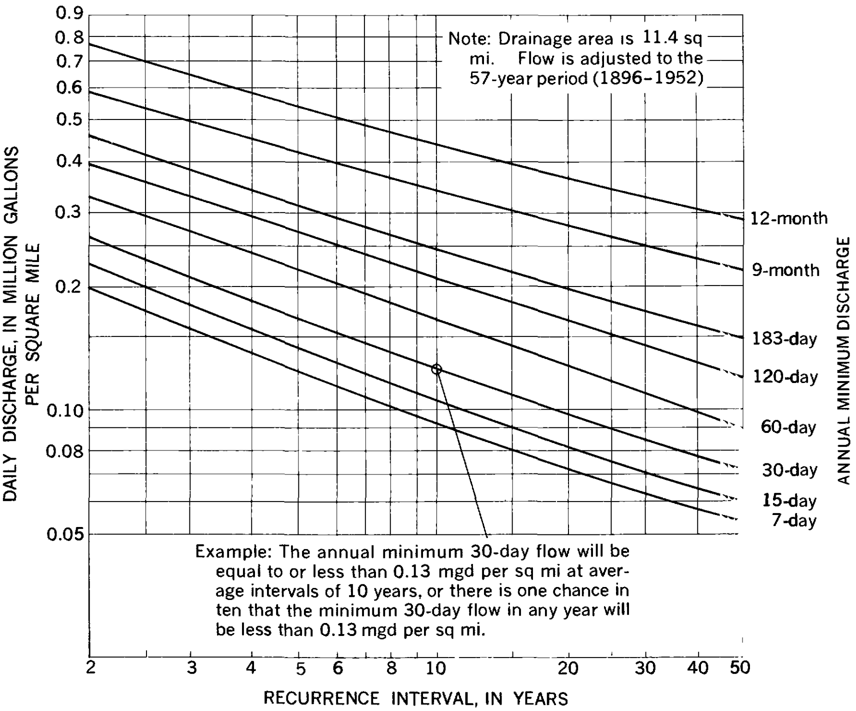

FIGURE 21.—Low-flow frequency curves, Piney Run near Sykesville, Md.

CHEMICAL QUALITY OF WATER

The water of North Branch Patapsco River near Reisterstown is of excellent chemical quality, reflecting the low rate at which the rocks are dissolved in the upper reaches of the basin. Based on chemical data for the Reisterstown area, the water impounded in Liberty Reservoir below Morgan Run will be satisfactory for all uses. Selected analyses of water from the Patapsco River basin obtained over a period of about 3 years at five gaging stations in the basin are given in table 3.

Although direct comparison should not be made on the basis of only two samples, the chemical quality of North Branch Patapsco River near Marriottsville appears similar to that of the North Branch Patapsco River near Reisterstown, but the dissolved solids and hardness are somewhat higher than at the upstream station near Reisterstown. The quality of water at Marriottsville is influenced by flow of Morgan Run. The two analyses in table 3 show less than 100 ppm dissolved solids and less than 60 ppm hardness. Color (55 units) of the water at Marriottsville was more prominent at the time of collection in March 1955 than at any other stations, although streamflow was extremely low (0.23 mgd).

The water of South Branch Patapsco River at Henryton is of excellent chemical quality, as it is low in dissolved-solids content. As with most streams in the area, the water has sufficient hardness to reduce the corrosive effect on metal surfaces. Calcium and bicarbonate are slightly dominant, and nitrate is somewhat more concentrated than for samples from the North Branch. The occurrence of nitrate may be attributed to upstream pollution, as the stream drains an area including many small towns and extending nearly to Frederick County. Nitrate in excess of natural concentrations of a few tenths of a part per million may enter the stream from several sources, such as municipal, domestic, or industrial sewage, or from the leaching of fertilizers in croplands.

The water of Piney Run near Sykesville was of excellent quality at the times of sampling. Calcium and bicarbonate are only slightly dominant, and hardness values are about one-half those of dissolved solids.

The Patapsco River at Hollofield is a mixture of the water of the North Branch and South Branch. At flows of 23 and 117 mgd, the water was of excellent quality and was nearly identical in dissolved-solids and hardness content. The principal difference in individual constituents was that sulfate and bicarbonate occurred in about equal proportions at the higher flow, whereas bicarbonate was dominant at the lower flow.

TEMPERATURE

Little data are available concerning the temperature range of surface water in the Patapsco River basin. Seven temperature measurements were made in Piney Run in 1956 near the Springfield State Hospital by the Water Pollution Control Commission and Maryland Department of Health (1957, p. 53). Water temperature ranged from 66° to 73° F during the period from June 20 to October 3.

WATER STORAGE

Liberty Reservoir, on the North Branch Patapsco River along the Carroll-Baltimore County line, is the largest reservoir in the Baltimore municipal system. The total storage capacity (43,330 million gallons) is about 115 percent of the average annual flow at the dam during 1950–54.

Using an 823-day, or 2¼-year, drought period (July 1, 1930, to September 30, 1932), consulting engineers (Requardt, Shaw, and Wolman, 1953) estimated the safe yield above the dam to be 50 mgd (0.305 mgd per square mile). A total safe yield of 95 mgd from the Patapsco River system was obtained by adding reservoir capacity sufficient to yield 45 mgd. Details concerning the reservoir above Liberty Dam are as follows:

Location:

Latitude	39°23′
Longitude	76°53′

Date of completion			1954
Drainage area	sq mi		164
Surface area	do		4.86
	acres		3,110
Volume of storage:			
Dead	million gal	1,260	
Usable	do	42,070	
Total	do	43,330	
Storage ratio	yr		1.0
Elevation of spillway crest	ft above mean sea level		420
Elevation of dead storage pool	do		320

The storage required to maintain various rates of flow of Piney Run near Sykesville are given in figure 22 and the following table.

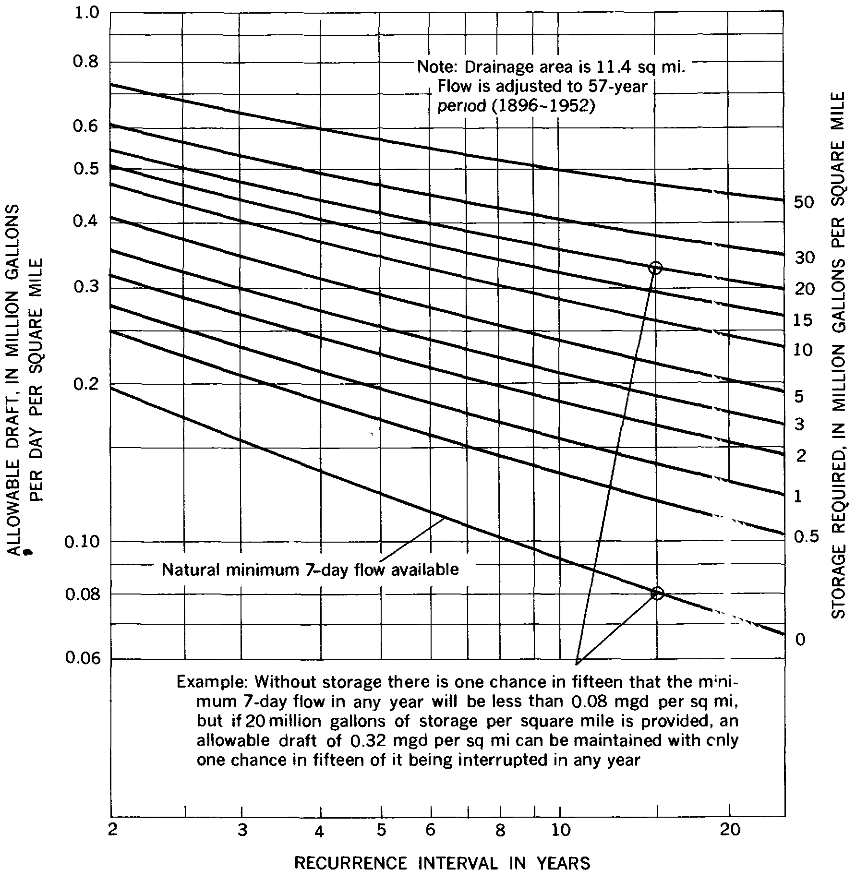

FIGURE 22.—Curves of storage required to sustain a given minimum 7-day flow with a specified recurrence interval, Piney Run near Sykesville, Md.

It should be borne in mind that this analysis of storage-required frequency makes no allowance for evaporation and seepage losses, and any design should make allowances for them.

Draft-storage data for selected streams

[Adjusted to 57-year period, 1896–1952, on basis of long-term streamflow records in adjacent areas]

No. on pl. 1	Gaging stations	Drainage area (sq mi)	Storage (million gallons)	Allowable draft (mgd) uncorrected for reservoir seepage and evaporation for recurrence intervals indicated			
				2 years	5 years	10 years	25 years
7	Western Run at Western Run	59.8	29.9	20.3	15.0	12.7	10.2
			59.8	22.1	16.4	14.1	11.4
			120	24.3	18.2	15.8	12.9
			179	26.3	19.9	17.2	14.2
			299	29.0	22.3	18.7	16.1
			598	33.5	25.7	22.1	19.0
			897	36.5	28.4	24.5	20.9
			1,200	38.6	30.4	26.4	22.7
			1,790	42.2	33.6	29.7	26.0
			2,990	48.5	39.6	35.5	31.5
	Natural 7-day minimum flow [1]...million gallons			16.7	11.8	9.69	7.71
12	Little Gunpowder Falls at Laurel Brook	36.1	18.0	11.7	9.02	7.22	5.67
			36.1	13.0	9.96	8.23	6.53
			72.2	15.0	11.4	9.46	7.76
			108	16.6	12.4	10.4	8.48
			180	18.8	13.9	11.7	9.67
			361	21.8	16.4	13.4	11.2
			542	23.6	17.8	15.0	12.5
			722	25.0	19.1	16.1	13.6
			1,080	27.5	21.3	18.2	15.6
			1,800	31.4	25.2	21.7	19.1
	Natural 7-day minimum flow [1]...million gallons			10.3	6.97	5.56	4.26
18	Piney Run near Sykesville	11.4	5.70	2.85	1.98	1.58	1.16
			11.4	3.20	2.21	1.79	1.38
			22.8	3.66	2.58	2.09	1.65
			34.2	4.05	2.91	2.36	1.87
			57.0	4.61	3.37	2.76	2.17
			114	5.37	3.94	3.28	2.63
			171	5.87	4.42	3.71	3.01
			228	6.32	4.80	4.06	3.36
			342	7.02	5.44	4.70	3.94
			570	8.30	6.54	5.83	4.97
	Natural 7-day minimum flow [1]...million gallons			2.20	1.40	1.05	.756
22	North River near Annapolis	8.5	4.25	3.31	2.48	2.13	1.73
			8.50	3.57	2.72	2.30	1.89
			17.0	3.88	3.03	2.62	2.16
			25.5	4.25	3.28	2.83	2.35
			42.5	4.63	3.60	3.12	2.63
			85.0	5.32	4.14	3.60	3.05
			128	5.75	4.50	3.96	3.37
			170	6.09	4.81	4.25	3.63
			255	6.64	5.34	4.74	4.11
			425	7.52	6.24	5.58	4.90
	Natural 7-day minimum flow [1]...million gallons			2.78	2.03	1.68	1.34
26	Little Patuxent River at Guilford	38.0	19.0	7.90	5.17	4.03	3.15
			38.0	8.82	6.04	5.05	3.80
			76.0	10.2	7.18	5.85	4.67
			114	11.4	8.09	6.57	5.21
			190	12.7	9.27	7.45	5.97
			380	15.4	11.2	9.31	7.30
			570	17.1	12.6	10.5	8.47
			760	18.5	13.8	11.6	9.50
			1,140	20.9	15.9	13.6	11.4
			1,900	25.1	19.8	17.0	14.4
	Natural 7-day minimum flow [1]...million gallons			5.70	3.59	2.75	2.00

[1] The natural 7-day flow is approximately equal to the dependable flow available without storage.

FLOODS

Maximum recorded flood flows at seven gaging stations in the Patapsco River basin are given in the following table. The flood of August 1933 was the greatest of record at 2 of the 3 gaging stations

Summary of floods in the Patapsco River basin

No. on Pl. 1	Gaging station	Drainage area (sq mi)	Period	Duration of record (complete water years)	Maximum recorded discharge			
					Date	Cfs	Mgd	Gage height feet)
14	North Branch Patapsco River at Cedarhurst.	56.6	Sept. 1954 to Sept. 1955.	10	8-13-55	4,130	2,669	10.38
15	North Branch Patapsco River near Reisterstown.	91.0	June 1927 to Dec. 1953.	26	8-24-33	11,000	7,109	14.6
16	North Branch Patapsco River near Marriottsville.	165	Oct. 1929 to Sept. 1953.[1]	23	8-24-33	19,500	12,600	20.8
17	South Branch Patapsco River at Henryton.	64.4	Aug. 1948 to Sept. 1955.	7	5-26-52	4,930	3,186	11.04
18	Piney Run near Sykesville.	11.4	Sept. 1931 to Sept. 1955.	24	7-24-46	2,100	1,357	6.95
19	Patapsco River at Woodstock.	260	Aug. 1896 to Mar. 1909.[2]	7	2-26-08	11,000	7,109	14.9
20	Patapsco River at Hollofield.	285	May 1944 to Sept. 1955.	11	6-2-46	13,500	8,725	[3] 11.62

[1] Liberty Reservoir started filling in 1954; records after then not comparable.
[2] Incomplete.
[3] Flood of August 1933 reached a gage height of 19.5 ft according to report by Maryland State Roads Commission.

then in operation. On August 24, 1933, the peak flow of the North Branch Patapsco River near Marriottsville was 19,500 cfs (or more than 12,600 mgd) with a crest gage height of 20.8 feet. During this storm, the highest flow of record (11,000 cfs on August 24) was reached on the North Branch Patapsco River near Reisterstown. Precipitation in August 1933 at Baltimore was 13.83 inches. Precipitation records since 1871 at the Baltimore weather station (Custom House) show 5 other months having more than 10 inches of rainfall; these were September 1876, July 1889, July 1905, August 1911, and August 1955. Flooding probably occurred in the Patapsco River basin at some time during all these months. There was no major flood at the Marriottsville gage in August 1955, owing to the effect of Liberty Reservoir, which began operation in 1954.

WATER USE

The Baltimore Bureau of Water Supply is the chief user of water in the Patapsco River basin. During 1956, 11,088 million gallons (about 15 percent of the public supply of the city) was obtained from Liberty Reservoir. A 25-month record (July 1955–July 1957) of diversions from the reservoir, of changes in storage, of water bypassed, and of computed flow of the North Branch Patapsco River are given in the following table. During the 25 months 25 percent of the flow was used. Monthly use ranged from 0 to 360 percent of the flow. The average use for 762 days was 39 mgd (60.3 cfs).

Water use by the Baltimore Bureau of Water Supply from the North Branch Patapsco River

[Results are for 25-month or 762-day period July 1955 through July 1957]

Year and month	Raw water used (million gallons)	Storage Change in reservoir (million gallons)	Bypassed at dam (million gallons)	Computed streamflow (million gallons)	Percent of streamflow used
1955					
July	1,662	−622		1,040	160
August	996	+9,702		10,698	9.3
September	687	+1,906		2,593	26
October	440	+3,603		4,043	11
November	91	+2,219		2,310	3.9
December	1,615	+234		1,849	87
1956					
January	2,834	−99		2,735	103
February	0	+2,073	6,590	8,663	0
March	98	+59	8,319	8,476	1.1
April	14	−42	7,214	7,186	.2
May	9	+75	5,272	5,356	.2
June	911	−217	3,651	4,345	21
July	994	+75	9,579	10,648	9.3
August	1,070	−92	3,078	4,056	26
September	1,069	+67	1,538	2,674	40
October	1,490	+16	1,597	3,103	48
November	1,589	−108	2,519	4,000	40
December	1,010	+92	4,027	5,129	20
1957					
January	1,044	+67	4,086	5,197	20
February	869	+58	5,571	6,498	13
March	957	−92	5,355	6,220	15
April	2,122	−83	5,177	7,216	29
May	2,599	−241	865	3,223	81
June	2,878	−1,069		1,809	159
July	3,082	−2,228		854	360
Total	30,130	+15,353	74,420	119,921	25
Daily average:					
Million gallons	39		98	157	
Cubic feet per second	60.3		151	243	

Several industrial plants along the river use water for processing and cooling. Among these are a linoleum plant near Cedarhurst, a textile plant at Daniels, and a box-board plant at Ilchester.

PATUXENT RIVER

Although a substantial part of the flow of Patuxent River is used by the Washington Suburban Sanitary Commission, sufficient water remains to make the stream important in the water economy of the Baltimore area. The total drainage area of the Patuxent River above its confluence with the Little Patuxent River in Anne Arundel County is 181 square miles. It becomes tidal near Governor Bridge about 14 miles south of Laurel, and an estuary extends southward several more miles to the Chesapeake Bay.

DISCHARGE

Five gaging stations have been operated in Patuxent River basin. (See following table and pl. 1.) The flow of the Patuxent River in its

Gaging-station data for Patuxent River basin

No. on pl. 1	Gaging station	Drainage area (sq mi)	Elevation of gage (feet above mean sea level)	Period of record	Average flow			
					Years	Cfs	Mgd	Mgd per sq mi
24	Patuxent River near Laurel.	133	150	Oct. 1944 to Sept. 1955.	11	[1] 148	[1] 95.7	--------
25	Patuxent River at Laurel	137	125	Aug. 1896 to Aug. 1898.	1	172	111	0.81
26	Little Patuxent River at Guilford.	38.0	260	May 1932 to Sept. 1955.	23	41.2	26.6	.70
27	Little Patuxent River at Savage.	98.4	125	Nov. 1939 to Sept. 1955.	15	102	65.9	.67
28	Dorsey Run near Jessup	11.6	120	July 1948 to Sept. 1955.	7	15.2	9.82	.85

No. on pl. 1	Minimum daily flow			Minimum monthly flow		
	Cfs	Mgd	Date	Cfs	Mgd	Date
24	[2] 18	[2] 11.6	Oct. 6, 9; Nov. 24, 1944	[2] 30.5	[2] 19.7	Oct. 1944
25	[3] 6	[3] .39	----------	[3] 50	32.3	----------
26	3.5	2.26	Sept. and Oct. 1932	3.88	2.51	Sept. 1932
27	7	4.52	Sept. 19, 1943	14.7	9.50	Oct. 1941
28	1.6	1.03	Aug. 6-7, 1955	2.39	1.54	Sept. 1954

[1] Flow highly regulated, adjusted for storage and diversion.
[2] Affected by storage and diversion.
[3] Affected by operation of a cotton mill 1 mile upstream.

lower reaches has been highly regulated by diversions for water supply and storage in Triadelphia Reservoir since June 27, 1942, and by storage in Rocky Gorge Reservoir since March 7, 1954. The flow at three gaging stations—Little Patuxent River at Guilford, Little Patuxent River at Savage, and Dorsey Run near Jessup—are not affected by storage or diversions. Duration curves of daily flow at these stations are given in figure 23. Low-flow frequency for Little Patuxent River at Guilford and Dorsey Run near Jessup are given in figures 24 and 25. (Also see table 2.)

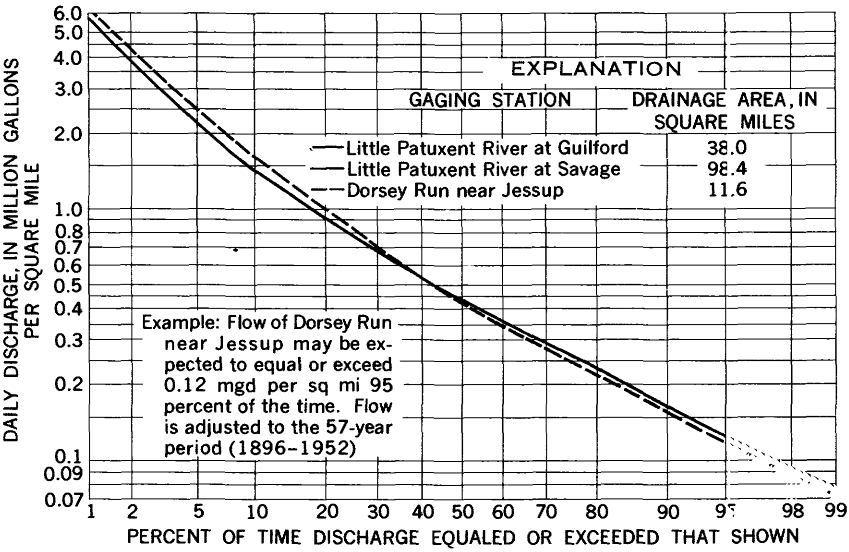

FIGURE 23.—Duration curves of daily flow for streams in the Patuxent River basin, Md.

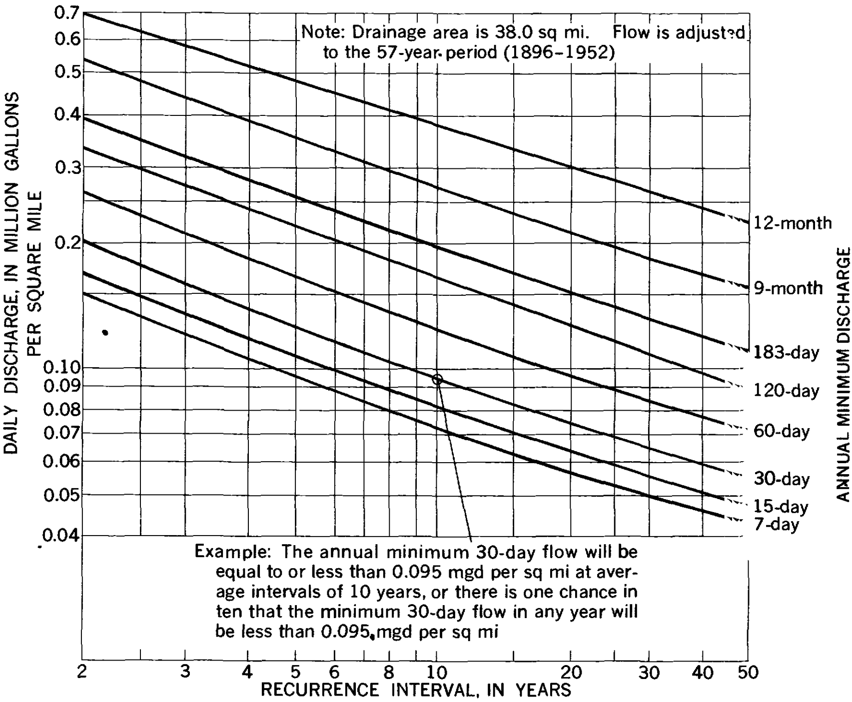

FIGURE 24.—Low flow frequency curves, Little Patuxent River at Guilford, Md.

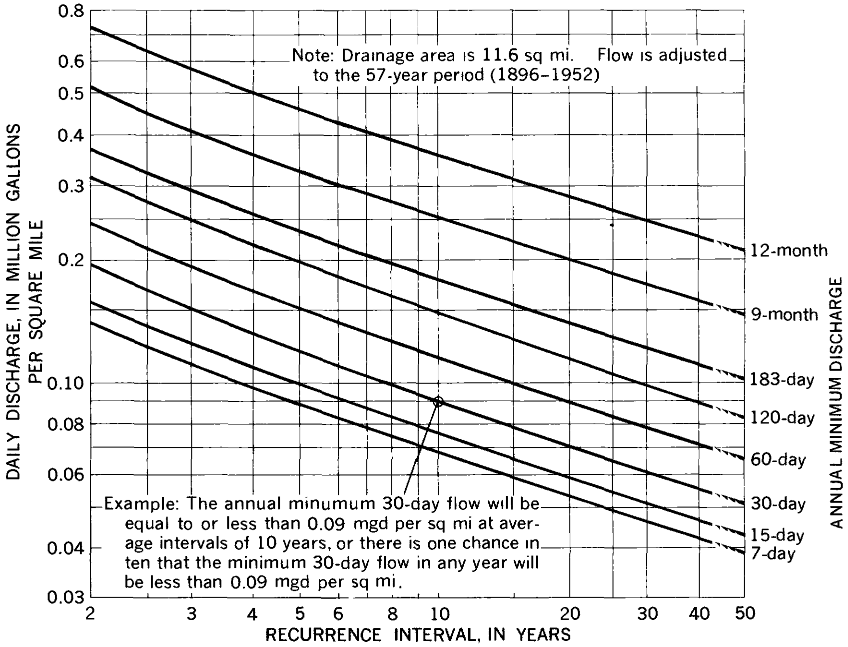

FIGURE 25.—Low-flow frequency curves, Dorsey Run near Jessup, Md.

CHEMICAL QUALITY OF WATER

Some data are available concerning the chemical characteristics of raw water from the Patuxent River. (See following table.) The water is of excellent quality.

Chemical analyses, in parts per million, of water from the Patuxent River

[Analyses by Washington Suburban Sanitary Commission]

Constituent	A	B	C
Silica (SiO_2)	9.7	5.1	5.3
Iron (Fe)	.02	.15	.02
Manganese (Mn)	.00	.17	.0
Calcium (Ca)	4.0	4.8	11
Magnesium (Mg)	1.1	2.0	2.8
Sodium (Na)	2.6		
Potassium (K)	1.2		
Carbonate (CO_3)	0		
Bicarbonate (HCO_3)	15	15	19
Sulfate (SO_4)	4.0	6.2	7.4
Chloride (Cl)	3.2	4.1	7.5
Fluoride (F)	.0	.1	1.0
Nitrate (NO_3)	1.9		
Dissolved solids	37	48	67
Hardness as $CaCO_3$	14	20	38
Noncarbonate	2		
Color	2		
pH	6.8	6.9	8.5
Turbidity	.9		

A. Raw water from the Patuxent treatment plant near Laurel, Md., April 1951.
B. Composite sample of raw water obtained in 1957 from Triadelphia and Rocky Gorge reservoirs.
C. Composite sample of treated water obtained in 1957 from both reservoirs.

TEMPERATURE

No data are available concerning the range of water temperature in the Patuxent River, which is probably similar to that of other large Piedmont streams in Maryland.

WATER STORAGE

Triadelphia Reservoir above Brighton Dam and Rocky Gorge Reservoir near Laurel are sources of water for the Washington Suburban Sanitary Commission. Overflow from the reservoirs plus the flow from the Middle and Little Patuxent Rivers is an important source of water for the Baltimore area. A description of these reservoirs follows:

Rocky Gorge Reservoir

Location:			
Latitude			39°07′
Longitude			76°52′
Date of completion			1954
Drainage area	sq mi		132
Surface area	do		1.21
	acres		773
Volume of storage:			
Dead	million gal	80	
Usable	do	5,920	
Total	do	6,000	
Storage ratio	yr		0.2
Elevation of spillway crest	ft above mean sea level		270
Elevation of dead storage pool	do		214

Triadelphia Reservoir

Location:			
Latitude			39°12′
Longitude			77°00′
Date of completion			1943
Drainage area	sq mi		78.4
Surface area	do		1.34
	acres		857
Volume of storage:			
Dead	million gal	0	
Usable	do	6,582	
Total	do	6,582	
Storage ratio	yr		0.2
Elevation of spillway crest	ft above mean sea level		350
Elevation of bottom of usable pool	do		302

Storage requirements for Little Patuxent River at Guilford are given in figure 26.

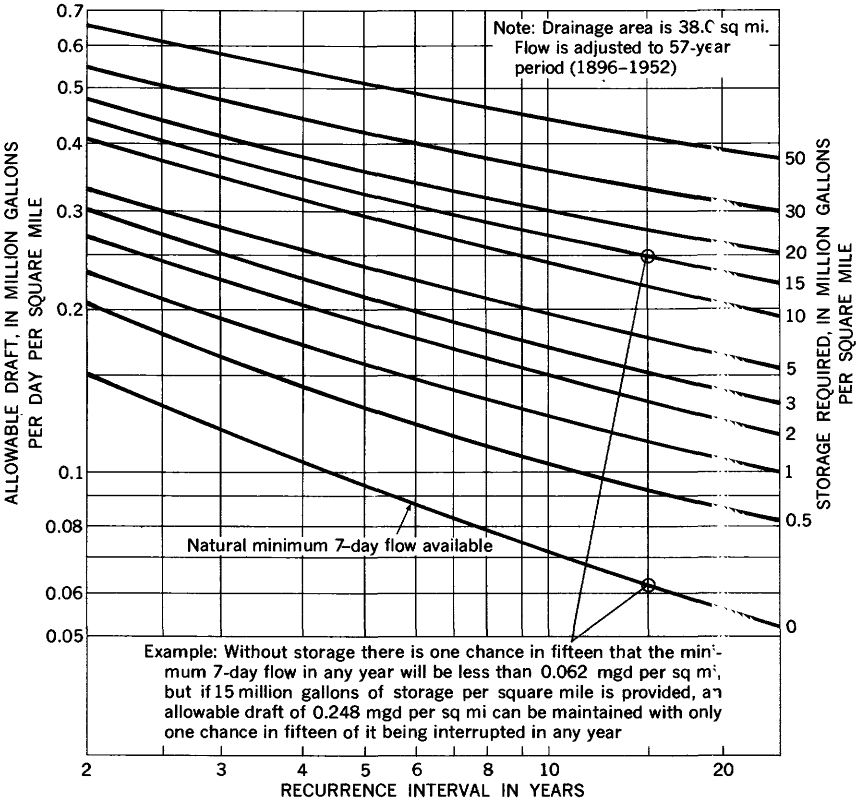

FIGURE 26.—Curves of storage required to sustain a given minimum 7-day flow with a specified recurrence interval, Little Patuxent River at Guilford, Md.

FLOODS

The greatest flood during the period of record (1933–55) on the Little Patuxent River at Guilford was 5,300 cfs (3,245 mgd) on September 1, 1952. (See following table.) The flood produced a peak flow of 6,280 cfs (4,059 mgd) on the Little Patuxent River at Savage. During September 1952, 6.37 inches of rain fell at the weather station at Fort George G. Meade, of which 5.20 inches fell in 24 hours on September 1. Large floods occurred in August 1933 and in August 1955.

Summary of floods in the Patuxent River basin

No. on plate 1	Gaging station	Drainage area (sq. mi.)	Period	Duration of record (complete water years)	Maximum discharge (flood-flow)			
					Date	Cfs	Mgd	Gage (feet)
24	Patuxent River near Laurel.	133	Oct. 1944 to Sept. 1955	11	9- 1-52	5,200	3,361	10.47
26	Little Patuxent River at Guilford.	38.0	May 1932 to Sept. 1955	23	9- 1-52	5,300	3,425	13.26
27	Little Patuxent River at Savage.	98.4	Nov. 1939 to Sept. 1955	15	9- 1-52	6,280	4,059	[1] 13.15
28	Dorsey Run near Jessup.	11.6	July 1948 to Sept. 1955	7	8-13-55	1,400	905	12.77

[1] Local residents reported a stage of 17.5 ft in August 1933.

WATER USE

The Washington Suburban Sanitary Commission is the principal user of water from the Patuxent River. During 1955, this agency diverted an average of 29 mgd from Rocky Gorge Reservoir above Laurel. This amounted to about 30 percent of the 11-year (1945–55) average flow of the stream. During the same year, the commission diverted approximately 1.7 mgd at their Mink Hollow pumping station near Ashton in Montgomery County. The commission diverted about 37 mgd from Rocky Gorge Reservoir during 1956, an increase of 28 percent over 1955. However, during 1956 the diversion at Mink Hollow was only about 0.007 mgd.

Most of the water diverted was supplied to residents of Montgomery and Prince Georges Counties in the suburbs surrounding the District of Columbia. The commission supplied Laurel with an average of 0.464 mgd in 1956 and Howard County with about 0.016 mgd. The U.S. Army at Fort Meade uses a small quantity of water from the Little Patuxent River. In 1955 this installation used an average of 2.2 mgd. In 1956 the average use was 2.1 mgd or about 3 percent of the mean flow. No nonwithdrawal uses, excepting recreation, are known in the Patuxent River basin.

WATER RESOURCES OF THE COASTAL PLAIN SUBAREA

The Coastal Plain subarea of this report occupies the area southeast of the Baltimore and Ohio Railroad and west of Chesapeake Bay; it is bordered on the south by the South River, the Washington-Annapolis Expressway, and the Patuxent River. The rocks of the Coastal Plain subarea consist chiefly of sand, gravel, clay, and sandy clay of early Cretaceous to Recent age, which form a wedge-shaped sedimentary mass. This wedge lies on the bevelled crystalline rocks exposed at the land surface west of the fall zone. The distribution of the major sedimentary formations is shown on plate 2. These sediments thicken eastward and are about 500 feet thick at Glen Burnie, about 750 feet thick at Sparrows Point, and more than 1,000 feet thick at Annapolis. The subarea is rolling, hilly, and well drained, except at some places along the major streams, such as the swampy areas along the Patuxent River. There are extensive flat terraces at several places along the bay shore. The maximum elevation in the subarea is slightly more than 200 feet near Jessup and Savage Station in eastern Anne Arundel County.

One-half to two-thirds of the industries of the Baltimore area are in this subarea. The Bethlehem Steel Co. Sparrows Point plant at the mouth of the Patapsco River is the State's largest industrial plant. Agriculture is an important activity in central Anne Arundel County and in the Back River and Patapsco River Neck sections of Baltimore County. However, in recent years the usable farm land is rapidly becoming urbanized.

Municipalities, commerce, and industry are the chief users of water. The major source of water in the Coastal Plain is ground water. Surface water is, however, a source of part of the supply for Annapolis. Substantial quantities of water are also used at installations such as the Army Chemical Center, the Naval Academy, and the Naval Engineering Experiment Station.

Enormous quantities of water are stored in the sand and gravel deposits and in associated clay and sandy clay of the Baltimore area. The logs of many drilled wells penetrating the Coastal Plain strata show that about 45 percent of the material consists of sand and gravel (Bennett and Meyer, 1952, p. 35; and Otton, 1955, p. 23). Assuming a porosity of 30 percent, a block of typical sediments 1 mile square and 500 feet deep would contain 14 billion gallons of water. Practically speaking, however, only a small amount of this stored water would be available to wells, because of the limitations imposed by the permeability of the materials through which the water must move to reach the wells and by the specific yield, which is less than porosity, and because hydraulic gradients sufficiently great to move large quantities of water can be created only near wells of high yield. Even the best wells in the Coastal Plain of Maryland furnish only about 1½ mgd. The table on page F59 shows the water-bearing properties of the formations of the Coastal Plain.

Ground water in the Coastal Plain subarea occurs under both water-table and artesian conditions. Under water-table conditions, the ground water is unconfined, and the upper surface of the saturated zone is called the water table. Under artesian conditions, the water is confined under pressure between relatively impermeable strata, commonly clay or sandy clay. The hydrostatic pressure in the confined

Hydrologic properties of units of the Coastal Plain

Formation	Locality	Character	Thickness (feet)	Yield of wells[1] (gpm): Number of wells	Yield of wells[1] (gpm): Range	Yield of wells[1] (gpm): Average	Specific Capacities[1] (gpm per ft): Number of wells	Specific Capacities[1] (gpm per ft): Range	Specific Capacities[1] (gpm per ft): Average	Hydrologic coefficients: Coefficient of transmissibility (gpd per ft)	Hydrologic coefficients: Coefficients of permeability (gpd per ft)	Hydrologic coefficients: Coefficient of storage
Quaternary (Pleistocene): Estuarine deposits.	Sparrows Point, Dundalk, and Havre de Grace.[2]	Sand, gravel, cobbles, sandy clay, and red and gray tough estuarine clay.	0–150	47	15–1,000	146	13	1.4–66.0	16.1	68,000 14,500 200,000	5,700 900 6,300	------------
Upper Cretaceous: Monmouth and Matawan.	Rock Hall[2]	Sandy clay and sand, glauconitic; in places, contain marine fossils.	0–140	2	Few–20	------	------	----------	------	4,500	150	0.0005
Magothy	Crownsville, Sandy Point, U.S. Naval Academy, and Annapolis Water Works.	White to light-gray sand and gravel, commonly lignitic and pyritic; contain interbedded clay layers.	0–130	17	20–1,000	200	13	0.3–10.2	3.2	74,200 38,000 23,100	2,960 1,600 370	.00003 .00014 ------------
Raritan and Patapsco.	Curtis Bay, Sparrows Point, Odenton, Glen Burnie, and Annapolis.	Interbedded sand, clay and sandy clay; color variegated but chiefly hues of red and yellow; locally contain indurated beds a few feet thick.	0–750	80	<50–1,000	210	55	.1–22.5	6.7	72,800 24,300 25,000 35,000 35,600 38,300	810 970 320 960 1,400 580	.0003 ------------ .003–.00005 .0001 .0002 .0003
Arundel clay	------------	Red to dark-gray clay; contains thin layers of ironstone; lignitic in places (not a water-bearing formation).	0–200	------	----------	------	------	----------	------	----------	----------	------------
Lower Cretaceous: Patuxent	Sparrows Point, Dundalk, Highlandtown, and Laurel.	Lenticular beds of sand, gravel, and clay.	0–300	54	<50–1,000	380	48	0.3–19.6	6.9	[3] 50,000 22,500 6,200 600	780 380 140 22	.00026 .00018 ------------ ------------

[1] Excludes domestic wells.
[2] Adjacent to the area of this report.
[3] Average value reported by Bennett and Meyer (1952, p. 53).

part of an aquifer is caused by higher water levels in the intake area. An artesian aquifer is always full of water, except locally where heavy pumping may draw the cone of depression or cone of influence, below the top of the aquifer.

Water moves downdip and laterally from the area of intake, underlain chiefly by beds of sand and gravel of Cretaceous age, to areas of discharge beneath the Chesapeake Bay and along the low-lying estuaries adjacent to the bay. Thus, most of the water in the artesian aquifers is in slow but continual motion from the areas of recharge (higher head) to areas of discharge (lower head). The rate of movement of ground water through the aquifers, however, is extremely slow. According to Bennett and Meyer (1952, p. 108), ground water northeast of Baltimore is moving toward centers of pumping at a rate of about 110 feet per year, and these are accelerated rates caused by pumping. Nearer the centers of pumping, it is moving as much as 700 feet per year.

The temperature of water from wells tapping the deposits of the Coastal Plain at depths below 50 to 75 feet tends to remain relatively constant throughout the year. This characteristic is desirable where the water is to be used for industrial cooling processes and for air conditioning. The observed range in temperature is from 52 to 64° F and the average is about 58° F.

In general, ground-water temperatures rise with increasing depths below 50 feet. This rate of increase, known as the geothermal gradient, is about 1° F for each 60- to 100-foot increment of depth in the Coastal Plain.

PATUXENT FORMATION

The Patuxent formation, the oldest sedimentary deposits of the Coastal Plain in the Baltimore area, consists of sand, gravel, sandy clay, and clay laid down by streams on the eroded crystalline rock surface during Early Cretaceous time. The sediments were deposited by streams draining the Appalachian and Piedmont highlands to the north and west. The Patuxent formation, one of the major water-bearing units in Maryland, crops out along a belt 3 to 5 miles wide, which is roughly the route of the Baltimore and Ohio Railroad. The sloping crystalline rock surface on which it rests dips generally southeastward at an average rate of 85 feet per mile. Locally, the slope of this surface is as much as 150 feet per mile, as in the Highlandtown and Canton districts of Baltimore. The upper surface of the Patuxent dips southeast but at a rate of only 45 to 50 feet per mile. (See plate 3.) The Patuxent formation is therefore wedge-shaped and is thinnest near its area of outcrop. In the vicinity of Baltimore its thickness, as shown by well borings, ranges from a few to as much as 300 feet. A few miles southeast of the area of this report, near Glen Dale in Prince Georges County, more than 400 feet of the formation was logged in a drilled well. Individual sand layers in the formation may attain a thickness in excess of 50 feet, although they are commonly somewhat thinner.

The Patuxent formation consists of a series of irregular beds of sand, sandy clay, and clay containing thin beds of sandstone cemented by iron oxide (hematite and limonite). Much of the sand is arkosic and contains disseminated white clay, chiefly kaolin. The beds of sand and clay are of various colors, chiefly yellow to white, tan, buff and light pink. Some of the clay is reddish ochre to blue or drab gray. Black lignitic material is commonly disseminated in the beds of clay and sand.

The most important hydrologic property of the formation is its ratio of permeable sand and gravel to clay, sandy clay, and other relatively impervious sediments. Bennett and Meyer (1952, p. 35) list many wells in the Baltimore area in which the logs show that an average of 49 percent of the material is sand and gravel. The proportion of sand and gravel to clay and related sediments decreases southwest of the Baltimore area toward the District of Columbia and the Potomac River (Otton, 1955, p. 23). The logs of several wells in the Potomac River valley indicate that only 29 percent of the material is sand and gravel. The transmissibility of the aquifers in the Patuxent formation and the yields of wells tapping the formation are significantly lower in the Potomac River valley than in the Baltimore area.

OCCURRENCE OF GROUND WATER

Wells tapping the Patuxent formation in the Baltimore area, exclusive of those for domestic purposes, yield from about 50 to 1,000 gpm. Several of the best wells are in the Fairfield and Sparrows Point districts of Baltimore, where the water-bearing sands are moderately thick and permeable and more elaborate wells are constructed. Generally, large-diameter wells tapping the formation in the outcrop area yield much less than those in more favorable areas. The average yield of six wells in the Laurel-Bowie area is only 68 gpm. With the exception of the Baltimore industrial area, the best wells reported in the Patuxent formation are at North Linthicum in Anne Arundel County (300 gpm) and at Edgewood in Harford County (400 gpm). However, it is likely that some of the water from the wells at Edgewood is derived from the overlying Pleistocene sand and gravel (Bennett and Meyer, 1952, p. 43).

The specific capacities of 54 wells ending in the Patuxent formation range from 0.3 to 19.6 and average 6.9 gpm per ft of drawdown. The maximum, 19.6 gpm per ft of drawdown, was reported for a 12-inch-diameter well at Fort Holabird in Baltimore. This well yielded 450 gpm but is no longer used. Coefficients of permeability and transmissibility range widely in the Patuxent formation, probably because the sediments are not uniform. (See "Definitions of terms used," p. F99.) The coefficients of permeability range from 22 gpd per sq ft near Laurel to 1,430 gpd per sq ft at Sparrows Point. Coefficients of transmissibility determined from aquifer tests range from 600 gpd per sq ft at Laurel to more than 180,000 gpd per ft at Sparrows Point. Coefficients of storage range from 0.00001 to 0.0008, both limits occurring in the Sparrows Point district.

WATER-LEVEL FLUCTUATIONS

The average water levels in seven wells tapping the Patuxent formation rose 14.30 feet in 13 years (1944–56), because many industries decreased their pumpage from the aquifer. (See following table.) Water levels were lower than those in 1944 in only 2 years, 1947 and 1948.

Cumulative change, in feet, in year-end water levels since 1944 in the Patuxent and Patapsco formations

Year	Patuxent formation (7 index wells)	Patapsco formation (3 index wells)
1944	0.00	0.00
1945	+10.07	+6.27
1946	+1.90	+3.47
1947	−1.12	−3.53
1948	−0.68	−0.39
1949	+4.31	+8.44
1950	+9.39	+0.20
1951	+11.10	+1.14
1952	+8.58	−2.20
1953	+11.32	−0.94
1954	+12.85	−5.12
1955	+10.57	−4.09
1956	+14.30	−1.91

CHEMICAL QUALITY OF GROUND WATER

Bennett and Meyer (1952) give a comprehensive discussion of quality of ground water in the Baltimore industrial area. Pumping of large amounts of ground water adjacent to estuaries has caused changes in the chemical character of water in some parts of the aquifers. Their report includes 129 analyses of water from 112 wells, nearly all of which tap the unconsolidated deposits. Bennett and Meyer restricted the quality-of-water inventory largely to wells tapping the Patapsco or Patuxent formations, which are the principal sources of ground water pumped for industrial use.

The collection of quality-of-water data subsequent to the 1952 study has been directed largely toward an inventory of uncontaminated sources of ground water in crystalline rock and sedimentary deposits outside of the immediate harbor area. The results of the chemical analyses of 20 water samples from aquifers in the Coastal Plain subarea are given in the table on page F64.

Chemical analyses of ground water from the Coastal Plain

[Analytical results in parts per million except as indicated]

Location of well	Well depth (feet)	Date of collection	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Residue of dissolved solids on evaporation at 180°C	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Carbon dioxide (CO_2)	Specific conductance (micromhos at 25°C)	pH	Color
Patuxent formation (uncontaminated by salt water)																						
Southeast Baltimore[1]	378	1-22-44	......	7.3	0.01	1.4	0.8	1.3		5	......	1.6	2.2	......	1.0	19	7	......	......	29	5.4	......
Do.[1]	378	2-14-52	......	8.5	.00	1.4	.7	2.0	0.5	6	0	2.0	3.0	0.0	2.1	[2] 23	6	2	......	27.2	5.4	4
Do.	400	2-9-45	......	7.3	.01	.9	.5	3.7		6	0	3.5	2.5	.0	.3	20	4	......	......	28.5	5.4	......
Back River	......	6-5-45	......	8.5	.53	1.4	.9	5.3		8	0	5.0	4.5	.0	1.1	30	7	......	......	45.8	5.3	......
Bear Creek	365	1-25-46	......	7.1	.71	1.5	1.0	6.3		6	0	6.5	7.2	.0	.9	33	10	......	......	49.4	5.3	......
Southwest Baltimore	115	5-7-45	......	......	......	4.1	......	......	......	24	0	......	......	......	1.1	......	46	26	24	127	6.0	......
East Baltimore[1]	145	7-8-55	......	......	......	......	......	16		8	0	7.4	20	......	16	......	20	13	......	131	5.9	5
Do.	153	7-8-55	......	......	......	......	......	13		6	0	2.8	14	......	15	......	12	7	......	85.4	5.4	2
Do.	108	3-19-54	57	8.6	.49	3.7	1.7	2.8	.8	10	0	.8	6.5	.0	11	[4] 42	17	9	25	54.3	5.9	10
Middle River	315	3-19-54	55	6.4	.94	1.2	1.4	1.6	.3	13	0	1.4	3.5	.1	.1	[3] 28	14	4	13	39.6	6.2	20
Patuxent formation (contaminated by salt water)																						
Central Baltimore	60	7-8-55	......	......	2.4	......	......	463		129	0	178	765	......	34	......	390	284	......	2960	6.3	2
South Baltimore	149	7-19-55	......	......	4.9	......	......	968		186	0	165	1690	......	20	......	620	468	......	5090	6.3	5

Patapsco formation (uncontaminated by salt water)

Fort Smallwood	------	8- 3-43	------	------	18	------	------	------	------	20	------	2	3.0	------	0.0	------	16	------	------	71	6.1	------
Curtis Bay	127	6-15-45	------	7.7	.04	2.2	0.9	4.5		6	0	.6	5.5	0.0	5.8	36	9	------	------	42	5.7	------
Marley Neck	137	3-18-54	55	5.9	.05	3.3	2.3	1.3	0.9	4.0	0	12	4.0	.0	1.2	[5]29	18	14	20	45.2	5.6	8
Sparrows Point	229	7- 7-55	------	------	.62	------	------	4.1		10	0	2.6	4.0	------	.5	------	8	0	------	35.7	5.8	2
Do	200	7- 7-55	------	------	.05	------	------	14		10	0	3.8	23	------	.4	------	14	6	------	102	5.8	5
Fort Howard	400	10-22-45	------	7.7	11	2.6	2.0	3.4		8.0	0	11	1.6	.2	.1	33	15	------	------	46.4	5.9	------
Do	400	6-30-55	------	7.5	6.5	1.7	2.0	4.4		8.0	0	11	1.6	.6	.2	[6]36	12	6	8.0	45.7	6.2	1

Patapsco formation (contaminated by salt water)

BS-1-WU	------	7- 7-55	------	------	[7]35	------	------	82		0	0	4.2	245	------	5.5	------	175	175	------	901	3.62	200

1 Resamples. See Maryland Dept. of Geol., Mines, and Water Resources Bull. 4, p. 113.
2 Manganese (Mn), 0.00 ppm; copper (Cu), 0.03 ppm; aluminum (Al), 0.0 ppm; zinc (Zn), 0.10 ppm; phosphate (PO_4), 0.0 ppm.
3 Aluminum (Al), 0.8 ppm; lithium (Li), 0.1 ppm; manganese (Mn), 0.1 ppm.
4 Aluminum (Al), 0.1 ppm; barium (Ba), 0.0 ppm; lithium (Li), 0.2 ppm.
5 Manganese (Mn), 0.02 ppm; lithium (Li), 0.1 ppm.
6 Phosphate (PO_4), 0.0 ppm.
7 Dissolved iron (Fe).

Salt-water contamination is common in parts of the Patuxent formation in the Baltimore area. Twenty analyses given by Bennett and Meyer (1952) were selected as representing uncontaminated sources of water in the Patuxent formation. Averages of mineral constituents reported for these waters are given in table 6. Most of these analyses

TABLE 6.—*Minimum, maximum, and average concentrations of chemical substances in water from principal uncontaminated aquifers*

[Results are given in parts per million except as indicated]

	Crystalline rocks			Patapsco formation				Patuxent formation			
						Average				Average	
	Minimum	Maximum	Average[1]	Minimum	Maximum	This report	After Bennett[2]	Minimum	Maximum	This report[3]	After Bennett[2]
Silica (SiO_2)	24	49	41	5.9	7.7	------	------	6.4	8.6	7.7	8.4
Iron (Fe)	.00	8.0	1.3	.04	18	4.2	3.8	.00	.94	.38	5.0
Manganese (Mn)	.02	.10	.08	------	------	------	------	------	------	------	------
Calcium (Ca)	19	63	33	1.7	3.3	------	------	.9	1.4	1.9	1.9
Magnesium (Mg)	7.2	32	13	.9	2.3	------	------	.5	1.7	1.0	1.2
Sodium (Na)	5.9	18	9.6	------	------	------	------	1.6	2.8	------	3.9
Potassium (K)	0.5	4.5	2.9	------	------	------	------	.3	.8	------	
Bicarbonate (HCO_3)	60	182	119	4.0	20	10	7.1	5	24	9	7.1
Carbonate (CO_3)	------	------	------	------	------	------	------	------	------	------	------
Sulfate (SO^4)	1.0	155	31	.6	12	5.4	4.7	.8	7.4	3.5	5.8
Chloride (Cl)	2.5	17	8.1	1.6	23	6.9	3.5	2.2	20	7.0	1.7
Fluoride (F)	.0	.2	.1	.0	.6	------	.2	.0	.1	------	.0
Nitrate (NO_3)[2]	.0	1.1	.3	.0	5.8	1.4	4.2	.1	16	------	1.1
Dissolved solids:											
Calculated	------	------	------	------	------	------	------	------	------	------	------
Residue on evaporation at 180° C	140	398	------	------	------	------	35	19	42	------	29
Hardness as $CaCO_3$	50	290	111	8	18	13	15	4	46	14	11
Noncarbonate hardness as $CaCO_3$	------	------	------	------	------	------	------	------	------	------	------
Alkalinity as $CaCO_3$	------	------	------	------	------	------	------	------	------	------	------
Specific conductance microohms at 25° C	146	525	282	35.7	102	56.9	------	27.2	131	61.7	------
pH	6.6	8.5	------	5.6	6.2	------	------	5.3	6.2	------	------
Color	2	28	13	1	8	------	------	2	20	------	------

[1] Average based on results for 20 samples.
[2] Does not include one analysis having 48 ppm nitrate (NO_3).
[3] Bennett and Meyer (1952).

are of water from wells in areas away from the highly industrialized sections of Baltimore. Other than the average for the iron content, which varies widely even locally, the average data reported for the two periods are strikingly similar.

Uncontaminated water from the Patuxent formation characteristically is low in mineral content, very soft, and acidic on the pH scale. Excessive iron content in some water from cased wells suggests that the water is corrosive to metal; otherwise, it is of excellent quality for general use.

Otton (1955), in describing the ground-water resources of the Coastal Plain of southern Maryland, reports as much as 227 ppm of dissolved solids for 33 samples of water from the Patuxent formation. The water varies widely in chemical composition. A few samples from the outcrop belt of the formation in northern Prince Georges and Anne Arundel Counties have a pH less than 7, a low content of dissolved solids, and a relatively high content of iron and manganese. The water is probably typical of the Patuxent formation, where this formation is not overlain by younger formations containing calcareous shell fragments. Water in the Cretaceous and Eocene aquifers changes markedly in character as it moves through strata containing base-exchange minerals, such as glauconite or hydrated aluminosilicates.

USE OF GROUND WATER

Only in the Coastal Plain subarea are public supplies obtained from ground-water sources. The Anne Arundel County Sanitary Commission, created and authorized by the Maryland legislature in 1922, is the chief user of ground water for public supplies. During 1955, this commission maintained and operated six well fields in northern and central Anne Arundel County in which 15 wells tapping chiefly sand and gravel deposits of the Patuxent and other aquifers of Cretaceous age were used. During 1955, the well fields of the commission delivered an average of about 1.6 mgd. This pumpage represented an increase of about 57 percent since 1951. (See table 7.)

TABLE 7.—*Use of ground water by the Anne Arundel County Sanitary Commission in 1951 and 1955*

Well field	Number of wells	Aquifers	Pumpage		Percent change
			1951 (gpd)	1955 (gpd)	
Linthicum Heights	3	Patuxent and Patapsco formations.	80,000	38,000	[1] −42
Glen Burnie	6	Patapsco formation	321,000	693,000	+115
Harundale	2	do	468,000	703,000	+50
Severna Park	1	do	74,000	110,000	+49
Gibson Island	2	Raritan formation	79,000	63,000	−25
Pines-on-Severn	1	do	14,000	25,000	+78
All fields	15	All aquifers	1,036,000	1,632,000	+57

[1] After 1952, some consumers were supplied with water from the Glen Burnie well field.

The U.S. military establishments are major users of ground water in the Baltimore area. Although the use of ground water by these establishments has increased, the increase has not been as great, in proportion, as that of the sanitary commission. The wells of the military establishments tap the Patuxent, Patapsco, Raritan, and Magothy formations. It is likely that some ground water used by the Army Chemical Center at Edgewood is obtained also from deposits of Pleistocene age. Pumpage figures for these users are given in table 8.

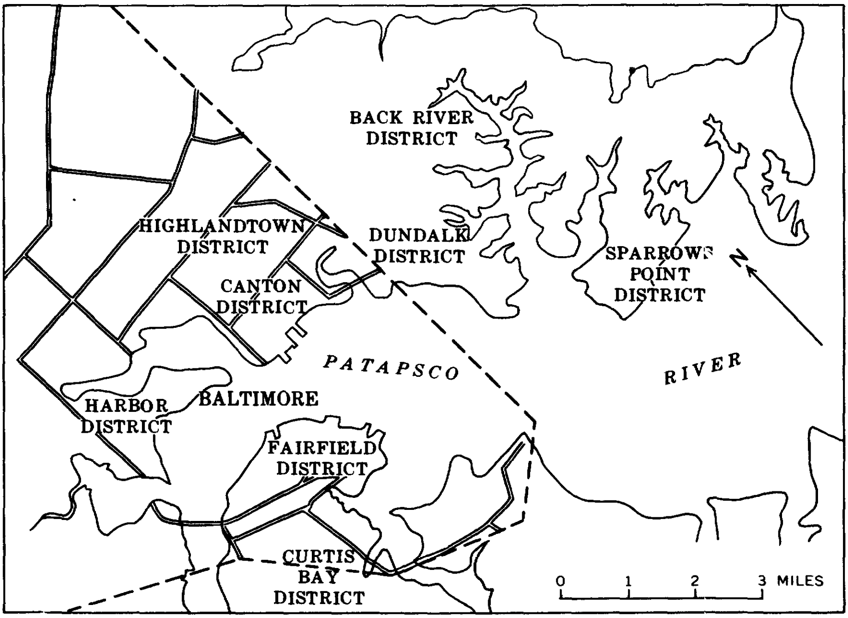

FIGURE 27.—Map showing location of industrial districts in the Baltimore area, Maryland. After Bennett and Meyer (1952).

TABLE 8.—*Use of ground water by military establishments in 1951 and 1955*

Military establishment	Number of wells	Aquifers	Pumpage (gpm)		Percent change
			1951	1955	
U.S. Army Chemical Center	8	Patuxent	650,000	820,000	+26
U.S. Naval Academy	2	Magothy and Raritan	1,000,000	1,090,000	+9
Naval Engineering Experiment Station.	3	Patapsco and Raritan	450,000	520,000	16

Bennett and Meyer (1952, p. 78–82) described in detail the use of ground water in the Baltimore area by industry prior to 1946. A detailed pumpage inventory of the Baltimore area was made in 1955 to bring their comprehensive summary up to date. (See table 9.) Districts for which data on pumpage are given are shown in figure 27, except St. Denis district, which is a few miles west of the map area, and North Baltimore district, which is the part of Baltimore north of Fayette Street.

TABLE 9.—*Use of ground water in the Baltimore industrial area in 1945 and 1955*

District and user	Aquifer	1945 (mgd)	1955 (mgd)	Percent change
Sparrows Point:				
Bethlehem Steel Co.	Patuxent and Patapsco formations.	10.30	12.13	+18
VA Hospital				
Dundalk:				
Western Elecrtic Co.				
The Glidden Co.				
Federal Yeast Corp.	Patuxent formation	5.05	4.58	−9
Reid-Avery Co.				
National Distillers Corp.				
Canton:				
Baugh Chemical Co.				
American Radiator and Standard Sanitary Corp.	Patuxent formation	.50	.09	−82
National Brewing Co.				
Back River:				
Eastern Stainless Steel Co.	Patuxent formation	2.00	1.08	−46
Highlandtown:				
Crown Cork and Seal Co.				
Esskay Packing Co.				
Paul Jones and Co.	Patuxent formation	2.80	1.11	−60
Penna. Water and Power Co.				
Monarch Rubber Co.				
North Balitimore:				
The Frank G. Schenuit Rubber Co.	Crystalline rocks	.70	.30	−57
Harbor:				
Chesapeake Paper Board Co.				
Proctor and Gamble Manufacturing Co.				
James Distillery Inc.				
Independent Ice Co.	Patuxent formation and Pleistocene deposits.	2.15	.25	−88
Carr-Lowrey Glass Co.				
Mutual Chemical Co.				
National Distillery Products Co.				
Fairfield:				
Food and Machinery Co.				
Bethlehem Steel Co.				
Continental Oil Co.				
F. S. Royster Guano Co.	Patuxent formation	5.20	2.51	−52
Maryland Drydock Co.				
American Oil Co.				
St Denis:				
Calvert Distillery Co.	Pleistocene deposits	1.30	1.05	−19
Monumental Dist. Co				
Curtis Bay:				
U.S. Industrial Chem. Co.				
Davidson Chemical Corp.	Patuxent and Patapsco formations.	3.70	.53	−86
Garrett Cooperage Co.				
Mathieson Chemical Co.				
All Baltimore industrial area	All aquifers	33.70	23.63	−30

Nearly all the major users of ground water in the Baltimore industrial area tap the Patuxent and Patapsco formations. Although the reasons for the decline in ground-water use in the Baltimore area during the decade 1945–55 are complex and not known entirely, the major reason appears to be the high cost of maintaining and operating wells which tap ground water contaminated with acid waste or with salty water from the bay. The high cost of replacement of these wells, the relatively short useful life of the pumps, well screens and casings, and the ready availability of water from the Baltimore City public supply all have been factors that decreased the use of ground water. It is significant that the area of greatest decline in use has been the Harbor, Fairfield, and Curtis Bay districts, which also has been the area of greatest salt-water contamination (pl. 1).

The water users beyond the reach of the mains of the public supply systems in the Baltimore area are almost entirely dependent upon wells and springs as a source of water. The average use per person in a rural household equipped with hot and cold running water and containing a kitchen, laundry, and bath is 50 gpd (U.S. Public Health Service, 1950, p. 5). The population of the Coastal Plain subarea without access to public water supplies is about 60,000—about 40,000 in northern Anne Arundel County and 20,000 in the Coastal Plain segment of Baltimore County. The total use of ground water by this population is about 3 mgd.

ARUNDEL CLAY

The Arundel clay, of Late Cretaceous age, was named from exposures in northern Anne Arundel County, where it crops out along an irregular belt from Baltimore southwestward to the Patuxent River. The unit also extends nearly 20 miles northeast of Baltimore. It consists of a few to more than 200 feet of red, brown, gray, to bluish tough clay. The formation commonly contains disseminated lignitic material, nodules and concretions of ironstone, and irregular bands of iron-cemented sandstone or sandy gravel. Locally, the formation may contain sand lenses of moderate permeability, although the lenses are uncommon and small. The formation is not regarded as an aquifer. It functions as a confining layer, or aquiclude, separating the water-bearing sands of the Patuxent formation from those in the Patapsco. Figure 28 shows the geology at the well field of the Anne Arundel Sanitary Commission at Glen Burnie. Here the Arundel clay separates the two major ground-water reservoirs, the Patuxent and the Patapsco formations.

PATAPSCO AND RARITAN FORMATIONS

The Patapsco and Raritan formations, also of Late Cretaceous age, overlie the Arundel clay throughout the Baltimore area. The two formations are similar in their lithologic and hydrologic properties, and for this reason are considered as a unit in this report. They crop out along a broad belt extending southwestward from the Gunpowder River in Baltimore County to the Patuxent River in Anne Arundel County. At some places the outcrop belt of both of the formations is more than 12 miles wide, and in many places the formations are covered with a veneer of sand, gravel, and clay of Pleistocene or Recent age. The formations consist of irregularly distributed beds of sand, gravel, sandy clay, and clay of continental origin derived mainly from the Piedmont highland to the west and northwest. The clay layers are commonly reddish brown, tan, or gray, and the sand layers are yellow, tan, or grayish white. Iron-stone bands and nodules are common in both the clay and the sand. The sand beds are commonly cross-bedded, arkosic, and, in places, clayey.

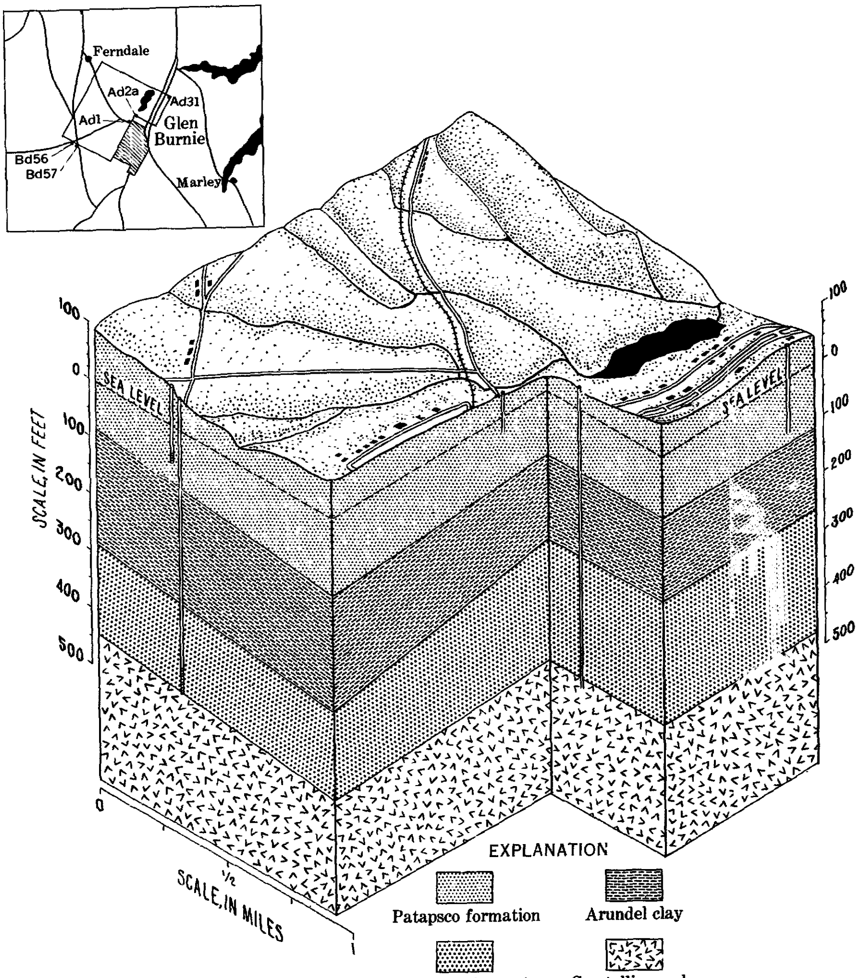

FIGURE 28.—Geology at the well field of the Anne Arundel County Sanitary Commission at Glen Burnie, Md.

The combined thickness of the formations ranges from a few feet along the northwest edge of the outcrop to nearly 600 feet near Annapolis (fig. 29). In the vicinity of Glen Burnie, a few wells have penetrated more than 250 feet of the Patapsco formation. In general, the thickness of the units increases to the southeast.

The hydrologic character of the formations is indicated by the proportion of sand to clay. Of more than 10,000 feet of strata logged, about 30 percent consists of permeable sand and gravel or, about the same percentage as in the Patuxent formation exclusive of the Baltimore industrial area.

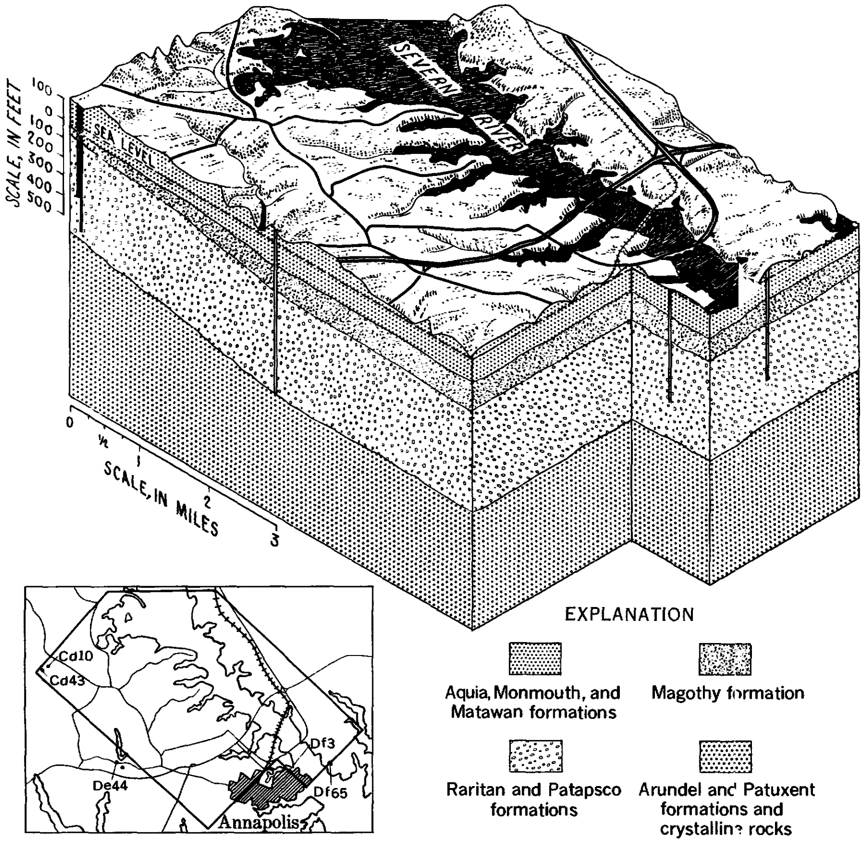

FIGURE 29.—Geology along the lower Severn River near Annapolis, Md.

OCCURRENCE OF GROUND WATER

Yields of about 80 large-diameter wells in the Patapsco and Raritan formations range from less than 50 to about 1,000 gpm and average about 210 gpm. In the Sparrows Point area, the average yield of several industrial wells tapping the Patapsco formation is 500 to 800 gpm (Bennett and Meyer, 1952, p. 65). Generally throughout the remainder of the area, yields of more than 500 gpm are exceptional. The specific capacities of 55 wells range from 0.1 to 22.5 gpm per ft of drawdown. The well having the highest specific capacity is at Sparrows Point and yielded 720 gpm in 1943.

Coefficients of permeability, as determined by aquifer tests, range from 320 to 1,400 and average about 850 gpd per sq ft. The maximum value was determined in the vicinity of Glen Burnie. Coefficients of transmissibility range from 24,300 to 38,300 and average about 31,600 gpd per ft. Coefficients of storage range from 0.00005 to 0.003. Both the upper and lower limits were computed from tests in the Sparrows Point area.

WATER-LEVEL FLUCTUATIONS

The history of water levels in the Patapsco formation is more complex because pumpage is variable. Water levels in the Patapsco formation rose substantially in 1945 and were still above 1944 levels at the end of 1946. However, they declined slightly in 1947. This decline changed to a rising trend in 1948, which continued through 1949. A downward trend began in 1952 and continued through 1954. During 1955 and 1956, water levels rose 3.2 feet, and the net decline in this aquifer was only 1.9 feet during the 13 years 1947–60. Water levels in the three key observation wells tapping this aquifer appear to be affected chiefly by pumping from wells in the Curtis Bay-Fairfield and Sparrows Point areas.

The year-end water-level record of one well tapping the Patapsco formation at Crownsville in Anne Arundel County showed a net decline of 5.5 feet during the 7-year period 1949–56. This decline apparently is the result of the increased use of ground water from the Patapsco formation at the Crownsville State Hospital.

CHEMICAL QUALITY OF GROUND WATER

Water from the Patapsco formation is soft, low in mineral content, high in iron locally, and similar in mineral quality to that from the Patuxent formation (table 6).

Otton (1955) shows that high iron content is typical of acid sulfate water in the Cretaceous strata in northern and central Anne Arundel and Prince Georges Counties. The available analyses show that in the southern part of the Coastal Plain, extending northward from the vicinity of Annapolis to near the mouth of the Patapsco River, wells tapping sands of Cretaceous age commonly yield water having an iron content of more than 10 ppm (pl. 1). Elsewhere in northern Anne Arundel County, iron commonly exceeds 1 ppm in the ground water.

USE OF GROUND WATER

Large quantities of water are taken from the Patapsco formation for industrial and public supply use. (See tables 7, 8, and 9.) In addition to industries listed in table 16 the National Plastics Products Co. at Odenton in Anne Arundel County uses water from the Patapsco formation. During 1951, this plant used an average of 1.0 mgd from wells tapping this formation at a depth of approximately 170 feet. By April 1956 the average pumpage of this concern had increased to 1.2 mgd.

MAGOTHY FORMATION

The Magothy formation of Late Cretaceous age is exposed along an irregular southwestward-trending belt extending from Sillery Bay near the mouth of the Magothy River to the vicinity of Priest Bridge on the Patuxent River. The formation thins to the southwest, and in Princes Georges County only a few outcrops have been noted. It extends northeastward across the bay and has been recognized in deep wells as far north as Long Island. It consists of lignitic or carbonaceous grayish-white to yellowish sand interspersed with layers of clay. The sand is commonly coarse and cross-bedded and may grade horizontally into clayey sand, sandy clay, or clay. Pyrite and glauconite are common in the sandy layers. The logs of 12 wells penetrating the formation in Anne Arundel County show that about 85 percent of it consists of sand and gravel. The Magothy formation ranges in thickness from a few feet near its northernmost limit of exposure to as much as 130 feet at Annapolis. Commonly at or near its outcrop it is 30 to 70 feet thick.

The yields of 17 large-capacity wells tapping the Magothy formation range from 20 to 1,000 gpm and average about 200 gpm. The two best wells are at the Annapolis Water Works a few miles west of Annapolis. One of these wells is 248 feet deep and contains 50 feet of screen opposite clean permeable sand. When the well was completed in 1947, its specific capacity was 10 gpm per ft of drawdown, the largest measured in any well tapping this aquifer. The specific capacities of 13 of the most productive wells in the formation range from 0.3 to about 10 and average about 3 gpm per ft of drawdown.

Coefficients of permeability, as computed from aquifer tests, range from 370 to 2,960 gpd per sq ft. The maximum value was determined from a test on a 232-foot well at the Crownsville State Hospital. The minimum value was determined from a recovery test on a 307-foot well at the U.S. Naval Academy. Coefficients of transmissibility range from 23,100 to 74,200 gpd per ft. The maximum value was determined from a test of the well at the Crownsville State Hospital. Coefficients of storage range from 0.00003 at Crownsville to 0.005 at Sandy Point. The U.S. Naval Academy is the major user of water from this formation. (See table 8.)

MONMOUTH FORMATION

The Monmouth formation, of Late Cretaceous age, crops out along an irregular belt a few miles wide extending southwestward from Gibson Island to the Patuxent River where it is crossed by U.S. Route 301. The formation, of marine origin, consists of grayish-black to black micaceous, glauconitic sandy clay. Although formerly thought not to be an aquifer, some wells have been drilled which tap sandy lenses in the formation. Generally the lenses are not large. In some places the formation contains no water-bearing zones. In Anne Arundel County, the Monmouth formation ranges in thickness from 50 to

80 feet and dips gently southeastward at a rate of about 20 feet per mile.

The maximum yield reported from the few wells in the Monmouth formation is 20 gpm. One such well drilled in 1943 at the now abandoned Sandy Point ferry terminal, had a specific capacity of 0.1 gpm per ft of drawdown and yielded 20 gpm. The well was abandoned because the water was of poor quality.

Although no tests of the Monmouth formation as an aquifer were made within the area of this report, test data are available for a drilled well at Rock Hall in Kent County across the Chesapeake Bay. Analysis of this test indicates a coefficient of permeability of 150 gpd per sq ft. The coefficient of transmissibility determined from the same test was 4,500 gpd per ft and the coefficient of storage was 0.0005. In general, the Monmouth formation is a much poorer aquifer than the underlying Magothy or Patapsco formations.

PLEISTOCENE AND RECENT DEPOSITS

The Pleistocene and Recent deposits in the Baltimore area have been divided into two units called upland and lowland deposits, by Bennett and Meyer (1952, p. 68). The lowland deposits, are those lying below an altitude of about 50 feet above sea level. Those above this altitude are classed as upland deposits. The upland deposits consist chiefly of coarse sand, gravel, and silty sand and underlie only a small part of the area of this report. They are, therefore, relatively unimportant with regard to the availability of groundwater supplies and are not discussed further.

The lowland deposits, consisting of clay, sand, gravel, and cobbles underlie an extensive area along the estuaries of Baltimore and Anne Arundel Counties. They are largely estuarine or marine in origin and range in thickness from 0 to 150 feet. The basal part of the deposits commonly consists of coarse gravel and sand overlain in places by clay, which may effectively seal the gravel from contact with the brackish water of the estuaries. Bennett and Meyer (1952, p. 69) report that the Pleistocene gravel is more than 60 feet thick at the Aberdeen Proving Ground.

The yields of 47 wells tapping the Pleistocene and Recent deposits range from 15 to 1,000 gpm and average about 146 gpm. The best well tapping the deposits (1,000 gpm) is in the valley of the Patapsco River near Relay. It is a collector-type well, 33 feet deep, which furnishes water for a distillery. The specific capacities of 13 wells tapping the deposits range from 1.4 to 66 and average 16 gpm per ft of drawdown. The maximum specific capacity was determined in 1943 on a 58-foot well, 10 inches in diameter, at Havre de Grace in southeastern

Harford County. The permeability of the deposits at this locality is exceptionally high.

Coefficients of permeability range from 900 to 6,300 gpd per sq ft. Coefficients of transmissibility range from 14,500 to 200,000 gpd per ft. The maximum value of 200,000 was determined at the 58-foot well at Havre de Grace. The coefficients of storage of the sand and gravel in the Pleistocene deposits in the Baltimore area are not known. Storage coefficients probably range from 0.0001 to 0.005 in areas where artesian conditions prevail.

Although the Pleistocene deposits are among the most permeable in the Maryland Coastal Plain, the chief concern in using them is the possibility of salt-water encroachment should they be pumped heavily. Such encroachment has occurred in the Baltimore harbor area and could readily take place in other areas, where the geologic conditions are similar, if the head in the aquifer is drawn below sea level by heavy pumping. This subject is discussed in detail by Bennett and Meyer (1952, p. 124–172). Some industrial water is obtained from these deposits. (See table 9.)

SAWMILL CREEK

Sawmill Creek, in northern Anne Arundel County, drains a small Coastal Plain area (5.1 square miles) underlain chiefly by sand and clay of the Patapsco formation. The topography is slightly rolling and, in a few places, nearly level. The maximum elevation is about 180 feet.

DISCHARGE

The most unusual streamflow record in Maryland probably is that of Sawmill Creek. The gage-height hydrograph for the 8-year record May 1944 to September 1952 has broad peaks and slow recessions, indicating a ground-water source for a large part of the discharge. The range in stage is remarkably small in comparison with other streams; the maximum range during the period of record was 3.05 feet. The average flow for the 8 years 1945–52 was 5.34 mgd (8.26 cfs). The minimum daily flow was 2.33 mgd (3.6 cfs) on September 7–8, 1950, and the lowest monthly flow was 3.29 mgd (5.09 cfs) in October 1947. The maximum daily flow was 101 mgd (157 cfs) on September 1, 1952.

The flow per square mile for Sawmill Creek is greater than that of any stream in the report area (fig. 30). However, because of the small drainage area, the flow of Sawmill Creek is much less than that of some of the larger streams.

Sawmill Creek is not regulated above the gaging station. Some water, however, is stored in a small pond, Wagners Pond, a short distance below the station.

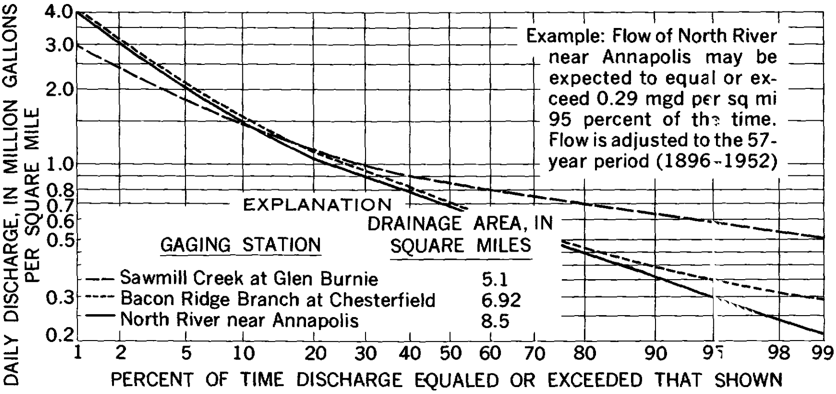

FIGURE 30.—Duration curves of daily flow for three streams in the Coastal Plain.

In 1957 several deep wells were drilled on Dorsey Road within the Sawmill Creek basin. These wells furnish water for Glen Burnie from the Patapsco formation near its outcrop area. Sawmill Creek has not been gaged since 1953, and present discharge may show the effect of recent heavy pumping from the nearby well field. Water is not known to be diverted from Sawmill Creek for use.

CHEMICAL QUALITY OF WATER

During the water year 1954–55, two chemical analyses were made of water from Sawmill Creek (table 10). These show the water to be slightly acidic and to be low in dissolved solids and hardness. The iron content of both samples was low. Nitrate, sometimes an indicator of pollution, was moderately high (15 ppm) in the sample collected on December 8, 1954.

BACON RIDGE BRANCH

Bacon Ridge Branch drains an area underlain by sedimentary deposits, chiefly beds of marine sandy clay and sand of Cretaceous and Eocene age. The topography is undulating to hilly in places. Some of the smaller drains and tributaries are ravinelike. Elevations in the basin range from sea level to approximately 180 feet above sea level.

Bacon Ridge Branch at Chesterfield (station 23, pl. 1) was gaged from November 1942 to September 1952. Records for the 6.92 square-mile drainage area above the station show a 9-year (1944–52) average flow of 6.72 mgd (10.4 cfs). The minimum daily flow was 1.94 mgd (3.0 cfs) during August 1943, and the lowest average monthly flow was 2.10 mgd (3.25 cfs) in August 1943. All records for this station include about 0.19 mgd of sewage effluent added to the stream at the Crownsville State Hospital. The low-flow frequency data (table 2)

TABLE 10.—*Chemical analyses of water from selected streams of the Coastal Plain*

[Analytical results in parts per million except as indicated]

Date of collection	Discharge (mgd)	Lithium (Li)	Manganese (Mn)	Silica (SO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Residue of dissolved solids on evaporation at 180°C	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
Sawmill Creek at Glen Burnie																				
Dec. 8, 1954	3.24	0.1	0.00	9.2	0.01	5.9	2.0	2.8	2.0	4.4	11	2.5	0.1	15	61	23	19	74.9	6.4	3
Mar. 7, 1955	3.43	.1	.02	5.9	.06	7.6	2.5	2.7	2.4	3.8	21	5.0	.1	8.5	61	29	26	92.6	5.8	7
North River near Annapolis																				
Jan. 21, 1955	2.40	0.2	0.03	16	0.04	3.5	1.8	2.1	2.0	9.4	9.0	3.6	0.2	1.2	52	16	9	56.9	6.3	5
Mar. 7, 1955	12.9	.1	.01	11	.17	5.2	2.0	1.7	2.2	2.8	19	4.4	.2	.8	58	22	19	63.1	5.4	7
Deep Run near Patapsco																				
Dec. 17, 1954	5.51	0.3	0.00	9.9	0.18	11	3.6	5.1	1.6	14	28	8.0	0.1	2.4	90	43	31	122	7.0	5
Mar. 7, 1955	27.4	.2	.01	9.0	.11	9.1	3.4	3.8	1.7	7.4	29	6.6	.2	3.8	83	37	31	108	6.3	14
Severn Run near Glen Burnie																				
Dec. 17, 1954	9.63	0.1	0.00	7.8	0.20	4.2	1.3	4.3	1.3	9.6	10	3.0	0.2	6.2	53	16	8	65.4	6.5	12
Mar. 7, 1955	31.1	.2	.17	5.8	.11	8.0	1.7	3.0	1.9	3.2	26	5.0	.3	2.0	66	28	25	90.2	5.0	8

indicate that during periods of low flow Bacon Ridge Branch basin yields a slightly higher flow per square mile than the adjacent North River basin. (Also see fig. 30.) The maximum discharge of this stream—1,340 mgd (2,100 cfs)—occurred August 2, 1944.

No data are available concering either the chemical character or the temperature of the water in this stream.

NORTH RIVER NEAR ANNAPOLIS

North River, a tributary of South River, drains an area similar in topography to the adjacent Bacon Ridge Branch. The surficial rocks are nearly the same, consisting of beds of sand and sandy clay of Cretaceous and Eocene age. The maximum elevation in the basin is about 180 feet. Locally, the topography is steep or rugged. North River has been gaged at Annapolis since December 1931 (station 22, pl. 1).

DISCHARGE

The flow for the 23-year period (1933–55) averaged 7.24 mgd (11.2 cfs). The minimum daily flow was 0.96 mgd (1.5 cfs) on September 4, 1932, and the lowest monthly flow was 1.6 mgd (2.55 cfs) in September 1932. Low-flow frequency curves are shown in figure 31 and

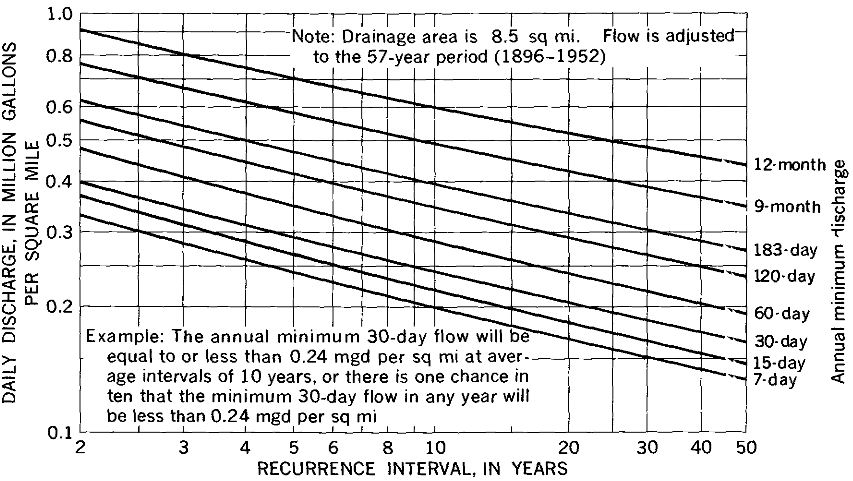

FIGURE 31.—Low-flow frequency curves for North River near Annapolis, Md.

curves of storage required to increase minimum flows are shown in figure 32. The maximum flow during the 23-year period of record was 3,232 mgd (5,000 cfs) on August 2, 1944. The maximum floodflow is more than 400 times greater than the average flow of the stream.

There are no withdrawal or recreational uses of water from the North River near Annapolis as far as is known.

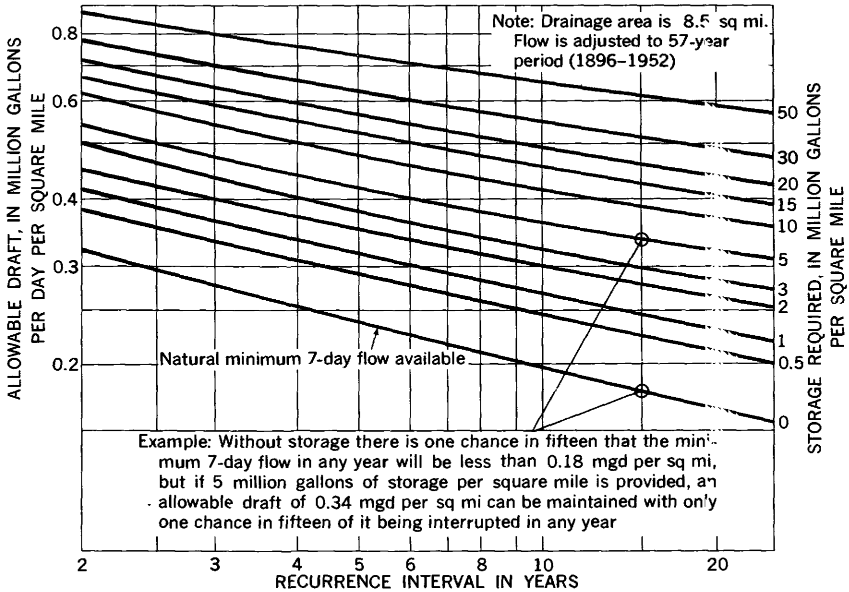

FIGURE 32.—Curves of storage required to sustain a given minimum 7-day flow with a specific recurrence interval for North River near Annapolis, Md.

CHEMICAL QUALITY OF WATER

Water of North River near Annapolis is very low in dissolved solids and hardness (table 10). Like a few other streams in the area having a low content of dissolved solids, the ratio of sulfate to bicarbonate increases with an increase in streamflow. This indicates that small streams in the Coastal Plain subarea may be slightly more acid at high flow than at low flow.

BALTIMORE HARBOR AS A SOURCE OF WATER

Baltimore Harbor is used extensively for navigation, industrial water supply (mainly for cooling), and recreation, as well as for domestic- and industrial-waste disposal. In recent years, the need for information on water quality in Baltimore Harbor became increasingly evident and led to a study, in 1947, by the Johns Hopkins University Department of Sanitary Engineering and Water Resources. The study was sponsored by the Chesapeake Biological Laboratory of the Maryland Department of Research and Education. Much of the water-quality observations given herein are based on the published results of this study (Garland, 1952).

Navigation is the principal use of Baltimore Harbor, which fortunately does not impose as severe or restrictive demands on the quality of the water as do some other uses. The harbor is also used as a disposal basin for millions of gallons of domestic and industrial wastes daily, a practice that has influenced industrial development of the area.

Garland (1952) classifies waste loadings into three broad groups: pollution contributed by tributary streams, domestic sewage, and industrial waste. The aggregate effect of waste loadings, both natural and artificial, contributed by tributary streams was evaluated from estimates of BOD (biochemical-oxygen demand) and main-stream discharge. BOD of tributary streams totaled about 8,000 pounds per day during the warm seasons covered by the study. (See table 11.)

TABLE 11.—*Distribution of known biochemical oxygen demand (BOD) loading to Baltimore Harbor, 1950*

[Based on data from Garland (1952)]

Source	5-day 20°C BOD (pounds per day)	Population equivalent [1]	Percent of total
Antecedent natural and artificial pollution from tributary streams	8,200	50,000	15
Raw and treated domestic sewage	16,700	100,000	30
Manufacturing wastes and industrial sanitary sewage	31,000	180,000	55
Total	55,900	330,000	100

[1] Population equivalent is useful to establish a common denominator for certain types of waste discharges. Studies have shown that in the United States the average daily per capita sewage discharge of 5-day 20°C BOD is about 0.17 pound. From this figure it is possible to convert quantities of BOD to equivalent population and vice versa.

At the time of Garland's study, Back River sewage-treatment plant served a population estimated to be 976,000. Effluent flow from this plant was about 130 mgd. Waste loadings from raw and treated domestic sewage equaled a BOD of nearly 17,000 pounds per day (table 11). Improvements effected as part of the long-range sewerage program are expected to reduce the BOD by about 9,000 pounds per day or about one-half the loading observed during the 1950 study. Increased sewage flow however, is expected to partly offset the improvement, so that the BOD will be about 14,000 pounds by 1970.

The BOD of Baltimore Harbor in general is low, normally less than 4.0 ppm. (See following table.) Appreciable oxygen deficiencies resulting from pollution occur principally in the innermost sections of the Harbor and during summer.

Summary of selected chemical characteristics of water, Baltimore Harbor, 1947–49

[Based on data from Garland (1952) for chloride-sampling points in Patapsco River (pl. 1)]

Constituent or characteristic	Range		
	Maximum	Median	Minimum
5-day, 20° C BOD [1] ppm	2.1 - 10.5	1.1- 3.5	1.0 - 2.5
Dissolved oxygen (DO) percent saturation	29 -190	3 -99	0 -87
Iron (Fe) ppm	.53–140	.29–11.18	.00– 1.40

[1] Summer BOD only.

The BOD loading from industries surveyed totals more than that from all other waste categories combined. Petroleum products, coke, gas and allied byproducts, and baker's yeast were principal sources of BOD.

Producers of pigment, iron and steel products, and fertilizers contribute daily large quantities of solids and several hundred tons of acids to the harbor estuary. Industrial-waste discharges to the harbor are predominantly acidic, either as acids or products of the hydrolysis and oxidation resulting from pigment and metal-pickling operations as for example, waste iron sulfate ($FeSO_4 \cdot 7H_2O$). Alkaline industrial wastes are few. Thus reaction with natural stream alkalinity affords the only significant neutralization of acidic waste.

CHLORIDE DISTRIBUTION IN WATER

Garland (1952) states, "An almost limitless variety of salinity distribution can develop within the Baltimore Harbor as a result of the complex interplay of forces due to tides, winds, and river runoff." Examination and evaluation of salinity data must consider that com-

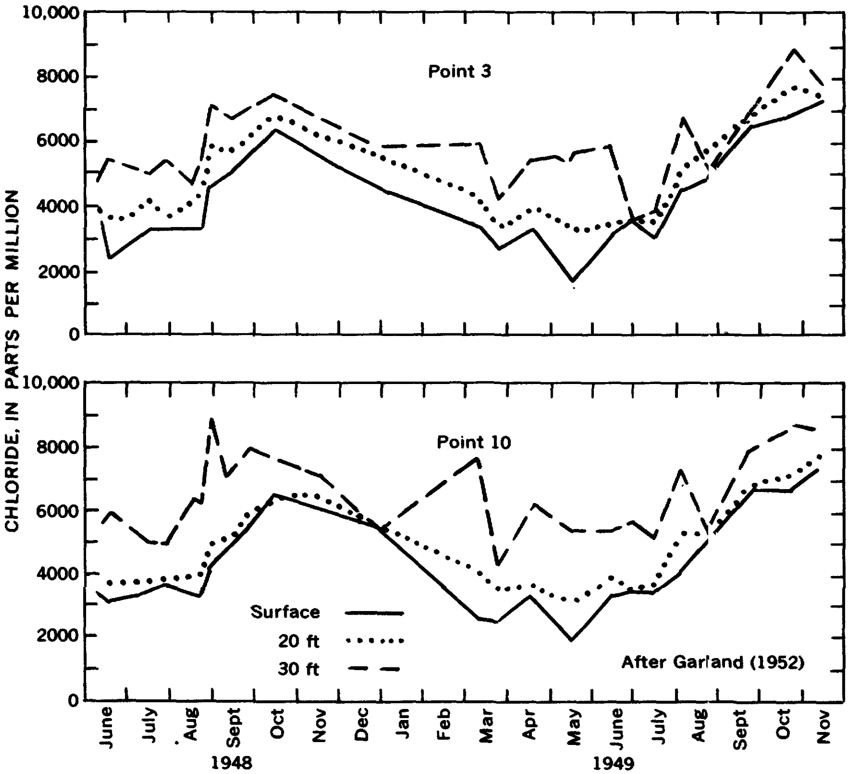

FIGURE 33.—Monthly chloride concentrations in main channel of Patapsco River, Baltimore Harbor, at sampling points 3 and 10 (pl. 1), June 1948 to November 1949.

prehensive data are lacking and that Chesapeake Bay is itself a much larger and more complicated estuary.

Chloride in the harbor water has a cyclic seasonal variation (fig. 33) which is attributed principally to a similar fluctuation of salinity in Chesapeake Bay (Beaven, 1946). The discharge of the Susquehanna River and the salinity of the harbor off Fort McHenry are related. Salinity of the upper bay is at a maximum during the fall, when runoff from the Susquehanna River is at a minimum, and is at a minimum during the spring, when runoff is at a maximum (table 12 and fig. 33).

There is practically no horizontal chloride gradient in the Patapsco estuary and the chloride content may be uniformly distributed across the estuary, but a vertical chloride gradient may exist at any one place. However, at any place there are periods when the chloride is uniformly distributed both horizontally and vertically. Stratification appears to develop during periods of calm (wind velocity, 0 to 3 mph), and mixing to the bottom of the estuary occurs in a matter of hours after winds of 10 to 15 mph. (See fig. 34.)

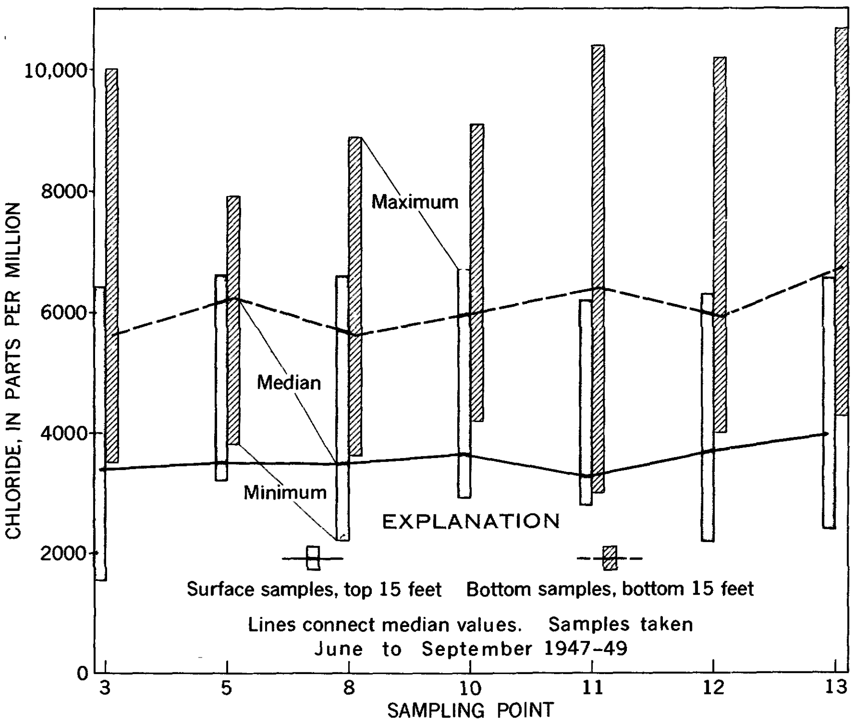

FIGURE 34.—Range and median chloride concentration in main channel, Baltimore Harbor, at selected sampling points (pl. 1). After Garland (1952).

TABLE 12.—*Observed chloride concentration, temperature, and pH in Baltimore Harbor during summers of 1947–49*

[Station: T, surface; B, bottom; number corresponds to location of station shown on pl. 1. Observations made June to September after Garland (1952)]

Station	Maximum	Median	Minimum
Observed chloride concentration, parts per million			
1–T	6,600	3,800	2,300
B	6,800	4,000	3,300
2–T	6,500	2,800	900
B	6,700	3,600	1,800
3–T	6,400	3,400	1,500
B	10,000	5,600	3,500
4–T	6,500	3,300	2,500
B	6,600	3,800	3,100
5–T	6,600	3,500	3,200
B	7,900	6,200	3,800
6–T	5,900	3,400	2,900
B	7,400	4,800	3,000
7–T	6,300	3,400	3,000
B	11,800	5,600	3,700
8–T	6,600	3,500	2,200
B	8,900	5,600	3,600
9–T	8,500	3,200	2,400
B	6,600	3,400	3,100
10–T	6,700	3,600	2,900
B	9,100	6,000	4,200
11–T	6,200	3,300	2,800
B	10,400	6,400	3,000
12–T	6,300	3,700	2,200
B	10,200	5,900	4,000
13–T	6,600	4,000	2,400
B	10,700	6,700	4,300
Observed temperature, °F			
1–T	84	77	68
B	82	77	68
2–T	86	79	66
B	82	75	68
3–T	86	79	70
B	82	77	64
4–T	86	77	68
B	82	77	68
5–T	84	77	68
B	92	75	68
6–T	84	77	68
B	82	75	68
7–T	82	77	70
B	81	77	63
8–T	84	77	68
B	82	75	63
9–T	84	79	68
B	84	79	72
10–T	84	77	68
B	82	75	66
11–T	81	75	66
B	81	75	61
12–T	82	77	66
B	81	75	63
13–T	82	75	66
B	81	75	63

TABLE 12.—*Observed chloride concentration, temperature, and pH in Baltimore Harbor during summers of 1947–49*—Continued

[Station: T, surface; B, bottom; number corresponds to location of station shown on pl 1. Observations made June to September after Garland (1952)]

Station	Maximum	Median	Minimum
Observed pH			
1–T	7.4	6.9	6.8
B	7.2	6.8	6.7
2–T	7.5	6.8	6.7
B	7.7	6.8	6.6
3–T	7.6	6.8	6.6
B	7.7	6.8	6.4
4–T	7.1	5.7	3.1
B	7.8	5.8	2.5
5–T	7.5	7.0	6.6
B	7.0	6.7	6.3
6–T	6.3	3.8	3.4
B	7.2	5.0	3.1
7–T	6.6	3.9	3.5
B	7.0	5.4	2.8
8–T	7.6	6.7	5.3
B	7.7	6.7	3.6
9–T	7.2	5.8	3.9
B	7.6	6.8	4.8
10–T	8.0	7.3	6.6
B	7.7	7.0	6.4
11–T	8.0	7.8	7.1
B	7.8	7.4	6.5
12–T	8.1	7.7	7.1
B	7.9	7.3	6.6
13–T	8.5	7.7	7.0
B	8.3	7.4	6.6

WATER TEMPERATURE

Water temperature in Baltimore Harbor closely parallels local air temperature. Garland (1952) reports that the inner harbor water is commonly 2° to 4° F warmer than that in the outer harbor, probably because of less mixing with the cooler bay water and industrial use of the inner harbor water. During spring and summer, the temperature of water in the bottom of the main channel does not rise as quickly as that of water near the surface. In the main channel, differences of as much as 12° F, between surface and bottom temperatures were measured. Ordinarily, however, the differences were less than 5° F.

The median summer (June to September) surface and bottom temperature of water for the period 1947–49 ranged from about 75 to 79° F for all stations. (See table 12.) However, maximum of 86° F were observed in the inner harbor. The harbor freezes over about once every 10 years.

pH, ALKALINITY, AND ACIDITY OF WATER

Water in the harbor normally is alkaline on the pH scale, averaging about 50 ppm alkalinity as $CaCO_3$ (Garland, 1952). The harbor survey showed that variation in pH of the water occurs principally in the highly industrialized Curtis Bay-Fairfield area, on Colgate Creek, and at Sparrows Point.

At the mouth of Colgate Creek, pH values less than 4.0 were observed nearly one-third of the time. Comprehensive sampling of Colgate Creek during the summer of 1948 showed that pH values for the entire stream were about 3.0. Values of pH in this range indicate high acidity, which would be toxic to most fish (California Water Pollution Control Board, 1952, p. 167).

About half of the water samples collected in Curtis Bay had a pH less than 5.0, and approximately half of these were less than 4.0, which is in the range of free mineral acid. Dilution by the alkaline water of the main channel was sufficient to neutralize acid loadings. In general, the pH of the main estuary water remained near the neutral point and ranged from about 6.3 to 8.5. (See table 12 and the following table.)

Trend in pH of surface water, Baltimore Harbor [1]

12-month period August to July	Percent of time pH was equal to or less than—stated value			
	7.0	6.0	5.0	4.0
1940–41	95	54	4	0
1943–44	96	82	50	13
1945–46	97	88	58	19
1949–50	98	89	62	21

[1] Curtis Bay at Pennington Avenue Bridge; from daily records of E. I. du Pont de Nemours and Co.

OTHER CHEMICAL CHARACTERISTICS OF WATER

Garland (1952) states that harbor water normally contains about 2 ppm of iron except in the vicinity of Curtis Bay, Colgate Creek, and Bear Creek, where the iron concentration is normally about 10 ppm but sometimes exceeds 100 ppm owing to concentrations of iron-bearing (ferrous sulfate) waste. The chemistry of iron as a pollutant in harbor water is as follows: Ferrous sulfate in waste discharges to the harbor is hydrolyzed to hydrous ferric oxides and sulfuric acid; also, the ferrous ions are oxidized by dissolved oxygen in the water to the trivalent state, principally as the sparingly soluble ferric hydroxide. When the ferric hydroxide floc reaches the organic sediments accumulating on the river bottom, it is placed in a reducing environment in which the ferric ion is reduced to the more soluble ferrous form. Later, the ferrous iron in solution is exposed to air in the upper layers of water, once again oxidized by dissolved oxygen to the insoluble trivalent form, and the cycle is repeated.

Garland concludes that pollution has been intensified during the past two decades. Although deterioration of water quality is more evident in periphery water than in the main channel, the downward trend in quality is general. Increasing industrial production in the area will largely determine trends in quality, as harbor pollution by domestic sewage is being reduced by increasing treatment capacity.

FLUSHING OF THE ESTUARY

The flushing of Baltimore Harbor is extremely complex. Three principal flushing forces are the Patapsco River, tides, and wind. Flushing time at Baltimore Harbor during summer is slightly more than 100 days, not including important local wind effects. Less time is required in summer than in winter because of seasonal distribution of winds.

SALINE-WATER USE

In December 1955, a study of 19 of the larger industrial plants in Baltimore Harbor was made to determine how much saline water was being pumped from the Patapsco River. The following data summarizes the results obtained:

Locality	*Average pumpage of saline water*
Northwest Branch:	
North side	3.7
East side	126.2
South side	20.0
Lower Patapsco River:	
North side	5.9
East side	838.5
West side	<.1
Curtis Bay:	
West side	36.5
East side	7.9
Middle Branch:	
North side	76.8
West side	241.5
Total	1,357.7

The foregoing total possibly is too low by at least 10 percent owing to incomplete coverage, although it includes some estimates. Thus the average pumpage in 1955 was probably about 1,500 mgd. This is about 7½ times as much water as was used for the 1956 total daily municipal water supply for the city of Baltimore (200 mgd) and shows the importance of the estuary as a source of industrial water.

The water has many uses, principally for cooling in condensers, air compressors, and as standby fire protection. About 47 percent of the pumpage is used by public-utility industries.

SALT-WATER ENCROACHMENT

The general relation between fresh and salt water in shallow aquifers near the estuaries in the Baltimore area is shown in figure 35.

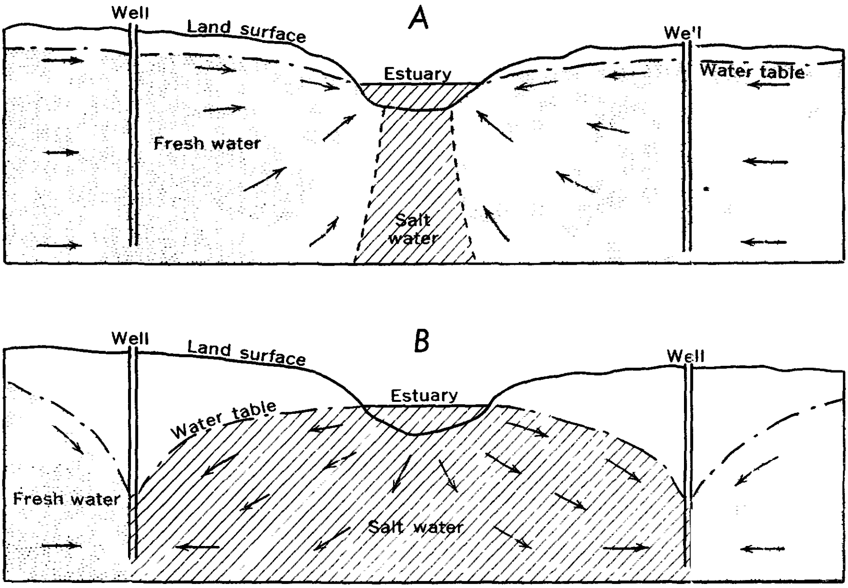

FIGURE 35.—Idealized sections showing movement of water in shallow aquifers. (*A*) Movement of fresh water prior to heavy pumping in industrial areas. (*B*) Movement of salt-water from Patapsco estuary induced by heavy pumping. After Bennett (1952).

Owing to confining clay beds, the position of the contact between salt water and fresh water probably is somewhat different than shown.

The major artesian aquifers in the Baltimore area dip southeastward toward the Atlantic Ocean. The position of the downdip salt-water front in the Patapsco and Patuxent formations has not been determined. In 1945, the salt-water front in the Patuxent formation may have been 10 to 20 miles southeast of the outcrop area. At that time the updip encroachment of salt water in the Patuxent formation probably did not constitute an immediate danger. Reduced pumping from this formation in the Baltimore area in recent years should retard salt-water encroachment.

Samples from a deep well in the Patuxent formation at the Bethlehem Steel Co. Sparrows Point plant indicate no significant increase in chloride in nearly 8 years of observations (1947–55). The chloride determinations of samples from this and other index wells in the Baltimore area are given in table 13.

The approximate areal extent of the salt-water encroachment in the Patuxent formation in 1945 was shown by Bennett and Meyer (1952, pls. 15 and 16). Contamination (assumed to be indicated by chloride concentrations greater than 15 ppm) occurred in practically all the Harbor district, a large part of the Canton district, the southern part of the Highlandtown district, and a part of the Fairfield district to

TABLE 13.—*Chloride concentration in periodic samples of water from four index wells*

Well at Sparrows Point

[Owner, Bethlehem Steel Co.; depth, 456 ft; aquifer, Patuxent formation]

Date	*Chloride (ppm)*
1947	
Feb. 12	9
1949	
Sept. 21	16
Dec. 30	14
1950	
Feb. 2	11
Feb. 27	14
Apr. 5	6
Dec. 7	12
Dec. 28	8
1951	
Feb. 6	12
Apr. 4	12
1951—Con.	
May 21	12
Aug. 16	16
Sept. 20	12
1952	
Jan. 3	14
Feb. 14	11
June 2	12
Aug. 27	9
Oct. 6	12
Nov. 24	12
1953	
Jan. 27	7
Mar. 30	11
June 12	11
July 29	12
1953—Con.	
Sept. 1	12
Oct. 9	10
Dec. 23	8
1954	
Feb. 4	10
Mar. 19	9.5
June 2	10
Sept. 8	13
Dec. 28	14
1955	
Feb. 14	13
July 18	12
Oct. 19	13
Nov. 25	13

Well at Sparrows Point

[Owner, Bethlehem Steel Co.; depth, 300 ft; aquifer, Patapsco formation]

Date	*Chloride (ppm)*
1944	
Sept. 7	80
Oct. 6	76
1946	
June	115
1949	
Mar. 11	125
May 18	112
Oct. 28	136
1950	
Feb. 2	131
May 25	148
Oct. 31	158
1951	
Feb. 6	162
May 21	178
Nov. 5	162
1952	
Nov. 24	50
Dec. 30	106
1953	
Jan. 26	42
Mar. 30	128
June 12	98
July 29	104
Dec. 23	108
1954	
Feb. 4	108
June 2	110
Sept. 8	96
Dec. 28	99
1955	
Apr. 27	120
July 18	118
Oct. 19	122
Nov. 25	127

Well in Curtis Bay area

Owner, E. I. du Pont de Nemours and Co.; depth, 245 ft, aquifer, Patuxent formation]

Date	*Chloride (ppm)*
1945	
July 27	4
Nov. 2	4
1949	
Sept. 21	6
1952	
Oct. 6	46
1953	
June 18	56
Sept. 1	52
1954	
Apr. 7	60
Sept. 8	55
Dec. 28	50
1955	
Feb. 26	48
Apr. 26	50
Sept. 28	46
Nov. 25	39

Well in east Baltimore

[Owner, American Radiator and Standard Sanitary Corp.; depth, 176 ft; aquifer, Patuxent formation]

Date	*Chloride (ppm)*
1943	
May 15	36
1949	
Mar. 14	44
Apr. 12	44
Aug. 30	70
Nov. 28	45
1950	
Feb. 2	51
Feb. 27	54
Apr. 5	52
Apr. 28	58
May 24	52
June 26	50
July 26	48
1950—Con.	
Sept. 29	58
Oct. 3	38
Dec. 7	50
1951	
Feb. 6	52
Apr. 4	50
May 21	50
Sept. 20	60
Nov. 5	50
1952	
Jan. 3	42
Feb. 14	43
Apr. 1	48
May 1	32
1952—Con.	
June 4	52
July 17	74
Aug. 27	48
Oct. 6	54
Nov. 24	54
Dec. 30	50
1953	
Mar. 30	50
June 12	62
July 29	54
Sept. 1	64
Nov. 9	54
Dec. 23	46

the south. (See fig. 27.) Some areas, particularly the Curtis Bay district, were not included in general areas of contamination because the problem is localized and probably is caused by leakage through well casings from the Patapsco formation or Pleistocene deposits. In the contaminated areas, a chloride content of more than 5,300 ppm has been reported (Bennett and Meyer, 1952, p. 131); this is about the chloride content of water from the Chesapeake Bay. Some wells in the Sparrows Point area have yielded water containing as much as 1,000 ppm of chloride.

In the Curtis Bay district, analysis of water from an E. I. du Pont de Nemours and Co. well in the Patuxent formation shows that the chloride content increased appreciably between 1949 and 1952, but remained fairly constant from 1952–56. (See table 13 and pl. 1.) In the absence of additional supporting data, it cannot be concluded that salt water in the Patuxent formation has spread in the Curtis Bay district since 1952. Low chloride content in water from a 115-foot well at the Westport stadium indicates that salt water has not spread that far northwestward.

Resampling of wells in the Patuxent formation in the lower Harbor and Canton districts shows that salt-water encroachment is continuing, in places, the chloride content of water is in excess of 1,600 ppm. Scattered data for eastern Highlandtown and lower Dundalk districts indicate no current problem there of salt-water encroachment in the Patuxent formation.

The Patapsco formation was contaminated by salt water chiefly between 1920 to 1940, when many large ground-water supplies were developed near the Patapsco River estuary (Bennett and Meyer, 1952).

Plate 1 shows also the extent of chloride contamination in the water-bearing material overlying the Arundel clay, chiefly the Patapsco formation. The contaminated area includes large parts of the Canton, Dundalk, Fairfield, and Curtis Bay districts and practically all the Sparrows Point district. The chloride content of water in the Patapsco formation at Sparrows Point has changed little since 1944 (table 13). The chloride content in 1952 and 1953 was not static but varied by a factor of three or more during a comparatively short period. Insufficient data have been collected for the Patapsco formation since 1945 to indicate precise changes in the area of chloride contamination from the Patapsco estuary. Analyses of several samples collected in the summer of 1955 from deep wells tapping the Patapsco formation in the Bear Creek area south of Inverness indicate little or no encroachment in that area.

PUBLIC WATER-SUPPLY SYSTEMS

The public water-supply system of the city of Baltimore is the major system in the area. Several small cities are served by public systems also. (See following table.)

Summary of information on public water supplies in the Baltimore area, Maryland

Community	Supplier	Population		Source	Treatment
		Number supplied	Year		
Baltimore	Metropolitan District, Baltimore County.	1,261,000	1954	Gunpowder River and North Branch Patapsco River.	Sedimentation, prechlorination, coagulation with alum, rapid sand filtration, adjustment of pH with lime.
Annapolis	Dreams Landing, Eastport, Forest Hills.	28,300	1950	Broad Creek and four wells, 242–270 ft. deep.	Lime, aeration, coagulation with alum, sedimentation, chlorination, and adjustment of pH.
Bel Air	Bel Air Community.			Bynum Run and Winters Run.	Prechlorination, coagulation, sedimentation filtration, postchlorination, and fluoridation.
Laurel	Washington Suburban Sanitary Commission.	(2)		Patuxent River and Northwest Branch Anacostia River.	Prechlorination, coagulation with alum, sedimentation, rapid sand filtration, postchlorination, fluoridation, and adjustment of pH.

Community	Treatment plant		Reservoir		Finished-water storage (million gallons)	Average daily consumption (mgd)	Remarks
	Name	Rated capacity (mgd)	Name	Storage (million gallons)			
Baltimore	Montebello	240	Loch Raven	23,470	773.5	[1] 199.3	Maximum daily consumption, 237.2 million gallons, July 14, 1954.
	Ashburton	120	Pretty Boy	19,751			
			Liberty	43,000			
		360		86,221			
Annapolis		5.0		80	2.25		Four wells have combined capacity of 3,500 gpm.
Bel Air	Bynum Run	.288					
	Winters Run	1.0					
		1.288					
Laurel	Patuxent	31.7	Triadelphia	6,118	[3] 45.295		
	Robt. B. Morse.	10.0	Rocky Gorge	6,000			

[1] Average daily consumption for 1954.
[2] Sanitary Commission supplied about 4,480 persons in Laurel in 1950 and a total of 385,000 persons in the entire system.
[3] Total finished water storage for Washington Suburban Sanitary Commission.

Before expansion in 1954, the raw-water supply for the city of Baltimore and its suburbs consisted of Loch Raven and Pretty Boy Reservoirs on the Gunpowder Falls, with a storage capacity of 43,266 million gallons. The system also included a large filtration plant treating 240 mgd. The Gunpowder Falls development for which ground was broken on December 3, 1875, consisted of Loch Raven Reservoir on the Gunpowder Falls at Raven's Rock and a tunnel for delivering water to two distributing reservoirs, namely Lake Montebello (484 million gallons) and Lake Clifton (256 million gallons). Water from Gunpowder Falls was introduced into the city of Baltimore through the new works on September 28, 1881. Most of the features of the original development are still in existence and are held in reserve.

The new Loch Raven Dam was started in 1912, but, owing to complications in acquiring certain property subject to inundation, the crest elevation was held to 188 feet. Tilting boards were added later to increase the effective elevation to 192 feet. The dam was completed in 1914. In 1915 a rapid-sand type filtration plant was completed, which has a capacity of 128 mgd, and in 1928 a second filtration plant was completed at Montebello, which has a capacity of 112 mgd.

Prettyboy Dam was started in 1929 and was completed in 1933. It provided about 19,400 million gallons of additional storage on the Gunpowder Falls. Provision was made to release water downstream into the Loch Raven Reservoir through hydraulically controlled valves. The new Gunpowder Falls-Montebello Tunnel was placed in service on December 23, 1940. Since that time, water has been delivered to the filtration plants at Montebello by gravity.

The average daily consumption of water from the Baltimore city supply was 137 mgd by 1941, whereas the dependable yield of the Gunpowder was about 148 mgd.

In 1942, consulting engineers (Requardt and Wolman, 1942) proposed that preliminary work toward the building of a second permanent additional supply begin immediately to meet deficiencies anticipated in the 1940's. They reported the most favorable permanent supply could be developed on the Patapsco River by the erection of "a dam (Liberty) at Falls Run Dam Site No. 4 and a tunnel to the Montebello Filters."

The required 10- and 7-foot tunnels from the Patapsco River at Liberty dam site to the Montebello filtration plants were completed in May 1951. During 1954, the construction of Liberty Dam on the North Branch of the Patapsco River was completed, and impoundment of water to supplement the Gunpowder Falls began. At an elevation of 420 feet, the reservoir impounds 43,000 million gallons of water which will provide an additional safe yield of 95 mgd. Owing to the fact that the crest of the dam is 160 feet above that of the Loch Raven impounding reservoir, it is possible to serve some of the higher zones in the city of Baltimore by gravity. In addition, it nearly doubles the Montebello Filters.

In addition to the dam, reservoir, and tunnels recommended by the engineering consultants in 1942, a modern filtration plant that can treat as much as 120 mgd has been built near the intersection of Liberty Heights Avenue and Druid Park Drive. The clear-water reservoir for this plant is Lake Ashburton, a storage reservoir used in the supply of the middle service area since 1908. As the elevation of this lake is 353 feet, the need is eliminated for raising from the low service area all the water used in the service areas above an elevation of 100 feet. In the years since 1945, growth in the suburbs exceeded estimates of the advisory engineers and, by 1952, it was apparent that the early construction of Ashburton filtration plant would be advisable. Construction began in 1953 and was completed in the spring of 1956.

By 1953 the population of Baltimore was growing so fast that a third water source to supplement supplies from the Gunpowder Falls and Patapsco Rivers was needed. The City of Baltimore is required by statute to furnish water to the Baltimore County Metropolitan District and in addition, by mutual agreement, to small parts of northern Howard and Anne Arundel Counties. Reasoning that it would be more economical for growing adjacent areas to obtain their water from the city of Baltimore, the city planners projected the water needs to a 709 square-mile service area, of which the city of Baltimore occupies 79 square miles (fig. 36).

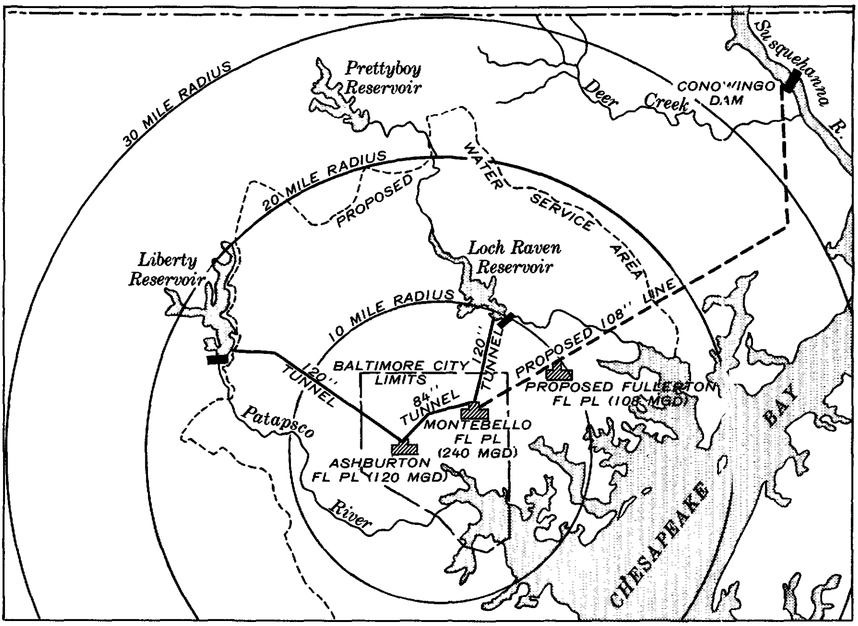

FIGURE 36.—Present and proposed sources of water supply and distribution, city of Baltimore. (Adapted from Requardt, Shaw, and Wolman, 1953.)

WATER SUPPLY FROM SEWAGE EFFLUENT

The Baltimore sewerage system is one of the most modern in the United States and usually is known as a separate system. That is, it transports domestic, industrial, and manufacturing wastes.

The Back River Sewage Treatments Works, where more than 95 percent of the sewage from the city is treated, is on the west shore of Back River south of Eastern Avenue. The sewage from a part of Baltimore County adjacent to the city is treated at this plant, also. The average sewage flow to the plant is approximately 130 mgd. Its maximum capacity is 291 mgd. The Patapsco Sewage Works is just north of Wagners Point on the west side of the Patapsco River. It receives sewage from the part of the city south of the Patapsco River, from a part of Anne Arundel County immediately adjacent to the city, and from the Catonsville area in Baltimore County to the west. Only about 5 percent of the city's sewage is treated at this plant.

The sewage at the Back River plant is treated for removal of solids and is filtered. It is also chlorinated during the summer. During 1960 about 52 mgd was discharged into the Back River, and about 101 mgd was sold to the Bethlehem Steel Co. for use as process cooling water and for other purposes.

POTENTIAL SUPPLY OF FRESH WATER

The potential available fresh-water supply for the Baltimore area is about 1,250 mgd. Of course, water is a reusable resource. Some of the 1,250 mgd is removed by wells near a stream or by direct pumping from the stream and may be used and returned as sewage effluent and be included in the flow past a downstream gaging station. For example, industries along the Patapsco River below Liberty Dam use and reuse the river water. Only the fresh water that is discharged directly into the bay or its estuaries or that lost by evapotranspiration is completely lost as a resource.

Figure 37 shows graphically the comparison of present use (1955–56) and potential fresh-water resources (exclusive of the Susquehanna River) in the Baltimore area. A proposed diversion for 220 mgd from the Susquehanna River is now under construction. In addition to the fresh water use, 1,500 mgd of saline water is used by industries in the area. The saline-water resource is nearly unlimited in quantity, but its use might be seriously curtailed if the bay water were to deteriorate markedly in chemical or physical quality.

PIEDMONT SUBAREA

The availability of ground-water supplies in the Piedmont subarea is inherently limited by the character of the reservoir rocks. The storage capacity of the rocks is governed largely by weathering and to a lesser degree by jointing and fracturing. Below depths of about 200 to 300 feet, the crystalline rocks become less water bearing, and the chances of obtaining even small supplies of ground water are reduced greatly.

Although a few wells yielding more than 100 gpm have been drilled

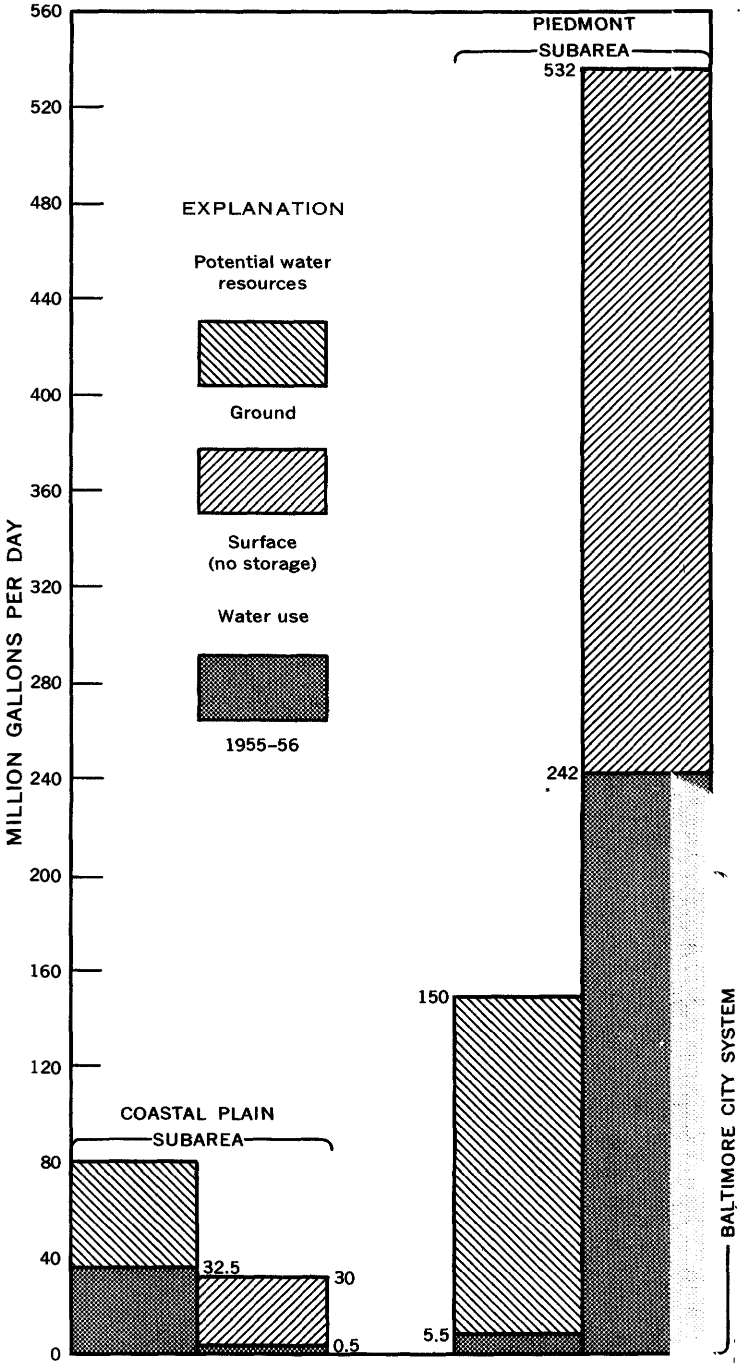

FIGURE 37.—Present use and the fresh-water supply in the Baltimore area, Maryland (exclusive of the Susquehanna River).

in the Piedmont subarea, such wells are exceptional; the average yield of 820 wells penetrating crystalline rock is only 12 gpm. To obtain a water supply of 1 mgd would require a well field of 60 such wells, assuming that these wells could deliver a sustained yield of 12 gpm, or about 17,000 gpd per well. During prolonged drought, when ground-water recharge is at a minimum, the yield of many of the crystalline-rock wells declines substantially, except where nearby streams or other water bodies provide recharge to the underlying rock aquifers.

A wide range in the behavior of individual wells may be expected, dependent largely on the local geologic and hydrologic conditions.

Only an indirect estimate can be made concerning the potential ground-water supplies in the Piedmont subarea. Dingman and Ferguson (1956, p. 52) estimated the average ground-water runoff, or the effective ground-water recharge, in Baltimore and Harford Counties to be about 500,000 gpd per sq mi. (See "Definition of terms used," p. F100.) Thus, for the approximately 900 square miles included in the Piedmont subarea of this report, the ultimate ground-water development is theoretically about 450 mgd. Of course to obtain this quantity of ground water would be impractical, because of the large number of wells required. The ultimate development of ground-water supplies thus is restricted largely by economic factors and may be expected to be far less than the theoretical maximum, probably about one-third, or 150 mgd.

Construction of storage reservoirs on a stream increases the dependable flow of the stream; however, it is usually not practical to build reservoirs large enough to make the entire flow dependable. Loch Raven Dam, Liberty Dam, and Rocky Gorge Dam create sufficient storage capacity so that the dependable flow is equal to the flow that would be available 63, 43, and 64 percent of the time if no storage were provided. Hence it may be assumed that it would be practicable to build sufficient storage capacity on other streams to make the dependable flow (with storage) equal to the natural flow available 60 or more percent of the time as shown by the flow duration curve.

A total flow of 244 mgd may be obtained 60 percent of the time from seven minor Piedmont streams. (See table 14.) This flow is the approximate limit of the dependable flow that can be developed from those streams in the Piedmont subarea that are not affected by regulations. The assumption also must be made that ground water will remain in its present state of development so as not to change surface-water base flow.

Winters Run and Broad Creek in Harford County are not included in table 14. Winters Run has been largely pre-empted as a source of water for the town of Bel Air and for the U.S. Army Chemical Cen-

TABLE 14.—*Summary of available flow in Piedmont streams unaffected by major storage reservoirs*

Piedmont stream	Drainage area sq mi	Flow (mgd) equaled or exceeded the indicated percentage of time [1]		
		50	60	90
Deer Creek	170.7	112	97	57
Bynum Run [2]	23.8	15	13	8
Little Gunpowder Falls	58.3	37	31	18
Piney Run	18.2	9	8	4
South Branch Patapsco River	85.7	40	33	14
Little Patuxent River	161.4	72	58	27
Dorsey Run	11.6	5	4	2
Total	529.7	290	244	130

[1] Based on flow records from nearest gaging station adjusted to the 57-year base period 1896–1952.
[2] Flow based on average rate of discharge of Deer Creek and Little Gunpowder Falls.

ter. Broad Creek, which drains an area of 41.4 square miles, is the source of water for a reservoir near its mouth. This reservoir is used chiefly for recreation.

The city planners concluded after studies in 1921, 1934, and 1942, that when closer and cheaper water sources were fully utilized, Baltimore would turn to the Susquehanna River for further water development. Water from the Susquehanna River is of excellent quality and is plentiful. Unlike the other two sources that feed by gravity, however, the water must be pumped to Baltimore.

The pumps at the Susquehanna would receive water stored by Conowingo Dam which has an 89-ft head utilized by the Conowingo Power Co. Flows in the river exceed 6,400 cfs for 90 percent of the time and are greater than 2,000 cfs for 99.9 percent. Even at the year 2000, water diversions will interfere with power production at Conowingo only intermittently and to a very slight extent.

The additional supply of fresh surface water that can be obtained for the Piedmont subarea, without use of the water from the Susquehanna River, is 290 mgd. The supply that is available from streams is as follows:

Drainage basin	*Safe yield (mgd)*	*Use (mgd)*
Gunpowder Falls	148	[1] 200
Patapsco River	95	-------
Patuxent River	45	[2] 42
Minor streams unaffected by storage reservoirs	244	-------
Total	532	-------

[1] Baltimore, 1956.
[2] Washington Suburban Sanitary Commission, 1957.

Proposed diversions from the Susquehanna River amount to as much as 220 mgd. Furthermore, widespread heavy withdrawals from wells might significantly reduce the streamflow.

Chemical analyses of the water from these streams are scarce, but the water has proven satisfactory for most uses. Treatment is required for the removal of suspended sediment, especially during spring runoff.

COASTAL PLAIN SUBAREA

The ultimate potential development of the ground-water resources in the approximately 400 square miles constituting the Coastal Plain subarea is difficult to evaluate accurately for many complex reasons. However, when examined from a broad perspective, the ultimate limit of the development of ground-water supplies in the Baltimore area is determined by precipitation and ground-water replenishment. The average annual rainfall of 43 inches is equivalent to about 2.1 mgd per sq mi. Recent studies by Meyer and Bennett (1955) and by others have shown that at Salisbury, Md., an area somewhat similar to the Baltimore area in geology and topography, the average annual ground-water discharge, or the effective ground-water recharge, over a 14-year period was about 0.6 mgd per sq mi. If 0.6 mgd of ground-water recharge is applied to the 400-square mile area in the Coastal Plain subarea, the ultimate ground-water potential for perennial withdrawal is about 240 mgd. This is nearly eight times the amount of ground water withdrawn for all uses in 1955. (See following table.)

Summary of ground-water use in the Coastal Plain subarea in 1955

Type of use	Mgd
Industrial and commercial	24. 5
Public supply	2. 6
Military installations	2. 4
Rural and domestic	3. 0
Total	32. 5

The amount of water recoverable from wells on a sustained basis probably is somewhat less than 240 mgd, probably about 80 mgd, because the governing factors in withdrawing water from aquifers is their permeability and the hydraulic gradients that can be created in them. These factors determine the rate at which water can move toward the pumped wells and, thus they limit the yield of the wells. Furthermore, recent information on drilling indicates that some of the water-bearing sand becomes thinner and less permeable near the outcrops. Therefore, the opportunity for recharge is less and the rates of transmission of water through them are reduced.

Although the quantity of ground water available in the area is enormous, several economic factors limit its development. Water quality and pumping costs are two such factors. For example, much of the ground water from the Patapsco, Raritan, and Magothy formations in northern Anne Arundel County and in places in Baltimore County is slightly acidic and very high in iron content (more than 30 ppm in places). This water is corrosive to pumps, well screens, and casings. Although the water can be improved by treatment, this increases its unit cost. Thus it might not be economical to use ground water of this quality, especially as water of better quality may be available from surface sources. On the other hand, ground water may be preferred if a uniform temperature is needed.

High pumping costs, brought about by the decline in pumping levels in heavily pumped well fields in the deeper parts of the aquifers, tend to cause a reduction in the use of ground water. Development of the surface-water resources in the Coastal Plain subarea is hampered by the small size of the drainage basins above tidewater. Only four streams in the subarea have drainage areas larger than 5 square miles. The total supplies of fresh surface water in the Costal Plain is estimated to be 30 mgd (see following table), assuming that storage will be provided.

Summary of available flow of Coastal Plain streams

Coastal Plain stream	Drainage area (sq mi)	Flow (mgd) equaled or exceeded the indicated percentage of time [1]		
		50	60	90
Sawmill Branch of Furnace Creek	5.1	4.3	4.0	3.2
North River near Annapolis	8.5	4.9	5.1	3.0
Bacon Ridge Branch near Chesterfield	6.9	5.8	4.3	2.7
Severn River above U.S. Highway 301 [2]	25	18.7	17.8	11.4
Total flow	45.5	33.7	31.2	20.3

[1] Based on flow records from nearest gaging station adjusted to the 57-year base period 1896–1952.
[2] Flow based on average flow duration per square mile for the three gaged Coastal Plain streams.

DEFINITION OF TERMS USED

Aquifer is a hydrologic unit composed of water-bearing earth materials in which water may collect in usable quantities; synonymous with **ground-water reservoir.**

Biochemical oxygen demand (BOD) is a measure of the amount of oxygen required to destroy organic wastes by bacterial action; thus it is a measure of the degree of pollution of stream water.

Climatic year, as used in this report for low-flow studies of surface water, is the 12-month period beginning April 1 and ending the following March 31. Designated as the year beginning April 1.

Coefficient of permeability (field) is a measure of the capacity of rocks to transmit water under head or pressure differentials; defined as the rate of flow of water, in gallons per day, through a cross section of the aquifer of 1 square foot under a unit hydraulic gradient (1 foot per foot) at the prevailing water temperature.

Coefficient of storage refers to the volume of water released or taken into storage in an aquifer per unit surface area per unit change in the component of head normal to that surface; it is a dimensionless value, as it expresses only magnitude and does not have a unit of measure.

Coefficient of transmissibility is the field coefficient of permeability multiplied by the saturated thickness of the aquifer.

Contamination is a general term referring to the introduction into water of microorganisms, chemicals, and other wastes, including sewage, which render water unfit for most uses without corrective treatment. The intrusion of saline water into fresh water also would be called contamination.

Cubic foot per second (cfs) is a rate of discharge equivalent to a stream whose channel is 1 square foot in cross section and whose average velocity is 1 foot per second.

Discharge is the rate of flow of water in a stream, usually expressed in cubic feet per second or million gallons per day (mgd). A stream flowing at the rate of 1 cfs discharges 646,317 gallons in 24 hours. The volume of flow is often expressed in cfs-days. One cfs-day is the volume of water represented by a flow of 1 cfs for 24 hours. A discharge of 1 mgd equals 1.5472 cfs.

Discharge per square mile as used in hydrologic studies, refers to an average number of units of water flowing per unit time from each square mile of area drained and is based on the assumption that runoff is distributed uniformly in time and area; expressed in cubic feet per second per square mile or in million gallons per day per square miles.

Dissolved oxygen refers to the weight of oxygen actually dissolved in a sample of water, expressed in parts per million.

Drainage area is the size of the drainage basin drained by a stream above a given location, expressed in square miles.

Effective ground-water recharge is used in this report as the maximum quantity of water that could be recovered from the aquifers without a permanent depletion of ground-water storage.

Equivalents per million (epm) refers to a unit chemical combining weight of a constituent in a million unit weights of water; it is calculated by dividing the concentration in parts per million by the chemical combining weight of the constituent.

Parts per million (ppm) is a unit weight of a constituent in a million unit weights of water. One part per million equals one ten-thousandth of 1 percent (0.0001 percent).

pH is a measure of the acidity or alkalinity of water. A pH of 7.0 is neutral, an acid solution has a pH less than 7.0, and a basic or alkaline solution has a pH more than 7.0.

Safe yield, as used for ground-water studies, is the rate at which water can be withdrawn from an aquifer without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible. The practicable rate of withdrawing water from an underground reservoir perennially for human use (Meinzer, 1923, p. 55). As used in this report, **safe yield** is defined as a technically derived practicable rate of perennial withdrawal for human use of the surface water as stored in a reservoir.

Specific capacity is the yield of a well per unit drawdown, usually expressed as gallons per minute per foot of drawdown; although the drawdown of a well varies with time of pumping, the definition does not include time as a factor. However, it implies a period of time sufficient to permit effective stabilization of the drawdown.

Storage ratio is the ratio, expressed in years, of usable capacity of a reservoir to the mean annual runoff; equivalent to the time, in years, required to impound a volume of water equal to the usable capacity of the reservoir, assuming an average rate of runoff.

Volume of storage refers to the reservoir content expressed in million gallons, or in million gallons per square mile of drainage basin.

Water year is the 12-month period beginning October 1 and ending the following September 30. Designated as the year ending September 30.

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