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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

MONTHLY SURFACE-WATER INFLOW TO CHESAPEAKE BAY

By

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Prepared in cooperation with the States of Maryland, Pennsylvania, and Virginia

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MONTHLY SURFACE-WATER INFLOW TO CHESAPEAKE BAY

Conrad D. Bue

PURPOSE AND SCOPE

This report presents a convenient and rapid means of estimating, on either a monthly or a yearly basis, the inflow from surface streams to Chesapeake Bay. The method was developed as a working base for the release entitled "Estimated stream discharge entering Chesapeake Bay" prepared by the U. S. Geological Survey in cooperation with the States of Maryland, Pennsylvania, and Virginia. This release, issued monthly beginning December 1967, is directed to the various groups who have need for such data in their studies of the environment and resources of the Bay. A copy of that release is included as an appendix to this report.

In addition to the methodology used in making estimates of inflow, the report presents considerable data on drainage basins and on streamflow patterns. The report thus serves as a reference for those receiving the monthly release on current conditions. No account is taken of ground-water inflow or of rainfall on and evaporation from the water surface of the Bay. The years referred to herein are calendar years unless water years are specified.

Current stream discharge into Chesapeake Bay, whether for monthly or longer periods, is estimated using current records at the most downstream gaging stations on the three principal rivers discharging into the Bay: Susquehanna River at Marietta, Pa.; Potomac River near Washington, D. C., adjusted for diversions in the Washington metropolitan area that return to the Potomac downstream from the gaging station; and James River near Richmond, Va., adjusted for diversion by the James River and Kanawha Canal, which returns to the James downstream from the Richmond gaging station. These estimates of inflow to the Bay are derived from graphical relations between the three gaging stations and the total discharge into the Bay as calculated for the 10-year period 1951-60 (water years).

Relation curves were prepared by plotting the discharge at these gaging stations by months and years for the period 1951-60 against the corresponding total discharge into the Bay (the Bay was divided into several segments). Figure 1, which shows the discharge of the Susquehanna River at Marietta plotted against the discharge into the Bay above cross-section B, is an example of the relation curves. Total discharge into the Bay had been calculated in a previous study by months and years for the 10 water years 1951-60 (referred to hereinafter as the basic computations) using all available streamflow records, and estimating the ungaged discharge on basis of streamflow records from nearby streams. A list of the gaging-station records used in the basic computations, and their drainage areas, is presented in table 1.

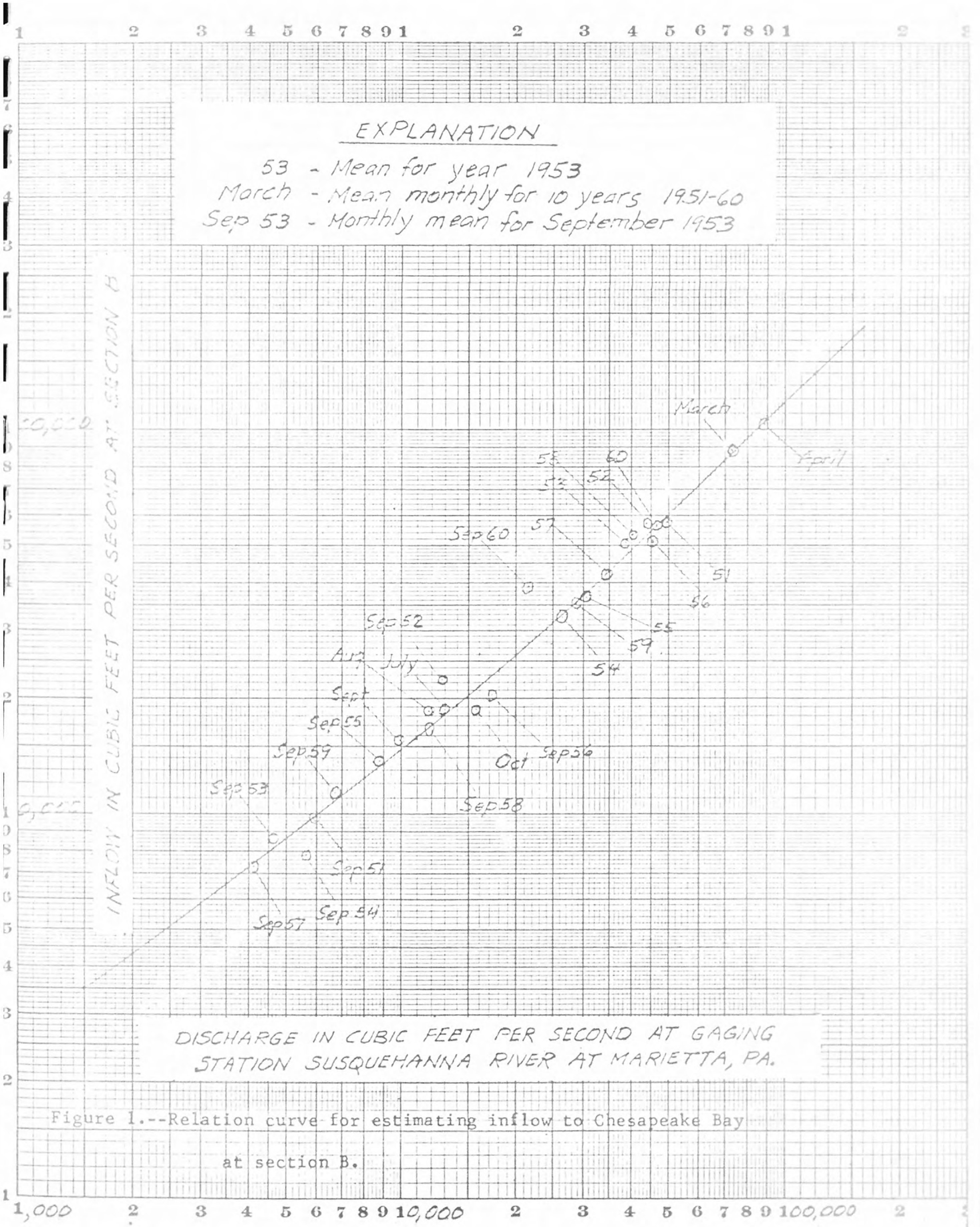


Figure 1.--Relation curve for estimating inflow to Chesapeake Bay at section B.

Table 1.--Streamflow records used in calculating flow into Chesapeake Bay for period 1951-60

	Gaging station	Dr. area (sq.mi.)
	Part 1-B	
4850.	Pocomoke River near Willards, Md.	60.5
4855.	Nassawango Creek near Snow Hill, Md.	44.9
4860.	Manokin Branch near Princess Anne, Md.	[a] 5.8
4865.	Beaverdam Creek near Salisbury, Md.	19.5
4870.	Nanticoke River near Bridgeville, Md.	75.4
4875.	Trap Pond Outlet near Laurel, Del.	16.7
4885.	Marshy Hope Creek near Adamsville, Del.	44.8
4890.	Faulkner Branch at Federalsburg, Md.	7.10
4895.	Rewastico Creek near Hebron, Md.	12.2
4900.	Chicamacomico River near Salem, Md.	15.0
4910.	Choptank River near Greensboro, Md.	113
4920.	Beaverdam Branch at Matthews, Md.	5.85
4930.	Unicorn Branch near Millington, Md.	22.3
4935.	Morgan Creek near Kennedyville, Md.	10.5
4950.	Big Elk Creek at Elk Mills, Md.	52.6
4955.	Little Elk Creek at Childs, Md.	26.8
4960.	Northeast Creek at Leslie, Md.	24.3
5760.	Susquehanna River at Marietta, Pa.	25,990
5765.	Conestoga Creek at Lancaster, Pa.	324

a Approximately.

Table 1.--Continued

Gaging station	Dr. area (sq.mi.)
Part 1-B	
5785. Octoraro Creek near Rising Sun, Md.----------------------	193
5800. Deer Creek at Rocks, Md.--------------------------------	94.4
5815. Bynum Run at Bel Air, Md.--------------------------------	8.52
5840. Gunpowder Falls near Carney, Md.------------------------	314
5845. Little Gunpowder Falls at Laurel Brook, Md.---------------	36.1
5890. Patapsco River at Hollofield, Md.------------------------	285
5900. North River near Annapolis, Md.-------------------------	a 8.5
5925. Patuxent River near Laurel, Md.-------------------------	132
5940. Little Patuxent River at Savage, Md.---------------------	94.4
5944. Dorsey Run near Jessup, Md.------------------------------	11.6
5945. Western Branch near Largo, Md.--------------------------	30.2
6465. Potomac River near Washington, D.C.----------------------	11,560
6470. Little Falls Branch near Bethesda, Md.--------------------	a 4.1
6480. Rock Creek at Sherrill Drive, Washington, D.C.------------	62.2
6495. Northeast Branch Anacostia River at Riverdale, Md.--------	72.8
6510. Northwest Branch Anacostia River nr Hyattsville, Md.------	49.4
6525. Fourmile Run at Alexandria, Va.--------------------------	14.4
6535. Henson Creek at Oxon Hill, Md.---------------------------	16.7
65[illegible]0. Accotink Creek near Accotink Station, Va.-----------------	37.0
6575. Occoquan Creek near Occoquan, Va.------------------------	570

a Approximately.

Table 1.--Continued

Gaging station		Dr. area (sq.mi.)
	Part 1-B	
6580.	Mattawoman Creek near Pomonkey, Md.----------------------	57.7
6585.	South Fork Quantico Creek nr Independent Hill, Va.-------	7.5
6610.	Chaptico Creek at Chaptico, Md.--------------------------	10.7
6615.	St. Marys River at Great Mills, Md.----------------------	24.0
6680.	Rappahannock River near Fredericksburg, Va.--------------	1,599
6685.	Cat Point Creek near Montross, Va.-----------------------	45
6695.	Dragon Run near Church View, Va.-------------------------	86
6700.	Beaverdam Swamp near Ark, Va.----------------------------	7.1
6730.	Pamunkey River near Hanover, Va.-------------------------	1,072
6735.	Totopotomoy Creek near Atlee, Va.------------------------	6.0
6745.	Mattaponi River near Beulahville, Va.--------------------	619
	Part 2-A	
375.	James River near Richmond, Va.---------------------------	6,757
385.	Falling Creek near Drewrys Bluff, Va.--------------------	54
415.	Appomattox River near Petersburg, Va.--------------------	1,335
425.	Chickahominy River near Providence Forge, Va.------------	249
	Total drainage area gaged----------------------	52,398.57

The drainage area of Chesapeake Bay is 65,476 square miles. The gaged area, i.e., the sum of the drainage areas of the gaging stations in table 1, is 52,399 square miles, or 80 percent of the drainage area of the Bay. The greater part of the highland area is gaged; the deficiency in streamflow records is largely in the Coastal Plain. For the purpose of appraising the distribution of gaged areas, the five largest gaging stations--those on the Susquehanna, Potomac, James, Rappahannock, and Appomattox Rivers, total drainage area 47,221 square miles--are considered as measuring flow from the highlands. The remaining gaging stations then--drainage area 5,152 square miles--measure flow from the Coastal Plain. The Coastal Plain is considered as occupying about one-fourth of the drainage area of the Bay, or about 16,370 square miles. Accordingly, about 96 percent of the highland area is gaged, but only about one-third of the Coastal Plain area is gaged.

ESTIMATION OF INFLOW TO CHESAPEAKE BAY

The inflow to Chesapeake Bay is estimated at five cross-sections in the Bay (fig. 2): A, mouth of the Susquehanna River; B, just above the mouth of the Potomac River; C, just below the mouth of the Potomac River; D, just above the mouth of the James River; and E, the mouth of Chesapeake Bay (a line between Cape Charles and Cape Henry).

Inflow at these sections is estimated from tables 2-6, which were derived from the relation curves discussed in the preceding section of this report. Inflow at cross-sections A and B is estimated by entering tables 2 and 3, respectively, with the discharge at the Marietta gaging station. The increment of inflow between cross-sections B and C is estimated by entering table 4 with the adjusted discharge at the Potomac River near Washington, D.C. gaging station. The increments of inflow between cross-sections C and D and cross-sections D and E are estimated by entering tables 5 and 6, respectively, with the adjusted discharge at the Richmond gaging station.

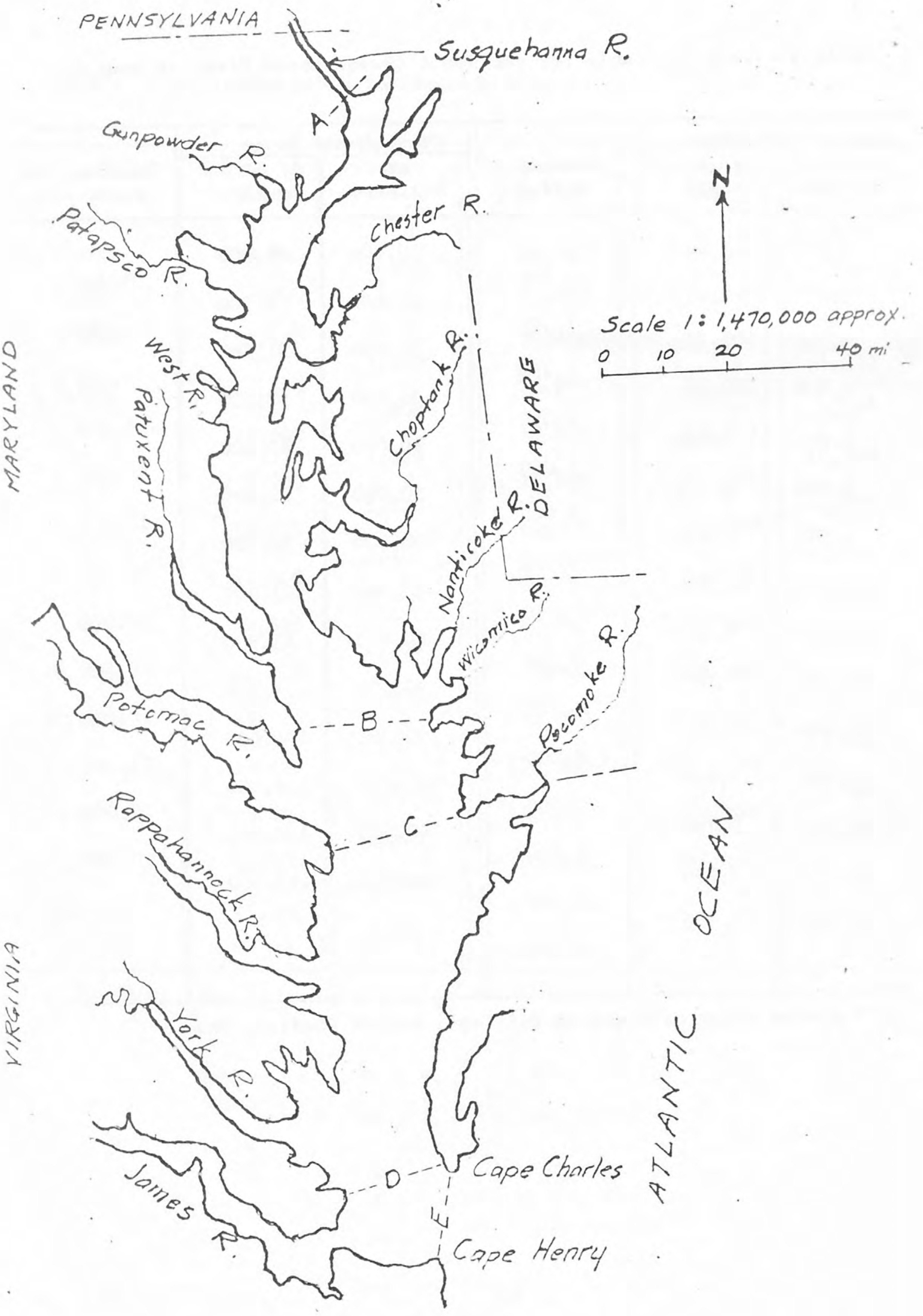


Figure 2.--Map of Chesapeake Bay showing sections at which inflow is estimated.

Table 2.--Relation table for section A (Susquehanna River at mouth)

Susquehanna River at Marietta	Susquehanna River 1/ at mouth	Tabular diff.	Susquehanna River at Marietta	Susquehanna River 1/ at mouth	Tabular diff.
1,500	1,900		20,000	21,400	
		550			5,100
2,000	2,450		25,000	26,500	
		1,100			5,000
3,000	3,550		30,000	31,500	
		1,100			5,500
4,000	4,650		35,000	37,000	
		1,050			5,500
5,000	5,700		40,000	42,500	
		1,050			10,000
6,000	6,750		50,000	52,500	
		1,050			10,000
7,000	7,800		60,000	62,500	
		1,050			10,500
8,000	8,850		70,000	73,000	
		1,050			10,500
9,000	9,900		80,000	83,500	
		1,100			10,500
10,000	11,000		90,000	94,000	
		1,100			10,000
11,000	12,100		100,000	104,000	
		1,000			21,000
12,000	13,100		120,000	125,000	
		2,000			20,000
14,000	15,100		140,000	145,000	
		2,100			20,000
16,000	17,200		160,000	165,000	
		2,100			
18,000	19,300				
		2,100			

1/ Includes water diverted to Baltimore and to Chester, Pa.

Table 3.--Relation table for section B

Susquehanna 1/River	Inflow to Bay	Tabular diff.	Susquehanna 1/River	Inflow to Bay	Tabular diff.
1,500	3,500		20,000	26,000	
		800			5,500
2,000	4,300		25,000	31,500	
		1,500			5,500
3,000	5,800		30,000	37,000	
		1,400			5,500
4,000	7,200		35,000	42,500	
		1,400			5,500
5,000	8,600		40,000	48,000	
		1,300			12,000
6,000	9,900		50,000	60,000	
		1,200			12,000
7,000	11,000		60,000	72,000	
		1,200			12,000
8,000	12,300		70,000	84,000	
		1,200			11,000
9,000	13,500		80,000	95,000	
		1,200			11,000
10,000	14,700		90,000	106,000	
		1,200			11,000
11,000	15,900		100,000	117,000	
		1,200			23,000
12,000	17,100		120,000	140,000	
		2,300			22,000
14,000	19,400		140,000	162,000	
		2,200			22,000
16,000	21,600		160,000	184,000	
		2,200			
18,000	23,800				
		2,200			

1/ At Marietta, Pa.

Table 4.--Relation table for increment B-C

Potomac 1/River	Inflow bet.secs. B and C	Tabular diff.	Potomac 1/River	Inflow bet.secs. B and C	Tabular diff.
			5,000	6,900	
					1,250
500	800		6,000	8,150	
		150			1,250
600	950		7,000	9,400	
		150			1,200
700	1,100		8,000	10,600	
		150			1,200
800	1,250		9,000	11,800	
		150			1,200
900	1,400		10,000	13,000	
		150			2,400
1,000	1,550		12,000	15,400	
		280			2,400
1,200	1,830		14,000	17,800	
		280			2,400
1,400	2,110		16,000	20,200	
		270			2,400
1,600	2,380		18,000	22,600	
		280			2,400
1,800	2,660		20,000	25,000	
		280			5,800
2,000	2,940		25,000	30,800	
		670			5,700
2,500	3,610		30,000	36,500	
		670			11,000
3,000	4,280		40,000	47,500	
		1,320			11,500
4,000	5,600		50,000	59,000	
		1,300			

1/ Near Washington, D.C., adjusted for diversions.

Table 5.--Relation table for increment C-D

James 1/River	Inflow bet.secs. C and D	Tabular diff.	James 1/River	Inflow bet.secs. C and D	Tabul diff
			5,000	4,500	
					950
			6,000	5,450	
					950
600	340		7,000	6,400	
		80			900
700	420		8,000	7,300	
		80			900
800	500		9,000	8,200	
		80			800
900	580		10,000	9,000	
		80			800
1,000	660		11,000	9,800	
		170			700
1,200	830		12,000	10,500	
		180			1,400
1,400	1,010		14,000	11,900	
		180			1,400
1,600	1,190		16,000	13,300	
		180			1,400
1,800	1,370		18,000	14,700	
		180			1,400
2,000	1,550		20,000	16,100	
		500			3,300
2,500	2,050		25,000	19,400	
		500			
3,000	2,550				
		950			
4,000	3,500				
		1,000			

1/ Near Richmond, Va., includes flow of James River & Kanawha Canal.

Table 6.--Relation table for increment D-E

James 1/River	Inflow bet.secs. D and E	Tabular diff.	James 1/River	Inflow bet.secs. D and E	Tabular diff.
			5,000	7,600	
					1,500
			6,000	9,100	
					1,400
600	800		7,000	10,500	
		150			1,400
700	950		8,000	11,900	
		150			1,400
800	1,100		9,000	13,300	
		150			1,400
900	1,250		10,000	14,700	
		160			1,400
1,000	1,410		11,000	16,100	
		310			1,400
1,200	1,720		12,000	17,500	
		310			2,500
1,400	2,030		14,000	20,000	
		320			2,500
1,600	2,350		16,000	22,500	
		310			2,500
1,800	2,660		18,000	25,000	
		320			2,500
2,000	2,980		20,000	27,500	
		770			6,500
2,500	3,750		25,000	34,000	
		800			
3,000	4,550				
		1,550			
4,000	6,100				
		1,500			

1/ Near Richmond, Va.; includes flow of James River & Kanawha Canal.

As already stated, the discharge at the mouth of the Susquehanna River (section A) is obtained from table 2. Discharges at the mouths of the Potomac and James Rivers are not needed to calculate the inflow to the Bay, but if desired they can be estimated from tables 4 and 6, as 98 percent of the inflow between sections B and C, and between sections D and E, respectively. Of the 14,897 sq mi of drainage basin that contribute to Chesapeake Bay between sections B and C, 14,670 sq mi (98.5 percent) are in the Potomac River basin; therefore about 98 percent of the total inflow between sections B and C may be considered an estimate of the flow of the Potomac River at its mouth. Similarly, 98 percent of the total inflow between sections D and E may be considered an estimate of the flow of the James River at its mouth.

Table 7.--Drainage areas at points indicated

Point	Square miles	
Susquehanna River at Marietta gaging station-------	25,990	
Susquehanna River at mouth, section A--------------		27,469
Increment between sections A and B------------	6,015	
Section B--		33,484
Potomac River at D.C. gaging station---------------	11,560	
Potomac River at mouth-----------------------------	14,670	
Increment between sections B and C 1/---------	14,897	
Section C--		48,381
Increment between sections C and D------------	6,843	
Section D--		55,224
James River at Richmond gaging station-------------	6,757	
James River at mouth-------------------------------	10,002	
Increment between sections D and E 2/	10,252	
Section E, mouth of Chesapeake Bay-----------------		65,476

1/ Includes 227 square miles on eastern shore of Bay opposite mouth of Potomac River.

2/ Includes 250 square miles south of James River basin that contributes to Chesapeake Bay.

PATTERN OF STREAMFLOW

The land drainage area of Chesapeake Bay is 65,480 square miles, of which 80 percent is gaged by stream-gaging stations on rivers and streams entering the Bay. The combined drainage area above the three reference gaging stations--Susquehanna River at Marietta, Potomac River near Washington, D.C., and James River near Richmond--constitutes 68 percent of the entire drainage area of the Bay exclusive of the water surface of the Bay. The combined drainage area of the three principal river basins at their mouth constitutes nearly 80 percent of the land drainage area of the Bay--the Susquehanna, 42 percent; the Potomac, 22.4 percent; and the James, 15.3 percent (fig.3). During the 10 water years 1951-60 the unit discharge of the Susquehanna River at mouth was 1.47 cubic feet per second (cfs) per square mile of drainage basin, the Potomac, 0.96, and the James, 1.00. The average discharge at the mouths of the eight largest river basins and their drainage areas are given in table 8.

Figure 3.--Chesapeake Bay drainage basin. Cross-hatched areas are basins of (S) Susquehanna, (P) Potomac, and (J) James Rivers. Stippled areas are basins of Rappahannock and York Rivers in Virginia and small basins rimming the Bay in Maryland and Virginia.

Table 8.--Average discharge into Chesapeake Bay, and average discharge of the principal tributaries at mouth, 1951-60 water years

Stream	Discharge		Drainage area	
	Cubic feet per second	Percent of total	Square miles	Percent of total
Chesapeake Bay	78,210	100	65,476	100
Susquehanna River	40,290	52	27,469	42
Potomac River	14,040	18	14,670	22
James River	10,030	13	10,002	15
Total, three rivers	64,360	82	52,141	80
Rappahannock River	2,480	3.2	2,720	4.2
York River	2,420	3.1	2,660	4.1
Total, five rivers	69,260	89	57,521	88
Choptank River	949	1.2	795	1.2
Patuxent River	943	1.2	932	1.4
Nanticoke River	934	1.2	815	1.2
Total, eight rivers	72,086	92	60,063	92

Note: Discharges shown in this table were calculated by using all available streamflow records, which accounted for 80 percent of the Chesapeake Bay drainage basin; discharge from the remaining 20 percent was estimated on basis of nearby gaged streams.

The total estimated inflow to the Bay by months for the calendar years 1951-67 is given in table 9. During this 17-year period the inflow ranged from 7,800 cfs in September 1964 to 230,700 cfs in April 1960. For the two months of highest mean flow, March and April, the range was less, percentagewise, than for the other months. August shows the greatest percentage range because of the extremely wet hurricane month in 1955. The highest October and November were also in 1955, reflecting the two hurricanes in October 1955 and carryover of high runoff into November. The data in table 9 are shown graphically by short horizontal lines in the chart on the first page of the appendix.

The estimated mean monthly inflow at each of the five sections for the period 1951-67 is shown in figure 4.

Table 9.--Estimated monthly mean inflow, in cubic feet per second, into Chesapeake Bay, 1951-67, based on three reference gaging stations

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1951	119,400	175,400	148,100	179,100	66,000	87,900	42,100	22,700	16,300	13,600	41,600	82,200	82,100
1952	173,500	123,300	182,100	180,100	142,100	47,000	33,500	30,400	38,800	16,800	68,300	97,100	94,300
1953	136,000	111,100	170,700	129,000	123,600	74,400	23,700	17,000	12,700	10,800	17,900	48,000	72,800
1954	39,700	71,800	135,100	95,200	99,900	45,400	19,100	14,000	13,600	41,600	51,100	78,300	58,700
1955	83,300	79,400	208,800	90,300	46,300	44,900	19,100	93,400	26,800	79,700	74,000	33,300	73,400
1956	27,400	107,900	161,400	161,500	82,800	45,000	49,900	39,500	30,700	36,400	69,400	101,900	76,000
1957	76,400	109,900	114,800	183,800	62,700	37,500	19,500	11,900	17,900	19,700	30,600	93,000	64,400
1958	89,100	72,900	160,900	216,300	154,400	51,500	43,000	40,400	24,900	25,400	37,400	37,500	79,500
1959	72,800	71,900	96,700	138,200	69,800	46,100	20,600	18,900	19,100	55,400	70,500	117,700	66,400
1960	95,500	118,100	84,000	230,700	145,700	92,900	32,100	26,100	42,600	22,100	24,300	20,100	77,300
1961	30,000	144,300	181,400	202,900	111,000	55,700	31,700	29,200	23,200	38,000	31,500	63,800	78,000
1962	78,500	71,800	207,200	195,300	61,000	38,800	21,900	16,800	13,700	31,500	60,500	41,700	69,800
1963	65,800	43,200	228,600	86,400	55,700	40,600	17,200	12,200	10,600	8,600	18,800	38,200	52,400
1964	103,400	80,600	222,700	127,300	88,700	23,600	16,300	11,400	7,800	13,000	14,000	33,200	61,900
1965	65,200	110,300	118,000	112,900	59,300	23,900	13,000	12,000	11,700	21,300	20,500	25,500	49,000
1966	29,600	110,200	130,100	66,500	105,800	30,700	10,500	9,300	23,600	35,000	30,500	61,400	53,300
1967	61,000	67,000	205,100	101,300	120,900	38,700	30,600	47,800	27,500	51,000	67,000	104,600	77,200
Mean	79,200	98,200	162,100	146,900	93,900	48,500	26,100	26,600	21,300	30,600	42,800	63,400	69,800

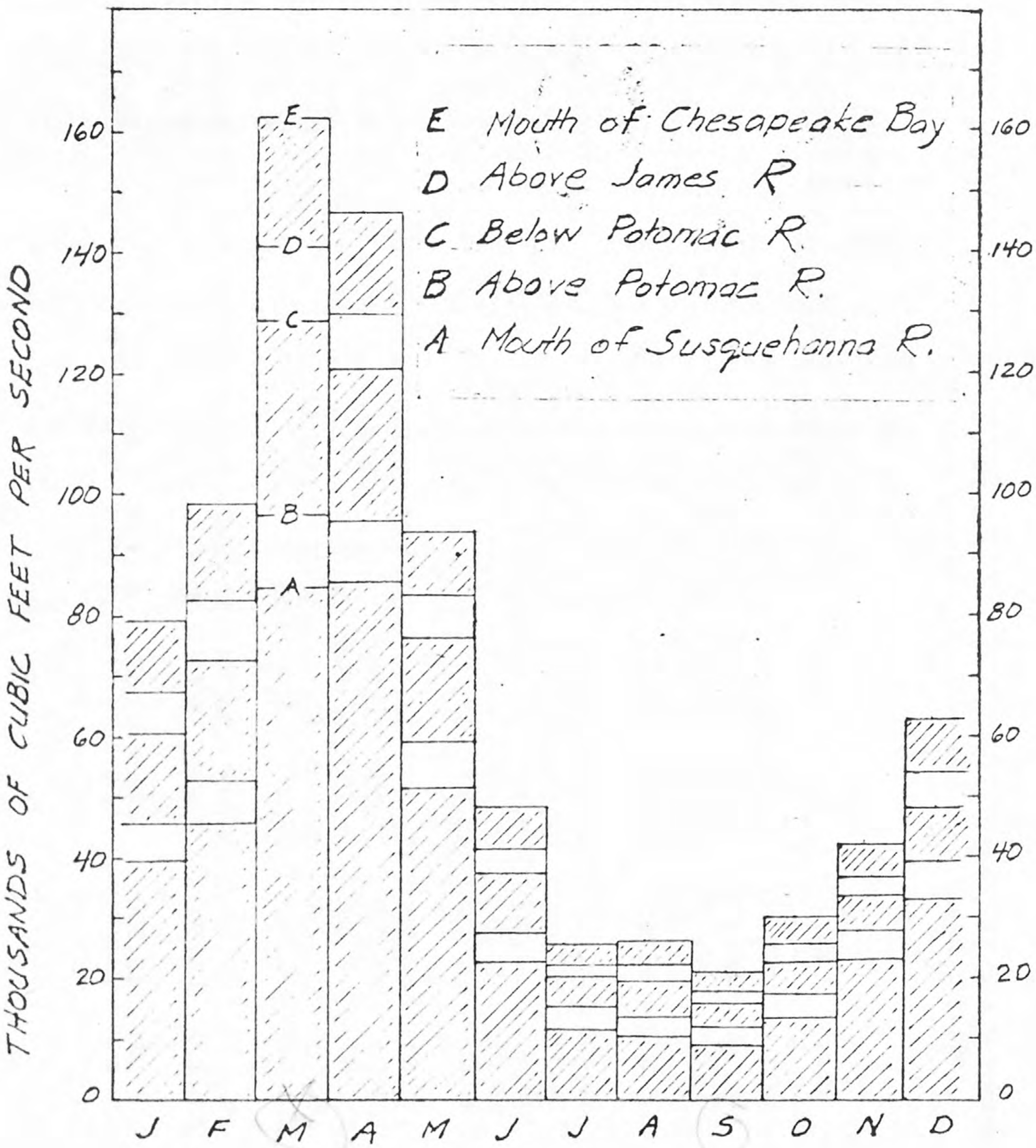


Figure 4.--Estimated cumulative mean monthly inflow to Chesapeake Bay at five sections, 1951-67.

Low lying streams in the upper Bay basin tend to contribute less, proportionately, at high discharges and more at low discharges than do the Susquehanna and Potomac Rivers. This is illustrated graphically in figures 5 and 6 by the Conestoga Creek and the South Branch Patapsco River. Other streams north of the Potomac, particularly those on the west side of the Bay, display this same tendency. Low-lying streams in Virginia, when compared with the James River near Richmond, do not display this tendency, but decline at a rate more nearly parallel to that of the James, or even more rapidly.

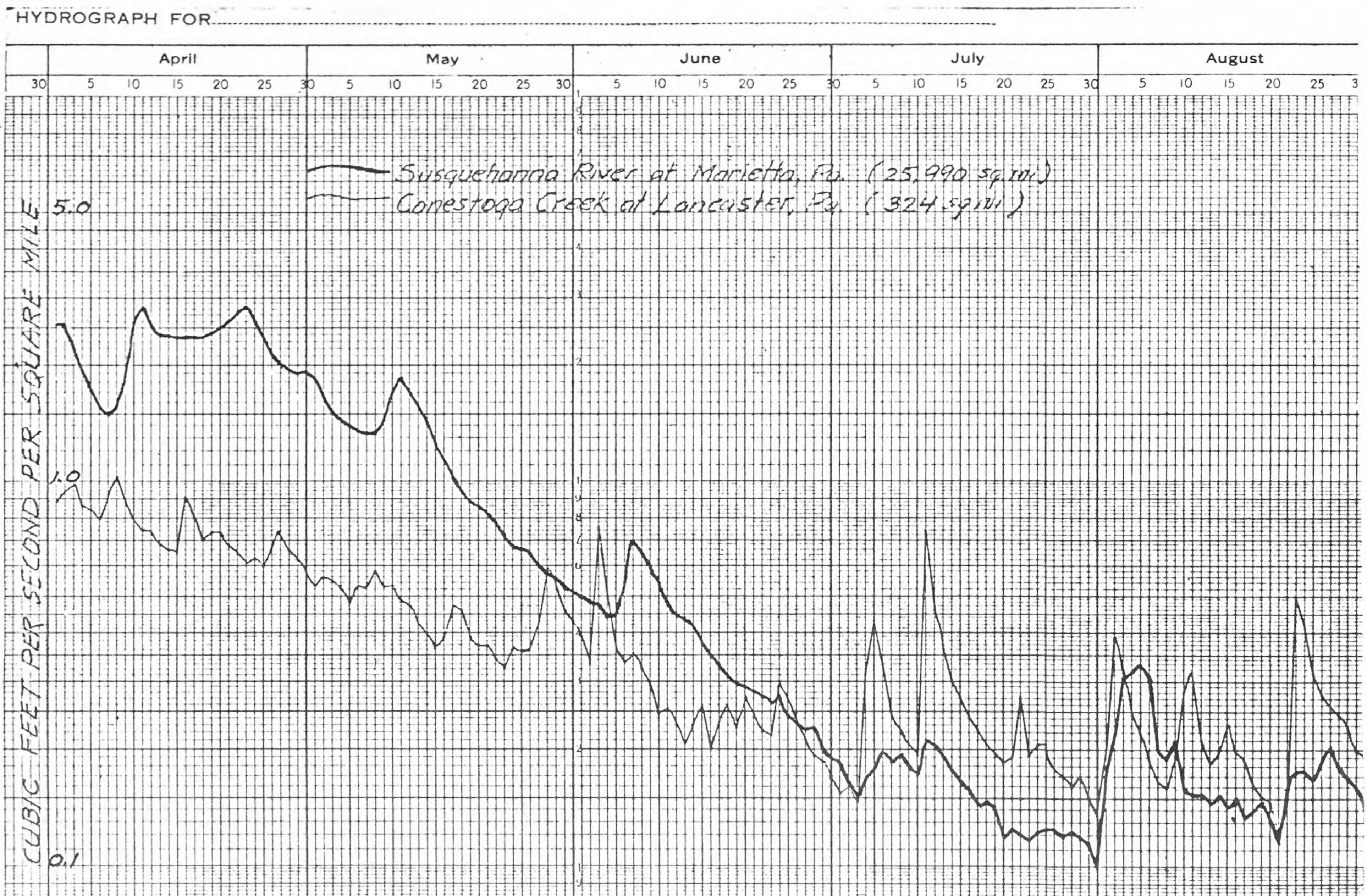


Figure 5.--Unit discharge of Susquehanna River and Conestoga Creek, April-August 1965.

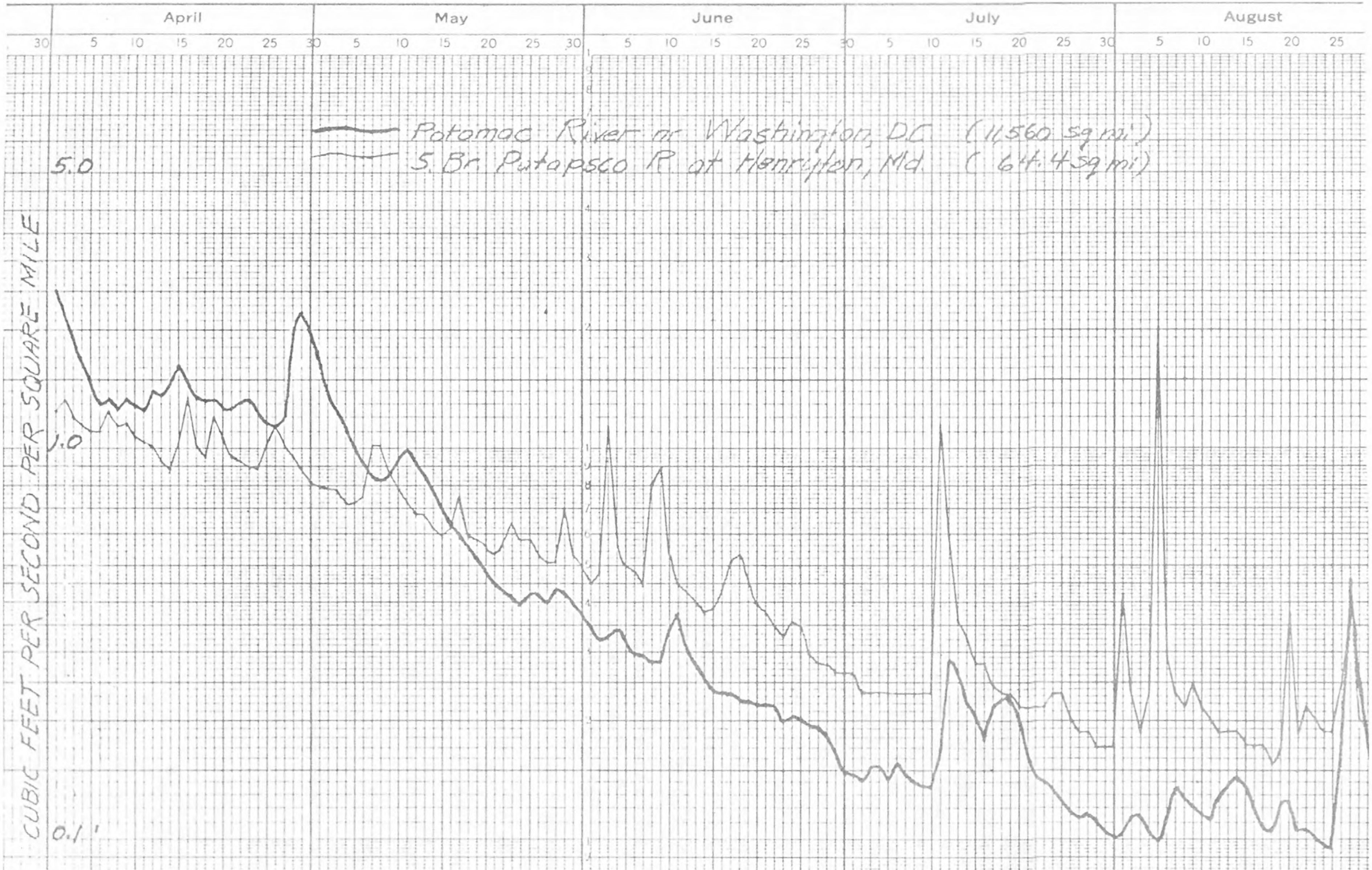


Figure 6.--Unit discharge of Potomac and South Branch Patapsco Rivers, April-August 1965.

RAINFALL AND EVAPORATION COMPARED WITH STREAMFLOW

On a yearly basis the net rainfall on the Bay constitutes only a small part of the total streamflow into the Bay. The average annual rainfall on the Bay is in the range 32-48 inches 1/, and the average annual evaporation is in the range 36-40 inches 2/. If the average annual rainfall is assumed to be 40 inches and the average annual evaporation 38 inches, the net rainfall is only 2 inches, which on the 2,800 square miles of water surface to the Bay is equivalent to about 400 cfs. A net annual rainfall of even as much as 10 inches would be equivalent to only 2,000 cfs, which is less than 3 percent of the average annual inflow to the Bay.

1/ U. S. Weather Bureau, Rainfall map entitled, "Mean annual total precipitation," based on years 1931-55.

2/ U. S. Weather Bureau, 1959, Evaporation maps for the United States: U. S. Weather Bur. Tech. Paper 37, plate 2.

Rainfall on and evaporation from the water surface of the Bay might be significant items in the water budget during months of very low streamflow, but would not be during months of high streamflow. If, during a March that was wet and cool, rainfall exceeded evaporation by 4 inches, the net contribution by rainfall on the surface of the Bay would be about 10,000 cfs, which would be negligible in months such as March 1963 and 1964 when the streamflow into the Bay was more than 220,000 cfs. But in a dry month such as September 1964 when the streamflow to the Bay was only 7,800 cfs, a net evaporation of as much as 3 inches might reduce the monthly outflow of the Bay almost to zero if ground-water inflow is neglected.

Accurate figures of monthly rainfall on and evaporation from the water surface of the Bay are not readily available. It may be, however, that in many summer months the evaporation is largely offset by rainfall. July and August 1966, for example, were consecutive months of low inflow--the inflow was the lowest for those months since at least 1951--but in each of these months Weather Bureau records from the Eastern Shore of Maryland and Tidewater Virginia, although showing exceedingly variable amounts of rainfall and evaporation, indicate that net evaporation probably was not significant.

DIVERSION AND WASTAGE

There are several large diversions from streams draining into Chesapeake Bay, but most of the diverted water is returned to the Bay as effluent from sewage treatment plants or by other means. The largest diversions, those from the Potomac River, have been considered in developing the procedures given in this report, and so do not affect the accuracy of the monthly estimates of inflow. A greater part of the wastage at the Back River treatment plant of the city of Baltimore is likewise considered. The diversions and wastage not adjusted for are relatively small and have little effect on the accuracy of the estimated inflow.

A large diversion from the Bay itself, which is not adjusted for, is the Chesapeake and Delaware Canal, a sea-level navigation canal. The water may move in either direction, depending on the tide, but the Corps of Engineers has found that there is a net movement of water eastward from Chesapeake Bay to the Delaware River. This canal is discussed in greater detail in a following section of this report.

A source of error in the estimated inflow--if not adjusted for--might be regulation of the monthly flow at reference stations, if the regulation were comparatively large. If, for example, the flow of the Potomac River near Washington, D.C., adjusted for diversion, were 1,000 cfs, the estimated inflow between sections B and C given by table 4 is 1,550 cfs, which indicates that 550 cfs would be contributed from the drainage area of the Potomac River downstream from Washington. Assume, then, that during the month an average of 100 cfs had been released from storage somewhere upstream so that the natural flow at Washington were only 900 cfs. Table 4 would then show 1,400 cfs inflow between sections B and C, or 500 cfs from the drainage area downstream from Washington. Thus, the estimated inflow below Washington would be in error by 50 cfs. Unless the regulation were much greater than that used in this example, however, the effect on the estimated inflow would be negligible.

Although flow records used in estimating monthly stream discharge into Chesapeake Bay are subject to some correction because of diversions above and below measuring stations, not all such corrections have been made because of their small magnitude and because most of the diverted waters enter the Bay not too far from the natural routes. The amounts not adjusted for are well within the probable limits of accuracy of the estimates of flow into the Bay.

For example, even during very low months diversions from the Susquehanna River that are not adjusted for are only about 1 percent of the flow of the Susquehanna River at its mouth, and wastage into the Potomac River that is not adjusted for is only about 2 percent of the flow of the Potomac River at its mouth. Practically all the water diverted from the James River below the Richmond gaging station is wasted back into the river.

The principal diversions and wastage on upper Chesapeake Bay not adjusted for in the monthly release are as follows (fig. 7): (1) diversion from Chesapeake Bay to the Chesapeake and Delaware Canal, which averages about 1,000 cfs; (2) diversion from the Susquehanna River basin to the Chester, Pa., area, which in 1967 averaged 40 cfs; (3) diversion from the Susquehanna River to the city of Baltimore, which in 1967 averaged 39 cfs; (4) effluent of 371 cfs by the city of Baltimore at the Back River treatment plant, less diversions of 318 cfs previously adjusted for, netted an average of 53 cfs wastage during 1967; and (5) wastage by the Washington Suburban Sanitary District into the Potomac River at the D.C. treatment plant, which in 1967 averaged 77 cfs. These diversions and wastage, in greater detail, including those on the Potomac River, which are adjusted for, are as follows:

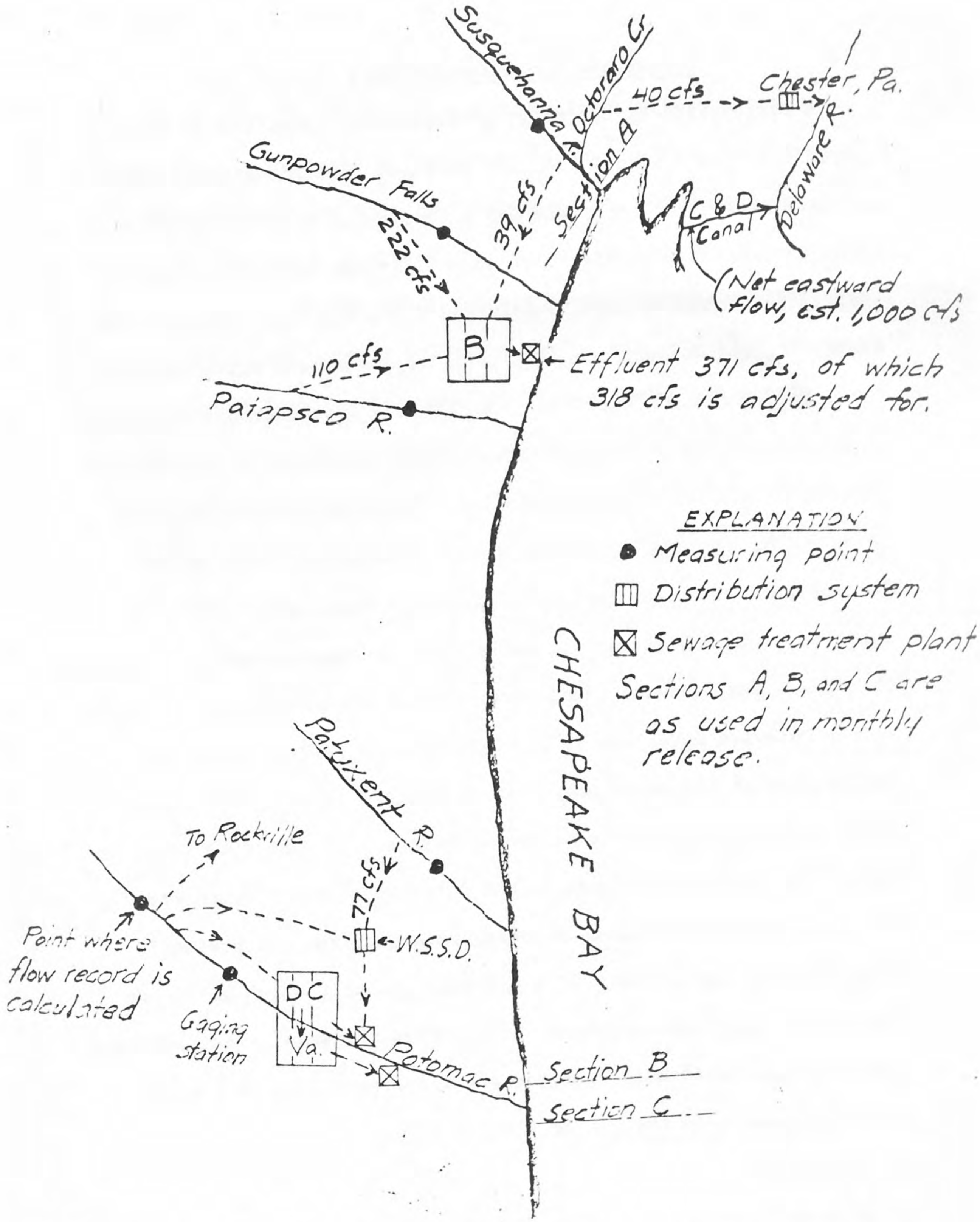


Figure 7.--Schematic diagram showing routes of water diverted from major streams flowing into upper and middle Chesapeake Bay. Figures shown are for 1967.

Chesapeake and Delaware Canal

A publication by the Corps of Engineers, Committee on Tidal Hydraulics, dated August 1965 and entitled "Inland Waterway between Delaware River and Chesapeake Bay - Problem of Disposal of Material to be Removed from a Portion of Channel in the Chesapeake Bay" states that "under present conditions (27 x 250 foot channel), the Chesapeake and Delaware Canal carries approximately 43,000,000 cubic feet more flow eastbound than it does westbound per tide cycle of 12.42 hours during normal tides." The estimated 43,000,000 cubic feet in 12.42 hours is equivalent to an average of about 960 cfs, or about 30 billion cubic feet per year. A pamphlet issued by the Philadelphia District, Corps of Engineers, dated April 1967 and entitled "Inland Waterway, Delaware River to Chesapeake Bay - Historic Chesapeake and Delaware Canal" states that "The mean range (of tide) at the Delaware River end is approximately 5½ feet while at the western end of the canal proper it is about 2 feet *** The mean level of the water surface at the western end is about 0.3 foot higher than mean river level in the Delaware at the eastern end." The canal is in the process of being enlarged from its present 27 x 250 foot channel to a 35 x 450 foot channel, which will more than double its cross-sectional area. When the enlargement has been completed the canal will likely carry proportionately more water from Chesapeake Bay than it does now 3/.

3/ Written Communication, P. N. Walker, June 7, 1968

Chester, Pa.

An average of 40 cfs (26 mgd) was diverted from Octoraro Creek, tributary to the Susquehanna, to the Chester, Pa., area in 1967. The maximum monthly rate was 48 cfs (30.8 mgd) in June. As the point of diversion is downstream from the measuring point on the river, the 40 cfs should be subtracted from the flow at section A (the monthly release makes no adjustment). The waste is discharged into the Delaware River after being given primary treatment. The average diversion of 40 cfs was less than 0.1 percent of the average flow at section A. The maximum monthly diversion of 48 cfs in June was 0.2 percent of the flow at section A that month.

Baltimore Md.

An average of 39 cfs (25 mgd) was diverted from the Susquehanna River. As the point of diversion is downstream from the measuring point on the river the diversion should be subtracted from the flow at section A (the monthly release makes no adjustment). This diversion was less than 0.1 percent of the average flow at section A. The maximum diversion was 155 cfs (100 mgd) in February, which was 0.5 percent of the flow at section A that month. Had the diversion of 155 cfs been made in September, the month of lowest streamflow, it would have been 1½ percent of the flow at section A. During six months in 1967--April, May, and September to December--no water was diverted from the Susquehanna. The present pumping capacity for this diversion is 387 cfs (250 mgd). Had 387 cfs been diverted in September 1967 it would have amounted to 3½ percent of the flow at section A.

An average of 222 cfs (143 mgd) was diverted from the Gunpowder and 110 cfs (71 mgd) from the Patapsco, or 332 cfs (214 mgd) from the two sources. The points of both of these diversions are upstream from the measuring points on the two rivers, so no adjustment is applicable to the records of inflow to the Bay.

The sum of the three diversions --from the Susquehanna, Gunpowder, and Patapsco--371 cfs (239 mgd), is wasted into the Bay at Baltimore's Back River treatment plant, and should be added to the inflow entering between sections A and B. However, the basic computations from which the monthly estimates are made include a flat adjustment of 318 cfs (205 mgd), which in 1967 left an average of only 53 cfs (34 mgd) unadjusted for. (Some of this waste is used by the Bethlehem Steel Company, which discharges its effluent at Sparrows Point, and whether or not all of it is subsequently returned to the Bay is not known.) The 53 cfs in 1967 was 0.1 percent of the average inflow above section B, and was 0.8 percent of the inflow to the Bay between sections A and B. During months of low streamflow these percentages could be somewhat greater, particularly if months of maximum diversion coincided with months of seasonal low streamflow.

Diversions from the Susquehanna

The two diversions from the Susquehanna averaged 79 cfs in 1967, or slightly less than 0.2 percent of the average flow at section A. The diversion by the city of Baltimore is supplemental and variable, but the diversion to the Chester area appears to be more uniform. If the average diversion to Chester, 40 cfs, is added to the maximum monthly diversion to Baltimore, 155 cfs in February, the total is 195 cfs, which in February would have been 0.6 percent of the flow at section A.

Diversions from the Patuxent

An average of 77 cfs (50 mgd) was diverted from the Patuxent River to the Washington Suburban Sanitary District in 1967. As the point of diversion is upstream from the measuring point on the river, the diversion is accounted for in the records of streamflow entering the Bay. The effluent is wasted into the Potomac River at the Washington, D.C. treatment plant and should be added to the inflow to the Bay between sections B and C (no adjustment is made in the monthly release). The 77 cfs was 0.1 percent of the average flow at section C, and 0.5 percent of the average inflow between sections B and C. During September, the month of lowest streamflow, the diversion of 79 cfs (51 mgd) was 0.3 percent of the flow at section C, and 0.9 percent of the inflow between sections B and C.

Diversions from the Potomac

The record of flow used for the Potomac River in preparing the monthly release represents the sum of: (1) the amounts of water diverted for public supply of Washington, D.C., Washington Suburban Sanitary District, and Rockville; (2) the amounts released into the lower reaches of the Chesapeake and Ohio Canal; and (3) the amounts discharged into the head of the Potomac estuary just upstream from Chain Bridge. Item 3 includes water diverted to the Corps of Engineers' hydro plant, which reenters the river just below Little Falls (and below the gaging station). The flow values for the Potomac River used in preparing the monthly release are determined by adjusting the flows at the gaging station, Potomac River near D.C., for the diversions cited in items 1 and 2, and the diversion to the hydro plant. A portion of the water diverted to Washington, D.C. is treated and pumped to Virginia communities for public supply (a few cubic feet per second is diverted directly to Fairfax). Except for the water which passes through the hydro plant, virtually all the water diverted returns to the Potomac River estuary either through the Washington, D.C. treatment plant or the treatment plant in metropolitan Virginia. The water diverted to the C & O Canal returns to the river at the terminus of the Canal at Georgetown.

The total diversion from the Potomac River in 1967 averaged 400 cfs, which was distributed about as follows: 230 cfs to Washington, D.C. water users; 70 cfs to the Washington Suburban Sanitary District; 50 cfs to communities in Virginia; 42 cfs to the hydro plant; and a few cubic feet per second each to Rockville and the C & O Canal.

ACCURACY OF ESTIMATES

The relation curves from which tables 2-6 are derived are well-defined by the ten yearly points for 1951-60 (water years) throughout the range of those points. The curves as defined by the yearly points do not, however, cover the range required for monthly estimations of inflow. To extend the curves, at both the high and low ends, mean monthly inflow for the ten years was computed for the two high months March and April, and for the four low months July to October. To further define the low ends of the curves, inflows for the ten individual Septembers--generally the lowest month--were computed. The monthly points scatter considerably but help define the low ends of the curves.

Streamflow records for the 10-year period show that the patterns of streamflow around the Bay can vary considerably from year to year. For example, a rise on the Susquehanna may have no counterpart on either the Potomac or the James. Even within a comparatively small area, in any given month the flow in one stream may be substantially less than in the same month of the preceding year, while in a nearby stream the flow in that month may be substantially greater than in the preceding year. If the pattern of flow from gaged areas is erratic it is safe to assume that the flow from nearby ungaged areas is equally erratic, and that estimates of flow from ungaged areas are subject to considerable error. These errors, however, are likely to be both plus and minus, and should to some extent tend to balance each other.

It is not possible to make a rigorous determination of the accuracy of the estimates obtained by use of tables 2-6, as the basic computations contain inherent errors owing to the fact that the inflow from 20 percent of the drainage area of the Bay was estimated. As nearly as can be determined, the standard error of the monthly estimates of total inflow to the Bay is about 20 percent, and that of yearly estimates about 10 percent.

The accuracy of the estimates could be improved by including gaging stations on one or more representative coastal streams as reference stations. The three reference stations now used measure streamflow that originates mainly in the highlands, so the accuracy of estimates based on those three stations is contingent, at least to some extent, on the uniformity in the pattern of streamflow throughout the Chesapeake Bay basin. Streamflow records show that the pattern of monthly streamflow can vary considerably, but that the yearly pattern is much more uniform. This is confirmed by the plotting of points on the relation curves: the ten yearly points plot very close to the average curve, but some individual months show considerable deviation, both above and below, from the average curve.

The fact is emphasized that the estimates of inflow at section E are estimates of total surface inflow to the Bay, which theoretically would equal the outflow to the ocean if adjustments were made for all diversions and wastage, for precipitation on and evaporation from the water surface of the Bay, and for ground-water inflow. During very low months when evaporation and precipitation might be significant items in the water budget, adjustments can be estimated on basis of climatic records collected by the Weather Bureau at points around the Bay.

Ground-water inflow is largely an unknown quantity, as no comprehensive estimate of it has ever been made. Ground-water inflow consists of two main components: (1) direct seepage from water-table aquifers along the shore, and (2) upward leakage into the Bay from artesian aquifers lying beneath it. The U. S. Geological Survey has estimated the upward leakage to be about 250 cfs, qualifying the estimate as possibly being in error by an order of magnitude but has made no estimate of the direct seepage along the shore. 4/

4/ Written Communication, E. G. Otton, Aug. 17, 1967

The outflow of the Bay could be gaged by techniques now available, but the project would be extremely involved and costly. Even if inflow and outflow could be measured within say 1 percent, the difference would be relatively very small and subject to such large percentage errors as to be meaningless. Hence, for the purpose of isolating gains or losses in the Bay itself, gaging the outflow by mechanical means would not be practicable.

APPENDIX

The following three pages are an example of the release that has been issued monthly since December 1967.

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

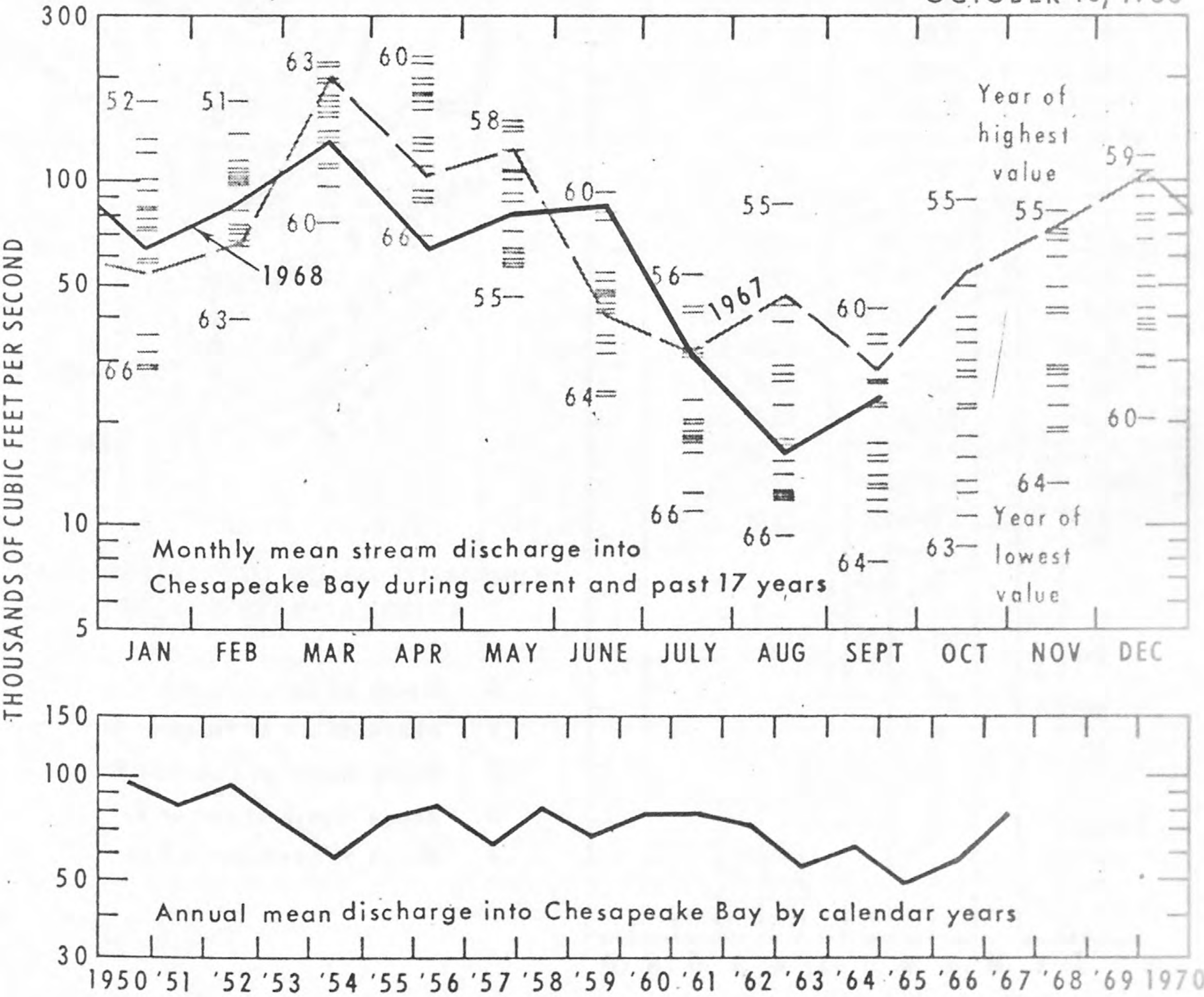
In Cooperation with

STATES OF MARYLAND, PENNSYLVANIA AND VIRGINIA

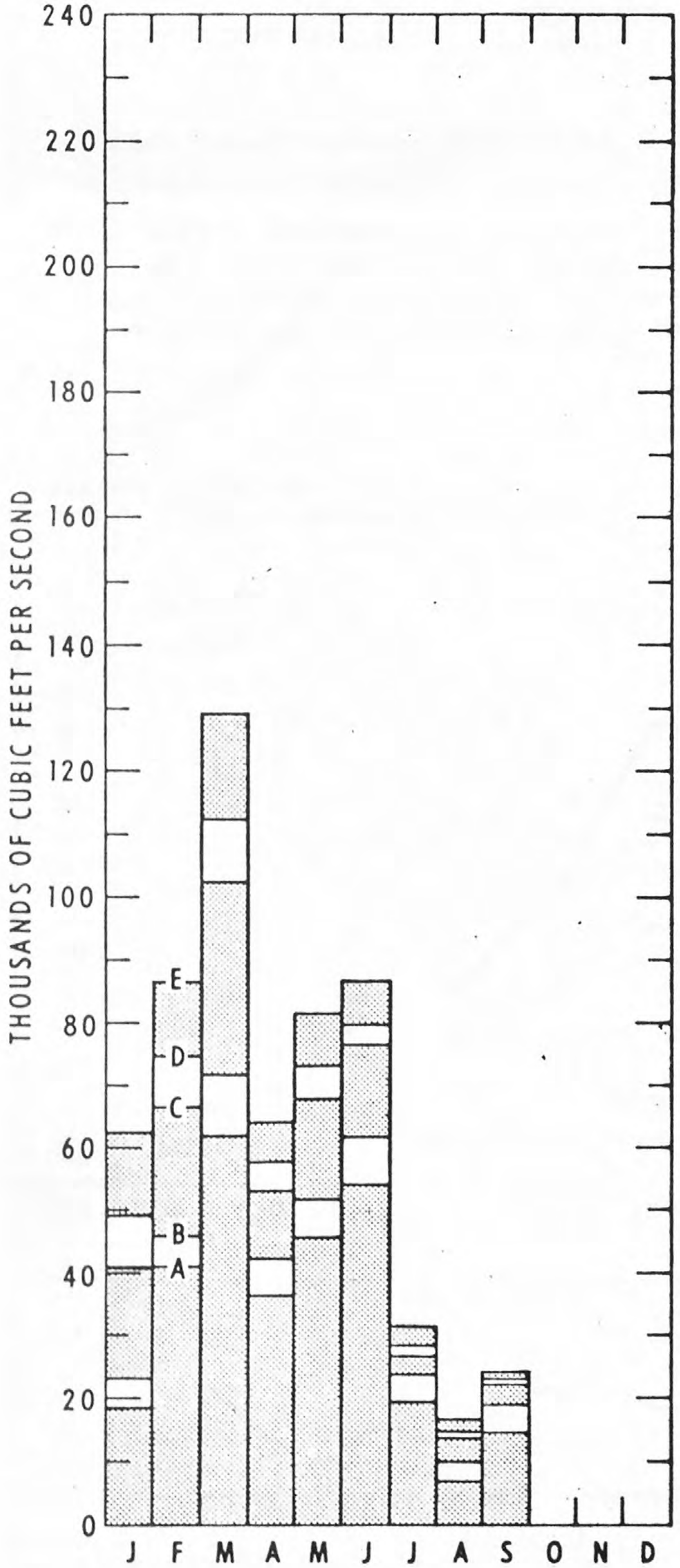
ESTIMATED STREAM DISCHARGE ENTERING CHESAPEAKE BAY

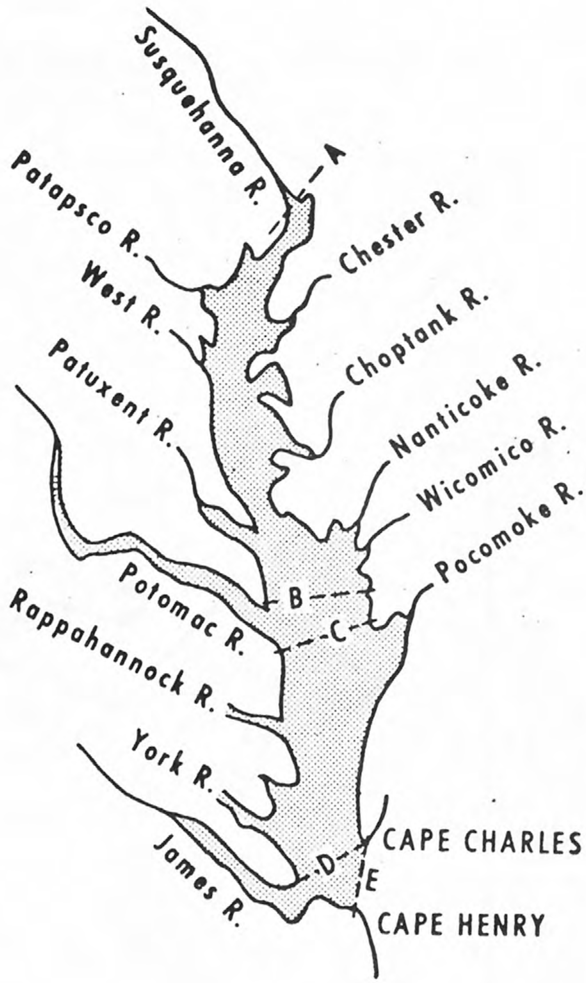
A monthly release for those making environmental and resource studies in which the fresh-salt water balance of the Bay is important. For information as to methods used and interpretation of content, contact Regional Hydrologist, USGS, 317 Washington Building, Arlington Towers, Arlington, Virginia 22209, Phone 202-343-8841.

OCTOBER 10, 1968



ESTIMATED CUMULATIVE STREAM DISCHARGE ENTERING CHESAPEAKE BAY ABOVE INDICATED SECTIONS BY MONTHS, DURING 1968.





CUMULATIVE INFLOW TO CHESAPEAKE BAY AT INDICATED CROSS SECTIONS

- A Mouth of Susquehanna R.
- B Above mouth of Potomac R.
- C Below mouth of Potomac R.
- D Above mouth of James R.
- E Mouth of Chesapeake Bay

ESTIMATED CUMULATIVE STREAM DISCHARGE ENTERING CHESAPEAKE BAY

		Cubic feet per second at section				
YEAR	MONTH	A	B	C	D	E
1967	January	21,800	26,400	39,000	47,400	61,000
	February	31,300	36,800	50,800	56,900	67,000
	March	105,400	120,800	163,800	179,100	205,100
	April	68,400	78,700	90,700	94,600	101,300
	May	72,100	83,000	104,300	110,600	120,900
	June	20,500	25,100	31,500	34,100	38,700
	July	15,600	20,000	26,300	27,800	30,600
	August	20,400	24,900	35,200	39,900	47,800
	September	11,000	14,700	23,400	24,800	27,500
	October	30,100	35,500	43,500	46,200	51,000
	November	48,500	55,200	61,600	63,500	67,000
	December	49,500	56,400	78,900	88,600	104,600
	Mean	41,300	48,300	62,600	68,000	77,200
1968	January	18,700	23,100	40,500	49,000	62,800
	February	40,600	46,100	66,700	74,300	86,600
	March	63,100	72,700	103,000	112,900	129,100
	April	36,800	42,300	53,700	57,800	64,800
	May	45,700	51,800	67,800	72,800	81,200
	June	54,000	61,800	76,300	79,800	86,000
	July	19,300	23,800	26,800	28,400	31,500
	August	6,700	9,900	13,300	14,500	16,900
	September	14,100	18,200	21,800	22,400	23,700
	October					
	November					
	December					
	Mean					