MARYLAND GEOLOGICAL SURVEY

Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 13

EXTENT OF BRACKISH WATER IN THE TIDAL RIVERS OF MARYLAND

by

W. E. Webb and S. G. Heidel

Prepared by

U.S. Geological Survey, Water Resources Division
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Contents

	Page
Abstract	1
Introduction	3
Purpose and scope	3
Previous investigations	3
Data collected for this study	6
Factors affecting extent of brackish water in Maryland	6
Fresh-water discharge and tidal action	6
Shape and size of the estuary and drainage basin	9
Effect of the Chesapeake and Delaware Canal	9
Effect of evaporation	9
Effects of hurricanes	10
Proportional effects of fixed and variable controls on extent of brackish water	10
Summary of extent of brackish water	11
Selected references	16
Appendix	19

Illustrations

	Page
Figure 1. Map showing basins of rivers discharging to Chesapeake Bay in Maryland	4
2. Graph showing relation of specific conductance to chloride, dissolved solids, and salinity	5
3. Graph of monthly mean stream discharge into Chesapeake Bay	6
4. Graph of monthly precipitation at Woodstock, Md.	6
5. Graph showing weekly average predicted low tides at Baltimore, Md. during 1968	7
6. Graph showing annual mean discharge into Chesapeake Bay compared with annual precipitation at Woodstock, Md.	8
7. Graphs showing relation of precipitation, discharge, specific conductance, and tides in Patuxent River basin	11
8. Graphs showing tide height, rainfall, specific conductance, wind direction and speed of Patuxent River during December 1968	12
9. Map showing sampling sites on the Wicomico River	13
10. Map showing summary of extent of brackish water	14
11. Map and graphs of Pocomoke River basin data	
A. Map of the Pocomoke River basin	20
B. Drainage area and river volume at locations along the river	20
C. Variation of discharge and specific conductance with time.	21
D. Specific conductance values, including observed maximum and minimum values, at locations along the river	21
12. Map and graphs of Nanticoke River basin data	
A. Map of the Nanticoke River basin	22
B. Drainage area and river volume of locations along the river	22
C. Variation of discharge and specific conductance with time	23
D. Specific conductance values, including observed maximum and minimum values, at locations along the river	23
13. Map and graphs of Choptank River basin data	
A. Map of the Choptank River basin	24
B. Drainage area and river volume of locations along the river	24

Illustrations—Continued

		Page
	C. Variation of discharge and specific conductance with time	25
	D. Specific conductance values, including observed maximum and minimum values, at locations along the river	25
14.	Map and graphs of Chester River basin data	
	A. Map of the Chester River basin	26
	B. Drainage area and river volume of locations along the river	26
	C. Variation of discharge and specific conductance with time	27
	D. Specific conductance values, including observed maximum and minimum values, at locations along the river	27
15.	Map and graphs of Sassafras River basin data	
	A. Map of the Sassafras River basin	28
	B. Drainage area and river volume of locations along the river	28
	C. Variation of discharge and specific conductance with time	29
	D. Specific conductance values, including observed maximum and minimum values, at locations along the river	29
16.	Map and graphs of Chesapeake Bay data	
	A. Map of Chesapeake Bay	30
	B. Drainage area and Bay volume at locations along the Bay	30
	C. Variation of discharge and specific conductance with time	31
	D. Specific conductance values, including observed maximum and minimum values, at locations along the Bay	31
17.	Map and graphs of Patuxent River basin data	
	A. Map of the Patuxent River basin	32
	B. Drainage area and river volume of locations along the river	32
	C. Variation of discharge and specific conductance with time	33
	D. Specific conductance values, including observed maximum and minimum values, at locations along the river	33
18.	Map and graphs of Potomac River data	
	A. Map of the Potomac River	34
	B. Drainage area and river volume of locations along the river	34
	C. Variation of discharge and specific conductance with time	35
	D. Specific conductance values, including observed maximum and minimum values, at locations along the river	35

Tables

			Page
Table	1.	Summary of extent of brackish water in Maryland's tidal rivers	15
	2.	Chemical and physical data for Pocomoke River basin	36
	3.	Specific conductance extremes, Pocomoke River at Pocomoke City	38
	4.	Chemical and physical data for Wicomico River basin	38
	5.	Chemical and physical data for Nanticoke River basin	40
	6.	Specific conductance extremes Nanticoke River at Sharptown	41
	7.	Chemical and physical data for Choptank River basin	42
	8.	Specific conductance and water temperature for Chester River basin	44
	9.	Specific conductance extremes Chester River at Chestertown	45
	10.	Specific conductance and water temperature for Sassafras River basin	45
	11.	Specific conductance extremes Sassafras River at Georgetown	46
	12.	Specific conductance extremes, and tidal height of Patuxent River at Nottingham	46

EXTENT OF BRACKISH WATER IN THE TIDAL RIVERS OF MARYLAND

by

W. E. Webb and S. G. Heidel

ABSTRACT

Fresh-water discharge, tide height and estuary size, shape, and salinity at the mouth are important controls on the extent of brackish water in tidal rivers (estuaries) of Maryland. Long-term predictions of the frequency or times at which brackish water will penetrate to a given section of an estuary are difficult because of the complex relations between the controls and the lack of quantitative predictions of the controls. Graphs and maps in the report show the historic extent of brackish water and may be used to estimate the probable extent of brackish water in the principal estuaries. For a distance of about 15 miles most of the estuaries will be brackish during one season, but will contain fresh water in the same section during another season of the year. In an estuary section containing a salt front, the water may be fresh at low tide but brackish at high tide. Extremes usually occur twice in 24 hours. The estuaries tributary to Chesapeake Bay usually contain relatively fresh water for 10 to 30 miles downstream from the point where tidal effect ceases. Data show that brackish water is flushed downstream by a sudden increase in discharge for a length of channel which will accommodate the volume discharged.

INTRODUCTION

Purpose and Scope

This report summarizes data on the extent of brackish water in tidal rivers (estuaries) tributary to Chesapeake Bay in Maryland, and discusses some of the factors that affect encroachment. The investigation was part of a cooperative program between the Maryland Geological Survey, Dr. Kenneth N. Weaver, Director, and the U.S. Geological Survey. The investigation and report preparation was under the supervision of W. F. White, District Chief, U.S. Geological Survey.

The main purpose of the report is to describe the location and volume of fresh water in the estuaries of Maryland to the extent that planners can reliably include this water as a resource. These estuaries contain tremendous volumes of water. The fraction of brackish water in each differs from estuary to estuary. A description of the principal controls and historic record of the extent of brackish water are presented in order to sufficiently describe the location and volume of the fresh-water resource in time and space. The principal controls are qualitatively described so that their effects may be understood, thereby insuring efficient utilization of the resource. A quantitative description of the controls and their interrelation is beyond the scope of this report. The record in time and space of the extent of brackish water is graphically presented for the estuaries of the river basins shown in figure 1. These basins were chosen for presentation because of their geographic coverage or their similarity to other basins in Maryland.

Field observations during the investigation were most extensive on the rivers east of Chesapeake Bay and on the Patuxent River. Most of the data used in this report came from previous investigations.

Previous Investigations

The Geological Survey and other agencies have made observations of salinity in several tidal rivers of Maryland at irregular intervals for many years. During July to October 1952 Murphy (1957) made a reconnaissance of the Pocomoke, Wicomico, Nanticoke, Choptank, and Chester Rivers. The U.S. Geological Survey has operated a water-quality monitor on the Patuxent River estuary at Benedict since 1963, and basic data from the monitor are included in two reports by Cory and Nauman, (1967, 1968).

The State of Maryland Department of Water Resources has made surveys of water quality in selected rivers. The principal objective of these studies usually is to determine the effect of industrial and municipal pollution. However, salinity observations have been made on these surveys. Longwell (1967) has reported on water quality in the upper Choptank River basin, and Allison (1967) reported on 10 water quality parameters measured in the Patuxent River basin during 1961–63.

The Chesapeake Bay Institute of The Johns Hopkins University has studied water of Chesapeake Bay, and its reports include numerous salinity measurements in the lower tidal reaches of tributary streams, particularly the Potomac, Choptank, and Patuxent Rivers. Since 1963, data collected by the Chesapeake Bay Institute have been sent to the National Oceanographic Data Center, Washington, D. C. for storage.

Other investigators have used specific conductance, dissolved-solids content, salinity, and chloride to describe the brackishness of water quantitatively. In this report specific conductance, in micromhos per centimeter at 25°C is used. It is a measure of the ability of water to conduct an electrical current and depends on the amount and type of material dissolved in water. The relations used to convert the units of other investigators to specific conductance is shown in figure 2. The relations are valid for the water in most estuaries of Maryland.

Fresh and brackish are convenient terms that are often used to describe water quality. In this report, water is considered brackish when the specific conductance significantly exceeds that of water in the nontidal part of the estuary and ionic ratios approach those of sea water. Fresh water is that in the rivers prior to mixing with brackish water from Chesapeake Bay.

As shown on figure 2, water with a specific conductance of 1,000 micromhos contains about 280 mg/l (milligrams per liter) of chloride and

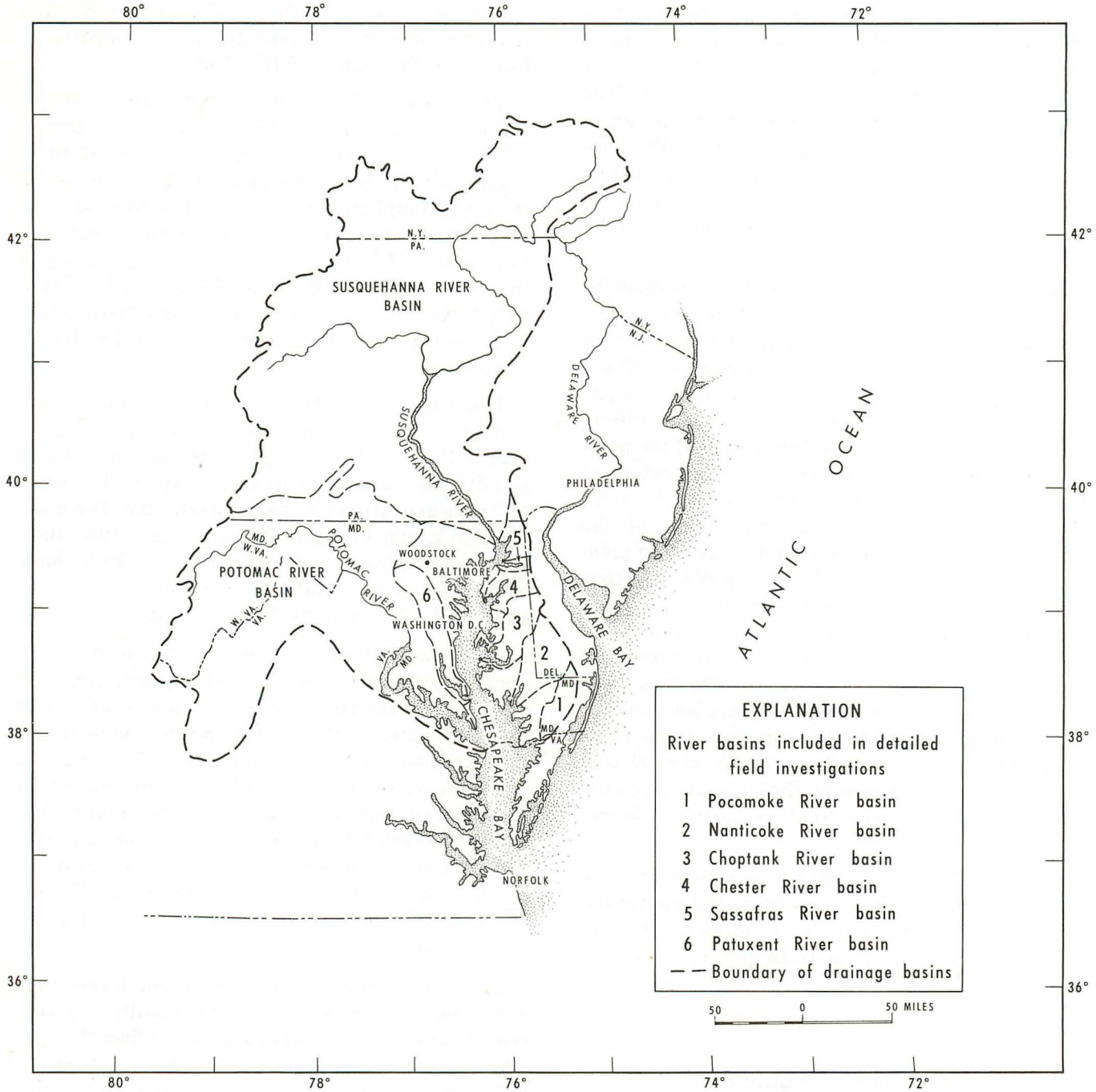


Figure 1—Map showing basins of rivers discharging to Chesapeake Bay in Maryland.

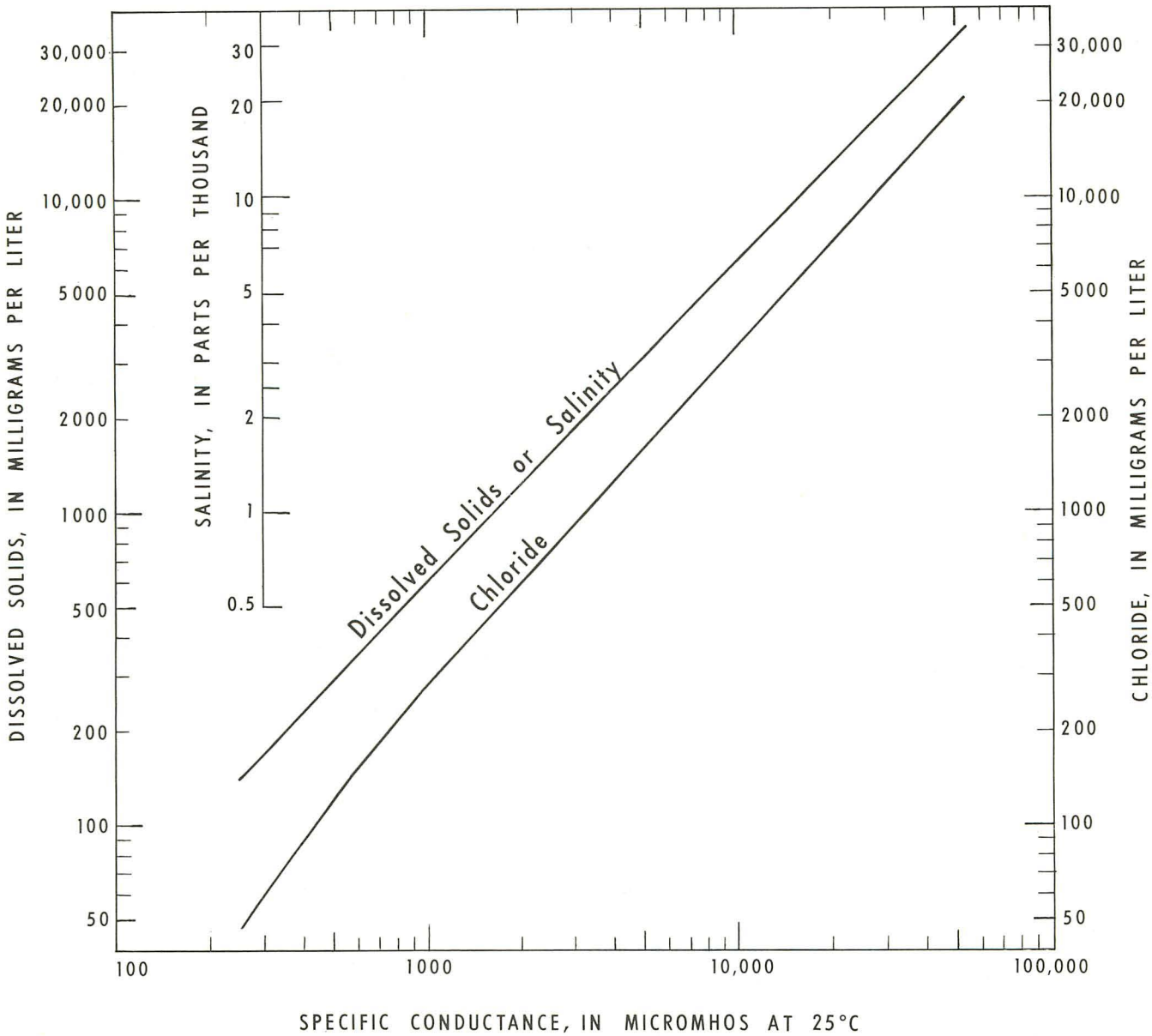


Figure 2—Graph showing relation of specific conductance to chloride, dissolved solids, and salinity.

about 600 mg/l of dissolved solids. For drinking water on interstate common carriers, the U.S. Public Health Service (1962) recommends a maximum limit of 250 mg/l for chloride, and 500 mg/l for dissolved solids. Therefore, water with a specific conductance of less than 1,000 micromhos would be suitable for domestic supply when considering dissolved solids and chlorides.

For agricultural use, water in the specific conductance range of 2,250 to 5,000 micromhos is classified as "very high salinity water" and not suitable for irrigation under ordinary conditions, although it may be used occasionally under very special circumstances (Wilcox, 1955). The dissolved minerals tolerated by livestock is different for each type of animal, adult sheep having the highest limit. Hem (1959) reports that they can consume water with a dissolved-solids content as high as 12,900 ppm or about 22,000 micromhos. Pigs and poultry can consume water with an upper limit of dissolved solids of 4,290 and 2,860 ppm respectively (Hem, 1959). In general therefore, water with a specific conductance above 10,000 micromhos would have very little utility for agricultural use in Maryland.

The maximum allowable dissolved-solids content for most industrial process water is less than 1,000 mg/l (McKee and Wolf, 1963). Therefore, water having a specific conductance around 2,000 micromhos or greater would have limited industrial utility.

Data Collected for this Study

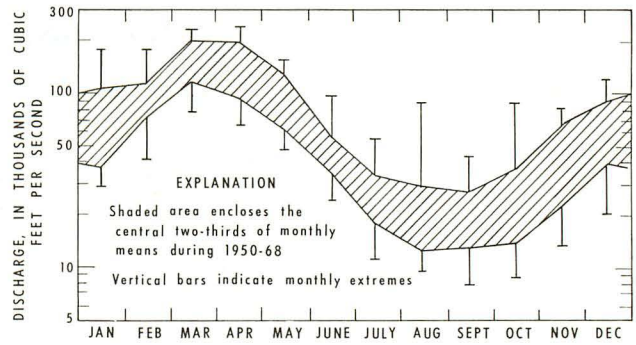
The analysis and conclusions reached in this study have been based on data obtained by the U.S. Geological Survey and other organizations. Field observations were made specifically for this project, by measuring tide heights and specific conductances continuously at critical sections of selected rivers. Data which have not been published elsewhere are summarized in tables 2 to 12 of the Appendix.

FACTORS AFFECTING EXTENT OF BRACKISH WATER IN MARYLAND

The location and movement of brackish water into tidal rivers (estuaries) depends on several factors. Chief among these are tides, currents, freshwater discharge, sea level, winds, depth and configuration of an estuary, the rotation of the earth, temperature of both sea and fresh water, evaporation, and rainfall. Some of the major factors affecting the extent of brackish water in Maryland's estuaries are discussed in the following section of the report.

Fresh-Water Discharge and Tidal Action

Fresh-water discharge and tidal action are the principal factors affecting the location at which fresh water and sea water meet and mix in an estuary. The Susquehanna River contributes most of the fresh-water discharge to the Maryland part of Chesapeake Bay. As the discharge of the Susquehanna River increases during periods of low evapotranspiration (October to March) the upstream advance of brackish water is usually halted about November, and fresh water begins to occupy more of the upper part of the Bay (see figure 3). Occasionally water with a specific conductance of less than 5,000 micromhos is observed in the Bay as far south as the mouth of the Chester River. During such times, tributaries entering the Bay north of the Chester River probably do not contain water with a specific conductance exceeding 5,000 micromhos. The extent of brackish water in any tributary to the Bay upstream of the Potomac River will be influenced by the prior discharge of the Susquehanna River. The influence is not instantaneous. Some time lag can be expected between a change in discharge of the Susquehanna and a change in specific conductance of the Bay at the mouth of the tributaries. One reason for the lag is that the volume of the Bay from the Susquehanna River to the Atlantic Ocean, 2.6 x 10^{12} cubic feet, is approximately equal to the average total annual discharge, 2.5 x 10^{12} cubic feet,[1] from all



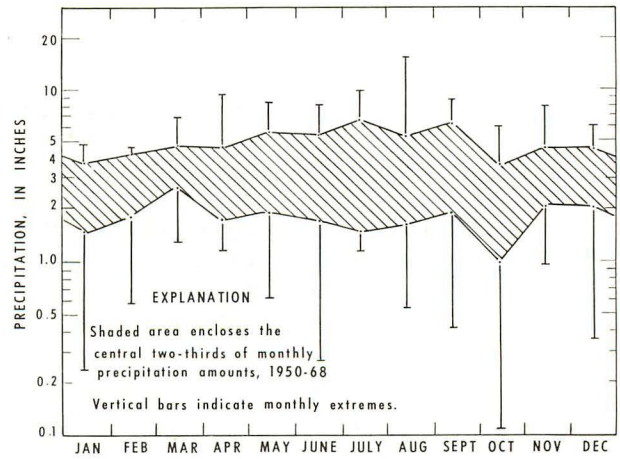


Figure 3—Graph of monthly mean stream discharge into Chesapeake Bay.

Figure 4—Graph of monthly precipitation at Woodstock, Md.

[1] Bue (1968) computed that the total discharge of all the tributaries to the Bay averaged 78,210 cfs during 1951–60 water years.

its tributaries. Another is that brackish water may not have advanced to the equilibrium point for the discharge of August and September so the brackish water would continue to advance until the discharge equalled or exceeded that required to move it back.

In the estuaries tributary to Chesapeake Bay, brackish water appears to be flushed downstream on a volume for volume basis (at least for moderately long storm periods). A sharp increase in discharge will flush the upstream part of an estuary a distance which will accommodate the volume of discharge. The distance that water in the estuary is flushed decreases downstream because the estuaries generally increase in volume per mile downstream.

The brackish water moves upstream in a stepwise fashion with each tidal cycle. Brackish water is introduced at the mouth of a tidal river from low-water slack to high-water slack. The brackish water introduced tends to move upstream near the bottom due to its greater density.

During ebb tide, fresh water moves downstream at the surface of the estuary, mixing as it moves with the underlying brackish water. On succeeding tidal cycles the brackish water continues to advance upstream, becoming more dilute by mixing with fresher, overlying water.

The maximum salinity generally occurs at high water slack, and the minimum at low water slack. Slack water occurs when there is no horizontal motion of water at the surface. High water slack tide occurs when the upstream or flood current stops and the ebb current is about to begin. Low water slack occurs when the downstream or ebb current stops and before the flood current begins. The duration of the slack periods may be from 1/2 to 2 hours and they frequently follow the high and low tides by times as great as 1 to 3 hours. The predicted times for high and low tides are calculated by the U.S. Coast and Geodetic Survey and published annually in "Tide Tables"; times of slack tides are also published by the U.S. Coast and Geodetic Survey in "Tidal Current Tables" (see selected references).

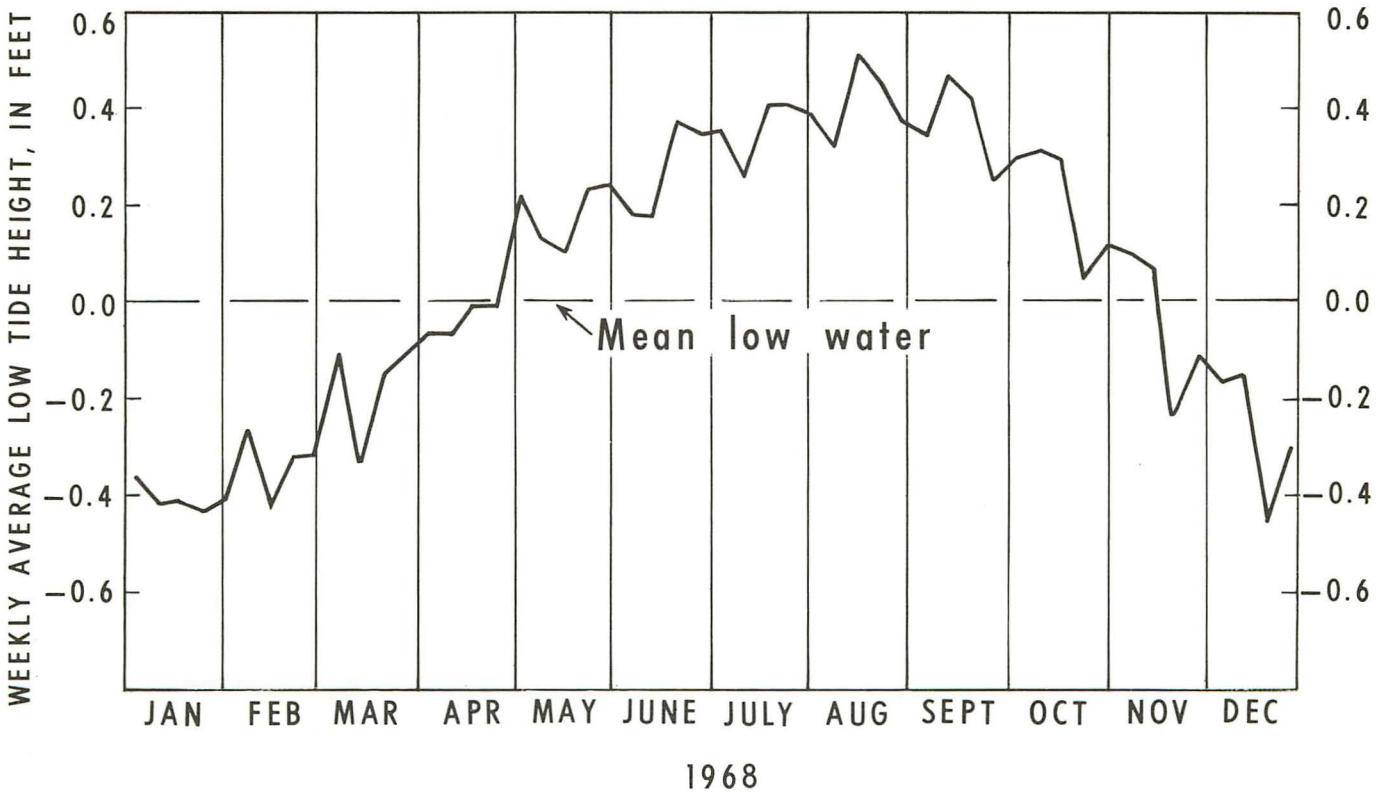


Figure 5—Graph showing weekly average predicted low tides at Baltimore, Md. during 1968.

Discharge and tide height are subject to seasonal variations. About four-fifths of the discharge enters Chesapeake Bay in the 6 months from December through May and one-fifth from June through November (figure 3). The change in discharge is caused by an increase in evapotranspiration and not a decrease in rainfall. Rainfall in the low flow period is absorbed in large part by the soil and subsequently returned to the atmosphere and thus does not become either direct runoff or ground-water outflow to the streams. Figure 4 shows the rainfall at Woodstock, Md. for the same 18-year period used in preparing figure 3. There is little if any summertime decrease in the rainfall. (Woodstock is near the centroid of the drainage area for the entire Chesapeake Bay.) This suggests that if the flow of Susquehanna River is low during December to May, brackish water will extend upstream farther in the summer.

The mean level of Chesapeake Bay varies seasonally by about a foot. This effect has been noted for several years and has been ascribed to wind action by some observers (Cory and Nauman, 1968). A plot of the weekly average of the predicted low tides for Baltimore during 1968 (figure 5) shows that as in all other years the lowest average low tides occur December through March, and that the highest average low tides occur June through September. This variation tends to aid flushing of brackish water downstream in the spring and accentuates the upstream incursion of brackish water in the fall.

Winds blowing parallel to the length of an estuary can significantly change tide heights. In the Delaware estuary a record low tide occurred December 31, 1962 as a result of a strong, persistent wind from the northwest. The wind velocity averaged 23 miles per hour for 48 hours (Lendo, 1966). Associated with the low tide was a sharp decrease in specific conductance. When the wind subsided and large volumes of brackish water moved upstream, the specific conductance values at most locations along the river were abnormally high. Similar conditions have been observed in the estuaries of Maryland.

Some long-term variations in discharge and mean sea level occur. The yearly average discharge to Chesapeake Bay is shown in figure 6 for the period 1950–68. The yearly total precipitation at Woodstock, Md. is plotted on the same graph for comparison. Assuming that precipitation at Woodstock is representative of the whole basin, there is a good correlation between annual precipitation and total annual discharge.

In 1950 the total discharge to Chesapeake Bay was 3.1 x 10^{12} cubic feet; in 1965 it was only 1.5 x 10^{12} cubic feet. Discharge to the Bay in 1950 was 1.2 times the total Bay volume, but in 1965 the discharge to the Bay amounted to only a little more than half the Bay volume. To determine the maximum possible extent of brackish water, the seasonal December to May discharge must be analyzed carefully along with data on long-term discharge variations.

Long-term variations in mean sea level are known to occur. In the Chesapeake Bay area, sea level is rising. Rates of rise as much as 2 feet per century have been reported (Keighton, 1954). The effect of a rise in sea level will be to increase the extent of brackish water penetration. Keighton (1966) suggested some of the increase in brackish

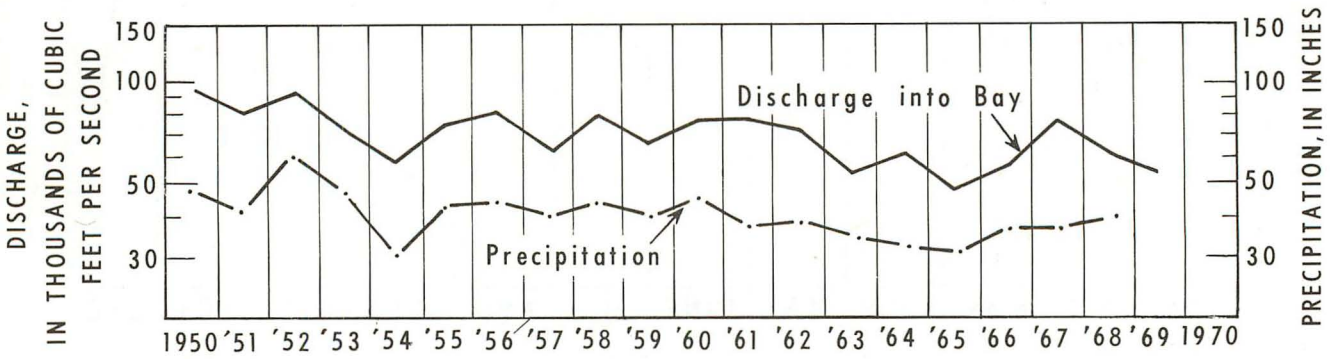


Figure 6—Graph showing annual mean discharge into Chesapeake Bay compared with annual precipitation at Woodstock, Md.

water penetration in the Delaware may be caused by the rise in sea level. Long-term sea level variations, however, are probably of less importance in planning water use than are seasonal changes in tide height and variations in annual discharge.

Shape and Size of the Estuary and Drainage Basin

The shape and size of an estuary and its drainage basin are the primary fixed controls on the extent of brackish water penetration. Although these controls do change with time, their year-to-year changes are slight compared to changes in discharge and tide height.

The Susquehanna and Potomac Rivers have large estuaries, large drainage basins, and comparatively high discharge. Chesapeake Bay above the mouth of the Potomac can be considered the estuarine part of the Susquehanna River. The discharge of the Susquehanna River, and to a lesser extent the discharge of the Potomac River, determine the extent of brackish-water penetration into their estuaries.

The Choptank, Nanticoke, Pocomoke, and Patuxent are much smaller rivers with correspondingly smaller estuaries and drainage basins. The discharge from these rivers and local tidal conditions determine where Chesapeake Bay water and river water will physically mix, but the extent of brackish water is controlled by the specific conductance of the water entering at the mouth of the river. The specific conductance of the Bay at the mouth of each river is in turn determined by the discharge of the Susquehanna and, to a lesser degree, by the discharge of the Potomac River. The smaller rivers generally contain relatively fresh water in the upstream 10 to 20 miles of estuary.

The Chester and Sassafras Rivers have very small drainage areas, and fresh-water discharge to their estuaries is low in comparison to estuary volumes. The drainage basin of each river is distributed evenly around the perimeter of the estuarine part. Thus, there is limited concentration of discharge at the head of these estuaries and water throughout the estuaries is almost undiluted by fresh-water discharge. Water in the Sassafras River, however, is usually much fresher than water of the Chester River because of the proximity of the Sassafras River to the Susquehanna River.

The length, depth, width, and sinuousity of an estuary strongly influences the extent of brackish-water penetration. The Pocomoke River is long, very sinuous, narrow, and relatively shallow at its mouth. It is rarely brackish above Pocomoke City, about 17 miles upstream from its mouth. The Patuxent River is long, wide, deep, but less sinuous. Brackish water is nearly always present at Benedict, 23 miles upstream from its mouth, although Chesapeake Bay is normally less brackish at the mouth of the Patuxent than at the mouth of the Pocomoke.

Effect of the Chesapeake and Delaware Canal

It is estimated that the net discharge through the C & D Canal from Chesapeake Bay to the Delaware Bay will increase from 700 to 2,200 cfs (cubic feet per second) when current improvements to the canal are completed (written communication, H. F. Michel, U.S. Corps of Engineers, Philadelphia District, December 11, 1968 to District Engineer, U.S. Corps of Engineers, Baltimore District.) A discharge of 2,200 cfs is less than the lowest monthly mean discharge to the Bay during the years 1951–69. The effect of diversion of an increased amount of water from near the mouth of the Susquehanna River to Delaware Bay would be to increase the extent of brackish water penetration in Chesapeake Bay, and thus increase the salinity at the mouths of the tributary rivers down the Bay.

Effect of Evaporation

One of the minor controls on the extent of brackish water in the estuaries of Maryland is the rate of evaporation. A moderate evaporation rate of 0.12 inches per day (3.76 inches per month) withdraws water from the surface of Chesapeake Bay at a rate of 14,000 cfs. Therefore, during periods of low discharge, deficient precipitation, and high evaporation, the net flow would be from the Atlantic Ocean to the Bay and result in an increase in the penetration of brackish water. From 1951 to 1968 the monthly rainfall and stream discharge was exceeded by evaporation for 14 months. During these months the highest estimated monthly average rate of inflow from the ocean of 17,000 cfs occurred during July 1966. The longest period of net inflow from the ocean was during July through September 1964 when an average of 2,000 cfs entered the Bay from the ocean.

Effects of Hurricanes

Storm systems which were hurricanes in the Caribbean Sea occasionally pass through the Chesapeake Bay area. These storm systems, although not of hurricane strength, are normally called hurricanes, and the name applied to the hurricane is associated with them. The net effect on the salinity of the Bay from such storms has not been measured.

Some effects of these storms, however, have been noted on Delaware Bay by Cohen and McCarthy (1962). Reduction in barometric pressure associated with a hurricane normally produces tide height rises of about 1 foot for each inch of mercury decrease in atmospheric pressure. This effect can be accentuated or decreased depending upon the path of the hurricane in relation to the Bay. When a hurricane passes to the west of Delaware Bay the counter-clockwise winds cause the tide height to increase even above the levels expected from the pressure drop. When a hurricane passes to the east of the Bay the winds tend to decrease the tide heights, but usually not enough to cancel the increase in tide height due to the pressure drop.

The tide height increase causes an increase in brackish-water penetration. However, the increased discharge caused by rain associated with a hurricane will often flush an estuary so that the extent of brackish water is less than it was before the hurricane moved in. Durfor (1961) noted that as a result of a hurricane the chloride content of the Potomac River at Indian Head, Md. dropped from 1,200 mg/l on October 19, 1954 to 13 mg/l on October 20, 1954.

PROPORTIONAL EFFECTS OF FIXED AND VARIABLE CONTROLS ON EXTENT OF BRACKISH WATER

The result of the several factors controlling the extent of brackish water can be shown by plotting them on a single graph that shows changes with time. On figure 7 the record of specific conductance on the Patuxent River at Benedict for 1964-67 is shown with discharge, tide height, and precipitation data for the same period.

The total discharge from December through May seems to control the maintenance of the minimum specific conductance for any extended period. In 1964 the total discharge for the year was much greater than the average for the 1965–67 period; the minimum of the weekly average specific conductances was much less. The maximum specific conductance at Benedict occurs prior to the first periods of sustained high discharge in the fall, normally about October. However, if rainfall is deficient in the fall, the maximum conductance may occur in late November or December as it did in 1964 and 1965. Momentary extremes may occur as a result of short-term events in almost any season. For example, Cory and Nauman, 1967, report the record low salinity at this site for the 1963–67 period on January 11, 1964.

The average of the observed weekly average high and weekly average low tide height shows that the tide height is about one-half a foot higher from March through October than from November through February. The half a foot rise seems to have less effect on the weekly average specific conductance than does discharge on a yearly basis. The tide height does have a direct relation to specific conductance on a daily basis as shown on figure 8.

Heidel and Frenier (1965) have shown that in the Patuxent River brackish water may be upstream or downstream from Nottingham seasonally. A continuous record of specific conductance and tide height was obtained for the present study at Nottingham. This record (figure 8) shows that on a daily basis the specific conductance is dependent upon the tide height at the section through which the salt front is moving. For example, if the height of a high tide is lower than the height of one of the preceding low tides the specific conductance will also be lower as shown in figure 8. The tide height from December 6–10, 1968 was almost a foot lower than adjacent periods; as a result water during this period was almost fresh at Nottingham. The absolute tide height at a given time appears to depend principally upon prevailing winds and weather conditions. Tide tables will accurately predict the time of high and

low tides within an hour in the report area, but for a period such as December 3–15, 1968 would not show the extent of weekly cyclic variations and actual range in tide height of about 4 feet. Specific conductance normally drops sharply after significant rainfall and builds up slowly.

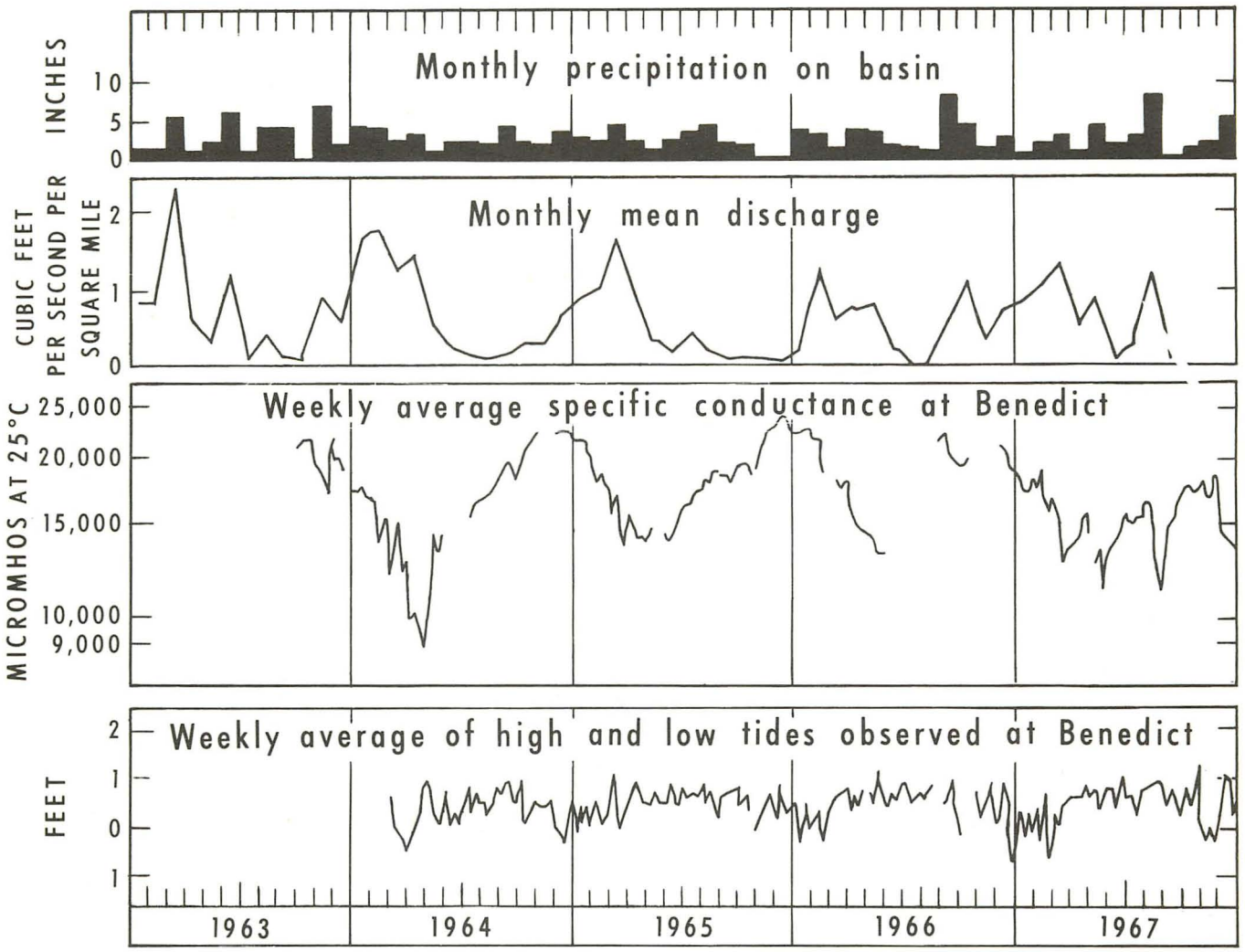


Figure 7—Graphs showing relation of precipitation, discharge, specific conductance, and tides in Patuxent River basin.

SUMMARY OF EXTENT OF BRACKISH WATER

Detailed information necessary to predict the frequency or time at which brackish water will penetrate upstream to a given section of any estuary in Maryland is not available. Most estuaries will usually contain fresh water for a considerable distance downstream from the maximum reach of tidal effect. However, definite distances cannot be reliably computed without many measurements over an extended period. For example, from Murphy's reconnaissance (1957) it might be assumed that the Wicomico River upstream from Upper Ferry is satisfactory for irrigation at any time regardless of tide height (figure 9). The maximum observed specific conductance at Upper Ferry in 1952 was 213 micromhos. As shown in table 4 in the appendix specific conductances as high as 2,760 micromhos (June 27, 1967) were observed at Upper Ferry during the present investigation, and "very high salinity water," (above 2,250 micromhos) according to Wilcox

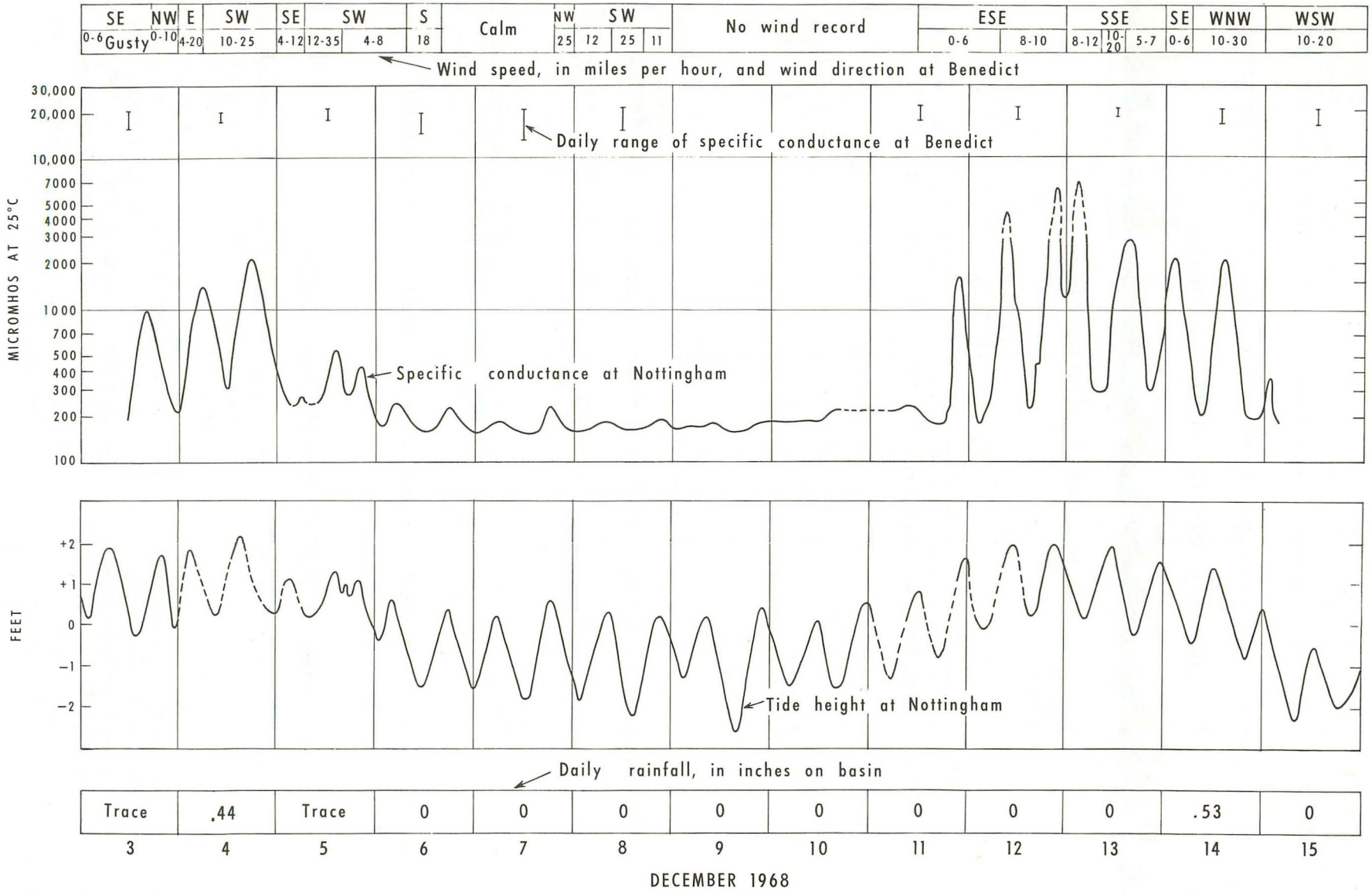


Figure 8—Graphs showing tide height, rainfall, specific conductance, wind direction and speed of Patuxent River during December 1968.

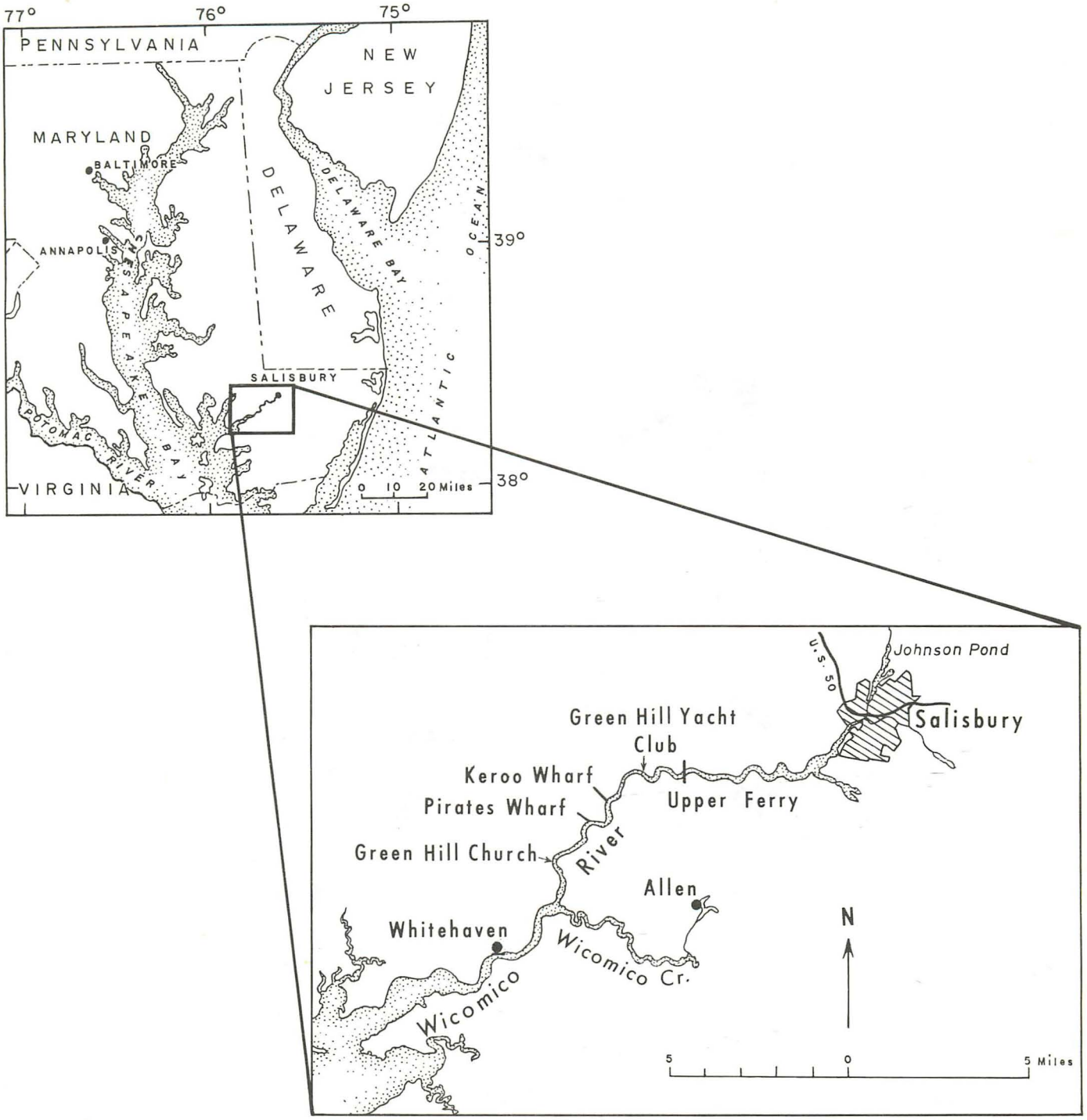
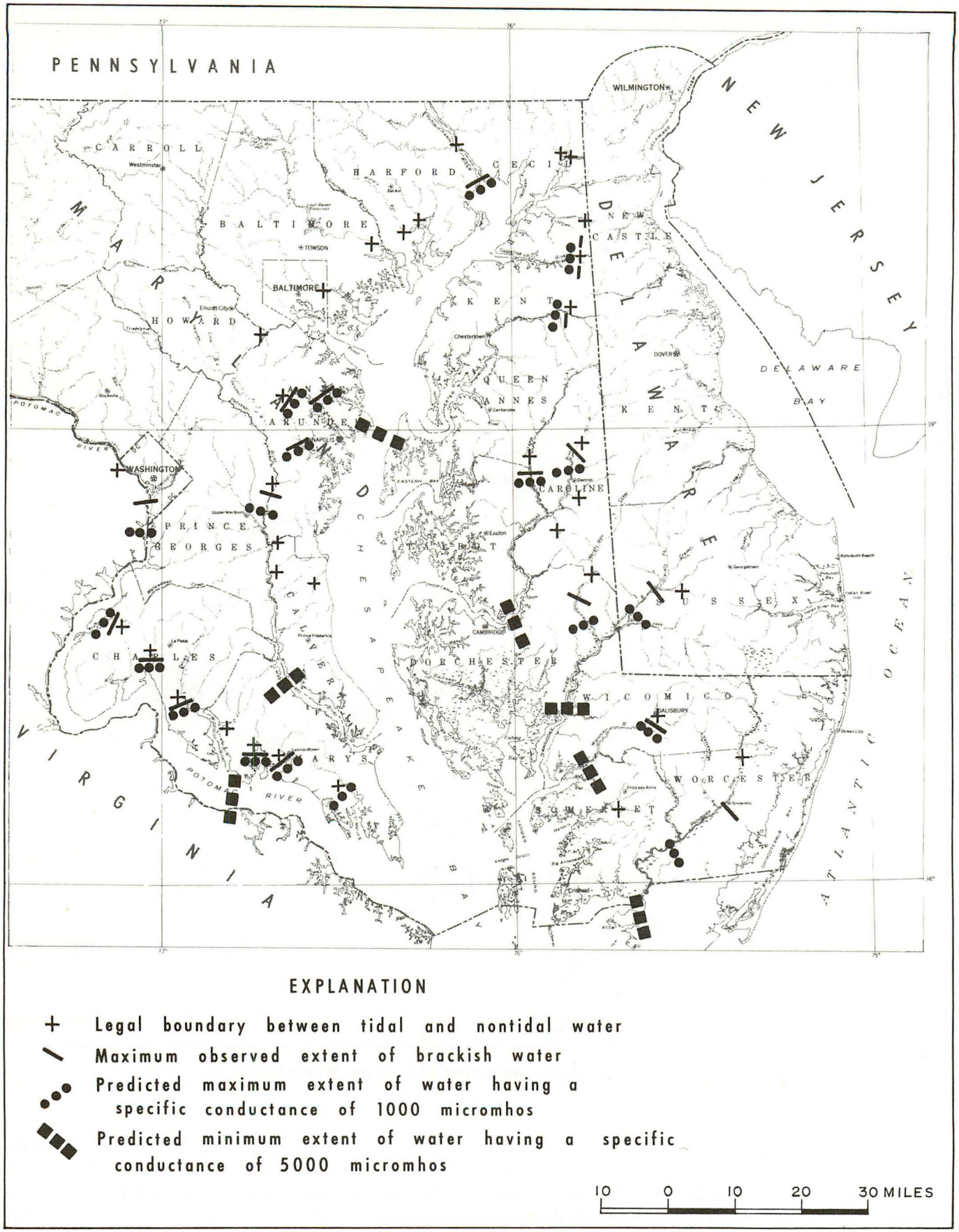


Figure 9—Map showing sampling sites on the Wicomico River.

(1955) is not suitable for irrigation under ordinary conditions. The present investigation covered a period of unusually low discharge, and table 1 shows specific conductances at several estuary sections which were higher than had been measured previously.

To summarize the preceding sections which describe the controls on the extent of brackish water one can say less brackish water will be found at times and places listed on the left below, and more brackish water can be found at times and places listed at the right below.



EXPLANATION

+ Legal boundary between tidal and nontidal water

/ Maximum observed extent of brackish water

●●● Predicted maximum extent of water having a specific conductance of 1000 micromhos

■■■ Predicted minimum extent of water having a specific conductance of 5000 micromhos

10 0 10 20 30 MILES

Figure 10—Map showing summary of extent of brackish water.

Table 1. Summary of extent of brackish water in Maryland's tidal rivers

River basin	River	Legal boundary between tidal and nontidal water		Maximum extent of brackish water observed			
		Location	River mile	Location	River mile	Maximum specific conductance	
						Date	Micromhos at 25°C
Pocomoke	Main stem	Whiton Crossing 3 mi south of Powellville, Md.	42	Snow Hill, Md.	32	10/19/66	150
Wicomico	Main stem	N. Prong; Dam at Johnson Pond, Md.	--	U.S. Hwy. 50 at Salisbury, Md.	21	10/20/66	185
Nanticoke	Main stem	11 river miles upstream from Delaware State line	45	Seaford, Del.	40	11/29/68	160
	Marshy-hope Creek	Md. Hwy. 313 at Federalsburg, Md.	--	Md. Hwy. 392 near Hurlock, Md.	--	11/29/68	290
Choptank	Main stem	Md. Hwy. 313 Alt. at Greensboro, Md.	60	Md. Hwy. 313 Alt. at Greensboro, Md.	60	9/10/64	138
	Tuckahoe Creek	Old dam about 3 mi. N. of Hillsboro, Md.	--	Md. Hwy. 404 at Hillsboro, Md.	--	11/28/68	150
Chester	Main stem	At Cypress Branch at Millington, Md.	42	U.S. Hwy. 301 near Millington, Md.	41	9/20/68	440
Sassafras	Main stem	U.S. Hwy. 301	16	U.S. Hwy. 301 near Sassafras, Md.	16	11/29/68	150
Susquehanna	Main stem	Line - Deer Creek to Granite Lodge, Md.	6	Mouth of Susquehanna River	--	9/-/57	1700
Patuxent	Main stem	Queen Anne Bridge at Hardesty, Md.	56	Md. Hwy. 4 near Upper Marlboro, Md.	49	9/4/62	1350
Potomac	Main stem	Little Falls near D. C. Line	120	Hains Pt., D. C.	110	1/7/66	540

	Less brackish	*More brackish*
Time	Spring	Autumn
	Low water slack	High water slack
Place	Up stream	Down stream
	Water surface	Near river bottom

Figure 10 summarizes the extent of brackish water by showing the legal boundary between tidal and nontidal water, the observed maximum extent of brackish water, the predicted maximum extent of water having a specific conductance of 1,000 micromhos and the predicted minimum extent of water having a specific conductance of 5,000 micromhos. The predictions are based on data shown in figures 11–18. Table 1 gives the legal boundary between tidal and nontidal water, and the location of the maximum observed extent of brackish water.

Figures 11 through 18 summarize the present knowledge of extent of brackish water in 7 rivers and Chesapeake Bay.

Figure	*River*
11	Pocomoke River
12	Nanticoke River
13	Choptank River
14	Chester River
15	Sassafras River
16	Chesapeake Bay
17	Patuxent River
18	Potomac River

Each figure contains four parts. Part A is a map of the river showing river mile points, towns, roads, sampling sites, and in most cases the entire river basin. Part B is a graph showing drainage area and the low tide volume of the river as a function of river miles. Part C is a graph showing the monthly mean discharge of the gaged part of the basin in cubic feet per second per square mile (cfsm) during 1950 to 1969, and measured specific conductance values at various points along the river. Part D is a specific conductance profile along the main stem of the river showing the maximum and minimum conductivities observed and some selected intermediate values to show ranges at selected sites.

The specific conductance of Chesapeake Bay also influences the extent of brackish water in many small tributary estuaries which have not been discussed in this report. However, the expected range in specific conductance and extent of brackish water in the small estuaries can be estimated by using data shown in figures 11–18.

Figures 11–18 are based on the information available for each river, and thus some of the figures are more likely to be reliable indicators of long-term conditions than are others. In general, the more observations available to construct the figures, the wider the divergence of the maximum and minimum specific conductance observed at any given point. Observations made during the spring months of the early 1950's usually were record low specific conductances at any given point. Observations made during the late summer and early fall in 1964 and 1965 are usually record high observations for the point. When data for these periods are missing the variations in specific conductance tend to be minimized. All extreme data available are plotted but only selected data are plotted within the extremes.

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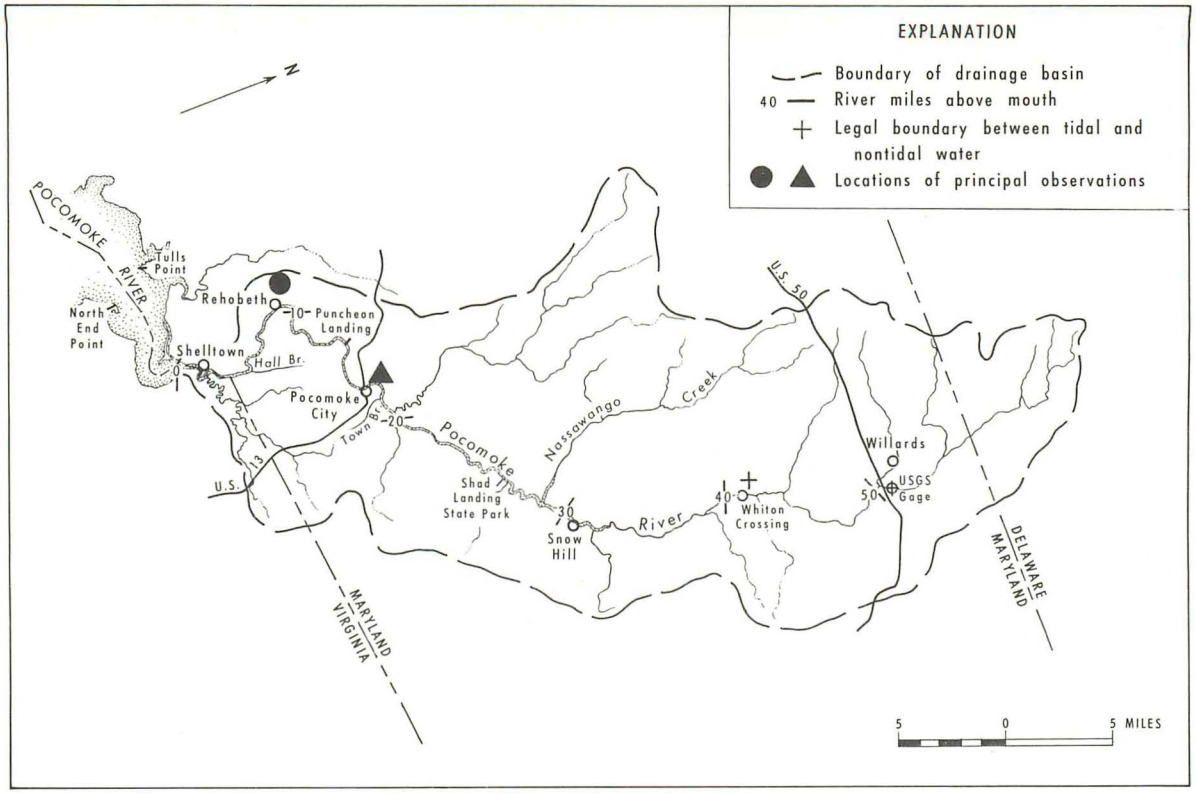
[1] The Maryland Department of Geology, Mines and Water Resources was renamed the Maryland Geological Survey in July 1964.

APPENDIX



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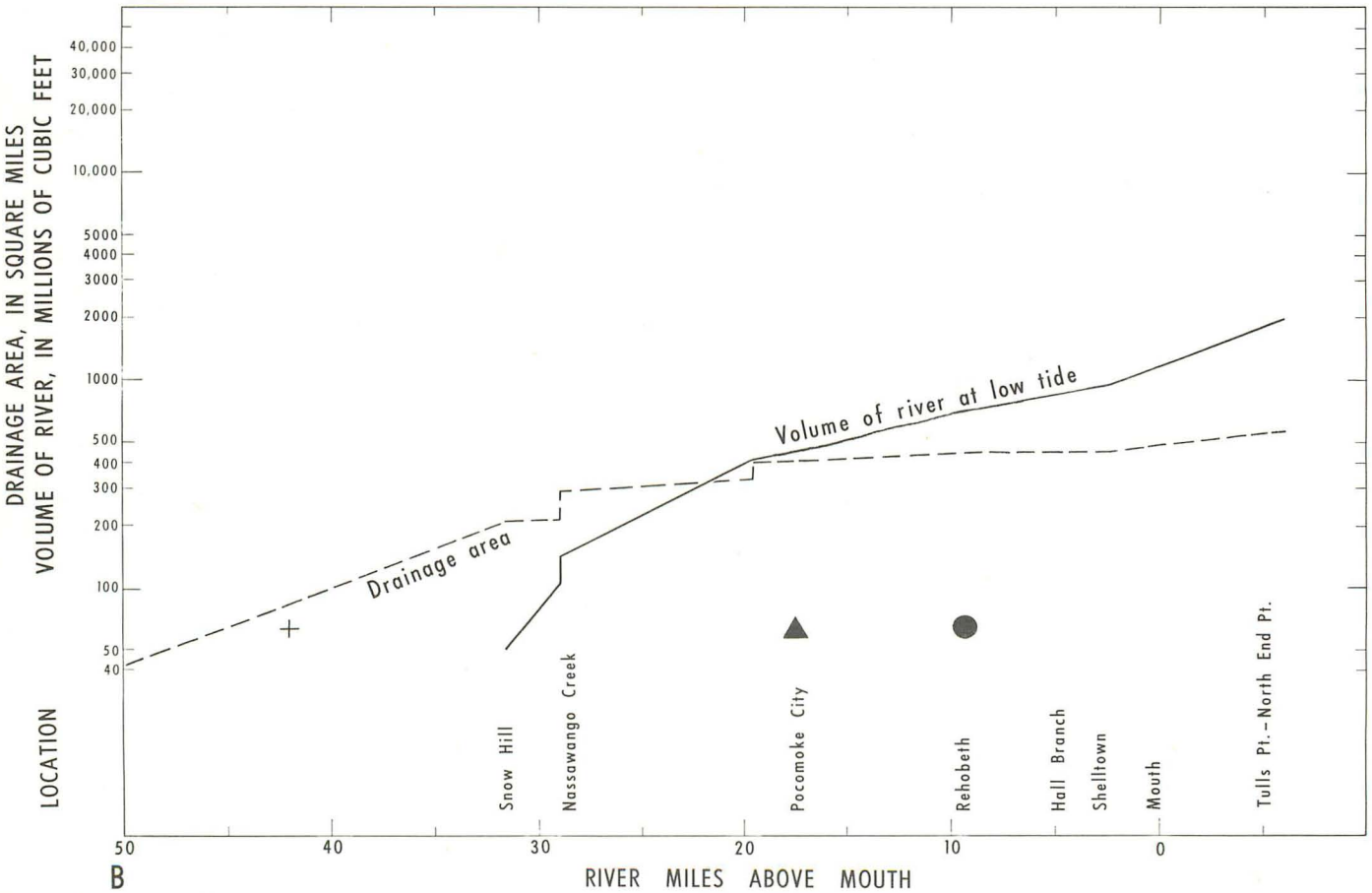
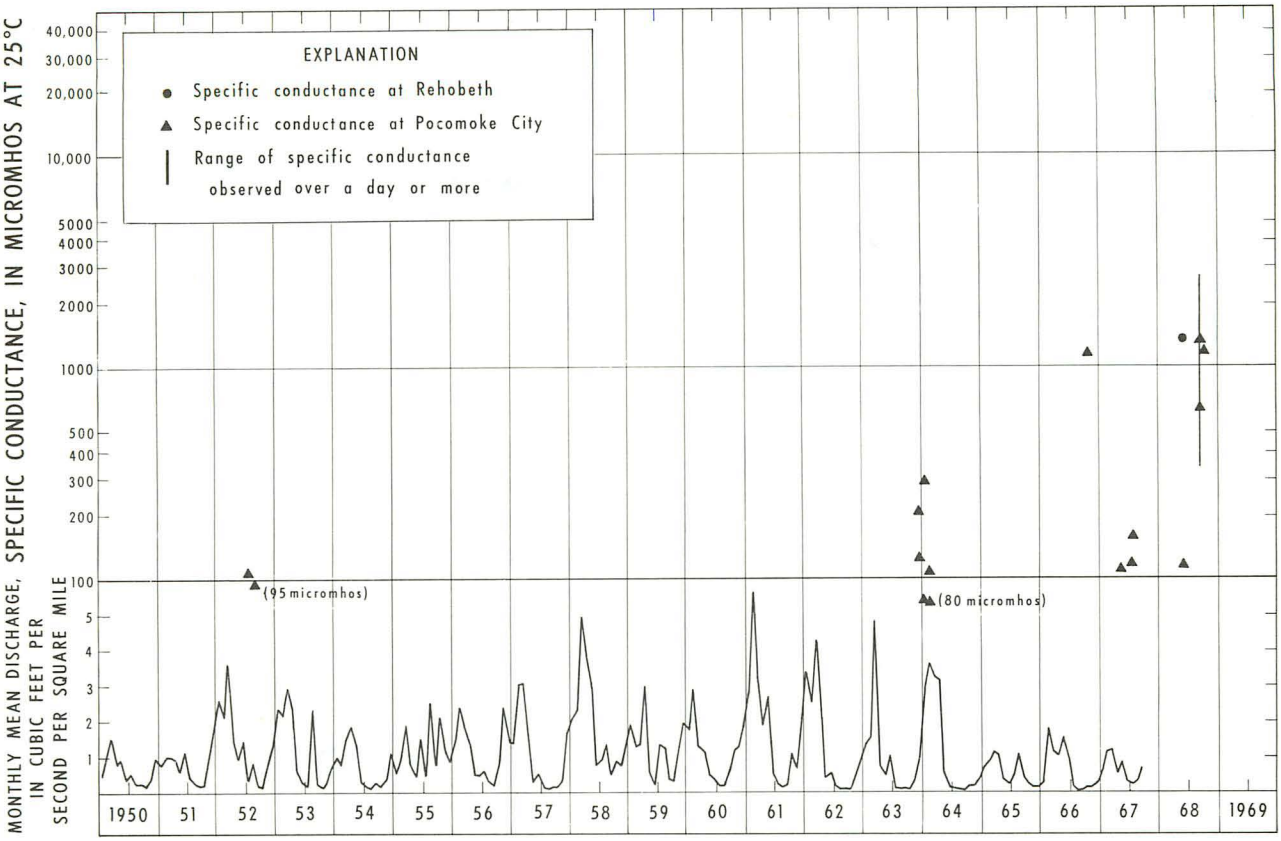


B

Figure 11—Map and graphs of Pocomoke River basin data.
A. Map of the Pocomoke River basin.
B. Drainage area and river volume at locations along the river.



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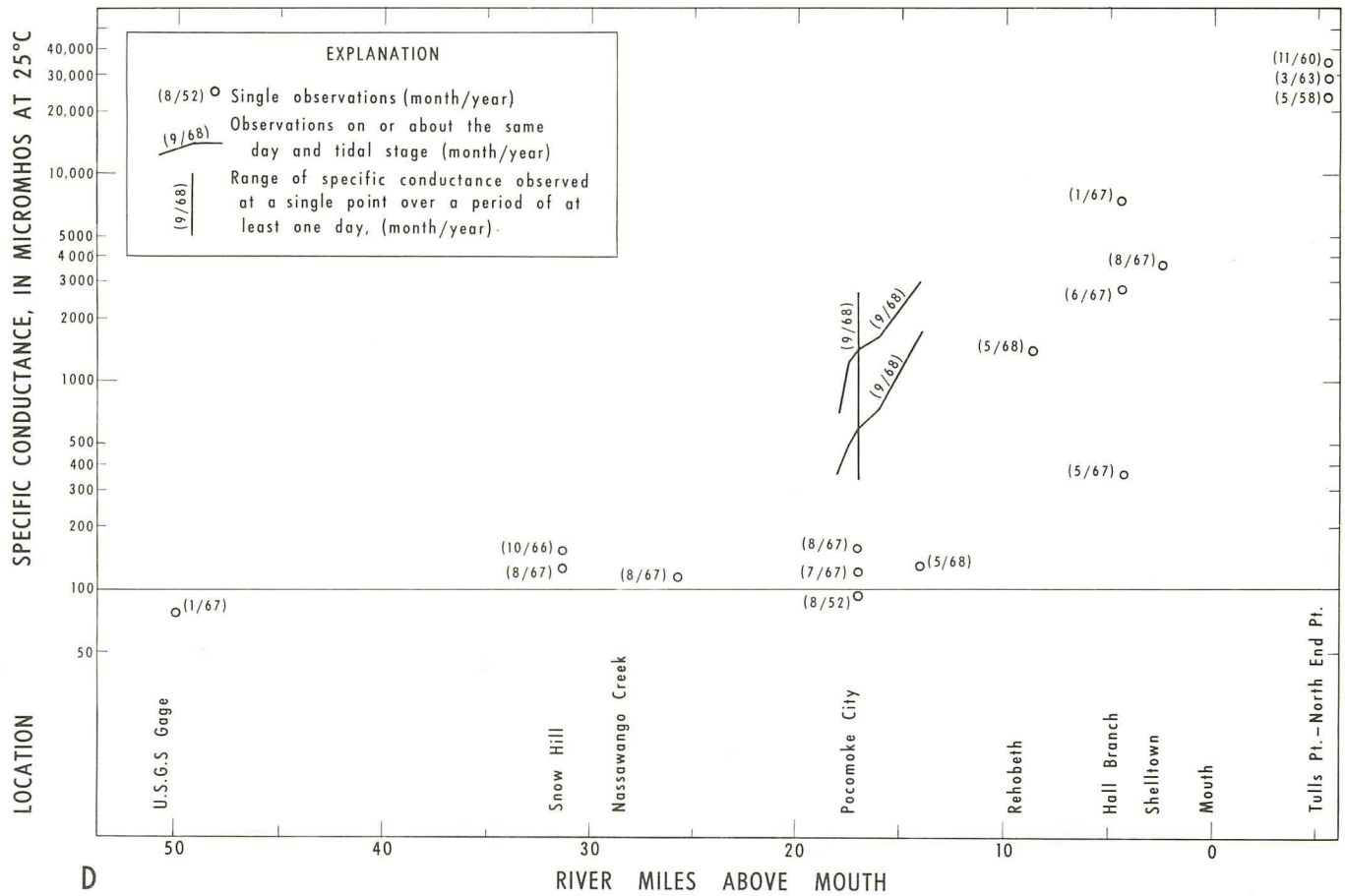
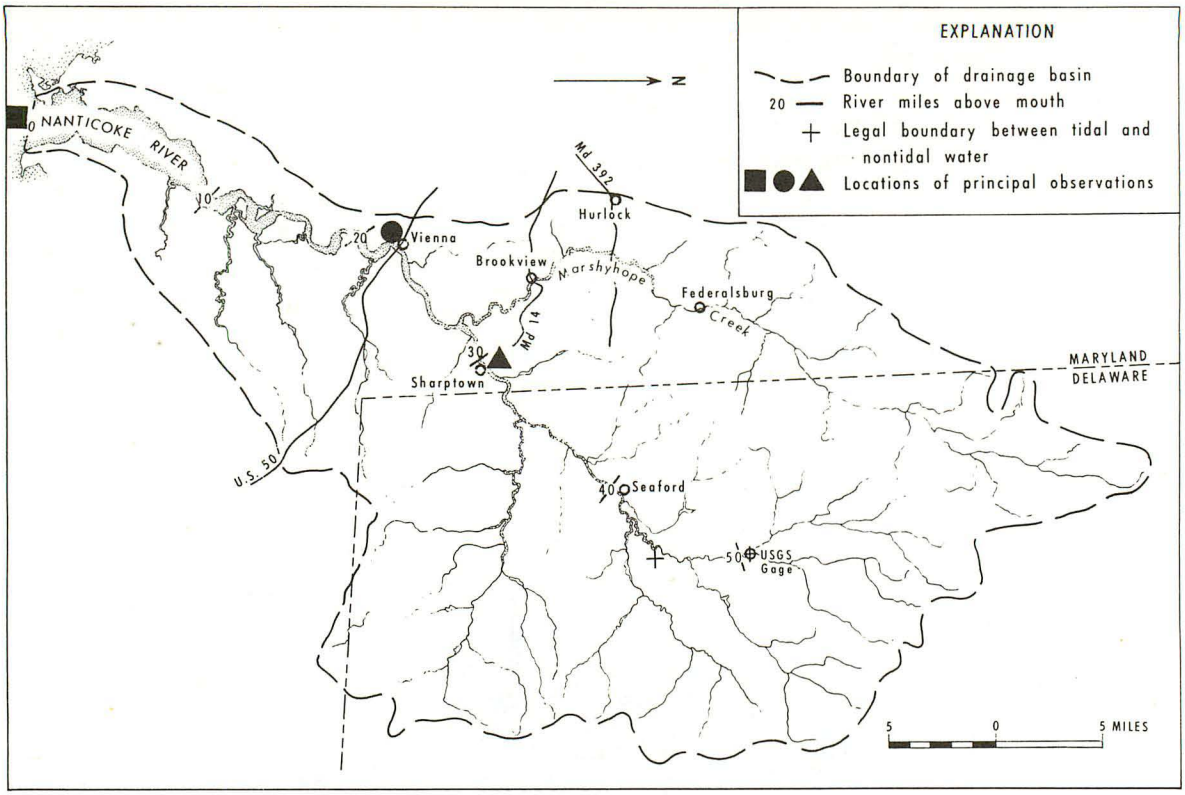


D

Figure 11—C. Variation of discharge and specific conductance with time.
D. Specific conductance values, including observed maximum and minimum values, at locations along the river.



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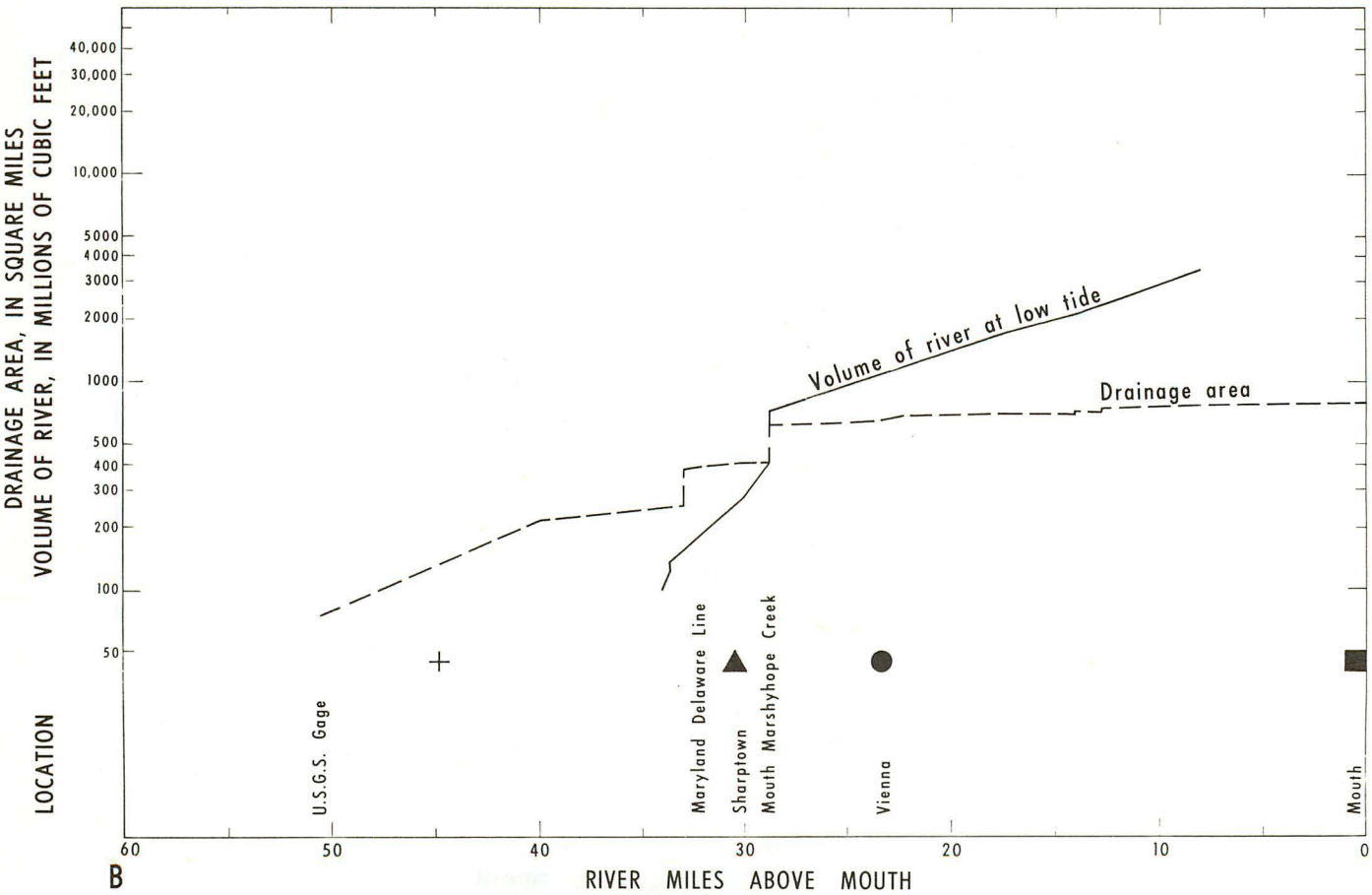
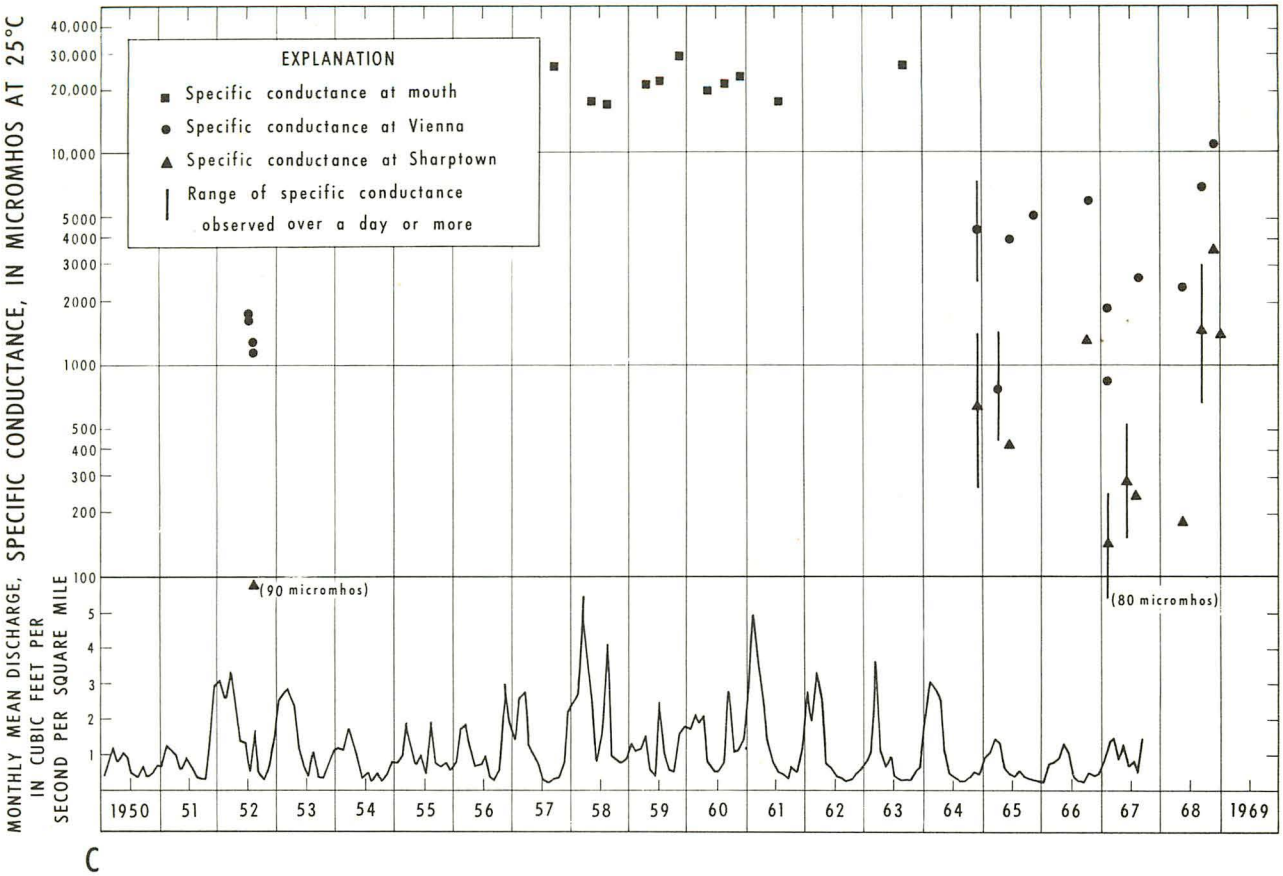


B

Figure 12—Map and graphs of Nanticoke River basin data.
A. Map of the Nanticoke River basin.
B. Drainage area and river volume at locations along the river.



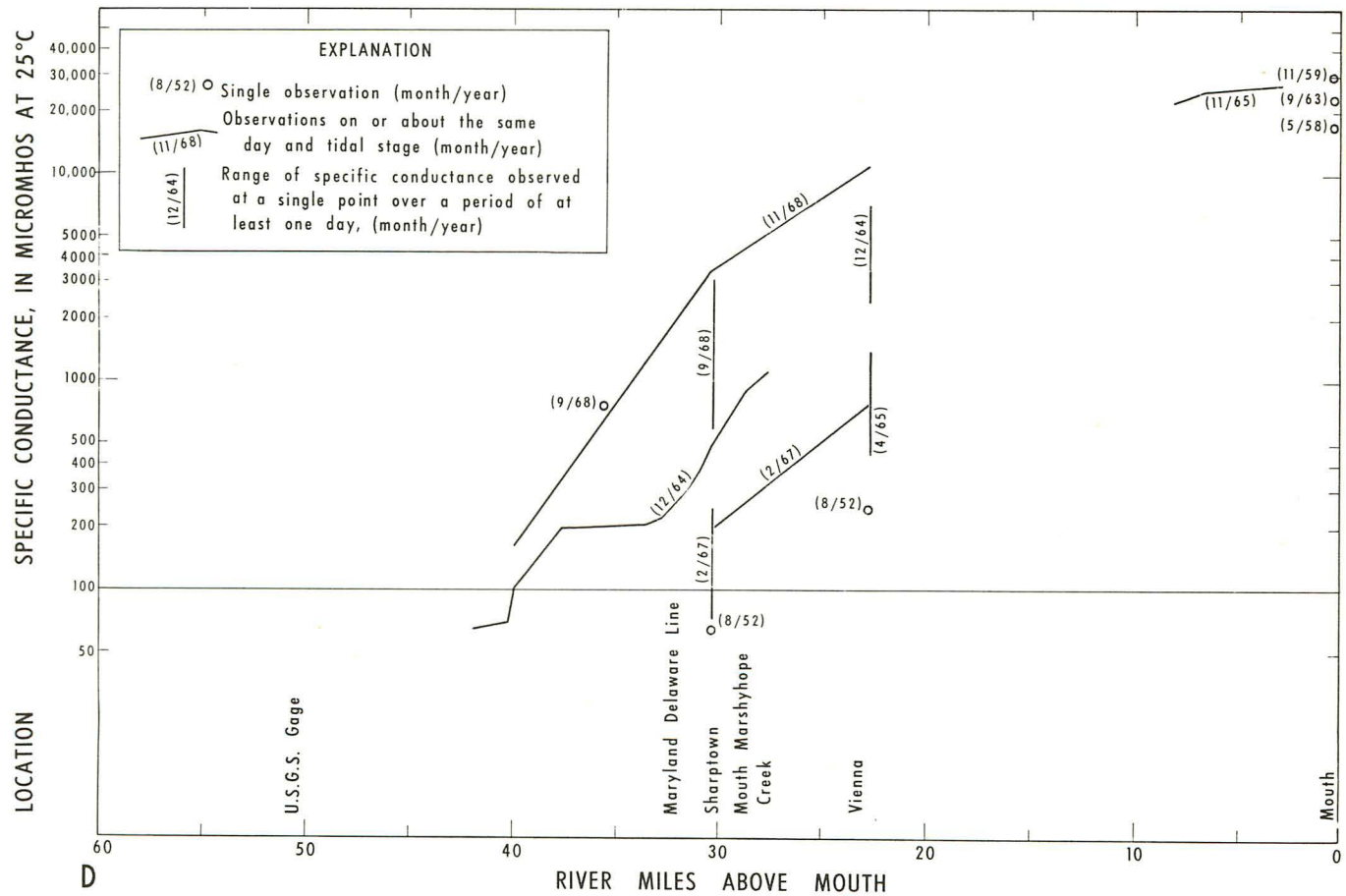
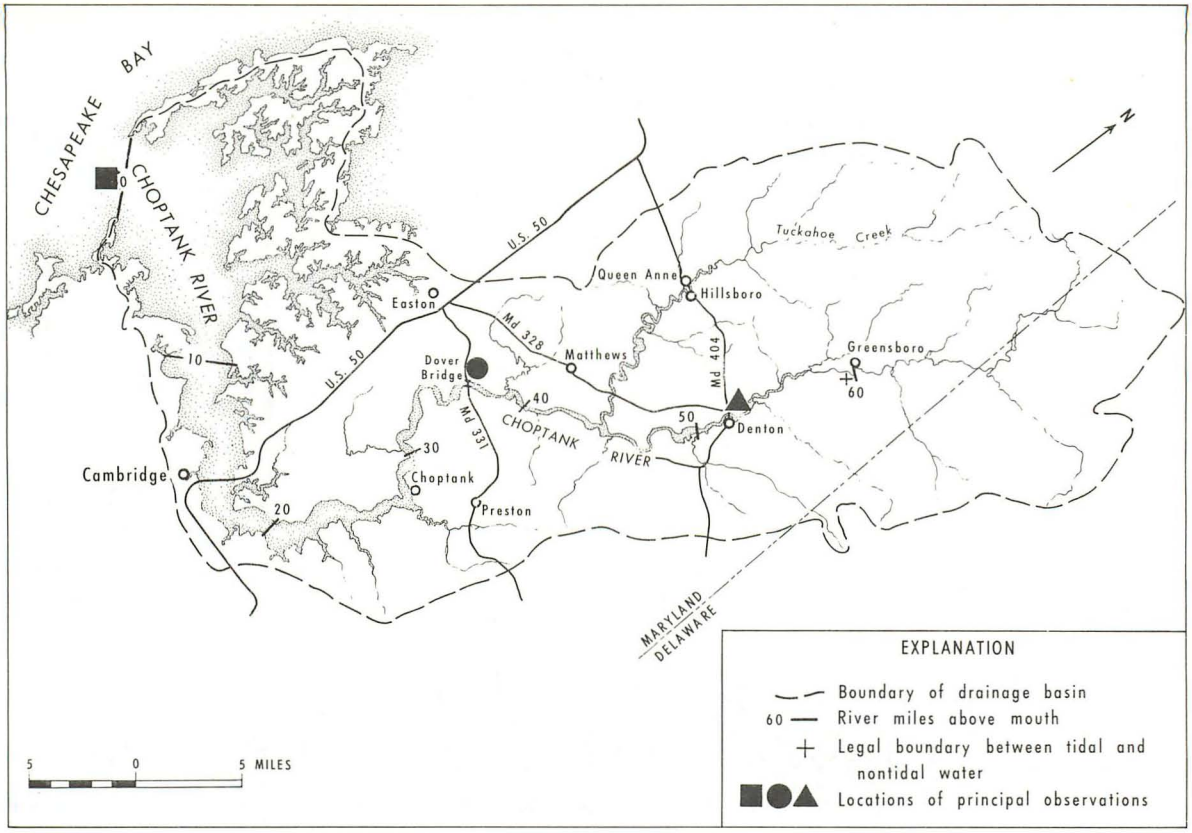


Figure 12—C. Variation of discharge and specific conductance with time.
D. Specific conductance values, including observed maximum and minimum values, at locations along the river.



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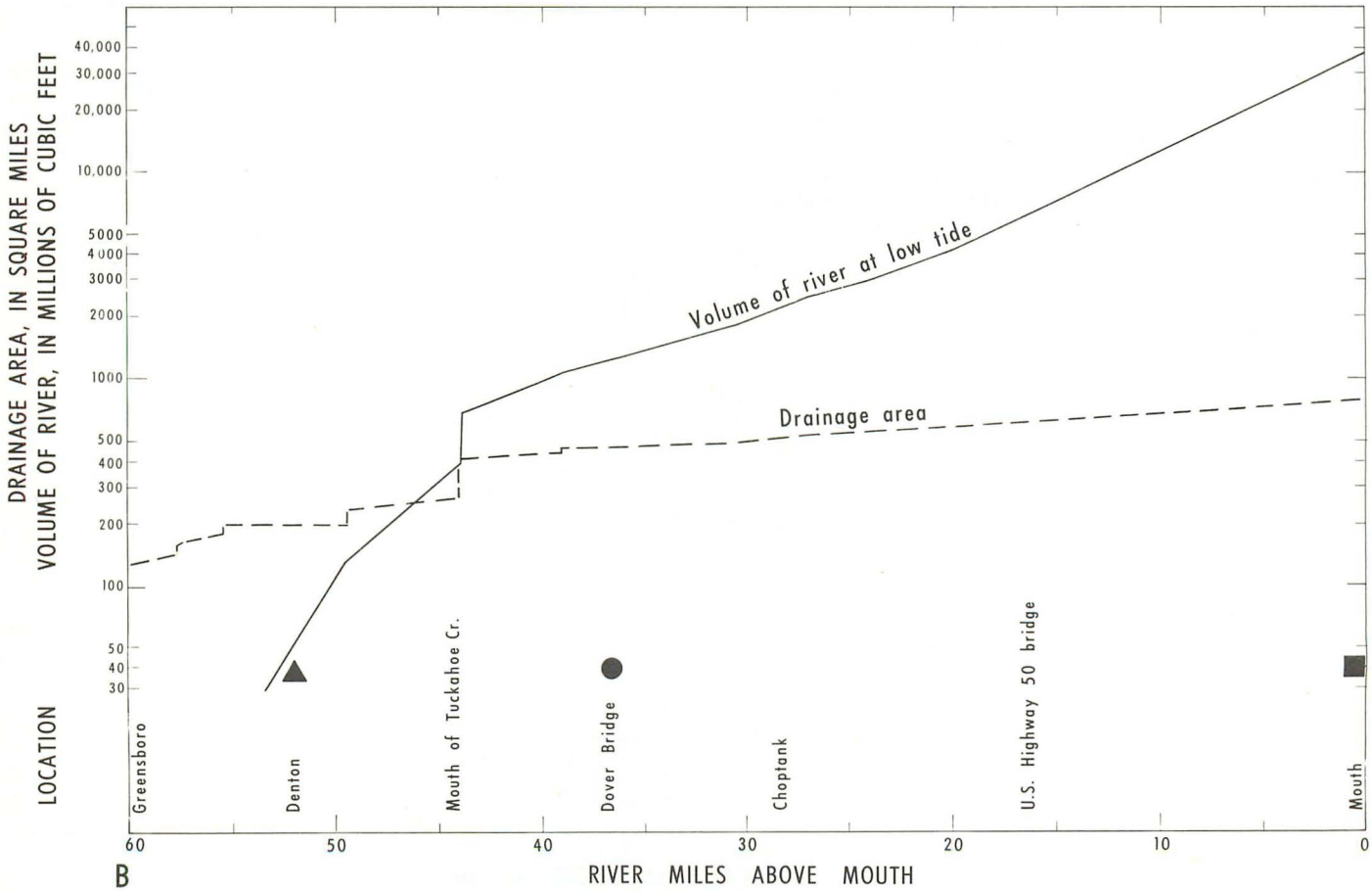

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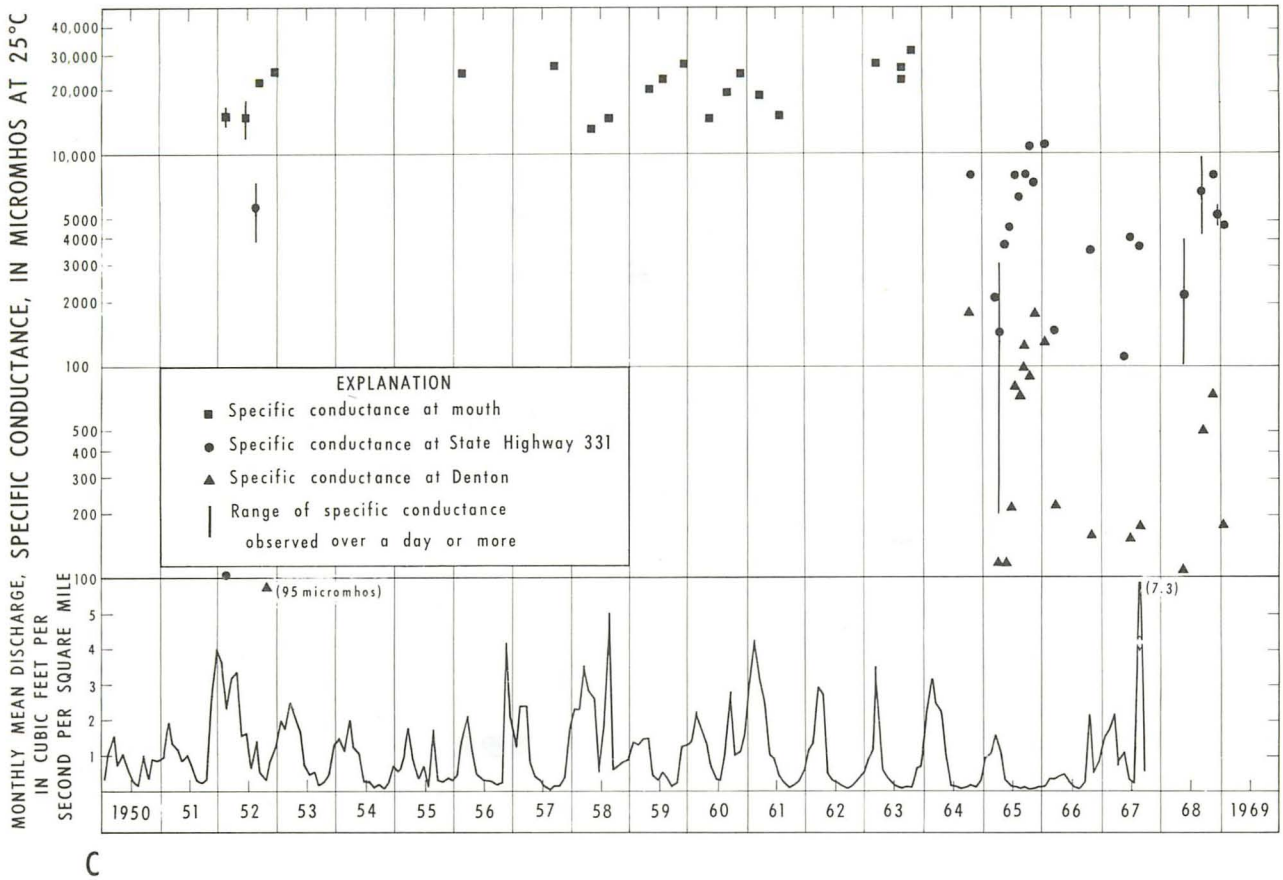
Figure 13—Map and graphs of Choptank River basin data.
A. Map of the Choptank River basin.
B. Drainage area and river volume at locations along the river.



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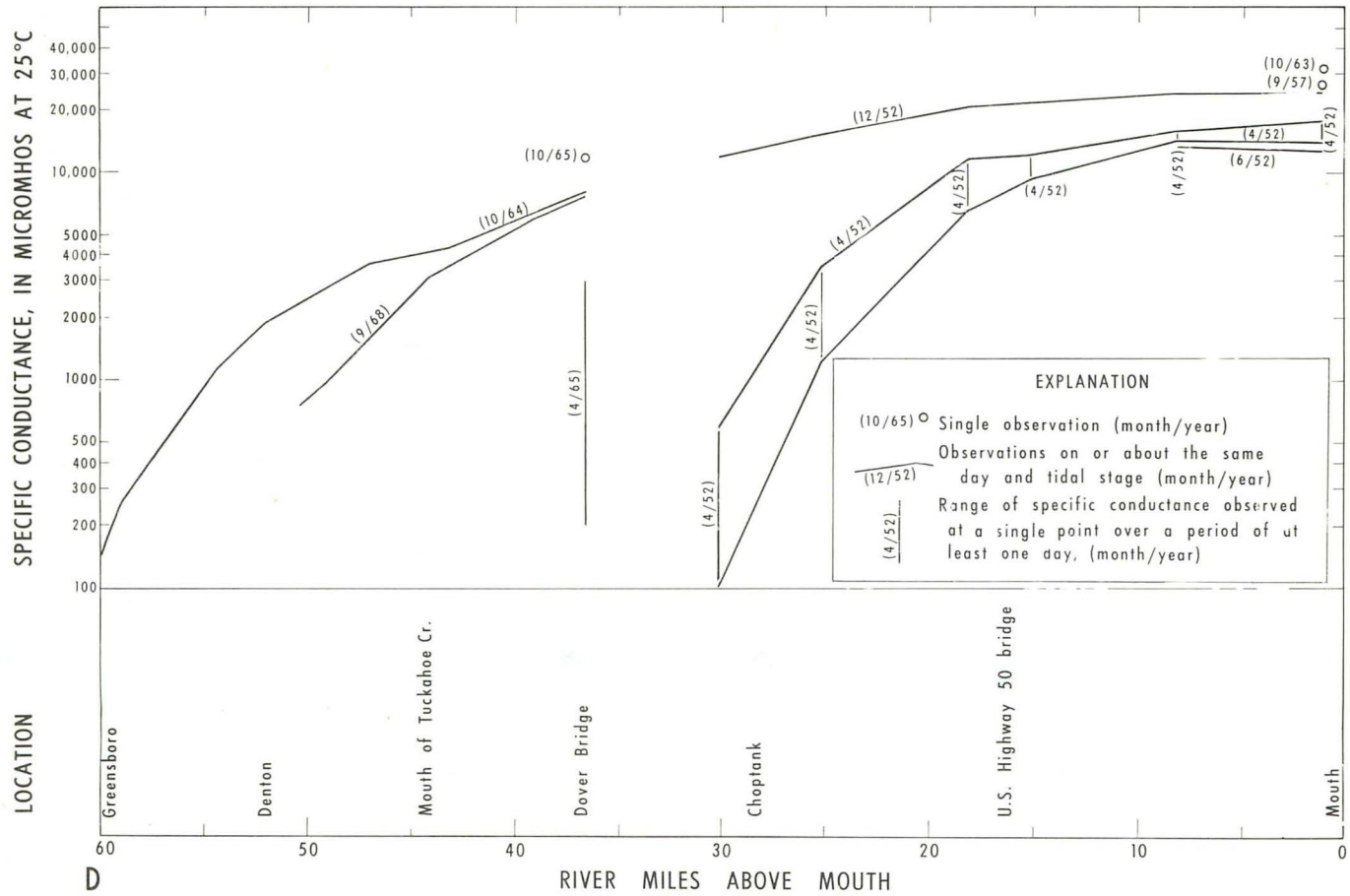

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Figure 13—C. Variation of discharge and specific conductance with time.
D. Specific conductance values, including observed maximum and minimum values, at locations along the river.

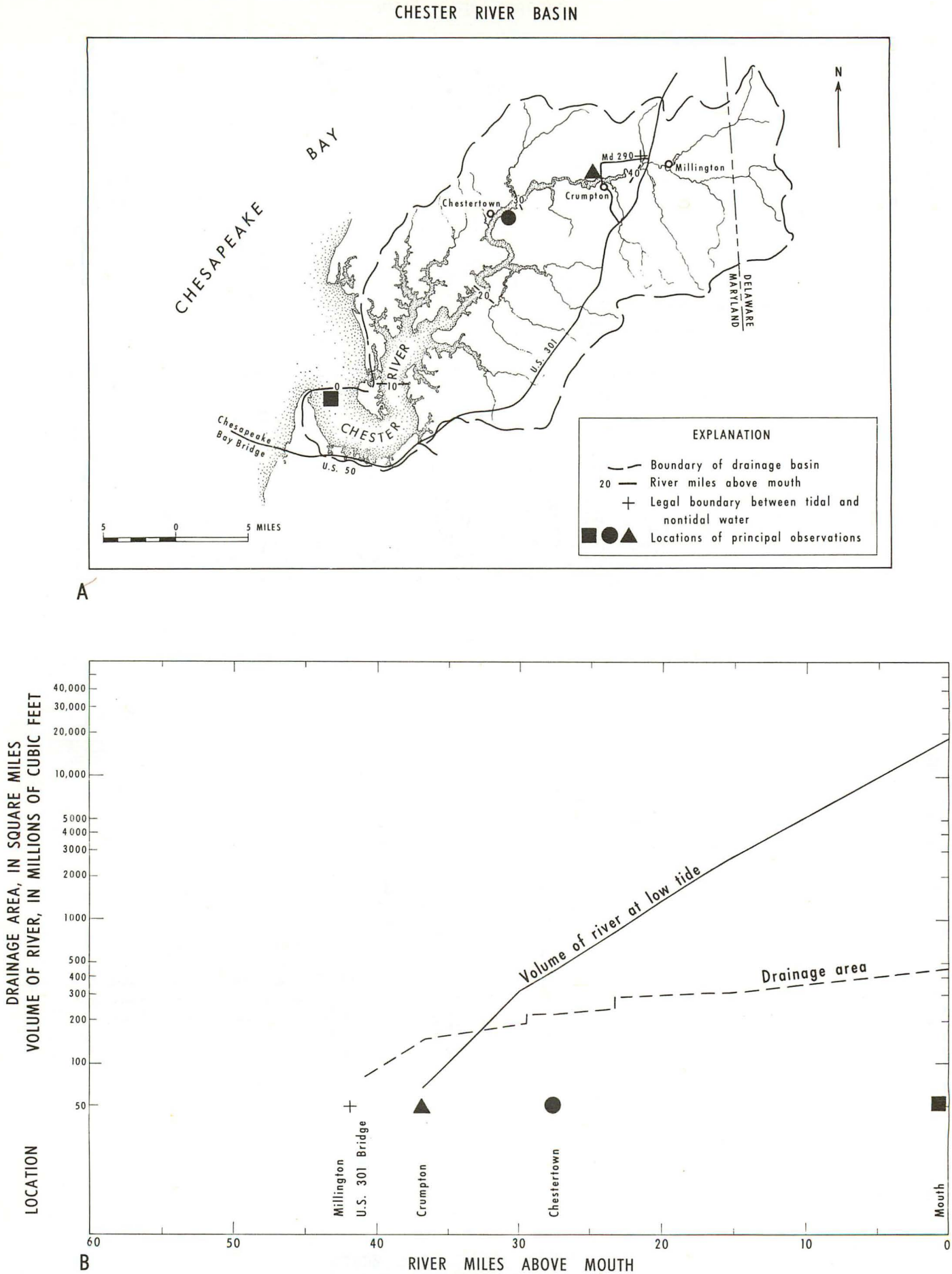
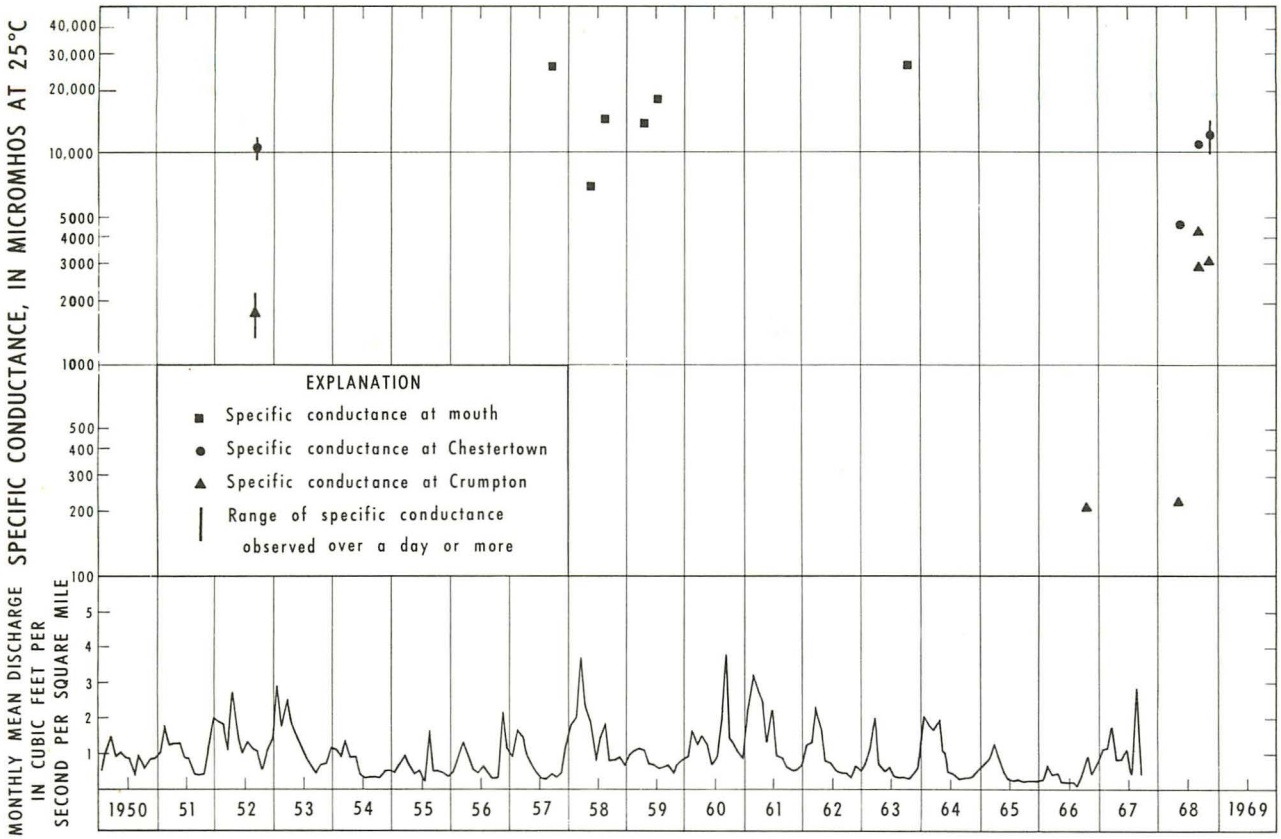


Figure 14—Map and graphs of Chester River basin data.
A. Map of the Chester River basin.
B. Drainage area and river volume at locations along the river.



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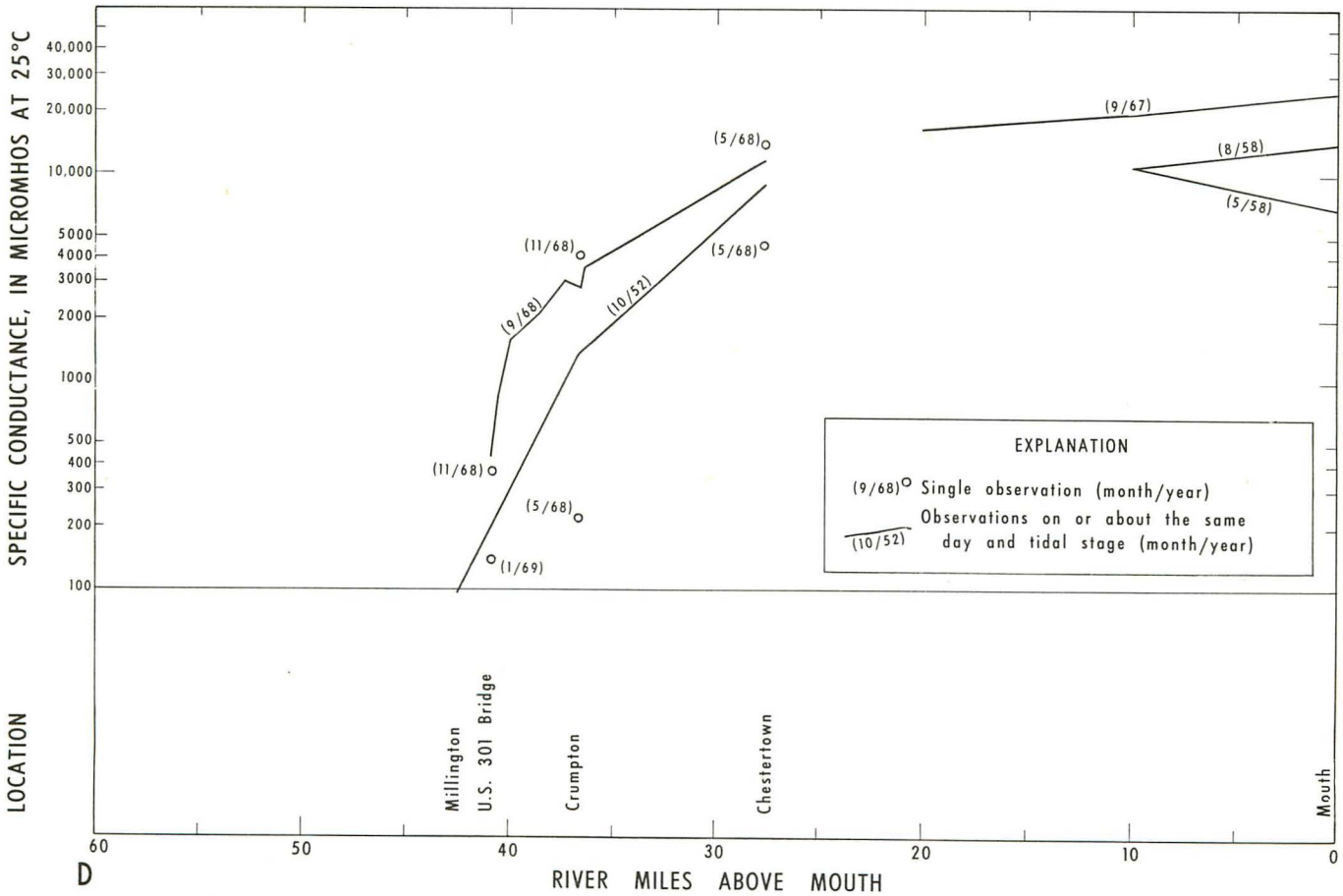


D

Figure 14—C. Variation of discharge and specific conductance with time.
D. Specific conductance values, including observed maximum and minimum values, at locations along the river.

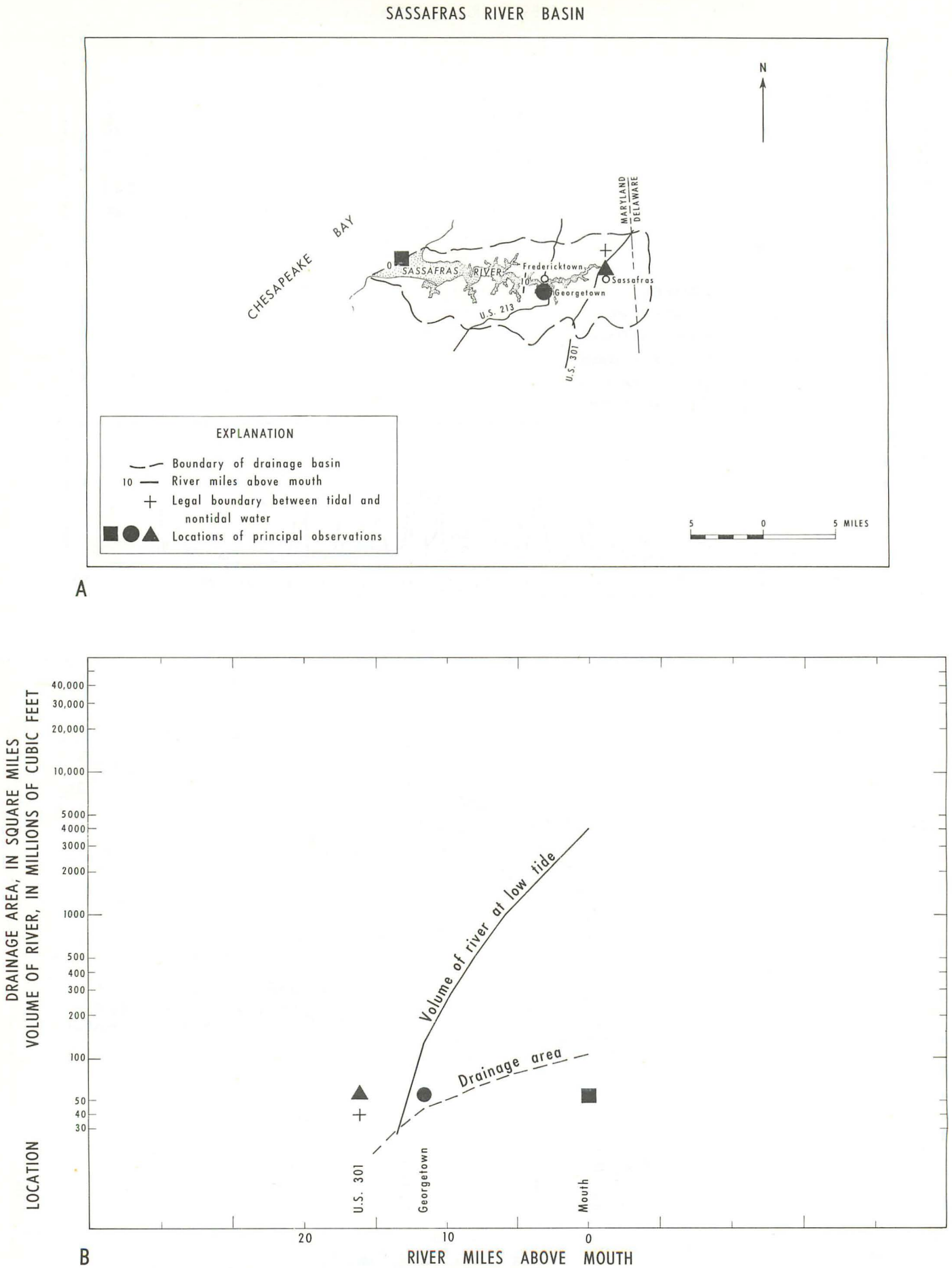
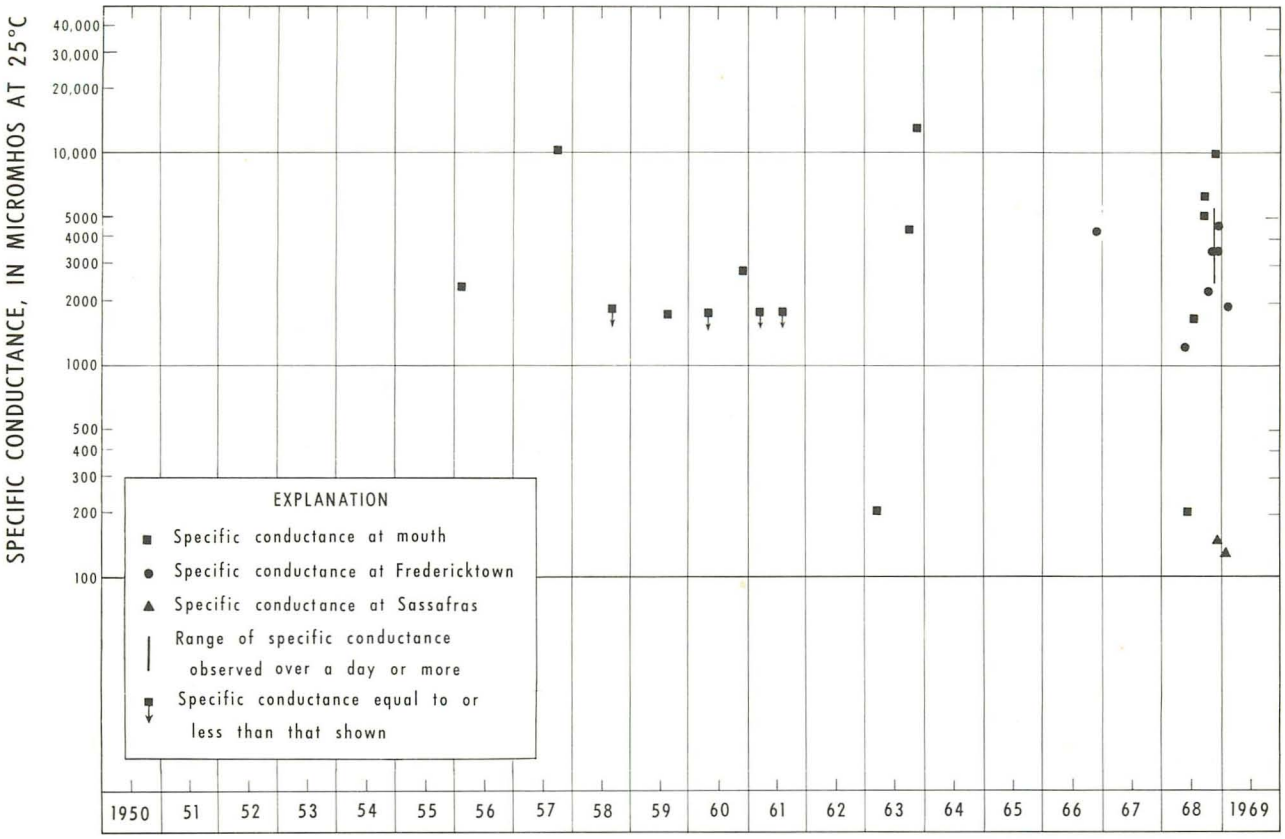


Figure 15—Map and graphs of Sassafras River basin data.
A. Map of the Sassafras River basin.
B. Drainage area and river volume at locations along the river.



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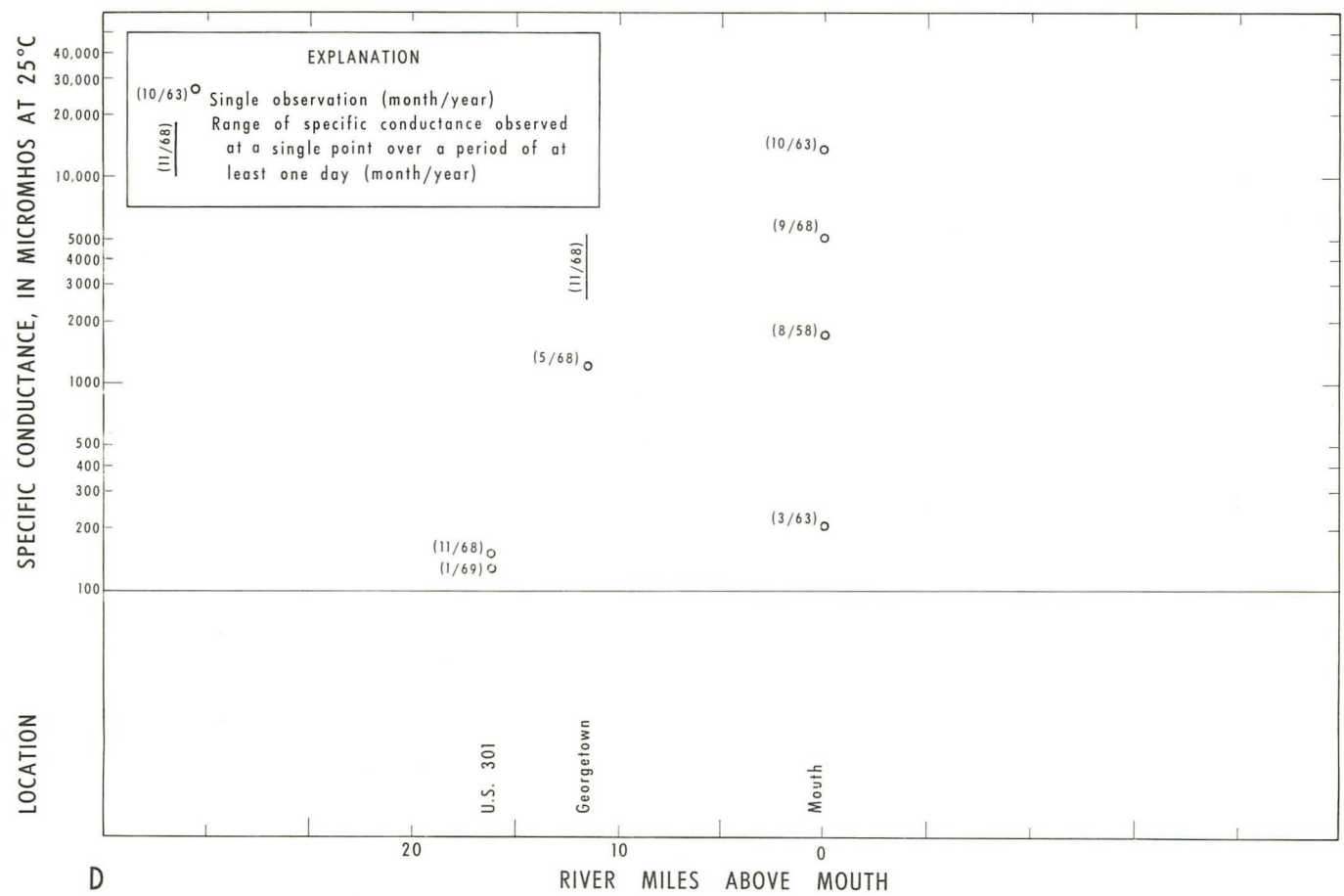

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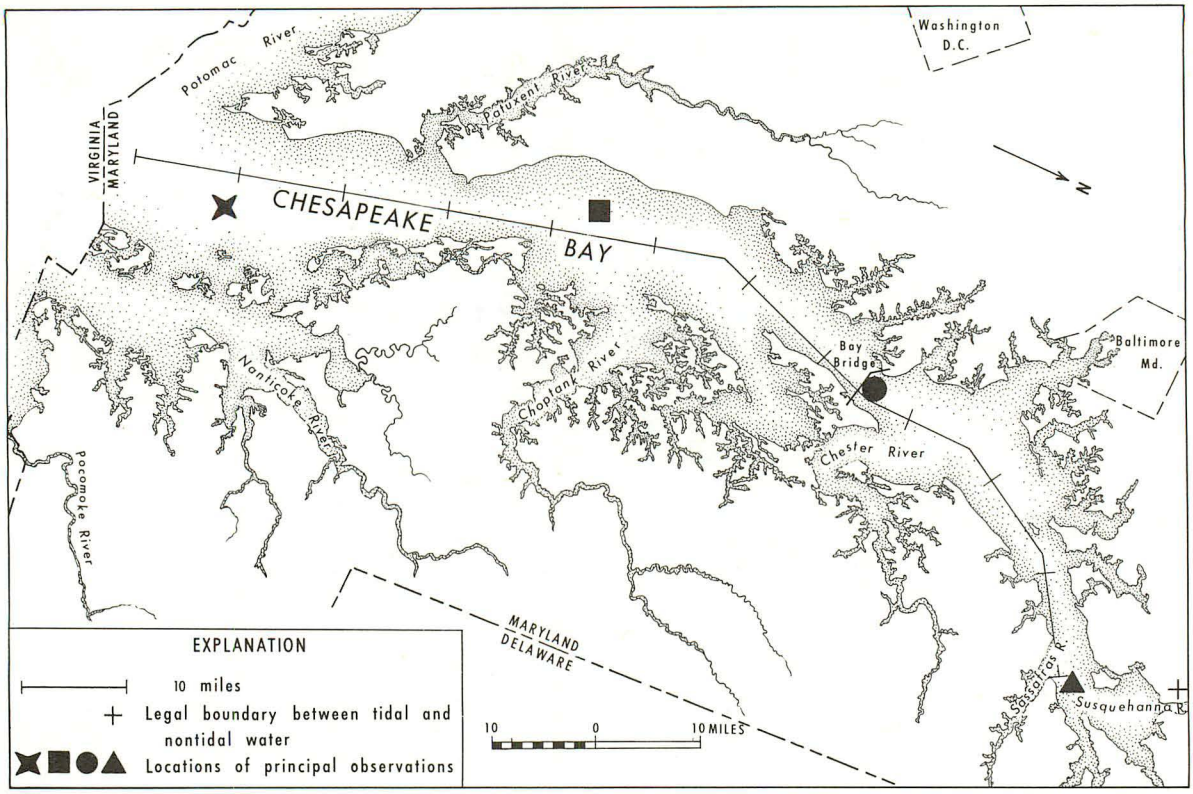
Figure 15—C. Variation of discharge and specific conductance with time.
D. Specific conductance values, including observed maximum and minimum values, at locations along the river.



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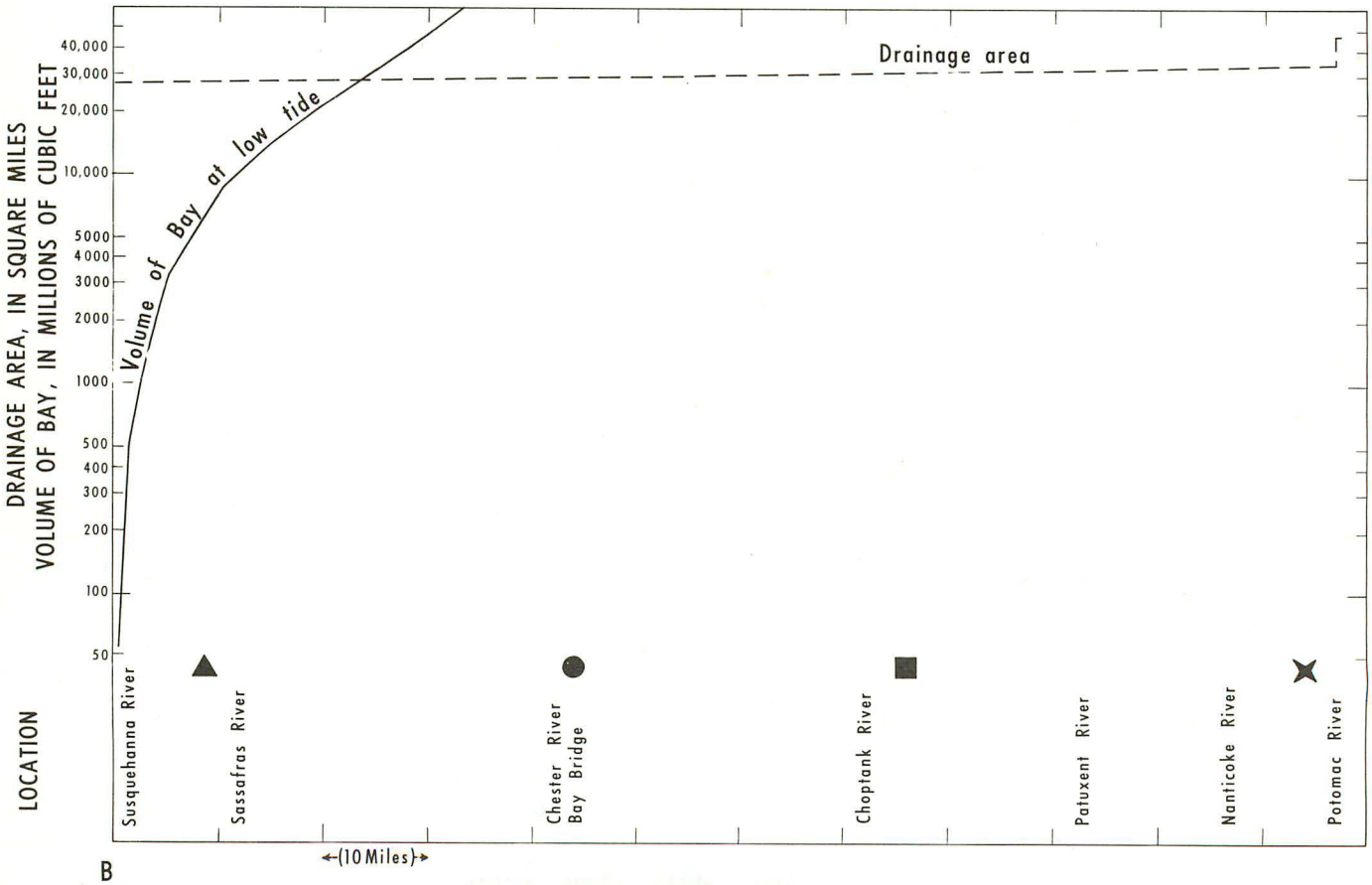
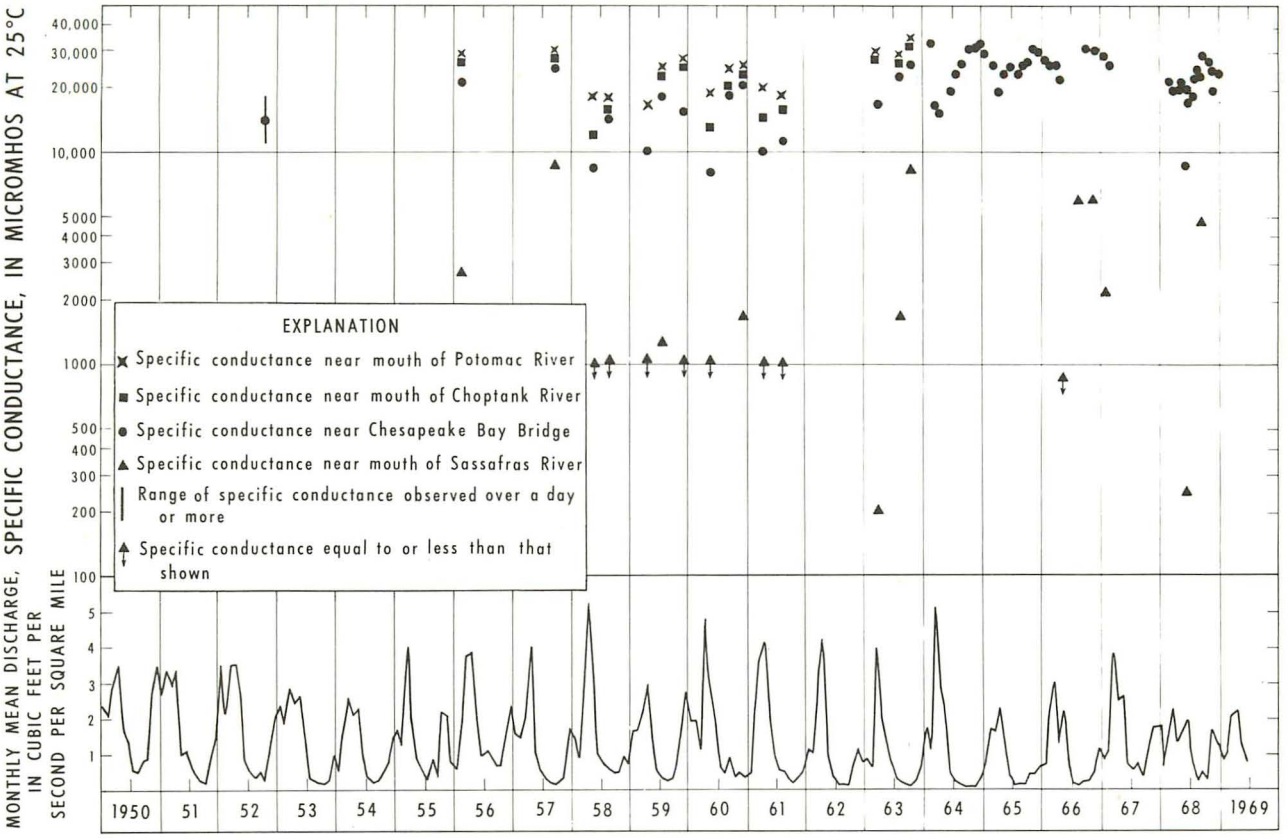


B

Figure 16—Map and graphs of Chesapeake Bay data.
A. Map of Chesapeake Bay.
B. Drainage area and Bay volume at locations along the Bay.



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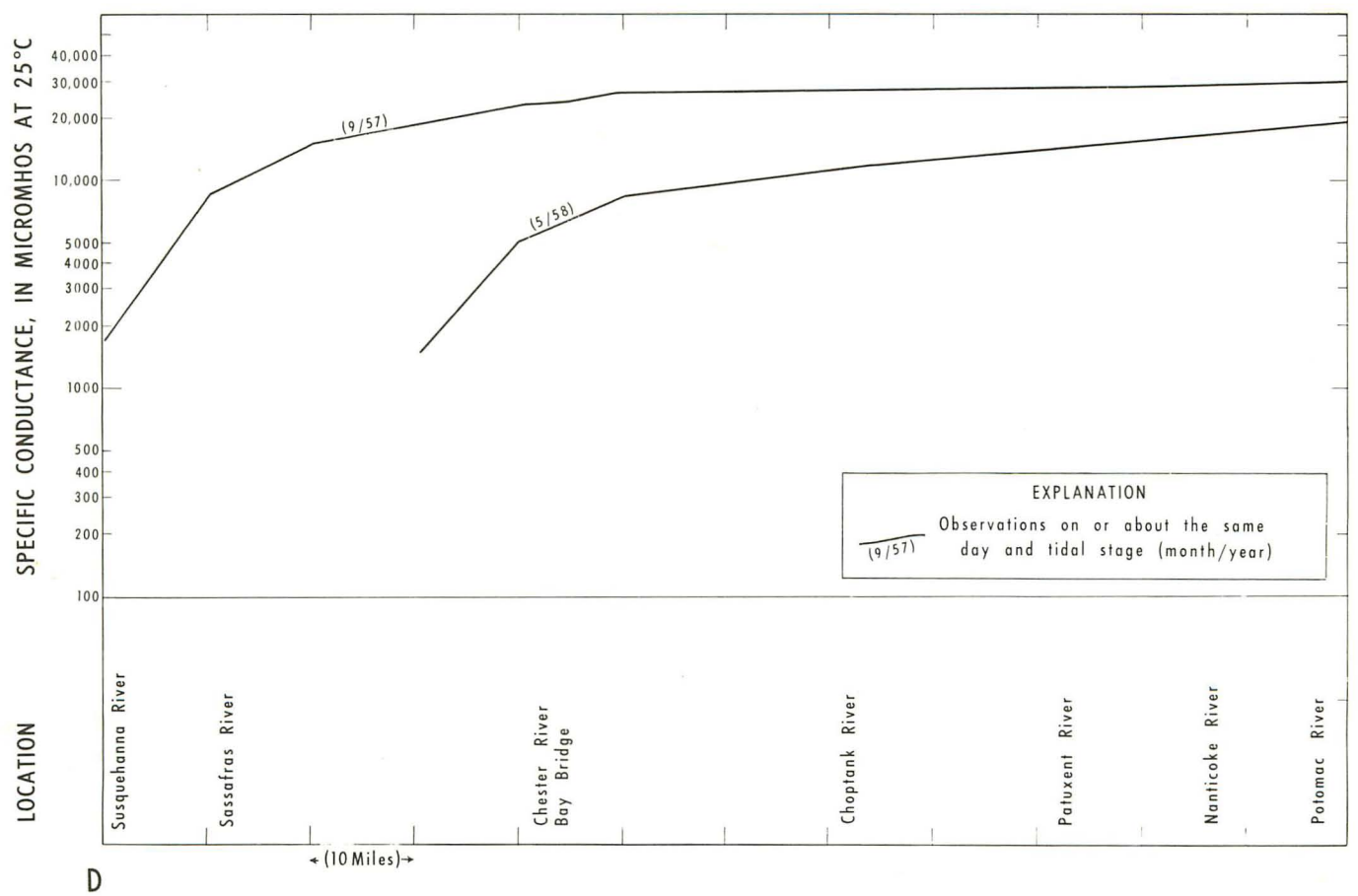

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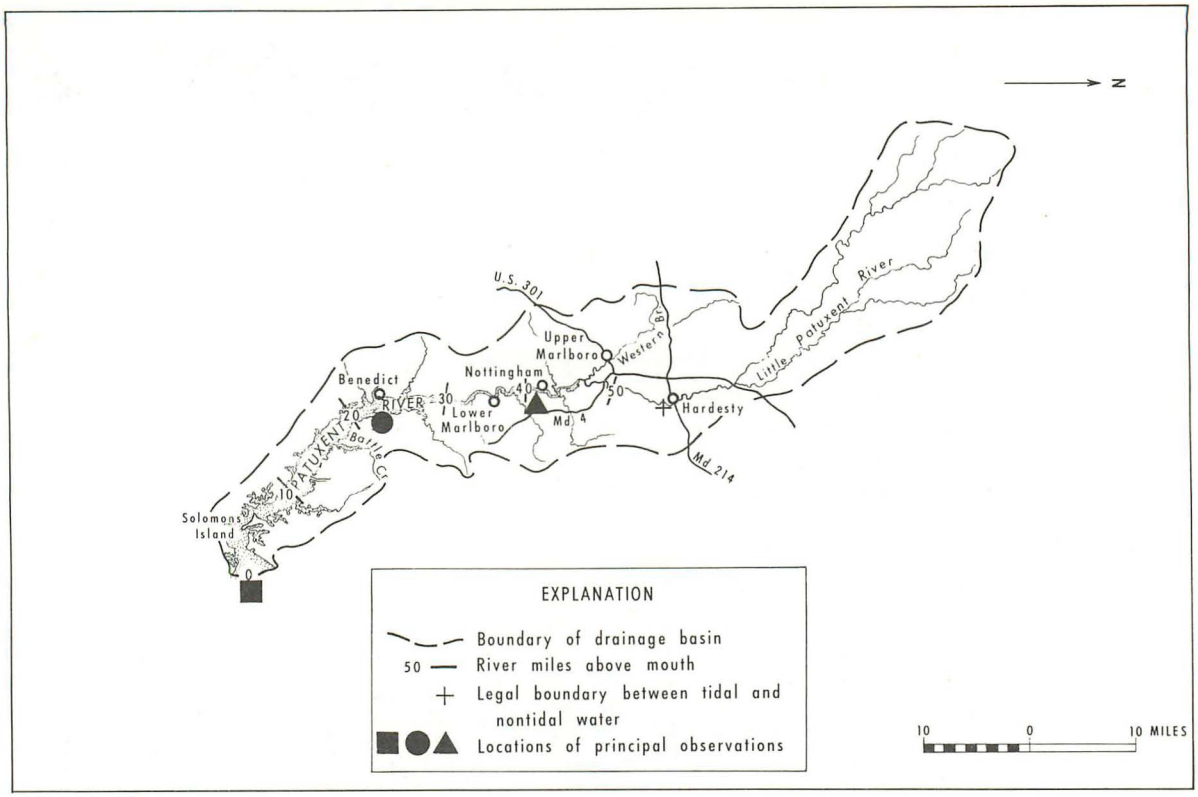
Figure 16—C. Variation of discharge and specific conductance with time.
D. Specific conductance values, including observed maximum and minimum values, at locations along the Bay.

PATUXENT RIVER BASIN



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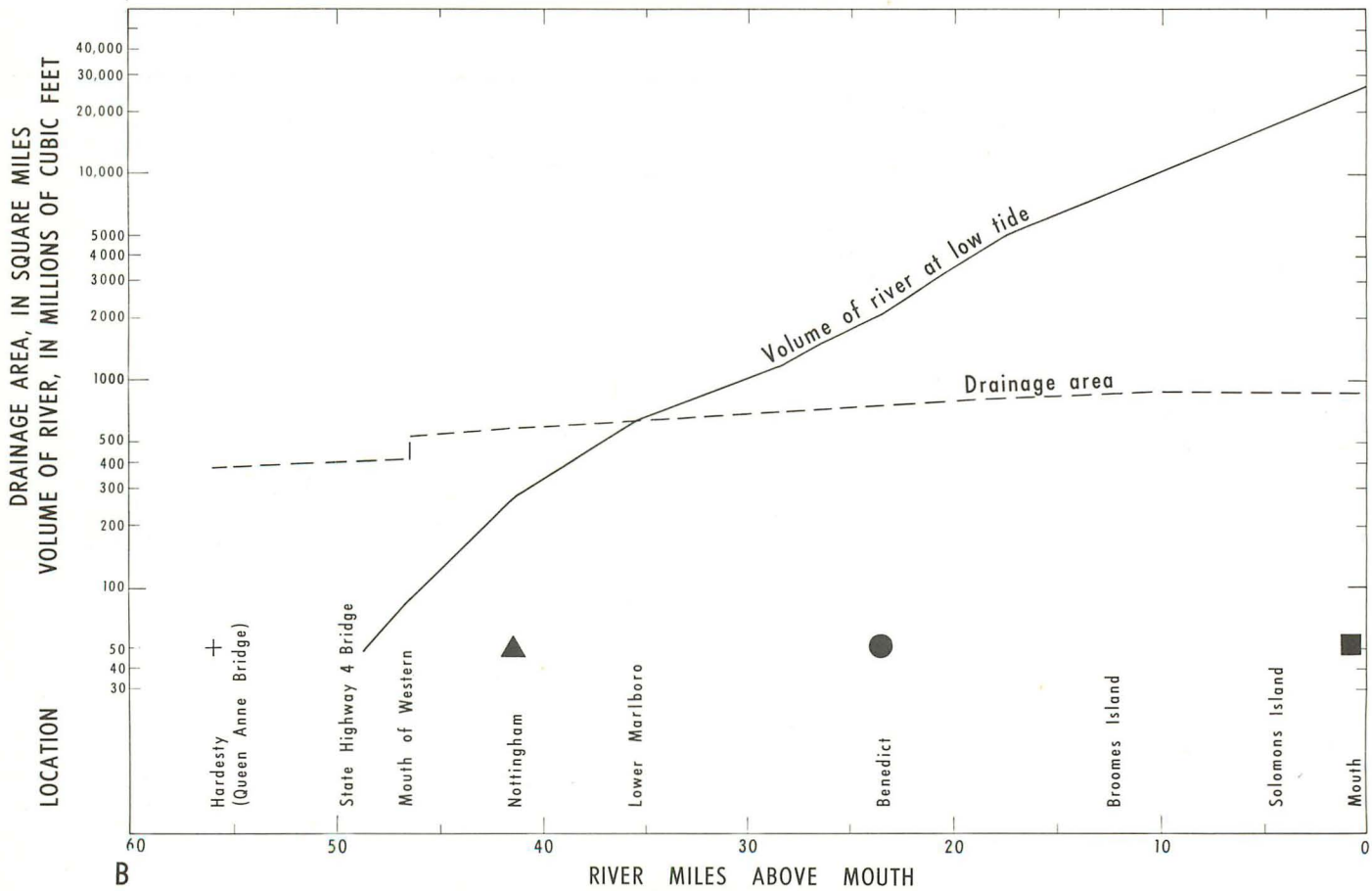
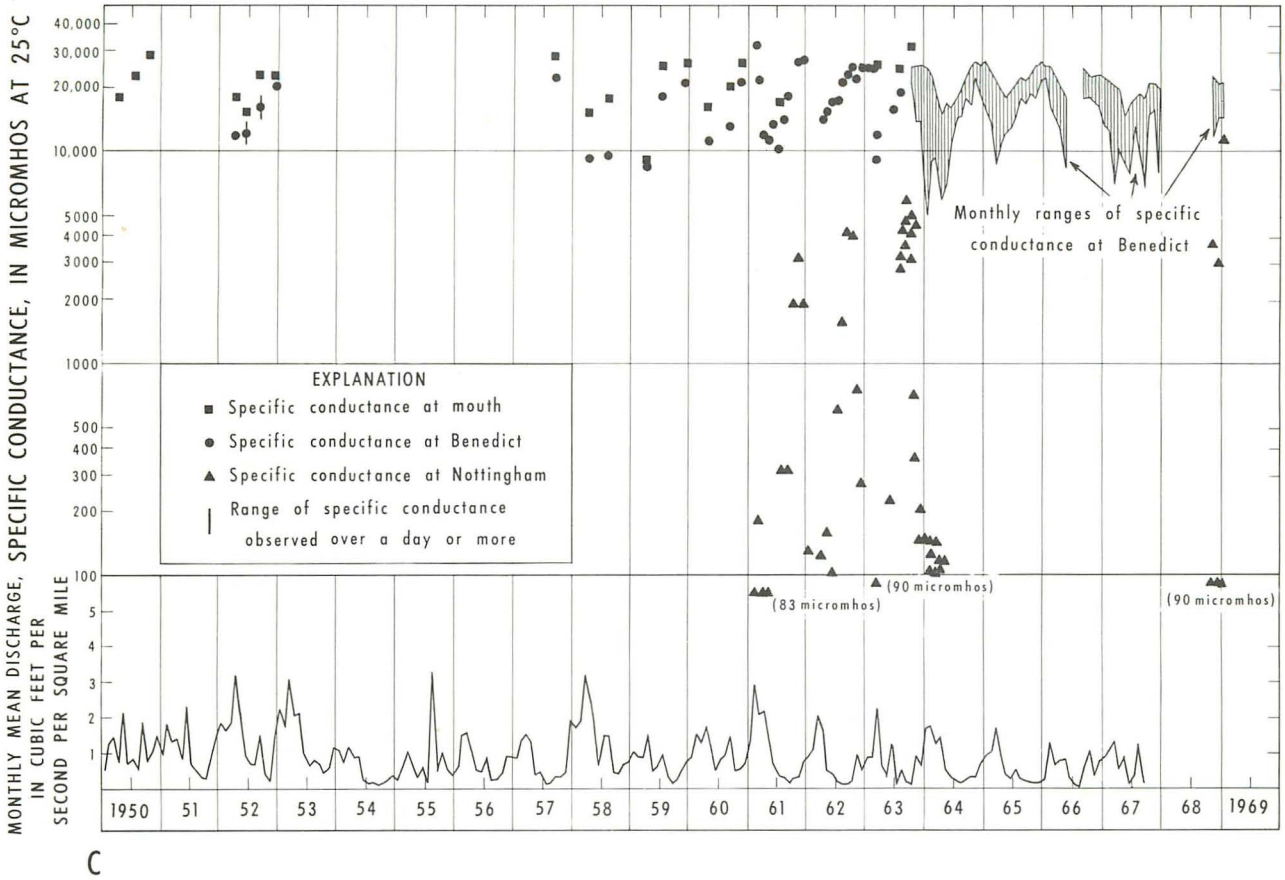


B

Figure 17—Map and graphs of Patuxent River basin data.
A. Map of the Patuxent River basin.
B. Drainage area and river volume at locations along the river.



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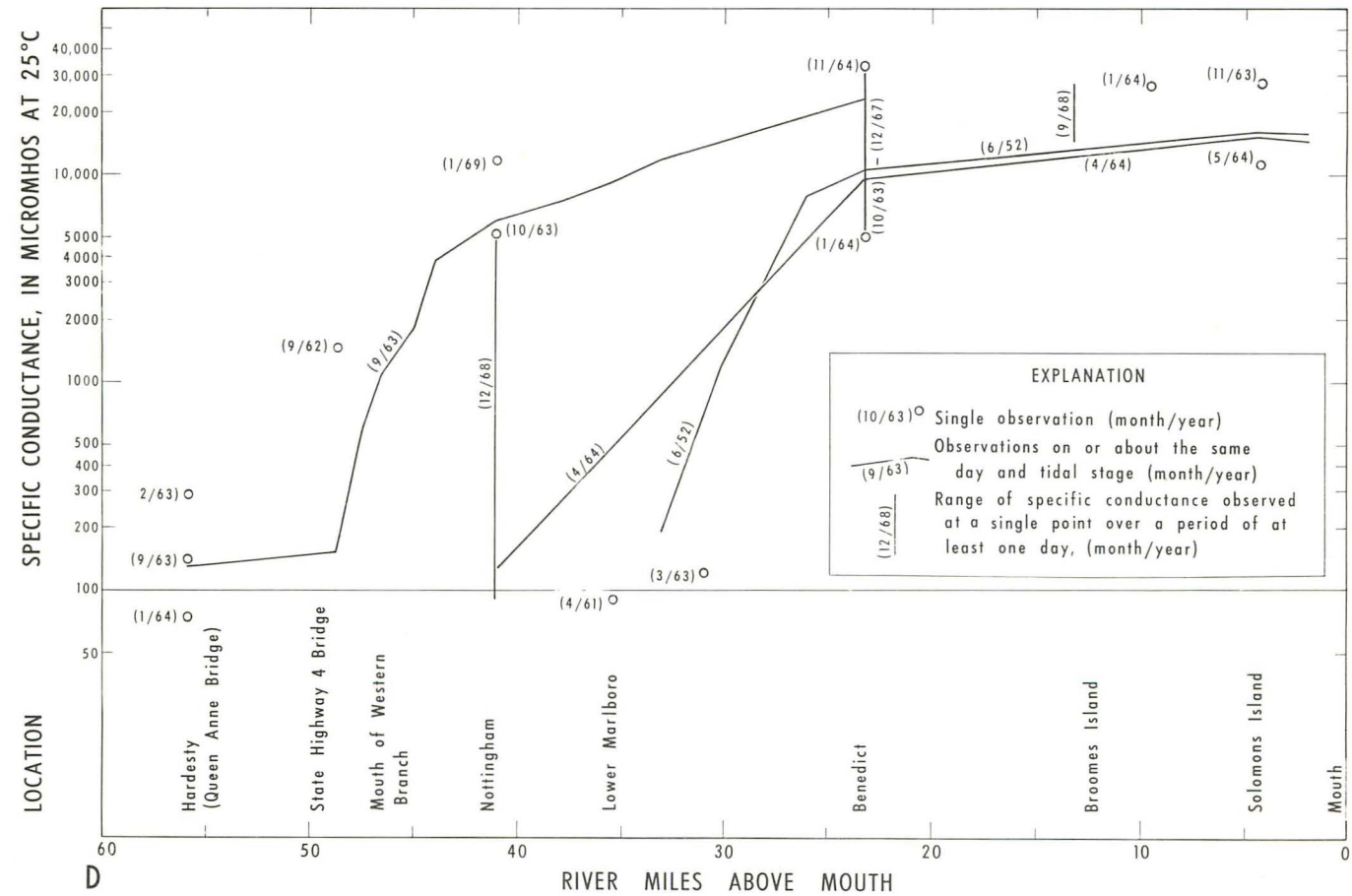
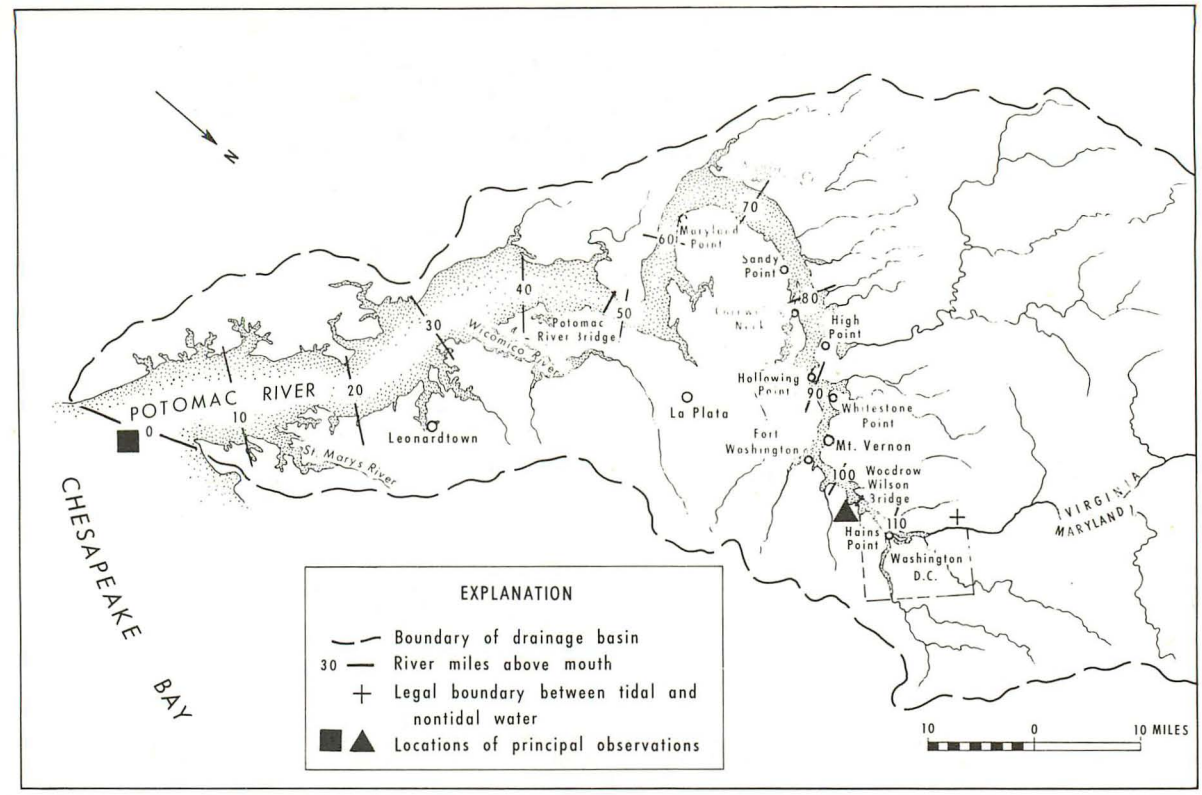


D

Figure 17—C. Variation of discharge and specific conductance with time.
D. Specific conductance values, including observed maximum and minimum values, at locations along the river.



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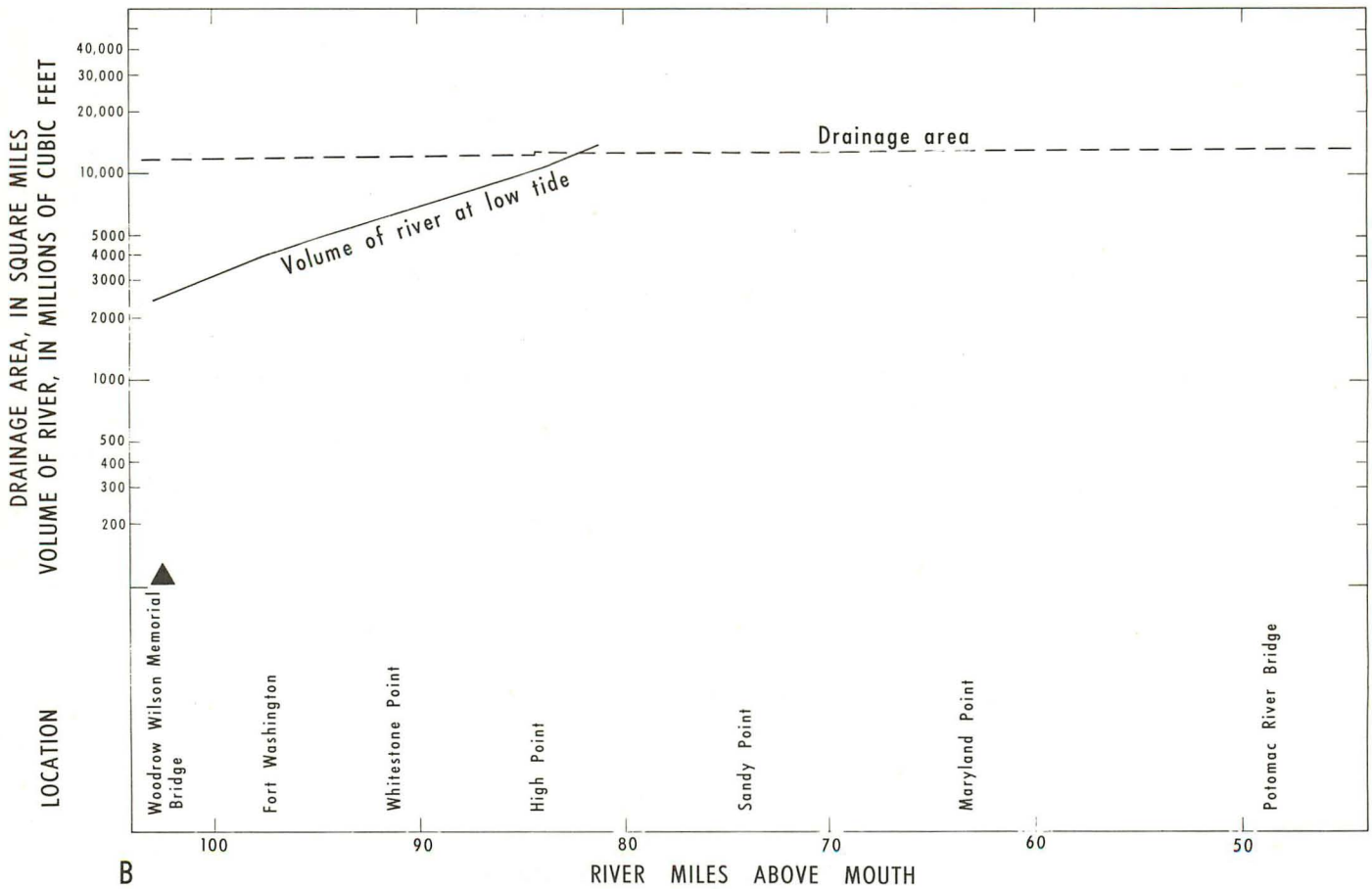
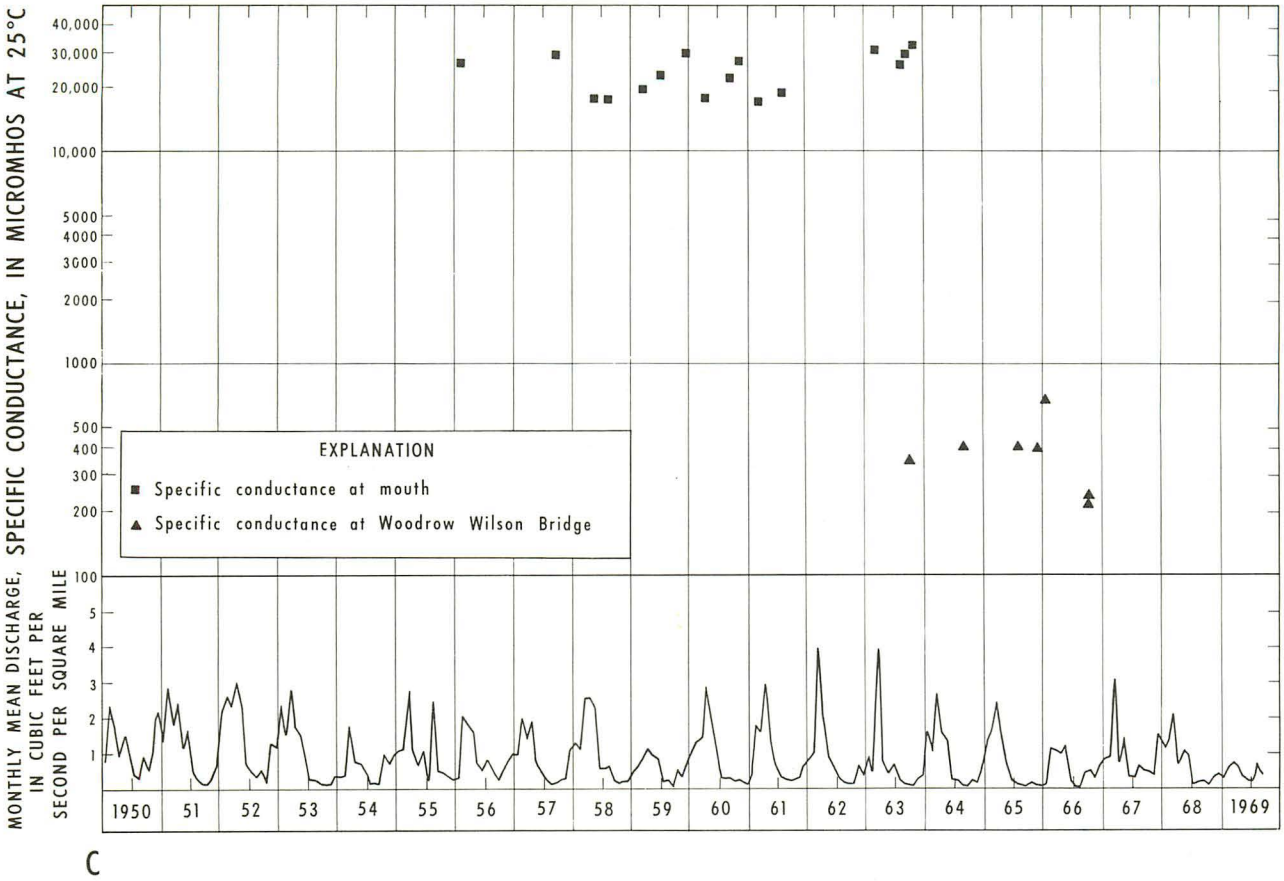


B

Figure 18—Map and graphs of Potomac River data.
A. Map of the Potomac River.
B. Drainage area and river volume at locations along the river.



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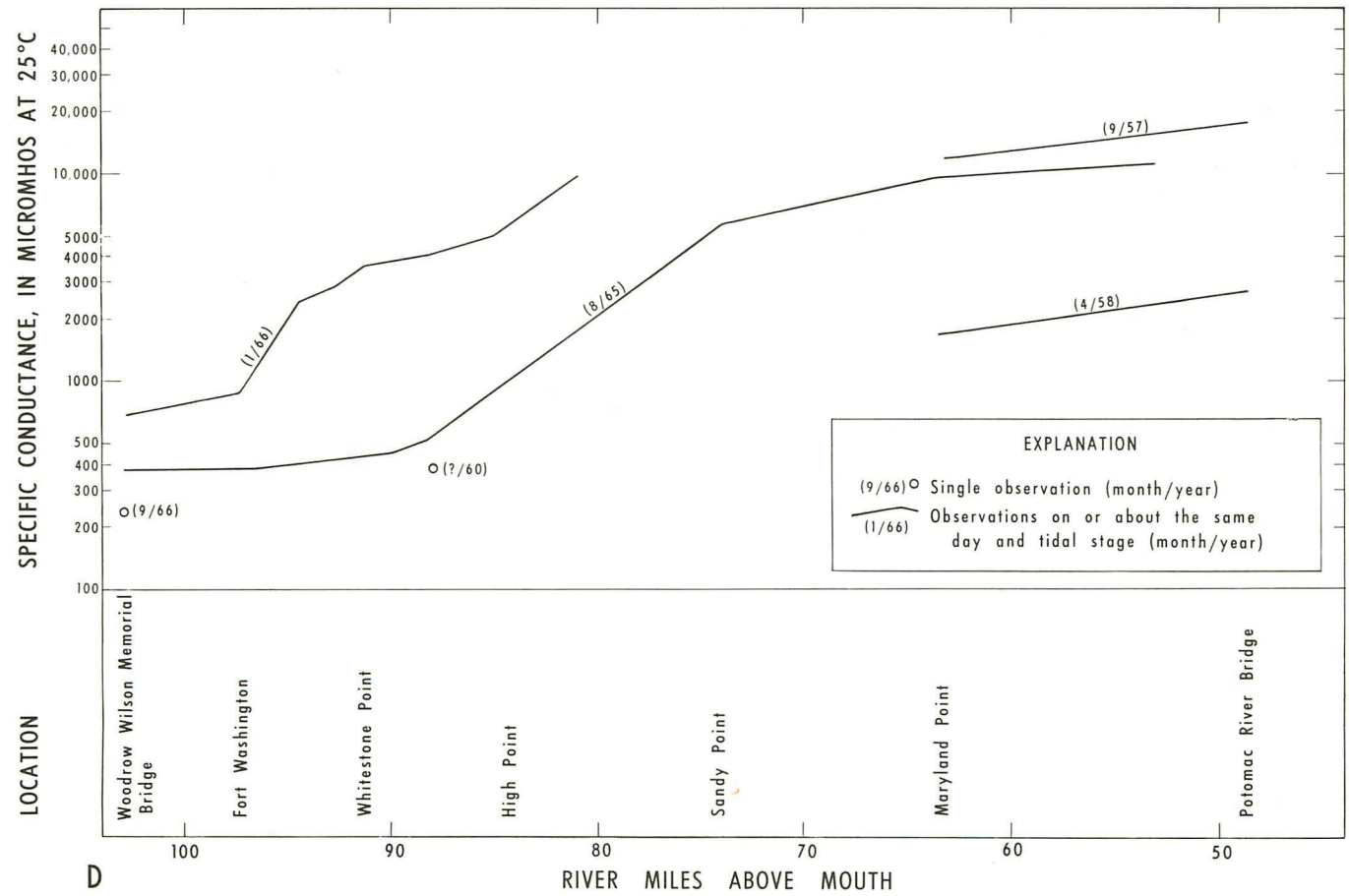

D

Figure 18—C. Variation of discharge and specific conductance with time.
D. Specific conductance values, including observed maximum and minimum values, at locations along the river.

Table 2. Chemical and physical data for Pocomoke River basin.

Date	Time	Water temperature (°C)	Field (F) or Laboratory (L)	Specific conductance (in micromhos at 25°C)	Chloride (mg/l)
Pocomoke River at U.S. Highway 50 near Willards					
Aug. 1, 1967	1300	23.5	(L)	77	6.9
Pocomoke River at Snow Hill					
Oct. 19, 1966	1300	17.0	(F)	150	--
May 18, 1967	0935	17.0	(L)	117	13
June 28, ...	0820	24.0	(L)	109	13
Aug. 1, ...	1130	28.0	(L)	125	14
Pocomoke River at Shad Landing State Park					
May 18, 1967	0915	17.0	(L)	108	12
June 28, ...	0900	25.0	(L)	100	12
Aug. 1, ...	1000	28.0	(L)	110	13
Pocomoke River at Town Branch at Pocomoke City					
Sept. 19, 1969	1420	--	(F)	720	--
Sept. 25, ...	1245	24.0	(F)	365	--
Pocomoke River at Alternate U.S. Highway 13 at Pocomoke City					
Oct. 19, 1966	1145	18.0	(F)	1100	--
May 18, 1967	0840	16.5	(L)	110	13
June 28, ...	0930	25.5	(L)	122	17
July 31, ...	1330	28.0	(L)	128	16
Aug. 1, ...	0900	28.0	(L)	152	24
May 3, 1968	1010	17.0	(F)	120	--
Sept. 19, ...	1500	23.0	(F)	1400	--
Sept. 25, ...	1320	23.0	(F)	630	--

Table 2. Chemical and physical data for Pocomoke River basin--Continued.

Date	Time	Water temperature (°C)	Field (F) or Laboratory (L)	Specific conductance (in micromhos at 25°C)	Chloride (mg/l)
Pocomoke River at Puncheon Landing Branch near Pocomoke City					
May 3, 1968	1010	17.0	(F)	130	--
Sept. 19, ...	1540	--	(F)	3000	
Sept. 25, ...	1410	--	(F)	1700	
Pocomoke River at Rehobeth					
May 3, 1968	1100	17.0	(F)	1380	--
Pocomoke River at Md. Highway 371 about 0.2 mile above Hall Branch					
May 18, 1967	0700	16.5	(L)	344	74
June 28, ...	1100	26.0	(L)	2710	796
Aug. 1, ...	0810	28.0	(L)	7300	2300
Pocomoke River at Shelltown					
Aug. 1, 1967	0745	28.0	(L)	12700	4220

Table 3. Specific conductance extremes for Pocomoke River at Pocomoke City.

(Portable battery-operated continuous conductivity recorder on Alt. U.S. Highway 13 drawbridge)

Date	Maximum		Minimum	
	Time	Specific conductance (in micromhos at 25°C)	Time	Specific conductance (in micromhos at 25°C)
Aug. 3, 1967	0200	265	2000	120
Aug. 4, ...	0300	290	--	--
Sept. 20, 1968	0400	2150	2230	345
Sept. 21, ...	0440	1800	2300	325
Sept. 22, ...	1730	2100	1120	350
Sept. 23, ...	1900	2000	1210	340
Sept. 24, ...	1950	2400	0140	355
Sept. 25, ... 1/	0600	2650	1320	630

1/ Only 14.5 hrs. record this day.

Table 4. Chemical and physical data for Wicomico River basin.

Date	Time	Water temperature (°C)	Field (F) or Laboratory (L)	Specific conductance (in micromhos at 25°C)	Chloride (mg/l)
Wicomico River at U.S. Highway 50 at Salisbury					
Oct. 20, 1966	1025	15.5	(F)	185	--
Feb. 23, 1967	1445	6.5	(L)	116	18
June 27, ...	0730	26.0	(L)	133	20
Aug. 2, ...	1615	29.0	(L)	122	16
Wicomico River at Upper Ferry					
Oct. 20, 1966	0945	15.0	(F)	3600	--
Feb. 23, 1967	1410	6.5	(L)	1400	366
June 27, ...	0710	26.0	(L)	2760	816
Aug. 2, ...	1600	29.0	(L)	960	245
May 3, 1968	0815	16.5	(F)	380	--
May 3, ...	0930	--	(F)	320	--

Table 4. Chemical and physical data for Wicomico River basin--Continued.

Date	Time	Water temperature (°C)	Field (F) or Laboratory (L)	Specific conductance (in micromhos at 25° C)	Chloride (mg/l)
Wicomico River at Green Hill Yacht Club					
May 3, 1968	0915	16.5	(F)	1400	--
Wicomico River at Keroo Wharf					
May 3, 1968	0900	16.5	(F)	3000	--
Wicomico River at Pirates Wharf					
May 3, 1968	0850	16.5	(F)	4700	--
Wicomico River at Green Hill Church					
May 3, 1968	0840	17.0	(F)	7600	--
Wicomico Creek below dam at Allen					
Feb. 23, 1967	1400	5.0	(F)	270	--
June 27, ...	0640	20.5	(L)	2320	676
Wicomico River at Whitehaven					
Feb. 23, 1967	1330	4.0	(L)	17000	5940
June 27, ...	0630	26.0	(L)	16200	6020
Aug. 2, ...	1530	29.0	(L)	12800	4220

Table 5. Chemical and physical data for Nanticoke River basin.

Date	Time	Water temperature (°C)	Field (F) or Laboratory (L)	Specific conductance (in micromhos at 25°C)	Chloride (mg/l)
Nanticoke River at Sharptown					
Oct. 20, 1966	1130	15	(F)	1300	--
Feb. 16, 1967	1140	8.5	(L)	257	44
Feb. 16, ...	1540	5.5	(F)	200	--
June 27, ...	0500	26.0	(F)	180	--
June 29, ...	0910	25.5	(L)	401	86
Aug. 2, ...	1430	29.0	(L)	245	47
May 2, 1968	0950	16.0	(F)	180	--
Sept. 14, ...	1520	23.0	(F)	630	--
Sept. 18, ...	1245	22.0	(F)	2280	--
Nov. 29, ...	1300	10.5	(F)	3500	--
Jan. 16, 1969	1755	2.0	(F)	1380	--
Marshyhope Creek at Md. Highway 392 near Hurlock					
Feb. 16, 1967	1055	5.5	(F)	95	--
Nov. 29, 1968	1340	10.5	(F)	290	--
Marshyhope Creek at Md. Highway 14 at Brookview					
June 10, 1965	1215	25.0	(F)	150	--
Oct. 20, 1966	1200	14.0	(F)	480	--
Feb. 16, 1967	1110	4.5	(F)	105	--
May 2, 1968	1005	15.5	(F)	100	--
Sept. 13, ...	1855	22.5	(F)	400	--
Nov. 29, ...	1050	10.0	(F)	1050	--
Jan. 16, 1969	1850	1.5	(F)	280	--

Table 5. Chemical and physical data for Nanticoke River basin--Continued.

Date	Time	Water temperature (°C)	Field (F) or Laboratory (L)	Specific conductance (in micromhos at 25°C)	Chloride (mg/l)
Nanticoke River at Vienna					
Oct. 20, 1966	1100	15.0	(F)	6000	--
Feb. 16, 1967	1230	5.0	(F)	1900	--
Feb. 16, ...	1515	5.0	(L)	843	211
Aug. 2, ...	1400	29.0	(L)	2260	622
May 2, 1968	0930	16.0	(F)	2300	--
Sept. 14, ...	0945	23	(F)	7000	--
Nov. 29, ...	1235	10.5	(F)	11000	--
Jan. 15, 1969	1730	2.0	(F)	3700	--

Table 6. Specific conductance extremes for Nanticoke River at Sharptown.

(Portable battery-operated continuous conductivity recorder)

Date	Maximum		Minimum	
	Time	Specific conductance (in micromhos at 25°C)	Time	Specific conductance (in micromhos at 25°C)
Dec. 8-11, 1964	2040 (12/8)	1400	1515 (12/10)	260
Feb. 16-23, 1967	1140 (2/16)	257	0900 (2/21)	69
June 27, ...	2230	500	1640	140
June 28, ...	2340	530	1700	150
Sept. 13, 1968	2230	2700	--	--
Sept. 14, ...	2300	2600	0430	600
Sept. 15, ...	2400	2900	1730	750
Sept. 16, ...	1300-1400	2950	1900	950
Sept. 17, ...	0100-0400	3200+	2000	950
Sept. 18, ...	0200-0430	3200+	2140	1040

Table 7. Chemical and physical data for Choptank River basin.

Date	Time	Water temperature (°C)	Field (F) or Laboratory (L)	Specific conductance (in micromhos at 25°C)	Chloride (mg/l)
Choptank River at Md. Highway 313 at Greensboro					
May 17, 1967	1240	15.0	(L)	96	9.0
June 29, ...	1200	15.5	(L)	120	12
Aug. 3, ...	1300	24.5	(L)	119	10
Choptank River at Md. Highway 404 at Denton					
Sept. 14, 1965	1000	22.0	(F)	1300	--
Oct. 20, 1966	1330	13.0	(F)	165	--
May 17, 1967	1230	16.0	(L)	90	8.0
June 29, ...	1145	25.5	(L)	158	24
Aug. 3, ...	1245	28.0	(L)	183	28
May 1, 1968	1850	16.0	(F)	110	--
Nov. 29, ...	1525	15.5	(F)	740	--
Jan. 16, 1969	2055	2.0	(F)	180	--
Tuckahoe Creek at Md. Highway 404 near Hillsboro					
Nov. 28, 1968	1540	10.0	(F)	150	--
Jan. 16, 1969	2015	1.5	(F)	130	--
Tuckahoe Creek at Md. Highway 328 near Matthews					
June 10, 1965	1925	25.5	(F)	800	--
Sept. 17, ...	1155	25	(F)	2600	--
Oct. 20, 1966	1315	13.5	(F)	625	--
May 17, 1967	1115	16.0	(L)	126	16
Jan. 16, 1969	2015	1.5	(F)	1090	--

Table 7. Chemical and physical data for Choptank River basin--Continued.

Date	Time	Water temperature (°C)	Field (F) or Laboratory (L)	Specific conductance (in micromhos at 25°C)	Chloride (mg/l)
Choptank River at Md. Highway 331 near Easton					
Oct. 20, 1966	1240	15.0	(F)	3500	--
May 17, 1967	1030	15.5	(L)	1070	292
June 29, ...	1100	25.5	(L)	4000	1220
Aug. 3, ...	1200	31.0	(L)	3600	1040
May 1, 1968	1945	16.0	(F)	1500	--
May 3, ...	1845	18.5	(F)	1600	--
Aug. 29, ...	1200	--	(F)	5400	--
Sept. 5, ...	1145	25	(F)	4900	--
Sept. 12, ...	1130	24	(F)	6230	--
Sept. 13, ...	1010	23.5	(F)	5600	--
Sept. 13, ...	1155	23.5	(F)	6400	--
Sept. 13, ...	1310	23.5	(F)	6000	--
Sept. 13, ...	1405	23.5	(F)	5390	--
Nov. 29, ...	1450	9.5	(F)	8000	--
Jan. 16, 1969	1950	1.5	(F)	4600	--
Choptank River at Choptank					
Jan. 16, 1969	1925	2.0	(F)	7300	--
Choptank River at U.S. Highway 50 at Cambridge					
May 17, 1967	0930	15.5	(L)	14800	5360
June 29, ...	1015	25.5	(L)	14200	5100
Aug. 3, ...	1100	29.0	(L)	16000	5510
Nov. 29, 1968	1200	9.5	(F)	20600	--

Table 8. Specific conductance and water temperature for Chester River basin.

Date	Time	Water temperature (°C)	Field (F) or Laboratory (L)	Specific conductance (in micromhos at 25°C)
Chester River at U.S. Highway 301 near Millington				
Sept. 29, 1964	--	16.5	(L)	118
Sept. 20, 1968	0950	--	(F)	440
Nov. 29, ...	1700	10.0	(F)	370
Jan. 15, 1969	1945	3.0	(F)	140
Chester River at Md. Highway 290 at Crumpton				
Oct. 19, 1966	1345	15.0	(F)	210
May 1, 1968	1710	15.0	(F)	220
Sept. 20, ...	0840	16.5	(F)	2800
Sept. 20, ...	1450	18.0	(F)	2700
Nov. 29, ...	1645	9.5	(F)	3000
Jan. 15, 1969	1930	3.0	(F)	1430
Chester River at U.S. Highway 213 at Chestertown				
May 1, 1968	1645	16.5	(F)	4600
Sept. 20, ...	1125	23.0	(F)	11100
Nov. 29, ...	1625	9.0	(F)	12200
Jan. 15, 1969	1900	2.0	(F)	5600

Table 9. Specific conductance extremes for Chester River at Chestertown.

(Portable battery-operated continuous conductivity recorder on bridge on U.S. Highway 213)

Date	Maximum		Minimum	
	Time	Specific conductnace (in micromhos at 25°C)	Time	Specific conductance (in micromhos at 25°C)
Sept. 26, 1968	2400	14000	1700	10000
Sept. 27, ...	2400	14000	1730	9900
Sept. 28, ...	0200	14300	1900	10400
Sept. 29, ...	0250	14200	2000	10500
Sept. 30, ...	0400	14000	2200	10500
Oct. 1, ...	0530	14000	2300	10000

Table 10. Specific conductance and water temperature for Sassafras River basin.

Date	Time	Water temperature (°C)	Field (F) or Laboratory (L)	Specific conductance (in micromhos at 25°C)
Sassafras River at U.S. Highway 301 near Sassafras				
Nov. 29, 1968	1740	11.0	(F)	150
Jan. 15, 1969	2025	4.0	(F)	135
Sassafras River at U.S. Highway 213 at Georgetown				
Oct. 21, 1966	1400	15.0	(F)	4200
May 1, 1968	1745	16.5	(F)	1200
Nov. 29, ...	1720	8.3	(F)	3500
Jan. 15, 1969	2005	1.5	(F)	1920

Table 11. Specific conductance extremes Sassafras River at Georgetown.

(Portable battery-operated continuous conductivity recorder on bridge at U.S. Highway 213)

Period	Maximum			Minimum		
	Date	Time	Specific conductance (in micromhos at 25°C)	Date	Time	Specific conductance (in micromhos at 25°C)
Oct. 3-8, 1968	Oct. 7	1200	3800	Oct. 5	1700	2600
Oct. 9-15, ...	Oct. 11	0130	3850	Oct. 9	1630	2850
Oct. 16-22, ...	Oct. 19	2030	5350	Oct. 17	1330	3200
Oct. 23-28, ...	Oct. 25	0250	5200	Oct. 23	1800	3800
Oct. 31-Nov. 5, ...	Nov. 5	0130	5300	Oct. 31	0330	3900

Table 12. Specific conductance extremes, and tidal height of Patuxent River at Nottingham.

(Portable battery-operated continuous conductivity recorder)

Date	Maximum		Minimum	
	Tide height 1/ (in feet)	Specific conductance (in micromhos at 25°C)	Tide height 1/ (in feet)	Specific conductance (in micromhos at 25°C)
Nov. 8, 1968	+ 0.09	3850	--	--
Nov. 9, ...	+ 1.8	3600	- 0.4	--
Nov. 11, ...	+ 2.9	3400	+ 1.1	--
Nov. 14-19, ...	+ 3.2	1730	+ 0.3	< 150
Nov. 22-24, ...	+ 2.1	480	- 1.2	160
Nov. 26-Dec. 4, ...	+ 2.5	2150	- 1.1	180
Dec. 5-11, ...	+ 1.4	1500	- 2.5	160
Dec. 12-19, ...	+ 1.9	> 3000	- 3.3	150
Dec. 20-26, ...	+ 1.8	> 3000	- 3.0	< 100
Dec. 27, '68-Jan. 2, '69	+ 1.0	> 3000	- 1.4	155
Jan. 13-15, 1969	+ 1.0	2380	- 2.4	175

1/ Above (+) or below (-) arbitrary mean level of 0.0

Note: Maximum observed specific conductance 11,200 micromhos from a sample Jan. 6, 1969 @ 1450.

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