T. Pickett

STATE OF DELAWARE

DELAWARE GEOLOGICAL SURVEY

REPORT OF INVESTIGATIONS NO. 1

SALINITY OF THE DELAWARE ESTUARY

by

BERNARD COHEN

Newark, Delaware
July, 1957

PREFACE

The Delaware River is an important source of industrial water supply from Trenton, New Jersey to Delaware City, Delaware. Possible water usage largely depends upon the quality of the River water, particularly its salinity. Also the welfare of Delaware's oyster industry depends upon salinity conditions in the Bay; therefore, a thorough knowledge of present conditions in the River, and of any trends toward salinity increases, or decreases, in the future are of major scientific and economic importance. Realizing this situation, the State of Delaware, through its Geological Survey, is supporting an investigation of the salinity of the Delaware River, in cooperation with the Delaware River Master and the City of Philadelphia. The results of the work done thus far by personnel of the U. S. Geological Survey are presented in this report, a factual account of salinity variations in the River between Philadelphia and Reedy Point between July, 1954 through December, 1956. It is expected that continued investigations will establish what trends in salinity changes exist, and what causes are responsible for them.

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Salinity of the Delaware Estuary

by

Bernard Cohen

Prepared by Quality of Water Branch - July 1957

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Abstract

The purpose of this investigation was to obtain data on and study the factors affecting the salinity of the Delaware River from Philadelphia, Pa. to Reedy Island, Del. The techniques of analyses of data and results of the analyses are presented.

The amount of salt water in the Delaware River at any location is dependent upon (1) the distance from the ocean; (2) the fresh water flow of the river; (3) the quantity of salty water moving upstream from the ocean; (4) the stage of tide; (5) the range of tide. During the summer and early fall months the fresh-water inflow is at a minimum and mean sea level (which governs the movement of sea water into the estuary) is a maximum, thus providing favorable conditions for movement of salt water upstream. During late October or early November the fresh-water flow increases and concurrently the sea level decreases, causing the salty water to recede downstream. Advance and retreat of salinity may occur at other times, depending upon the fresh-water inflow and the sea level. The severity of a salinity invasion may be estimated from sea level, river level, and fresh-water discharge data. Hurricanes affect salinity as a result of wind direction and velocity, and runoff from precipitation.

In the reach of the river studied the dissolved solids increase, the greater the distance downstream from the Walt Whitman Bridge (Philadelphia, Pa.) The amount of dissolved solids present in the water varies with the stage of tide, reaching a maximum at or near high-water slack and a minimum at or near low-water slack.

Cross-section studies indicate that there is little or no variation in the dissolved solids across the navigation channel. In the lower reaches of the river the dissolved solids concentration increased with depth.

Introduction

This progress report summarizes the U. S. Geological Survey's water-quality investigation of the Delaware River between the Walt Whitman Bridge, Philadelphia, Pa. (Gloucester City, N. J.) and Reedy Island, Del. from July, 1954, through December 1956.

The Delaware River (see fig. 1) is tidal from Trenton, N. J. to Delaware Bay. Trenton is 46 miles above the Walt Whitman Bridge and the reach of the river under investigation extended 44 miles below this bridge to Reedy Island, Del. There are many tributaries entering the Delaware River in this reach; the major ones are the Schuylkill River, the Christina River, the Salem River, and the Chesapeake and Delaware Canal. The Delaware River is 3,900 feet wide at the Walt Whitman Bridge; 6,600 feet wide at the Delaware Memorial Bridge; and 12,300 feet wide at Reedy Point, The navigation channel is approximately 40 feet deep in this reach of the river at mean low water and has a width of 900 feet. The remaining portion of the river from the area adjacent to the channel to the shore decreases in depth. There are five islands in the area studied--Little Tinicum Island on the Pennsylvania side of the navigation channel at Essington, Pa.; Chester Island on the New Jersey side of the channel off Chester, Pa.; Cherry Island Flats off Edgemoor, Del. on the New Jersey side of the channel; Pea Patch Island on the Delaware side of the channel off Delaware City; and Reedy Island on the Delaware side of the channel off Port Penn, Del.

There are several important cities along the river, Philadelphia being the largest. Among the others are Chester, Pa.,

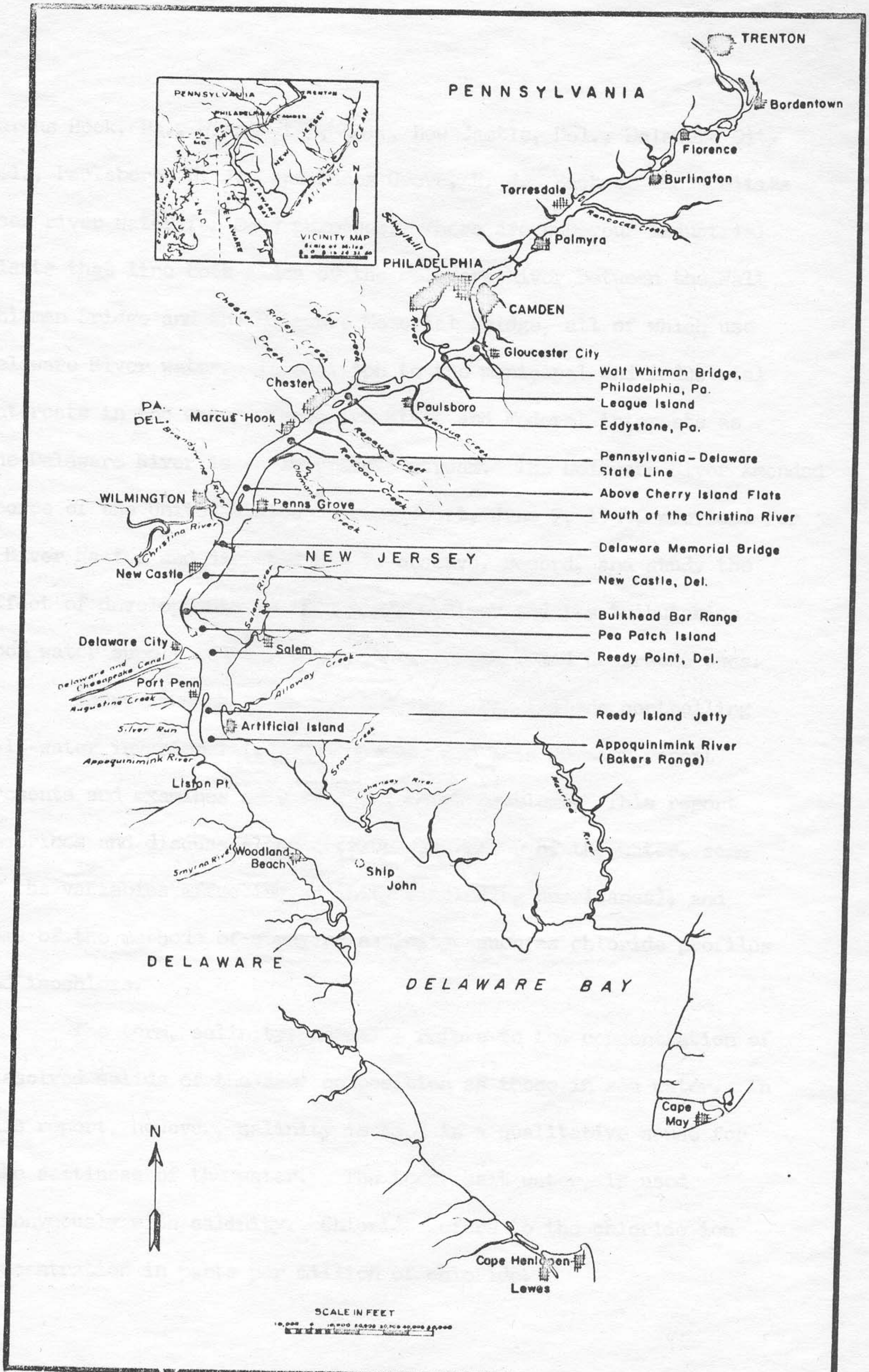


Figure 1.- Location of sampling stations between Philadelphia, Pa. and Appoquinimink River, Del. (Bakers Range)

Marcus Hook, Pa., Wilmington, Del., New Castle, Del., Delaware City Del., Paulsboro, N. J., and Penns Grove, N. J. Each of these cities uses river water for many purposes. There are numerous industrial plants that line both sides of the Delaware River between the Walt Whitman Bridge and the Delaware Memorial Bridge, all of which use Delaware River water. In addition to the municipal and industrial interests in the water, there are State and Federal interests as the Delaware River is an interstate stream. The Delaware River Amended Decree of the United States Supreme Court, June 7, 1954, provided for a River Master and directed him to observe, record, and study the effect of developments on the Delaware River and its tributaries upon water supply and other necessary, proper, and desirable uses.

There is much to be learned about the factors controlling salt-water invasion into tidal rivers, and this summary report presents and examines some of the general problems. This report describes and discusses the chemical character of the water, some of the variables affecting salinity (including hurricanes), and some of the methods of studying salinity, such as chloride profiles and isochlors.

The term, salinity, normally refers to the concentration of dissolved solids of the same composition as those in sea water. In this report, however, salinity is used in a qualitative sense for "the saltiness of the water." The term, salt water, is used synonymously with salinity. Chloride refers to the chloride ion concentration in parts per million of chloride.

Acknowledgments

This investigation was conducted by the U. S. Geological Survey under the general direction of S. K. Love, Chief of the Quality of Water Branch, Washington, D. C., and N. H. Beamer, District Chemist of the Pennsylvania, Delaware, and New Jersey areas, under whose direction the analyses were performed. The work was performed in cooperation with the City of Philadelphia through its Water Department; S.S. Baxter, Water Commissioner; the Delaware River Master, C. G. Paulson; and the State of Delaware through its Geological Survey; J. J. Groot, State Geologist. The writer is grateful to his colleagues, C. N. Durfor and W. B. Keighton. The former gathered field data in 1954 and both have been most helpful with advice and guidance during the study.

Records of water discharge of the Delaware River and its tributaries were furnished by the district offices of the Surface Water Branch of the U. S. Geological Survey at Harrisburg, Pa. and Trenton, N. J. Much of the surface-water data used in this report are preliminary and subject to revision. Data on the tides at Philadelphia, Pa. and Atlantic City, N. J. were furnished by the U. S. Coast and Geodetic Survey. Water samples were collected in a boat furnished by the U. S. Coast Guard Station at Gloucester City, N. J.

Acknowledgment is made to the U. S. Army Engineers for their assistance in the collection of samples, and to the authorities of the Delaware Memorial Bridge for their cooperation. Data on hurricanes were supplied by the Philadelphia Weather Bureau. Acknowledg-

ment is also made to Scott Paper Company, Chester, Pa.; to the Deepwater Operating Company of New Jersey; and to the many other industries, too numerous to mention.

Previous Investigation

The Pennsylvania Department of Health (1935) issued a comprehensive report on salinity studies in the Delaware estuary. Mason and Pietsch (1940) developed a diagram which was intended to show the rate of fresh-water discharge required to hold the 50 parts per million (ppm) isochlor at various locations in the river. The New York City Board of Water Supply (1953) also studied the salinity behavior of the estuary and established relationships between the fresh-water flow and the distribution of salinities. B. H. Ketchum (1953) prepared a report on "The distribution of salinity in the estuary of the Delaware River." This report and a supplement are unpublished. C. N. Durfor and W. B. Keighton (1954) describe the "Chemical characteristics of Delaware River water, Trenton, N. J. to Marcus Hook, Pa." The Corps of Engineers, U. S. Army, has chloride analyses of Delaware River water on file in Philadelphia.

Field Program

During 1955 and 1956, an intensified study was made of the chemical quality of the Delaware River water. It was assumed that maximum dissolved solids occurred at the time of high-water slack in the tidal cycle and minimum dissolved solids at the time of low-water slack. Since most saline invasions occur in the summer months, samples were collected at frequent intervals during this time. During 1954 some information was collected between Philadelphia, Pa. and Delaware Memorial Bridge, Pa. In 1955, 11 sampling locations were selected between Philadelphia, Pa. and Reedy Point, Del. In 1956, two additional sites were added which extended the study to the Appoquinimink River (Bakers Range). These are indicated on figure 1. Table 1 gives the locations of the sampling points by buoy numbers which appear on navigation maps (U. S. Coast and Geodetic Survey Navigation Maps No. 294, No. 295).

Samples were collected during the period of study as close as possible to the time of slack water. A Coast Guard utility boat used in the sampling maintained the speed (20 knots) necessary to follow slack water upstream. All samples were collected within 1 hour of the predicted time of slack water. The approximate times of slack water were obtained from "Current Tables Atlantic Coast North America (U. S. Coast and Geodetic Survey)."

Several trips were made to collect cross-sectional data. Top and bottom samples were collected across the navigation channel to determine salinity distribution with depth and cross section. These samplings were performed on an ebb or flood tide.

From July 1955 to December 1955, comprehensive analyses were made once a month on samples collected at the Delaware Memorial Bridge and at Reedy Point, Del. These samples were collected either at a particular stage of tide or composited from daily samples. The comprehensive analyses of these samples consisted of determinations of silica, iron, calcium, magnesium, sodium, potassium, bicarbonate,

Table 1.--Midstream Stations Delaware River

Based upon Army Engineers data using an arbitrary datum line at New Castle, Del. of 400,000 feet.

Buoy Marker*	Location	Thousands of feet
"39"	Walt Whitman Bridge, Phila., Pa.	243.5
R44A	League Island	255.0
R"2T"	Eddystone	303.1
Quarantine Wharf	Marcus Hook--Pennsylvania and Delaware State Line	332.5
C"3B"-R"6B"	Above Cherry Flats	353.1
C"5C-RB	Mouth of Christina River	373.5
	Delaware Memorial Bridge	386.5
"5D"-N"6D"	New Castle	399.3
"1B"-R"4B"	Bulkhead Bar Range	414.7
Bell on Island RN"2"	Fort Delaware--Pea Patch Island	428.0
C"27"-N"2N"	Reedy Point	442.3
C"3R"-N"4R"	Reedy Island Jetty	462.5
C"1B"-R"2B"	Appoquinimink River (Bakers Range	478.3

*See U. S. C & G Navigation Maps No. 295, No. 294.

sulfate, chloride, fluoride, nitrate, dissolved solids, hardness, specific conductance, pH, and color. For the majority of the other samples collected, determinations were made only for specific conductance, chloride, sulfate, and dissolved solids.

A Geological Survey bucket sampler containing a 12-ounce bottle with pressure seal was used to collect top samples, and a Foerst underwater sampler was used to collect bottom samples. Top samples were collected 3 feet below the surface to avoid getting any scum, oil or other debris in the sample, and bottom samples 3 feet from the bottom of the river to avoid picking up mud or sediment from the bottom. A metal enclosed glass thermometer (20°-110°F graduated to 1°F) was used to take the temperature of the samples. For reconnaissance temperature measurements, the Whitney underwater thermometer, sensitive to 0.2°F, was used. All field measurements of conductivity, including reconnaissance studies, were made with the Solu Bridge (a Wheatstone Bridge with an electron ray eye tube as a balance indicator).

A recorder which measured electrical resistance and can be interpreted in terms of specific conductance was in operation for a short period in 1955 at the Delaware Memorial Bridge. Two line-operated continuous specific conductance recorders were used in the study during 1956. One was located on the Delaware Memorial Bridge (1,000 feet west of the main river channel); the other at Reedy Island Jetty (one-half mile west of the main river channel). These recorders recorded specific conductance directly.

A Stevens type A-35 water-stage recorder was put into operation at Reedy Island Jetty in September 1956. Figure 2 has a detailed map of the locations of the recorders.

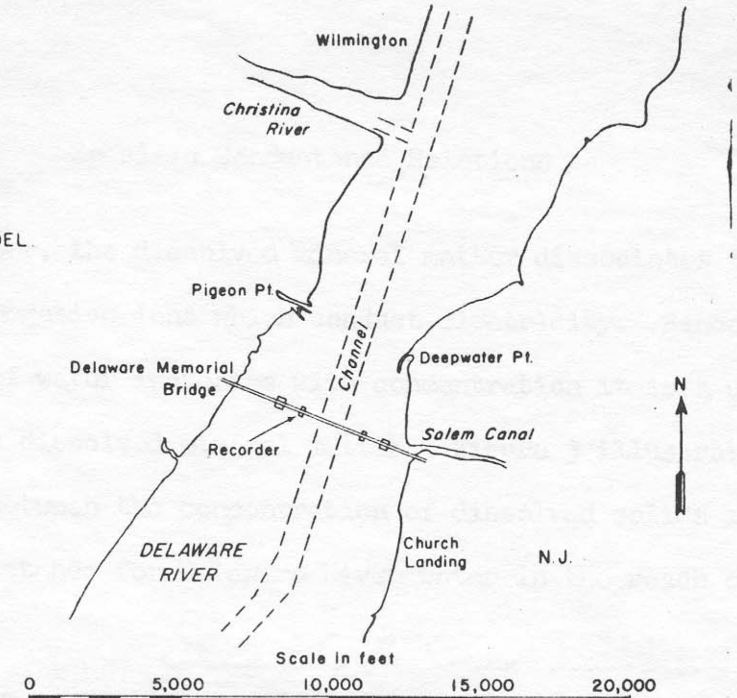
Chemical Characteristics of the Water

The principal dissolved constituents in the reach between the Delaware Memorial Bridge and Reedy Point are calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride. Minor quantities of other constituents such as silica, iron, fluoride, and nitrate as well as unmeasured substances are present also.

The specific conductance, the concentration of dissolved solids, and the concentration of most of the ions in solution increased from Philadelphia downstream to Reedy Island (table 20, p. 82). However, the nitrate-ion concentration at Reedy Point was slightly less than that at the Delaware Memorial Bridge. The concentrations of fluoride, iron, and of silica were not significantly different in a downstream direction.

The water was generally more saline in a downstream direction at all locations sampled. At low rates of fresh-water flow the salinity increased sharply at points downstream from the Delaware Memorial Bridge. There was a tendency for slightly more saline water to move upstream on the bottom of the river.

Under the conditions of heavy runoff following the hurricane of 1955, the chloride concentration was less than 30 ppm for stations as far downstream as the Delaware Memorial Bridge but increased downstream from this sampling point.



Note: Recorder is on the west pier of the bridge, 1000 feet west of the navigation channel of the river, and 1.9 miles directly south of the Christina River.

Figure 2a.—Location of specific conductance recorder at the Delaware Memorial Bridge.

Note: Recorders are on the Jetty 0.4 miles south of Reedy Island, approximately 0.5 miles west of the navigation channel, and southwest of Augustine Beach, Delaware.

Figure 2b.—Location of conductance and water-stage recorders at Reedy Island Jetty.

Specific Conductance Relations

In water, the dissolved mineral matter dissociates into positive and negative ions which conduct electricity. Since the conductivity of water increases with concentration it is a useful measure of the dissolved mineral matter. Figure 3 illustrates the relationship between the concentration of dissolved solids and specific conductance for Delaware River water in the reach of the river studied.

Maximum concentration of dissolved solids occurs when the fresh-water flow is lowest, usually between June and October, due to the invasion of ocean water into normally fresh-water regions of the river. Dissolved solids ranged from about 100 ppm to about 6,000 ppm at the Delaware Memorial Bridge, and at Reedy Point from 500 ppm to more than 10,000 ppm during the summer of 1955.

The concentration of dissolved solids increases from Philadelphia, Pa. to Reedy Island, Del. at all times. The straight-line relationship of specific conductance and dissolved solids in figure 3 is based upon samples whose specific conductance ranges from 4,000 to 16,500 micromhos. The approximate equation defining the curve in the range 2,500 to 10,500 ppm dissolved solids is:

$$\text{Dissolved solids (ppm)} = \frac{\text{Specific conductance(micromhos)} - 780}{1.5}$$

A plot of specific conductance (micromhos) against chloride concentration (ppm) on rectilinear paper (fig. 4) is a straight line from 4,000 to 16,000 micromhos. A good approximation of the chloride (ppm) can be made by using the equation for a straight line over the

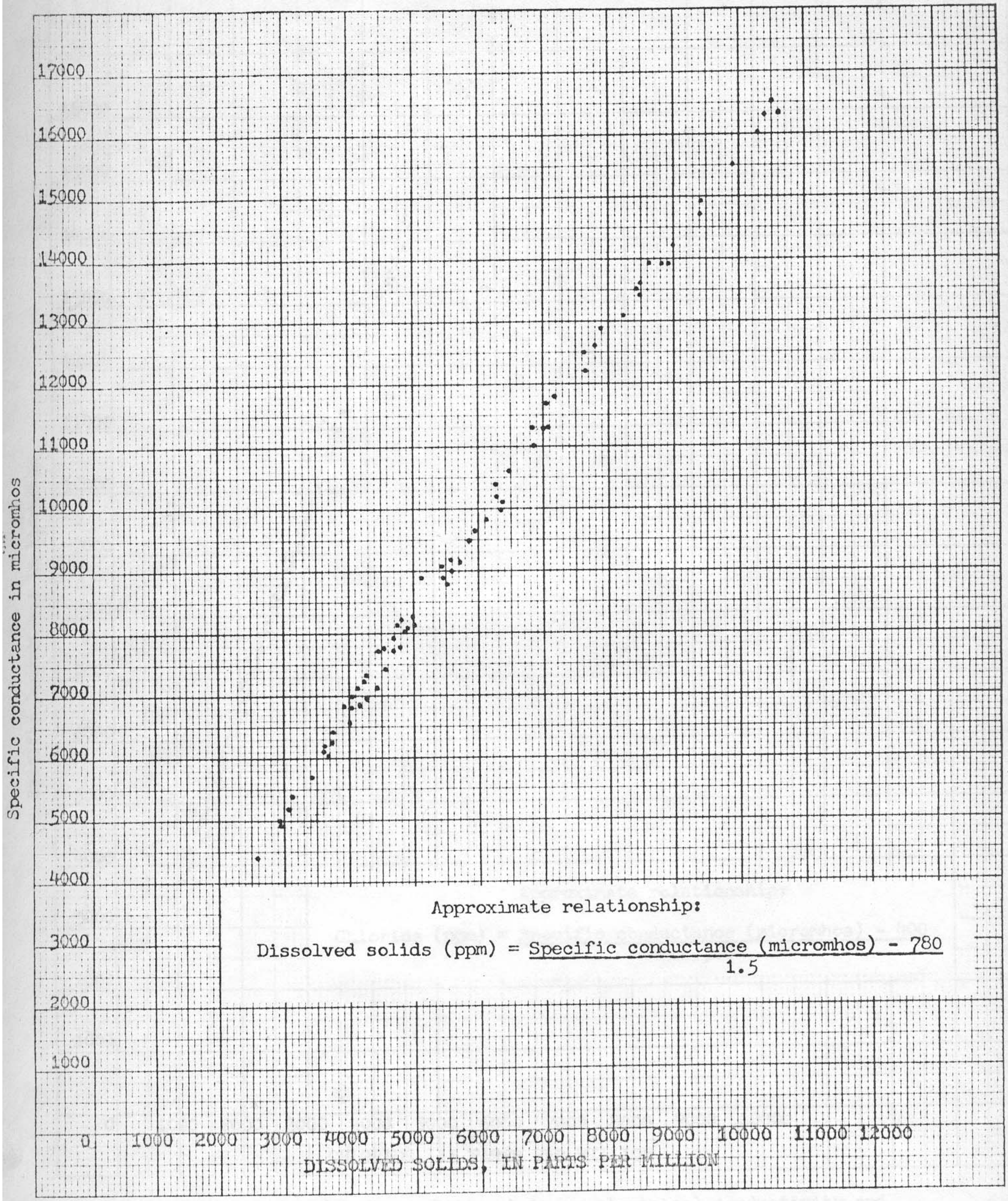


Figure 3.--The relation between electrical conductivity and dissolved solids (2,500 - 10,500 ppm)

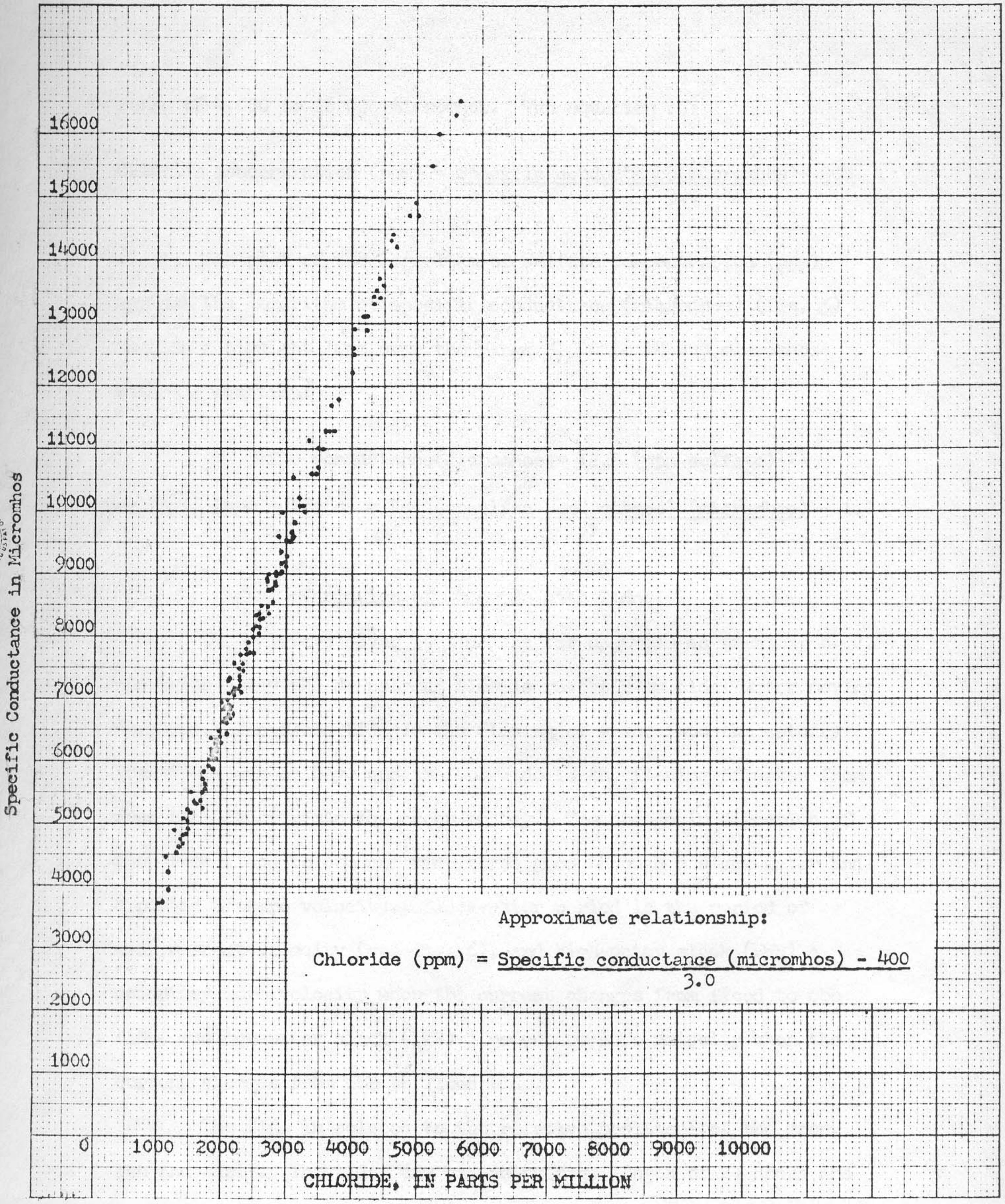


Figure 4.--The relation between electrical conductivity and chloride concentration (1,000 - 6,000 ppm)

range of 4,000 to 16,000 micromhos. The equation is:

$$\text{Chloride concentration (ppm)} = \frac{\text{Specific conductance(micromhos)} - 400}{3.0}$$

The plot of the logarithm of sulfate concentration (ppm) against the logarithm of specific conductance (micromhos) (fig. 5) is also a straight line over the range 3,500 to 14,000 micromhos with the equation:

$$\text{Specific conductance(micromhos)} = 12.0\ (\text{ppm sulfate})^{1.1}$$

$$\text{or } \text{Log}_{10}\ (\text{ppm sulfate}) = \frac{\text{Log (specific conductance) (micromhos)}}{1.1} - 1.0$$

Variation of Chloride with Tide

The Delaware River is tidal as far upstream as Trenton, N. J. and twice a day the downstream flow is reversed by tidal water moving upstream. The flood tide is the flowing of water into the estuary from the ocean or bay, and the ebb tide is the flowing of water from from the estuary into the ocean or bay. The change in direction of flow from flood to ebb and vice versa goes through a slack water and a period of zero velocity. Slack-water period is the period of weak current velocity (see fig. 6), and high-water slack (HWS) a momentary zero velocity when the current changes from flood to ebb tide, and low-water slack (LWS) a momentary zero velocity when the current changes from ebb to flood tide.

The tide is related to the relative positions of the moon, sun and earth. The tidal day has an average length of 24 hours and 50 minutes, like the lunar day. Tides of greatest range (called

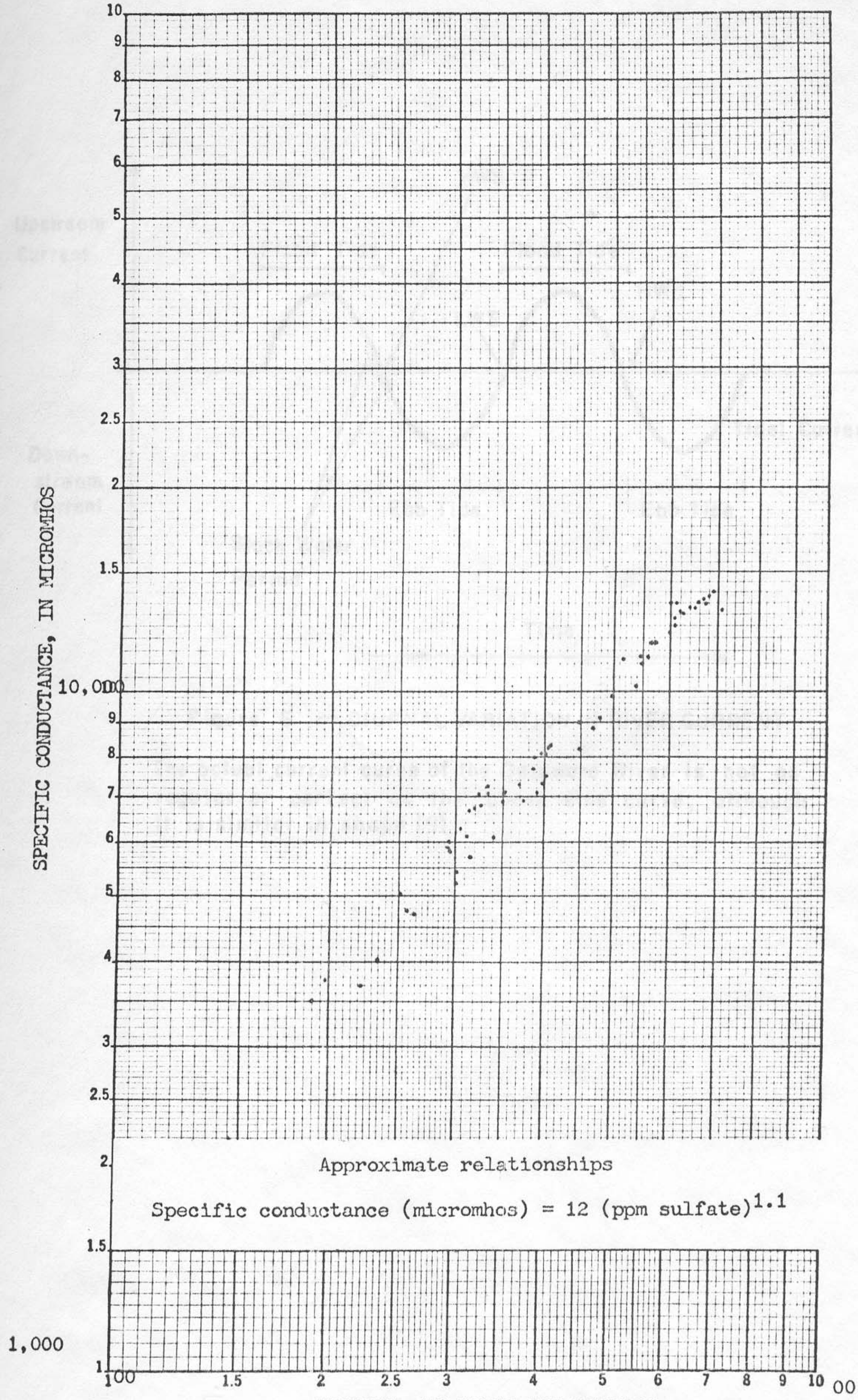


Figure 5.--The relation between electrical conductivity and sulfate concentration (200 to 700 ppm)

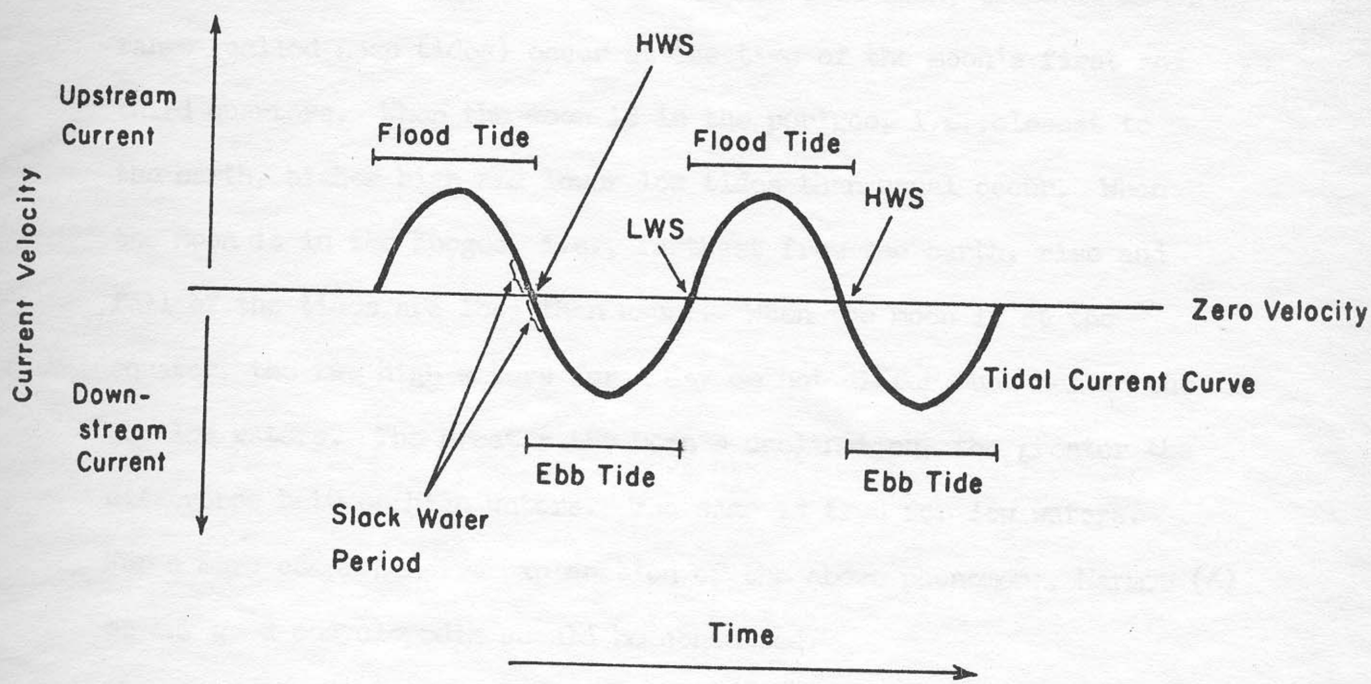


Figure 6 .— DIURNAL VARIATION IN RIVER CURRENT

The actual current curve of the Delaware River is not as regular or perfect as the above sine curve, although it is similar in shape (9).

spring tides) occur at the time of new and full moon; tides of least range (called neap tides) occur at the time of the moon's first and third quarters. When the moon is in the perigee, i.e., closest to the earth, higher high and lower low tides than usual occur. When the moon is in the apogee, i.e., farthest from the earth, rise and fall of the tides are less than usual. When the moon is at the equator, the two high waters for a day do not differ much nor do the two low waters. The greater the moon's declination, the greater the difference between high waters. The same is true for low waters. For a more comprehensive explanation of the above phenomena, Marmer (6) or any good encyclopedia should be consulted.

In the Delaware River there are usually two complete tidal cycles each day; one high-water slack and one low-water slack with each cycle. Slack-water period in the Delaware River in this reach occurs from 1 to 2 hours after high or low tide. The time of slack water occurs at a shorter time interval in an upstream direction after high or low tide. At the Delaware Memorial Bridge, the time between a high-water slack and a low-water slack is about 6.5 hours, and between low-water slack and high-water slack 6.0 hours, although this will vary with flow, mean river level, and astronomical and meteorological conditions. The duration of rise of tide decreases and the duration of fall of tide increases in an upstream direction.

At the Delaware Memorial Bridge, maximum and minimum conductivity at the site of the conductivity recorder usually occurs within half an hour of the predicted times of slack water for the navigation channel. At the conductivity recorder at Reedy Island Jetty the maximum and minimum conductivity occurs within $1\frac{1}{2}$ hours of the predicted times of slack water for the navigation channel. This time discrepancy may be due to the distance of the conductivity recorder from the navigation channel. High- or low-water slack should occur somewhere near or in the navigation channel before it does so on the sides of the river. For example, while water is flooding in the navigation channel off Reedy Island Jetty, the water around the conductivity instrument (at the Jetty) may still be ebbing. For an ebbing tide, the reverse should be true. From table 2, which is typical of the data collected, the times of maximum and minimum conductivity usually occur after the predicted times of high- and low-water slack in the navigation channel. At the Delaware Memorial Bridge, due to the contour of the river, it is possible for slack water to occur at the site of the conductivity instrument before it occurs in the navigation channel.

Highest chloride concentrations usually occur at or near high high-water slack and lowest chloride concentrations at or near low low-water slack. As fresh water is discharged seaward during the ebb tide, the total dissolved solids decrease until the flood tide begins. Saline water is diluted and pushed downstream by fresh-water run off. The flushing action continues until low-water slack, at which time the ensuing flood waters carry salt water upstream.

A curve of tidal cycle in the Delaware is somewhat similar in shape to a sine curve, and the specific conductance curve for a tidal cycle follows the tidal curve in form.

Figures 7a and 7b illustrate continuous records of conductivity

Table 2.--Comparison of the Predicted Time of Slack Waters and the Maximum and Minimum Chloride at the Delaware Memorial Bridge and Reedy Island Jetty (all times are EST)

Delaware Memorial Bridge

Date	HWS or LWS	Pred. time of slack for naviga- tion channel	Time of max. and min. chloride	Differ- ence
9/1/56	Low	3:44 AM	4:25 AM	+41
	High	9:17 AM	9:50 AM	+33
	Low	3:44 PM	4:05 PM	+21
	High	9:59 PM	10:05 PM	+ 6
9/2	Low	4:45 AM	5:05 AM	+20
	High	10:22 AM	10:50 AM	+31
	Low	4:46 PM	5:05 PM	+19
	High	10:56 PM	10:55 PM	+ 1
9/3	Low	5:39 AM	5:45 AM	+ 6
	High	11:22 AM	11:50 AM	+28
	Low	5:43 PM	6:10 PM	+27
	High	11:48 PM	12:00 noon	+12
9/4	Low	6:28 AM	7:05 AM	+37
	High	12:16 PM	12:35 PM	+19
	Low	6:36 PM	7:05 PM	+29
	High	12:36 AM	1:05 AM	+29
	Low	7:15 AM	7:45 AM	+30
	High	1:06 PM	1:40 PM	+34
	Low	7:26 PM	7:45 PM	+19

Reedy Island Jetty

Date	HWS or LWS	Pred. time of slack for naviga- tion channel	Time of max. and min. chloride	Differ- ence
9/1/56	Low	4:19 AM	3:20 AM	- 57
	High	9:52 AM	8:10 AM	-100
	Low	4:19 PM	4:25 PM	+ 6
	High	10:34 PM	9:50 PM	- 48
9/2	Low	5:20 AM	5:50 AM	+ 30
	High	10:57 AM	10:15 AM	- 46
	Low	5:21 PM	4:50 PM	- 19
	High	11:31 PM	10:35 PM	- 61
9/3	Low	6:14 AM	5:25 AM	- 49
	High	11:57 AM	10:45 AM	- 72
	Low	6:18 PM	5:40 PM	- 36
9/4	High	12:23 AM	11:20 PM‡	- 61
	Low	7:03 AM	6:05 AM	- 62
	High	12:51 PM	11:50 AM	- 59
	Low	7:11 PM	6:20 PM	- 49
9/5	High	1:11 AM	12:40 AM	- 33
	Low	7:50 AM	7:05 AM	- 49
	High	1:41 PM	1:05 PM	- 40
	Low	8:01 PM	8:45 PM	+ 44

‡ Occurs on 9/3.

at the Delaware Memorial Bridge and at Reedy Island Jetty. It will be noted from figures 7a and 7b that the general shape of the conductivity curve through a tidal cycle is sinusoidal with rapid fluctuation occuring after each high-water slack.

A comparison of the water stage and conductivity appears in figure 8. Maximum and minimum conductivity occur after maximum and minimum stage.

The maximum and minimum specific conductance read from conductivity records at the Delaware Memorial Bridge for 1955 are given in table 3. The data from August to October were collected during flood conditions and do not represent salinity invasion or conditions usually existing at this time of year.

The maximum and minimum specific conductance for 1956 at the Delaware Memorial Bridge and Reedy Island Jetty are given in tables 4a, 4b, and 4c.

Longitudinal Variation of Chloride Concentration

The chloride profiles in figure 9 represent the farthest advance of salinity in the center of the channel at a high-water slack on a particular day. They do not represent a condition actually existing at any given time, but rather the succession of maximum salinities, occurring at the various stations at various times, as the crest of the tidal wave advances upstream. Each profile is a plot of chloride concentration at high-water slack against distance. Since it is difficult to collect samples in a number of sampling locations at exactly high-water slack, a method has been devised for

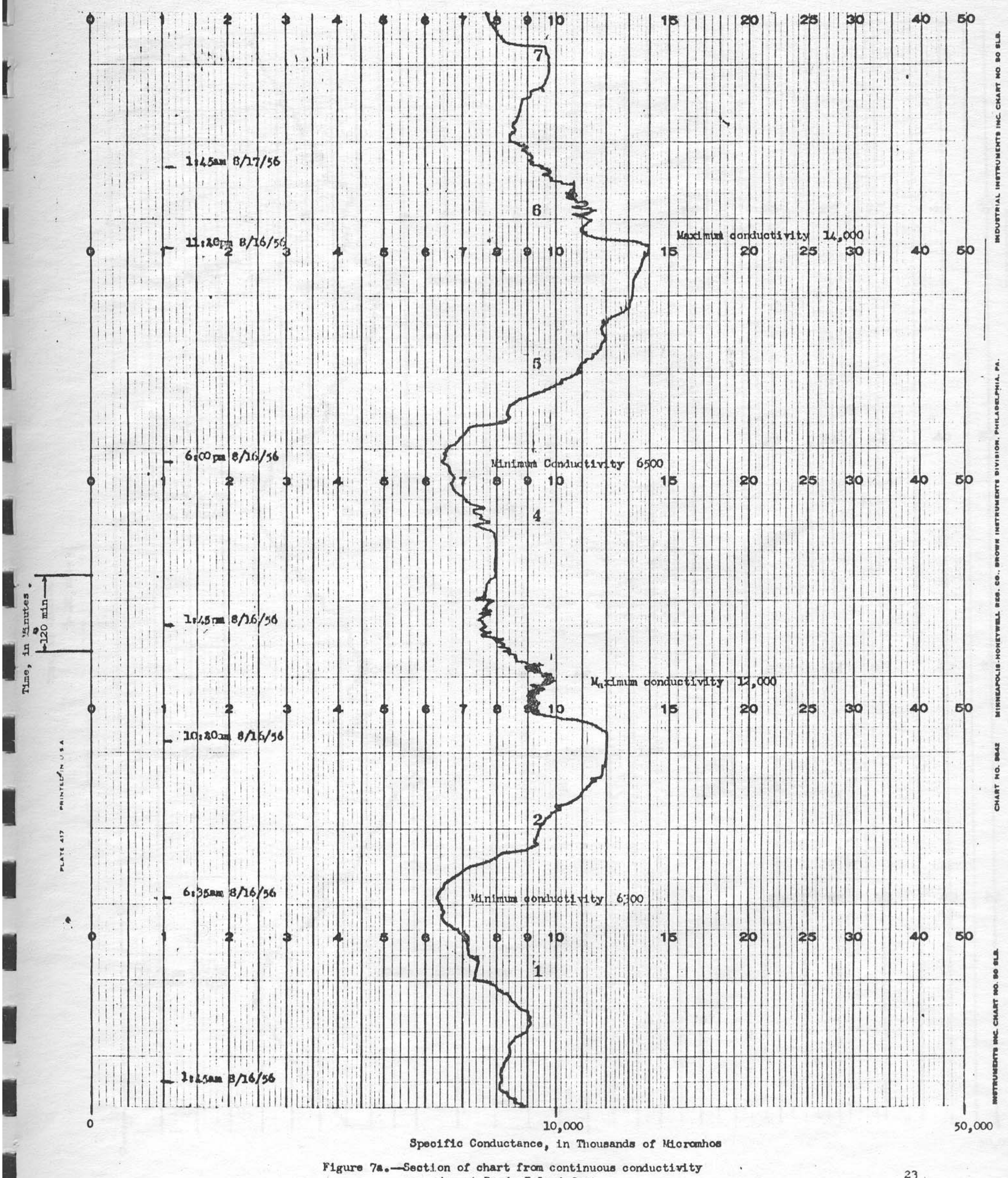
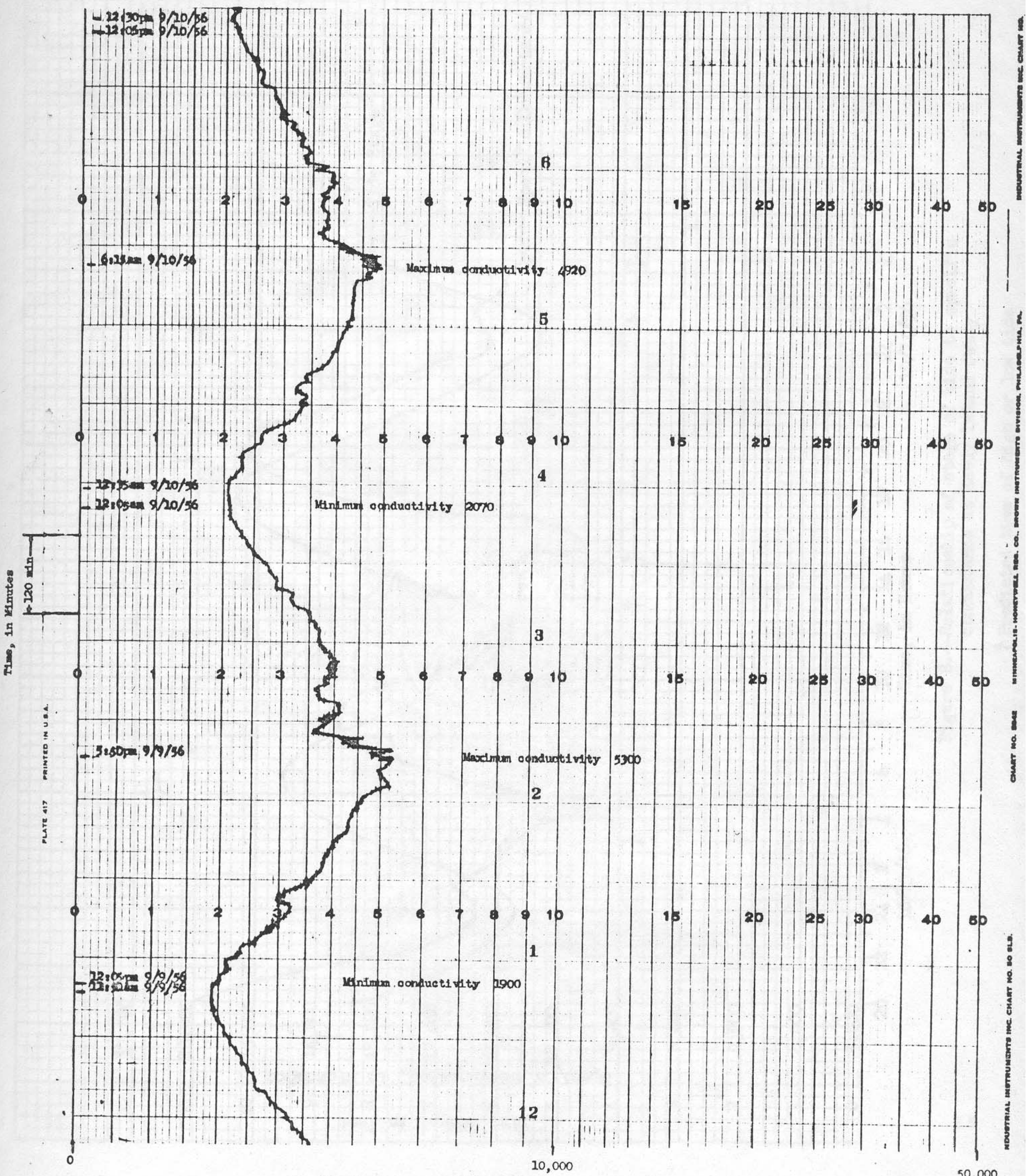


Figure 7a.—Section of chart from continuous conductivity recorder at Reedy Island Jetty



Specific Conductancy, in Thousands of Micromhos

Figure 7b.—Section of chart from continuous conductivity recorder at the Delaware Memorial Bridge

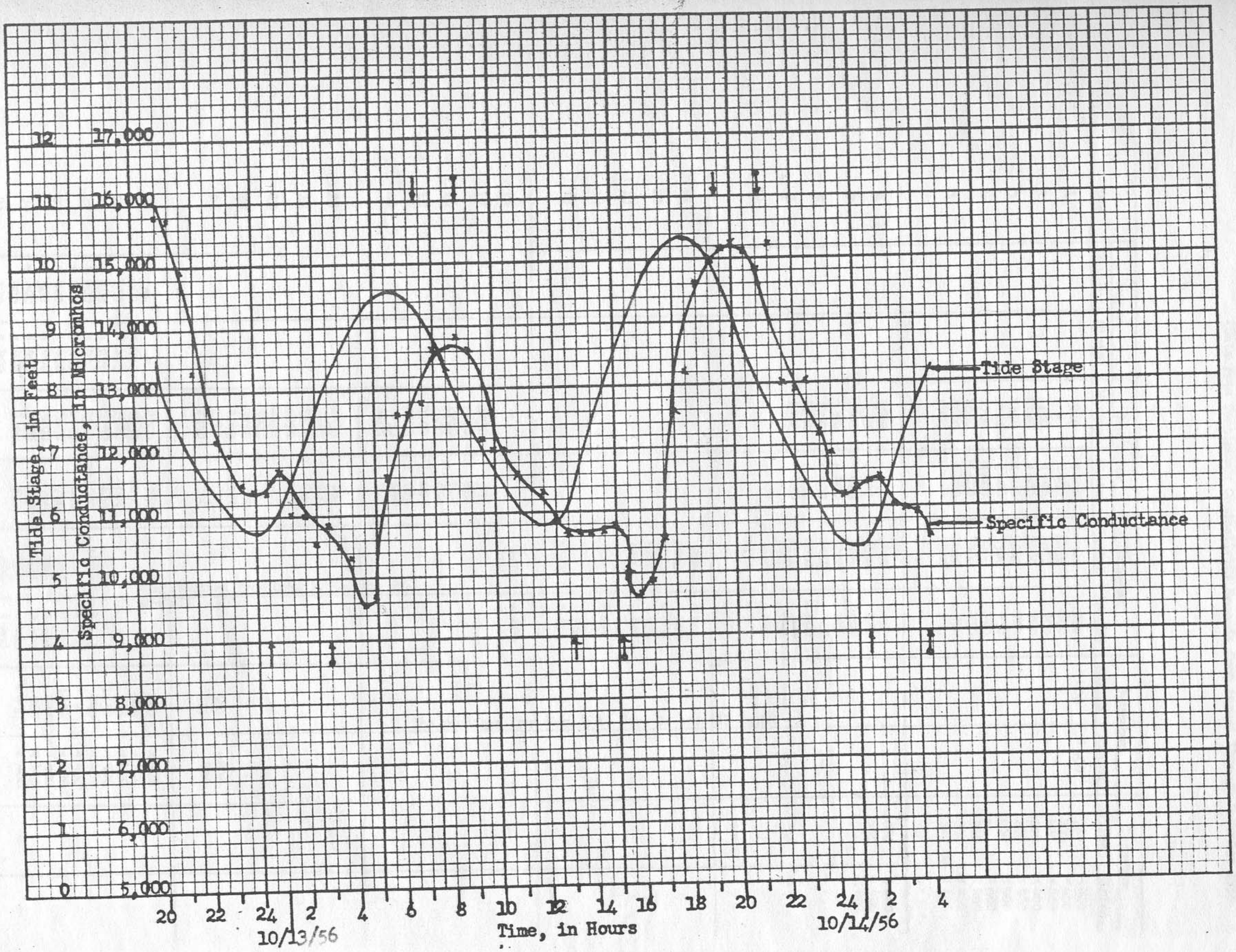


Figure 8.—Relationship of stage of tide to specific conductance at Reedy Island Jetty

↑ Predicted time of high or low tide

↕ Predicted time of high-or low-water slack

Table 3.-- Specific Conductance (in micromhos) of Water at the Delaware Memorial Bridge
(Data from Continuous Conductivity Records from August through December 1955

Day	August		September		October		November		December	
	Maxima	Minima	Maxima	Minima	Maxima	Minima	Maxima	Minima	Maxima	Minima
1			940	<400	-	720	<400	<400	760	<400
			-	<400	2850	680			755	<400
2			1180	<400	2680	700	The readings from Nov. 1 to Nov. 25 are all <400		1400	<400
			1190	<400	3100	760			1000	<400
3			1350	<400	3200	720			1200	<400
			1400	<400	3500	750			1050	<400
4			1700	<400	3000	720			-	<400
			1650	<400	3400	810			1380	<400
5			1600	<400	2950	750			1300	<400
			1790	-	2680	840			1320	<400
6			1500	<400	2950	-			1080	<400
			1850	<400	3550	880			1100	<400
7			1790	420	3000	880			1380	<400
			2300	<400	3200	780				
8			1590	<400	2450	420				
			2230	<400	2000	<400				
9			1750	460	1150	<400				
					1370	<400				
10					1020	<400				
					1150	<400				
11					880	<400				
					1020	<400				
12					1080	<400				
					1100	<400				
13					1020	<400				
					1300	<400				
14					1800	<400				
					1450	425				
15					-	<400				
					1150	<400				
16			-	-	620	<400				
					<400	<400				
17			2850	580	The readings from Oct. 17 to Oct. 28 are all <400					
			2850	620						
18			2750	620						
			2800	650						
19			2400	695						
			2950	690						
20			2750	840						
			3100	940						
21			2850	900						
			2850	900						
22			2500	820						
			2950	870						
23			2250	900						
			3000	-						
24			2750	1220						
			3200	1120						
25			2200	845			500	<400		
			2350	800			625	<400		
26	-	-	2300	750			620	<400		
	<400	<400	2850	1050			880	<400		
27	<400	<400	2420	880			785	<400		
	<400	<400	3250	880			1250	<400		
28	<400	<400	2550	1000	<400	<400	440	<400		
	<400	<400	2600	620	505	<400	-	<400		
29	<400	<400	2650	700	540	<400	1020	<400		
	560	<400	3200	740	595	<400	740	<400		
30	<400	<400	3100	870	695	<400	565	<400		
	900	<400	3100	810	880	<400	<400	<400		
31	520	<400			635	<400				
	940	<400			740	<400				

<400 means that the specific conductance was less than 400 micromhos

Table 4a.-- Specific Conductance (in micromhos) of Water at the Delaware Memorial Bridge
(Data from Continuous Conductivity Records from September through November 1956)

Day	SEPTEMBER				OCTOBER				NOVEMBER			
	Maxima		Minima		Maxima		Minima		Maxima		Minima	
	Time (EST)	S.C.*	Time (EST)	S.C.*	Time (EST)	S.C.*	Time (EST)	S.C.*	Time (EST)	S.C.*	Time (EST)	S.C.*
1	9:50 AM	5350	4:25 AM	2200	10:50 AM	5500	5:05 AM	2280	12:05 PM	5640	6:20 AM	2480
	10:05 PM	6300	4:05 PM	2100	10:55 PM	6600	5:30 PM	2100	-	-	7:20 PM	2400
2	10:55 AM	5500	5:05 AM	2250	11:30 AM	6200	6:25 AM	2250	12:40 AM	5000	7:30 AM	2220
	10:55 PM	6300	5:05 PM	2050	11:50 AM	6900	6:50 PM	2400	12:40 PM	4850	8:10 PM	1900
3	11:50 PM	5220	5:45 AM	2090			7:05 AM	2320	1:15 AM	3400	7:45 AM	1800
	12:00 AM	6600	6:10 PM	2150	-	-	7:10 PM	2450	1:30 PM	4060	8:50 PM	1740
4	12:35 PM	5600	7:05 AM	2100	12:30 AM	5880	7:20 AM	2320	2:00 AM	2980	8:50 AM	1640
	-	-	7:05 PM	2050	1:40 PM	7100	8:00 PM	2460	2:30 PM	2840	9:15 PM	1600
5	1:05 AM	6800	7:45 AM	2200	1:25 AM	6070	8:35 PM	2370	2:30 AM	2370	8:50 AM	1550
	1:40 PM	6020	7:45 PM	2200	1:25 PM	6600	8:35 PM	2500	3:30 PM	2620	9:55 PM	1520
6	1:40 AM	6900	8:30 AM	2250	2:30 AM	5900	8:50 AM	2600	3:40 AM	2240	10:10 AM	1500
	2:10 PM	6400	9:05 PM	2400	2:25 PM	6600	9:20 PM	2760	3:45 PM	2480	11:30 PM	1480
7	2:40 AM	6200	9:35 AM	2170	3:05 AM	6700	9:30 AM	2850	4:10 AM	2080	10:50 AM	1440
	2:30 PM	5300	9:50 PM	2150	3:00 PM	6120	10:20 PM	2500	4:30 PM	2120	11:30 PM	1420
8	3:30 AM	5200	10:05 AM	2000	3:05 AM	5080	10:00 AM	2400	5:30 AM	1860	11:30 AM	1400
	3:50 PM	5800	10:55 PM	2000	3:30 PM	6070	11:00 PM	2600	5:10 PM	1970	-	-
9	4:15 PM	4870	10:50 AM	1900	4:15 AM	5100	11:20 AM	2250	7:30 AM	1450	1:00 AM	1350
	4:50 PM	5300	11:35 AM	2070	4:55 PM	5120	11:40 PM	2500	6:55 PM	1730	11:30 AM	1350
10	5:15 AM	4920	11:30 PM	2050	5:20 AM	4900	11:40 AM	2620	7:15 AM	1480	2:00 AM	1320
	5:05 PM	5580	-	-	5:40 PM	5200	-	-	7:25 PM	1620	12:50 PM	1300
11	5:45 AM	4750	12:20 AM	2150	6:20 AM	4890	12:20 AM	2650	8:20 AM	1710	1:30 AM	1300
	6:00 PM	5450	12:10 PM	2200	6:30 PM	5480	12:35 PM	2770	8:20 PM	2190	2:10 PM	1300
12	6:35 AM	4300	1:20 AM	2250	6:40 AM	5100	1:25 AM	2800	9:25 AM	1660	3:30 AM	1190
	7:05 PM	5000	1:05 PM	2050	7:05 PM	5730	1:00 PM	2950	9:30 PM	1670	3:30 PM	2240
13	8:50 AM	4300	2:25 AM	2000	7:45 AM	5480	2:30 AM	3050	11:10 AM	1300	4:50 AM	1040
	7:50 PM	5150	2:00 PM	2150	8:15 PM	6100	2:10 PM	3350	10:30 PM	1490	4:50 PM	1000
14	8:35 AM	4500	3:25 AM	2200	8:40 AM	5970	3:10 AM	3500	10:30 AM	1580	4:50 AM	960
	9:20 PM	4820	3:25 PM	1950	9:30 PM	6520	3:20 PM	3600	11:10 PM	1360	5:30 PM	880
15	10:10 AM	4280	4:05 AM	1900	9:40 AM	6000	4:05 AM	3650	11:40 AM	1550	5:30 AM	820
	9:50 PM	5500	4:00 PM	2250	10:10 PM	6620	4:35 PM	3600	-	-	6:10 PM	810
16	11:05 AM	5400	4:50 AM	2220	10:10 AM	6400	5:00 AM	3700	12:00 AM	1500	6:10 AM	830
	11:05 PM	6000	5:05 PM	2500	11:10 PM	6600	5:30 PM	3570	12:25 PM	1800	6:50 PM	820
17	11:35 AM	5500	5:50 AM	2200	11:25 AM	6500	5:55 AM	3550	12:25 AM	1640	6:50 AM	790
	-	-	5:45 PM	2270	11:45 PM	6500	6:10 PM	3500	1:00 PM	1970	7:30 PM	820
18	11:50 PM	5600	6:10 AM	2060	12:25 PM	6520	6:30 AM	3650	2:40 AM	1560	8:10 AM	800
	12:00 PM	4620	6:25 PM	1920	-	-	6:50 PM	3500	1:25 PM	1880	8:50 PM	800
19	12:10 AM	5000	6:50 AM	2170	12:30 AM	7290	7:05 AM	3630	1:50 AM	1660	8:10 AM	800
	12:25 PM	5380	7:05 PM	2450	12:20 PM	7200	7:45 PM	3690	1:45 PM	1880	9:30 PM	780
20	12:50 AM	6600	7:45 AM	2430	1:00 AM	6920	7:40 AM	3620	2:45 AM	1620	9:30 AM	770
	1:20 PM	5270	7:55 PM	1900	1:10 PM	7250	8:10 PM	3450	3:05 PM	1970	9:40 PM	590
21	2:05 AM	5180	8:20 AM	2000	1:10 AM	6490	8:10 AM	3400	3:05 AM	2380	9:40 AM	630
	2:05 PM	5500	8:40 PM	2020	1:30 PM	7400	8:50 PM	3300	4:15 PM	3390	11:00 PM	910
22	2:25 AM	5400	9:05 AM	2100	2:25 AM	6400	8:50 AM	3400	3:05 AM	2040	10:20 AM	580
	2:50 PM	5400	9:45 PM	2000	2:30 PM	7620	10:00 PM	3640	4:10 PM	2380	-	
23	3:35 AM	4700	9:50 AM	1920	2:15 AM	6690	9:45 AM	3600	4:20 AM	1270	12:05 AM	600
					2:55 PM	7550	10:30 PM	3560	5:20 PM	1500	11:05 AM	550
24					3:10 AM	6400	10:50 AM	3060	5:40 AM	1140	12:45 AM	540
					4:15 PM	5890	11:30 PM	3050	6:20 PM	2000	1:05 PM	560
25					5:05 AM	5600	11:30 AM	3260	6:55 AM	1750	2:10 AM	590
					5:10 PM	6630	-	-	7:15 PM	2000	1:25 PM	600
26					6:30 AM	5690	12:50 AM	3290	8:05 AM	2520	2:05 AM	700
					6:25 PM	6170	1:00 PM	3380	8:25 PM	2200	2:45 PM	700
27					6:50 AM	5600	1:45 AM	3080	9:05 AM	2180	3:05 AM	690
					6:50 PM	5730	2:00 PM	2940	10:45 PM	1920	4:15 PM	600
28	8:20 AM	6100	2:40 AM	3150	8:20 AM	5420	3:05 AM	2700	10:10 AM	1570	4:10 AM	620
	8:10 PM	6300	2:25 PM	2820	8:50 PM	5500	3:10 PM	2820	10:50 PM	1600	4:35 PM	620
29	8:55 AM	6030	3:05 AM	2490	9:30 AM	5400	4:00 AM	2750	11:20 AM	2260	5:25 AM	620
	8:50 PM	6500	3:30 PM	2300	9:30 PM	5420	4:10 PM	2740	10:45 PM	1350	5:25 PM	620
30	9:45 AM	6100	4:05 AM	2250	10:20 AM	5710	4:50 AM	2630	12:00 PM	2120	5:45 AM	590
	9:40 PM	6900	4:25 PM	2400	10:50 PM	5300	5:05 PM	2580			6:45 PM	610
31					11:40 AM	5810	5:30 AM	2600				
					11:30 PM	5420	6:15 PM	2520				

* S.C. = Specific conductance

Table 4b.-- Specific Conductance (in micromhos) of Water at Reedy Island Jetty
(Data from Continuous Conductivity Records from July through September 1956)

Day	JULY				AUGUST				SEPTEMBER			
	Maxima		Minima		Maxima		Minima		Maxima		Minima	
	Time EST	S.C.*	Time EST	S.C.*	Time EST	S.C.*	Time EST	S.C.*	Time EST	S.C.*	Time EST	S.C.*
1	5:40 AM	9590	12:50 AM	4150	7:05 AM	10000	2:35 AM	4100	8:10 AM	12100	3:20 AM	8200
	6:05 PM	9200	12:35 PM	3370	8:00 PM	11100	2:45 PM	3750	9:50 PM	14000	4:25 PM	7800
2	6:35 AM	8590	2:35 AM	4160	8:00 AM	8700	4:05 AM	3910	10:15 AM	12600	5:50 AM	7900
	7:30 PM	10000	1:35 PM	3420	8:50 PM	12500	3:30 PM	4140	10:35 PM	14000	4:50 PM	7850
3	6:45 AM	8130	3:05 AM	3620	9:00 AM	10000	4:55 AM	5150	10:45 AM	12000	5:25 AM	7700
	8:25 PM	10800	3:00 PM	3440	9:30 PM	12000	4:35 PM	4250			5:40 PM	7700
4	8:40 AM	8990	4:05 AM	4090	10:30 AM	9100	6:30 AM	4900	11:20 PM	14100	6:05 AM	7700
	9:00 PM	11000	3:55 PM	3850	10:50 PM	12500	4:55 PM	4500	11:50 AM	12700	6:20 PM	7550
5	9:35 AM	8750	5:15 AM	4710			4:10 AM	5300	12:40 AM	14400	7:05 AM	7800
	9:15 PM	10600	3:45 PM	4040					1:05 PM	13000	8:45 PM	7900
6	10:20 AM	9450	4:10 AM	4400					12:25 AM	13900	8:30 AM	7900
	11:20 PM	11700	5:00 PM	4620					2:05 PM	14200	8:20 PM	7950
7	11:50 AM	9800	7:30 AM	4750					2:05 AM	12800		
	-	-	8:00 PM	4520	3:50 PM	11800	8:15 PM	6050				
8	11:50 PM	11800	8:30 AM	5000	2:30 AM	13300	10:10 AM	6100				
	12:30 PM	9200	7:30 PM	5050	2:50 PM	11900	9:25 PM	5400				
9	12:50 AM	11900	9:00 AM	5020	3:20 AM	12200	10:20 AM	5800				
	12:35 PM	9400	9:00 PM	4610	3:50 PM	11500	10:10 PM	5930				
10	1:15 AM	11200	10:10 AM	4480	4:10 AM	12200	11:40 AM	5800				
	2:25 PM	8720	10:10 PM	4000	4:50 PM	11600	11:45 PM	5900				
11	2:55 AM	10000	10:50 AM	3820	4:55 AM	11000	11:40 AM	5800				
	3:35 PM	8850	10:05 PM	3500	5:40 PM	12000	-	-				
12	3:50 AM	9140	10:55 AM	3430	5:50 AM	11500	12:45 AM	6190				
					6:50 PM	12200	12:55 PM	5820				
13					6:55 AM	11000	1:45 AM	6420				
					7:30 PM	12300	1:30 PM	6050				
14					7:50 AM	10700	2:50 AM	6500				
					8:25 PM	12000	2:45 PM	6150				
15					9:10 AM	11000	3:40 AM	6350				
					9:30 PM	13200	4:00 PM	5980				
16					9:40 AM	12000	5:35 AM	6300				
					10:40 PM	14000	5:00 PM	6500				
17					10:45 PM	12500	6:35 AM	6550				
					11:15 PM	14300	6:15 PM	6880				
18					11:45 AM	12300	7:25 AM	6600				
	10:00 PM	10600	4:40 PM	3650	-	-	5:55 PM	7200			7:00 PM	8600
19	10:15 AM	8050	5:30 AM	3820	12:00 AM	15000	7:30 AM	7000	11:50 PM	15200	7:05 AM	9090
	10:50 PM	10200	5:15 PM	4100	12:30 PM	12100	7:50 PM	6650	12:10 PM	15000	5:50 PM	10200
20	10:50 AM	7630	5:00 AM	4070	12:50 AM	13800	8:15 AM	6900	11:55 PM	16200	7:30 AM	10200
	10:45 PM	9600	5:00 PM	4425	1:00 PM	11000	8:00 PM	7380	2:00 PM	14400	7:00 PM	8500
21	11:15 AM	8580	8:00 AM	4680	1:00 AM	14400			12:00 AM	14400	7:50 AM	8400
	11:30 PM	8400	6:35 PM	3300					1:25 PM	15200	8:05 PM	8900
22	12:15 PM	8060	7:55 AM	3300					1:25 AM	14800	8:30 AM	8600
	-	-	7:00 PM	3030					1:50 PM	14600	9:20 PM	8200
23	2:45 AM	9150	8:35 AM	2950					1:20 AM	12400	9:50 AM	7400
	1:05 PM	7790	7:45 PM	3050					2:45 PM	15000	10:05 PM	8000
24	1:25 AM	9100	8:55 AM	2950					2:55 AM	13900	9:45 AM	7500
	1:45 PM	8000	8:15 PM	2850					3:25 PM	15000	11:10 PM	8000
25	1:50 AM	8990	8:45 AM	2900					3:30 AM	14200	11:15 AM	7900
	2:25 PM	8250	8:55 PM	3100					4:10 PM	14800	-	-
26	2:30 PM	9380	10:00 AM	3160					4:20 AM	12100	12:20 AM	8600
	2:45 PM	8380	10:00 PM	3470					4:05 PM	16000	11:40 AM	8750
27	3:05 AM	9590	10:30 AM	3400					4:50 AM	15200	10:30 PM	11800
	3:30 PM	8800			4:30 PM	13500			5:40 PM	17200	11:00 AM	12000
28	3:35 AM	8900	11:15 PM	3550	4:40 AM	12500	12:10 AM	7980	6:40 AM	16000	12:20 AM	12500
	3:15 PM	8000	10:45 PM	3220	5:30 PM	13800	11:30 PM	7420	6:55 PM	17000	2:40 PM	11400
29	4:10 AM	8300	10:35 PM	2500	4:40 AM	12000	1:10 AM	7780	7:45 AM	15300	3:10 AM	9500
	4:55 PM	9600	11:00 AM	3650	5:30 PM	13800	1:10 PM	7600	8:15 PM	16100	3:00 PM	9700
30	5:05 AM	7700	12:35 PM	3650	6:30 AM	13300	1:50 AM	8050	8:55 AM	15000	4:10 AM	9250
	5:45 PM	10400			6:50 PM	14600	1:30 PM	7700	9:20 PM	17400	3:55 PM	9800
31	5:45 AM	9590	1:30 AM	3900	7:35 AM	13400	3:10 AM	8700				
	6:55 PM	10800	1:45 PM	3400	8:10 PM	14400						

* S.C. = Specific conductance

Table 4c.--Specific Conductance (in micromhos) of Water at Reedy Island Jetty
(Data from Continuous Conductivity Records from October through December 1956)

Day	OCTOBER				NOVEMBER				DECEMBER			
	Maxima		Minima		Maxima		Minima		Maxima		Minima	
	Time EST	S.C.*	Time EST	S.C.*	Time EST	S.C.*	Time EST	S.C.*	Time EST	S.C.*	Time EST	S.C.*
1	11:25 AM	14000	4:00 AM	9550	11:40 AM	13700	6:10 AM	8400	11:55 AM	12400	6:30 AM	4400
	10:20 PM	16200	4:45 PM	9000	11:45 PM	11800	6:20 PM	8300	-	-	7:20 PM	4400
2	11:00 AM	16000	4:55 AM	9200			7:05 AM	7550	1:35 AM	8500	6:50 AM	4100
	11:15 AM	16600	6:05 PM	9650					12:40 PM	11600	8:10 PM	4700
3	11:40 PM	15800	5:20 AM	9400					12:55 AM	8320	6:40 AM	4680
	-	-	5:55 PM	9200					1:15 PM	12400	9:05 PM	4500
4	12:05 AM	15400	6:45 AM	9000					3:00 AM	8390	8:45 AM	4450
	12:40 PM	16500	7:00 PM	9200					1:40 PM	11200	9:25 PM	4000
5	12:40 AM	14400	7:05 AM	9100					1:25 AM	7300	9:40 AM	4510
	1:15 PM	14900	8:25 PM	9150					2:25 PM	11200	10:05 PM	4700
6	1:35 AM	14600	7:30 AM	9200					2:55 AM	9720	10:05 AM	4920
	2:15 PM	15500	9:45 PM	9750					3:00 PM	10800	11:15 PM	4860
7	2:25 AM	14800	8:55 AM	9550					3:35 AM	8890	10:50 AM	4750
	3:00 PM	14400	10:45 PM	8900					3:50 PM	10900	11:20 PM	4660
8	3:05 AM	12000	10:30 AM	8750					4:15 AM	8250	11:55 AM	4750
	3:50 PM	14500	10:35 PM	9300					4:45 PM	9700	12:05 AM	4800
9	3:45 AM	13100	10:00 AM	7500								
	4:40 PM	13200	11:45 AM	8000								
10	4:00 AM	12200	12:25 PM	8550								
	5:15 PM	14600	-	-								
11	5:45 AM	13800	1:05 AM	8800								
	6:15 PM	15300	12:35 PM	8900								
12	6:15 AM	13600	2:05 AM	9150								
	6:25 PM	16000	1:45 PM	9350								
13	7:45 AM	14200	3:25 AM	9500								
	6:50 PM	15300	3:05 PM	9650								
14	8:10 AM	15200	4:05 AM	9390								
	9:15 PM	15600	4:15 PM	9180								
15	9:40 AM	15200	5:05 AM	9050								
	9:35 PM	15800	5:05 PM	9080								
16	9:35 AM	15000	5:20 AM	9150								
	10:40 PM	16200	5:45 PM	9490								
17	10:40 AM	14800	6:10 AM	9680								
	11:08 PM	15000	6:15 PM	9520								
18	11:40 AM	16000	5:55 AM	10800								
	11:55 PM	17300	7:10 PM	10200								
19	12:25 PM	17200	6:25 AM	11100								
	11:30 PM	16300	7:35 PM	10700					1:35 PM	5500	9:30 PM	910
20	12:55 PM	16500	7:55 AM	11000					1:20 AM	2320	10:30 AM	710
	-	-	8:30 PM	10200			9:40 PM	5490	1:45 PM	3270	11:00 PM	750
21	12:10 AM	14600	8:30 AM	10200	2:20 AM	9800	9:20 AM	5320	2:05 AM	1940	11:05 AM	750
	12:30 PM	16500	9:40 PM	10000	2:55 PM	13200	9:05 PM	7250	2:20 PM	4050	11:05 PM	820
22	1:40 AM	14000	8:55 AM	10200	2:10 AM	9200	11:45 AM	5090	3:05 AM	3000	11:50 AM	800
	1:25 PM	17000	10:00 PM	10400	3:25 PM	9820	11:35 PM	4400	5:20 PM	3600	-	-
23	1:30 AM	15100	9:40 AM	10400	4:05 AM	6500	12:45 AM	4150	4:30 PM	2510	12:55 AM	800
	2:40 PM	17000	11:10 PM	10100	4:30 PM	8600			4:10 PM	4120	12:00 PM	810
24	2:15 AM	14400	10:00 AM	9470	5:35 AM	6950	12:40 AM	3300	5:35 AM	3770	12:10 AM	700
	3:35 PM	13800	11:35 PM	9520	5:40 PM	10200	12:25 PM	3400	5:35 PM	3120	1:40 PM	650
25	4:00 AM	13200	10:25 AM	10400	5:40 AM	9000	11:45 PM	3700				
	4:30 PM	16400	-	-	6:35 PM	11900	12:25 PM	4250				
26	4:55 AM	13900	12:55 AM	11500	7:20 AM	12400	1:55 AM	5000				
	5:00 PM	15500	1:35 PM	10600	7:40 PM	12100	2:35 PM	5190				
27	6:00 AM	14500	2:00 AM	10100	8:20 AM	11500	2:50 AM	5000				
	6:10 PM	14300	2:05 PM	10000	9:10 PM	9350	4:35 PM	5000				
28	7:10 AM	12200	3:05 AM	9100	9:25 AM	10900	4:55 AM	4620				
	8:25 PM	15000	2:15 PM	9750	9:55 PM	10600	4:40 PM	4350				
29	8:25 AM	14200	3:30 AM	9880	10:20 AM	11200	5:30 AM	4140				
	8:50 PM	13800	4:10 PM	9280	11:55 PM	7800	6:20 PM	3900				
30	8:50 AM	13400	5:00 AM	8850	11:20 AM	11500	5:20 AM	3900				
	10:15 PM	13200	5:20 PM	8550	11:35 PM	8900	7:25 PM	3950				
31	10:30 AM	13200	5:25 AM	8800								
	10:40 PM	12800	5:55 PM	8800								

* S.C. = Specific conductance

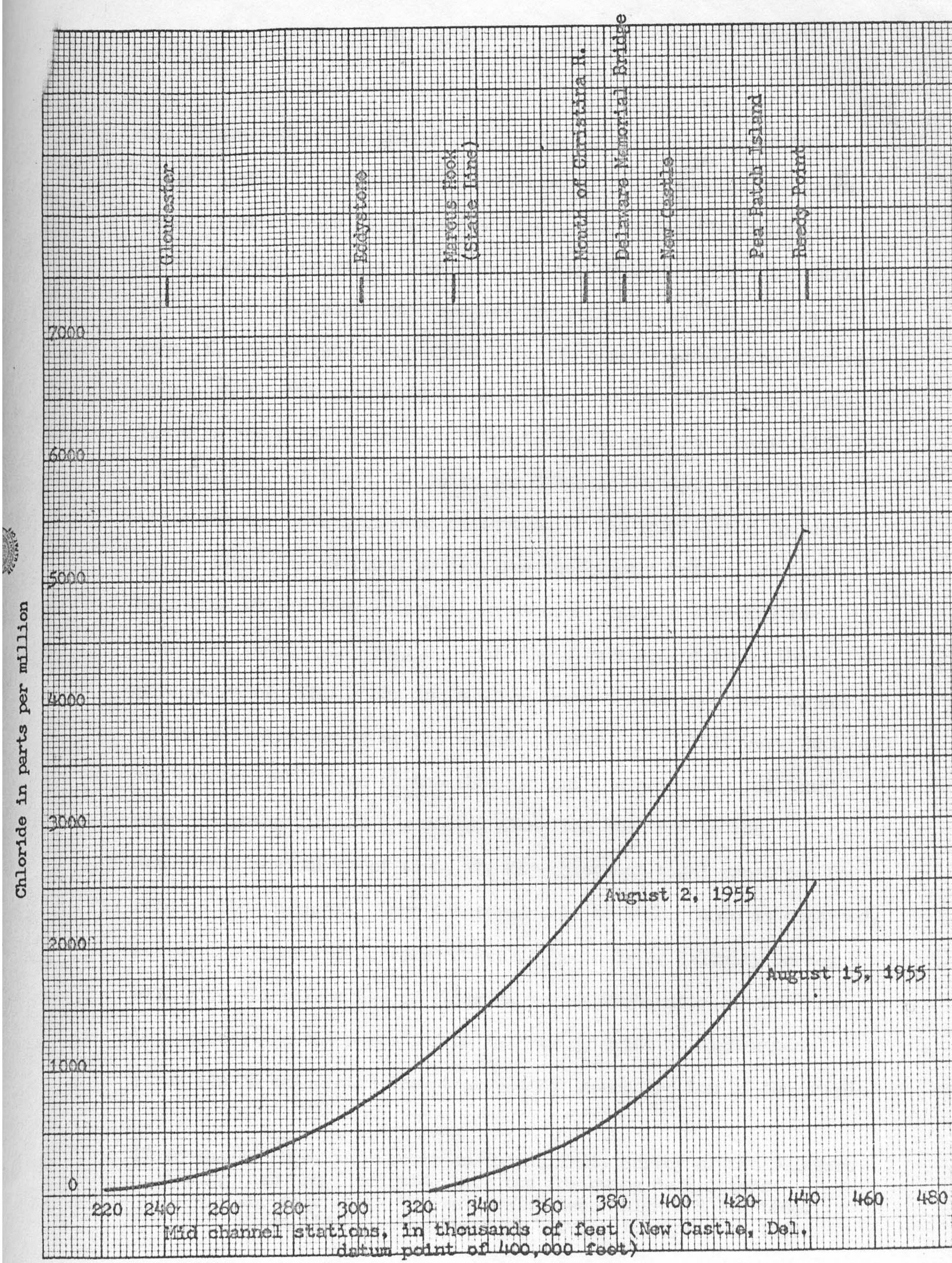


Figure 9.--Chloride profiles for August 2 and 15, 1955

the Delaware River to estimate the chloride concentration at high-water slack. The method is satisfactory only for samples collected within 1 or 2 hours of high-water slack. The estimation involves converting the specific conductance of the water to chloride concentrations or analyzing water samples for chloride content. Figure 4, page 16, can be used to estimate chloride concentration from specific conductance. The predicted times of high and low tide at each sampling location can be obtained from "Tide Tables of the East Coast" (15), a publication of the U. S. Coast and Geodetic Survey. From these times and the actual time of collection of the sample, the "percentage of time" can be found by dividing the minutes before or after high tide by the time interval, in minutes, between high and low tide, and multiplying by 100. From the percentage of time, the percentage of tidal range is found by using a plot from the "Report on the salinity survey of the Delaware River."1/. This curve has the percentage of time as the abscissa and the percentage of tidal range as the ordinate. By moving along the abscissa to the determined percentage of time, the percentage of tidal range can be read on the ordinate. Once the percentage of tidal range is obtained, one of the "teardrop" graphs of the Delaware River Salinity Survey will give the percentage of chloride ion at high-water slack. From this percentage the parts per million of chloride at high-water slack can be calculated from the chloride concentration of the sample.

1/ In the graph of the "Report on the Salinity Survey of the Delaware River," ebb and flood tide have the following definitions:
Ebb tide - the interval between high and low tide.
Flood tide - the interval between low and high tide.

A plot of estimated chloride in parts per million, at high-water slack (ordinate) against distance downstream (abscissa) represents an approximate longitudinal chloride profile (see figure 9). The method was checked by estimating the maximum chloride concentration from each of two samples, one taken before and the other after high-water slack. By plotting two profiles on the same graph and measuring the horizontal distance between the two curves at any location, the resultant net advance or retreat of the salinity between sampling periods may be ascertained.

In a comparison of chloride profiles, if plotted as shown in figure 9, movement of a profile curve to the left indicated an increase of salinity; movement to the right indicates a decrease. Sample calculations for determining the relation of sampling time to high-water slack on August 2, 1955 have been worked out in table 5. Table 6 has the necessary data tabulated for the profiles in figure 9. The profiles of August 2 and 15, 1955 have been plotted on figure 9 to demonstrate how the method is applied. The distance between the two curves represents the movement of saline water. Since the movement is to the right, it represents a decrease in salinity. During the period from the 2nd to 15th, the salinity may actually have advanced and retreated, but the net movement was a decrease. In this plot the 500-ppm isochlor moved about 86,000 feet and the 250-ppm isochlor moved about 68,000 feet, both seaward, from August 2 to 15.

In 1954, there was sufficient information collected for seven high-water slack profiles. In 1955, there was enough for 10

Table 5.--Calculation of the Relation of Sampling Time to the Time of High Water Slack (percentage of time) for August 2, 1955

Location (1)	Time of collection of sample (2)	Difference between time of collection and time of high tide (in minutes) (3)	Difference between time of high and low tide (in minutes) (4)	Percentage of time $100 \times \frac{(3)}{(4)}$
Reedy Point	12:45	99	389	25
Pea Patch Island	13:00	104	389	27
Deepwater	13:33	107	389	28
Cherry Island Flats	14:15	144	389	37
Marcus Hook	14:26	121	420	29
Eddystone	14:47	122	420	29
Gloucester City	15:19	109	420	26

Table 6.--Estimation of Chloride Concentrations at High-Water Slack from Observed Chloride Concentrations

High-water slack sampling August 2, 1955

Location	Percentage of Time1/	Percentage of Tidal Range2/	Chloride in parts per million (Analysis)	Percentage of Chloride3/	Chloride in parts per million at HWS (est.)
Gloucester	26	70	75	89	84
Eddystone	29	65	450	83	540
Marcus Hook	29	65	1200	87	400
Above Cherry Flats	37	55	1700	80	2100
Deepwater	28	67	2600	92	2900
Pea Patch Island	27	68	4400	92	4800
Reedy Point	25	72	5000	93	5400

High-water slack sampling August 15, 1955

Location	Percentage of Time1/	Percentage of Tidal Range2/	Chloride in parts per million (Analysis)	Percentage of Chloride3/	Chloride in parts per million at HWS (est.)
Gloucester	27	69	16	96	17
Eddystone	28	67	48	95	51
Marcus Hook	28	67	80	95	84
Above Cherry Flats	36	56	240	76	320
Deepwater	30	64	450	82	550
Pea Patch Island	30	64	1600	81	2000
Reedy Point	27	69	2400	93	2500

1/ From table 5

2/ From "A report on the salinity of the Delaware by the Pennsylvania Department of Health" (9).

3/ Ibid.

high-water slack profiles. Profiles for low-water slack can be drawn up but since there is no reliable way at present of converting chloride concentrations to minimum values, it is necessary that samples be collected at low-water slack.

This method of determinimg the extent of chloride invasion or retreat has certain limitations. The profile curves are based on estimates of the chloride concentrations at high-water slack, and the estimates are made from measurements usually not at high-water slack. As a result of uncertainties in the estimate, the maximum error in the position of a chloride profile is ±4,000 feet. Therefore, an apparent movement of a chloride concentration of ±4,000 feet or less may be due to errors of estimate, and not necessarily represent an actual advance or retreat of salinity.

Longitudinal Movement of Salinity

An isochlor is a line representing equal values of chloride concentration. The isochlors in figures 10 and 11 represent parts per million of chloride at high-water slack in the center of the navigation channel between July and November for 1954 and 1955. Chloride profiles were used to arrive at the positions of the various isochlors. The data for profiles were obtained from top samples. In the Delaware River, as an isochlor moves upriver, its advancing rate decreases with time. The isochlors of lower chloride concentration will advance or retreat more rapidly than those isochlors of higher chloride concentration. Tables 7 and 8 give data for several isochlors for 1954 and 1955.

While it is to be expected that an increased flow of water

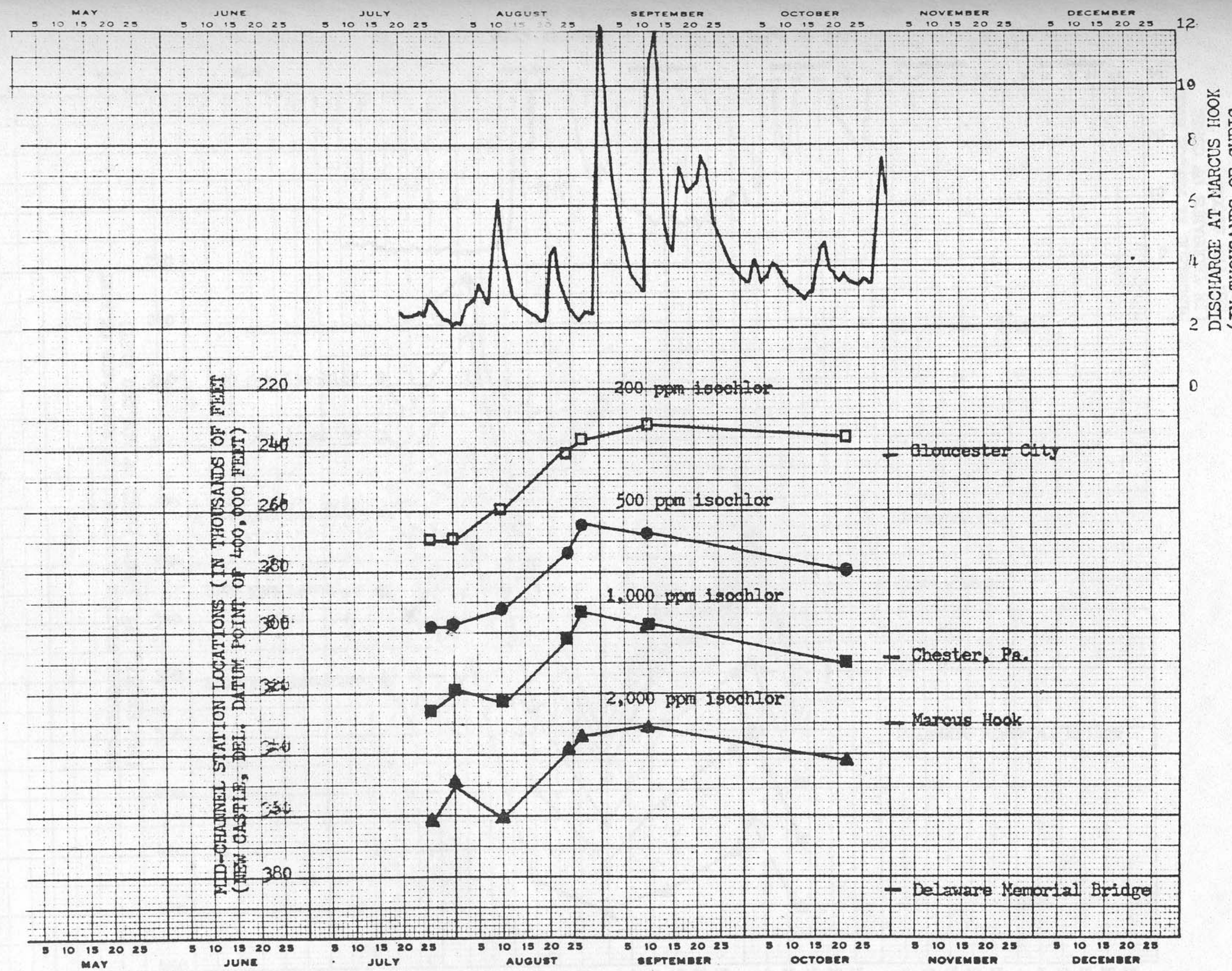


Figure 10.--Position of Isochlors in 1954

Note: Position of 200, 500, 1,000, 2,000, ppm isochlors for selected days in 1954 with a hydrograph at Marcus Hook, Pa. Points are connected by straight lines for clarity; between points the interpolations are not necessarily correct. All of the above isochlor values are at high water slack.

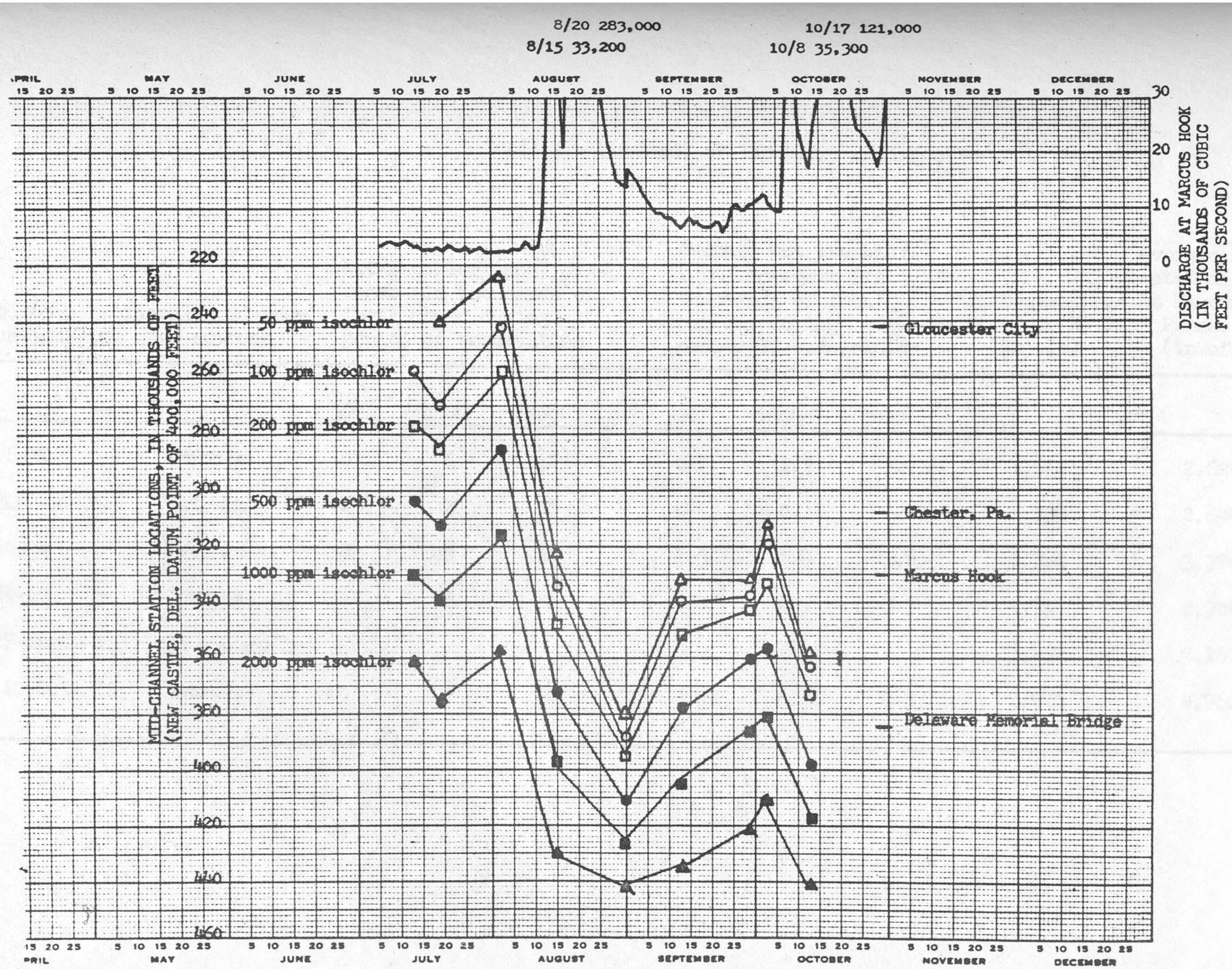


Figure 11.--Position of Isochlors in 1955

Note: Position of 50, 100, 200, 500, 1,000, 2,000, ppm isochlors for selected days in 1955 with a hydrograph at Marcus Hook, Pa. Points are connected by straight lines for clarity; between points the interpolations are not necessarily correct. All of the above isochlor values are at high water slack.

Table 7.--Movement of Isochlors during 1954

Period of Observation	Isochlor advance or retreat	Net isochlor (ppm) distance (in thousands of feet) moved during period of observation			Average net isochlor (ppm) movement (in thousands of feet) per day during period of observation			Average discharge at Trenton, N. J. (in cfs)	Average estimated discharge at Marcus Hook, Penna. (in cfs)
		500	1000	2000	500	1000	2000		
July 26-30	Advance	0	6	12	0	1.5	3.0	1,680	2,620
July 30-Aug. 10	Retreat	0	2	7	0	0.18	0.40	1,730	2,840
Aug. 10-24	Advance	18	20	22	1.30	1.4	1.6	1,780	3,390
Aug. 24-27	Advance	6	6	4	2.0	2.0	1.3	1,700	2,720
Aug. 27-Sept. 10	No change							3,230	5,150
Sept. 10-Oct. 22	Retreat	10	12	10	0.33	0.40	0.33	2,820	4,960

Table 8.--Movement of Isochlors during 1955

Period of observation	Isochlor advance or retreat	Net isochlor (ppm) distance (in thousands of feet) moved during period of observation			Average net isochlor (ppm) movement (in thousands of feet) per day during period of observation			Average discharge at Trenton, N. J. (in cfs)	Average estimated discharge at Marcus Hook, Penna. (in cfs)
		500	1000	2000	500	1000	2000		
July 13-19	Retreat	6	8	12	1.0	1.3	2.0	2,250	3,090
July 19-Aug. 2	Advance	24	23	16	1.7	1.6	1.1	2,240	2,860
Aug. 2-15	Retreat	86	81	72	6.6	6.2	6.0	6,320	14,400
Aug. 15-30	Retreat	36	28	12	2.4	1.9	0.80	55,600	74,400
Aug. 30-Sept. 1	Advance	10	5	4	5.0	2.5	2.0	11,300	14,300
Sept. 1-13	Advance	14	6	0	1.2	0.50	0.00	8,950	11,100
Sept. 13-29	Advance	17	19	13	1.1	1.2	0.81	6,170	7,820
Sept. 29-Oct. 3	Advance	4	5	10	1.0	1.3	2.5	8,690	11,200
Oct. 3-13	Retreat	19	18	17	1.9	1.8	1.7	10,700	20,700

down-river should flush the salt water seaward, one cannot state that under all conditions some specified minimum flow of fresh water is required to keep the isochlors from advancing. For example, from August 10 to 24, 1954 (see table 7) the 500 parts per million isochlor moved an average of 1,280 feet per day, while the average flow at Marcus Hook1/ was 3,390 cfs (cubic feet per second). The advance was checked by an increase of flow to 5,150 cfs (average for the period August 27 to September 10). On the other hand, an average flow from September 1 to 13, 1955 of 11,100 cfs at Marcus Hook was insufficient to prevent the advance of the 500 parts per million isochlor an average of 1,170 feet per day.

An isochlor may be held in a relatively stationary position in the Delaware River by a specific flow but this situation will not hold for the same flow and isochlor in all reaches of the river below that particular portion, all other things being equal.

Table 9 gives the tabulated isochlor data for 1954 and 1955 for the 50, 100, 200, 500, 1000, and 2000 parts per million isochlors.

There are many difficulties involved in using isochlors to trace salinity movement when there are large gaps between samplings. In the example cited for August 10-24, 1954 and September 1-13, 1955, the advance of the salinity for the August 10-24 period was more than likely checked by the heavy discharge at the beginning of September rather than the average flow for the period. Another factor which has to be taken into consideration is the location of the isochlor

1/ See note 1/, page 49, for explanation of how flow data were obtained.

Table 9.--Location of Isochlors

Position of isochlors, in thousands of feet on the date indicated for 1954 (Reference point: New Castle, Delaware, 400,000 feet) all values are at high water slack.

Date	Chloride, in parts per million: 50	100	200	500	1000	2000
July 26	240	250	270	300	330	360
July 30	240	250	270	300	320	350
Aug. 10	230	240	260	300	320	360
Aug. 24	-	-	240	270	300	340
Aug. 27	-	220	240	260	290	330
Sept. 10	-	-	230	270	300	330
Oct. 22	-	-	240	280	310	340

Position of isochlors, in thousands of feet on the date indicated for 1955 (Reference point: New Castle, Del. 4000,000 feet) all values are at high water slack.

Date	Chloride, in parts per million: 50	100	200	500	1000	2000	4000
July 13	-	260	280	300	330	360	-
July 19	240	270	290	310	340	380	420
Aug. 2	220	240	260	290	320	360	420
Aug. 15	320	330	350	370	400	430	-
Aug. 30	380	390	400	410	430	440	-
Sept. 1	350	360	370	400	420	440	-
Sept. 13	330	340	350	380	410	440	-
Sept. 29	330	340	340	360	390	420	-
Oct. 3	310	320	330	360	380	410	-
Oct. 13	360	360	370	400	420	440	-

in the river. In the example cited the 500-ppm isochlor in 1954 was approximately 28 miles farther upstream than the 500 ppm isochlor for 1955 to which it was compared. For best results in using this type of analysis of salt water movement, data must be available at 2 or 3 day intervals.

Effects of Fresh- and Salt-Water Inflow on Salinity Distribution

Salinity distribution in a tidal river is, for the most part, a resultant of the fresh-water inflow and the salt-water inflow. Fresh water flows in from above the head of tide, from tributaries, as direct runoff from the land and from ground-water seepage. The total inflow of fresh water above the head of tide is usually measured by a gaging station. The fresh water which enters the river below the gaging station, when significant, should be considered when working with the total fresh-water inflow of the estuary. Inflow of ocean water will increase the salinity of the river. Ocean water inflow is favored by increases in sea level. Under actual conditions a longitudinal gradient of salinity occurs in the Delaware, ranging from negligible values in the upper tidal portion of the river to maximum values at the seaward end.

The mixing of salt and fresh water and the resulting distribution are related to fluctuations of river flow. The tidal prism concept (3) has been used to evaluate the ability of an estuary to distribute salinity. The tidal prism is equal to the difference between the volumes of water in the estuary at high and low. tide. Part of this volume is contributed by the fresh-water flow and part by salt water entering from the ocean on the flood tide. The boundary between fresh and salt water is dynamic since the inner end of the estuary moves upstream and downstream with changes in the volume of river flow. By means of tidal exchange, salt water may move up or downstream.

The fresh water discharge in the Delaware River varies with the season. In general, it is greatest in March and April due to spring thaws--least in the June to October period--when the growing plants are removing soil moisture rapidly and evaporation is at its peak. Normally during this period a greater proportion of the rainfall soaks into the ground and a lesser proportion runs off directly to the streams. The monthly average fresh-water discharge at Trenton, N. J., at the head of tide in the Delaware River, shown in figure 12. is based on the 33-year period 1923-1955. The greater fresh-water discharge of March and April flushes the salt water seaward, and the lower flows of June to October give an opportunity for the salt water to move upstream.

Since part of the water in a tidal prism is contributed by the ocean, changes in sea level will affect the quantity of sea water in the prism. As the sea level rises, increasing amounts of saline water are introduced into the tidal prism. When the opposite condition arises, i.e., the sea level decreases, the quantity of salty water in the prism decreases. As the quantity of salt water entering the river increases, favorable conditions are established for the salt water to move upstream. The sea level varies seasonally outside of Delaware Bay with the lower sea levels in December, January, February, and the higher sea levels in August, September

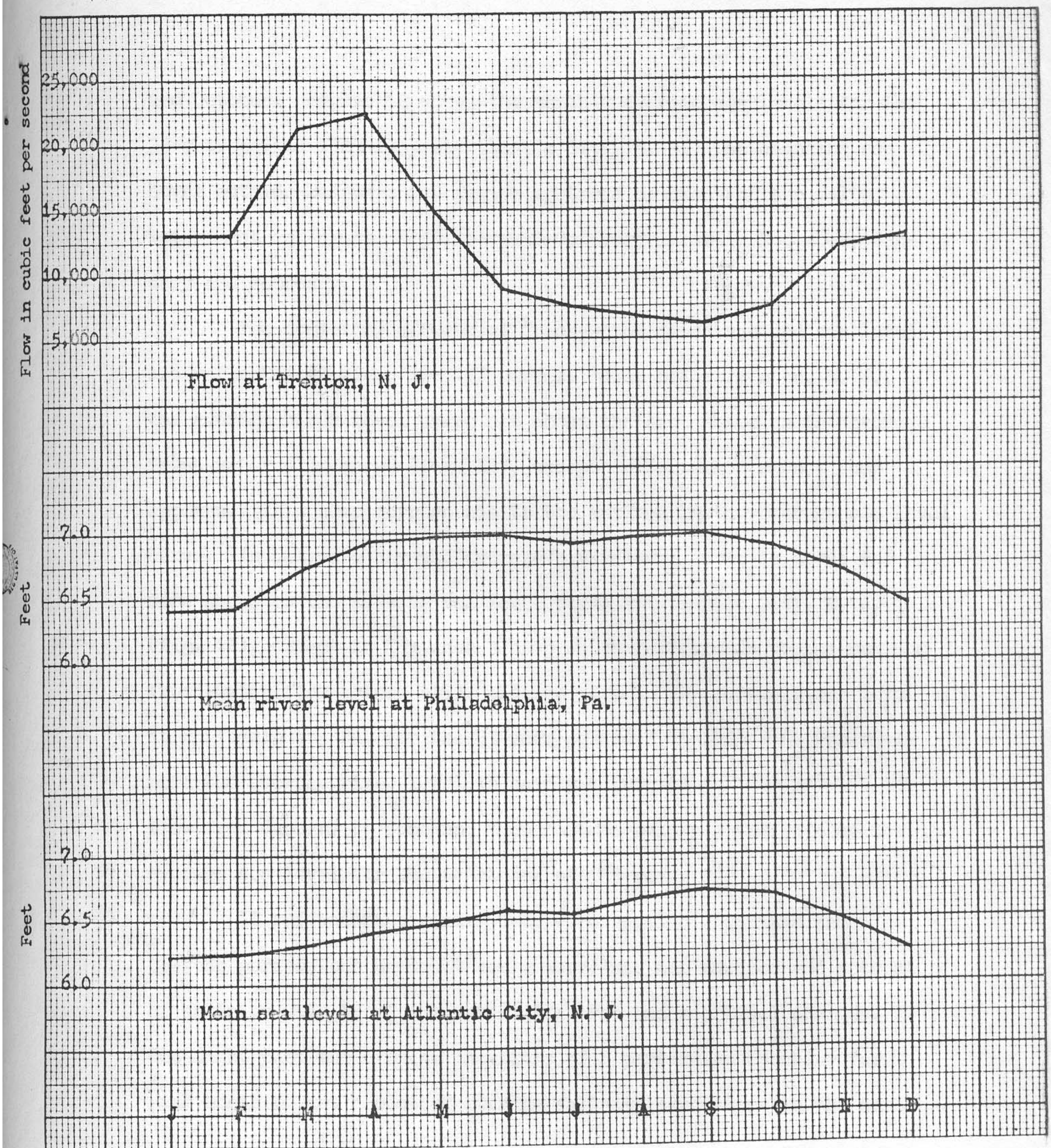


Figure 12.--Average curves of the flow at Trenton, N. J., the mean river level at Philadelphia, Pa. and the mean sea level at Atlantic City, N. J. (based on 33 years of record 1923-1955)

Note: Points are connected by straight lines for clarity; between points the interpolations are not necessarily correct.

and October. Figure 12 shows the monthly average sea levels for the 33-year period 1923-1955 at Atlantic City, N. J. The changing sea level outside Delaware Bay favors upstream movement of the salt water most in August, September and Octover; least in December, January and February.

The competing effects of fresh-water discharge and sea level are reflected in river level1/ curves. Just below Trenton, N. J., the average river level curve has about the same shape as the average fresh-water flow curve (fig. 12), except in September when a hump appears. This hump corresponds to the maximum in the average sea level curve. In Delaware Bay the average river level curve is about the same shape as the average sea level curve at Atlantic City, N. J. (fig. 12), except in May when a hump which corresponds to the maximum fresh-water flow occurs (19). Figure 12 has the average river level at Philadelphia, Pa. for the 33-year period 1923-1955. At Philadelphia the average river level is mainly a function of the fresh-water flow from January to June and then becomes mainly a function of the average sea level for the remainder of the year.

If sufficient salinity data were available for the same 33-year period, one no doubt could correlate the advance and retreat of salinity with the fresh-water discharge and sea level changes. One might plot the average locations of a particular isochlor for each month to get a plot of average salinity conditions in the same

1/ Daily mean river level: the average height of the surface of a river at any point for all stages of the tide over a 24-hour period, usually determined from hourly height readings.

sense that figure 12 represents the average discharge, average sea level and average river level for each month. Variations from average discharge or sea level in any individual year causes variations from the average salinity. For example, during January 1956 the average sea level at Atlantic was 6.88 feet (0.68 feet above average), and the average flow at Trenton was 7,100 cfs (5,900 cfs below the average). The average specific conductance at Reedy Point was 13,000 micromhos. In May of 1956, the average sea level was 6.68 feet (0.31 feet above average) and the average flow at Trenton 31,000 cfs (8,540 cfs above average). The average specific conductance at Reedy Point was 801 micromhos. The increased fresh-water discharge and the decrease in sea level in May moved the salt water seaward, and the salinity at Reedy Point and elsewhere decreased.

Other examples of variation effects of yearly sea level and fresh-water flow can be obtained by comparing the sea level and the fresh-water flow curves for a particular year with average curves. Table 10 has the estimated salinity conditions and the actual conditions for 1949 from curve comparison:

Table 10.*--Estimated salinity conditions for 1949 from comparison of 1949 sea level and fresh-water flow curves. All data is for Marcus Hook, Pa.

<u>Prediction</u>

June	-	Salinity began to move upstream slowly at Marcus Hook.
July	-	Salinity advanced upstream but at a faster rate than in June.
Aug.	-	A greater advance than in July.
Sept.	-	Salinity still advancing.
Oct.	-	Farthest advance of the salt for the summer of 1949.
Nov.	-	Still some evidence of a salinity intrusion at Marcus Hook. but retreat of the salt had started.
Dec.	-	No evidence of salinity invasion at Marcus Hook.

Actual Salinity Conditions		Average salinity for month (ppm Cl)
June	- Salinity began to increase very slowly......	22
July	- Salinity continued to increase.............	197
Aug.	- Salinity increasing.......................	512
Sept.	- Salinity increasing.......................	839
Oct.	- Maximum salinity reached (1,520 ppm Cl).....	1140
Nov.	- Large decrease in salinity but still considerable evidence of a saline invasion........	762
Dec.	- Salinity decreasing, reaching a value of 48 ppm Cl on Dec. 18 and continuing to decrease to about 18 ppm Cl.................	215

During the summer of 1955, the average fresh-water flow increased above the normal for this time of year. Table 11 shows a comparison of the salinity (in terms of specific conductance), the fresh-water flow and sea level for the period of October to November 1955 and April to May 1956.

Table 11.--Salinity, flow and sea level comparison (monthly averages)

Period		Average specific conductance at Reedy Point, Del. (micromhos)	Average flow at Trenton, N. J. (cfs)	Mean sea level at Atlantic City, N. J. (foot)
1955				
	Oct.	5,910	28,700	7.03
	Nov.	2,800	21,600	6.68
1956				
	Apr.	800	31,000	6.68
	May	630	18,300	6.36

The flow at Trenton was approximately the same in October 1955 and April 1956, but the salinity in April 1956 was about one-seventh that in October 1955. The 0.35 foot lower average monthly sea level for April is the major factor contributing to the salinity

*Table 10 covers the period of June to December as analyses were not available for the first 5 months of 1949.

decrease. Again, the flows are approximately the same in November 1955 and May 1956, but the salinity in May 1956 was only about one-fifth that of November 1955. Similarly, the 0.32 foot lower monthly average sea level for May was the major factor accounting for the decrease in salinity.

The severity of salinity invasions may be predicted each year from sea level at Atlantic City, N. J. and the river level at Philadelphia, Pa. The predictions are based on a method illustrated in Appendix A (page 81). The predicted order and the actual order of salinity invasions (in order of decreasing severity of the invasion) are given in table 12. Severity is based on average contamination at Marcus Hook, Pa.

Table 12.--Order of salinity invasions (most severe invasion at the top of the list).

Predicted order of saline invasion	Order of saline invasion based on avg. salinity at Marcus Hook, Pa.
1954	1954
1949	1949
1953	1953
1950	1955
1951	1950
1955	1951
1952	1952

Variation of Chloride with Discharge and River Level

The river flow1/ and the daily mean river level have an effect on the chloride concentration of the river. Prolonged periods of low flows result in high chloride concentrations at Chester, Pa. If the flow at Trenton drops to less than 4,000 cfs for 30 to 60 days, the chloride concentration increases at Chester. For example, in June 1954 the flow at Trenton decreased and became steady at approximately 2,000 cfs during July and August (fig. 13). During these two months the daily maximum chloride concentration increased steadily from 200 ppm on July 1 to more than 1,500 ppm at the end of August (fig. 13). Similarly, in 1949 the chloride concentration increased from 50 ppm to 800 ppm at the same location (fig. 14) after a period of low flow at Trenton. The maximum chloride curve at Chester reached a leveling-off point about 30 days after the start of its rise. In 1949, the maximum chloride leveled out at 900 ppm in September; in 1954, at 1,300 ppm in early August. When the chloride concentration has increased to approximately 1,000 ppm any sharply increased discharge--even of a few days' duration--is likely to produce a corresponding

1/Since the discharge of the Delaware River below Trenton is difficult to measure because of the tidal nature of the river, the streamflow discharge at several points south of Trenton has been estimated. All flow figures used at Chester or Marcus Hook, Pa. are a result of these estimates. These evaluations, which were started in August 1953, are based on the record of flow of the Delaware River at Trenton plus the estimated contribution from the drainage area below Trenton. This contribution is estimated from the records at gaging stations on tributaries entering the Delaware River below Trenton. Such gaged tributaries comprise 85 per cent of the total drainage area above Marcus Hook on the Pennsylvania side, and only 28 per cent of the area above Marcus Hook on the New Jersey side. Contribution from the ungaged area is determined by use of a drainage area ratio.

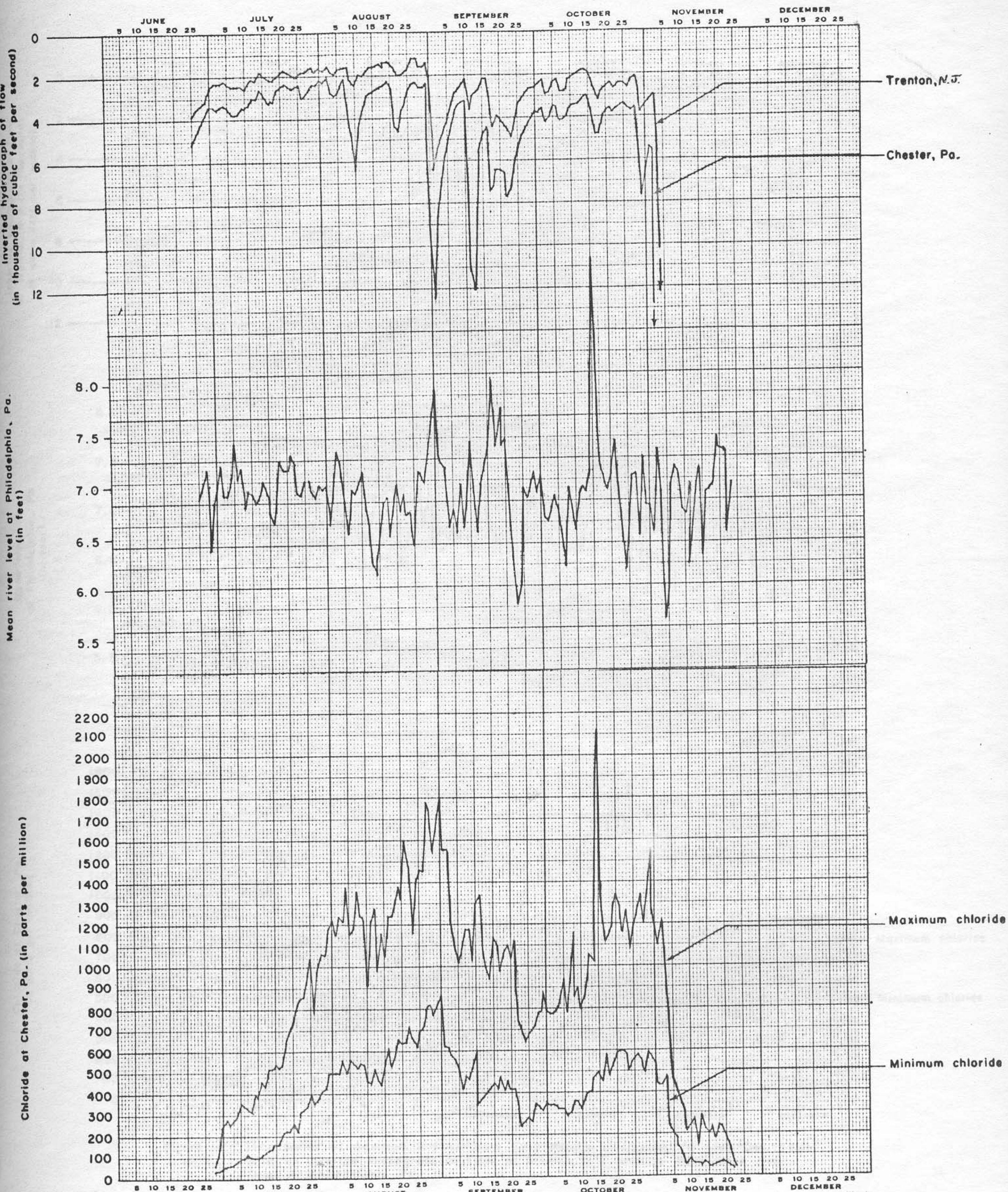


Figure 13.— Time series of maximum and minimum daily chloride at Chester, Pa. (July–Nov. 1954) with an inverted hydrograph of flow at Trenton, N.J. and Chester, Pa. and the daily mean river level at Philadelphia, Pa.

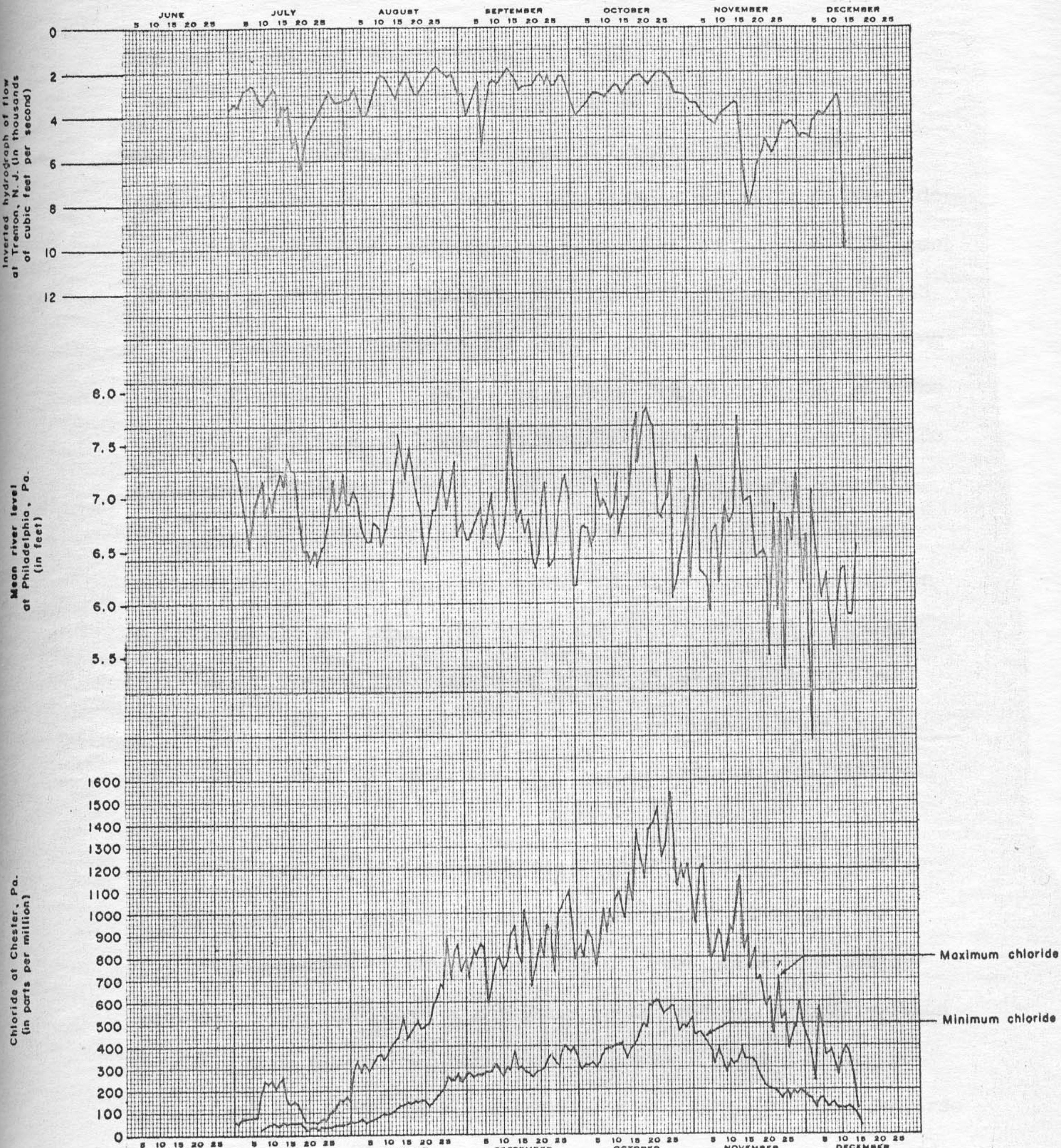


Figure 14.— Time series of maximum and minimum daily chloride at Chester, Pa. (July-Dec. 1949), with an inverted hydrograph of flow at Trenton, N. J. and the daily mean river level at Philadelphia, Pa.

decrease in chloride concentration.

In 1954, increases in flow on August 10 and 22 at Chester were followed by decreases in chloride concentration at Chester (fig. 13). Large increases in flow result in a reduction of chloride concentration which may continue for some weeks until again persistent low flow causes the chloride concentration to increase. The effects of flow on chloride concentration can be seen more easily on a moving weighted average chloride curve, as is represented in figure 15. The curve gives a weight of 0.4 to the maximum parts per million chloride of a particular day; 0.3 of the maximum parts per million chloride to the day preceding; 0.2 of the maximum parts per million chloride to the day before this one, and 0.1 of the maximum parts per million chloride to the day three days before the one in question. Irregularities are removed and pronounced prolonged effects due to flow can be seen. Major increases in flow at Trenton or Chester are generally followed by a decrease in chloride concentration at Chester.

An increase in daily mean river level occurs as a result of an increase in the quantity of water in the river. This can occur by the introduction of large quantities of fresh water, but usually results from the addition of sea water to the river. Generally, when the daily mean river level increases, quantities of salt water are moving into the river and the salt water moves upstream. The converse is true when the daily mean river level falls. Decreases in chloride concentration are usually a result of increased flow or decreased daily mean river level. A combination of both of these factors should

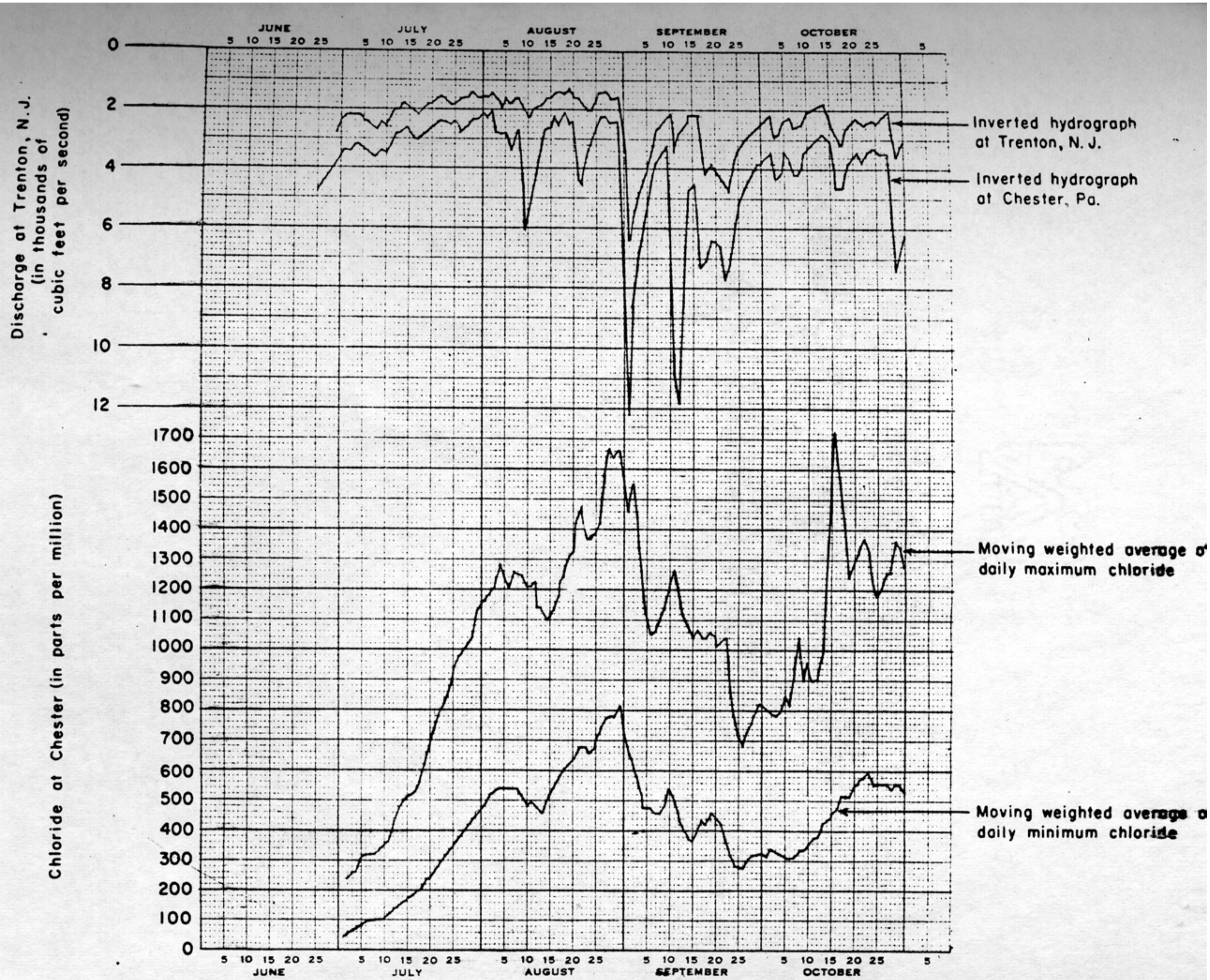


Figure 15.— Time series of moving weighted average of daily maximum and minimum chloride concentrations at Chester, Pa. (July — Oct. 1954), with inverted hydrograph of flow at Trenton, N.J. and Chester, Pa.

produce large decreases in the chloride concentration. The variations in chloride concentrations due to variations in daily mean river level are more pronounced when the chloride concentration is at least several hundred parts per million. The drop in the daily maximum chloride September 17, 1954 (fig. 13) is a result of increased flow and decreased mean river level. The lowest salt concentration for 1954 occurred on September 24. This was a result of decreased mean river level. On August 6 and 13, 1954, the fall in mean river level was accompanied by a decrease in chloride concentration. On August 3, 1954, the mean river level began to drop and reached a minimum on August 6. The maximum chloride decreased. On August 13, 1954, although the flow decreased, the maximum chloride nevertheless decreased. The fall in mean river level was the major contributing factor to the decrease.

During the period from 1931-1939, the Corps of Engineers made some measurements of the effects of fresh-water flow on mean river levels. At Philadelphia the difference between mean low water at sustained flows of 6,000 cfs and mean low water at a sustained flow of 11,800 cfs was 0.15 ft. The difference between mean high water at a sustained flow of 6,000 cfs and 11,800 cfs was 0.1 ft. For flow below 6,000 cfs, the difference between mean low water was less than 0.1 ft. The same is true for mean high water. Downstream, the difference between mean highs and likewise mean lows for various flow rates decreases. For example, at New Castle, Del. the difference for 16,400 cfs and 30,700 cfs was 0.1 ft. for mean high water at these flows. The same was true for mean low water.

From August 3-6, 1954, the fresh-water flow increased about 1,000 cfs, but the total flow was below 3,000 cfs. The small increase in fresh-water flow could contribute considerably less than 0.1 ft. to the river level. The river level change for this period was approximately 0.85 ft. (at Philadelphia). For the period of August 6-13, 1954, the river level decreased by approximately 0.95 ft. The flow increase of 3,000 cfs could account for less than 0.1 ft. of this change.

Often the changes in the chloride concentration are a result of the simultaneous action of both flow and daily mean river level. From the period August 25-31, 1954, there are two peaks in the maximum chloride curve (fig. 13); one on August 27 and the other on the 31st. Both of these peaks are of the same height. There are two corresponding peaks in the daily mean river level curve; the one on the 31st, though, is considerably higher than the one on the 27th. By comparing the daily mean river level curve and the chloride curve to a hydrograph of flow at Chester, the apparent inconsistency is removed. The higher flow on August 31st was sufficient to offset the effects of the higher daily mean river level. The peak chloride of 2,120 ppm for the summer of 1954 occurred on October 15. This peak resulted from the sudden and large increase in river level (fig. 13).

Figure 16 is a time-series plot of the maximum and minimum chloride concentrations at Chester, Pa. with an inverted hydrograph at Trenton, N. J. for 1955. The chloride concentrations increased

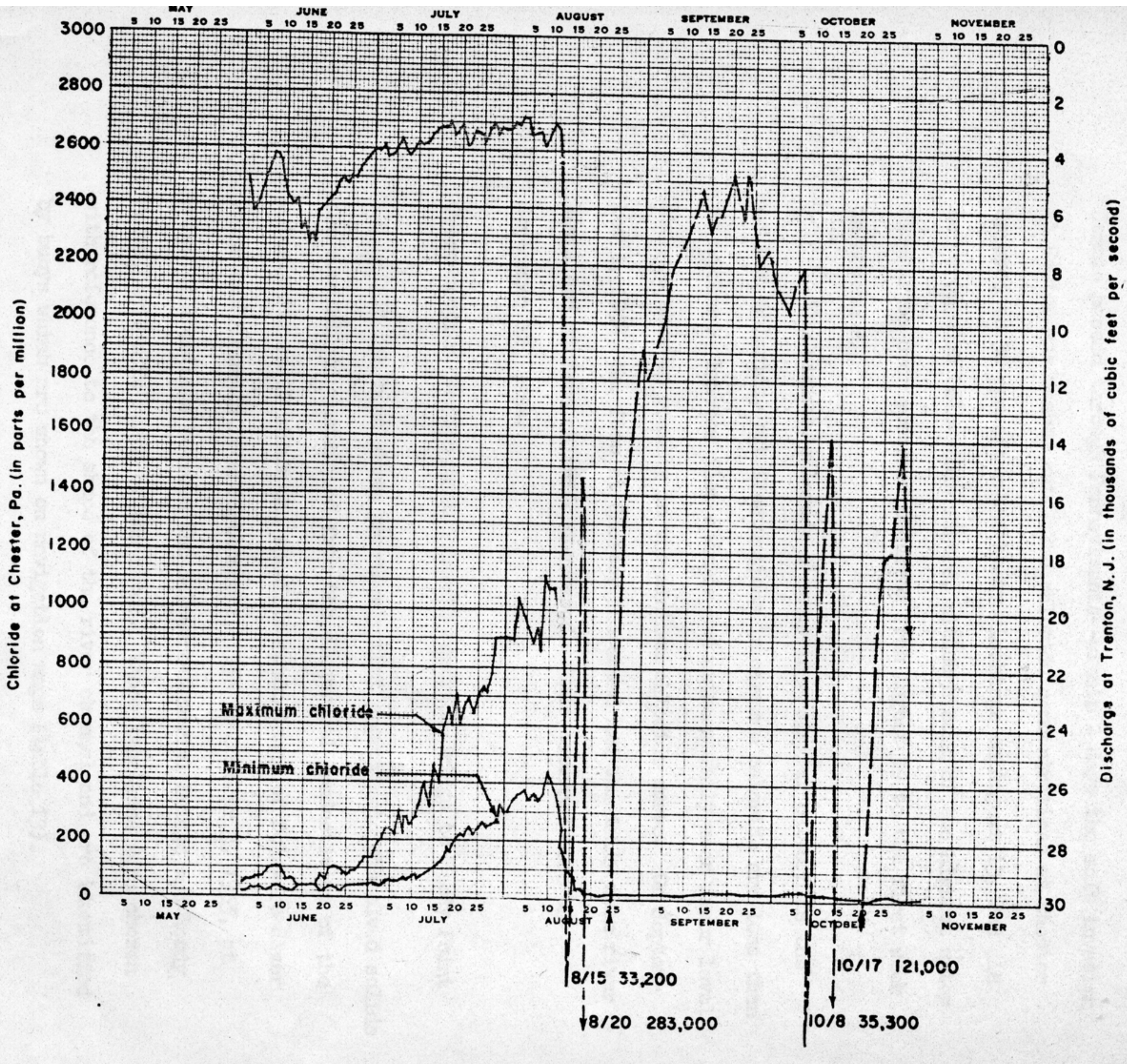


Figure 16. — Time series of maximum and minimum daily chloride concentrations at Chester, Pa. (June – Oct. 1955), with an inverted hydrograph of flow at Trenton, N. J.

in July as the flow at Trenton decreased. On August 13, Hurricane Connie passed through Pennsylvania--within 2 days the salt invasion at Cester was washed out. The chloride concentrations at Chester dropped to 30 ppm after the heavy discharge on August 13, and did not drop much below this figure, although some of the highest water discharges ever recorded occurred from August 19 to the first week in November.

The minimum chloride changes in a similar pattern as the maximum chloride, but fluctuations in minimum chloride are less than in maximum. Extreme flow changes and extreme daily mean river level changes show up readily in the minimum chloride curve. On September 1, 1954, the flow at Chester increased and the daily mean river level and minimum chloride decreased. This occurred also on September 12, 1954.

Cross-section Studies from Delaware Memorial Bridge to Reedy Point

It has been shown previously that approximate dissolved solids are conveniently estimated from the electrical conductivity of the water. Figure 17 shows the specific conductance of Delaware River water on four dates from September 1, 1955 to October 3, 1955, at selected locations between the Delaware Memorial Bridge and Reedy Point, a 10-mile reach of the river. These locations were chosen with reference to the shape of the river channel and are identified by buoys which are shown on navigation maps (table 13).

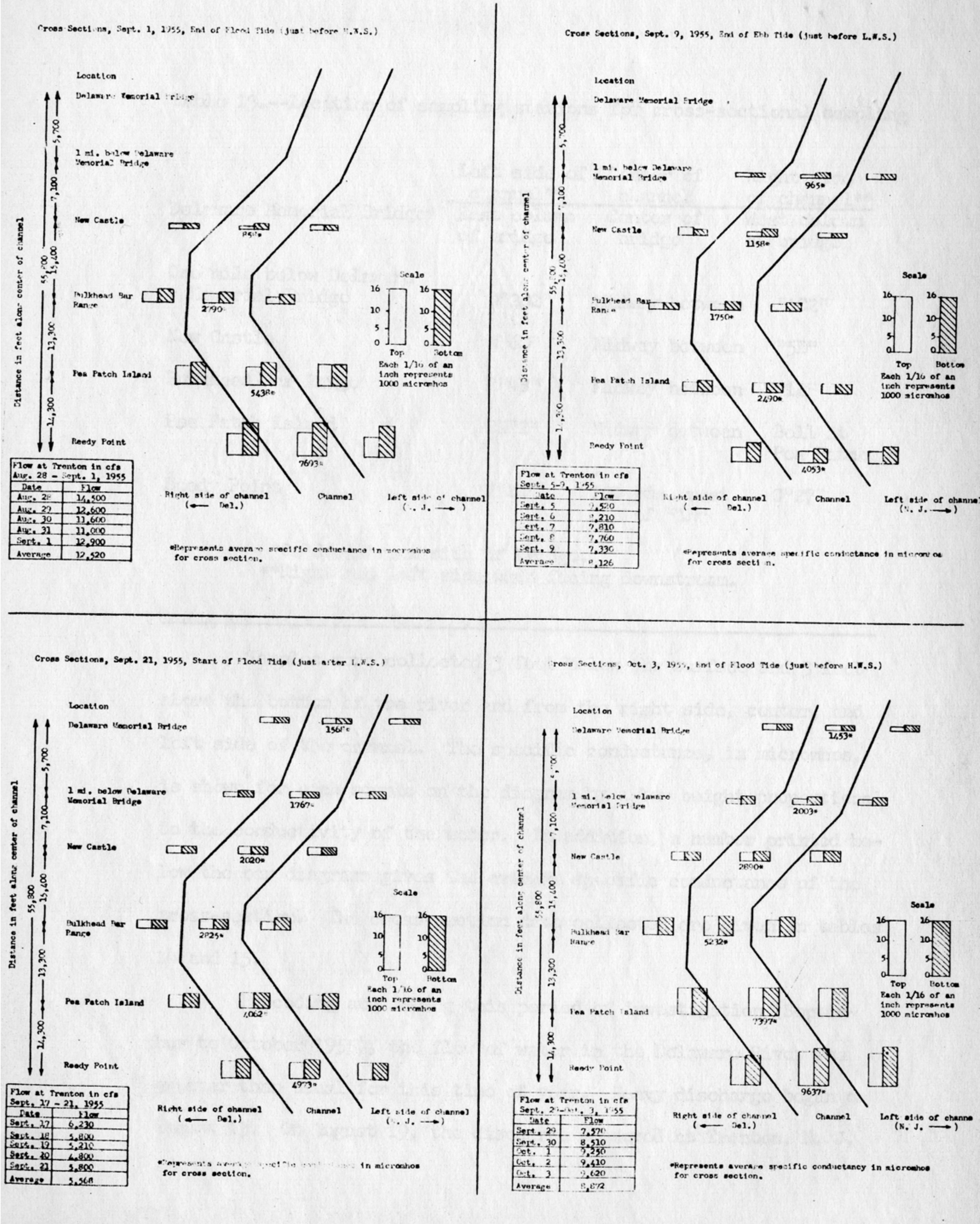


Figure 17.—Cross-sectional variation of specific conductance from the Delaware Memorial Bridge to Reedy Point from September to October 1955

Table 13.--Location of sampling stations for cross-sectional sampling

	Left side of channel**	Center of channel	Right side of channel**
Delaware Memorial Bridge*	East column of bridge	Center of bridge	West column of bridge
One mile below Delaware Memorial Bridge	N"2C2"	Midway between	"1C2"
New Castle	N"6D"	Midway between	"5D"
Bulkhead Bar Range	R"4B"	Midway between	"1B"
Pea Patch Island	RN"2"	Midway between	Bell at Pea Patch
Reedy Point	N"2N"	100 yds. west of "1N"	C"27"

*On downstream side of bridge.
**Right and left side when facing downstream.

Samples were collected 3 feet below the surface and 3 feet above the bottom of the river and from the right side, center, and left side of the channel. The specific conductance, in micromhos, is shown for each sample on the diagram by a bar height proportional to the conductivity of the water. In addition, a number printed below the bar diagrams gives the average specific conductance of the cross-section. The cross-section data collected are given in tables 14 and 15.

Preceding and during this period of investigation (September to October 1955), the flow of water in the Delaware River was greater than usual for this time of year. Heavy discharge began on August 13. On August 19, the discharge measured at Trenton, N. J.

Table 14.—Specific Conductance of Cross-Section Samples, September 1 - October 3, 1955

(All times are EST)

Date and Tidal Condition	Station		Delaware Memorial Bridge		One mile below Delaware Memorial Bridge		New Castle		Bulkhead Bar Range		Pea Patch Island		Reedy Point	
			Time	Micromhos	Time	Micromhos	Time	Micromhos	Time	Micromhos	Time	Micromhos	Time	Micromhos
September 1 End of flood tide just before H.W.S.	Right	Top					10:04 a.m.	749	10:29 a.m.	2,420	10:41 a.m.	5,100	11:35 a.m.	5,900
		Bottom					10:04 a.m.	779	10:29 a.m.	3,590	10:41 a.m.	5,970	11:35 a.m.	8,900
	Center	Top					10:10 a.m.	789	10:24 a.m.	2,860	10:44 a.m.	5,100	11:30 a.m.	6,700
		Bottom					10:10 a.m.	1,190	10:24 a.m.	3,240	10:44 a.m.	6,400	11:30 a.m.	9,520
	Left	Top					10:01 a.m.	811	10:21 a.m.	1,920	10:46 a.m.	5,070	11:25 a.m.	6,130
		Bottom					10:01 a.m.	830	10:21 a.m.	2,710	10:46 a.m.	4,980	11:25 a.m.	9,010
	Average							858		2,790		5,440		7,690
September 9 End of ebb tide just before L.W.S.	Right	Top			9:51 a.m.	819	10:03 a.m.	1,150	10:24 a.m.	1,480	10:37 a.m.	2,600	10:58 a.m.	3,980
		Bottom			9:51 a.m.	821	10:03 a.m.	1,090	10:24 a.m.	1,510	10:37 a.m.	2,640	10:58 a.m.	5,230
	Center	Top			9:54 a.m.	800	10:07 a.m.	1,060	10:20 a.m.	1,500	10:41 a.m.	2,400	11:02 a.m.	3,260
		Bottom			9:54 a.m.	960	10:07 a.m.	1,160	10:20 a.m.	1,770	10:41 a.m.	2,440	11:02 a.m.	3,420
	Left	Top			9:58 a.m.	1,140	10:11 a.m.	1,260	10:16 a.m.	1,930	10:33 a.m.	2,400	11:06 a.m.	3,690
		Bottom			9:58 a.m.	1,250	10:11 a.m.	1,230	10:16 a.m.	2,310	10:33 a.m.	2,460	11:06 a.m.	4,840
	Average					965		1,160		1,750		2,490		4,050
September 21 End of flood tide just after L.W.S.	Right	Top	1:04 p.m.	1,780	12:53 p.m.	1,570	12:41 p.m.	2,060	12:23 p.m.	2,580	11:57 a.m.	3,360	11:45 a.m.	5,150
		Bottom	1:04 p.m.	1,780	12:53 p.m.	1,640	12:41 p.m.	2,110	12:23 p.m.	2,560	11:57 a.m.	3,700	11:45 a.m.	5,280
	Center	Top	1:02 p.m.	1,400	12:50 p.m.	1,790	12:38 p.m.	1,920	12:18 p.m.	2,890	12:00 p.m.	4,470	11:40 a.m.	4,760
		Bottom	1:02 p.m.	1,470	12:50 p.m.	1,830	12:38 p.m.	2,020	12:18 p.m.	2,890	12:00 p.m.	4,560	11:40 a.m.	5,490
	Left	Top	1:00 p.m.	1,420	12:48 p.m.	1,900	12:34 p.m.	1,980	12:15 p.m.	2,670	12:04 p.m.	4,070	11:36 a.m.	4,540
		Bottom	1:00 p.m.	1,560	12:48 p.m.	1,870	12:34 p.m.	2,030	12:15 p.m.	3,360	12:04 p.m.	4,210	11:36 a.m.	4,620
	Average			1,570		1,770		2,020		2,820		4,060		4,970
September 21 End of ebb tide just before L.W.S.	Right	Top	9:47 a.m.	1,000	9:55 a.m.	1,120	10:10 a.m.	1,400	10:28 a.m.	2,070				
		Bottom	9:47 a.m.	1,050	9:55 a.m.	1,120	10:10 a.m.	1,410	10:28 a.m.	2,110				
	Center	Top	9:45 a.m.	1,040	9:52 a.m.	1,070	10:07 a.m.	1,280	10:26 a.m.	1,750				
		Bottom	9:45 a.m.	1,060	9:52 a.m.	1,180	10:07 a.m.	1,430	10:26 a.m.	1,810				
	Left	Top	9:43 a.m.	1,020	9:50 a.m.	1,020	10:04 a.m.	1,210	10:20 a.m.	2,200				
		Bottom	9:43 a.m.	1,000	9:50 a.m.	1,070	10:04 a.m.	1,470	10:20 a.m.	2,250				
	Average			1,030		1,100		1,370		2,040				
September 29 End of flood tide just before H.W.S.	Right	Top	9:59 a.m.	2,450	10:15 a.m.	2,790	10:29 a.m.	3,790					11:10 a.m.	8,920
		Bottom	9:59 a.m.	2,530	10:15 a.m.	3,850	10:29 a.m.	4,880					11:10 a.m.	10,000
	Center	Top	10:02 a.m.	2,280	10:17 a.m.	3,320	10:31 a.m.	3,530					11:13 a.m.	9,850
		Bottom	10:02 a.m.	2,990	10:17 a.m.	3,370	10:31 a.m.	4,490					11:13 a.m.	11,000
	Left	Top	10:05 a.m.	2,670	10:19 a.m.	2,510	10:34 a.m.	3,930					11:16 a.m.	9,110
		Bottom	10:05 a.m.	2,760	10:19 a.m.	3,610	10:34 a.m.	4,430					11:16 a.m.	8,960
	Average			2,610		3,300		4,180						9,640
October 3 End of flood tide just before H.W.S.	Right	Top	10:02 a.m.	1,710	10:15 a.m.	1,580	10:33 a.m.	2,630	10:54 a.m.	4,160	11:11 a.m.	7,220	11:56 a.m.	8,240
		Bottom	10:02 a.m.	1,670	10:15 a.m.	2,470	10:33 a.m.	2,690	10:54 a.m.	4,930	11:11 a.m.	7,350	11:56 a.m.	8,590
	Center	Top	10:04 a.m.	1,200	10:17 a.m.	1,830	10:38 a.m.	2,850	10:57 a.m.	5,830	11:13 a.m.	7,480	12:03 p.m.	10,100
		Bottom	10:04 a.m.	1,330	10:17 a.m.	2,080	10:38 a.m.	3,010	10:57 a.m.	5,840	11:13 a.m.	7,430	12:03 p.m.	10,600
	Left	Top	10:08 a.m.	1,300	10:20 a.m.	1,880	10:40 a.m.	2,950	11:00 a.m.	5,050	11:16 a.m.	7,470	12:10 p.m.	9,590
		Bottom	10:08 a.m.	1,510	10:20 a.m.	2,180	10:40 a.m.	3,090	11:00 a.m.	5,580	11:16 a.m.	7,430	12:10 p.m.	10,700
	Average			1,450		2,000		2,890		5,230		7,400		9,640

Table 15.--Specific Conductance of Cross-Section Samples, July 13 - October 13, 1955

At Delaware Memorial Bridge

Date and Tidal Condition	Station	Time EST	Specific Conductance in Micromhos: Top	Bottom
July 13 Ebb tide 1½ hours before L.W.S.	Right	12:05 p.m.	3,900	3,910
	Center	12:10 p.m.	3,870	4,160
	Left	11:55 a.m.	4,510	4,760
	Average		4,190	
July 19 at H.W.S.	Right	1:14 p.m.	7,150	7,750
	Center	1:12 p.m.	7,260	8,590
	Left	1:10 p.m.	7,190	7,770
	Average		7,620	
July 25 at L.W.S.	Right	12:35 p.m.	4,560	4,890
	Center	12:37 p.m.	4,430	5,450
	Left	12:39 p.m.	4,970	5,210
	Average		4,920	
August 2 at H.W.S.	Right	12:40 p.m.	8,920	9,520
	Center	12:33 p.m.	8,300	9,650
	Left	12:30 p.m.	8,250	9,710
	Average		9,060	
August 15 at H.W.S.	Right	11:21 p.m.	1,690	2,690
	Center	11:19 p.m.	1,730	2,730
	Left	11:17 p.m.	1,930	2,580
	Average		2,220	
August 30 Ebb tide 1½ hours after H.W.S.	Right	12:44 p.m.	205	199
	Center	12:42 p.m.	199	246
	Left	12:40 p.m.	244	236
	Average		222	
September 1 at H.W.S.	Right	12:24 p.m.	763	864
	Center	12:19 p.m.	853	1,450
	Left	12:14 p.m.	687	844
	Average		910	
September 9 Ebb tide ½ hour before L.W.S.	Right	12:04 p.m.	444	714
	Center	12:00 p.m.	384	416
	Left	11:56 a.m.	433	575
	Average		494	
September 13 at H.W.S.	Right	11:13 a.m.	1,960	2,020
	Center	11:05 a.m.	1,780	2,020
	Left	11:02 a.m.	1,790	2,010
	Average		1,930	
September 21 Ebb tide 1 hour before L.W.S.	Right	9:42 a.m.	1,000	1,050
	Center	9:45 a.m.	1,040	1,060
	Left	9:43 a.m.	1,020	1,000
	Average		1,030	
September 21 2 hours after start of flood tide	Right	1:04 p.m.	1,780	1,780
	Center	1:02 p.m.	1,400	1,470
	Left	1:00 p.m.	1,420	1,560
	Average		1,570	
September 22 Flood tide 1 hour after L.W.S.	Right	12:14 p.m.	1,090	1,390
	Center	12:17 p.m.	873	1,110
	Left	12:20 p.m.	961	967
	Average		1,060	
September 29 Flood tide 1 hour before H.W.S.	Right	9:59 a.m.	2,450	2,530
	Center	10:02 a.m.	2,280	2,990
	Left	10:05 a.m.	2,670	2,760
	Average		2,610	
September 29 Ebb tide 1 hour after H.W.S.	Right	12:17 p.m.	2,100	2,170
	Center	12:20 p.m.	1,790	2,590
	Left	12:23 p.m.	2,200	2,430
	Average		2,210	
October 3 Ebb tide 2 hours after L.W.S.	Right	10:02 a.m.	1,710	1,670
	Center	10:04 a.m.	1,200	1,670
	Left	10:08 a.m.	1,300	1,510
	Average		1,450	
October 3 Flood tide 1 hour before H.W.S.	Right	12:56 p.m.	3,400	3,440
	Center	1:01 p.m.	2,870	4,720
	Left	1:05 p.m.	3,080	3,440
	Average		3,490	
October 13 Flood tide 1 hour after H.W.S.	Right	12:40 p.m.	1,020	1,160
	Center	12:43 p.m.	875	1,170
	Left	12:45 p.m.	830	950
	Average		1,000	

At Reedy Point

Date and Tidal Condition	Station	Time EST	Specific Conductance in Micromhos: Top	Bottom
July 13 Flood tide just after L.W.S.	Right	1:30 p.m.	9,020	10,100
	Center	1:27 p.m.	8,760	9,840
	Left	1:22 p.m.	8,810	9,180
	Average		9,290	
July 19 at L.W.S.	Right	12:27 p.m.	13,500	14,700
	Center	12:25 p.m.	14,100	14,700
	Left	12:23 p.m.	13,300	13,900
	Average		14,000	
July 25 at L.W.S.	Right	11:28 a.m.	9,600	10,000
	Center	11:40 a.m.	10,000	10,560
	Left	11:42 a.m.	9,730	11,130
	Average		10,100	
August 2 at H.W.S.	Right	11:45 a.m.	15,500	16,000
	Center	11:37 a.m.	14,900	16,500
	Left	11:30 a.m.	13,900	16,300
	Average		15,500	
August 15 at H.W.S.	Right	10:27 a.m.	9,290	10,200
	Center	10:29 a.m.	7,590	10,600
	Left	10:31 a.m.	7,090	10,400
	Average		9,200	
August 30 Ebb tide 1 hour after H.W.S.	Right	11:45 a.m.	6,950	9,540
	Center	11:47 a.m.	5,210	8,760
	Left	11:49 a.m.	4,490	8,380
	Average		7,220	
September 1 Flood tide 1½ hours before H.W.S.	Right	11:35 a.m.	5,900	8,900
	Center	11:30 a.m.	6,700	9,520
	Left	11:25 a.m.	6,130	9,010
	Average		7,690	
September 9 Ebb tide 1 hour before L.W.S.	Right	10:58 a.m.	3,880	5,230
	Center	11:02 a.m.	3,260	3,420
	Left	11:06 a.m.	3,690	4,840
	Average		4,053	
September 13 at H.W.S.	Right	10:12 a.m.	5,960	8,380
	Center	10:15 a.m.	7,210	9,030
	Left	10:18 a.m.	6,690	8,510
	Average		7,630	
September 21 Flood tide 1½ hours after L.W.S.	Right	11:45 a.m.	5,150	5,280
	Center	11:40 a.m.	4,760	5,490
	Left	11:36 a.m.	4,540	4,620
	Average		4,970	
September 22 Flood tide ½ hour after L.W.S.	Right	11:31 a.m.	4,430	4,510
	Center	11:26 a.m.	4,680	5,640
	Left	11:23 a.m.	4,300	5,090
	Average		4,780	
September 29 at H.W.S.	Right	11:10 a.m.	8,920	10,000
	Center	11:13 a.m.	9,850	11,000
	Left	11:16 a.m.	9,110	8,960
	Average		9,640	
October 3 Flood tide ½ hour before H.W.S.	Right	11:56 a.m.	8,240	8,590
	Center	12:03 p.m.	10,100	10,600
	Left	12:10 p.m.	9,590	10,700
	Average		9,640	
October 13 Ebb tide ½ hour after H.W.S.	Right	11:44 a.m.	5,880	7,680
	Center	11:48 a.m.	5,510	8,140
	Left	11:51 a.m.	5,860	7,530
	Average		6,770	

was the greatest in 53 years.

The cross-sectional information collected in 1956 is given in table 22. The cross-sectional studies of 1955 and 1956 indicate that there is little or no variation in salinity across the navigation channel of the river. The salinity of the Delaware River varies with depth, being saltier on the bottom. The variation between top and bottom becomes greater, as the concentration of dissolved solids and density increases. This relationship is maintained throughout each tidal cycle.

Frequency of Chloride Occurrence

Frequency curves for chloride, in parts per million, at Marcus Hook, Pa. (1950-1955), Camden, N. J. (1950-1955), and Bridesburg, Pa. (1952-1955) have been constructed (fig. 18). These curves indicate the frequency of various chloride concentration, irrespective of the chronological sequence, and are based on a spot sample each day at Camden, the maximum chloride concentration each day at Bridesburg and on the average chloride each day at Marcus Hook. At least 64 percent of the time at Marcus Hook and 90 percent of the time at Camden and 95 percent of the time at Bridesburg, the chloride concentration is equal to or less than 40 ppm. It is interesting to note that between Camden and Bridesburg there is very little change in the chloride concentration. Only about 5 percent of the time is there an appreciable difference and this usually amounts to no more than about 50 ppm chloride. The daily sample at Camden 90 percent of the time is within 20 ppm of the max-

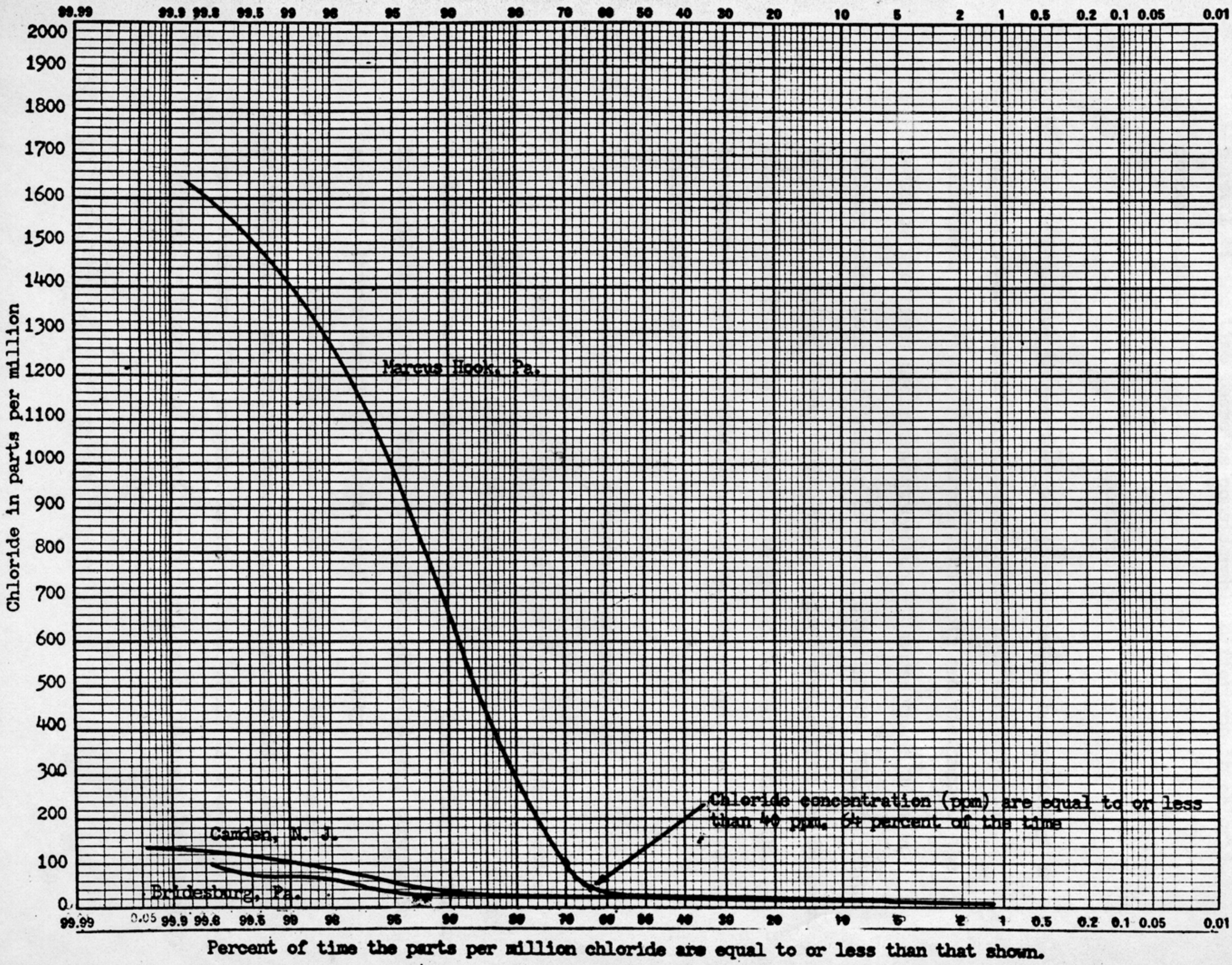


Figure 18.--Frequency of occurrence of chloride, in parts per million, in the Delaware River at Marcus Hook, Camden, N. J., and Bridesburg, Pa. (Marcus Hook, Pa. and Camden N. J. are composites of data from 1950 to 1955; Bridesburg, Pa. is a composite of data from 1952 to 1955)

imum chloride at Bridesburg. Between Camden and Marcus Hook, 35 percent of the time there is considerable difference in chloride concentration.

Temperature

The water temperature varied seasonally, being warmest in the late summer months and coldest in the late winter months. Differences of 1° to 2°F occurred with depth and distance in the reach of the river under investigation. A measurement using a Whitney underwater thermometer of water entering the Delaware River from the Christina River (which was 1 degree cooler than the Delaware River at the time of measurement) indicated that water from this tributary could not be distinguished by temperature once it had entered the Delaware.

Effects of Hurricanes on Salinity

Hurricanes usually affect tides as a result of wind action and increasing runoff due to precipitation. Winds blowing up the bay will blow salt water from the ocean into the bay, increasing the river level and the salinity. Winds from another direction may blow water seaward, thus reducing the river level and salinity.

The winds which produce high tides cause increases in salinity, while the rains accompanying a hurricane will tend to decrease salinity. The increase in river level which is caused by wind usually takes place first, producing a rapid increase in salinity, and the increased runoff then causes an equally rapid decrease, forcing the salt water bayward. The total effect upon salinity is a resultant of both wind velocity and direction--the runoff associated with the precipitation and the duration of the wind and precipitation. Table 16 shows the daily mean river level at the time of the hurricanes of 1954 and 1955.

Table 16.--Daily Mean River Level at Philadelphia, Pa.

Hurricane	Days during which river level was influenced by hurricanes	Daily mean river level at Phila., Pa. (in feet)
Carol	August 30, 1954*	7.45
	August 31, 1954*	7.92
	Sept. 1, 1954	7.29
Edna	Sept. 9, 1954	6.72
	Sept. 10, 1954*	7.43
	Sept. 11, 1954	6.97
Hazel	Oct. 14, 1954	7.15
	Oct. 15, 1954*	9.18
	Oct. 16, 1954	7.95
	Oct. 17, 1954	7.20
Connie	August 12, 1955*	7.15
	August 13, 1955*	10.55
	August 14, 1955	8.50
Diane	August 17, 1955	7.83
	August 18, 1955*	8.96
	August 19, 1955*	9.42
	August 20, 1955*	10.73
	August 21, 1955	9.18

*Date of hurricane in Philadelphia area.

With each hurricane there was an increase in daily mean river level. These increases were a result of wind velocity and, in a few instances, of runoff. (See page 54 for the contributions made by runoff to river level.)

The winds of a hurricane in the Northern Hemisphere circulate counterclockwise around the low ("eye") as shown in figure 19. The effects of hurricane winds upon salinity in the Delaware River depend upon the path of the hurricane in relation to the river. If the hurricane passes to the east of the Delaware River, i.e., out in the Atlantic Ocean, the winds blow water out of the Delaware River into the Bay, figure 20A, causing the salt water to move downstream. Should the hurricane pass inland, west of the Delaware River, the winds tend to blow bay water into the river, figure 20B, causing the salt water to move upstream.

The path of Hurricane Carol in 1954 was offshore (fig. 21) from SSW to NNE. Thus, the Delaware Bay was west of the hurricane and the prevailing winds in the bay were WNW, which blew water out of the Delaware Bay. The river level, from table 16, was not much higher than usual, and little increase in salinity due to tides was to be expected. Heavy rainfall, table 17, in combination with the wind velocity and direction produced flushing of the chlorides seaward. On August 31, 1954, the daily mean river level increased and there was a corresponding increase in the chloride concentration at Chester, Pa. This increase in salinity is attributed to salty water moving upstream. Hurricane Edna followed shortly after Carol.

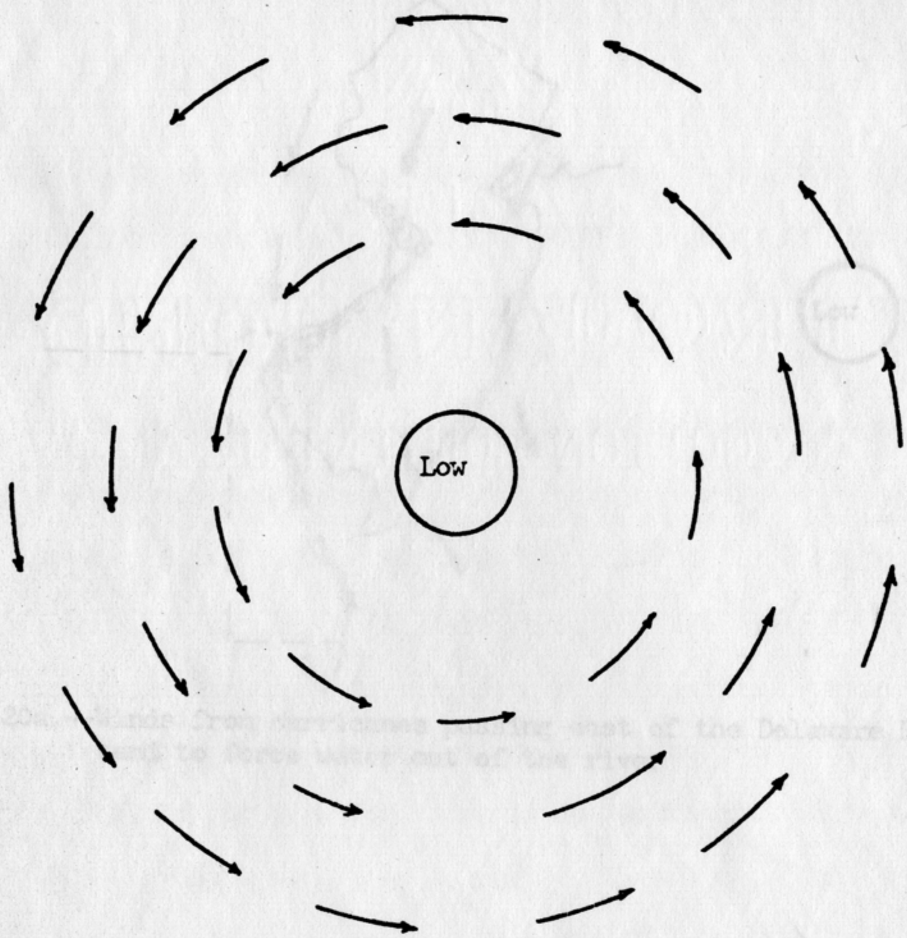


Figure 19.--Hurricane winds-circulate counterclockwise around the low ("eye") of the hurricane

Figure 20a.--Winds from hurricanes passing east of the Delaware River tend to force water out of the river

Figure 20b.--Winds from hurricanes passing west of the Delaware River tend to force water into the river

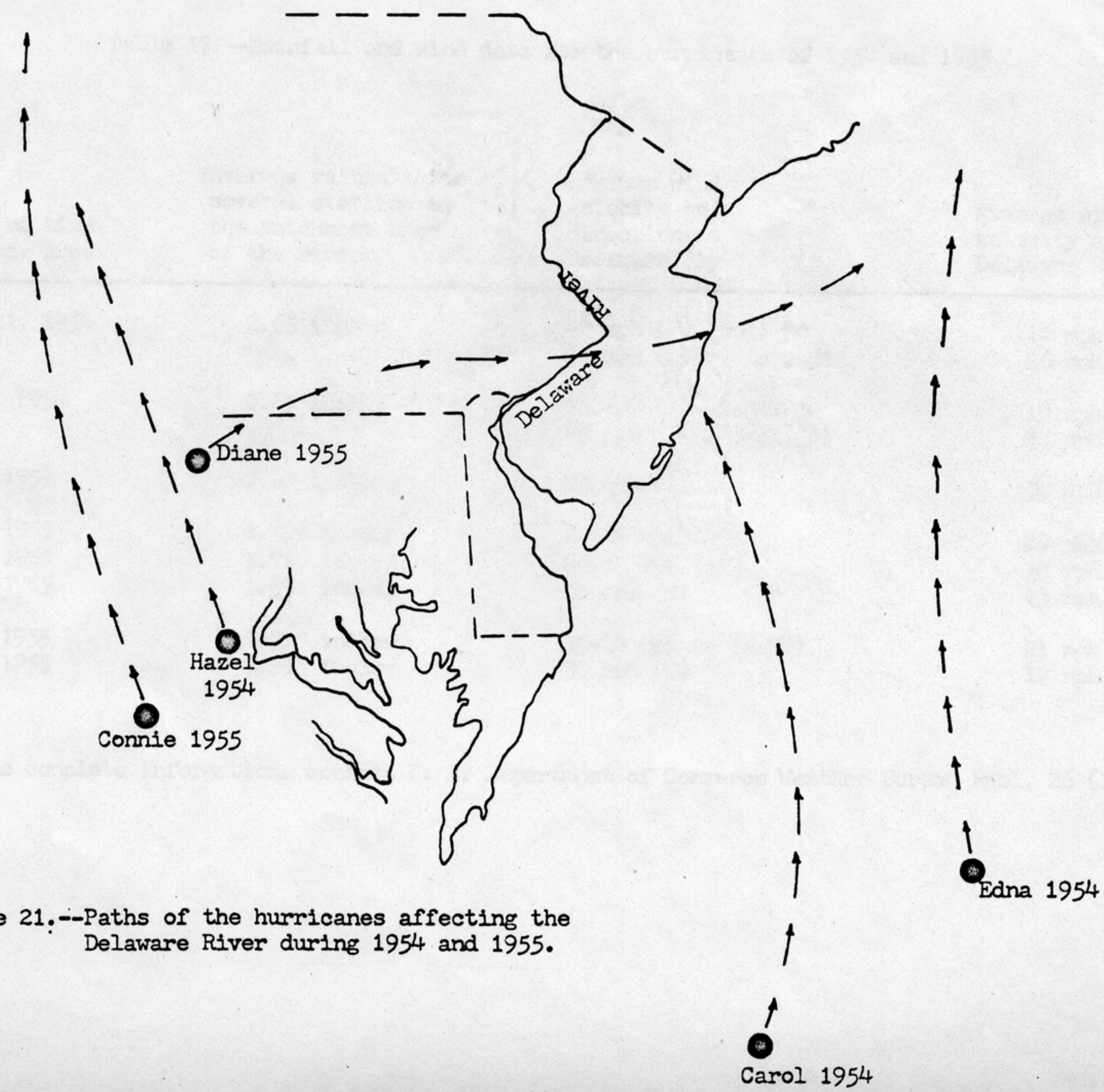


Figure 21.--Paths of the hurricanes affecting the Delaware River during 1954 and 1955.

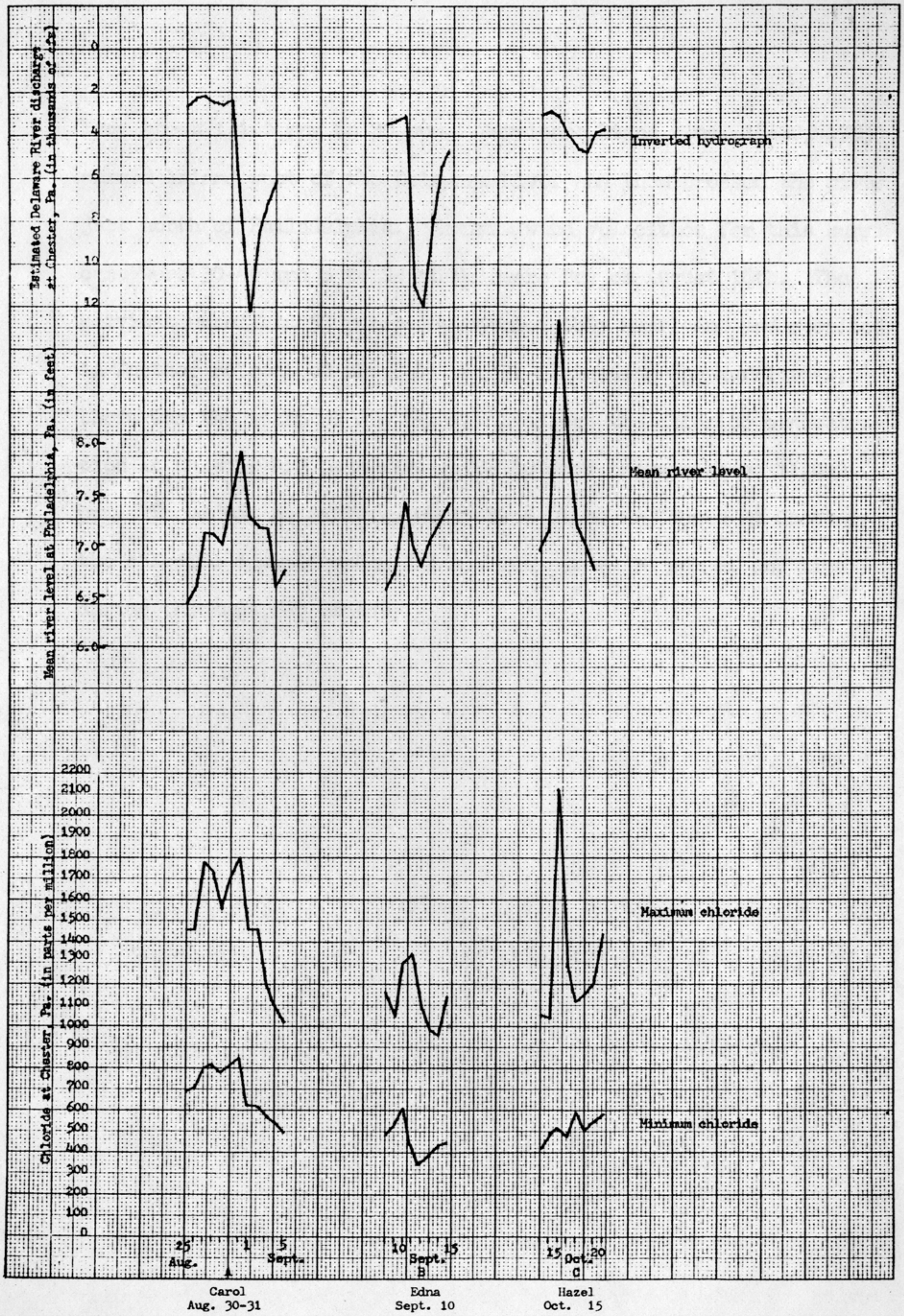
Table 17.--Rainfall and wind data for the hurricanes of 1954 and 1955

Hurricane	Period of time in Phila. area	*Average rainfall for several stations in the catchment area of the river	Maximum wind velocity and direction at Delaware Bay	Average wind velocity at Delaware Bay
Carol	Aug. 30-31, 1954	2.65 inches	40 mph (N), Aug. 30	10 mph
			42 mph (WNW), Aug. 31	26 mph
Edna	Sept. 10, 1954	0.65 inches	26 mph (E), Sept. 10	19 mph
			49 mph (NW), Sept. 11	32 mph
Hazel	Oct. 15, 1954	0.60 inches	75 mph (S)	31 mph
Connie	Aug. 12, 1955	0.897 inches	40-45 mph (SE)	29 mph
	Aug. 13, 1955	3.72 inches	40-45 mph (SE)	30 mph
	Aug. 14, 1955	1.53 inches	20 mph (S)	13 mph
Diane	Aug. 18, 1955	1.81 inches	35-40 mph (S to SW)	21 mph
	Aug. 19, 1955	3.99 inches	30 mph (W)	17 mph

* For more complete information, consult U. S. Department of Commerce Weather Bureau Publ. 26 (17).

Hurricane Edna, in 1954, had a path approximately the same as Carol (fig. 21). Winds were from the northwest and again a salinity retreat occurred. The drop in the maximum chloride concentration was about 28 percent (graph 22B). For the 5 days following the hurricane there was essentially no recovery of the chloride concentration at Chester. The path of Hazel, in 1954, was more or less parallel to that of Carol, but inland, so Hazel passed to the west of Delaware Bay (fig. 20). The winds in Delaware Bay were from the southeast and blew ocean water into the bay, causing higher tides than normal (table 16) and increased salinity. During the period of high tide on October 15, a 60-mph wind blew for 1 hour up the Delaware River, forcing salt water into the estuary. On October 16, the wind shifted and subsided, and the daily mean tidal elevation dropped. Very little rain accompanied this hurricane (table 17) and the major effects upon salinity were a result of winds. The chloride concentration increased approximately 1,000 ppm from the 14th to the 15th of October, and decreased 700 ppm on the 16th. The particular conditions causing these changes are indicated in graph 22C. The chloride concentration recovered immediately and increased after this hurricane.

The path of Hurricane Connie (Aug. 13, 1955) was inland and west of the Delaware River (fig. 21). Maximum wind velocities were 40 to 45 mph SE on August 12 and 13. The unusual heavy precipitation accompanying this hurricane produced extremely thorough flushing of the Delaware River. The chloride concentration dropped at Chester



Conditions During Hurricanes

Figure 22.--Selected time series of maximum and minimum daily chloride concentrations at Chester, Pa. for 1954, with an inverted hydrograph of flow at Chester, Pa. and mean river level at Philadelphia, Pa.

from about 1,100 ppm to 30 ppm. Hurricane Diane (Aug. 18-20, 1955) passed inland west of the Delaware River and then crossed the river just north of Philadelphia. Maximum wind velocities for this hurricane were 30-40 mph S to SW at Delaware Bay on August 18th. The heaviest runoff in 53 years accompanied this hurricane and resulted in farther retreat of the salt water. Preceding the hurricanes, there was the start of a salinity invasion; the chloride concentration at Chester had been rising for 40 days and was above 11,000 ppm. There was no early recovery from Diane or Connie at Chester; the chloride concentration did not rise above 30 ppm at any time during the next few months.

Summary

During the summer months, under conditions of reduced flow, salt water invades the fresh water areas of the Delaware River. The salinity invasion followed a general pattern of advancing from June to late October, and retreating at the beginning of November. Dissolved solids increased downstream from Philadelphia to Reedy Point, Del., as did most of the chemical constituents. However, the nitrate ion decreased slightly and the fluoride and silica were not significantly different. Dissolved solid concentration varies with the tide. On the ebb tide the dissolved solids decrease and do so until the following flood tide when they again begin to increase.

A comparison of water-stage data and conductivity data showed that maximum dissolved solids occurred sometime after maximum stage. Minimum dissolved solids occurred sometime after minimum stage. The maximum dissolved solid concentration occurs at or near high-water slack and the minimum at or near low-water slack. There are two high-water slacks and two low-water slacks each day.

The advance and retreat of salinity, for the most part, are a resultant of the fresh-water flow of the river and the sea level outside the bay. Increases in sea level will move the saline water upstream; decreases will allow the salty water to move downstream. Increases in fresh-water flow will move the saline water downstream and decreases will allow the saline water to move upstream. The general movement of saline water may be estimated from the average fresh-water flow curve and the average sea level curve for the Delaware River. The most favorable conditions for salinity intrusions in the Delaware River occur in the period from August to October. During this period the sea level is at its highest and river flow at its lowest. Salinity intrusion usually starts in June and builds up until September. From October to December there are marked decreases in salinity in the estuary. The water of the Delaware River will usually contain less dissolved solids in the period from December to May than at any other time of the year.

Isochlors of lower chloride concentration will advance or retreat more rapidly than those isochlors of higher chloride concentration.

Little variation in salinity across the navigation channel of the river was detected between the Delaware Memorial Bridge and Reedy Point. The salinity varied in the vertical, being more saline on the bottom in the reach of the river where salinity invasion was prevalent. This condition becomes more pronounced with increasing salinities.

This frequency of occurrence of chloride is equal to or less than 35 parts per million at least 64 percent of the time at Marcus Hook, and 96 percent of the time at the Benjamin Franklin Bridge, Philadelphia. The water temperature varies seasonally with a temperature difference of 1° to 2°F with depth and length of the segment studied.

Hurricanes affect salinity as a resultant of wind direction and velocity and runoff from precipitation. A hurricane whose eye passes to the west of the Delaware River is usually accompanied by winds that force salt water into the estuary, increasing the salinity. If this phenomena is followed by heavy rainfall in the upstream reaches, the increased fresh-water runoff quickly drives the salinity seaward. A hurricane passing to the east of the Bay and River is accompanied by winds which move water seaward. This, and any subsequent rainfall, both result in moving the saline water seaward.

At the beginning of the summer of 1955, the water from Reedy Point, upstream, contained less than 2,200 ppm of chloride. On July 19, at high-water slack the chloride concentration at Reedy Point and the Delaware Memorial Bridge, in the center of the navigation channel, were 4,950 ppm and 2,420 ppm, respectively. On August 2, the concentrations were 5,380 ppm at Reedy Point and 2,880 ppm at the Delaware Memorial Bridge. After heavy runoff from precipitation accompanying hurricanes in August (Connie, August 12-14; Diane, August 18-19), the chloride concentrations at Reedy Point had decreased to 2,050 ppm and at the Delaware Memorial Bridge to 32 ppm.

No appreciable salinity invasion occurred in 1956. The average of the maximum chloride at Chester, Pa.--between mid-August and October--was 134 parts per million. During the other summer months, prior to mid August, the maximum chloride concentration was below 40 parts per million.

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Methods of Analyses

Determination or Measurement	Method
Temperature....................	Field thermometer sensitivity 1°F or Whitney thermometer sensitive to 0.2°F.
pH.............................	Electrometric with glass electrodes.
Specific conductance	Laboratory Wheatstone bridge; cell with platinum electrodes calibrated against standard potassium chloride at 25°C. For field determinations--portable direct-reading, Solu Bridge and direct-reading, line-operated continuous specific conductance recorders with a range of 0 to 50,000 micromhos.
Silica	Spectrophotometer measurement of color developed by addition of ammonium molybdate.
Iron	Spectrophotometer measurement of the color developed by the addition of 2,2' bipyridine solution.
Calcium	Titration with standard Titra Ver Solution in the presence of Cal Ver Indicator.
Magnesium	Spectrophotometer measurement of color developed by addition of Eriochrome Black T.
Sodium and Potassium	Determined with flame photometer.
Bicarbonate	Titration with standard sulfuric acid to pH of 4.5 as determined by Calomel-Glass-Electrode pH meter.
Sulfate	Spectrophotometer titration of Alcoholic solution with barium chloride in presence of thorin indicator.
Chloride	Titrated with silver nitrate in presence of potassium chromate.

Fluoride	Compared colorometrically with standards of zirconium nitrate-alizarin red solution.
Nitrate	Spectrophotometer measurement of the color developed by the addition of phenoldisulphonic acid and ammonium hydroxide.
Dissolved Solids	Residue upon evaporation of solution and heating at 180°F for one hour in platinum dish.
Hardness	Calculated from the equivalent calcium and magnesium, or titrated with standard Titra Ver Solution in the presence of Univer II.

Appendix A.--Method of predicting the order of saline invasions for a number of years on the basis of river level at Philadelphia and sea level at Atlantic City. (Prediction on a relative basis only)

The difference between river level at Philadelphia and sea level at Atlantic City (table 18) has been assigned values of 1 to 7 for each month from June to October, depending upon the difference. The largest difference receives a value of 7; the next largest 6; and so on (table 19). The total value of the 1 to 7 assignments when arranged from the lowest to the highest gives the predicted arrangement shown in table 12, page 48.

Table 18.--Difference between river level and sea level (in feet).

Year / Month	1949	1950	1951	1952	1953	1954	1955
June	0.47	0.48	0.37	0.42	0.49	0.43	0.32
July	.37	.34	.32	.47	.30	.28	.29
Aug.	.17	.20	.24	.38	.22	.16	.79
Sept.	.15	.11	.28	.38	.19	.26	.34
Oct.	.07	.11	.20	.11	.02	.20	.62

Table 19.--Arrangement of years on the 1 to 7 assignments.

Month / Year	June	July	Aug.	Sept.	Oct.	Total
1949	5	6	2	2	2	17
1950	6	5	3	1	3	18
1951	2	4	5	5	4	20
1952	3	7	6	7	3	26
1953	7	3	4	3	1	18
1954	4	1	1	4	4	14
1955	1	2	7	6	7	23

Table 20a.—Chemical Quality of the Water of the Delaware River at the Delaware Memorial Bridge, Wilmington, Delaware

LOCATION.—Center of the navigation channel at the center of the Delaware Memorial Bridge, 1.9 miles downstream from the mouth of the Christina River.
DRAINAGE AREA.—11,030 square miles.
RECORDS AVAILABLE.—Chemical analysis: July 1955 to September 1956.
EXTREMES.—1955-56.—Dissolved solids: Maximum, 5,910 ppm Aug. 2, 1955; minimum, 134 ppm Mar. 2.
Hardness: Maximum, 1,090 ppm Aug. 2, 1955; minimum, 70 ppm Mar. 2.
Specific Conductance: Maximum 9,690 micromhos Aug. 2, 1955; minimum 223 micromhos Mar. 2.
Water temperatures: Maximum, 79°F Sept. 6; minimum, 35°F Jan. 11.

9-268 d

Chemical analysis, in parts per million, water year October 1955 to September 1956

71172

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color
														Calcium & Magnesium	Non-carbonate			
July 13, 1955		3.6	0.22	51	75	750		9	318	1,220	0.8	5.6	2,530	436	428	4,410	6.6	8
August 2, 1955		2.8	.25	87	212	1,760		18	497	3,100	.8	2.2	5,910	1,090	1070	9,690	6.8	8
September 1, 1955		7.6	.16	21	26	222		14	94	375	.4	4.0	789	159	148	1,400	6.8	14
October 3, 1955		7.3	.26	55	88	632		14	226	1,140	.6	4.7	2,310	499	488	3,960	6.7	8
January 11, 1956		6.2	.12	67	170	1,370		32	414	2,400	.6	.4	5,120	866	840	8,250	6.9	10
March 2		6.8	.00	17	6.5	16		14	55	14	.3	9.4	134	70	58	223	6.0	4
July 12		6.3	.00	19	7.9	47		7	73	66	.5	7.2	255	80	74	495	6.6	5
August 7		5.8	.03	41	82	621		19	212	1,100	.7	1.7	2,260	440	424	3,790	7.1	6
September 6		2.6	.00	56	131	1,010		20	317	1,790	.7	3.0	3,530	678	666	5,950	6.3	7

Table 20b.—Chemical Quality of the Water of the Delaware River at Reedy Point, Delaware

LOCATION.—One hundred yards west of buoy "1F", 0.8 miles southeast of the Chesapeake and Delaware Canal and 2.1 miles south of Pea Patch Island.
DRAINAGE AREA.—11,220 square miles
RECORDS AVAILABLE.—Chemical analysis: July 1955 to September 1956
Water temperatures: October 1955 to September 1956
EXTREMES,1955-56.—Dissolved solids: Maximum, 10,600 ppm Aug. 2, 1955; minimum, 204 ppm May 1, 3-5, 7-10.
Hardness: Maximum, 1720 ppm Aug. 2, 1955; minimum, 64 ppm May 1, 3-5, 7-10.
Specific Conductance: Maximum daily, 16500 micromhos Aug. 2, 1955; minimum daily, 194 micromhos Apr. 20.
Water temperature: Maximum daily, 82°F Aug. 19; minimum daily, 31°F Jan 22.
REMARKS.—The composites are composed of samples collected within one hour of high-water slack.

9-268 d

Chemical analysis, in parts per million, water year October 1955 to September 1956

71172

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium & Magnesium	Hardness as $CaCO_3$: Non-carbonate	Specific conductance (micromhos at 25°C)	pH	Color
July 13, 1955		3.2	0.22	85	216	1,860		27	510	3,250	0.6	1.7	6,310	1,100	1080	10,200	6.9	7
August 2, 1955		3.0	.22	131	340	2,570		42	820	4,650	.6	.2	10,600	1,720	1690	16,500	7.2	9
September 1, 1955		6.2	.18	67	214	1,680		33	430	3,000	.4	1.2	5,720	1,050	1020	9,360	7.1	12
October 3, 1955		6.2	.22	85	240	1,880		36	515	3,350	.6	1.3	6,660	1,200	1,170	10,800	6.9	10
November 1-4, 7-10		11	.07	25	35	413		22	125	675	.3	3.7	1,120	206	188	2,020	7.1	
December 1-10		6.9	.11	44	90	874		22	233	1,500	.4	2.8	2,590	480	462	4,580	7.0	
January 12,16,19,20,1956		6.5	.06	119	340	3,170		50	762	5,500	.6	.1	9,820	1,700	1,650	15,400	7.1	
February 1,2,4,6-10		13	.03	78	157	1,590		24	401	2,730	.5	1.3	5,420	840	820	8,860	7.2	2
March 1,3,5-8,10		12	.02	71	18	333		23	143	570	.3	3.5	1,250	251	232	2,180	7.2	4
April 1-10		13	.02	27	38	291		17	115	510	.3	3.5	1,090	224	210	1,930	7.2	3
May 1,3-5, 7-10		14	.01	13	7.6	33		11	43	54	.3	4.8	204	64	55	334	7.2	3
June 1-10		10	.17	33	44	360		14	138	630	.4	2.4	1,380	263	252	2,330	6.9	4
June 21		3.5	.00	55	122	864		5	264	1,580	.3	2.0	3,270	639	635	5,330	6.7	5
August 1-10		5.0	.02	60	134	1,280		30	361	2,180	.5	2.3	4,220	701	676	7,160	7.3	6
September 6		2.6	.01	100	261	2,300		41	614	4,000	.6	.9	7,540	1,320	1,290	12,300	6.7	7

Table 21.—Data Collected on Sampling Trips at High Water Slack
Between Philadelphia and Bakers Range During 1956
(All times are EST)

Date	Data: Center of Channel		Philadelphia, Pa.	Marcus Hook	Delaware Memorial Bridge	New Castle	Pea Patch Island	Reedy Point	Reedy Island Jetty	Bakers Range
July 23, at HWS	Time		3:24 PM	2:28 PM	2:03 PM	1:42 PM	1:23 PM	1:08 PM	12:53 PM	12:44 PM
	Specific conductance (micromhos)	T	207	261	895	1250	3820	4860	7150	8750
		B	208	259	1060	2260	4280	5960	8690	1100
	Chloride in parts per million	T	9.0	17	210	310	1110	1460	2200	2700
		B	10	17	240	620	1270	1820	2720	3560
Sept. 6, start of ebb tide	Time				2:40 PM		2:04 PM	1:48 PM	1:27 PM	1:11 PM
	Specific conductance (micromhos)	T			5850		10300	11800	15600	17400
		B			6600		10500	11800	16800	18100
	Chloride in parts per million	T			1750		3400	3900	5400	6000
		B			2050		3400	3900	5700	6300
Sept. 20, at HWS	Time		3:25 PM	2:30 PM	1:50 PM	1:33 PM	1:10 PM	12:48 PM	12:27 PM	
	Specific conductance (micromhos)	T	295	1260	3730	5810	9940	10700	15100	
		B	287	1460	5420	8030	11200	13300	15900	
	Chloride in parts per million	T	21	290	1050	1710	3120	3390	4950	
		B	18	340	1590	2460	3700	4450	5400	

Specific Conductance of Cross-Section Samples, Aug. 7, 1956
(All times are EST)

Date and Tidal Conditions			Delaware Memorial Bridge Time	Delaware Memorial Bridge Micromhos	New Castle Time	New Castle Micromhos	Bulkhead Bar Range Time	Bulkhead Bar Range Micromhos	Pea Patch Island Time	Pea Patch Island Micromhos	Reedy Point Time	Reedy Point Micromhos	Reedy Island Jetty Time	Reedy Island Jetty Micromhos	Bakers Range Time	Bakers Range Micromhos
August 7, end of flood tide just before HWS	Right	Top	1:31 PM	3460	1:11 PM	4360	12:58 PM	6620	12:45 PM	9420	12:35 PM	8460	12:09 PM	13800	11:43 AM	13000
		Bottom	1:31 PM	3580	1:11 PM	5120	12:58 PM	6870	12:45 PM	9620	12:35 PM	9750	12:09 PM	13900	11:43 AM	15900
	Center	Top	1:34 PM	3190	1:13 PM	3980	1:00 PM	6260	12:47 PM	9060	12:24 PM	9280	12:11 PM	14200	11:57 AM	14000
		Bottom	1:34 PM	3490	1:13 PM	5760	1:00 PM	7990	12:47 PM	9090	12:24 PM	10900	12:11 PM	14200	11:52 AM	16200
	Left	Top	1:38 PM	3230	1:15 PM	3960	1:02 PM	4970	12:49 PM	8420	12:31 PM	8370	12:13 PM	14200	11:54 AM	13500
		Bottom	1:38 PM	3580	1:15 PM	5460	1:02 PM	7450	12:49 PM	9420	12:31 PM	9330	12:13 PM	14900	11:54 AM	14100
	Average			3420		4780		6690		9170		9350		14200		14500

Table 22.— Data collected on sampling trips at high and low water slack between Philadelphia, Pa. and Reedy Point, Delaware from July through October 1955.

(All times are EST)

Date	Data		Philadelphia, Pa.	League Island	Eddystone	Penna./Delaware State Line (Marcus Hook)	Above Cherry Island Flats	Below Cherry Island Flats	Delaware Memorial Bridge	New Castle	Bulkhead Bar Range	Pea Patch Island	Reedy Point
July 13 Ebb Tide	Time		9:30 a.m.	9:45 a.m.	10:15 a.m.	10:35 a.m.	10:52 a.m.	11:15 a.m.	12:15 p.m.		12:37 p.m.	12:46 p.m.	1:27 p.m.
	Specific conductance (micromhos)	T	284	320	747	1490	2470	3830	3870		5740	6980	8760
		B		324	815	1630	2690	4420	4160		6280	7160	9840
	Chloride in parts per million	T									1700	2100	
		B										2200	3150
July 13 Flood Tide	Time				3:22 p.m.	3:05 p.m.		2:45 p.m.	2:30 p.m.		1:55 p.m.	1:42 p.m.	1:27 p.m.
	Specific conductance (micromhos)	T			429	798		2880	3300		6080	7140	8760
		B						3870	4540		6890		9840
	Chloride in parts per million	T									1890		
		B									2190		
July 19 at HWS	Time		3:05 p.m.	2:50 p.m.	2:20 p.m.	2:00 p.m.	1:46 p.m.	1:32 p.m.	1:12 p.m.		12:50 p.m.	12:43 p.m.	12:25 p.m.
	Specific conductance (micromhos)	T	354	422	1460	2790	4580	6250	7260		11000	12200	14100
		B			1710	4000	5380	7440	8590		11300	13100	14700
	Chloride in parts per million	T									3500	4000	4650
		B									3600	4200	4900
July 25 at LWS	Time		2:20 p.m.	2:10 p.m.	1:44 p.m.	1:12 p.m.	1:00 p.m.		12:37 p.m.		12:07 p.m.	11:58 a.m.	11:40 a.m.
	Specific conductance (micromhos)	T	333	375	784	1590	2440		4430		7560	8480	10000
		B			795	1650	2740		5450		8460	8770	10560
	Chloride in parts per million	T			145	360	600		1150		2200	2300	2950
		B							1350				3100
August 2 at HWS	Time		2:30 p.m.	2:19 p.m.	1:49 p.m.	1:26 p.m.	1:15 p.m.	12:55 p.m.	12:33 p.m.		12:10 p.m.	12:00 p.m.	11:37 a.m.
	Specific conductance (micromhos)	T	512	649	1920	4210	5370	7340	8300		11300	13500	14900
		B					7130	8780	9640		13100	14200	16500
	Chloride in parts per million	T	75	113	450	1200	1700	2150	2650		3650	4400	5000
		B					2350	2800	3100		4250	4700	5650
August 15 at HWS	Time		1:06 p.m.	12:55 p.m.	12:25 p.m.	12:04 p.m.	11:48 a.m.	11:34 p.m.	11:19 a.m.		10:59 a.m.	10:49 a.m.	10:29 a.m.
	Specific conductance (micromhos)	T	212	247	383	512	1050	1310	1730		5210	5400	7590
		B	216	232	379	535	1060	1800	2730		6490	8170	10600
	Chloride in parts per million	T	17	23	48	80	245	340	450		1580	1600	2350
		B									1980		3400
August 30 at HWS	Time		2:35 p.m.	2:23 p.m.	1:47 p.m.	1:25 p.m.	1:10 p.m.	12:57 p.m.	12:42 p.m.	12:29 p.m.	12:16 p.m.	12:05 p.m.	11:47 a.m.
	Specific conductance (micromhos)	T	148	165	164	172	167	187	199	515	2200	2610	5210
		B	144	161	160	165	165	187	247	1139	3300	3310	8760
	Chloride in parts per million	T	6.0	8.0	9.0	10	10	18	20	107	308	726	1500
		B											2750
September 1 at HWS	Time		2:01 p.m.	1:50 p.m.	1:23 p.m.	1:06 p.m.	12:53 p.m.	12:41 p.m.	12:24 p.m.	11:57 a.m.	11:53 a.m.	11:46 a.m.	11:30 a.m.
	Specific conductance (micromhos)	T	181	169	175	187	228	370	853	2110	2350	6290	6700
		B		166	178	185	218	477	1450	4660	5020	6200	9520
	Chloride in parts per million	T	7.0	8.0	10	10	26	64	200	583	633	1930	2100
		B									1500	1880	3050
September 9 at LWS	Time		1:42 p.m.	1:35 p.m.	1:00 p.m.	12:40 p.m.	12:23 p.m.	12:08 p.m.	12:00 p.m.	11:43 a.m.	11:30 a.m.	11:20 a.m.	11:02 a.m.
	Specific conductance (micromhos)	T	188	196	212	212	218	252	384	611	1130	1990	3260
		B	184	197	221	215	215	264	416	754	1130	2200	3420
	Chloride in parts per million	T	10	10	11	12	12	22	58	125	270	525	825
		B											
September 13 at HWS	Time		12:48 p.m.	12:35 p.m.	12:07 p.m.	11:48 a.m.	11:36 a.m.	11:21 a.m.	11:05 a.m.	10:53 a.m.	10:42 a.m.	10:30 a.m.	10:15 a.m.
	Specific conductance (micromhos)	T	230	226	231	363	688	1260	1780	2620	4590	4910	7210
		B	227	221	231	384	711	1800	2020	3880	5190	5800	9030
	Chloride in parts per million	T	23		26	49	145	320	475	762		1500	2300
		B											2950
September 22 at LWS	Time		2:00 p.m.	1:48 p.m.	1:20 p.m.	1:01 p.m.	12:48 p.m.	12:32 p.m.	12:17 p.m.	12:04 p.m.	11:53 a.m.	11:44 a.m.	11:26 a.m.
	Specific conductance (micromhos)	T	245	238	255	283	322	616	873	1230	2220	3190	4680
		B	226	238	260	272	329	627	1110	1470	2580	3160	5640
	Chloride in parts per million	T	14		16	19	29	115	188	290		950	1380
		B											
September 29 at HWS	Time		2:42 p.m.	2:18 p.m.	1:38 p.m.	1:11 p.m.	12:54 p.m.	12:36 p.m.	11:20 a.m.	11:55 a.m.	11:42 a.m.	11:29 a.m.	11:13 a.m.
	Specific conductance (micromhos)	T	259	269	291	379	918	1750	1790	3740	5790	6230	9850
		B	285	269	288	444	1090	2230	2590	4060	7030	7600	11000
	Chloride in parts per million	T	16		22	42	210	442	475	1200		1950	3150
		B											3600
October 3 at HWS	Time		2:40 p.m.	2:31 p.m.	2:03 p.m.	1:45 p.m.	1:33 p.m.	1:17 p.m.	1:01 p.m.	12:46 p.m.	12:35 p.m.	12:25 p.m.	12:03 p.m.
	Specific conductance (micromhos)	T	268	274	320	803	1381	2500	2870	5540	6340	9320	10100
		B	269	278	318	817	1780	2680	4720	5540	6950	9370	10600
	Chloride in parts per million	T	16		26		340	700	800	1750		2950	3250
		B											3450
October 13 at HWS	Time		2:25 p.m.	2:12 p.m.	1:44 p.m.	1:22 p.m.	1:09 p.m.	12:55 p.m.	12:43 p.m.	12:26 p.m.	12:14 p.m.	12:03 p.m.	11:48 a.m.
	Specific conductance (micromhos)	T	158	180	232	274	345	616	875	1510	3030	3550	5510
		B	159	180	232	267	375	669	1170	2600	3680	5770	8140
	Chloride in parts per million	T	7.0		7.5	22	31	108	185	367		1030	1730
		B											

Table 23.— Daily Samples at Reedy Point, Delaware

Samples are collected at Reedy Point at Buoy R"2" (U. S. Coast and Geodetic Navigation Map No. 294) which is 1,000 feet west of the center of the channel. These samples are from September 1, 1955 to October 2, 1956. The time listed with each sample is close to high-water slack. For the exact time difference between the collection of the samples and predicted time of high-water slack, "Tide Tables, East Coast North and South America" (U.S.C&GS) should be consulted. Where no chloride value is listed, an estimation of the chloride concentration can be obtained by using figure 4, page 16.

Date	September, 1955				October, 1955				November, 1955				December, 1955			
	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)
1	12:00 pm	79	5,660	1,780	9:30 am	68	8,380	2,600	12:15 pm	56	2,080	542	1:10 pm	40	3,290	950
2	1:00 pm	79	6,930	2,050					1:30 pm	57	2,640	738	-	-	4,510	-
3	1:30 pm	78	6,690	2,150	12:30 pm	69	8,940	2,850	-	-	2,940	-	3:00 pm	44	4,640	1,380
4	2:00 pm	80	6,400	2,000	2:00 pm	68	8,860	2,850	3:00 pm	54	1,250	310	3:30 pm	42	4,530	1,330
5	2:00 pm	78	5,360	1,630	1:00 pm	66	8,290	2,600	3:30 pm	52	954	-	3:30 pm	41	3,090	-
6					1:25 pm	68	6,780	-	-	-	968	-	7:50 am	39	4,810	1,450
7	2:00 pm	77	6,410	2,100	2:30 pm	70	8,490	2,750	8:40 am	51	1,380	-	8:10 am	39	4,930	1,500
8	2:30 pm	75	5,860	1,880	6:30 am	68	6,000	1,850	9:45 am	51	1,140	-	8:10 am	38	5,210	1,530
9	2:30 pm	75	3,930	1,200	6:30 am	65	4,780	-	8:30 am	50	2,220	616	8:30 am	38	4,950	-
10	6:50 am	72	6,170	1,950	7:00 am	65	4,740	1,400	8:30 am	50	2,380	650	10:00 am	36	5,180	-
11	7:00 am	73	6,340	2,000	8:00 am	66	4,030	-	10:00 am	50	3,320	-				
12	7:45 am	73	5,550	1,580	9:00 am	66	3,740	1,080	10:30 am	50	3,280	930	12:00 pm	39	4,870	1,250
13	7:30 am	72	6,630	2,100					12:15 pm	57	2,720	775				
14	10:00 am	72	7,760	2,450	12:15 pm	67	5,440	-	12:00 pm	55	2,960	838				
15	12:10 pm	73	7,130	2,300					12:00 pm	52	5,090	1,500	1:30 pm	36	9,340	2,800
16	12:00 pm	74	6,630	2,050					2:10 pm	53	2,830	825	12:00 pm	35	5,280	1,550
17	-	-	6,780	2,200					2:30 pm	49	2,380	665	1:00 pm	35	6,870	2,150
18	2:00 pm	75	7,800	2,450					2:30 pm	50	827	200	-	-	6,500	2,000
19	2:00 pm	72	6,720	2,150					12:15 pm	47	819	-	3:00 pm	35	6,020	1,850
20	2:00 pm	74	8,150	2,600					1:00 pm	-	2,160	-				
21		-	8,160	2,550												
22	2:30 pm	70	5,900	-					3:10 pm	48	1,400	-	8:00 am	32	8,350	2,650
23	6:30 am	69	6,810	2,150					8:00 am	45	5,910	1,830				
24	6:30 am	69	8,500	2,650					-	-	2,160	-	8:30 am	34	8,850	2,750
25	7:00 am	67	6,350	1,950					8:30 am	44	4,670	1,430	8:30 am	35	9,360	2,900
26	7:00 am	67	7,440	-	8:30 am	60	2,770	712	9:30 am	43	5,230	-	10:00 am	33	8,860	2,650
27	9:20 am	67	5,860	1,750					9:00 am	43	5,040	-				
28	10:00 am	67	6,070	1,900					-	-	5,040	-				
29					9:00 am	57	4,120	-	11:10 am	41	3,780	1,130	12:45 pm	34	9,910	3,000
30	8:00 am	68	8,160	-	9:00 am	57	4,720	-	12:30 pm	41	3,590	1,030	12:30 pm	32	9,530	3,050
31					-	-	4,430	-					3:00 pm	32	10,500	3,200

Date	January, 1956				February, 1956				March, 1956				April, 1956			
	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)
1	3:00 pm	33	9,310	3,000	2:00 pm	36	9,630	3,040	4:00 pm	39	1,940	520	4:00 pm	44	882	210
2					-	-	10,400	3,340	4:00 pm	42	2,130	580	4:00 pm	45	1,020	240
3									4:00 pm	42	1,520	390	8:30 am	44	605	150
4					-	-	10,000	3,160					9:00 am	44	3,970	1,180
5									8:00 am	45	2,360	650	9:00 am	45	4,000	1,180
6	8:00 am	34	11,400	3,700	8:30 am	34	11,000	3,610	8:00 am	39	2,160	520	8:00 am	45	2,870	820
7					11:00 am	37	6,540	1,960	9:30 am	43	1,480	380	9:00 am	46	2,500	690
8					10:30 am	36	7,600	2,320	10:00 am	43	4,800	1,480	10:00 am	44	611	130
9					10:00 am	36	9,590	3,000	11:00 am	41	2,480	-	11:00 am	45	596	125
10					12:00 pm	27	6,890	2,280	11:50 am	44	1,250	315	10:00 am	44	399	67
11					12:00 pm	37	6,520	-	11:00 am	44	982	-	11:45 am	44	407	70
12					2:30 pm	39	7,900	-	1:00 pm	42	1,230	-	12:00 pm	49	336	50
13					1:00 pm	38	7,150	-	12:00 pm	44	870	-	1:00 pm	48	220	22
14					1:30 pm	41	3,760	1,120	8:00 am	43	1,700	-	2:00 pm	50	360	58
15					2:00 pm	43	3,990	-	3:00 pm	43	421	71	3:00 pm	50	320	50
16					2:30 pm	39	2,310	-					3:30 pm	53	336	54
17					3:00 pm	38	2,710	-	3:00 pm	42	236	26	8:30 pm	52	336	56
18					8:00 am	39	3,510	1,040					8:00 am	52	337	55
19					8:00 am	39	2,760	-	3:15 pm	39	407	72	8:00 am	48	226	26
20					8:00 am	40	3,930	-	8:00 am	40	710	160	8:30 am	49	194	20
21	8:00 am	32	13,000	4,200	9:30 am	39	3,780	-	8:30 am	40	722	160	9:00 am	49	210	23
22	8:30 am	31	14,200	4,650	10:00 am	39	3,910	1,180	9:00 am	39	3,350	980	9:00 am	50	218	24
23	8:30 am	33	14,400	4,700	9:00 am	37	3,750	-	8:30 am	43	2,680	770	1:00 pm	50	243	30
24	11:00 am	34	14,100	4,750	11:00 am	37	3,700	-	10:00 am	42	2,730	780	12:30 pm	50	204	20
25					11:00 am	44	5,230	1,640	3:00 pm	42	695	160	3:00 pm	55	366	65
26					1:30 pm	40	3,720	-	11:00 am	43	1,470	385	1:00 pm	51	387	67
27	12:30 pm	34	13,800	4,550	4:00 pm	30	2,250	-	1:00 pm	43	2,290	640	3:00 pm	57	372	67
28	12:30 pm	33	14,000	4,700	11:00 am	39	1,890	-	2:00 pm	43	1,080	270				
29	1:00 pm	34	12,700	4,200	11:30 am	39	1,790	475	3:00 pm	40	1,780	480	2:30 pm	58	320	51
30	2:00 pm	35	13,900	4,650					3:30 pm	43	2,200	610	3:00 pm	59	308	49
31	1:35 pm	35	11,800	3,750					4:00 pm	42	1,000	245				

Date	May 1956				June, 1956				July, 1956				August, 1956			
	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)	Time EST	Temperature (°F)	Specific Conductance (micromhos)	Chloride (ppm)
1	2:30 pm	53	241	32	6:30 am	67	1,570	420	6:30 am	76	4,340	1,260	7:30 am	78	4,260	1,250
2					7:00 am	66	2,490	710	7:20 am	77	4,880	1,430	8:00 am	76	5,460	1,650
3	7:00 am	56	218	24	7:00 am	66	2,470	700	6:50 am	77	4,080	1,170	8:30 am	76	6,560	2,020
4	7:00 am	56	204	20	7:30 am	66	1,990	630	7:00 am	77	4,790	1,390	8:30 am	78	5,820	1,730
5	8:00 am	58	285	39	7:15 am	69	2,160	550	7:45 am	77	3,980	1,190	11:30 am	75	7,840	2,400
6					8:30 am	69	1,990	550	11:00 am	76	5,740	1,850	11:30 am	75	7,130	2,150
7	9:30 am	59	410	96	11:30 am	70	2,290	600	10:30 am	76	6,280	2,050	12:30 pm	76	8,130	2,490
8	10:45 am	57	439	84	12:00 pm	71	2,420	660	12:30 pm	78	6,370	2,090	1:30 pm	76	8,820	2,720
9	11:15 am	57	415	158	12:30 pm	70	2,380	670	1:00 pm	77	6,330	2,070	3:00 pm	79	7,840	2,350
10	12:00 pm	59	457	100	1:30 pm	70	2,940	840	2:00 pm	77	5,460	1,720	4:07 pm	79	8,420	2,600
11	12:00 pm	60	338	58	2:00 pm	71	2,380	660	2:00 pm	77	4,900	1,520	5:14 pm	78	8,640	2,670
12	2:00 pm	61	578	130	2:00 pm	71	2,420	660	4:30 pm	78	5,110	1,590	7:00 am	78	6,430	1,920
13	2:00 pm	66	589	135	2:10 pm	71	2,440	680	5:00 pm	77	5,170	1,620	7:00 am	78	8,080	2,470
14	2:30 pm	66	546	115	5:05 pm	78	2,690	760	7:00 am	76	4,670	1,430	8:00 am	78	7,900	2,450
15	7:00 am	66	746	170	7:00 am	74	3,300	900	7:00 am	74	4,930	1,520	8:00 am	77	7,700	2,420
16	7:30 am	60	746	170	7:30 am	74	3,170	900	7:15 am	75	5,130	1,610	9:00 am	80	8,100	2,520
17	6:30 am	60	698	160	8:00 am	76	3,510	1,000	7:00 am	77	4,660	1,430	9:00 am	79	8,090	2,500
18	7:00 am	60	919	220	8:00 am	70	2,890	810	7:00 am	76	4,090	1,230	11:00 am	80	9,740	3,080
19	8:30 am	61	700	160	10:00 am	75	4,260	1,260	11:00 am	79	4,940	1,530	11:00 am	82	7,860	2,480
20	9:30 am	62	782	175	11:00 am	74	3,490	990	10:30 am	76	5,900	1,900				
21	10:30 am	62	997	240	11:30 am	73	3,780	1,090	11:30 am	78	4,410	1,340	1:00 pm	75	7,560	2,320
22	-	67	243	30	11:00 am	75	3,770	1,090	12:00 pm	77	4,520	1,380	2:00 pm	77	10,000	3,180
23	12:20 pm	68	243	29	12:00 pm	76	3,940	1,140	1:00 pm	78	4,840	1,430	2:00 pm	77	10,630	3,400
24	12:30 pm	67	1,320	355	1:00 pm	80	4,520	1,340	1:30 pm	76	4,640	1,370	2:30 pm	75	10,340	3,300
25	1:30 pm	65	1,210	305	1:30 pm	78	4,860	1,400	1:45 pm	76	4,760	1,400	2:30 pm	77	10,040	3,120
26	2:00 pm	64	754	145	2:00 pm	80	4,590	1,350	2:30 pm	80	4,900	1,450	3:20 pm	76	10,520	3,330
27	2:00 pm	65	659	150	2:30 pm	80	4,830	1,410	3:00 pm	81	5,250	1,630	4:00 pm	76	9,660	3,100
28	2:00 pm	67	1,130	290	4:00 pm	78	5,140	1,510	3:00 pm	79	5,070	1,490	5:45 pm	79	10,300	3,300
29	2:10 pm	66	1,280	320	5:00 pm	76	4,680	1,370	6:30 pm	75	3,620	1,020	7:10 am	77	3,900	1,130
30	2:00 pm	67	583	120	6:30 am	76	5,470	1,620	6:30 am	76	4,480	1,320	6:30 am	76	9,540	3,000
31	4:30 pm	72	499	101					7:00 am	75	5,880	1,800	1:00 pm	77	10,900	3,600

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