Delaware River Water Quality Bristol to Marcus Hook Pennsylvania August 1949 to December 1963

By W. B. KEIGHTON

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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DELAWARE RIVER WATER QUALITY, BRISTOL TO MARCUS HOOK, PENNSYLVANIA, AUGUST 1949 TO DECEMBER 1963

By W. B. KEIGHTON

ABSTRACT

During the 14-year period from August 1949 to July 1963, the U.S. Geological Survey, in cooperation with the city of Philadelphia, collected samples of river water once each month in the 43-mile reach of the Delaware River from Bristol to Marcus Hook, Pa., and daily at Trenton, 10 miles upstream from Bristol. This part of the Delaware is an estuary into which salt water is brought by tides; fresh water flows into the estuary at Trenton, N.J., and farther downstream from the Schuylkill River and other tributaries of the Delaware.

In March, April, and May, when fresh-water flow is high, the average concentration of dissolved solids in the water at Bristol was 76 ppm (parts per million), and at Marcus Hook 112 ppm. In August and September, streamflow is lower, and the average concentrations of dissolved solids increased to 117 ppm at Bristol and 804 ppm at Marcus Hook. Major salinity invasions of the Delaware River occurred in 1949, 1953, 1954, 1957, and 1963. In each of these years the fresh-water flow into the tidal river at Trenton was low during the period from July to October. The greatest dissolved-solids concentrations in these monthly samples were 160 ppm at Bristol and 4,000 ppm at Marcus Hook.

At times the dissolved-oxygen concentration of the river water has become dangerously low, especially in that reach of the river between Wharton Street and League Island. At the Benjamin Franklin Bridge, one-third of the samples of river water were less than 30 percent saturated with oxygen; however, no trend, either for better or for worse, was apparent during the 14-year period.

It is useful now to summarize these monthly analyses for the period 1949–63 even though a much more detailed description of water quality in this reach of the estuary will soon become available through the use of recording instruments. This period includes a range of conditions and exhibits the extent to which water-quality parameters varied with change in hydrologic and environmental conditions. This compendium of water-quality data is useful as an explicit statement of water quality during the 14-year period and is valuable for directing attention to water-quality problems, for selecting instrument sites, and for making comparative studies with the more detailed information which is already being obtained with the aid of recording instruments.

INTRODUCTION

The Delaware River from Trenton to the ocean is an estuary in which saline water moves down and upstream twice daily with the ebb and flood of the tide and mixes with the fresh water that flows into the estuary from the head of tide at Trenton and from the Schuylkill River and other tributaries below the head of tide. The changes in chemical quality of the river water are of interest to those who would understand water quality in this or any estuary. Furthermore, these changes are important because that part of the estuary described in this report is within a populous and industrialized region that depends upon the estuary for a source of water for household and industrial use and also makes use of the estuary to dilute and carry away its wastes. Because the estuary is a major source of water in this region, a knowledge of water quality in the estuary is of interest to many municipalities and industries, as well as to individual citizens, sportsmen, and conservation groups.

The U.S. Geological Survey has collected monthly water samples in the Delaware estuary since August 1949 at eight sampling stations from Bristol, Pa., to the Pennsylvania-Delaware State line at Marcus Hook, Pa. The location of these stations is shown in figure 1, and

TABLE 1.—*Distance relations and drainage area of sampling stations in Delaware estuary, Burlington-Bristol Bridge to Marcus Hook, Pa.*

	Station[1]	Drainage area, in square miles	River distance, in miles, of midchannel stations	
			Between stations	From Trenton, N.J.
1	Bristol (Pa.)-Burlington (N.J.) Bridge	7,160		15.2
2	Torresdale, Philadelphia, Pa	7,781	8.1	23.3
3	Lehigh Avenue, Philadelphia, Pa	7,935	8.0	31.3
4	Benjamin Franklin Bridge	7,993	1.8	33.1
5	Wharton Street, Philadelphia, Pa	7,998	1.5	34.6
6	League Island, Philadelphia, Pa	8,072	5.4	40.0
7	Eddystone, Pa	10,190	8.7	48.7
8	Marcus Hook, Pa	10,370	6.0	54.7

[1] For location of stations, see fig. 1.

the stations are listed in table 1. In addition, a daily sampling station has been operated, above the head of tide, on the Delaware River at Trenton, N.J., since 1944. The four upstream stations were sampled on one day, and the four downstream stations on the following day, or vice versa. Sampling trips were scheduled without regard to possible tidal, climatic, or other environmental conditions. Most of the trips to date have been completed within the first 10 days of each month. At times, owing to inclement winter weather, it was hazardous to sample by boat. For this reason, actual data are occasionally missing for a winter month; however, in compiling the summaries of data in this report such missing data have been estimated empirically from long-term information.

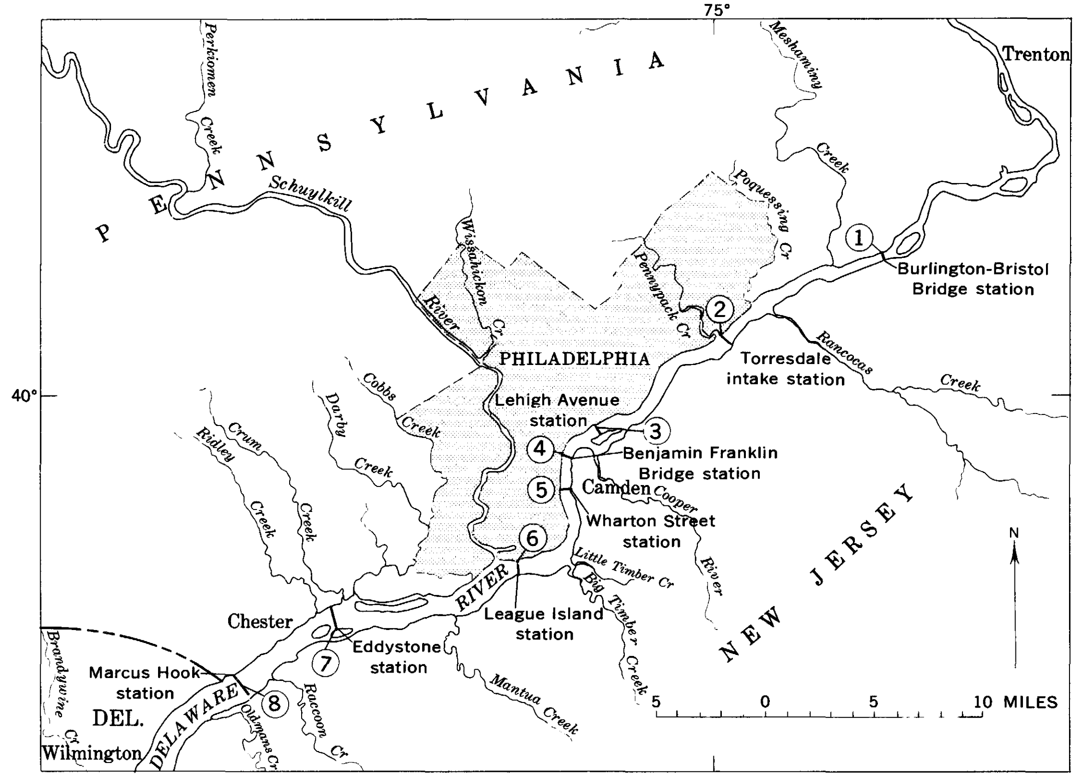

Figure 1.—Location of water-quality sampling stations along Delaware estuary, Trenton, N.J., to Marcus Hook, Pa.

PURPOSE AND SCOPE

In the 14-year period from August 1949 to December 1963, many analytical data were collected describing the chemical and physical quality of water in the Delaware estuary between Bristol and Marcus Hook. Most of these analyses have already been published in annual reports of the U.S. Geological Survey. To refer to these data, it is necessary, however, to consult more than a dozen publications; and to comprehend the meaning of the many analyses, it is necessary to compare water quality at eight sampling locations for 14 years and for the 12 months of each year.

This report presents, in summary form, the water-quality facts discovered at these eight sampling stations during the period August 1949 to December 1963. It has been written to serve as a reference book of the important facts concerning the water quality of the Delaware River from Bristol to Marcus Hook and presents a historical record of the variations in water quality without analyzing their causes. It does not record the basic chemical analyses, water temperatures, or suspended sediment analyses which have already been published but instead summarizes, plots, and compares the basic data in order to facilitate comprehension of them. Water-quality facts are presented in two complementary ways: on pages O9–O36 the salient features are shown graphically; on pages O36–O51 the data are summarized in tabular form for each of the eight sampling stations. In both the graphic and the tabular section, I have tried to distill the analyses to obtain the essence.

It is hoped that this compendium will facilitate the task of those who need to know the quality of water in the estuary, or who desire to study the factors that influence the quality of the water and that cause the variations observed. It should also be useful in directing attention to water-quality problems and in selecting future sites for instruments and observations.

PREVIOUS INVESTIGATIONS AND ACKNOWLEDGMENTS

Analyses of water samples collected from August 1949 to December 1952 are reported and interpreted in "Chemical Characteristics of Delaware River Water, Trenton, New Jersey, to Marcus Hook, Pennsylvania" (Durfor and Keighton, 1954). Since 1952 the water analyses have been published in the annual Geological Survey Water-Supply Paper series entitled "Quality of Surface Waters of the United States." These papers are listed below:

Year	Water-Supply Paper	Year	Water-Supply Paper
1952	1250	1957	1520
1953	1290	1958	1571
1954	1350	1959	1641
1955	1400	1960	1742
1956	1450		

In addition to these compilations of water-quality data, three recent publications of the Geological Survey have reported on interpretations of these data. Cohen and McCarthy (1962) in "Salinity of the Delaware Estuary" discuss the environmental variables affecting salinity in the estuary. Durfor and Anderson (1963) in a report describing the chemical character of streams in Pennsylvania briefly discuss water quality in the estuary. A third report is a comprehensive discussion of the quality of water entering the estuary at Trenton—"Quality of Delaware River Water at Trenton, New Jersey" by McCarthy and Keighton (1964).

These investigations of the chemical quality of the Delaware estuary from 1949 to 1963 have been conducted by the Geological Survey, in cooperation with the city of Philadelphia Water Department, Samuel S. Baxter, commissioner. They were under the general supervision of W. F. White, district chemist, 1948–52, and N. H. Beamer, district chemist from 1952 to the present. The author wishes to express his debt to Leo T. McCarthy, Jr., and Frederick L. Schaefer for compiling the tables and preparing the illustrations which are the backbone of this report.

SOME BASIC PHYSICAL AND HYDROLOGIC FACTS

The Delaware estuary begins at the head of tide at Trenton, N.J. Approximately 1 mile upstream from the head of tide, the U.S. Geological Survey maintains a stream-gaging station that has been in continuous operation since 1912. Upstream from this gage the Delaware River has a drainage area of 6,780 square miles, which is about 95 percent of the drainage area at Burlington-Bristol Bridge but only about 65 percent of the drainage area at Marcus Hook. The seasonal variations in water discharge of the river at Trenton have a direct influence on the chemical, physical, and sanitary quality of the Delaware estuary. To aid in the interpretation of the water-quality data presented in this report, the annual mean discharges and the monthly mean discharges at Trenton, N.J., for 1945–63 are presented in table 2 and plotted in figures 2 and 3.

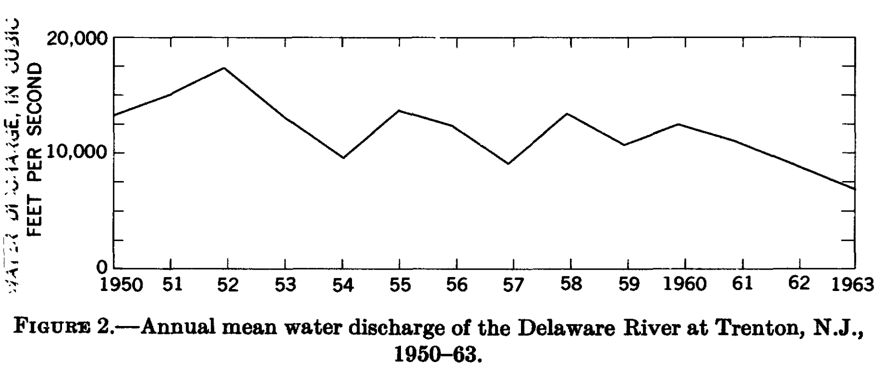

FIGURE 2.—Annual mean water discharge of the Delaware River at Trenton, N.J., 1950–63.

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TABLE 2.—*Monthly and annual mean water discharge, in cubic feet per second, Delaware River at Trenton, N.J., 1945–63*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1945	10, 060	9, 341	37, 100	16, 310	19, 730	14, 280	25, 380	14, 050	12, 390	13, 230	18, 010	15, 300	17, 098
1946	17, 730	7, 954	23, 920	8, 841	20, 010	17, 720	7, 885	5, 505	4, 317	5, 807	4, 750	4, 648	10, 757
1947	12, 440	12, 050	19, 250	25, 710	30, 350	14, 290	19, 730	9, 074	5, 015	3, 159	14, 700	8, 030	14, 483
1948	6, 142	11, 450	34, 170	26, 010	21, 980	12, 920	7, 727	5, 726	3, 272	3, 107	6, 202	10, 770	12, 456
1949	32, 430	19, 070	13, 560	16, 050	16, 030	5, 682	3, 721	2, 701	2, 719	2, 785	4, 661	10, 940	10, 862
1950	13, 870	13, 320	21, 860	24, 360	13, 560	11, 550	7, 574	4, 915	4, 721	3, 149	14, 250	26, 050	13, 265
1951	18, 500	27, 550	23, 230	29, 600	8, 533	8, 049	8, 336	6, 874	4, 206	5, 640	24, 350	18, 590	15, 288
1952	24, 070	18, 680	24, 460	36, 230	22, 750	13, 520	12, 010	6, 307	10, 040	3, 640	12, 850	26, 130	17, 557
1953	22, 160	19, 560	25, 690	26, 620	20, 050	7, 224	3, 783	2, 435	2, 695	2, 409	5, 866	17, 830	13, 027
1954	7, 518	14, 530	17, 300	13, 980	16, 980	5, 092	2, 080	1, 828	3, 495	2, 487	12, 770	13, 110	9, 264
1955	10, 400	8, 881	20, 970	13, 110	6, 455	5, 017	2, 477	30, 290	7, 410	28, 710	21, 630	7, 742	13, 591
1956	6, 855	13, 150	19, 790	30, 900	18, 040	10, 150	8, 413	4, 045	5, 613	5, 180	8, 192	16, 170	12, 208
1957	9, 698	9, 983	13, 370	25, 260	8, 385	4, 297	2, 907	2, 018	2, 254	2, 381	3, 905	19, 830	8, 691
1958	14, 180	10, 330	20, 930	39, 230	20, 280	6, 214	4, 667	3, 700	4, 029	8, 235	12, 100	9, 285	12, 765
1959	10, 490	10, 900	14, 740	20, 540	8, 246	4, 598	3, 868	4, 018	4, 255	8, 030	13, 380	19, 400	10, 205
1960	15, 530	18, 220	8, 782	33, 280	11, 280	10, 790	6, 197	7, 433	19, 340	7, 623	6, 221	5, 010	12, 476
1961	4, 711	15, 690	24, 900	27, 520	16, 120	7, 130	5, 150	5, 605	4, 205	2, 903	5, 343	6, 334	10, 468
1962	12, 970	8, 133	19, 340	23, 440	6, 147	3, 407	2, 489	3, 010	2, 631	4, 515	10, 860	7, 318	8, 688
1963	6, 541	6, 075	23, 500	14, 540	8, 092	4, 332	3, 116	2, 928	2, 556	2, 108	4, 025	7, 271	7, 090
Maximum	32, 430	27, 550	37, 100	39, 230	30, 350	17, 720	25, 380	30, 290	19, 340	28, 710	24, 350	26, 130	17, 557
Average	13, 486	13, 413	21, 313	23, 768	15, 399	8, 751	7, 238	6, 445	5, 535	6, 058	10, 740	13, 145	12, 113
Minimum	4, 711	6, 075	8, 782	8, 841	6, 147	3, 407	2, 080	1, 828	2, 254	2, 108	3, 905	4, 648	7, 090

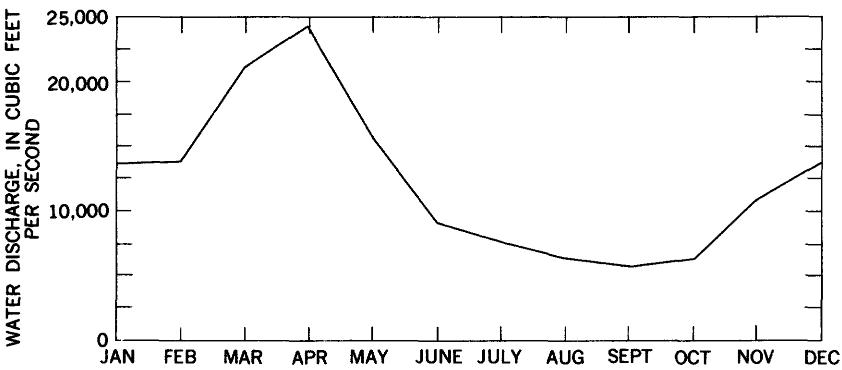

FIGURE 3.—Mean monthly water discharge of the Delaware River at Trenton, 1949–63.

Fresh water flowing into the estuary both dilutes salt water and tends to flush it downstream. For example, a discharge of 6,000 cfs (cubic feet per second) for 1 day is 5.18×10^8 cubic feet per day. The volume of water (at midtide) in the river between Trenton and Marcus Hook is 170×10^8 cubic feet. On this basis it is estimated that 33 days (170/5.18) would be required to flush the river to Marcus Hook. The results of such calculations for several discharge rates are given in table 3; however, fresh water also dilutes salt water by tidal mixing, so that the river is generally freshened more rapidly than indicated in the table. When the fresh-water flow is very low, salt water may advance upstream in spite of the fresh-water discharged.

TABLE 3.—*Time required to flush Delaware River upstream from sampling locations, at various discharge rates*

Water discharge at Trenton, N.J. (cfs)	Flushing time, in days, from Trenton to station indicated [1]							
	1	2	3	4	5	6	7	8
6,000	3.2	6.0	10	11	12	17	25	33
10,000	1.9	3.6	6.2	6.8	7.4	10	15	20
40,000	.5	.9	1.6	1.7	1.9	2.5	3.8	4.9

[1] For location of stations 1–8, see fig. 1.

The average concentration of dissolved solids in water of the Delaware River at Trenton from 1945 to 1961 was 86 ppm and ranged from 57 to 126 ppm 90 percent of the time. In March, April, and May the median concentration of dissolved solids was 66 ppm, and in August and September 107 ppm. The dissolved solids averaged, in terms of equivalents, 28 percent calcium, 14 percent magnesium, 8 percent sodium plus potassium, 43 percent bicarbonate plus sulfate, 5 percent chloride, and 2 percent nitrate (McCarthy and Keighton, 1964).

Other tributaries also contribute fresh water to the estuary and thereby have some influence on water quality. Of these, the principal tributary is the Schuylkill River, which flows into the Delaware River close to, but downstream from, station 6—League Island (fig. 1). The Schuylkill River may be expected to exert some influence on water quality downstream from its confluence, at Chester, Eddystone (sta. 7), and Marcus Hook (sta. 8). On a flood tide, water from the Schuylkill River may flow upstream in the Delaware River and dilute the water at League Island (sta. 6).

A gaging station has been maintained since 1931 on the Schuylkill River 8.4 miles upstream from the mouth and above tidal influences; the monthly and yearly mean discharges are reported annually in U.S. Geological Survey publications. The quantity of fresh water from the Schuylkill River flowing into the Delaware River each year is generally no more than one-quarter of the fresh-water inflow into the Delaware River at Trenton, N.J.; furthermore, the fresh water discharged from the Schuylkill River is mixed with a tidal flow many times as large.

An additional factor in the downstream movement of fresh water is the mixing effect of the twice daily ebbing and flooding of the tide. Ketchum (1951a, b) devised a method of calculating the time required for water to move from one part of a tidal estuary to another downstream location, taking into consideration the tidal mixing. In 1952 the author applied Ketchum's method to calculate the time of travel of a volume element of water from Trenton to several downstream locations. For example, at mean tidal range and a water discharge of 6,000 cfs at Trenton, N.J., calculations according to Ketchum's method show that 14.5 days are required for water to travel from Trenton to Marcus Hook. The water contributed by the Schuylkill River was included in these calculations. The "age" of fresh water at several locations, as calculated by Ketchum's method, is given in table 4. At a discharge of 3,000 cfs at Trenton, fresh water or a slug of pollution requires 6.6 days (17.6–11.0) at mean tidal range to travel from Benjamin Franklin Bridge to Marcus Hook. This flushing time is more rapid than that represented in table 3.

TABLE 4.—*"Age" of river water at mean tidal range*

[Calculated by the method of B. H. Ketchum]

Water discharge at Trenton, N.J. (cfs)	"Age" of river water, in days, from Trenton to station specified [1]		
	Burlington-Bristol Bridge	Benjamin Franklin Bridge	Marcus Hook
3,000	5.8	11.0	17.6
6,000	4.2	8.6	14.5
12,000	2.7	6.3	11.5

[1] When the tidal range is a foot greater than the mean range, the "age" of the water at Marcus Hook is 1-2 days less; when the tidal range is a foot less than the mean, the "age" is 1-4 days greater.

GRAPHIC SUMMARIES OF WATER-QUALITY FACTS

The conspicuous variations in water quality in the river from Bristol to Marcus Hook, over the period from 1950 to 1963, are presented graphically in this section. Generally, the water-quality characteristics are not plotted for all eight sampling locations, but only for enough of them so that the characteristics at the other locations may be estimated by interpolation.

Water-quality data are summarized on pages O36–O51, in tables which give an additional quantitative view of the variations in water quality. For example, the maximum, minimum, and mean values are given for several water-quality characteristics at each of the eight stations for the total period and for each month of the year. In addition, frequency distributions are given for several characteristics. Thus, the graphic and tabular presentation of the quality-of-water facts both complement and supplement each other.

WATER TEMPERATURE

The annual mean water temperatures varied from 55° to 62°F (fig. 4) in the reach, the mean temperature at Marcus Hook being about 2°F warmer than at Bristol. The maximum water temperature recorded in any year was 86°F, and the minimum temperature 33°F. The frequency with which various water temperatures occurred is plotted in figure 5. For example, the median temperature was between 57° and 60°F for the eight stations between Bristol and Marcus Hook; 10 percent of the samples had temperatures of 82°F or greater; and about one-third of the samples had temperatures exceeding 67°F. The distribution of water temperatures is shown for each month in figure 6. Water temperatures are coldest in January, February, and March and warmest in July and August. The

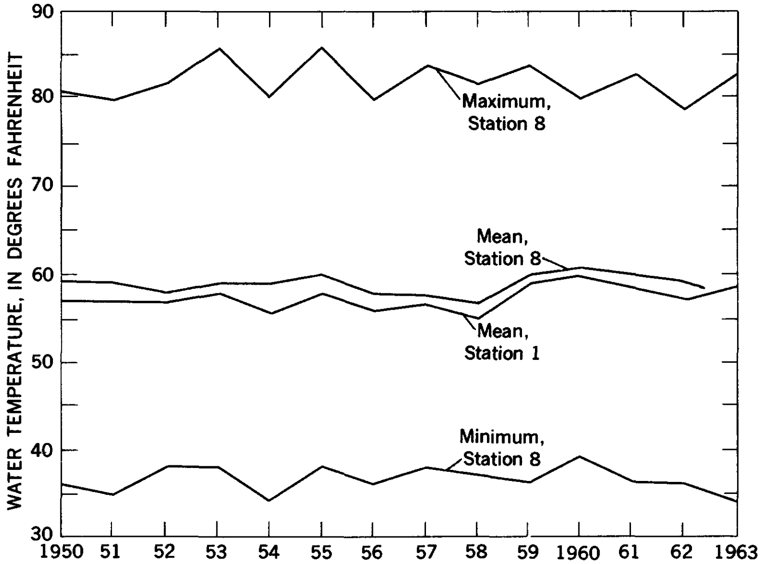

FIGURE 4.—Annual mean water temperatures, Delaware River at Bristol, Pa. (sta. 1) and Marcus Hook (sta. 8), and annual maximum and minimum temperature at Marcus Hook, 1950–63.

greatest variability or range in temperatures from year to year is in June, September, October, and November.

HYDROGEN-ION CONCENTRATION (pH)

Hydrogen-ion concentration is expressed in pH units. A water having a pH of 7.0 is termed "neutral"; pH values greater than 7.0 indicate alkalinity; and those less than 7.0, acidity. Water in the Delaware River between Bristol and Marcus Hook varies from slightly basic to slightly acidic. The pH decreases slightly as the water flows downstream (figs. 7 and 8). From Burlington-Bristol Bridge to Torresdale, the median pH is 6.9; from Lehigh Avenue to League Island, 6.6; and from Eddystone to Marcus Hook, 6.5. More than half of the pH values at all locations are within 0.2 pH units of these medians. There is no evidence of seasonal change in pH.

DISSOLVED-SOLIDS CONCENTRATION

Because most of the substances dissolved in the water of the Delaware River estuary are ionized salts, the water conducts electricity. The specific electrical conductance of the water, therefore, is a measure of the dissolved-solids concentration. As the analytical determi-

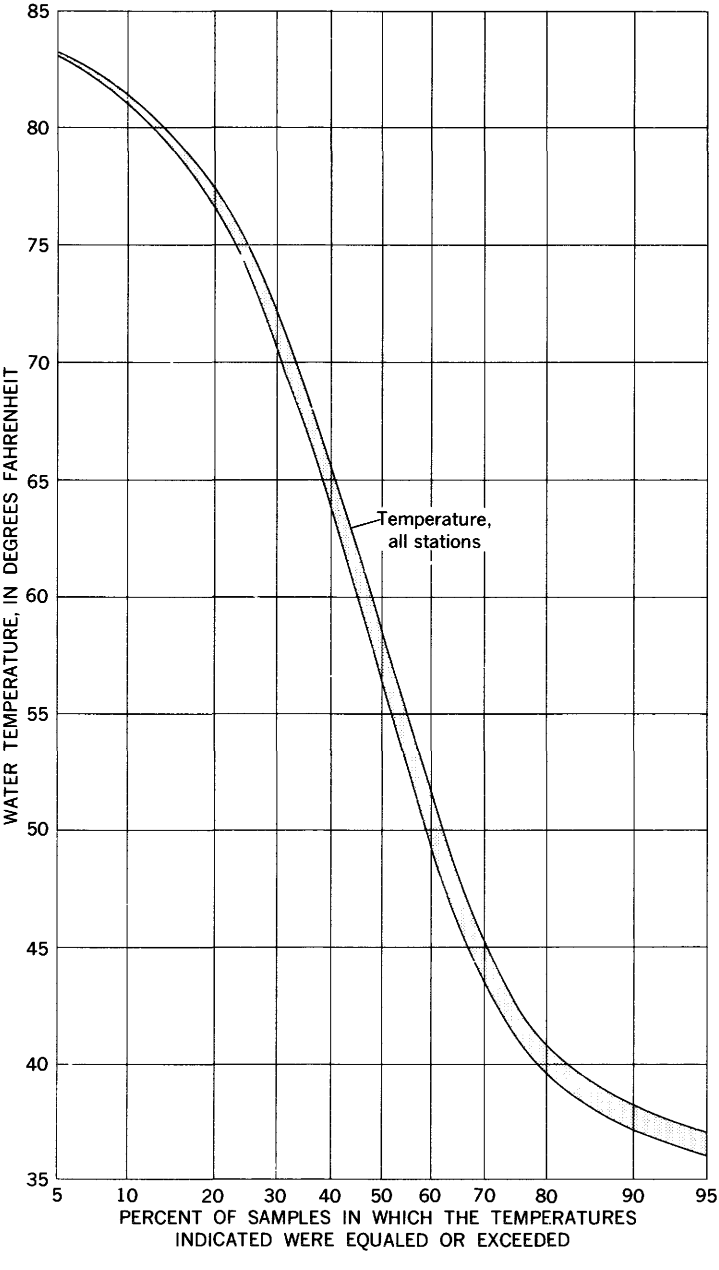

FIGURE 5.—Frequency of any given water temperature in Delaware River between Bristol and Marcus Hook, 1950–62.

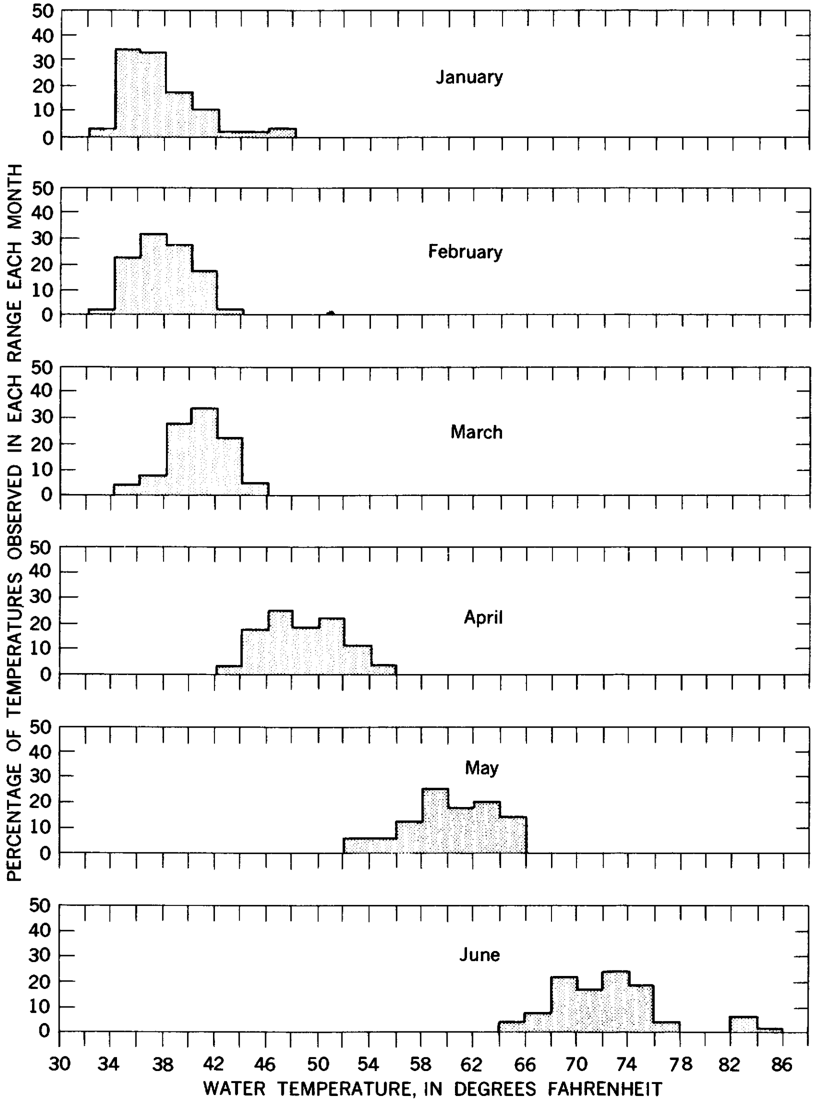

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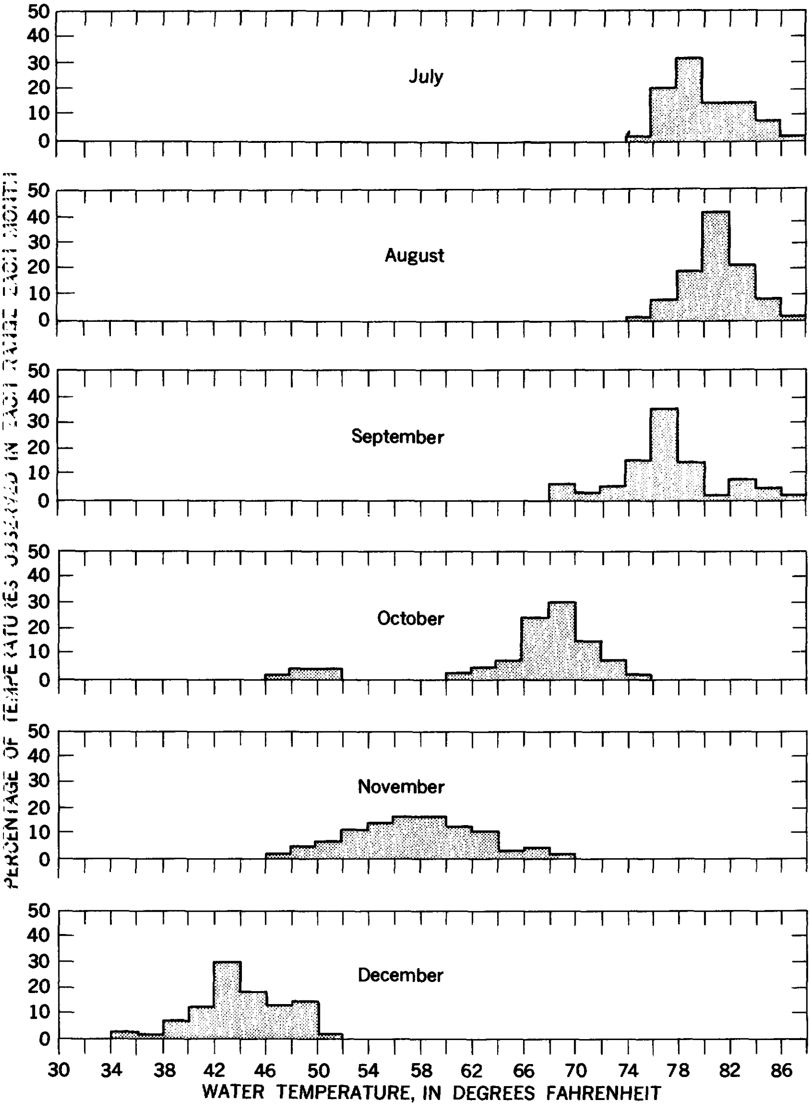
Figure 6.—Distribution of water temperatures each month



B

in Delaware River, Bristol to Marcus Hook, 1950–62.

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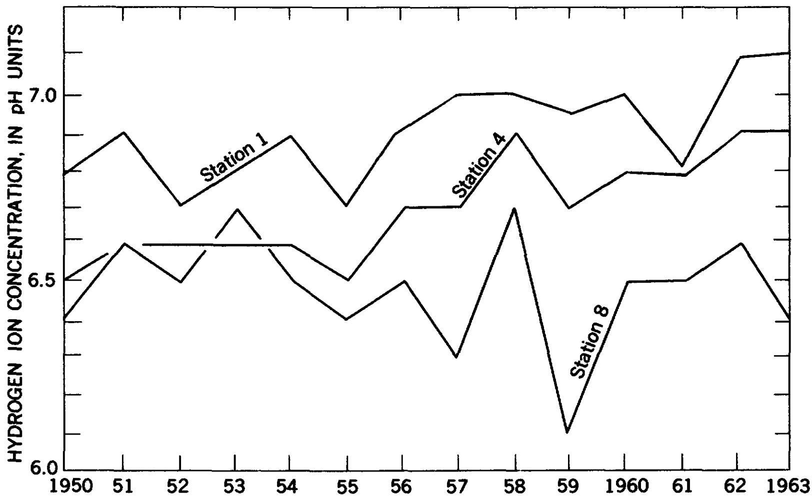

FIGURE 7.—Annual median pH values of water in Delaware River at Bristol (sta. 1), Benjamin Franklin Bridge (sta. 4), and Marcus Hook (sta. 8), 1950–63.

nation of dissolved solids is more expensive than the measurement of electrical conductivity, specific conductance is often available when the dissolved-solids concentrations are not. If specific conductance is the only data available, the dissolved-solids concentration may be estimated from it. Figures 9 and 10 are useful for making such estimates. In the range from 200 to 2,500 ppm dissolved solids, the concentration is directly proportional to the specific conductance. From 2,500 to 4,500 ppm the concentration can be estimated from the plotted X's.

The yearly variations in mean specific conductance are shown in figure 11, in which conductivity is plotted on a logarithmic scale. The annual mean conductivity at Bristol-Burlington Bridge varied from 135 to 186 micromhos (86–113 ppm dissolved solids), and at Marcus Hook from 228 to 2,330 micromhos (135–1,400 ppm dissolved solids). The maximum specific conductance for each year at six of the stations is plotted in figure 12. During the period 1950–63 the maximum specific conductance ranged from 167 to 266 micromhos at Bristol-Burlington Bridge (105–160 ppm dissolved solids) and from 370 to 6,120 micromhos (220–4,000 ppm dissolved solids) at Marcus Hook.

The frequencies of various concentrations of dissolved solids are plotted in figure 13. These concentrations have been estimated from the frequency of specific conductances.

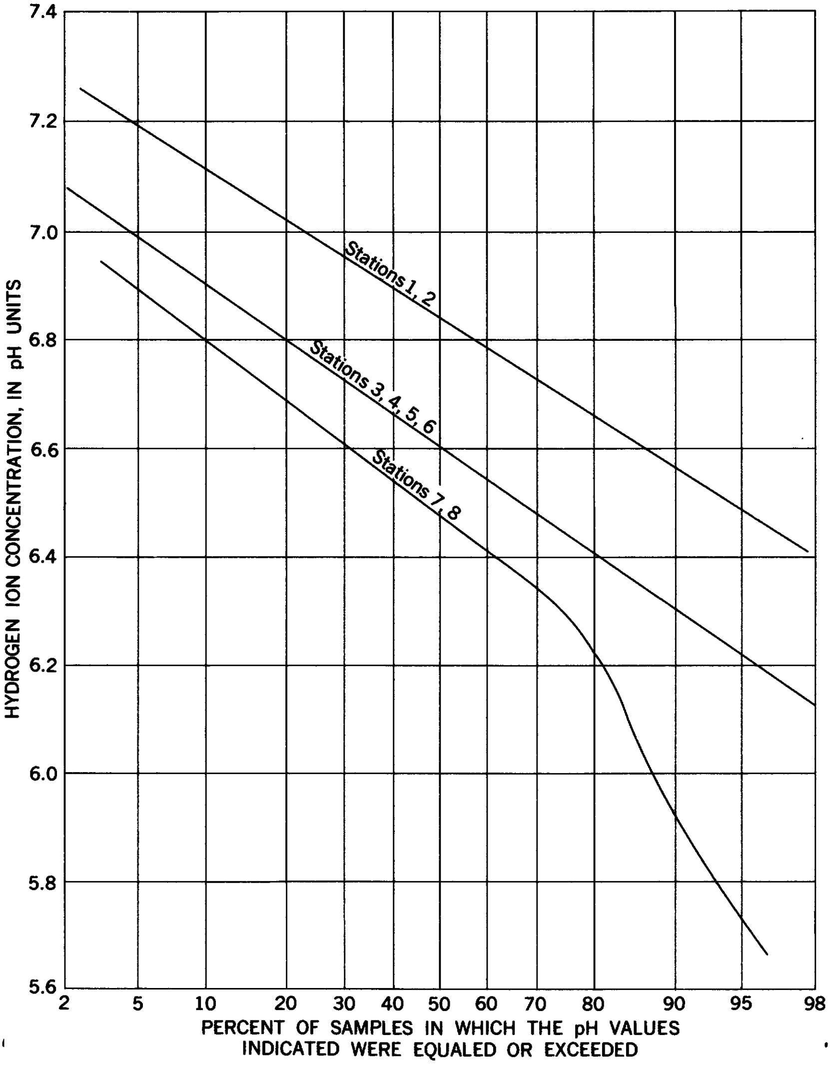

FIGURE 8.—Frequency of given pH values in Delaware River between Bristol and Marcus Hook, 1950–62. See figure 1 for location of stations.

In general, the greater the discharge of fresh water into the estuary, the lower is the specific conductance, and the lower the dissolved solids. If the fresh-water flow into the estuary at Trenton is less than 4,000 cfs for 30–60 days, the dissolved solids at Marcus Hook generally increases. When dissolved solids are high, an abrupt increase in streamflow, even for a few days duration, is likely to flush the salty water downstream. After an increase in fresh-water dis-

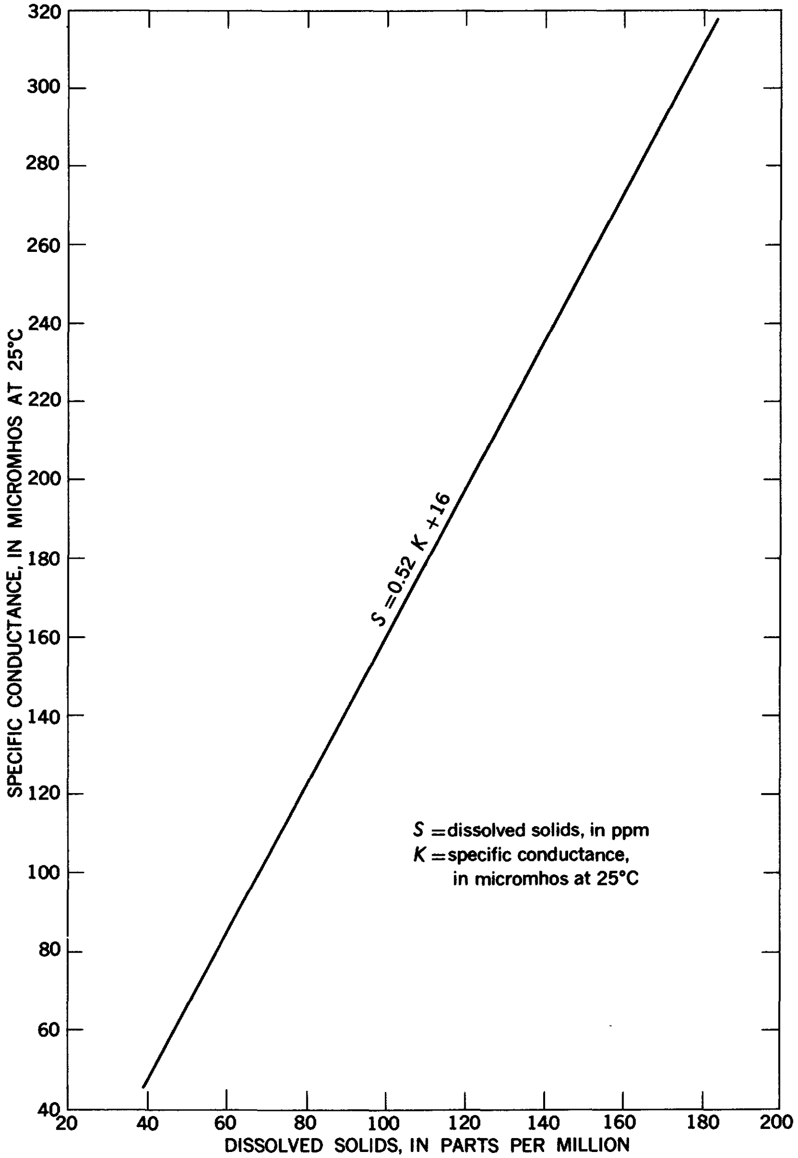

Figure 9.—Relation between electrical conductivity and dissolved solids (below 200 ppm) in Delaware River between Bristol and Marcus Hook, from Durfor and Keighton (1954).

charge, the salinity is reduced first in the upstream section of the river, then progressively downstream, if the increased fresh-water discharge persists. If the fresh-water flow decreases, the salinity increase first takes place far downstream below Marcus Hook and

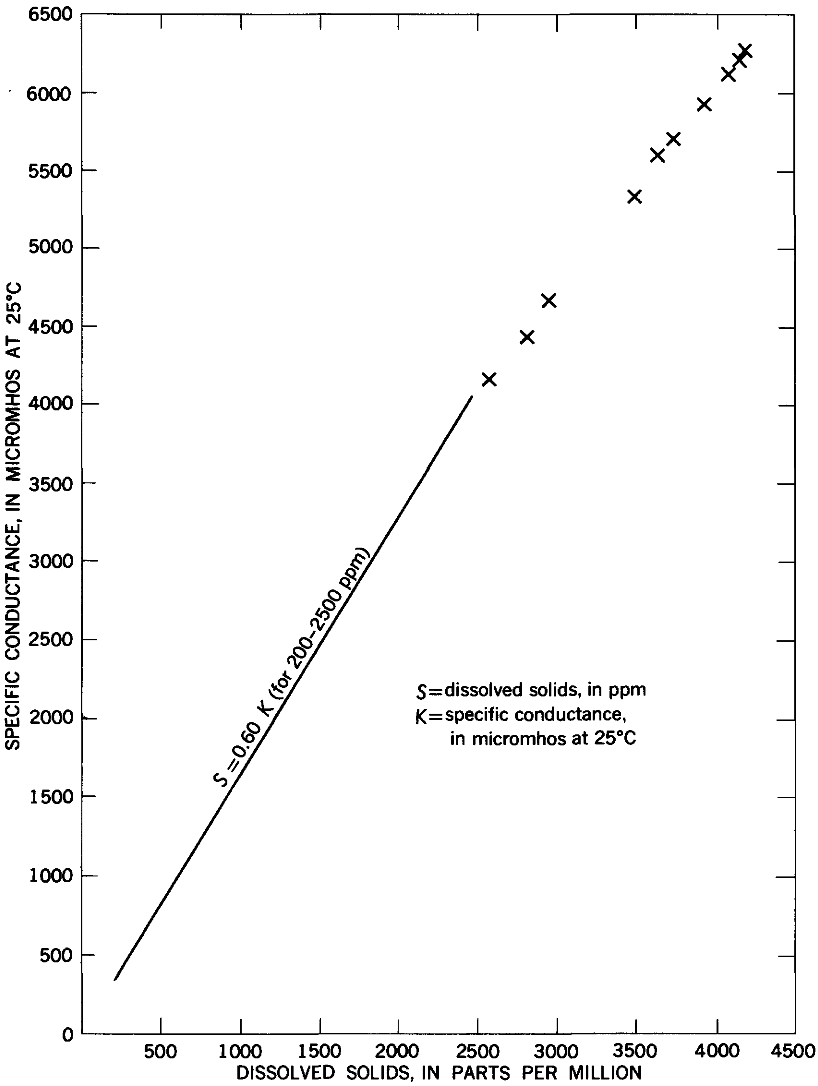

FIGURE 10.—Relation between electrical conductivity and dissolved solids (200–4,000 ppm) in Delaware River between Bristol and Marcus Hook, 1950–62.

then moves up river. Other factors, including wind direction and intensity, sea level, barometric pressure, and tidal range also affect the salinity of the water in the Delaware estuary; therefore, it is not possible to predict reliably the specific conductance of the water from the magnitude of the fresh-water discharge alone.

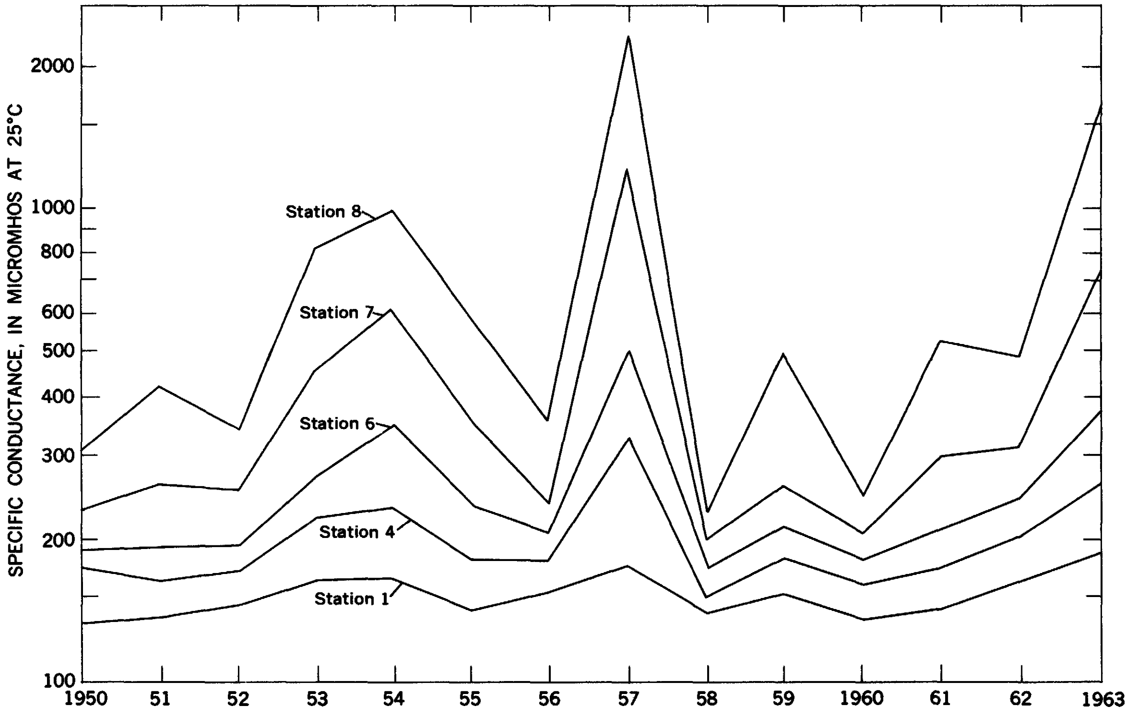

FIGURE 11.—Annual mean conductivities of water in Delaware River between Bristol and Marcus Hook, 1950–63. See figure 1 for location of stations 1, 4, 6, 7, and 8.

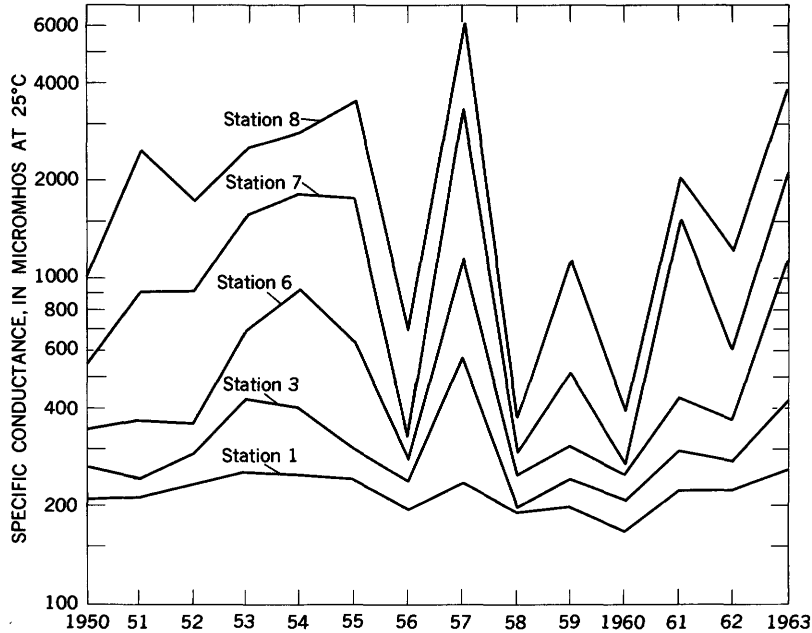

FIGURE 12.—Annual maximum conductivities of water in Delaware River between Bristol and Marcus Hook, 1950–63. See figure 1 for location of stations 1, 3, 6, 7, and 8.

The specific conductance decreases after a substantial increase in fresh-water discharge and increases after a sufficient reduction in fresh-water discharge. The gross effect of streamflow on salinity is evident in figure 14; in this figure the specific conductance at Marcus Hook and at Benjamin Franklin Bridge, and the fresh-water discharge at Trenton are plotted for each month of 1954. The mean monthly conductivity during 1949–63 for several locations is plotted in figure 15. Conductivity and dissolved solids are lowest in March, April, and May—months in which the fresh-water discharge is generally large—and highest in August to November.

COMPOSITION OF DISSOLVED SOLIDS

Composition of dissolved solids in the lower part of the estuary changes with concentration. Higher concentrations are generally the result of the sea water mixing with river water, and consequently, as the dissolved solids increase in concentration, the proportion of the several ions founds in the estuary water trends toward the proportion found in sea water. Thus, at higher concentrations sodium and chloride ions supplant the calcium bicarbonate and sulfate ions,

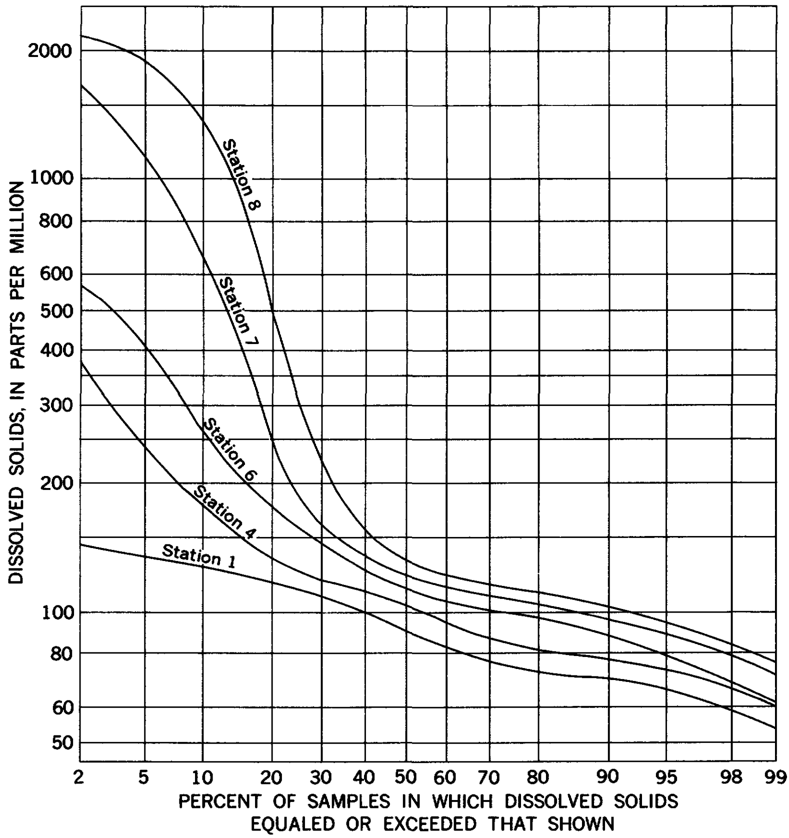

FIGURE 13.—Frequency of various dissolved-solids concentrations in Delaware River between Bristol and Marcus Hook, 1950–62. See figure 1 for location of stations 1, 4, 6, 7, and 8.

which predominate at lower concentrations. This phenomenon is illustrated in figure 16. Compared to the water entering the estuary at Trenton, water in the estuary has less bicarbonate and more chloride at all concentrations. Estuary water is compared with the fresh water at Trenton in figure 17, the comparison being based on the chemical equivalents of each ion. The water at Trenton is a calcium bicarbonate-type. In the estuary the proportion of bicarbonate decreases and sulfate increases so that, at low concentrations, the estuary water can be described as a calcium bicarbonate-sulfate type. At higher concentrations the estuary water becomes a sodium chloride water, similar to ocean water.

Because they are related to specific conductance, dissolved-solids concentrations are also related to streamflow. Dissolved solids are

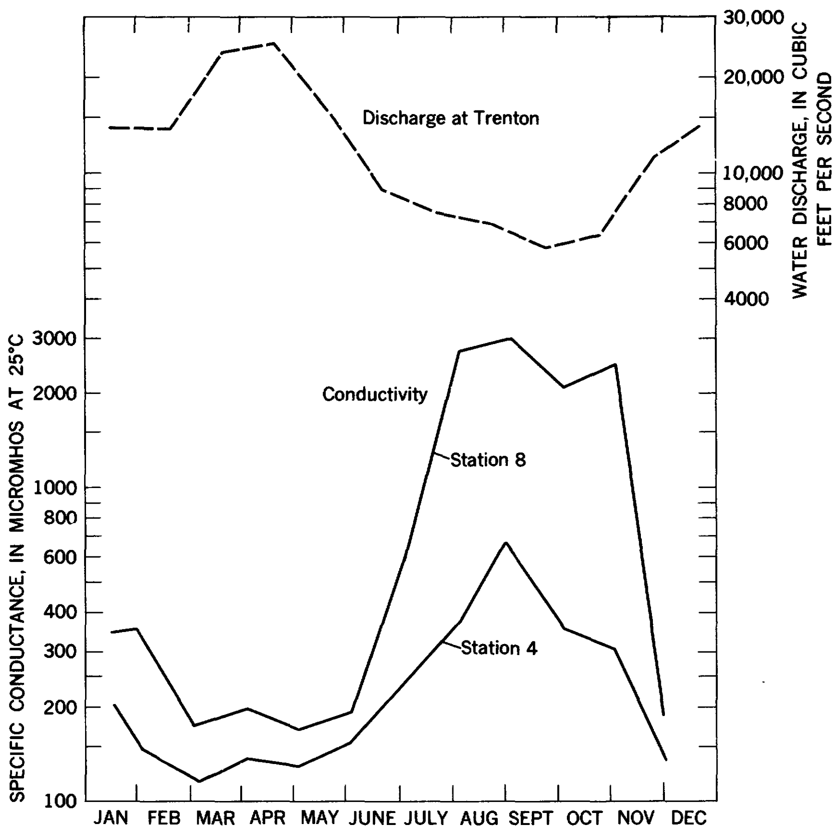

FIGURE 14.—Monthly mean conductivity of water in Delaware River at Benjamin Franklin Bridge (sta. 4) and Marcus Hook (sta. 8), and the mean monthly water discharge at Trenton, 1954.

brought into the estuary largely in the river water entering at the head of the tide at Trenton. In March, April, and May the river water at Trenton contains 50–90 ppm of dissolved solids most of the time, whereas the concentration at Marcus Hook during these months averages from 100 to 125 ppm. In August and September, when the dissolved-solids concentration at Trenton is generally 70–145 ppm, the concentration at Marcus Hook averages about 800 ppm; however, the greatest quantities of dissolved solids are carried by the river at Trenton in March and April, when the streamflow is high, and lesser quantities are transported in August and September, when the rate of flow into the estuary is generally much less.

The increase in dissolved-solids concentration between Trenton and Marcus Hook is due in small part to added industrial and municipal

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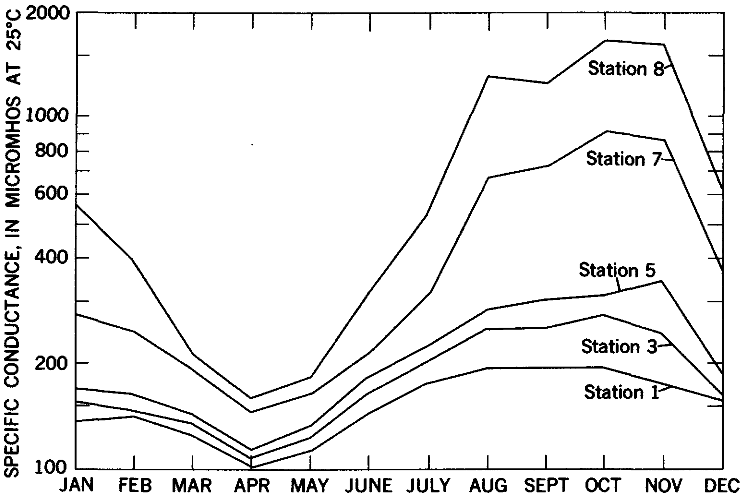

FIGURE 15.—Mean monthly conductivity of water in Delaware River between Bristol and Marcus Hook, 1949–63. See figure 1 for location of stations 1, 3, 5, 7, and 8.

wastes, but mostly to sea water brought upstream by tidal action. That a relation exists may be shown by comparing the composition of the dissolved solids in the water at Marcus Hook with that of the dissolved solids at Trenton and in ocean water. In table 5 the composition of the dissolved solids in river water at Trenton and in estuary water at Marcus Hook are compared to ocean water in terms of the ratios, by weight, of chloride to sulfate, chloride to magne-

TABLE 5.—*Comparison of ratios of dissolved solids in Delaware River at Trenton and Marcus Hook with ratios of dissolved solids in ocean water*

	Date	Discharge at Trenton (cfs)	Dissolved-solids concentration (ppm)		Ratio (by weight)			
			Trenton	Marcus Hook	Solids	Trenton	Marcus Hook	Ocean water
a	Oct. 8, 1957	1,740	121	3,840	$Cl:SO_4$	0.4	4.7	7.2
					Cl:Mg	1.5	16.3	14.8
					Mg:Ca	.3	1.7	3.1
b	Aug. 2, 1955	1,970	132	2,180	$Cl:SO_4$	.4	4.0	7.2
					Cl:Mg	1.9	15.3	14.8
					Mg:Ca	.4	1.6	3.1
c	Apr. 3, 1958	33,000	56	142	$Cl:SO_4$	.1	.1	7.2
					Cl:Mg	1.1	1.3	14.8
					Mg:Ca	.2	.2	3.1
d	May 4, 1953	27,900	72	91	$Cl:SO_4$	.3	.2	7.2
					Cl:Mg	1.6	1.8	14.8
					Mg:Ca	.3	.3	3.1

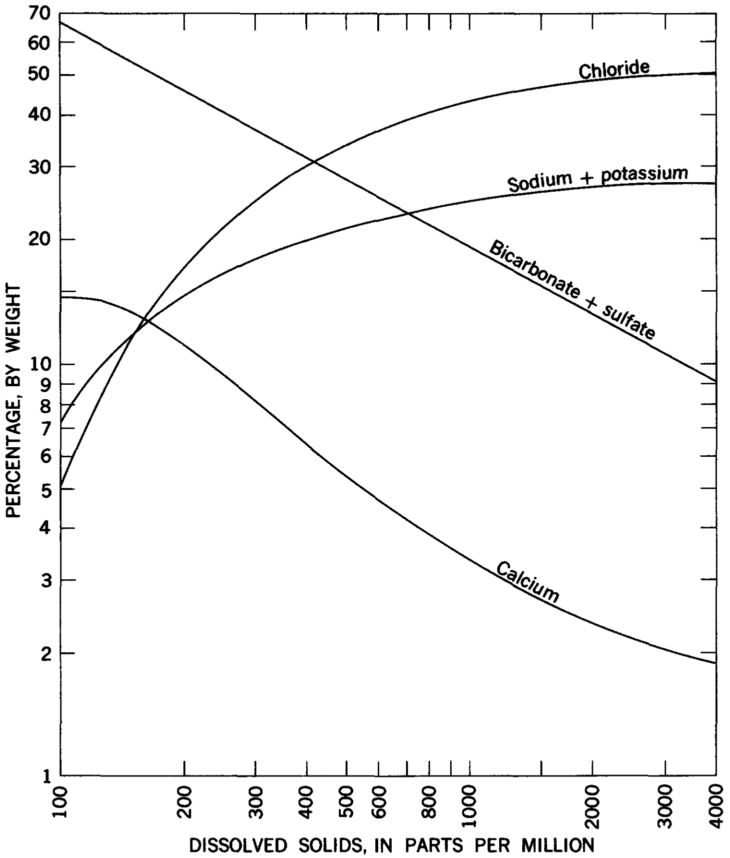

FIGURE 16.—Relation between concentration and composition of dissolved solids in Delaware River water between Bristol and Marcus Hook, 1950–62.

sium, and magnesium to calcium. At low flow the ratios at Marcus Hook (table 5), items a and b are much more like those for ocean water than for fresh water (Trenton), and this similarity indicates that the increase in salinity between Trenton and Marcus Hook is largely due to the admixture of ocean water with the fresh river water.

At high fresh-water discharge rates, there is less mixing with sea water in this lower reach of the river, because of the flushing effect of the fresh water. This fact is evident from items c and d in table 5. Thus, at high flows the dissolved solids at Marcus Hook have nearly the same composition as those in the fresh water at Trenton. At low flows the composition of the dissolved solids in Delaware River water approaches that of the dissolved solids in ocean water.

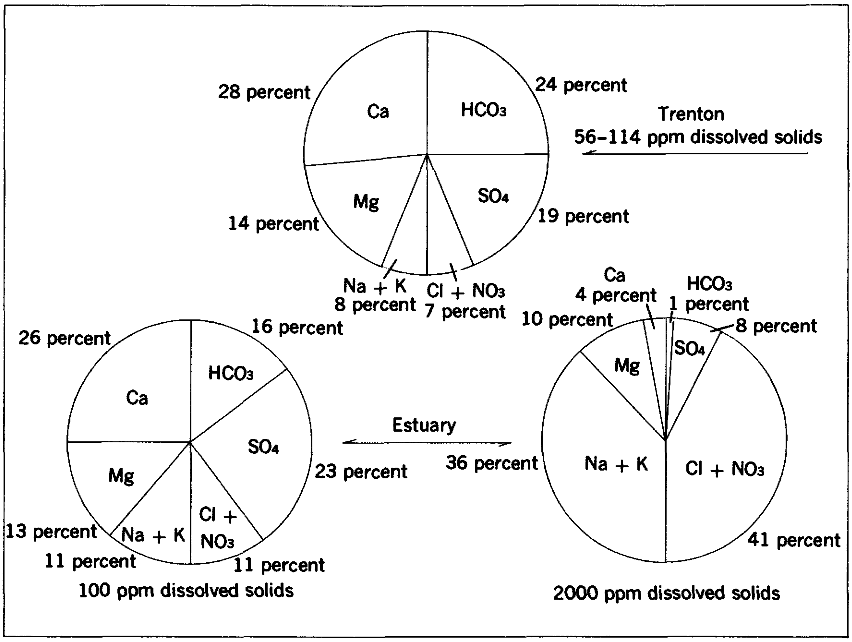

FIGURE 17.—Typical composition of dissolved solids in the Delaware River and estuary, by percentage of chemical equivalents.

CHLORIDE

The annual mean chloride concentration at Marcus Hook varied from 19 to 663 ppm, and at Burlington-Bristol Bridge from 5.1 to 9.0 ppm (fig. 18). The highest chloride concentrations in the river below Philadelphia were experienced in 1953, 1954, 1957, and 1963. Salinity incursions may also be described in terms of the maximum salinity each year (fig. 19) or, with more significance for the user of water, in terms of the number of days each year during which a given salinity is reached or exceeded at some point in the river. Table 6 shows the number of days each year when the average chloride concentration exceeded 400 ppm at Marcus Hook, and the daily maximum chloride concentration exceeded 50 ppm at Bridesburg, Pa., and 400 ppm at Chester, Pa. Again the years of greatest salt-water incursion were 1949, 1953, 1954, 1957, and 1963. In each of these 5 years (except in 1953), the annual flow was below the average; however, the annual flow was below average in 1950, 1955, 1959, 1961, and 1962 also, but the chloride concentration was not unusually high in these years. The monthly discharge of fresh water at Trenton was below average in each of the months from June to October in 1949, 1953, 1954, 1957, and 1963, and also in 1962.

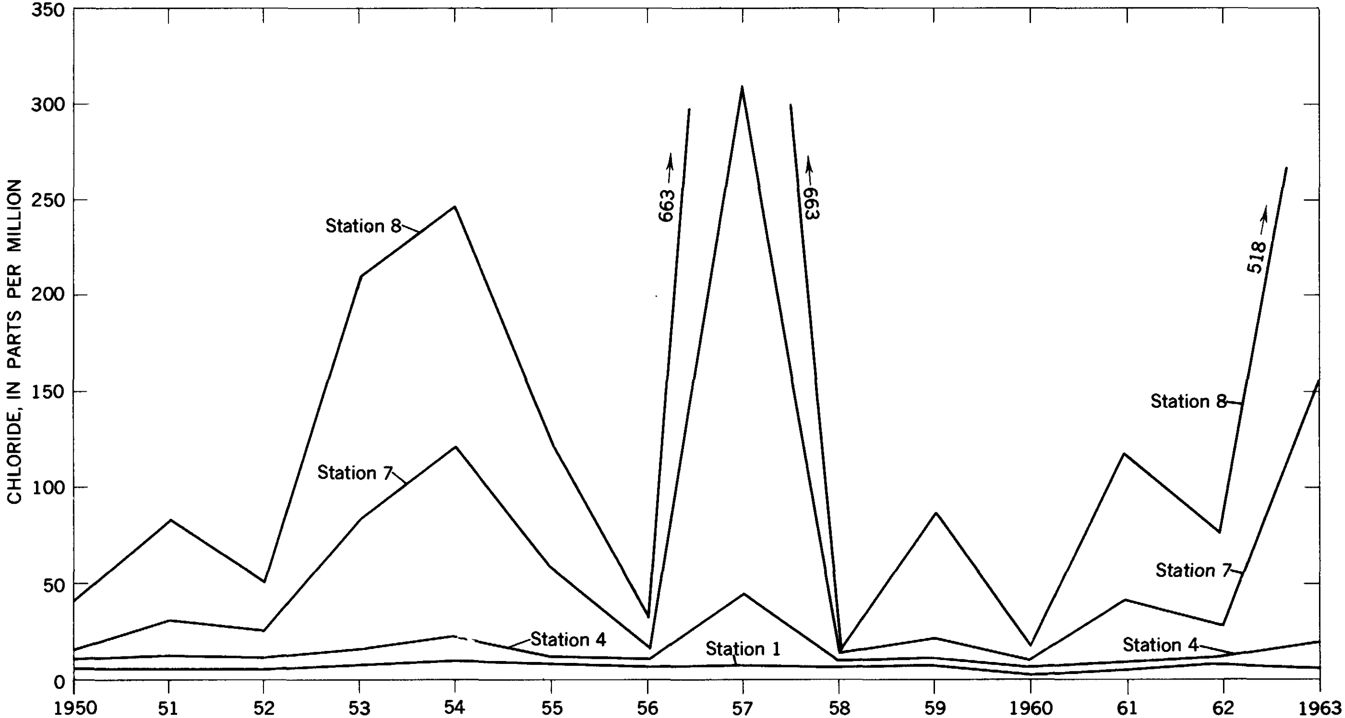

Figure 18.—Annual mean chloride concentrations in Delaware River between Bristol and Marcus Hook, 1950–63. See figure 1 for location of stations 1, 4, 7, and 8.

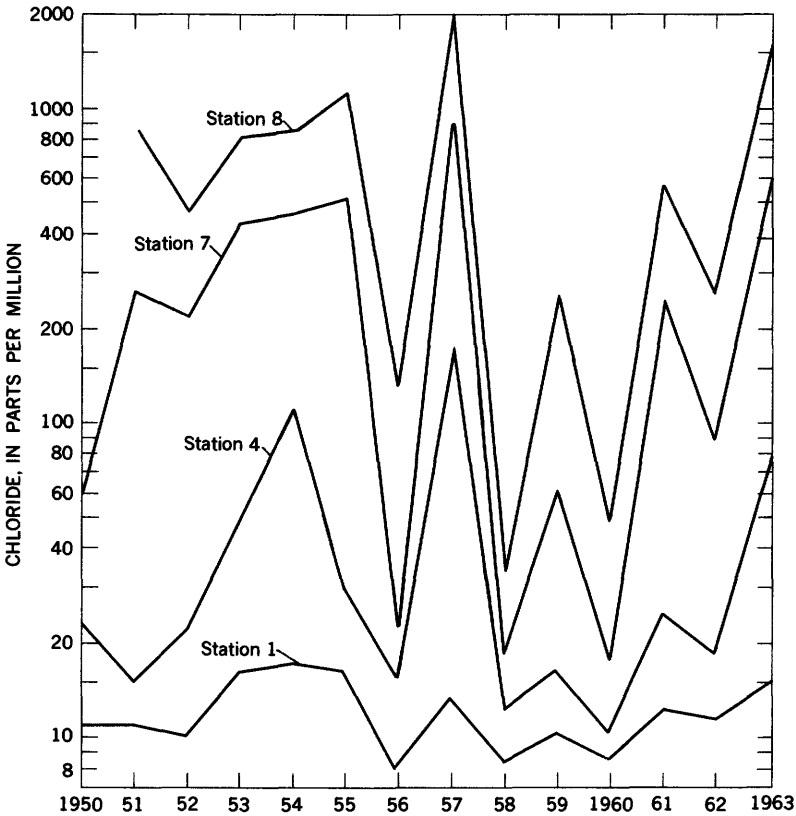

FIGURE 19.—Annual maximum chloride concentrations in Delaware River between Bristol and Marcus Hook, 1950–63. See figure 1 for location of stations 1, 4, 7, and 8.

The frequency with which various chloride concentrations in the estuary occurred during 1950–63 is shown in figures 20 and 21. For example, a chloride concentration of 10 ppm or greater occurred 15 percent of the time at Burlington-Bristol Bridge, 45 percent of the time at Benjamin Franklin Bridge, 56 percent of the time at Eddystone, and 74 percent of the time at Marcus Hook. A chloride concentration of 100 ppm or greater was observed at Benjamin Franklin Bridge only 2 percent of the time, at Eddystone 9 percent of the time, and at Marcus Hook 24 percent of the time.

The mean monthly chloride concentrations during 1950–62 are plotted in figure 22. As with dissolved solids and conductivity (fig. 15), the chloride concentrations are least in December to May and greatest in August to November.

TABLE 6.—*Number of days each year in which selected chloride concentrations were exceeded for a salt-water invasion, Delaware River at Bridesburg, Chester, and Marcus Hook, Pa., and average June to October discharge at Trenton, N.J., for each year.*

[Chloride data furnished by Rohm and Haas Co. for Bridesburg; Scott Paper Co. for Chester; Sun Oil Co. for Marcus Hook]

Year	Days daily maximum chloride concentration exceeded—		Days daily average chloride concentration exceeded—	Average daily discharge at Trenton, N.J., June to October (cfs)
	50 ppm	400 ppm	400 ppm	
	Bridesburg, Philadelphia, Pa.[1]	Chester, Pa.[1]	Marcus Hook, Pa.[2]	
1949	----------	111	120	3,522
1950	0	9	17	6,382
1951	0	6	22	6,621
1952	0	11	17	9,103
1953	9	----------	98	3,709
1954	32	119	128	2,996
1955	0	29	36	14,781
1956	0	0	0	6,680
1957	86	132	144	2,771
1958	0	0	0	5,369
1959	0	0	0	4,954
1960	0	0	0	10,277
1961	0	21	35	4,990
1962	0	13	31	3,210
1963	16	122	141	3,009

[1] Bridesburg and Chester data are based on samples collected at high tides.
[2] Marcus Hook data represent the analyses of daily composites of hourly samples (compiled by Frederick Schaefer for report of the River Master for the year ending Nov. 30, 1963).

DISSOLVED OXYGEN

The annual mean dissolved-oxygen concentrations at five locations in the Delaware estuary are plotted in figure 23. Dissolved oxygen decreases from Bristol to Marcus Hook, the sharpest decrease occurring between Torresdale and Lehigh Avenue. Minimum dissolved-oxygen concentrations are plotted in figure 24. The very low minima in 1950–53 have not been repeated in later years. In general, the lowest concentrations are found near Wharton Street, and a slight recovery is made between there and Marcus Hook. Figure 25 is a frequency plot of dissolved oxygen in percent saturation. Five percent of the samples at Marcus Hook, 15 percent of those at Benjamin Franklin Bridge, 62 percent of those at Torresdale, and 76 percent of those at Bristol were at least 75 percent saturated. All these samples were taken in the daytime, and the average daily dissolved-oxygen concentrations very possibly were lower than those represented by the figures tabulated and plotted. For example, upstream at Trenton the dissolved-oxygen concentration varies diurnally as a

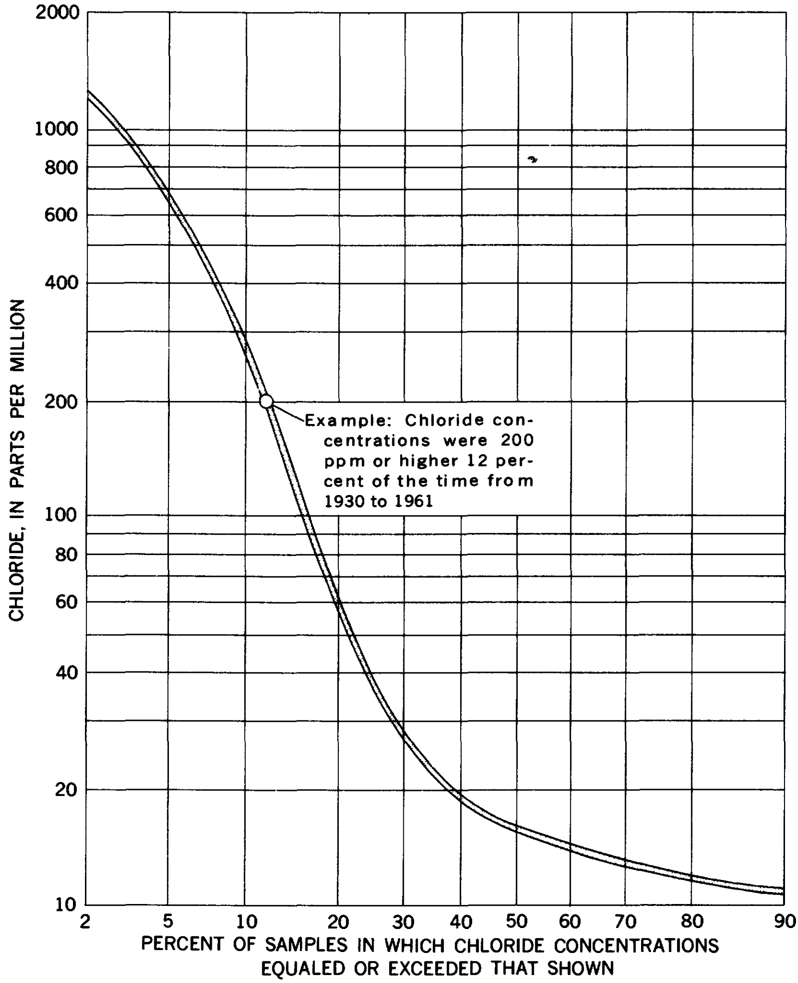

FIGURE 20.—Frequency of various chloride concentrations in Delaware River at Chester, Pa., 1930–61.

result of photosynthesis. The minimum daily dissolved oxygen, about 6–8 ppm, occurs between 5:00 and 6:00 a.m. in the morning. During daylight hours the dissolved-oxygen concentration increases to as high as 14 ppm.

In recent years, dissolved oxygen in the estuary has been measured by instruments that record continuously so that daily average concentrations could be obtained. Table 7 shows the frequency with which low values of dissolved oxygen have been experienced at three dissolved-oxygen recorders on the estuary.

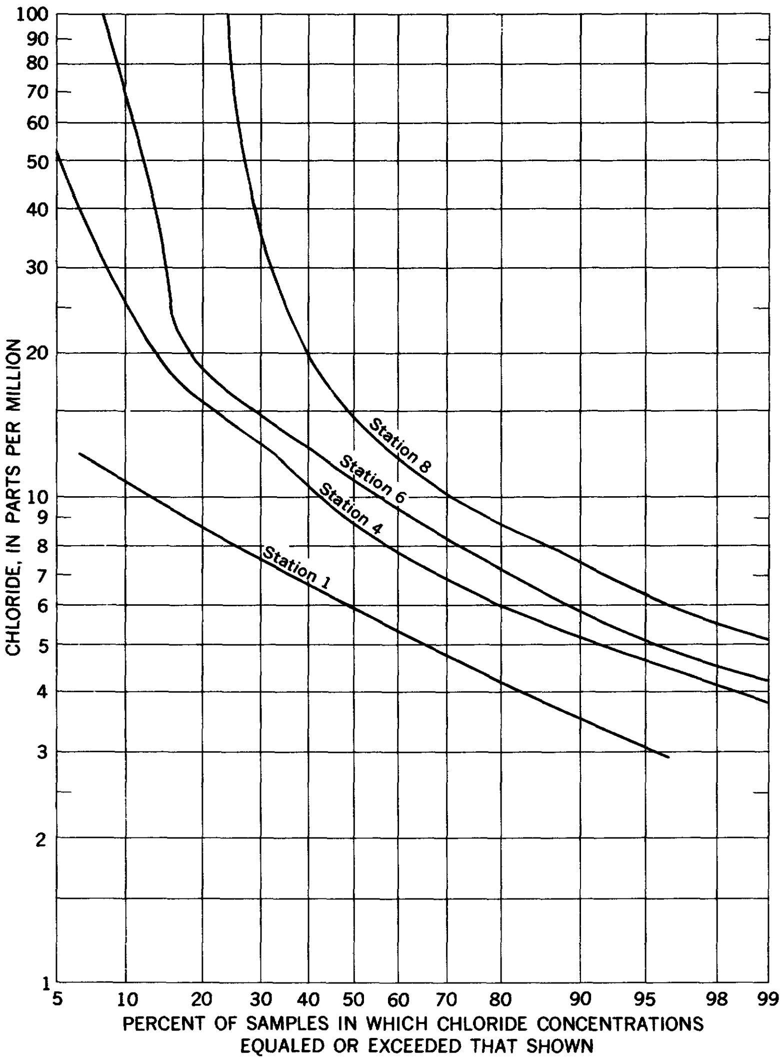

FIGURE 21.—Frequency of various chloride concentrations in Delaware River, 1950–62. See figure 1 for location of stations 1, 4, 6, and 8.

Figure 26 shows the monthly variation in dissolved-oxygen concentration during 1950–63. The concentration is lowest in those months when the water temperature is highest, because less oxygen dissolves in warm water than in cold water and because the biochemical reactions that consume oxygen occur at accelerated rates at higher temperatures.

TABLE 7.—*Number of days dissolved-oxygen concentration was less than 1 and 3 ppm at three dissolved-oxygen recorders in the Delaware River, March 1961–December 1963*

	Number of days					
	Concentration<1 ppm			Concentration<3 ppm		
	Torresdale	Benjamin Franklin Bridge	Chester	Torresdale	Benjamin Franklin Bridge	Chester
1961						
March	0	0	----------	0	0	----------
April	0	0	----------	0	0	----------
May	0	0	----------	0	9	----------
June	0	26	----------	5	30	----------
July	0	31	----------	22	31	----------
August	0	31	----------	17	31	----------
September	0	30	----------	7	30	----------
October	0	31	----------	0	31	----------
November	0	23	----------	0	27	----------
December	0	0	----------	0	0	----------
1962						
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	0	0	1	2
May	0	26	29	2	31	31
June	14	30	27	30	30	30
July	10	31	31	26	31	31
August	9	31	31	31	31	31
September	0	30	30	24	30	30
October	0	29	26	0	31	31
November	0	2	7	0	5	13
December	0	0	0	0	0	0
1963						
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	0	0	6	7
May	0	21	26	0	31	30
June	2	30	29	21	30	30
July	----------	31	31	25	31	31
August	0	31	31	14	31	31
September	0	30	30	9	30	30
October	0	31	31	3	31	31
November	0	26	23	0	30	30
December	0	0	3	0	8	14

Additional information on dissolved-oxygen concentrations is shown in figure 27. The average dissolved-oxygen concentration and the range of concentrations is plotted for stations (a) upstream from central Philadelphia, (b) near central Philadelphia, and (c) downstream from central Philadelphia, for four periods of the year. The data show that the concentration of dissolved oxygen is lowest in June to September and highest in December to March, that it decreases as the water flows downstream past Philadelphia, and that it decreases still further in December to May as the water flows on to Marcus Hook.

SUSPENDED SEDIMENT

The yearly changes in suspended-sediment concentration are shown in figure 28. The determinations shown in this figure are the ratio

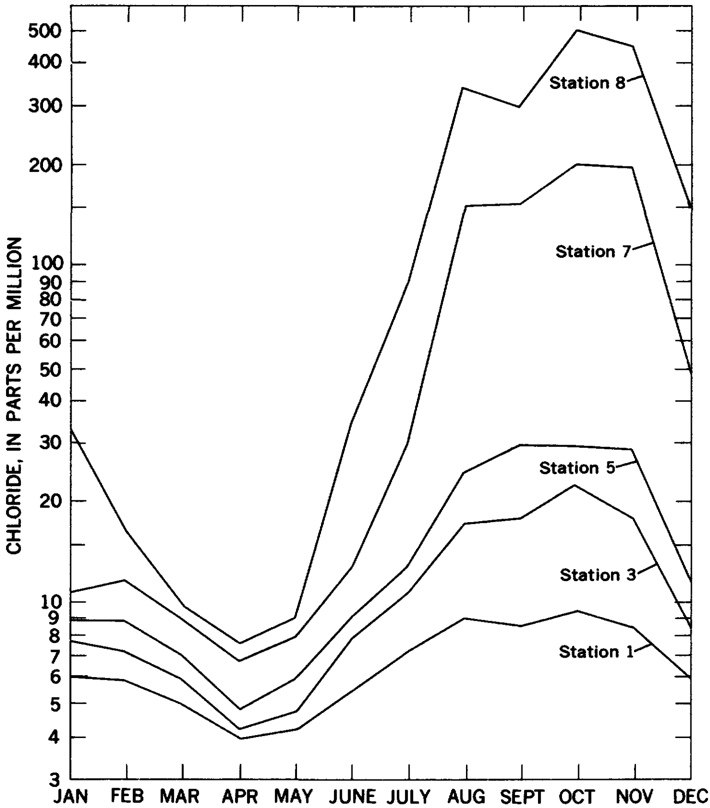

FIGURE 22.—Mean monthly chloride concentrations in Delaware River, 1950–62. See figure 1 for location of stations 1, 3, 5, 7, and 8.

of dry weight of sediment to the total weight of the water-sediment sample as measured on composite samples at each station. Although the sediments are composite, the determinations are adequate to show gross changes in suspended-sediment concentration; however, they should not be used to calculate the load of sediment transported, for no consideration has been given to the differences in rates of flow in different parts of the cross sections.

Until 1957 the sediment concentration increased from Bristol downstream to Marcus Hook. The change in this situation after 1959 is probably related to channel-dredging activities in the river upstream from the Benjamin Franklin Bridge. At times the increase in sediment was evident in the muddy appearance of the river

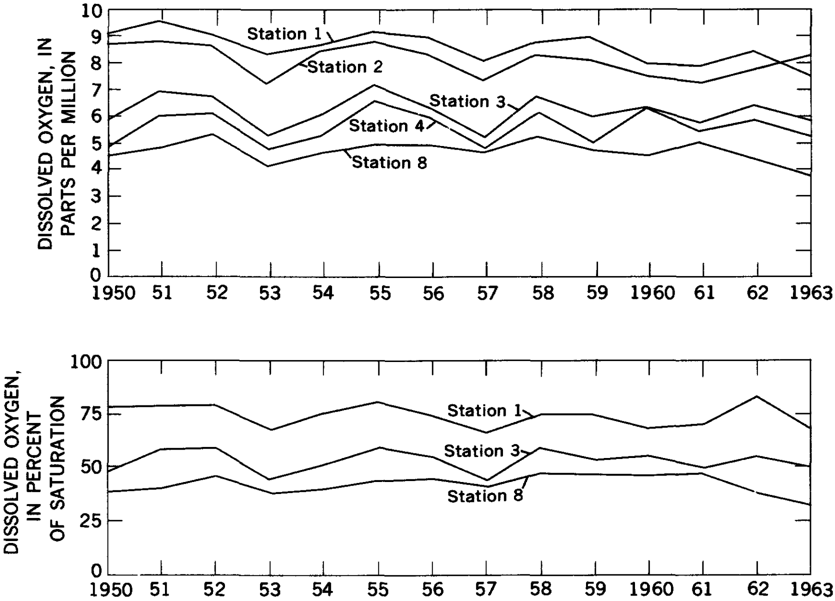

FIGURE 23.—Annual mean dissolved-oxygen concentrations in Delaware River, 1950–63. See figure 1 for location of stations 1, 2, 3, 4, and 8.

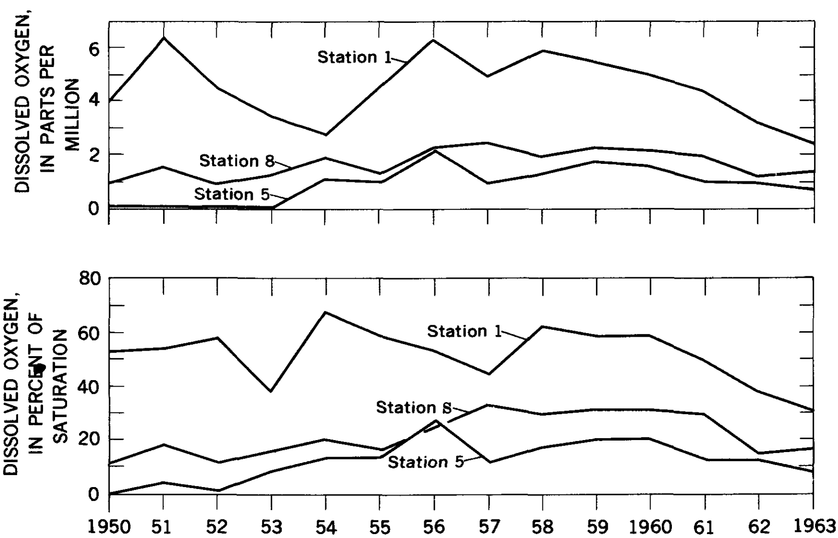

FIGURE 24.—Annual minimum dissolved-oxygen concentrations in Delaware River, 1950–63. See figure 1 for location of stations 1, 5, and 8.

at Philadelphia. Monthly sediment concentrations shown in figure 29 are based on data from August 1949 to December 1959. Higher concentrations generally occur in the months of higher streamflow, when the water is more turbulent than in the low-flow months.

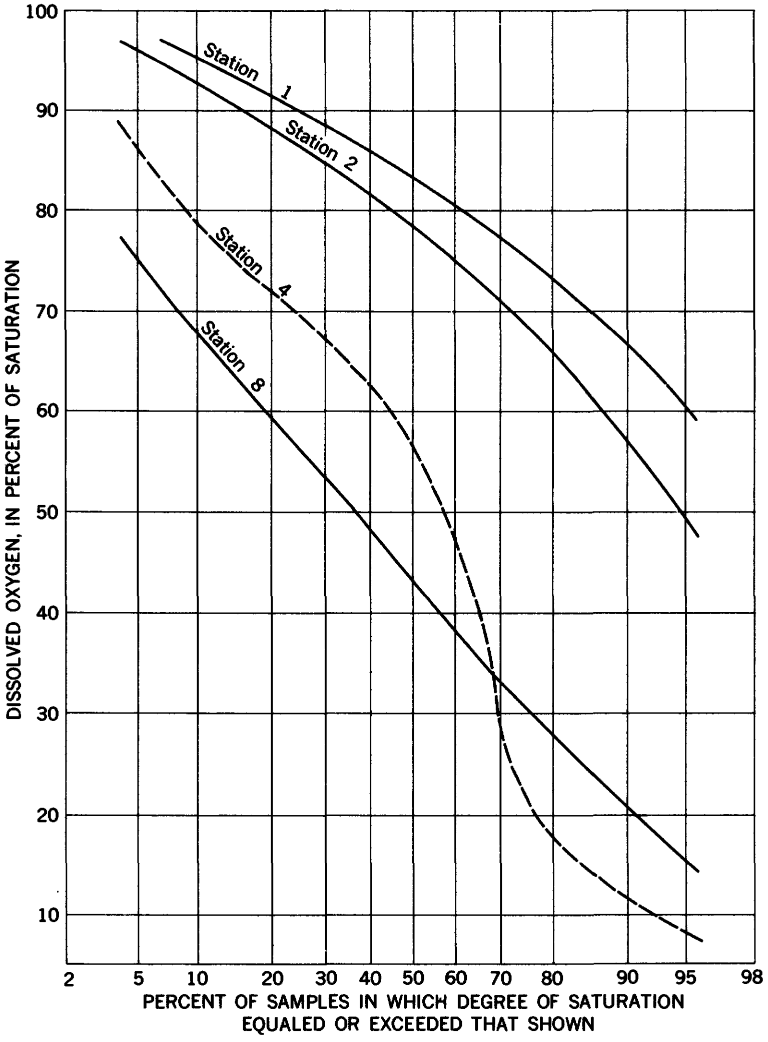

FIGURE 25.—Frequency of given dissolved-oxygen concentrations in Delaware River, 1950–63, in percent saturation. See figure 1 for location of stations 1, 2, 4, and 8.

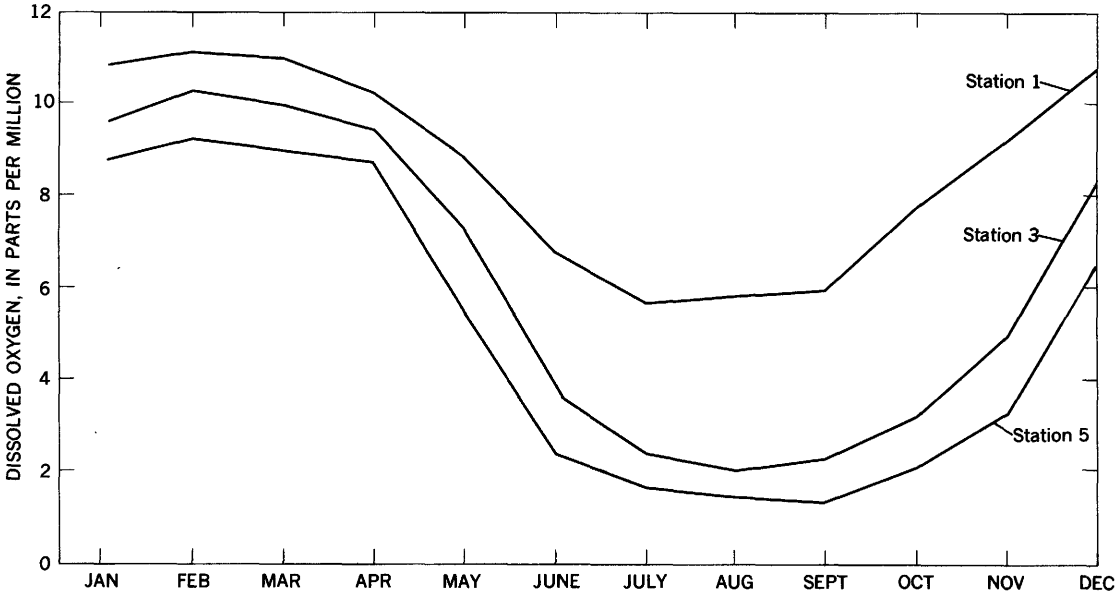

FIGURE 26.—Mean monthly dissolved-oxygen concentrations in Delaware River, 1950–62. See figure 1 for location of stations 1, 3, and 5.

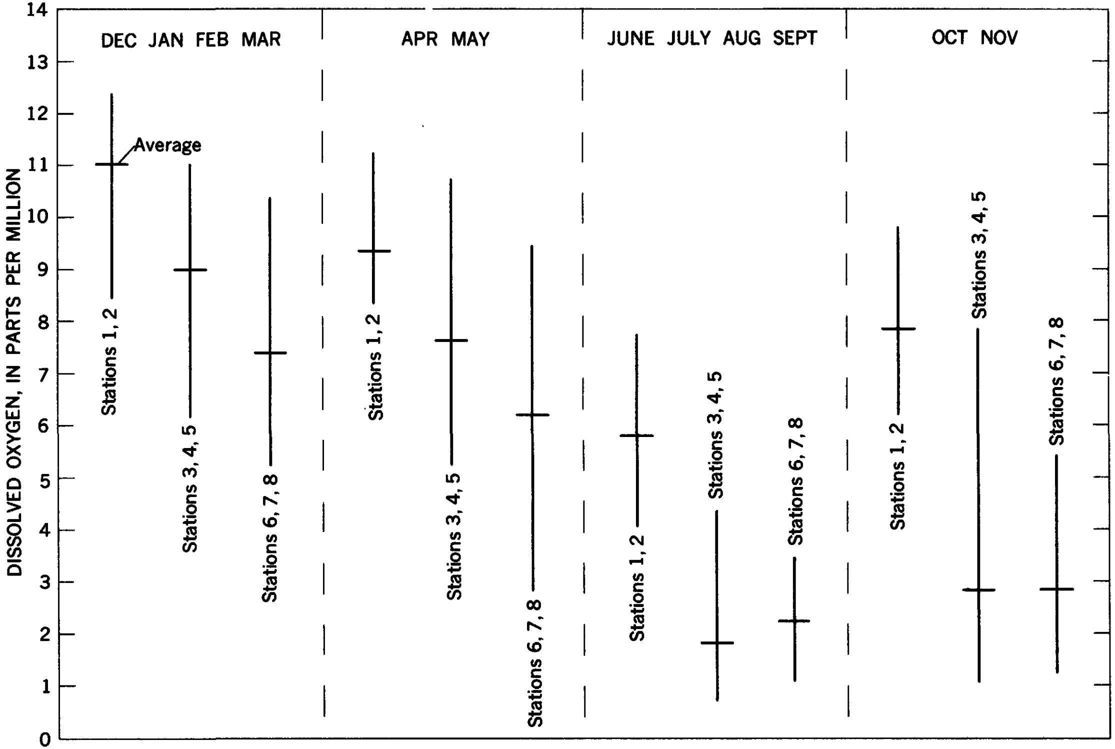

Figure 27.—Average dissolved-oxygen concentration and range of central 80 percent of concentrations at selected groups of stations in each of four periods of the year, 1950–63. See figure 1 for location of stations.

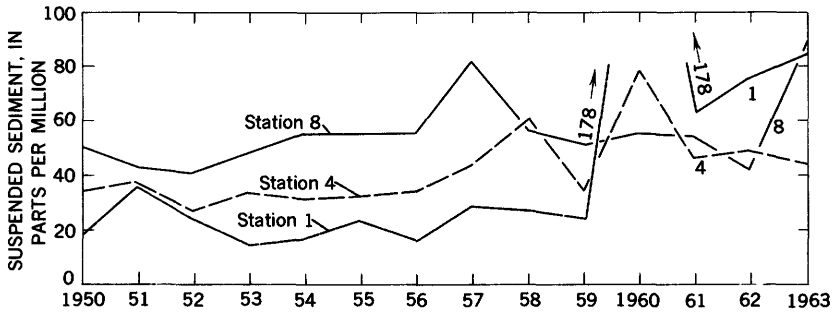

FIGURE 28.—Annual mean suspended-sediment concentrations in Delaware River, 1950–63. See figure 1 for location of stations 1, 4, and 8.

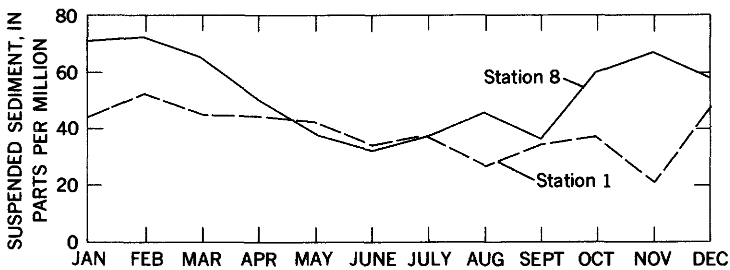

FIGURE 29.—Mean monthly suspended-sediment concentrations in Delaware River at Bristol and Marcus Hook, 1950–62. See figure 1 for location of stations 1 and 8.

TABULAR SUMMARIES OF WATER-QUALITY CHARACTERISTICS

The monthly analyses of the 14-year period are summarized in tables 9, 10, and 11. Each table contains eight divisions, one for each of the eight sampling locations; these divisions are identified by title and by the number used to identify the sampling location in figure 1 and in table 1. For example, table 9 (3) gives a summary for station 3, Lehigh Avenue, Philadelphia.

Table 8 gives physical descriptions of each of the eight sampling stations. The locations are given in distances upstream or downstream from Allegheny Avenue, Philadelphia, Pa., measured along the centerline of the navigation channel in units of 1,000 feet. Locations upstream from Allegheny Avenue are labeled (−), and those downstream (+). Thus, the Bristol-Burlington Bridge station is 79,200 feet upstream from Allegheny Avenue. Details of each sampling location are given in the maps referred to in table 8. These maps can be obtained from the Corps of Engineers, Philadelphia

District, and from the U.S. Coast and Geodetic Survey. Included in the physical description is the "Accumulated volume" for each station, that is, the quantity of water to fill the river at midtide level, from head of tide to the sampling station.

Table 9 is a frequency distribution for selected percentile groups of pH, specific conductance, chloride, water temperature, and dissolved oxygen for each of the eight sampling stations. For example, table 9 (1) shows that at Bristol-Burlington Bridge cross section the pH ranged from 6.2 to 7.8 and that the median pH was 6.9 (that is, that the pH was less than 6.9 as frequently as it was greater).

Table 10 gives the annual maximum, mean, and minimum measurements of specific conductance, chloride, suspended sediment, water temperature, and dissolved oxygen; and for pH, the annual maximum, median, and minimum. Monthly maximum, mean (median for pH), and minimum measurements for the same characteristics are listed in table 11.

TABLE 8.—*Physical description of sampling locations*

1. Bristol (Pa.)-Burlington (N.J.) Bridge station

LOCATION: In Devlin navigation range 1,300 ft upstream from bridge on a line from Pennsylvania bank (right) through channel station −79.2 to Lehigh range light on New Jersey bank (left), approximately 15 miles downstream from head of tide at Trenton, N.J.

SAMPLING POINTS:

Right side: 200 ft from Pennsylvania bank on line with No. 2 suspender which is to the right of right tower of bridge.

Right center: 475 ft from Pennsylvania bank on line with right tower and buoy C–43.

Center: 825 ft from Pennsylvania bank on line 40 ft left of centerline of bridge.

Left center: 1,050 ft from Pennsylvania bank on line with left tower of bridge.

Left side: 1,275 ft from Pennsylvania bank (25 ft from New Jersey and Lehigh range light).

DRAINAGE AREA: 7,160 sq mi.

ACCUMULATED VOLUME: 1,635 million cu ft, below the head of tide at Trenton, N.J.

REFERENCE MAPS:

Corps of Engineers, Delaware River, Burlington to Bristol, file No. 25006.

U.S. Coast and Geodetic Survey, Delaware River, Philadelphia, Pa., to Trenton, N.J., No. 296.

2. Torresdale, Philadelphia, station

LOCATION: On a line from brick building on bulkhead line at filter plant through channel station —37.0 to New Jersey bank. (Brick building is the site of an inactive water intake for filter plant. Present intake to sedimentation basin is 2,400 ft upstream from sampling location).

SAMPLING POINTS:

Right side: 30 ft from intake building.

Right center: 425 ft from intake building.

Center: 900 ft from intake building.

Left center: 1,400 ft from intake building.

Left side: 1,800 ft from intake building (400 ft from New Jersey bank).

DRAINAGE AREA: 7,781 sq mi.
ACCUMULATED VOLUME: 3,088 million cu ft, below the head of tide at Trenton, N.J.
REFERENCE MAPS:
Corps of Engineers, Delaware River, Ten Mile Point to Rancocas River, file No. 25003.
U.S. Coast and Geodetic Survey, Delaware River, Philadelphia, Pa. to Trenton, N.J., No. 296.

3. Lehigh Avenue, Philadelphia, station

LOCATION: On a line midway between piers 14 and 18 Port Richmond Terminal through channel station +5.0 to pierhead line on Petty Island. (Aug. 1949–Dec. 1952, 800 ft upstream from here.)
SAMPLING POINTS:
Right side: 50 ft from Pennsylvania pierhead line.
Right center: 500 ft from Pennsylvania pierhead line.
Center: 950 ft from Pennsylvania pierhead line.
Left center: 1,450 ft from Pennsylvania pierhead line.
Left side: 1,850 ft from Pennsylvania pierhead line (50 ft from pierhead line on Petty Island).
DRAINAGE AREA: 7,935 sq mi.
ACCUMULATED VOLUME: 5,363 million cu ft, below the head of tide at Trenton, N.J.
REFERENCE MAPS:
Corps of Engineers, Delaware River, Cooper Point to Fisher Point, file No. 17112.
U.S. Coast and Geodetic Survey, Delaware River, Philadelphia and Camden waterfronts, No. 280.

4. Benjamin Franklin Bridge station

[At one time this was known as the Philadelphia-Camden Bridge station]

LOCATION: On a line 200 ft upstream of bridge from north side of pier 12 North through channel station +14.3 to pierhead line on New Jersey side of river. (Aug. 1949–Dec. 1952, 400 ft upstream from here.)
SAMPLING POINTS:
Right side: At Philadelphia pierhead line.
Right center: 425 ft from Philadelphia pierhead line (midway between right bridge abutment and centerline of bridge).
Center: 850 ft from Philadelphia pierhead line (centerline of bridge).
Left center: 1,250 ft from Philadelphia pierhead line (midway between left bridge abutment and centerline of bridge).
Left side: 1,700 ft from Philadelphia pierhead line (on line with right side of left bridge abutment on pierhead line).
DRAINAGE AREA: 7,993 sq mi.
ACCUMULATED VOLUME: 5,869 million cu ft, below the head of tide at Trenton, N.J.
REFERENCE MAPS:
Corps of Engineers, Delaware River, Gloucester, N.J., to Cooper Point, file No. 17111.
U.S. Coast and Geodetic Survey, Delaware River, Philadelphia and Camden waterfronts, No. 280.

5. Wharton Street, Philadelphia, station

LOCATION: On a line between piers 53 and 55 South, Philadelphia, through channel station +22.6 to coal pier on New Jersey side of river. (Aug. 1949–Dec. 1952, 250 ft downstream from here.)

SAMPLING POINTS:

Right side: 50 ft from Philadelphia pierhead line.

Right center: 500 ft from Philadelphia pierhead line.

Center: 1,000 ft from Philadelphia pierhead line.

Left center: 1,500 ft from Philadelphia pierhead line.

Left side 1,950 ft from Philadelphia pierhead line (50 ft from coal pier on New Jersey side).

DRAINAGE AREA: 7,998 sq mi.

ACCUMULATED VOLUME: 6,380 million cu ft, below the head of tide at Trenton, N.J.

REFERENCE MAPS:

Corps of Engineers, Delaware River, Gloucester, N.J., to Cooper Point, file No. 17111.

U.S. Coast and Geodetic Survey, Delaware River, Philadelphia and Camden waterfronts, No. 280.

6. League Island, Philadelphia, station

LOCATION: On a line from north side of naval yard pier 4 through channel station +51.3 to covered wharf at Red Bank, N.J. (below ferry slip). (Aug. 1949–Dec. 1952, on line from pier 2 through channel station +50.8.)

SAMPLING POINTS:

Right side: 25 ft from naval yard pierhead line.

Right center: 600 ft from naval yard pierhead line.

Center: 1,200 ft from naval yard pierhead line.

Left center: 1,800 ft from naval yard pierhead line.

Left side: 2,200 ft from naval yard pierhead line (50 ft from wharf, New Jersey side).

DRAINAGE AREA: 8,072 sq mi.

ACCUMULATED VOLUME: 8,507 million cu ft, below the head of tide at Trenton, N.J.

REFERENCE MAPS:

Corps of Engineers, Delaware River, Schuylkill River to Gloucester, N.J., file No. 17110.

U.S. Coast and Geodetic Survey, Delaware River, Philadelphia and Camden waterfronts, No. 280.

7. Eddystone, Pa., station

LOCATION: In Tinicum navigation range on a line between piers 11 and 12 just above Chester Front light through channel station +97.2 to the middle of Monds Island on New Jersey shore. (Aug. 1949–Dec. 1952, 400 ft upstream from here.)

SAMPLING POINTS:

Right side: 20 ft from pierhead line, on Pennsylvania side.

Right center: 800 ft from pierhead line, on Pennsylvania side.

Center: 1,600 ft from pierhead line, on Pennsylvania side.

Left center: 2,500 ft from pierhead line, on Pennsylvania side.

Left side: 3,300 ft from pierhead line, on Pennsylvania side.

DRAINAGE AREA: 10,190 sq mi.

ACCUMULATED VOLUME: 13,274 million cu ft, below the head of tide at Trenton, N.J.

REFERENCE MAPS:

Corps of Engineers, Delaware River, Marcus Hook to Eddystone, Pa., file No. 25603.

U.S. Coast and Geodetic Survey, Delaware River, Wilmington to Philadelphia, No. 295

8. Marcus Hook, Pa., station

LOCATION: In Marcus Hook navigation range on a line (below State line) from the water end of the Maritime Exchange reporting station pier through channel station +128.7 to vertical lift bridge over Oldmans Creek.

SAMPLING POINTS:

Right side: 25 ft from pierhead line, on Pennsylvania side.
Right center: 825 ft from pierhead line, on Pennsylvania side.
Center: 1,700 ft from pierhead line, on Pennsylvania side.
Left center: 2,200 ft from pierhead line, on Pennsylvania side.
Left side: 3,100 ft from pierhead line, on Pennsylvania side.

DRAINAGE AREA: 10,370 sq mi.

ACCUMULATED VOLUME: 17,068 million cu ft. below the head of tide at Trenton, N.J.

REFERENCE MAPS:

Corps of Engineers, Delaware River, Edgemoore, Del., to Marcus Hook, Pa., file No. 25602.
U.S. Coast and Geodetic Survey, Delaware River, Wilmington to Philadelphia, No. 295.

LOCAL VARIATIONS IN WATER-QUALITY PATTERNS

Because the river water was sampled each month at eight locations, it is possible to show the water-quality changes from month to month and from year to year at each of these sampling locations. Furthermore, the median or average values of the water-quality parameters and the frequency of occurrence of various values of these parameters are also shown. Because cross-section samples were taken at each of the eight sampling locations, variations in the water-quality parameters may also be discussed for each of the cross sections.

At Burlington-Bristol Bridge, Benjamin Franklin Bridge, and Marcus Hook (stations 1, 4, and 8), top and bottom water samples were collected at five points in the river cross section. Top samples were collected 3 feet below the water surface; bottom samples, approximately 3 feet above the riverbed. At the other stations (2, 3, 5, 6, and 7, fig. 1), top samples were collected at five points in the cross section, but bottom samples only at the three center points.

In general, the cross sections are uniform in water quality, but river curvature, channel depth, islands, bars, and physical structures do affect the direction of ebb and flood currents. These features may influence the mixing of tributary streams, wastes, or sediment with the water in the main stream, thus causing variations in water quality across the cross section of the river.

At Bristol and at the Benjamin Franklin Bridge, the water on the Pennsylvania side generally has a higher specific conductance (about 5 percent higher) than the water in the rest of the cross section. At Marcus Hook the water on the Pennsylvania side of the river has a higher conductance when the specific conductance is less than 600

(Text continues on page O52.)

TABLE 9.—*Range and frequency distribution of selected percentile groups of water-quality parameters, Delaware River, 1949–63* [1]

[Percent of average cross-section water-quality measurements in which parameter equaled or exceeded value tabulated]

	Maximum value	Value, in parts per million, equaled or exceeded by indicated percent of samples							Minimum value
		5	10	25	50	75	90	95	
1. Delaware River at Bristol-Burlington Bridge, 1949–63									
Hydrogen ion concentration pH	7.8	7.3	7.2	7.1	6.9	6.8	6.7	6.5	6.2
Specific conductance micromhos at 25° C	266	225	215	190	145	115	105	95	60
Chloride ppm	17	13	11	8.2	6.0	4.5	3.6	3.1	2.2
Water temperature ° F	86	83	81	74	56	41	37	36	33
Dissolved oxygen ppm	13.3	12.0	11.8	11.0	8.8	7.0	5.5	4.6	2.3
Do percent saturation	106	98	96	90	84	76	67	60	30
2. Delaware River at Torresdale intake, Philadelphia, Pa., 1949–63									
Hydrogen ion concentration pH	8.7	7.2	7.2	7.0	6.9	6.7	6.6	6.5	6.1
Specific conductance micromhos at 25° C	278	232	216	180	150	120	105	95	57
Chloride ppm	26	15	13	8.5	6.2	4.9	3.8	3.0	2.0
Water temperature ° F	86	83	80	75	56	41	37	36	33
Dissolved oxygen ppm	13.4	12.2	11.6	10.5	8.4	6.2	4.7	4.0	2.3
Do percent saturation	104	97	93	87	79	69	55	45	29
3. Delaware River at Lehigh Avenue, Philadelphia, Pa., 1949–63									
Hydrogen ion concentration pH	7.6	7.1	7.0	6.9	6.7	6.6	6.5	6.4	6.0
Specific conductance micromhos at 25° C	571	375	280	215	165	130	110	105	57
Chloride ppm	97	35	22	12	8.0	5.3	4.0	3.7	2.5
Water temperature ° F	85	83	81	75	56	41	37	36	33
Dissolved oxygen ppm	12.7	11.4	10.8	9.5	6.5	2.5	1.6	1.0	.2
Do percent saturation	101	89	85	78	60	30	20	11	3

See footnote at end of table.

TABLE 9.—*Range and frequency distribution of selected percentile groups of water-quality parameters, Delaware River, 1949–63*[1]—Con.

[Percent of average cross-section water-quality measurements in which parameter equaled or exceeded value tabulated]

	Maximum value	Value, in parts per million, equaled or exceeded by indicated percent of samples							Minimum value
		5	10	25	50	75	90	95	
4. Delaware River at Benjamin Franklin Bridge, 1949–63									
Hydrogen ion concentration pH	7.7	7.1	7.0	6.8	6.7	6.5	6.4	6.3	6.0
Specific conductance micromhos at 25° C	876	390	310	230	170	130	120	110	61
Chloride ppm	172	48	27	14	8.8	6.3	5.0	4.5	3.3
Water temperature ° F	84	83	80	75	56	42	37	36	33
Dissolved oxygen ppm	12.5	10.7	10.0	9.2	5.7	2.0	1.0	0.8	0.0
Do percent saturation	100	87	80	70	55	22	15	9.0	0
5. Delaware River at Wharton Street, Philadelphia, Pa., 1949–63									
Hydrogen ion concentration pH	7.5	7.0	6.9	6.8	6.6	6.5	6.4	6.3	5.9
Specific conductance micromhos at 25° C	753	465	335	250	185	140	120	110	68
Chloride ppm	137	62	28	15	9.6	6.6	5.1	4.4	2.0
Water temperature ° F	85	83	81	75	59	43	38	36	34
Dissolved oxygen ppm	11.6	10.5	9.9	8.5	4.1	1.8	1.0	.5	.0
Do percent saturation	91	86	80	66	42	20	11	5	0
6. Delaware River at League Island, Philadelphia, Pa., 1949–63									
Hydrogen ion concentration pH	7.6	7.0	6.9	6.7	6.6	6.4	6.3	6.2	5.9
Specific conductance micromhos at 25° C	1,180	680	470	270	210	160	135	120	75
Chloride ppm	275	144	50	16	11	7.7	5.8	4.8	1.7
Water temperature ° F	86	83	81	75	59	43	38	37	34
Dissolved oxygen ppm	12.1	10.3	9.5	7.9	3.4	1.9	1.2	.5	0
Do percent saturation	94	82	71	63	38	23	15	10	0

7. Delaware River at Eddystone, Pa., 1949–63

Hydrogen ion concentration……pH	7.4	7.0	6.9	6.7	6.6	6.4	6.3	6.2	6.0
Specific conductance……micromhos at 25° C	3, 620	1, 600	980	310	220	180	150	140	78
Chloride……ppm	972	440	230	25	13	9.0	6.8	5.8	4.0
Water temperature……° F	86	83	81	75	58	43	39	37	34
Dissolved oxygen……ppm	11.4	9.6	8.5	7.2	4.0	2.3	1.3	1.0	.5
Do……percent saturation	91	77	68	58	40	26	17	12	6

8. Delaware River at Marcus Hook, Pa., 1949–63

Hydrogen ion concentration……pH	7.7	6.9	6.8	6.6	6.5	6.3	5.9	5.7	5.0
Specific conductance……micromhos at 25° C	6, 500	3, 100	2, 200	550	250	190	160	145	89
Chloride……ppm	1, 940	1, 140	620	90	15	9.8	7.4	6.4	4.7
Water temperature……° F	86	83	81	75	57	44	39	38	34
Dissolved oxygen……ppm	10.7	9.5	8.5	7.0	4.5	2.5	1.7	1.4	1.0
Do……percent saturation	87	76	67	57	43	30	20	15	11

[1] Averages of 5-point cross-section samples collected monthly August 1949–July 1963.

TABLE 10.—*Annual maximum, mean, and minimum of water-quality parameters, Delaware River, 1950–63* [1]

Year	Hydrogen ion (pH)			Specific conductance (micromhos at 25° C)			Chloride (ppm)			Suspended sediment (ppm)			Water temperature (°F)			Dissolved oxygen					
																Parts per million			Percent saturation		
	Max	Median	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
1. Delaware River at Bristol-Burlington Bridge, 1950–63																					
1950	7.1	6.8	6.5	213	135	76	11	5.9	3.3	40	18	8	79	57	34	13.3	9.1	4.0	98	80	53
1951	7.2	6.9	6.5	216	138	60	11	5.3	2.7	142	36	7	76	57	34	12.9	9.6	6.4	104	81	54
1952	7.2	6.7	6.4	235	147	86	10	5.1	2.2	73	24	9	81	57	38	12.2	9.1	4.5	97	81	58
1953	7.0	6.8	6.6	256	163	90	16	8.0	3.6	38	15	7	86	58	36	11.7	8.4	3.5	94	67	38
1954	7.2	6.9	6.7	252	165	97	17	9.0	4.0	32	17	7	80	56	36	11.8	8.7	2.8	89	78	67
1955	7.1	6.7	6.2	245	145	84	16	6.7	2.7	53	23	9	85	58	34	11.5	9.2	4.5	93	83	59
1956	7.3	6.9	6.7	197	155	95	7.9	5.5	2.9	26	16	10	80	56	35	11.7	9.0	6.3	88	77	54
1957	7.2	7.0	6.7	236	178	119	13	8.4	4.4	61	28	13	85	57	36	11.5	8.1	5.0	84	67	45
1958	7.3	7.0	6.4	193	141	104	8.1	5.1	3.2	54	27	11	82	55	33	11.7	8.8	5.9	97	76	62
1959	7.4	6.9	6.6	200	152	91	10	6.6	4.0	39	24	14	84	59	35	11.8	9.0	5.5	92	76	59
1960	7.3	7.0	6.8	167	139	81	8.4	5.3	2.6	332	178	18	76	60	38	11.9	8.0	5.0	93	70	59
1961	7.1	6.8	6.7	222	143	95	12	7.0	3.1	208	62	21	84	58	34	11.9	7.9	4.4	90	72	50
1962	7.2	7.1	6.9	223	164	80	11	7.9	4.0	238	75	21	81	57	34	12.6	8.4	3.2	95	79	38
1963	7.3	7.1	6.8	266	186	80	14	8.6	2.3	167	81	30	83	59	35	12.9	7.4	2.3	95	68	30
2. Delaware River at Torresdale intake, Philadelphia, Pa., 1950–63																					
1950	7.2	6.8	6.5	189	130	76	9.7	6.1	2.9	34	20	7	78	57	35	13.4	8.8	4.4	98	80	53
1951	7.1	6.8	6.6	215	136	60	9.3	5.3	3.0	91	30	11	76	57	35	12.9	8.9	4.9	104	81	54
1952	7.1	6.6	6.3	224	145	92	11	5.2	2.0	49	23	10	81	57	38	12.4	8.7	4.7	97	81	58
1953	7.0	6.8	6.5	278	166	86	20	8.7	4.0	37	21	10	86	58	36	11.9	7.3	3.3	94	67	38
1954	7.8	6.9	6.5	244	160	94	16	8.7	4.0	------	------	------	80	56	35	11.6	8.5	5.5	89	78	67
1955	7.2	6.8	6.4	235	150	107	14	7.1	3.3	35	23	9	84	58	34	12.4	8.9	4.7	93	83	59
1956	7.1	6.8	6.6	185	149	92	7.5	5.4	2.0	47	22	13	79	56	34	11.3	8.4	5.5	88	77	54
1957	7.2	6.8	6.5	268	189	108	26	12	4.0	146	44	21	83	56	35	10.8	7.4	3.6	84	67	45
1958	7.4	7.0	6.2	165	102	108	7.6	5.3	3.0	110	40	14	81	55	34	10.6	8.3	5.7	97	76	62
1959	7.2	6.9	6.7	210	155	92	12	7.0	3.0	42	28	13	83	58	35	11.3	8.1	4.6	92	76	59
1960	7.4	6.9	6.8	184	145	88	7.5	5.0	2.0	120	86	15	79	59	36	11.6	7.6	3.9	97	74	48
1961	7.2	6.9	6.7	162	142	85	12	6.2	2.5	84	44	22	82	58	34	11.9	7.3	4.0	89	67	41
1962	7.2	7.0	6.8	222	165	89	12	8.8	4.0	121	42	15	80	58	34	12.9	7.8	2.9	93	71	34
1963	7.2	7.0	6.8	259	191	79	18	11	2.0	143	59	33	82	57	33	12.0	8.3	2.3	89	73	29

1950	7.0	6.6	6.3	270	159	84	14	7.7	3.7	61	24	10	79	57	35	12.7	5.9	0.7	101	50	8
1951	6.9	6.7	6.3	247	153	58	11	6.7	3.0	101	32	13	78	57	36	12.3	7.0	.9	100	60	11
1952	7.0	6.7	6.5	290	165	104	18	7.3	3.3	48	20	7	83	58	38	12.4	6.8	.9	94	61	12
1953	7.0	6.6	6.4	429	214	106	43	14	4.0	35	25	13	85	59	36	11.6	5.4	.5	85	46	7
1954	6.9	6.6	6.4	404	198	102	40	14	4.0	------	------	------	80	57	34	11.5	6.1	1.3	82	53	15
1955	7.0	6.6	6.2	307	174	127	25	9.4	4.0	41	25	12	83	58	33	10.9	7.2	1.9	85	61	23
1956	7.1	6.8	6.4	239	178	100	14	8.3	3.3	30	21	13	80	56	34	10.2	6.4	2.0	81	57	25
1957	7.4	6.7	6.3	571	286	127	97	31	4.3	139	38	15	84	57	35	10.7	5.2	1.3	76	45	16
1958	7.2	6.9	6.2	195	145	114	11	6.5	3.8	245	53	19	82	55	35	10.4	6.8	2.4	86	60	30
1959	7.1	6.7	6.3	241	173	88	12	8.6	2.5	67	31	13	83	59	35	9.6	6.0	1.6	80	55	19
1960	7.1	6.8	6.6	208	155	88	12	6.8	3.0	120	86	15	80	58	38	12.0	6.4	2.8	90	58	19
1961	7.2	6.9	6.6	298	172	84	21	9.0	2.5	84	44	22	83	58	34	11.8	5.8	1.7	89	50	18
1962	7.1	6.9	6.7	277	192	109	19	10.9	4.0	121	42	15	81	58	36	11.4	6.4	1.7	88	56	21
1963	7.2	6.9	6.5	408	244	89	48	19	3.0	108	45	24	81	58	34	10.9	5.8	1.3	78	50	16

4. Delaware River at Benjamin Franklin Bridge, Philadelphia, Pa., 1950–63

1950	6.7	6.5	6.0	309	175	85	23	10	4.4	68	34	14	79	57	36	10.3	4.9	0.0	87	41	0
1951	6.9	6.6	6.3	261	163	61	15	8.4	3.3	97	36	15	79	57	36	12.4	6.1	.6	100	53	7
1952	6.8	6.6	6.3	218	171	101	22	7.1	3.9	36	25	9	82	58	38	12.5	6.2	1.0	95	55	12
1953	6.9	6.6	6.4	453	225	116	50	16	6.0	45	33	13	83	59	36	9.9	4.8	.6	76	42	7
1954	6.8	6.6	6.3	642	238	113	110	23	4.6	49	31	13	81	57	34	11.0	5.3	1.1	79	45	12
1955	6.9	6.5	6.2	334	183	130	29	11	5.1	64	32	18	83	58	33	10.5	6.6	1.5	90	58	19
1956	7.0	6.7	6.5	252	183	105	15	9.2	4.7	99	34	14	79	57	35	9.9	6.0	1.9	78	53	22
1957	7.7	6.7	6.3	821	337	130	172	44	6.1	79	43	25	83	57	35	9.6	4.8	1.1	69	41	13
1958	7.1	6.9	6.1	204	151	115	12	7.1	4.1	259	60	22	82	55	35	10.4	6.2	.9	90	54	9
1959	7.0	6.7	6.3	255	182	92	16	10	4.5	60	34	16	83	59	35	9.6	5.0	1.7	81	46	22
1960	7.0	6.8	6.4	215	161	91	10	7.9	4.8	122	79	20	80	58	38	11.6	6.3	2.4	88	57	26
1961	7.0	6.8	6.6	306	177	85	24	9.6	3.5	84	46	20	83	59	34	12.0	5.6	1.3	88	48	16
1962	7.1	6.8	6.5	287	202	112	18	12	4.0	78	49	4	79	58	36	11.0	5.9	1.5	86	52	18
1963	7.2	6.8	6.5	520	270	97	67	22	4.7	82	44	25	81	58	34	10.3	5.3	1.1	86	46	14

5. Delaware River at Wharton Street, Philadelphia, Pa., 1950–63

1950	6.7	6.5	6.2	305	175	81	21	10	4.7	51	34	11	80	57	37	11.5	4.9	0.0	91	40	0
1951	6.8	6.6	6.4	327	163	70	24	8.4	3.0	80	36	11	81	57	36	10.8	6.1	.3	89	48	4
1952	6.8	6.6	6.0	325	171	98	22	7.1	3.0	57	25	6	82	58	38	11.6	6.2	.1	91	49	1
1953	6.8	6.6	6.4	500	225	109	73	16	4.0	34	33	11	84	59	37	10.4	4.8	.8	85	41	9
1954	6.8	6.6	6.2	666	238	111	123	23	4.0	------	------	------	80	57	34	11.1	5.3	1.1	83	41	13
1955	6.7	6.5	6.1	432	183	143	57	11	7.0	49	32	11	85	58	34	9.7	6.6	1.2	77	47	13
1956	7.0	6.7	6.3	250	183	104	16	9.2	5.0	43	34	14	80	57	35	9.0	6.0	2.3	71	49	27
1957	7.5	6.7	6.3	646	337	140	116	44	5.3	61	43	18	84	57	35	9.5	4.8	1.0	79	38	12
1958	7.1	6.9	6.1	209	151	118	12	7.8	4.0	134	60	19	82	55	35	10.5	6.2	1.4	78	49	18
1959	6.9	6.7	6.4	270	182	95	18	9.7	3.5	67	34	11	84	59	36	9.1	5.0	1.8	69	45	20
1960	7.0	6.7	6.4	229	167	73	14	8.2	2.0	124	56	19	81	61	39	10.9	4.7	1.6	83	43	20
1961	7.0	6.7	6.2	352	198	93	32	12	3.5	104	47	12	82	59	34	11.4	4.9	1.1	86	42	13
1962	7.0	6.8	6.4	300	218	104	21	14	5.0	93	41	11	79	58	36	10.3	4.8	1.0	90	41	12
1963	7.1	6.8	6.5	748	296	86	137	39	3.0	61	39	23	81	59	34	10.4	4.2	.8	86	37	8

See footnote at end of table.

TABLE 10.—*Annual maximum, mean, and minimum of water-quality parameters, Delaware River, 1950–63*[1]—Continued

Year	Hydrogen ion (pH)			Specific conductance (micromhos at 25° C)			Chloride (ppm)			Suspended sediment (ppm)			Water temperature (°F)			Dissolved oxygen: Parts per million			Dissolved oxygen: Percent saturation		
	Max	Median	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
6. Delaware River at League Island, Philadelphia, Pa., 1950–63																					
1950	6.6	6.4	6.2	351	193	90	26	11	4.0	55	31	16	80	59	38	11.9	4.4	0.0	94	37	0
1951	7.6	6.6	6.3	374	197	84	35	11	4.0	90	20	10	80	58	35	10.8	5.1	.3	84	39	4
1952	6.8	6.5	6.2	362	196	107	28	10	4.0	82	27	7	83	58	37	12.1	5.4	.1	93	48	4
1953	6.8	6.5	6.3	700	273	114	128	27	4.3	52	28	12	83	59	37	9.4	4.4	1.0	73	39	9
1954	6.8	6.4	6.2	945	354	129	193	49	6.0	-----	-----	-----	80	58	34	10.3	4.9	1.2	82	42	14
1955	6.7	6.4	6.0	639	241	161	131	21	7.0	58	29	10	85	59	34	9.3	5.1	1.2	73	46	15
1956	7.0	6.7	6.2	281	210	111	18	11	6.0	44	25	14	80	57	36	7.8	4.7	2.3	65	42	27
1957	7.5	6.6	6.3	1,180	502	161	275	86	8.0	102	36	16	84	58	37	8.8	4.0	1.4	66	36	16
1958	7.1	6.8	5.9	243	177	132	15	9.1	4.5	177	51	18	82	56	36	10.0	5.9	2.0	72	50	25
1959	6.9	6.7	6.4	303	216	114	22	12.0	5.0	51	30	13	84	60	36	9.2	5.0	1.8	79	46	19
1960	6.9	6.6	6.5	250	185	82	14	9.5	3.0	72	41	9	80	61	39	11.0	4.6	1.8	89	42	18
1961	6.9	6.6	6.1	438	216	101	56	15	3.5	100	42	13	83	61	34	10.4	4.7	1.2	84	42	17
1962	6.9	6.7	6.5	373	249	107	29	15	1.7	95	39	14	79	58	36	10.3	4.4	.8	83	38	7
1963	6.9	6.6	6.4	1,070	392	97	206	47	3.5	68	42	16	81	58	35	10.4	3.5	.6	86	31	6
7. Delaware River at Eddystone, Pa., 1950–63																					
1950	6.6	6.4	6.0	556	234	102	62	17	4.7	83	56	25	80	59	37	10.6	4.5	0.7	85	38	8
1951	6.8	6.5	6.3	933	261	83	262	31	4.0	84	43	11	81	58	36	10.7	4.8	.5	86	42	6
1952	6.8	6.5	6.2	935	254	132	220	27	4.0	57	33	14	82	58	38	11.4	5.4	.5	86	46	6
1953	7.0	6.5	6.3	1,590	472	142	433	87	6.0	89	35	16	83	59	38	8.1	4.0	1.4	63	36	13
1954	6.7	6.4	6.0	1,860	619	150	467	126	7.0	-----	-----	-----	80	58	34	9.2	4.6	1.3	74	40	15
1955	6.6	6.4	6.0	1,820	362	165	518	58	7.0	119	51	17	86	59	34	8.2	4.6	1.4	70	42	17
1956	7.0	6.6	6.1	320	239	137	22	14	7.0	78	40	12	80	58	35	7.3	4.5	2.5	59	41	30
1957	7.4	6.5	6.0	3,420	1,210	192	972	312	8.0	203	69	32	83	58	37	7.9	3.8	1.4	58	36	17
1958	7.1	6.8	6.1	290	200	144	18	11	6.0	161	63	19	82	57	37	9.1	5.7	2.0	68	50	26
1959	6.9	6.6	6.3	510	268	131	60	22	5.5	64	46	17	85	60	36	8.9	4.9	2.2	69	46	24
1960	6.9	6.6	6.4	269	210	122	17	11	4.0	93	45	18	81	62	40	9.9	4.7	1.8	88	45	18
1961	7.0	6.6	6.3	1,060	303	118	245	41	4.5	104	55	12	83	62	36	11.2	5.3	2.1	91	48	25
1962	6.9	6.7	6.4	595	315	134	86	28	7.0	111	52	12	79	59	37	8.4	4.5	1.4	68	40	18
1963	7.0	6.5	6.0	2,020	765	107	496	154	5.0	205	69	16	82	58	35	9.0	3.4	.6	75	30	6

8. **Delaware River at Marcus Hook, Pa., 1950–63**

1950	7.2	6.4	6.0	1,000	313	117	222	40	5.7	123	51	24	81	59	36	10.6	4.6	1.0	84	39	11
1951	7.5	6.6	6.3	1,250	421	92	872	86	4.7	88	43	13	80	59	35	10.7	4.9	1.6	87	43	18
1952	7.5	6.5	5.7	1,750	342	143	466	51	5.2	63	41	14	82	58	38	10.7	5.4	1.0	82	47	12
1953	7.1	6.7	6.3	2,550	829	147	802	214	7.8	120	48	17	86	59	38	7.6	4.2	1.3	59	38	16
1954	6.9	6.5	5.7	2,870	998	162	848	250	8.6	85	55	21	80	59	34	9.4	4.7	1.9	70	42	20
1955	6.9	6.4	5.2	3,590	581	180	1,110	124	8.5	106	53	19	86	60	38	9.0	5.0	1.4	76	45	17
1956	7.2	6.5	6.0	694	310	143	129	32	6.2	130	56	16	80	58	36	7.6	5.0	2.3	63	46	25
1957	7.7	6.3	5.3	6,120	2,330	201	1,940	663	11	230	82	33	84	58	38	7.9	4.7	2.5	58	43	33
1958	7.0	6.7	5.5	370	228	150	33	15	6.0	124	57	18	82	57	37	8.8	5.3	2.0	71	47	25
1959	6.8	6.1	5.0	1,150	499	139	250	88	7.4	73	51	21	84	60	36	7.9	4.8	2.3	71	45	27
1960	7.0	6.5	6.0	393	250	141	48	19	6.7	119	55	20	81	61	39	9.6	4.6	2.2	77	44	27
1961	6.9	6.5	6.0	2,080	565	126	560	120	5.8	93	54	21	83	60	36	10.7	5.1	2.0	82	47	25
1962	6.7	6.6	5.6	1,200	493	141	252	69	7.5	88	42	26	79	59	35	8.3	4.4	1.3	69	39	15
1963	7.1	6.4	5.1	3,860	1,700	117	1,460	518	5.1	136	87	28	82	58	34	8.6	3.9	1.4	72	35	16

[1] Averages of 5-point cross-section samples collected monthly January 1950–December 1963. The figures tabulated under maximum, mean, median, or minimum represent the averages of cross sections. The measurements represented in the pH tables are the median of 5 top samples and 3 to 5 bottom samples; in the specific conductance tables, the average of 5 top samples; for the chloride tables, the average of 1 to 3 bottom samples; in the suspended-sediment tables, a composite top sample; in the temperature tables, the average of 5 top and 3 to 5 bottom samples; for dissolved oxygen, the average of 3 to 5 top samples.

TABLE 11.—*Monthly maximum, mean, and minimum of water-quality parameters, Delaware River, 1949–63* [1]

Month	Hydrogen ion (pH)			Specific conductance (micromhos at 25° C)			Chloride (ppm)			Suspended sediment (ppm)			Temperature (°F)			Dissolved oxygen					
																Parts per million			Percent saturation		
	Max	Median	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
1. Delaware River at Bristol-Burlington Bridge, 1949–63																					
January	7.3	6.9	6.4	172	140	97	10.1	6.2	3.0	213	45	7	39	36	33	12.1	10.9	8.7	99	80	61
February	7.3	7.1	6.2	188	144	104	8.6	6.1	3.3	238	54	10	41	37	34	12.6	11.3	7.9	95	84	57
March	7.4	7.0	6.5	216	131	85	12	5.6	3.1	332	45	8	43	40	34	13.2	11.2	8.4	104	86	63
April	7.3	6.9	6.6	139	98	60	5.3	3.9	2.3	216	54	7	52	48	43	11.6	10.3	6.7	98	88	56
May	7.3	7.0	6.6	156	115	88	8	4.3	2.9	192	50	11	67	60	52	9.8	8.9	8.0	97	88	81
June	7.4	6.9	6.6	204	146	84	10	5.8	2.2	113	34	9	85	72	65	8.3	6.8	3.2	93	77	38
July	7.5	7.0	6.7	207	176	124	10	7.4	4.1	189	41	14	86	80	74	8.2	5.5	2.3	102	67	30
August	7.5	6.9	6.2	255	193	141	17	9.1	4.1	64	30	15	85	80	76	8.1	5.7	3.8	101	71	49
September	7.8	7.0	6.6	256	195	136	16	8.7	3.2	205	41	7	85	76	70	8.0	5.8	2.6	88	72	31
October	7.5	7.0	6.7	242	198	136	16	9.6	4.2	170	44	8	71	64	49	9.3	7.7	4.4	93	79	47
November	7.7	6.9	6.5	266	181	82	14	8.8	2.7	38	22	12	60	53	44	11.4	9.1	7.0	98	81	68
December	7.5	7.1	6.4	185	168	105	8.7	6.2	3.7	208	47	9	45	42	34	13.3	10.8	6.3	106	85	50
2. Delaware River at Torresdale intake, Philadelphia, Pa., 1949–63																					
January	7.2	6.8	6.2	197	144	102	10	6.7	4.0	143	52	13	39	36	33	12.1	10.5	7.4	91	77	52
February	7.1	6.8	6.5	190	141	112	11	6.0	2.7	122	49	12	41	37	34	12.9	10.9	7.4	97	80	54
March	7.3	6.9	6.4	214	130	85	13	5.6	2.0	245	54	14	43	39	35	13.4	10.9	6.9	104	82	52
April	7.3	6.9	6.6	137	100	57	6	3.7	2.0	101	40	10	53	48	43	11.9	10.1	8.7	98	86	76
May	7.4	6.9	6.5	170	115	86	9	4.8	2.5	76	28	14	65	60	53	9.7	8.7	7.8	94	85	78
June	7.1	6.9	6.6	194	145	91	10	6.0	2.0	76	30	13	83	72	65	7.7	6.2	3.6	83	70	34
July	7.2	6.9	6.6	211	169	114	11	7.6	4.0	109	28	9	85	79	75	8.2	5.3	2.3	97	64	29
August	7.4	6.8	6.1	273	190	155	20	9.7	4.0	48	29	13	85	80	75	7.1	5.2	3.5	92	64	43
September	7.1	6.9	6.3	278	191	141	17	9.6	5.0	85	29	10	86	76	68	7.5	5.5	3.1	95	66	37
October	7.1	6.8	6.4	273	201	146	26	11.2	4.0	109	33	7	72	65	48	9.3	6.6	3.3	97	69	38
November	7.2	6.9	6.5	256	184	96	18	9.7	3.0	139	39	9	62	53	45	10.7	8.5	5.3	95	79	50
December	8.7	7.0	6.4	198	145	103	13	7.0	4.0	120	42	13	47	42	35	12.4	10.2	5.1	98	81	41

3. Delaware River at Lehigh Avenue, Philadelphia, Pa., 1949–63

January	7.6	6.7	6.2	265	162	118	14	8.5	4.0	115	48	14	42	36	34	12.0	9.6	7.2	90	65	52
February	7.0	6.8	6.4	205	152	111	12	7.5	4.3	121	48	15	41	37	33	12.4	10.4	7.6	94	77	55
March	7.4	6.8	6.2	251	137	84	10	6.9	2.5	245	55	16	44	39	35	12.3	9.9	7.7	100	76	60
April	7.2	6.8	6.4	163	107	57	6.3	4.2	2.5	101	38	13	52	47	44	11.0	9.5	7.6	92	81	64
May	7.1	6.8	6.4	178	125	89	9	5.0	2.5	76	26	13	65	59	52	9.7	7.2	5.5	82	71	55
June	7.0	6.6	6.3	237	166	111	13	7.9	3.3	76	31	13	84	72	67	8.7	3.8	1.3	72	39	15
July	7.0	6.8	6.5	287	205	135	22	11.4	5.5	109	28	11	85	79	76	4.1	2.4	.5	49	29	7
August	7.3	6.8	6.0	483	253	163	67	18	7.0	48	28	13	83	80	76	5.5	2.2	.2	73	28	3
September	6.9	6.7	6.5	443	257	162	61	18	6.5	85	28	9	85	77	73	6.6	2.4	.7	79	29	8
October	7.1	6.7	6.3	571	284	136	97	27	4.5	109	31	7	73	66	50	6.5	3.1	.7	57	34	8
November	7.1	6.7	6.3	455	258	115	65	21	4.0	139	38	8	65	55	47	10.2	4.9	.9	86	46	9
December	7.2	6.7	6.3	216	166	106	15	9.2	4.0	120	42	17	48	43	37	12.7	8.5	2.1	101	67	18

4. Delaware River at Benjamin Franklin Bridge, 1949–63

January	7.7	6.7	6.1	285	172	122	20	9.9	5.7	99	51	22	41	37	34	11.6	8.8	6.6	88	65	48
February	7.2	6.8	6.4	222	154	85	13	8.4	3.5	112	49	13	43	37	33	12.5	9.5	7.7	95	70	56
March	7.7	6.8	6.2	263	156	102	18	8.3	4.6	259	57	22	44	39	36	12.4	9.6	7.6	100	73	59
April	7.2	6.8	6.4	166	111	61	7.0	5.1	3.3	104	44	22	52	48	44	11.1	9.2	7.2	93	78	61
May	7.1	6.8	6.4	193	131	90	9.0	5.9	3.5	79	38	4	65	59	52	8.0	6.6	5.3	76	65	53
June	7.3	6.6	6.3	242	172	113	14	9.0	4.1	53	29	13	83	71	66	6.5	3.3	1.1	74	37	12
July	7.4	6.8	6.4	299	219	141	22	12	5.7	89	33	18	83	79	76	5.2	2.0	.6	44	22	7
August	7.5	6.7	6.1	503	261	166	74	20	6.8	39	27	15	84	81	77	3.4	1.9	.0	41	23	0
September	7.6	6.8	6.3	876	313	169	172	32	8.1	89	37	13	83	77	69	5.8	1.7	.0	69	20	0
October	7.4	6.7	6.3	647	311	135	115	31	5.0	109	40	9	73	66	50	5.9	2.5	.4	63	26	4
November	7.5	6.8	6.3	516	283	117	72	25	5.1	94	41	10	64	55	47	10.2	4.5	.1	90	41	1
December	7.2	6.9	6.0	231	175	110	16	9.9	6.1	122	49	24	48	44	38	10.5	7.9	3.5	83	65	29

5. Delaware River at Wharton Street, Philadelphia, 1949–63

January	7.5	6.6	6.0	238	175	109	18	9.4	5.3	104	41	17	45	37	34	11.5	8.9	5.8	86	69	42
February	7.0	6.6	5.9	264	170	123	17	9.6	4.3	93	45	14	41	37	34	11.6	9.3	6.5	91	69	46
March	7.1	6.6	6.3	295	156	93	21	8.2	3.5	134	47	16	43	40	37	11.4	8.8	6.4	86	67	48
April	7.0	6.7	6.3	173	112	68	9.0	4.8	2.0	80	40	14	53	48	43	10.8	8.9	6.3	90	73	56
May	7.0	6.7	6.3	193	136	95	11	6.0	3.5	61	30	11	63	60	54	8.8	5.6	3.4	85	56	34
June	6.8	6.5	6.3	247	181	117	15	9.1	4.0	35	24	11	83	72	65	6.3	2.3	1.0	65	26	11
July	7.0	6.7	6.4	292	231	140	21	13	6.5	124	38	16	84	79	75	3.3	1.7	.1	39	21	1
August	6.9	6.7	5.9	561	283	189	89	25	8.5	54	29	11	85	81	77	3.0	1.6	.0	37	20	0
September	6.9	6.6	6.4	692	315	171	123	32	8.5	65	29	6	84	78	69	4.2	1.4	.0	50	17	0
October	7.0	6.6	6.3	646	318	155	116	30	6.5	49	31	15	74	67	50	3.8	2.0	.0	39	22	0
November	7.1	6.6	6.3	753	344	127	137	37	6.0	99	38	12	66	56	47	9.1	3.1	.0	75	29	0
December	7.1	6.6	6.0	332	193	115	29	12	4.7	78	39	18	50	45	40	11.5	6.5	2.5	91	53	21

See footnote at end of table.

TABLE 11.—*Monthly maximum, mean, and minimum of water-quality parameters, Delaware River, 1949–63* [1]—Continued

Month	Hydrogen ion (pH)			Specific conductance (micromhos at 25° C)			Chloride (ppm)			Suspended sediment (ppm)			Temperature (°F)			Dissolved oxygen: Parts per million			Dissolved oxygen: Percent saturation		
	Max	Median	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
6. Delaware River at League Island, Philadelphia, Pa., 1949–63																					
January	7.5	6.5	5.9	312	191	130	22	11	5.3	100	44	16	46	38	34	11.0	8.1	5.4	86	60	39
February	7.0	6.5	5.9	318	188	140	22	12	5.7	95	45	16	41	37	34	12.1	8.4	6.3	93	64	44
March	7.0	6.6	6.2	322	168	101	22	9.1	4.0	177	50	21	43	40	38	10.8	8.6	6.1	84	64	45
April	7.0	6.7	6.2	184	125	75	9.0	5.6	3.0	90	42	15	54	48	44	10.6	8.2	6.3	89	70	29
May	7.6	6.6	6.2	229	153	101	12	7.4	3.5	44	22	10	64	60	54	7.5	4.4	1.8	72	45	18
June	6.8	6.5	6.2	286	202	115	17	9.8	1.7	57	23	9	82	72	65	5.7	2.3	.9	39	26	10
July	6.9	6.7	6.3	350	256	182	33	16	9.0	82	30	12	84	79	76	3.3	1.9	.1	40	24	10
August	6.9	6.6	6.0	1,020	358	192	220	45	11	42	25	10	86	81	76	3.3	1.8	.2	42	22	2
September	6.9	6.6	6.2	945	404	194	182	52	9.2	51	25	7	84	78	69	3.3	1.7	.0	39	20	0
October	7.1	6.6	6.3	1,180	446	156	275	57	6.5	52	34	14	72	67	49	3.6	2.0	.1	38	22	1
November	7.0	6.6	6.2	1,060	458	153	206	64	7.0	102	39	12	66	56	48	7.7	3.0	.2	73	28	2
December	6.9	6.4	6.1	436	220	116	48	16	4.0	68	38	19	49	44	40	11.9	6.3	3.0	94	50	25
7. Delaware River at Eddystone, Pa., 1949–63																					
January	7.4	6.4	6.0	972	271	144	185	23	6.3	205	79	25	49	38	34	10.5	7.8	6.3	78	58	41
February	6.9	6.5	6.0	657	247	145	105	19	6.0	119	71	19	41	38	34	11.4	7.8	5.9	86	58	43
March	7.0	6.6	6.2	342	196	118	26	10	4.5	161	73	31	43	38	37	11.2	7.9	5.4	86	62	43
April	7.1	6.8	6.2	198	143	78	10	6.7	4.0	82	55	22	54	49	44	10.5	7.8	3.6	91	69	44
May	6.9	6.6	6.2	271	173	120	14	8.4	5.0	44	31	16	64	60	55	6.6	4.0	1.8	64	39	18
June	6.8	6.5	6.2	329	221	126	28	14	4.0	70	32	12	82	72	65	5.2	2.5	1.0	57	29	11
July	6.9	6.6	6.2	830	330	215	165	34	12	57	34	11	83	80	77	4.2	2.3	.8	52	29	10
August	7.0	6.5	6.0	3,360	666	230	920	145	14	70	37	16	86	81	76	3.5	2.2	.5	43	27	6
September	7.0	6.5	6.3	2,720	779	202	723	166	9.7	120	40	12	85	78	69	3.3	2.0	.5	40	24	6
October	7.1	6.5	6.0	3,620	973	160	972	227	18	101	50	24	72	67	48	4.0	2.2	.7	37	24	8
November	7.0	6.5	6.2	3,410	947	175	955	221	7.3	203	57	24	65	56	50	5.8	3.5	.6	52	33	6
December	7.2	6.4	6.0	1,680	362	151	297	50	7.0	93	50	23	50	45	41	10.6	5.7	1.5	85	47	13

8. Delaware River at Marcus Hook, Pa., 1949–63

January	7.7	6.5	5.5	4,300	572	156	1,460	138	7.8	136	77	33	46	38	34	9.6	7.6	6.0	75	56	43
February	7.1	6.5	6.0	2,380	394	158	43	17	6.2	124	73	27	41	39	34	10.7	7.8	6.3	82	59	47
March	7.5	6.7	6.1	452	207	126	43	12	6.2	114	69	38	45	41	36	10.7	8.1	6.3	85	62	46
April	7.1	6.7	5.4	201	157	89	11	7.8	4.7	78	51	34	55	49	45	10.1	7.8	5.6	87	67	50
May	7.1	6.6	5.9	315	194	138	16	9.7	5.2	64	39	17	64	60	55	6.7	4.2	1.9	64	31	20
June	6.8	6.4	5.0	979	325	139	216	40	5.2	59	33	19	83	72	65	4.6	2.7	1.3	51	30	15
July	6.9	6.4	5.2	2,110	599	224	530	115	13	67	36	13	84	80	76	3.6	2.3	1.0	43	29	12
August	7.2	6.4	5.5	5.810	1,340	226	1,720	349	14	94	49	18	86	81	77	3.1	2.1	1.0	39	26	12
September	7.5	6.5	5.9	5,370	1,340	207	1,560	344	10	130	44	14	86	77	69	4.7	2.3	1.0	55	28	12
October	7.2	6.4	5.1	6,500	1,840	169	1,940	581	7.7	143	64	27	73	67	47	6.3	2.9	1.0	54	30	11
November	7.4	6.4	6.0	5,970	1,770	194	1,920	515	8.5	230	71	39	64	56	50	5.2	3.7	1.2	48	35	12
December	7.2	6.6	5.7	3,730	629	139	1,030	153	7.3	85	60	34	50	46	41	10.6	6.1	2.7	84	51	43

[1] Averages of cross-section samples collected monthly August 1949–December 1963. The figures tabulated under maximum, mean, median, or minimum represent the average of cross sections. The measurements represented in the pH tables are the median of 5 top samples and 3 to 5 bottom samples; in the specific conductance tables, the average of 5 top samples; for the chloride tables, the average of 1 to 3 bottom samples; in the suspended-sediment tables, a composite top sample; in the temperature tables, the average of 5 top and 3 to 5 bottom samples; for dissolved oxygen, the average of 3 to 5 top samples.

micromhos; however, when the conductance exceeds 600 micromhos (which it did in nearly one-quarter of the samples), the conductance on the New Jersey side often exceeds that on the Pennsylvania side.

Because salt water is heavier than fresh water, ocean water may move up the estuary along the river bottom with the fresher water overriding the tongue of salt water and eroding it. This overriding happens in some parts of the estuary at some times, but in the river between Trenton and Marcus Hook such a salt tongue has not been observed. The salinity of the bottom samples at Marcus Hook is generally 5–10 percent greater than that of the top samples, but at upstream locations there is no significant difference in salinity between the top and bottom water. Occasionally top samples will have a slightly greater salinity than bottom samples. This salinity is presumably a temporary result of salt water, which is sometimes warmer and therefore, less dense than the cooler bottom water.

In any cross section the temperature variations are generally less than 1°F. Top and bottom samples normally have the same pH, within 0.2 pH units, but occasionally large differences have been observed. The bottom samples on the right and left sides most frequently deviate in pH from the average for the cross section; this deviation is possibly the effect of pollution, tributary streams, or ground water inflow.

During most of the period covered by this report (1949–63), dissolved oxygen was determined on top samples only. Dissolved-oxygen concentration at Bristol is nearly uniform in the top cross section. From Lehigh Avenue to Eddystone the oxygen concentration is more depleted on the Pennsylvania side of the River than on the New Jersey side, the difference averaging 0.7 ppm. At Marcus Hook the dissolved oxygen is approximately 1.0 ppm lower on the Pennsylvania side.

On the twice-daily flood tide, salt water flows upstream, and the salinity at each sampling station increases. The maximum salinity occurs at high-water slack, the time at which the flood current reverses and becomes an ebb current. During the ebb tide the salty water is swept seaward by the downstream flow of fresher water, and the increase in fresh water causes the salinity at any sampling station to reach a minimum at low-water slack. Thus, the salinity at any location in the estuary each day goes through two maxima, not necessarily identical, and two minima, also not necessarily identical.

Onshore winds blow sea water shoreward and may raise the sea level at the south of Delaware Bay. This rise in sea level causes water to move upriver and salinity to increase in the lower estuary. Offshore winds may cause a decrease in sea level and a corresponding flow of water seaward throughout the river and estuary, thereby decreasing the salinity; however, when sea levels return to normal as the offshore winds subside, ocean water flows into the estuary replacing that which had been blown out. The end result is, therefore, saltier water in the estuary. The magnitude of these changes in salinity depends upon the force and direction of the wind and its duration.

The samples referred to in this report were taken at random times with respect to stage of tide, tidal range, and sea level. In the present sampling program specific conductivity, pH, temperature, and dissolved oxygen are recorded continuously at several locations. As a result, there soon will be a more comprehensive knowledge of water-quality changes and of the precise times that they occur. This knowledge will help in evaluating the relative effects of such factors as sea level and fresh-water discharge.

SUMMARY AND CONCLUSIONS

That reach of the Delaware River from Bristol to Marcus Hook was sampled in detail once each month during the 14 years from August 1949 to the end of 1963. This period embraces a range of fresh-water inflow conditions. The 50-year average discharge at Trenton is 11,830 cfs; the largest annual mean discharge in the 14-year period was 150 percent as large as the 50-year average, and the smallest annual mean discharge 60 percent as large. In general, the salinity of this reach of the river is influenced by the discharge. In the lower half of this reach, the concentration of dissolved solids can be estimated from the measured specific conductance (expressed in micromhos at 25°C). For concentrations less than 200 ppm, the dissolved-solids concentration (in ppm) is approximately 16 ppm plus 52 percent of the specific conductance. From 200 to 2,500 ppm, the dissolved-solids concentration is 60 percent of the specific conductance at 25°C.

Although the annual mean discharge in 1952 was substantially larger than in any other year in the 1950–1963 period, this was not the year in which the river water contained the lowest concentration of dissolved solids. The river water was the least saline in 1958. The highest salinities were observed in 1954, 1957 and 1963. In each of these years the annual mean discharge was low, and the discharge for July, August, and September was also low. In 1953 and 1962 the July to September discharge was also low and the salinity high, but not as high as in 1954, 1957 and 1963.

The dissolved-solids concentration in the river water is lowest in the spring and highest in late summer and early autumn because the fresh-water discharge is greatest in March, April, and May and least in August, September, and October. For example, in March, April, and May the mean dissolved-solids concentration is 76 ppm at Bristol, and 112 ppm at Marcus Hook. In August and September the mean is 117 ppm at Bristol and 804 ppm at Marcus Hook. There is a greater variation of concentrations in the estuary at Marcus Hook than at Trenton, as a result of tidal action. The greatest dissolved-solids concentrations represented by these monthly samples were 160 ppm at Bristol and 4,000 ppm at Marcus Hook.

The chloride concentration at Marcus Hook exceeded 100 ppm 24 percent of the time and 10 ppm 70 percent of the time. At Benjamin Franklin Bridge, however, 100 ppm chloride was exceeded only 2 percent of the time and 10 ppm less than 40 percent of the time. At Chester, for a 31-year period, 250 ppm chloride was exceeded 10 percent of the time, 60 ppm 20 percent of the time, and 15 ppm 50 percent of the time.

The worst salinity invasions of the Delaware River were in 1949, 1953, 1954, 1957 and 1963. Significant increases in salinity were observed upstream from Lehigh Avenue, Philadelphia, Pa. In these 5 years the mean monthly discharge at Trenton for each month from July to October was less than 4,000 cfs; however, from July to September, 1962, the mean monthly discharge at Trenton was also less than 4,000 cfs each month, but the annual mean dissolved-solids concentration was not as great as in the 5 years referred to above.

Perhaps the major factor controlling the salinity of this reach of the estuary is the amount of fresh-water discharge into the estuary, especially in July, August, and September. For example, in those years in which the mean monthly discharge during July, August, and September exceeded 4,000 cfs at Trenton, the average annual dissolved-solids concentration of the river water at Benjamin Franklin Bridge, Philadelphia, was approximately 100 ppm and varied little with change in discharge. For a mean monthly discharge of less than 4,000 cfs in these 3 months, the dissolved-solids concentration at the Benjamin Franklin Bridge is greater than 100 ppm, and the concentration increases as the discharge becomes smaller. At Marcus Hook the annual mean dissolved-solids concentration is 180–300 ppm and is relatively uninfluenced by variation in water discharge if the discharge rate at Trenton exceeds 5,000 cfs. At lower rates of flow the mean annual dissolved-solids concentration increases as the July-August-September discharge decreases. The principal source of fresh water is the Delaware River at Trenton, although some fresh water comes also from the Schuylkill River and other tributaries. A high rate of fresh-water discharge flushes out the river and opposes factors such as high sea level or onshore winds that favor the intrusion of salt water from the sea.

The median pH is 6.9 in the reach of the river from Bristol-Burlington Bridge to Torresdale, 6.6 from Lehigh Avenue to League Island, and 6.5 from Eddystone to Marcus Hook. Water temperatures range from 33° to 86°F, the median temperature being near 58°F.

Dissolved oxygen is brought into the estuary with fresh water at Trenton, by tidal water in the lower estuary, by photosynthesis, and through the air-water interface. This oxygen is consumed in the oxidation of organic pollutants, a process which proceeds faster in the warm water of summer than in the cold water of the other seasons. Dissolved oxygen is at a lower concentration from May or June to October or November than during the winter months. As the water moves downstream, dissolved oxygen is consumed, and its concentration generally reaches a minimum near Wharton Street but increases slightly from there to Marcus Hook.

Owing to photosynthesis, the concentration of dissolved oxygen is greater in daylight than at night. Since the samples of water were always taken in daytime, the daily mean dissolved-oxygen concentrations were probably lower than those reported in the plots and tables. There is no evidence of a trend in dissolved-oxygen concentrations over the 14-year period, except that the lowest minimum concentrations were those of the July to November 1950 period in the reach of the river from Wharton Street to League Island. At Benjamin Franklin Bridge one-half of the samples were more than 55 percent saturated with dissolved oxygen, one-third less than 30 percent saturated.

When streamflow is high, sediment is picked up by the moving water and carried downstream, so that the sediment concentration increases from Bristol to Marcus Hook. Dredging also stirs up sediment and increases its concentration in the water at and downstream from the dredging area.

In the reach of river which includes the eight sampling stations, the water quality generally varied little in the cross section of the river. In most of this reach of river most of the time, the specific conductance of the water on the Pennsylvania side may be 5 percent greater than on the New Jersey side, and the dissolved-oxygen concentration about 0.7 ppm less on the Pennsylvania side than on the New Jersey side, but temperature and pH are uniform. This situation may be the result of a greater concentration of industries and people on the Pennsylvania side with a consequent greater flow of wastes to the river. The analyses presented in this report, however, are of the cross section, including the channel and therefore are representative of most of the water flowing past each of the eight sampling stations.

The cross-sectional variation in water quality at Marcus Hook is somewhat greater than at the upstream stations. Here the bottom samples usually have specific conductances 5–10 percent greater than the top samples, and dissolved-oxygen concentrations are about 1.0 ppm lower on the Pennsylvania side. Most of the time the conductance of water on the Pennsylvania side is slightly greater than that of the water on the New Jersey side, but this situation is often reversed when the dissolved-solids concentration of the water is greater than 360 ppm.

At all stations the water quality varies twice daily with the ebb and flood of the tide. The salinity is greatest at time of slack water following high tide and lowest at the time of the slack water following low tide. The maxima and minima in dissolved-oxygen concentration often occur at slack water also, but whether the concentration of dissolved oxygen increases or decreases as the tide floods depends upon the dissolved-oxygen concentration in the reach of stream directly downstream from the sampling station.

This report summarizes the results of monthly sampling over a 14-year period. During most of this period, there were few instruments to continuously record water-quality data.

In 1955 the U.S. Geological Survey installed the first recording instrument in the estuary for continuously measuring and recording specific conductance, and in 1959 dissolved-oxygen and temperature recorders were installed. In 1964, in the reach of the estuary between Bristol and Marcus Hook, temperature was continuously recorded at or near four of these monthly sampling stations, specific conductance at three, dissolved oxygen at four, pH at one, and turbidity at one. In addition, tidal-flow volume is measured at one point (Palmyra, N.J.), and tide gages record water-level fluctuations at about a dozen locations in this reach (Miller, 1962). Hand sampling is still required to establish a relation between the cross section and the continuously recorded values to check on the accuracy of the instrument record and to collect samples for types of analyses which have not yet been adapted to recording instruments such as biochemical-oxygen demand. Obviously, in the future the greater frequency of measurement by automatic instruments will give more information about the range in water-quality characteristics and determine more precisely when variations occur.

Although a much more detailed description of water quality in this reach of the estuary will soon become available through the use of recording instruments, it is nevertheless useful now to summarize these monthly analyses for the period 1949–63. This period includes a range of conditions and exhibits the extent to which water-quality parameters varied with change in hydrologic and environmental conditions. This compendium of water-quality data is useful as an explicit statement of water quality during the 14-year period and is valuable for directing attention to water-quality problems, for selecting instrument sites, and for making comparative studies with the more detailed information which is already being obtained with the aid of recording instruments.

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