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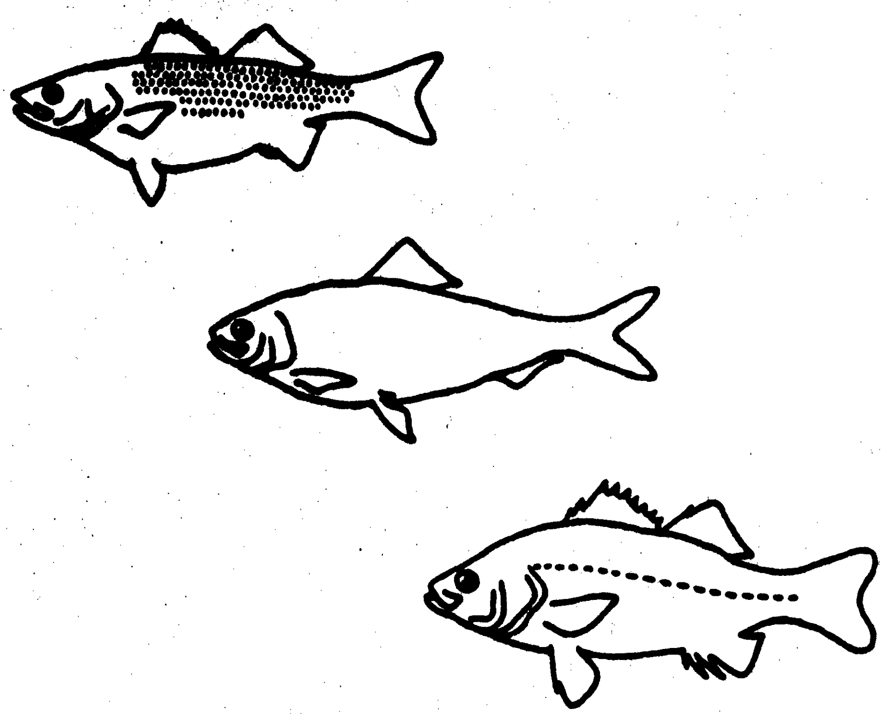
John L. Wood

RAPPAHANNOCK RIVER SURVEY 1951



Virginia Fisheries Laboratory

1 December 1952

Volume II

A BIOLOGICAL SURVEY

OF THE

RAPPAHANNOCK RIVER

VIRGINIA

PART II

By

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1 December 1952

Virginia Fisheries Laboratory
Special Scientific Report
No. 6.

INVERTEBRATES TAKEN IN NET HAULS

Syrton

The nylon nets, one meter in diameter, used primarily for the collection of eggs and larvae of fishes, collected also considerable numbers of drifting invertebrates or syrton, and often tremendous quantities of organic debris. The presence of this debris, mostly partially decayed leaves and twigs, interfered considerably with the sorting of collections. Because the number of samples taken by this method was large, it was impractical to isolate the smaller organisms, but rough estimates of the relative abundance of the larger forms were possible. These estimates were coded as follows:

Order of abundance	Numbers of organisms	
0	0	(absent)
1	1 - 10	(rare)
2	11 - 100	(common)
3	101 - 1,000	(abundant)
4	1,001 - 10,000	(very abundant)

Many of these organisms were immature stages of insects. These were classified as follows: Odonata (dragonfly nymphs), Ephemerida (mayfly nymphs), and Chaoborus (fly larvae). Amphipods, represented by the genus Gammarus, Cladocera, or water fleas, represented by the genus Leptodora, and Isopods, were also recorded. These organisms are important items in the food of fishes in fresh waters, and therefore the records give information on the relative abundance of fish food in various sections of the river throughout the season.

With the exception of Leptodora and Chaoborus, which are typical planktonic forms, these organisms live normally on the bottom. When two nets were fished, one at the surface and one near the bottom, the bottom net nearly always captured the larger numbers of drifting forms.

The accompanying illustrations (figures 24-27) show the average relative abundance of Gammarus, Chaoborus, Leptodora, and all invertebrates at each station from Fredericksburg to Tappahannock. The scale of abundance is approximately logarithmic, that is, each unit increase in the index of abundance represents a tenfold increase in the number of organisms. From station 76 upstream to Fredericksburg, 10 organisms or less were taken per unit volume of water. Downstream from station 76, the abundance of organisms rose rather rapidly, and from stations 50 to 37 it decreased again. Since Chaoborus and Leptodora do not live in brackish or sea water, this decrease in abundance in the vicinity of Tappahannock would be expected. The large numbers of Gammarus in this region may indicate the intrusion of brackish-water or marine species. Mayflies, dragon-flies, and isopods were not sufficiently abundant to give a clear picture of their distribution along the river.

The average indices of abundance of Gammarus over the period of the first nine cruises indicate that the genus was most abundant during cruise 1, and became progressively less abundant as the season progressed. Chaoborus, on the other hand, seemed to increase to its maximum abundance during cruise 5, and then decreased rather regularly in abundance to cruise 9. Data on the other groups of organisms are too scanty for analysis.

Figure 24

Relative abundance of Gammarus per station in the Rappahannock River in 1951

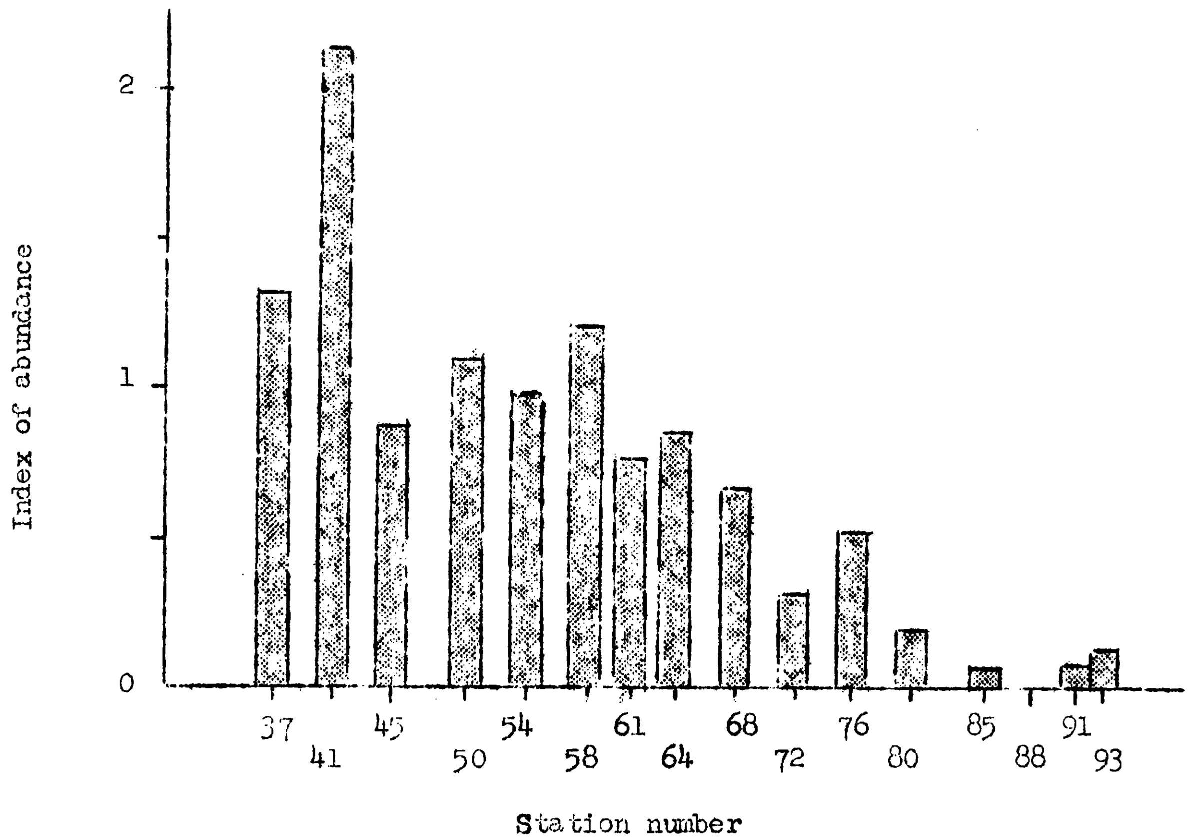


Figure 25

Relative abundance of Chaoborus per station in the Rappahannock River in 1951

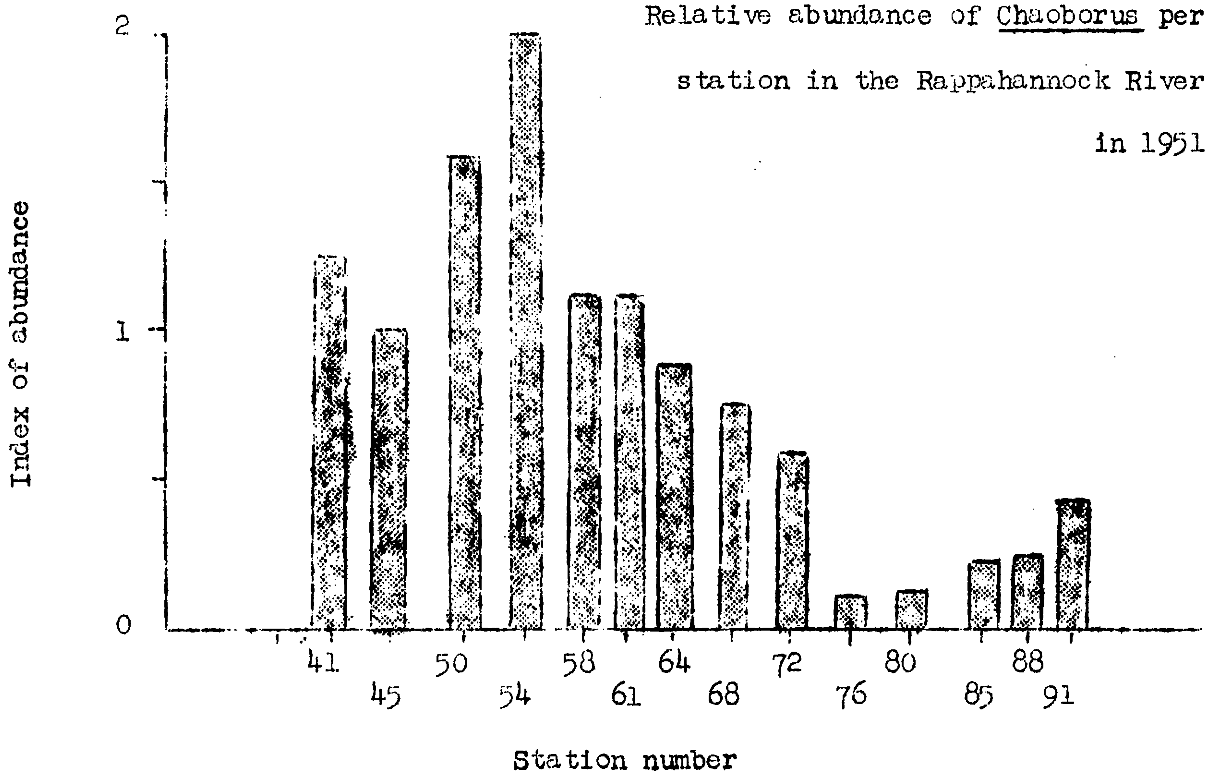


Figure 26

Relative abundance of Leptodora per station

in the Rappahannock River in 1951

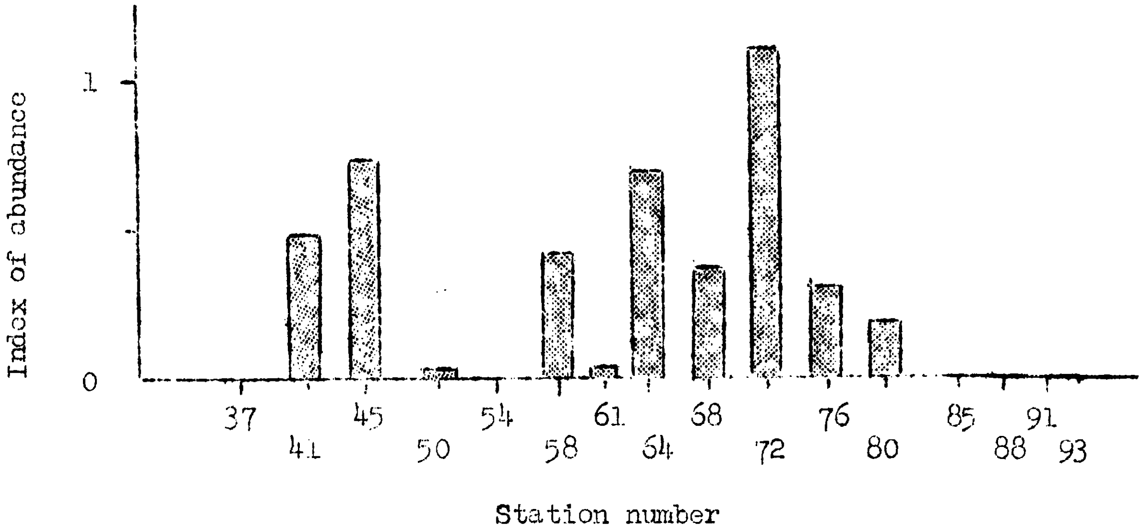
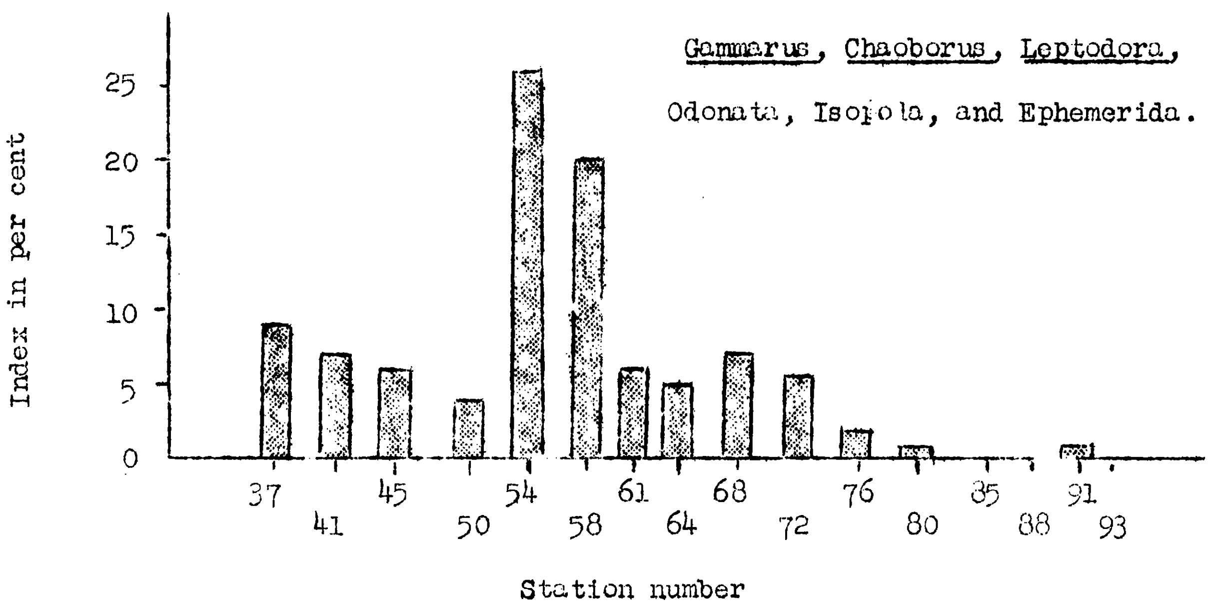


Figure 27

Relative abundance of all invertebrates caught by meter nets in the Rappahannock River in 1951. Based on the unweighted averages of the indices of abundance of Gammarus, Chaoborus, Leptodora, Odonata, Isopoda, and Ephemerida.



Limited information on the distribution of <u>Gammarus</u> (the most abundant invertebrate in the net hauls) in the Pamunkey River indicates that this genus was most abundant from station 48 to station 51 and less abundant upstream and downstream. In the Mattaponi River, on the other hand, <u>Gammarus</u> seems to increase in abundance going upstream from station 27 to station 50.

Plankton

At each station, on each cruise, a 50-liter sample of surface water was taken. This was strained through a plankton net made of #19 bolting silk, and the sample of plankton was preserved in 5 per cent formalin. The sample was thoroughly mixed in the laboratory, and all organisms contained in a one-milliliter subsample were counted. The counts were converted by appropriate correction factors to give the total number of organisms per unit volume of water strained.

Specific identification of the organisms was not possible in the time available. Instead, they were classified according to major groups as follows:

<u>Phytoplankton</u>

Algae: non-filamentous

filamentous

Diatoms

<u>Zooplankton</u>

Protozoa

Rotifers

Copepods and copepod nauplii

<u>Algae</u>.--The production of algae remained at a relatively low level until cruise 6, when a considerable bloom appeared in the river in

the vicinity of Portobago Bay (stations 50 to 64). This condition persisted through cruise 9, and during this period the tremendous concentration of algae, particularly filamentous forms, interfered with the collection of fish eggs and larvae by clogging the nets.

(1) Non-filamentous forms.--The greatest average production per station was encountered during cruise 6 (figure 28), when large numbers of non-filamentous algae were taken at stations 58, 61, and 64. Counts of 500 or more cells per liter were encountered at the following stations:

Cruise	Stations	Average number of cells per liter
6	58, 61, 64	3800
7	45, 50, 61	700
8	50	900
9	61, 64	600
13	91	600
14	64	600
15	50, 58, 61, 64	1400
16	50, 58	1700
17	64	600
19	85	600

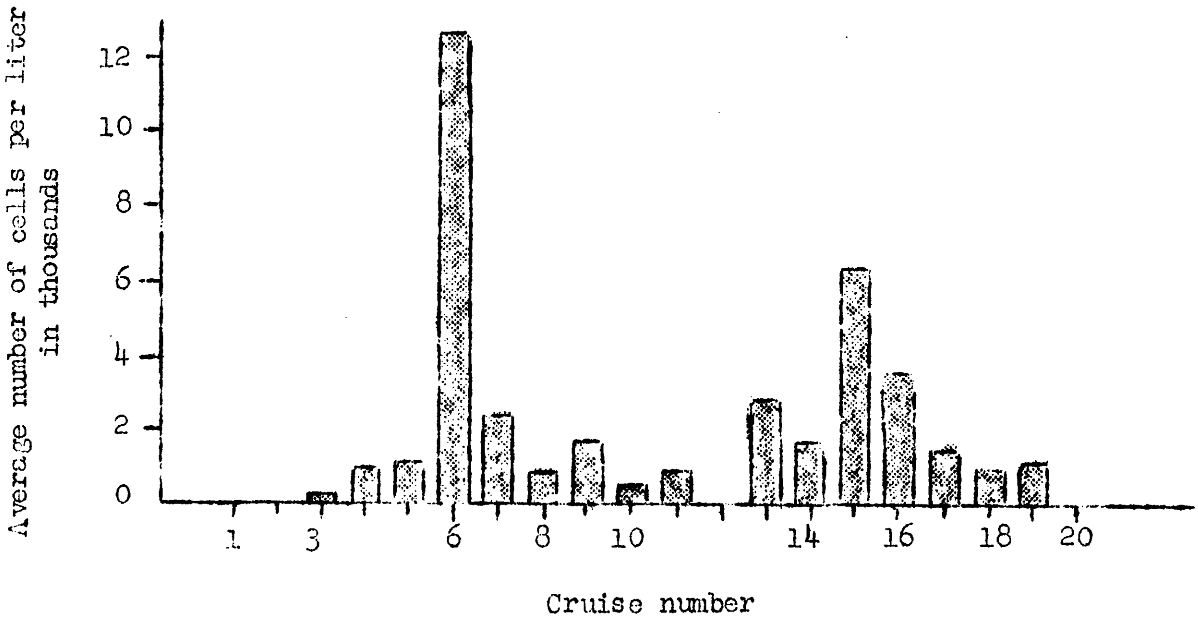
A maximum was reached during cruise 6, and a second, but lower maximum during cruises 15 and 16. During the period of the survey the average standing crop was highest at stations 58, 61, and 64, and fairly high at station 50.

(2) Filamentous forms.--Filamentous algae were relatively scarce until cruise 6, when the numbers began to rise sharply at stations 50

Figure 28

Average numbers of non-filamentous algae per liter

of water in the Rappahannock River in 1951



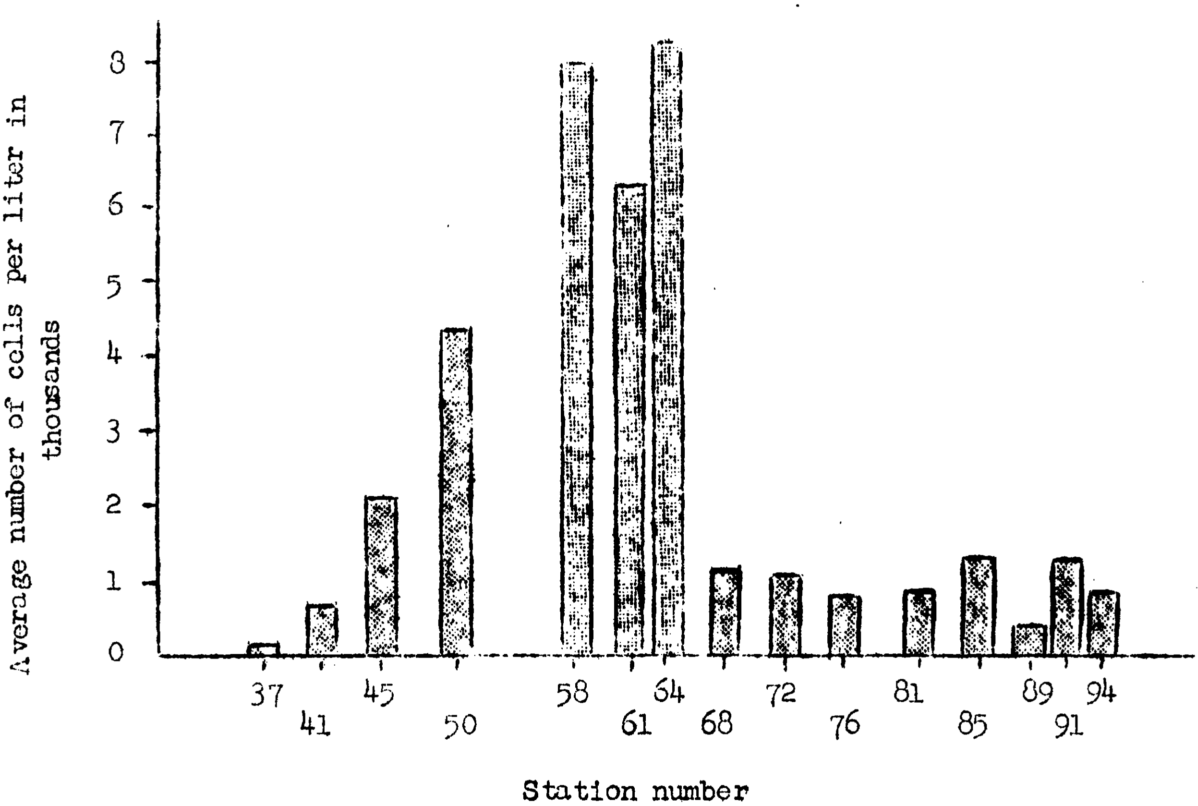
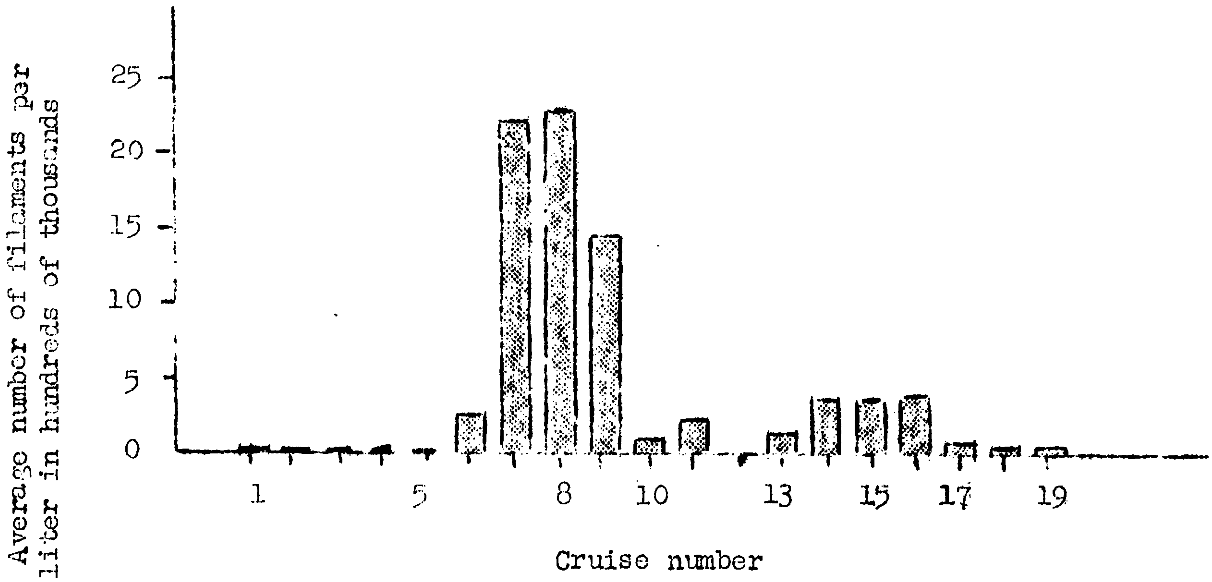
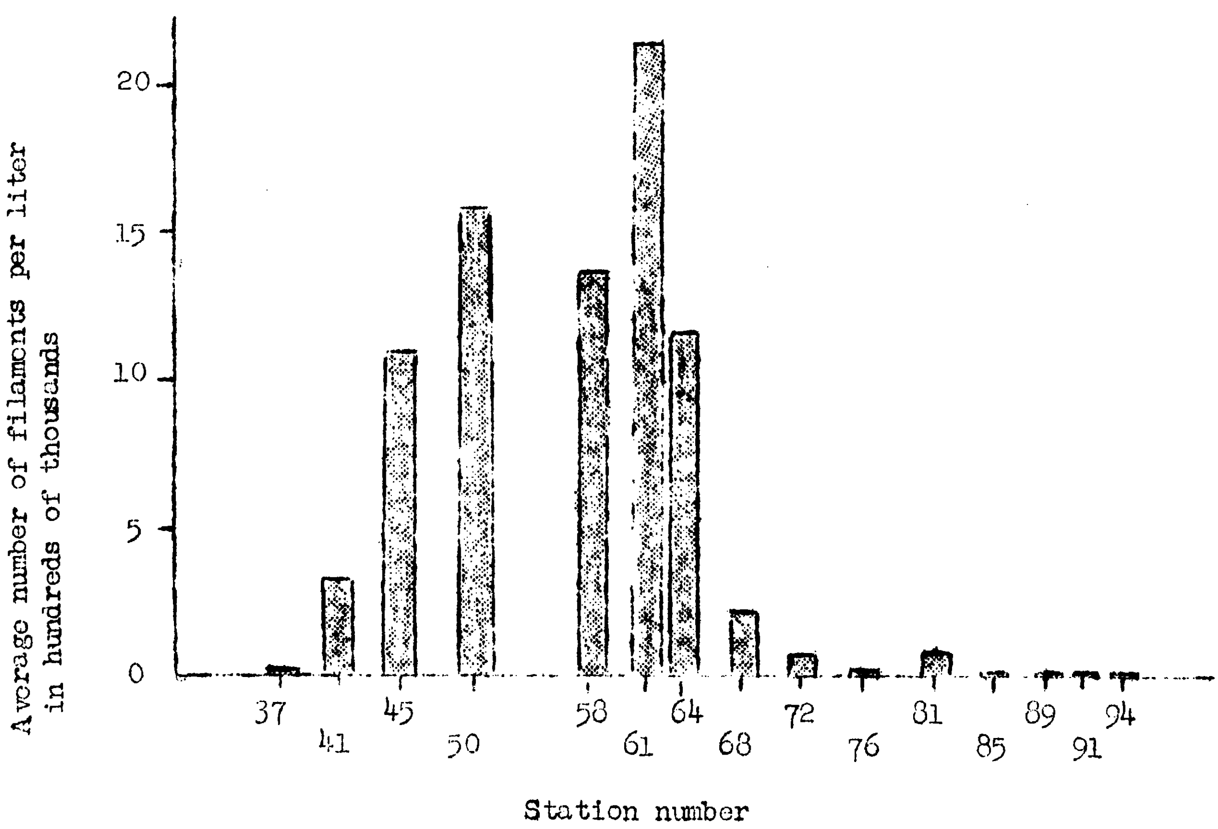


Figure 29

Average number of filaments of filamentous algae

in the Rappahannock River in 1951





to 64 inclusive (figure 29). The stations at which counts of 50,000 or more filaments per liter were made are listed below:

Cruise	Stations	Average number of filaments per liter
6	61, 64	84,000
7	45, 50, 58, 61, 64	433,000
8	41, 45, 50, 58, 61	453,000
9	45, 50, 58, 61, 64	292,000
11	45	168,000
13	81	72,000
14	50, 58, 61, 64	91,000
15	58, 61, 64, 68	80,000
16	61, 64	150,000

The height of the bloom was reached during cruise 7, when 756,000 filaments per liter of water were taken at station 61, and cruise 8, with 618,000 at the same station. A second maximum occurred on cruise 16, with 183,000 at station 64. This tremendous production of phytoplankton was centered in the region of Portobago Bay. Similar conditions were observed in this vicinity during 1950.

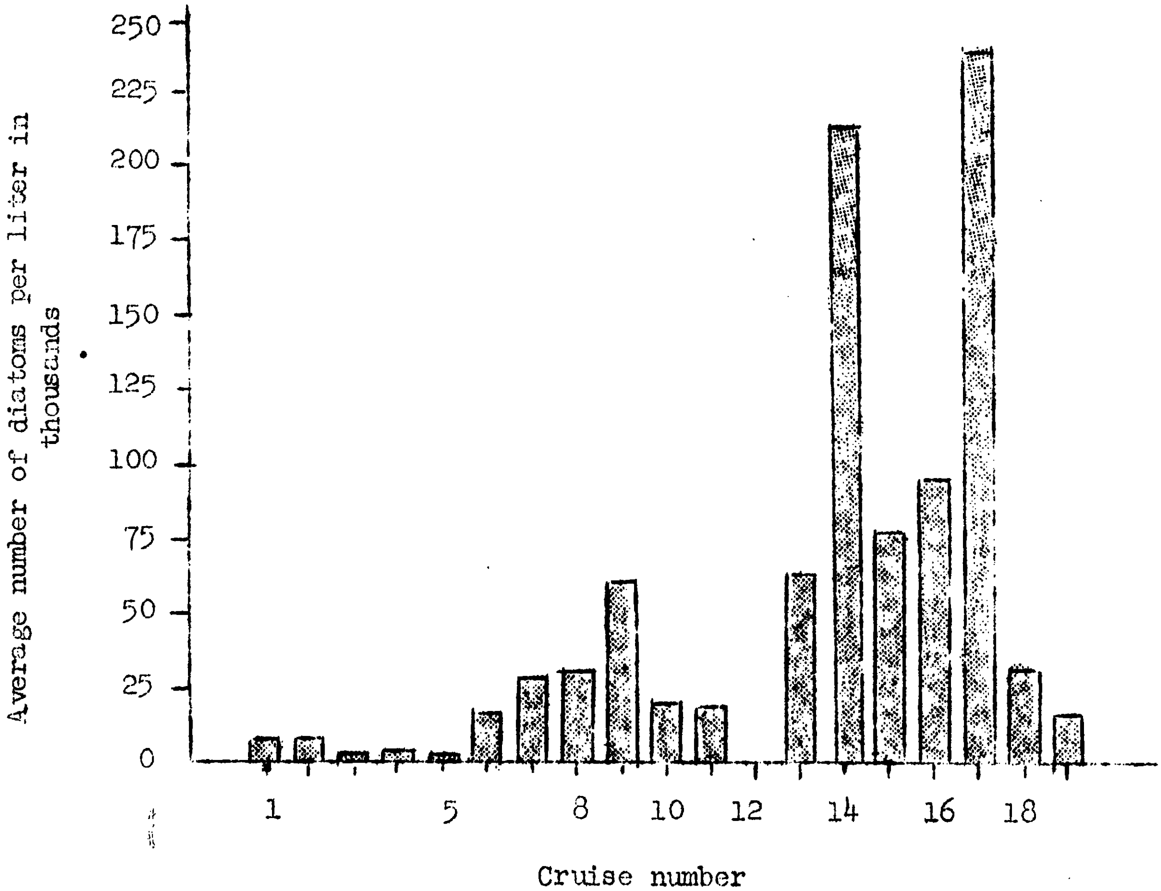
Diatoms.--The production of diatoms first reached 5,000 cells per liter of water on cruise 6 at station 58 (figure 30). During the period of the survey, counts of 5,000 cells or more were recorded at the following stations:

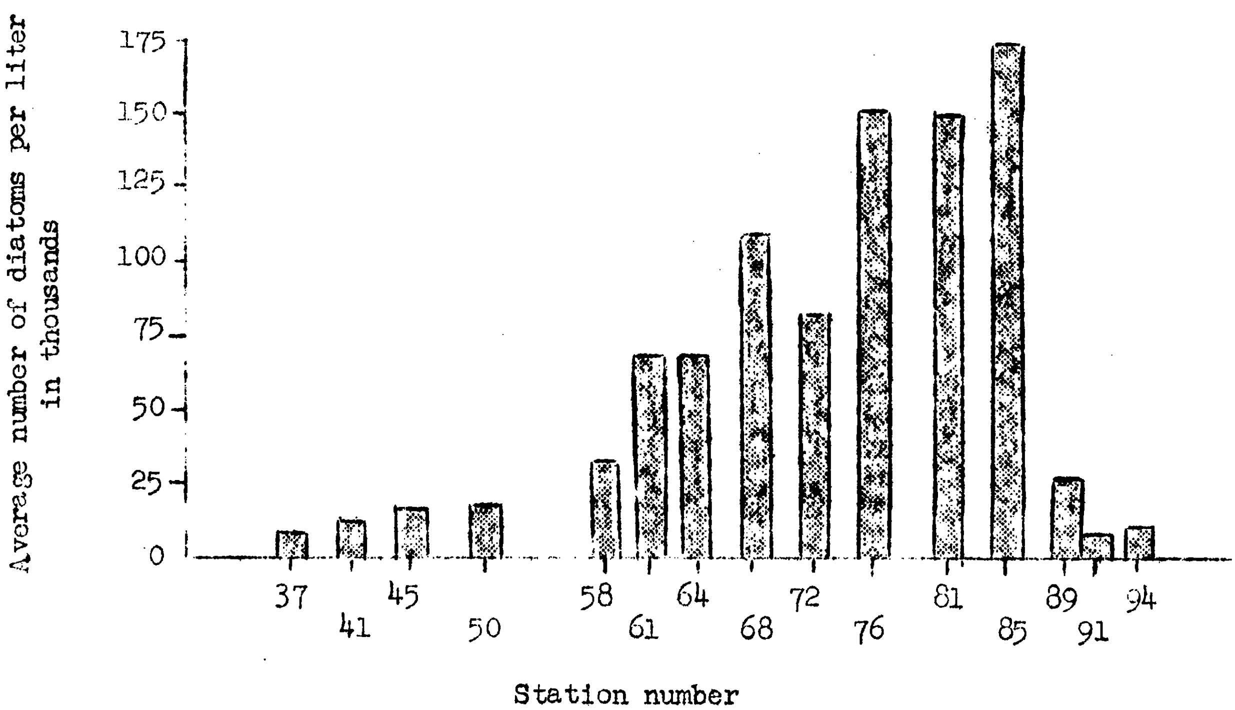
Cruise	Stations	Average number of Cells per liter
6	58	5,200
7	61	12,100
8	61	14,400

Figure 30

Average number of diatoms per liter of water

in the Rappahannock River in 1951





Cruise	Stations	Average number of cells per liter
9	58, 61, 64	15,300
10	76, 81	7,900
13	68, 72, 76	18,000
14	58, 61, 64, 68, 72, 76, 81, 85	25,800
15	68, 72, 76, 85	15,500
16	64, 72, 81, 85, 89	16,500
17	76, 81, 85, 89	56,000
18	72	13,700

Three maxima were recorded: cruise 9, with more than 21,000 cells per liter at station 61; cruise 14, with more than 69,000 at stations 68 and 76; and cruise 17, with over 100,000 at station 85. The point of maximum diatom abundance shifted gradually upstream throughout the period of the survey.

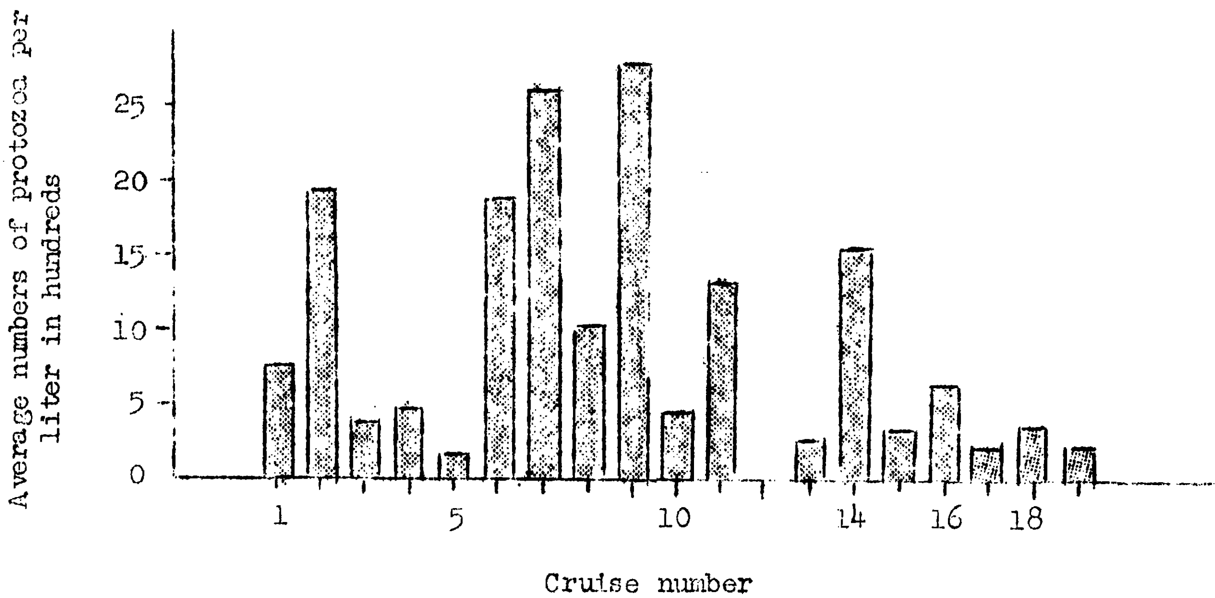
Protozoa.--Counts of protozoa were based on certain readily identified forms such as Difflugia. The numbers observed were not large, and this, in conjunction with the difficulty of identification, probably has contributed to the irregular distribution of these organisms in time and space (figure 31). In general, protozoa seem to have been most abundant in the early part of the season, and in the vicinity of stations 50 to 76. Relatively large numbers were also taken at station 94, above the American Viscose Corporation plant.

Rotifers.--In general, rotifers were more abundant than protozoa, but less abundant than diatoms. The counts reached 500 individuals or more per liter of water at stations 61 and 64 on cruise 6 (figure 32). During the period of the survey, 500 or more per liter were

Figure 31

Average numbers of protozoa per liter of water

in the Rappahannock River in 1951



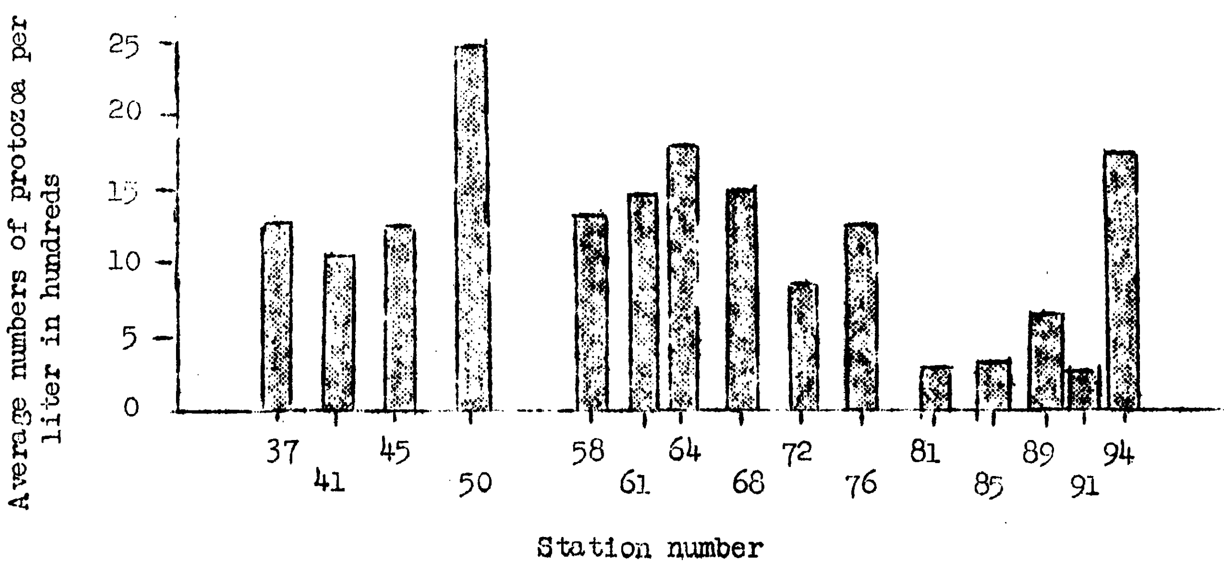
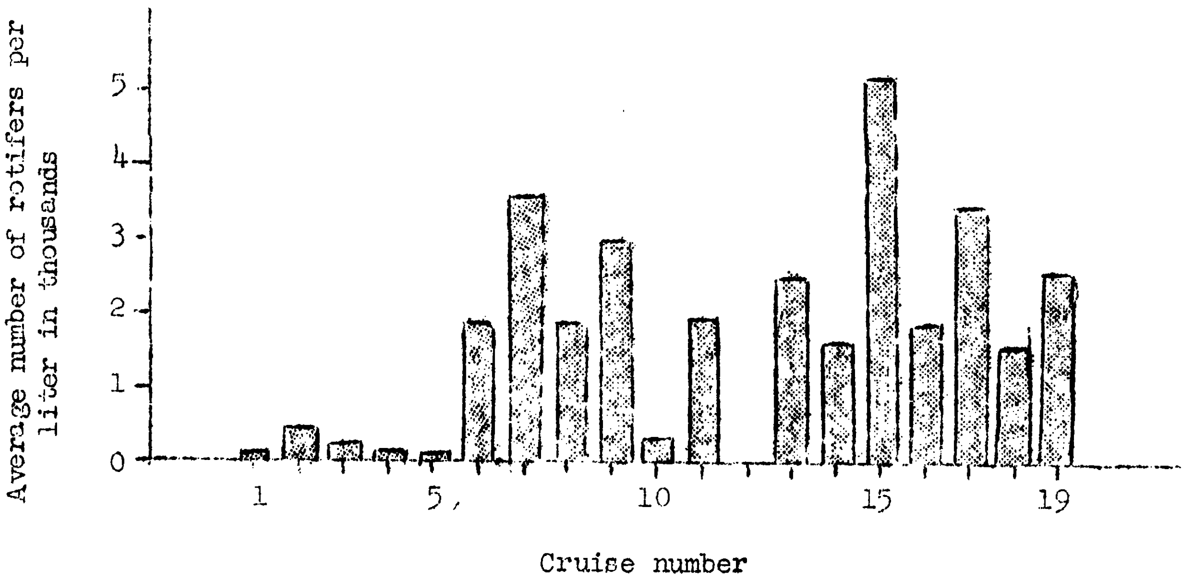
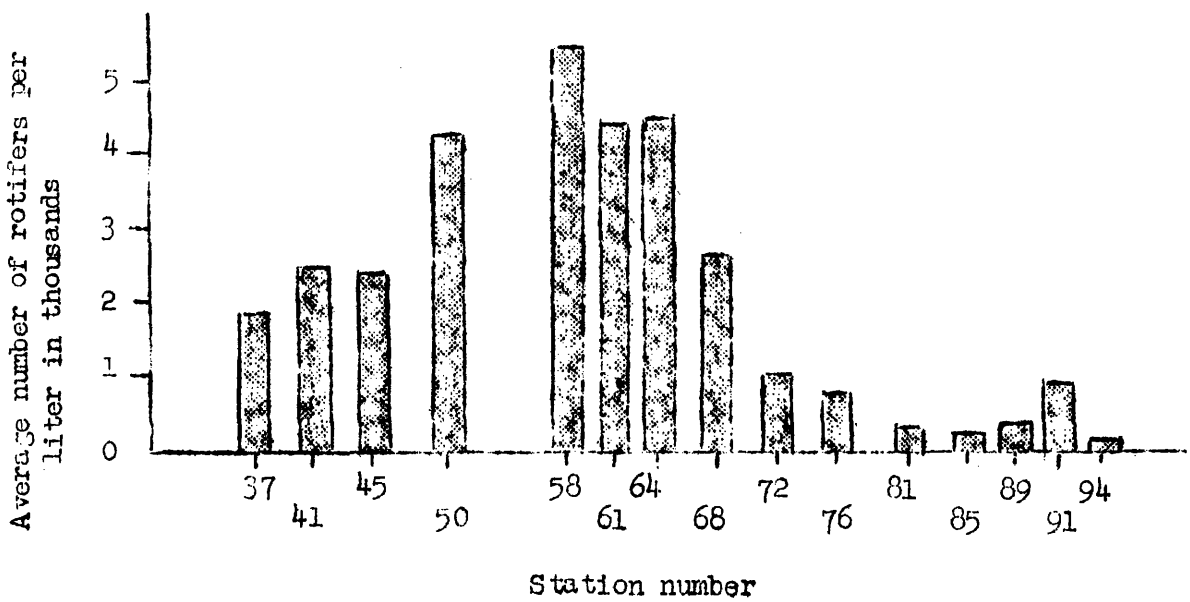


Figure 32

Average numbers of rotifers per liter of water

in the Rappahannock River in 1951





counted at the following stations:

Cruise	Stations	Average number of rotifers per liter
6	61, 64	600
7	50, 58, 61	1,000
8	41, 50, 58	600
9	50, 58, 61, 64	700
11	45	900
13	58	500
14	58, 61	700
15	58, 61, 64, 68	1,000
16	64	900
17	37, 41, 45, 64, 68	600
18	41	500

Two rather broad maxima occurred, during cruises 6 to 9, and cruises 13 to 19. Abundance was greatest in the region from station 50 to station 68. Toward the end of the season the abundance of rotifers was also relatively high from station 37 to station 45.

Copepods and Copepod nauplii.--On the average, copepods and their nauplii were slightly less abundant than rotifers. Counts of 300 or more per liter of water were distributed as follows:

Cruise	Stations	Average number of copepods per liter
2	37	300
3	37	400
5	37, 41	300
6	37	300
7	61, 64	900

Cruise	Stations	Average number of copepods per liter
8	37, 41, 61	1,100
9	41, 50, 58, 64	500
13	45	400
14	61, 68	1,000
15	37, 41, 61, 72	700

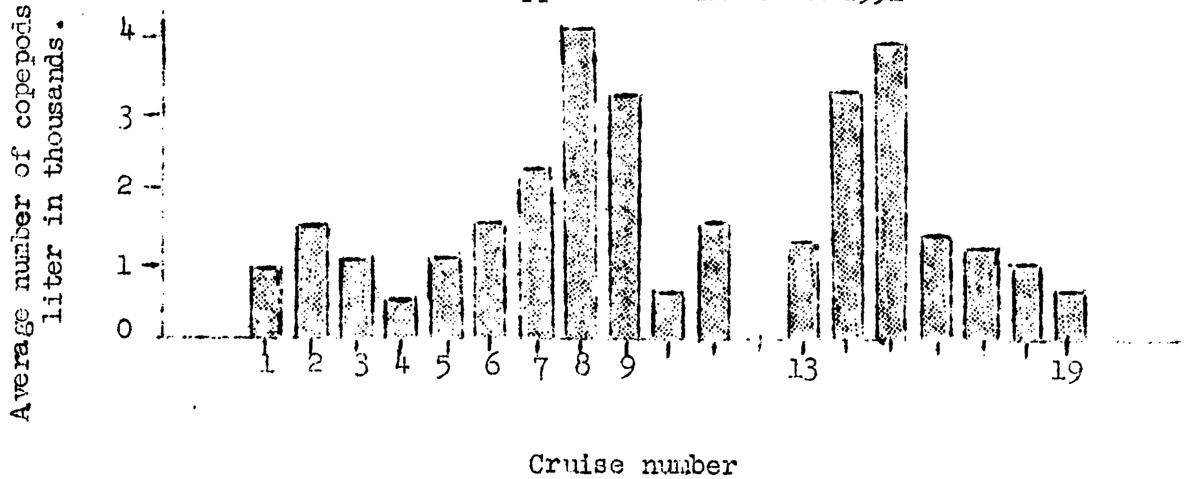
The increase in average abundance in the region from station 45 to station 37 (figure 33) is probably associated with the intrusion of brackish-water and marine species. Abundance in the fresh-water section of the river was greatest at station 61.

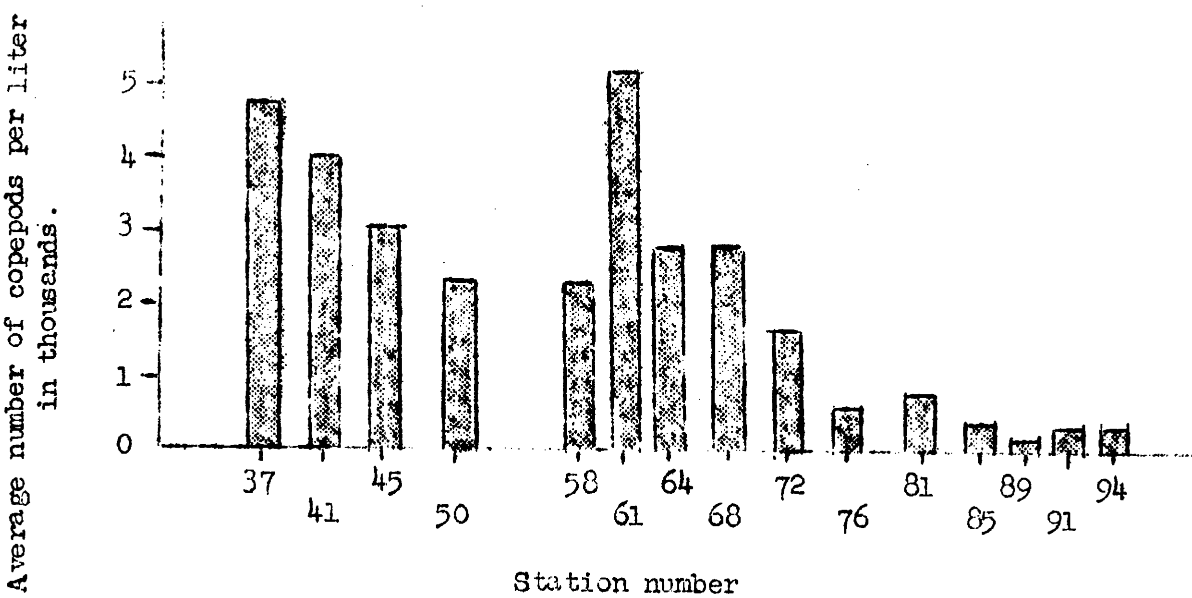
Copepods were especially abundant during two periods: cruise 8 to cruise 9, and cruises 14 and 15. The first maximum was due chiefly to an increase in abundance at stations 37 and 41, although copepods were also numerous at station 61 during cruises 7 and 8, at stations 50, 58, and 64 during cruise 9, and at station 64 during cruise 7. The second maximum was largely caused by high counts at stations 61 to 68, although copepods were also more abundant than usual at stations 37 and 41 during cruise 15. The smaller maximum on cruise 2 was caused by relatively high numbers of copepods at station 37.

Comparison of the Rappahannock with other rivers.--Although the Pamunkey and Mattaponi Rivers were not investigated as thoroughly as the Rappahannock during 1951, the distribution and relative abundance of plankton organisms may be compared for cruises that were made at approximately the same time. For this purpose, data are available for cruises R 10 (4 June 51), P 2 (28-29 May 51), and M 1 (30 May 51); and cruises R 18 (17 August 51), P 3 (11 August 51), and M 2 (14 August 51).

Figure 33

Average numbers of copepods and copepod nauplii per liter of water in the Rappahannock River in 1951





The numbers of organisms per liter of water strained were averaged for the three sections of each river, and the indices of abundance expressed as ratios of the abundance in section I of the Rappahannock (tables 37 and 38).

The data indicate that in late May and early June the Rappahannock exceeded the other rivers in the production of filamentous algae in all three areas, in production of non-filamentous algae in sections I and II, and in production of diatoms and protozoa in section III. In August the Rappahannock was highest in the production of algae (filamentous and non-filamentous, and diatoms) and equalled or slightly exceeded the other rivers in numbers of rotifers. In general it would appear that more phytoplankton and fewer zooplankton organisms per unit volume of water are produced in the Rappahannock than in the Pamunkey and the Mattaponi Rivers. However, it must be remembered that this is based on measures of the standing crop of organisms, and also that there is often an inverse relationship between the standing crops of phyto- and zooplankton.

CHEMICAL AND PHYSICAL CHARACTERISTICS

Water samples were taken from surface and bottom at each station on cruises 1 to 19 in the Rappahannock River, cruises 2 and 3 in the Pamunkey River and cruises 1 and 2 in the Mattaponi River. Determinations were made of dissolved oxygen, pH, salinity, and sulphates. Records also were made of water temperature, light penetration, and current velocity. The chemical and physical determinations are summarized in appendix tables A-1 through A-11.

Five series of observations were made at short intervals over complete tidal cycles. The results of these determinations are

Table 37

Relative abundance of plankton organisms in the Rappahannock, Pamunkey, and Mattaponi Rivers, May 28 to June 4, 1951

Organisms	Cruise	River areas I	II	III
Non-filamentous algae	R 10	1	8.10	1.25
	P 2	0	0	24.91
	M 1	0	0	- *
Filamentous algae	R 10	1	2.87	0.13
	P 2	0.01	0.06	0.05
	M 1	0.04	0.15	-
Diatoms	R 10	1	1.98	9.21
	P 2	2.43	8.28	3.58
	M 1	38.07	15.03	-
Protozoa	R 10	1	1.25	26.34
	P 2	23.66	21.18	0
	M 1	11.63	29.90	-
Rotifers	R 10	1	1.25	4.16
	P 2	4.99	27.72	19.31
	M 1	24.91	29.48	-
Copepods and copepod nauplii	R 10	1	0	0.20
	P 2	3.74	1.39	3.22
	M 1	0.49	4.89	-

* No stations were occupied in Section III of the Mattaponi River.

Table 38

Relative abundance of plankton organisms in the Rappahannock, Pamunkey, and Mattaponi Rivers, August 11 - 17, 1951

Organisms	Cruise	River areas I	II	III
Non-filamentous algae	R 18	1	1.25	1.25
	P 3	0	0.37	0.12
	M 2	0	0.50	0.50
Filamentous algae	R 18	1	2.06	0.02
	P 3	1.83	0.99	0.10
	M 2	0.70	0.17	0.05
Diatoms	R 18	1	9.23	2.93
	P 3	1.68	1.84	0.91
	M 2	1.39	2.19	0.30
Protozoa	R 18	1	0.47	0.21
	P 3	6.70	0.94	0.47
	M 2	4.78	0.83	0.31
Rotifers	R 18	1	0.20	0.20
	P 3	0.30	0.06	0.26
	M 2	0.83	0.35	0.20
Copepods and copepod nauplii	R 18	1	1.67	0.04
	P 3	5.39	1.14	0.52
	M 2	3.88	1.11	0.63

summarized in appendix tables A-12 through A-16.

Chemical Determinations

Dissolved oxygen.--Dissolved oxygen was measured by the Winkler method, as outlined in Standard Methods for the Examination of Water and Sewage (American Public Health Association, 1946). To check on the validity of the unmodified Winkler method in this area the Standard Winkler and the alkaline-hypochlorite modification were compared in the vicinity of the waste discharge from the American Viscose Corporation May 4, 1951. Only small differences were obtained:

Station	Standard Winkler	Alkaline-hypochlorite modification
91.2	8.20 p.p.m.	8.05 p.p.m.
91.8	8.22 p.p.m.	8.15 p.p.m.
92.8	8.59 p.p.m.	8.56 p.p.m.

The use of the Standard Winkler method in the Fredericksburg vicinity appears justified. For general analysis, the results of surface and bottom samples have been averaged. Since the per cent of saturation is probably of greater significance biologically, all values have been converted to this figure.

On cruises 1 to 9 river runoff was sufficient to maintain oxygen levels above 50 per cent of saturation. This level is believed to be the minimum for the maintenance of a well-balanced, warm-water fish fauna in Virginia tidal rivers. On cruises 10, 14, 15, 17, 18, and 19, dissolved oxygen fell below 50 per cent of saturation at one or more stations (table 39). The extent of the region affected by low oxygen values is shown in table 40 and figure 34. Approximately 3.9

Table 39

Oxygen saturation values for the Rappahannock River at stations 68.2-93.6 between June 4, 1951, and November 9, 1951./1 The double lines enclose areas in which saturation values were below 50 per cent. Where the limits of this area were not specifically determined, the approximate limits are indicated by dashed lines.

Survey	Date	Station 68.2	72.3	76.3	80.6	85.2	88.6	91.2	93.6
Virginia Fisheries Laboratory	6- 4	90	78	69	60	62	42	69	93
	6-14	67	72	84	89	90	92	91	96
	6-19	70	73	67	74	77	80	84	96
	6-27	99	77	94	75	63	51	63	98
	7- 4	84	68	63	58	44	51	73	100
	7-11	102	73	72	94	56	45	53	100
	7-17	76	82	84	103	51	52	74	96
	8- 3	88	90	96	66	55	39	12	89
	8-17	88	79	20	29	21	12	8	79
	8-28	86	66	62	53	35	11	6	83
American Viscose Corporation	9- 6	86	-	-	-	47	-	3	77
	9-13	102	-	-	-	44	-	0	76
U.S. Public Health Service	9-26	98	91	87	75	49	16	0	50
	10- 3	100	97	93	88	43	40	8	105
	10-10	84	76	73	68	27	0	0	71
American Viscose Corporation	10-19	93	-	-	-	83	-	0	79
	10-28	88	-	-	-	2	-	2	87

/1 This time interval includes all determinations in which oxygen values were less than 50 per cent saturation.

Table 40

Approximate length, area, and volume of the zone in the Rappahannock River between Tappahannock and Fredericksburg where oxygen values of less than 50 per cent saturation were found 1951./1

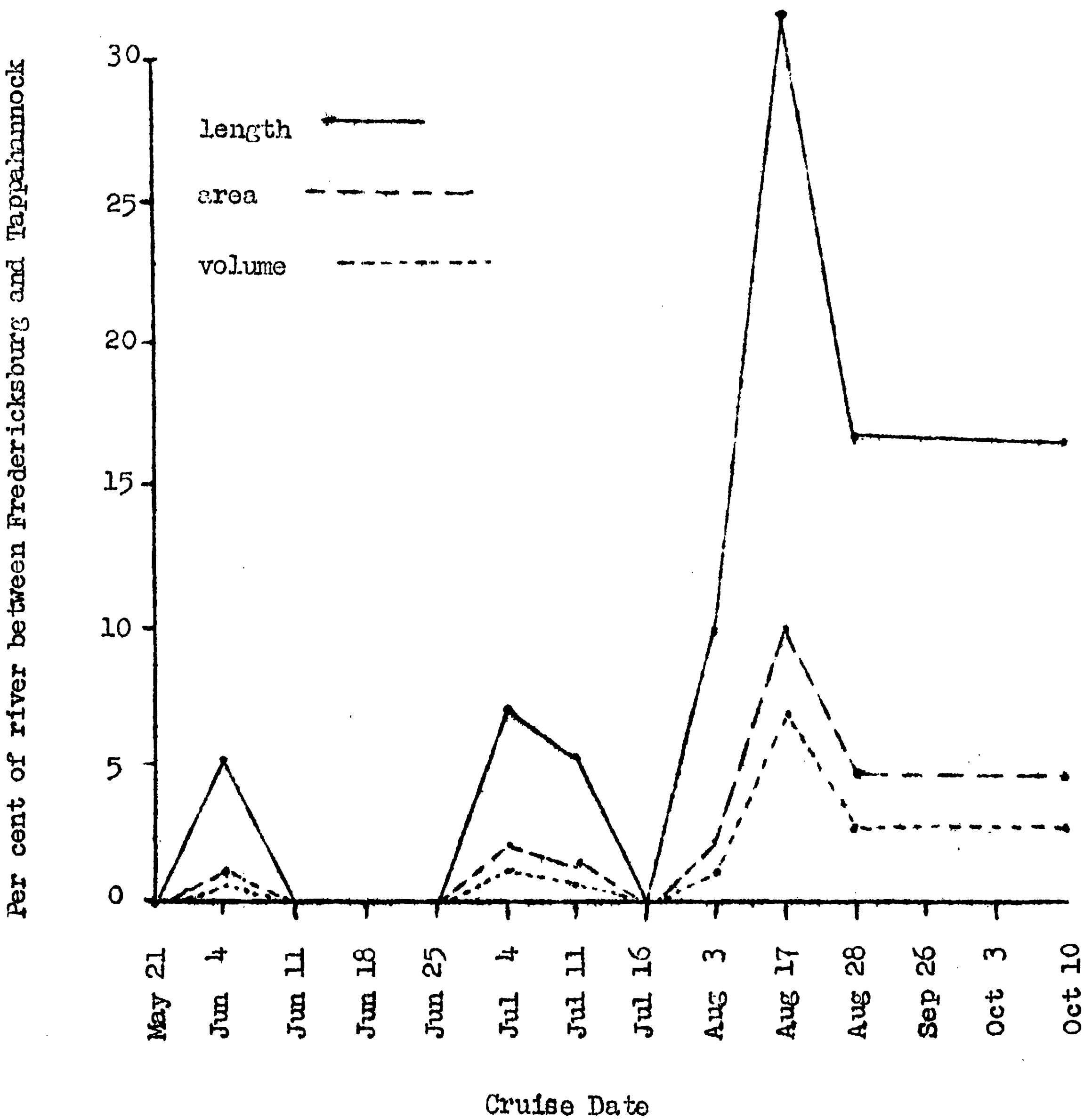
Cruise	Date	Extent of the low oxygen zone					
		Downriver station	Upriver station	Length miles	Per cent of length	Per cent of area	Per cent of volume
10	6- 4	88.6	88.6	3.0	5.3	1.4	0.8
14	7- 4	85.2	85.2	4.0	7.1	2.2	1.4
15	7-11	88.6	88.6	3.0	5.3	1.4	0.8
17	8- 3	88.6	91.2	5.5	9.7	2.4	1.4
18	8-17	76.3	91.2	18.1	31.9	10.2	6.9
19	8-28	85.2	91.2	9.5	16.8	4.6	2.8
/2	9-26	85.2	91.2	9.5	16.8	4.6	2.8
/2	10- 3	85.2	91.2	9.5	16.8	4.6	2.8
/2	10-10	85.2	91.2	9.5	16.8	4.6	2.8
Average of 9 cruises				7.9	14.1	4.0	2.5

/1 Hydrographic data collected at each station are assumed to be representative of water conditions half the distance to the next station.

/2 Data furnished by the U. S. Public Health Service.

Figure 34

Relative size of the region in the Rappahannock River between March 26 and October 10, 1951, where oxygen values were less than 50 per cent of saturation.



per cent of the total river area between Tappahannock and Fredericksburg and 2.5 per cent of the river volume was affected during the period June 4 to October 10.

To compare the oxygen saturation values on the Rappahannock River with those from rivers not affected by industrial and domestic wastes a cruise was made in the Pamunkey River on August 11, and in the Mattaponi River on August 14. Oxygen saturation values are compared with the August 17 cruise in the Rappahannock River in figure 35. With the exception of the low oxygen zone, the Rappahannock River is generally higher in dissolved oxygen than either of the other rivers. Results of oxygen determinations on the Mattaponi River indicate that during the summer months oxygen levels may approach the minimum levels found in unpolluted river waters.

Hydrogen ion concentration.--Hydrogen ion concentrations were measured using a Coleman pH meter on cruises 1 to 9 and a Beckman pH meter on cruises 10 to 19. In the vicinity of Fredericksburg pH values did not go below pH 6. Downstream greater variations were noted, the pH ranging from 7 to 9. As illustrated in figure 36, the range of variation per cruise varied from 1 to 2.3 pH units. The higher pH values appear to coincide with the more intense plankton blooms. A hydrogen ion concentration of 6.3 cannot be considered lethal to fishes; however, pH 9.0 is rather close to the limit of toleration for some of the more delicate species and may have a detrimental effect on fish larvae.

A comparison of the mean pH for the spring and summer cruises on the Mattaponi, Pamunkey and Rappahannock Rivers is shown below:

Figure 35

Comparison of the dissolved oxygen in the Rappahannock, Pamunkey and Mattaponi Rivers in August 1951.

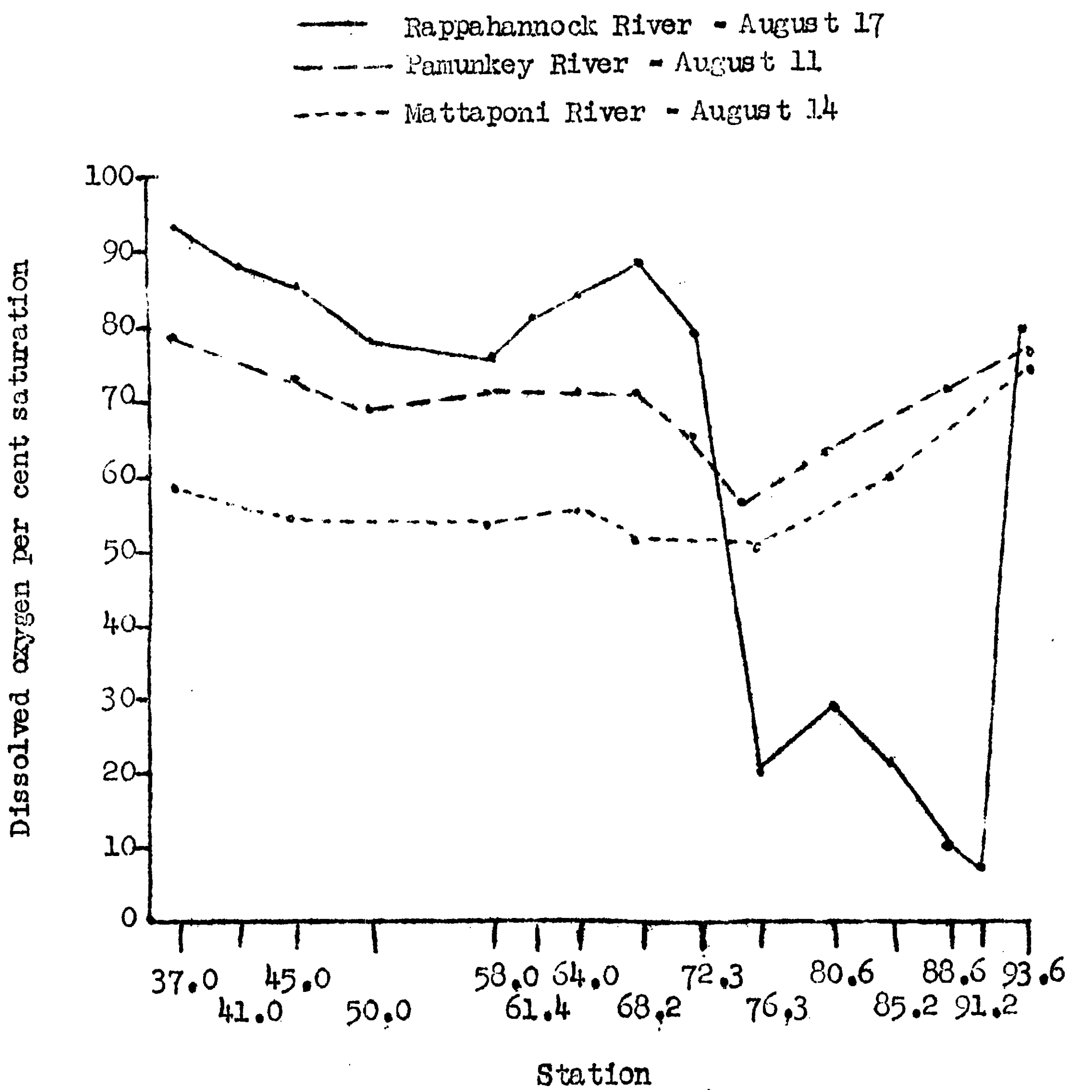
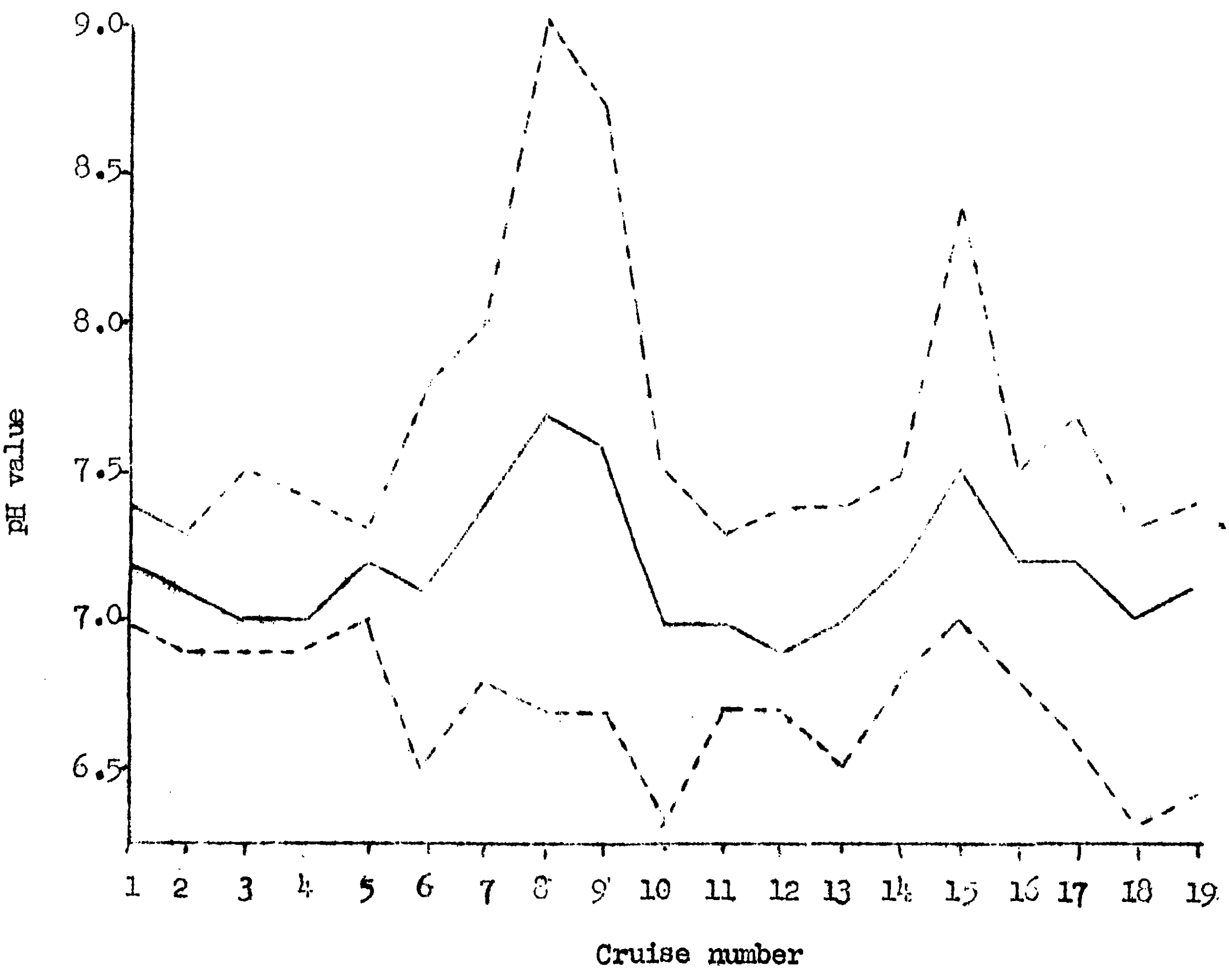


Figure 36

Hydrogen ion concentration at the surface for 19 cruises in the Rappahannock River 1951 showing maximum, minimum, and average reading for each cruise.



Cruise Week	Rappahannock River	Pamunkey River	Mattaponi River
April 16	7.0	7.0 *	-
May 21	7.7	-	-
May 28	-	7.1	6.8
Aug. 6	-	7.0	7.0
Aug. 13	7.0	-	-

* Determinations made only on stations 50.7, 54.2, 55.2, and 56.2.

The most important difference between the three rivers appears to be the high pH values found in the Rappahannock River during part of the spring period.

Salinity.--Salinities were measured in the lower sections of the river to indicate the extent of brackish water intrusion in the section of river sampled. Salinities were computed from hydrometer readings made with a standard salinometer and corrected for temperature. Hydrometers are not precise instruments, the errors becoming relatively larger as the salinity decreases. Salinity values obtained by titration are compared with the corrected readings from 3 salinometers used in the study. This comparison was made by Richard Whaley of the Chesapeake Bay Institute in the Rappahannock River in March 1951 and is listed below:

Titrated salinity 0/00	Water Temp. degrees C.	Corrected hydrometer readings in instrument No. 191659	No. 191661	No.11209	Maximum error
12.52	12.0	12.9	12.7	12.6	0.4
11.22	11.0	11.2	11.4	11.2	0.2
9.34	14.5	9.8	9.6	9.9	0.6
6.98	13.0	7.2	6.6	6.6	0.4
5.14	20.0	6.0	6.0	5.9	0.9
3.89	20.0	5.0	4.8	4.6	1.1
2.36	22.0	3.0	3.0	2.9	0.6
1.33	12.0	1.6	1.8	1.7	0.5

Although hydrometers do not give precise determinations, they are of some value in giving general information on the extent of salt water intrusion. Figure 37 shows the approximate location of the boundary between brackish and fresh water. The location of this zone varies with the tide, wind, and fresh water runoff. During the present survey the mean upper limit of sensible salt water intrusion occurred between stations 41 and 45.

Although only limited data are available on the extent of salt water intrusion into the Pamunkey and Mattaponi Rivers from this survey, past records show this change may occur between West Point and station 38.2 in each river.

Sulphates.--Sulphate determinations were made on water samples submitted to the American Viscose Corporation. A helige turbidimeter was used in calculating sulphate values.

Sulphates are relatively stable and not toxic to aquatic

Figure 37

Approximate extent of salt water intrusion in the Rappahannock River 1951. Determinations are the mean of surface and bottom values obtained with a standard salinometer.

life in concentrations found in the Rappahannock River. Figure 38 shows the mean sulphate values for each cruise. Since salt water contains high concentrations of sulphate, those stations where brackish water was encountered have not been considered. For cruises 16 to 19 the higher sulphate values are assumed to result from lower fresh water runoff. The mean sulphate values are plotted by station in figure 39. A gradual increase is apparent upriver to station 91. The sharp drop is the difference between the sulphate normally present in the river and that added at Fredericksburg. The mean sulphate value at Tappahannock, where saline waters are present, was eight times that at station 91.

The mean sulphate values in the fresh water portion of the Rappahannock, Pamunkey, and Mattaponi Rivers differ considerably:

Cruise week	Sulphate in parts per million		
	Rappahannock River	Pamunkey River	Mattaponi River
May 21	15.3	-	-
May 28	-	8.5	5.2
Aug. 6	-	12.4	6.9
Aug. 13	53.1	-	-

Although sulphate concentration was highest in the Rappahannock River, this represented only a small fraction of the amount of sulphate found in the brackish and salt-water portions of the estuaries.

Physical Determinations

Water temperature.--Water temperatures were taken from surface and bottom at each station for each cruise. Surface temperatures were

Figure 38

Mean sulphate values on 19 cruises in the Rappahannock River 1951. Average of surface and bottom samples. Stations 37.0, 41.0 and 45.0 have been excluded.

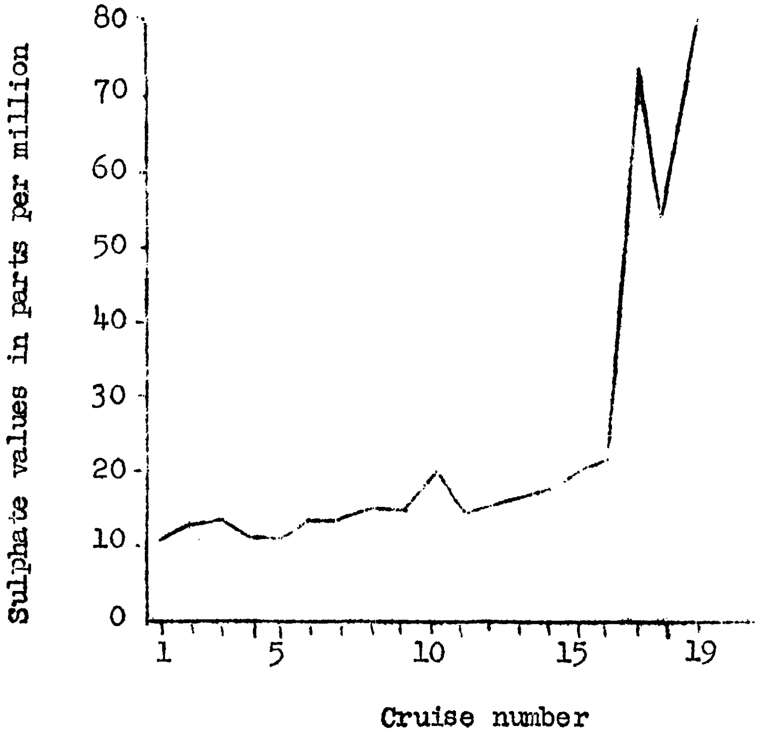
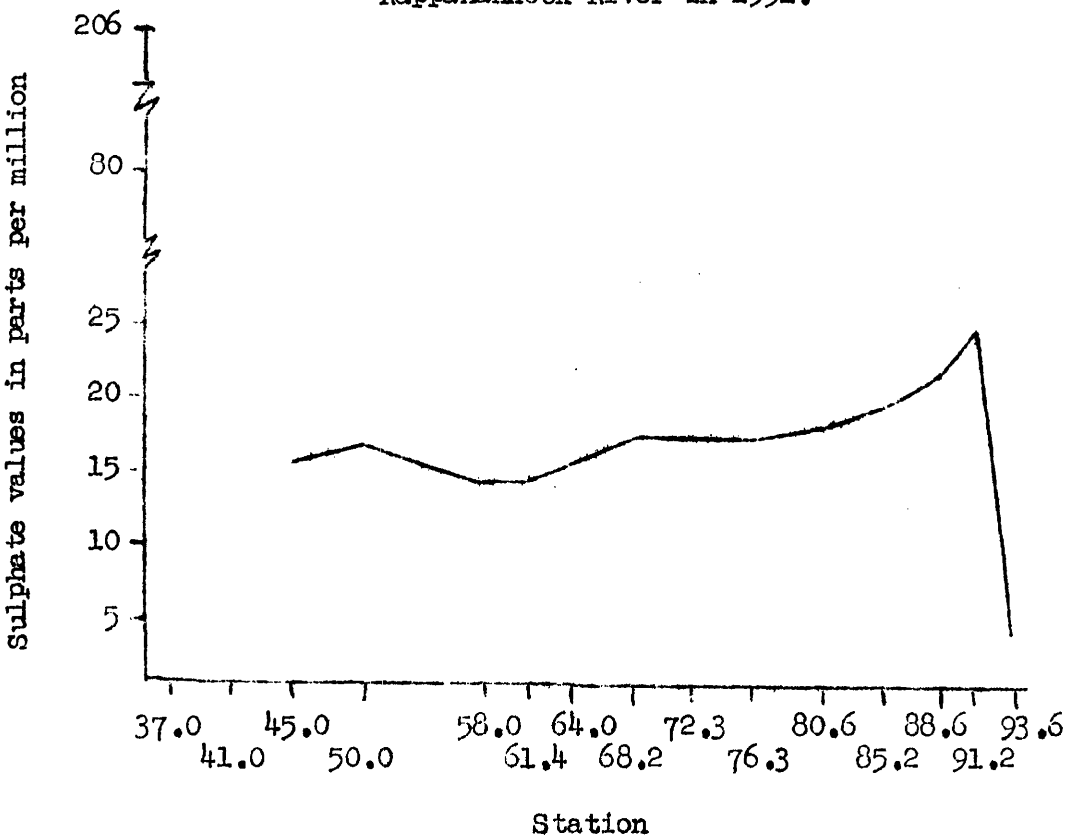


Figure 39

Mean sulphate values at each station for 19 cruises in the Rappahannock River in 1951.



measured with a bucket thermometer, bottom temperatures with a reversing thermometer. Readings were made to the nearest tenth of a degree Centigrade. The instruments used were accurate to within ± 0.1°C.

Comparison of surface and bottom temperatures shows that the river did not become thermally stratified during the investigation. In figure 40 the mean temperatures are plotted for each station during the spring and summer periods. At downriver stations the gradual drop in temperature during the summer months was probably caused by mixing with cooler salt water. The water temperatures on all other stations show no marked changes from station to station.

Figure 41 shows the mean temperature on each cruise. River waters respond rapidly to changes in air temperature and precipitation, the sharp increases in temperature being caused by periods of hot weather, while the passage of cold fronts, usually accompanied by heavy rainfall, caused the sharp drops.

Since winds, currents, and sampling time often have a considerable influence on local temperatures, a more detailed analysis of water temperatures is not justified.

A comparison of spring and summer temperatures in the Rappahannock, Pamunkey, and Mattaponi Rivers is listed below:

Cruise week	Mean water temperature in °C		
	Rappahannock River	Pamunkey River	Mattaponi River
April 16	12.1	13.5	-
May 21	21.0	-	-
May 28	-	21.0	21.6
Aug. 6	-	27.2	27.0
Aug. 13	28.9	-	-

Figure 40

Mean water temperature at each station in the Rappahannock River for spring and summer 1951.

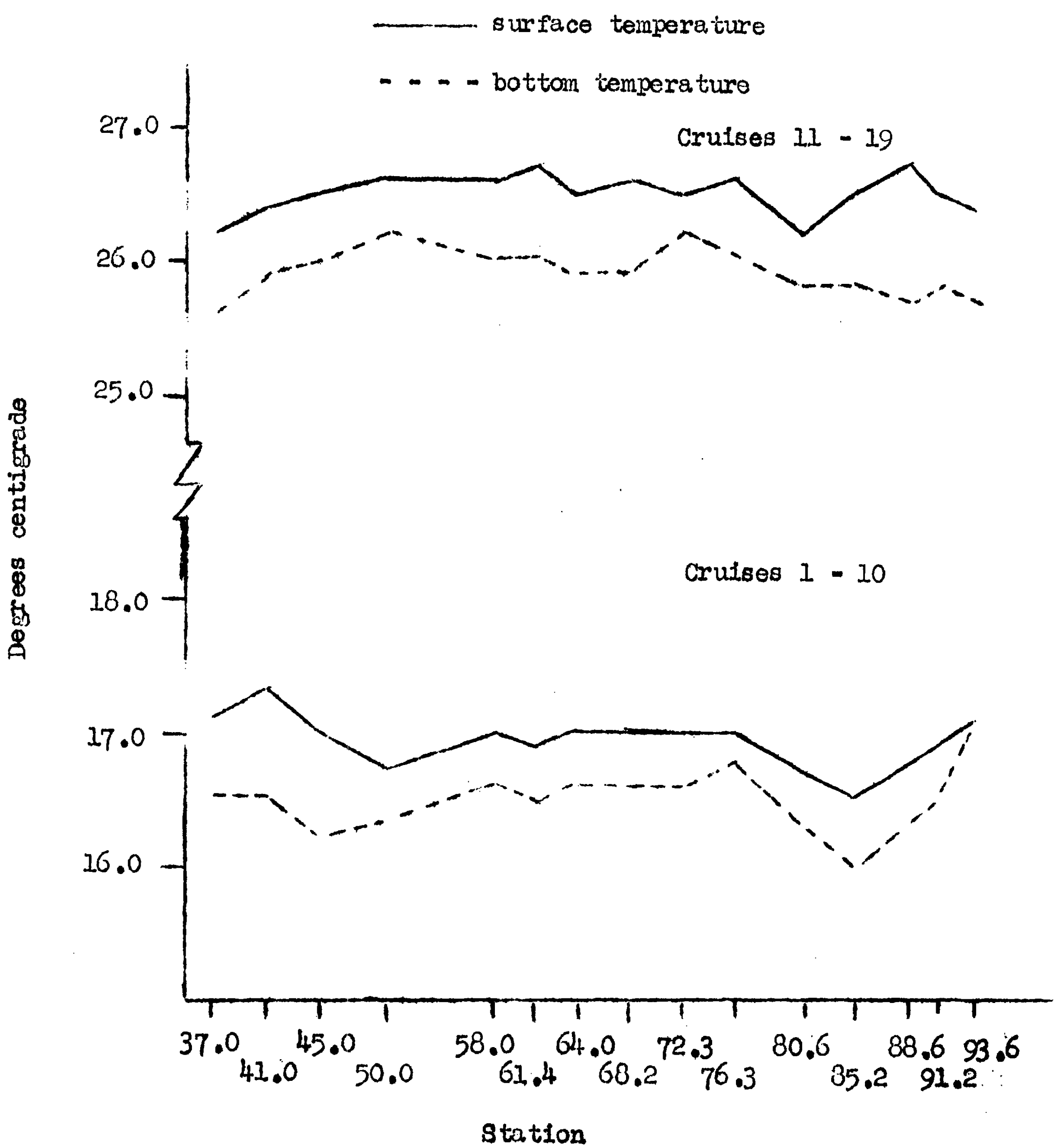
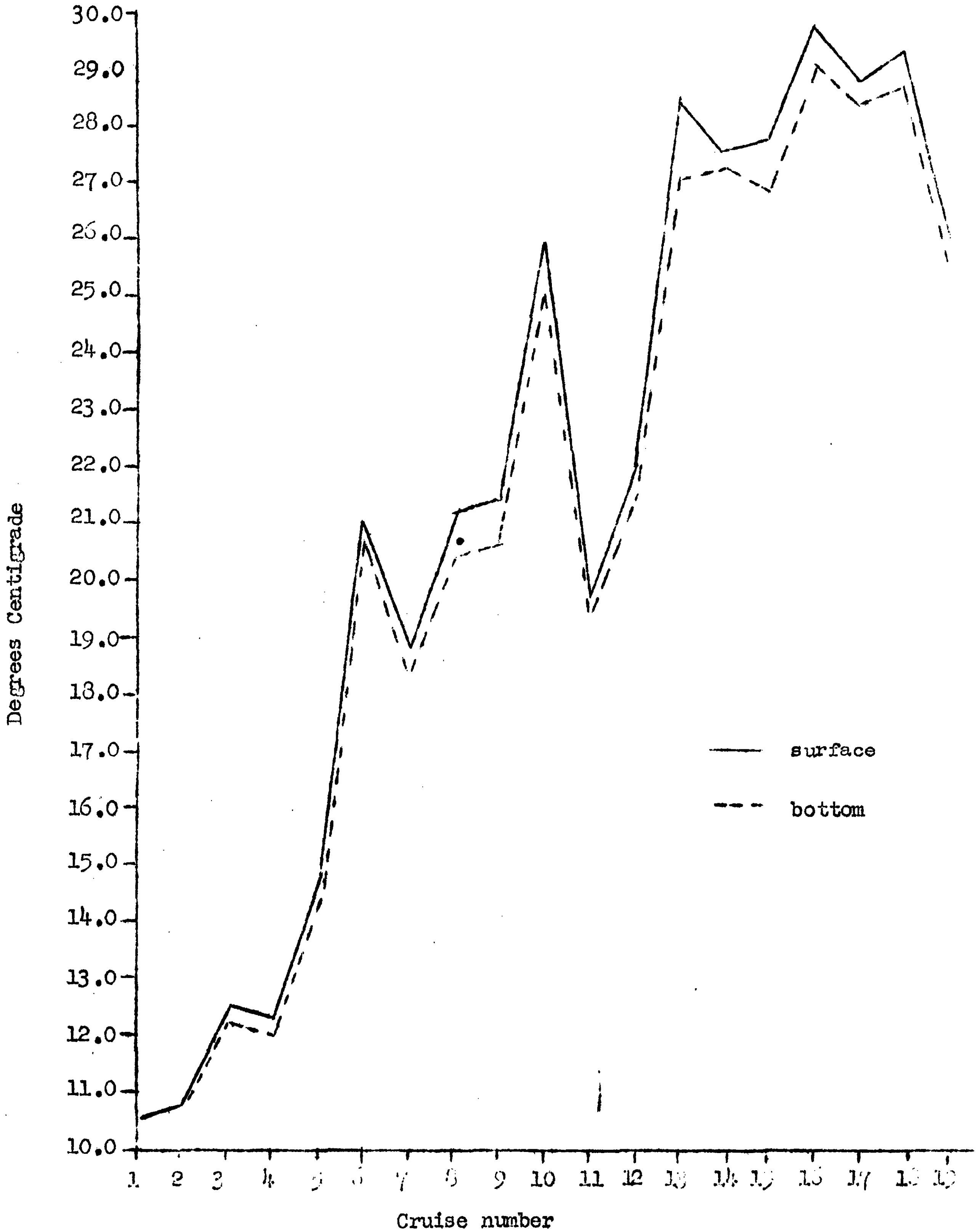


Figure 41

Mean water temperature on each cruise in the Rappahannock River 1951.



During the spring, water temperatures in the three rivers are generally similar. The single set of comparative observations made during late summer indicate at this time a slightly higher temperature for the Rappahannock River.

<u>Light penetration</u>.--Light penetration was measured with a 20 cm. secchi disk divided into four equal quadrants painted alternately black and white. Readings were made to the nearest centimeter; however, variations in time of day, weather, and water surface conditions somewhat affect the accuracy of the readings.

Figure 42 shows the mean secchi disk reading at each station for the spring cruises (1 to 10) and the summer cruises (11 to 19). The most turbid water, present at station 41.0, appears to be associated with the intrusion of salt water. Upstream the water became clearer, station 93.6 being clearest of all. This contrast was greatest during the spring cruises. The great variations in light penetration that occurred between successive cruises (figure 43) were caused by fluctuations in runoff. During cruise 11 heavy runoff decreased the river temperature almost five degrees C. and secchi disk readings 63 cm. The rapidity with which these changes may occur is illustrated in figure 44 when on one cruise in the Mattaponi River secchi disk readings decreased 107 cm. in seven miles. Figure 45 compares turbidity readings on a single mid-summer cruise on the Rappahannock, Pamunkey, and Mattaponi Rivers. During this cruise, heavy rains caused a sharp decrease in light penetration at the upriver stations. On these cruises the mean secchi disk reading for the Mattaponi River was about 20 cm. higher than the readings from the Rappahannock and Pamunkey Rivers.

<u>Current Velocity</u>.--Current velocities were measured with current drags

Figure 42

Mean light penetration at each station in the Rappahannock River during spring and summer 1951.

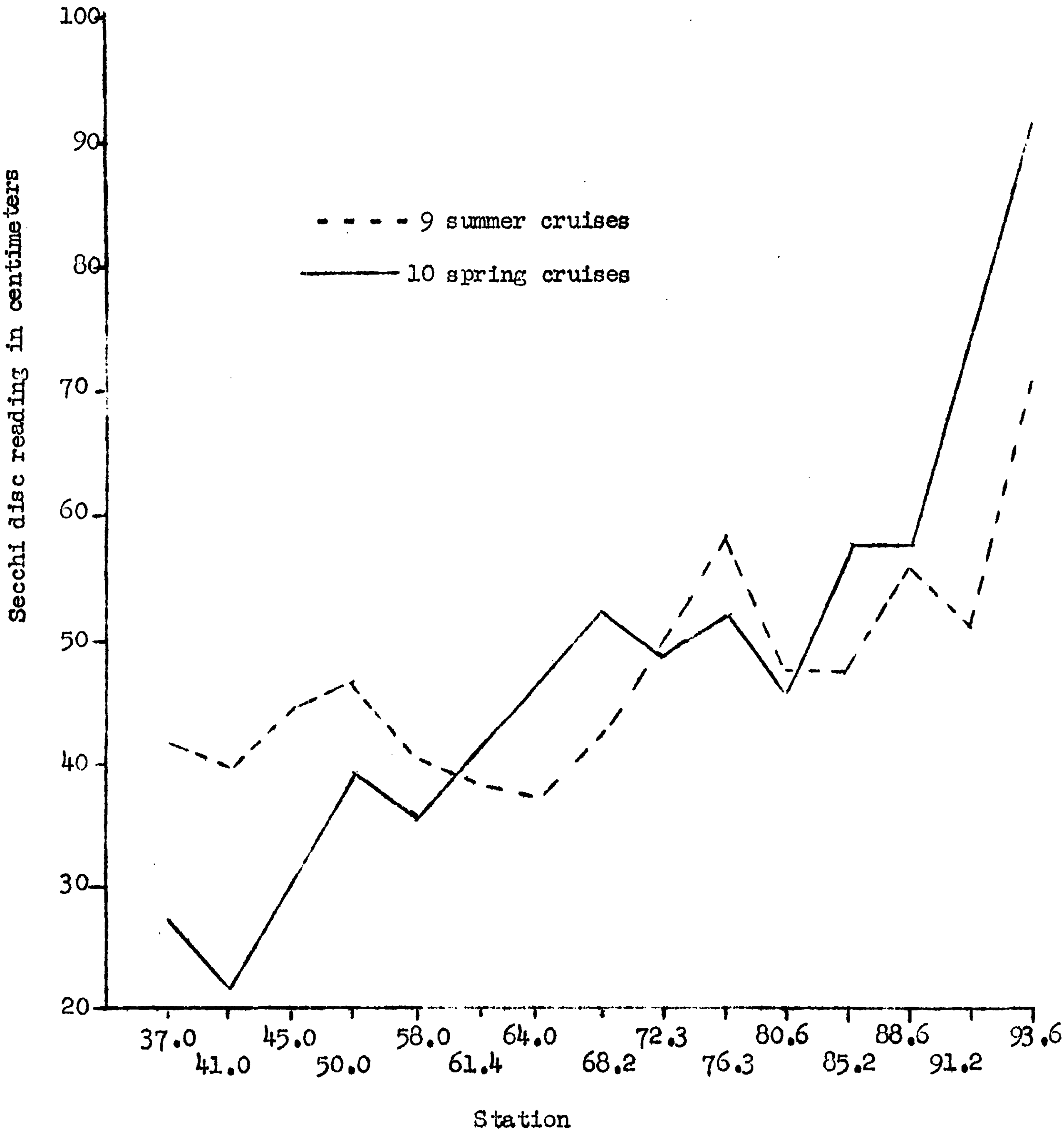


Figure 43

Mean light penetration on each cruise in the Rappahannock River 1951.

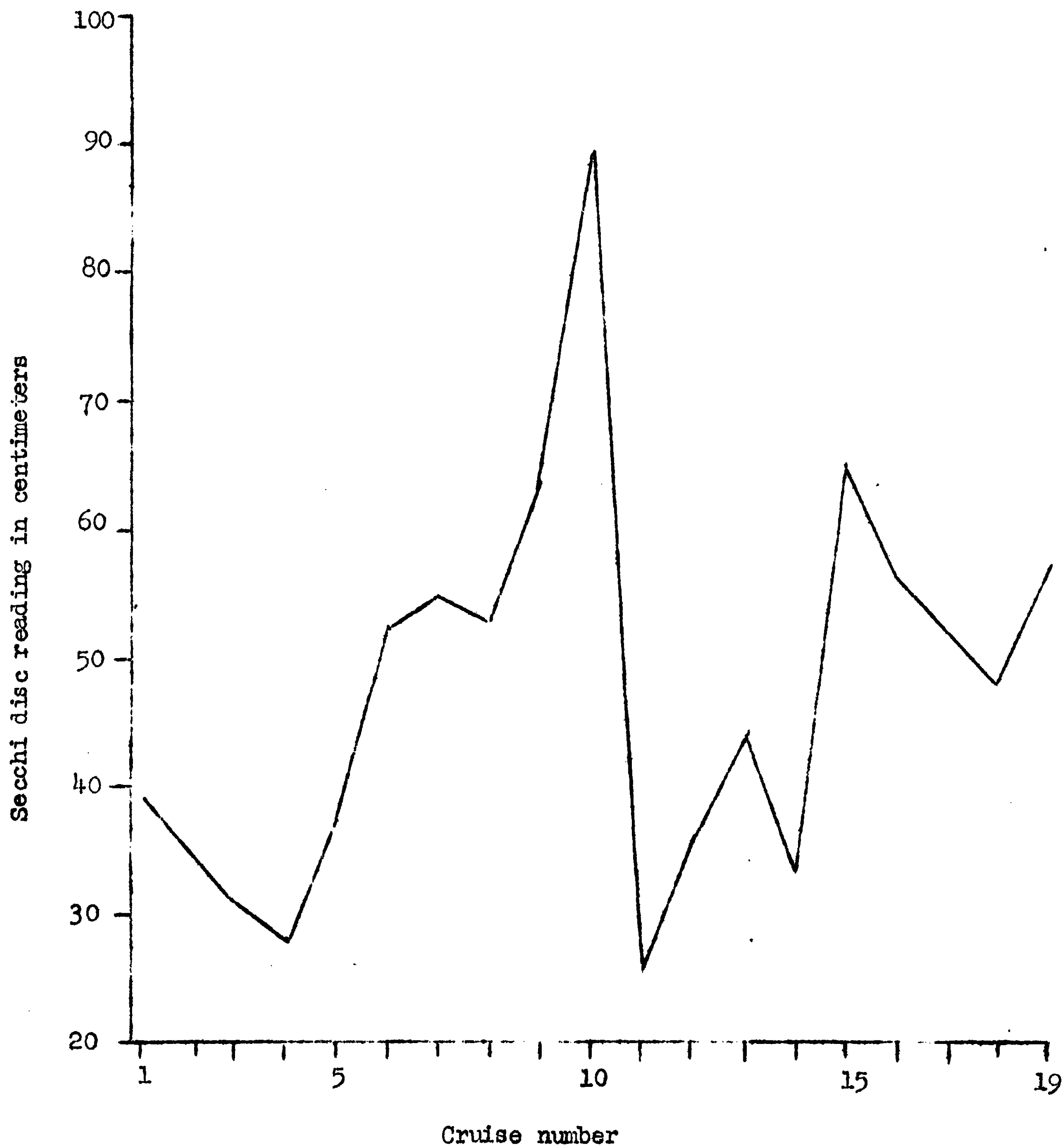


Figure 44

Light penetration in the Mattaponi River on August 14, 1951.

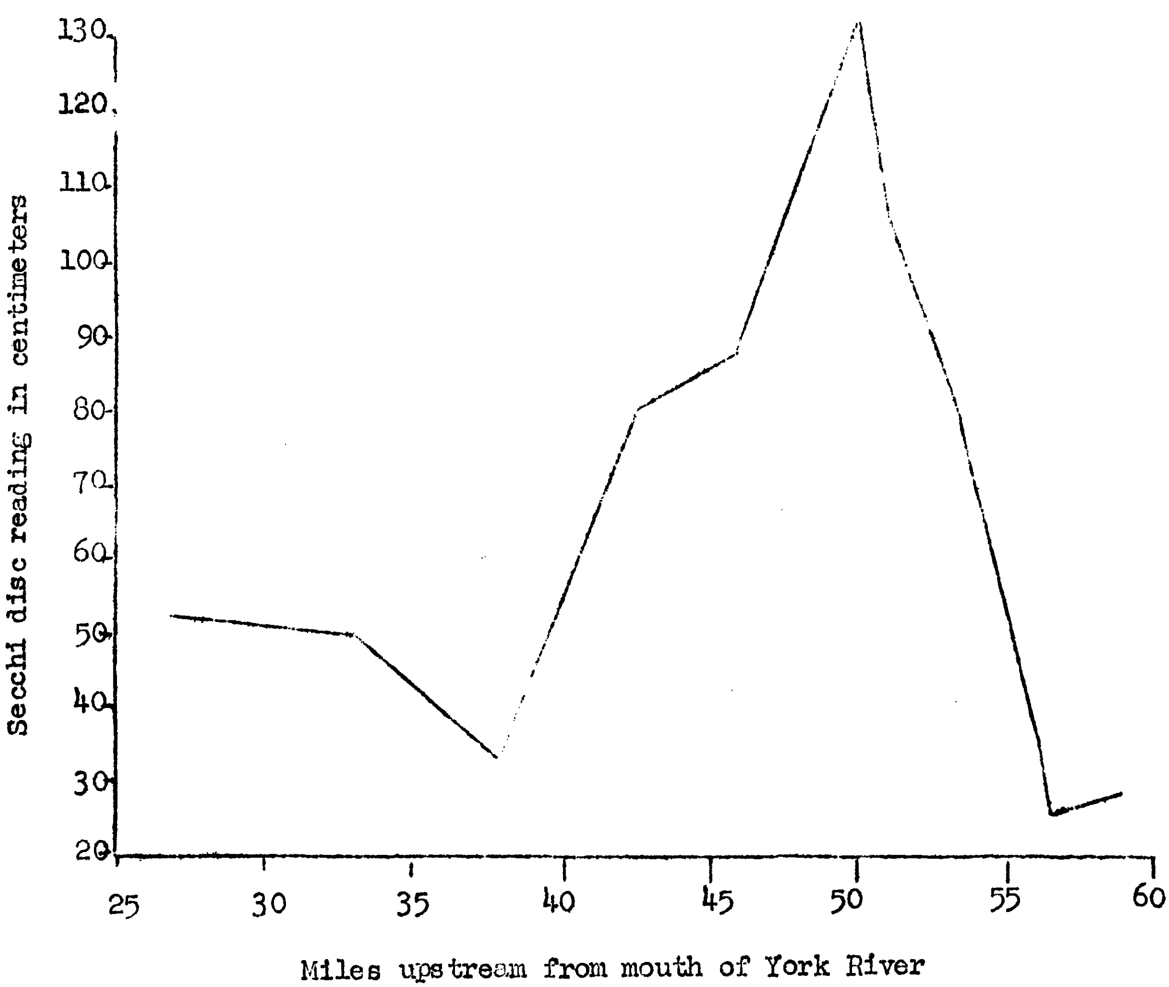
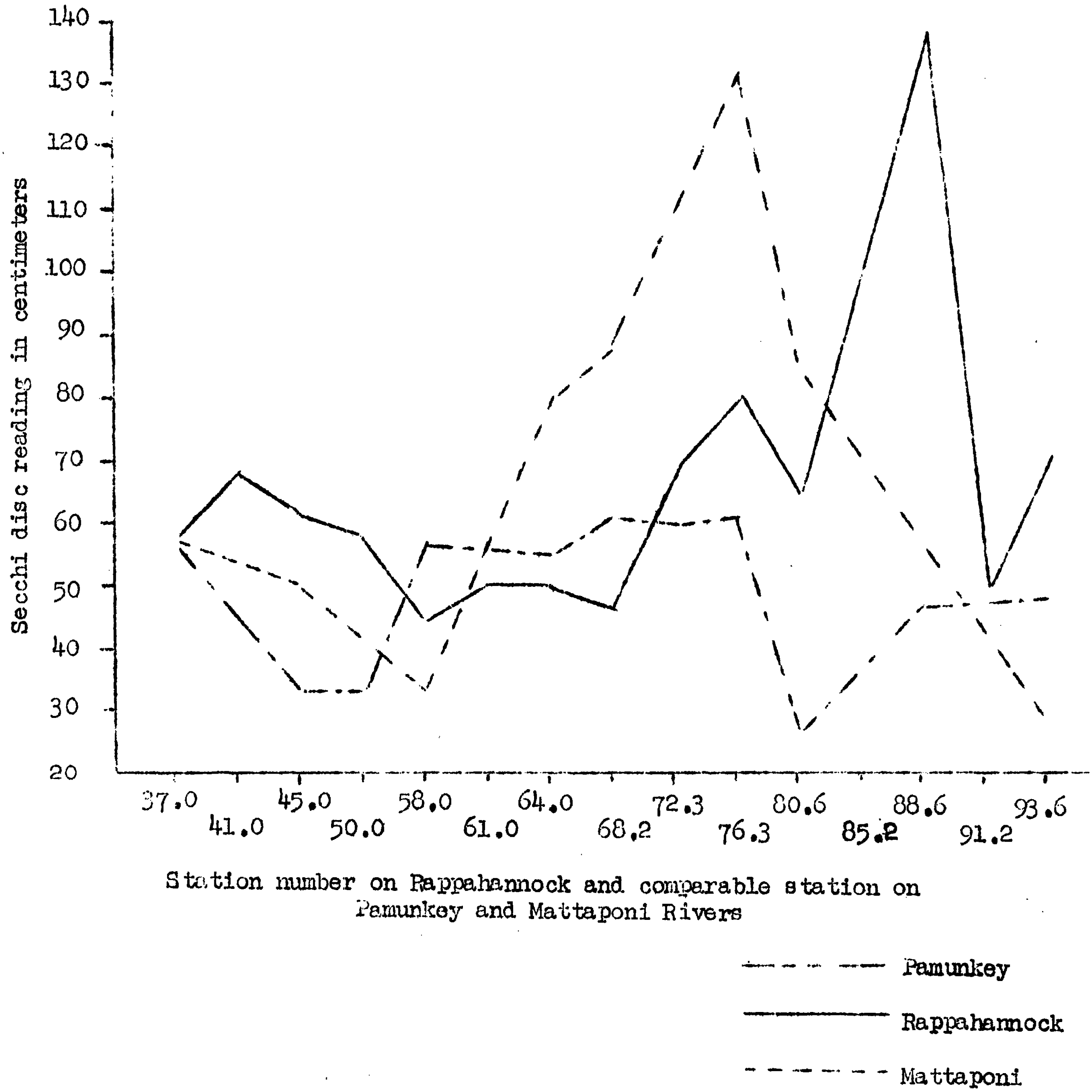


Figure 45

Comparison of light penetration in the Pamunkey, Rappahannock and Mattaponi Rivers August 11, 13, and 14, 1951.



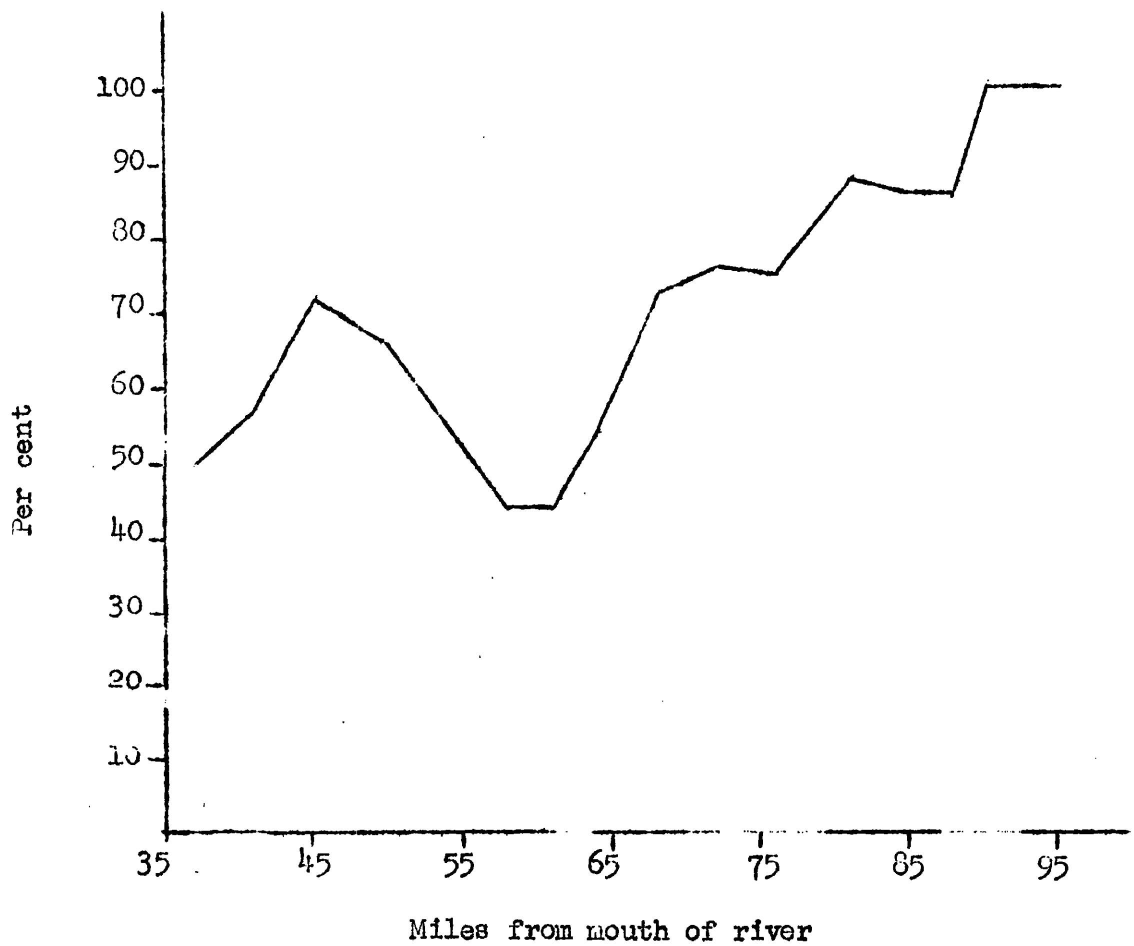
developed by the Chesapeake Bay Institute of Johns Hopkins University (Pritchard and Burt 1951). Two hundred and seventy current velocity measurements were made on cruises 1 to 9, half of which were at the surface and half at the bottom. Surface currents exceeded bottom currents by an average of 0.14 knots. Although an average is only roughly indicative of actual river flow, the value for each station has been expressed as the mean of surface and bottom readings. Current measurements made at stations below Port Royal differed from those made above. Tides had more influence on the current directions and velocity at the downriver stations while river runoff was most important upriver. As shown in figure 46 the transition was gradual. Since the number of current determinations made at each station was small, all the data have been grouped to obtain general information on the currents between stations 37.0 - 68.2, and 72.3 and 93.6.

	Stations	
	37.0 - 68.2	72.3 - 93.6
Maximum flood velocity	1.09 knots	0.80 knots
Maximum ebb velocity	1.34 knots	1.79 knots
Mean flood velocity	0.70 knots	0.37 knots
Mean ebb velocity	0.89 knots	0.76 knots
Approximate rate of downstream drift	0.17 knots	0.55 knots

The data are not sufficiently complete to warrant definite conclusions regarding the rate at which water is displaced downstream. Upriver variations are influenced by river runoff and to a lesser extent by tides and winds. From the information above, water would require

Figure 46

Percentage of observations made during an ebb tide on cruises 1 - 9 Rappahannock River 1951.



a minimum of about two days to move from Fredericksburg to Port Royal and a minimum of about 8 days to move from Port Royal to Tappahannock. Since river flow is turbulent rather than laminar, these estimates probably are low.

In spite of the fact that tidal currents were not observed at stations 91.2 and 93.6 during the spring period, a rise and fall of the water level or tide was noticeable, although sometimes obliterated by the effect of freshets. The river therefore had the characteristics of a true river in that the flow was always downstream, but the effect of tides was present as a vertical oscillation of the surface.

Chemical and physical determinations on anchor stations

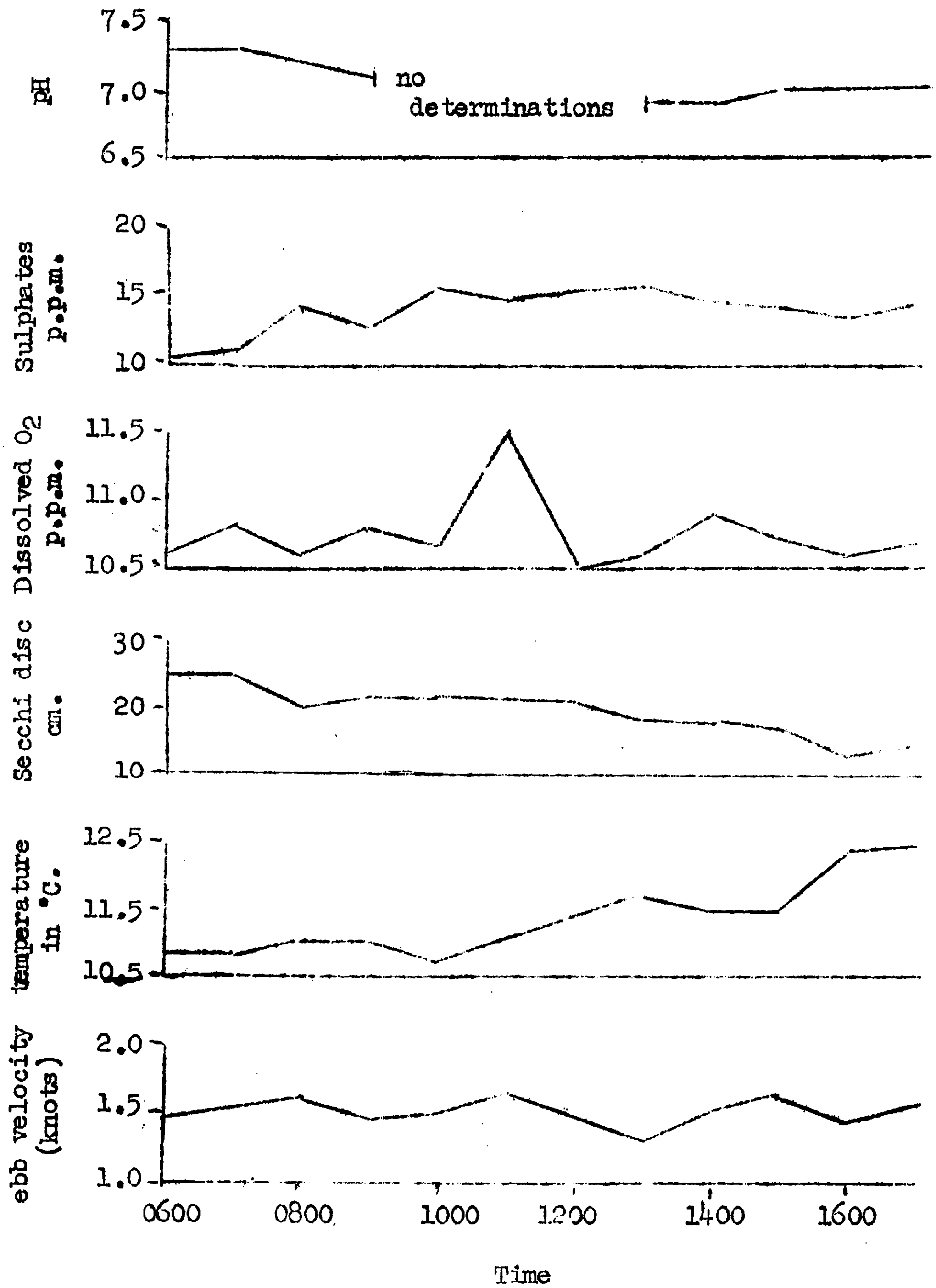
To obtain more detailed information on physical and chemical changes with time in a limited area, serial samples were taken at certain stations from an anchored vessel. Stations 37 and 64 were sampled for one day each during the spring period for biological information. Anchor stations were run in the Fredericksburg vicinity during the spring, summer, and fall to obtain specific information on the effect of tidal currents on the distribution of dissolved oxygen, pH and sulphates.

Station 91.3 was occupied at hourly intervals from 0600 to 1700 hours on April 11 (figure 47). The distribution of pH, sulphates, dissolved oxygen, turbidity, temperature, and current velocity was rather uniform. The uniformity was maintained by a rather constant flow of water downstream which was not greatly affected by tides.

Eight stations were occupied almost simultaneously on August 22 between 0625 and 1815. By using a fast outboard motorboat the 4.8

Figure 47

Distribution of pH, sulphates, dissolved oxygen, turbidity, temperature and current velocity at station 91.3 in the Rappahannock River on April 11, 1951.



mile run was made in about 30 minutes. Ten runs were completed. Sampling was not sufficiently extensive to bracket completely the pool of low oxygen water, only the upper portion being covered. Decreased river runoff and tidal currents created conditions different from those observed in the spring. Run #1 began at low slack water (figure 48). The short period of flood tide moved the upriver limit of the low oxygen pool upstream about one-half mile while the succeeding ebb carried it about one mile downstream. It is probable that the lower limit of the low oxygen pool was displaced in a similar manner. This movement was approximately half that indicated by current velocity readings suggesting that the rate of displacement by mixing was almost equal to the rate by tidal currents. The net effect would appear to be a concentration of low oxygen waters by rather weak tidal currents and extensive mixing. This would account for the rather abrupt oxygen recovery zone encountered on most cruises and shown in figure 35 for cruise 18.

On October 3 another set of anchor stations was occupied from 0735 until 1810. Samples were obtained at stations 85.2, 88.6, 91.2, and 93.6. Sampling began soon after high slack water when the low oxygen pool was present at station 93.6 (figure 49). The succeeding ebb displaced the low oxygen water a short distance downstream. The distribution of pH was generally similar.

During the entire summer of 1951 the pool of low oxygen water was continuous, the zones of degradation and recovery being quite short. This pattern appears to have been caused by a combination of weak tidal currents and rather thorough mixing.

Figure 48

Distribution of dissolved oxygen in the Rappahannock River at Fredericksburg August 22, 1951.

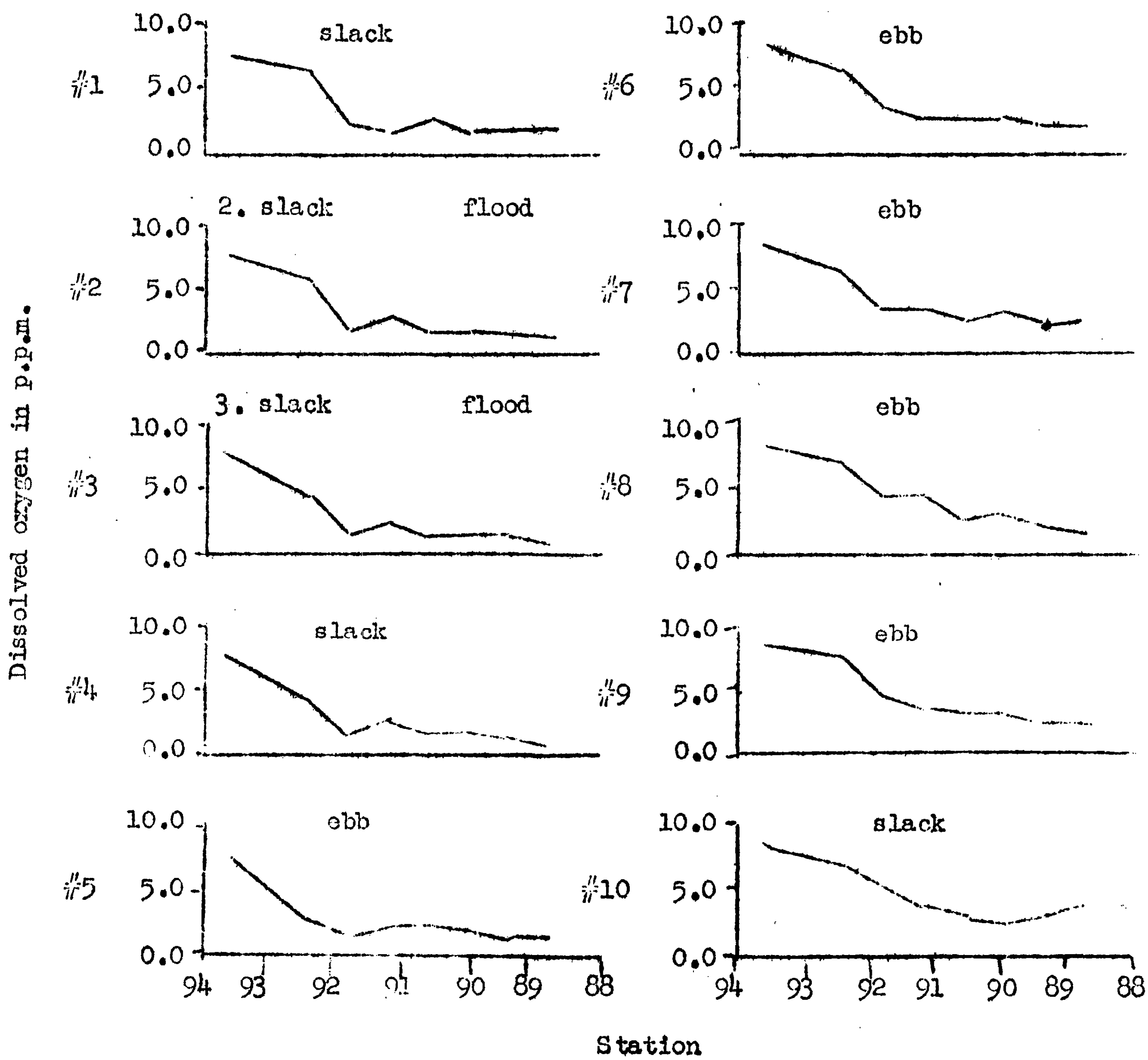
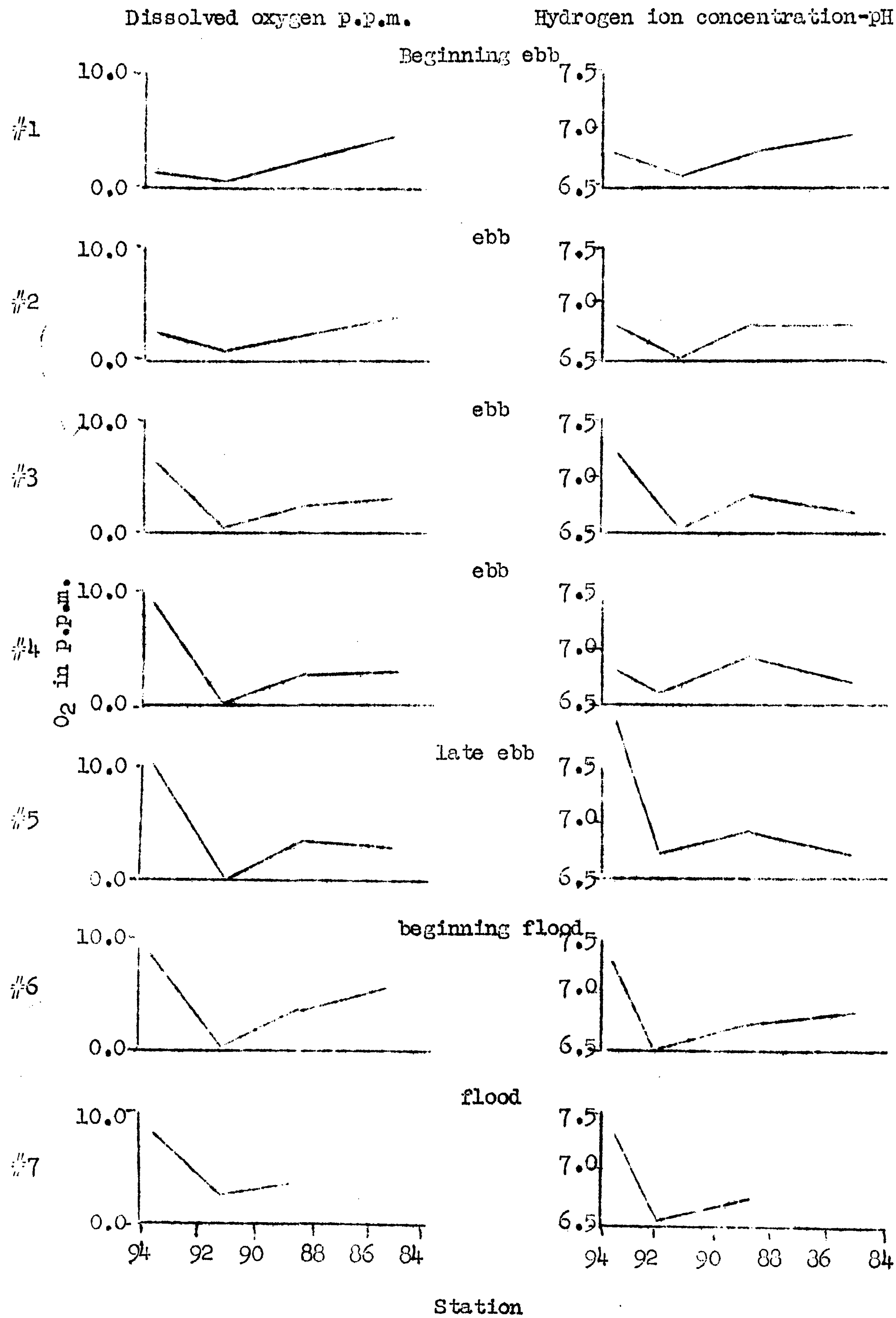


Figure 49

Distribution of dissolved oxygen and pH in the Rappahannock River at Fredericksburg October 3, 1951.



SUMMARY

The Rappahannock River drains an area of about 2700 square miles in northeastern Virginia. The river is approximately 160 nautical miles in length, and is subject to tidal influence from its point of junction with the Chesapeake Bay, to Fredericksburg, a distance of 93 nautical miles. The upper limit of salt water in the estuary lies about 35 to 40 miles above the mouth, in the vicinity of Tappahannock.

At Falmouth, three miles above Fredericksburg, the Rappahannock is blocked by a dam constructed prior to 1887. About two miles downstream from the city is situated the Sylvania plant of the American Viscose Corporation, engaged chiefly in the manufacture of cellophane. In the manufacturing process, the plant takes in large quantities of river water, which is discharged back into the river with added wastes.

The organic materials, which by reason of their high oxygen demand deplete the dissolved oxygen content of the water, are broken down by bacterial action within a relatively short time after they enter the river, and the river appears to have recovered completely from this pollution at a distance of 12 to 15 miles below the source of the Sylvania effluent. The principal permanent alteration in the content of the water is the addition of sodium sulphate.

The principal commercial fishes caught in the region between Fredericksburg and Tappahannock are shad, striped bass, alewives, glut herring, white perch, and white catfish. It is impossible to determine with any degree of accuracy the proportion of the total commercial catch of Virginia that is taken in this region, for the State does not collect statistics on the commercial catch, and the information gathered by the U. S. Fish and Wildlife Service is of questionable accuracy for this purpose. On the basis of available information, however, during the period 1929-1947 the commercial catch in the Rappahannock has increased relative to the entire Virginia catch. Furthermore, this trend parallels closely the catch trend in the York River and its tributaries, rivers that are relatively free from pollution of any magnitude.

No interpretation is offered of this apparently favorable picture. Since total catch is of no value as an index of abundance unless adjusted to compensate for changes in fishing effort, it cannot be concluded that no harmful effects are present in the river. The Laboratory is severely handicapped in this, as in other investigations by the lack of adequate statistics on the commercial fisheries.

Of the 50 species of fishes collected in the Rappahannock River during the course of the survey, 13 were marine, 8 were anadromous, 5 were normally upland stream species, and 24 were species that live in this section of the river throughout life. In general the fish faunas of the Rappahannock and Pamunkey Rivers are similar, and the slight differences probably can be explained on the basis of sampling variation.

In general, along the shore zone, fishes become progressively more abundant per unit area from Fredericksburg to Tappahannock. By far the most abundant species in the section below Fredericksburg was the mummichog, a fish that normally lives in salt marshes. By minnow seine, 22 species were taken in this section of the river (section III) as compared with 20 species in section II, and because mummichog were relatively abundant in section III (absent in section II) slightly more fish per unit net haul were captured in the upper section of the river.

When the concentration of dissolved oxygen reached values below 50 per cent of saturation the numbers of fishes caught in minnow seines were considerably reduced. It is believed that this reduction in numbers was caused by direct avoidance of the area, rather than by mortality, for practically no dead fishes were found in the river during the survey. This is in contrast to the condition in the James River near Hopewell, where rather large-scale fish mortalities are often observed along the edge of the polluted area.

The density of fishes in the shore zone of the Rappahannock River is approximately the same as in the Pamunkey, although the Pamunkey River appears to support a somewhat greater variety of species. Striped bass and white perch were relatively more abundant in the Rappahannock; shad, alewives, and glut herring in the Pamunkey.

Fishes were less abundant along shore in section II of the Rappahannock than in the comparable sections of the Pamunkey and James Rivers. Since no pollution exists in this section of the Pamunkey, whereas the James is heavily polluted in the same region, the most obvious conclusion is that the middle section of the freshwater tidal waters of the Rappahannock is naturally less productive.

Trawl hauls made in the open waters of the Rappahannock River indicate that in general the abundance of fishes tended to increase in a downstream direction. It is noteworthy that no fishes were taken at station 89, just below the point of outflow of effluent from the American Viscose Corporation Plant. River section III contained about

10 per cent of the glut herring, 15 per cent of the alewives; and 25 per cent of the shad caught by trawl in the entire survey area. When oxygen values were below 50 per cent of saturation, no fishes were collected in the trawl.

Although fishes were less abundant in the offshore waters of the Mattaponi than in the Rappahannock, the more important commercial species (shad, striped bass, and glut herring) were more abundant in the Mattaponi.

Shad spawning in 1951 commenced in March and continued until about the middle of May. At least half the spawning was concentrated in the period April 16 to 25. Although shad eggs were found from station 58 to station 85, over 70 per cent were taken in Portobago Bay (station 64), almost 30 nautical miles downstream from Fredericksburg. It must be remembered, however, that although relatively few young shad were taken in the river, these were most abundant upstream from the major spawning area, where they might be subject to the effects of wastes. Surveys in other Virginia rivers have shown that young shad disperse upstream from the area of major spawning during the summer months.

Striped bass spawning in 1951 was restricted to late April and early May. The center of spawning occurred in the vicinity of station 50, although eggs occurred in hauls as far upriver as station 81, only 12 miles below Fredericksburg.

Available information seems to indicate that alewives, glut herring, and hickory shad spawn throughout the entire freshwater tidal section of the Rappahannock River. Since we are not able to distinguish between the eggs of these three species, no conclusions can be reached regarding their individual spawning distributions. Spawning intensity was somewhat greater in section II of the river.

Menhaden larvae were rather abundant in the lower reaches of the survey area until late April. The young were abundant in shallow water near shore in summer.

Other clupeid larvae (including probably shad, alewives, glut herring, hickory shad, and gizzard shad) were most abundant at station 72. Only 5 per cent of those collected were captured in river section III. Larvae of this group were less abundant in the Rappahannock than in either the Pamunkey or Mattaponi Rivers.

The larvae of all other fishes (probably mainly white perch, striped bass, killifish, and minnows) were most abundant between stations 41 and 50. Only 2 per cent were caught in section III of the river. These larvae also appeared to be least abundant in the Rappahannock River.

The more common drifting invertebrates occurred in greatest abundance from station 54 to station 58, and gradually decreased in numbers upstream to Fredericksburg.

Planktonic algae reached two peaks of abundance during the survey, first during cruises 6 to 9 and second during cruises 14 to 17. Diatoms in general increased in abundance upstream to station 85, than fell off rapidly in numbers toward Fredericksburg. Filamentous and other non-filamentous algae, on the other hand, were most abundant from station 50 to station 64, where tremendous blooms occurred in Portobago Bay and its vicinity. Copepods, copepod nauplii, and rotifers also tended to show two peaks of abundance, each occurring somewhat later in the season than the two peaks of algal production. The region of greatest production of zooplankton was also in the vicinity of Portobago Bay. The relatively great plankton production in this region of intense shad spawning is perhaps favorable for the survival of shad during the larval and early postlarval stages. No conclusions can be drawn at present as to the cause of the phytoplankton blooms in this region.

Downstream from Fredericksburg, as shown by surveys of the U. S. Public Health Service (Appendix I), the numbers and types of bottom organisms were characteristic of a heavily polluted stream. The zone of degradation and decomposition extended from the point of outflow of the Sylvania effluent downstream for a distance of 4 nautical miles. The zone of recovery extended another 8 miles downstream. Below this zone, the bottom organisms did not appear to be affected by pollution. A control survey in the equivalent section of the Pamunkey River revealed no such evidence of response to polluted conditions.

During the period June 4 to October 10, 1951, approximately 4 per cent of the river area and 2.5 per cent of the river volume between Fredericksburg and Tappahannock were subject to dissolved oxygen concentrations below 50 per cent of saturation. In the Pamunkey and Mattaponi Rivers the concentrations was not observed to fall below this level. Above and below this low oxygen zone, which appears to be associated with the introduction of domestic and industrial wastes at Fredericksburg, the Rappahannock exceeded the York River tributaries in oxygen content. The low oxygen zone extended downstream from station 85 (6 miles below the Sylvania plant) on only one cruise. On this occasion, August 17, 1951, the oxygen concentration fell below 50 per cent saturation from station 91 to station 76 inclusive.

A dissolved oxygen content of 5 parts per million has been set arbitrarily by some authorities as the level below which aquatic organisms suffer distress and may die. Except on one occasion, at station 58 on cruise 11, the dissolved oxygen content in the Rappahannock River did not fall below 5 p.p.m. farther downstream than station 76 (table A-2). In the Pamunkey River the oxygen content fell below this value at station 57 on August 11, 1951, and in the Mattaponi on August 14 all stations from 27 to 50 inclusive yielded values below 5 p.p.m. It is not universally agreed that the 5 p.p.m. level represents the danger point for aquatic organisms. Some investigators have shown that certain fishes and other animals can survive at lower concentrations. Since the capacity of water to hold oxygen in solution varies inversely with temperature, it would seem reasonable for biological purposes to report saturation values rather than absolute quantities. Somewhat arbitrarily, we have set the 50 per cent saturation level as the lower limit of tolerance for fishes.

Hydrogen ion concentrations, represented by pH values, were close to 7.0 in the Rappahannock, Pamunkey, and Mattaponi Rivers. The range of pH observed in the Rappahannock was 6.3 to 9.0, the high readings coinciding with the intense phytoplankton blooms. Although these high pH values may be detrimental to some fishes, there is no evidence that their occurrence is in any way related to conditions in the Fredericksburg area.

Only the lower reaches of the survey area were subject to salt water intrusion. The upper limit of brackish water sometimes reached almost to station 50, normally the boundary between salt and fresh water lay between stations 41 and 45.

Excluding all stations downstream from station 45, the average sulphate content of the Rappahannock River water increased from an average of about 15 p.p.m. at station 45 to an average of about 25 p.p.m. at the Sylvania plant. Between the plant and Fredericksburg, the sulphate load dropped sharply to an average of less than 5 p.p.m., the normal load of the upper Rappahannock. Sulphate in the Pamunkey River varied from 8.5 to 12.4 p.p.m., and in the Mattaponi from 5.2 to 6.9 p.p.m. The concentration of sulphate in the Rappahannock below the Sylvania plant varied inversely with river runoff, from an average of about 10 p.p.m. at the end of March to approximately 80 p.p.m. in August. There is no evidence that the presence of sulphate in unusually high concentrations in the Rappahannock is detrimental to aquatic life.

Water temperature conditions in the Rappahannock River did not differ materially from those in other Virginia streams. Although water temperature fluctuated in response to changes in air temperature, in general the temperature increased from an average of about 11°C. in April to about 29°C. in August.

Turbidity of the water, as measured by light penetration, was greatest in the region of station 41 and decreased gradually in an upstream direction. Deviations from this trend were associated with fluctuations in river runoff.

Although the entire Rappahannock below Fredericksburg is subject to tidal oscillation, the duration of ebb decreases upstream. No reverse flow was observed at station 91.2 and 93.6, during the weekly hydrographic cruises, although an appreciable rise and fall of water level was noted. Above station 72 the approximate average rate of downstream drift was about half a knot, below this point to station 37 the approximate average was about one-sixth of a knot.

Information on the movements of the pool of low oxygen water in the Fredericksburg area was obtained through series of samples taken at short intervals of time. Apparently the effect of tidal action causes this water to oscillate up and down stream for a distance of about one mile under conditions of low runoff.

The principal effect of the introduction of domestic and industrial wastes into the Rappahannock River at Fredericksburg appears to be a significant increase in B.O.D. and consequent reduction in dissolved oxygen. The area affected in 1951 extended downstream from Fredericksburg an average of eight miles and a maximum of 18 miles. These fluctuations appeared to be related to variations in river runoff. The production of invertebrate forms was severely depressed within this region, and fishes in general were effectively blocked from the region when dissolved oxygen content fell below 50 per cent of saturation.

CONCLUSIONS

On the basis of the information gathered during 1951, the following answers to the questions raised by the American Viscose Corporation can be given.

1. Spawning of shad and striped bass, the two most important commercial fishes in the Rappahannock River is restricted to the spring period and occurs almost entirely in the lower part of the river, well below the region of pollution. The spawning areas of alewives, glut herring, and hickory shad extend into the region affected by wastes, and the possibility exists that the production of these species may be affected. The area and volume of the river affected by wastes, however, represents a rather small proportion of the total water available for spawning.
2. In the absence of adequate statistics on the commercial fisheries of Virginia, it is impossible to assess the relative contribution of the spawning grounds in the survey area to the entire fisheries production. All spawning of shad, striped bass, alewives, glut herring, and hickory shad, species of considerable commercial importance, occurs between Fredericksburg and Tappahannock. As a shad spawning stream, the Rappahannock appears to be intermediate between the two tributaries of the York on the one hand, and the James River on the other. There is some evidence that commercial fisheries production in the Rappahannock and York Rivers has increased in recent years relative to the production of the

entire state. This increase, however, might be caused by conditions outside the river itself.

3. There is little evidence that conditions in the Fredericksburg area cause direct mortality of either young or adult fishes. However, the young of shad and other commercial species remain in fresh water for some months before migrating seaward, and when conditions are favorable, are able to traverse the river to Fredericksburg. During periods of low runoff, when dissolved oxygen is also low, the young may be prevented from entering the upper 8 to 10 miles of nursery grounds otherwise available to them. Others may become isolated in the short stretch of river between the dam at Fredericksburg and the Sylvania outfall as demonstrated by the capture of young shad in this region in late September (table 34). These fish were somewhat abnormal in structure, a condition that is often associated with restricted space and atypical water conditions.

4. The addition of waste definitely affects the production of bottom organisms in the region immediately below the Sylvania plant. The absence of fishes, and reduced abundance or absence of drifters and plankton forms testifies to the low productivity of this stretch of river. In the absence of wastes, an additional 10 to 15 miles of stream, representing about 4 per cent of the total area and 2.5 per cent of the volume of water between Fredericksburg and Tappahannock, might be restored to natural biological productivity.

5. Since no significant fish mortalities were observed in the river, it is presumed that the zone of pollution and recovery acts as a barrier to fish movement. As already stated, some fish may traverse this area under favorable conditions of dissolved oxygen and become isolated between the Sylvania plant and the dam at Falmouth when oxygen content of the water decreases. It is not known whether this has a significant effect on fish production in the river.

6. Reduction of the waste load in the river might result in an increase in production of fishes. Assuming that such an increase would be proportional to the increase in river area or volume restored to natural productivity, the advantage conferred would be of the order of 2.5 to 4 per cent. However, this is pure conjecture. Actually, as shown by the surveys in the York River tributaries, the upper parts of the tidal portions of the estuaries are less productive biologically. Therefore, their capacity to support young of shad and other commercial species is probably rather limited.

LITERATURE CITED

American Public Health Association
1946. Standard Methods for the examination of water and sewage. Lancaster Press Inc., New York. 9th ed.

Baird, Spencer F.
1880. U. S. Commission Fish and Fisheries. Past VI. Rept. of the Commissioner for 1878.

Cable, Louella E. and Edgar H. Hollis.
A survey of the shad fisheries of Virginia with recommendation for improving their condition.(Unpublished manuscript, not dated).

Fiedler, R. H.
1938. Fishery Industries of the United States. 1936 U. S. Dept. Comm. Bur. Fisheries Administrative Report No. 27.

1938. Fishery Industries of the United States. 1937 U. S. Dept. Comm. Bur. Fisheries Administrative Report No. 32.

1940. Fishery Industries of the United States. 1938 U. S. Dept. Comm. Bur. Fisheries Administrative Report No. 37.

1942. Fishery Statistics of the United States. 1939 U. S. Dept. Int. Fish and Wildlife Service Statistical Digest No. 1

1943. Fishery Statistics of the United States. 1940 U. S. Dept. Int. Fish and Wildlife Service Statistical Digest No. 4.

1945. Fishery Statistics of the United States. 1941 U. S. Dept. Int. Fish and Wildlife Service Statistical Digest No. 7

Gunter, Gordon
1942. A list of fishes of the mainland of north and middle America recorded from both fresh water and sea water. Amer. Midland Naturalist 28(2):305-326.

Haight, F. J., H. E. Finnegan and G. L. Anderson.
1930. Tides and Currents in Chesapeake Bay and Tributaries. U. S. Dept. of Commerce. Coast and Geodetic Survey, Special Pub. No. 162.

Hildebrand, Samuel F. and William C. Schroeder.
1928. Fishes of Chesapeake Bay. Bull. U. S. Bur. Fish., 43(part 1)

McDonald, Marshall.
1887. The Fisheries of the Chesapeake Bay and its Tributaries. Fisheries and Fishery Industries of the U. S. Sect V, Vol. I

Massmann, William H.
1952. A net assembly for collecting eggs of shad and other anadromous fishes. (Unpublished manuscript).

Massmann, William H.
1952. Characteristics of shad Alosa sapidissima Wilson, spawning areas in some Virginia streams. Trans. Amer. Fish Soc., Vol.81. (in press).

Massmann, William H. and Ernest C. Ladd
1951. Hopewell, Virginia - Pollution Survey. Report of the Virginia Fisheries Laboratory on fish sampling 30-31 August 1951.

Massmann, William H., Ernest C. Ladd, and Henry N. McCutcheon
1952. A surface trawl for sampling young fishes in tidal rivers. Trans. 17th N. Amer. Wildlife Conf. (in press).

Patrick, Ruth
1949. A proposed biological measure of stream conditions, based on a survey of the Conestogoo Basin, Lancaster County, Pennsylvania. Proc. Acad. Nat. Sci. Philadelphia 101:277-341.

Power, E. A.
Catch records for the principal fisheries of the Rappahannock River, 1929 - 1941. (Unpublished manuscript, not dated).

Pritchard, D. W. and W. V. Burt.
1951. An inexpensive and rapid technique for obtaining current profiles in estuarine waters. Jour. Mar. Res. 10(2):180-190.

Raney, Edward C.
1950. Freshwater fishes. (In) The James River Basin, Past, Present, and Future. Va. Acad. Sci., Richmond, Virginia. :151-194.

Raney, Edward C. and William H. Massmann
1952. Fishes of the tidewater section of the Pamunkey River. (Unpublished manuscript).

Surber, Eugene W.
1944. The probable effects of the construction of the Salem Church Dam on fishes in the Rappahannock River. Manuscript report to U. S. Corp of Engineers.

Tresselt, Ernest Frederick
1952. The spawning grounds of striped bass Roccus saxatilis (Walbaum) in Virginia waters. Bull. Bingham Ocean. Coll. (in press).

U. S. Corps of Engineers.
1947. Rappahannock River and its tributaries.
Virginia House Document No. 119, 80th Congress 1st session,
U. S. Government Printing Office, Washington, D. C.

Virginia State Planning Board
1935. Report of Virginia State Planning Board Natural Resources.
Vol. 11. Virginia State Planning Board, Richmond, Virginia.

APPENDIX I

Distribution and Abundance
of Bottom Organisms
in the Rappahannock and
other Virginia Rivers.

RAPPAHANNOCK RIVER POLLUTION INVESTIGATION

Biological Studies on the Rappahannock and Pamunkey Rivers

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These studies were carried out in conjunction with a chemical and bacteriological investigation of the Rappahannock River performed by a Field Survey Crew of the Environmental Health Center, U. S. Public Health Service, R. Vanderhoof in charge. The work of the Field Survey Crew was at the request of the Corps of Engineers who desired an assessment of pollution in the river and the benefits to be derived from low water regulation from a proposed dam on the Rappahannock River.

The biological studies are intended to supplement the chemical and bacteriological information. The types, numbers and distribution of aquatic organisms are helpful in demonstrating the extent and degree of pollution in a stream. The biological studies on the Rappahannock and Pamunkey Rivers were limited to a sampling of bottom organisms. This type of biological information is particularly useful where there are fluctuations in pollution discharges or river flow or river oscillations due to tides. In addition to the sampling of this investigation there are extensive plankton and fisheries collections available from the sections of the rivers under study. These collections were made by the Virginia Fisheries Laboratory over a 4-5 month period preceding the current studies. The bottom samples round out the available biological information on these rivers.

Bottom samples were taken with a Peterson dredge at all stations on the Rappahannock River downstream of Fredericksburg, Virginia on the survey of October 2, and 3, 1951. The upstream stations were sampled by hand by random collections from appropriate bottom materials. The dredged samples were sieved in the field through a 30 mesh screen. Relative estimates were made of the organisms present at all stations and specimens of each type were taken and preserved for specific identification. The physical characteristics of the river bottom were described at each station. The collections were made under optimum river conditions for determining the effects of pollution, following an extended period of low flow.

In addition to the field sampling from the Rappahannock River during the first week in October a second series of samples were taken

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* Division of Water Pollution Control
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one month later on November 6. These samples were taken at a series of representative stations for comparison with the data of the October survey. Eleven stations in all were resampled. This survey was carried out from boat facilities provided by the Virginia Fisheries Laboratory. The bottom samples were taken with an Ekman dredge and a quantitative analysis made of the bottom organisms.

In view of the natural changes in the ecology of the tidal streams it was felt that a survey of a non-polluted stream which would duplicate the ecology of the Rappahannock, in its tidal sector, would provide information that would help to evaluate the considerable fluctuations in numbers of bottom organisms that were found on the Rappahannock. For this purpose the Pamunkey River, flowing parallel to and a few miles south of the Rappahannock was selected. Eleven stations were sampled on the Pamunkey River at locations coinciding with stations of the Virginia Fisheries Laboratory and in approximately the same length of river as the polluted and recovery zone of the Rappahannock. This is a distance extending from the head of tide downstream for 18-20 miles. Boat facilities were again provided by the Virginia Fisheries Laboratory. The bottom samples from the Pamunkey were sampled and analyzed quantitatively.

The results of these studies are summarized for each river in a series of tables. These describe the physical characteristics of the river bottoms at the sampling stations, the general types and numbers of bottom organisms at the sampling stations and the specific identifications of aquatic organisms and stations at which they were encountered.

There are no significant sources of pollution on the Pamunkey River and it served as a control for the Rappahannock River. There are two principal pollution discharges on the Rappahannock in the area under study, one from the city of Fredericksburg, Virginia consisting solely of sanitary waste with a daily population equivalent (B.O.D.) of about 17,000 and another from a large industrial operation with a daily population equivalent (B.O.D.) of about 59,000. At present neither discharge receives any treatment. The effluent locations are noted on the map of the Rappahannock River. Sampling stations A,B,C,D,E,F,G, and H,K,N, and O, as noted on this map, are the same locations as used by the Environmental Health Center Field Survey for their sampling points. The stations downstream of Fredericksburg also coincide with stations of the Virginia Fisheries Laboratory studies. Stations noted A-1, A-2, etc. are supplementary stations used in the biological studies.

At the twenty-eight stations sampled, in the October survey on the Rappahannock River from Fredericksburg downstream, all but one had a soft mud bottom usually overlying a base of coarser sand.

(table 1) Station D-6 at a sharp narrow bend in the river, had a pebbly bottom apparently resulting from the scouring action of the water removing the finer materials at this point. The bottoms of the upstream stations usually consisted of soft muds in the back eddies and hard pebbly bottoms in the riffles. The layers of the dredged bottom samples all contained varying amounts of natural organic matter in the form of plant debris. At some stations this plant debris in the subsurface layers comprised a large proportion of the total sample volume. In the stretch of the Rappahannock River from stations A-3 to B-4, a distance of 4.1 miles (nautical) * the surface layer of the river bottom was black with a soupy sludge like consistency. At some points in this section, an oily irridescent film was noted on the surface of the bottom mud. The river bottom between stations A-3 and B-4 appeared to be under anerobic conditions and the area coincided with the zone of maximum pollution effect as indicated by the low oxygen values obtained by the Field Survey.

The fauna and flora sampled from and observed in the Rappahannock and Rapidan Rivers, upstream from Fredericksburg, indicated a clean stream free of pollution. There were a variety of plants and animals at each station with no unusual dominance of any one type. Snails were noted at stations N and O in considerable number but were all of gill breathing species, which require adequate dissolved oxygen. (Tables 2 and 3).

From Fredericksburg downstream, the numbers and types of bottom aquatic organisms presented a typical picture of response of the biota of a stream to heavy pollution. At station A, above the pollution effluents the bottom showed no evidence of obvious pollution, but no bottom organisms were noted in the samples taken. However, the physical characteristics of this station were not conducive to a large bottom population, consisting of a thin silt layer over very coarse sand. The next two stations A-1 and A-2, also upstream from the first source of pollution, the effluent from the city of Fredericksburg, are apparently subjected to some contributions of organic matter due to the tidal movement of the river. A few tubificid worms and chironomid larvae were noted in the bottom sample taken at this station.

Stations A-3 and A-4, opposite and below the first source of pollution, respectively, had only a few tubificid worms in the bottom sample and from this point downstream to station B-4 the bottom samples showed a paucity of organisms. At station A-5 only a snail (Physa heterostropha), in a very few numbers, was noted whereas at station B another species of snail (Helisoma anceps) and a very few specimens of the freshwater clam (Musculium transversum) were found in addition to tufts of the blue-green algae Oscillatoria sp. on the surface of the mud. All these organisms are pollution tolerant types.

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* Distances on the tidal sectors of the Rappahannock and Pamunkey Rivers are measured in nautical miles since the distance and location net established by the Chesapeake Bay Institute for the entire Chesapeake Bay area is measured on this base.

At the next station there had been a set of the clam M. transversum, but growth had been apparently limited. Six-tenths of a mile downstream at station B-2 the same species of clam was again found but here the specimens were of mature size, and of more significance they were actively feeding. The shells of this species of clam being translucent, ingested material can be seen, particularly when of a contrasting color. In this case all the clams appeared to be black inside the shell since they had been ingesting the bottom mud to utilize the organic matter in the mud. This is noteworthy since the clams are gill breathers and require dissolved oxygen. Through station B-4 where the black bottom ended, "black" clams were noted. With the termination of the soupy black mud on the surface of the river bottom the numbers of the clam M. transversum increased enormously reaching a peak at station C-2 where the population was on the order of more than 1000 per sq. foot of bottom surface.

Paralleling the increase in the clam population, the chironomid larvae also increased. It is of interest to note that whereas the chironomid larvae were found at stations B-2 and B-3 and then again from station C through D-1 the tubificid worms did not appear again in the bottom samples until station C-4 after last being noted at station A-4. The tubificid worms continued to be found at nearly all downstream stations working over the natural organic debris while the larvae of the chironomid, Tendipes decorus (a red species) disappeared and were replaced at the farthest downstream stations by larvae of the chironomid, Clinotanypus sp., (a yellow species). At the one hard bottom station sampled, D-4, a planarian and a leech were found. A leech was also collected at station D-6. The downstream stations E through H were characteristic of non-polluted waters in that there were more types of aquatic organisms but each group was represented by fewer numbers. The larvae of the culicid fly, Chaeborus punctipennis, was noteworthy in the bottom samples since it has been reported as being tolerant of very low oxygen concentrations.

The resurvey of the Rappahannock carried out on November 6, 1951 showed that even within the month since the original sampling, changes had taken place in the distribution of the bottom organisms. The black bottom which previously had extended only to station B-4 was now noted to extend 1.5 miles further downstream as far as station C-2. This shift was most probably due to an increase in run-off resulting from a series of heavy rains. At station C-2, a sample taken near the shore brought up the black mud but another sample taken in the channel showed a sandy bottom. The distribution of organisms and their numbers on the resurvey are shown in Table 4. As in the original sampling, the largest clam population was found at station C-2 numbering about 2800 per sq. ft. of bottom in the second survey. The magnitude of this clam productivity is emphasized by comparison with samples reported from the Illinois River. Richardson 1/ investigating the

1/ Richardson, Robert E. The small bottom and shore fauna of the Middle and Lower Illinois River and its connecting lakes, Chillicothe to Grafton; its valuation; its sources of food supply; and its relation to the fishery. Bull. Illinois State Laboratory of Natural History. XIII. 363-352. 1919.

effect of pollution from the Chicago Drainage Canal on the Illinois River reported the largest M. transversum sample taken at 3496.9 per square yard. This is approximately a clam concentration of 388 per square foot, in comparison to the 2800 per square foot on the Rappahannock. In addition to the clam M. transversum, another species, Pisidium sp., was also present in considerable numbers, reaching a peak of 880 per sq. ft. However, this clam population consisted completely of young stages.

Of particular note in the changes of bottom organisms was the presence of the larvae of the midge, Chaoborus punctipennis at stations B-4 and C-2 in addition to stations F and H where it had been found on the first survey. Paralleling the downstream shift in the black bottom considerable numbers of M. transversum were noted to have recently died, their shells were open but still hinged together or their soft parts were decomposing. Dead clams averaged about 30% of the total M. transversum population.

The control survey on the Pamunkey River showed both a difference in bottom characteristics and organisms association from that found on the Rappahannock. Nearly all the bottoms sampled on the Rappahannock in the tidal sector were soft muds or clays over coarser sand whereas on the Pamunkey nearly all the bottoms sampled were fine to coarse sands. (Table 5).

Both in numbers and species the bottom organisms of the Pamunkey differed from that found on the Rappahannock. (Table 6 and 7). The dominant clam of the Rappahannock, M. transversum, was not encountered in any of the bottom samples taken. However, it may have been present but in so few numbers that it was not sampled. In contrast the considerably larger species Elliptio complanata was the dominant pelecypod on the Pamunkey River. This species was found over a distance of 7 miles from stations E through H reaching a peak in numbers at station G. An unusual concentration of these clams may be present near the south west shore of the Pamunkey at station J. Attempts to obtain a bottom grab at this point were unsuccessful. The heavy Peterson dredge would not dig in but would nip off a few clams at each lowering. There may be a clam "reef" at this point. The reported sample at station J was taken from a softer bottom toward the north east shore of the river.

Overlapping at the upstream edge of the stretch of the Pamunkey River in which E. complanata occurred was a zone dominated by the snail, Lioplex subcarinata. This zone extended for 3.5 miles from stations D to G. This species was found in the first survey on the Rappahannock at stations D and D-1, just 3.3 miles from the edge of the zone of degradation and within the zone of recovery. This snail species is a gill breather and therefore requires dissolved oxygen in its immediate aquatic environment. There were no unusual numbers of organisms on the Pamunkey that are usually associated with severe pollution conditions.

It is of interest to note that the bottom sample taken at station G on the Pamunkey River contained a fossil shark tooth. This tooth was identified as belonging to a genus of sand sharks (Carcharias) and probably of Tertiary origin.

On both rivers two species of clams were the dominant bottom organisms. On the Rappahannock, M. transversum achieved the dominating rôle and on the Pamunkey, E. complanata. In comparison, on a numerical basis, the Rappahannock appeared to be the more productive river achieving in the peak sample about 2800 clams per square foot. However, comparison on a weight basis presents a different picture of productivity. Representative samples of the two species, indicated an average wet weight for M. transversum of .0937 gms. and 304.2 gms for E. complanata. Thus on a wet weight basis the productivity on the Pamunkey River based on the maximum clam sample was 12,168 gms per square foot but only 262.3 gms per square foot for the Rappahannock River. Although the Rappahannock productivity analysis accounts for only M. transversum, the young of the other clam species present, Pisidium sp. was even smaller than M. transversum, averaging only about 1-1.5 mm in largest dimension, and their contribution to the total productivity on a weight basis can be considered negligible. It appears that the contribution of nutrients to the Rappahannock River by the organic pollution enabled a surge in productivity. However, this was limited to pollution tolerant species and on a weight basis did not compare as well with the clam productivity of the non-polluted Pamunkey River.

In summary, based on the physical characteristics and the distribution and numbers of the bottom organisms in the Rappahannock River, the zone of degradation and decomposition early in October, extended from station A-3 to B-4, a distance of 4.1 miles (nautical). The zone of recovery extended from station C to about station E, a distance of 8.0 miles (nautical) and for the remainder of the river that was examined the bottom organisms did not appear to be materially affected by the upstream pollution. The comparatively short distances involved is of course a result of the tidal action in the river which tends to limit downstream movement of polluting materials and compresses the zones of pollution effects.

The unusual numbers of fresh water clams found in the Rappahannock River is of particular interest. These bottom organisms are present in the numbers observed due to the fact that an unusual food supply has developed which can support this large population, which itself is tolerant of pollution. In turn the clams are very actively working over the organic matter in the river bottom utilizing it as a source of food and simultaneously stabilizing the organic materials.

The enrichment of the Rappahannock River by organic pollution enabled the development of the enormous numbers of the clam M. transversum. However, this enrichment did not surpass the total clam productivity, on a weight basis, of the Pamunkey River. The natural productivity of the latter stream maintained a weight of clams, at the best station sampled, of more than 46 times that found on the Rappahannock River. It should be noted, however, that the pill clams belonging to the family Sphaeriidae serve as food for many species of fish. Thus the Rappahannock with the fish food chain supplemented by the enormous numbers of M. transversum may sustain a greater fish population than the Pamunkey along the comparable stretches of river.

Acknowledgement: This investigator wishes to acknowledge the identification service provided by the U.S. National Museum for most of the insect larvae and molluscs collected in these studies. Dr. Bobb Schaeffer of the American Museum of Natural History identified the shark tooth and Dr. Libbie H. Hyman of this same institution identified some of the other invertebrate forms.

Table 1

Rappahannock River Pollution Investigation
Biological Studies
October 2, 1951

BOTTOM CHARACTERISTICS

		Surface Layers								Sub-Surface Layers				
		Color												
Station	** River Mile	Red or Brown	Gray	Black	Fine silt	Mud	Sand	Pebbles	Plant Debris *	Mud	Clay	Sand	Plant Debris *	Remarks
A	93.5	x			x				1			x	1	
A-1	93.3	x				x			1			x	1	
A-2	93.0	x				x			1			x	1	
A-3	92.9			x		x			1	x			1	
A-4	92.8			x		x			1	x		x	3	Top layers soupy & oily
A-5	92.4			x		x			1	x		x	1	As A-4
B	91.3			x		x			1			x	1	As A-4
B-1	90.4			x		x			1			x	1	Sur.mud soupy
B-2	89.8			x		x			1	x			1	As B-1
B-3	89.2			x		x			1	x			3	As B-1
B-4	88.8			x		x			1			x	1	As B-1
C	88.6		x			x			2			x	2	Subsurface lay dk. coarse san
C-1	87.8	x				x			1			x	1	As C
C-2	87.3	x				x			1			x	1	As C
C-3	86.7	x				x	x		1			x	3	
C-4	85.8	x				x	x		1			x	2	
D	85.2	x			x				1			x	1	
D-1	84.1	x			x				1	x			1	
D-2	83.1	x				x	x		1		x		1	
D-3	82.5	x				x			2			x	2	
D-4	82.1	x				x	x		2			x	3	
D-5	81.6	x				x	x		1			x	2	
D-6	81.3							x						
E	80.6	x			x	x	x		1			x	2	
E-1	78.2	x				x			1	x			2	
F	76.3	x			x	x	x		2			x	3	
G	72.3	x				x	x		1		x		3	
H	68.2	x				x			1		x		3	
K	35	x			x				1			x	2	
N	13***	x				x	-	x	1			x	1	
O	6.5							x						

* Approx. Quantity
1 = (1-10% of sample)
2 = (10-25% ")
3 - (25-50% ")

*** On Rapidan River. River miles measured from confluence with Rappahannock River.

** Stations A through H downstream from Fred. River miles (nautical) from zero point at mouth of river. Sta. K,N&O, upstream from Fred. Distances upstream in statute miles with zero point at Fred.

Table 2

Rappahannock River Pollution Investigation
Biological Studies
October 2, 1951

			BOTTOM ORGANISMS											
			Insect Larvae		Snails		Clams				Algae		
Station	River Mile*	Tubificidae (Segmented worms)	Chironomidae	Other Dipterous Larvae	Prosobranchiata	Pulmonata	Unionidae	Sphaeriidae	Platyhelminthes (flat worms)	Hirudinae (Leeches)	Cyanophyceae	Chlorophyceae	Remarks
A	93.5												No organisms in sampl.
A-1	93.3	1											
A-2	93.0	1	1										
A-3	92.9	1											
A-4	92.8	1											
A-5	92.4					1							
B	91.3					1		1			1		Algae growing on bot.
B-1	90.4							1					Clams set but did not grow
B-2	89.8		1					1					Clams black from ingesting mud
B-3	89.2		1					1					Clams black
B-4	88.8							1					Clams black
C	88.6		1			1	1	2					
C-1	87.8		1					3			1		Algae growing on bot.
C-2	87.3		3				1	4					
C-3	86.7		3					3					
C-4	85.8	1	3					3					
D	85.2	2	2		1		1	3					
D-1	84.1	2	2		1			2					
D-2	83.1	1						2					
D-3	82.5	2						1					
D-4	82.1	1								1			Broken shell of Unionidae
D-5	81.6		1					1					
D-6	81.3					1			1	1			
E	80.6	1	2					1					
E-1	78.2	1	2	1				1					
F	76.3	1	1	1			1						
G	72.3	1	1	1									
H	68.2	1	1	2									
K	35			2									Many small fish
N	13			2	3							2	Many small fish
O	6.5			2	3							2	Many small fish

*Stations A through H downstream from Fredericksburg. River miles (naut.) measured from zero point at mouth of river. Stations K,N&O upstream from Fred. Distances upstream in statue miles from 0 point at Fred. Sta. N is 13 miles up Rapidan River measured from confluence with Rappahannock River. Numbers indicate estimated populations per square ft. 1, <10; 2, 10-100; 3, 100-1000; 4, > 1000.

Table 3

Rappahannock River Pollution Investigation
Biological Studies
October 2, 3, 1951

Organisms Collected in Bottom Samples

Organisms	Stations
Algae	
Cyanophyceae	
Oscillatoria sp.	B, C-1
Chlorophyceae	
Cladophora sp.	O
Spirogyra sp.	N, O
Ulothrix sp.	N, O
Turbellaria	
Dugesia tigrina	D-6
Annelida	
Tubificidae	A-1, A-2,A-3,A-4,C-4, D,D-1,D-2,D-3,D-4,E, E-1,F,G, H.
Hirudinea	
Glossiphonia sp.	D-4, D-6
Mollusca	
Pelecypoda	
Andonta cataracta Say	C-2
Elliptio complanatus (Solander)	G, F
Lampsilis ochraceus Say	C, D
Musculium transversum Say	B,B-1,B-2,B-4,C-1,C, C-2,C-3,C-4,D,D-1,D-2, D-3,D-5,E,E-1
Pisidium compressum Prime	B
Pisidium sp.	C,D-1,C-2,C-3,C-4,D
Gastropoda	
Ferrissia tarda Say	D-6
Goniobasis virginica (Gmelin)	N
Helisoma anceps (Menke)	B
Lioplax subcarinata (Say)	D,D-1
Mudalia carinata (Brugiere)	N,O
Physa heterostropha (Say)	A-5,C

Table 3 (continued)

Rappahannock River Pollution Investigation
Biological Studies
October 2, 3, 1951

Organisms Collected in Bottom Samples

Organisms	Stations
Insecta	
Tendipedidae (Chironomidae)	
Tendipes decorus (Johannsen)	A-2,B-2,B-3,C-1,C-2,C-3, C-4,D,D-1,D-5,E,E-1
Clinotanypus sp.	E,E-1,F,G,H
Culicidae	
Chaeborus punctipennis (Say)	E-1,F,G,H
Hydropsychidae (Caddis flies)	
Hydropsyche sp.	K
Elmidae (Beetles)	
Macronychus sp.	K
Macronychus glabratus (Say)	K
Stenelmis sp.	K
Simsonia vittata (Melsh)	K
Bryozoa	
Plumatella sp.	D-6

Table 4
Rappahannock River Pollution Investigation
Biological Studies
November 6, 1951

BOTTOM ORGANISMS
Numbers per square foot

Station	River Mile	Tubificidae	Chironomidae Tendipes decorus	Culicidae Chaoborus Punctipennis	Unionidae Ellipto Complanatus	Sphaeriidae Musculium trans.	Sphaeriidae Pisidium sp.
B-2	89.8	8	4	0	0	4	0
B-4	88.8	300	60	72	0	152	40
C	88.6	500	240	0	0	160	32
C-2 Shore	87.3	560	16	24	0	480	350
C-2 Channel	87.3	0	0	8	0	2800	880
C-3	86.7	1020	8	0	0	735	290
D	85.2	200	240	0	0	240	88
D-3	82.5	170	32	0	4	28	16
E	80.6	160	24	0	4	8	0
F	76.3	100	90	8	0	0	0
G	72.3	0	20	0	0	0	0
H*	68.2	8	24	12	0	4	0

* One unknown genus of Unionicolidae (water mite) also collected.

Table 5

Rappahannock River Pollution Investigation
Biological Studies on the Pamunkey River
November 7, 1951

BOTTOM CHARACTERISTICS

Station	River Mile*	Color: Red or Brown	Gray	Black	Fine silt	Mud	Clay	Fine sand	Coarse sand	Pebbles	Plant Debris **
A	68.0	x							x		1
B	66.2	x							x		2
C	64.3	x							x		2
D	62.9	x						x	x		2
E	61.2	x							x		2
F	60.2	x							x	x	<1
G	59.4	x							x		1
H	58.3	x						x	x		<1
I	57.2	x							x		1
J	54.2	x				x					3
K	50.7	x				x	x				1

* River miles (nautical) from zero point at mouth of river.

** Approximate Quantity

1 - (1-10% of sample)
2 - (10-25% of sample)
3 - (25-50% of sample)

Table 6

Pamunkey River Biological Studies

In Conjunction with the Rappahannock River Pollution Investigation

November 7, 1951

BOTTOM ORGANISMS

Numbers per square foot

Station	River Mile	Tubifi-cidae	Chironomidae Tendipes decorus	Proso-branchiata Lioplax subcarinata	Pul-monata Menetus dilatatus	Unionidae Elliptio complanatus	Sphaeri. Pisidium abdi.
A	68.0	50	4	0	0	0	0
B	66.2	5	0	0	0	0	0
C	64.3	24	16	0	4	0	0
D	62.9	28	32	16	0	0	0
E	61.2	8	20	52	0	17	4
F	60.2	0	0	0	0	16	0
G	59.4	48	12	16	0	55	4
H	58.3	0	0	0	0	4	0
I	57.2	15	4	0	0	24	0
J	54.2	0	0	0	0	6	0
K	50.7	0	0	0	0	0	0

Table 7

Pamunkey River Biological Studies

In Conjunction with the Rappahannock River Pollution Investigation

November 7, 1951

Organisms Collected in Bottom Samples

Organism	Station
Annelida	
Tubifex sp.	A,B,C,D,E,G,I
Limnodrilus sp.	A
Mollusca	
Pelecypoda	
Elliptio complanatus (Solander)	E,F,G,H,I,J
Pisidium abditum Haldemen?	E,G
Gastropoda	
Lioplax subcarinata	D,E,G,
Menetus dilatatus (Gould)	C
Insecta	
Trichoptera	
Genus sp.?	K
Ephemeroptera	
Hexagenia munda Eaton	D
Plecoptera	
Gomphus sp.	G

APPENDIX II

Physical and Chemical Data from the Rappahannock and other Virginia Rivers.

Table A-1

Location, date, and time of physical and chemical sampling on the Rappahannock River 1951.

Station	Average Depth Feet	Cruise #1			Cruise #2			Cruise #3			Cruise #4		
		Date	Time	Tide	Date	Time	Tide	Date	Time	Tide	Date	Time	Tide
37.0	24	3-28	1000	E	4- 2	1150	F	4- 9	1455	F	4-16	1455	E
41.0	13	"	1145	E	"	1315	S	"	1610	F	"	1515	E
45.0	23	"	1335	E	"	1520	E	"	1715	F	"	1620	E
50.0	20	"	1445	E	"	1635	E	"	1815	F	"	1735	E
58.0	17	3-29	0830	F	4- 3	0840	E	4-10	0600	F	"	1910	E
61.4	17	"	1115	E	"	1000	E	"	0720	F	4-17	0745	F
64.0	13	"	1415	E	"	1300	S	"	1000	E	"	0945	F
68.2	20	"	1530	E	"	1430	-	"	1120	E	"	1030	F
72.3	17	"	1740	E	"	1625	E	"	1330	E	"	1130	F
76.3	13	"	1845	F	"	1735	E	"	1430	E	"	1400	E
80.6	14	3-30	0800	F	4- 4	0755	E	"	1530	E	"	1445	E
85.2	19	"	0900	F	"	0935	E	"	1630	E	"	1530	E
88.6	17	"	0955	S	"	1100	E	"	1735	E	"	1605	E
91.2	15	"	1040	E	"	1215	E	4-11	0600	E	"	1640	E
93.6	8	"	1120	E	"	1415	E	"	1800	E	"	1700	E

Table A-1 (continued)

Location, date, and time of physical and chemical sampling on the Rappahannock River 1951.

Station	Average Depth Feet	Cruise #5			Cruise #6			Cruise #7			Cruise #8		
		Date	Time	Tide	Date	Time	Tide	Date	Time	Tide	Date	Time	Tide
37.0	24	4-23	1515	F	5- 2	1535	E	5- 8	1300	F	5-15	1505	E
41.0	13	"	1620	F	"	1635	E	"	1405	F	"	1550	E
45.0	23	"	1730	S	"	1725	E	"	1450	F	"	1635	E
50.0	20	"	1820	S	"	1810	E	"	1550	F	"	1720	E
58.0	17	4-24	1010	E	5- 3	1100	F	"	1700	F	5-16	1100	F
61.4	17	"	1055	E	"	1205	F	"	1735	F	"	1155	F
64.0	13	"	1130	E	"	1235	F	"	1805	F	"	1350	E
68.2	20	"	1220	E	"	1330	F	5- 9	0745	S	"	1430	E
72.3	17	"	1315	E	"	1500	F	"	0955	E	"	1510	E
76.3	13	"	1545	E	"	1545	F	"	1038	E	"	1552	E
80.6	14	"	1535	E	"	1620	S	"	1120	E	"	1640	E
85.2	19	"	1620	S	"	1700	S	"	1205	E	5-17	0700	E
88.6	17	"	1715	F	"	1740	S	"	1332	E	"	0748	E
91.2	15	"	1750	S	"	1810	E	"	1405	E	"	0820	E
93.6	8	"	1815	E	"	1835	E	"	1435	E	"	0845	E

Table A-1 (continued)

Location, date, and time of physical and chemical sampling on the Rappahannock River 1951.

Station	Average Depth Feet	Cruise #9			Cruise #10			Cruise #11			Cruise #12		
		Date	Time	Tide	Date	Time	Tide	Date	Time	Tide	Date	Time	Tide
37.0	24	5-21	1455	S	6- 4	0845	E	6-14	0745	F	6-19	0755	E
41.0	13	"	1540	S	"	0910	E	"	0810	F	"	0820	E
45.0	23	"	1625	S	"	0935	E	"	0825	F	"	0840	E
50.0	20	"	1710	S	"	1000	E	"	0900	F	"	0905	E
58.0	17	"	1830	E	"	1050	E	"	0940	F	"	1000	E
61.4	17	"	1925	E	"	1100	E	"	1000	F	"	1020	E
64.0	13	5-22	0815	E	"	1125	E	"	1015	F	"	1040	E
68.2	20	"	0910	E	"	1150	E	"	1040	F	"	1100	E
72.3	17	"	0955	E	"	1205	E	"	1110	E	"	1125	E
76.3	13	"	1035	E	"	1230	E	"	1135	E	"	1145	E
80.6	14	"	1120	E	"	1250	E	"	1200	E	"	1215	E
85.2	19	"	1205	E	"	1310	E	"	1225	E	"	1235	E
88.6	17	"	1320	E	"	1330	E	"	1245	E	"	1355	E
91.2	15	"	1350	E	"	1345	E	"	1305	E	"	1310	E
93.6	8	"	1415	E	"	1400	E	"	1320	E	"	1325	E

Table A-1(continued)

Location, date, and time of physical and chemical sampling on the Rappahannock River 1951.

Station	Average Depth Feet	Cruise #13			Cruise #14			Cruise #15			Cruise #16		
		Date	Time	Tide	Date	Time	Tide	Date	Time	Tide	Date	Time	Tide
37.0	24	6-27	0825	F	7-4	-	E	7-11	0800	S	7-17	0810	E
41.0	13	"	0850	F	"	0800	E	"	0845	S	"	0835	E
45.0	23	"	0910	F	"	0840	E	"	0850	S	"	0900	E
50.0	20	"	0925	F	"	0915	E	"	0920	S	"	0920	E
58.0	17	"	1015	F	"	1000	E	"	1020	E	"	1005	E
61.4	17	"	1030	F	"	1025	E	"	1035	E	"	1025	E
64.0	13	"	1045	F	"	1040	E	"	1055	E	"	1040	E
68.2	20	"	1105	F	"	1100	E	"	1110	E	"	1100	E
72.3	17	"	1125	F	"	1225	E	"	1125	E	"	1120	E
76.3	13	"	1200	F	"	1245	E	"	1230	E	"	1140	E
80.6	14	"	1215	F	"	1305	E	"	1250	E	"	1220	E
85.2	19	"	1240	E	"	1330	E	"	1310	E	"	1245	E
88.6	17	"	1300	E	"	1345	E	"	1325	E	"	1300	E
91.2	15	"	1315	E	"	1400	E	"	1350	E	"	1320	S
93.6	8	"	1320	E	"	1420	E	"	1405	E	"	1335	S

Table A-1 (continued)

Location, date, and time of physical and chemical sampling on the Rappahannock River 1951.

Station	Average Depth Feet	Cruise #17			Cruise #18			Cruise #19			
		Date	Time	Tide	Date	Time	Tide	Date	Time	Tide	
37.0	24	8- 3	0530	E	8-17	0735	E	8-28	0710	S	
41.0	13	"	0600	E	"	0805	E	"	0730	S	
45.0	23	"	0620	E	"	0815	E	"	0755	S	
50.0	20	"	0645	E	"	0835	E	"	0820	S	
58.0	17	"	0720	E	"	0925	E	"	0915	F	
61.4	17	"	0740	E	"	0940	E	"	0940	F	
64.0	13	"	0750	E	"	1000	E	"	0955	S	
68.2	20	"	0812	E	"	1017	E	"	1010	E	
72.3	17	"	0830	E	"	1035	E	"	1030	E	
76.3	13	"	0850	E	"	1055	E	"	1100	E	
80.6	14	"	0910	E	"	1115	E	"	1120	E	
85.2	19	"	0930	E	"	1140	E	"	1140	E	
88.6	17	"	0950	E	"	1210	E	"	1155	E	
91.2	15	"	1005	E	"	1220	E	"	1210	E	
93.6	8	"	1015	E	"	1230	E	"	1220	E	

Table A-2

Dissolved oxygen in the Rappahannock River 1951. Readings in parts per million.

Station	Cruise #1		Cruise #2		Cruise #3		Cruise #4		Cruise #5		Cruise #6		Cruise #7	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	10.4	10.4	9.7	9.7	9.6	9.6	9.8	9.8	9.6	9.6	8.3	8.3	8.9	8.8
41.0	10.6	10.8	10.4	10.3	10.1	10.0	9.8	9.9	9.6	9.6	8.8	8.8	9.0	9.0
45.0	10.9	11.0	10.4	10.3	10.0	10.0	9.9	9.8	9.6	9.5	8.9	8.9	9.7	9.2
50.0	10.4	10.6	10.3	10.2	9.9	9.8	9.7	7.3	9.2	9.6	8.9	8.9	10.1	10.0
58.0	10.4	10.4	9.9	10.2	9.5	9.5	9.8	9.8	9.5	9.5	9.0	9.0	10.3	10.3
61.4	10.6	10.6	10.1	10.0	9.7	9.5	9.5	9.8	9.7	9.7	9.0	9.0	10.3	10.3
64.0	10.4	10.2	10.1	10.1	9.9	9.8	9.7	9.7	9.6	9.7	9.0	9.0	9.7	9.7
68.2	10.1	10.0	9.5	9.5	9.6	9.6	10.1	10.0	9.2	9.2	8.2	7.6	8.5	8.5
72.3	10.1	10.1	10.1	10.0	9.7	9.6	10.1	10.0	9.1	9.1	7.0	7.2	6.3	6.6
76.3	9.7	9.9	10.1	10.1	9.2	9.2	10.0	10.2	8.6	8.6	6.9	6.9	6.7	6.5
80.6	10.0	10.0	11.1	11.0	9.6	10.0	10.0	10.1	8.4	8.5	6.3	6.2	7.5	7.5
85.2	10.3	10.3	11.6	11.4	10.0	10.0	10.4	10.4	9.2	9.4	6.6	6.6	8.2	8.2
88.6	10.4	10.4	12.0	11.7	10.3	10.5	10.5	10.5	9.2	9.4	7.3	7.3	8.5	8.7
91.2	10.1	10.2	11.7	11.7	10.5	10.7	10.7	10.7	9.8	9.8	7.9	7.9	9.2	9.2
93.6	10.5	10.6	11.9	11.9	10.7	11.0	11.0	11.0	10.4	10.4	9.4	9.4	10.0	10.2

Table A-2 (continued)

Dissolved oxygen in the Rappahannock River 1951. Readings in parts per million.

Station	Cruise #8		Cruise #9		Cruise #10		Cruise #11		Cruise #12		Cruise #13		Cruise #14	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	10.1	8.9	9.0	8.1	6.7	6.7	7.9	7.3	6.9	6.9	6.5	6.0	-	-
41.0	9.5	11.0	9.5	8.7	7.3	7.1	7.8	7.7	7.0	6.6	6.1	5.8	6.5	6.5
45.0	11.0	10.5	9.3	8.8	7.7	7.7	8.1	8.1	6.1	5.5	7.1	6.1	6.9	6.5
50.0	10.7	10.4	10.3	9.4	8.0	7.8	7.1	6.7	5.8	5.7	6.7	6.1	6.9	6.3
58.0	10.2	10.2	10.0	9.5	9.1	8.9	4.9	4.7	6.6	6.3	6.6	6.0	7.3	6.7
61.4	10.6	10.4	10.4	9.8	9.0	8.9	6.7	6.2	7.2	6.3	6.4	6.3	7.9	7.3
64.0	10.4	10.3	9.6	9.6	8.9	8.5	6.8	6.7	6.3	6.3	7.1	6.9	7.5	4.7
68.2	9.0	8.6	7.4	7.4	7.8	7.2	6.3	6.4	6.5	6.3	8.4	7.2	6.8	6.8
72.3	7.0	6.9	5.3	5.6	6.8	6.5	7.1	6.4	6.8	6.4	7.1	5.4	6.5	5.0
76.3	6.8	6.5	5.7	5.7	6.3	5.5	7.8	8.0	6.4	5.8	8.2	6.6	5.3	4.9
80.6	6.5	6.5	5.7	5.7	5.4	5.0	8.8	8.4	7.0	6.4	6.9	5.0	4.9	4.7
85.2	6.5	6.5	6.3	6.3	5.4	5.0	9.0	8.4	7.0	6.8	5.5	4.7	3.4	3.7
88.6	7.5	7.5	6.5	6.6	3.8	3.0	9.0	8.8	7.1	7.0	4.3	3.9	4.4	4.1
91.2	9.2	9.2	8.5	8.9	5.6	5.6	8.7	9.0	7.6	7.6	5.0	5.1	6.5	6.4
93.6	8.6	8.6	9.4	9.4	7.6	7.6	8.8	9.0	8.5	8.4	8.0	7.1	8.0	8.2

Table A-2 (continued)

Dissolved oxygen in the Rappahannock River 1951. Readings in parts per million.

Station	Cruise #15		Cruise #16		Cruise #17		Cruise #18		Cruise #19	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	6.5	6.6	6.1	6.1	7.2	6.7	7.6	7.0	6.1	6.4
41.0	5.8	7.0	6.6	6.3	7.1	6.6	7.0	6.8	7.2	6.8
45.0	7.3	7.0	6.8	6.3	7.1	6.1	6.8	6.6	8.1	6.8
50.0	8.5	7.1	7.2	6.8	6.5	6.5	6.3	6.0	6.5	6.4
58.0	8.7	7.2	7.1	7.4	6.8	6.6	6.5	5.7	7.0	6.9
61.4	8.4	7.1	7.3	7.1	6.9	6.6	6.5	6.3	7.1	7.1
64.0	8.7	7.3	7.7	7.4	7.0	6.6	6.7	6.5	7.2	7.6
68.2	9.1	7.1	6.2	5.7	7.0	6.8	7.0	6.8	6.3	6.3
72.3	6.5	5.3	6.6	6.1	7.0	7.0	6.4	6.0	5.5	5.4
76.3	6.3	5.4	7.0	6.5	7.5	7.6	2.2	1.0	5.2	5.0
80.6	9.1	5.9	8.5	7.3	5.7	5.1	2.3	2.1	4.6	4.1
85.2	8.6	8.4	4.9	3.1	4.3	4.3	2.1	1.4	3.1	2.6
88.6	4.3	2.9	4.4	3.8	3.3	3.0	1.6	0.2	1.5	0.5
91.2	4.6	3.9	5.7	5.7	0.9	1.1	1.1	0.2	0.8	0.4
93.6	8.0	8.0	7.4	7.5	7.1	6.9	6.1	6.1	7.1	7.1

Table A-3

Per cent saturation of dissolved oxygen in the Rappahannock River 1951.

Station	Cruise #1		Cruise #2		Cruise #3		Cruise #4		Cruise #5		Cruise #6		Cruise #7	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	89	88	92	92	90	88	95	92	95	91	90	90	93	93
41.0	92	94	96	96	95	93	93	86	96	92	99	97	96	95
45.0	94	94	94	94	94	93	94	92	94	92	98	96	104	96
50.0	90	90	93	93	93	91	92	68	88	91	97	97	107	105
58.0	92	91	91	93	88	87	93	91	90	90	100	99	109	108
61.4	93	93	91	91	88	86	87	89	95	94	101	100	108	108
64.0	94	92	92	92	90	89	87	87	93	93	100	99	103	102
68.2	91	91	87	87	88	87	90	89	88	87	90	82	91	90
72.3	91	92	93	93	90	86	90	89	87	87	78	68	67	71
76.3	87	89	93	93	86	85	92	91	84	83	76	76	72	71
80.6	90	90	96	96	89	92	93	93	83	82	68	67	78	78
85.2	92	92	99	98	93	92	96	95	91	93	73	72	80	82
88.6	95	95	102	100	95	96	95	95	90	92	70	69	90	91
91.2	93	94	100	100	95	96	97	96	97	97	86	85	95	92
93.6	97	102	102	102	100	102	100	99	102	102	106	106	106	109

Table A-3(continued)

Per cent saturation of dissolved oxygen in the Rappahannock River 1951.

Station	Cruise #8		Cruise #9		Cruise #10		Cruise #11		Cruise #12		Cruise #13		Cruise #14	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	114	97	100	90	79	78	88	80	78	78	80	71	-	-
41.0	105	120	108	95	87	83	88	86	73	75	76	71	80	80
45.0	125	114	105	96	91	89	90	90	67	61	90	75	87	80
50.0	120	114	115	102	96	92	79	85	66	63	82	75	87	79
58.0	115	113	111	104	110	105	53	51	74	70	82	74	93	84
61.4	120	115	115	106	109	108	73	67	80	71	80	78	87	92
64.0	119	115	105	105	108	103	74	72	71	69	90	86	95	58
68.2	104	95	83	80	96	85	67	67	71	67	108	90	85	83
72.3	79	76	58	60	80	76	76	68	71	70	88	67	79	62
76.3	75	72	63	61	73	65	82	86	72	63	105	80	65	60
80.6	70	70	64	63	63	58	91	86	78	70	89	61	60	57
85.2	69	69	69	67	65	59	94	86	78	75	70	57	41	46
88.6	80	79	71	71	48	36	94	90	78	78	54	48	53	49
91.2	101	101	97	99	70	67	90	93	86	85	64	62	69	78
93.6	95	95	106	106	93	94	91	100	96	95	103	87	99	100

Table A-3 (continued)

Per cent saturation of dissolved oxygen in the Rappahannock River 1951.

Station	Cruise #15		Cruise #16		Cruise #17		Cruise #18		Cruise #19	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	78	78	77	77	90	84	97	89	75	78
41.0	70	84	85	80	90	84	89	86	87	82
45.0	90	85	87	80	91	77	86	84	98	81
50.0	104	89	92	86	83	82	80	76	79	77
58.0	108	90	92	95	86	84	83	72	85	83
61.4	104	89	95	93	87	84	83	79	84	84
64.0	108	89	100	95	89	84	85	82	86	91
68.2	115	89	79	73	90	86	90	86	86	85
72.3	81	66	85	78	90	90	83	76	68	65
76.3	78	66	86	83	96	96	28	12	63	60
80.6	115	72	110	95	71	62	29	28	56	50
85.2	108	105	63	39	55	54	27	16	38	31
88.6	54	35	57	47	42	37	21	2	17	6
91.2	57	47	76	73	11	13	14	3	8	4
93.6	100	100	96	95	90	87	80	78	83	83

Table A-4

Determinations of hydrogen ion concentration in the Rappahannock River 1951.

Station	Cruise #1		Cruise #2		Cruise #3		Cruise #4		Cruise #5		Cruise #6		Cruise #7	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	7.3	7.5	7.1	7.1	7.3	7.2	7.0	7.0	7.3	7.3	7.1	7.1	7.1	7.1
41.0	7.3	7.4	7.3	7.3	7.3	7.3	7.1	7.0	7.2	7.1	7.3	7.4	7.5	7.3
45.0	7.1	7.9	7.1	7.1	7.3	7.3	7.1	7.0	7.2	7.2	7.3	7.1	7.5	7.5
50.0	7.3	7.1	7.1	7.0	7.1	7.1	6.9	6.8	7.2	7.2	7.4	7.2	7.9	7.8
58.0	7.4	7.1	7.2	7.1	7.1	7.1	7.0	7.0	7.3	7.3	7.3	7.4	8.1	8.1
61.4	7.0	7.0	7.2	7.1	7.1	7.1	7.0	7.1	7.3	7.2	7.4	7.5	8.0	7.9
64.0	7.1	7.1	7.1	7.1	6.9	6.9	7.0	7.1	7.2	7.2	7.4	7.4	7.8	7.7
68.2	7.0	7.0	7.1	7.0	6.9	6.9	7.1	7.1	7.1	7.1	7.1	7.0	7.3	7.2
72.3	7.2	7.3	7.1	7.0	6.6	6.6	7.1	7.1	7.0	7.0	6.9	6.9	6.9	6.9
76.3	7.1	7.1	7.4	7.1	6.9	6.9	7.0	7.0	7.0	7.0	6.9	6.9	6.8	6.8
80.6	7.2	7.2	7.0	7.2	6.9	6.9	7.0	7.0	7.0	7.0	6.9	6.9	6.9	6.9
85.2	7.0	7.0	6.9	7.0	7.0	7.1	7.0	7.1	7.1	7.1	6.9	6.9	7.0	6.9
88.6	7.2	7.2	6.9	6.9	7.2	7.4	7.0	7.0	7.2	7.2	6.7	6.7	6.8	6.8
91.2	7.4	7.1	7.1	7.4	7.5	7.4	7.0	7.0	-	-	6.5	6.4	7.0	7.0
93.6	7.3	7.0	6.9	7.2	7.0	-	7.4	7.5	7.3	7.5	7.8	8.0	7.8	7.8

Table A-4 (continued)

Determinations of hydrogen ion concentration in the Rappahannock River 1951.

Station	Cruise #8		Cruise #9		Cruise #10		Cruise #11		Cruise #12		Cruise #13		Cruise #14	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	7.6	7.3	7.6	7.4	7.0	7.0	7.2	7.1	7.1	7.1	6.9	7.0	-	-
41.0	8.7	8.4	7.8	7.7	7.1	7.0	7.3	7.3	7.0	7.0	7.2	7.2	7.3	7.3
45.0	9.0	8.7	7.9	7.7	7.2	7.1	7.3	7.3	6.7	6.7	7.1	7.0	7.3	7.3
50.0	9.0	8.8	8.7	8.3	7.2	7.1	6.9	7.1	6.7	6.7	7.0	6.9	7.0	7.2
58.0	8.4	8.1	8.7	8.7	7.5	7.3	6.8	6.7	6.8	6.7	6.9	6.9	7.2	6.8
61.4	8.5	8.5	8.7	8.4	7.4	7.4	6.7	6.7	6.7	6.7	7.0	7.0	7.3	7.4
64.0	8.4	8.3	7.9	7.8	7.4	7.2	6.8	6.8	6.8	6.7	7.0	7.0	7.4	7.3
68.2	7.2	7.1	7.2	7.1	6.9	6.8	6.7	6.6	6.8	6.7	7.2	6.9	7.3	7.1
72.3	6.8	6.7	6.8	6.8	6.8	6.7	6.6	6.7	-	6.8	6.9	6.8	7.2	7.1
76.3	6.8	6.7	6.7	6.7	6.7	6.7	6.9	6.9	6.8	6.7	6.9	6.8	7.1	7.0
80.6	6.7	6.6	6.8	6.8	6.6	6.6	7.1	7.0	6.9	6.8	6.9	6.8	6.9	7.0
85.2	6.7	6.7	6.9	6.9	6.3	6.3	7.0	7.0	6.9	6.9	6.8	6.8	7.0	6.9
88.6	6.8	6.8	7.0	7.1	6.6	6.5	7.1	7.0	7.0	7.0	6.8	6.8	6.8	7.3
91.2	7.2	7.4	7.0	6.9	6.9	6.8	7.0	7.0	7.0	7.0	6.5	6.2	7.5	6.9
93.6	7.6	7.7	7.8	7.9	7.3	7.7	7.0	-	7.4	7.4	7.4	7.4	7.5	7.6

Table A-4 (continued)

Determinations of hydrogen ion concentration in the Rappahannock River 1951.

Station	Cruise #15		Cruise #16		Cruise #17		Cruise #18		Cruise #19	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	7.3	7.2	7.0	7.1	7.2	7.3	7.2	7.3	7.2	7.3
41.0	7.2	7.2	7.0	7.0	7.4	7.4	7.3	7.2	7.4	7.4
45.0	7.3	7.1	7.2	7.1	7.4	7.3	7.2	7.1	7.4	7.3
50.0	7.7	7.3	7.5	7.2	7.3	7.3	7.2	7.2	7.1	7.1
58.0	8.1	7.4	7.3	7.3	7.4	7.3	7.3	7.2	7.2	7.2
61.4	8.1	7.5	7.4	7.3	7.3	7.3	7.3	7.2	7.3	7.3
64.0	8.1	7.5	7.4	7.2	7.3	7.4	7.2	7.3	7.5	7.3
68.2	7.3	7.2	7.0	6.9	7.4	7.4	7.2	7.1	7.2	7.2
72.3	7.1	7.0	7.0	6.9	7.3	7.2	7.1	6.9	7.1	7.0
76.3	7.2	6.9	7.1	7.0	7.3	7.2	6.9	6.7	6.9	7.0
80.6	7.7	6.9	7.0	6.9	6.9	6.9	6.8	6.7	6.9	6.8
85.2	7.5	7.4	6.8	6.8	6.9	6.8	6.8	6.7	6.8	6.8
88.6	7.0	6.9	6.9	6.9	6.7	6.7	6.6	6.6	6.4	6.4
91.2	7.1	7.1	7.2	7.3	6.6	6.7	6.3	6.4	6.5	6.6
93.6	8.0	7.9	7.5	7.4	7.7	7.6	7.2	7.2	7.3	7.3

Table A-5

Salinity determinations in the Rappahannock River 1951. Salinity in parts per thousand.

Station	Cruise #1		Cruise #2		Cruise #3		Cruise #4		Cruise #5		Cruise #6		Cruise #7	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	2.5	2.5	2.8	2.8	3.3	4.7	1.3	1.8	3.4	3.7	2.0	2.2	2.1	2.2
41.0	1.4	1.6	1.6	1.6	1.3	1.3	0.9	0.9	1.2	1.2	2.0	1.3	1.6	1.6
45.0	0.8	0.8	1.2	1.2	0.8	0.8	F	F	F	F	F	F	F	F
50.0	0.9	0.9	0.9	0.9	0.9	0.9	F	F	F	F	F	F	F	F
58.0	0.9	0.9	1.1	1.1	0.8	0.8	F	F	F	F	F	F	F	F
61.4	F*	F	F	F	F	F	F	F	F	F	F	F	F	F

* Fresh water

Station	Cruise #8		Cruise #9		Cruise #10		Cruise #11		Cruise #12		Cruise #13		Cruise #14	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	1.8	3.0	4.1	4.5	4.1	4.1	2.1	2.6	F	F	4.1	4.2	No determinations	
41.0	F	F	2.1	2.5	2.8	3.4	F	F	F	F	F	F		
45.0	F	F	1.7	2.4	F	F	F	F	F	F	F	F		
50.0	F	F	F	F	F	F	F	F	F	F	F	F		
58.0	F	F	F	F	F	F	F	F	F	F	F	F		
61.4	F	F	F	F	F	F	F	F	F	F	F	F		

Station	Cruise #15		Cruise #16		Cruise #17		Cruise #18		Cruise #19	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	5.8	6.8	5.4	5.4	5.1	5.9	4.3	4.8	No determinations	
41.0	3.9	3.9	3.5	3.9	3.9	5.0	2.4	2.5		
45.0	F	F	F	F	-	3.2	F	F		
50.0	F	F	F	F	F	F	F	F		
58.0	F	F	F	F	F	F	F	F		
61.4	F	F	F	F	F	F	F	F		

Table A-6

Sulphate determinations in the Rappahannock River 1951. Measurements in parts per million.

Station	Cruise #1		Cruise #2		Cruise #3		Cruise #4		Cruise #5		Cruise #6		Cruise #7	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	156.0	156.0	128.0	189.0	194.0	276.0	57.0	218.0	154.0	188.0	75.0	75.0	75.0	123.0
41.0	14.4	14.4	19.2	20.2	18.2	19.2	13.6	13.3	21.2	29.2	12.5	13.1	16.7	20.6
45.0	10.8	10.8	11.8	12.7	12.0	12.2	13.3	14.1	14.4	13.3	10.8	11.4	13.6	12.8
50.0	10.8	10.5	12.7	13.6	10.8	10.2	12.8	11.6	10.2	11.7	12.5	11.9	12.2	12.0
58.0	10.8	10.8	12.5	13.6	11.4	10.8	11.6	13.3	11.1	10.8	11.1	11.1	11.4	11.7
61.4	11.1	11.4	12.7	12.7	10.2	11.1	11.1	11.1	12.2	12.2	11.1	11.1	12.2	13.1
64.0	11.0	11.4	12.7	13.6	11.2	12.5	11.4	10.8	10.8	9.6	11.9	11.7	13.1	13.1
68.2	11.0	10.8	12.7	12.7	13.3	14.9	9.9	9.9	10.8	10.8	11.4	11.4	14.2	13.9
72.3	11.7	12.2	12.2	12.2	16.8	16.2	10.2	10.2	11.7	11.9	11.9	11.4	15.7	15.7
76.3	12.2	12.5	12.7	13.6	16.0	16.2	10.8	10.8	11.9	12.5	13.1	12.2	16.2	14.9
80.6	10.8	11.7	12.2	12.2	11.7	12.2	11.4	11.7	11.7	11.9	14.9	15.2	13.1	13.1
85.2	13.6	13.3	13.1	12.2	10.8	10.2	14.2	13.9	9.6	9.6	13.9	13.9	14.2	14.2
88.6	10.2	10.2	12.7	12.7	12.0	11.1	15.5	14.7	10.8	10.2	17.5	17.7	23.7	23.7
91.2	12.8	11.9	12.3	12.2	10.2	10.2	11.6	15.2	12.2	11.9	31.2	28.7	16.5	13.9
93.6	0.0	0.0	10.0	10.5	13.6	-	3.7	4.3	3.7	3.4	5.0	2.4	2.9	2.9

Table A-6 (continued)

Sulphate determinations in the Rappahannock River 1951. Measurements in parts per million.

Station	Cruise #8		Cruise #9		Cruise #10		Cruise #11		Cruise #12		Cruise #13	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	99.0	167.0	250.0	278.0	230.0	254.0	81.9	138.9	31.2	99.0	110.0	150.0
41.0	13.6	13.1	111.0	142.0	102.0	102.0	19.7	19.9	17.8	17.8	30.0	32.2
45.0	11.9	11.6	64.0	59.0	26.2	27.2	19.0	19.2	15.0	15.0	14.7	17.2
50.0	12.2	12.2	13.3	11.7	17.8	16.5	23.5	23.3	15.0	15.8	15.7	14.4
58.0	14.2	13.6	14.2	12.2	15.3	16.3	13.2	12.8	13.1	12.8	17.8	15.4
61.4	14.7	13.9	13.9	13.9	15.8	15.3	12.6	12.5	12.5	13.1	12.5	14.7
64.0	19.7	20.2	14.2	16.0	16.3	17.3	11.4	11.4	13.9	14.7	15.0	13.2
68.2	15.2	15.7	16.0	15.2	21.1	20.2	14.9	14.9	16.0	15.2	12.8	12.8
72.3	14.9	15.5	15.5	15.7	22.1	21.1	21.1	20.9	-	16.2	14.4	15.8
76.3	13.3	11.1	13.3	13.3	31.6	31.6	13.8	13.3	17.8	16.4	16.4	18.2
80.6	16.3	15.6	16.0	16.2	27.2	29.2	11.7	11.7	14.4	16.4	15.0	21.2
85.2	21.1	20.6	18.8	18.8	23.0	21.6	12.2	12.2	16.8	14.8	15.4	13.8
88.6	22.1	20.6	26.4	27.2	31.6	32.6	13.4	12.5	19.2	17.8	19.2	19.2
91.2	15.3	12.2	23.5	21.6	22.1	18.1	12.0	11.1	20.2	17.8	30.2	32.7
93.6	2.7	2.5	1.1	1.1	5.7	3.0	10.5	-	7.8	6.9	5.0	5.0

Table A-6 (continued)

Sulphate determinations in the Rappahannock River 1951. Measurements in parts per million.

Station	Cruise #14		Cruise #15		Cruise #16		Cruise #17		Cruise #18		Cruise #19	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	-	-	450.0	500.0	158.0	148.0	315.0	430.0	254.0	264.0	385.0	430.0
41.0	17.8	17.8	226.0	259.0	82.0	87.0	290.0	320.0	144.0	158.0	290.0	288.0
45.0	14.4	14.4	132.0	112.0	44.0	59.0	106.0	164.0	63.5	82.0	98.0	124.0
50.0	13.2	14.4	19.2	16.4	13.8	16.8	38.0	38.0	25.8	27.6	33.2	49.5
58.0	11.2	13.8	15.0	15.0	16.8	16.0	14.8	16.4	22.0	24.0	25.4	28.8
61.4	13.8	13.8	15.0	16.8	16.0	16.0	19.8	19.2	22.0	25.8	27.8	25.4
64.0	16.4	16.4	17.4	17.4	16.8	15.4	22.6	22.2	26.4	25.4	24.0	24.5
68.2	20.2	19.2	20.2	18.2	16.8	20.2	33.2	31.6	25.8	30.6	30.6	30.6
72.3	16.4	18.2	17.4	20.2	25.4	26.4	29.8	25.9	26.4	29.6	28.0	21.6
76.3	13.8	14.8	24.4	23.6	25.8	28.2	15.8	13.8	32.3	22.6	26.8	23.6
80.6	18.8	19.2	25.8	25.0	30.6	34.2	23.0	26.4	22.6	22.0	31.2	27.8
85.2	24.0	23.6	31.2	30.2	34.5	34.0	28.8	28.8	15.8	28.6	45.0	41.0
88.6	27.8	19.8	27.2	24.0	24.0	22.2	31.5	31.5	28.0	31.5	57.5	63.5
91.2	18.8	29.2	28.8	38.0	33.0	29.0	42.0	41.0	49.5	53.5	67.0	57.5
93.6	6.8	10.0	5.0	2.6	3.8	3.4	2.4	1.4	5.6	4.2	5.0	2.4

Table A-7

Surface and bottom temperatures from the Rappahannock River 1951.

Station	Cruise #1		Cruise #2		Cruise #3		Cruise #4		Cruise #5		Cruise #6		Cruise #7	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	9.0	8.6	13.0	13.0	13.0	12.0	14.0	13.4	15.0	14.1	20.5	20.5	18.0	17.8
41.0	9.4	9.4	12.5	12.5	13.0	12.5	13.4	13.1	15.9	14.0	21.8	20.6	19.0	18.2
45.0	9.0	8.5	11.5	11.5	13.0	12.5	13.3	13.0	14.6	14.1	20.3	19.8	19.0	18.3
50.0	9.0	8.5	11.0	11.0	13.0	12.3	13.2	12.9	14.0	13.6	20.0	19.9	19.0	18.4
58.0	10.0	9.5	12.0	12.0	12.0	12.4	13.2	13.0	14.0	13.7	21.0	20.5	19.0	18.6
61.4	10.0	10.0	11.0	11.0	12.2	11.8	12.0	11.5	14.9	14.5	21.4	21.0	18.5	18.5
64.0	11.0	11.0	11.5	11.5	12.0	11.5	11.5	11.5	14.1	14.0	21.0	20.6	19.0	18.5
68.2	11.0	11.2	12.0	12.0	12.0	11.5	11.0	11.0	14.0	13.9	21.0	20.6	19.4	18.9
72.3	11.0	11.2	12.0	12.0	12.3	12.0	11.0	11.0	14.4	14.1	21.0	20.5	19.6	19.2
76.3	11.0	11.0	12.0	12.0	12.8	12.5	12.2	11.5	15.0	14.9	21.3	20.9	19.8	19.1
80.6	11.0	11.0	9.0	9.0	12.5	12.2	12.5	11.9	15.0	14.9	21.5	21.2	18.0	17.9
85.2	10.5	10.5	8.5	8.5	12.7	12.4	12.1	11.9	15.9	15.5	21.5	21.0	18.0	17.2
88.6	11.5	11.5	8.5	8.5	12.2	12.0	11.4	11.4	15.0	15.0	21.3	21.0	18.9	18.0
91.2	12.0	12.0	8.5	8.5	11.0	10.6	11.8	11.5	15.1	15.0	21.0	20.8	17.8	16.9
93.6	12.0	14.0	9.0	9.0	12.8	12.5	12.0	11.8	15.1	15.0	21.0	21.0	19.0	19.0

Table A-7 (continued)

Surface and bottom temperatures from the Rappahannock River 1951.

Station	Cruise #8		Cruise #9		Cruise #10		Cruise #11		Cruise #12		Cruise #13		Cruise #14	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	22.0	20.0	21.0	21.2	25.0	24.5	21.2	20.8	23.6	23.2	27.7	25.0	-	-
41.0	21.0	20.0	22.8	19.9	25.6	24.5	22.0	21.2	23.0	22.9	28.0	27.0	28.0	27.4
45.0	22.1	20.0	22.0	20.0	25.0	24.3	22.0	21.3	22.1	21.8	28.0	27.0	28.0	27.7
50.0	21.2	20.2	22.0	20.0	25.0	24.3	22.0	21.3	22.1	21.8	27.1	26.9	28.2	28.0
58.0	21.9	21.0	21.2	20.5	25.3	24.8	20.0	21.0	22.0	21.6	28.0	27.1	28.5	28.0
61.4	22.0	21.0	21.0	20.4	26.0	25.0	19.8	19.2	22.0	21.7	28.0	27.5	28.0	27.8
64.0	22.9	21.7	21.0	20.9	26.0	25.8	20.0	19.0	21.5	21.2	28.7	27.7	28.0	27.6
68.2	23.0	21.0	21.2	21.1	25.5	24.6	20.0	19.0	21.0	20.6	29.0	27.1	28.0	27.5
72.3	22.0	20.9	21.2	20.4	25.0	24.5	20.0	19.5	21.1	20.8	27.2	27.0	27.6	27.5
76.3	21.0	20.9	20.5	20.4	25.2	24.5	19.0	19.4	21.6	20.8	28.8	27.2	27.5	27.0
80.6	20.0	19.7	22.0	21.5	25.0	24.4	18.0	18.0	21.6	21.0	29.0	27.3	27.0	26.8
85.2	19.0	19.0	20.9	19.9	26.0	24.7	17.9	17.9	21.9	21.0	29.0	27.4	26.9	26.2
88.6	20.0	19.8	21.0	20.0	27.8	26.0	17.9	17.6	22.2	21.3	29.0	27.4	26.3	26.0
91.2	21.0	20.9	22.0	20.9	28.0	26.5	17.9	17.6	21.9	21.3	29.0	27.3	26.3	26.0
93.6	20.1	20.0	22.0	21.8	27.5	27.0	18.0	17.2	22.1	21.9	29.5	27.0	27.0	26.5

Table A-7 (continued)

Surface and bottom temperatures from the Rappahannock River 1951.

Station	Cruise #15		Cruise #16		Cruise #17		Cruise #18		Cruise #19		
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	
37.0	26.0	25.5	28.2	28.0	28.0	28.0	28.5	28.2	27.0	26.5	
41.0	26.0	25.4	29.0	28.4	28.2	28.2	28.3	28.0	25.2	25.2	
45.0	26.4	25.8	29.0	28.5	28.7	28.5	28.5	28.1	26.0	25.8	
50.0	27.0	26.5	29.0	28.5	29.0	28.5	28.9	28.3	26.2	26.0	
58.0	27.6	26.5	29.5	29.0	29.0	28.5	29.0	28.6	26.0	25.5	
61.4	28.0	26.6	29.5	29.0	29.0	28.6	29.0	28.6	25.0	24.9	
64.0	27.5	26.3	29.8	29.2	28.5	28.4	29.1	29.0	25.5	25.0	
68.2	28.4	26.7	29.8	29.1	29.0	28.5	29.2	29.0	26.0	25.5	
72.3	28.0	27.8	29.5	29.0	29.0	28.9	29.2	28.9	26.5	26.0	
76.3	28.2	27.9	30.0	29.0	29.0	28.2	29.2	28.9	26.4	25.9	
80.6	28.4	26.8	30.0	29.5	28.0	27.5	29.2	29.0	26.5	26.0	
85.2	28.1	27.8	30.0	29.4	29.4	29.0	29.2	28.2	26.8	26.0	
88.6	29.0	27.0	31.0	29.7	29.0	28.5	29.4	28.5	26.2	25.6	
91.2	28.4	27.2	31.0	29.8	29.0	28.8	31.0	29.0	26.0	25.5	
93.6	28.0	27.8	30.0	29.0	28.0	27.8	31.0	29.1	24.2	24.0	

Table A-8

Turbidity determinations in the Rappahannock River 1951. Measurements are Secchi disk readings in centimeters.

Station	Cruise number																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
37.0	27	17	28	18	25	18	18	28	40	56	42	18	38	-	52	39	50	38	57
41.0	18	10	16	20	11	13	17	28	37	49	52	22	22	16	52	37	51	38	68
45.0	20	17	17	25	16	22	25	43	37	82	74	20	25	31	50	43	53	48	61
50.0	23	18	30	35	19	26	41	47	42	110	62	26	29	45	50	52	51	48	58
58.0	18	25	19	16	20	51	36	50	58	62	12	23	34	43	58	50	52	48	44
61.4	18	36	23	12	25	55	48	67	73	53	12	18	40	35	59	45	46	40	50
64.0	20	33	21	13	30	60	66	94	76	52	12	19	46	33	50	43	42	40	50
68.2	43	46	37	15	41	61	76	87	51	65	15	24	60	44	55	45	46	45	46
72.3	43	28	46	25	45	70	61	63	33	72	20	30	68	43	63	43	57	57	69
76.3	43	33	64	43	50	67	50	63	34	58	27	41	65	18	58	50	50	139	80
80.6	58	13	41	31	43	71	56	21	66	57	18	56	48	29	54	53	23	84	64
85.2	89	13	63	47	63	43	49	21	67	120	11	56	51	24	72	56	30	28	98
88.6	94	11	28	22	48	48	31	40	85	168	9	59	31	28	80	68	63	28	138
91.2	108	13	25	53	68	72	100	68	127	137	7	63	42	32	83	87	74	20	49
93.6	108	13	13	50	58	105	150	83	133	198	8	64	58	44	147	135	96	12	71

Table A-9

Surface and bottom current determinations in the Rappahannock River 1951.
Measurements are in knots (nautical miles per hour)

Station	Cruise #1		Cruise #2		Cruise #3		Cruise #4		Cruise #5		Cruise #6	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	1.46	0.97	0.54	0.39	1.15	1.02	1.05	0.87	0.55	0.47	1.57	1.10
41.0	0.90	0.78	0.00	0.00	0.54	0.50	1.10	1.00	0.19	0.20	1.44	1.10
45.0	1.02	1.02	0.58	0.58	0.50	0.54	1.29	1.00	-	-	1.49	0.95
50.0	0.00	0.00	0.95	0.90	0.33	0.29	0.96	0.83	-	-	0.95	0.69
58.0	0.72	0.69	1.27	0.78	0.42	0.58	0.56	0.45	1.39	1.01	0.80	0.86
61.4	0.55	0.81	1.02	0.75	0.32	0.28	0.66	0.59	1.12	0.78	1.10	1.07
64.0	0.95	0.78	-	-	0.72	0.70	0.78	0.69	1.10	1.07	0.95	0.95
68.2	0.78	0.75	-	-	0.95	1.02	1.05	0.97	0.84	0.81	0.95	0.84
72.3	0.19	0.19	1.00	0.91	1.12	0.95	0.69	0.63	0.59	0.57	0.90	0.69
76.3	0.20	0.42	1.24	1.15	1.07	0.66	-	-	0.59	0.46	0.63	0.50
80.6	0.58	0.58	1.27	0.92	0.96	0.80	0.44	0.53	0.37	0.20	-	-
85.2	0.32*	0.35*	1.27	1.07	0.95	0.66	0.90	0.90	-	-	-	-
88.6	0.00	0.00	1.39	1.10	0.78	0.81	0.87	0.87	0.58	0.39	-	-
91.2	0.17	0.41	1.31	1.06	1.61	1.39	0.78	0.47	-	-	0.39	0.34
93.6	0.60	0.54	1.89	1.68	1.57	1.64	1.12	0.90	0.35	-	0.50	0.47

* Ship swinging.

Table A-9 (continued)

Surface and bottom current determinations in the Rappahannock River 1951.
Measurements are in knots (nautical miles per hour)

Station	Cruise #7		Cruise #8		Cruise #9	
	Surf.	Bot.	Surf.	Bot.	Surf.	Bot.
37.0	0.95	0.84	0.78	0.50	-	-
41.0	1.05	1.01	0.59	0.42	-	-
45.0	0.78	0.84	0.66	0.42	-	-
50.0	1.02	0.95	0.50	0.47	-	-
58.0	1.27	0.81	0.69	0.47	0.63	0.55
61.4	0.81	0.81	0.47	0.36	1.05	0.78
64.0	0.63	0.63	-	-	1.07	0.97
68.2	-	-	0.75	0.69	0.90	1.15
72.3	1.07	0.84	1.07	0.50	1.35	0.95
76.3	0.69	0.63	0.69	0.50	0.92	0.75
80.6	0.81	0.69	0.81	0.66	0.81	0.69
85.2	0.63	0.50	0.47	0.47	0.66	0.50
88.6	0.55	0.47	0.47	0.47	0.63	0.50
91.2	0.62	0.37	0.43	0.43	0.47	0.42
93.6	0.62	0.42	0.61	0.59	0.59	0.59

Table A-10

Hydrographic data Pamunkey River 1951

Station	Time	Tide	Current velocity knots	Temperature °C.	Secchi disk cm.	Salinity 0/00	Dissolved O_2 p.p.m.	Oxygen per cent saturation	Sulphates p.p.m.	pH
			Cruise #1 April 11 (average of surface and bottom determinations)							
50.7	1540	E	-	13.9	27	-	9.0	-	-	6.9
54.2	1530	E	-	13.4	32	-	9.3	-	-	6.9
55.2	1515	E	-	13.3	34	-	9.1	-	-	7.0
56.2	1500	E	-	13.4	30	-	9.0	-	-	6.9
			Cruise #2 May 28-29 (average of surface and bottom determinations)							
27.2	1530	F	1.07	21.0	57	8.9	6.6	-	588	7.1
32.2	1620	F	1.64	21.2	33	4.1	6.8	-	214	7.1
38.2	1720	F	1.05	21.1	33	2.3	7.2	-	35	7.1
44.0	1815	F	0.96	21.5	57	-	8.0	-	9	7.2
48.2	1850	F	0.60	21.7	55	-	7.9	-	8	7.2
50.7	1020	S	-	21.7	61	-	7.4	-	7	7.1
54.2	1430	E	-	21.5	60	-	7.8	-	8	7.2
57.2	1450	E	-	21.0	61	-	7.0	-	7	6.9
61.2	1515	E	-	20.3	27	-	7.1	-	8	7.0
66.2	1545	E	-	19.9	47	-	7.5	-	8	7.1
69.0	1605	E	-	19.7	48	-	7.5	-	13	6.9
			Cruise #3 August 11 (all determinations at 6 feet)							
27.2	0815	E	-	27.4	73	12.6	6.1	79	1100	7.3
32.2	0840	E	-	27.5	52	8.6	5.9	73	550	7.2
38.2	0905	E	-	27.3	65	-	5.6	69	8	6.9
44.0	0930	E	-	27.5	56	-	5.8	71	29	7.1
48.2	0950	E	-	27.4	48	-	5.9	71	10	7.0
50.7	1000	E	-	27.4	55	-	5.8	71	10	6.9
54.2	1025	E	-	27.5	57	-	5.2	65	10	6.8
57.2	1040	E	-	27.4	60	-	4.6	56	9	6.9
61.2	1120	E	-	26.7	54	-	5.2	63	19	6.9
66.2	1145	E	-	25.6	55	-	6.0	72	10	6.9
69.0	1200	E	-	25.8	39	-	6.5	78	11	7.0
73.0	1220	E	-	25.5	35	-	6.4	77	8	7.0

Table A-11

Hydrographic data Mattaponi River 1951

Station	Time	Tide	Current velocity knots	Temperature °C.	Secchi disk cm.	Salinity 0/00	Dissolved O_2 p.p.m.	Oxygen per cent saturation	Sulphates p.p.m.	pH
Cruise #1 May 30 (average of surface and bottom determinations)										
27.2	1535	S	-	21.2	50	6.0	6.6	-	420	7.0
32.7	1635	F	1.10	21.3	24	1.9	6.7	-	21	6.9
38.2	1720	F	1.05	21.5	46	-	7.4	-	7	6.8
42.7	1800	F	1.02	21.8	66	-	7.4	-	5	6.8
46.2	1834	F	0.88	21.8	100	-	7.4	-	6	6.7
50.2	1915	F	0.70	21.7	100	-	7.5	-	5	6.7
Cruise #2 August 14 (all determinations made at 6 feet)										
27.2	0745	F	-	28.6	52	11.1	4.7	59	975	6.9
32.7	0810	F	-	27.6	50	3.7	4.5	55	320	7.0
38.2	0835	F	-	27.3	33	-	4.4	54	15	7.2
42.7	0855	F	-	27.4	80	-	4.6	56	9	7.1
46.2	0912	F	-	27.4	88	-	4.2	52	6	6.9
50.2	0930	F	-	27.6	131	-	4.1	51	5	6.9
54.5	1015	F	-	25.6	85	-	5.0	60	6	6.7
59.0	1035	E	-	24.1	28	-	6.3	74	9	6.7

Table A-12

Results of sampling at anchor station 37 Rappahannock River May 10, 1951

Time	Tide	Current velocity (knots) Surface	Current velocity (knots) Bottom	Temperature °C. Surface	Temperature °C. Bottom	Secchi disk cm.	Salinity 0/00 Surface	Salinity 0/00 Bottom
1100	E	1.31	1.00	19.8	18.9	27	2.9	2.9
1200	E	0.61	0.37	-	-	28	2.4	2.1
1300	F	0.22	0.44	20.2	19.0	28	2.1	2.6
1400	F	1.19	1.19	21.8	19.0	26	2.0	-
1500	F	1.57	1.39	20.6	18.8	29	3.4	-
1600	F	1.19	1.07	20.0	18.5	30	4.2	-
1700	F	-	-	20.5	18.5	30	4.6	-

Table A-13

Results of sampling at anchor station 64 Rappahannock River April 26, 1951

Time	Tide	Current velocity (knots) Surface	Current velocity (knots) Bottom	Temperature °C. Surface	Temperature °C. Bottom	Secchi Disk cm.
0855	E	-	-	16.0	16.0	44
1010	E	0.85	0.75	16.3	16.0	42
1100	E	1.15	1.02	16.4	16.2	38
1215	E	1.39	1.27	16.8	16.6	38
1315	E	1.34	0.95	17.0	16.5	35
1415	E	1.22	1.02	17.0	16.9	35
1515	E	1.05	0.81	16.9	16.5	35
1615	E	0.35	0.28	17.0	16.7	44
1715	F	0.84	0.78	17.0	16.8	40

Table A-14

Results of sampling at anchor station 91.3 Rappahannock River April 11, 1951 /1

Time	Tide	Current velocity (knots)	Temperature °C.	Secchi disk cm.	Dissolved oxygen p.p.m.	Sulphates p.p.m.	Hydrogen ion concentration pH
0600	E	1.50	10.8	25	10.6	10.2	7.3
0700	E	1.55	10.8	25	10.8	11.7	7.3
0800	E	1.59	11.0	20	10.6	14.4	7.2
0900	E	1.48	11.0	22	10.8	12.6	7.1
1000	E	1.51	10.7	21	10.7	15.3	-
1100	E	1.64	11.1	21	11.5	14.9	-
1200	E	1.49	11.4	21	10.5	15.4	-
1300	E	1.35	11.7	18	10.6	15.7	6.9
1400	E	1.54	11.5	18	10.9	14.8	6.9
1500	E	1.63	11.5	17	10.7	14.2	7.0
1600	E	1.44	12.3	13	10.6	13.5	7.0
1700	E	1.54	12.4	15	10.7	14.5	7.0

/1 Average of surface and bottom samples.

Table A-15

Results of sampling at anchor stations 88.8 to 93.6 Rappahannock River August 22, 1951. All determinations made at six feet.

	Station	Time	Tide	Current velocity knots	Temperature °C.	Secchi disk cm.	Dissolved O_2 p.p.m.	Oxygen per cent saturation	Sulphates p.p.m.	pH
	93.6	0705	S	-	27.4	70	7.3	90	3.4	7.9
	92.4	0700	S	-	28.0	62	6.2	78	17.4	7.9
	91.8	0655	S	-	28.5	54	2.0	28	28.8	7.0
1	91.2	0650	S	-	28.2	61	1.6	20	40.4	6.9
	90.6	0645	S	-	28.0	70	2.6	32	41.2	6.7
	90.0	0635	S	-	28.0	75	1.6	20	52.8	6.5
	89.4	0630	S	-	28.0	75	1.7	21	63.2	6.6
	88.8	0625	S	-	28.1	75	1.8	21	42.4	6.7
	93.6	0805	S	-	27.5	70	7.4	92	3.4	8.0
	92.4	0800	S	-	28.2	61	5.5	70	14.4	7.1
	91.8	0753	S	-	28.4	62	1.9	24	34.8	7.1
2	91.2	0750	F	0.29	28.0	70	2.8	35	30.6	6.8
	90.6	0740	F	0.32	27.8	72	1.8	23	48.8	5.6
	90.0	0735	F	0.47	28.0	74	1.6	20	45.2	6.5
	89.4	0730	F	0.59	28.0	74	1.3	16	45.2	6.7
	88.8	0725	F	0.50	28.2	75	1.2	16	38.4	6.7
	93.6	0930	S	-	27.2	59	7.7	96	1.4	8.1
	92.4	0920	S	-	28.8	55	4.7	60	24.4	6.7
	91.8	0915	S	-	28.2	68	1.7	22	31.6	7.0
3	91.2	0910	S	-	28.0	80	2.5	31	40.4	6.7
	90.6	0907	S	-	28.2	83	1.4	18	59.2	6.6
	90.0	0900	S	-	28.0	80	1.5	19	55.6	6.7
	89.4	0855	F	0.20	28.0	88	1.1	14	36.6	6.8
	88.8	0850	F	0.20	28.0	87	1.0	13	30.5	6.9
	93.6	1035	S	-	27.4	63	7.7	96	4.2	8.2
	92.4	1030	S	-	28.2	52	4.2	53	44.0	7.2
	91.8	1025	S	-	28.1	68	1.5	18	35.5	7.0
4	91.2	1018	S	-	28.0	70	2.3	28	30.5	6.9
	90.6	1015	S	-	28.0	84	1.6	17	46.5	6.6
	90.0	1010	S	-	28.0	85	1.9	23	44.0	6.8
	89.4	1005	S	-	28.0	86	1.1	13	37.5	6.8
	88.8	1000	S	-	28.0	89	0.9	11	33.0	6.8
	93.6	1145	E	0.55	27.8	66	7.5	94	6.2	8.0
	92.4	1135	E	0.22	29.0	54	2.8	36	30.6	7.1
	91.8	1130	E	0.47	28.5	65	1.8	22	31.2	7.0
5	91.2	1125	E	0.47	28.5	65	2.2	27	30.2	6.8
	90.6	1120	E	0.47	28.4	71	2.6	32	53.5	6.5
	90.0	1115	E	0.47	28.0	72	2.0	26	48.5	6.5
	89.4	1105	E	0.47	28.0	78	1.3	16	37.5	6.7
	88.8	1100	E	0.49	28.2	83	1.1	14	37.5	6.7

Results of sampling at anchor stations 88.8 to 93.6 Rappahannock River August 22, 1951. All determinations made at six feet.

	Station	Time	Tide	Current velocity knots	Tempera-ture °C.	Secchi disk cm.	Dissolved O_2 p.p.m.	Oxygen per cent saturation	Sulphates p.p.m.	pH
6	93.6	1345	E	0.21	28.2	53	8.0	100	5.0	8.2
	92.4	1340	S	-	28.9	51	6.1	78	16.4	7.5
	91.8	1335	E	0.47	28.8	49	3.3	45	27.2	7.0
	91.2	1330	E	0.47	29.0	54	2.9	37	29.5	7.0
	90.6	1325	E	0.47	28.5	66	2.7	34	36.5	6.8
	90.0	1320	E	0.47	28.5	60	2.8	35	54.5	6.5
	89.4	1315	E	0.47	28.4	61	2.0	26	56.0	6.5
	88.8	1310	E	0.47	28.7	86	2.0	27	47.5	6.6
7	93.6	1507	E	0.19	28.5	56	8.2	103	8.2	8.2
	92.4	1502	E	0.17	28.5	61	6.6	84	15.8	7.5
	91.8	1457	E	0.27	28.8	43	3.5	45	31.5	6.9
	91.2	1452	E	0.27	29.0	48	3.5	45	42.0	7.0
	90.6	1445	E	0.31	29.0	42	2.7	35	34.5	7.0
	90.0	1435	E	0.27	29.0	53	3.1	39	42.4	6.7
	89.4	1415	E	0.33	28.5	59	2.2	27	66.0	6.5
	88.8	1400	E	0.47	28.5	58	2.5	31	51.6	6.7
8	93.6	1620	E	0.19	28.5	53	8.2	103	4.2	8.4
	92.4	1615	E	0.19	28.4	52	7.0	89	14.8	7.8
	91.8	1610	E	0.26	29.0	57	4.6	58	25.4	7.3
	91.2	1605	E	0.27	29.1	45	4.5	56	32.0	7.0
	90.6	1600	E	0.27	29.0	61	2.7	35	40.0	7.0
	90.0	1557	E	0.27	29.0	56	3.1	39	46.5	6.8
	89.4	1550	E	0.27	28.5	70	2.3	29	73.5	6.5
	88.8	1545	E	0.33	28.8	57	2.0	27	65.0	6.4
9	93.6	1730	E	0.08	28.5	58	8.2	103	4.2	8.2
	92.4	1720	E	0.12	28.4	50	7.5	96	14.4	8.5
	91.8	1715	E	0.17	28.5	51	4.6	59	19.2	7.3
	91.2	1711	E	0.22	29.0	50	3.7	48	28.8	7.0
	90.6	1708	E	0.22	29.0	55	3.1	40	36.0	7.0
	90.0	1705	E	0.22	28.9	51	3.1	40	36.6	6.9
	89.4	1700	E	0.22	28.5	58	2.7	34	49.5	6.6
	88.8	1655	E	0.26	28.5	55	2.5	32	52.0	6.6
10	93.6	1815	S	-	27.5	56	8.3	104	3.6	7.7
	92.4	1810	S	-	28.0	56	7.0	89	28.6	8.8
	91.8	1805	S	-	28.4	54	5.1	64	44.0	6.9
	91.2	1800	S	-	28.4	45	4.0	50	72.5	6.8
	90.6	1755	S	-	28.5	56	3.2	40	41.0	6.8
	90.0	1750	S	-	28.4	52	2.8	35	37.5	6.7
	89.4	1745	S	-	28.4	58	3.0	38	57.5	6.5
	88.8	1740	S	-	27.8	45	3.7	46	42.0	6.7

Table A-16

Results of sampling at anchor stations 85.2 to 93.6 Rappahannock River
October 3, 1951. All determinations made at six feet.

	Station	Time	Tide	Current velocity knots	Temperature °C.	Secchi disk cm.	Dissolved O_2 p.p.m.	Oxygen per cent saturation	Sulphates p.p.m.	pH
1	85.2	0735	S	-	-	-	-	-	-	-
	93.6	0805	E	-	22.0	76	1.1	12	90.0	6.8
	91.2	0815	E	-	22.0	102	0.2	3	69.0	6.6
	88.6	0825	E	-	22.0	142	2.0	22	56.0	6.8
	85.2	0835	E	0.39	22.0	95	4.3	48	51.0	6.9
2	93.6	0935	E	-	21.5	82	2.2	24	58.0	6.8
	91.2	0943	E	-	22.0	95	0.7	7	78.0	6.5
	88.6	0954	E	-	22.0	155	2.0	22	57.0	6.8
	85.2	1005	E	0.63	22.5	105	3.8	43	50.0	6.8
3	93.6	1055	E	-	21.9	93	6.3	70	17.0	7.2
	91.2	1106	E	-	23.0	84	0.0	0	84.0	6.5
	88.6	1115	E	-	23.0	130	2.5	28	51.0	6.8
	85.2	1129	E	0.27	22.9	100	3.1	35	51.0	6.7
4	93.6	1229	E	-	21.9	78	9.3	105	4.7	6.7
	91.2	1239	E	-	25.4	87	0.0	0	89.0	6.6
	88.6	1305	E	-	25.5	118	2.7	32	48.0	6.8
	85.2	1320	E	0.37	25.1	119	3.0	35	50.0	6.7
5	93.6	1410	E	-	23.7	108	10.0	115	1.8	7.9
	91.2	1425	E	-	23.8	70	0.0	0	142.0	6.7
	88.6	1430	F	-	23.7	110	3.4	38	51.0	6.9
	85.2	1445	F	0.35	23.9	148	3.1	36	44.0	6.7
6	93.6	1615	F	-	21.8	94	8.3	93	13.1	7.3
	91.2	1625	F	-	23.0	84	0.0	0	78.0	6.5
	88.6	1635	F	-	23.0	112	3.6	42	57.0	6.7
	85.2	1645	F	0.87	23.0	75	5.2	58	-	6.8
7	93.6	1810	F	-	22.0	86	7.9	89	92.0	7.3
	91.2	1750	F	-	23.0	110	2.3	25	66.0	6.5
	88.6	1730	F	-	23.0	114	3.4	39	51.0	6.7