EVALUATION OF WATER QUALITY TRENDS
SHENANDOAH RIVER, VIRGINIA
FRONT ROYAL TO BERRYVILLE

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TECHNICAL REPORT 2

U.S. DEPT. OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMIN
MIDDLE ATLANTIC REGION
918 EMMET STREET
CHARLOTTESVILLE VIRGINIA
DECEMBER 1968

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ACKNOWLEDGEMENTS

The author is deeply indebted to Mr. Eugene W. Surber, Virginia Commission of Game and Inland Fisheries, who graciously supplied long-termed bottom fauna data which were invaluable in showing eutrophication trends in the Shenandoah River. Bottom fauna information provided by Mr. John H. Tackett, Virginia State Water Control Board was also very useful in this evaluation.

Grateful acknowledgement is expressed to Mr. Lowell E. Keup, Technical Advisory and Investigations Branch of the Federal Water Pollution Control Administration, Cincinnati, for his helpful suggestions in editing this Report.

I. INTRODUCTION

The U. S. Army Corps of Engineers Western Virginia Area Office near Berryville, Virginia, obtains its water supply from the Shenandoah River. In recent years, Corps officials have expressed concern with increased pollution and the presence of certain planktonic organisms found in untreated river water and problems associated with removing them in water purification systems. In anticipation of a potential need to alter water treatment facilities, Corps of Engineers officials, by letter dated May 9, 1968, requested the Middle Atlantic Region, Federal Water Pollution Control Administration, to determine pollution trends in the River.

This Report contains the findings of our evaluation of water quality trends in the Shenandoah River. The physical, chemical and biological information investigated was obtained from several sources. These include data collected at the Federal Water Pollution Control Administration Water Pollution Surveillance System Station at the Corps of Engineers facility, information in reports published by the U. S. Fish and Wildlife Service, Virginia Commission of Game and Inland Fisheries, and the Virginia State Water Control Board.

II. SUMMARY

The lower Shenandoah River has had a long history of pollution problems, dating back to 1940 when toxic industrial wastes discharged in the stream all but decimated aquatic life downstream from Front Royal. Subsequent abatement of this pollution resulted in the recovery of the River; however, increased discharges of organic wastes and runoff from agricultural lands have caused significant nutrient enrichment.

Physical and chemical data collected at the Berryville Surveillance Station were evaluated to determine pollution and eutrophication trends in the main stem downstream from Front Royal. It was found that the chemical quality was within the raw water criteria established for public water supplies; however, total phosphorus and nitrogen content of river water was sufficiently high to indicate a fertile stream capable of producing abundant aquatic organisms.

Eutrophication trends are also borne out by biological data collected near Berryville. Thirteen years of bottom samples collected over a 30-year period in this reach show a gradual increase in the productivity of aquatic invertebrates. For the most part, these samples were comprised of clean water and facultative forms which indicate the presence of relatively clean water.

One of the most significant indicators of organic enrichment in the lower Shenandoah River are the changes in phytoplankton populations from 1962 through 1965. Phytoplankton numbers and population composition during this period indicate a change from a diatom dominated

population to one dominated by green algae. Although several species of nuisance algae were found in Berryville samples, at no time were they present in quantities sufficient to cause water treatment problems.

III. WATER QUALITY

The Shenandoah River originates in the mountains of Northern Virginia, the North Fork in the Allegheny Mountains and the South Fork in the Blue Ridge (Figure 1). Each fork flows approximately 150 miles through fertile limestone valleys to Front Royal, Virginia. From Front Royal, the main stem flows north about 60 miles before entering the Potomac at Harpers Ferry, West Virginia. The Corps of Engineers' raw water intake is located on the main stem approximately 30 miles downstream from Front Royal near the Town of Berryville, Virginia.

Recent investigations of the Shenandoah River system (Tackett, 1962, 63; Surber, 1964, 65, 66) indicated that the North and South Forks are relatively free from the serious effects of water quality degradation. At Front Royal, the South Fork receives treated organic and chemical wastes from a synthetic fibers company, untreated organic wastes from a fruit packing company, and sewage which has undergone primary treatment from the City of Front Royal.

In order to determine the effects of this pollution on water quality in the lower Shenandoah River, an analysis was made of water quality data collected at the FWPCA Water Pollution Surveillance Station located at the Corps of Engineers' water supply intake near Berryville.* These data were compared to the raw water standards for public water supplies and criteria required to maintain a favorable environment for fish and other aquatic life developed by the National Technical Advisory Committee on Water Quality Criteria.

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* Unpublished STORET data, FWPCA Surveillance Station No. 510087. Shenandoah River at Berryville, Virginia.

Based on our analysis of composite samples collected at Berryville between 1962 and 1967, the chemical constituents of Shenandoah River water were within the raw water criteria established for public water supplies. However, wastes discharged into the River at Front Royal have had an adverse affect on water quality and aquatic life immediately downstream from the source. These wastes and runoff from agricultural lands are also important sources of nutrients which influence phytoplankton growth in the lower river.

Eutrophication and Phytoplankton

Eutrophication is a term that is commonly used today to mean the nutrient enrichment of waters by man-created or natural means. Urban and industrial growth have combined to increase the fertilization of lakes and streams through the discharge of nutrients in various forms. Nutrient enrichment has resulted in aquatic weed and algal nuisances in areas where before this did not exist. One of the major problems associated with excessive growths of aquatic vegetation is the interference which these organisms have in the treatment of a potable water supply. Many forms of algae have been known to impart undesirable tastes and odors to drinking water, while others have clogged filters in water treatment plants.

Within the past two decades, there has been a significant increase in the frequency of plankton blooms in the Shenandoah River. Surber (1964) noted the difficulty in counting smallmouth bass nests downstream from Front Royal because of a phytoplankton bloom which had occurred and indicated that "blooms" were not known to have occurred prior to 1950.

In 1965, Sorber recorded a four-fold increase in turbidity on the South Fork in the Strasburg reach from Goods Mill to Front Royal, which he attributed to phytoplankton. He concluded that significant eutrophication had occurred after 1940, since prior to that date the South Fork was as clear as the North Fork is at the present time. This eutrophication trend was substantiated further by changes in vegetation. In the period between 1940 and 1950, coarse weeds choked the River, but sometime later phytoplankton developed in such abundance that the quantity of light available to rooted aquatic vegetation was greatly reduced. As a result, the coarse vegetation decreased in abundance.

Present knowledge indicates that nitrogen (N) and phosphorus (P) are the fertilizing elements which contribute most to increased growths of aquatic vegetation and algal blooms. High N concentrations result in phytoplankton populations dominated by green algae and a high concentration of P encourages the growth of blue-greens. The Report of the National Technical Advisory Committee on Water Quality Criteria (1968) points out that different species of algae have different phosphorus requirements with a range of available phosphorus usually falling between 0.01 and 0.05 mg/l. At these levels, when other conditions are favorable, blooms may be expected. The Committee also reported that with concentrations greater than 0.10 mg/l in flowing waters, problems with excessive algal growths may be encountered. The nitrogen-phosphorus ratio is also of importance in natural waters as an indicator of the type of algae which can be expected to grow. A 10:1 ratio has been

established as a guideline for indicating normal conditions.

Three years of nitrogen and phosphorus data were available for analysis from the FWPCA Surveillance Station. Nutrient concentrations in the lower Shenandoah River during the period 1965-1967 were high with total phosphorus ranging from 0.01 and 0.38 mg/l. During this period, the 0.10 mg/l guideline was exceeded five times (22% of samples taken), indicating fertile conditions favoring dense plankton blooms. Levels of total nitrogen averaged 1.4 mg/l and ranged from less than 0.1 mg/l to 4.3 mg/l. Inorganic nitrogen compounds were also found at high concentrations adding to the overall fertility of the stream. In addition, fertile conditions were exemplified by the nitrogen-phosphorus ratio which exceeded the 10:1 guideline in 83% of samples taken with a high of 108:1 recorded on May 3, 1967.

Perhaps one of the most striking indications of eutrophication in the lower Shenandoah River is the pronounced change which has occurred in the composition of the plankton population. According to the National Technical Advisory Committee on Water Quality Criteria, conditions indicative of organic enrichment include a change from a diatom-dominated plankton population to one dominated by blue-green and/or green algae, associated with increases in amounts and changes in relative abundance of nutrients. Plankton samples collected at Berryville during the period 1962-1965 show a significant increase in green algae with a corresponding decline in diatoms (Figure 2). Although the water was not analyzed for nitrogen and phosphorus content during this period, this shift in

plankton population supports the conclusion that eutrophication has taken place in the lower Shenandoah River.

Algae samples were also evaluated to determine the presence of species known to cause problems in water treatment and if concentrations were sufficient to warrant concern. Several algal forms were found that have been known to clog filters in water treatment plants, including the diatoms synedra, navicula, nitzschia and others. However, at no time were the numbers of these organisms sufficient to result in serious filter clogging problems.

Bottom Fauna

In considering biological conditions within a flowing stream, the quantity and species composition of the bottom organism community can be indicative of water quality. Because the life histories of many bottom aquatic invertebrates are one year or longer and because these organisms are relatively immobile, they are invaluable indicators of long-term water quality conditions. For example, pollution of organic wastes may fertilize a stream to the point at which certain kinds of bottom animals become very abundant. Conversely, the continuous exposure of bottom animals to toxic chemicals can cause complete mortality. It is possible to classify bottom animals as to their sensitivity to pollution, tolerance of it, or somewhere in between (facultative). In graphs found in this report, the bottom animals have been designated as pollution tolerant, facultative or able to adapt to mildly polluted conditions, and sensitive forms which are intolerant of pollution.

The number of bottom organisms collected in the Shenandoah River below Front Royal has varied considerably during the period 1936-1967. In the early 1940's, highly toxic industrial wastes containing high concentrations of zinc were discharged into the River at Front Royal and all but decimated bottom fauna and fish populations downstream from the pollution source (Figure 3). Implementation of improved waste treatment facilities in the late 1940's produced improved water quality and subsequent return of large numbers of invertebrate bottom animals. Comparing the number of organisms per square foot of bottom collected in 1948 to numbers in 1965, shows a significant increase in bottom fauna downstream from the main source of pollution (Figure 4). Although part of this increase can be related to removal of toxic wastes from the stream, the primary reason for the substantial upsurge in numbers can be attributed to organic enrichment or eutrophication, which provides increased quantities of food for these animals.

Recent bottom fauna studies of the Shenandoah River system indicate that the North Fork of the Shenandoah is relatively free from the serious effects of water quality degradation. The South Fork is also characterized by good water quality throughout most of its length except at Front Royal where it receives industrial and domestic wastes.

While conducting field investigations of the Shenandoah River, Tackett (1963) found that the South Fork immediately downstream from Front Royal was badly polluted with organic wastes and contained dense growths of Sphaerotilus, a filamentous bacteria

characteristic of exceptionally poor water quality. Consequently, this sector of the River was practically devoid of bottom-dwelling invertebrates.

Pollution entering the South Fork at Front Royal has also influenced water quality and the aquatic biota in the Main Stem downstream from the confluence. In recent years, this reach of the River has experienced several fish kills, some of which resulted from dissolved oxygen deficiencies during low flow periods. However, the cause of some of the larger fish kills has remained unsolved, which has led to continuing biological investigations in the River downstream from Front Royal. Adverse water quality conditions are also demonstrated by the bottom samples taken at Morgan Ford, ten miles downstream from Front Royal. Review of data from this station indicates a bottom community comprised of more pollution-tolerant forms and fewer sensitive species than were collected at stations located upstream from the pollution source (Figure 5). However, the increase in clean water bottom fauna collected at Berryville shows that the stream has almost totally recovered from the very poor water quality conditions found upstream. Surber, (1966) in analyzing the results of bottom sampling concluded (1) the North and South Forks remain rich in fauna and apparently unaffected by pollution, (2) pollution adversely affects the bottom fauna of the Main Stem of the Shenandoah River for at least half its length in Virginia.

IV. CONCLUSIONS

Biological and chemical water quality data can be summarized as follows:

(1) Constituents of river water at Berryville were within the raw water criteria established for public water supplies.

(2) Treated organic and inorganic wastes discharged into the South Fork at Front Royal have an adverse affect on bottom fauna in immediate downstream reaches.

(3) As the River recovers from this pollution, the environmental response is an increase in numbers of bottom fauna near Berryville.

(4) Phosphorus and nitrogen concentration in water samples taken at Berryville are sufficient to cause phytoplankton blooms.

(5) Changes in phytoplankton populations from one predominantly diatoms to a population of predominantly green algae are indicative of organic enrichment in the lower Shenandoah River.

(6) Phytoplankton numbers have not increased to the point where they could cause serious problems in the treatment of potable water.

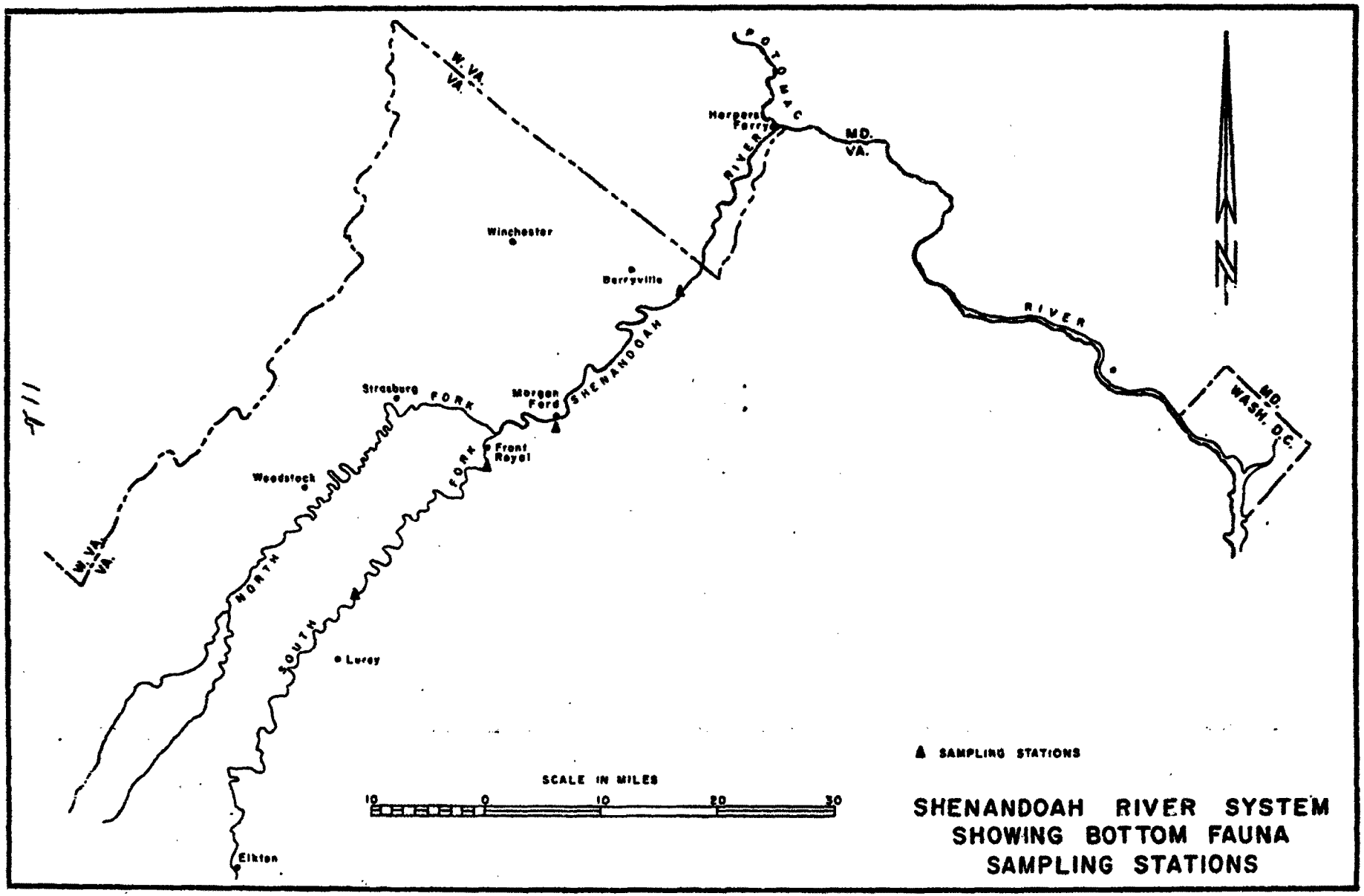

W. VA.
VA.
POTOMAC
RIVER
Harpers Ferry
MD.
VA.
Winchester
Berryville
RIVER
Strasburg
FORK
Morgan Ford
SHENANDOAH
Front Royal
Woodstock
NORTH
FORK
SOUTH
Luray
Elkton
MD.
WASH. D.C.
SAMPLING STATIONS
SCALE IN MILES
10 0 10 20 30
SHENANDOAH RIVER SYSTEM
SHOWING BOTTOM FAUNA
SAMPLING STATIONS

FIGURE 1

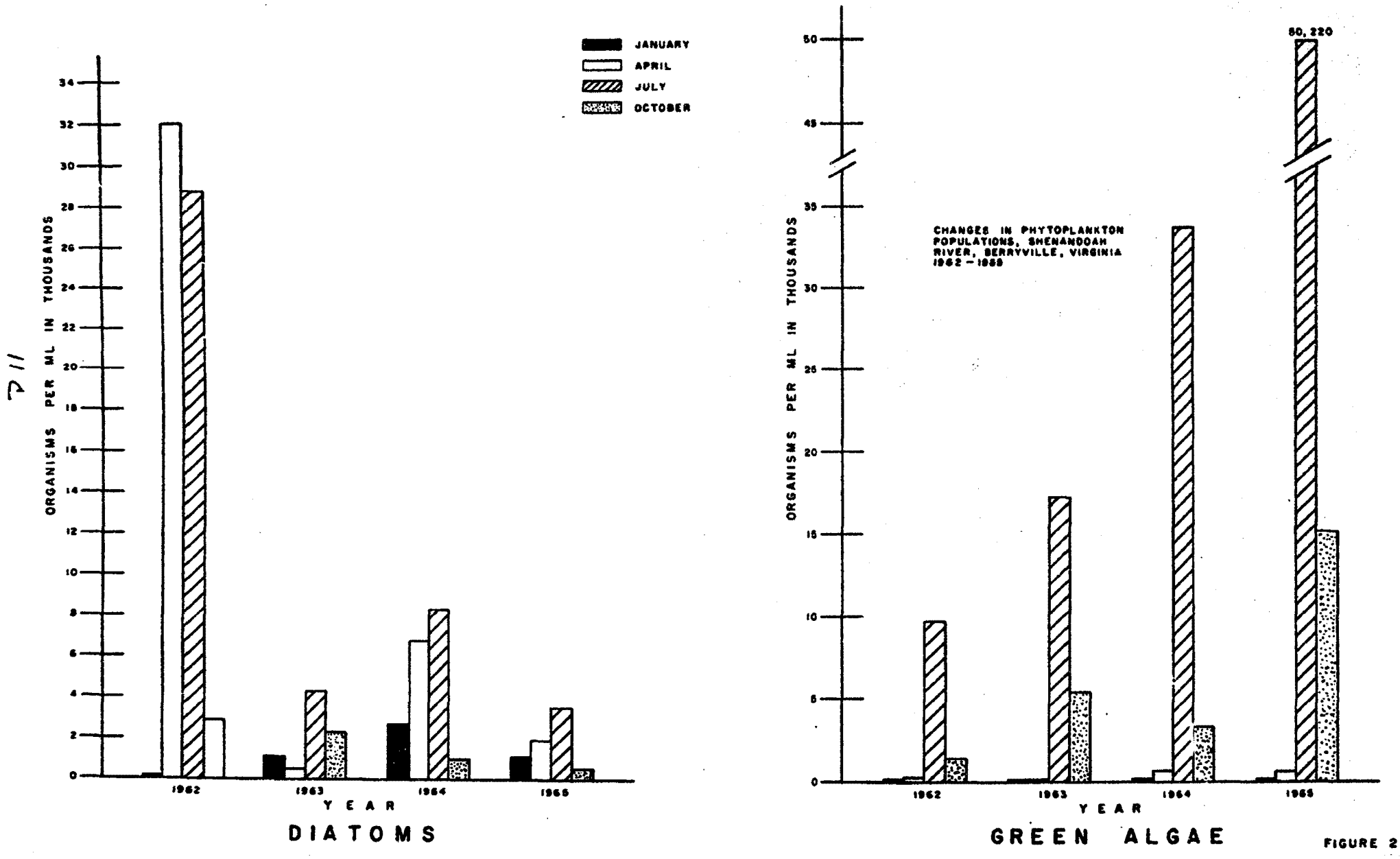

JANUARY
APRIL
JULY
OCTOBER
ORGANISMS PER ML IN THOUSANDS
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
1962
1963
1964
1965
YEAR
DIATOMS
50, 220
45
50
35
30
25
20
15
10
5
0
CHANGES IN PHYTOPLANKTON POPULATIONS, SHENANDOAH RIVER, BERRYVILLE, VIRGINIA 1962 – 1965
ORGANISMS PER ML IN THOUSANDS
1962
1963
1964
1965
YEAR
GREEN ALGAE

FIGURE 2

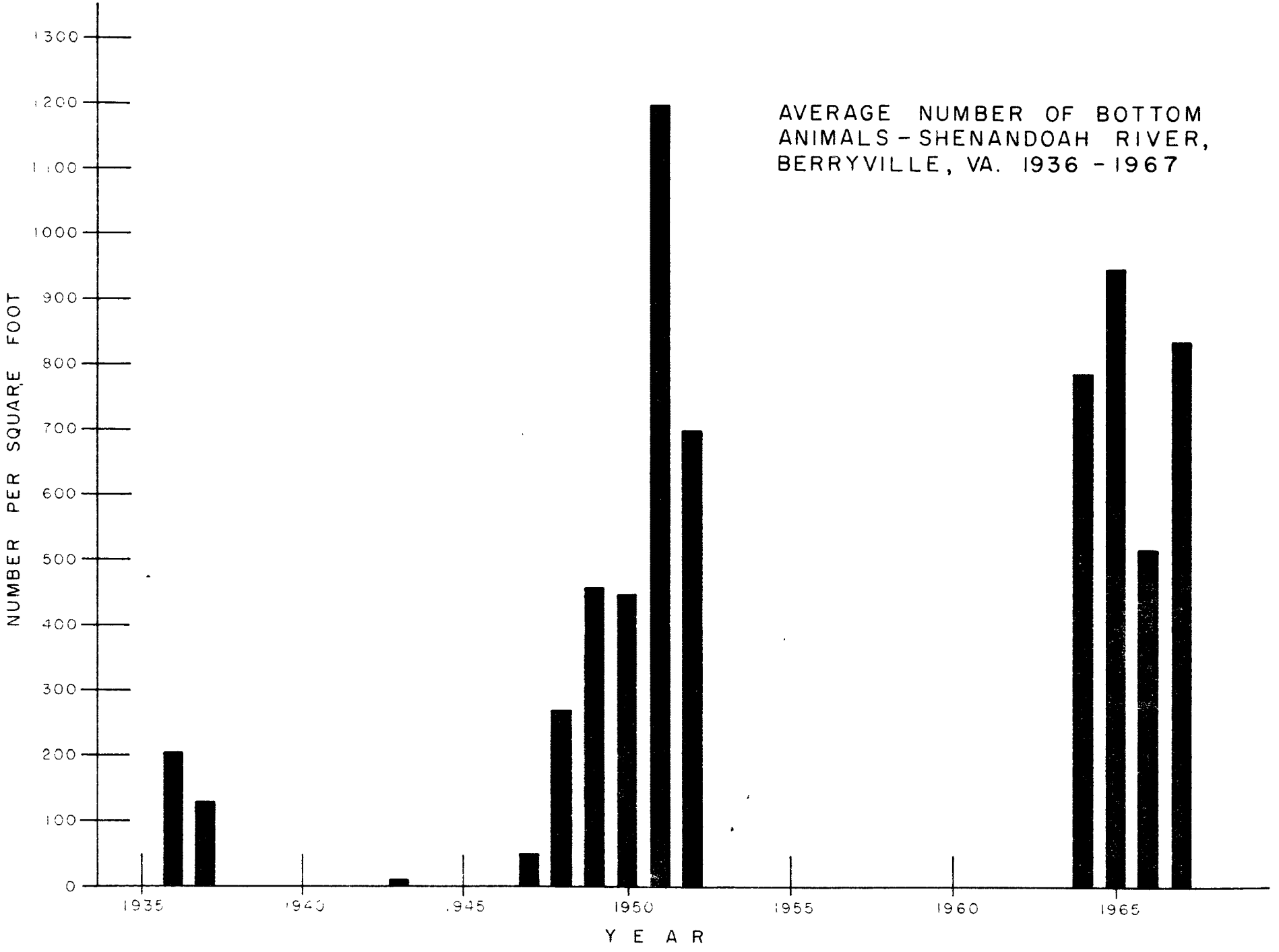
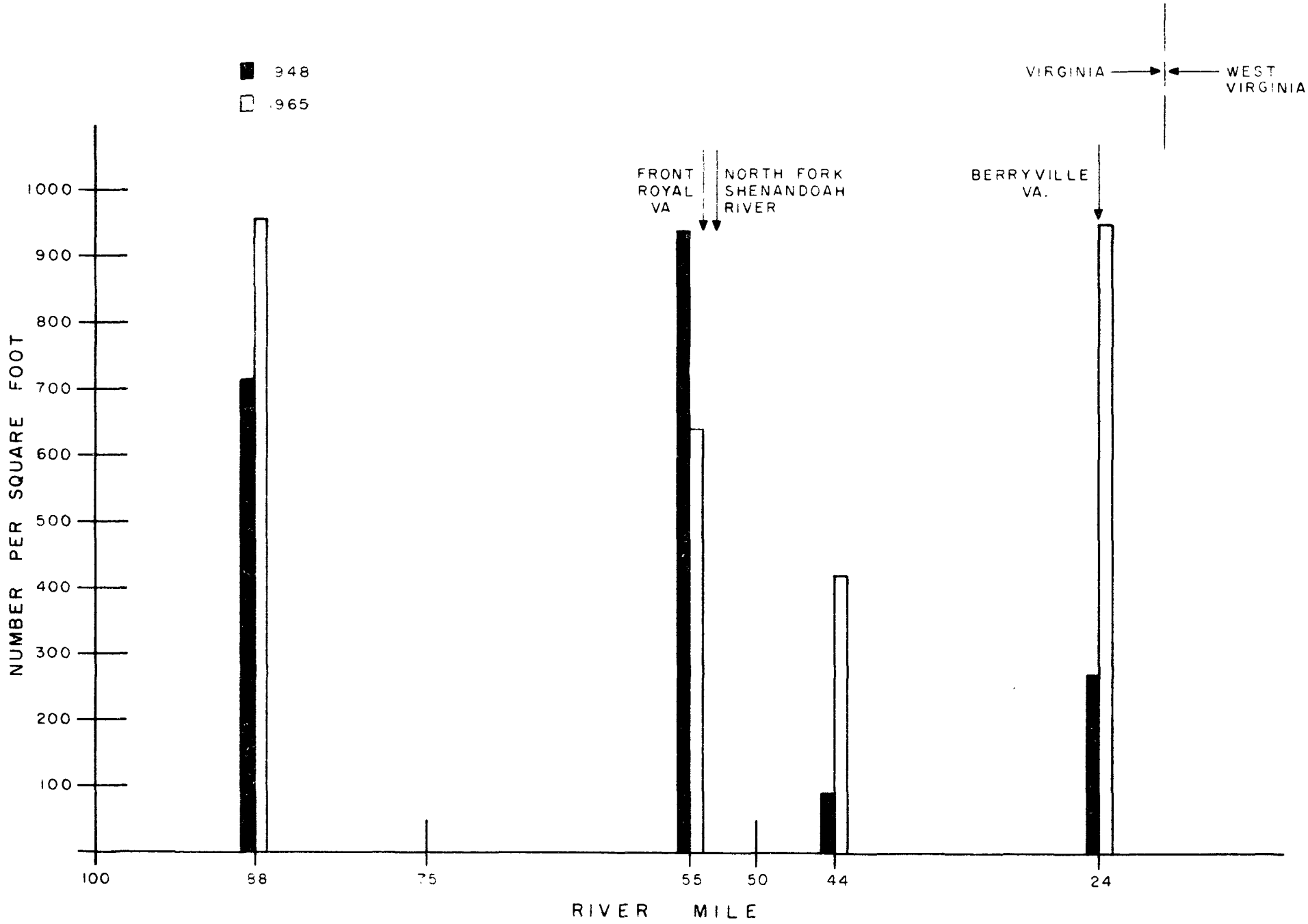
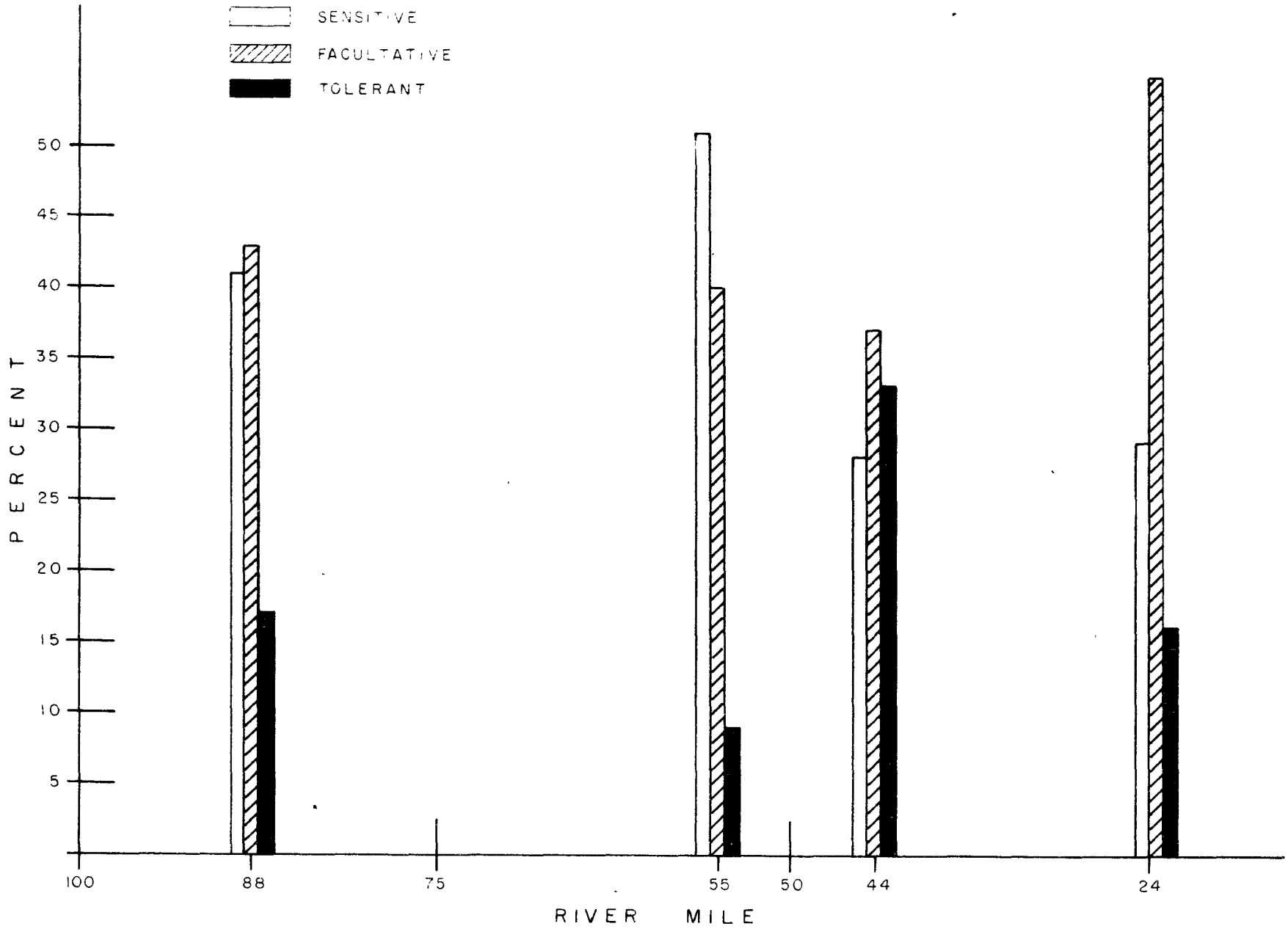

AVERAGE NUMBER OF BOTTOM ANIMALS - SHENANDOAH RIVER, BERRYVILLE, VA. 1936 - 1967
NUMBER PER SQUARE FOOT
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1935
1940
1945
1950
1955
1960
1965
YEAR

FIGURE 3



AVERAGE NUMBER OF BOTTOM ANIMALS - SHENANDOAH RIVER, VA.

FIGURE 4



AVERAGE PERCENTAGE OF KINDS OF BOTTOM ANIMALS
SHENANDOAH RIVER, VA. 1964 — 1967

FIGURE 5

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A P P E N D I X

TABLES

TABLE 1. SELECTED WATER CHEMISTRY DATA.
SHENANDOAH RIVER NEAR BERRYVILLE, VIRGINIA [1/]

Date	D.O. mg/l	pH	Alkalinity mg/l	Hardness mg/l	Sulfates mg/l
10/24/62	8.6	7.8	156	192	94
1/23/63	13.3	7.6	92	128	31
4/3/63	9.2	8.3	104	124	26
7/24/63	--	8.4	120	160	90
10/16/63	8.4	8.3	144	196	150
1/22/64	--	8.4	74	90	34
4/22/64	9.2	8.2	76	90	38
7/29/64	7.4	8.8	120	172	138
10/14/64	--	8.3	140	200	150
1/20/65	--	8.4	88	124	57
4/21/65	--	8.2	76	105	39
7/28/65	--	8.4	114	180	70
10/12/66	--	8.3	97	109	41
1/18/67	--	8.5	81	92	43
5/24/67	--	8.4	80	86	34
7/12/67	--	8.7	97	126	86
10/4/67	--	8.1	131	155	50

[1/] STORET data. FWPCA Surveillance Station No. 510087. Shenandoah River at Berryville, Virginia.

TABLE 2. NITROGEN AND PHOSPHORUS CONCENTRATIONS IN THE SHENANDOAH RIVER NEAR BERRYVILLE, VIRGINIA, 1965-1967. 1/

(All values in milligrams per liter)

Date	Total Phosphorus	Ammonia N + Organic N	Nitrate N + Nitrate N
1/6/65	0.05	0.5	0.7
2/3/65	0.02	--	0.6
3/3/65	0.38	0.3	0.7
4/7/65	0.05	--	0.6
5/5/65	0.02	--	0.4
7/7/65	0.05	2.8	--
9/8/65	0.06	0.9	--
10/6/65	0.03	0.8	--
11/3/65	0.01	0.2	0.1
1/5/66	0.02	--	1.4
3/9/66	0.06	0.7	--
4/6/66	--	1.3	0.5
5/4/66	0.15	1.0	0.8
6/8/66	0.05	--	0.4
7/6/66	0.07	1.3	--
8/3/66	0.14	2.2	--
9/7/66	0.08	--	0.2
10/5/66	0.12	0.9	1.4
11/2/66	0.04	0.2	0.8
12/7/66	--	--	0.8
1/7/67	0.03	0.2	1.0
2/8/67	--	0.3	1.0
5/3/67	0.04	3.4	0.9
7/5/67	0.2	0.9	0.3
9/6/67	0.04	0.6	0.7

1/ STORET data. FWPCA Surveillance Station No. 510087. Shenandoah River at Berryville, Virginia.

TABLE 3. PHYTOPLANKTON POPULATION OF THE SHENANDOAH RIVER NEAR BERRYVILLE, VIRGINIA FOR SELECTED DATES. 1/

(Number per milliliter)

Date of Sample	Blue-Green	Green	Flagellated (Pigmented)	Diatoms	Total
1/3/62	0	20	20	110	200
4/3/62	0	210	1,280	32,000	33,500
7/6/62	6,960	9,620	40	28,700	45,300
10/3/62	230	1,350	0	2,840	4,400
1/9/63	0	0	20	1,010	1,000
4/3/63	40	70	90	440	600
6/19/63	1,010	17,390	130	4,220	22,700
10/9/63	430	5,400	50	2,160	8,000
1/22/64	20	180	0	2,710	2,900
4/8/64	160	660	1,230	6,650	8,700
7/22/64	0	33,680	410	8,110	42,200
10/7/64	0	3,240	160	860	4,300
1/6/65	0	180	20	1,040	1,200
4/7/65	0	580	160	1,880	2,600
7/7/65	0	50,220	180	3,460	53,900
9/8/65	0	15,560	220	1,890	17,700

1/ STORET Data, FWPCA Surveillance Station No. 510087, Shenandoah River at Berryville, Virginia.

TABLE 4. PERCENTAGE OF VARIOUS TOLERANCE FORMS OF BOTTOM ANIMALS, SHENANDOAH RIVER 1964-1966 [1/], [2/], [3/]

STATION	YEAR	TOLERANT	FACULTATIVE	SENSITIVE
33 Miles Upstream from Front Royal	1964	13	37	50
	1965	11	52	37
	1966	26	40	34
	Average %	17	43	40
Front Royal	1964	13	33	54
	1965	8	38	54
	1966	11	49	40
	Average %	9	40	51
Morgan Ford	1964	29	31	40
	1965	30	51	19
	1966	42	32	26
	Average %	34	38	28
Berryville	1964	2	76	22
	1965	27	36	37
	1966	18	53	29
	Average %	16	55	29

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[3/] Surber, E. W., 1966. Smallmouth Bass Stream Investigations. Job No. 2 Shenandoah River Study, 1966. Commission of Game and Inland Fisheries, Richmond, Virginia. 72 pp.

TABLE 5. AVERAGE NUMBER OF BOTTOM ANIMALS, SHENANDOAH RIVER, 1948 AND 1965

(Number per sq. ft.)

Station	Year 1948 [1]	1965 [2]
33 Miles Upstream from Front Royal	714	952
Front Royal	937	637
Morgan Ford	85	419
Berryville	270	96

[1] Henderson, C., 1949. The Value of the Bottom Sampler in Demonstrating the Effects of Pollution on Fish Food Organisms and Fish in the Shenandoah River. The Progressive Fish Culturist, Volume 11, No. 4, pp. 217-230.

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