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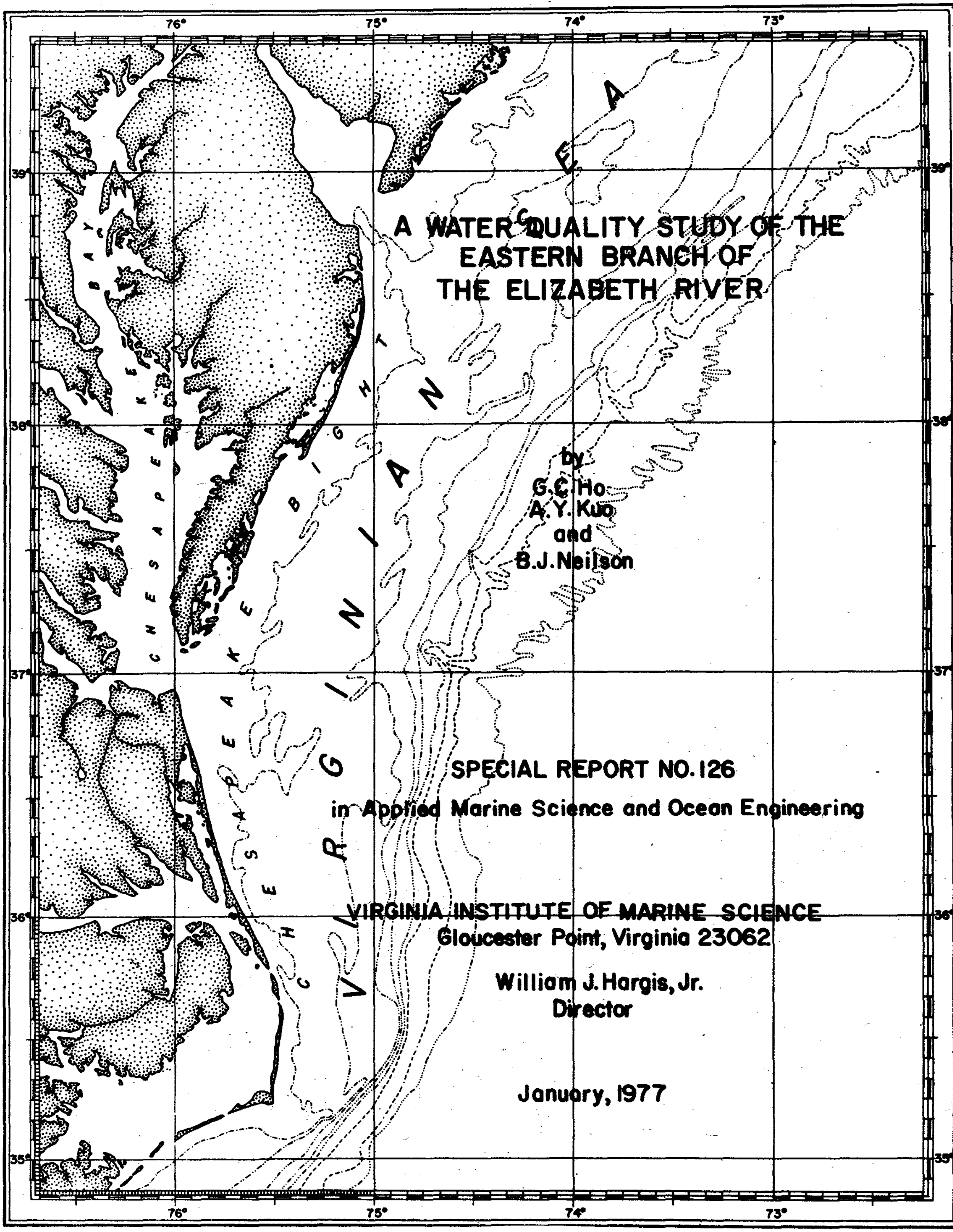

A WATER QUALITY STUDY OF THE EASTERN BRANCH OF THE ELIZABETH RIVER

by
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and
B.J. Neilson

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VIRGINIA INSTITUTE OF MARINE SCIENCE
Gloucester Point, Virginia 23062

William J. Hargis, Jr.
Director

January, 1977

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Prepared under
The Cooperative State Agencies Program

of

The Virginia State Water Control Board
and The Virginia Institute of Marine Science

Project Officers

Dale Jones
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ACKNOWLEDGEMENTS

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ABSTRACT

This special study of the water quality in the Eastern Branch of the Elizabeth River was requested by the Tidewater Regional Office (TRO) of the State Water Control Board (SWCB) under the Cooperative State Agencies (CSA) program. A dye study and surveys of water quality in this branch were conducted in August and September, 1976. The results of dye study provide input data to a "near field" model to calculate the pollutant distributions resulting from Carolanne Farms Sewage Treatment Plant discharge. The phosphorus and nitrogen removals for the effluent were calculated based on the assumption that EPA suggested criteria for the Upper Chesapeake Bay are applicable here.

I. SUMMARY AND CONCLUSIONS

1. The study reported herein was conducted as part of the Cooperative State Agencies (CSA) Program. The program is a continuing joint effort between the Virginia State Water Control Board (SWCB) and the Virginia Institute of Marine Science, devoted to (1) the development of water quality models of Virginia's tidal water, (2) monitoring of water quality, and (3) conducting special studies when water resources problem related to tidal water arise.

2. This problem-oriented special study, requested by the Tidewater Regional Office of State Water Control Board through the CSA program, is concerned with the water quality in the upper Eastern Branch of the Elizabeth River. The major point source of pollutants to this branch of the river is the Carolanne Farms Sewage Treatment Plant.

3. Since the concerned water quality problem is local, a "near field" model study was conducted.

4. A field study, conducted in August and September of 1976, included both a dye-release experiment and surveys of water quality in the river.

5. The results of the dye study provide input data to the "near field" model (also developed under CSA program) to calculate the pollutant distributions due to the effluent from the Carolanne Farms Sewage Treatment Plant. The

model results were compared with field surveys to assess the relative contribution of pollutants from point and non-point sources.

6. Concentrations of total phosphorus in the Eastern Branch of the Elizabeth River as high as 0.8 mg/l as P were found near the Carolanne Farms Sewage Treatment Plant discharge site during the field survey. The model predicted concentrations of total phosphorus in this branch due to the effluent discharge alone can be as high as 0.37 mg/l as P and 0.52 mg/l as P at 0.615 MGD (August, 1976) and 0.98 MGD (1976 NPDES permit) respectively.

7. The concentration of total nitrogen in the Eastern Branch of the Elizabeth River was found to be as high as 3.5 mg/l as N near the Carolanne Farms Sewage Treatment Plant discharge site at the time of the field survey. The model predicted concentration of total nitrogen in this branch due to the effluent discharge alone can be as high as 0.97 mg/l as N and 1.55 mg/l as N at 0.615 MGD (August, 1976) and 0.98 MGD (1976 NPDES permit) respectively.

8. The study reveals that the Eastern Branch of the Elizabeth River may have an algal bloom problem, which, at times, may cause dissolved oxygen concentrations below 5 mg/l. DO concentrations around 2 mg/l have been observed.

9. Algal blooms are related to the high nutrient levels in the water. While non-point sources of pollutants contribute a significant portion of the nutrients, the model predicts that the contribution from the sewage treatment plant alone exceeds the EPA suggested criteria for avoiding undesirably high chlorophyll "a" concentrations.

10. If EPA suggested criteria for critical ambient nutrient concentrations (total phosphorus = 0.04 mg/l as P and inorganic nitrogen = 0.8 mg/l as N) to avoid eutrophication in the Upper Chesapeake Bay are applied here, and neglecting other pollutant sources, the Carolanne Farms wastewater treatment plant should not discharge more than 3.1 kg (6.8 lb) of total phosphorus (as P) and 60 kg (132 lb) of inorganic nitrogen (as N) per day. With present effluent characteristics, this would require 89% and 92% phosphorus removal at 0.615 MGD (August, 1976) and 0.98 MGD (1976 NPDES permit) respectively. If the total nitrogen content is considered, then 17% and 48% nitrogen removals are required for the same flow rates. If only the inorganic nitrogen in the effluent is considered, no additional treatment is required at 1976 flow rates but 30% nitrogen removal is needed at the 1976 NPDES permit flow rate (0.98 MGD).

11. Information regarding the origin and quantity of non-point sources is very limited, but these sources are believed to contribute significant amounts of nutrients.

It is possible that both point and non-point sources will need to be controlled to prevent the continuation of water quality problems in the Eastern Branch of the Elizabeth River.

II. INTRODUCTION

On September 25, 1975, the Tidewater Regional Office (TRO) of the State Water Control Board (SWCB) conducted a water quality survey of the Eastern Branch of the Elizabeth River. The results of the survey are shown in Figures 1, 2, 3, and 4.

In order to limit the maximum algal standing crop to 40 μg/l chlorophyll "a" in the Upper Chesapeake Bay, the United State Environmental Protection Agency (EPA) has suggested that total phosphorus and inorganic nitrogen concentrations should not exceed 0.04 mg/l as P and 0.8 mg/l as N, respectively (Clark, et al., 1973). If these criteria are applied to this estuary, it is observed that:

1) the nitrogen criterion is exceeded throughout the upstream reach of this tributary estuary at both high and low tides.
2) the phosphorus concentrations throughout the upstream reach of this tributary estuary are at or near the critical level at both high and low tides.
3) dissolved oxygen (DO) levels as low as 4 mg/l were observed.

In order to estimate whether a significant portion of the nutrient loads in this estuary is the result of the Carolanne Farms Sewage Treatment Plant's discharge, VIMS made bathymetric measurements of the water bodies in February, 1976. This data was combined with effluent discharge information gathered by the Tidewater Regional Office of the SWCB (Table 1) to calculate expected nutrient concentrations under various assumptions concerning mixing and flushing in the stream. However, the available information was too limited and the results were inconclusive.

In order to ascertain the mixing and flushing rates for this estuary, a dye study was conducted. The results of this dye study were analyzed with a mathematical model developed by VIMS to give the expected concentration distributions for the various constituents of a continuous point source discharge. These distributions then could be compared to actual distributions obtained from field measurements to determine what portion of the loads can be attributed to the Carolanne Farms Sewage Treatment Plant discharge.

TABLE 1. CHARACTERISTICS OF CAROLANNE FARMS SEWAGE TREATMENT PLANT'S EFFLUENT (SWCB)

Parameters	Units	Proposed Permit Limitations		Survey Results						
Date		7/1977	Future	3/8/74	4/17/75	9/25/75	10/25/76	1/25/76	4/19/76	6/8/76
Flow	MGD	0.98								
BOD_5	mg/l	30	30	56	130	70	31	56	142	22
T.S.S.	mg/l	30	30	19	60	78	36	34	470	30
Total-P	mg/l as P	1.0	1.0	13	8.0	12	10.5	10.8	17	8.3
Ortho-P	mg/l as P			10.4	8.0	11	8.0	9.5	14.9	7.5
Total-N	mg/l as N		0.5	34.45	17.24	28.22	34.9	30.21	44.08	28.16
TKN-N	mg/l as N			34.0	17.0	28	34.0	30	44	28
NH_3-N	mg/l as N	2.0		21.0	17.0	21.5	22.0	25.0	27.5	25
NO_2-N	mg/l as N			0.05	0.04	0.03	0.55	0.08	0.06	0.05
NO_3-N	mg/l as N			0.40	0.20	0.35	0.35	0.13	0.02	0.11

III. MATHEMATICAL MODEL

The mathematical model used for this study was developed by VIMS under the CSA program (Kuo and Jacobson, 1975) to predict the concentration distributions of sewage constituents resulting from a waste discharge in an estuary or the coastal seas. The model is based on the theoretical relationship between the concentration distributions of conservative and nonconservative substances. The decay of nonconservative substances is assumed to be a first order process.

Briefly, if a non-decaying tracer is released continuously over a single tidal cycle from slack-before-flood to slack-before-flood, the equilibrium concentration field at slack-before-flood and slack-before-ebb for a nonconservative substance released continuously may be expressed as

$$CL_{\infty}(x,y) = \sum_{n=1}^{\infty} CL_n(x,y) \exp\left(-\frac{2n-1}{2} kT\right) \tag{1}$$

$$CH_{\infty}(x,y) = CH_1(x,y) \exp\left(-\frac{1}{4}kT\right) + \sum_{n=2}^{\infty} CH_n(x,y) \exp\{-(n-1)kT\} \tag{2}$$

where $CL_{\infty}(x,y)$ is the equilibrium concentration field at slack-before-flood.

$CH_{\infty}(x,y)$ is the equilibrium concentration field at slack-before-ebb.

$CL_n(x,y)$ is the measured dye concentration field at the nth slack-before-flood after dye release begins.

$CH_n(x,y)$ is the measured dye concentration field at nth slack-before-ebb after dye release begins.

k is the first order decay rate for the particular substance under consideration.

T is the duration of dye release, which is one tidal cycle.

For a non-decaying substance, equations (1) and (2) become

$$CL_\infty(x,y) = \sum_{n=1}^{\infty} CL_n(x,y)$$

$$CH_\infty(x,y) = \sum_{n=1}^{\infty} CH_n(x,y)$$

Similar equations for the concentration fields can be written for the case of a dye release from slack-before-ebb to slack-before ebb, but are not included for the sake of brevity.

IV. FIELD STUDY

A study using the fluorescent dye, Rhodamine WT, as a tracer was conducted from August 29 through September 3, 1976. The dye was released for one tidal cycle from slack-before-flood to slack-before-flood. Dye samples were taken at each slack-before-flood and slack-before-ebb until sufficient data had been collected at the preselected stations. ISCO automatic samplers which collected samples hourly were also used for dye sampling at four intensive stations (Figures 5a and 5b). In addition, nutrient, DO, BOD, coliform bacteria and chlorophyll "a" samples were taken at slack-before-flood and slack-before-ebb.

The dye used was Rhodamine WT which is manufactured and sold by E. I. DuPont de Nemours and Company, and came in 20% solution with a density of 1.2 g/cm^3. Half a 250 lb. barrel of this dye was used for the study. The dye was diluted to a total volume of 250 gallons with tap water and then pumped at a rate of 20 gal/hr. to the Carolanne Farms Sewage Treatment Plant discharge ditch.

At 2015 hours, August 29, 1976, the dye release was begun on flooding tide. The dye flow was stopped at 0845 hours August 30, 1976, at slack-before-flood after an entire tidal cycle and after releasing a total of 250 gallons of diluted dye solution into the Eastern Branch of the Elizabeth River.

A preliminary run was made before dye release on August 28, 1976, to determine the background fluorescence. The order of natural fluorescence was found equivalent to hundredths of a part per billion (ppb) dye concentration with an average about 0.05 ppb.

Dye samples were collected hourly at four "intensive" stations (Figure 5b, stations 7, 8, 9 and 12) to provide detailed information on the movement of the dye. Dye samples were collected at slack water stations (Figure 5b, stations 1, 2, 3, 4, 5, 6, 10 and 11) at slack water periods to provide additional information for the mathematical model. Water quality samples were taken at slack water periods at each station.

Dye concentration was determined by a Turner Design Fluorometer which measures the amount of light given off by any fluorescent substance absorbing light in the green region of the spectrum (546 nm) and emitting light in the red region (590 nm). By using a photomultiplier tube, the light measurement can be compared to actual dye concentrations measuring in the hundredths of a part per billion.

Water samples were collected during slack water periods by two boats, a small Jon boat for the shallow upstream portion and a large Thunderbird for the downstream portion. Samples collected were kept on ice and brought to VIMS laboratory for analysis. Analytical methods used are those listed in "Standard Methods for the Examination of Water and Wastewater" 14th edition, 1975 (APHA, AWWA and WPCF. 1975).

V. RESULTS AND DISCUSSION

The water quality data gathered during the field studies (by both VIMS and SWCB) are given in tabular and graphical form. In addition, two maps showing the study area, intensive and slack water sampling stations are presented. The dye study data are summarized in Appendix A.

(1) Phosphorus

Figure 6a shows actual and predicted total phosphorus profiles. It is obvious that a significant amount of total phosphorus is contributed from the mouth of the river which could be the result of sewage discharges to the Southern Branch and Main Stem of the Elizabeth River. If there are no other pollutant sources along the Eastern Branch of the Elizabeth River, a uniform distribution of total phosphorus (background total phosphorus) would be expected due to tidal mixing. Therefore, a baseline adjustment is necessary if a meaningful presentation of field data is to be made. This is done by subtracting the background value from actual field values. Figure 6b shows the adjusted total phosphorus profile and model predicted total phosphorus profile. It clearly shows that Carolanne Farms Sewage Treatment Plant does not contribute all of the adjusted total phosphorus in the Eastern Branch, but it does contribute a significant portion of the total phosphorus. Total phosphorus attributable to this sewage treatment plant ranges as high as 0.37 mg/l as P near the effluent discharge site.

In Figure 6b, the area between adjusted and model predicted curves is the total phosphorus contributed from non-point sources along this reach of the river. It is possible that phosphorus is exported (washed out) from marshes to the estuary or that fertilizer applied to lawns was washed out in runoff which ultimately flows to the river. Another possibility is that the water table is very close to the surface, which could result in malfunctioning septic tanks and drain fields. The septic tank effluents may flow laterally to the river, resulting in high BOD and nutrient levels. Other possible sources of contamination are boating activities and wildlife, although there is no data available to quantify these sources.

The 1976 NPDES (National Pollutant Discharge Elimination System) permit for the Carolanne Farms Sewage Treatment Plant allows 0.98 MGD (Million Gallons per Day) of flow. The present flow is 0.615 MGD. As shown in Figure 6c, if the plant operates at present efficiency but at its rated flow capacity, the predicted total phosphorus concentration in the estuary can be as high as 0.52 mg/l as P. If EPA's guideline for critical ambient nutrient concentration levels (total phosphorus = 0.04 mg/l as P) to avoid eutrophication in the Upper Chesapeake Bay is applied here, the sewage treatment plant should not discharge more than 3.1 kg (6.8 lb) of total phosphorus (as P) per day. To meet this requirement, the plant would need to be upgraded to provide 89% and 92% phosphorus removal at 0.615 MGD (August, 1976) and 0.98 MGD

(1976 NPDES permit) respectively.

The dissolved ortho-phosphate levels of this estuary, shown in Figure 7, are somewhat higher at the mouth of the river than in the upstream portion. This could be the result of sewage discharges to the Southern Branch and Main Stem of the Elizabeth River. This figure indicates that the dissolved ortho-phosphate (passing through 0.45 μm filter paper) alone exceeds the EPA suggested criterion for the Upper Chesapeake Bay (total phosphorus = 0.04 mg/l as P) at both high and low tides.

(2) Nitrogen

In September 1975, the organic nitrogen level of this estuary (Figure 1) was negligible while inorganic nitrogen (Figure 1) was as high as 1.14 mg/l as N. In September 1976, the inorganic nitrogen concentrations (Figure 8a) were less than 0.8 mg/l as N for most of the stations while organic nitrogen concentrations (Figure 8b) ranged up to 2.8 mg/l as N which was much higher than those found in the Upper Chesapeake Bay during periods of maximum algal bloom (0.4~0.5 mg/l as N) (Clark, et al., 1973).

It is noted in EPA's report (Clark, et al., 1973) that (a) inorganic nitrogen levels (nitrate + ammonia) were minimal and organic nitrogen levels were greatest during periods of maximum algal blooms, and (b) total phosphorus and inorganic nitrogen concentrations should not exceed 0.12 mg/l as PO_4 (0.04 mg/l as P) and 0.8 mg/l as N if maximum algal standing crop is to be limited to 40 µg/l or less in Upper Chesapeake Bay. Obviously, the Eastern Branch of the Elizabeth River was highly enriched with inorganic nitrogen, enough to cause an algal bloom, in September 1975 although no chlorophyll "a" samples were collected at that time. The high organic nitrogen levels observed in August, 1976, suggest that an algal bloom was occurring then.

The total nitrogen levels during this study are shown in Figure 8c. A significant part of the total nitrogen is contributed from the mouth of the river. A baseline adjustment (similar to that for total phosphorus) was made in order to subtract out these contributions. Figure 8d shows the adjusted total nitrogen levels and model predictions. It clearly shows that Carolanne Farms Sewage Treatment Plant does contribute a significant amount of total nitrogen to the Eastern Branch of the Elizabeth River.

In Figure 8d the area between adjusted total nitrogen curve and model predictions for the sewage treatment plant discharge is the total nitrogen contributed from non-point sources along the estuary. The possible sources of contamination are (1) malfunctioning septic tanks and drain fields, (2) lawn fertilizer, and (3) nitrogen exported from the marshes to the estuary, but no measurements of these contributions were made.

The predicted total nitrogen distributions contributed by the Carolanne Farms Sewage Treatment Plant discharge at

0.615 MGD (August, 1976) and 0.98 MGD (1976 NPDES permit) are shown in Figure 8e. They are as high as 0.97 mg/l and 1.55 mg/l as N at 0.615 MGD and 0.98 MGD, respectively. If EPA's critical ambient nutrient concentration (inorganic nitrogen = 0.8 mg/l) to avoid eutrophication in the Upper Chesapeake Bay is applied here, the sewage treatment plant should not discharge more than 60 kg (132 lb) of inorganic nitrogen (as N) per day. If we assume that the organic nitrogen in the effluent will be transformed to inorganic forms within the estuary, then the total nitrogen content of the effluent must be considered. In this case, the plant must be upgraded to provide 17% and 48% nitrogen removal at 0.615 MGD (August, 1976) and 0.98 MGD (1976 NPDES permit) respectively. If only the inorganic nitrogen in the effluent is used for these calculations, no nitrogen removal is required at present flow rates, but removal of 30% of the inorganic nitrogen will be required at the 1976 NPDES permit flow rate.

(3) Dissolved Oxygen, Biochemical Oxygen Demand and Chlorophyll "a"

Dissolved oxygen (DO) concentrations are controlled by many factors. As salinity and temperature increase, the saturation value decreases. Pollutants normally exert an oxygen demand due to biochemical reaction and decomposition. Bacteria, phytoplankton, zooplankton and large organisms in general require oxygen to live. The phytoplankton do produce oxygen as a by-product of phytosynthesis, but the major supply of oxygen is the atmosphere.

A diurnal trend of the DO values was found. Oxygen is produced by the algae during daylight hours resulting in supersaturated DO concentrations. During the night algal respiration results in a net consumption of DO in addition to BOD requirements. Figures 9a and 9b show the DO profiles at two different sampling times. Both slack-before-flood surveys were made during sunny days. The data shown in Figure 9a were collected when chlorophyll "a" level was high (Figure 10a) while those shown in Figure 9b were collected during a low chlorophyll "a" period (Figure 10b). The high concentrations (supersaturated) of DO are primarily the result of algal activity.

Biochemical oxygen demand is a measure of the amount of oxygen which will be consumed as water constituents are oxidized by a variety of biological and chemical reactions. In general, the BOD level in this stream is controlled by the sewage treatment plant's discharge and the non-point pollution loading entering from the surrounding land, especially during rainy periods. BOD values as high as 12 mg/l were found in the upstream portion of the river at slack-before-flood (Figure 11).

EPA has suggested an upper limit for the desirable concentrations of algae in the Upper Chesapeake Bay. The suggested limit is 40 μg/l of chlorophyll "a" which is a measure of the algae concentration. The chlorophyll "a" levels observed at the time of the survey are quite high

(Figure 10a) as compared with the value suggested by EPA.

A review of data collected during the field study indicates that eutrophication is a problem. Chlorophyll "a" concentrations exceeded the EPA suggested criterion of 40 μg/l in the upstream portion of the river. Nutrient data corroborate this finding. Although the EPA suggested chlorophyll "a" and nutrient criteria appear to be appropriate from biological consideration for the Upper Chesapeake Bay, they may be high for the small stream. Because this water body is more shallow than those studied by EPA, oxygen consumption or production due to algae dynamics will be averaged over a relatively shallow water column. Therefore, the impact can be great. Extremely low dissolved oxygen levels could result during nights or early morning.

(4) Bacterial Contamination

Water quality standards for various water uses have been set by State Water Control Board. For primary contact recreation the mean fecal coliform count should not exceed 200 MPN/100 ml. For secondary contact recreation and propagation of marine organisms the mean fecal coliform level may not exceed 1000 MPN/100 ml.

Standards for shellfish growing waters are set by both the State Department of Health and the Federal Food and Drug Administration which regulates interstate transport of shellfish. The standards are 70 MPN/100 ml and 14 MPN/100 ml for total coliforms and fecal coliforms respectively. The total coliform group includes some bacteria which are present in soil and decaying leaves so that total coliform count is not always a good indicator of pollution. It is anticipated that in the near future the fecal coliform criterion will be used exclusively.

Water samples taken in September, 1975 and August, 1976 showed high fecal coliform levels in the Eastern Branch of the Elizabeth River. Fecal coliforms ranged up to 15,000 MPN/100 ml (Figures 12a and 12b). Obviously the bacterial quality of this estuary is not suitable for shellfish propagation or primary contact recreational activities.

VI. CONCLUSION

Extremely low dissolved oxygen levels (ca. 2 mg/l) were found in the Eastern Branch of the Elizabeth River and could be related to algal activity as evidenced by high chlorophyll "a" levels. High organic nitrogen and phosphorus levels and low inorganic nitrogen concentrations strongly corroborate this finding.

The model predicted that the concentration of total phosphorus can be as high as 0.37 mg/l as P and 0.52 mg/l as P due to effluent discharge from Carolanne Farms Sewage Treatment Plant at 0.615 MGD (August, 1976) and 0.98 MGD (1976 NPDES permit) respectively. Predicted total nitrogen concentrations range as high as 0.97 mg/l as N and 1.55 mg/l as N for the August, 1976 (0.615 MGD) and 1976 NPDES permit (0.98 MGD) flow rates respectively. If EPA suggested criteria for ambient nutrient concentration levels are applied here, the sewage treatment plant should not discharge more than 3.1 kg (6.8 lb) of total phosphorus (as P) and 60 kg (132 lb) of inorganic nitrogen (as N) per day. To meet this requirement the plant would need to provide 89% and 92% phosphorus removal at 0.615 MGD and 0.98 MGD respectively. If the total nitrogen content of the effluent is considered, then 17% and 48% nitrogen removals also are required at 0.615 MGD and 0.98 MGD respectively. If only the inorganic nitrogen in the effluent is used in calculations, no removal is required at present, but 30% nitrogen removal is needed for the 1976 NPDES permit flow rate (0.98 MGD).

Since non-point sources of pollutants appear to contribute significant amounts of nutrients to the estuary, water quality problems could persist even if the treatment plant were upgraded. Considerably more information on the origin and quantity of non-point sources is needed. It is very likely that both point and non-point sources will need to be controlled to prevent the continuation of water quality problems in the Eastern Branch of the Elizabeth River.

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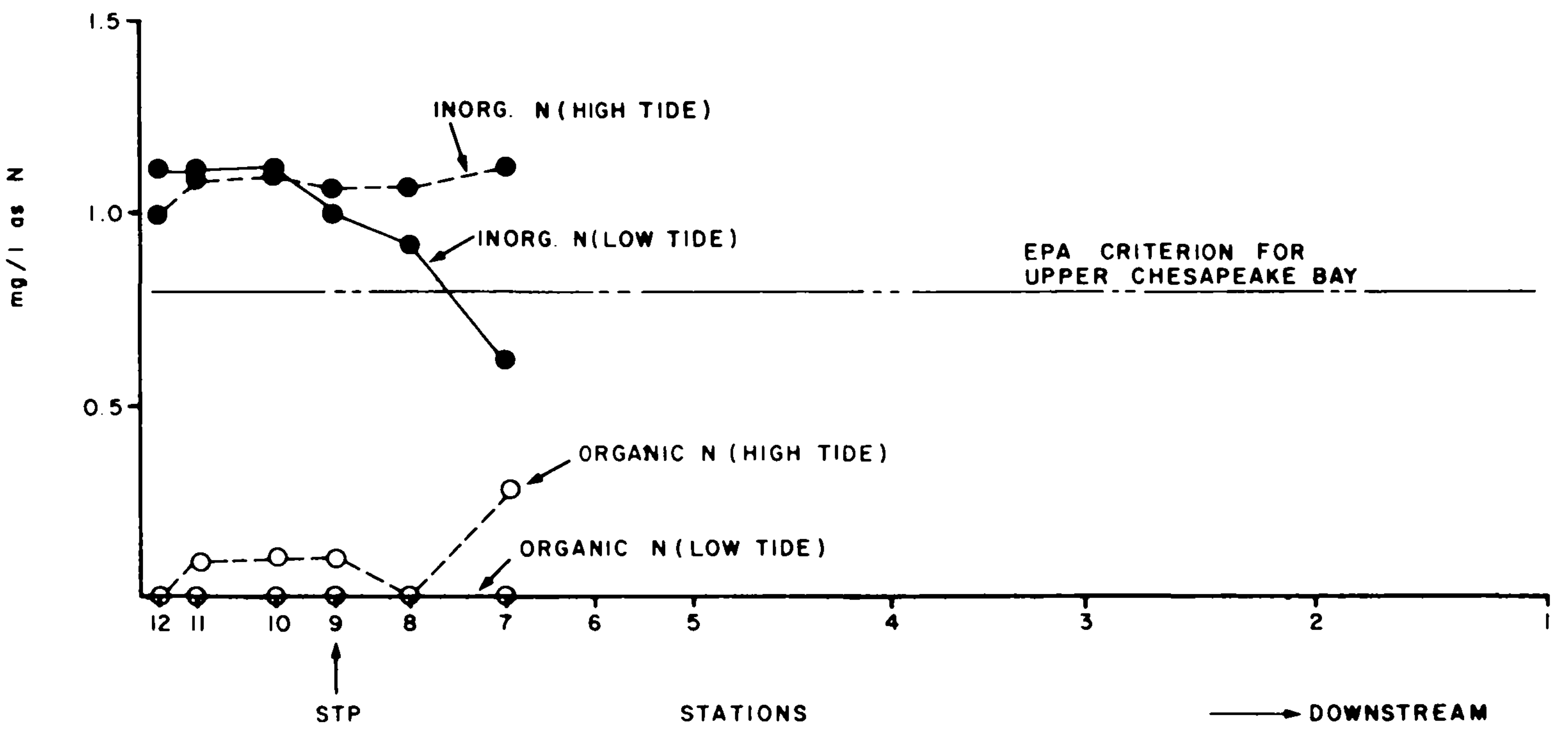

Figure 1. Total inorganic nitrogen and organic nitrogen in the E. Branch of the Elizabeth River (SWCB, 9/25/75).

Refer to Figure 5b for stations.

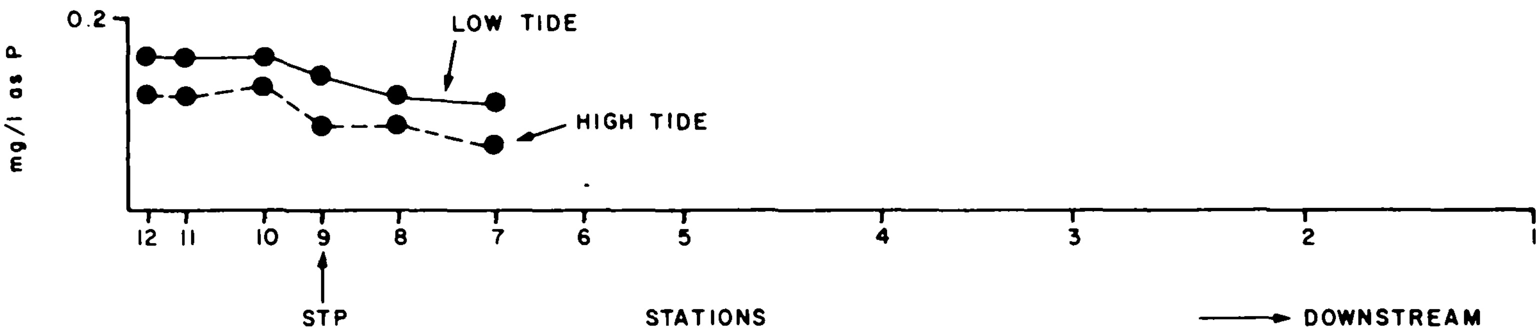

Figure 2. Ortho-phosphate in the E. Branch of the Elizabeth River (SWCB, 9/25/75).

Refer to Figure 5b for stations.

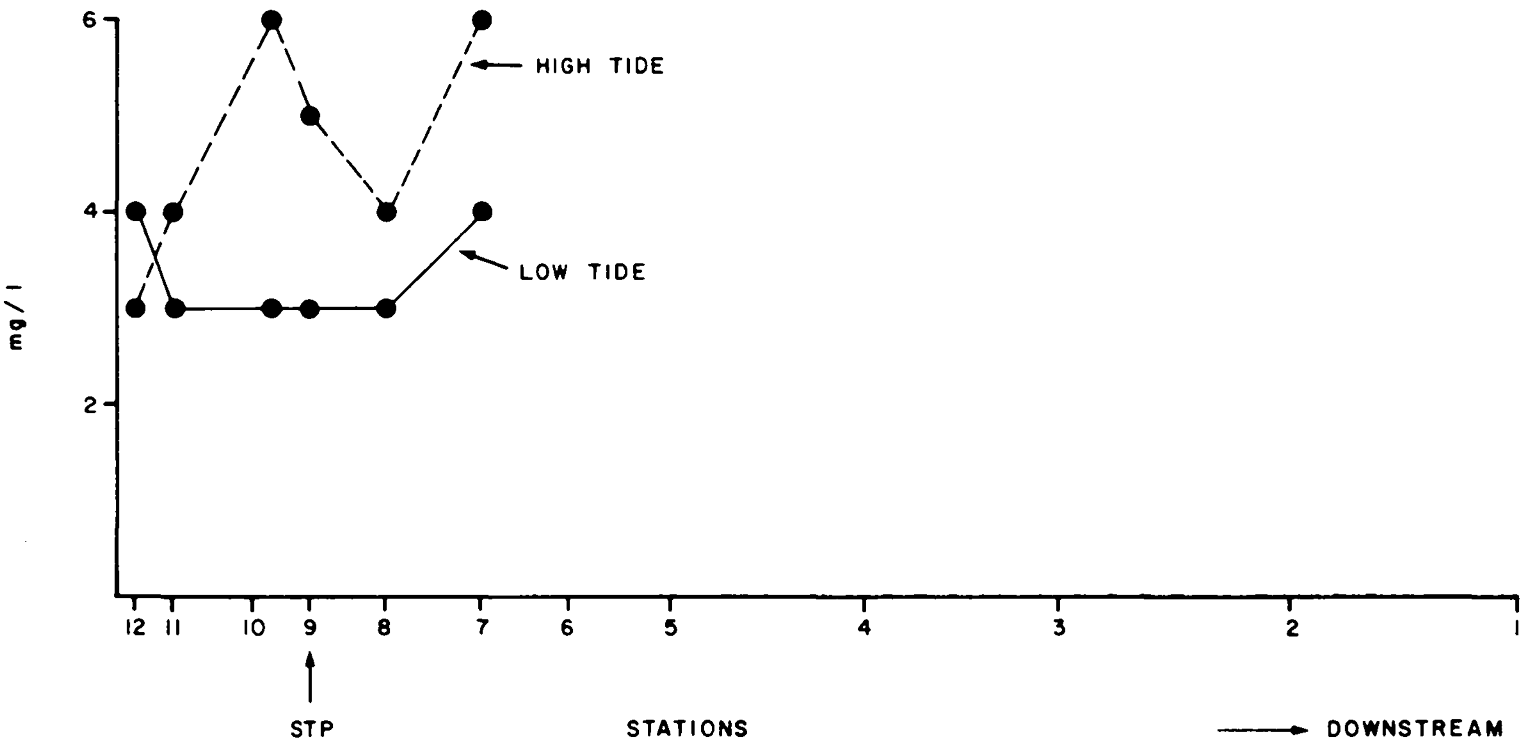

Figure 3. 5-day BOD in the E. Branch of the Elizabeth River (SWCB, 9/25/75).

Refer to Figure 5b for stations.

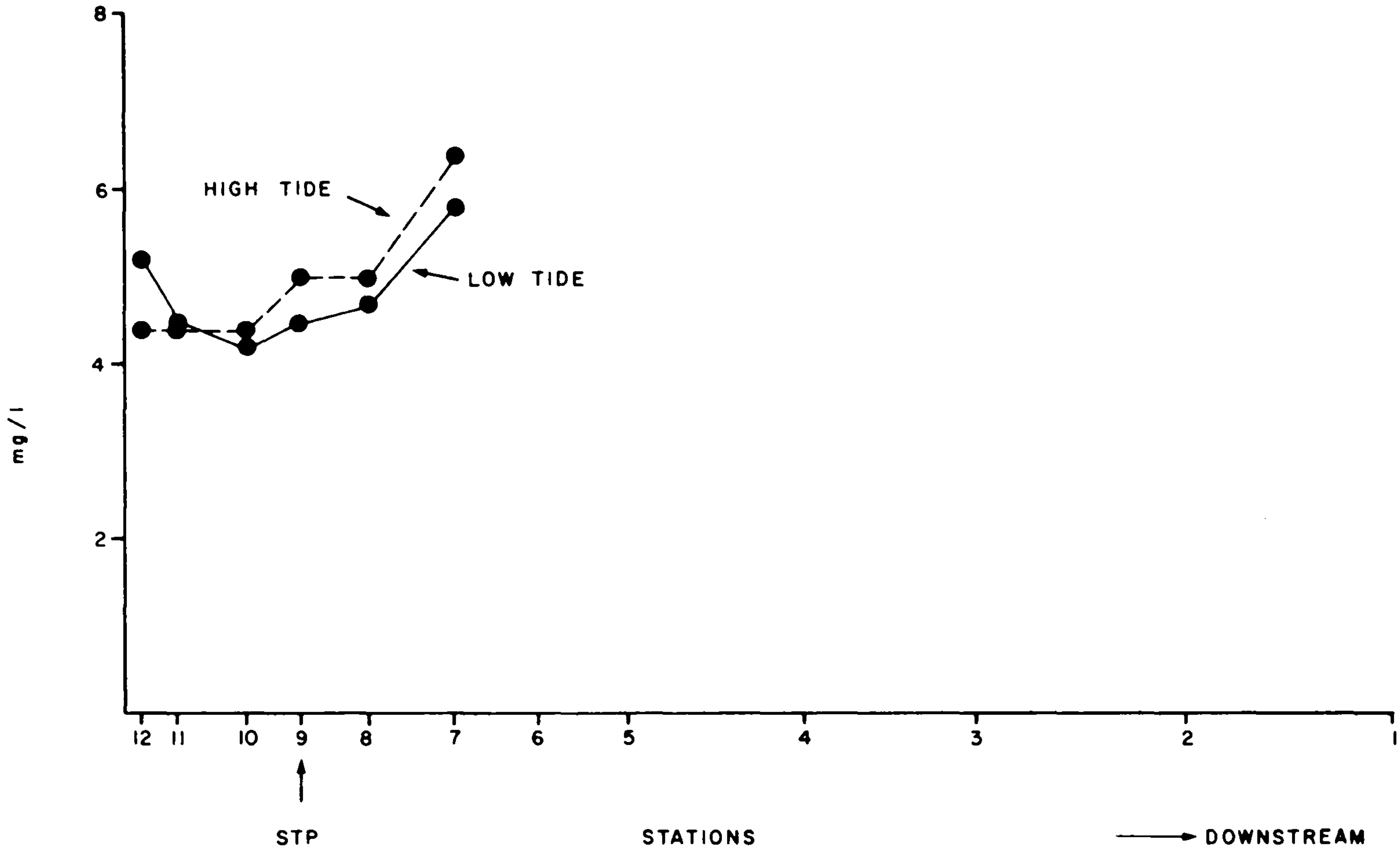

Figure 4. Dissolved oxygen in the E. Branch of the Elizabeth River (SWCB, 9/25/75).

Refer to Figure 5b for stations.

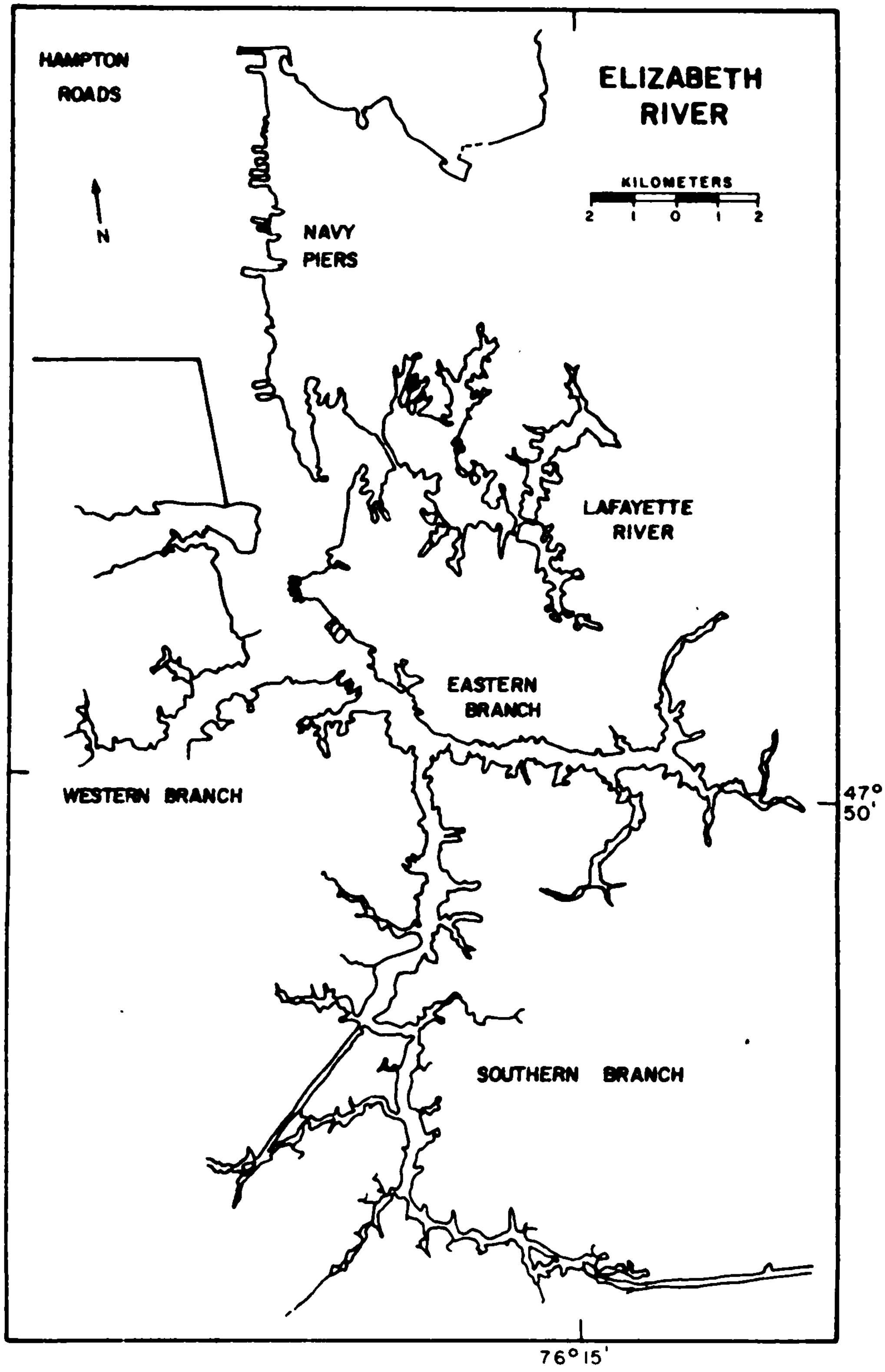

Figure 5a. Location of the Eastern Branch of the Elizabeth River.

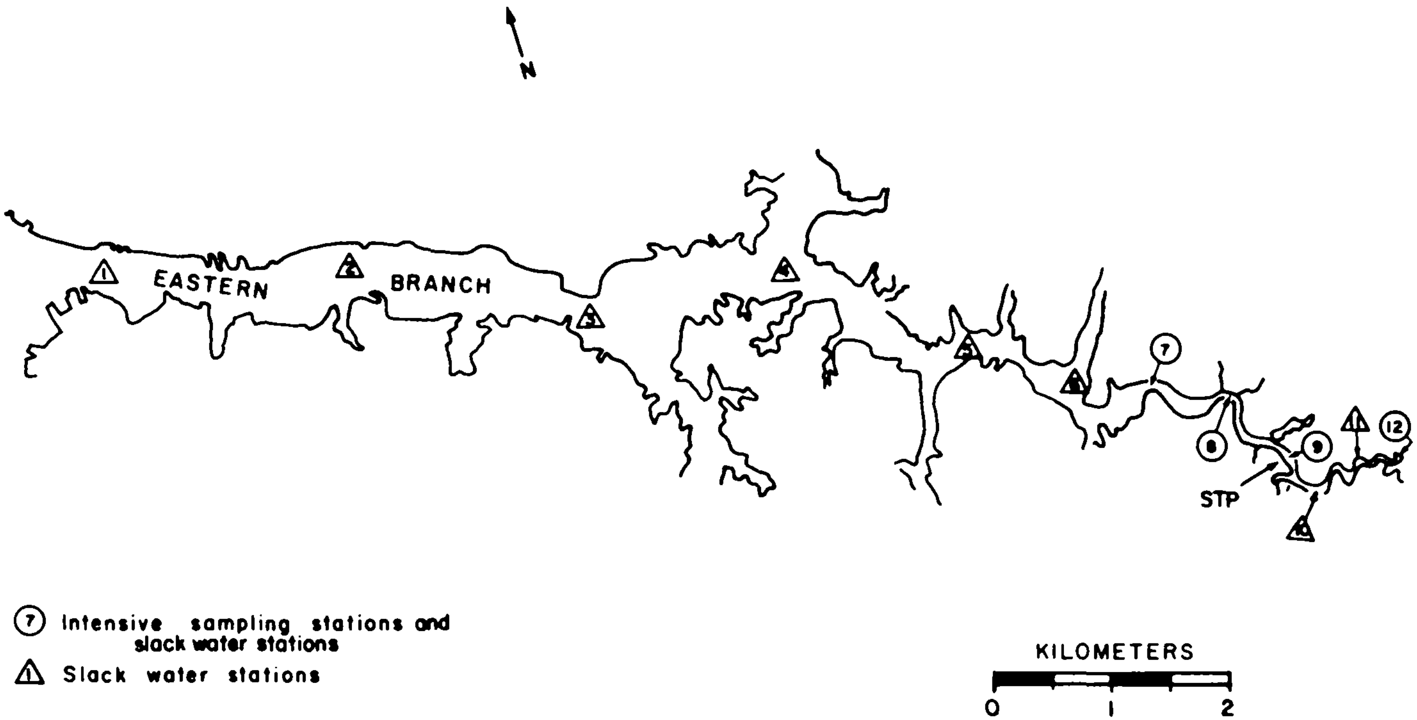

Figure 5b . Locations of the Eastern Branch of the Elizabeth River and stations.

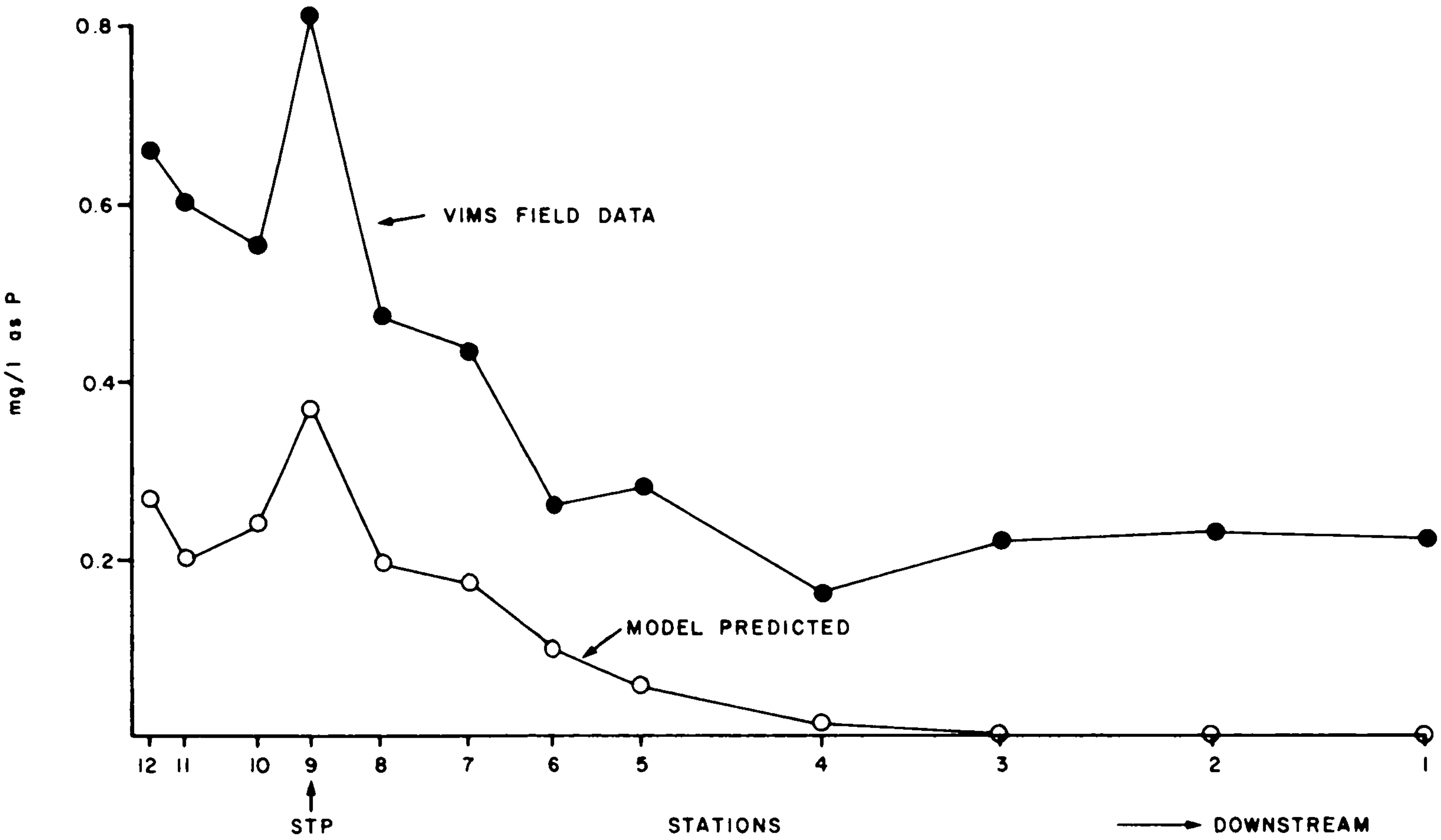

Figure 6a . Total phosphorus in the E. Branch of the Elizabeth River at SBF (VIMS, 8/31/1976).

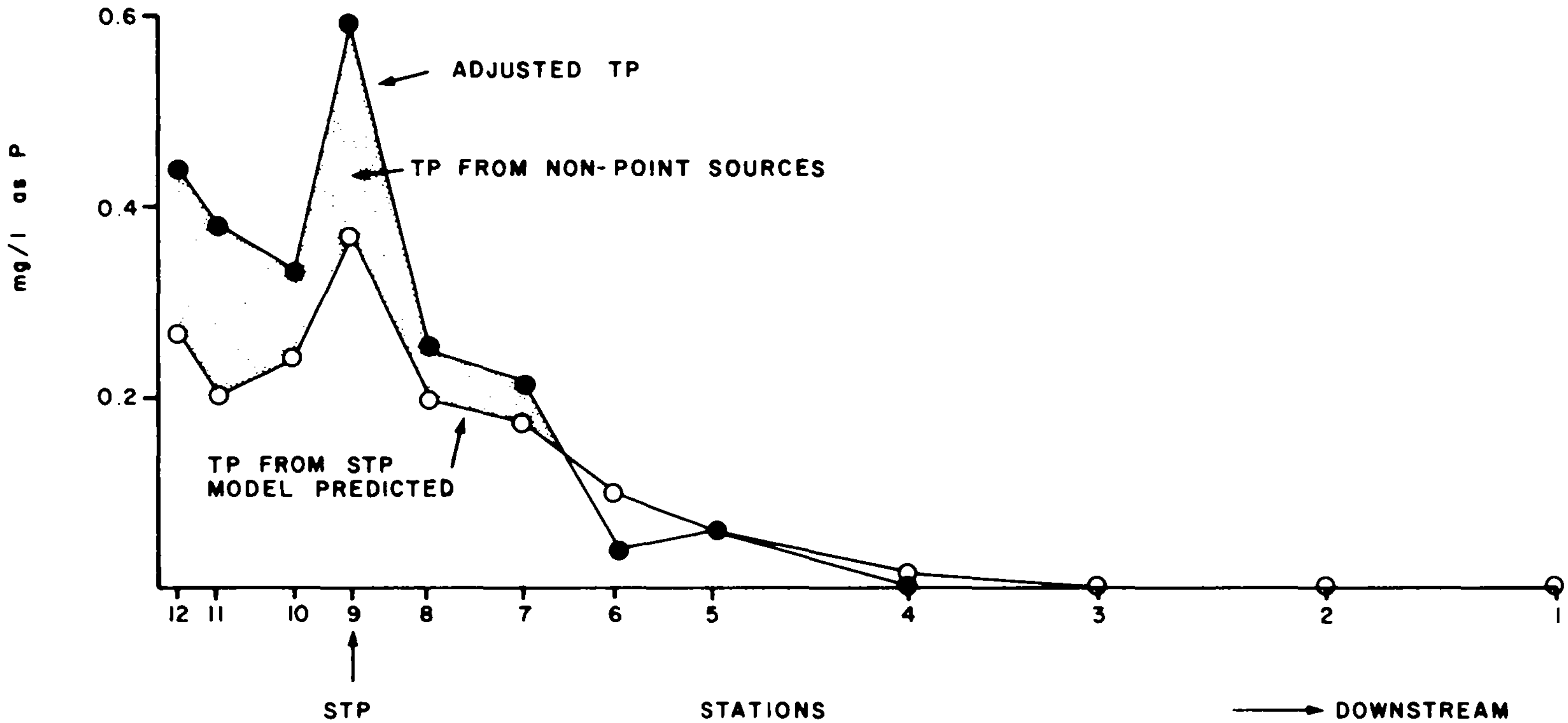

Figure 6b. Adjusted total phosphorus in the E. Branch of the Elizabeth River at SBF (VIMS, 8/31/1976).

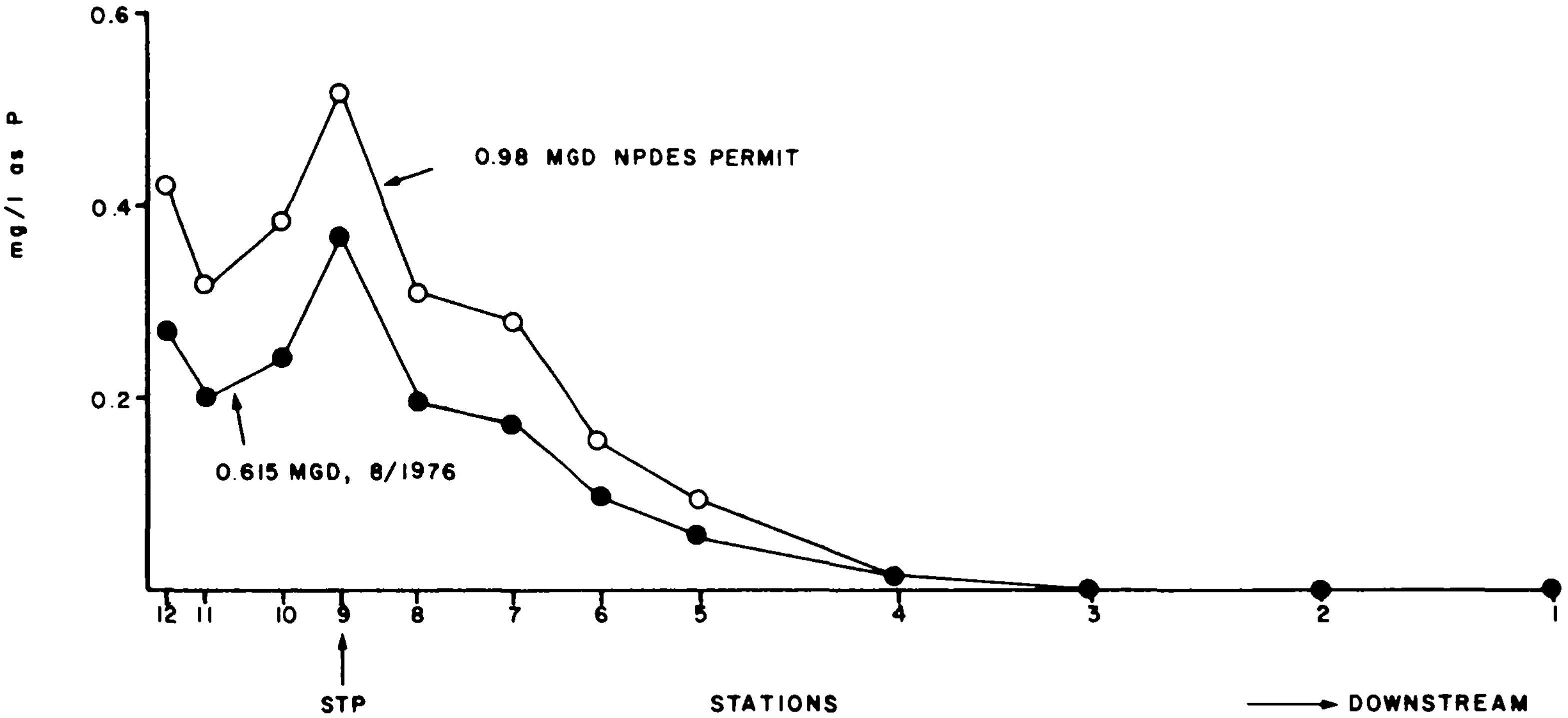

Figure 6c. Predicted total phosphorus in the E. Branch of the Elizabeth River at SBF at different STP's discharge rates.

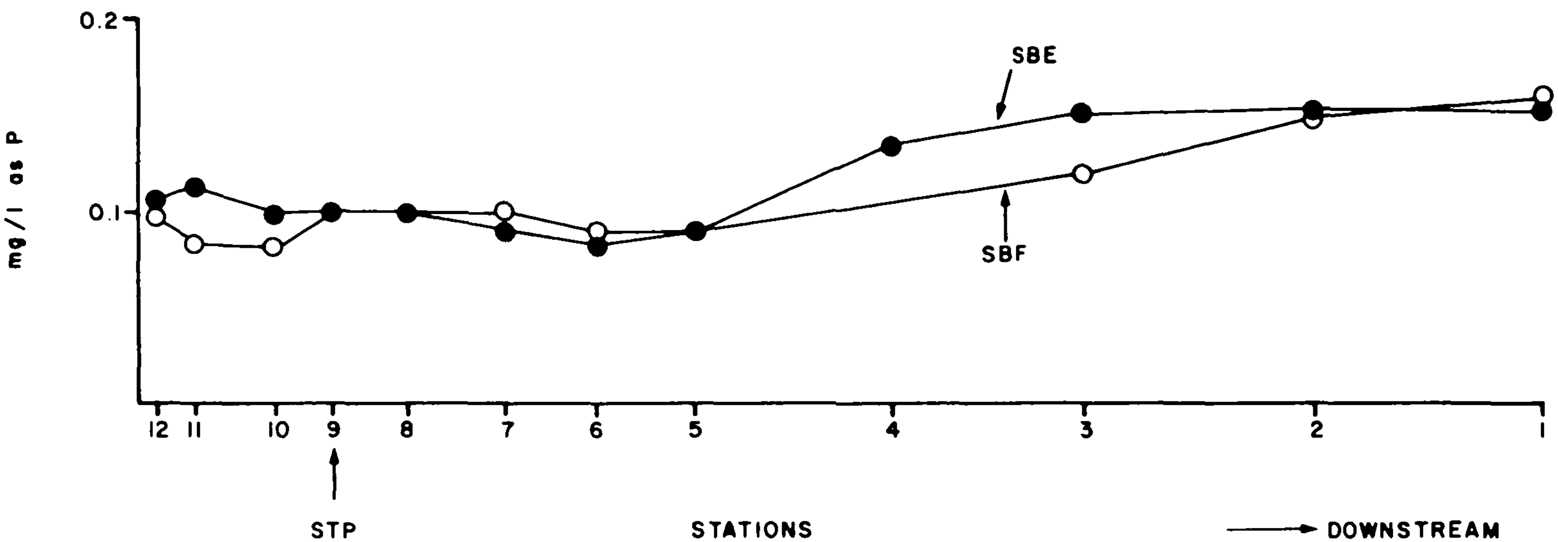

Figure 7. Dissolved ortho-phosphate in the E. Branch of Elizabeth River (VIMS, 8/31/1976).

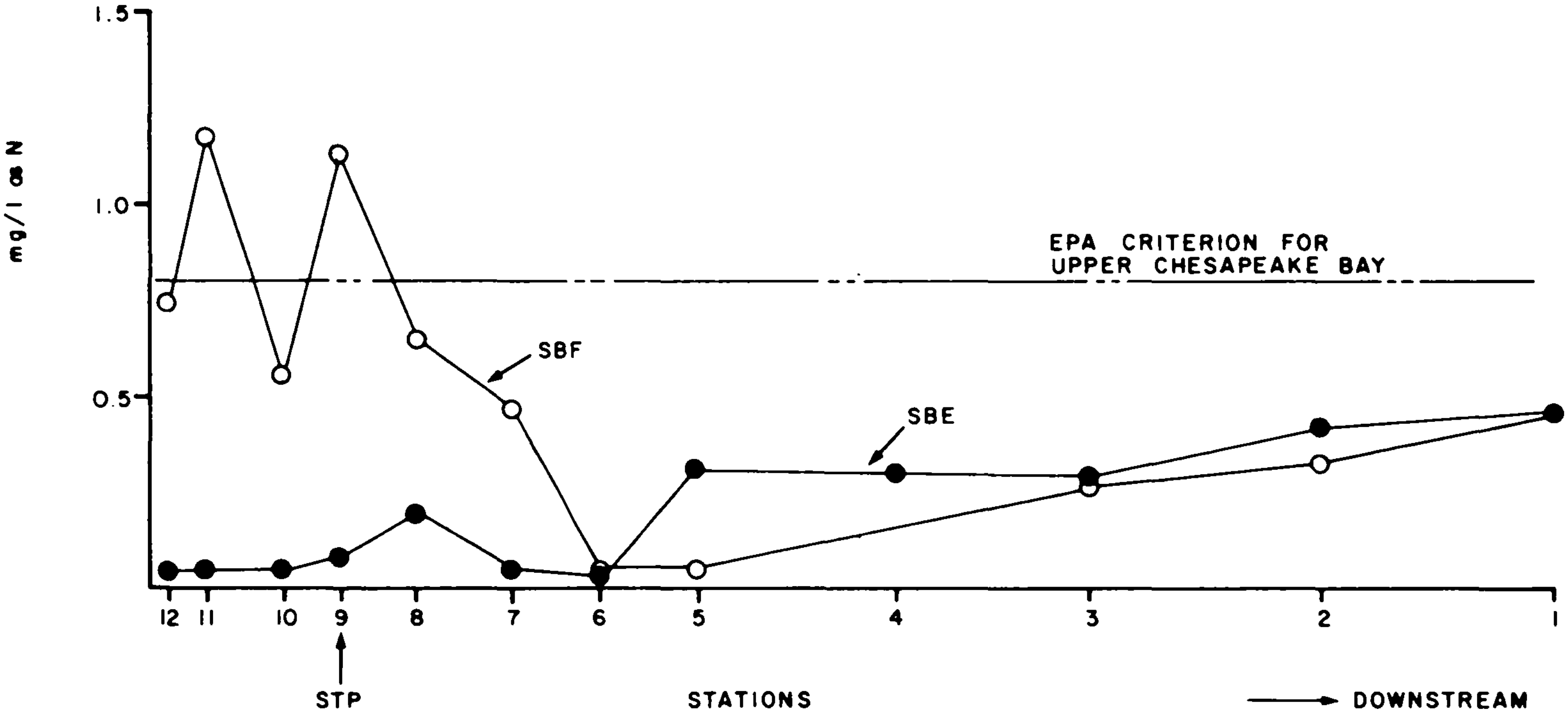

Figure 8a. Total inorganic nitrogen in the E. Branch of the Elizabeth River (VIMS, 8/31/1976).

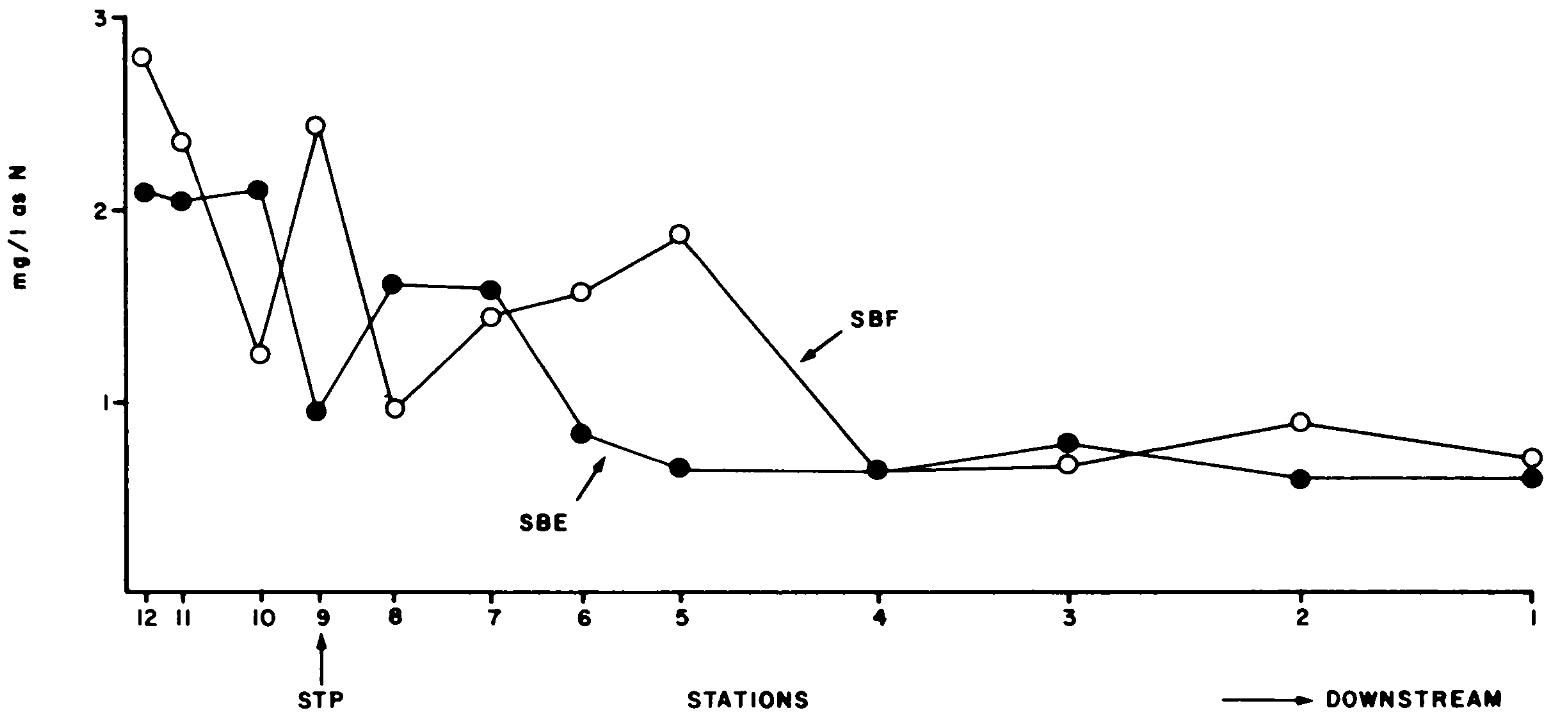

Figure 8b. Organic nitrogen in the E. Branch of the Elizabeth River (VIMS, 8/31/1976).

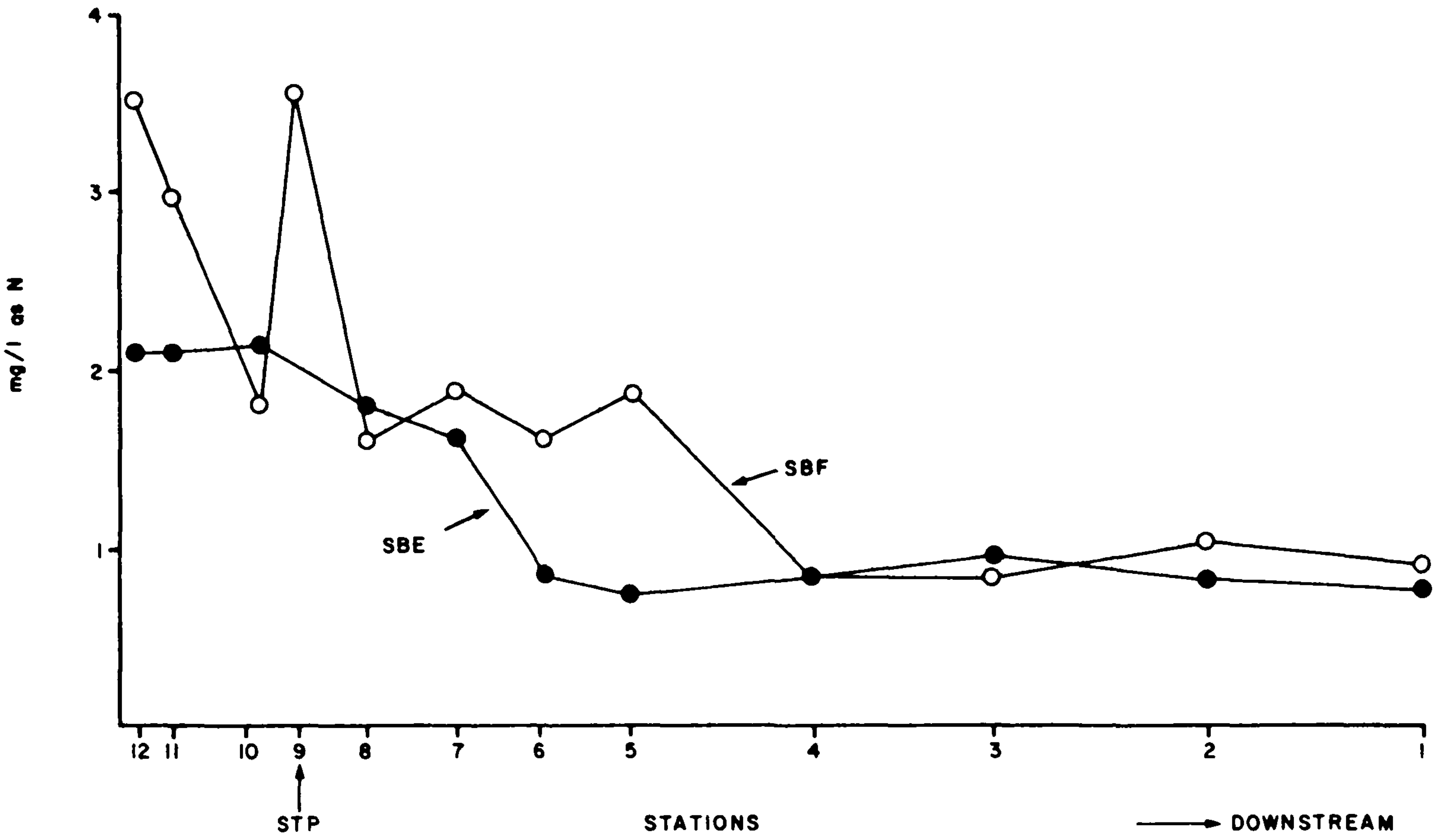

Figure 8c Total nitrogen in the E. Branch of the Elizabeth River (VIMS, 8/31/1976).

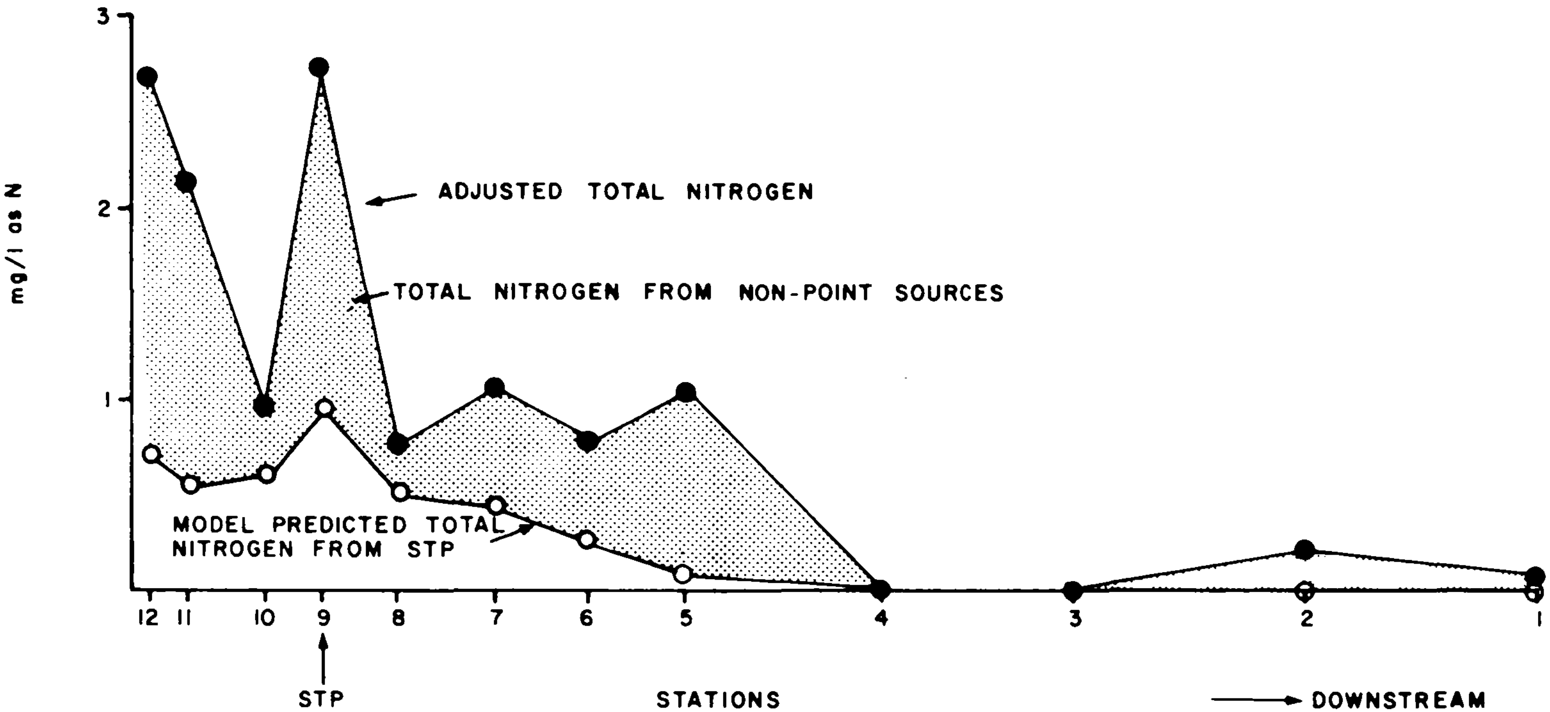

Figure 8d. Adjusted and predicted total nitrogen in the E. Branch of the Elizabeth River at SBF.

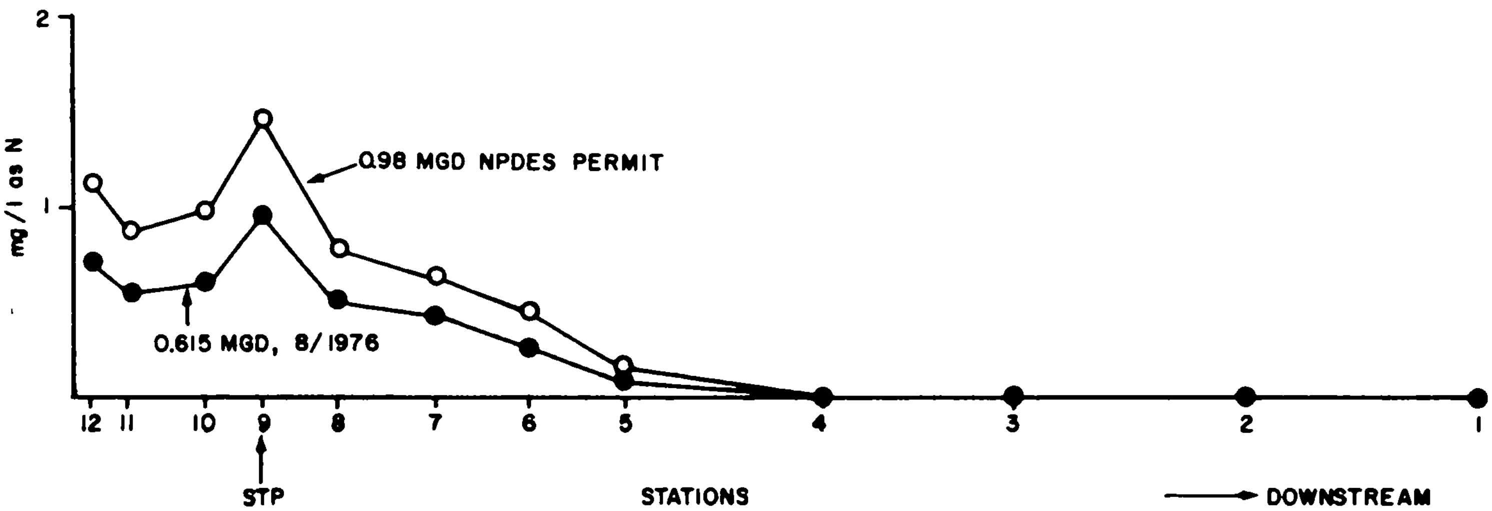

Figure 8e. Predicted total nitrogen in the E. Branch of the Elizabeth River at different STP's discharge rates.

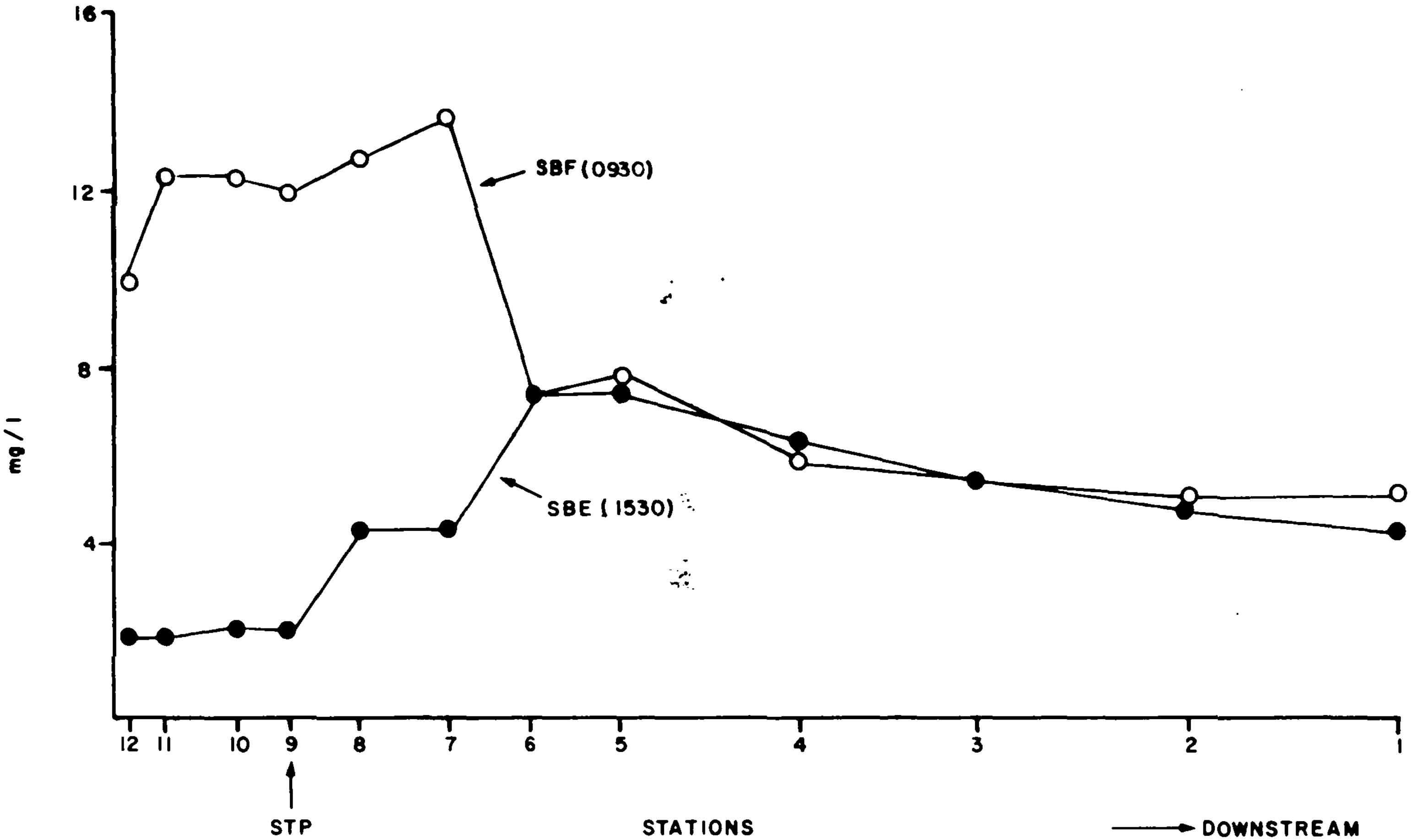

Figure 9a. Dissolved oxygen in the E. Branch of the Elizabeth River (VIMS, 8/31/1976).

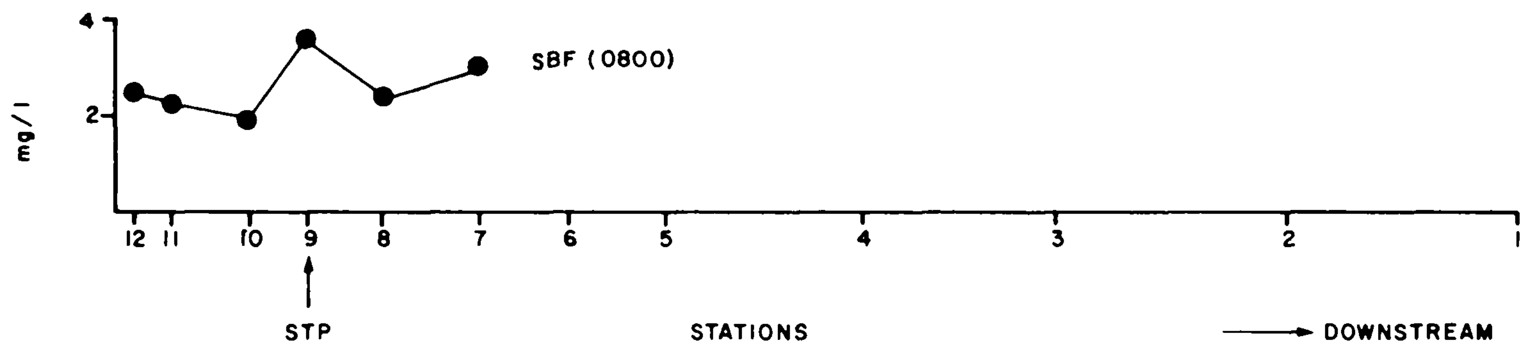

Figure 9b. Dissolved oxygen in the E. Branch of the Elizabeth River at SBF (0800) (VIMS, 9/23/1976).

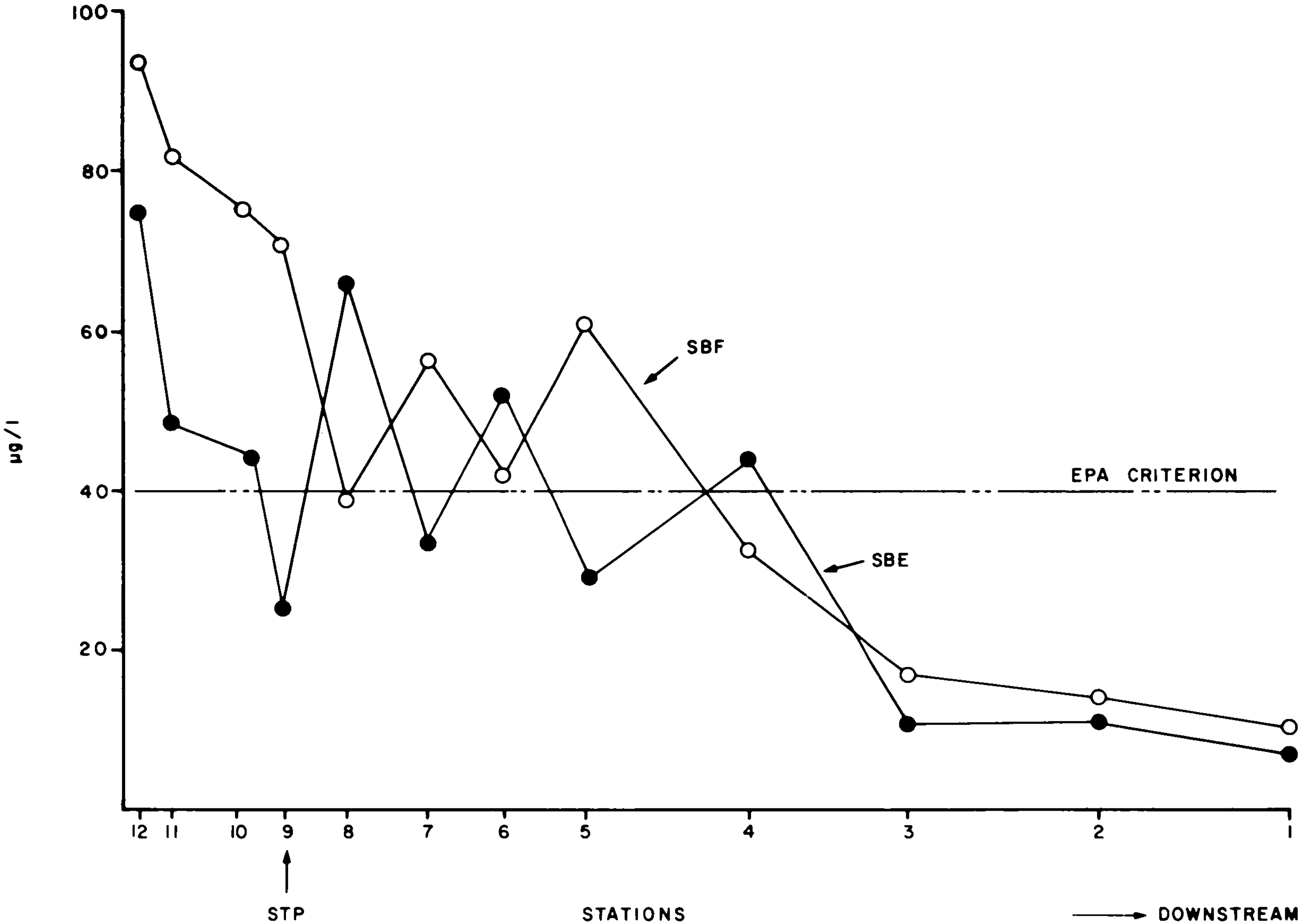

Figure 10a. Chlorophyll "a" in the E. Branch of the Elizabeth River (VIMS, 8/31/1976).

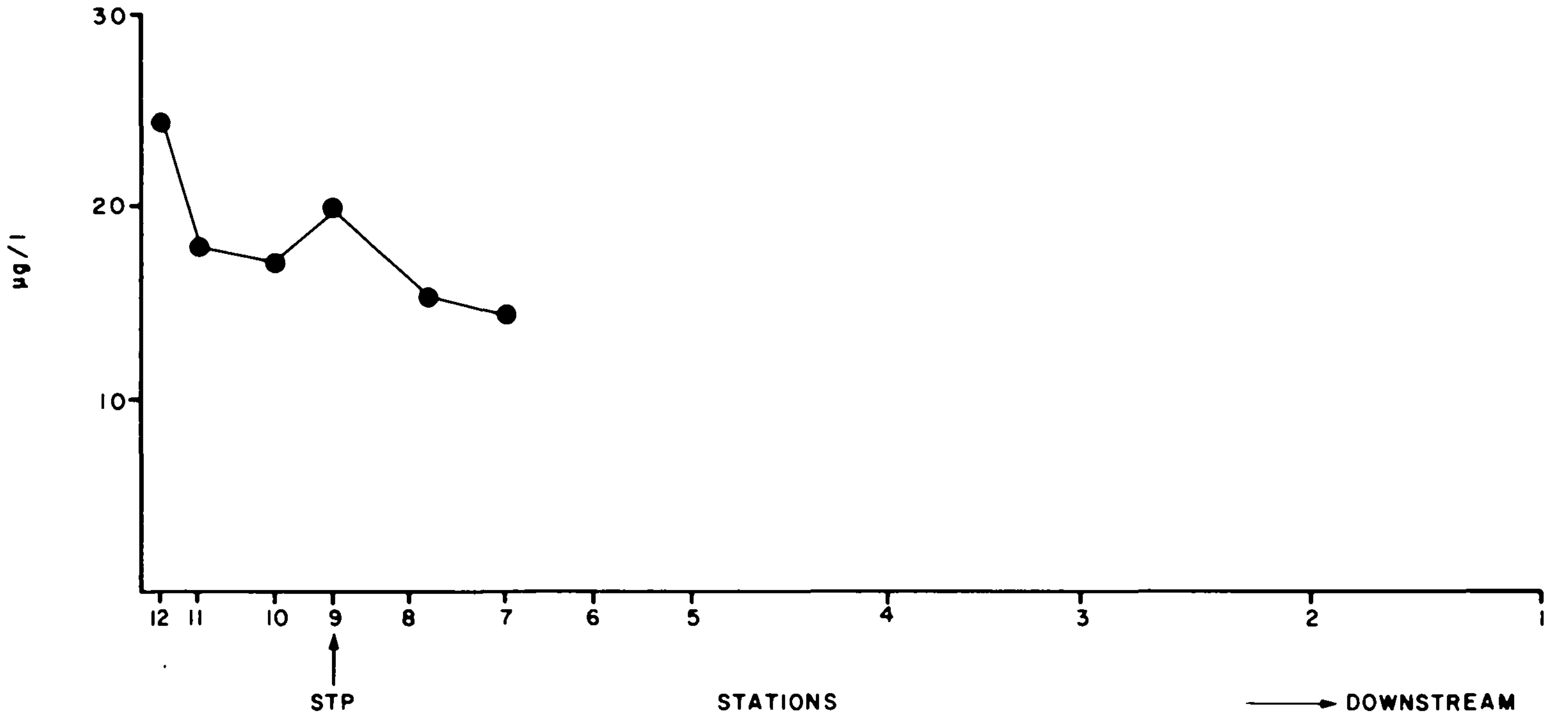

Figure 10b. Chlorophyll "a" in the E. Branch of Elizabeth River at SBF (0800)
(VIMS, 9/23/1976).

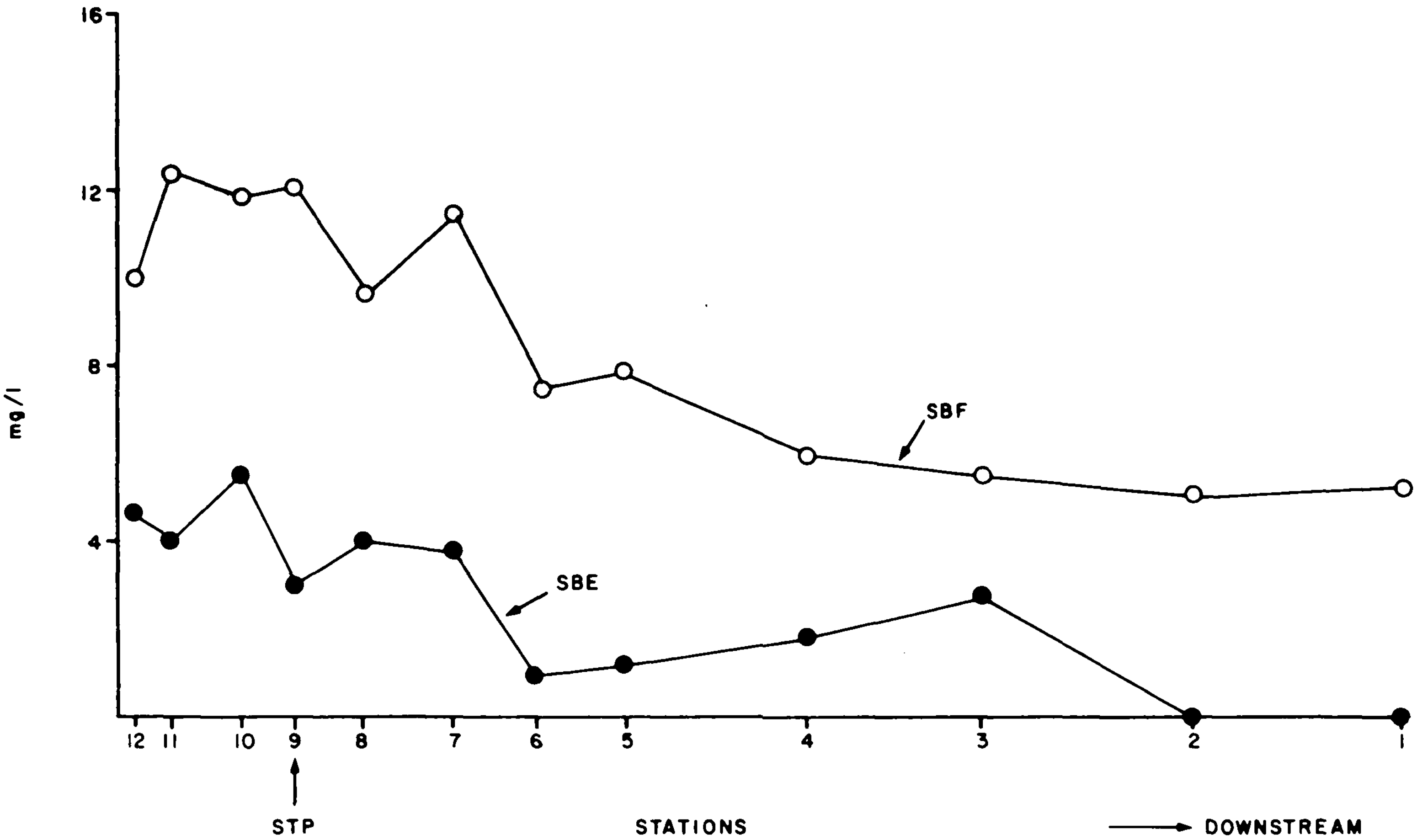

Figure 11. 5-day BOD in the E. Branch of the Lynnhaven Bay (VIMS, 8/31/1976).

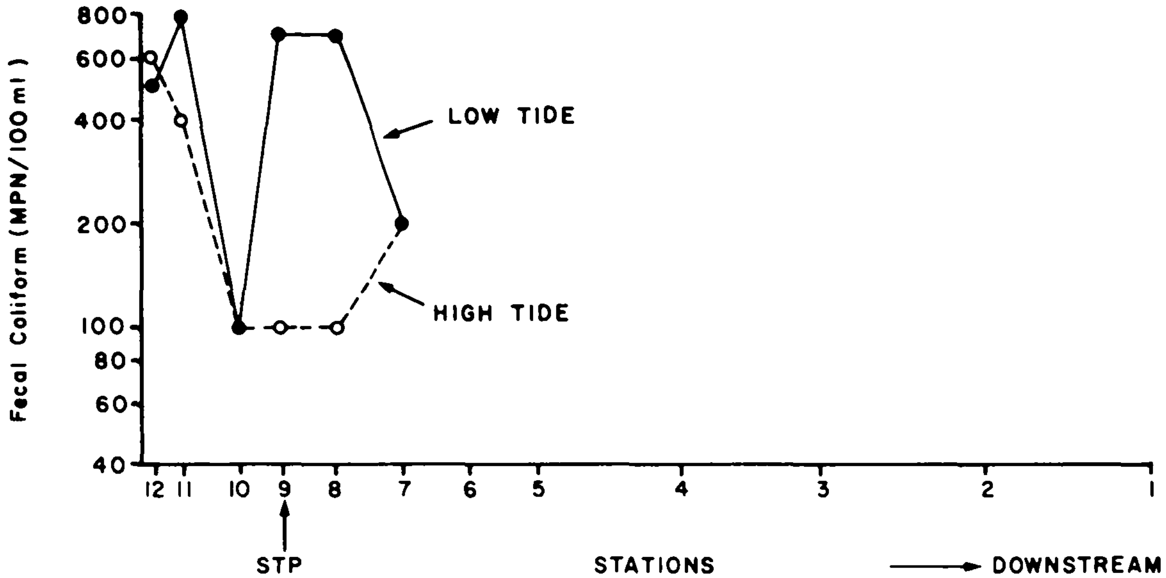

Figure 12a. Fecal coliform levels in the E. Branch of Elizabeth River (SWCB, 9/25/75).

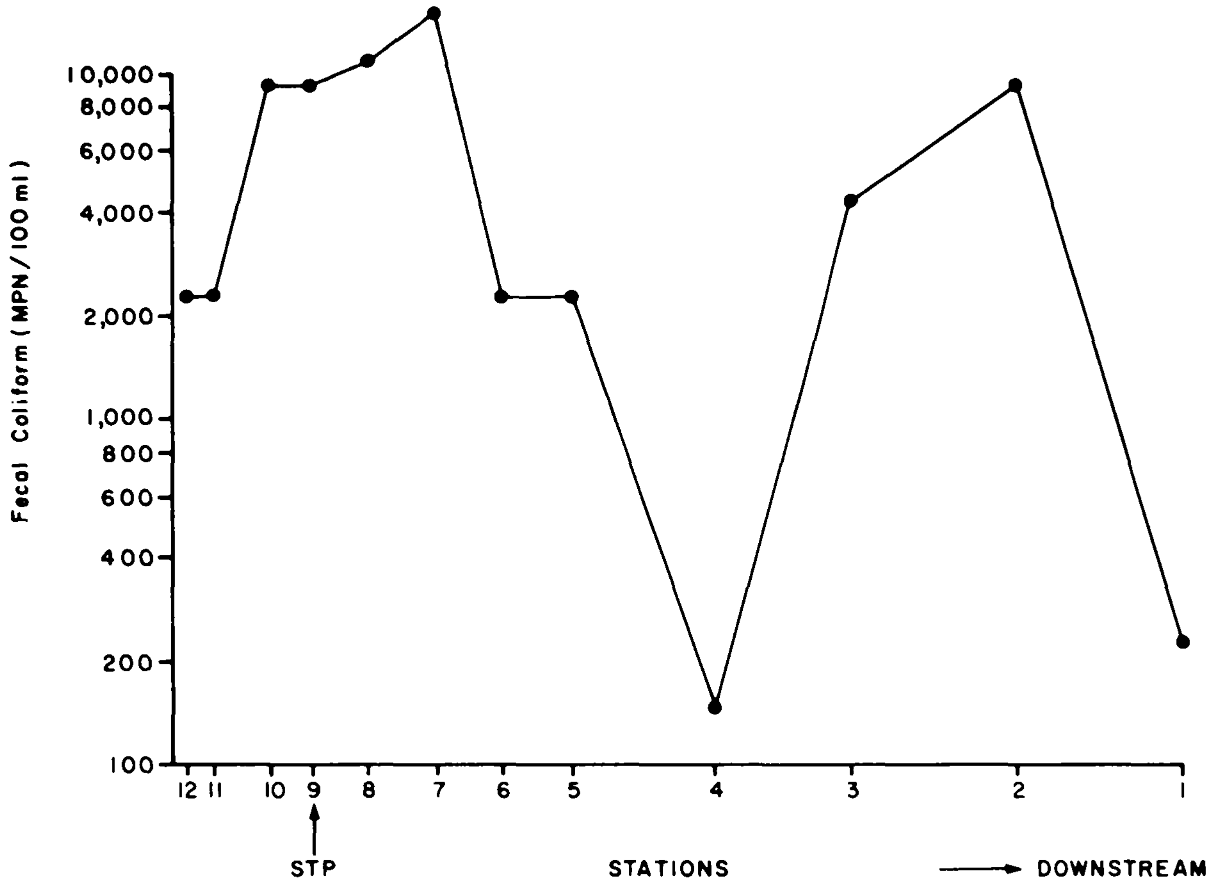

Figure 12b. Fecal coliform levels in the E. Branch of the Elizabeth River at SBF (VIMS, 8/31/1976).

APPENDIX A-1

TABULAR SUMMARY OF OBSERVED DYE DISTRIBUTIONS AT FOUR INTENSIVE STATIONS

August 30, 1976 - September 4, 1976

TIME VARIATION OF DYE CONCENTRATION AT INTENSIVE STATIONS NOs. 7, 8, 9, 12

	Sta. 7		Sta. 8		Sta. 9		Sta. 12	
Date	Time	Dye Conc. ppb	Time	Dye Conc. ppb	Time	Dye Conc. ppb	Time	Dye Conc. ppb
8/29/76	1631	0.25	1606	0.22	1629	0.07	1604	0.07
	1731	0.08	1706	0.15	1729	0.07	1704	0.06
	1831	0.10	1806	0.14	1829	0.08	1804	0.06
	1931	0.07	1906	0.27	1929	0.08	1904	0.06
	2031	0.08	2006	0.15	2029	0.09	2004	0.06
	2131	0.06	2106	0.16	2129	0.09	2104	0.06
	2231	0.10	2206	0.22	2229	3.8	2204	0.10
	2331	0.22	2306	0.45	2329	0.1	2304	1.40
8/30/76	0031	0.08	0006	0.25	0029	0.06	0004	27.5
	0131	0.15	0106	0.11	0129	0.05	0104	23.5
	0231	0.19	0206	0.55	0229	0.13	0204	17.0
	0331	0.06	0306	0.15	0329	7.0	0304	20.5
	0431	0.24	0406	21.0	0429	9.1	0404	19.5
	0531	17.8	0506	28.8	0529	16.8	0504	23.8
	0631	24.5	0606	40	0629	19	0604	18
	0731	33.8	0706	41.9	0729	21	0704	18.5
	0831	22.0	0806	42	0829	91	0804	20.2
	0931	11.2	0906	36	0929	70	0904	17.8
	1031	10.0	1006	31	1029	30.5	1004	16.8
	1131	3.5	1106	14.3	1129	17	1104	11.8
	1231	0.83	1206	7.2	1229	8.5	1204	36
	1331	0.32	1306	3.1	1329	3.7	1304	18.5
	1430	0.74	1406	2.4	1429	2.5	1404	10.8
	1530	2.2	1506	2.4	1532	5.5	1500	12
	1630	3.9	1610	11.5	1632	16	1600	16.5
	1730	7.2	1710	15.5	1732	30.3	1700	27.5
	1830	12.5	1810	25.5	1832	36	1800	40
	1930	23	1910	31	1932	35	1900	46
	2030	27	2010	34	2032	34	2000	36
	2130	25.5	2110	33.5	2132	32	2100	36
	2230	15.8	2210	32	2232	34	2200	42
	2330	9.6	2310	27.5	2332	31	2300	37
8/31/76	0030	5	0010	15.3	0032	21.5	0000	31
	0130	3.4	0110	8.6	0132	11.5	0100	31
	0230	3	0210	6.4	0232	7.7	0200	25.5
	0330	4.9	0310	5.9	0332	10.7	0300	21.5
	0430	5.7	0410	8.6	0432	18	0400	28
	0530	7.2	0510	13.0	0532	24.	0500	30
	0630	10.5	0610	19.5	0632	26.8	0600	29
	0730	16.5	0710	23.7	0732	26	0700	30
	0830	20	0810	24.8	0832	26.8	0800	30.5
	0930	21	0910	24.5	0932	27.5	0900	32
	1030	12.8	1010	23.5	1032	24.5	1000	32.5
	1130	7.5	1110	19.8	1132	23.2	1100	28.5
	1230	5.4	1210	11	1232	14.5	1200	24.9

TIME VARIATION OF DYE CONCENTRATION AT
INTENSIVE STATIONS NOs. 7, 8, 9, 12

	Sta. 7		Sta. 8		Sta. 9		Sta. 12	
Date	Time	Dye Conc. ppb	Time	Dye Conc. ppb	Time	Dye Conc. ppb	Time	Dye Conc. ppb
8/31/76	1315	3.3	1310	7.1	1332	8.1	1300	22
	1415	2.3	1410	4.6	1432	5.7	1400	15.5
	1515	2.1	1508	4.2	1545	5.6	1532	11.5
	1615	3.5	1608	5.3	1645	8.5	1632	11.8
	1715	4.4	1708	7.4	1745	12	1732	20.5
	1815	5.3	1808	9.1	1845	15.2	1832	22.9
	1915	7.2	1908	12.8	1945	17.8	1932	24.2
	2015	10.5	2008	16	2045	19.0	2032	24.5
	2115	12.5	2108	17.9	2145	20.8	2132	23
	2215	12.5	2208	18.2	2245	19.0	2232	23
	2315	10.9	2308	17.	2345	18	2332	23.5
9/1/76	0015	6.1	0008	14	0045	14.8	0032	21.5
	0115	4.4	0108	8.9	0145	9.0	0132	18
	0215	3.5	0208	5.6	0245	6.1	0232	14.5
	0315	3.3	0308	4.8	0345	5.8	0332	12.5
	0415	4.2	0408	5.5	0445	8.2	0432	15.5
	0515	4.8	0508	6.4	0545	11.2	0532	17
	0615	5.5	0608	8.6	0645	13.5	0632	18.5
	0715	6.5	0708	11.5	0745	15.0	0732	19.5
	0815	9.4	0808	13.9	0845	15.9	0832	19.5
	0915	11.5	0908	15	0945	17.0	0932	19
	1015	12.4	1008	15.5	1045	16.5	1032	18.9
	1115	8.7	1108	14.2	1145	14.8	1132	18
	1215	6.0	1208	12.5	1245	12.5	1232	18
	1315	4.9	1308	7.8	1345	8.0	1332	15.5
	1415	3.7	1408	5.9	1420	5.9	1408	13.2
	1507	2.7	1553	3.7	1534	4.3	1518	8.0
	1607	2.6	1653	3.85	1634	4.4	1618	7.0
	1707	3.1	1753	4.3	1734	5.5	1718	9.0
	1807	3.7	1853	4.6	1834	6.5	1818	10.7
	1907	4.1	1953	5.3	1934	8.4	1918	12.0
	2007	4.9	2053	5.8	2034	10.0	2018	13.8
	2107	6.2	2153	6.5	2134	11.0	2118	14.0
	2207	8.0	2253	5.9	2234	12.0	2218	13.0
	2307	8.5	2353	4.8	2334	11.0	2318	13.0
9/2/76	0007	7.9	0053	4.9	0034	11.0	0018	13.2
	0107	5.5	0153	4.2	0134	10.3	0118	13.1
	0207	4.1	0253	3.8	0234	8.2	0218	11.5
	0307	3.5	0353	3.7	0334	5.4	0318	10.5
	0407	3.3	0453	3.7	0434	4.8	0418	9.1
	0507	3.4	0553	3.7	0534	5.1	0518	9.2
	0607	3.9	0653	3.9	0634	6.9	0618	10.1
	0707	4.6	0753	4.2	0734	7.8	0718	10.5
	0807	4.8	0853	4.5	0834	8.1	0818	11.0
	0907	5.8	0953	4.6	0934	9.2	0918	10.9

TIME VARIATION OF DYE CONCENTRATION AT INTENSIVE STATIONS NOs. 7, 8, 9, 12

Date	Sta. 7 Time	Sta. 7 Dye Conc. ppb	Sta. 8 Time	Sta. 8 Dye Conc. ppb	Sta. 9 Time	Sta. 9 Dye Conc. ppb	Sta. 12 Time	Sta. 12 Dye Conc. ppb
9/2/76	1007	6.9	1053	5.6	1034	10.0	1018	10.9
	1107	6.5	1153	5.8	1134	8.5	1118	10.9
	1207	4.8	1253	5.7	1234	8.3	1218	10.0
	1307	4.2	1353	5.0	1334	7.5	1318	10.4
	1407	3.7	1453	----	1434	6.2	1418	8.8
	1507	2.9	1525	3.7	1555	3.9	1540	6.6
			1625	3.2	1655	3.6	1640	5.6
			1725	3.0	1755	3.7	1740	5.6
			1825	3.2	1855	4.4	1840	6.4
			1925	3.7	1955	4.8	1940	7.2
			2025	4.1	2055	5.9	2040	7.9
			2125	4.7	2155	6.5	2140	8.3
			2225	5.2	2255	7.3	2240	8.2
			2325	6.2	2355	7.5	2340	7.9
9/3/76			0025	6.2	0055	6.9	0040	8.0
			0125	5.9	0155	6.6	0140	7.7
			0225	5.3	0255	5.6	0240	7.3
			0325	3.7	0355	4.0	0340	6.3
			0425	3.1	0455	3.3	0440	5.5
			0525	3.0	0555	3.3	0540	4.9
			0625	3.0	0655	3.4	0640	5.3
			0725	3.0	0755	3.8	0740	5.4
			0825	3.3	0855	4.4	0840	6.1
			0925	3.9	0955	5.2	0940	6.6
			1025	4.3	1055	5.5	1040	6.5
			1125	4.8	1155	6.0	1140	6.2
			1255	5.5	1255	5.7	1240	6.2
			1355	4.3	1332	5.3	1300	7.0
			1455	3.8	1432	4.7	1400	6.8
			1555	3.2	1532	3.7	1500	6.0
			1655	2.8	1632	3.1	1600	4.8
			1755	2.45	1732	2.75	1700	4.8
			1855	2.10	1832	2.45	1800	3.9
			1955	2.6	1932	2.65	1900	4.3
			2055	2.95	2032	3.0	2000	4.2
			2155	3.4	2132	3.6	2100	4.7
			2255	4.0	2232	4.2	2200	5.6
			2355	4.5	2332	4.8	2300	6.0
9/4/76			0055	4.8	0032	4.8	0000	5.9
			0155	4.6	0132	4.8	0100	5.8
			0255	3.7	0232	4.5	0200	5.7
			0355	2.8	0332	4.0	0300	5.6
			0455	2.6	0432	3.2	0400	4.9
			0555	2.3	0532	2.8	0500	4.9
			0655	2.6	0632	2.75	0600	4.5

TIME VARIATION OF DYE CONCENTRATION AT
INTENSIVE STATIONS NOs. 7, 8, 9, 12

	Sta. 8		Sta. 9		Sta. 12	
Date	Time	Dye Conc. ppb	Time	Dye Conc. ppb	Time	Dye Conc. ppb
9/4/76	0755	2.6	0732	2.65	0700	4.0
	0855	2.9	0832	2.45	0800	4.3
	0955	3.0	0932	3.0	0900	4.5
	1055	3.7	1032	3.8	1000	5.0
	1155	3.8	1132	4.6	1100	5.2
	1255	4.0	1232	4.9	1200	4.4
	1355	4.1	1332	4.4	1300	4.9
	1455	3.9	1432	4.4	1400	4.9

APPENDIX A-2

GRAPHICAL SUMMARY OF OBSERVED SLACK WATER DYE DISTRIBUTIONS

August 30, 1976 - September 4, 1976

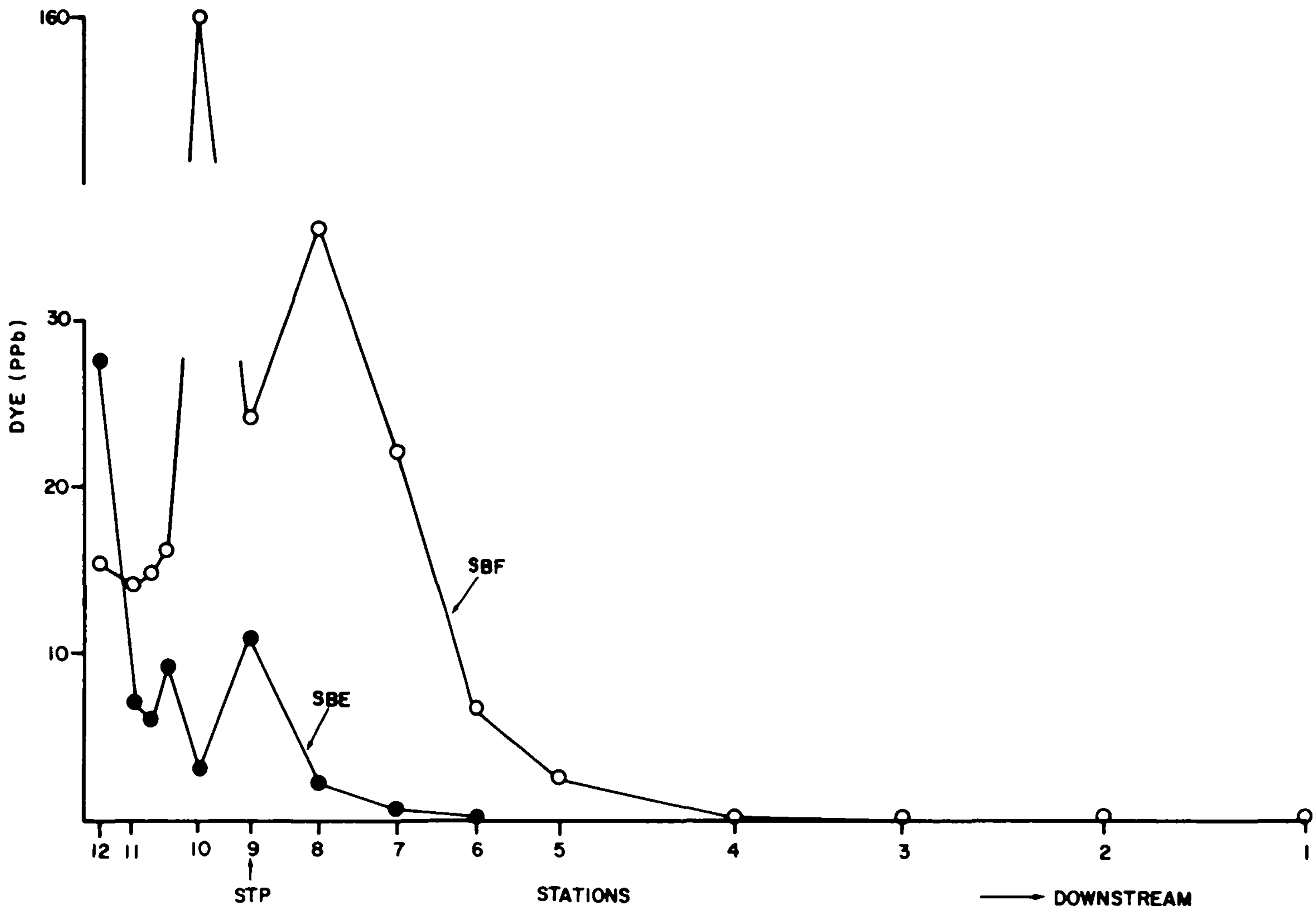

Figure A-1. The concentration profiles of dye at 1st SBF and 2nd SBE after dye release (VIMS, 8/30/76).

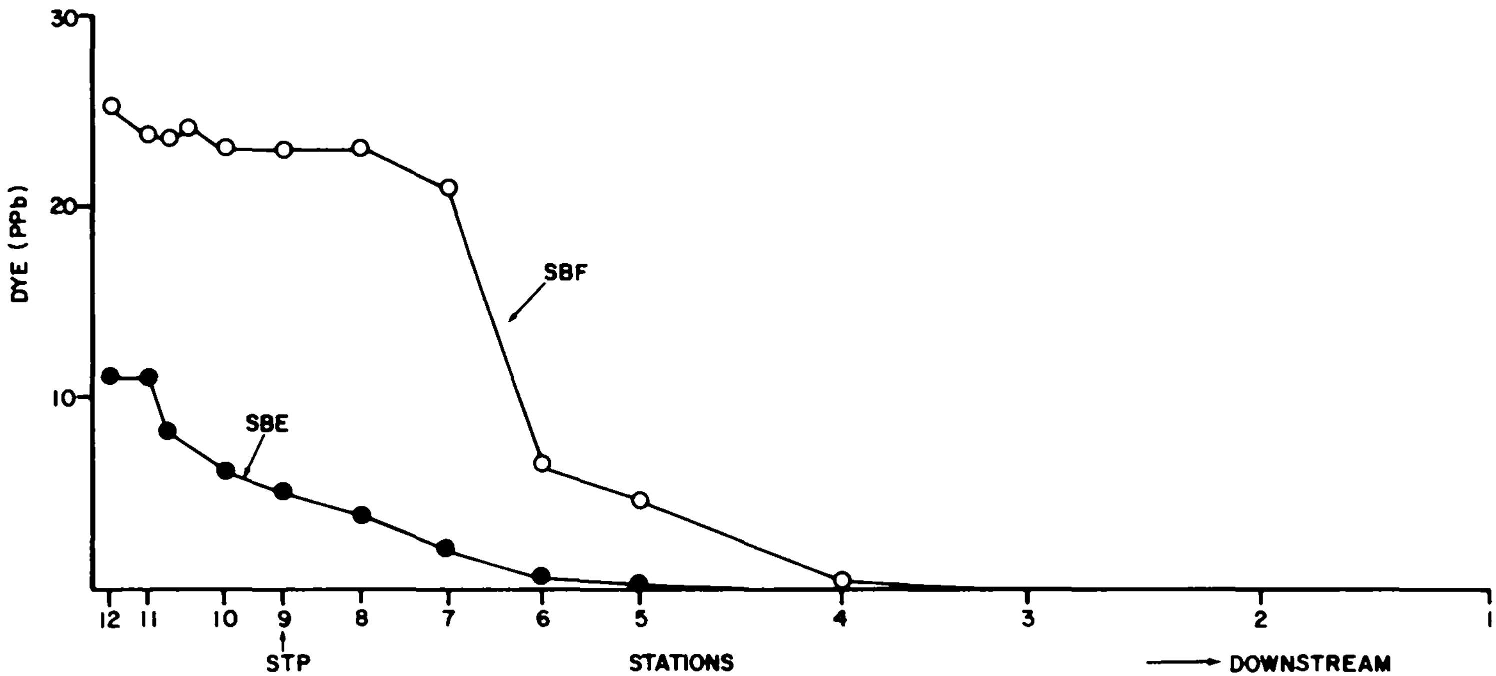

Figure A-2. The concentration profiles of dye at 3rd SBF and 4th SBE after dye release (VIMS, 8/31/76).

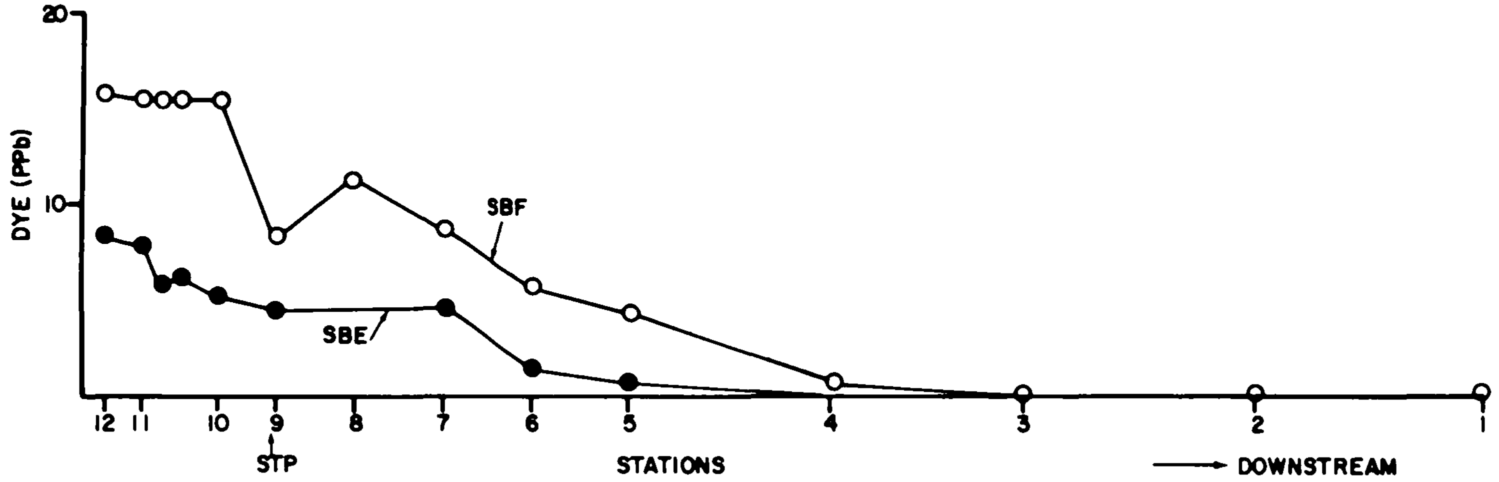

Figure A-3. The concentration profiles of dye at 5th SBF and 6th SBE after dye release (VIMS, 9/1/76).

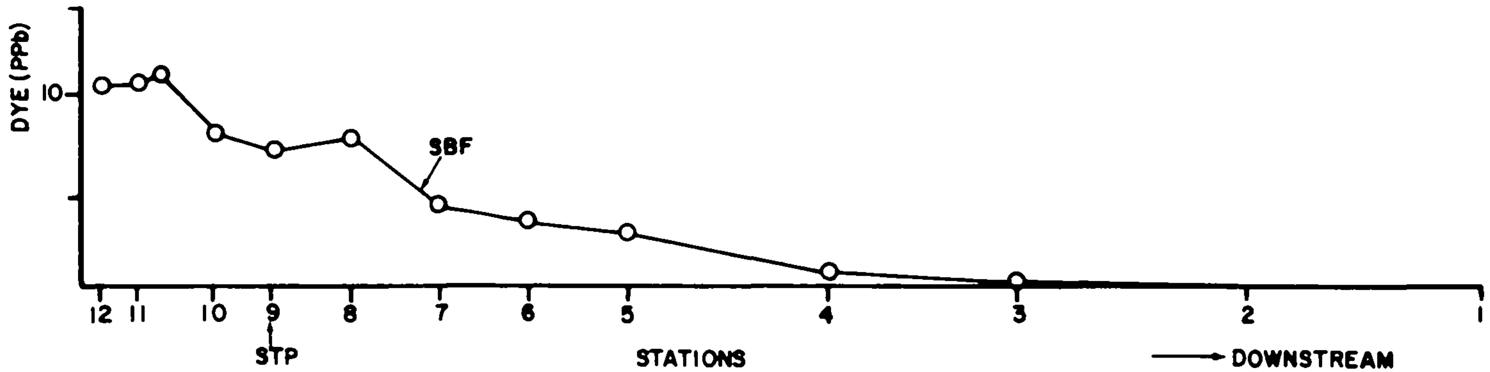

Figure A-4. The concentration profile of dye at 7th SBF after dye release (VIMS, 9/2/76).

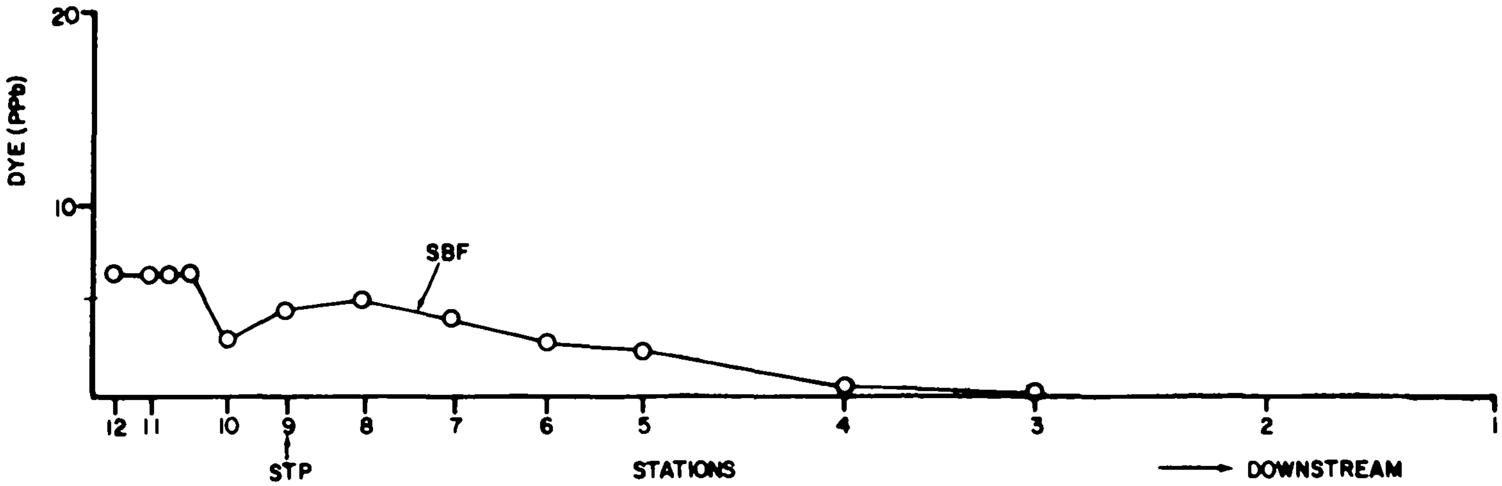

Figure A-5. Concentration profile of dye at 9th SBF after dye release (VIMS, 9/3/76).

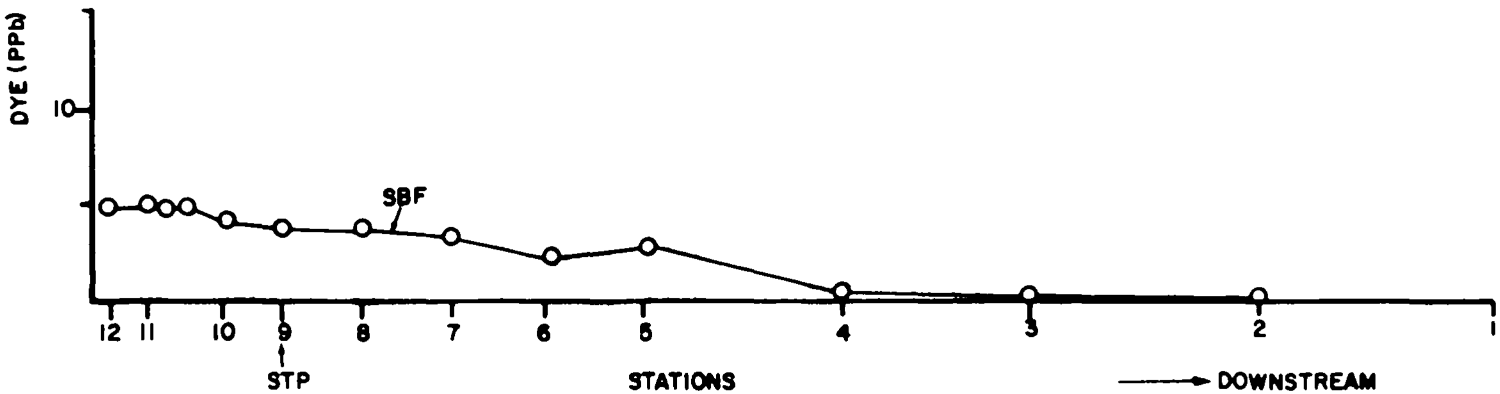

Figure A-6. Concentration profile of dye at 11th SBF after dye release (VIMS, 9/4/76).