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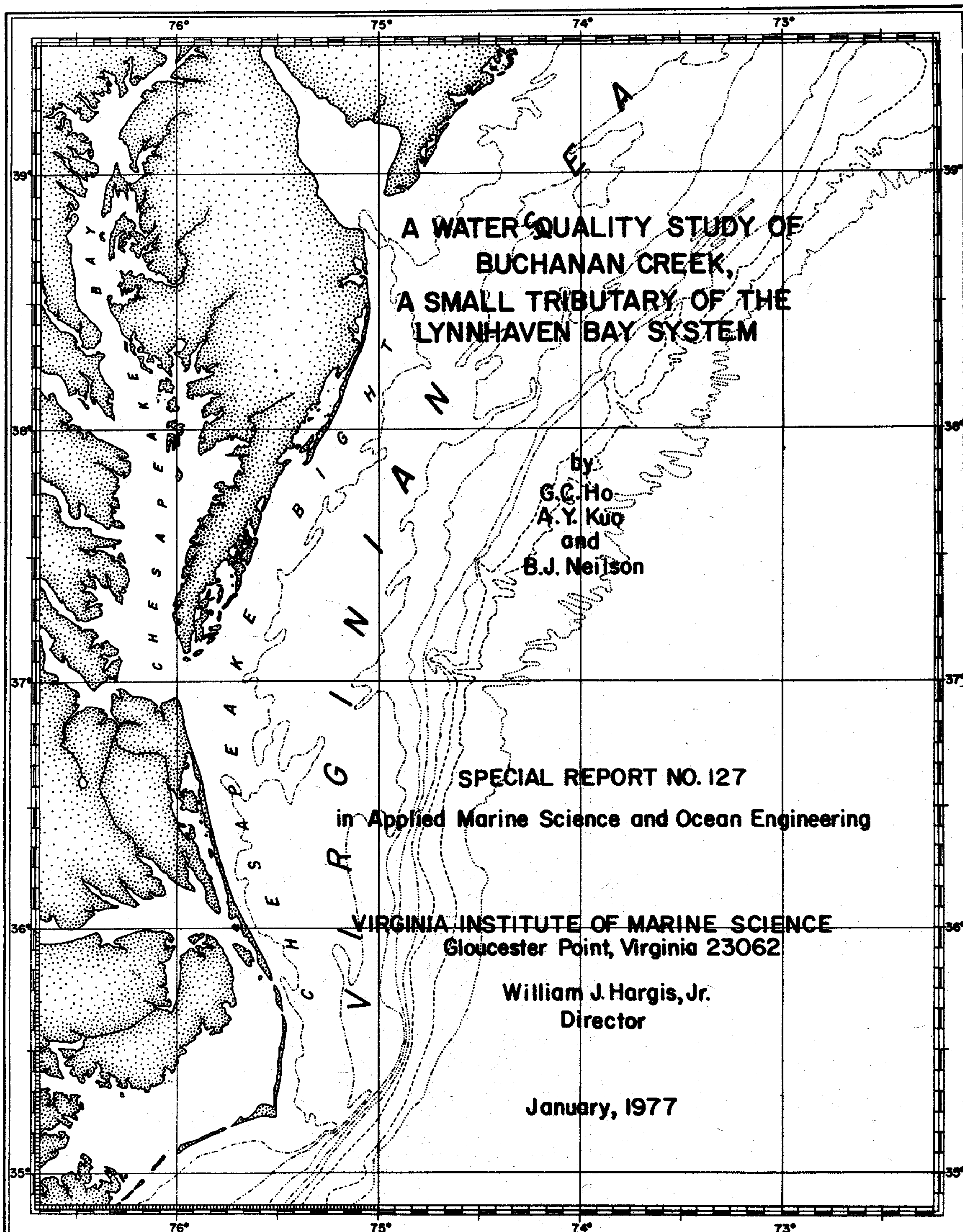

A WATER QUALITY STUDY OF BUCHANAN CREEK, A SMALL TRIBUTARY OF THE LYNNHAVEN BAY SYSTEM

by
G.C. Ho
A.Y. Kuo
and
B.J. Neilson

SPECIAL REPORT NO. 127
in Applied Marine Science and Ocean Engineering

VIRGINIA INSTITUTE OF MARINE SCIENCE
Gloucester Point, Virginia 23062

William J. Hargis, Jr.
Director

January, 1977

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G. C. Ho
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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
Raymond Bowles

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (con't)

LIST OF TABLE

ACKNOWLEDGEMENTS

The comments and criticisms of Messrs. Dale Jones, Raymond Bowles, and Robert Jackson, Jr. of the Virginia State Water Control Board are appreciated.

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ABSTRACT

This is a problem-oriented special study of the water quality in Buchanan Creek and the Western Branch of Lynnhaven Bay, which 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 these water bodies were conducted in August, 1976. The results of dye study provide input to a "near field" model to calculate the pollutant distributions resulting from the Birchwood Gardens Sewage Treatment Plant discharge. The necessary phosphorus and nitrogen removals for the effluent were calculated based on the assumption that the EPA suggested criteria for the Upper Chesapeake Bay were applicable.

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) conductinq special studies when water resources problems related to tidal waters 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 Buchanan Creek and the Western Branch of the Lynnhaven Bay. The major point source of pollutants to this part of Lynnhaven Bay is the Birchwood Gardens Sewage Treatment Plant.

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

4. A field study, including a dye release experiment and surveys of water quality in the river, was conducted in August, 1976.

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 discharge from the Birchwood Gardens Sewage

Treatment Plant. The model results were compared with field survey data to assess the relative contribution of pollutants from point and non-point sources.

6. Concentrations of total phosphorus in Buchanan Creek as high as 0.54 mg/l as P were found at 750 meters downstream from Birchwood Gardens Sewage Treatment Plant during the field survey. The model predicted concentrations of total phosphorus in this tributary estuary due to the STP discharge alone can be as high as 0.34 mg/l as P and 0.68 mg/l as P at 0.4 MGD (August, 1976) and 0.8 MGD (1976 NPDES permit) respectively.

7. Concentrations of total nitrogen in Buchanan Creek were found to be as high as 1.8 mg/l as N 450 meters downstream from Birchwood Gardens Sewage Treatment Plant at the time of the field survey. The model predicted concentration of total nitrogen in this tributary estuary due to the STP discharge alone can be as high as 0.9 mg/l as N and 1.8 mg/l as N at 0.4 MGD (August, 1976) and 0.8 MGD (1976 NPDES permit) respectively.

8. The study reveals that Buchanan Creek may have an algal bloom problem, which, at times, may cause dissolved oxygen concentrations below 5 mg/l. DO concentrations around 4 mg/l have been observed.

9. Usually an algal bloom is due to 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 the 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 assuming no other pollutant sources, the Birchwood Gardens Sewage Treatment Plant should not discharge more than 1.9 kg (4.2 lb) of total phosphorus (as P) and 37.5 kg (82.7 lb) of total nitrogen (as N) per day. This is equivalent to 88% phosphorus removal at 0.4 MGD (August, 1976) and 94% phosphorus removal at 0.8 MGD (1976 NPDES permit). If only the inorganic nitrogen content of the effluent is considered, no additional treatment is required at 0.4 MGD, but 44% removal is needed at 0.8 MGD. If total nitrogen is used, then 11% and 56% nitrogen removal are required at 0.4 MGD and 0.8 MGD respectively.

11. The field surveys and modeling studies indicate that the non-point sources of pollutants are large, and both point and non-point source loads should be reduced. More information regarding the origin and quantity of these loadings is needed. Control of non-point source loadings also may be required to prevent the continuation of water quality problems in Buchanan Creek.

II. INTRODUCTION

On September 18, 1975, the Tidewater Regional Office (TRO) of the State Water Control Board (SWCB) conducted a water quality survey of Buchanan Creek. 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 States 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 greatly exceeded in the upper 10% of this tributary estuary at high tide and exceeded in the lower part at low tide.

(2) the phosphorus criterion is greatly exceeded in the upper half of this tributary estuary at high tide, while the concentrations in the lower half are very close to the critical levels. At low tide the criterion is greatly exceeded throughout the creek.

(3) BOD concentrations of 6 to 8 mg/l were observed.

In order to estimate whether a significant portion of the nutrient loads in this estuary is the result of the Birchwood Gardens 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, many aspects of the system were unknown, for example the flushing rate, and the results were inconclusive.

In order to ascertain the mixing and flushing rates for this estuary, a dye study was conducted in August, 1976. 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 could be attributed to the Birchwood Gardens Sewage Treatment Plant discharge.

TABLE 1. CHARACTERISTICS OF BIRCHWOOD GARDENS SEWAGE TREATMENT PLANT'S EFFLUENT (SWCB)

Parameters	Units	Proposed Permit Limitations		Survey Results							
Date		7/1977	Future	1/23/74	2/10/75	4/3/75	9/18/75	10/28/75	1/26/76	4/19/76	6/8/76
Flow	MGD	0.8									
BOD_5	mg/l	30	30	10	23	66	26	16	11	27	44
T.S.S.	mg/l	30	30	26	12	58	11	2	10	64	50
Total-P	mg/l as P	1.0	1.0	13	16		14.1	11.5	10.7	10.6	10.6
Ortho-P	mg/l as P			12	7.5		11.6	8.5	8.0	10.3	8.0
Total-N	mg/l as N		0.5	22.17	21.44		28.26	30.37	29.12	28.73	21.45
TKN-N	mg/l as N			22	21		27.2	30	29.8	28.6	21.0
NH_3-N	mg/l as N	2.0		22	16.6		21.3	22.5	24.0	20.5	17.0
NO_2-N	mg/l as N			0.03	0.01		0.24	0.13	0.05	0.06	0.25
NO_3-N	mg/l as N			0.14	0.43		0.82	0.24	0.07	0.07	0.20

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-ebb to slack-before-ebb, the equilibrium concentration field at slack-before-flood and slack-before-ebb for a nonconservative substance released continuously may be expressed as

$$CL_\infty(x,y) = CL_1(x,y)\ \exp\left(-\frac{1}{4}kT\right) + \sum_{n=2}^{\infty} CL_n(x,y)\ \exp\{-(n-1)kT\} \qquad (1)$$

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

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-flood to slack-before-flood, 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 22 through August 27, 1976. The dye was released for one tidal cycle from slack-before-ebb to slack-before-ebb. 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. A barrel (250 lbs.) 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 Birchwood Gardens Sewage Treatment Plant discharge ditch.

At 2015 hours, August 22, 1976, the dye release was begun on ebbing tide. The dye flow was stopped at 0845 hours August 23, 1976, at slack-before-flood after an entire tidal cycle and after releasing a total of 250 gallons of diluted dye solution into Buchanan Creek.

A preliminary run was made before dye release on August 22, 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 1, 3, 4, and 6) to provide detailed information on the movement of the dye. Dye samples were collected at slack water stations (Figure 5b, stations STP., 1-a, 3, 5, 7, and 9) at slack water periods to provide additional information for the mathematical model. Water quality samples were also 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 a small Jon boat. 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 (Figures 5a and 5b) 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 non-point sources along the Western Lynnhaven River. If there were no other pollutant or sources along Buchanan Creek, 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 the observed field values. Figure 6b shows the adjusted total phosphorus profile and model predicted total phosphorus profile. It clearly shows that Birchwood Gardens Sewage Treatment Plant does not contribute all of the adjusted total phosphorus in Buchanan Creek, but it does contribute a significant portion of the total phosphorus. Total phosphorus attributable to this sewage treatment plant ranges as high as 0.34 mg/l as P at 750 meters downstream from Birchwood Gardens Sewage Treatment Plant.

In Figure 6b, the area between the adjusted and model predicted total phosphorus curves is the total phosphorus contributed from non-point sources. 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. Another possibility is that the water table is very close to the surface which could result in malfunctioning septic tanks and drain fields. Also, 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 Birchwood Gardens Sewage Treatment Plant allows 0.8 MGD (Million Gallons per Day) of flow. The present flow is 0.4 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 0.68 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 1.9 kg (4.2 lb) of total phosphorus (as P) per day. This means that the plant must be upgraded to provide around 88% and 94% phosphorus removal at 0.4 MGD (August, 1976) and 0.8 MGD (1976 NPDES permit) respectively.

The levels of dissolved ortho-phosphate (passing through 0.45 μm filter paper) of this estuary, shown in Figure 7, are much higher in the upstream reaches than at the mouth of the river. The data show that the dissolved ortho-phosphate 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 and inorganic nitrogen levels of this estuary (Figure 1) were both as high as 2.7 mg/l as N. In August, 1976, the inorganic nitrogen concentrations (Figure 8a) were less than 0.1 mg/l as N for most of the stations while organic nitrogen concentrations (Figure 8b) ranged up to 1.7 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, Buchanan Creek was highly enriched with nitrogen, enough to cause an algal bloom in September, 1975. The chlorophyll "a" data for August, 1976, (Figure 10a) indicated an algal bloom occurred.

The total nitrogen levels during this study are shown in Figure 8c. A significant part of the total nitrogen is contributed from the Western Branch of Lynnhaven Bay. A baseline adjustment (similar to that for total phosphorus) was made in order to subtract out this contribution. Figure 8d shows the adjusted total nitrogen levels and model predictions. It clearly shows that the Birchwood Gardens Sewage Treatment Plant does contribute a significant amount of total nitrogen to Buchanan Creek.

In Figure 8d the area between the adjusted total nitrogen curve and model predictions for the sewage treatment plant discharge is the total nitrogen contributed from non-point sources along the creek. Possible sources are (1) malfunctioning septic tanks and drain fields, (2) lawn fertilizer, and (3) nitrogen exported from the marshes to the estuary, but no data is available to document the origin and quantity of non-point contributions.

The predicted total nitrogen distributions resulting from the Birchwood Gardens Sewage Treatment Plant discharge at 0.4 MGD (August, 1976) and 0.8 MGD (1976 NPDES permit) are shown in Figure 8e. They are as high as 0.9 mg/l as N and 1.8 mg/l as N at 0.4 MGD and 0.8 MGD, respectively.

In order to meet EPA's suggested nitrogen criterion, (inorganic nitrogen less than 0.8 mg/l as N) the plant should not discharge more than 37.5 kg (82.7 lb) of inorganic nitrogen as N per day. If we assume that organic nitrogen in the effluent will be transformed rapidly to inorganic forms while within the estuary, then the total nitrogen concentration of the effluent should be used for calculations. For this case, the treatment plant must be upgraded to provide 11% and 56% nitrogen removal at 0.4 MGD and 0.8 MGD, respectively. If, on the other hand, we consider only the inorganic nitrogen in the effluent, no nitrogen removal is required for 0.4 MGD, but 44% removal is required for 0.8 MGD.

(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 photosynthesis, but the major supply of oxygen is the atmosphere.

A diurnal trend of the DO values was found since oxygen produced by the algae during daylight hours results in supersaturated DO concentrations. During the night phytoplankton respiration results in a net consumption of DO in addition to biochemical oxygen demand (BOD) requirements. The two slack-before-flood surveys shown in Figures 9a and 9b were made during sunny days, but that shown in Figure 9a was made in the late afternoon (1630) while that shown in Figure 9b was made in the morning (0800). The higher concentration of DO during daylight hours and lower concentration in the early morning are primarily the result of algal activity. Chlorophyll "a" data (Figures 10a and 10b) corroborate this statement. DO levels as low as 4 mg/l were observed at slack-before-ebb (Figure 9a).

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 6 mg/l were found in the upstream portion of the river at slack-before-flood (Figure 11).

EPA has suggested that an upper limit for the desirable concentration of algae in the Upper Chesapeake Bay 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 (Figure 10a) often were above 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 streams. 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 high dissolved oxygen levels could result during afternoons, as shown in Figure 9a, and very low levels could occur during the night.

(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 by SWCB in September 1975 showed high total fecal coliform levels in Buchanan Creek (Figure 4).

Total coliform levels exceeding 1000 MPN/100 ml were observed near the sewage treatment plant discharge site. The corresponding fecal coliforms were less than 100 MPN/100 ml at the same time.

VI. CONCLUSION

Low dissolved oxygen levels (ca. 4 mg/l) were found in Buchanan Creek 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 conclusion.

After subtracting downstream and non-point sources of nutrients, the model predicted that the concentration of total phosphorus can be as high as 0.34 mg/l as P and 0.68 mg/l as P due to effluent discharge from Birchwood Gardens Sewage Treatment Plant at 0.4 MGD (August 1976) and 0.8 MGD (1976 NPDES limit) respectively. Predicted total nitrogen concentrations range as high as 0.9 mg/l as N and 1.8 mg/l as N for the August, 1976 (0.4 MGD) and 1976 NPDES permit (0.8 MGD) flow rates respectively. If the EPA suggested criteria for ambient nutrient concentration levels are applied here, the sewage treatment plant should not discharge more than 1.9 kg (4.2 lb) of total phosphorus (as P) and 37.5 kg (82.7 lb) of inorganic nitrogen (as N) per day. To meet this requirement, the plant would need to be upgraded and provide around 88% and 94% removal of phosphorus at 0.4 MGD (August, 1976) and 0.8 MGD (1976 NPDES permit) respectively. The need for nitrogen removal is dependent on whether the inorganic nitrogen or the total nitrogen content in the effluent is considered. If only the inorganic nitrogen is considered, no additional treatment is required at 0.4 MGD, but 44% removal is required at 0.8 MGD.

If the total nitrogen concentration is used, then 11% and 56% nitrogen removal are needed at 0.4 MGD and 0.8 MGD respectively.

Since non-point sources of pollutants also contribute significant amounts of nutrients to this water body, they must be reduced along with point source loadings. More information on the origin and quantity of non-point sources is needed. Control of these loadings may be required to prevent continuation of water quality problems.

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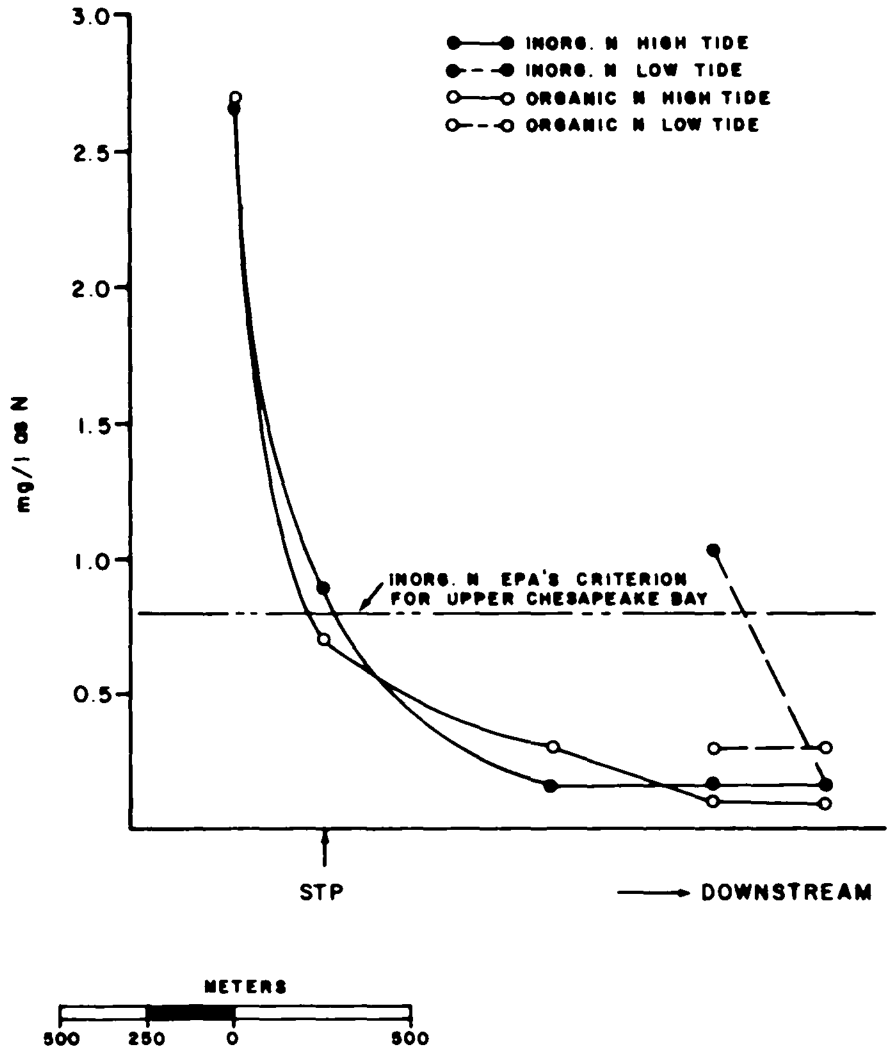

Figure 1. Total inorganic nitrogen and total organic nitrogen in Buchanan Creek (SWCB, 9/18/75).

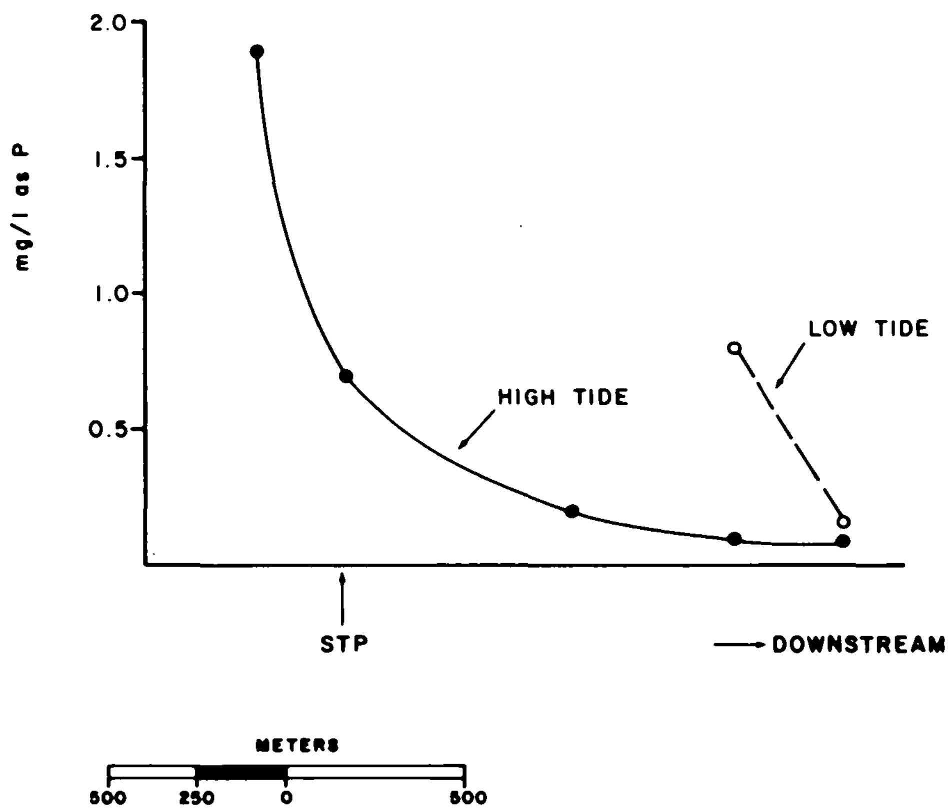

Figure 2. Ortho-phosphate in Buchanan Creek (SWCB, 9/18/75).

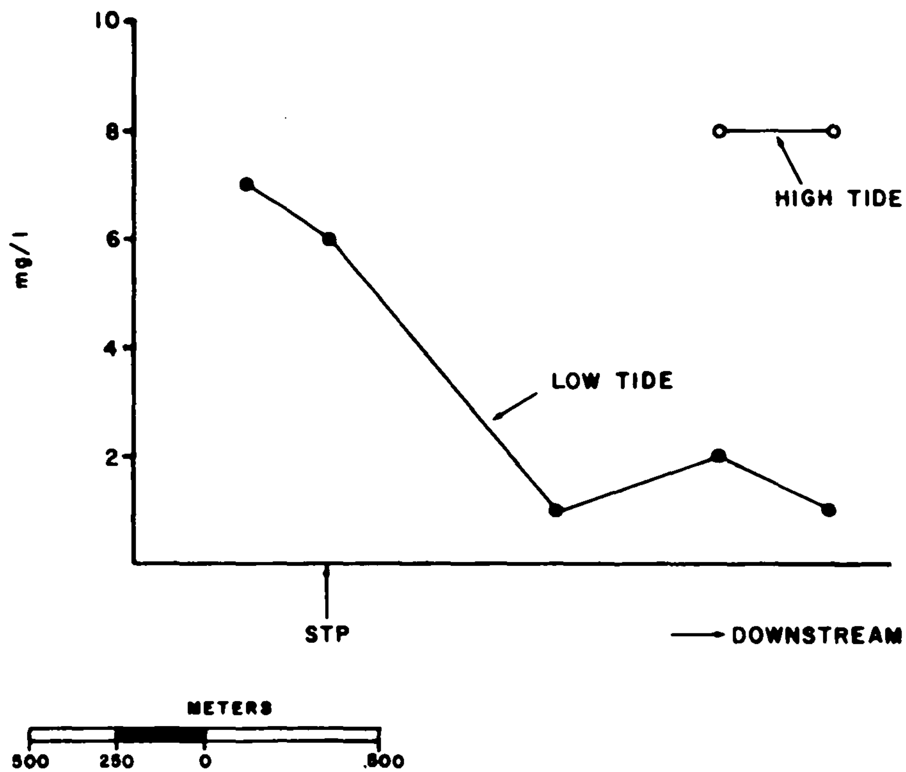

Figure 3. 5-day BOD in Buchanan Creek (SWCB, 9/18/75).

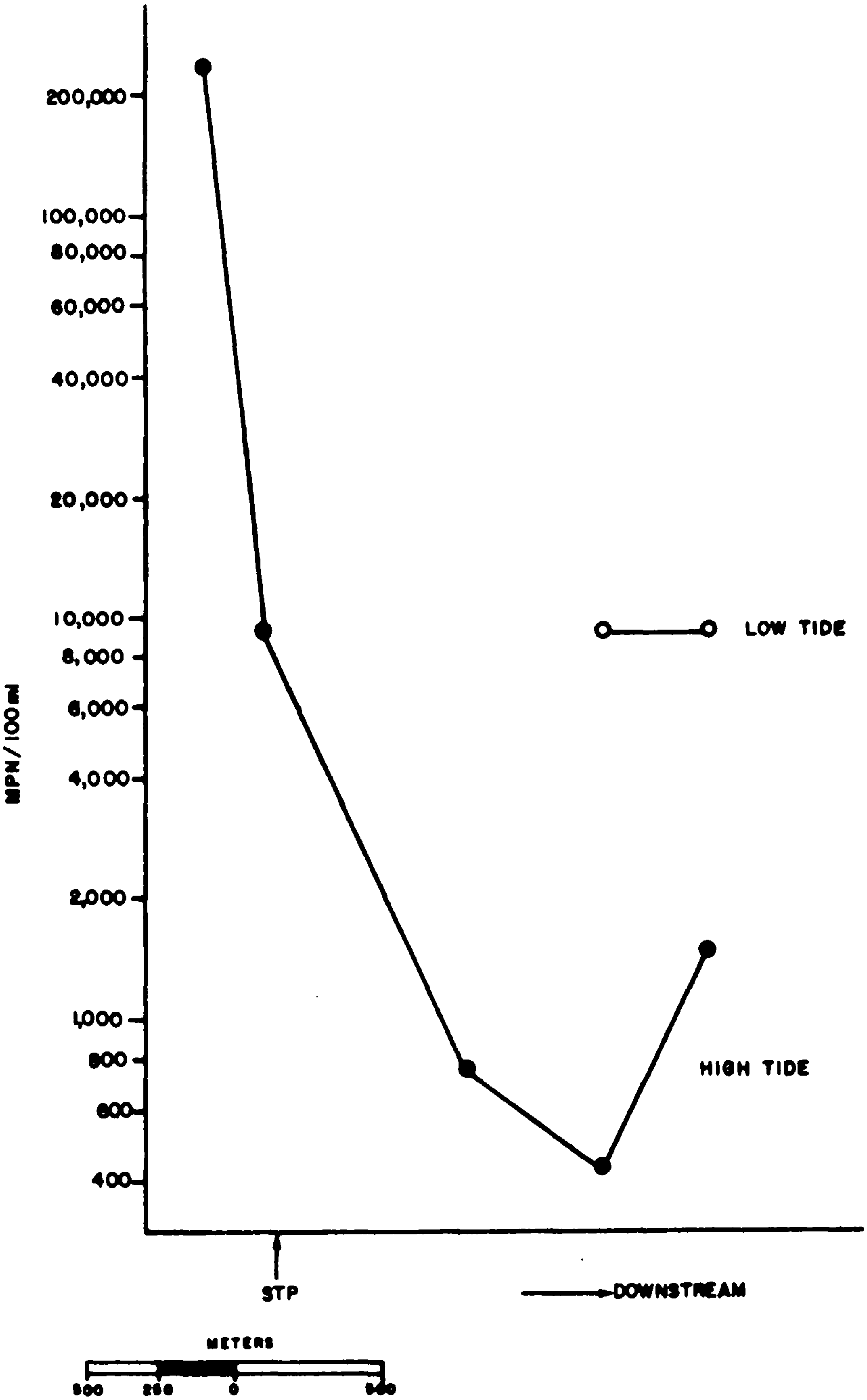

Figure 4. Total coliforms in Buchanan Creek (SWCB, 9/18/73).

Note: Fecal coliform levels were below 100 MPN/100 ml at all stations.

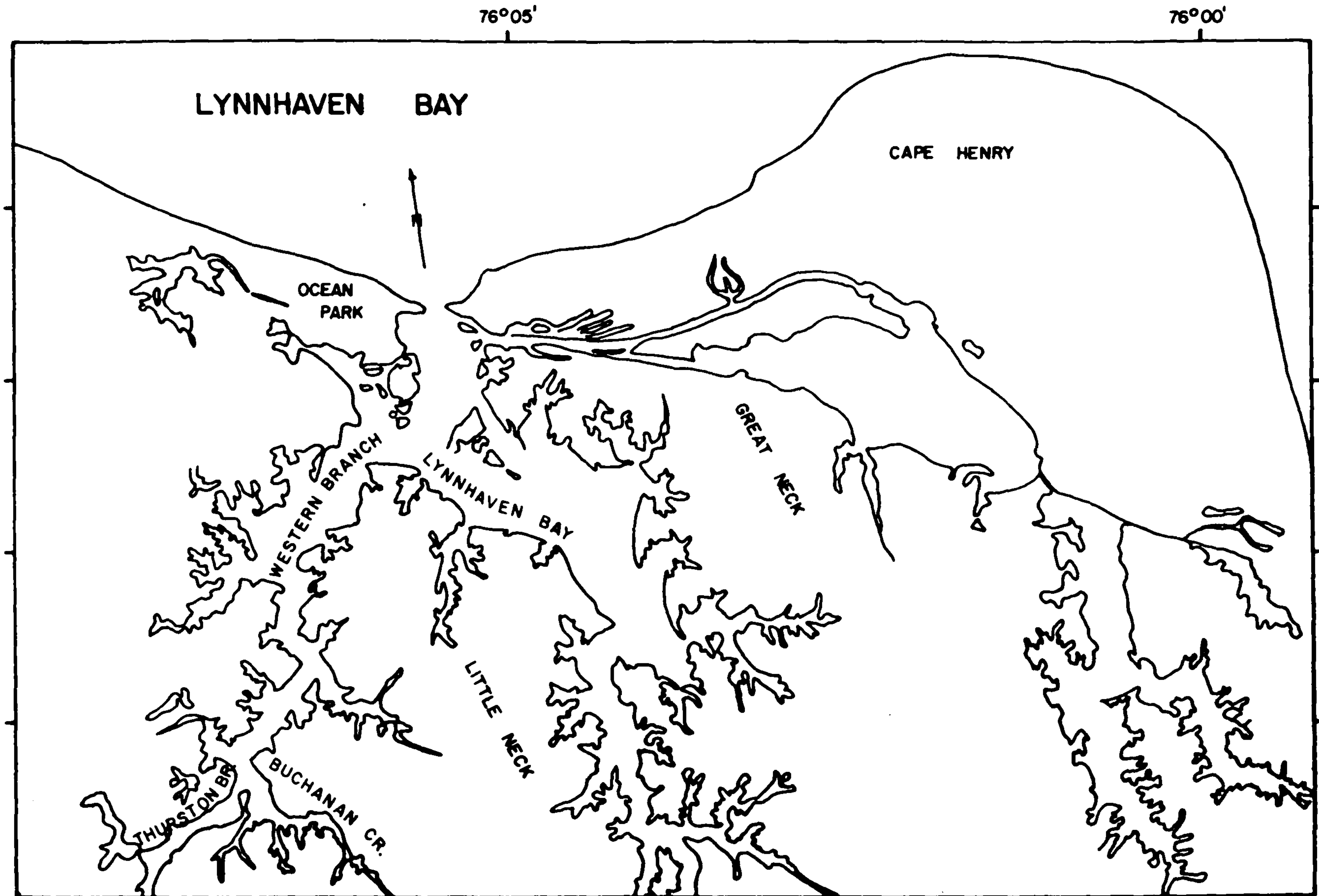

Figure 5a. Location of the Western Branch of Lynnhaven Bay.

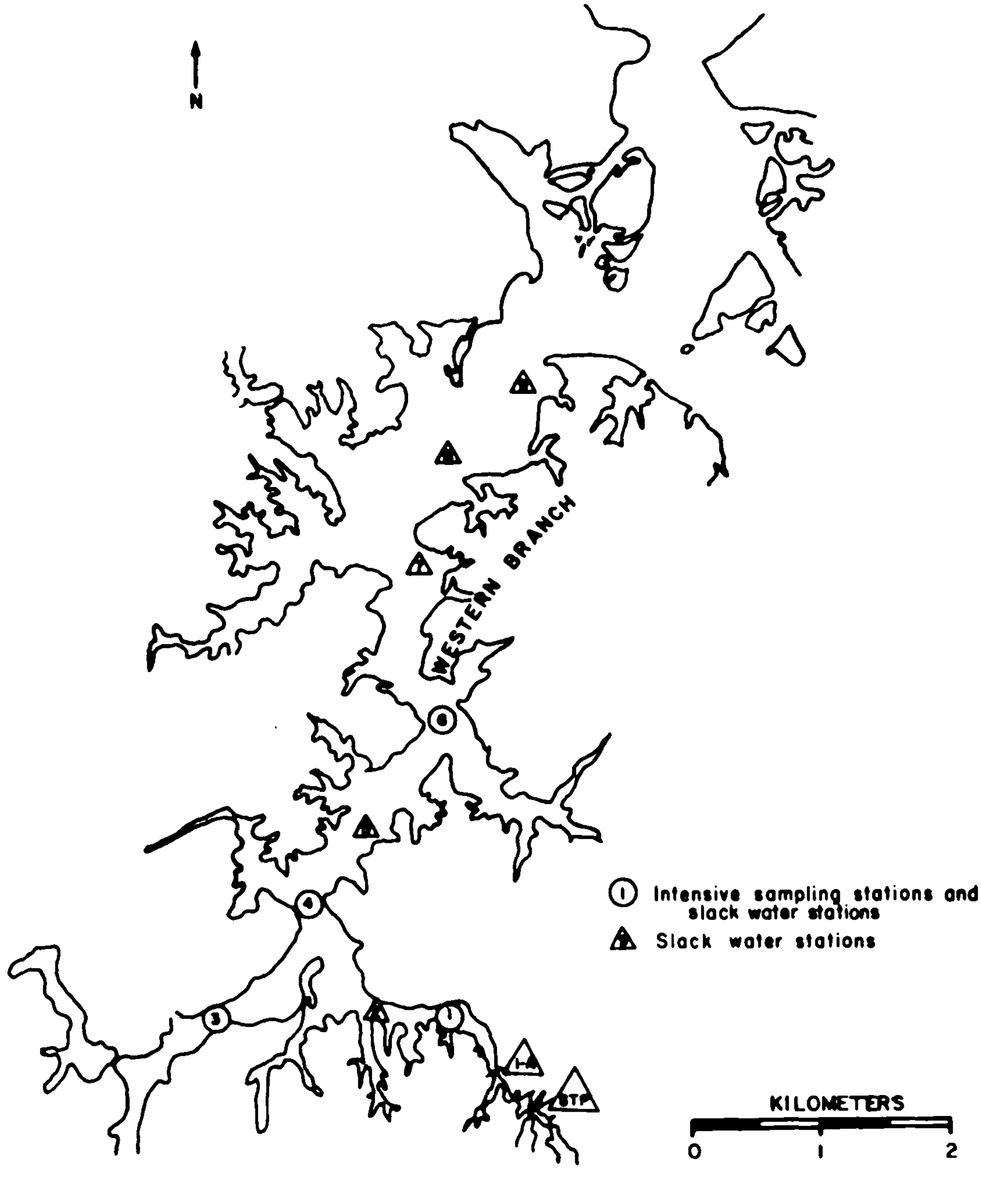

Figure 5b. Locations of Buchanan Creek and the Western Branch of the Lynnhaven Bay and stations.

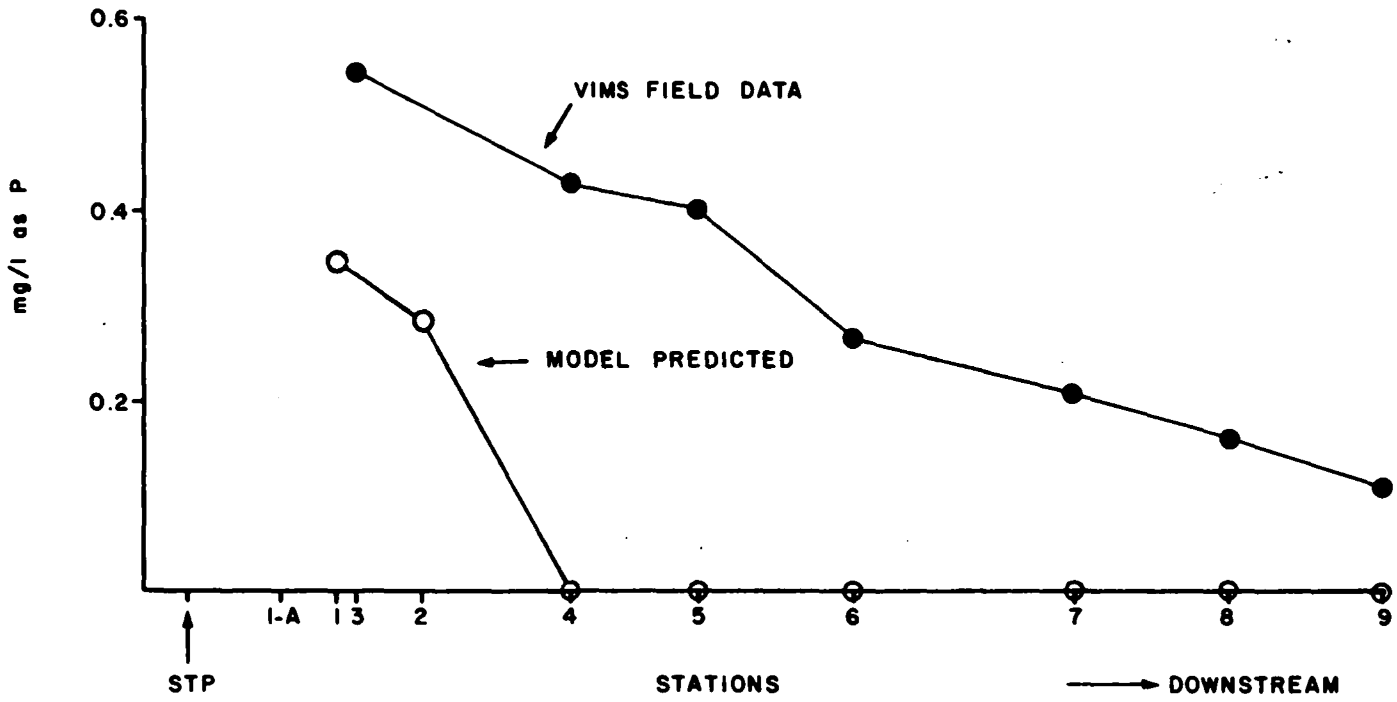

Figure 6a. Total phosphorus in Buchanan Creek and the W. Branch of the Lynnhaven Bay at SBF (VIMS, 8/26/1976).

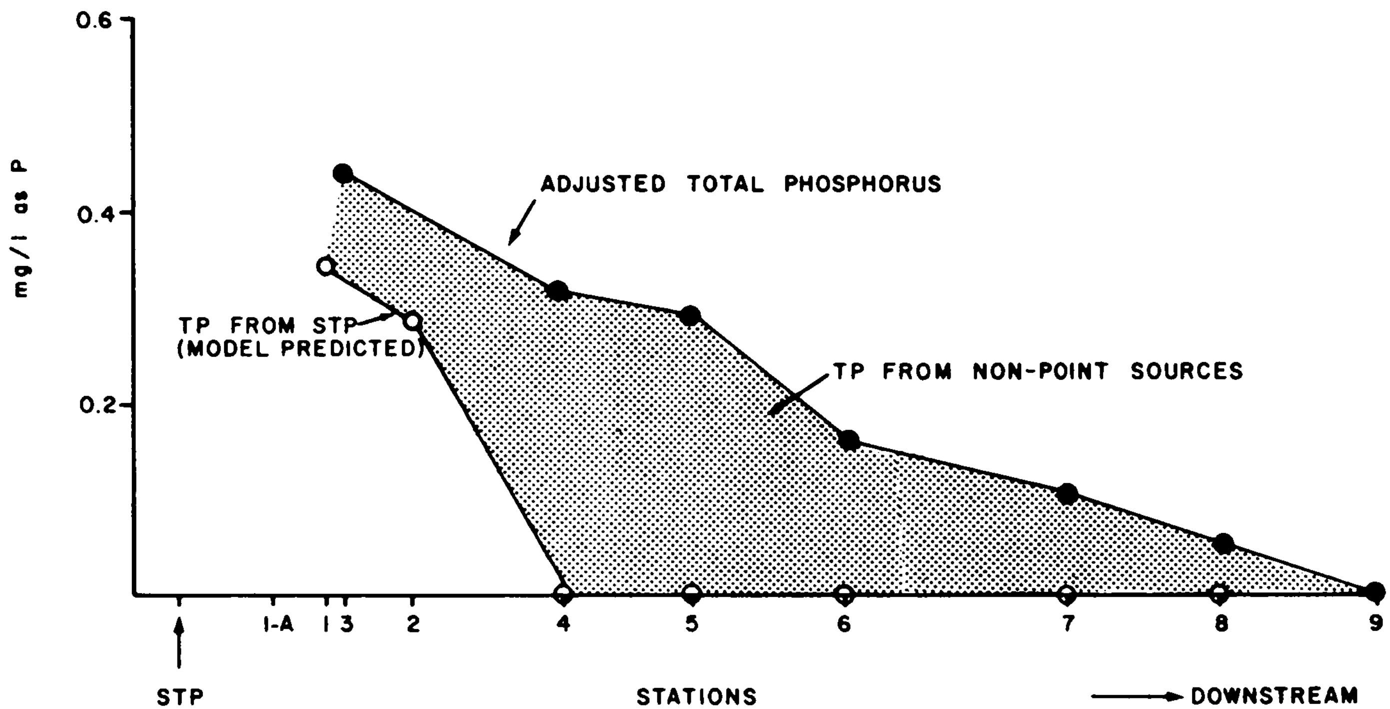

Figure 6b. Adjusted total phosphorus in Buchanan Creek and the W. Branch of the Lynnhaven Bay.

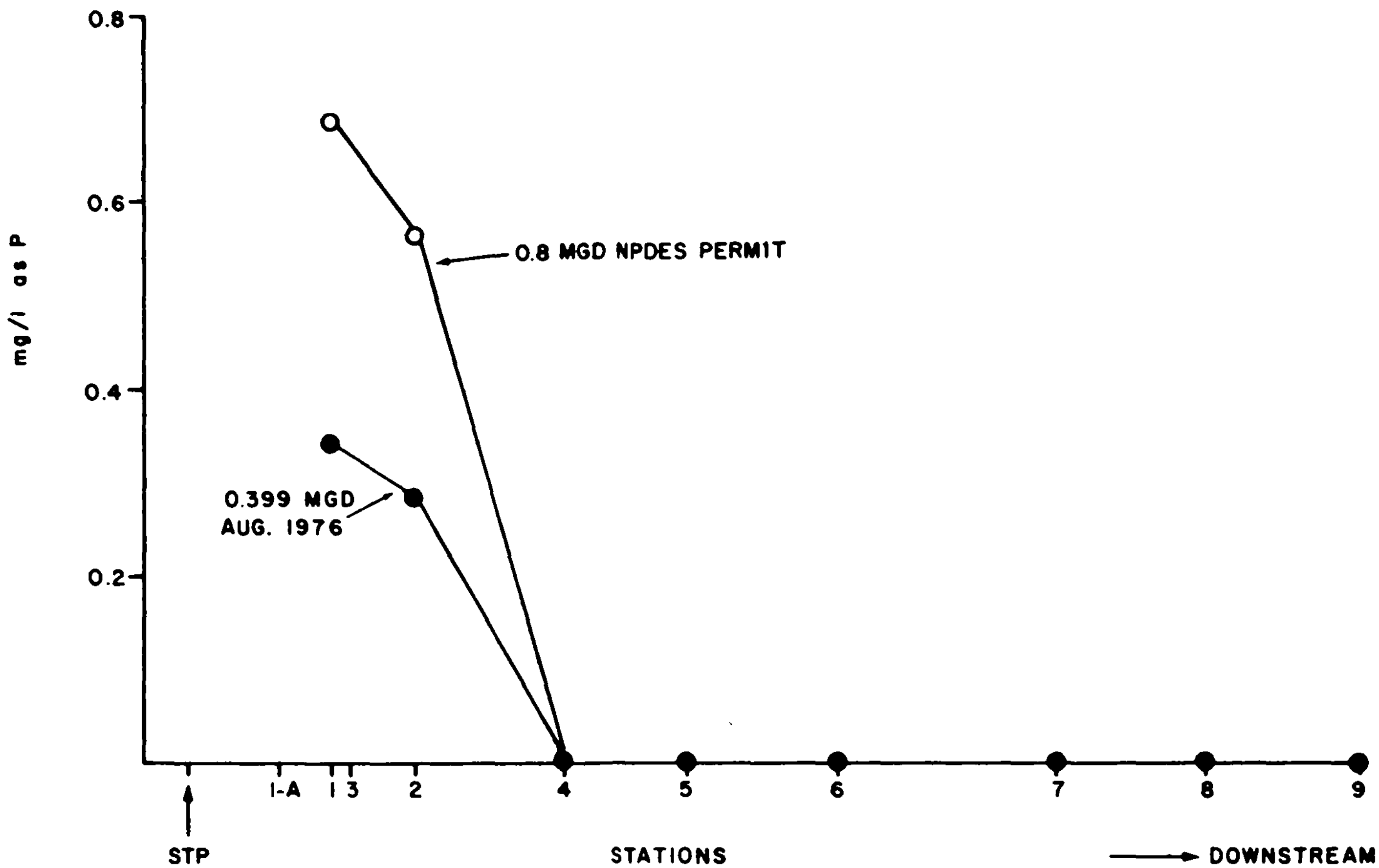

Figure 6c. Predicted total phosphorus in Buchanan Creek and the W. Branch of the Lynnhaven Bay at SBF at different STP's discharge rates.

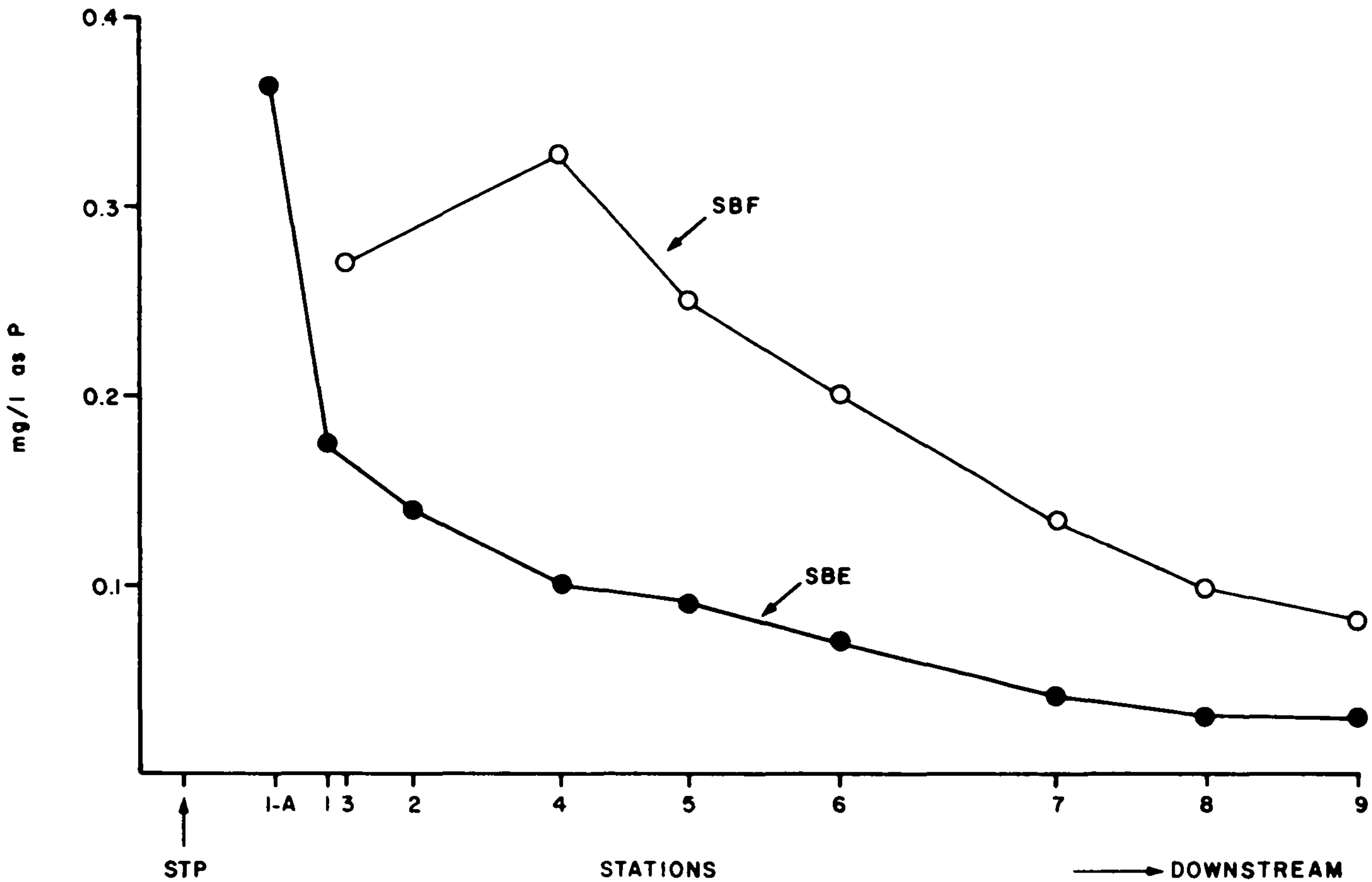

Figure 7. Dissolved ortho-phosphate in Buchanan Creek and the W. Branch of the Lynnhaven Bay. (VIMS, 8/26/76)

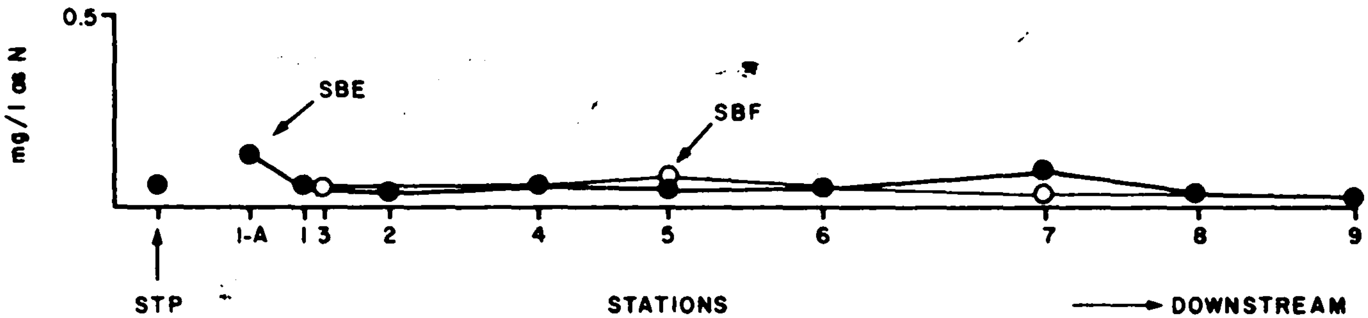

Figure 8a Total inorganic nitrogen in Buchanan Creek and the W. Branch of the Lynnhaven Bay (VIMS, 8/26/1976).

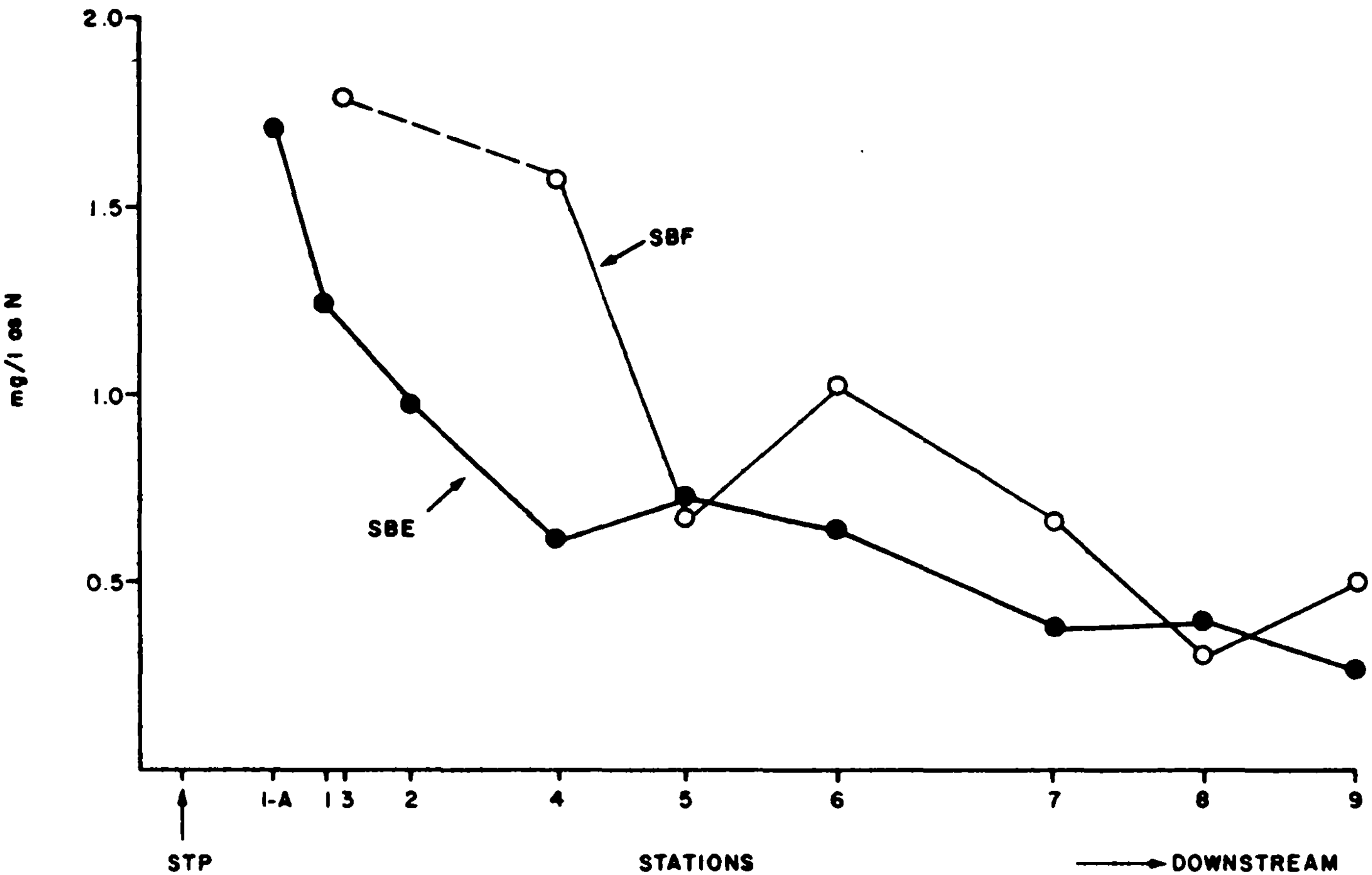

Figure 8b. Organic nitrogen in Buchanan Creek and the W. Branch of the Lynnhaven Bay (VIMS, 8/26/1976).

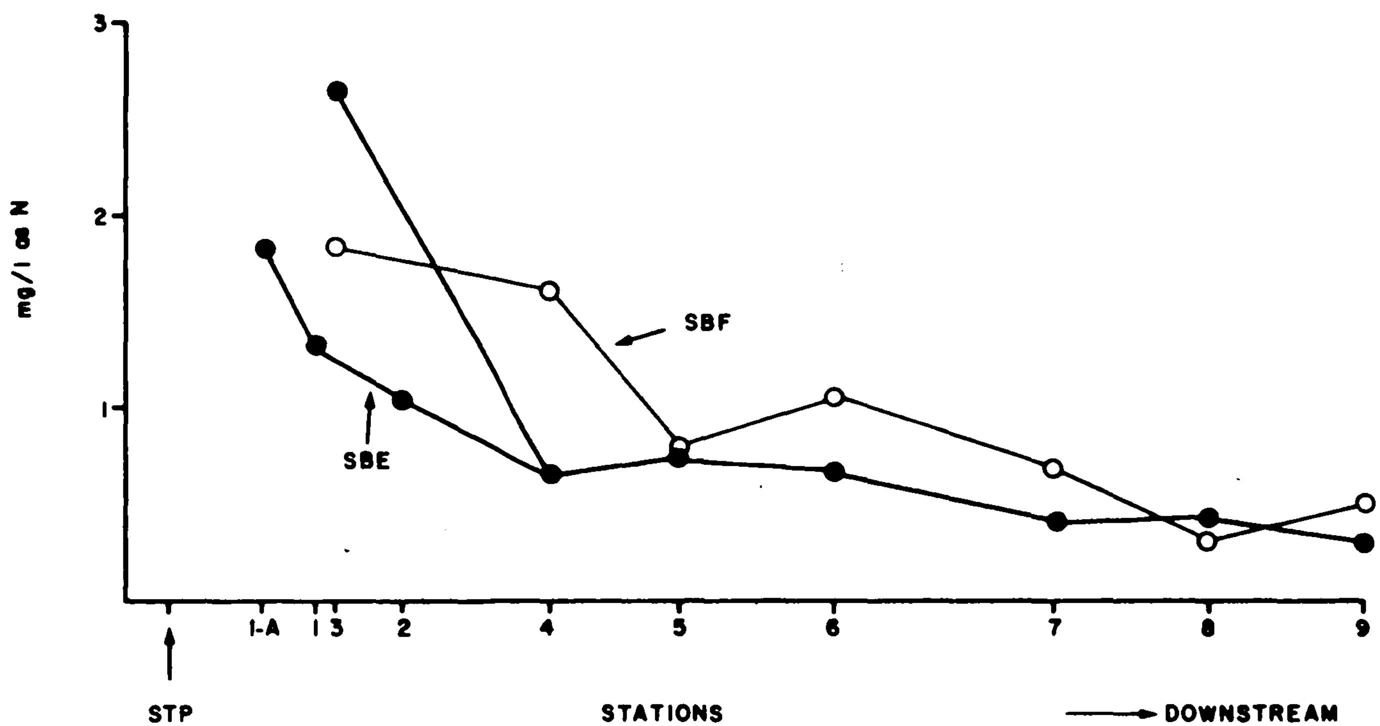

Figure 8c. Total nitrogen in Buchanan Creek and W. Branch of Lynnhaven Bay (VIMS, 1976).

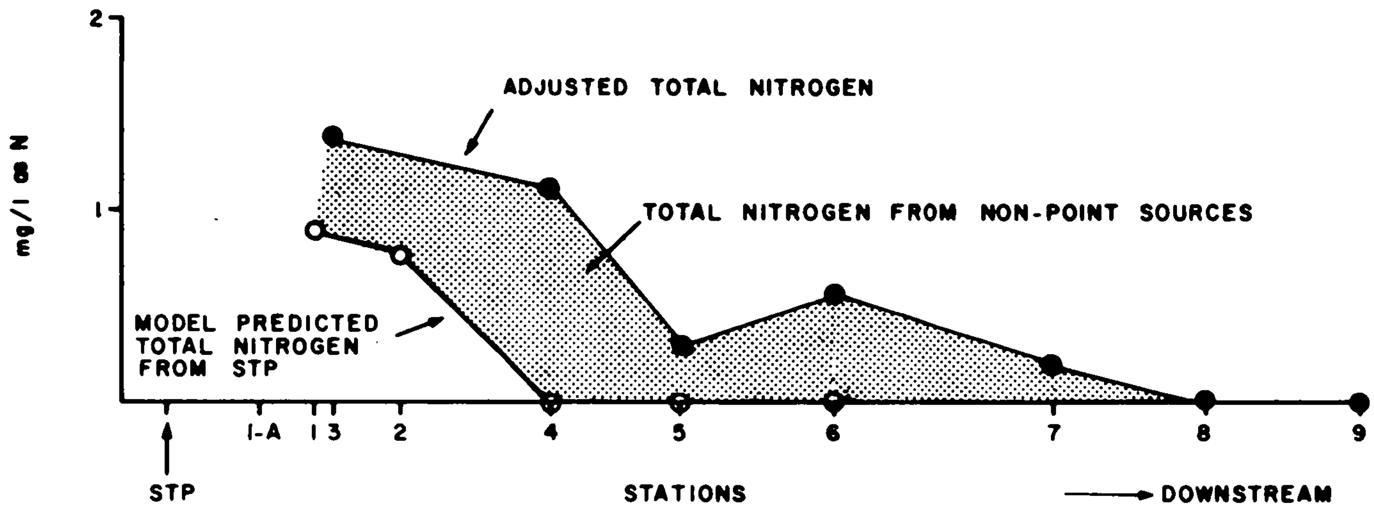

Figure 8d. Adjusted and predicted total nitrogen in Buchanan Creek and the W. Branch of the Lynnhaven Bay at SBF.

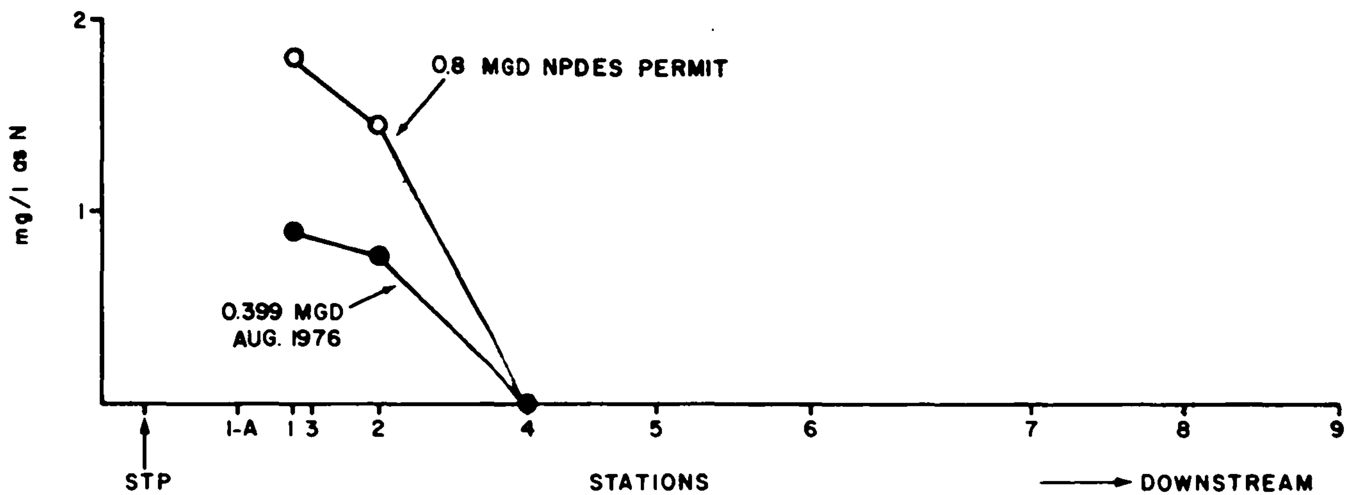

Figure 8e. Predicted total nitrogen in Buchanan Creek and the W. Branch of the Lynnhaven Bay at SBF at different STP's discharge rate.

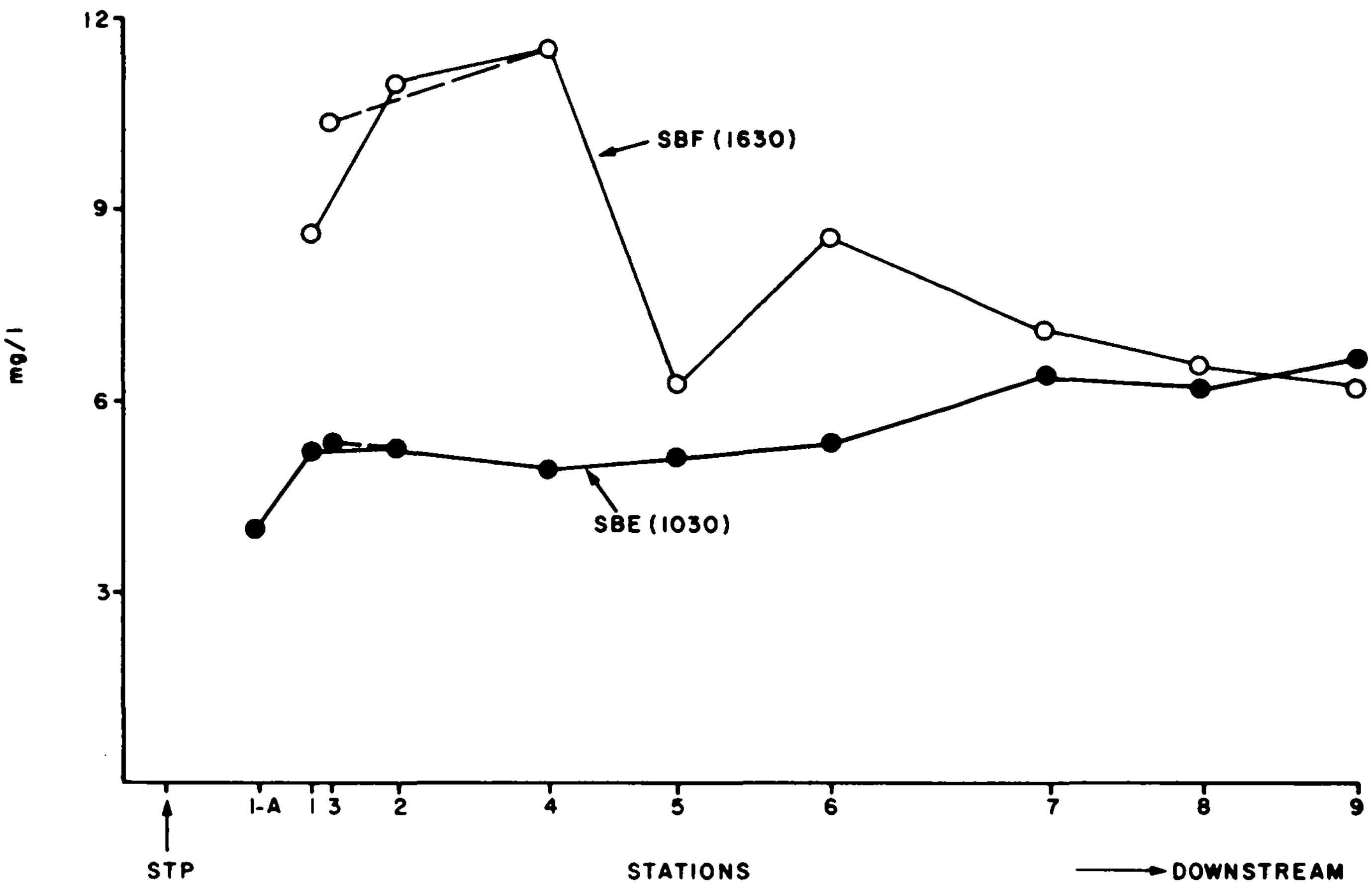

Figure 9a. Dissolved oxygen in Buchanan Creek and the W. Branch of the Lynnhaven Bay (VIMS, 8/25/1976).

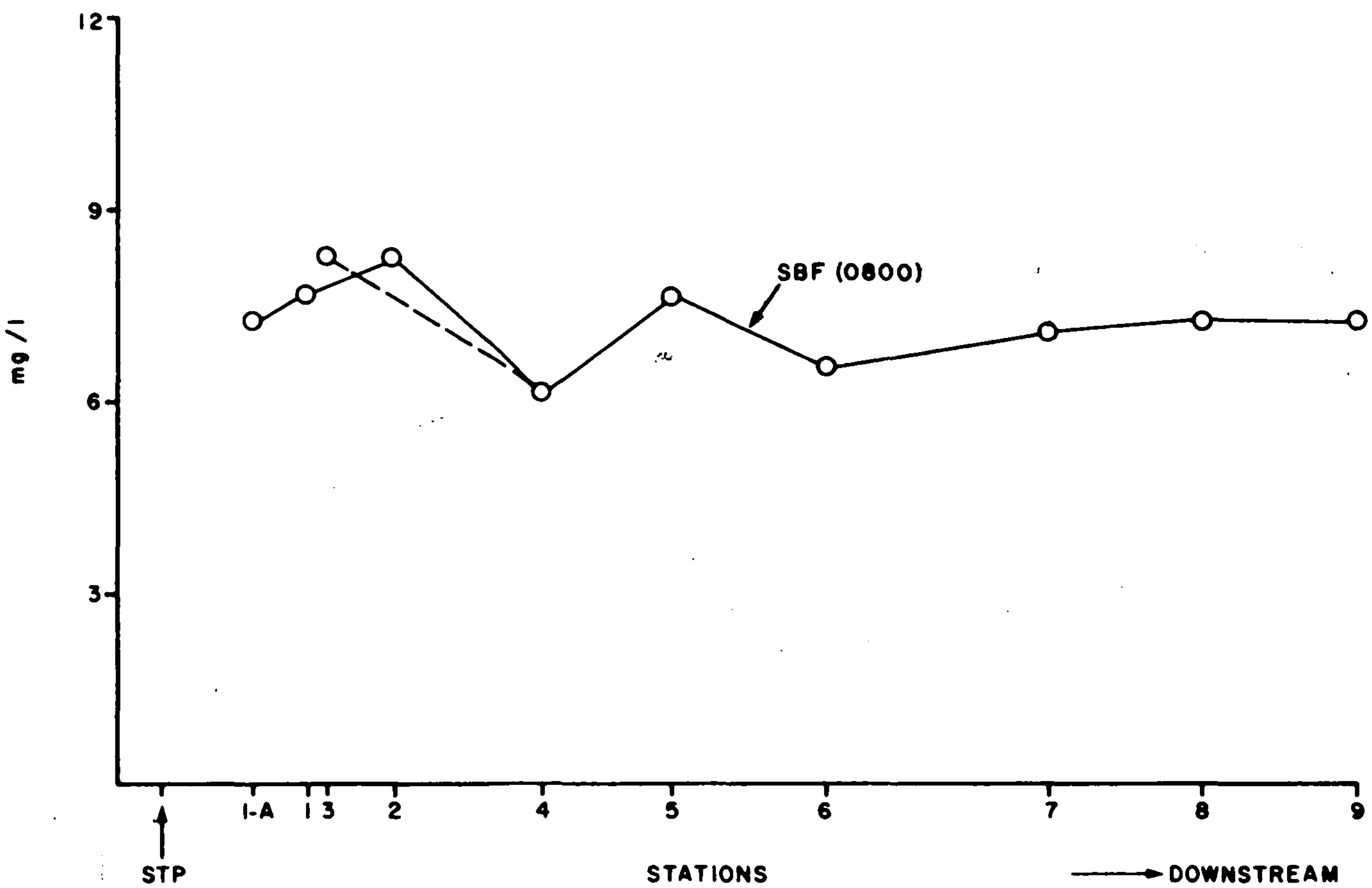

Figure 9b. Dissolved oxygen in Buchanan Creek and the W. Branch of Lynnhaven Bay (VIMS, 10/14/1976).

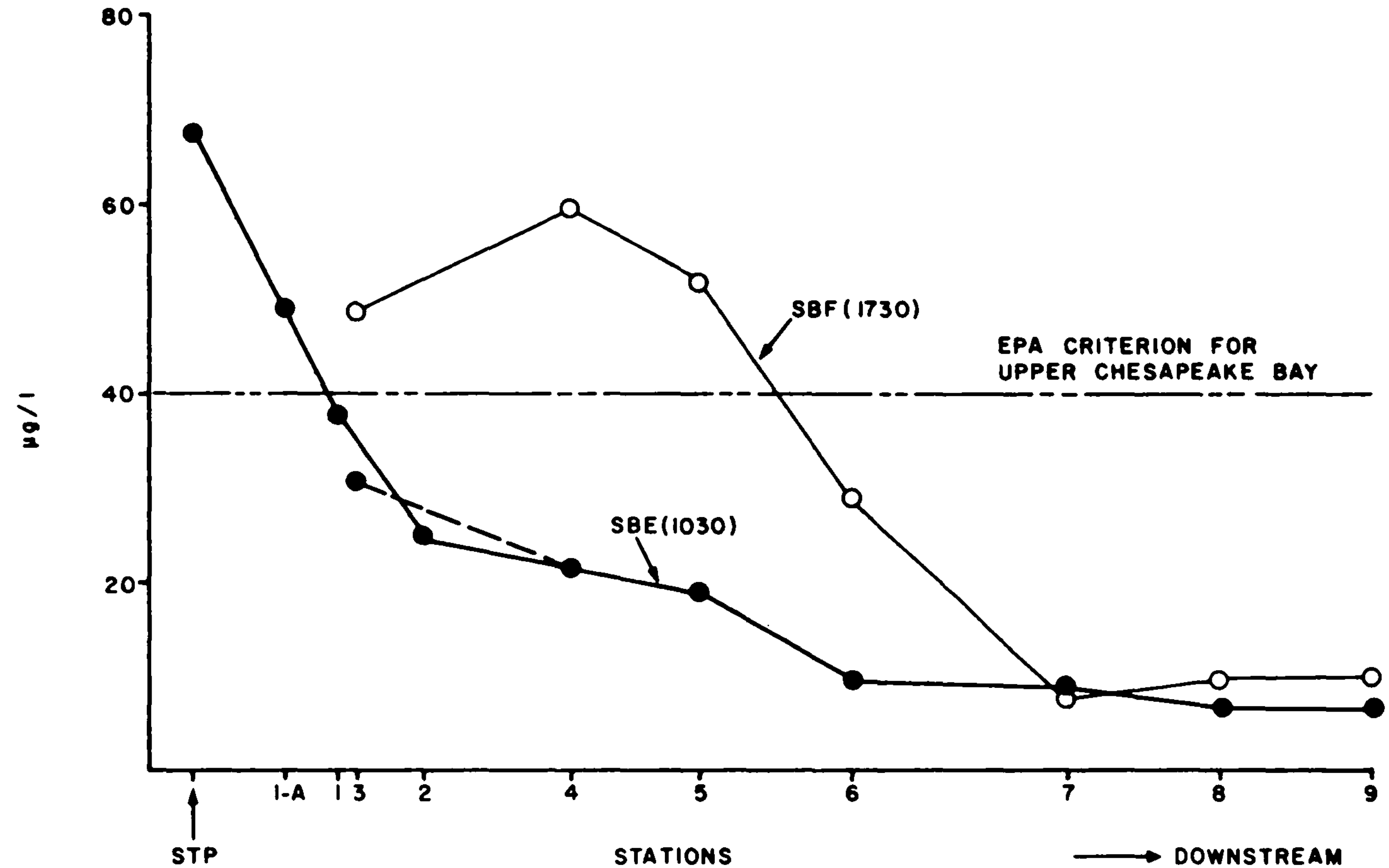

Figure 10a. Chlorophyll "a" in Buchanan Creek and the W. Branch of the Lynnhaven Bay (VIMS, 8/26/1976).

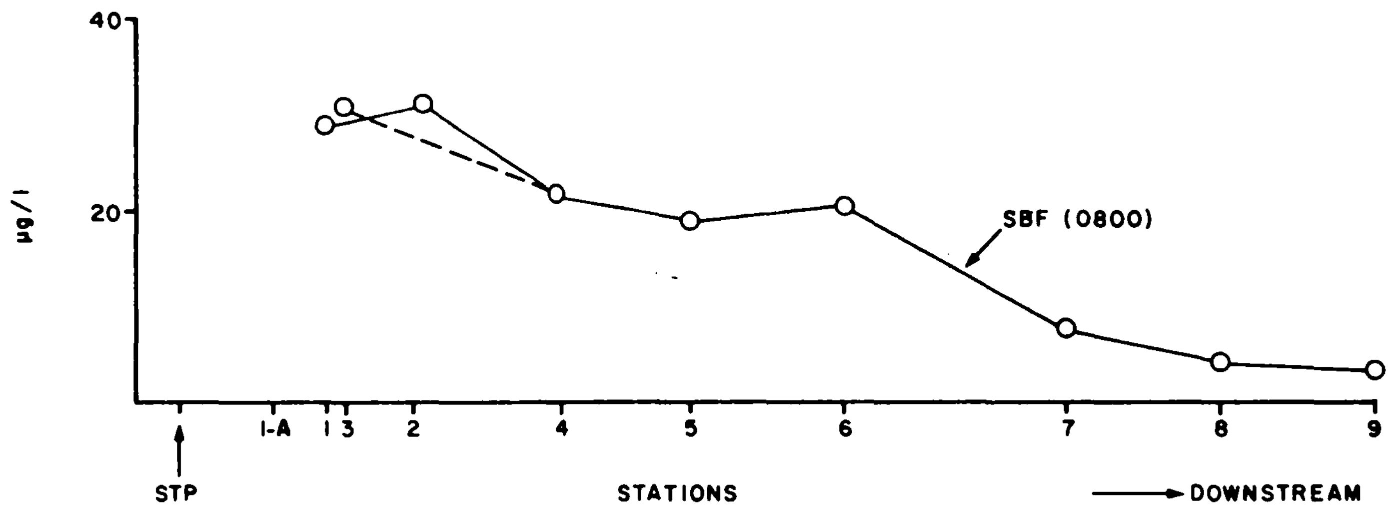

Figure 10b. Chlorophyll "a" in Buchanan Creek and the W. Branch of the Lynnhaven Bay (VIMS, 10/14/1976).

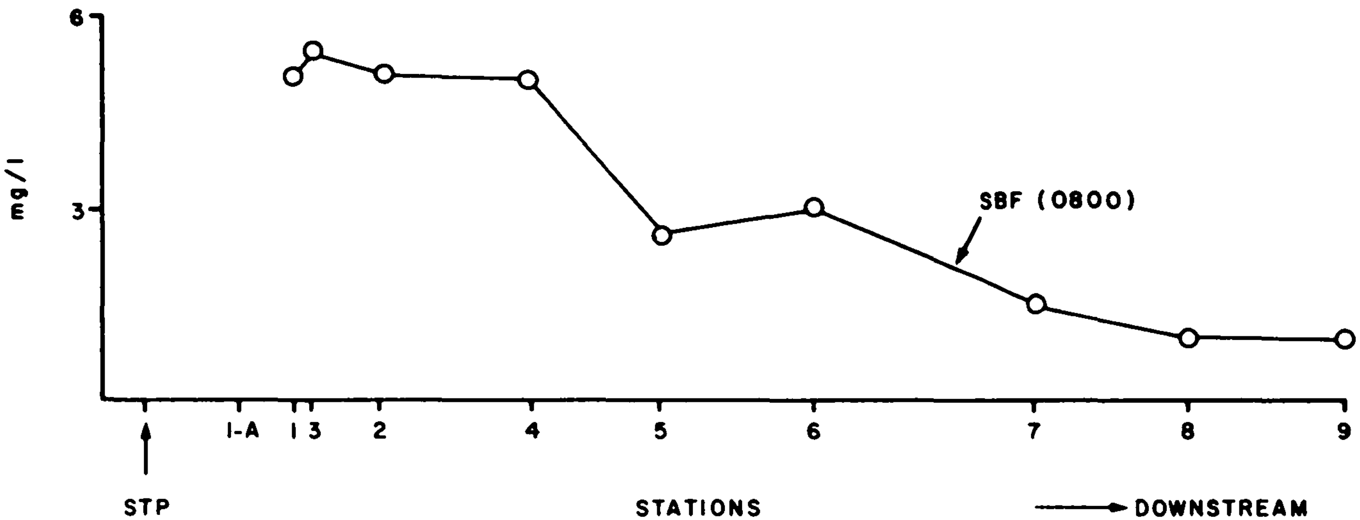

Figure 11. 5-day BOD in Buchanan Creek and the W. Branch of Lynnhaven Bay (VIMS, 10/14/1976).

APPENDIX A-1

SUMMARY OF OBSERVED DYE DISTRIBUTIONS AT SLACK-BEFORE-EBB

APPENDIX A-1. Summary of Observed Dye Distributions (in ppb) at Slack-Before-Ebb (VIMS).

	Date and Time								
	8/23/76		8/24/76		8/25/76		8/26/76		8/27/76
Stations	0830	2030	0930	2130	1030	2230	1130	2330	1230
1		8.6	16	9.8	7.8	3.3	3.2	2.8	2.0
2			3.1		3.9		4.1		
3			4.2		3.9	6.5	4.9	4.1	3.6
4		0.62	0.7	1.22	1.35	0.86	1.0	0.9	0.46
5			0.7		1.07		1.9		
6			0.3	1.0	0.74	0.85	0.82	0.35	0.31
7			0.2		0.05		0.04		
8			0.06		0.05		0		
9			0.07		0.03		0		

APPENDIX A-2

SUMMARY OF OBSERVED DYE DISTRIBUTIONS AT FOUR INTENSIVE STATIONS

APPENDIX A-2. Summary of Observed Dye Distributions at Four Intensive Stations (VIMS).

Date	Sta. 1 Time	Sta. 1 Dye (ppb)	Sta. 3 Time	Sta. 3 Dye (ppb)	Sta. 4 Time	Sta. 4 Dye (ppb)	Sta. 6 Time	Sta. 6 Dye (ppb)
8/23/76	1138	23			1100			
	1238	33			1200			
	1338	48			1300	1.5		
	1438				1400	12.0		
	1538				1500	11.5		
	1638				1600	20.0		
	1738	20			1700	4.4		
	1838	31			1800	0.9		
	1938	15			1900	0.6		
	2038	8.6			2000	0.6		
	2138	3.3			2100	0.9		
	2238	6.5			2200	0.9		
	2338	17.5			2300	1.2		
8/24/76	0038	33			0000	3.0		
	0138	47			0100	4.7		
	0238	61			0200	9.5		
	0338	56			0300	18.5		
	0438				0400	26.5		
	0538				0500	13.5		
	0638	100			0600	4.9		
	0738	39			0700	1.6		
	0838	31			0800	0.7		
	0938	16			0900	1.1		
	1038	7.8			1000	1.5		
	1138	16.2			1100	3.4		
	1238	36.4			1200	4.3		
	1338	44			1300	5.7		
	1438	49.9			1400	10.6		
	1538	47.5			1500	12.8		
	1638				1600	33.5		
	1738				1700	15.5	1735	3.3
	1838	65			1800	7.8	1835	1.5
	1938	30.4			1900	2.8	1935	0.6
	2038	16.4			2000	1.2	2035	0.5
	2138	9.8			2100	1.2	2135	1.0
	2238	4.6			2200	3.1	2235	1.6
	2338	15.3			2300	2.9	2335	1.3
8/25/76	0038	17.8			0000	2.3	0035	1.9
	0138	26			0100	4.2	0135	2.3
	0238	28			0200	6.3	0235	3.0
	0338	32.1			0300	8.5	0335	4.2
	0438				0400	11.1	0435	6.2
	0538				0500	10.9	0535	4.0
	0638				0600	10.1	0635	2.6
	0738	32.0			0700	4.5	0735	1.1
	0838	24			0800	2.2	0835	0.4

Appendix A-2 (con't)

Date	Sta. 1 Time	Sta. 1 Dye (ppb)	Sta. 3 Time	Sta. 3 Dye (ppb)	Sta. 4 Time	Sta. 4 Dye (ppb)	Sta. 6 Time	Sta. 6 Dye (ppb)
8/25/76	0938	11.9			0900	1.4	0935	0.3
	1038	7.8			1000	1.8	1035	0.7
	1138	7.3			1100	2.9	1135	0.9
	1238	11.5	1250	8.6	1200	3.5	1235	1.7
	1338	18.4	1350	8.9	1300	5.5	1335	2.8
	1438	24.5	1450	8.7	1400	7.7	1435	3.5
	1538	30	1550	7.9	1500	8.9	1535	4.3
	1638	30	1650	7.4	1600	10.2	1635	6.5
	1738	30.5	1750	7.8	1700	14.5	1735	4.8
	1838	33	1850	11.0	1800	9.1	1835	2.8
	1938	24.5	1950	7.7	1900	3.8	1935	1.4
	2038	11.5	2050	6.2	2000	2.1	2035	0.4
	2138	6.3	2150	4.6	2100	0.9	2135	0.3
	2238	3.3	2250	6.5	2200	1.9	2235	0.8
	2338	4.1	2350	6.4	2300	3.5	2335	0.9
8/26/76	0038	5.9	0050	6.8	0000	2.6	0035	1.8
	0138	9.9	0150		0100	4.0	0135	2.6
	0238	14.0	0250	7.7	0200	5.3	0235	2.9
	0338	17.5	0350	7.6	0300	6.8	0335	3.2
	0438	21.5	0450	7.4	0400	8.3	0435	4.3
	0538	23.2	0550	6.5	0500	8.4	0535	5.9
	0638	22.7	0650	6.1	0600	9.7	0635	4.0
	0738	22.5	0750	6.8	0700	6.7	0735	2.6
	0838	15.0	0850	7.8	0800	3.3	0835	1.13
	0938	9.4	0950	6.0	0900	1.6	0935	.45
	1038	4.7	1050	4.5	1000	1.0	1035	1.5
	1138	3.2	1150	4.9	1100	3.2	1135	..8
	1238	6.3	1250	4.9	1200	3.3	1235	1.6
	1338	8.5	1350	5.9	1300	3.8	1335	2.1
	1438	10.5	1450	6.8	1400	4.9	1435	2.8
	1538	12.5	1550	6.5	1500	5.7	1535	3.4
	1638	14.5	1650	6.9	1600	6.6	1635	3.7
	1738	15.5	1750	6.3	1700	5.9	1735	4.5
	1838	16.0	1850	6.1	1800	7.4	1835	
	1938	13.0	1950	6.2	1900	5.5	1935	2.6
	2038	8.5	2050	7.1	2000	3.1	2035	1.4
	2138	4.2	2150	5.9	2100	1.7	2135	0.5
	2238	2.8	2250	4.1	2200	0.9	2235	0.3
	2338	2.8	2350	5.3	2300	2.5	2335	0.4

Appendix A-2 (con't)

Date	Sta. 1 Time	Sta. 1 Dye (ppb)	Sta. 3 Time	Sta. 3 Dye (ppb)	Sta. 4 Time	Sta. 4 Dye (ppb)	Sta. 6 Time	Sta. 6 Dye (ppb)
8/27/76	0038	3.8	0050	4.7	0000	2.5	0035	1.1
	0138	5.9	0150	4.6	0100	2.3	0135	1.9
	0238	7.9	0250	5.7	0200	3.2	0235	2.0
	0338	9.6	0350	6.1	0300	3.8	0335	2.6
	0438	11.0	0450	6.2	0400	4.7	0435	3.2
	0538	11.5	0550	0.9	0500	5.4	0535	3.5
	0638	11.5	0650	5.4	0600	6.1	0635	3.9
	0738	11.0	0750	5.4	0700	5.4	0735	2.8
	0838	7.4	0850	5.5	0800	3.4	0835	1.6
	0938	4.5	0950	6.0	0900	2.0	0935	0.7
	1038	2.7	1050	3.9	1000	0.9	1035	0.3
	1138	2.0	1150	3.6	1100	0.5	1135	0.9
	1238	3.2	1250	3.9	1200	1.3	1235	0.5
					1300	1.8	1335	1.1
					1400	2.3	1435	1.4
					1500	2.7	1535	1.8
							1635	1.8