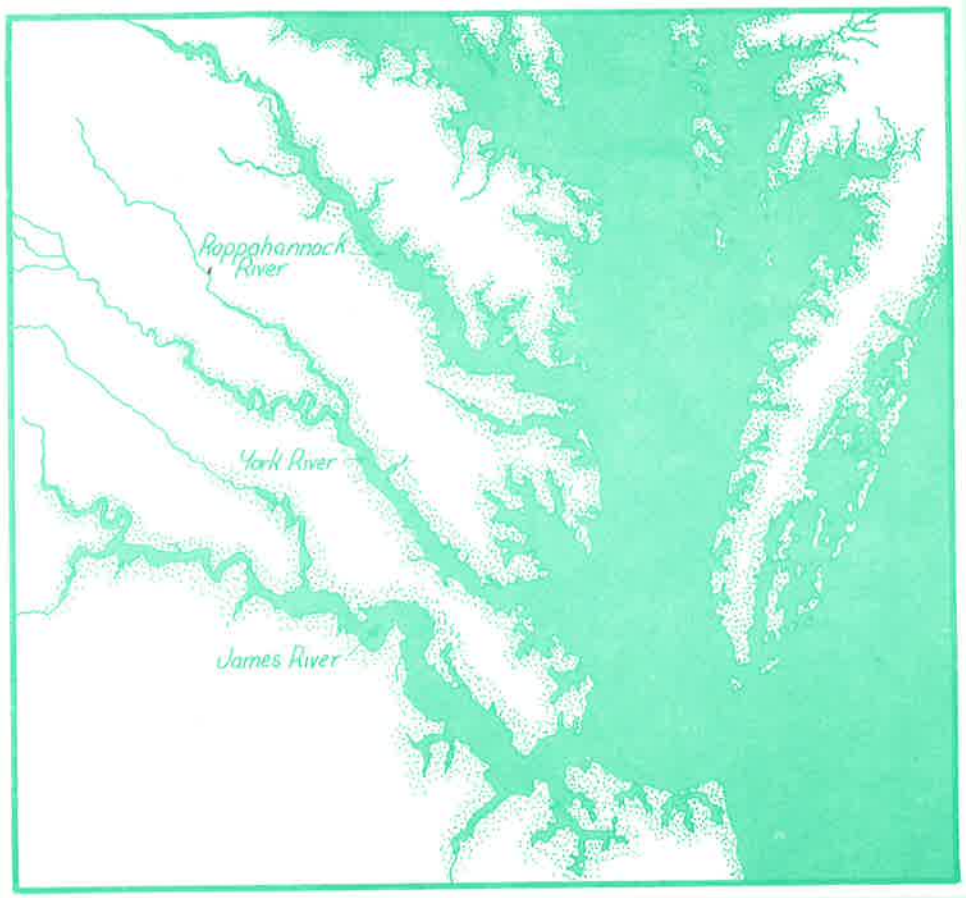
TRIBUTARY WATER QUALITY 1987

CHARACTERIZATION REPORT



Chesapeake Bay Water Quality Monitoring Program
Chesapeake Bay Office
Virginia Water Control Board

TRIBUTARY WATER QUALITY

1987

CHARACTERIZATION REPORT

BASIC DATA BULLETIN 77

prepared by

CHESAPEAKE BAY OFFICE
VIRGINIA WATER CONTROL BOARD
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ACKNOWLEDGMENTS

The contents of this report, from the field sampling through final data analysis, represents the work and dedication of a large number of persons who should be recognized for their efforts. The field sampling was conducted by the Tidewater, Northern, and Piedmont Regional Offices of the Virginia Water Control Board (VWCB). The nutrient laboratory of the Division of Consolidated Laboratory Services provided the analytical services with the exception of chlorophyll analysis which was performed by VWCB personnel. The Division of Information Services of the VWCB was responsible for the entry of data. The Graphics Communication Office assisted in cover design and layout.

The Chesapeake Bay Office was responsible for data management, analysis and reporting. The storage and analysis of the data was performed on the Chesapeake Bay Program Computer. This monitoring program is an element of the multi-state/federal Chesapeake Bay monitoring program coordinated through the Chesapeake Bay Program Monitoring Subcommittee. Any questions concerning this report or the Chesapeake Bay Monitoring Program in Virginia can be directed to Frederick A. Hoffman at (804) 367-6683 or Debra J. Trent at (804) 367-0073.

I. EXECUTIVE SUMMARY

1. During the summer of 1984, the Commonwealth of Virginia established the Tributary Water Quality Monitoring Program as part of the Chesapeake Bay Monitoring Program. The Chesapeake Bay Monitoring Program encompasses water quality and biological monitoring of the Bay and its tributaries. This report summarizes the results of the tributary water quality component of the overall monitoring program for the sampling period December 1986 through November 1987. The tributary program includes 32 stations from the fall line to the mouths of the Rappahannock, York, and James rivers. A variety of physical and chemical measurements are collected twenty times per year on each tributary.

2. The Tributary Water Quality Monitoring Program has three major objectives: to describe or characterize the current water quality conditions; to detect long-term trends in water quality due to increased nutrient loadings and/or management actions to control nutrients; and to improve our understanding of the processes that control water quality and its relationship to living resources.

3. The Rappahannock, and to a lesser extent the James, exhibited high nonpoint inputs of inorganic nitrogen from above the fall line during winter and spring. The York also exhibited a winter/spring pulse of inorganic nitrogen, but it originated below the fall line and may have been largely the result of natural wetlands processes.

4. The James exhibited dramatic increases in nitrogen in the Richmond and Hopewell areas due to the large loadings of nitrogen from point sources. The state's ammonia toxicity criteria was exceeded several times during the summer in the tidal freshwater James. Extensive instream nitrification was evident and contributed to the oxygen demand on the upper tidal portion of the James.

5. Phosphorus was higher at the fall line and upper tidal James than in corresponding areas of the Rappahannock and York. This was due to both very high fall line concentrations of orthophosphate and large loadings of orthophosphate from point sources. The phosphorus levels at the fall line of the James were higher than comparable rivers and have been increasing since the 1970's. The York generally had higher phosphorus concentrations at the fall line than the Rappahannock.

6. The occurrence of nutrient limitation at the fall lines of the York and Rappahannock was equally divided between phosphorus and nitrogen. The James was predominately nitrogen limited at the fall line, due to extremely high orthophosphate concentrations. Throughout much of the upper James, the river is nutrient saturated such that for all practical purposes there is neither nitrogen or phosphorus limitation. Other factors such as light, carbon dioxide, or micronutrients probably control algal productivity in these regions. The tidal waters of the Rappahannock were generally phosphorus limited.

The tidal York was also predominately phosphorus limited, except in the transition zone where elevated particulate phosphorus concentrations resulted in intermediate ratios. In the James, large inputs of both phosphorus and nitrogen created complex changes in the limiting nutrient. In general, the limiting nutrient shifted from nitrogen to phosphorus as the river flowed from the fall line toward the estuary. Understanding this complex shift in nutrient limitation in the James is important in management of nutrients in the river.

7. Contrary to intuition, the most anthropogenically impacted river, the James, experienced the least hypoxia (low dissolved oxygen) in its lower tidal portion. The lower Rappahannock and the lower York experienced hypoxia during the summer despite lower nutrient loadings. Important hydrological differences between the James, York, and Rappahannock may be responsible for this difference. Due to these circulation differences, the York and Rappahannock may be more susceptible to the impact of increased urbanization than the James.

II. INTRODUCTION

As part of the Chesapeake Bay Program, the Commonwealth of Virginia is engaged in extensive water quality and biological monitoring of the Virginia portion of the Chesapeake Bay and its tributaries. All of the monitoring programs have three basic objectives:

- To establish a 'baseline' of comparison for further assessment.
- To identify long-term spatial and temporal trends.
- To improve our understanding of the processes that control the water quality of the Bay and the relationship between water quality and the living resources.

Achieving these objectives will give a basis upon which to make judgements about the present condition of the Chesapeake Bay and its tributaries, to measure the effectiveness of pollution control strategies, to provide verification and calibration for water quality modeling efforts, and to allow for better informed management decisions.

Accurately determining trends in a system as large and variable as the Chesapeake Bay and its tributaries requires a large amount of data collected over a broad area for a long period of time. In the summer of 1984, the Environmental Protection Agency, the Commonwealth of Virginia, and the State of Maryland instituted a mainstem water quality monitoring program to study the Chesapeake Bay. The Commonwealth of Virginia also developed and instituted a tributary water quality monitoring program in the summer of 1984. This program complements the efforts within the mainstem of the Bay and provides vital information about the James, York, and Rappahannock Rivers as well as some of their major sub-tributaries. During the 1984-1986 biennium, Virginia also initiated plankton and benthic monitoring programs in the mainstem and tributaries. The benthic program samples eleven tributary and five mainstem stations four times per year. The plankton program samples six tributary and seven mainstem stations up to twenty times per year. All of the stations sampled under the biological programs are also monitored for water quality, thus allowing for the integration of water quality information with the biological data. A large amount of information is gained through the integration of the water quality and biological monitoring programs and detailed analysis of the data collected within these programs. This integrated approach is especially important since this is the first time that water quality and biological data for the entire Bay and its tributaries have been collected and examined in a uniform manner.

This report presents the tributary water quality data collected from December 1986 through November 1987 on the James, Rappahannock, York, and Pamunkey rivers. Individual stations located on the Appomattox, Chickahominy, Mattaponi, and Corrotoman rivers will be reported on separately. This report is a description of the conditions or a 'characterization' of the water quality during the reporting period using simple statistics and graphical presentations. Each chapter has a brief discussion of the concepts involved, followed by presentation of the monitoring results. Data presentations first focus on individual rivers, then a general comparison between rivers is made. Appendices which present tables of summary statistics for each station have been bound separately and are available upon request.

Other results of the various Chesapeake Bay Monitoring Programs are reported in the following publications. Copies of these reports can be obtained through the Chesapeake Bay Office of the VWCB. The report title, period of data covered, authors, and data published are cited.

PUBLICATIONS ON THE CHESAPEAKE BAY MONITORING PROGRAMS

- The State of the Chesapeake Bay 1984 - 1985; CBP Monitoring Subcommittee (1987).
- The State of the Chesapeake Bay 1984 - 1985 Compendium; CBP Monitoring Subcommittee (1987).
- Tributary Water Quality 1984 - 1985 Characterization Report; Chesapeake Bay Office, Virginia Water Control Board (1987).
- Tributary Water Quality 1986 Characterization Report; Chesapeake Bay Office, Virginia Water Control Board (1987).
- Organic Compounds in Sediments from Chesapeake Bay and its Tributaries 1984 - 1986; Paul deFur, VIMS (1986).
- Lower Chesapeake Bay Mainstem Plankton Monitoring Program July 1985 - June 1986; R.S. Birdsong, H.G. Marshall, R.W. Alden and R.M. Ewing, ODU (1987).
- Lower Chesapeake Bay Mainstem Plankton Monitoring Program July 1986 - June 1987; R.S. Birdsong, H.G. Marshall, R.W. Alden and R.M. Ewing, ODU (1988).
- Macrobenthic Communities of the Lower Chesapeake Bay March 1985 - June 1986; D.M. Dauer, R.M. Ewing, and J.A. Ranasinghe, ODU (1987).
- Macrobenthic Communities of the Lower Chesapeake Bay March 1986 - June 1987; D.M. Dauer, M.E. Ewing, and J.A. Ranasinghe, ODU (1988).
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- Summary of Chesapeake Bay Water Quality Monitoring Data 1984 - 1987; K.E. Curling, VIMS (1988)

III. PROGRAM DESCRIPTION

Under the tributary water quality monitoring program, data were collected at 28 tidal and 4 fall line stations located throughout the James, York, and Rappahannock rivers. The stations are located to characterize the salinity and circulation regimes found in the tributaries. In addition, several stations are located in smaller tributaries of the major rivers. Figures 3.1 through 3.3 depict the location of the stations within each river basin as well as major point sources of nutrients. Between January and June 1986 the U.S. Geological Survey conducted the field and laboratory work for the fall line stations. The Virginia Water Control Board (VWCB) Piedmont Regional Office has had responsibility for the collection of fall line data since July, 1986. The fall line stations were sampled once per month. All field work for the tidal stations was conducted by the Tidewater and Piedmont Regional Offices of the VWCB and most laboratory analyses were conducted by the Virginia Division of Consolidated Laboratory Services (DCLS). Chlorophyll samples were analyzed at the VWCB chlorophyll laboratory in the headquarters office.

The 28 tidal stations are sampled during monthly cruises between November and February. During the months of March through October, when biological activity is highest and water quality problems are most evident, cruises are scheduled twice per month. Sampling cruises are scheduled to coincide with low slackwater, the period during low tide when tidal currents are at a minimum. An effort was made to schedule tributary sampling close to the dates that Bay sampling was conducted. Due to tide and weather considerations, only about half of the tributary cruises fell within a week of the mainstem cruises. The actual sampling dates during the period covered by this report are listed in Table I.

Table II lists the station names, locations, river miles, and notes which stations are also included in the biological monitoring programs.

TABLE I

WATER QUALITY MONITORING DATES FOR 1987

MONTH	CRUISE #	MAINSTEM	RAPP.	JAMES	YORK
DEC, 1986	51	9-10	15	22	23
JAN	52	5-7	5	5	7
FEB	53	23-25	Canc.	Canc.	Canc.
MARCH	54	9-11	3	4	5
MARCH	55	20-22	17	18	23
APRIL	56	6-8	3/31	8	2
APRIL	57	20-22	15	14	22
MAY	58	4-6	4/30	6	7
MAY	59	18-20	14	18	19
JUNE	60	1-3	2	1	4
JUNE	61	15-17	16	15	17
JULY	62	6-8	6/30	6/29	7
JULY	63	20-22	14	13	15
AUG	64	3-5	10	11	Canc.
AUG	65	17-19	24	25	26
SEPT	66	1-3	8	9	Canc.
SEPT	67	14-16	23	24	28
OCT	68	5-7	7	8	Canc.
OCT	69	19-21	26	27	29
NOV	70	16-18	5	9	10

FIGURE 3.1

MAP OF RAPPAHANNOCK RIVER STATIONS

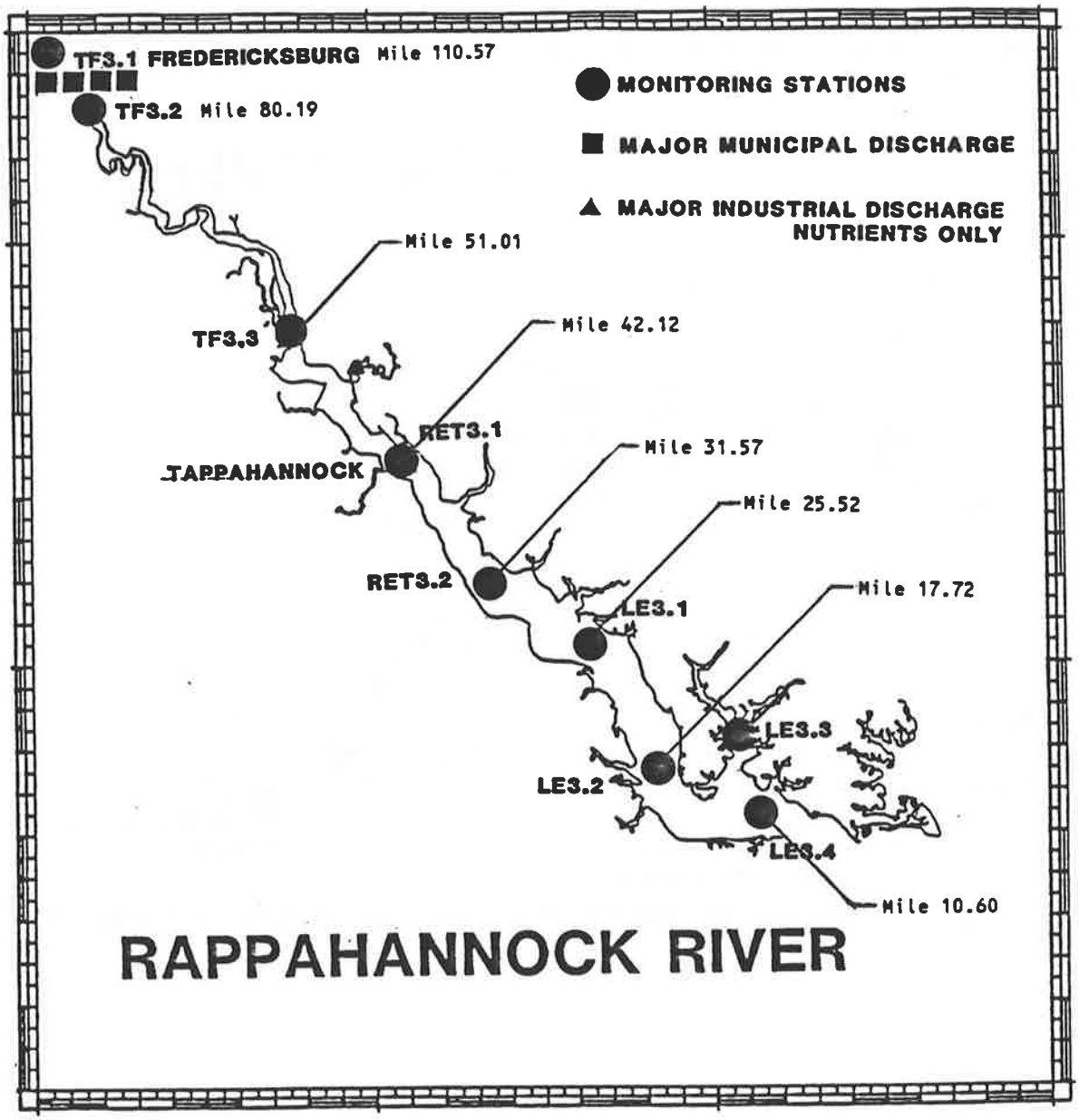


FIGURE 3.2

MAP OF YORK RIVER STATIONS

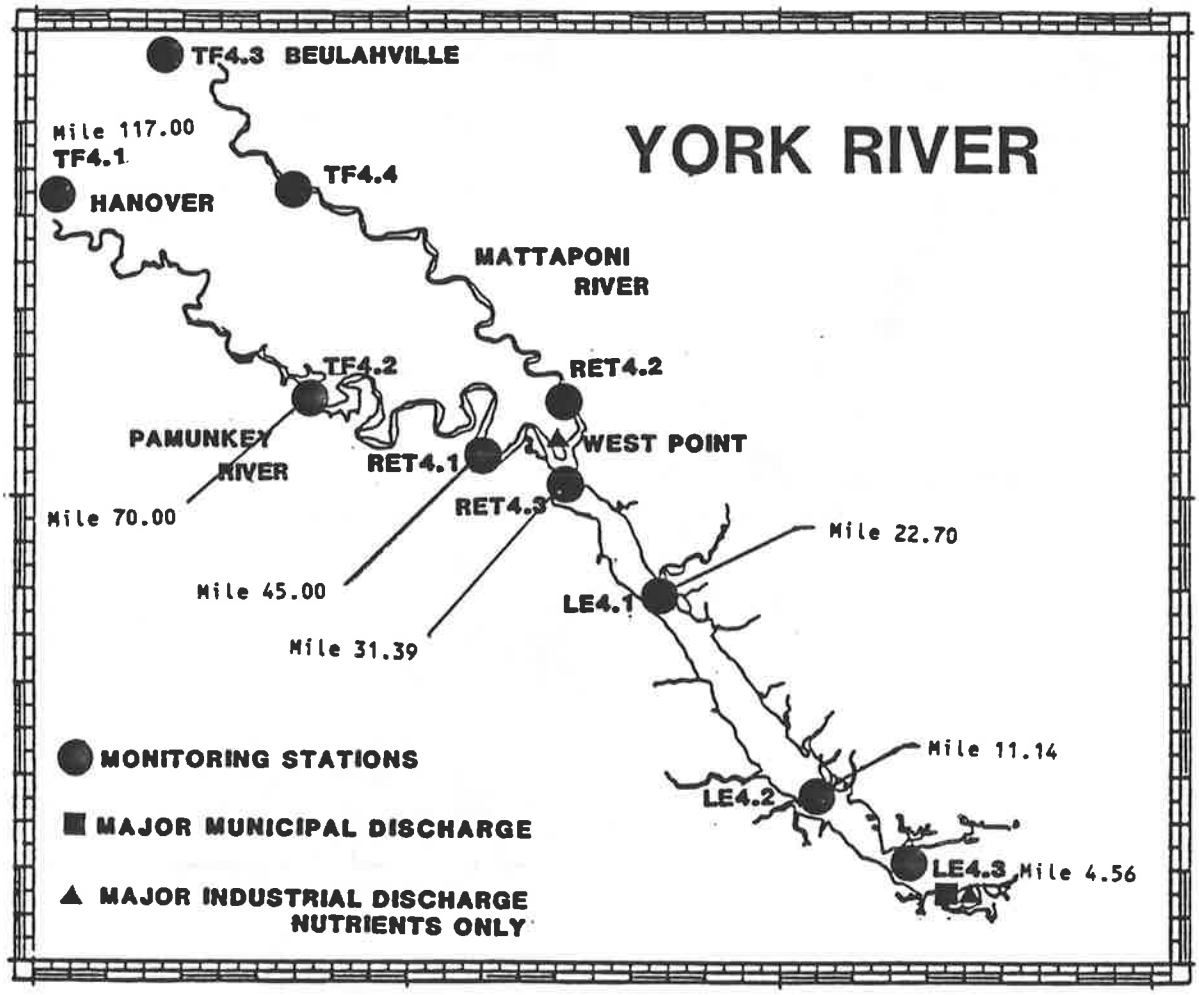


FIGURE 3.3

MAP OF JAMES RIVER STATIONS

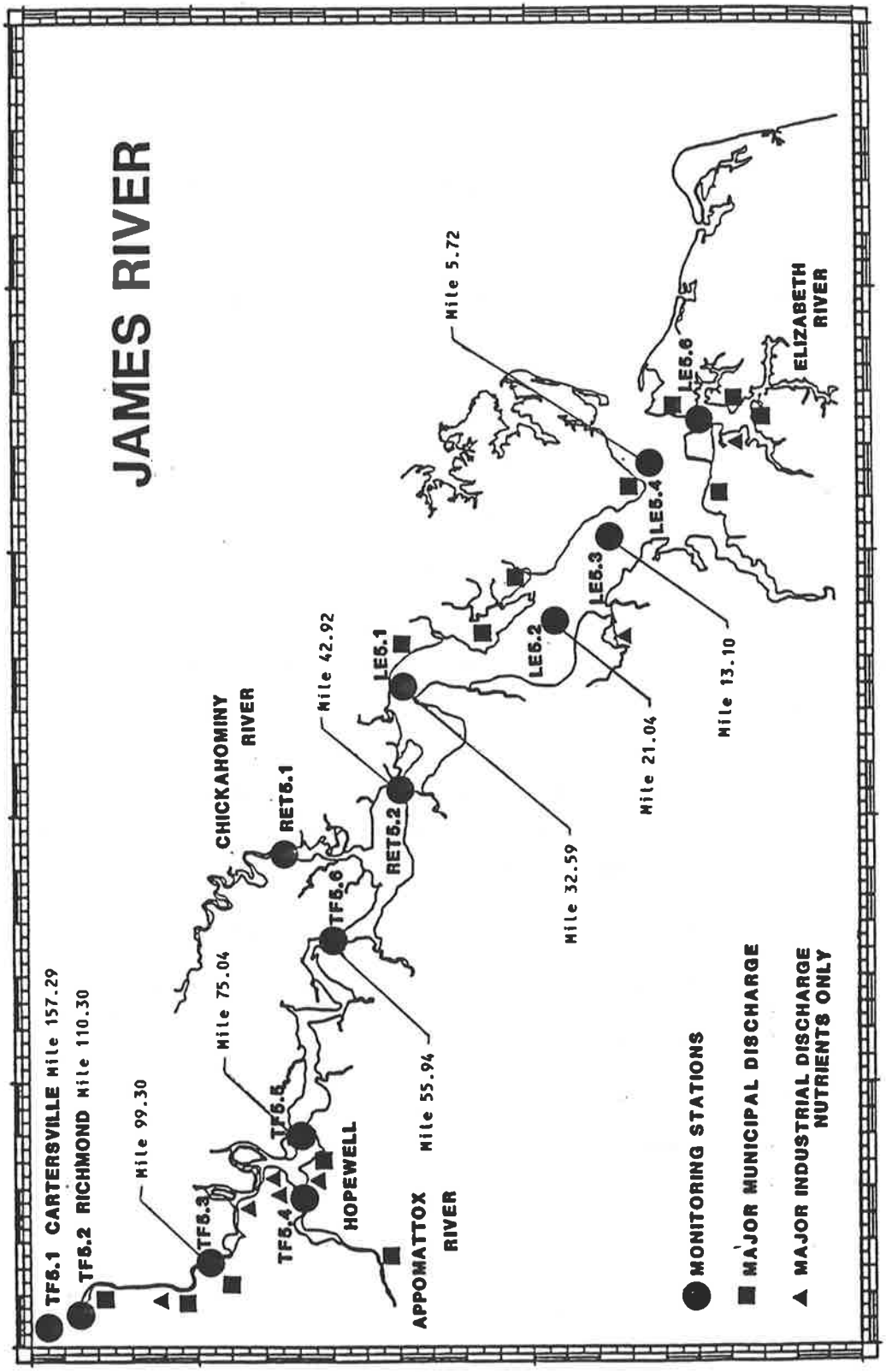


TABLE II

STATION, LOCATION, AND INFORMATION

Rappahannock River Basin

River	Sta. No.	STORET Code (River mile)	Location	Description
Rapp.	TF3.1	3-RPP110.57	Fredericksburg	Fall Line
Rapp.	TF3.2	3-RPP080.19	Port Royal	
Rapp.	TF3.3	3-RPP051.01	Buoy 40	Plankton, Benthos
Rapp.	RET3.1	3-RPP042.12	Buoy 10	Plankton, Benthos
Rapp.	RET3.2	3-RPP031.57	Buoy 16	
Rapp.	LE3.1	3-RPP025.52	Buoy 11	
Rapp.	LE3.2	3-RPP017.72	Near Buoy 8	Benthos
Corrotoman	LE3.3	3-CRR003.38	Buoy 6	
Rapp.	LE3.4	3-RPP010.60	Orchard Point	

York River Basin

River	Sta. No.	STORET Code (River mile)	Location	Description
Pamunkey	TF4.1	8-PMK082.34	Hanover	Fall Line
Pamunkey	TF4.2	8-PMK034.17	Whitehouse	Plankton, Benthos
Mattaponi	TF4.3	8-MPN054.17	Beulahville	Fall Line
Mattaponi	TF4.4	8-MPN029.08	Walkerton	
Pamunkey	RET4.1	8-PMK006.36	South of Lee Marsh	
Mattaponi	RET4.2	8-MPN004.39	Muddy Point	
York	RET4.3	8-YRK031.39	Buoy 57	Plankton, Benthos
York	LE4.1	8-YRK022.70	Buoy 44	Benthos
York	LE4.2	8-YRK011.14	Buoy 34	
York	LE4.3	8-YRK004.56	Buoy 26	Benthos

TABLE II (CONTINUED)

STATION, LOCATION, AND INFORMATION

James River Basin

River	Sta. No.	STORET Code (River mile)	Location	Description
James	TF5.1	2-JMS157.28	Cartersville	Fall Line
James	TF5.2	2-JMS110.30	Mayo's Bridge	Head of Tide
James	TF5.3	2-JMS099.30	Buoy 157	
Appomattox	TF5.4	2-APP001.53	Buoy 8	Mouth of river
James	TF5.5	2-JMS075.04	Buoy 107	Plankton, Benthos
James	TF5.6	2-JMS055.94	Buoy 74	
Chickahominy	RET5.1	2-CHK008.28	Shipyard Landing	
James	RET5.2	2-JMS042.92	Swann's Point	Plankton, Benthos
James	LE5.1	2-JMS032.59	Buoy 36	
James	LE5.2	2-JMS021.04	Buoy 12-13	Benthos
James	LE5.3	2-JMS013.10	Buoy 15	
James	LE5.4	2-JMS005.72	Buoy 9	Benthos
Elizabeth	LE5.6	2-ELI002.00	Buoy 18	

NOTE: Station numbers are intended to give some indication of the general salinity regime found at each station. A "TF" prefix denotes "tidal fresh" areas where salinity is generally negligible. The "RET" prefix is used for stations in the "river - estuary transition" zone where salinity is low and highly variable. The "LE" prefix is used for stations found in the "lower estuary" towards the mouths of the rivers where salinity is higher and less variable.

Two basic types of data are collected at each station: physical and chemical. Physical parameters measured at each station include a vertical profile of temperature, dissolved oxygen, salinity, and conductivity. These measurements are taken one meter below the surface and then every two meters downward through the water column until a depth of one meter above the sediment. A dissolved oxygen sample for Winkler titration and pH readings are also collected from the surface and bottom depths. A Secchi reading is taken to measure turbidity. Sampling is conducted directly from bridges at several stations located in the tidal freshwater region of the three rivers. This simplifies sampling but sometimes results in profiles and secchi readings being unavailable due to the height of the bridge above the water. A further factor limiting some of the analyses of this report is the lack of sufficient station coverage in sections of the tidal fresh Rappahannock. This problem has been rectified through the addition of several stations and these data will be reported on in future reports.

In addition to the physical parameters measured, samples are collected at one meter below the water surface and one meter above the bottom for nutrient analysis. The types of nutrient analyses conducted by the Virginia Division of Consolidated Laboratory Services (DCLS) are listed in Table III, along with detection limits and the EPA reference number for the analytical method. The analytical procedure for Ammonium/Ammonia determines the sum of Ammonium plus un-ionized Ammonia. The relative contribution of each form is a function of pH and temperature. Under normal conditions the major form is Ammonium, therefore this report uses the term 'Ammonium'. Chlorophyll samples were analyzed by VWCB staff.

TABLE III

LISTING OF NUTRIENT ANALYSES

NUTRIENT	DETECTION LIMIT (MG/L)	EPA METHOD[1]
Total Kjeldahl Nitrogen (TKN)	0.1	351.2
Nitrate (NO3 as N)	0.04	353.1
Nitrite (NO2 as N)	0.01	353.2
Ammonia/Ammonium (NH3/4 as N)	0.02	350.1
Total Phosphorus (TP as P)	0.01	363.4
Total Dissolved Phosphorus (TDP as P)	0.01	365.1
Orthophosphate (PO4 as P)	0.01	365.3
Total Organic Carbon (TOC as C)	1.0	415.1
Silica (Si as SiO4)	0.1	370.1
Chlorophyll-a	0.0001	D3731-79[2]

(1) Methods for Chemical Analysis of Water and Wastes, EPA, 1979.

(2) 1982 Annual Book of ASTM Standards, ASTM, 1982.

IV. PHYSICAL VARIABLES

CIRCULATION

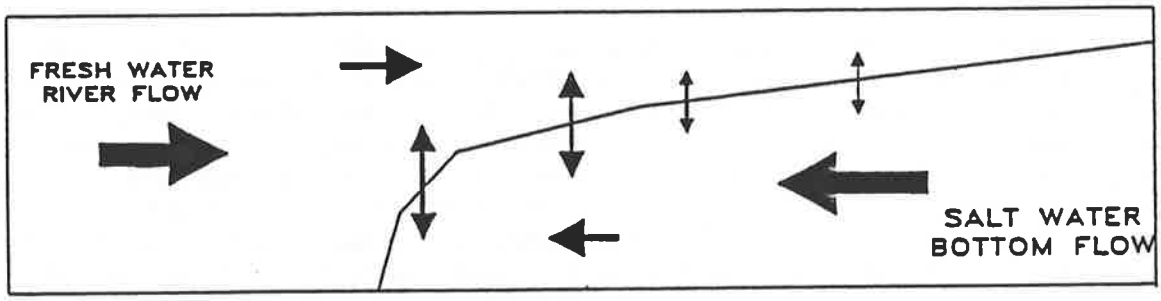
A rise in sea level since the last ice age flooded large river valleys and created the Chesapeake Bay and its tributaries. The geological feature called the fall line separates the free flowing river from the tidally influenced portion of the river. As the freshwater flows toward the mouth of each river it encounters saline water intruding up river from Chesapeake Bay, creating an estuarine environment. In general, the tributaries can be described as partially mixed estuaries with a less dense, lower salinity surface layer flowing downriver over a more dense, high salinity bottom layer which has a net flow upstream (Figure 4.1).

Salinity is the measure of dissolved salts in waters. Units are measured in parts per thousand (grams of salts per kilogram of water) expressed as ppt. All natural waters have some salts and Chloride is typically the predominate salt. Specific definitions are used to describe salinity conditions found in the Chesapeake Bay. Fresh waters are less than 0.5 ppt. Oligohaline waters are 0 to 3 ppt; mesohaline waters are 3 to 17 ppt. Waters of 17 to 30 ppt are polyhaline. Greater than 30 ppt are considered marine waters.

The two layers of water have two important dimensions, longitudinal and horizontal, along which mixing and diffusion of materials takes place. Intermixing is due to salinity differences and, to a lesser extent, temperature. The major gradient is the longitudinal direction along the length of the river, where freshwater mixes with incoming saltwater. The longitudinal density gradient is the force that drives the two-layered estuarine circulation. The strength of the longitudinal gradient is dependent on the length of the mixing zone between fresh and saline waters and the magnitude of the increase in salinity along the river's length. A strong longitudinal gradient (i.e. large salinity change over a short distance) may result in a strong net nontidal flow up the estuary in the bottom layer and may dramatically influence nutrient and dissolved oxygen dynamics.

FIGURE 4.1

DIAGRAM OF ESTUARINE FLOW



TURBIDITY MAXIMUM

The area of mixing at the upriver limit of saltwater intrusion is often called the 'salinity transition' zone. This area of the river experiences the most dramatic changes in salinity in response to tides, changing streamflow, and climatic events. In this area of increasing salinity much of the material suspended in the freshwater layer flocculates and settles into the bottom layer and is then transported back upriver where it is reintroduced into the surface layer or settles to the sediment. This creates an area of high turbidity, greater resuspension and increased deposition rates; thus an alternative name is 'turbidity maximum' zone. As a result, the estuarine zone becomes a trap for nutrients, sediment, and toxics. This characteristic is important in our understanding of the relationship between the Bay and its tidal tributaries.

Another important gradient in the estuarine system is in the vertical direction. The vertical density gradient is often termed stratification. The interface between the surface and bottom layers of the water column is called the pycnocline. It is defined as the area in the water column with the greatest vertical rate of change in density, usually the depth which exhibits the greatest vertical change in salinity. Stratification is typically strongest midway between the upriver extent of salinity intrusion and the river mouth. It is also stronger during low slack water and neap tides when tidal mixing forces are reduced and during periods of high freshwater flows or warming of surface waters. Winds and storms, strong tides, and cooling temperatures can result in a decrease or break up of vertical density stratification. In strongly stratified systems vertical mixing is inhibited and exchange of nutrients and dissolved oxygen between the surface and bottom waters is limited.

The two major forces responsible for the salinity structure of the tributaries are freshwater streamflow and sea level fluctuations. Freshwater input is highly variable between the different river basins and is episodic in nature, but is relatively easy to measure with gauging stations. The seasonal pattern of high freshwater flows in the late winter/early spring and low flows in the late summer/early fall are reflected in the seasonal changes in salinity. Sea level exhibits a low in January and a high in September, but hurricanes and 'Northeaster' storms can create short term local rises in sea level. Superimposed over the fluctuations in streamflow and sea level are the tidal cycles. The Bay and its tributaries experience twice daily tidal fluctuations which are modified by a fortnightly cycle of stronger and weaker tidal forcing (spring/neap cycle). In order to reduce the confounding influences of tidal cycles, most cruises are conducted near low slackwater.

The Tributary Water Quality Monitoring Program collects both temperature and salinity data, which are important in defining density gradients and seasonal patterns that control many biological activities. In addition to data collected under this program, other sources of data are useful in interpreting the monitoring results. Long-term freshwater discharge data for the fall line stations are collected by the U.S.G.S. This data is valuable in interpreting not only streamflow data and its effect on salinity but also the contribution of nutrients from above the fall line. Within the discussion of streamflow for each river, the long-term median monthly flows are compared with the mean monthly flow for the months of October 1986 through November 1987. The long-term median streamflow was used instead of the long-term mean since medians are less influenced by extreme events, such as major hurricanes. A source of freshwater inflow not measured by the fall line gauges is the runoff from the drainage basins below the fall line.

CLIMATE[2]

After two years of severe drought conditions, precipitation in 1987 was generally at or above normal. October and November, 1986, experienced normal levels of precipitation, signaling the end of the 1986 drought. Four to seven inches of rain fell during December, 1986. In January, two separate storms, on the 22nd and the 25th each dumped up to 12 inches of snow across the state. The state received an average of 40 inches of snow, making January 1987 one of the snowiest on record. February and March recorded slightly below normal precipitation. April experienced several storm events, resulting in heavy rainfall and flooding. On April 1st, over 30 inches of snow fell in the upper elevations of southwest Virginia. Several storms approached the state from the south during mid month, resulting in heavy rains from April 15 through 18. These rains produced substantial flooding in most river basins. The total amount of melted precipitation averaged over the entire state (7.4 inches) was one inch greater than the previous record precipitation for April. The central and southwest areas of the state recorded over twice (8-9 inches) the normal rainfall for April. The total snow fall from January through April set a new state record (when averaged over entire state). Rainfall from May through August was below normal. Rainfall associated with a pair of weak tropical storms on September 7th and 8th, ended the short summer deficit in precipitation. In September the state averaged 7.85 inches of rainfall, the fifth highest on record. Much of the rain was concentrated in the Roanoke Valley and Albermarle and Green Counties. Charlottesville reported almost 18 inches of rain in September.

The rain associated with late summer/early fall tropical storms and hurricanes is very important to Virginia. The droughts of 1985 and 1986 would have been much worse without the multiple storms during the fall of 1985, and the August 1986 hurricane. On average, 10 to 20 percent of the rain in August is due to hurricanes. From July to November 1985, 60 - 100 percent of the rainfall in Virginia was due to hurricanes and tropical storms. These late summer/early fall storms greatly influence the hydrology and water quality of the receiving streams and rivers and are also very important to the water quality of the lower Bay.

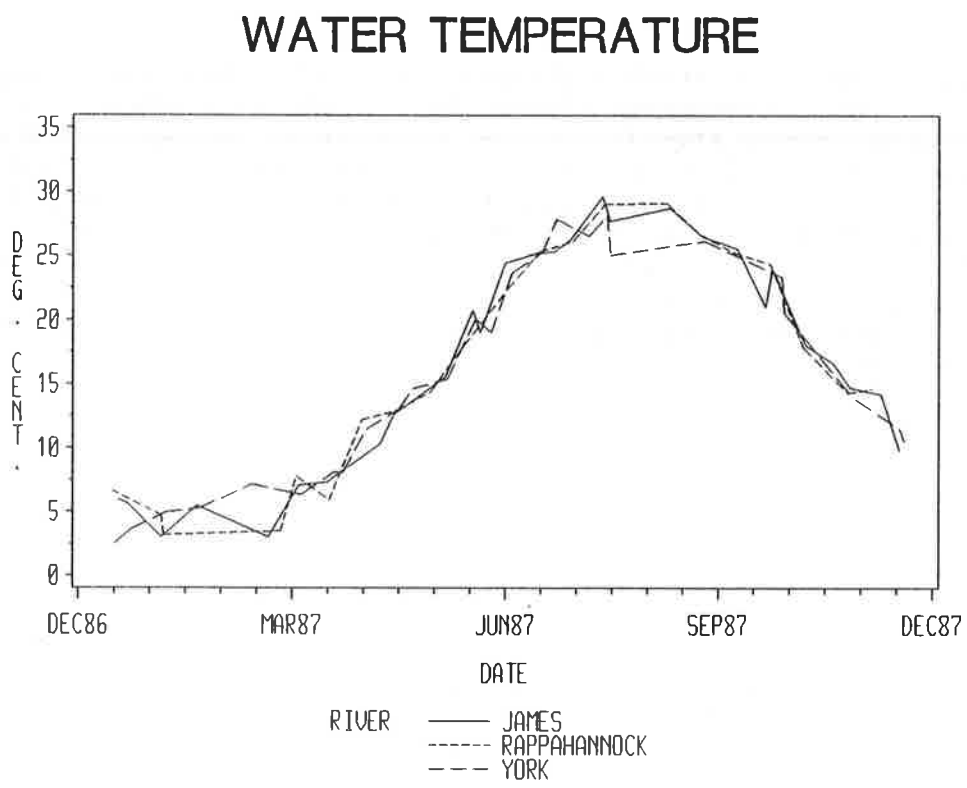
Air temperature is an important component of the climate, directly influencing water temperature and biological processes. During 1987, Virginia experienced a very cold, snowy winter and early spring, a very hot summer, and a cool fall. Temperatures in January were 1-4°F below the normal, continuing an eleven year trend of increasingly colder temperatures in January. February was also below normal but March was slightly above normal. April was 3.9°F below normal, coldest on record. Starting in May temperatures averaged well above normal. Temperatures from June through August were more than 2.0°F above normal, which is above the 90 percentile range. The summer months of 1987 were the fourth hottest on record. The fall started off cool, with October being 5.87°F below normal, an all time record low for this month.

2 Information summarized from Virginia Climate Advisory, Office of State Climatologist, Clark Hall, Univ. of Va., Charlottesville, VA 22903.

WATER TEMPERATURE

Seasonal fluctuations in water temperature in each river are depicted in Figure 4.2. Differences in sampling dates and number of stations are responsible for some of the differences between the rivers, but are overshadowed by the seasonal pattern in temperature. Tidal freshwater experiences wider variations in temperature than the estuary, which is influenced by the more stable Bay waters. The water temperature cycle typically has a minimum in January and a maximum in late July or August.

FIGURE 4.2



Annual seasons were defined to allow comparisons within years and between years. The traditional three month seasonal divisions do not reflect the actual temperature changes in the rivers due to the time lag between air temperature and water temperature. Water tends to warm more slowly in the spring and cool more slowly in the fall than does the atmosphere. There are also other factors such as streamflow and hypoxia that are characteristic of certain seasons, but are not accounted for by traditional seasons. The seasonal definitions used in this report are based on water temperature. The average temperature for each individual cruise was calculated and then each set of river cruises was classified as a particular season. Table IV describes which months were included in each season. The same definitions for the seasons based on temperature were used in previous reports. Due to annual variations in temperature patterns, the same seasons in different years may contain data from slightly different months.

Winter cruises are those with average temperatures below 10°C. This included December, 1986 through January, 1987. Spring is the period of rapid warming from 10°C to 24°C, which occurred from March through early June. Summer included those cruises which had average water temperatures above 24°C, which encompassed mid June through early September. Fall was defined as the period of rapid decrease in temperature from 24°C to 10°C, occurring from mid September to November. Data for December 1987 will be evaluated as part of the winter season in the 1988 report.

TABLE IV

Definition of Seasons

SEASON	NUMBER OF CRUISES	MONTHS INCLUDED
Winter	2	Dec. 1986 - Feb. 1987
Spring	7	March - early June
Summer	5	mid June - early Sept.
Fall	4	mid Sept. - Nov.

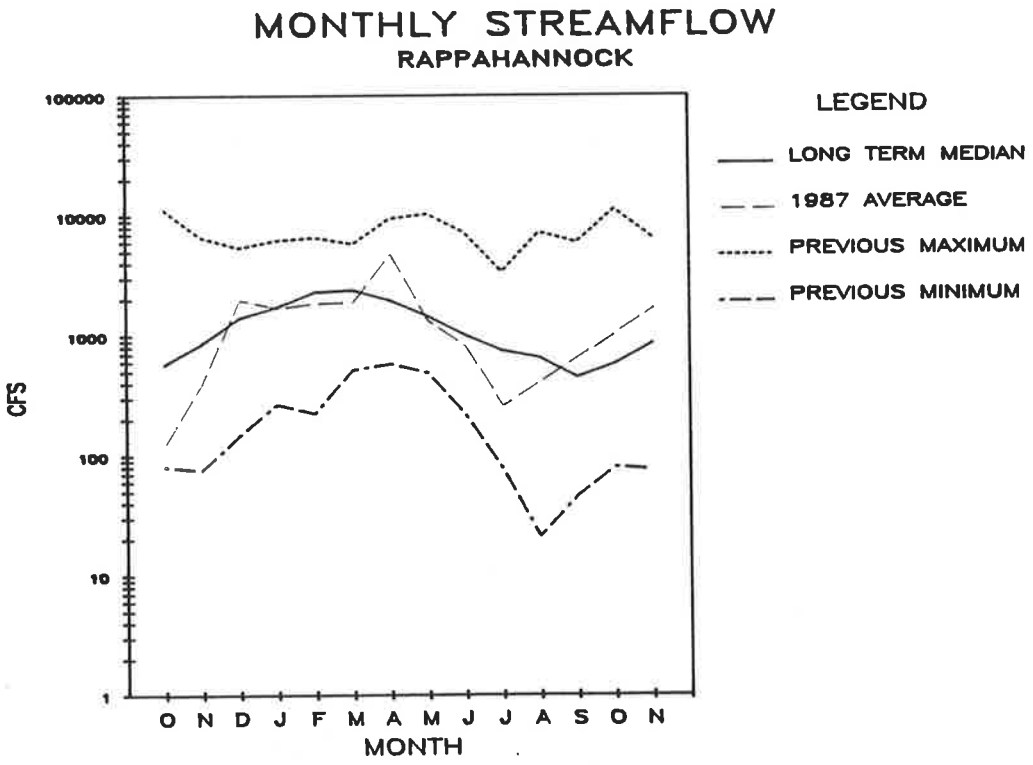
RAPPAHANNOCK RIVER

RIVER DISCHARGE - RAPPAHANNOCK

The fall line station on the Rappahannock is slightly upstream of Fredericksburg, Virginia, and measures drainage from 1,596 square miles. This station was established in 1910 and has a long-term median discharge of 1,631 cubic feet per second (cfs). The long-term median flow in the Rappahannock exhibits a seasonal peak in streamflow of approximately 2,000 cfs from February through April, then declines to below 750 cfs from July through October (Figure 4.3). The two previous years experienced very dry conditions but streamflows were generally near or above normal during most of 1987.

The extremely low flow conditions of 1986 are reflected in the October 1986 streamflow, the third lowest on record. The snows in late January resulted in slightly above normal streamflow for this month. In April, several storm events resulted in a high monthly average. The prolonged rains during the middle of the month resulted in moderate flooding, which crested at 30,100 cfs on April 16th. Streamflows decreased steadily during the dry months of May through August.

FIGURE 4.3



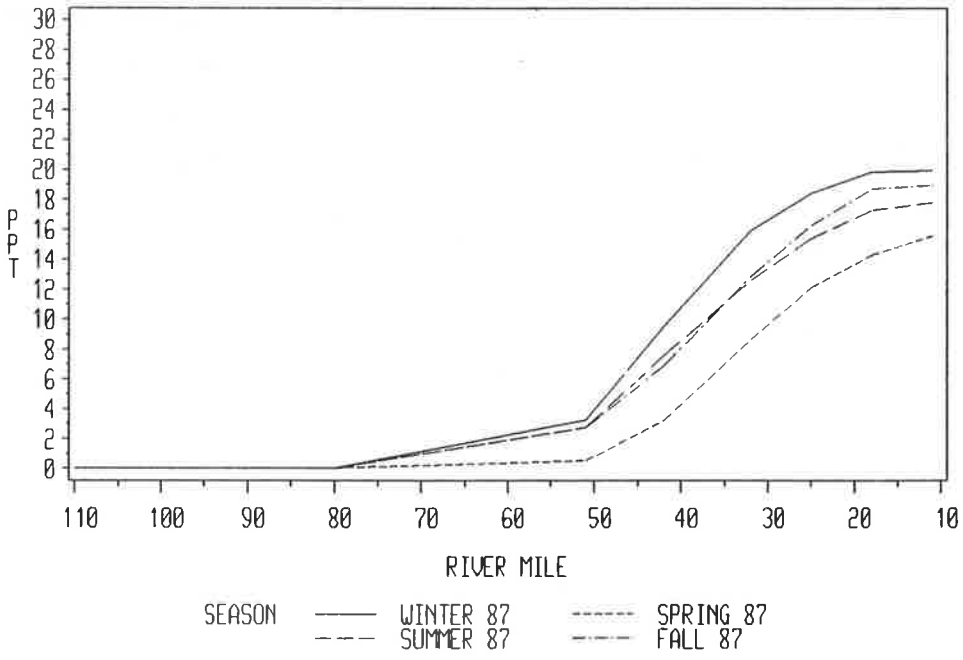
SALINITY - RAPPAHANNOCK

Seasonal changes in the upriver extent of salinity intrusion are presented in Figure 4.4. Salinity intrusion, defined as the upriver limit of detectable salinity (0.5 ppt), varies in response to the seasonal fluctuations in streamflow. The seasonal concentration of salinity at each station was calculated as the arithmetic average of all salinity data collected at that station during each season. Data for the upper tidal Rappahannock (miles 50 - 80) is limited; thus the true extent of salinity intrusion is not well defined for 1987. The extent of salinity intrusion appeared limited to between mile 50 and 60, which is not as far upriver as in previous years. Salinity was very low during the spring, reflecting the above normal rainfall and streamflows. Summer and fall had similar salinity distributions, both of which were approximately 4 ppt higher than in the spring. Winter had highest salinity readings.

FIGURE 4.4

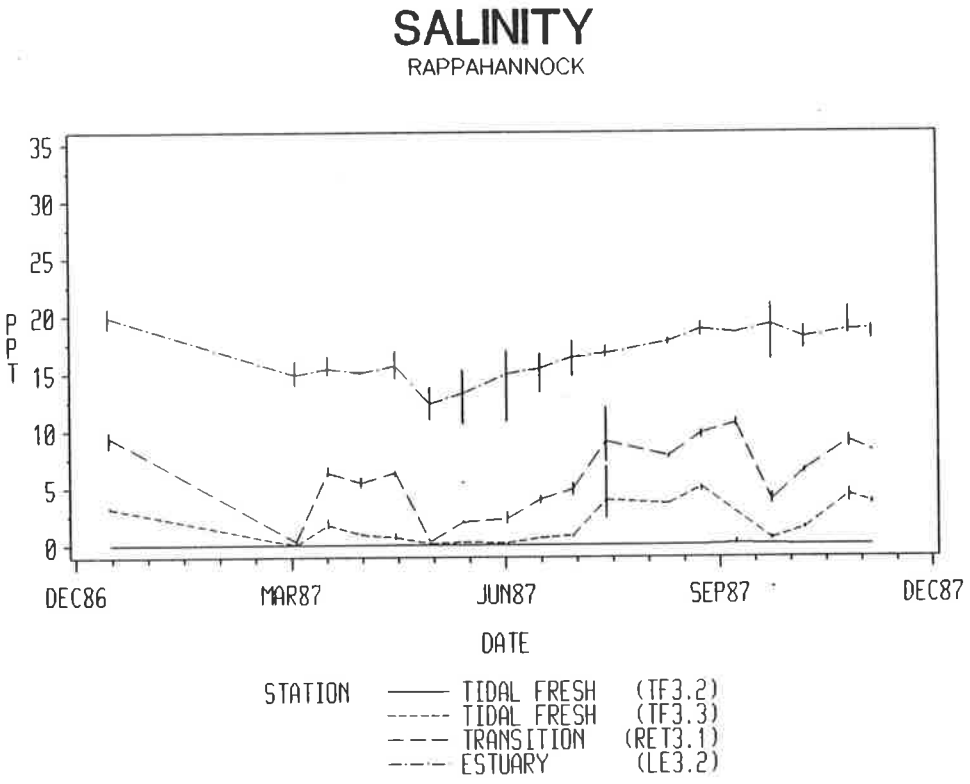
SALINITY

RAPPAHANNOCK



Temporal changes in salinity for individual stations are shown in Figure 4.5. The tidal fresh station TF3.2 experienced salinities ranging from zero during high flow events, to a maximum of .50 ppt during the fall. At the transition zone station, RET3.1, salinity averaged from 0.1 to 10.0 ppt, thus making it oligohaline and mesohaline. High streamflows in early March, mid April, and mid September resulted in sharp decreases in salinity at this station. The estuarine station ranged from 12 - 16 ppt in the spring and 15 - 19 ppt in the summer and fall. All Estuarine stations were predominately mesohaline during the winter and spring, but as streamflow decreased in the summer, polyhaline conditions (18+ ppt) were experienced at the stations nearest to the mouth of the river. Except for the effects of high flow periods resulting from rain events, all stations showed a general decline in salinity from the winter through the spring, then a slow but steady increase through the summer and fall.

FIGURE 4.5



YORK RIVER

RIVER DISCHARGE - YORK

In the York River Basin, streamflow is measured at Hanover on the Pamunkey and at Beulahville on the Mattaponi. The Pamunkey gauge measures drainage from 1,081 square miles and the Mattaponi River gauge measures drainage from 601 square miles. These long-term gauging stations were established in 1942. The long-term median streamflow for the Pamunkey and Mattaponi are 990 cfs and 553 cfs, respectively. The streamflow gauging station on the Mattaponi river was dismantled in September, 1987, thus ending the streamflow records for this station.

Previous reports in this series have shown that baseflows are very similar between the Pamunkey and the Mattaponi, but they respond differently to storm events. While an increase in discharge in both rivers is seen during a storm event, the Pamunkey responds quicker and with much higher flows than the Mattaponi. As a result, storm crests on the Pamunkey are narrower, more intense and peak sooner than those of the Mattaponi.

Long term records show that streamflow peaks in February and March at over 800 cfs in the Mattaponi (Figure 4.6) and over 1,500 cfs in the Pamunkey (Figure 4.7). The seasonal period of low streamflow is usually July through October with flows below 400 cfs in the Pamunkey and below 300 cfs in the Mattaponi. The rising streamflows of November and December 1986 signaled the end to the 1986 drought. Storm activity was much more frequent in 1987 than during the previous two years. Streamflows from December through March were near or above normal. The April streamflow was the 3rd highest recorded for the Pamunkey, and the 4th highest for the Mattaponi. Streamflows remained very high through the remainder of the spring and into the summer. The below normal precipitation during the summer resulted in moderately low flows during August. The storm events in September resulted in monthly streamflows in the Pamunkey slightly above normal. The Pamunkey continued to show near normal streamflow throughout the rest of the fall. Data were not available for the Mattaponi river after August. In summary, compared to the previous two years, 1987 had much higher streamflows, especially in the spring and early summer.

FIGURE 4.6

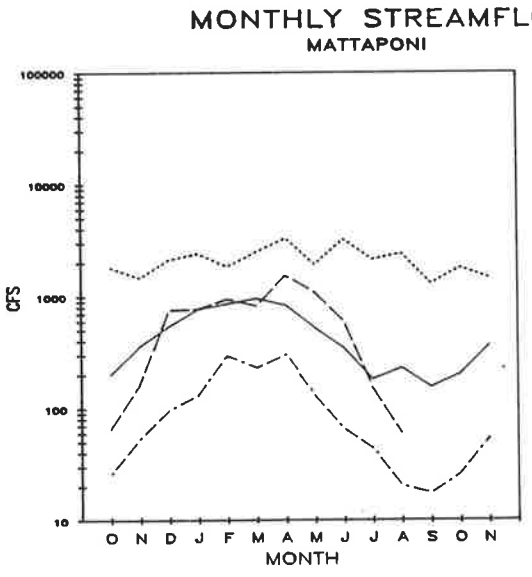
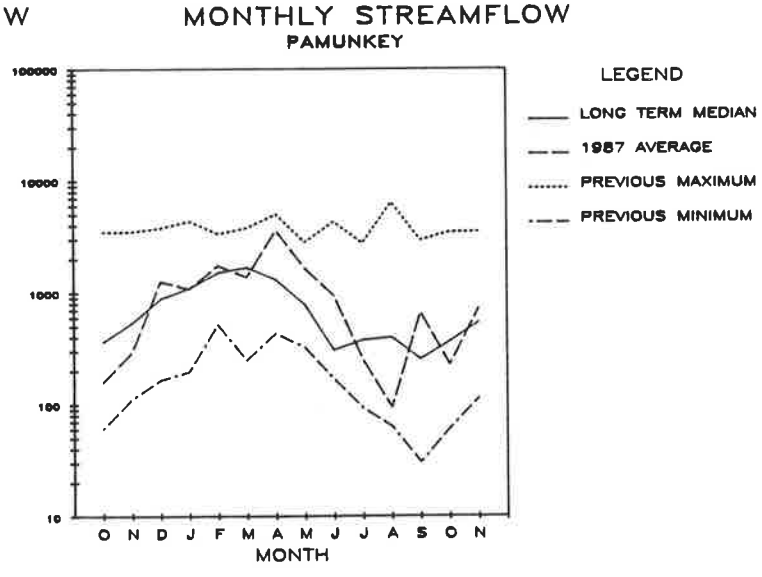


FIGURE 4.7



SALINITY - YORK

Above normal streamflows from April through June resulted in salinity concentrations approximately four ppt lower in the spring than the summer or fall (Figure 4.8). Mile 45 was the upriver limit of salinity intrusion during the spring, but the intrusion progressed upriver to near mile 60 by the fall. The fall exhibited a slight increase in salinity over the summer.

Figure 4.9 presents salinity data for several selected stations in the York and Pamunkey rivers. Most stations exhibited stable low salinities during the spring, with a general increase in the summer and leveling off in the fall. Station TF4.2 on the Pamunkey was strictly tidal freshwater. The transitional station, RET4.1, is located several miles upriver of West Point on the Pamunkey. Oligohaline conditions predominated at this station during the spring. During the summer and fall, lower streamflows resulted in salinities ranging from 5 to 10 ppt (low mesohaline). The 'estuarine' stations are composed of mesohaline and polyhaline stations. Station LE4.1 exhibited mesohaline salinities (11 - 17 ppt) while stations LE4.2 and LE4.3 were generally polyhaline with seasonal averages between 17 and 25 ppt. The mesohaline and polyhaline stations exhibited very strong vertical stratification during the spring, as indicated by large vertical bars in Figure 4.9. Early March, which experienced high streamflow, exhibits high vertical stratification. The period of greatest vertical stratification was recorded after the record rainfall and flooding in April. During the summer and fall, the vertical stratification is almost absent.

FIGURE 4.8

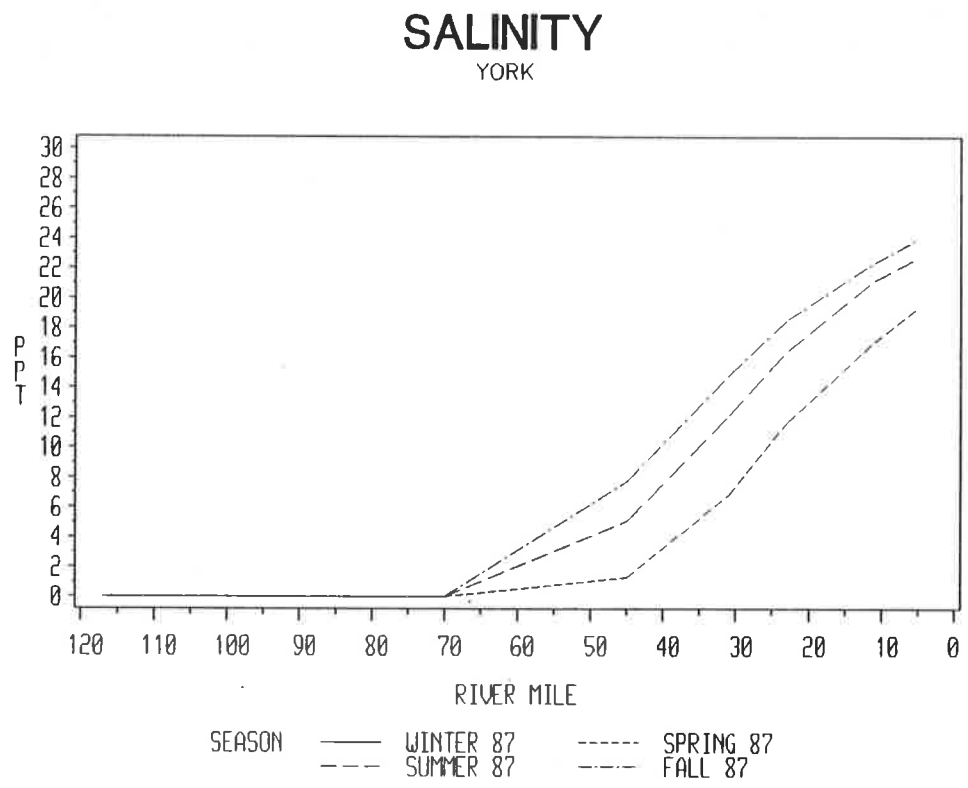
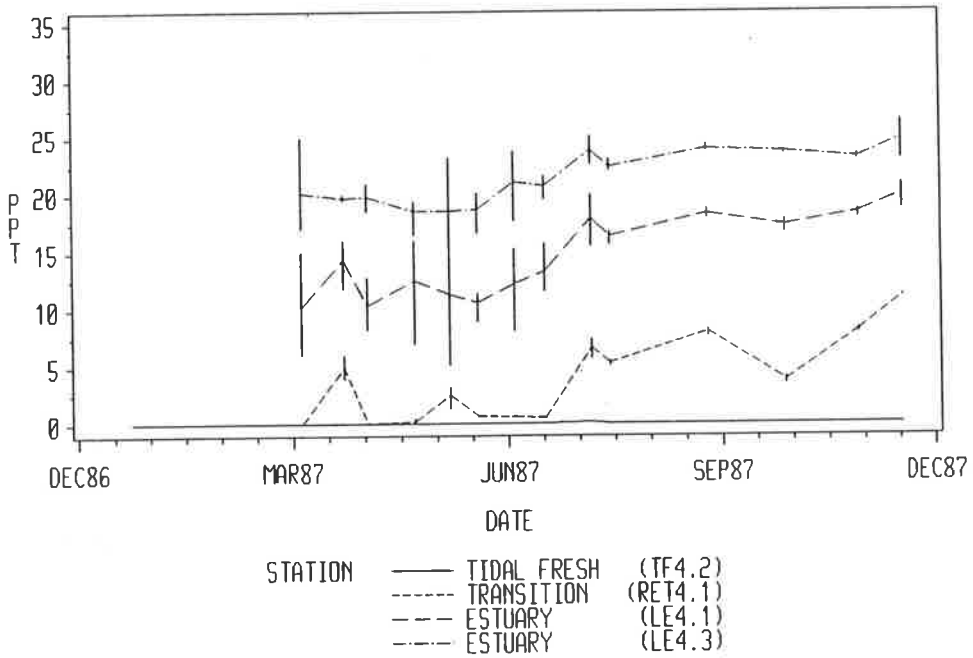


FIGURE 4.9

SALINITY

YORK



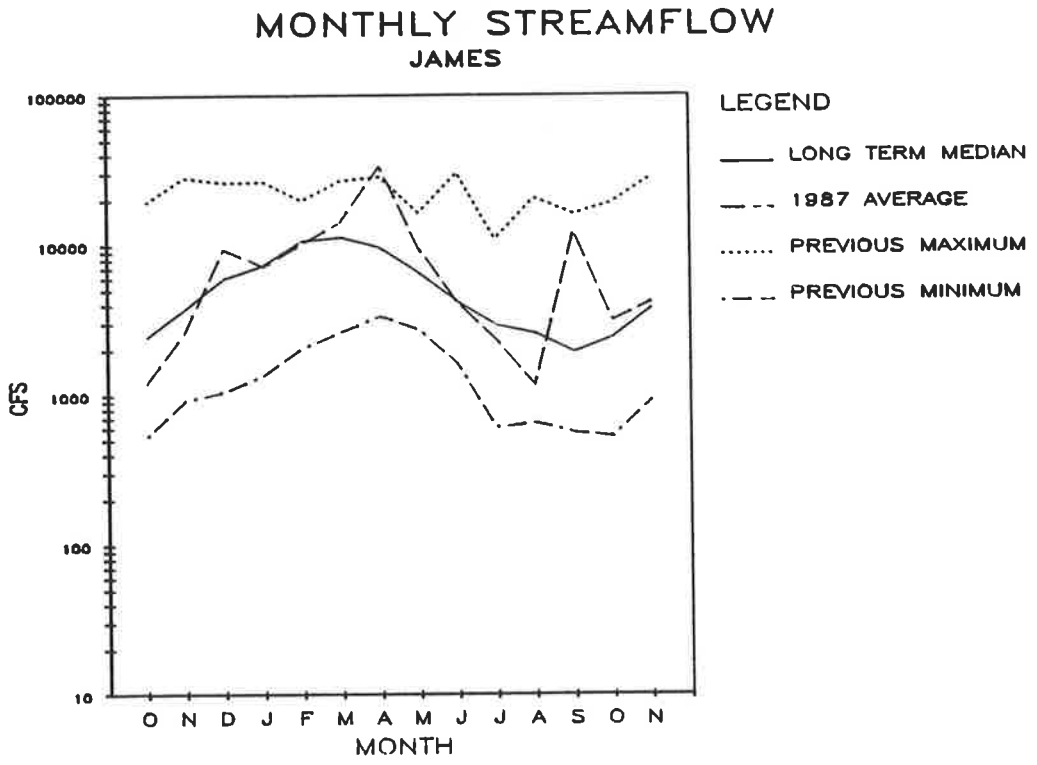
JAMES RIVER

RIVER DISCHARGE - JAMES

The USGS established the fall line gauge at Cartersville, Virginia, in 1923. It is located at mile 157, approximately 50 miles upstream from the actual fall line in Richmond, Virginia (mile 110). The James at Cartersville drains 6,257 square miles and has a long-term median flow of 6,433 cfs. The long-term median streamflow exhibits a seasonal peak of 10,000 to 12,000 cfs during late winter/early spring, and less than 4,000 cfs from July through November (Figure 4.10).

In 1987, the James exhibited the same general pattern of streamflow as observed in the other rivers: near or above normal during the winter and spring, a short period of low streamflow in August, then higher streamflows in September. Two major storm events, the prolonged mid April storms and the weak tropical storm in September, resulted in substantial increases in streamflow. Since the rainfall associated with these storms was concentrated in the southwest and central portion of the state, the James river basin was more impacted then either York or Rappahannock river basins. The monthly average streamflow for April (33,500 cfs) exceeded the previous highest monthly average by 5,000 cfs. The actual storm crest peaked at Cartersville on April 18th, at approximately 134,000 cfs. The September storm crest peaked on the 9th, at approximately 102,000 cfs. In September the monthly average streamflow was the fifth highest recorded for that month. This year was more consistently influenced by storm runoff and its associated NPS nutrient loadings than the previous two drought plagued years.

FIGURE 4.10



In addition to the freshwater input from above the fall line of the James, the tidal estuary also receives freshwater from the Appomattox River. The Appomattox's long-term median discharge is 1,332 cfs. Streamflow was above normal from December, 1986 through April, 1987. The storm events in April created near record streamflows. In August, monthly average streamflows were the lowest recorded for that month. The storm activity in September eliminated the streamflow deficit, and flows remained high for the remainder of the fall. During 1987, the Appomattox appeared to exhibit greater variation from its long-term median streamflow than the James.

SALINITY - JAMES

Changes in salinity generally reflect the patterns of freshwater streamflow. Based on analysis of slackwater data, salinity in the James typically increases by 4 ppt from early spring through late summer (Bradshaw and Kuo, 1987, Salinity Distribution in the James Estuary). Salinity intrusion varies from mile 33 during March and April to mile 53 during August through October. The long-term average extent of salinity intrusion is 44 $\pm$ 12 miles at low slack water and 50 $\pm$ 11 miles during high slack water (Bradshaw and Kuo, 1987).

The seasonal extent of salinity intrusion in 1987 is depicted in Figure 4.11. The upriver extent of salinity intrusion during the spring was approximately 45 miles. During the summer and fall, intrusion ranged between mile 50 and 60. The James experienced a sharp increase in salinity between spring and summer followed by a slight decline in the fall. Compared with the long-term average reported by Bradshaw and Kuo, the salinity intrusion in the James was near normal during 1987.

FIGURE 4.11

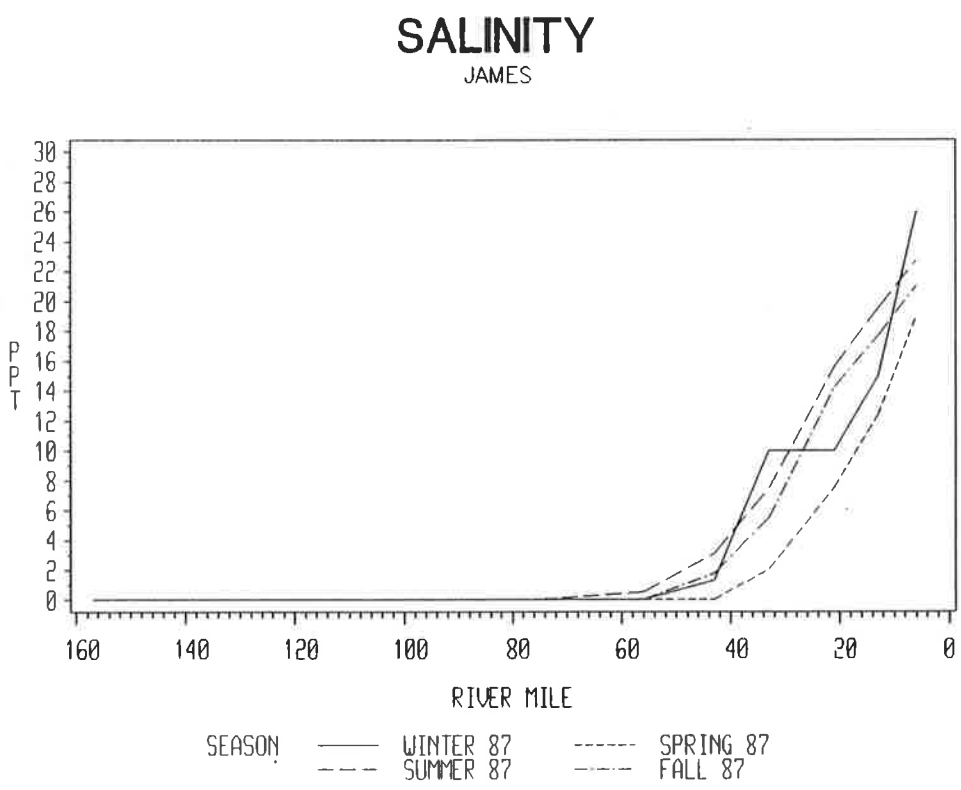
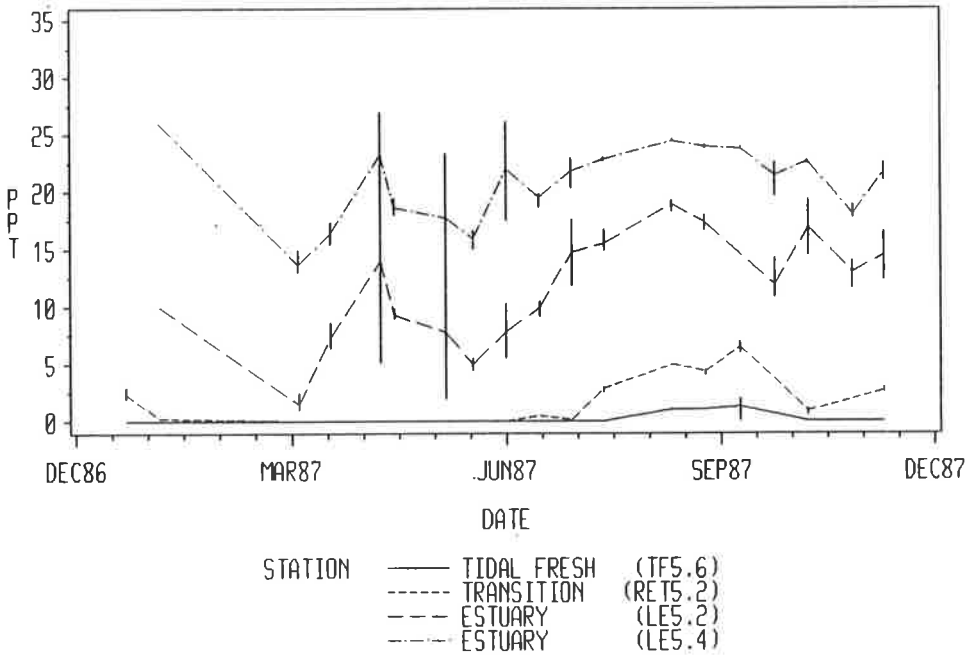


Figure 4.12 presents information for several selected stations. Station TF5.6 is located at mile 56, which during typical low flow conditions is the station furthest upriver that salinity is detected. During 1987, this station exhibited salinities of up to 2 ppt during August and early September. The station located between Jamestown and the Chickahominy (RET5.2) exhibited freshwater and oligohaline conditions (averaging 0-5 ppt) with salinities ranging from 0 ppt during the winter and spring, to maximum of 7.0 ppt in the late summer. The estuarine stations have average seasonal salinities ranging from 2-7 ppt at LE5.1 to 19 - 22 ppt at LE5.4. Station LE5.2 exhibited the largest variation in salinity, with a range from 0.9 to 20.0 ppt. Both stations also exhibited a large vertical gradient in salinity as depicted by the vertical bars in Figure 4.12; indicating strongly stratified conditions. Vertical stratification was most apparent in the spring due to high streamflows. During the low flows of the summer months vertical stratification became very weak. The estuarine stations in the lower James ranged from 2.5 ppt through 25 ppt.

FIGURE 4.12

SALINITY

JAMES



RIVER COMPARISONS

STREAMFLOW

The seasonal and episodic patterns of streamflow contribute to the characteristics of each of Virginia's tidal tributaries and their impacts on the Chesapeake Bay. The York and Rappahannock combined contribute only one fifth as much freshwater to the Bay as does the James. The James in turn contributes less than 20 percent of the total freshwater input to the Bay, the majority coming from the Susquehanna and Potomac rivers. While the fluctuations in streamflow in the Virginia tributaries may have a relatively minor impact on the Bay, the seasonal and annual changes have profound impacts within the tributaries themselves. In turn, the Bay as the source of the saline waters to the tidal tributaries can profoundly influence the water quality of the saline portions of the tidal rivers.

The summer and fall of 1986 streamflows were significantly below normal, but by early 1987, streamflows were near or above normal for most of the state. Heavy rains in April, especially in the southwest area of the James river basin, resulted in flooding conditions. May through August had below normal rainfall, resulting in extremely low streamflows by August. During September, heavy rainfall produced moderate flooding and brought streamflows up to normal levels for the remainder of the year. The rainfall associated with the September storms was located in the southwest and central mountain areas of the state, consequently the York River did not exhibit as intense flooding as the James.

SALINITY

Comparisons of the winter salinity conditions are not possible due to the lack of data in the York River. In the spring, the York and Rappahannock exhibited similar longitudinal salinity distributions (Figure 4.13). As observed in previous years, the longitudinal gradient in salinity in the James was stronger than in the other tributaries, i.e. salinity increases faster over a shorter distance as compared to the other rivers. This results from a combination of higher freshwater discharge of the James and the higher salinity of the Bay water at its mouth. The lower salinity at the mouth of the Rappahannock reflects the lower salinity of the central Chesapeake Bay in contrast to the higher salinities in the lower Bay. All rivers increased in salinity during the summer, but remained the same relative to each other (Figure 4.14). Also, salinity intrusion extends further upstream than in the spring, and the longitudinal gradient is not as strong in the James River. During the fall, the York shows an increase in salinity, the Rappahannock remains similar to the summer, while the James shows a strong decline in salinity (Figure 4.15). These changes reflect variations in the impacts of the fall storms.

In summary, since the James is influenced by Bay water of higher salinity and has higher streamflows than the other rivers, it has the strongest vertical and longitudinal salinity gradient. The York becomes stratified during neap tides, but becomes well mixed after spring tides. The Rappahannock has comparatively weak longitudinal and vertical salinity gradients, but can experience strong vertical gradients during high streamflow periods. Vertical stratification in the Rappahannock breaks down somewhat during the spring/neap cycle and storm events, but not to the extent seen in the York. These vertical and longitudinal salinity gradients are very important in determining the biological communities that inhabit the rivers, as well as the ecological processes that determine the water quality.

FIGURE 4.13

SALINITY

ALL RIVERS – SPRING 1987

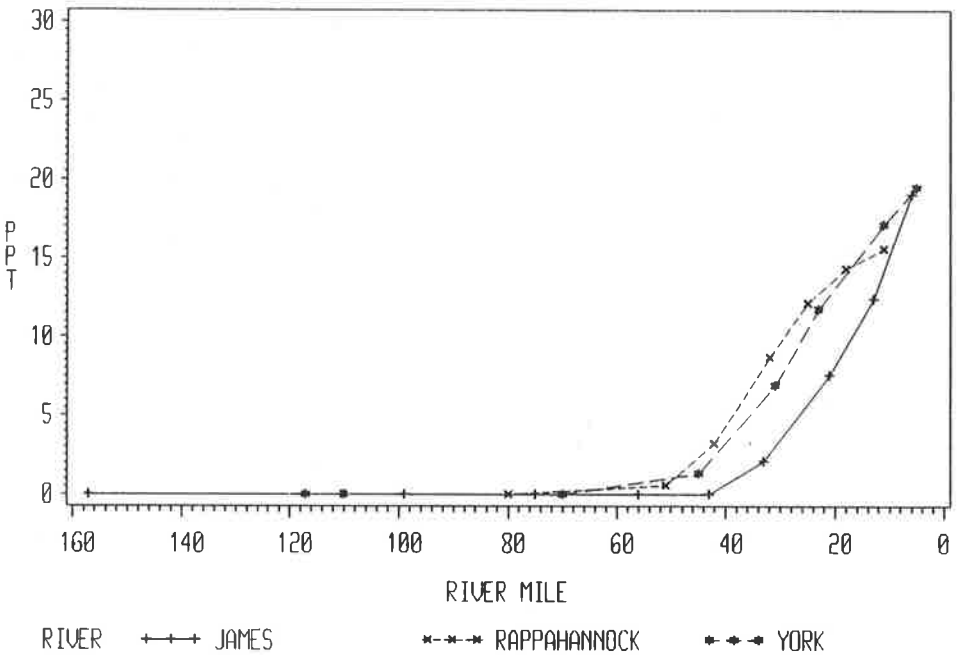


FIGURE 4.14

SALINITY

ALL RIVERS – SUMMER 1987

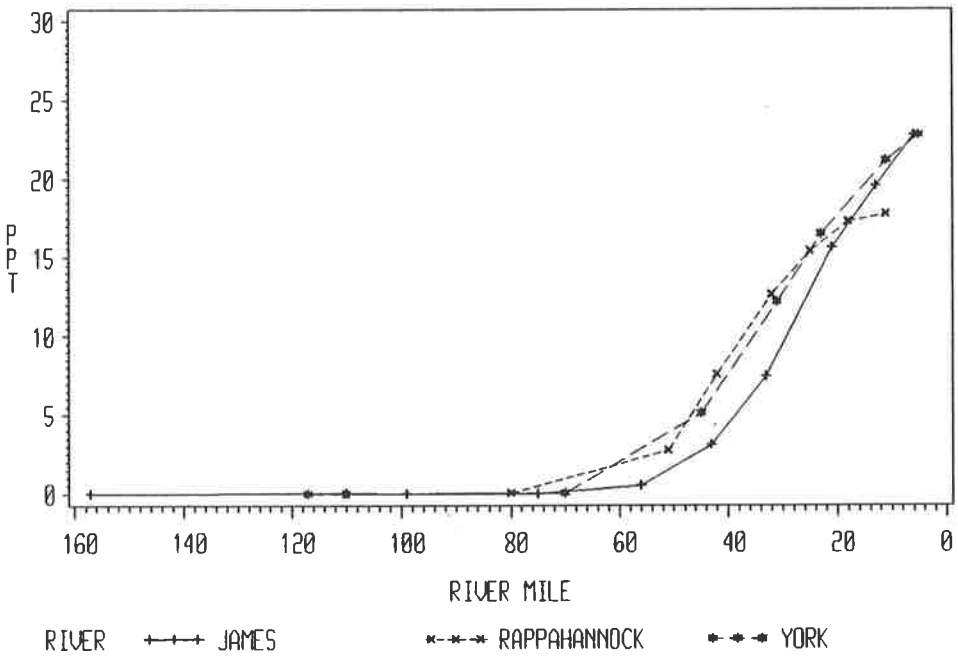
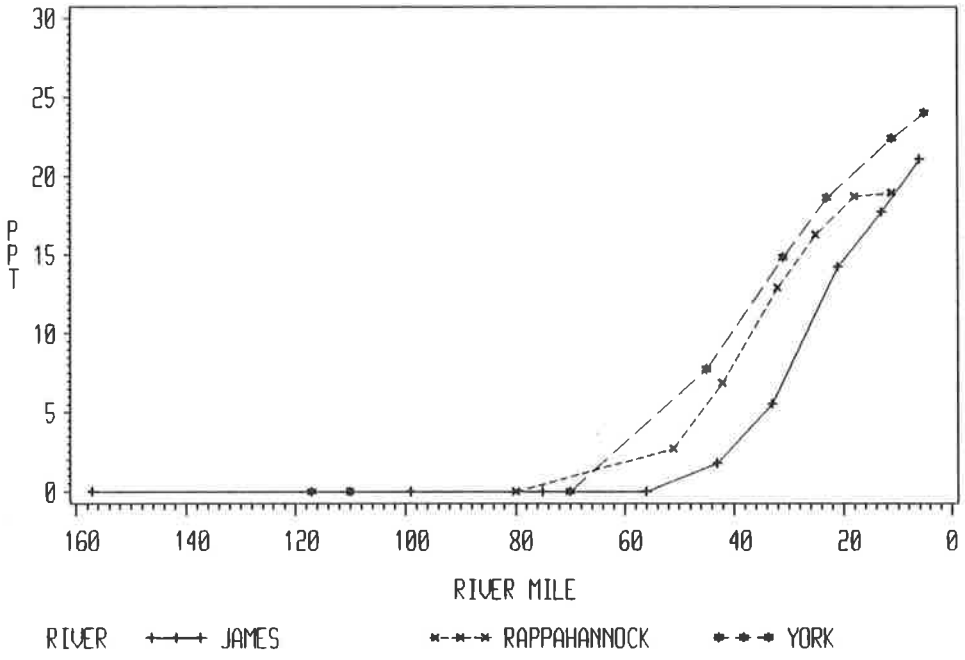


FIGURE 4.15

SALINITY

ALL RIVERS – FALL 1987



V. CHEMICAL VARIABLES

INTRODUCTION

The chemical variables monitored in this program are listed in Table III (p. 12). These include major chemical forms of four important nutrients: Nitrogen (N); Phosphorus (P); Carbon (C); and Silicon (Si). Inorganic forms of these nutrients (Nitrite (NO2), Nitrate (NO3), Ammonium (NH4), Orthophosphate (PO4), and Silicate (SiO4)) are necessary for the growth of primary producers such as phytoplankton and submerged aquatic vegetation (SAV). Organic forms of these nutrients (metabolic products and by-products) serve as nutrient sources for constituents of the food web such as bacteria, zooplankton, and fish before being converted back to inorganic forms.

Because these elements are fundamental to the base of food web (phytoplankton and bacteria), anthropogenic influences on the cycling of these elements can profoundly impact the aquatic ecosystem. If the natural balance of these nutrients is disturbed, the complete ecosystem may be disturbed. Noxious algal blooms, anoxic waters, fish kills, changes in biological community composition, and decreased fisheries harvests are a few of the perturbations that may result. The factors which influence concentrations of these nutrient elements can be grouped into two classes: inputs and instream cycling. In the following brief introduction, each of these elements (N, P, Si, and C) will be discussed with respect to these two influences. Each river is then discussed separately with graphical presentations which are used to illustrate processes influencing the nutrient dynamics of each river. Unless otherwise noted, these graphs represent the average of surface and bottom values. The final section contains a comparison of nutrient dynamics among all three rivers.

NUTRIENT LOADING

Information on nutrient loadings to the tributaries is available from several sources. In 1979-1981, a study was conducted to examine nutrient loads at the fall line of the James River. (Water Quality of Three Major Tributaries to the Chesapeake, U.S.G.S., 1982.) This study included sampling during all stages of streamflow and contains estimates of nutrient loading at the fall line. Much information on both point and non-point loading can be found in several final reports of the original EPA Chesapeake Bay Program (Chesapeake Bay Program Technical Studies: A Synthesis, USEPA., 1982; Chesapeake Bay: A Framework For Action, USEPA., 1983). These reports were based on summaries of information collected before 1980 and do not include recent wastewater facility or treatment upgrades or new discharging facilities. Raw information from these reports was used to calculate nutrient loading information for previous monitoring reports (Tributary Water Quality Characterization Report, 1984-1985; 1986). The EPA reports also contain loadings that were generated by a computer simulation model. These loadings represent only a March-October time period and contain assumptions which may make this data less reliable than non-model generated loadings.

Other information comes from various programs of the Virginia Water Control Board (VWCB). The fall line sampling of this tributary monitoring program can be used for calculating loads from above the fall line. The lack of intensive sampling during high flow events decreases the accuracy of our loading estimates and an improved fall line sampling program planned for 1988 - 1990 will correct this problem. Other VWCB programs provide data on point source inputs. The dischargers in the Potomac river embayments are required to report detailed information on the various forms of nitrogen and phosphorus in their effluent, due to the stringent effluent limitations required by their permits. While most dischargers in the rest of the state are required to provide monthly data pertaining to their

permit, permits typically do not include measurements of nitrogen and phosphorus. In order to obtain this information without making it a requirement of a discharger's permit, the Virginia Water Control Board (VWCB) initiated a Voluntary Nutrient Monitoring Program. Twenty-eight (28) major municipal and nine (9) industrial dischargers have agreed to participate in this program. For a majority of the dischargers, effluent nutrient data has been reported since July 1987. This program provides detailed information on the current point source loads to the tributaries. Previously, the only detailed information available was from a 1983-1985 James River Water Quality Monitoring Program. This program provided detailed effluent concentrations and loadings for the dischargers in the upper tidal James. When actual monitoring data is not available for a discharger, then default concentrations can be used in load estimation. These default concentrations are based on the level of treatment at the plant and were derived from known values at similar plants.

The effluent of municipal dischargers is characterized by relatively stable flows and concentrations. Municipal wastewater treatment plants are the major point source dischargers of nitrogen. The average effluent concentration of nitrogen is 18.4 mg/l. Most of the loading is the organic nitrogen and ammonia/ammonium. Ammonia/ammonium is the form of nitrogen most available for phytoplankton growth. The predominant species is dependent on pH and temperature (i.e. the ammonium species is predominant below pH 9 at 16° C.). In high concentrations ammonia is toxic to many organisms. If a municipal discharger is required to nitrify its effluent, then much of the ammonia is converted to nitrate. This reduces the nitrogenous oxygen demand of the effluent and also makes the nitrogen less readily available to algae.

As with nitrogen, the largest point sources of phosphorus are from municipal wastewater treatment plants. The biologically important inorganic form (orthophosphate) is the largest fraction of this input and accounts for 70-80% of the total phosphorus input from municipal wastewater plants. The average effluent concentration of total phosphorus is 6.4 mg/l. After the implementation of the phosphorus ban in January 1988, this concentration decreased by 35 percent.

Loadings from industrial point sources of nutrients are more difficult to estimate than municipal sources. Industrial discharges tend to be episodic and loadings vary as production cycles change. Also, the types of nutrients present change as different types of production go on-line. Much of the industrial discharges originate from cooling water operations, where the nutrient concentration of the influent must be subtracted from the nutrient concentration of the effluent in order to calculate a net loading to the river. Many industrial sources are high in ammonia, a byproduct of cooling water process. Meat processing plants have high effluent concentrations of nitrite and nitrate.

Nonpoint source (NPS) loadings are more difficult to estimate than point sources. NPS loadings are highly variable and dependent on land uses as well as rainfall and streamflow. In general, NPS loads are highest in the late winter and early spring when streamflow is at a maximum. Heavy streamflow associated with major storm events, particularly during the hurricane season from late summer and early fall, can also contribute substantial loadings.

NITROGEN

The majority of nitrogen in the rivers comes from nonpoint sources such as surface runoff and groundwater. Nitrate is the form most commonly transported by groundwater because it is very soluble. Though ammonia is also soluble, it will readily adsorb to particles and is usually transported in surface runoff. Storm events are significant factors for organic nitrogen loading due to several reasons. The greatly increased river flow means that a significant amount of organic nitrogen is discharged during storms. Also, much of this nitrogen is particulate organic nitrogen from surface runoff and flushing of small tributaries and wetlands. Particulate organic nitrogen is more biodegradable than the dissolved fraction which usually comprises the majority of the organic nitrogen pool. While runoff from all types of land use contributes nitrogen, the application of fertilizers and lack of conservation management practices often leads to particularly high inputs from agricultural land.

Nitrogen can also be introduced by the atmosphere through rainwater or diffusion of nitrogen gas. Rainwater contains many nitrogen compounds, but the relatively small surface area of rivers generally precludes this as a significant direct input. Certain microbial organisms and some blue-green algae have the ability to utilize nitrogen gas as a nitrogen source through a process called nitrogen fixation. This can be an important localized factor for some nuisance algal blooms, but it is a small factor as far as nitrogen inputs are concerned.

Once the nitrogen has entered the river, it can undergo several biologically and chemically mediated transformations which are important to water quality. The major biological cycle transforms nitrogen from inorganic to organic forms and then back to inorganic form. The inorganic forms such as ammonium, nitrite, and nitrate are used by primary producers for the production of protein and other organic nitrogen compounds necessary for growth. For phytoplankton, the preferred inorganic form is ammonium, but when concentrations are low they will utilize nitrite or nitrate. As organisms die, decomposition of organic nitrogen compounds produces ammonium and the cycle can then repeat itself.

Sometimes inorganic nitrogen is utilized for purposes other than incorporation into biomass. Under conditions of excess ammonium, some bacteria will utilize ammonium as an energy source and convert it to nitrite and nitrate. This process is called nitrification and results in consumption of oxygen from the water column. Nitrite concentrations are generally below detection except where nitrification is occurring. Under low oxygen conditions, some bacteria utilize nitrate or nitrite as an oxidizing agent and reduce it to ammonium or gaseous nitrogen. When nitrogen compounds are reduced to gaseous forms, a process called denitrification, the nitrogen can be released to the atmosphere and lost from the aquatic ecosystem. Denitrification is particularly active in estuarine areas and is thought to be largely responsible for the 'nitrogen limitation' generally found in many coastal aquatic systems.

There are also many chemical and physical processes which influence nitrogen cycling. Uptake or release of dissolved nutrients from the river sediments is an important factor influencing concentrations in the water column. This can sometimes be driven solely by a concentration gradient, i.e. if concentrations are higher in the water column there will be a transfer into the sediments; likewise, if concentrations are higher in the sediment there will be a transfer from the sediments to the water column. Low oxygen concentrations in waters close to the sediment surface can also stimulate the release of ammonium from sediments. An oxidized layer at the sediment surface usually inhibits the release of ammonium because it is either adsorbed onto sediments or is oxidized to nitrate. When the sediment surface becomes a reduced environment due to the presence of anoxic water then

these processes are not as active and ammonium is released to the water column. Exchanges between the water and sediment can also be activated by changes in pH or oxidation/ reduction potential.

PHOSPHORUS

Phosphorus is essential in biological metabolism because of its role in the formation of energy storing enzymes such as ATP (adenosine triphosphate). It is also important in genetic compounds such as DNA and RNA which have sugar-phosphate structural components. The major biological transformation of phosphorus is its uptake by primary producers in the inorganic form (orthophosphate) and its incorporation into an organic form. The organic form is then eventually returned to the inorganic form through biological decomposition. Orthophosphate can also cycle between the particulate form and its dissolved state solely through chemical processes. Under oxygenated conditions, dissolved orthophosphate will adsorb to sediments containing metal oxides. Under anoxic conditions, the metal-phosphate compounds break down and the orthophosphate is released. It has also been found that conditions of high pH, such as created during an algal bloom, can cause an orthophosphate release from sediments. In this report orthophosphate includes only the dissolved form of orthophosphate. Particulate phosphorus was calculated as the difference between total phosphorus and dissolved phosphorus. It includes both particulate organic phosphorus and orthophosphate adsorbed onto sediment particles.

ORGANIC CARBON

The majority of carbon is derived from nonpoint sources. Inputs from municipal wastewater treatment plants can be significant and are regulated by the VWCB. Some industries such as wood processing plants can also discharge large amounts of carbon. The fall line loading of organic carbon is largely composed of refractory compounds (e.g. humic and fulvic acids) that are relatively resistant to decomposition.

Organic carbon is formed through primary production by organisms such as phytoplankton and aquatic macrophytes (autotrophs). Primary production may be controlled by several factors such as light, temperature, nutrient concentration, predation and toxic compounds. Organic carbon from autotrophs serves as an energy and carbon source up the food web. At each step oxygen is consumed as the carbon is utilized. The source of oxygen may be dissolved oxygen in the water or inorganic oxidized compounds such as nitrate or sulfate. Decomposition of an overabundance of organic carbon can deplete oxygen from the water column and create ecological problems.

As with organic nitrogen, high flow events are important in introducing organic carbon into riverine systems. This is because of the large load delivered and also because much of the load is particulate carbon from surface runoff and the flushing of wetlands. This particulate carbon is generally more biodegradable than the dissolved organic carbon that comprises the largest fraction during base flow conditions.

SILICA

The majority of silica input is due to natural weathering of silica minerals. Thus, nonpoint source runoff is the major contributor and point sources are generally insignificant. Silica is a necessary nutrient for the growth of certain phytoplankton and is taken up in the inorganic form and incorporated into the outer shells of both freshwater and saltwater diatoms. Zooplankton which feed on diatoms have little need for silica and the shells are excreted relatively intact. Also, if cells die before being grazed they sink to the sediment surface. The subsequent breakdown into an inorganic form is accomplished mainly through abiotic dissolution. Silica is often the limiting nutrient for diatoms. Its cycling in relation to nitrogen and phosphorus has been suggested to be important in the development of eutrophication related problems. A more complete discussion of silica cycling in Virginia tributaries is given in Anderson, G. F. (Estuarine, Coastal and Shelf Science, 1986, Vol. 22, pp. 83-197).

RAPPAHANNOCK RIVER

NUTRIENT LOADINGS - RAPPAHANNOCK

A summary of nitrogen and phosphorus loading from both point and nonpoint sources is presented in Table V. Approximately one third of the total point source (PS) flow and nitrogen (N) loadings originates above the fall line. The discharge in the Fredericksburg area contributes the majority (65-71%) of the nitrogen and phosphorus PS loadings to the Rappahannock. Estimates for non-point source (NPS) N loadings to the Rappahannock River have ranged from 3.8 to 4.2 million pounds per year (MPY). The EPA estimated an annual NPS N loading to the Rappahannock basin of 3.8 MPY. The calculation of NPS N loadings from VWCB baseflow fall line monitoring program results in a load estimation of 2.5 million pounds at the fall line. If extrapolated to the entire basin (41% below fall line), the total loadings would be 4.2 million pounds. The EPA estimates for a normal year agree favorably with the estimates based on the data from VWCB baseflow fall line monitoring program during 1985.

EPA estimated the annual NPS phosphorus (P) loadings for a normal year to be approximately 0.25 MPY. Based on VWCB baseflow monitoring at the fall line in 1985, a dry year, the P loading at the fall line was approximately 0.21 million pounds. If these loads are adjusted for the 41% of the basin below the fall line, then the total annual NPS P load would be 0.35 M pounds

TABLE V

LOADINGS OF NUTRIENTS TO RAPPAHANNOCK RIVER

SOURCE	FLOW MGD (%)	NITROGEN MILLIONS POUNDS/YEAR	PHOSPHORUS (%)
POINT[1]			
ABOVE FALL LINE	2.3 (30)	0.13 (30)	0.03 (21)
FREDERICKSBURG	5.0 (65)	0.28 (65)	0.10 (71)
LOWER RAPP.	0.4 (5)	0.02 (5)	0.01 (8)
TOTAL PS	7.7	0.43	0.14
NON POINT[2]		3.8 - 4.2	.25 - .35

1) Loading calculated from VWCB discharge permit information.
2) Loadings calculated from this monitoring program and information from Chesapeake Bay Program Technical Studies: A Synthesis; USEPA, September, 1983.

NITROGEN - RAPPAHANNOCK

Ammonium

Ammonium concentrations at the fall line ranged from below detection (<0.02 mg/l) to 0.10 mg/l (Figure 5.1). Longitudinal plots show that seasonally averaged concentrations were generally below 0.15 mg/l throughout the river (Figure 5.2). Municipal point sources are the major input of ammonium below the fall line and most are located near Fredericksburg (mile 105). The station closest to these sources is 25 miles downriver, consequently, the longitudinal plots do not show any indication of the point sources in Fredericksburg. The general pattern observed was similar to that noted for previous years. The winter and spring season had low values at the fall line and yet showed quite high values in the tidal freshwater region. In the summer and fall, concentrations were generally low throughout the river due to biological uptake, except in the bottom waters of the estuary where ammonium is released from sediments.

FIGURE 5.1

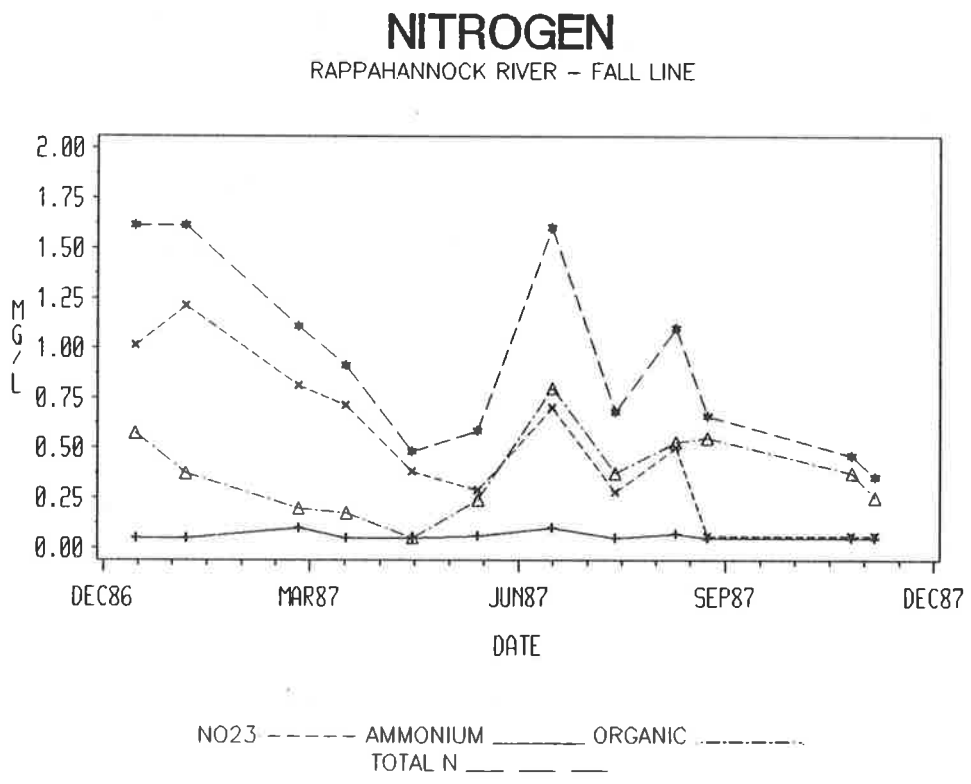
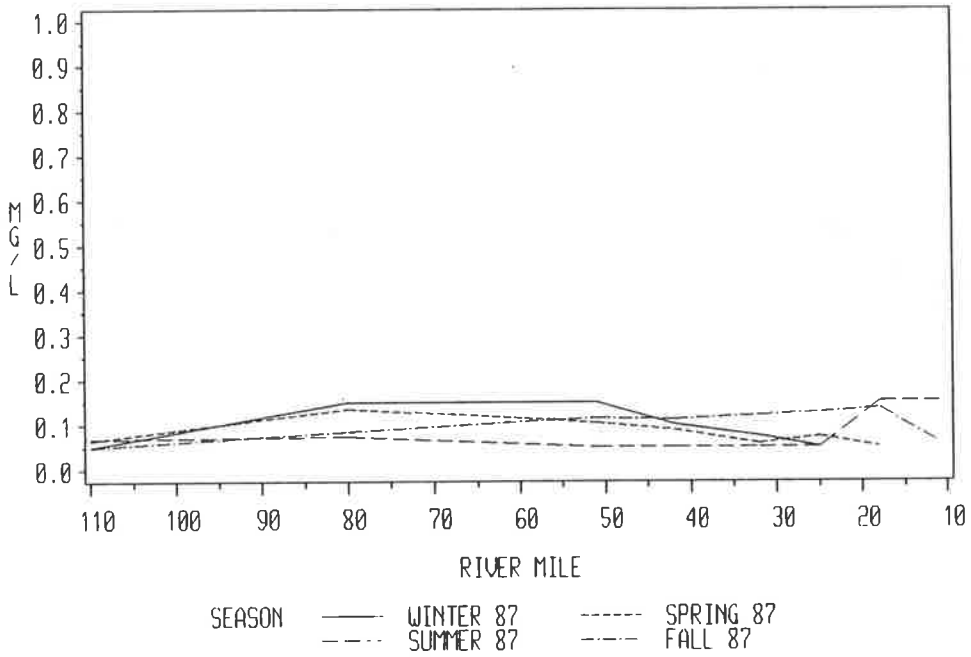


FIGURE 5.2

AMMONIUM

RAPPAHANNOCK



As discussed previously, sediments can represent a major ammonium contribution to a water column. During much of the year, organic nitrogen from the water column is deposited to the sediment where it undergoes decomposition and ammonium is produced. Normally most of this ammonium is converted to oxidized nitrogen (i.e. nitrite or nitrate) or adsorbed to sediment particles. Exceptions occur when low concentrations of oxygen slow normal conversion of ammonium to oxidized nitrogen. Periods of low oxygen concentrations tend to occur during periods of vertical stratification when there is minimal exchange of water between the surface and bottom layers. This reduction of vertical mixing allows large concentrations of ammonium to accumulate in the bottom waters. Upon mixing, the ammonium reserve can provide a significant amount of nitrogen to the surface water and promote increased algal production.

This process is often important as a source of ammonium in the lower Rappahannock River and has been observed since the beginning of the monitoring program. Longitudinal plots of data from an August cruise illustrate this process. Dissolved oxygen levels in the bottom waters during the cruise were very low between river miles 10 and 18 (Figure 5.3A). Further upriver there was little oxygen depletion in bottom waters. In the area of oxygen depletion there were substantially elevated ammonium concentrations in the bottom waters, while ammonium concentrations upriver of mile 18 were below detection (Figure 5.3B).

FIGURE 5.3A

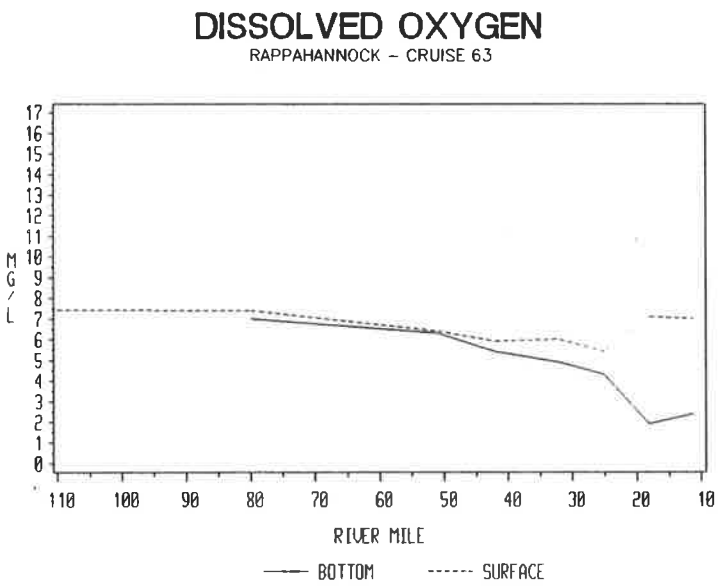
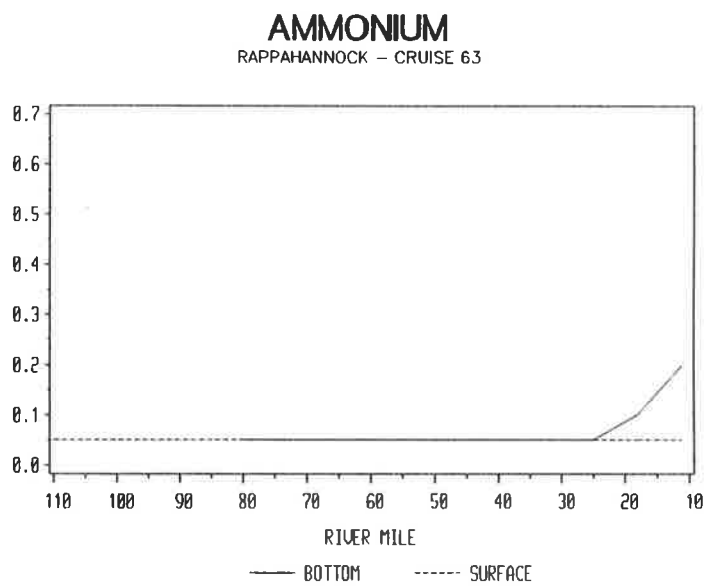


FIGURE 5.3B



Nitrite plus Nitrate (NO2+3)

The majority of NO2+3 input from above the fall line originates from nonpoint source runoff. This is indicated by the elevated concentrations throughout the upper portion of the river during the high streamflow of winter (Figure 5.4). Concentrations of NO2+3 during the winter of 1987 were higher than those observed during the winters of 1985 and 1986. This may be due to the higher streamflows seen during 1987. The downriver decrease in concentration seen during winter and spring is due to dilution by lower concentration of NO2+3 in estuarine waters. Spring had lower concentrations than winter. Concentrations were lowest in the river during summer and fall due to both lower inputs at the fall line and increased biological activity during these seasons.

Organic Nitrogen

Organic Nitrogen concentrations at the fall line were lowest during spring (Figure 5.1). Below the fall line, the concentration of organic nitrogen reflected the seasonal pattern of phytoplankton production (Figure 5.5). In the winter and spring, concentrations were highest in the estuarine area (miles 30-40) where chlorophyll values were highest. Likewise, in the summer and fall, organic nitrogen was highest in the tidal freshwater region (mile 80) where chlorophyll values were highest during these seasons.

FIGURE 5.4

NITRATE + NITRITE

RAPPAHANNOCK

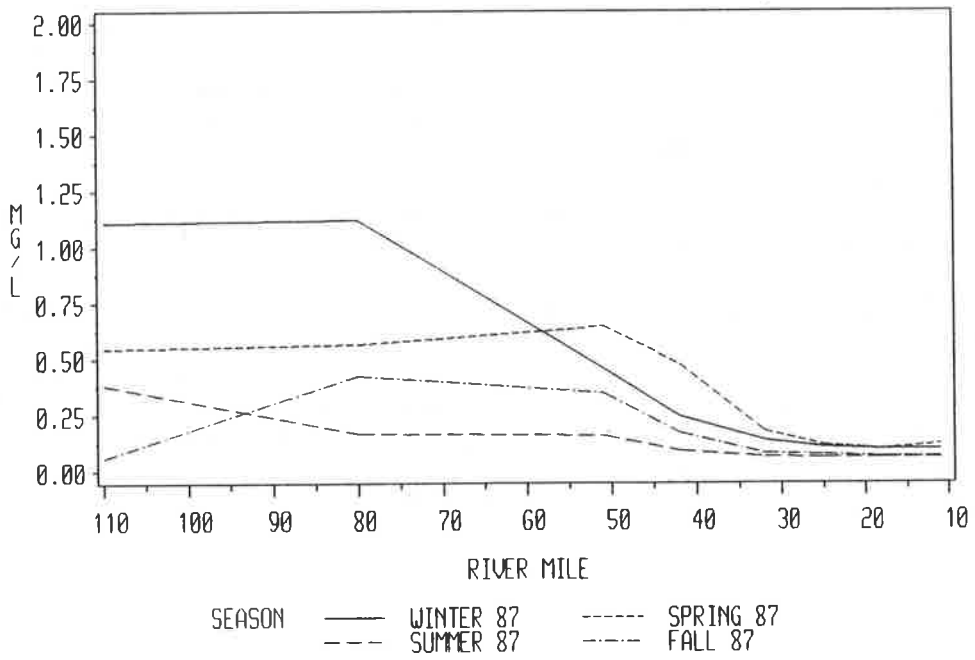
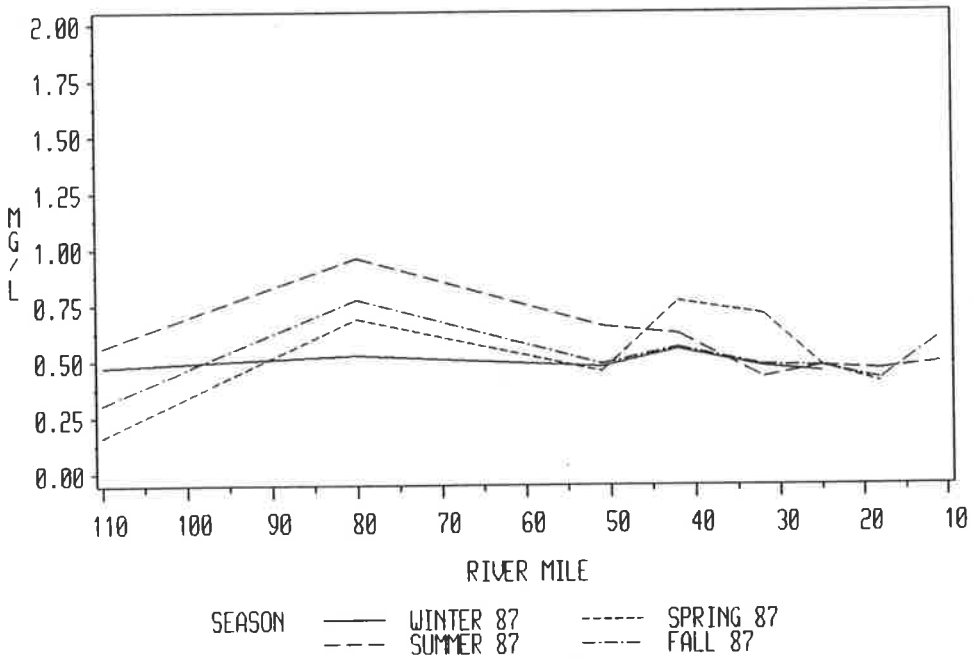


FIGURE 5.5

ORGANIC NITROGEN

RAPPAHANNOCK



Total Nitrogen

Total Nitrogen concentrations at the fall line were quite variable and ranged from 0.37 to 1.62 mg/l (Figure 5.1). During the high streamflow months of winter and spring, the nitrogen input at the fall line was dominated by NO2+3, while in the summer and fall, organic nitrogen was the largest fraction of the total. Figure 5.6 shows the longitudinal distribution of total nitrogen. There were high nitrogen concentrations throughout the upper river during winter due to the high concentration of inorganic nitrogen. The high nitrogen concentrations in the lower river (miles 20 - 50) during spring were due to high concentrations of organic nitrogen. Nitrogen concentrations during summer and fall peaked in the tidal freshwater area and then decreased downriver. The peak during these seasons was lower than observed in winter. This pattern was also observed in 1986.

Seasonal change in contributions of various forms of nitrogen to the total nitrogen pool was the same as observed during previous years. During winter, inorganic nitrogen dominated the freshwater portions of the river (Figure 5.7A). In the estuarine area organic nitrogen increased due to algal production while the inorganic nitrogen decreased due to both uptake by the algae and dilution. During the summer, lower inorganic nitrogen nonpoint source input and increased biological productivity led to organic nitrogen being the dominant form throughout the river (Figure 5.7B).

FIGURE 5.6

TOTAL NITROGEN

RAPPAHANNOCK

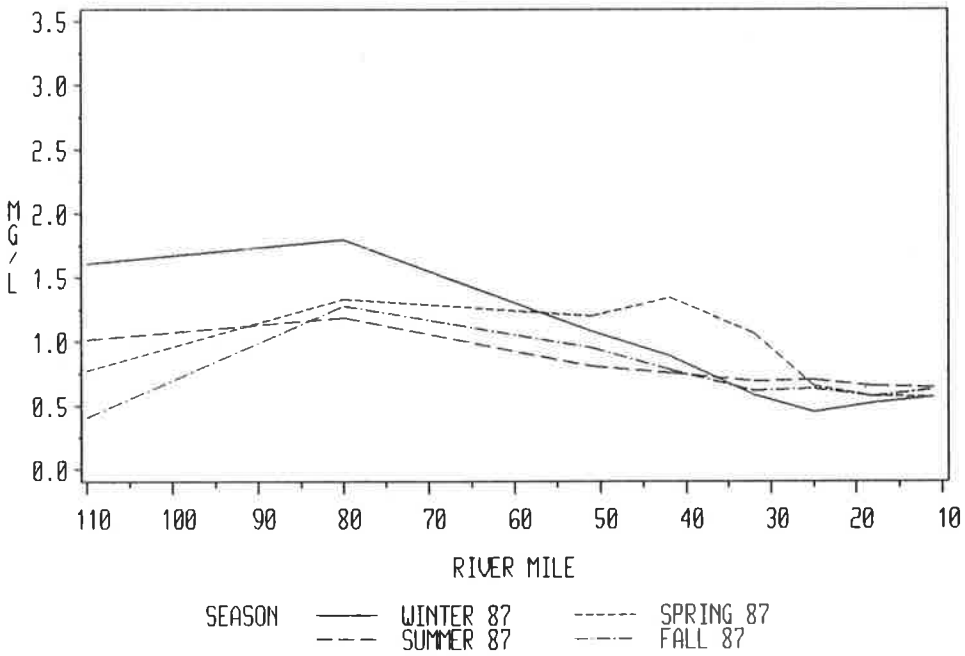
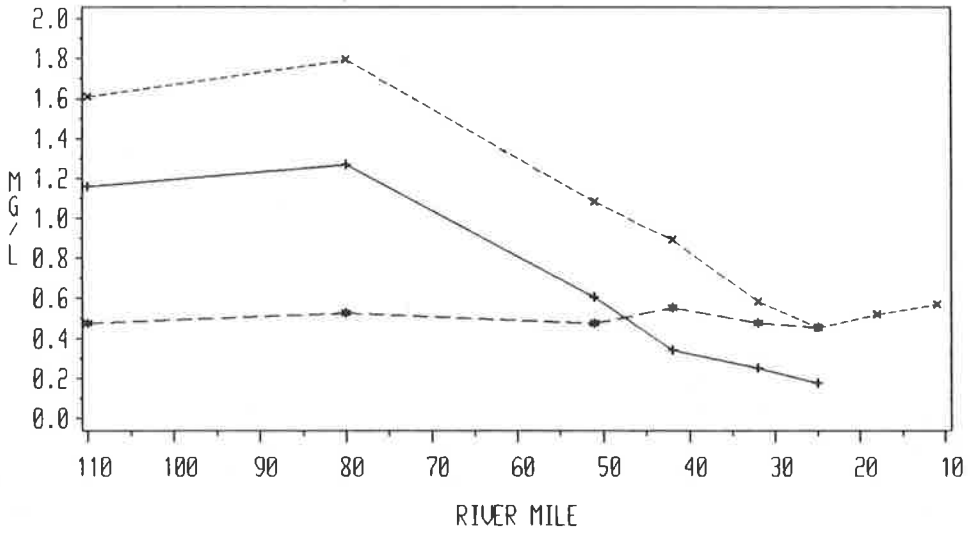


FIGURE 5.7A

NITROGEN

RAPPAHANNOCK RIVER – WINTER 1987

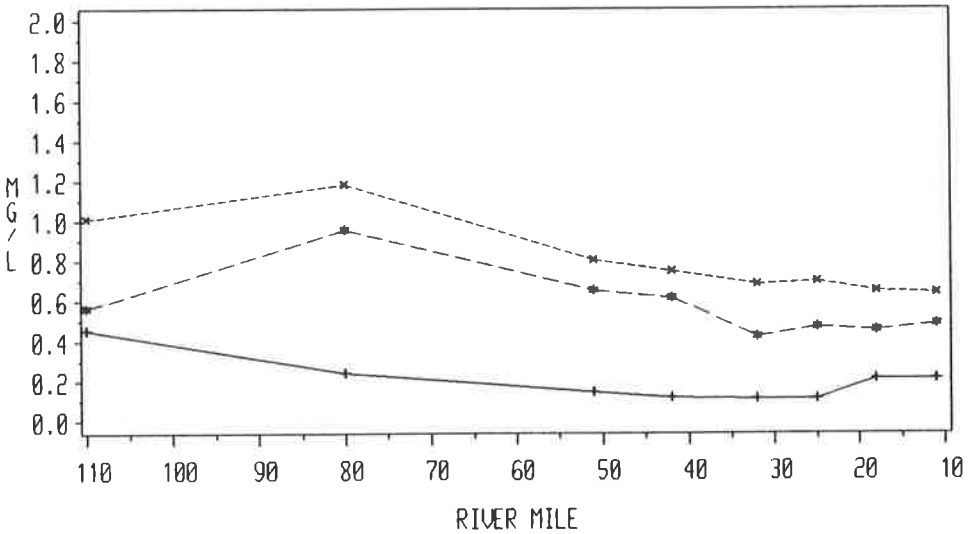


INORGANIC N _____ ORGANIC N ___ ___ ___
TOTAL N _ _ _ _

FIGURE 5.7B

NITROGEN

RAPPAHANNOCK RIVER – SUMMER 1987



INORGANIC N _____ ORGANIC N ___ ___ ___
TOTAL N _ _ _ _

PHOSPHORUS - RAPPAHANNOCK

Orthophosphate

Orthophosphate concentrations at the fall line ranged from below detection (<0.01 mg/l) to 0.05 mg/l (Figure 5.8). Values were very low throughout the river during all seasons with slightly elevated levels in the estuarine zone during summer as a result of sediment releases during periods of anoxia. As with ammonium, the influence of point sources in Fredericksburg is not evident in VWCB data because of the distance between discharges and the nearest monitoring station.

Particulate Phosphorus

Fall line concentrations of particulate phosphorus ranged from below detection (<0.01 mg/l) to 0.11 mg/l (Figure 5.8). Figure 5.9 shows the longitudinal distribution of particulate phosphorus reflecting the influences of both algal production and suspended sediments. A peak was observed at mile 42 during spring. This area had the highest observed turbidity and a lack of elevated chlorophyll, suggesting this is due to an accumulation of suspended sediments in the 'turbidity maximum' zone rather than accumulation of organic phosphorus. During summer and fall particulate phosphorus was highest at mile 80. A higher percentage is probably organic in nature as these seasons have higher biological productivity and lower inputs of sediment.

FIGURE 5.8

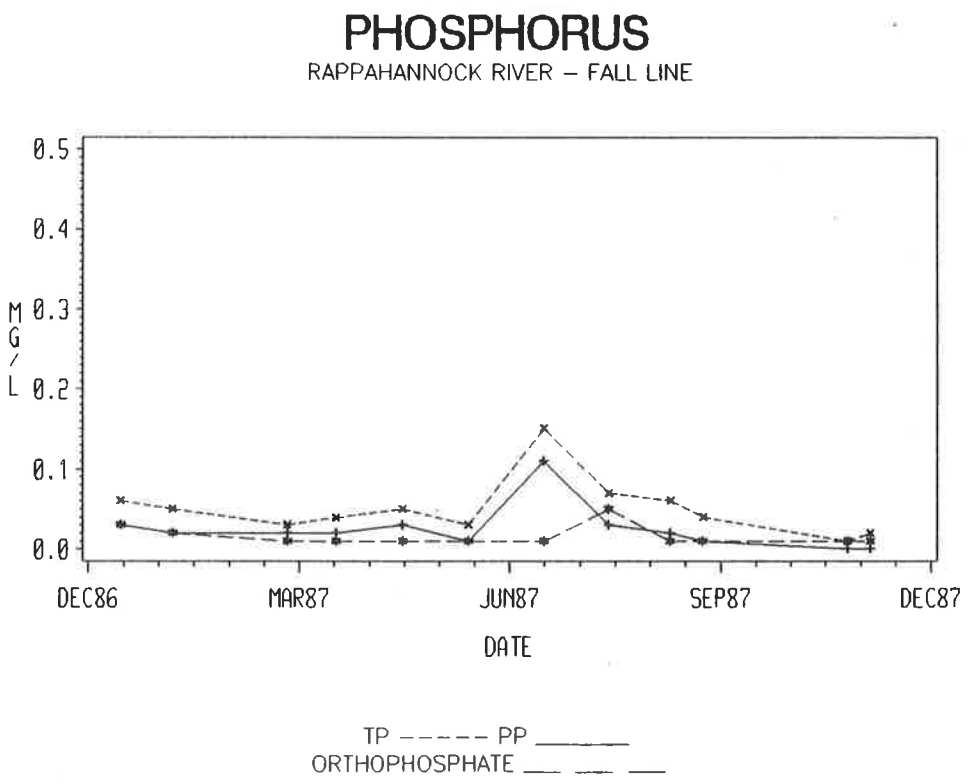
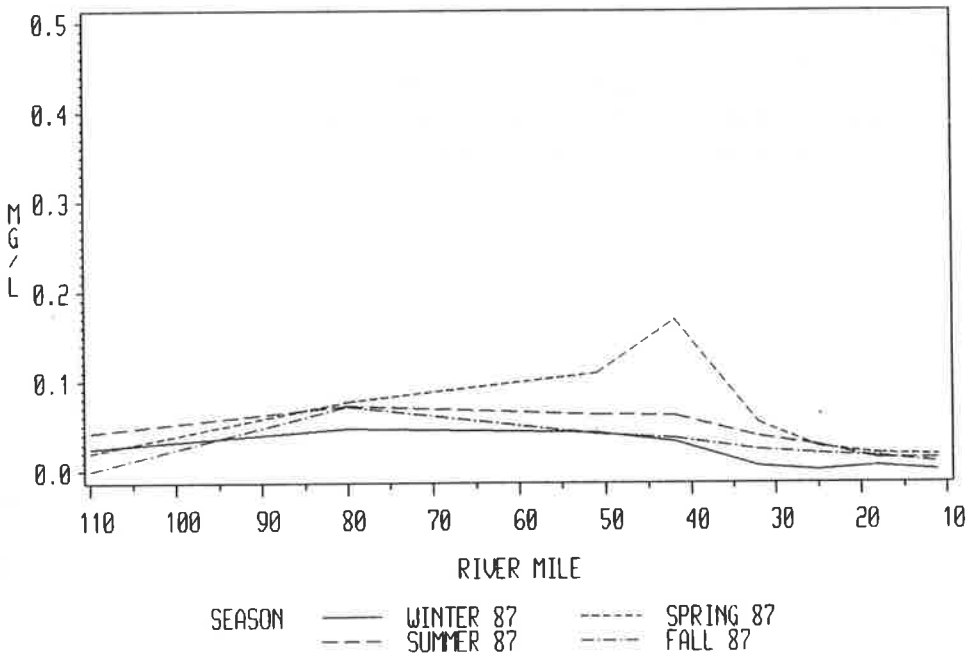


FIGURE 5.9

PARTICULATE PHOSPHORUS

RAPPAHANNOCK



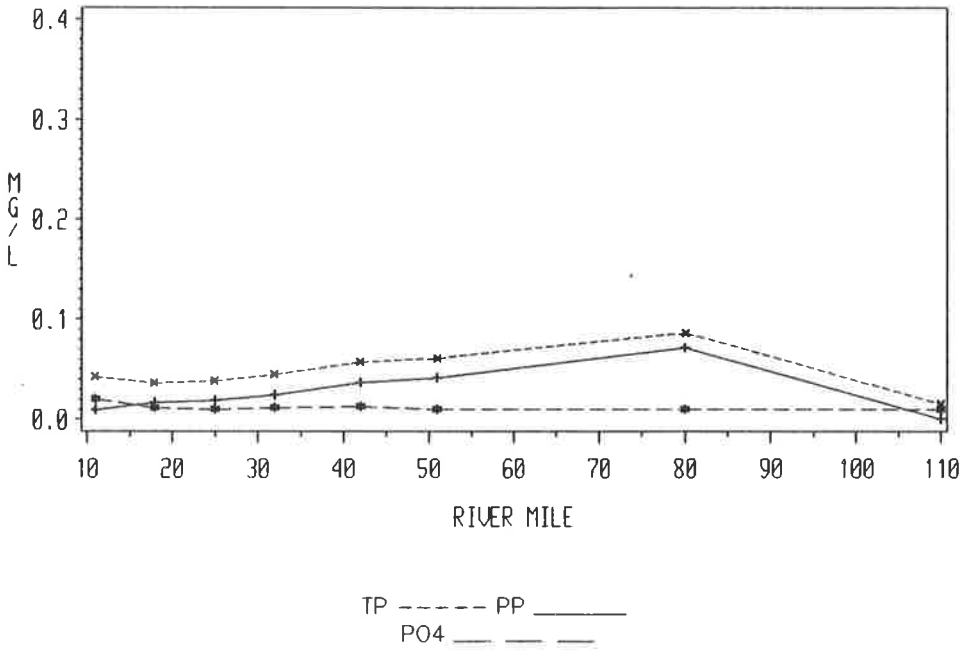
Total Phosphorus

In general, the fall line input of total phosphorus was composed of approximately equal amounts orthophosphate and particulate phosphorus (Figure 5.8). Figure 5.10 illustrates the longitudinal concentrations of each phosphorus form during fall and is fairly typical of the rest of the year. The tidal fresh and transition zones show a dominance of particulate phosphorus. At the fall line and estuarine areas particulate concentrations are lower and about equal to orthophosphate concentrations.

FIGURE 5.10

PHOSPHORUS

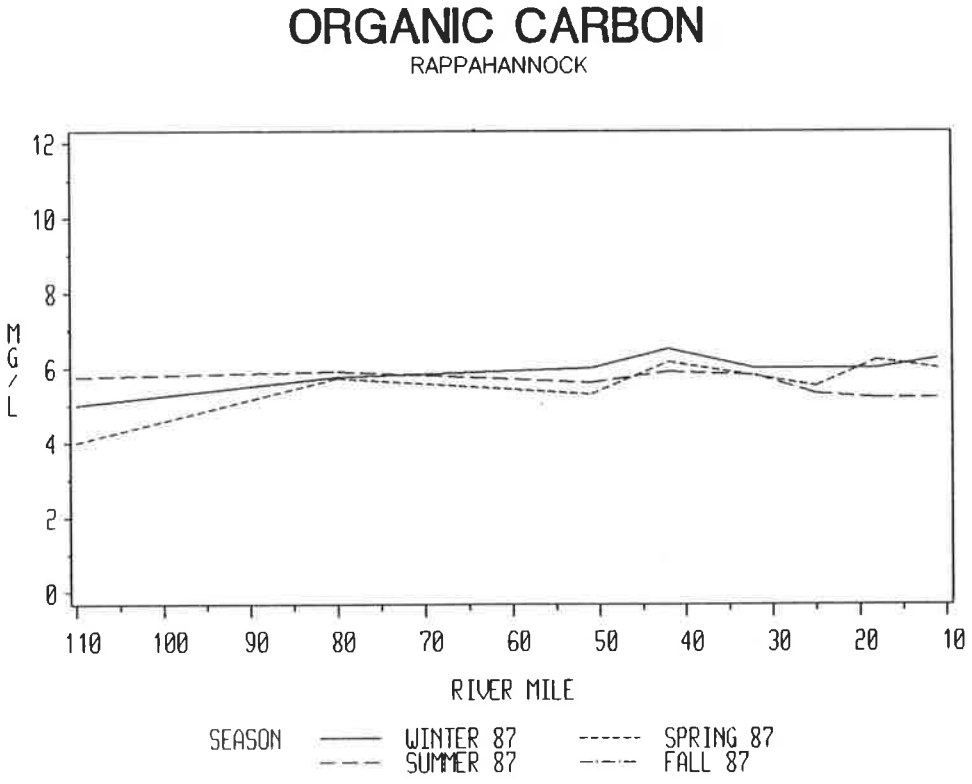
RAPPAHANNOCK RIVER – FALL 1987



ORGANIC CARBON - RAPPAHANNOCK

The seasonally averaged concentrations of organic carbon were similar to those observed in previous monitored years (Figure 5.11). The fall line exhibited the greatest amount of seasonal variability and lowest average concentrations. Concentrations at the fall line ranged from a seasonal average of 4.0 mg/l during spring to 5.9 mg/l during summer. The highest seasonal averages were always found in the upper estuary/lower transition zone between miles 15 and 45.

FIGURE 5.11



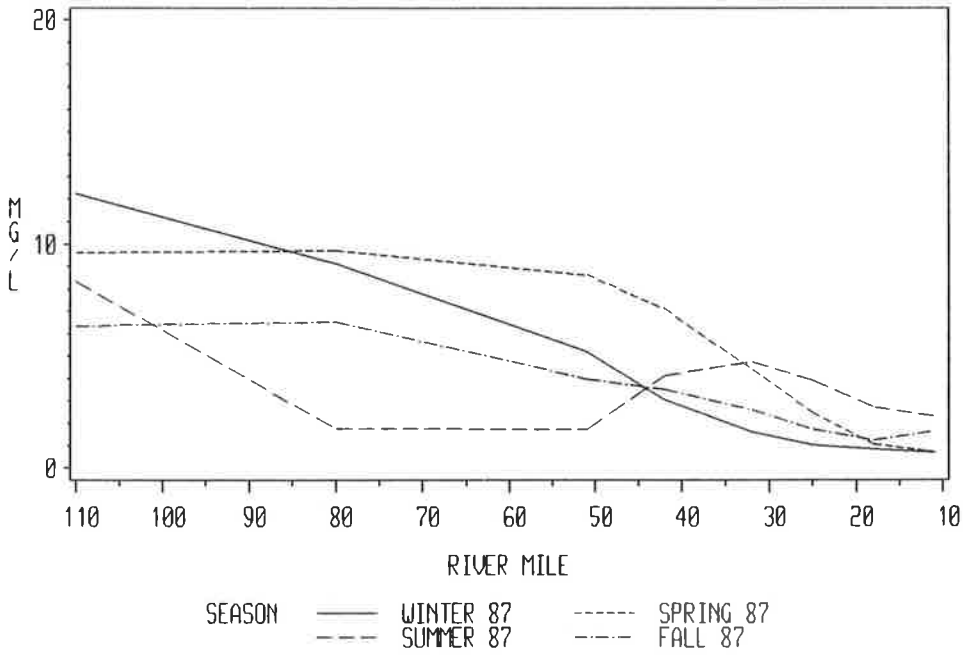
SILICA - RAPPAHANNOCK

The seasonally averaged concentrations of silica presented in Figure 5.12 indicate silica is a biologically reactive nutrient. Concentrations at the fall line ranged from 12.2 mg/l during winter to 6.3 mg/l during spring. The high winter concentration at the fall line declined to very low values in the estuarine zone largely due to uptake by estuarine diatoms. During the summer, silica concentrations were still relatively high at the fall line but decreased greatly in the tidal fresh area where algal biomass was greatest. However, in the summer, diatom communities in the estuary are replaced by algal species that do not utilize silica. Consequently, the lack of silica demand and subsequent silica remineralization leads to elevated levels of silica in the summer estuary.

FIGURE 5.12

DISSOLVED SILICA

RAPPAHANNOCK



YORK RIVER

NUTRIENTS LOADINGS - YORK

Nutrient loadings to the York River are presented in Table VI. There are five major point source dischargers of nutrients in the York river basin (four municipals and one industrial). The majority of the PS loadings are delivered below the fall line. Previous estimates of industrial point sources of phosphorus were in the range of .05-.06 MPY (Chesapeake Bay Program Technical Studies: A Synthesis; USEPA, September, 1983) and appear accurate. The same report estimates industrial N loadings at 0.16 MPY, an apparent underestimate. Based on four months of nutrient data from the Voluntary Nutrient Monitoring Program, the industrial N loadings may be 0.5 - 0.6 MPY. Industrial point source information is not included in Table VI because of the preliminary nature of this data.

Estimates for NPS nitrogen loadings to the York river range from 3.0 to 6.0 MPY. EPA estimated the NPS nitrogen loadings for a normal year to be approximately 3.0 million pounds. Based on baseflow monitoring at the fall line in 1985, a dry year, the loading at the fall line was approximately 2.0 million pounds. If these loads are adjusted for 65% of the basin below the fall line, then the total NPS loads would be near 6.0 million pounds.

Estimates for NPS phosphorus loadings range from 0.22 to 0.25 MPY. The EPA estimates for a normal year agree favorably with the estimates based on the data from VWCB baseflow fall line monitoring program during 1985.

TABLE VI

LOADINGS OF NUTRIENTS TO THE YORK RIVER

SOURCE	FLOW MGD (%)	NITROGEN MILLIONS POUNDS/YEAR (%)	PHOSPHORUS MILLIONS POUNDS/YEAR (%)
POINT[1]			
ABOVE FALL LINE	1.2 (13)	0.07 (11)	0.02 (12)
BELOW FALL LINE	7.9 (87)	0.51 (89)	0.16 (88)
TOTAL PS	9.1	0.58	0.18
NON POINT[2]		3.0-6.0	0.2-0.3

1) Loading calculated from VWCB discharge permit information, municipal point source only.
2) Loadings calculated from this monitoring program and information from Chesapeake Bay Program Technical Studies: A Synthesis; USEPA, September, 1983.

NITROGEN - YORK

Ammonium

Concentrations of ammonium at the fall line were often below the limit of detection (<0.02 mg/l) and reached a maximum of only 0.10 mg/l (Figure 5.13). An increase of ammonium was observed during winter at river mile 45, just below the confluence of the Mattaponi and Pamunkey rivers (Figure 5.14). As in previous years, concentrations at the river mouth were slightly elevated in the fall season due to occasional periods of hypoxia and the resultant release of ammonium from sediments. With the exception of these two areas, concentrations were very low throughout the river.

Nitrite plus Nitrate (NO2+3)

Concentrations at the fall line were relatively low, ranging from 0.12 to 0.55 mg/l (Figure 5.13). There was no clear seasonal trend in concentrations at the fall line, but the highest values were observed during low flow summer months of July and August.

FIGURE 5.13

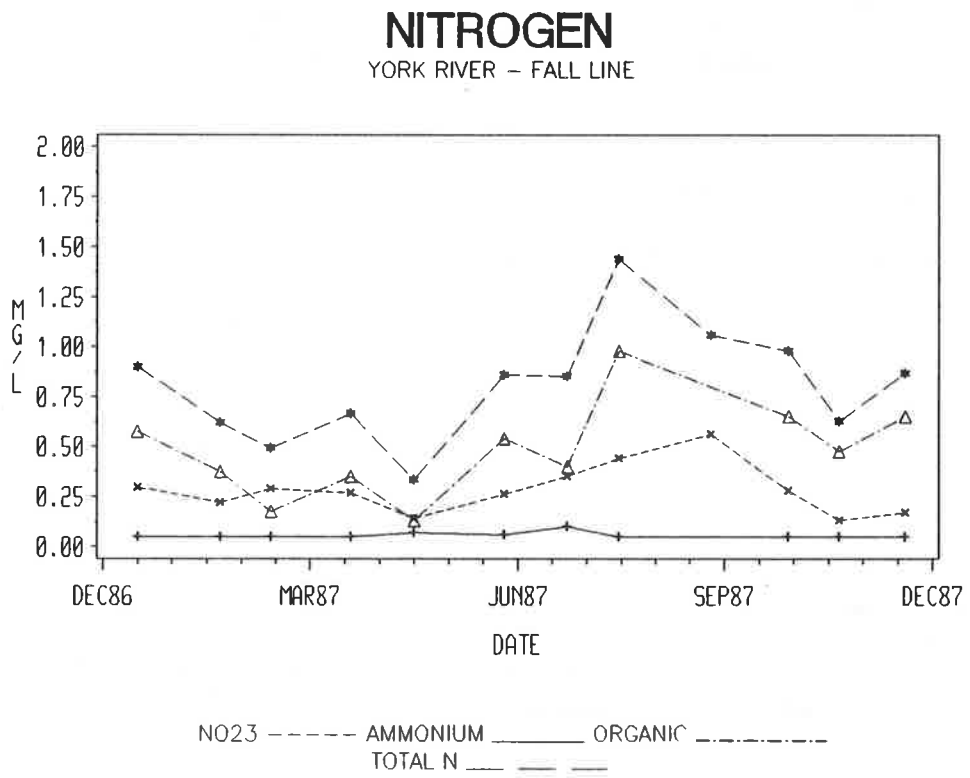
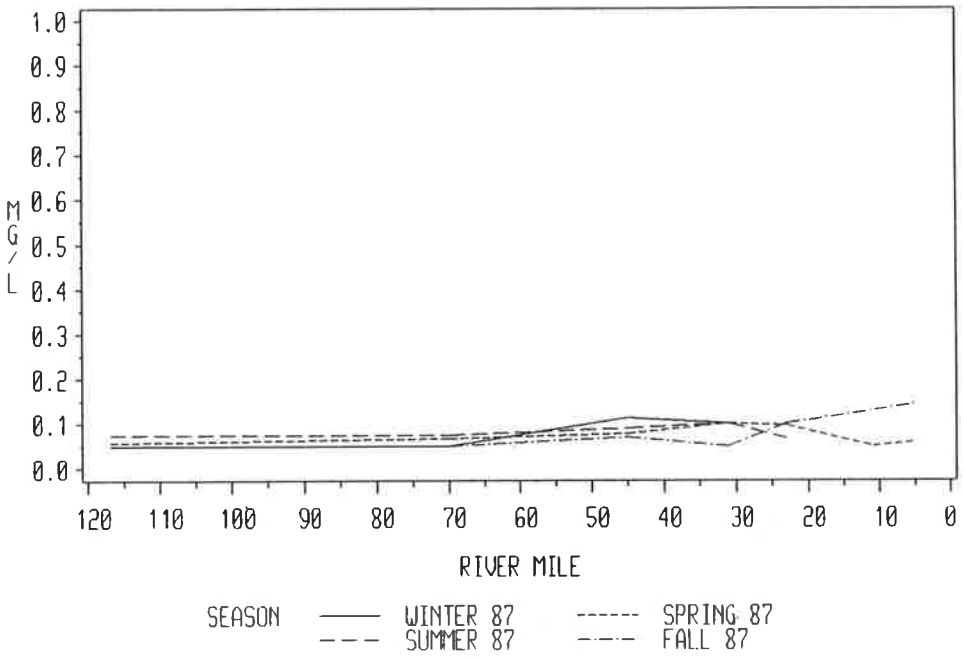


FIGURE 5.14

AMMONIUM

YORK

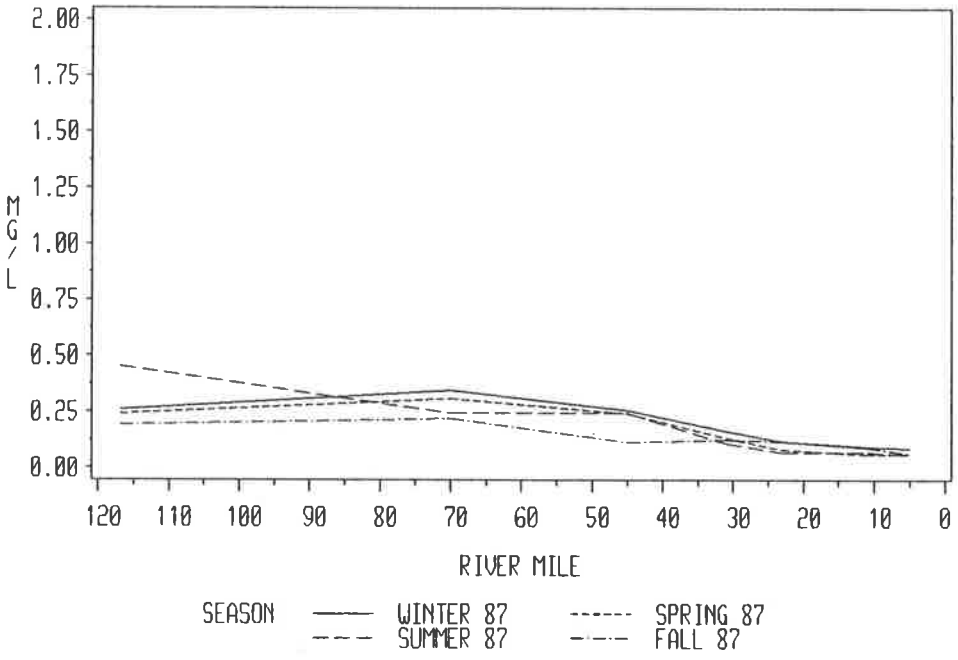


Throughout the river, nitrite is a minor component of the NO2+3, except during hypoxic periods in the estuarine portion of the river. Nitrite was undetectable (<0.01 mg/l) in the tidal freshwater zone 94 percent of the time, but the estuarine portion had undetectable nitrite concentrations only 64 percent of the time. While the fall line and estuarine concentrations of NO2+3 were relatively stable, there was more variability in the tidal freshwater and transition zones (Figure 5.15). There was an increase in NO2+3 concentration in tidal freshwater (miles 70 - 30) during the winter. The same increase was observed during the winters of 1985 and 1986. This increase may be the result of both increased inputs from the extensive tidal marshes in this area and lowered biological uptake during the colder months. During the warmer seasons of summer and fall, decreases occurred in tidal freshwater due to uptake by both the tidal marshes and phytoplankton. During the growing seasons marshes tend to retain inorganic nutrients, while during colder months inorganic nutrients are lost to the river. The estuarine portion (miles 5 - 20) had low NO2+3 concentrations throughout the year because of dilution by high salinity Bay water, which typically has low NO2+3 concentrations.

FIGURE 5.15

NITRATE + NITRITE

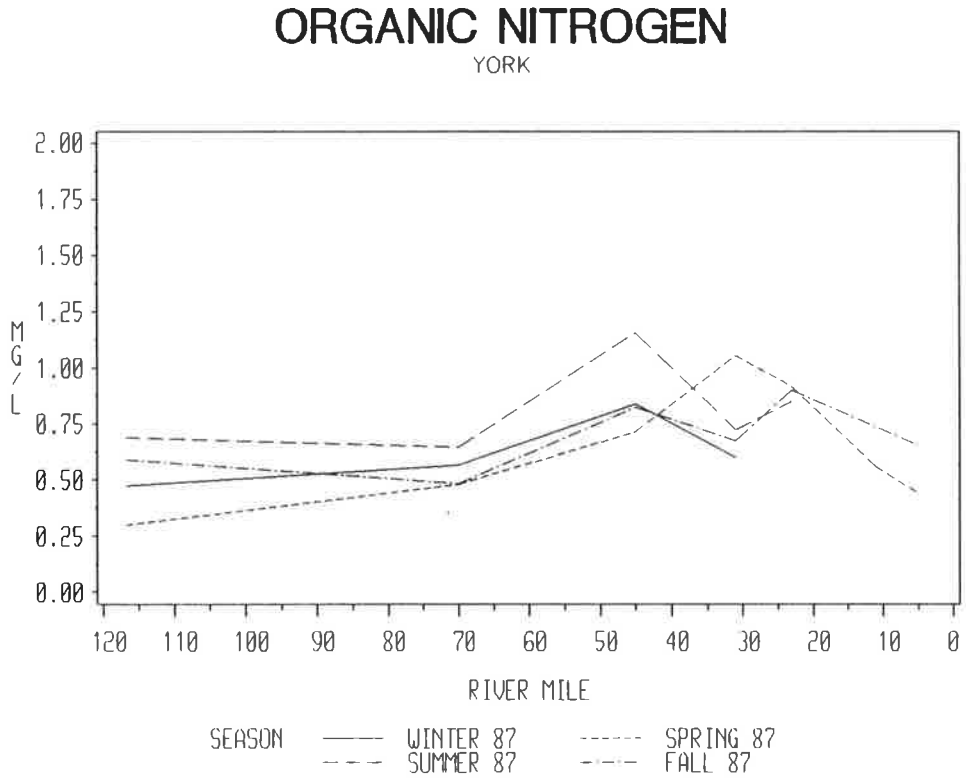
YORK



Organic Nitrogen

Figure 5.16 shows the longitudinal distribution of organic nitrogen. The average summer concentration of nitrogen at the fall line was 0.73 mg/l. During the summer, organic nitrogen remained high throughout much of the river, then decreased to 0.43 mg/l near the river mouth. The other seasons exhibited a peak in organic nitrogen in the transition zone (miles 25 - 45) and then decreased toward the river mouth. Despite the occasional increases seen during storm events, the fall line concentration of organic nitrogen seems to be greatest during the warmer, low flow seasons. Fall 1984, Fall 1985, Summer 1986 and Summer 1987 all had the highest concentrations observed during their respective years. Another consistent feature observed since 1984 is the increase of organic nitrogen near the town of West Point (mile 45) near the mouth of Pamunkey River. Input from the tidal marshes along the river probably contribute much of this organic nitrogen. There are also discharges from a kraft paper mill nearby which may contribute to the increase in organic nitrogen. Preliminary estimates from the Voluntary Nutrient Monitoring Program indicate that this industry may be discharging approximately 0.5 - 0.6 MPY of nitrogen.

FIGURE 5.16



Total Nitrogen

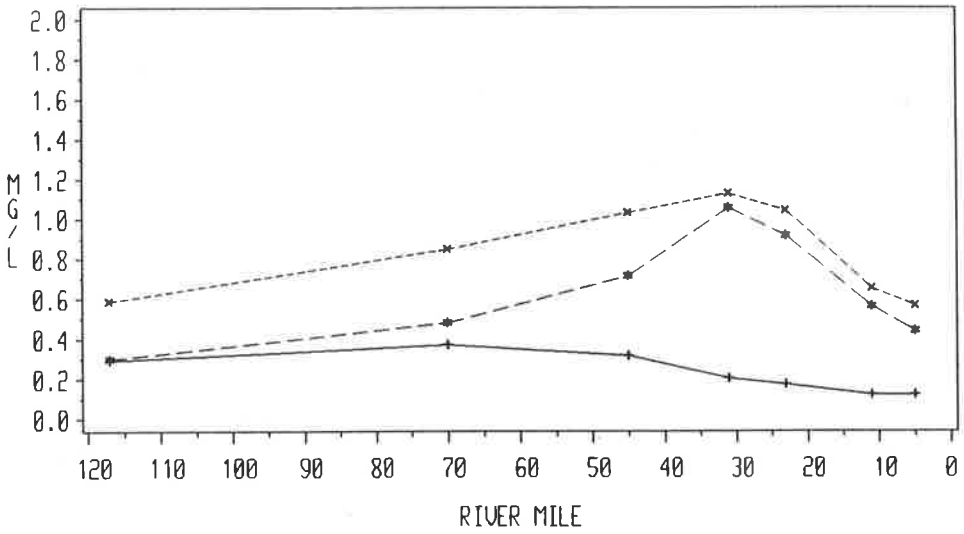
Due to low inorganic nitrogen concentrations, the nitrogen pool in the York is usually dominated by organic nitrogen. At the fall line, organic nitrogen concentrations can be several times higher than inorganic nitrogen. Thus the seasonally averaged distribution of total nitrogen is similar to that of organic nitrogen.

As observed in 1984-1986, there were two main seasonal patterns of nitrogen evident in the York River. In the spring, nonpoint source runoff is higher and biological activity is lower. This results in increased inorganic nitrogen concentrations and low organic nitrogen concentrations (Figure 5.17A). Total nitrogen concentrations peaked in the transition zone and then decreased toward the river mouth. In the warmer months, biological activity transforms inorganic nitrogen to organic nitrogen causing organic nitrogen to clearly become the dominate form of nitrogen (Figure 5.17B). This pattern was particularly pronounced in the tidal freshwater area of the river, while the estuarine area was dominated by organic nitrogen year around.

FIGURE 5.17A

NITROGEN

YORK RIVER – SPRING 1987

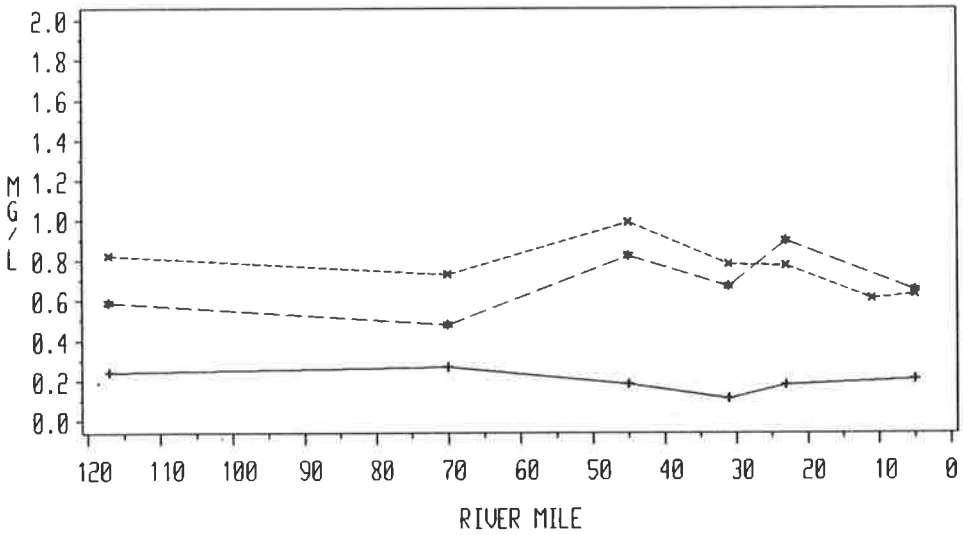


INORGANIC N _____ ORGANIC N ___ ___ ___
TOTAL N _ _ _ _

FIGURE 5.17B

NITROGEN

YORK RIVER – FALL 1987



INORGANIC N _____ ORGANIC N ___ ___ ___
TOTAL N _ _ _ _

PHOSPHORUS - YORK

Orthophosphate

Concentrations at the fall line ranged from below detection limit (<0.01 mg/l) to 0.11 mg/l (Figure 5.18). The tidal freshwater portion of the river (miles 40 - 70) had the lowest concentrations of orthophosphate and least amount of seasonal variability (Figure 5.19). In the estuary, orthophosphate concentrations were low in spring due to uptake by phytoplankton, and elevated during fall probably as a result of sediment release.

Particulate Phosphorus

The concentration of particulate phosphorus at the fall line ranged from <0.01 (below detection limit) to 0.06 mg/l (Figure 5.18). Several of the peak concentrations occurred during or after high streamflow events. Most of the particulate phosphorus at the fall line was probably inorganic orthophosphate adsorbed to sediment particles. The combination of high streamflows and high concentrations results in a significant amount of the annual loading occurring during high flow events.

FIGURE 5.18

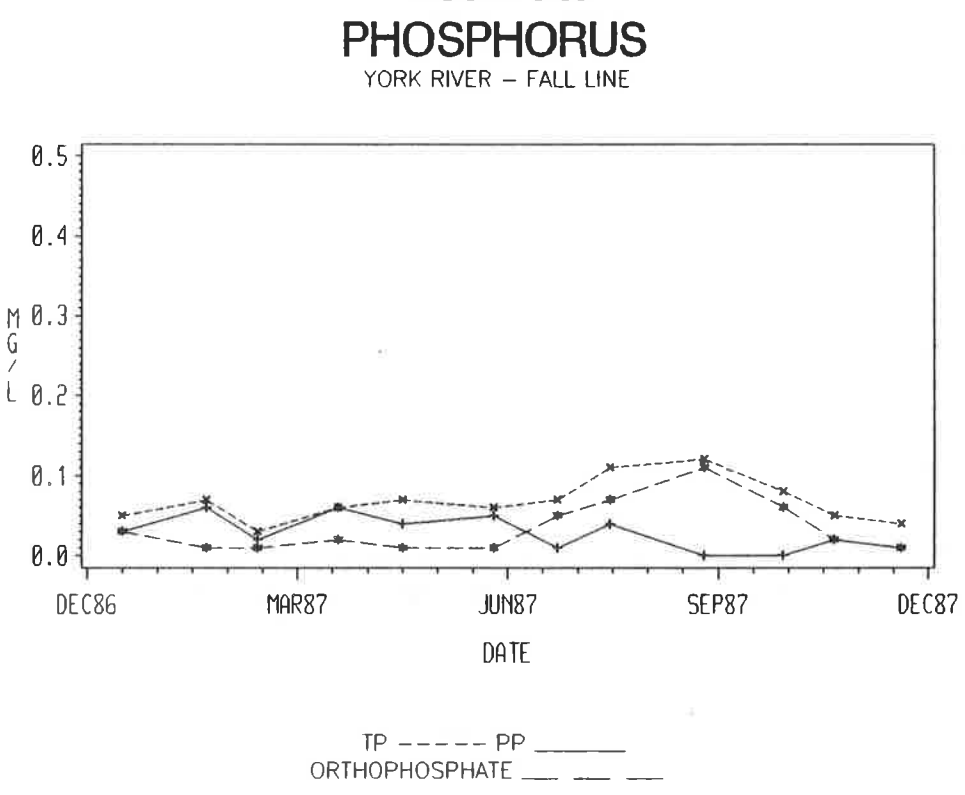


FIGURE 5.19

ORTHOPHOSPHATE

YORK

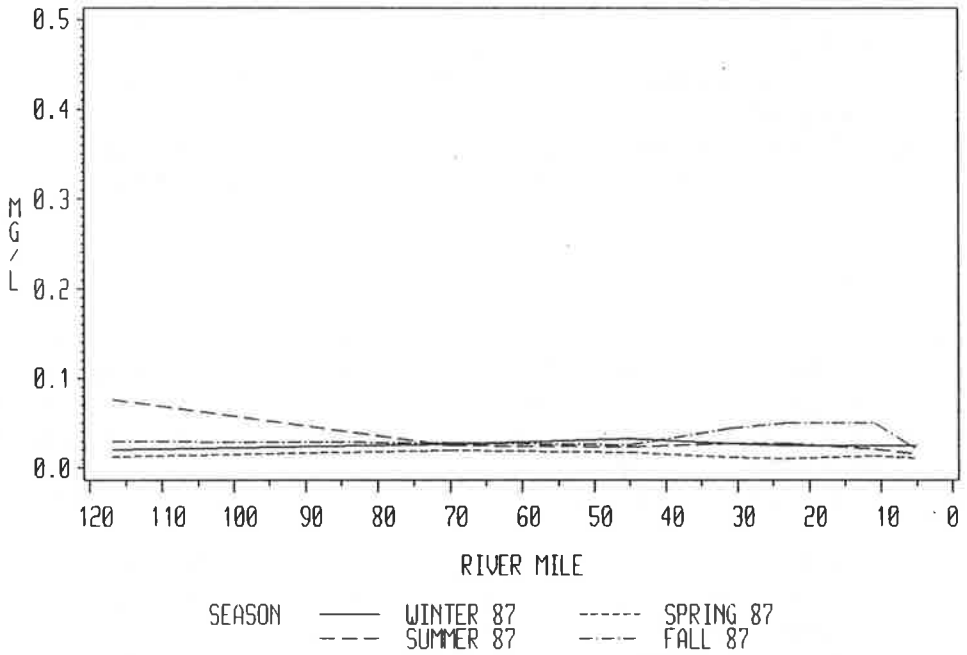
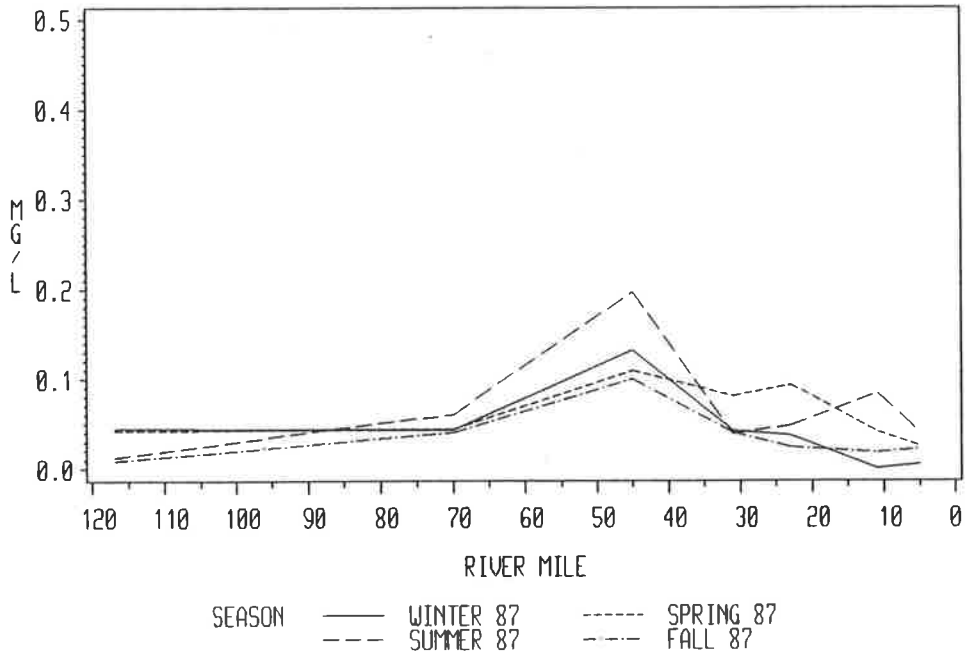


FIGURE 5.20

PARTICULATE PHOSPHORUS

YORK



The seasonally averaged downriver concentration of particulate phosphorus is depicted in Figure 5.20. As in previous monitoring reports, a very distinct peak in concentration occurs at mile 45, near the upriver limit of saltwater intrusion. Though this peak in particulate phosphorus occurred in the turbidity maximum where sediment concentrations are high, the occurrence of high organic nitrogen and carbon at the same location suggests that this peak is also a response to a large input of organic matter. This station is located just upstream of the confluence of the York and the Pamunkey Rivers. The Pamunkey has very extensive marshes along its border and undoubtedly some of the organic production in these marshes contributes to the particulate phosphorus peak. Some of the organic matter may be a result of discharges from the kraft paper mill located in West Point.

Total Phosphorus

Concentrations at the fall line ranged from 0.03 to 0.12 mg/l (Figure 5.18). As observed in previous years, dissolved orthophosphate was the dominant form passing across the fall line during much of the low flow periods. However, particulate phosphorus probably accounts for the largest fraction of the annual phosphorus load due to the large loads of particulate phosphorus delivered during storm events. As stated above, much of this particulate phosphorus is orthophosphate adsorbed to sediment particles.

Longitudinal profiles of phosphorus concentration during the spring and the fall illustrate some of the similarities and differences between seasons (Figure 5.21-A&B). During the high flow period of spring, the phosphorus at the fall line is mainly particulate, due to the nonpoint runoff of sediments and increased turbulence which keeps particulate material suspended in the water column. Because the streamflow during the fall is mainly contributed by groundwater input and the river is flowing slower, the input at the fall line is largely dissolved forms (i.e. orthophosphate) and particulates tend to settle out of the water column. In the transition zone (mile 30-50), there is always a peak of particulate phosphorus due to inputs of organic materials and the presence of a turbidity maximum (see: Section IV. PHYSICAL VARIABLES; Circulation).

FIGURE 5.21A

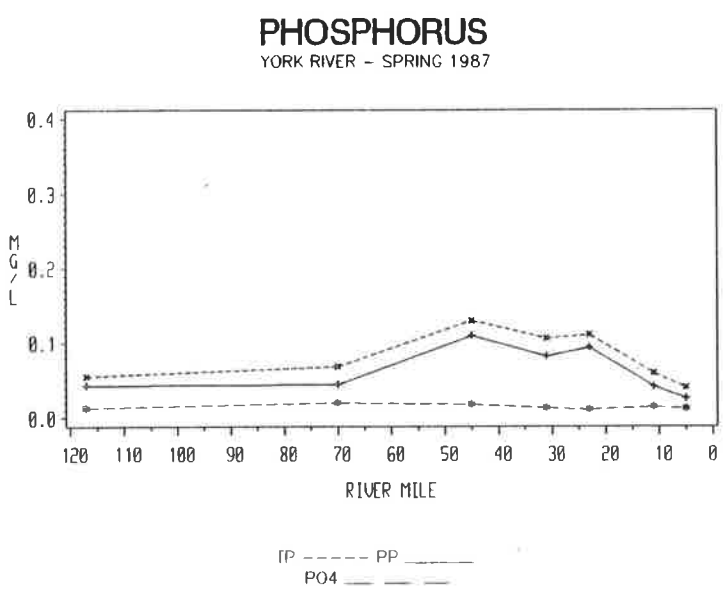
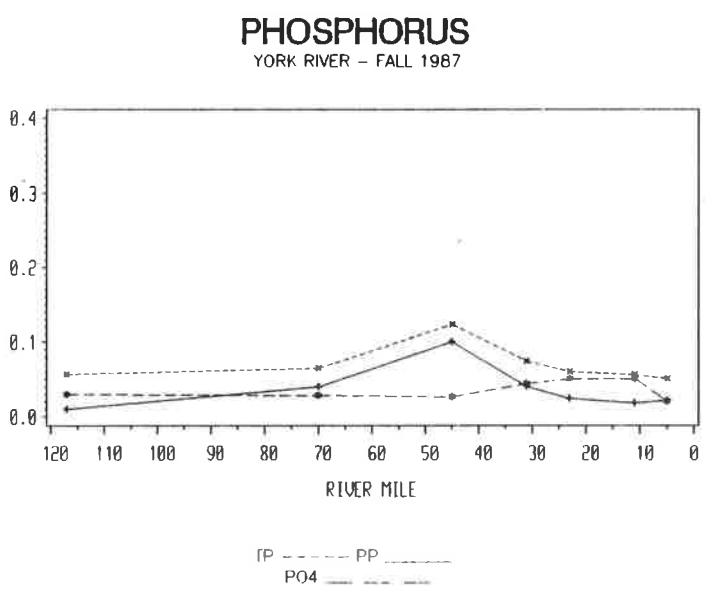


FIGURE 5.21B

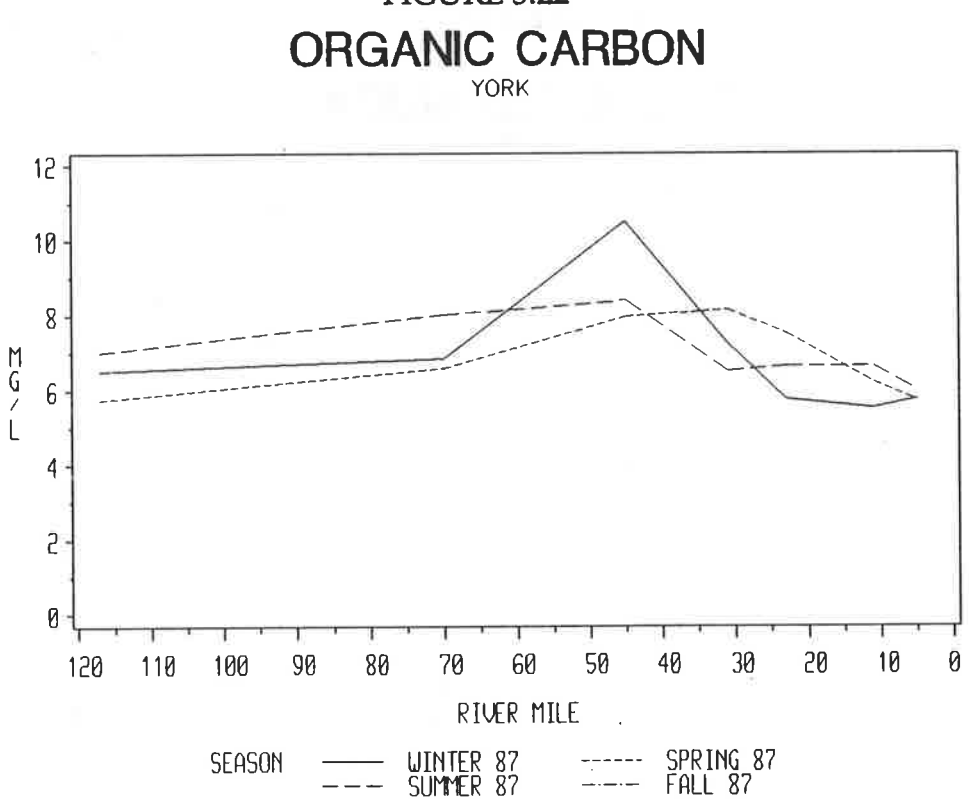


In the estuarine portion (miles 0-20), particulate and dissolved phosphorus are both relatively low during the spring with orthophosphate levels relatively high in the fall. This is a result of the increased frequency of hypoxia which develops in the fall and triggers the release of orthophosphate from the sediments.

ORGANIC CARBON - YORK

Figure 5.22 shows the seasonal distribution throughout the river. During summer, concentrations were high at the fall line and remained high into the tidal freshwater and transition areas then declined in the estuarine portion. Spring had lower concentrations at the fall line and tidal freshwater stations, peaked in the transition zone, and then decreased in the estuarine zone. The winter season had very high levels in the transition zone and the lowest levels in the estuary.

FIGURE 5.22

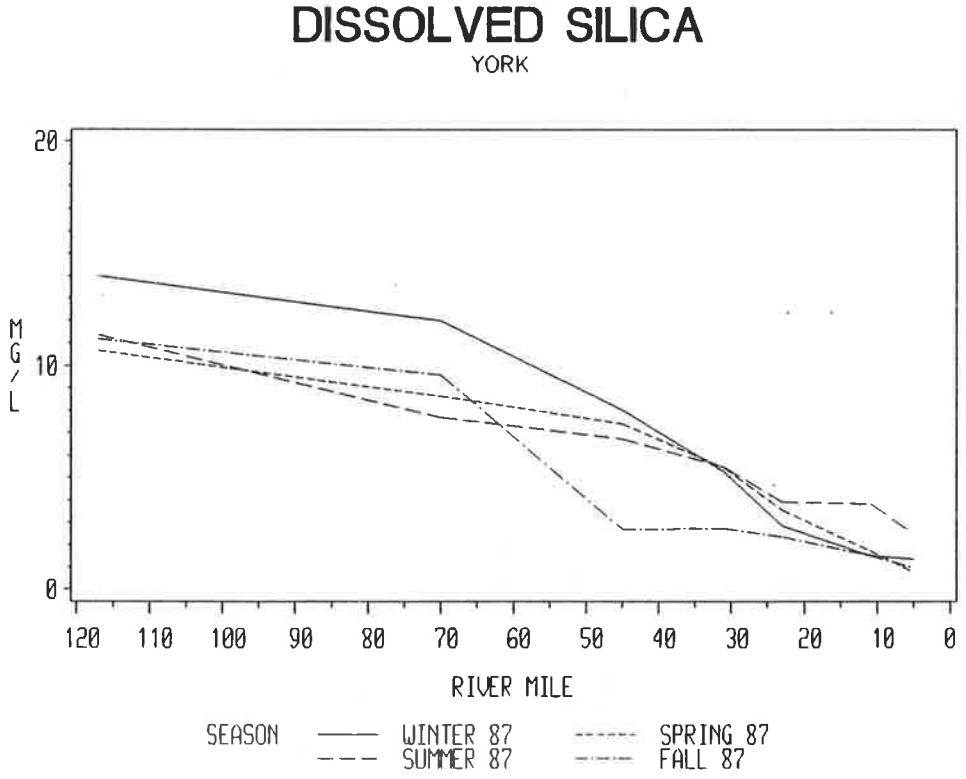


The organic carbon peak in the transition zone corresponded with elevated concentrations of organic nitrogen and particulate phosphorus. Similar to organic nitrogen, the elevated level may be a function of the tidal wetlands or discharges from the kraft paper mill in West Point. As the river water flows past the estuarine stations and mixes with Chesapeake Bay water, the organic matter concentration declines.

SILICA - YORK

The fall line concentration of silica ranged from 7.2 to 14.5 mg/l. Seasonally averaged concentrations throughout the river are depicted in Figure 5.23. During the winter, silica concentrations were high from the upper river to mile 70. Downriver, silica concentrations decreased due to estuarine dilution and possible phytoplankton uptake. Other seasons, particularly summer and fall, exhibit a decrease in silica concentrations in the transition zone due to phytoplankton uptake. In the estuarine zone, silica increased during summer as a result of recycling particulate silicate previously taken up by freshwater diatoms.

FIGURE 5.23



JAMES RIVER

NUTRIENT LOADINGS

The James River basin receives substantially more point source discharges than do the York or Rappahannock basins. There are 20 STP's and numerous industrial sources of nutrients located along the river and its tributaries. A summary of nitrogen and phosphorus loading to the James is presented in Table VII. Point source (PS) discharges at Richmond, and in the lower James account for the majority of the effluent and phosphorus loading delivered to the James. The discharger with the largest volume of effluent is the Richmond STP, which averages 66 MGD. Despite the relatively low phosphorus content of the Richmond STP effluent (4.2 mg/l), this plant's high volume of discharge makes it the largest PS for phosphorus to the James.

Hopewell area dischargers, and to a lesser extent the dischargers in the lower James, are responsible for the majority of the PS N loadings. Because the Hopewell STP receives most of its wastewater from industrial sources, its effluent is high in nitrogen (65 mg/l) and low in phosphorus (1.9 mg/l). The Hopewell STP's large flow (30 MGD) and high nitrogen content in the effluent makes it the single largest point source of nitrogen to the James river.

There is a fairly large discrepancy between the various calculations of annual nonpoint source (NPS) nitrogen loadings. The estimates reported in the 1983 EPA report appear to consistently underestimate the loadings of N from NPS. EPA estimated the annual NPS N loadings for a normal year to be approximately 12 MPY. Based on VWCB baseflow monitoring in 1985, a dry year, the N loading at the fall line was approximately 11 MPY. If this load is adjusted for the area of basin below the fall line, then the total NPS N load would be approximately 16 MPY. Therefore, during a dry year using baseflow data, the loadings of N appear greater than the EPA estimate for a year of normal rainfall.

In 1979 and 1980, the USGS conducted a sampling program and estimated annual N loading at the fall line. Streamflow during 1979 was well above normal, averaging 12,030 cfs for the year, and yielded an estimate of 25 million pounds of NPS nitrogen load. The streamflow for 1980 was near normal (6,912 cfs), and fall line estimates of NPS nitrogen load was 12.8 million pounds. If adjusted for the percentage of the basin below the fall line the annual NPS N loadings for 1979 and 1980 would be 42 MPY, and 21 MPY, respectively.

The EPA estimates of annual NPS P loadings in a normal year (1.0 MPY) agree favorably with the estimates based on the data from VWCB baseflow fall line monitoring program during 1985 (0.9 MPY), which was a dry year (excluding the November flood). The USGS study monitored baseflows and storm events at the fall line during 1979 and 1980. The estimates of P loads at the fall line were much higher than the EPA estimates. The EPA estimate of total NPS for a normal year (1.0 MPY), is substantially below the estimate by USGS of 5.7 MPY at the fall line during 1980, a year with normal streamflow. The USGS estimated that during 1979, which had twice the flow of 1980, there was also a twice the P loadings at the fall line. If the fall line estimates were extrapolated to the entire drainage basin, then these estimates would be an order of magnitude greater than the EPA estimates.

TABLE VII

LOADINGS OF NUTRIENTS TO THE JAMES RIVER

SOURCE	FLOW MGD (%)	NITROGEN MILLIONS POUNDS/YEAR	PHOSPHORUS (%)
POINT[1]			
ABOVE FALL LINE	29 (12)	1.6 (8)	0.56 (16)
RICHMOND	80 (34)	3.4 (18)	1.11 (31)
HOPEWELL AREA	40 (17)	8.3 (44)	0.52 (15)
LOWER JAMES	86 (37)	5.6 (30)	1.33 (38)
TOTAL	235	18.9	3.52
NON POINT[2]			
TOTAL		12-16 (21)	1-2 (10)

1) Loading calculated from VWCB discharge permit information.

2) Loadings calculated from this monitoring program and information from Chesapeake Bay Program Technical Studies:A Synthesis; USEPA, September, 1983.

Number in parenthesis is USGS data from a fall line monitoring program in 1980, a year with normal precipitation.

NITROGEN - JAMES

Ammonium

The concentration of ammonium at the fall line ranged from below detection (<0.02 mg/l) to 0.11 mg/l (Figure 5.24). Municipal point sources are estimated to contribute 90% of the ammonium loading to the James, thus having a major influence on the distribution of ammonium within the river. As seen in Table VIII, ammonia concentrations sometimes were above the recommended instream criteria adopted by the VWCB. Ammonium exhibited a consistent peak in concentration at mile 99, between Richmond and Hopewell (Figure 5.25). Also, the majority of the observations above the criteria were at mile 99. The low streamflows and higher temperatures of summer and fall resulted in higher instream concentrations and more observations above the criteria. High streamflow and lower biological activity during the winter and spring resulted in the displacement of the peak downriver. The subsequent decline in estuary concentration is due to a combination of algal uptake, dilution, and nitrification. The James River Water Quality Monitoring Program (JRWQMP), with its more spatially intensive sampling, located the peak in ammonium at mile 103, below the Richmond area wastewater treatment plants.

FIGURE 5.24

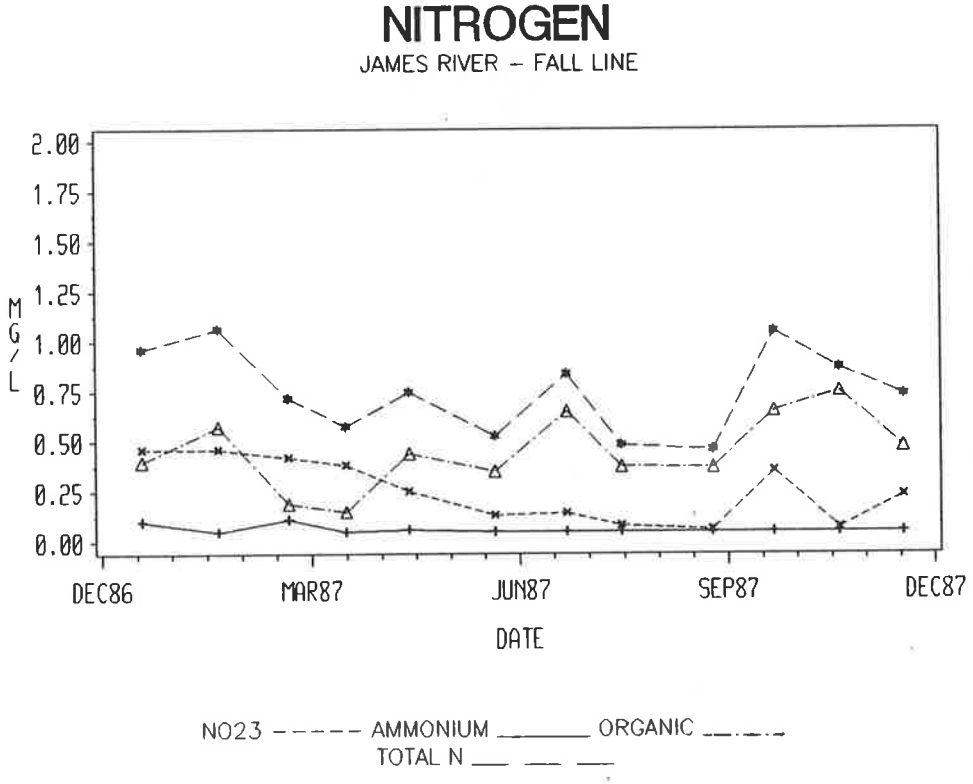


TABLE VIII

OBSERVATIONS ABOVE STATE AMMONIA CRITERIA - 1987

STATION	DEPTH	DATE	AMMONIA *	CRITERIA**
RET5.2	SURFACE	MARCH 4	0.46	0.34
RET5.2	BOTTOM	MARCH 4	0.43	0.05
TF5.6	BOTTOM	APRIL 8	0.32	0.04
TF5.3	SURFACE	MAY 18	0.22	0.09
TF5.3	BOTTOM	MAY 18	0.24	0.18
TF5.3	SURFACE	JULY 13	0.50	0.30
TF5.3	BOTTOM	AUG. 11	0.70	0.32
TF5.3	SURFACE	AUG. 25	1.10	0.92
TF5.3	BOTTOM	AUG. 25	1.10	0.36

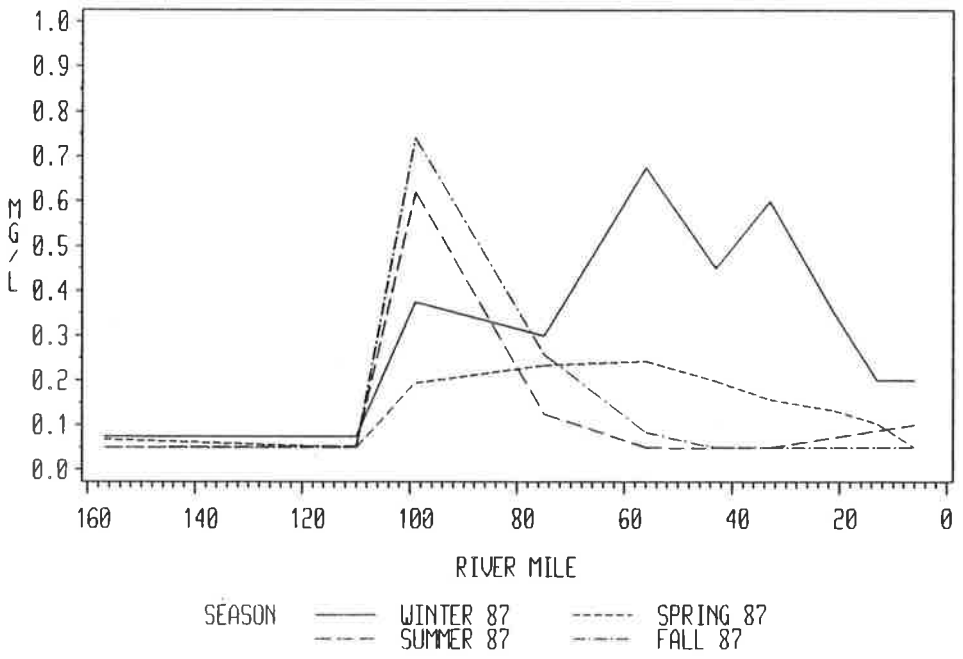
* mg/l as total ammonia (ammonium + un-ionized ammonia)

** Virginia Water Quality Criteria (VR680-21-0.32). Total Ammonia Criteria data are based on pH and temperature.

FIGURE 5.25

AMMONIUM

JAMES



Nitrite plus Nitrate (NO2+3)

Concentrations at the fall line ranged from 0.10 to 0.46 mg/l (Figure 5.24). The downriver distribution of NO2+3 indicated a marked increase in the tidal freshwater and upper transition zones of the river (Figure 5.26). These elevated levels are followed by a decrease in the estuarine zone due to dilution by Bay waters and biological uptake. As with ammonium, there is a downriver shift of the peak during winter. These peaks are a result of instream nitrification of ammonium and to a lesser extent point source discharge of NO2+3. The variable location of these peaks result from complex interrelationships between inputs, river flow, and biological processing.

Figure 5.27 illustrates the process of nitrification during summer 1987. The peak of ammonium at mile 99 reflects inputs from Richmond area municipal discharger. Downriver a decline in ammonium and a peak in nitrite are evident, reflecting the first step of nitrification (oxidation of NH4 to NO2). Further downriver, nitrite decreases and nitrate increases, indicative of the second step of nitrification (oxidation of NO2 to NO3). Nitrification is a major oxygen consuming process and an important impacting factor on the water quality of the upper tidal James. For every 1 mg of ammonium that undergoes the process of nitrification, 4.6 mg of oxygen are utilized.

FIGURE 5.26

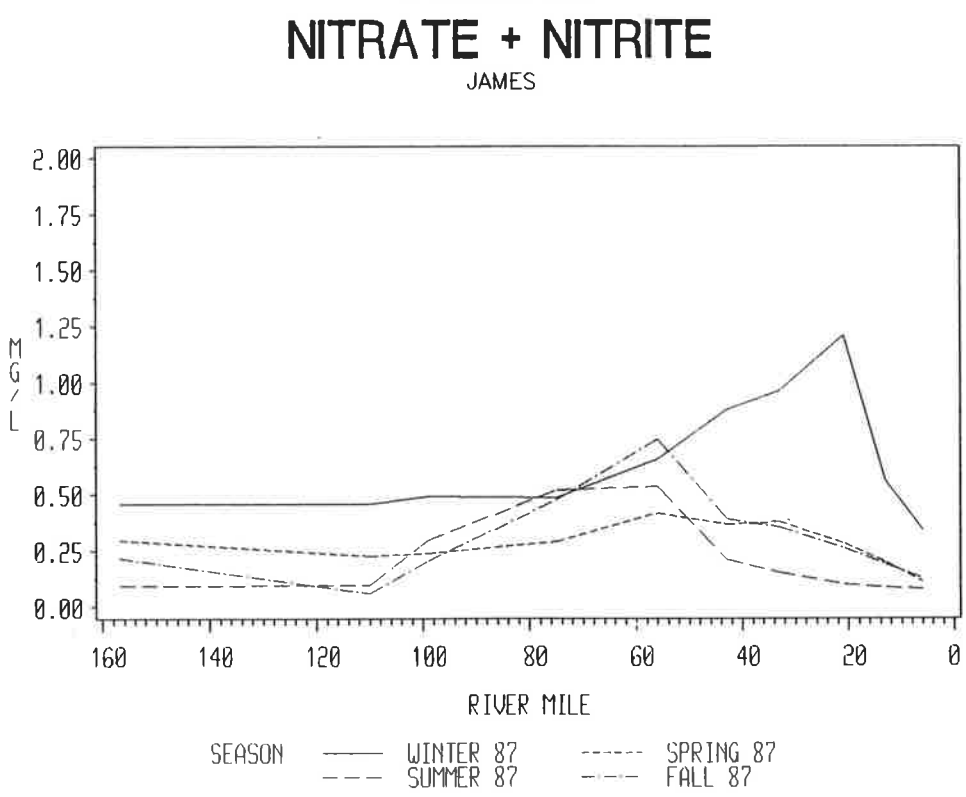
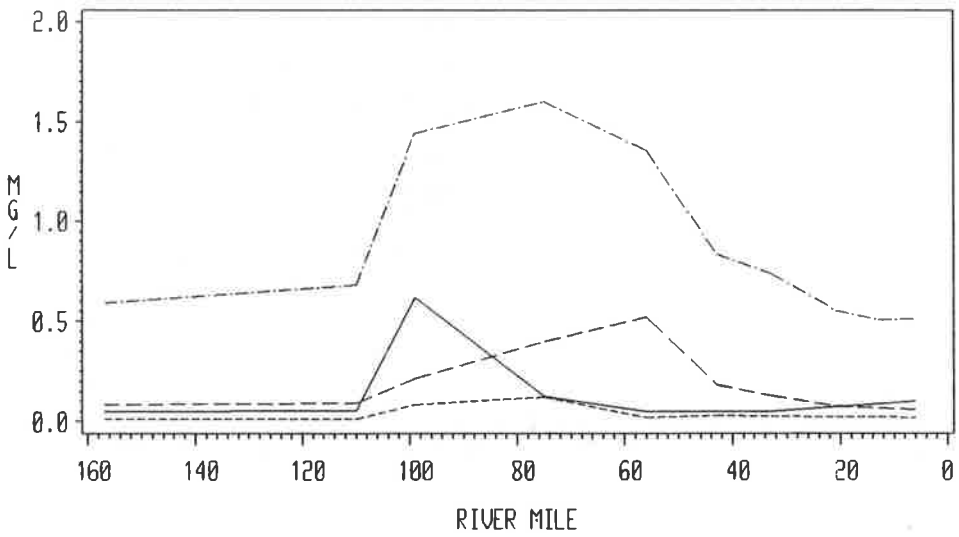


FIGURE 5.27

NITROGEN

JAMES RIVER – SUMMER 1987

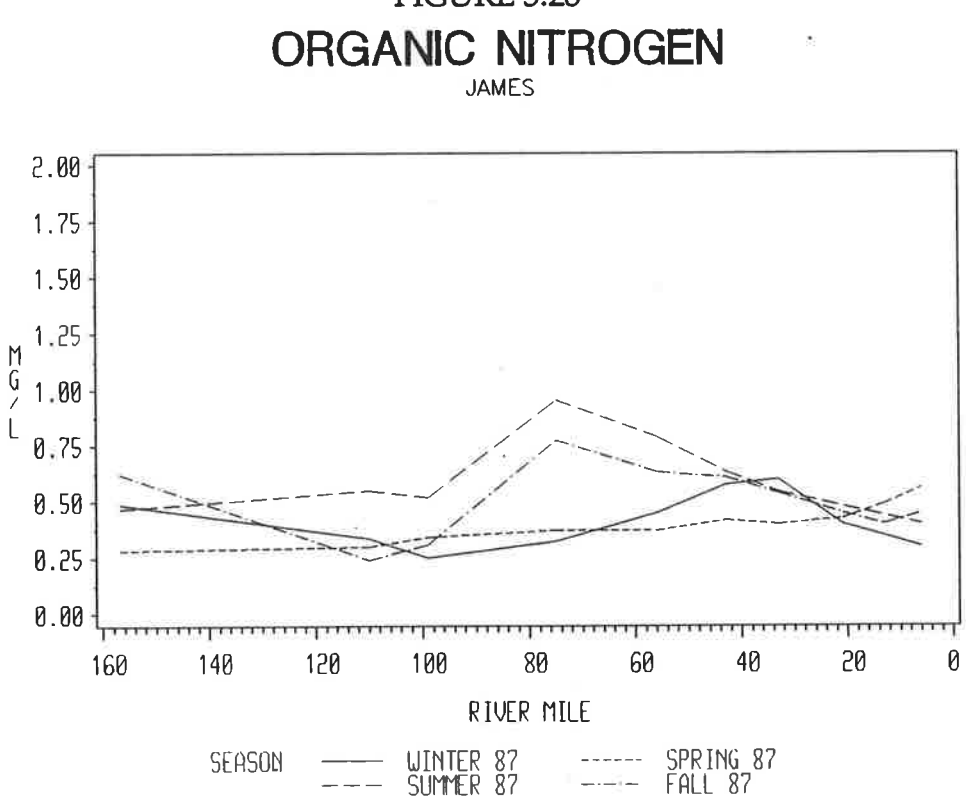


NITRITE – – – – – – AMMONIUM _____
NITRATE ___ ___ ___ TOTAL N _____

Organic Nitrogen

Organic Nitrogen concentrations at the fall line ranged from 0.13 to 0.75 mg/l (Figure 5.24). Figure 5.28 depicts the seasonally averaged concentrations throughout the river. In the tidal freshwater and transition zones, there was a great amount of variation between seasons and between stations. Concentrations in these areas were greater during summer and fall than winter and spring. Municipal and industrial sources are partially responsible for the increase. Increase is also due to algal production, as well as input from the Appomattox River. In the estuarine zone there was less variation, with the highest seasonal concentration occurring in spring.

FIGURE 5.28



Total Nitrogen

Total Nitrogen concentrations at the fall line ranged from 0.48 to 1.09 mg/l (Figure 5.24). Typically, the major form of nitrogen at the fall line was organic.

Downriver, an increase in total nitrogen occurs in the Richmond/Hopewell area (Figure 5.29). A large percentage (44%) of the total point source nitrogen loading occurs in this region (Table VII). High streamflow during winter and spring acted to shift the total nitrogen peaks downriver. Another higher streamflow effect is that the total nitrogen peaks observed during the summer and fall of 1987 were lower than the peaks observed during the summer and fall of 1986.

The nitrogen distribution in the James varied between seasons as a result of streamflow changes and biological utilization. The distribution of nitrogen during winter and summer is depicted in Figures 5.30A and 5.30B, respectively. During summer, the dominant form of nitrogen at the fall line is organic, when biological productivity is high. Organic and inorganic nitrogen exhibited comparable concentrations in the tidal freshwater area. Further downriver, in the estuarine zone, inorganic nitrogen decreased rapidly and organic nitrogen became the dominant form. In winter, lowered biological activity yielded lower organic nitrogen concentrations and allowed inorganic nitrogen to remain high throughout much of the river.

FIGURE 5.29

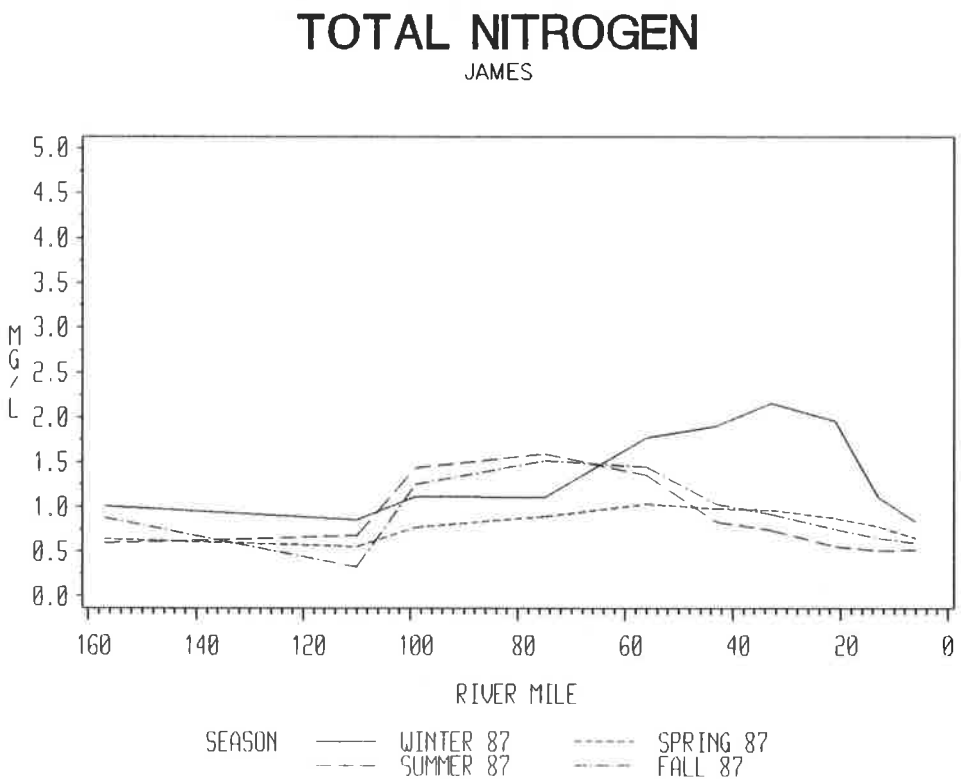
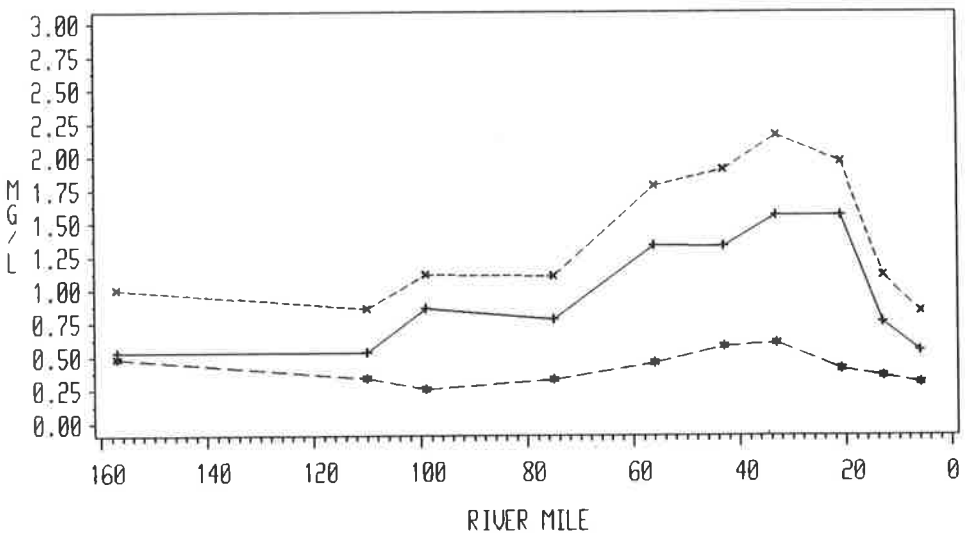


FIGURE 5.30A

NITROGEN

JAMES RIVER – WINTER 1987

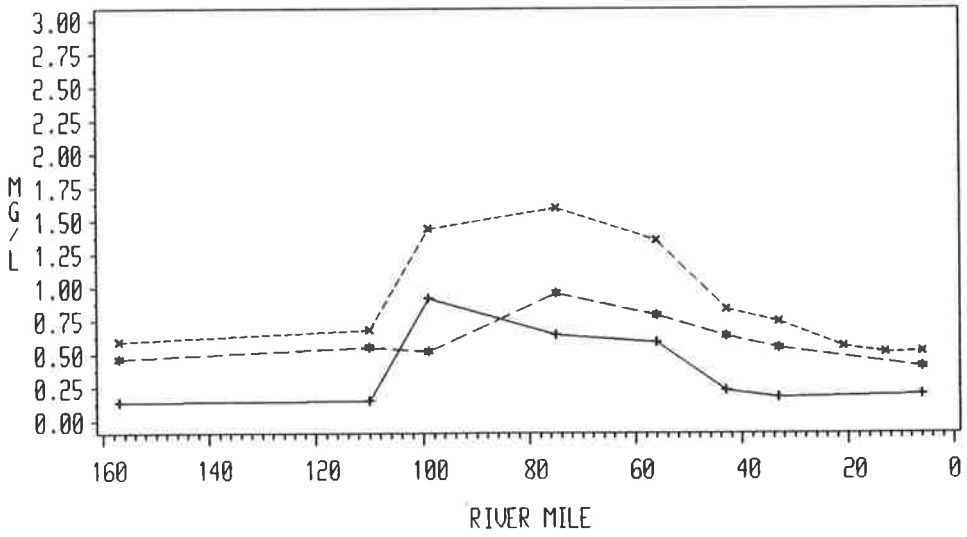


INORGANIC N _____ ORGANIC N ___ ___ ___
TOTAL N _ _ _ _

FIGURE 5.30B

NITROGEN

JAMES RIVER – SUMMER 1987



INORGANIC N _____ ORGANIC N ___ ___ ___
TOTAL N _ _ _ _

PHOSPHORUS - JAMES

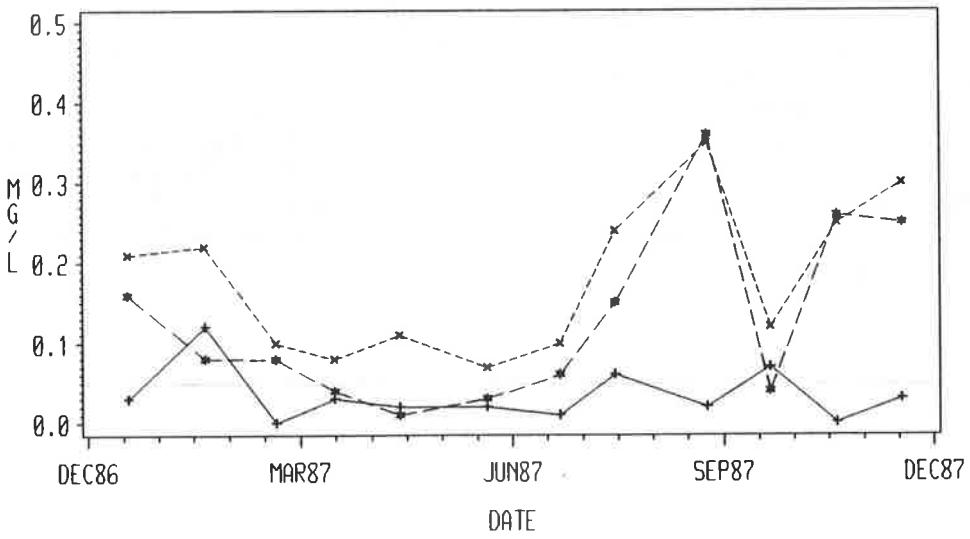
Orthophosphate

Orthophosphate concentrations at the fall line were inversely related to streamflow increases with a steady decline December through April. Values increased May through August as flow decreased (Figure 5.31). September had an abnormally high streamflow which decreased the concentration. The high concentration at the fall line generally decreased below the fall line to Richmond (Figure 5.32). The impact of inputs from the Richmond municipal wastewater treatment plant is evident as a large peak in orthophosphate concentration between Richmond and Hopewell (mile 99). Downriver orthophosphate concentration again decreased due to a combination of sediment sorption processes, biological uptake, and dilution. In the estuarine zone, concentrations were typically low during winter and spring. During summer and fall concentrations were slightly elevated.

FIGURE 5.31

PHOSPHORUS

JAMES RIVER – FALL LINE



TP ----- PP _____

ORTHOPHOSPHATE ___ ___ ___

Particulate Phosphorus

Particulate phosphorus concentrations at the fall line ranged from less than 0.01 (detection limit) to 0.12 mg/l (Figure 5.31). The fall line concentrations seemed to be positively related to streamflow. The highest concentration was observed on January 20 during a short term high flow event; streamflow on this date was 10,500 cfs. Flow the previous day was only 4,160 cfs. The second highest concentration observed was on September 21. The streamflow was 15,900 cfs, the previous day streamflow was only 6540 cfs. The majority of this particulate phosphorus was probably orthophosphate adsorbed to sediment particles.

Figure 5.33 illustrates the seasonal pattern of longitudinal concentrations. The highest values were typically found in the tidal fresh and transitional areas. The elevated concentrations at mile 75 during summer and fall are partly a result of high algal biomass observed there.

Total Phosphorus

Concentrations at the fall line ranged from 0.02 to 0.48 mg/l and were dominated by orthophosphate on all but one date (Figure 5.31). An analysis of James River historical data has shown that total phosphorus fall line concentrations have almost tripled since 1974 and has increased at a rate of about six percent a year (USGS, Report VA. 85-1, 1985; 86-1, 1986). These increases (mostly orthophosphate) may mean that present estimates of the relative roles of nonpoint sources versus point source inputs are incorrect. The cause of high fall line total phosphorus concentrations is not apparent, but it is important and may affect the water quality of the James River and lower Chesapeake Bay.

The longitudinal distribution of phosphorus forms varied seasonally, influenced by streamflow and biological processing. The spring season is shown in Figure 5.34. Orthophosphate was low at the fall line and throughout the James due to high streamflow dilution effect . Particulate forms are high in much of the river due to surface runoff contributing sediment bound phosphorus. Longitudinal distributions during fall are shown in Figure 5.35. Orthophosphate was greatly elevated throughout the upper river due to decreased dilution during this low flow period. High algal productivity during this season converted much of the inorganic orthophosphate into the particulate organic form in the middle stretch of the James. In the estuarine zone, decreased algal productivity and dilution by Bay waters decreased the particulate concentrations. The lowered rate of biological uptake and increased input from both point source and sediment fluxes yielded an increase of orthophosphate in the estuarine zone.

FIGURE 5.32

ORTHOPHOSPHATE

JAMES

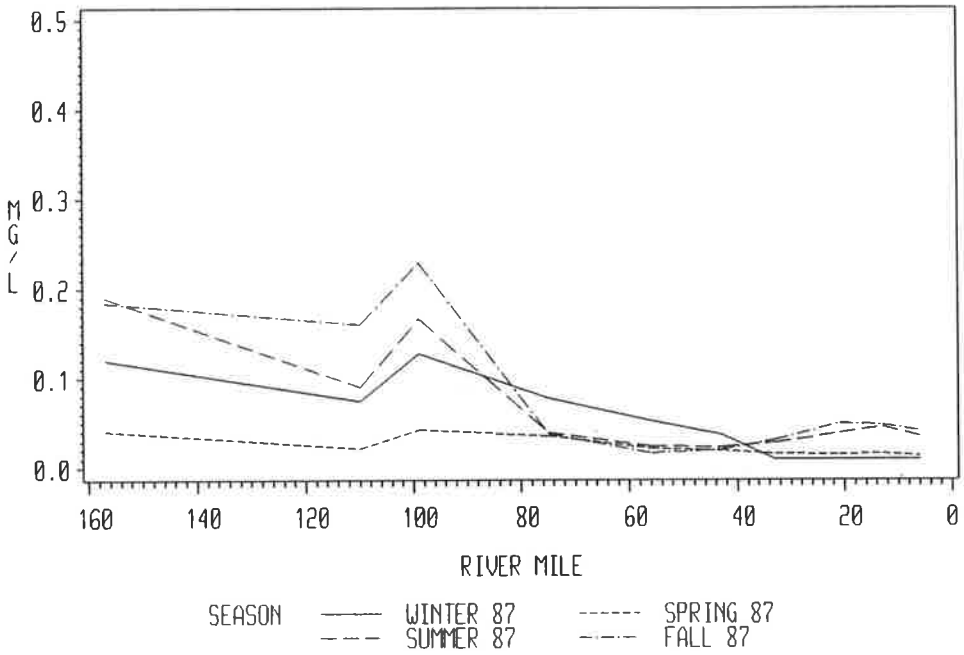


FIGURE 5.33

PARTICULATE PHOSPHORUS

JAMES

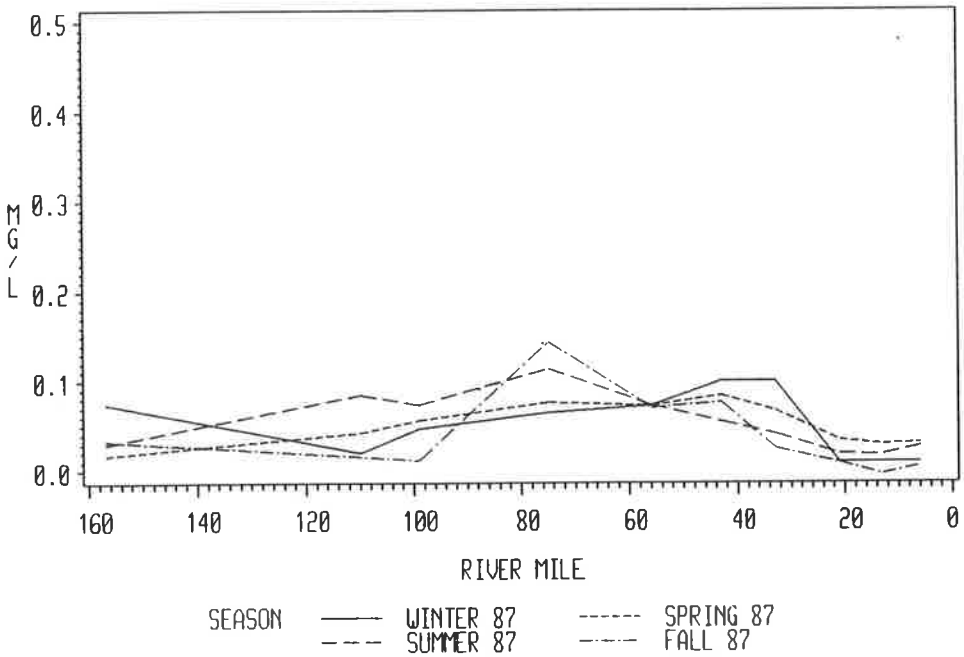
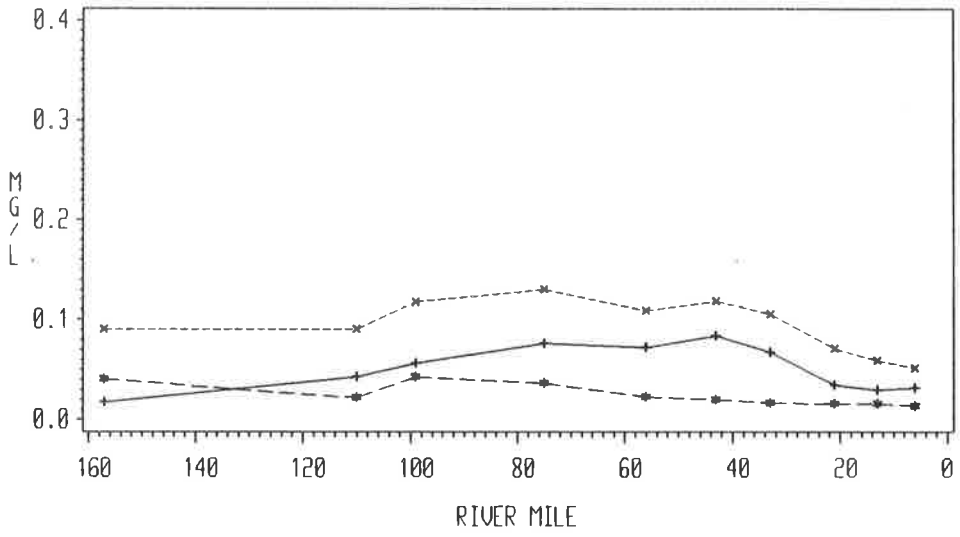


FIGURE 5.34

PHOSPHORUS

JAMES RIVER – SPRING 1987

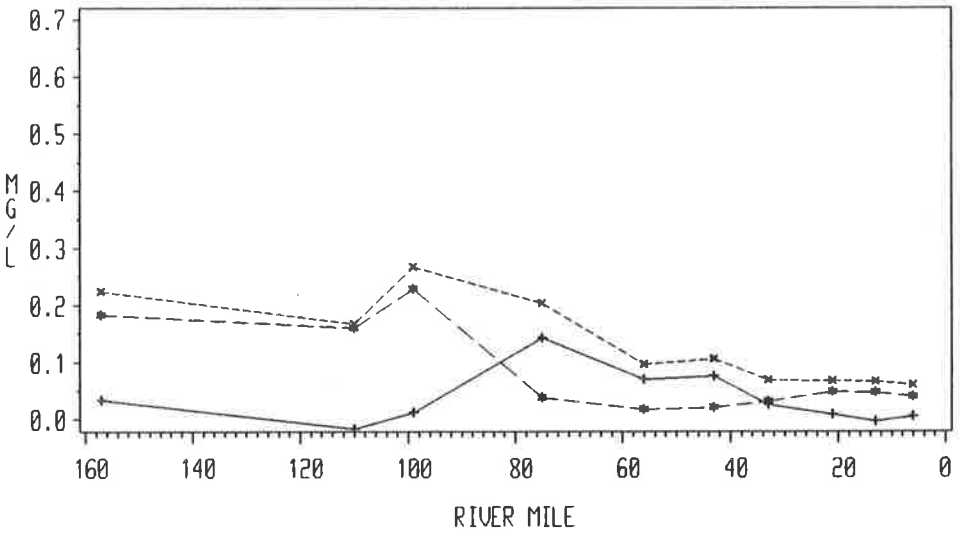


TP – – – – – PP _____
PO4 __ __ __

FIGURE 5.35

PHOSPHORUS

JAMES RIVER – FALL 1987

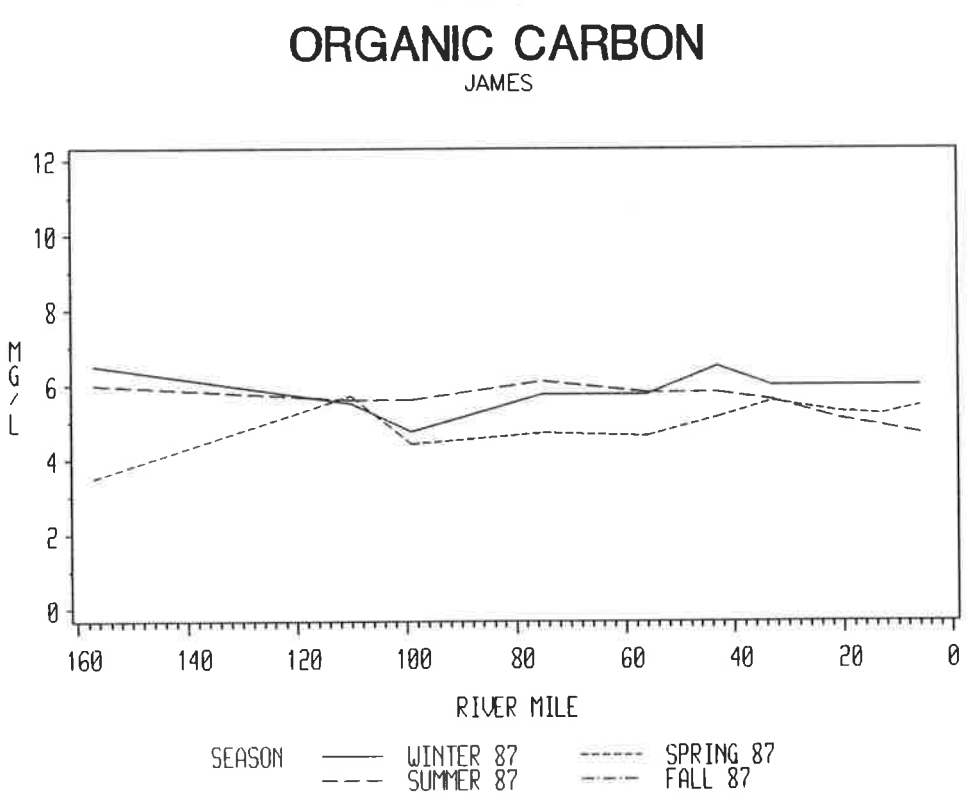


TP – – – – – PP _____
PO4 __ __ __

ORGANIC CARBON - JAMES

Organic carbon concentrations at the fall line ranged from 1.8 to 7.0 mg/l. In the transition area, organic carbon concentrations were higher in summer than in spring (Figure 5.36). In the estuarine waters (miles 0-40), organic carbon concentrations were highest in winter. The greater carbon concentrations during summer and winter are probably a result of greater biological productivity during these months. Another contributing factor is the greater streamflow during spring which dilutes riverborne carbon and lowers concentrations.

FIGURE 5.36



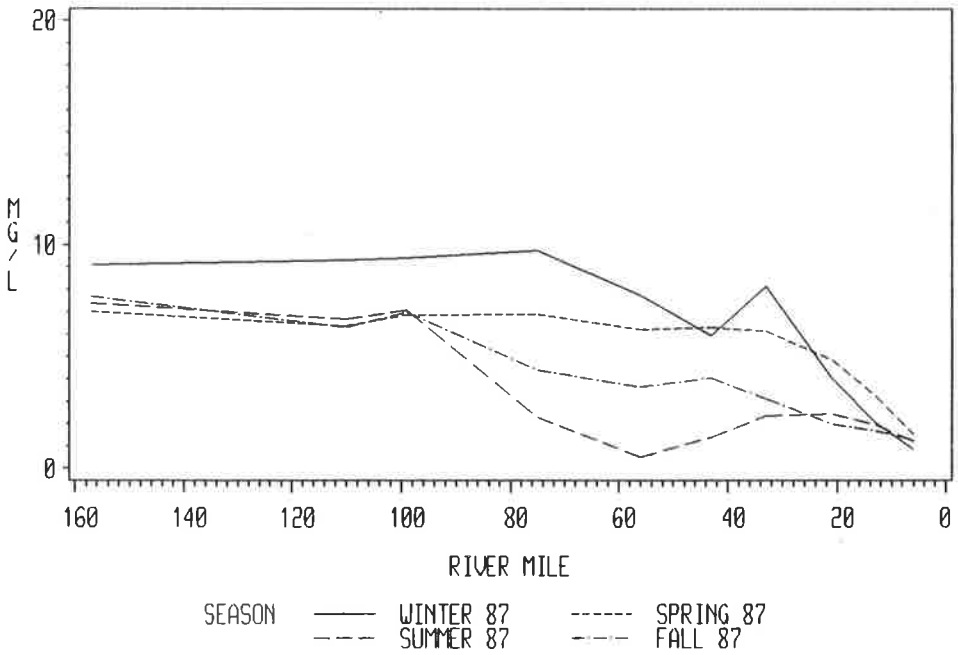
SILICA - JAMES

Silica concentrations at the fall line ranged from 1.7 to 8.8 mg/l. The seasonally averaged distribution of silica throughout the James is presented in Figure 5.37. During winter, when biological uptake is lowest, silica remained high in the freshwater zone and decreased in the estuarine waters due to dilution. During other seasons a decrease was observed in tidal freshwater (miles 80-50) followed by a subsequent increase downriver. This decrease is a result of uptake by freshwater diatoms. Production is highest in the area just upstream of the freshwater and the saltwater interface. The increasing concentration further downriver is a result of the remineralization of diatom silica that was previously incorporated into diatom shells. Further downriver, the concentration again decreased due to uptake by estuarine diatoms and dilution by Bay waters.

FIGURE 5.37

DISSOLVED SILICA

JAMES



RIVER COMPARISONS

NUTRIENT LOADINGS

A comparison of nutrient loading by river basin is presented in Table IX. The James River receives substantially larger loadings of N and P than the other two river basins. The point source loadings of N to the James are 30 to 40 times greater than the loads delivered to the York or Rappahannock. P loadings are 20 times greater than the loads delivered to the York or Rappahannock. The James is a point source dominated estuary. The York and Rappahannock Rivers receive a greater percentage of their nutrients from non-point sources. As previously illustrated in nutrient concentration data, the impact of point source nutrient loadings to the James exceeds those of the York and Rappahannock even when the larger freshwater flow of the James is taken into account.

TABLE IX

YEARLY LOADINGS IN MILLIONS OF POUNDS[1]

NITROGEN

SOURCE	JAMES (%)	YORK (%)	RAPPAHANNOCK (%)
MUNICIPAL	16 (52)	.57 (15)	.43 (10)
INDUSTRIAL	3.2 (10)	.16 (5)	.18 (4)
NON POINT	12 (38)	3.0 (80)	3.8 (86)

PHOSPHORUS

SOURCE	JAMES (%)	YORK (%)	RAPPAHANNOCK (%)
MUNICIPAL	3.1 (67)	.17 (40)	.11 (27)
INDUSTRIAL	.50 (11)	.04 (10)	.04 (11)
NON POINT	1.0 (22)	.21 (50)	.25 (62)

Number in parenthesis represents percentage of total loading from each source.

1) Municipal and Industrial loadings calculated from VWCB discharge permit information. Non Point Loadings calculated from Chesapeake Bay Program Technical Studies: A Synthesis; USEPA, September, 1983.

NITROGEN - RIVER COMPARISONS

In general, the comparisons between rivers revealed the same patterns observed during the 1984-1986 monitoring period. As described previously, several differences between rivers are evident and can be attributed to different patterns of nutrient inputs. Inorganic nitrogen concentrations of the three rivers during high streamflows of spring are presented in Figure 5.38A. The Rappahannock, being dominated by nonpoint inputs above the fall line, exhibited high inorganic nitrogen concentrations at the fall line through tidal freshwater. In the York and James, inorganic nitrogen reached maximum concentrations in tidal freshwater, indicating a source of nitrogen below the fall line. In the James River, the peak in inorganic nitrogen was due to point source inputs in the Richmond/Hopewell area. In the York River, elevated levels of inorganic nitrogen were probably the result of nonpoint input from the bordering wetlands or upland areas below the fall line. In the estuarine areas of the three rivers, inorganic nitrogen concentrations are low due to dilution by Bay waters.

During the low streamflows of summer (Figure 5.38B), point source discharges to the James had a more pronounced influence than during the winter. Conversely, the NPS inputs to the York and Rappahannock are decreased during low flow periods. This, and biological uptake, lowered concentrations in the York and Rappahannock Rivers. During the warmer seasons, ammonia was released from sediments in the estuarine zone (stimulated by conditions of low dissolved oxygen) in the York and Rappahannock but not in the James.

FIGURE 5.38A

INORGANIC NITROGEN

ALL RIVERS – SPRING 1987

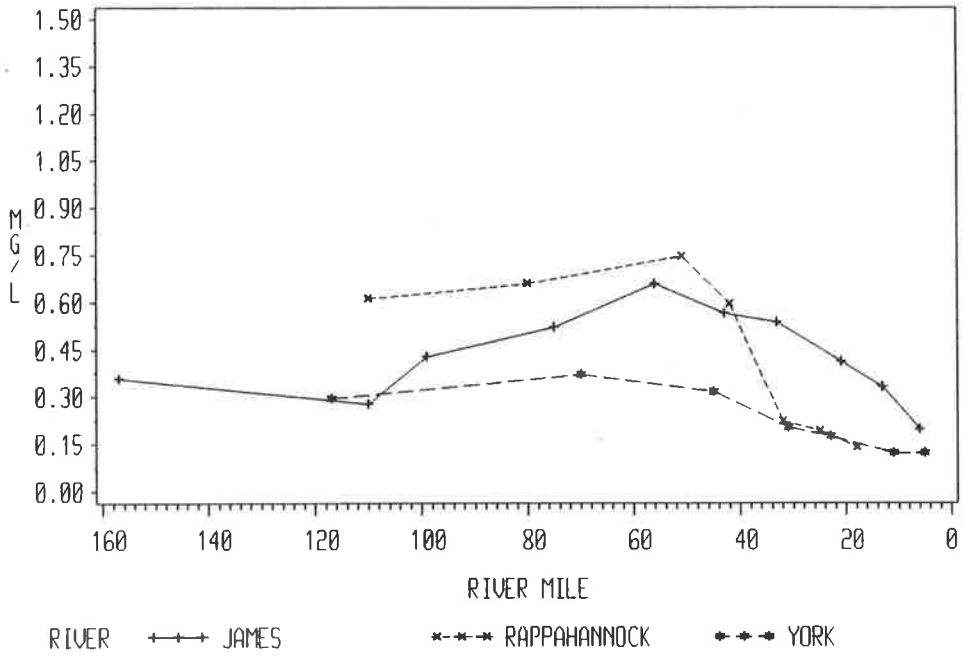
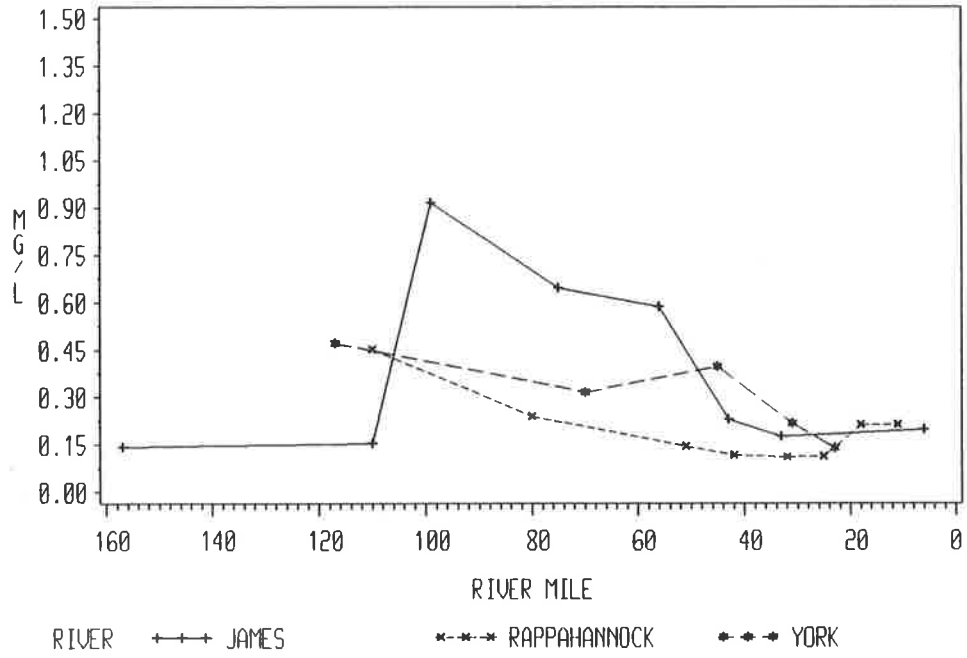


FIGURE 5.38B

INORGANIC NITROGEN

ALL RIVERS – SUMMER 1987



Concentrations and distributions of organic nitrogen were relatively similar among the three rivers. During spring, the rivers had a peak in the estuarine area due to phytoplankton production (Figure 5.39A). In summer, peak concentrations were further upriver (Figure 5.39B). For the James, this summer peak is related to both point source inputs and algal production. The Rappahannock peak is mainly a result of high algal production. The York has neither the high point source inputs of the James nor the high algal production of the Rappahannock. It does, however, have extensive tidal wetlands which could account for the majority of organic nitrogen input.

FIGURE 5.39A

ORGANIC NITROGEN

ALL RIVERS – SPRING 1987

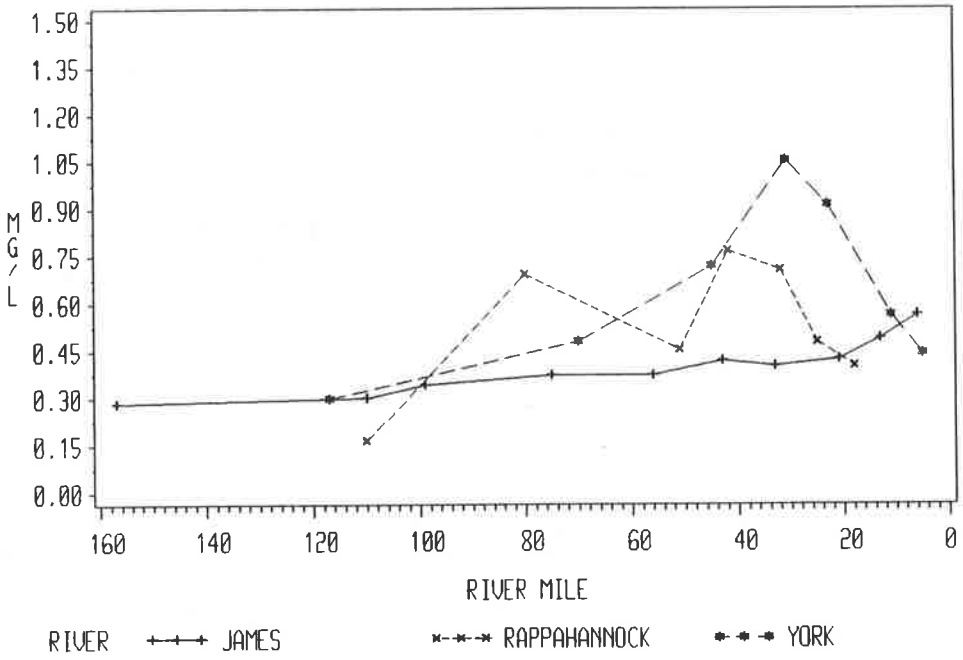
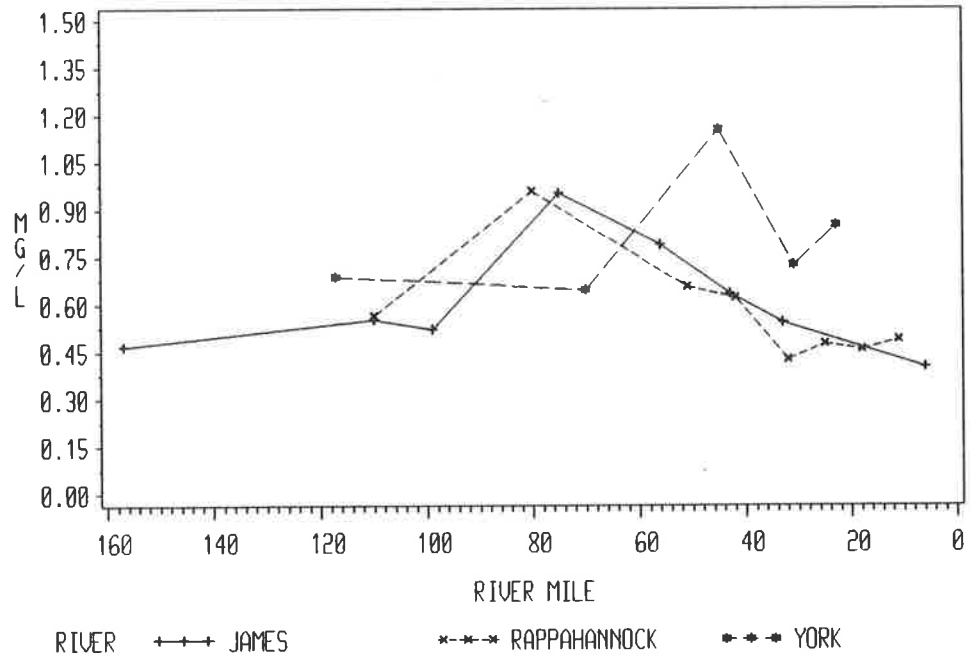


FIGURE 5.39B

ORGANIC NITROGEN

ALL RIVERS – SUMMER 1987



PHOSPHORUS - RIVER COMPARISONS

As observed in previous reports, the James had much higher phosphorus levels at the fall line than either the York or the Rappahannock Rivers, due to high orthophosphate concentrations (Figure 5.40). The York had the next highest concentration at the fall line, unlike 1984-1985, when the York and Rappahannock exhibited similar phosphorus concentrations. Reasons for elevated phosphorus concentrations at the fall line of the James River are presently not well understood.

A comparison of orthophosphate during fall in longitudinal profiles of the three rivers is presented in Figure 5.41. The large increase in concentration that occurred between Richmond and Hopewell, on the James River (mile 99), is due to loadings from Richmond area municipal dischargers. The combination of high fall line and point source loadings resulted in generally higher concentrations throughout most of the James. Unfortunately, the possible impact of point sources input of phosphorus to the upper tidal Rappahannock is not detected by the current program. However, the addition of several stations during 1988 will allow the VWCB to examine this in future reports.

All rivers had elevated orthophosphate concentrations in the estuarine regions during some seasons, though to different degrees and for slightly different reasons. In the Rappahannock, the elevated levels were a result of hydrologic conditions which lead to low dissolved oxygen concentrations in bottom waters and a subsequent release of orthophosphate from sediments.

FIGURE 5.40

TOTAL PHOSPHORUS

FALL LINE

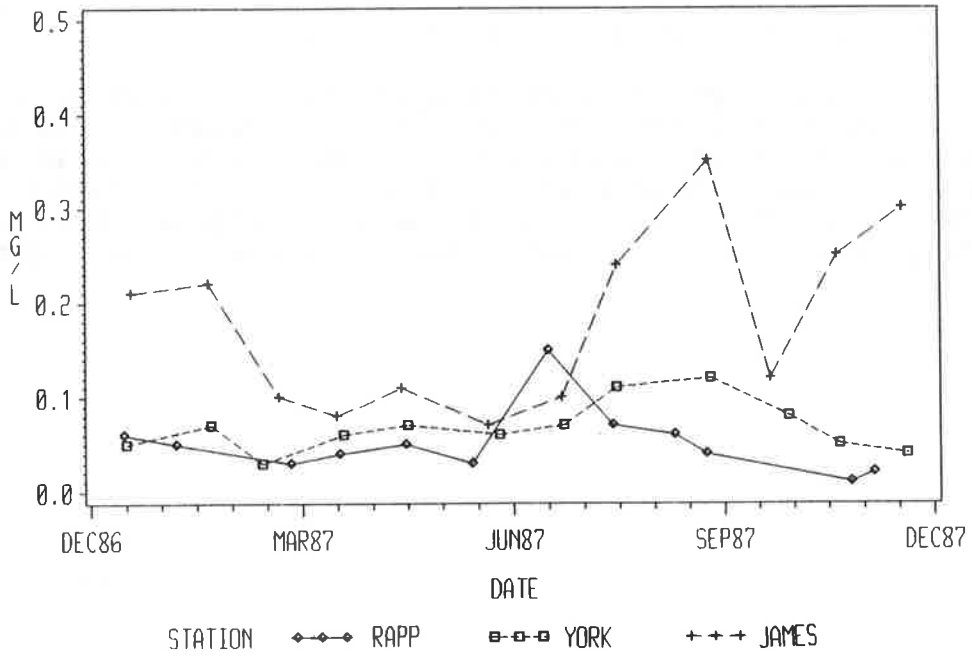
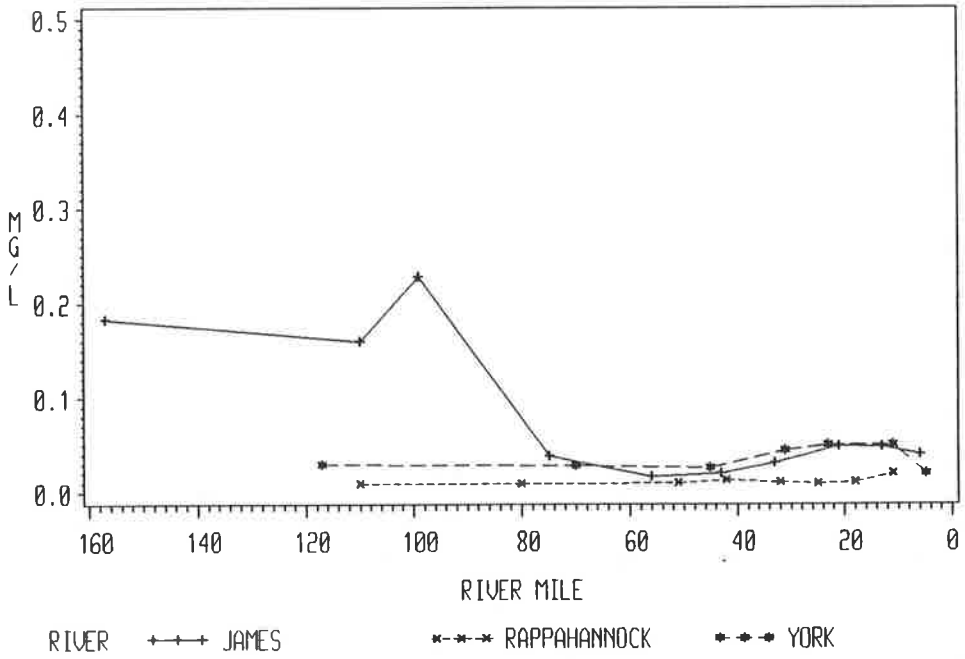


FIGURE 5.41

ORTHOPHOSPHATE

ALL RIVERS – FALL 1987



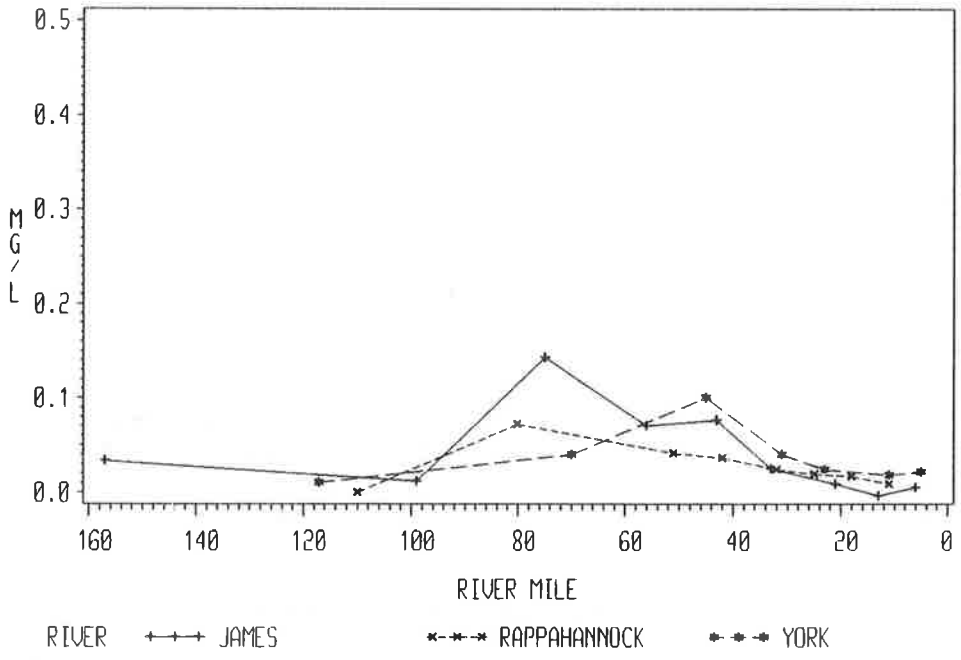
In the estuarine portion of the York, similar sediment release is evident and there is a small but significant amount of point source input. The estuarine James does not experience as much phosphorus release from the sediment (driven by low oxygen levels) but does have larger point source input which increase phosphorus loads.

Particulate phosphorus generally exhibited a peak in the tidal freshwater and upper transition zones of the three rivers (Figure 5.42). In the James, the elevated concentrations at mile 75 were largely a result of algal production. The York had typically elevated concentrations of particulate phosphorus at mile 45, largely as a result of detritus export from wetlands. The Rappahannock typically exhibited a broader peak in concentration of particulate phosphorus, extending from tidal freshwater into the oligohaline zone.

FIGURE 5.42

PARTICULATE PHOSPHORUS

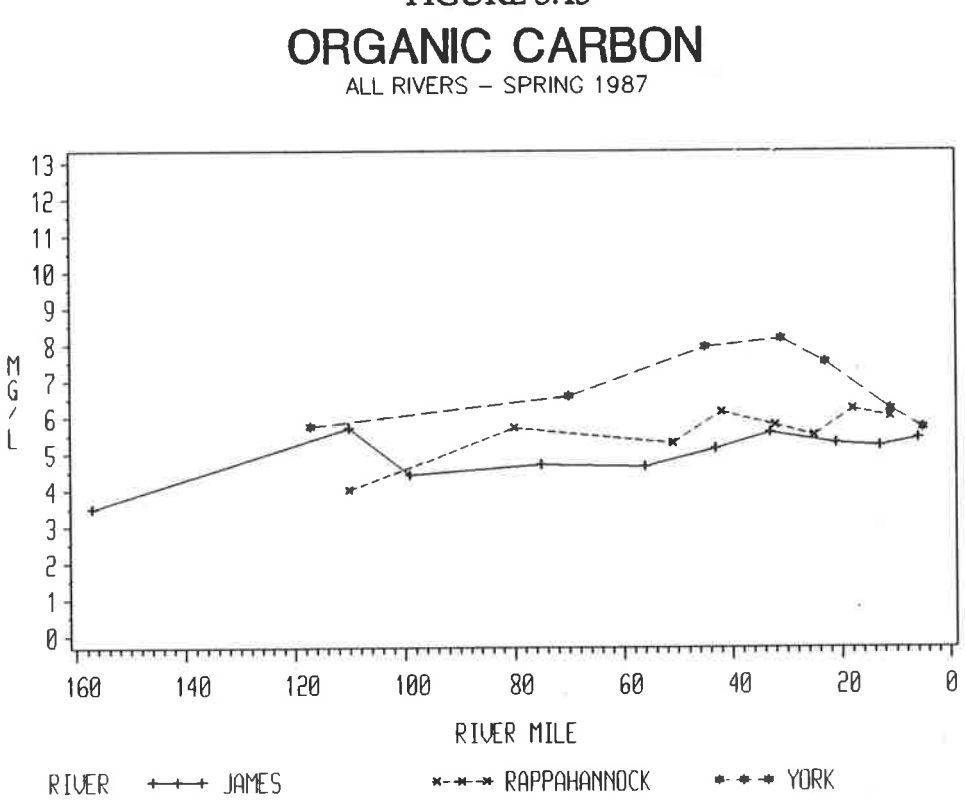
ALL RIVERS – FALL 1987



ORGANIC CARBON - RIVER COMPARISONS

Of the three tributaries, the York generally had the highest levels of organic carbon at the fall line. This could be due to inputs from nontidal wetlands and/or discharges from the Doswell municipal facility. Figure 5.43 compares longitudinal distribution of organic carbon during spring. During spring, and the other seasons, the York exhibited the largest organic carbon concentration, except in the estuarine regions where concentrations were similar among rivers. The higher concentrations of organic carbon in the York were particularly evident in the salinity transition zone. The James and Rappahannock exhibited an increase in the estuarine area, particularly during spring, possibly reflecting the spring diatom bloom.

FIGURE 5.43



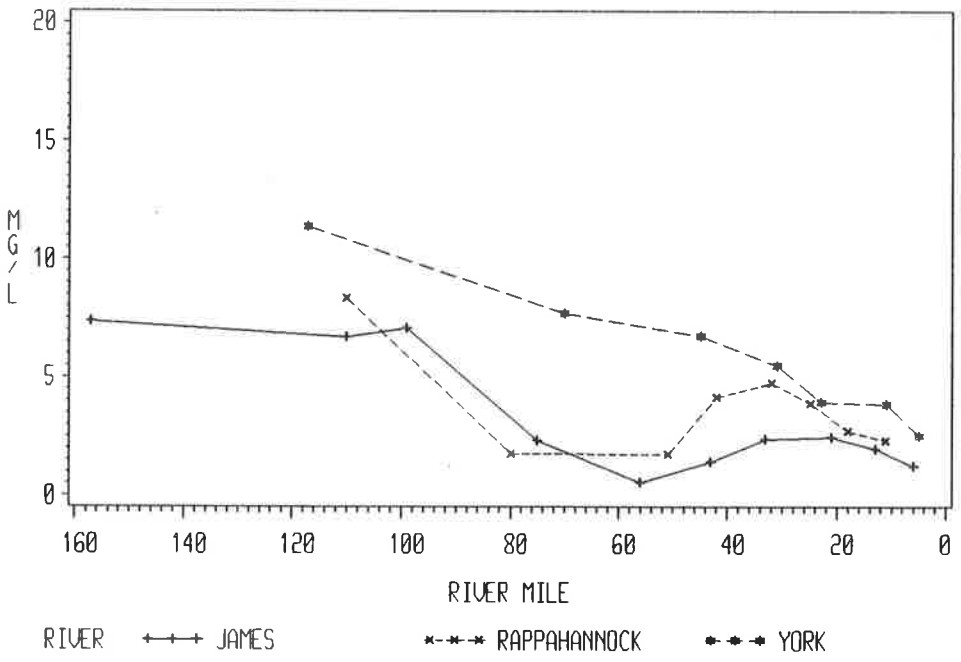
SILICA - RIVER COMPARISONS

The concentrations of silica at the fall lines of the three rivers did not appear to have a seasonal or streamflow related pattern. All the rivers exhibited a strong pattern of biological cycling of silica during the year. This is illustrated by the longitudinal distribution during the summer (Figure 5.44). In the tidal freshwater portions of the tributaries, concentrations decreased due to uptake by freshwater diatoms. Downriver, near the limit of salinity intrusion, silica concentrations increased due to remineralization of particulate silica. In the estuarine zone, concentrations decreased again as a result of uptake by estuarine diatoms and dilution by Bay waters. This pattern was generally evident during all seasons except winter. The tidal Pamunkey and York usually exhibited the highest silica concentrations of the three tributaries; this is probably related to the lower algal production of the York.

FIGURE 5.44

DISSOLVED SILICA

ALL RIVERS – SUMMER 1987



VI. RESPONSE VARIABLES

The previous chapters characterized water quality in terms of their physical and chemical variables. The physical variables (e.g. salinity, temperature) are controlled primarily by the natural environment, while the chemical variables (e.g. nutrients) are the result of both natural and anthropogenic inputs and instream cycling. This section will focus on measurements such as nitrogen/phosphorus ratios, chlorophyll-a, water clarity and dissolved oxygen. These variables respond to, or are a product of, the physical and chemical variables previously discussed. These 'response variables' also interact with each other through a complex variety of chemical and biological interrelationships. The 'response variables' are often intended to be indirect indicators or measurements of other variables; e.g. chlorophyll-a concentration is a measurement of algal biomass. The 'response variables' are usually more readily associated with water quality problems than the physical or chemical variables. Conditions such as low dissolved oxygen, high chlorophyll levels, and high turbidity directly impact the quality of a water body, but defining the cause of the problem is a complex task.

NITROGEN/PHOSPHORUS RATIOS

Most of the data presented in the previous chapter focused on actual instream concentrations of different chemical forms of nitrogen and phosphorus. In addition to the actual concentrations, the relative abundance of nitrogen (N) to phosphorus (P) is an important characteristic of each tributary. Phytoplankton production is controlled by the availability of nutrients such as nitrogen and phosphorus, as well as other factors such as predation, temperature, and sunlight. A typical phytoplankton community requires approximately 16 atoms of nitrogen for every atom of phosphorus utilized for growth. When the ratio of nitrogen to phosphorus exceeds 16:1 (N/P), phosphorus is in short supply relative to nitrogen, thus becoming the nutrient limiting growth. When the ratio is below 16, then nitrogen becomes the limiting nutrient. Freshwater is typically phosphorus limited due to high concentrations of nitrate, while marine water is nitrogen limited because of its very low nitrogen concentration. The estuary, which is a gradient between fresh and marine water, exhibits both phosphorus and nitrogen limitation varying by location and season.

Therefore, N/P ratios help describe which nutrient may be limiting phytoplankton production. In areas where high algal production is creating a water quality problem, managers can implement strategies to control the limiting nutrient(s) and reduce phytoplankton production. These ratios may also be beneficial when considering a nutrient management strategy for an area which receives a heavy nutrient loading from upstream. A freshwater river high in nitrogen may not experience algal blooms due to phosphorus limitation, a nitrogen limited estuary located downstream from this river may experience blooms due to the high nitrogen loadings from upstream.

The results of the laboratory analyses, which are recorded in mg/l as N or P, must be converted to ug atoms/liter prior to calculating N/P ratios. Two different types of N/P ratios are generally calculated. The ratio of dissolved inorganic nitrogen (NO_{2+3} + NH_4) to dissolved inorganic phosphorus (orthophosphate) can be calculated. A DIN/DIP ratio measures the dissolved nutrients in the water column which are readily available for uptake. This calculation may be appropriate if algal levels are low, but during periods of high production much of the nitrogen and phosphorus is incorporated into organic compounds. These compounds can be quickly recycled. So, DIN/DIP ratios do not adequately account for organic nitrogen and phosphorus which may represent the majority of nutrients available to algal populations. Another problem with calculating DIN/DIP

ratios is that a large number of observations are below the detection limits for orthophosphate, nitrite, and ammonium (Table X). This results in a ratio of detection limits and not true concentrations, which cannot be used for data analysis.

The second ratio that can be calculated is total nitrogen/total phosphorus (TN/TP). This ratio measures the dissolved and particulate fractions of nitrogen and phosphorus, thus presenting a more accurate representation of the nutrient ratios. With this ratio, both the dissolved nutrients available for algal uptake and those already incorporated into organic compounds can be taken into account. The data from which TN/TP ratios are calculated are not as likely as DIN\DIP ratios to be below detection limits, thus providing more data for an analysis. For these reasons, TN/TP ratios were used in this report. Seasonally averaged TN/TP ratios were calculated for each station. Since the ratio of 16:1 is an approximate value which changes with phytoplankton species composition, in this report, TN/TP ratios were classified as nitrogen limited (< 10:1), phosphorus limited (>20:1) or intermediate (10 - 20:1). The percentage of ratios in each one of these categories was determined for each station.

CHLOROPHYLL-A

Chlorophyll-a is a pigment found in plants, including phytoplankton, which is necessary for photosynthesis. Since this compound is unique to plants, analyses for chlorophyll-a can provide an indirect measurement of algal concentration or biomass in the water column. As primary producers in aquatic systems, phytoplankton are the base of the food web which supports the biological community. Low to moderate chlorophyll-a concentrations indicate a normal algal abundance while high chlorophyll-a concentrations often indicate a system that is experiencing high loadings of nitrogen and/or phosphorus, a condition termed 'nutrient enriched'. These high algal concentrations often create many water quality problems. During daylight, algae photosynthesize and produce oxygen, while at night algae respire and consume oxygen from the water column. This creates a daily swing in dissolved oxygen that can result in supersaturation in the day and oxygen depletion or hypoxic conditions during the night. When large algal populations die off and settle out of the water column, the decay of this organic matter also consumes large amounts of oxygen.

Phytoplankton, or 'algal', blooms are natural phenomena but species composition, duration, and intensity can be altered by anthropogenic impacts. Different types of phytoplankton reach maximum population levels or 'bloom' at various times of the year. Diatoms, which are the major algal group grazed by zooplankton and fishes, typically bloom in the estuary in the late winter and early spring. They also can produce a less intense fall bloom. The intensity and duration of the spring bloom and its contribution to oxygen consuming processes may be important in the establishment and continuation of low dissolved oxygen during the summer in Chesapeake Bay and some of its tributaries. During the warmer summer months other groups of phytoplankton can reach bloom conditions. Very high populations of blue-green algae in freshwater can create aesthetic and drinking water problems. In estuarine waters, summer blooms of dinoflagellates are often termed 'red tides' and may produce toxins which can result in fish kills. High algal concentrations also reduce water clarity, preventing light from reaching submerged aquatic vegetation.

Within the Virginia CBP Tributary Water Quality Monitoring Program, chlorophyll-a collection started in the summer of 1985 and continues to the present. The chlorophyll-a data presented in this report have been corrected for pheophytin content, a breakdown product of chlorophyll-a.

TABLE X

PERCENT OF ANALYTICAL RESULTS BELOW DETECTION LIMITS

RIVER SECTION

	Fall Line	Tidal Fresh (TF)	Transition (RET)	Estuary (LE)
Rappahannock				
NH34	30	20	14	7
NO3	10	19	31	52
NO2	50	57	76	85
TKN	10	0	0	0
PO4	30	44	51	52
TP	0	0	1	1
York				
NH34	36	34	23	5
NO3	5	3	10	56
NO2	72	94	76	64
TKN	0	0	0	0
PO4	0	2	6	19
TP	0	0	0	0
James				
NH34	44	26	40	10
NO3	0	6	14	15
NO2	77	46	65	54
TKN	0	0	0	0
PO4	0	6	9	15
TP	0	0	0	0

WATER CLARITY

Water clarity is an important characteristic of any aquatic system. The depth to which light penetrates a water column determines the area where photosynthesis can take place. Submerged aquatic vegetation (SAV) can only exist where light penetration reaches the sediments. The reduction of water clarity has been cited as a major contributing factor in the decline of SAV in Chesapeake Bay. Phytoplankton can also be limited by water clarity. In areas of high non-point source runoff, high loads of suspended sediment can reduce light penetration and limit phytoplankton production. In areas of high algal production, the algal biomass near the surface can also reduce light penetration, thus limiting algal production in deeper water as well as SAV production near the bottom.

Secchi depth is a direct measurement of water clarity and an indirect measurement of light penetration. Greater secchi readings indicate increased water clarity while lower secchi readings indicate less water clarity. Water clarity is a function of the concentration of suspended sediment and organic matter in the water column, thus secchi depth acts as an indirect measurement for these parameters. Suspended sediments are characteristic of agricultural and urban runoff. Sediment is also resuspended from the river bed into the water column due to high river flows or tidal action. Extremely high concentrations, as seen during major storm events, impact living organisms by burial, and by interfering with respiration and reproduction. The suspended sediments may also carry a large load of phosphorus adsorbed to the surface of clay particles. Organic matter in the water column can be in the form of living or dead phytoplankton and bacteria. It can also be detritus (dead organic matter) transported into the river from wetlands and terrestrial habitats. A further source of organic matter or suspended solids comes from the discharge from municipal or industrial treatment plants.

DISSOLVED OXYGEN

Dissolved oxygen (DO) is a important indicator of water quality. Low oxygen (hypoxia), or no oxygen (anoxia), has been identified as one of the major problems facing Chesapeake Bay and some of its tributaries. A lack of adequate oxygen in a habitat precludes its use by most aquatic organisms. Thus, many benthic organisms which would normally serve as food for predatory fish are absent in areas impacted by hypoxia. Periodic upwelling of hypoxic water into near shore areas causes mortality in shellfish beds. Anoxic water also contributes to the problems of nutrient enrichment. In the absence of oxygen, both nitrogen and phosphorus compounds may flux out of the sediment into the overlying water column.

The DO content of a water body changes in response to many physical and biological processes. Both temperature, and to a lesser extent salinity, control the amount of oxygen that can be dissolved in the water column (i.e. saturation level). Oxygen demands from processes in the sediment and water column, and oxygen production from photosynthesis modify the actual dissolved oxygen concentrations. The atmosphere, a large source of oxygen for the surface waters, introduces oxygen through diffusion and turbulent mixing. Photosynthesis also introduces dissolved oxygen into the surface water, even to the point of supersaturation during intensive algal blooms. The water near the bottom of the water column receives oxygen from the surface through vertical mixing. Throughout much of the year, when temperatures are low and the water column is well mixed, oxygen concentrations are near saturation. During the late spring and summer, rising water temperatures and increasing water column and sediment oxygen demands, coupled with limited vertical mixing, combine to cause depletion of oxygen in the deeper waters.

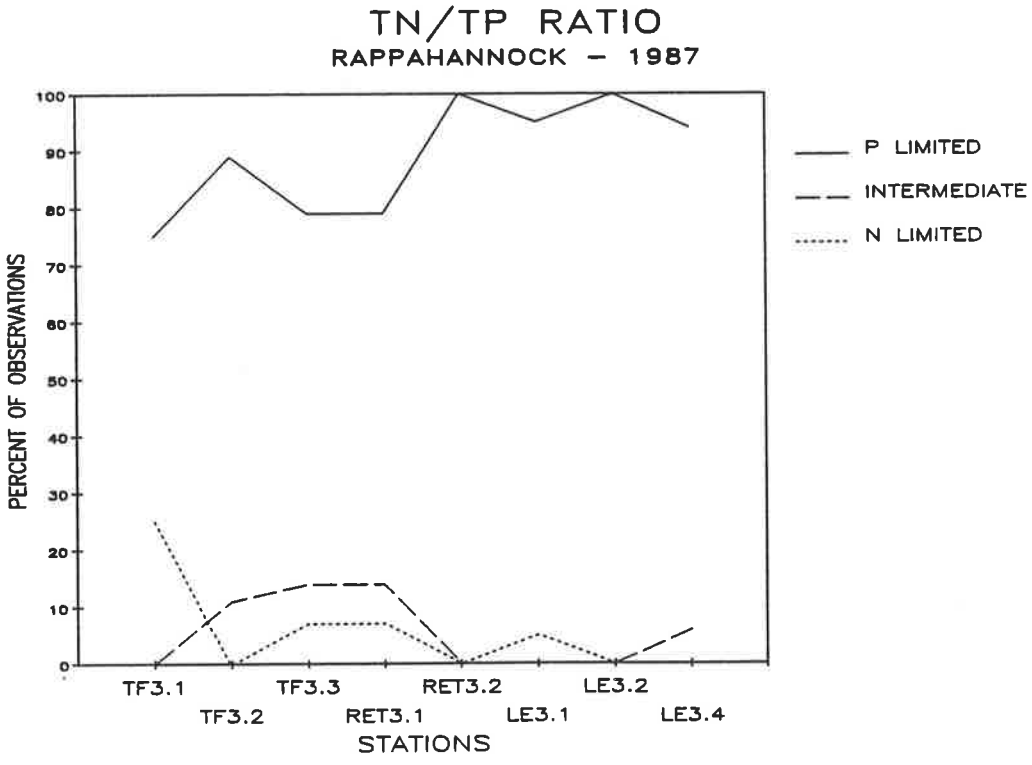
Virginia has a dissolved oxygen water quality standard for estuarine waters of 4.0 mg/l, below which is generally considered hypoxic conditions. It should be noted that the number of violations of the standard as measured in this program may be a low estimate. If sampling was conducted just prior to daylight, when dissolved oxygen is at the minimum of the diurnal swing, then a larger percentage of violations of the standard may be expected.

RAPPAHANNOCK RIVER

TN/TP RATIOS - RAPPAHANNOCK

The number of nutrient concentrations below the limit of detection were quite high, resulting in few TN/TP ratios being calculated. Most stations had 20 to 30 calculated ratios, but few in the summer due to the low concentrations of nutrients during this season. General patterns for the river can be described, but detailed comparisons between seasons are limited. Generally, over 75% of the TN/TP ratios in the Rappahannock indicated phosphorus limitation, while 5 to 15% indicated nitrogen limitation (Figure 6.1). At the fall line, TN/TP ratios were about equally divided between phosphorous and nitrogen limitation. The low phosphorus concentrations in the Rappahannock resulted in the predominance of phosphorus limitation during the majority of the year. During the summer when nitrogen concentrations are also low, TN/TP ratios may be lower.

FIGURE 6.1



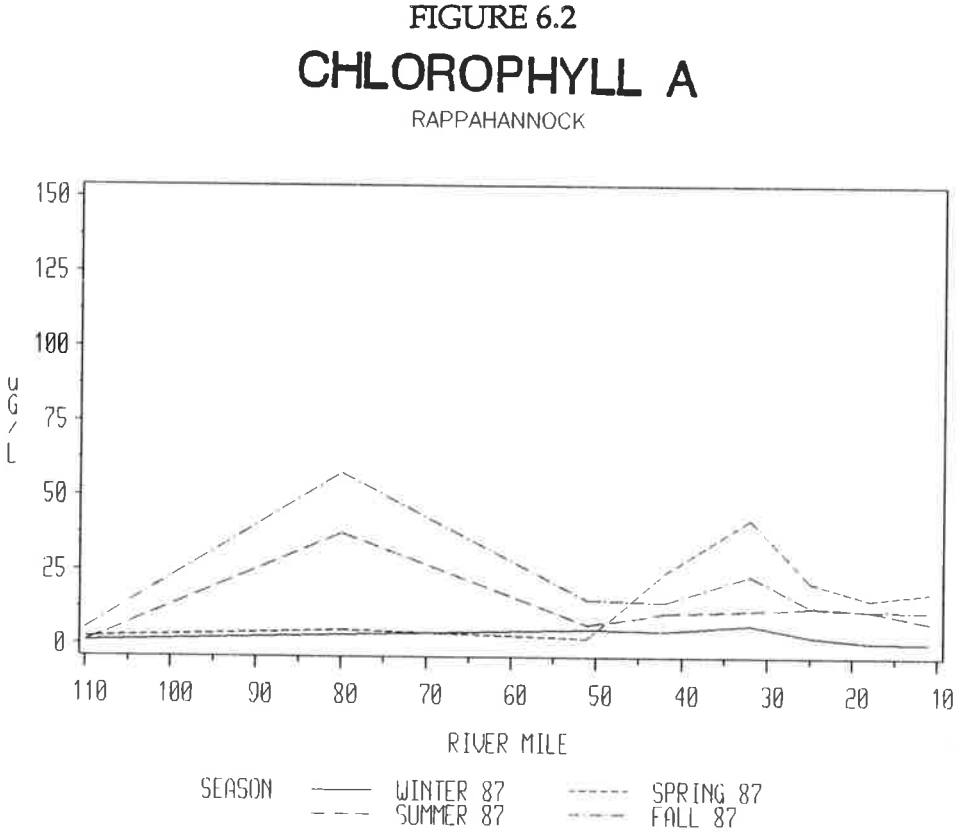
CHLOROPHYLL-A - RAPPAHANNOCK

The concentration of chlorophyll-a at the fall line of the Rappahannock, as was the case with all the tributaries, was very low. Most algae above the fall line is benthic (i.e. periphyton), while in the tidal portion of the river the majority of algae is planktonic or free floating. During 1987 there were no stations located in the first 25 miles below Fredericksburg. As a result, there was poor monitoring coverage of the tidal freshwater section of the river.

Although chlorophyll-a concentrations during the winter and spring were very low in the upper tidal Rappahannock, increases in chlorophyll-a were evident in the lower estuarine Rappahannock (Figure 6.2). Chlorophyll-a concentrations peaked at mile 32 (RET3.2) which exhibited salinities averaging 8 ppt. The estuarine peak in chlorophyll-a reflects the typical late winter and spring bloom of estuarine phytoplankton, particularly diatoms.

As the winter/spring estuarine bloom declined, a summer tidal freshwater bloom became evident. Station TF3.2, the only tidal freshwater station sampled by this program, exhibited an average chlorophyll-a concentration of 57 ug/l, with a maximum of 114 ug/l during fall. Chlorophyll-a concentrations may be greater upriver between station TF3.2 and Fredericksburg but were not evident because of the lack of data from this area.

FIGURE 6.2

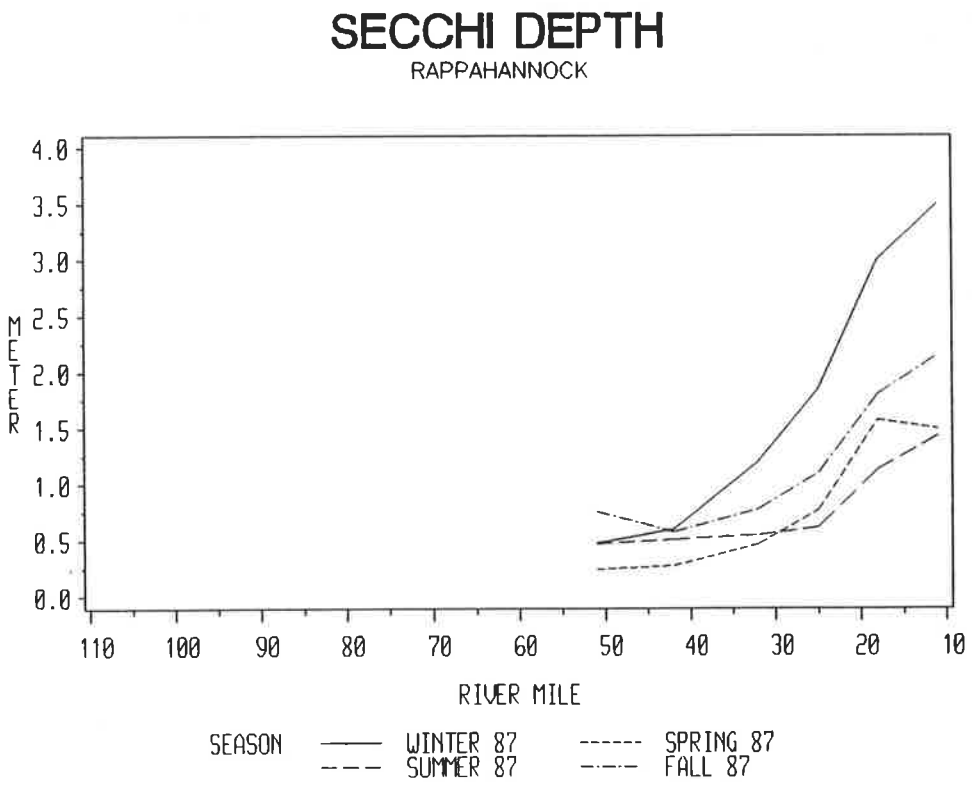


The estuarine stations during summer exhibited relatively low concentrations (5 - 10 ug/l), except for short-term blooms where 18 ug/l was reported. During fall, peaks in the tidal freshwater and estuarine areas were apparent. The fall bloom of estuarine phytoplankton is a common occurrence but is usually less intense and of shorter duration than the winter/spring bloom.

WATER CLARITY - RAPPAHANNOCK

The amount of information on water clarity in the tidal freshwater section of the Rappahannock is limited. Stations upriver from mile 50 are located on bridges which are not suitable for collecting secchi readings. During the winter, water clarity in the transition zone of the Rappahannock was low (0.5 meters), but steadily increased downstream to a maximum of 3.5 meters at the mouth of the river (Figure 6.3). Water clarity in the spring was even lower than winter, reflecting the winter/spring increase in streamflow and associated input of suspended sediment. Unlike the winter, the water clarity in the spring remained low downriver to mile 20, where a sharp increase in water clarity occurred. Water clarity during the summer exhibited a pattern similar to the spring, but with slightly higher water clarity in the transition zone and slightly lower clarity toward the mouth. The Fall exhibited relatively greater water clarity in the upper Rappahannock, decreased slightly at mile 42, and then increased again in the estuary. The greater water clarity at the mouth is probably a result of the influence of mixing with the mid-Bay water which generally is much clearer than river water.

FIGURE 6.3



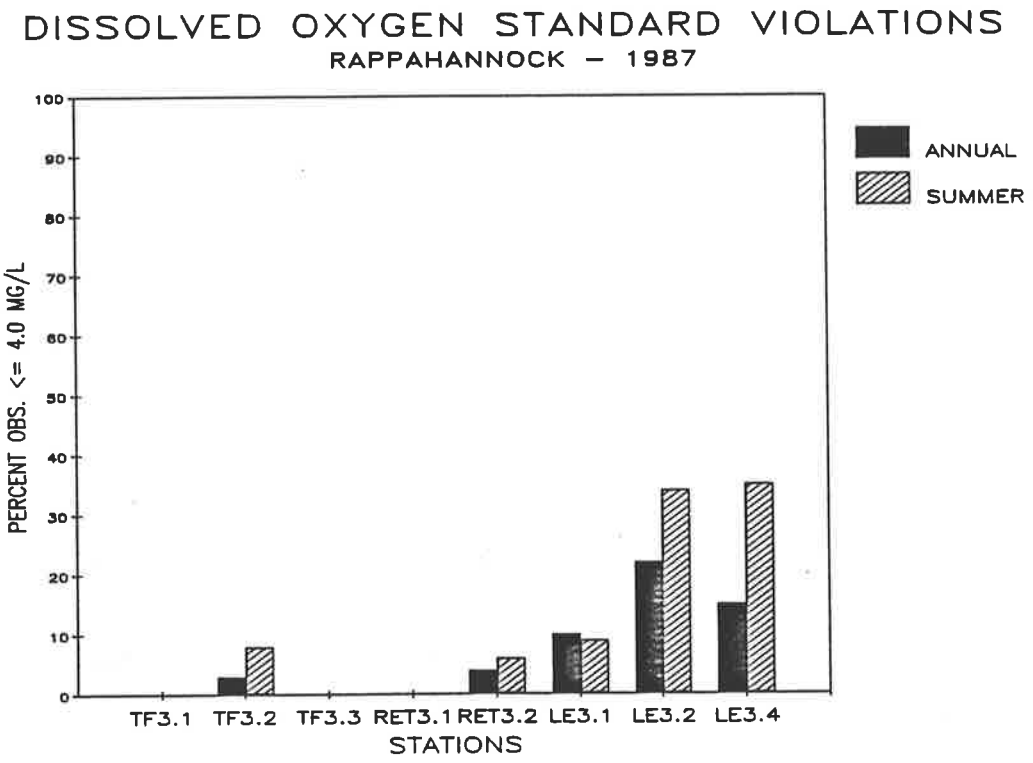
Two general spatial patterns are evident in water clarity. As seen in the winter and fall, water clarity steadily increases from tidal freshwater toward the mouth of the river. This can be attributed to normal dilution of turbid river water with less turbid bay water. The second pattern, which was also seen in 1985, is a fairly stable water clarity from tidal freshwater downriver to mile 20, where a sharp increase in water clarity occurs. Downstream of this increase, average water clarity ranged from 1.4 to 1.8 m in the spring and summer to 2.4 meters in the winter and fall. The reduced water clarity at the mouth of the Rappahannock during the spring coincides with the decrease in salinity in the central Bay, as discussed in chapter IV.

DISSOLVED OXYGEN - RAPPAHANNOCK

This river has historically exhibited depressed dissolved oxygen (hypoxia) in the deep channel near the mouth of the river. One measure of the extent and duration of hypoxia is the number of observations recorded below the state's dissolved oxygen standard of 4.0 mg/l. In the Rappahannock, the freshwater and transitional stations generally do not experience hypoxia, while the estuarine stations exhibit varying degrees of hypoxia depending on numerous hydrological and climatic factors. On an annual basis, 11 - 29% of the observations at the estuarine stations were below the state standard (Figure 6.4). The majority of violations typically occur during the summer, with 10 - 38% of the observations at the estuarine stations below the standard during the summer of 1987 (Figure 6.4).

The dissolved oxygen concentration of samples collected 1 meter above the sediment exhibit an inverse relationship with water temperature, resulting in the seasonal changes in dissolved oxygen. The normal seasonal fluctuation usually does not result in hypoxic conditions, but the estuarine stations exhibited a much more dramatic decline in dissolved oxygen during the summer. This decline typically begins when water temperatures rise above 20°C, generally in June. By early to mid September the lower Rappahannock usually becomes well mixed and hypoxia is dissipated.

FIGURE 6.4


DISSOLVED OXYGEN STANDARD VIOLATIONS
RAPPAHANNOCK – 1987
PERCENT OBS. <= 4.0 MG/L
100
90
80
70
60
50
40
30
20
10
0
TF3.1
TF3.2
TF3.3
RET3.1
RET3.2
LE3.1
LE3.2
LE3.4
STATIONS
ANNUAL
SUMMER

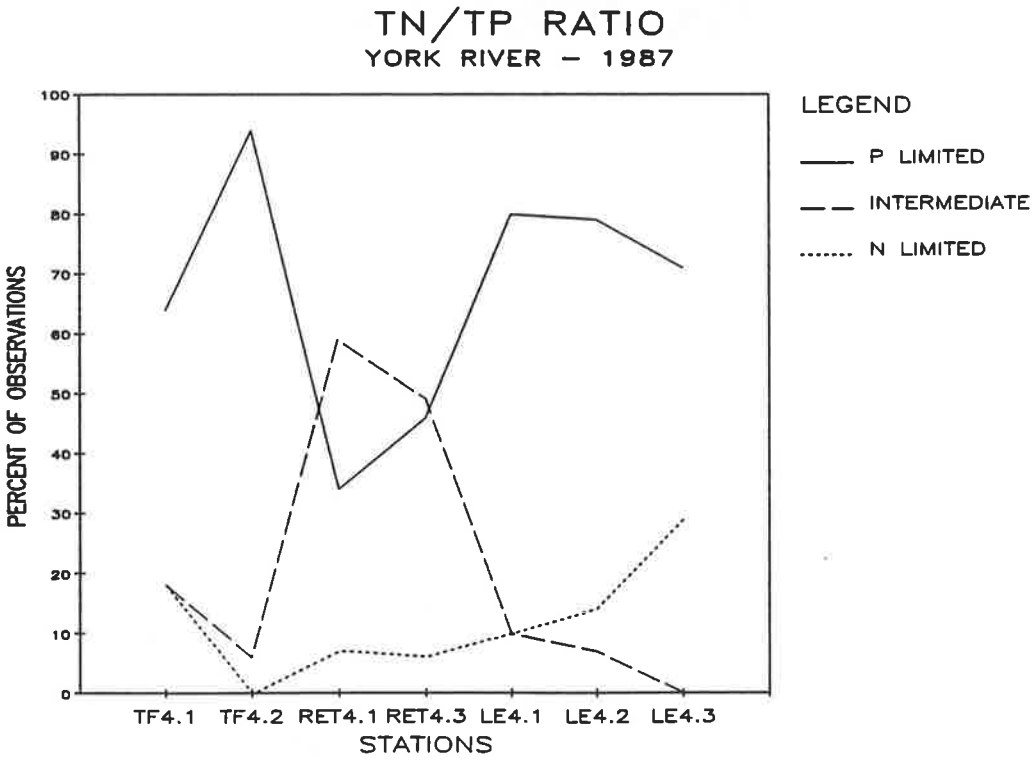
YORK RIVER

TN/TP RATIOS - YORK

A slightly larger number of TN/TP ratios (20-40) was calculated for each station in the York than in the Rappahannock. Figure 6.5 illustrates the occurrence of nutrient limiting conditions throughout the York. In the tidal fresh and estuarine sections, there was a predominance of phosphorus limiting conditions. In the oligohaline zone (RET4.1) there was a marked increase in phosphorus concentrations, which resulted in lower TN/TP ratios and more frequent occurrence of nitrogen limitation. This same pattern has been observed since 1985.

Examined on a seasonal basis, all stations exhibited over 70% phosphorus limitation in the winter, but this percentage decreased through the spring and summer into the fall. For example, station RET4.1 exhibited 75% phosphorus limitation in the winter, but this decreased to no phosphorus limitation by the fall. This may be a reflection of the decrease in streamflow and increase in salinity during the course of 1987.

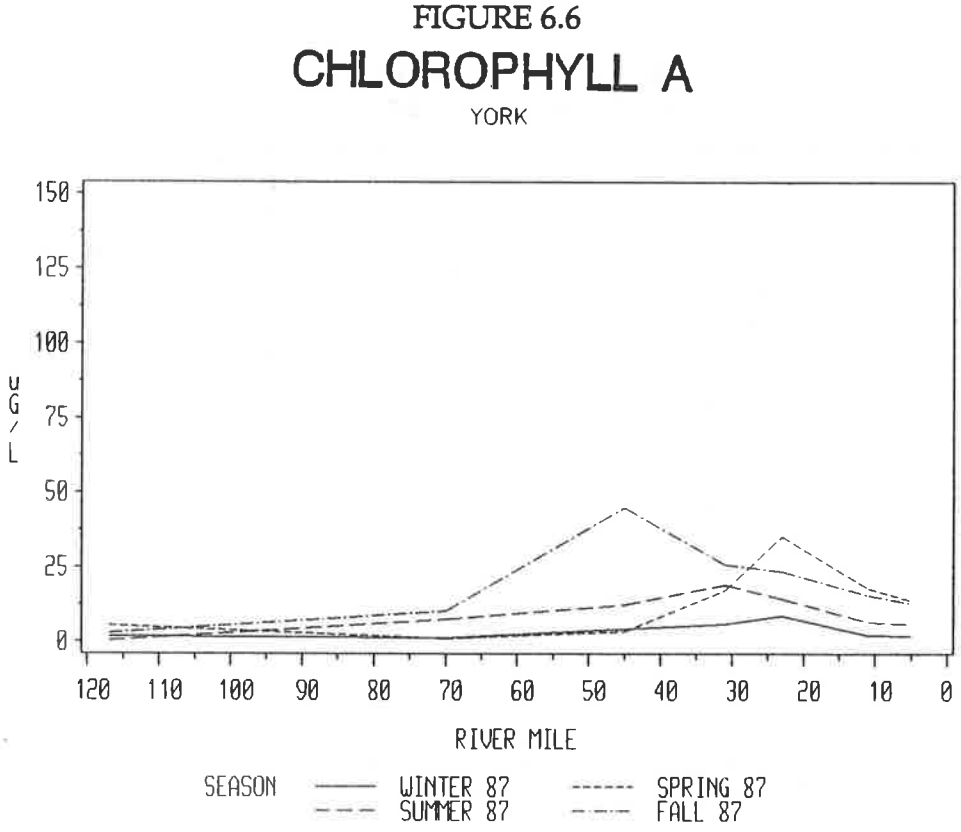
FIGURE 6.5



CHLOROPHYLL-A - YORK

Seasonal chlorophyll-a concentrations throughout the York River are given in Figure 6.6. Chlorophyll was always highest in the transition and estuarine areas of the river. Levels were highest during the spring and fall and there was no summer bloom as observed in the other rivers. When compared to previous years, the chlorophyll levels during 1987 appeared to be somewhat higher.

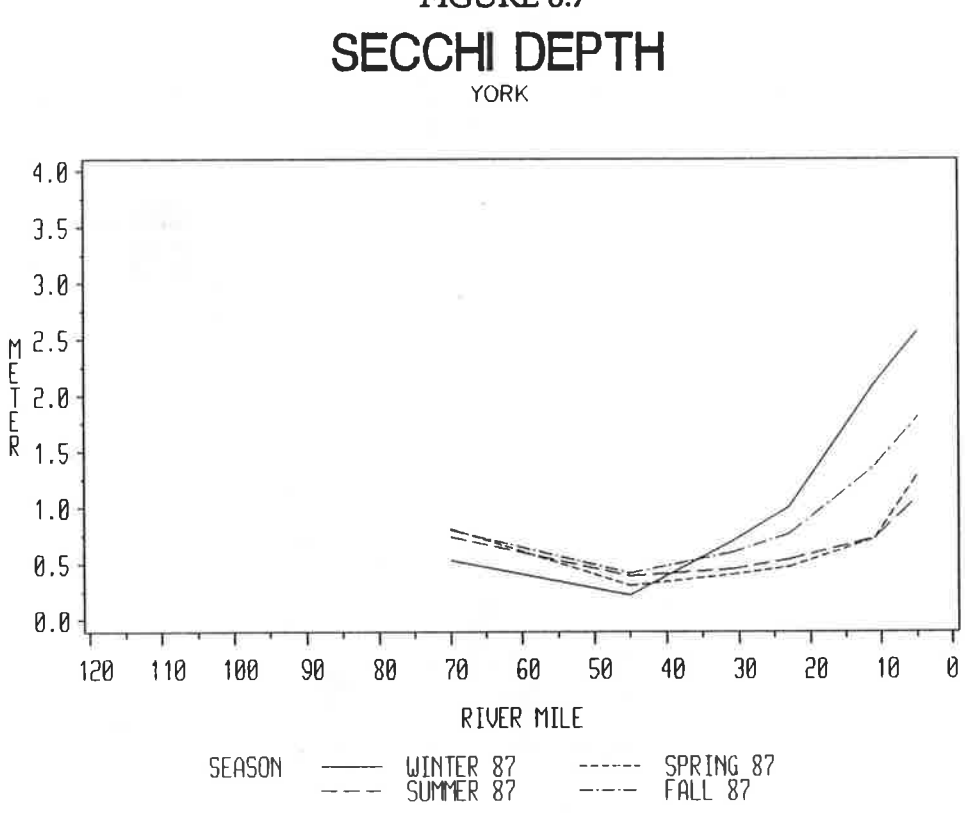
FIGURE 6.6



WATER CLARITY - YORK

In the Pamunkey and York, the same general pattern in water clarity is apparent in all seasons (Figure 6.7). Water clarity decreases to a minimum at mile 45, then increased toward the river mouth. The tidal freshwater station (TF4.2) exhibits water clarity between 0.5 and 0.8 meters. The stations where water clarity is usually at a minimum (RET4.1), exhibited seasonal averages between 0.2 and 0.4 meters. The location of this station in the 'turbidity maximum' zone and flushing of the extensive marshes in the area are probably responsible for the low water clarity. A sharp increase in water clarity is evident between mile 10 and the mouth of the river, but not as pronounced as in the Rappahannock. The winter exhibited lower water clarity in tidal freshwater zone, then increased downriver to the mouth. Water clarity in the spring was higher in the tidal freshwater zone, but reached a minimum near mile 45. It remained relatively low throughout much of the river until increasing sharply near the mouth of the river.

FIGURE 6.7

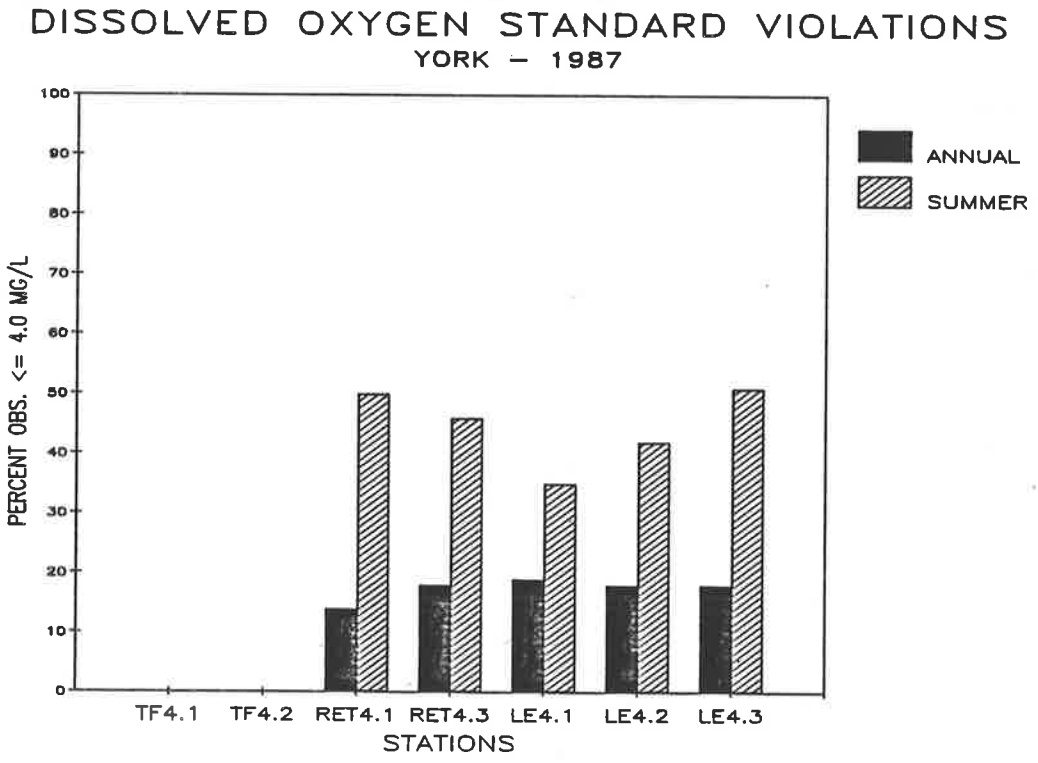


DISSOLVED OXYGEN - YORK

Figure 6.8 gives the percent of observations which violated the state dissolved oxygen standards. In the York, violations of the dissolved oxygen standard are usually restricted to the channel near the mouth of the river. As is typical for the York river, the estuarine stations exhibited violations of the state's dissolved oxygen standard. On an annual basis, violations accounted for 14 - 20% of all observations. When examined on a seasonal basis, all violations occurred during the summer, with up to 51% of the observations below the standard. The average summer dissolved oxygen concentration for stations in the lower York was between 4.0 and 4.7 mg/l. The station near the mouth of the York (LE4.3) typically experiences the lowest dissolved oxygen and during 1987 the minimum concentration observed there was 2.5 mg/l.

The occurrence of hypoxia in the lower York river has been linked to temporary stratification during neap tides. This is when mixing is greatly reduced between the surface and bottom layers. Shortly after spring tides, strong tidal forces result in a complete mixing of the system. The short term stratification results in lower oxygen concentrations and higher nutrient levels in the bottom waters. The CBP Benthic Monitoring Program has shown little evidence of long-term negative impacts to the benthos, probably due to the temporary nature of the hypoxia, yet short term impacts on the benthos may be present and would be difficult to detect.

FIGURE 6.8

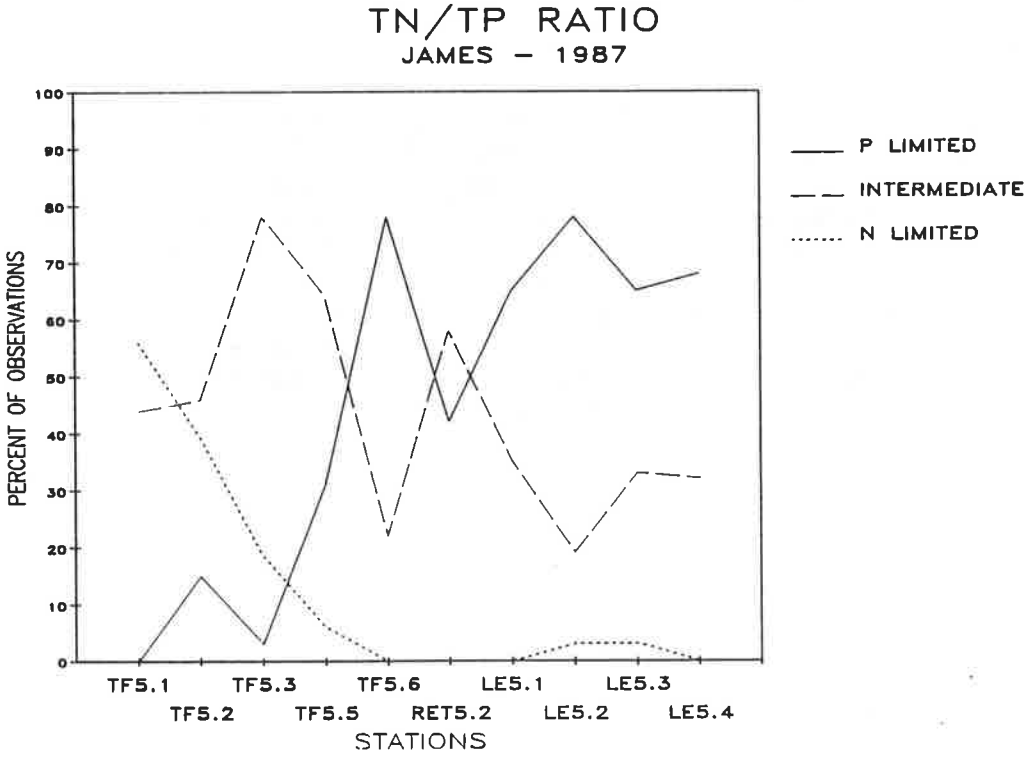


JAMES RIVER

TN/TP RATIOS - JAMES

In the James, higher instream concentrations of nutrients resulted in more TN/TP ratios being calculated, thus allowing for better interpretations and comparisons. In general, the TN/TP ratios indicate the upper James is nitrogen limited near the fall line, then becomes intermediate (10-20:1) between nitrogen and phosphorus limited below the Richmond area dischargers. It became predominately phosphorus limited downriver of the Hopewell area. At the fall line, 56% of the TN/TP ratios indicated nitrogen limitation (Figure 6.9). The Mayo's Bridge station (TF5.2) also exhibited high occurrences of nitrogen limitation (40%), but with more occurrences of phosphorus limitation. Between Richmond and Hopewell (TF5.3) TN/TP ratios indicated that nutrient limitation was intermediate between nitrogen and phosphorus. Very little phosphorus limitation occurred at this station except during periods of high nitrate concentration in the spring. The large loading of nitrogen and phosphorus from Richmond area sewage treatment plants, which results in high instream concentrations, is also responsible for the shift from predominately nitrogen limitation at the fall line to intermediate ratios. Despite these N/P ratios, its is probable that algal productivity in Richmond-Hopewell area of the James is seldom nutrient limited. The high nutrient concentrations create a "nutrient saturated" situation and factors such as water clarity, carbon dioxide levels, micronutrient concentrations, hydrologic conditions, toxics, predation or other unidentified factors probably control algal productivity. Downstream of Hopewell, the TN/TP ratios increase sharply between TF5.3 and TF5.6 and remain relatively high downriver, with 40 - 80% of the TN/TP ratios indicating phosphorus limitation. This increase in the TN/TP ratios is the result of an increase in nitrogen and a decrease in phosphorus concentrations.

FIGURE 6.9



CHLOROPHYLL-A - JAMES

Of the three tributaries, the James has the highest loadings of nitrogen and phosphorus, and the highest instream concentrations. It has long been considered nutrient enriched and several previous monitoring programs have investigated nutrient and chlorophyll-a concentrations. Analysis of the V.I.M.S. long-term slackwater surveys indicates a peak during summer at mile 68, between Hopewell and the confluence of the Chickahominy River. During 1983-1985, the James River Water Quality Monitoring Program identified an increase in chlorophyll-a starting at river mile 99 and peaking between miles 65 and 75. Based on these previous reports, stations TF5.5 (mile 75) and TF5.6 (mile 56) appear to be located on either side of the actual chlorophyll-a peak. Therefore, data from this program probably represents an underestimation of the actual maximum chlorophyll-a concentrations in the tidal freshwater areas. A monitoring station has been added here to collect data to be reported in future reports.

During 1987, James River experienced maximum chlorophyll-a concentrations in the tidal freshwater zone during summer and fall, with a more moderate peak in the estuary during spring (Figure 6.10). The typical winter/spring bloom of estuarine phytoplankton was indicated by the moderate chlorophyll-a concentrations at the estuarine stations. The dominant feature of the chlorophyll-a concentrations in the James was the intense peak at mile 75 (TF5.5).

The section of river between Richmond and Hopewell had concentrations of inorganic nutrients as high as the section below Hopewell, but only experienced sporadic algal blooms. High turbidity has sometimes been identified as the limiting factor for algal growth in this area, but water clarity is generally higher than further downstream. A change in the hydrodynamics of the river, from a narrow, faster flowing, to a broader, slower flowing river may be a major factor in the apparent differences. The additional nitrogen and phosphorus loading in the Hopewell area may also be responsible for some of the increase in chlorophyll-a.

WATER CLARITY - JAMES

Figure 6.11 shows the seasonally averaged secchi depth observed in the James. Generally, water clarity was relatively high between Richmond and Hopewell, decreased in the lower tidal freshwater and transition areas, then increased in the estuary. Water clarity was highly variable, and the area of minimum water clarity varied seasonally over a broad area from Hopewell to below Jamestown Island. This area includes river miles 32 through 75, where salinity ranges from 0 to 5 ppt. In the winter, water clarity was the lowest at mile 32 but increased toward the river mouth. During the spring, water clarity in the upper tidal portion was greater, while the lower tidal portion had lower water clarity. In the summer, water clarity in the upper tidal James was similar to the spring, but in the transition zone, water clarity was markedly higher.

FIGURE 6.10

CHLOROPHYLL A

JAMES

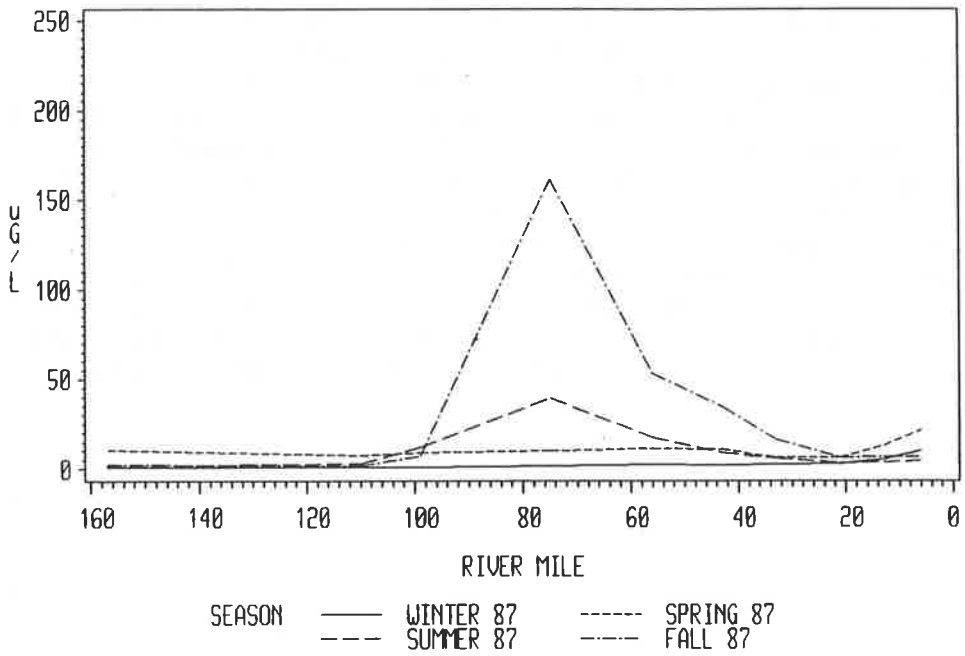
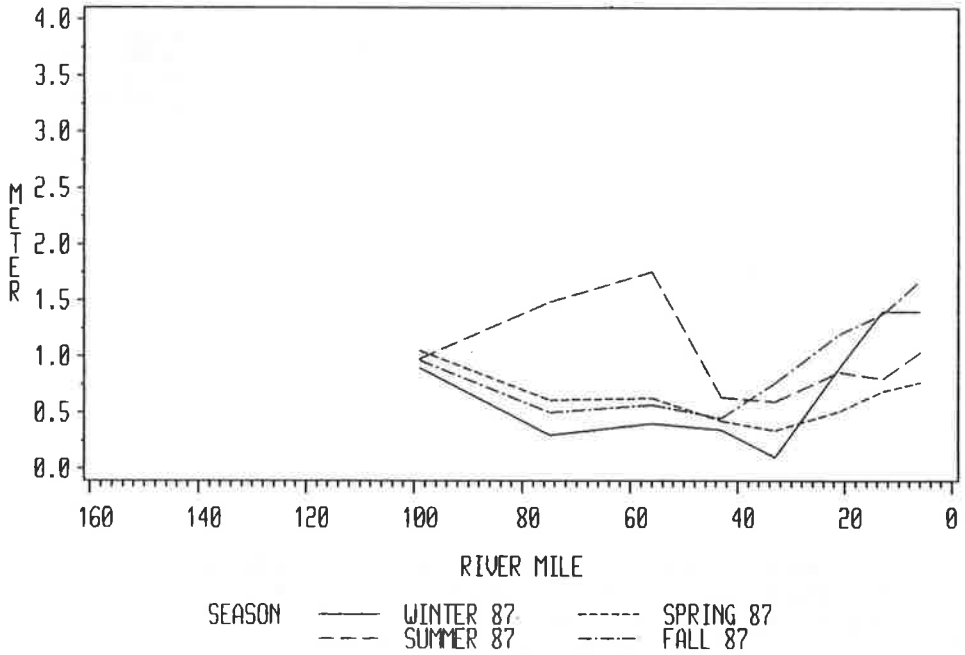


FIGURE 6.11

SECCHI DEPTH

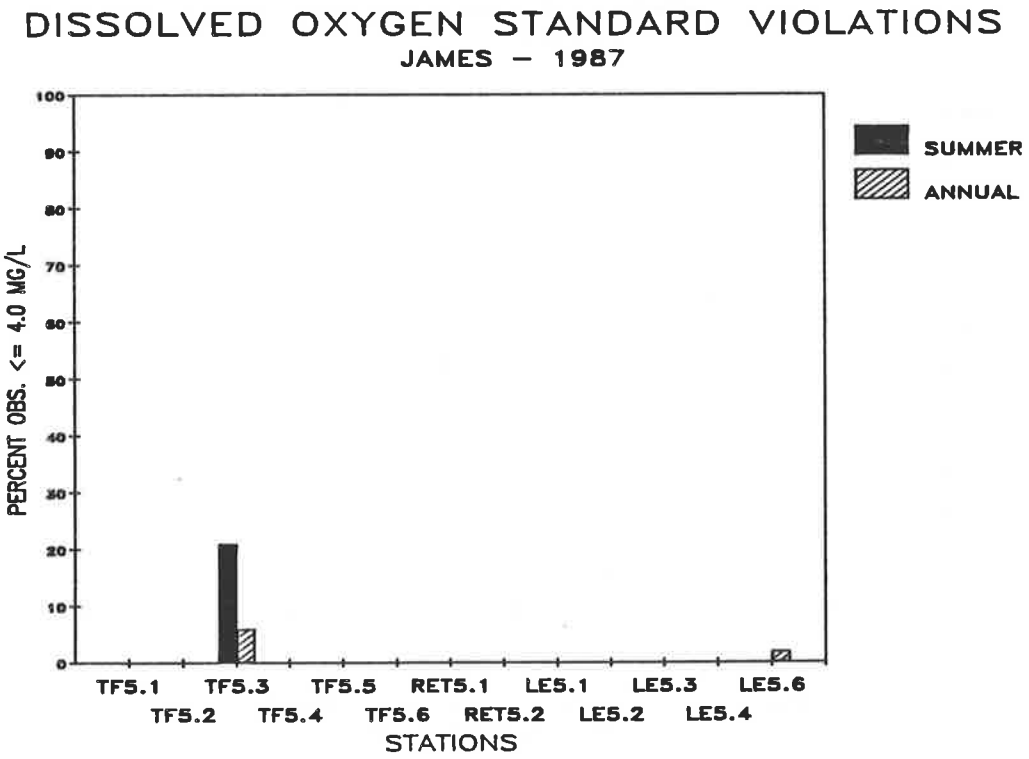
JAMES



DISSOLVED OXYGEN - JAMES

Figure 6.12 gives the percent of observations which violated the state dissolved oxygen standards. The James was relatively free of low dissolved oxygen events during 1987. The station exhibiting the most violations was between Richmond and Hopewell (TF5.3), where 20% of the summer observations were below 4.0 mg/l. The only other station exhibiting violations was LE5.6, where 2% of the 1987 observations were below the standard. This station is located at the mouth of the Elizabeth river, which is a highly industrialized and developed basin. The more spatially intensive monitoring conducted by the Richmond Regional Planning District Commission during 1984-1985 identified a dissolved oxygen depression below Richmond, and another below the Hopewell area. Neither depression resulted in dissolved oxygen concentrations below State standards during those years. Data from the VIMS slackwater surveys, from 1970 to 1985, show a reduction in the occurrence of low dissolved oxygen in the upper tidal James over the last decade.

FIGURE 6.12



RIVER COMPARISONS

TN/TP RATIOS

When examining the results of the response variables from the James, York, and Rappahannock, some important contrasting characteristics become evident. The TN/TP ratios for the three river systems provide a good example of these contrasts. During 1987, Rappahannock and York Rivers exhibited phosphorus limitation at the fall line, but the James was predominately nitrogen limited. The tidal freshwater of the York and the Rappahannock Rivers remained largely phosphorus limited while the James exhibited a wide range of nitrogen and phosphorus limitation. The much higher phosphorus concentrations at the fall line of the James represents a major deviation from typical conditions for free flowing streams, resulting in nitrogen limitation. The predominance of nitrogen limitation near the fall line of the James contradicts the traditional view that freshwaters are normally phosphorus limited. In the tidal freshwater areas of the James, the nitrogen and phosphorus loadings from non-point and point sources and subsequent processing within the river results in a complex range of nutrient concentrations and ratios. Any nutrient management strategy for the tidal James must take in to account the large phosphorus contribution from above the fall line as well as the phosphorus and nitrogen loadings from point sources in the tidal waters.

The transition stations in the York appear to have a lower occurrence of phosphorus limitation than either of the other two rivers. This is largely a function of the increase in phosphorus seen in this section of the York. The estuarine section of the three rivers appear similar, with 60 - 100% of the TN/TP ratios indicating phosphorus limitation. The estuarine area has the lowest nitrogen and phosphorus concentrations and thus the fewest number of ratios calculated, so seasonal comparisons are limited, especially in the summer. Recent microcosm research has indicated that the estuarine waters of the Chesapeake Bay may be phosphorus limited in the winter and nitrogen limited in the summer. These seasonal changes are in part due to high nitrogen loadings from increased streamflow in the winter/spring resulting in phosphorus limitation, while in the summer during low streamflows with less nitrogen loading, nitrogen becomes limiting. Loss of nitrate through denitrification, and increased release of phosphorus from the sediment may also contribute to nitrogen limiting conditions during the summer.

CHLOROPHYLL-A

Chlorophyll-a concentrations during 1987 indicate that prolonged and intensive blooms of freshwater phytoplankton occurred in the Rappahannock and James. During the winter, moderate blooms of estuarine phytoplankton were apparent in the estuarine areas of all three rivers (Figure 6.13A). The estuarine blooms continued into the spring in the Rappahannock and York rivers, but were not as evident in the James (Figure 6.13B). During the summer both the tidal freshwater Rappahannock and James exhibited chlorophyll-a peaks of approximately 40 ug/l, (Figure 6.13C). During fall, chlorophyll-a peaks in the tidal freshwater sections of the Rappahannock and James were as intensive and persistent as during the summer. The data from the Rappahannock seem to indicate a fall bloom of estuarine phytoplankton, which is typical for estuarine waters, but is usually of shorter duration and intensity than the winter/spring bloom.

James River, with the highest phosphorus concentrations of the three rivers, experienced the most intense and prolonged tidal freshwater blooms. Rappahannock River, with low phosphorus but high nitrate concentrations, experienced tidal freshwater blooms of less intensity and shorter duration than the James. In contrast, chlorophyll-a peaks in York River were much less intense and always located in saline waters.

FIGURE 6.13A

CHLOROPHYLL A

ALL RIVERS – WINTER 1987

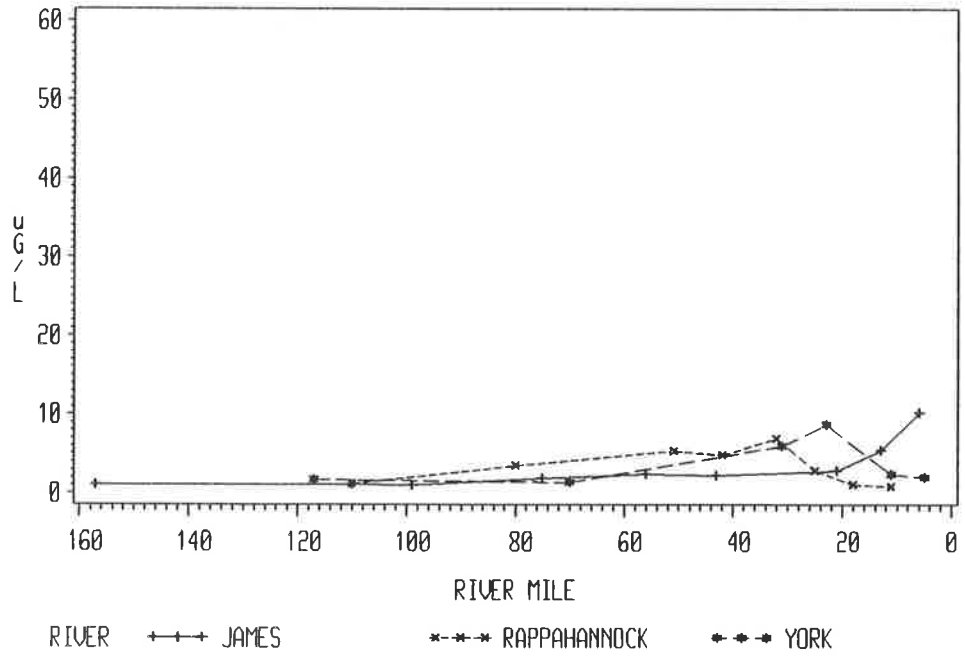


FIGURE 6.13B

CHLOROPHYLL A

ALL RIVERS – SPRING 1987

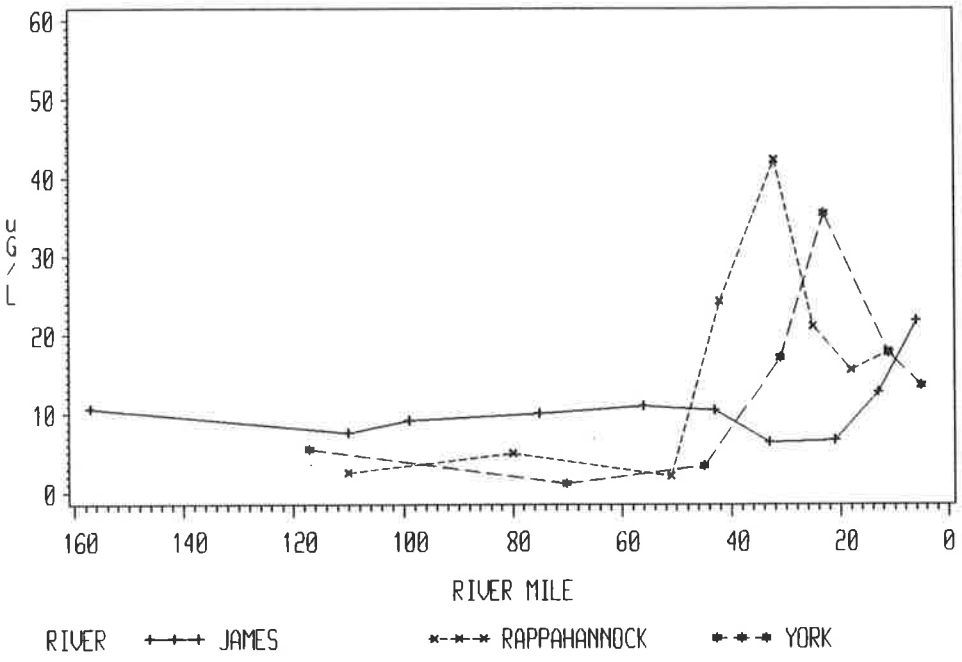
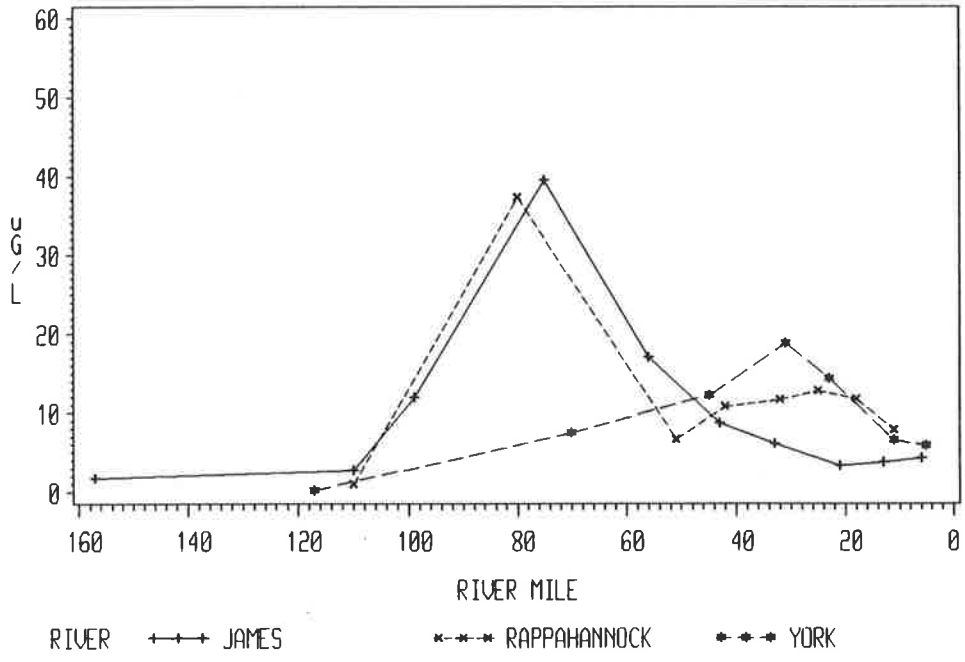


FIGURE 6.13C

CHLOROPHYLL A

ALL RIVERS – SUMMER 1987



WATER CLARITY

Figure 6.14A - 6.14D compare secchi depth readings between the three rivers. Water clarity was usually at a minimum in the transition or 'turbidity maximum' zone of all rivers (mile 30-50). During all seasons, the Rappahannock had greater water clarity at its mouth than the other two rivers. This may be due to the importation into the Rappahannock of relatively clear water from central Chesapeake Bay. The water clarity in the York and James may be influenced by the low water clarity of the Bay water near their mouths. During the spring and summer, water clarity remained fairly low throughout the rivers due to relatively high streamflows in the spring and algal biomass during the summer. The lower streamflows and higher salinities that occurred in the fall resulted in a substantial increase in water clarity, particularly in the estuarine portion of all three rivers.

DISSOLVED OXYGEN

The James River is subjected to the most urban and industrial development, yet experiences the least occurrence of low dissolved oxygen or hypoxia. Isolated occurrences of low dissolved oxygen were reported but they were usually associated with urban areas. Near the mouth of the Rappahannock and York, 10 - 50% of the dissolved oxygen concentrations during the summer were below 4.0 mg/l, with minimums well below 1.0 mg/l. The occurrence of hypoxia near the mouth of the Rappahannock is usually more prolonged and covers a larger area than in the lower York.

The lack of hypoxia in the James may be attributed to the strong and complex circulation in the lower river which allows for more vertical and lateral mixing. This, combined with shorter residence times may be keeping the water column well aerated. Kuo and Neilson (1987) have suggested that the difference in longitudinal salinity gradients between the three rivers is responsible for the occurrence of hypoxia in the Rappahannock and lack of it in the James. The upriver flow of saline water along the bottom of the James is much stronger than the Rappahannock, thus resulting in a shorter residence time for water. The shorter residence time in the James does not allow sufficient time for the water column to be depleted to hypoxic levels. In the Rappahannock, longer residence time allows the slower upriver flow of the bottom layer time for oxygen utilization to produce hypoxia. Another factor under investigation in the Rappahannock is the possibility that central Chesapeake Bay water flowing into the Rappahannock is already low in oxygen. Hypoxic waters from the main channel of the Bay may be at the mouth of the Rappahannock during certain tidal conditions or storm events. Bay waters at the mouth of the James and York typically do not experience hypoxia.

KUO, A.Y., and Neilson, B.S. 1987, Hypoxia and Salinity in Virginia Estuaries. Estuaries V10:277-283

FIGURE 6.14A

SECCHI DEPTH

ALL RIVERS – WINTER 1987

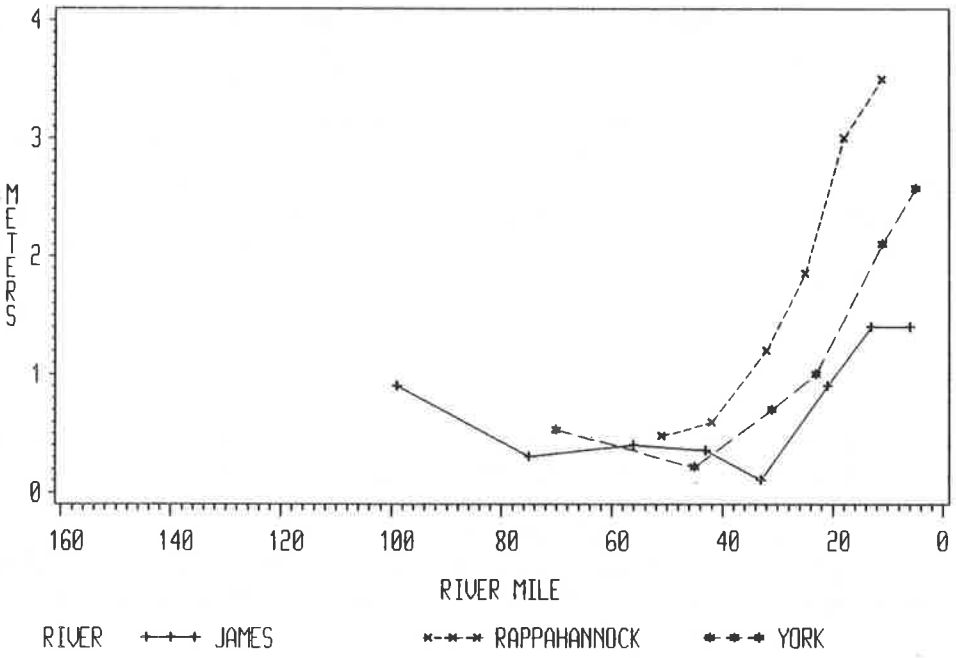


FIGURE 6.14B

SECCHI DEPTH

ALL RIVERS – SPRING 1987

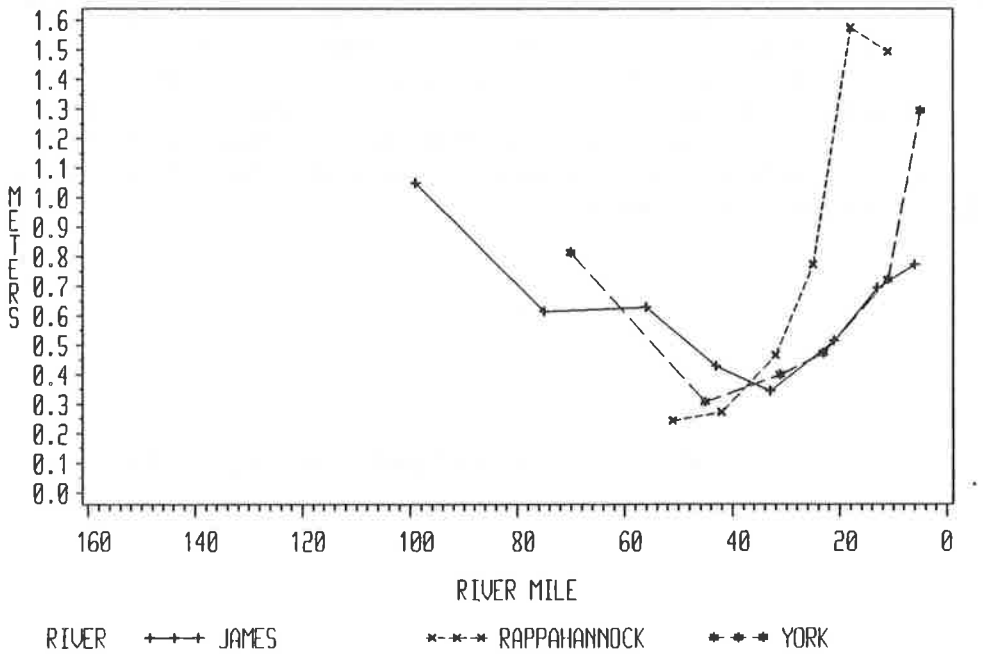


FIGURE 6.14C

SECCHI DEPTH

ALL RIVERS – SUMMER 1987

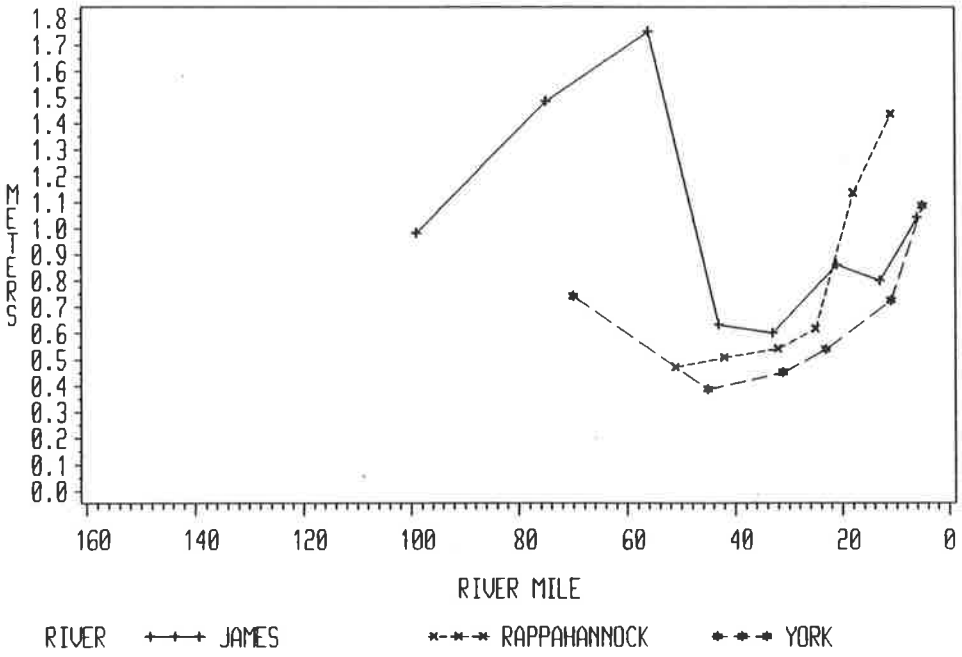
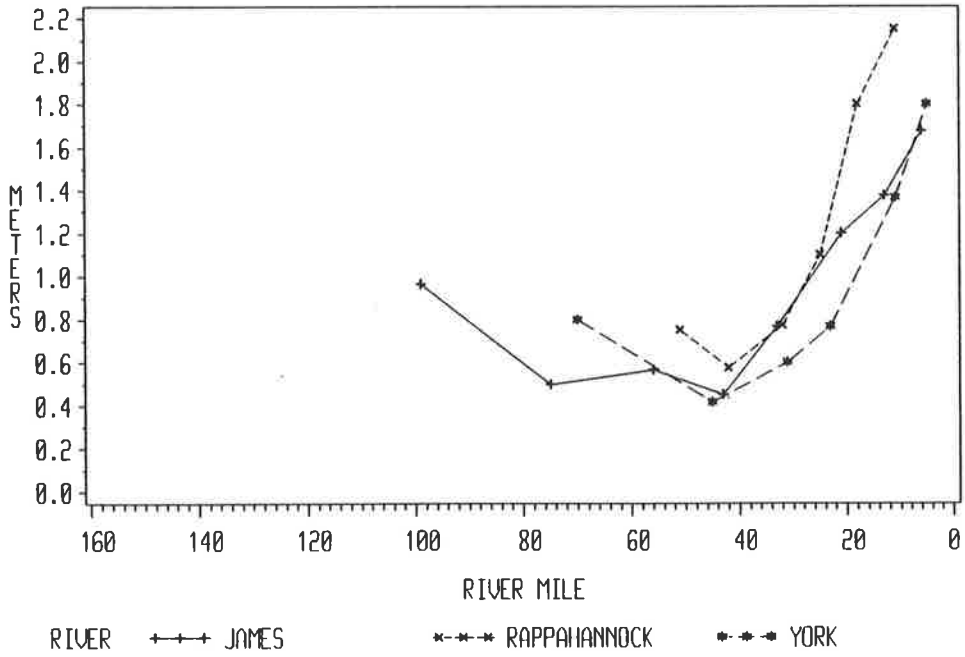


FIGURE 6.14D

SECCHI DEPTH

ALL RIVERS – FALL 1987