1983

Interpretation of water quality data from the Nansemond and Chuckatuck estuaries with respect to point and nonpoint sources of pollution : a report to the Hampton Roads Water Quality Agency

Cindy L. Bosco
Virginia Institute of Marine Science

Bruce J. Neilson
Virginia Institute of Marine Science

INTERPRETATION OF WATER QUALITY DATA
FROM THE NANSEMOND AND CHUCKATUCK ESTUARIES
WITH RESPECT TO POINT AND NONPOINT SOURCES OF POLLUTION

A Report to the Hampton Roads Water Quality Agency

by

Cindy Bosco
Bruce Neilson

Department of Physical Oceanography
and
Environmental Engineering

The preparation of this report was financed in part through a grant from the United States Environmental Protection Agency under Section 208 of the Federal Clean Water Act (Grant No. P003085-04). The contents do not necessarily reflect the views and policies of the EPA, nor does the mention of trade names or commercial products constitute an endorsement or recommendation.

College of William and Mary

Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

Frank O. Perkins
Director

May 1983

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

We would like to thank the staff of the Department of Physical Oceanography and Environmental Engineering for conducting the slackwater surveys and sample analyses with care and skill.

To Nancy Courtney, who processed the data and drafted the figures, and Shirley Crossley, who typed the manuscript, we also express our gratitude.

We also extend appreciation to the Water Department, City of Portsmouth and the Water Division, City of Norfolk for expeditiously providing data on reservoir spillover.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Recently the Nansemond and Chuckatuck basins have been designated as a Rural Clean Water Program demonstration area. This designation means that federal funds will be available to share the costs incurred by farmers when they implement the so-called Best Management Practices on their croplands, pastures, and feedlots. One requirement of the federal funding agency is that local governmental bodies monitor the quality of the waters in the area to document changes. One element in that monitoring effort is the study of conditions in the estuaries of these two water bodies. The Hampton Roads Water Quality Agency contracted with VIMS to conduct field studies during 1982 and 1983 under the provisions of their grant (No. P003085-04) from the U. S. Environmental Protection Agency. This report presents and summarizes the findings of those field studies.

The study in the Nansemond River occurred at a particularly opportune time. Under the direction of state and federal regulatory agencies, the Hampton Roads Sanitation District and local jurisdictions have been implementing a wastewater management plan which will result in the removal of most point source discharges to the Nansemond River. The present study provided an opportunity to assess the effectiveness of those control measures. In addition the data from the surveys provides a baseline against which future water quality conditions can be compared. In particular one would expect additional improvements in water quality as BMP's are installed or implemented on farms throughout the basin.

Water quality in the Nansemond has been degraded for many years. For example, much of the river has been closed to direct marketing of shellfish harvested therein since 1933. However, a comparison of oxygen, nutrient and chlorophyll-a levels for the present and 15 years ago indicates that water quality has shown an improvement. With a significant portion of the point discharges diverted outside the watershed, annual mean oxygen levels in the estuary just below the Lake Meade dam have risen from 4.4 mg/l in 1966-67 to 5.8 mg/l in 1982-83. It should be noted that the water quality standards require oxygen levels to be above 4 mg/l at all times and for the daily average value to be 5 mg/l or more. The frequency and severity of violations of the DO standards has been reduced significantly for the most upstream reach of the Nansemond estuary.

Chlorophyll-a concentrations, which previousy had been reported as high as 130 ug/l upstream, currently range between 22-43 ug/l. Annual mean total phosphorus concentrations have been reduced by 50-80% over the years and presently average 0.07-0.09 mg/l along the estuary. The maximum observed value was 0.73 mg/l upstream in 1967; the highest concentration recorded over an annual cycle decreased to 0.5 mg/l in 1982. Average orthophosphorus levels for the estuary similarly declined by roughly 70% in the past 15 years. Annual mean concentrations at the sampling stations were in the range 0.02-0.04 mg/l in 1982-83. This contrasts with 1966-67 conditions when there was a strong longitudinal gradient of 0.03-0.33 mg/l. In other words concentrations near the mouth have remained at comparable levels, whereas levels in the upper segments of the estuary have decreased dramatically over the years. Maximum observed values were 0.48 mg/l in 1967 and 0.29 mg/l in 1982. Although orthophosphorus concentrations are still elevated in the warmer months, the net result is a significant improvement. No widely applied water quality standards for nutrients exist. Consequently it is difficult to evaluate the recent changes in the Nansemond. However chlorophyll levels recommended for other areas are in the 25-40 ug/l range. For example, in the Chowan the summer mean target level is 25-30 ug/l with maximum levels of 40 ug/l. Similar targets have been set for the Potomac River and upper Chesapeake Bay. Thus current conditions in the Nansemond appear to be satisfactory.

Despite the improvement in water quality resulting from the reduction in point source loadings, nonpoint sources of pollution appear to continue to impact water quality in the Nansemond River. Periods of increased freshwater inflow were seen to correlate with depressed dissolved oxygen conditions, which suggests that runoff from land contributes significant loadings to the estuary. Conditions were most severe when the water was warm (>15 C) and at low water slack periods. Oxygen levels in the 8 km segment of the river extending from roughly 17 km to 25 km upstream of the mouth were always depressed for these conditions. When water temperatures dropped below 15 C, dissolved oxygen levels remained above 4 mg/l despite tidal or meteorological circumstances.

Elevated biochemical oxygen demand, chlorophyll-a, ammonia nitrogen, total kjeldahl nitrogen, nitrite- and nitrate-nitrogen, orthophosphorus and total phosphorus were also present in the area of the dissolved oxygen sag following periods of runoff. Biochemical oxygen demand levels doubled during wet surveys and chlorophyll-a concentrations underwent a sharp increase in the upstream area.

It can be concluded that water quality in the Nansemond has undergone significant improvement in the past 15 years. Although chlorophyll-a levels above 40 ug/l were seldom observed in 1982, other nutrient and oxygen concentration problems still remain. Elevated levels of inorganic phosphorus and nitrogen were found to occur during the summer and winter/spring respectively. Low dissolved oxygen concentrations are still of concern; oxygen levels are particularly sensitive to the combination of environmental factors producing runoff into the estuary at low tide during warm weather. However, any additional reductions in point source loadings when combined with anticipated reductions in nonpoint loadings from agricultural runoff should continue the present trend of improving water quality conditions.

It is recommended that additional data be gathered to better characterize and quantify stormwater impacts. Measurements before and following a rain event would be required. This could be accomplished by conducting sequential slack water surveys or by the placement of automatic sampling and/or monitoring equipment within the affected area.

Also recommended is a more detailed survey of the most upstream segment of the river where nutrient, BOD, and fecal coliform levels are often high and oxygen levels low. Specifically information should be gathered that would allow one to assess the relative importance of the factors at work. The factors believed to be important are reservoir spillover, runoff from the urbanized area, agricultural runoff flowing down Shingle Creek and perhaps other creeks, and the remaining point source discharges.

Water quality in Chuckatuck Creek was seen to have generally acceptable nutrient levels. Concentrations were fairly homogeneous throughout the estuary, although somewhat greater levels of organic matter and chlorophyll were present upstream. This resulted in slightly higher biochemical oxygen demand and lower dissolved oxygen concentrations. As expected the upstream areas were more sensitive to stormwater runoff and nutrient levels increased following rain events.

Observed orthophosphorus concentrations were highest in the summer surveys, and inorganic nitrogen levels were high in December and March due to high concentrations of nitrite- and nitrate- nitrogen, presumably associated with runoff.

Chlorophyll-a levels were low throughout the year. Oxygen values below Virginia's 4.0 mg/l standard were observed in the upstream area during the May 26th sampling and during the intensive survey. The oxygen minimum occurred at low water slack, in warm weather and followed runoff. This combination of environmental factors appears to depress oxygen level concentration in the estuarine environment.

It is recommended that future sampling efforts in Chuckatuck Creek estuary be augmented by sampling in the freeflowing portions of the creek.

I. INTRODUCTION

PURPOSE OF THE STUDY

It is common practice in water quality management to utilize mathematical models to predict future water quality conditions. By comparison of current conditions and these projected conditions, one can assess the effects of increased or decreased pollutant loads from wastewater treatment facilities, altered land use patterns and other factors which affect water quality. Important management decisions are made with the math model projections being one component in that decision-making process.

Unfortunately there have been few occasions where field studies have been conducted during subsequent periods to document whether the projected changes have or have not occurred, or if the changes differ in some way from those projected by the models. The Nansemond-Chuckatuck system provides a virtually unique opportunity to observe the results of water quality related actions. Over the past decade the point source loadings, that is treated wastewater loads, to the Nansemond River have been changing, recently they have been decreasing. The designation of these two basins as a Rural Clean Water Program area means that federal funds are available to share the costs incurred by farmers who utilize agricultural "Best Management Practices". Implementing these "BMPs" means that runoff loads or nonpoint source pollution also should be decreasing over the coming decade.

The purpose of this report is to describe current conditions and when possible to relate observed features to point and nonpoint source inputs. The description of current conditions can be used in at least two ways. First, comparison of present water quality with conditions observed in earlier studies will provide an indication of the effectiveness of point source control efforts. Second, the data will provide the baseline conditions that can be used at later dates to assess water quality trends following implementation of the agricutural BMP's.

DESCRIPTION OF THE STUDY AREA

The Nansemond River is a small tributary of the James, entering Hampton Roads along the southern shore approximately 15 kilometers upriver from Fort Wool (see Figure 1). The drainage basin lies primarily in the City of Suffolk but also includes portions of Chesapeake, Portsmouth and Isle of Wight County. The total drainage area is around 50,000 hectares (200 square miles), but nearly two-thirds of this area is upstream of water supply reservoirs operated by the cities of Norfolk and Portsmouth. Consequently, freshwater runoff to the river is greatly reduced. The predominant land uses are forest (38%), cropland (24%) pastures (7%) and marshes (22%). The remainder of the area is in residential, industrial and commercial uses. Much of the developed area is in or near the old city of Suffolk although some development has occurred and more is projected for the area near Pig Point.

The climate for this area is "humid, subtropical". During 1982 monthly average temperatures at Lake Kilby near Suffolk ranged from 1 C (34 F) in January to 24 C (76 F) in July. The maximum temperature measured was 33 C (91 F) on July 28 and the minimum temperature was -14 C (7 F) on January 11. Rainfall during 1982 was slightly above average; the yearly total was 127.25 cm (50.1 in.). The rainfall at Driver was slightly lower, 121.79 cm (47.95 in.) but was 7 cm (2.75 in.) above the average annual rainfall recorded there over the last 34 years. On the average, the rainfall is evenly distributed over the year (Fig. 2) but significant short term deviations can occur. For example the April rainfall at Lake Kilby was only 5 cm (2 in.) while February, May, July, August and December each had rainfall greater than 10 cm (4 in.). One aspect of this is that storms large enough to produce runoff can and do occur at all times of the year.

The Nansemond River has a geometry typical of many estuaries: the channel is narrow (less than 100 meters) in the upper reaches, widens in an exponential fashion in the seaward direction and is very broad (4,000 meters) at the mouth. A navigation channel 12 feet deep and 100 feet wide was dredged

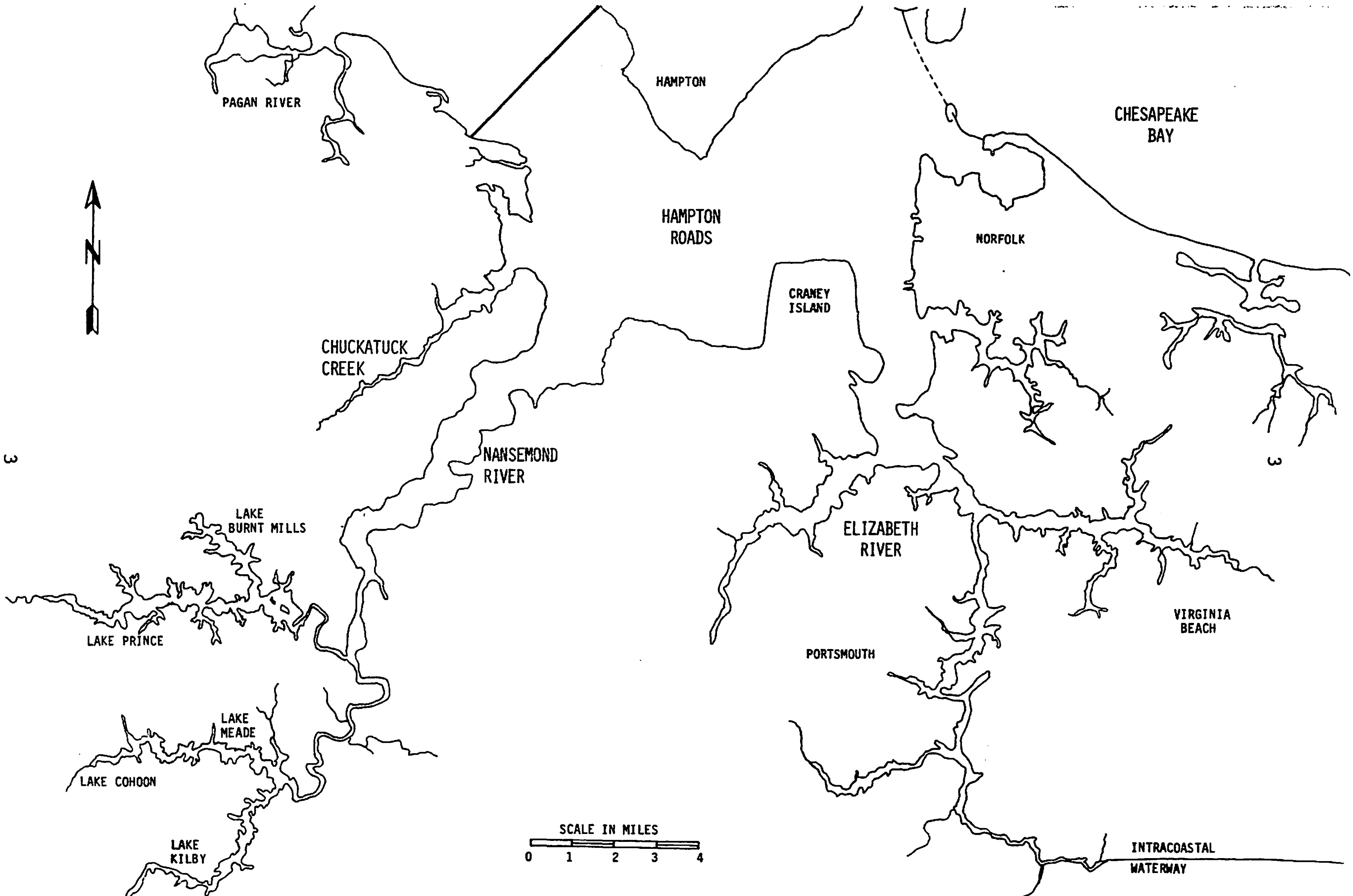


Figure 1. Location of the Nansemond River and Chuckatuck Creek.

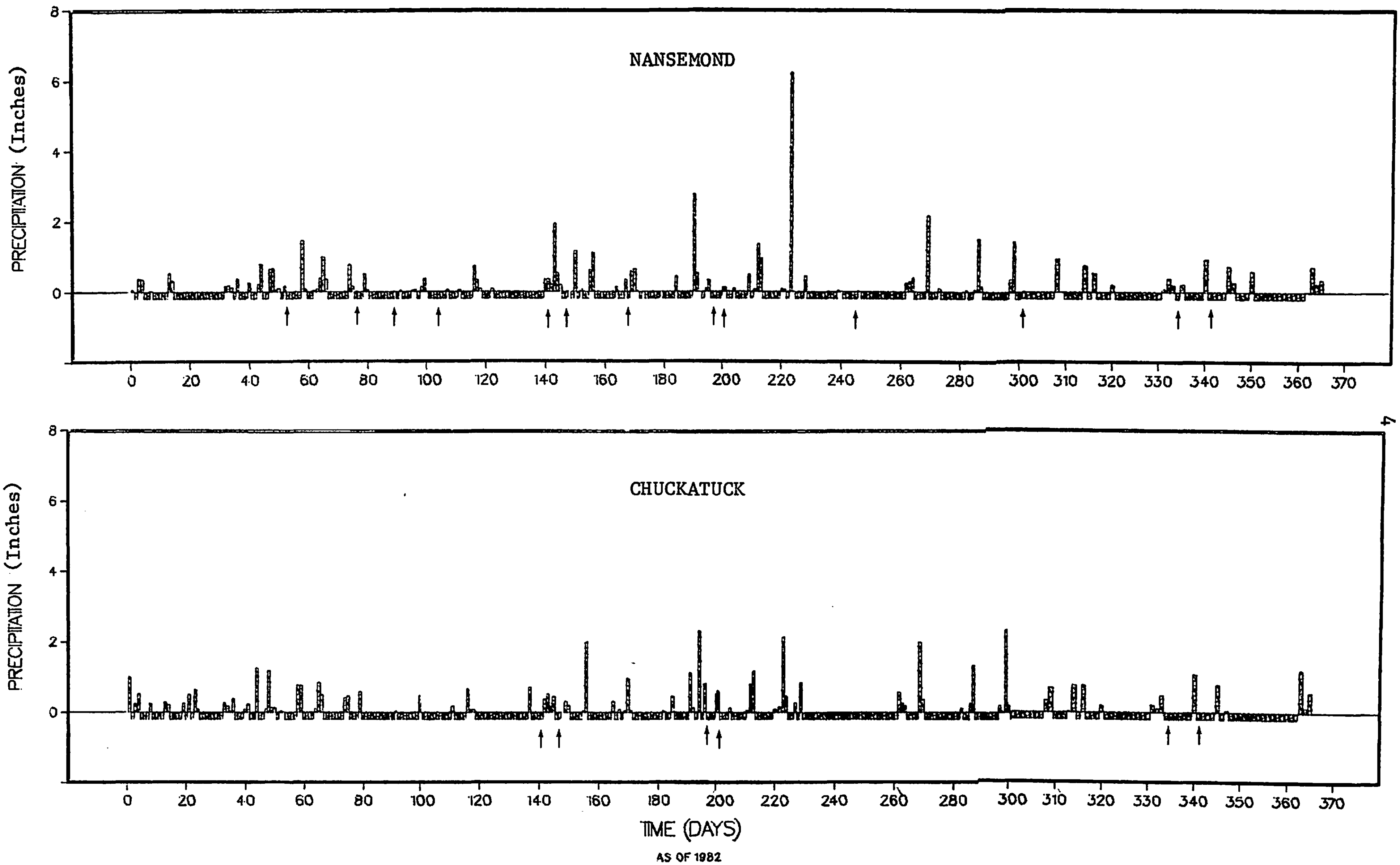


Figure 2. Daily precipitation as recorded at Suffolk (Nansemond) and Driver (Chuckatuck), Virginia. Arrows indicate slackwater survey dates. The shading below the zero line has no significance, but was added to give visual emphasis to periods with no rainfall.

in the early 1930's. Maintenance dredging occurred in 1957. Future dredging activities are expected to be limited to the downstream reaches and the Western Branch where recreational boating occurs. Near Suffolk the river course is sinuous and bordered by extensive tidal marshes. Freshwater flow to the river is not great because the drainage area is small and the water supply reservoirs impound much of the runoff. Consequently, brackish waters often reach all the way to the old city of Suffolk and there is little stratification in the water column. During winter and spring the freshwater runoff usually increases, resulting in some salinity stratification and a downriver migration of the brackish water.

The rapid narrowing of the river channel from the mouth towards the headwaters results in a reflection of the tidal wave and an increase in the mean tidal range. The range near the mouth is only 0.85 m (2.8 ft) but increases to 1.16 m (3.8 ft) at the head. There also is a phase lag of about one hour between the river mouth and the head. Tidal currents are reasonably uniform throughout the estuary and have maximum values of about 0.5 m/sec (1 knot).

Because freshwater flows are regulated and reduced by the reservoirs, at times there is very little flow to advect materials through the system. That is, pollutants entering the system tend to stay there and are not flushed through the system when freshwater inflow is small. Tidal currents will tend to disperse and mix pollutants in the system. However, for the moderate currents in the Nansemond River, this will not occur rapidly, nor will reaeration be especially great. The end result is that the physical characteristics of the Nansemond lead to more severe water quality problems than are observed in some nearby estuaries.

DATA REVIEW

There is a considerable amount of water quality information available on the Nansemond River. Since the mid-1970's monthly point-source loadings to the estuary (biochemical oxygen demand, suspended solids and flow rates) have been monitored (11). Records on fecal coliform levels are available for an even longer period from the Bureau off Shellfish Sanitation (BSS) of the State Department of Health (3). Water quality characteristics in the estuary have been documented, dating back to 1966 when monthly surveys were conducted over an annual cycle (1). The Virginia State Water Control Board (SWCB) samples the waters of the Nansemond on a regular basis and these conditions have been documented either by or for the SWCB (2,4,5,8,12). A review of the above studies can be found in a report to the Hampton Roads Water Quality Agency entitled "Field and Modelling Studies of Water Quality in the Nansemond River" (9).

Very little data is available about the water quality in the Chuckatuck estuary. The Bureau of Shellfish Sanitation collects information on fecal coliform levels in their Shoreline Surveys (3) on a routine basis. No discharge Certificates* issued since the Clean Water Act was enacted in 1972, and some water quality monitoring data are available from the SWCB (10). Since the Chuckatuck is fairly rural, these certificates primarily document changes in herd sizes grazing along the shoreline as well as location of feed lot area. Water quality surveys in the main body of the estuary, however, have not been undertaken to date.

----

*No-discharge Certificates are issued to operations which involve wastewaters but none of which are discharged to state waters. For example one food processing operation in the Nansemond basin disposes of its wastewaters by spray irrigation and therefore there is no discharge to nearby streams.

II. WATER QUALITY IN THE NANSEMOND ESTUARY

Because large sums of money have been invested in pollution control measures, it is appropriate to ask if there has been an improvement in water quality in the Nansemond. Four pairs of slackwater surveys and an intensive survey of the Nansemond River were conducted in 1982-83 to gather data. This work was funded by the Hampton Roads Water Quality Agency through a grant from the Environmental Protection Agency (P003085-04). Additional slackwater surveys were made at other times; these were supported by the Virginia State Water Control Board and the Virginia Institute of Marine Science through their Cooperative State Agencies Program. Sampling station locations are shown in Figure 3. Both data sets for 1982-83 and historical data sets (1,9) will be used in the following interpretations. Seasonal variations will be presented in order to give the reader some understanding of the range of water quality conditions. The present conditions will be contrasted with historical information to see what changes have accompanied point source control measures. Finally the impact of runoff on river water quality will be discussed.

SEASONAL VARIATIONS IN WATER QUALITY

Water temperatures observed in the Nansemond ranged from 7-28 C during the study period. The range of salinity values at the mouth of the estuary was 15-22 ppt; 29 km upstream values varied from 0-8 ppt over the year. In addition to tidal variation, the upstream area can be subjected to periods of continuous freshwater flow from spillover at the Lake Meade Dam. Conversely, during dry meteorological conditions or times of heavy water usage (generally in the summer due to the influx of tourists as well as increased evapotranspiration from vegetation), extended cycles of no freshwater inflow may occur.

The annual variation in nutrient concentrations showed ammonia nitrogen, soluble reactive phosphorus and total phosphorus to be highest in the summer

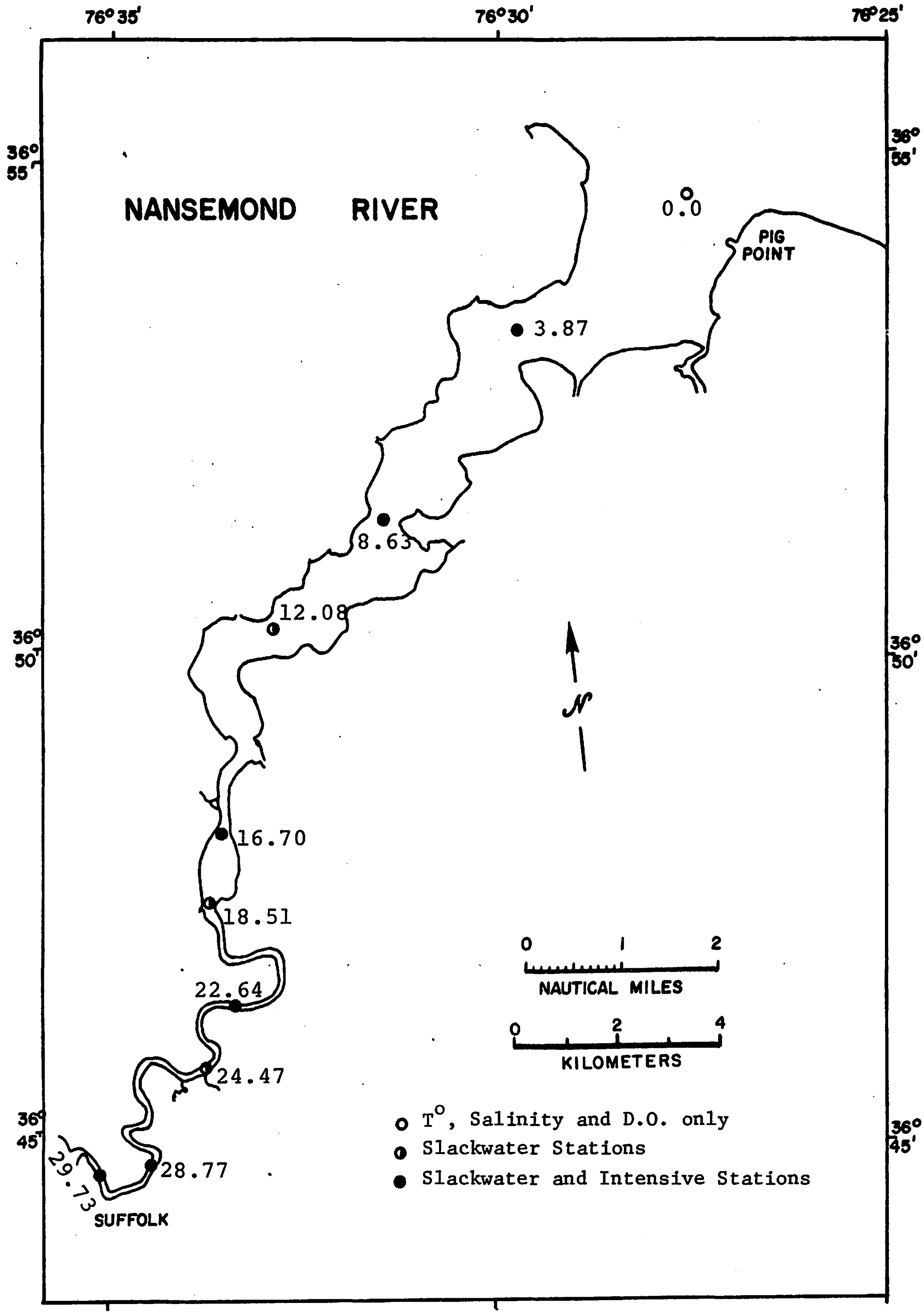


Figure 3. Station locations in the Nansemond River with kilometers from mouth.

months. Concentrations not only exhibited a wider range of values in the upstream portion but were also generally two times higher there than at the mouth of the estuary. Nitrite- plus nitrate- nitrogen concentrations showed a significant increase in the spring surveys (Fig. 4), and upstream values were twice the level found at the mouth. Silica concentrations were elevated during the warm season (July - Nov.), and maximum values occurred in the mid-reach of the estuary.

Chlorophyll-a levels were generally quite moderate in the first 20 km of the estuary throughout the year. Chlorophyll-a concentrations were 4 times greater at the head of the estuary than at the mouth, and the maximum observed value (43 ug/l) occurred 29 km upstream in November.

Biochemical oxygen demand was low, especially in the downstream area. Highest observed levels (2.5 mg/l) occurred concomitant with the chlorophyll-a maximum noted above. Biochemical oxygen demand levels averaged two times higher upstream than at the mouth of the estuary.

Fecal coliform concentrations showed no discernible annual trend, however levels were exceptionally elevated in December (Fig 7). Bacterial counts ranged from 2-43 mpn downstream to 47-3100 upstream during the study.

Oxygen showed a distinct temperature dependent annual variation. Dissolved oxygen percent saturation values were lowest in July (78%) and highest in March (101%). December levels were 97%; May oxygen saturation was 82%. Downstream oxygen levels were always above 4.0 mg/l. Levels ranged from 4.9-9.8 mg/l, with an annual mean value of 7.7 mg/l. Upstream, however, dissolved oxygen values fell below 4.0 mg/l in May, June, July and September. Values varied from 1.9-9.6 mg/l, with an annual mean concentration of 5.2 mg/l.

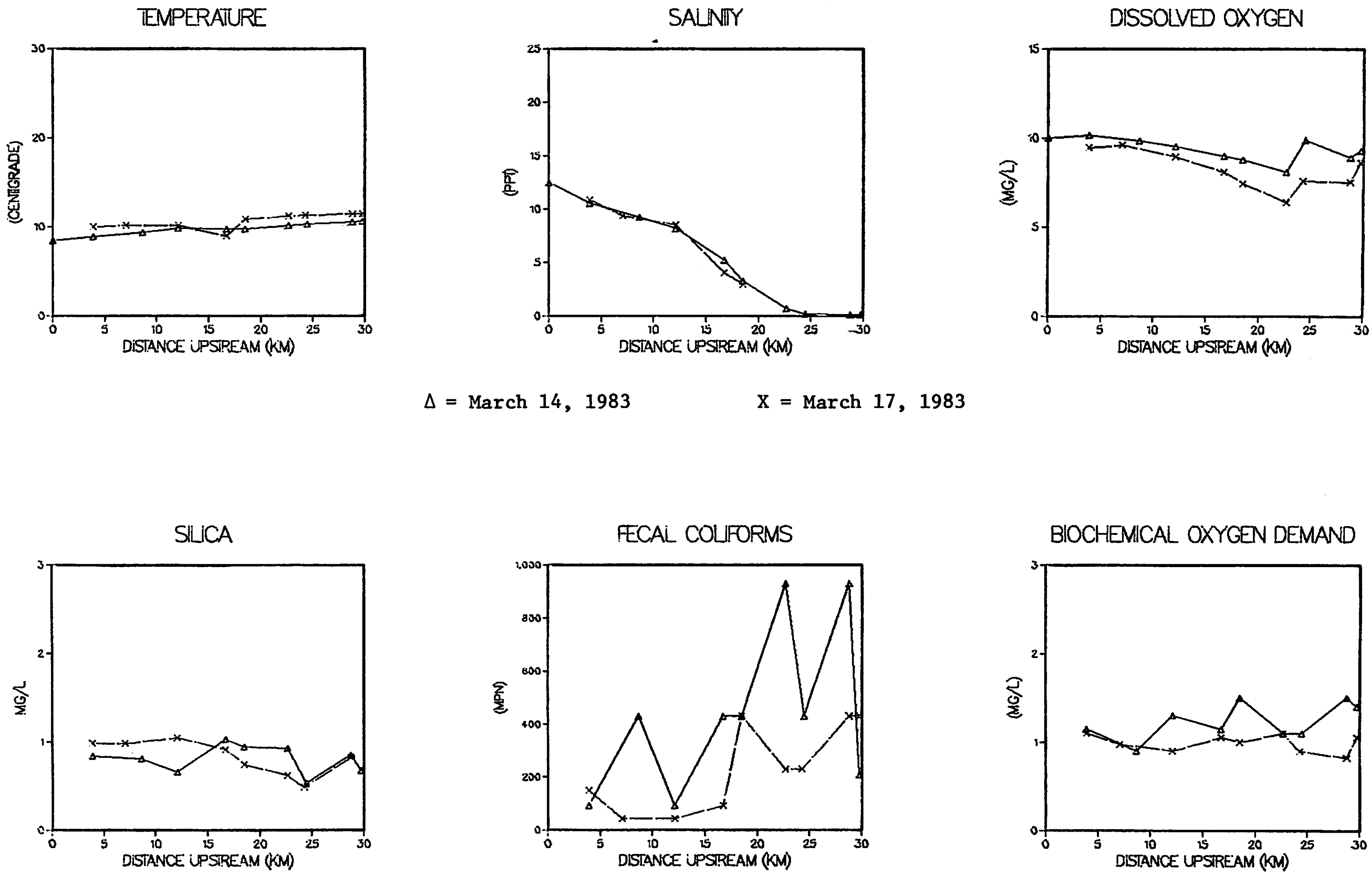


Figure 4a. March 14, 1983 high slackwater (Δ) and March 17, 1983 low slackwater (X) surveys in the Nansemond River.

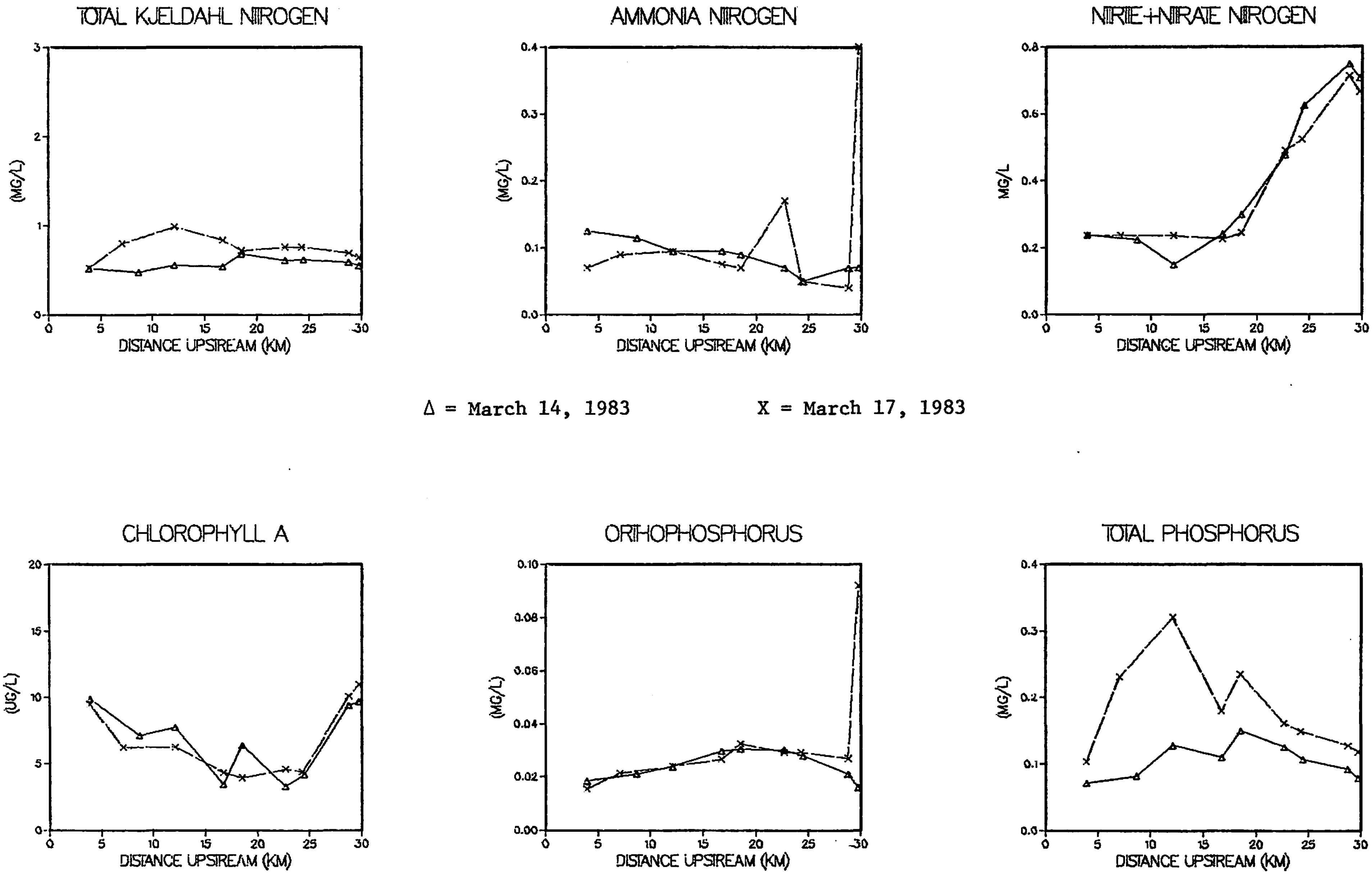


Figure 4b. March 14, 1983 high slackwater (Δ) and March 17, 1983 low slackwater (X) surveys in the Nansemond River.

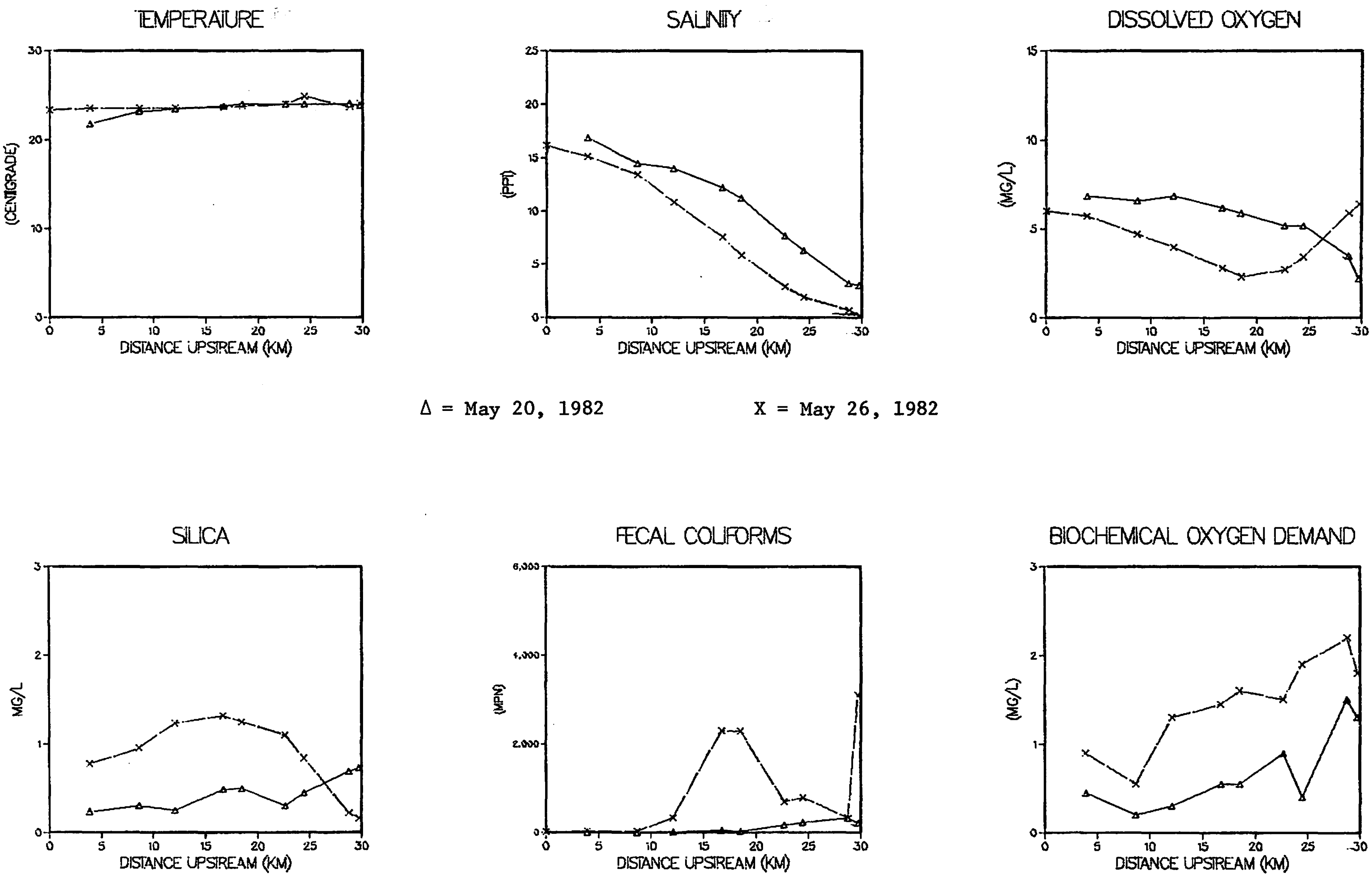


Figure 5a. May 20, 1982 high slackwater (Δ) and May 26, 1982 low slackwater (X) surveys in the Nansemond River. The first survey was conducted under "dry" conditions, the latter under "wet" conditions.

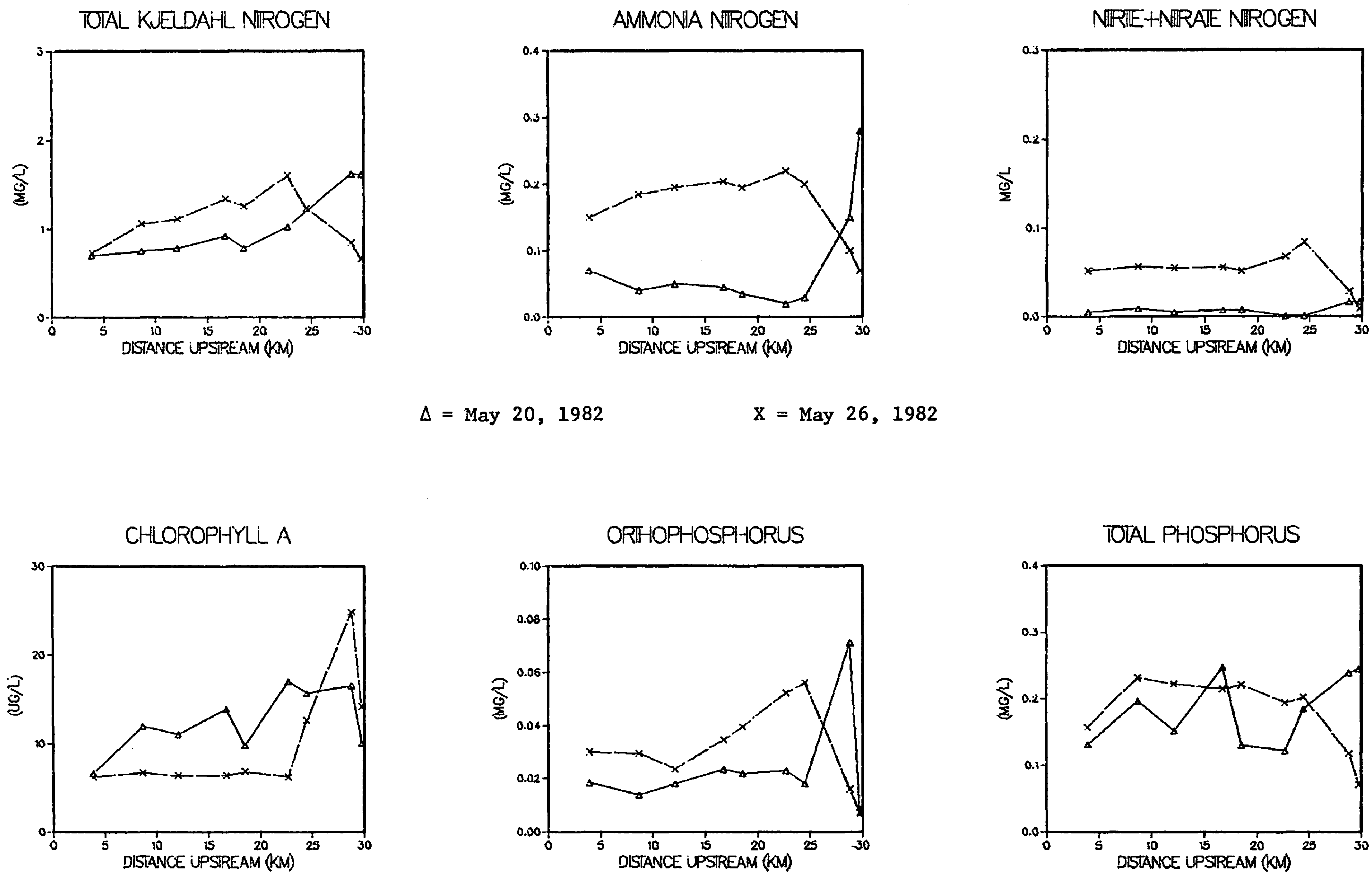


Figure 5b. May 20, 1982 high slackwater (Δ) and May 26, 1982 low slackwater (X) surveys in the Nansemond River. The first survey was conducted under "dry" conditions, the latter under "wet" conditions.

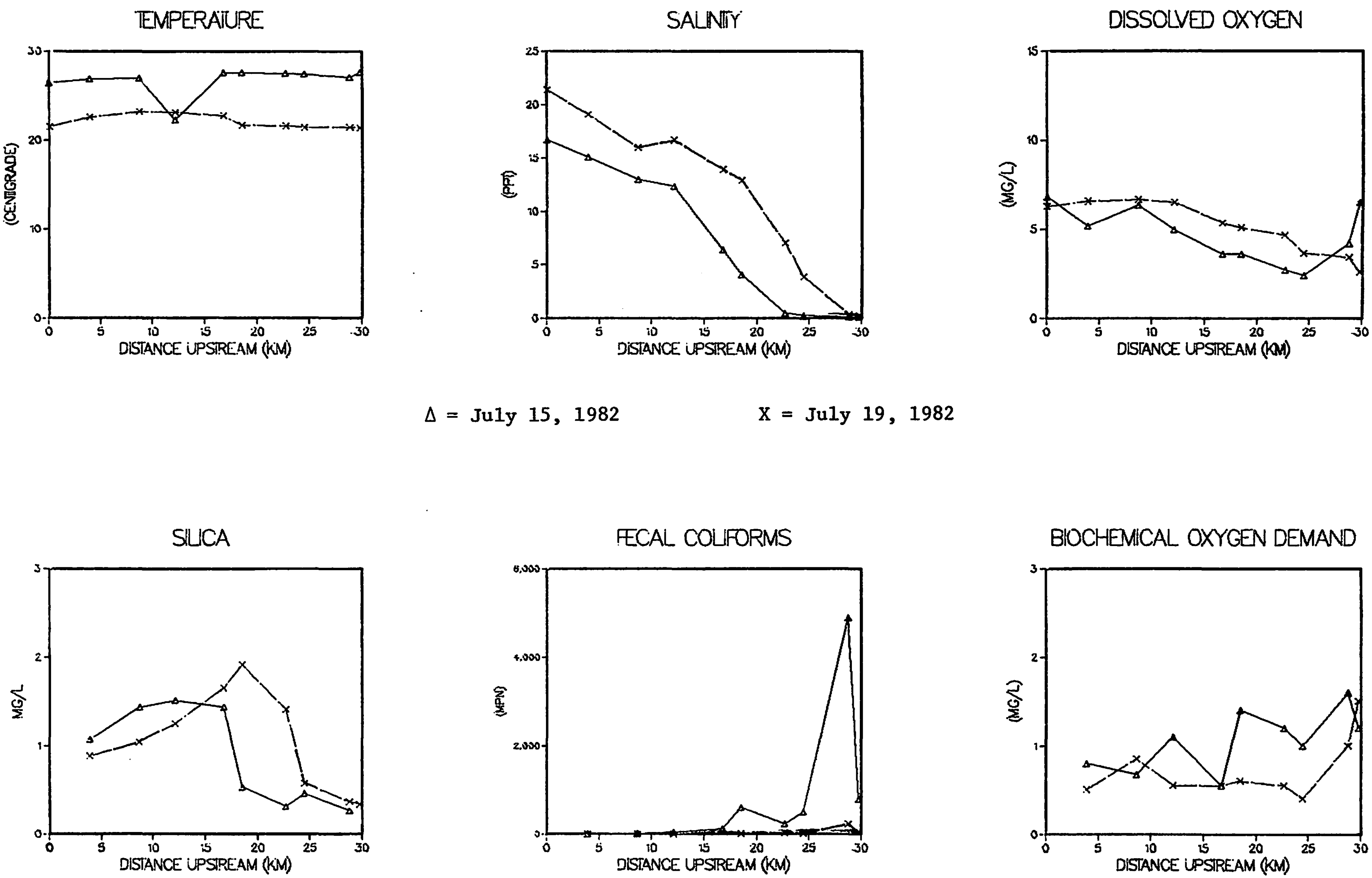


Figure 6a. July 15, 1982 low slackwater (Δ) and July 19, 1982 high slackwater (X) surveys in the Nansemond River. The first survey was conducted under "wet" conditions, the latter under "dry" conditions.

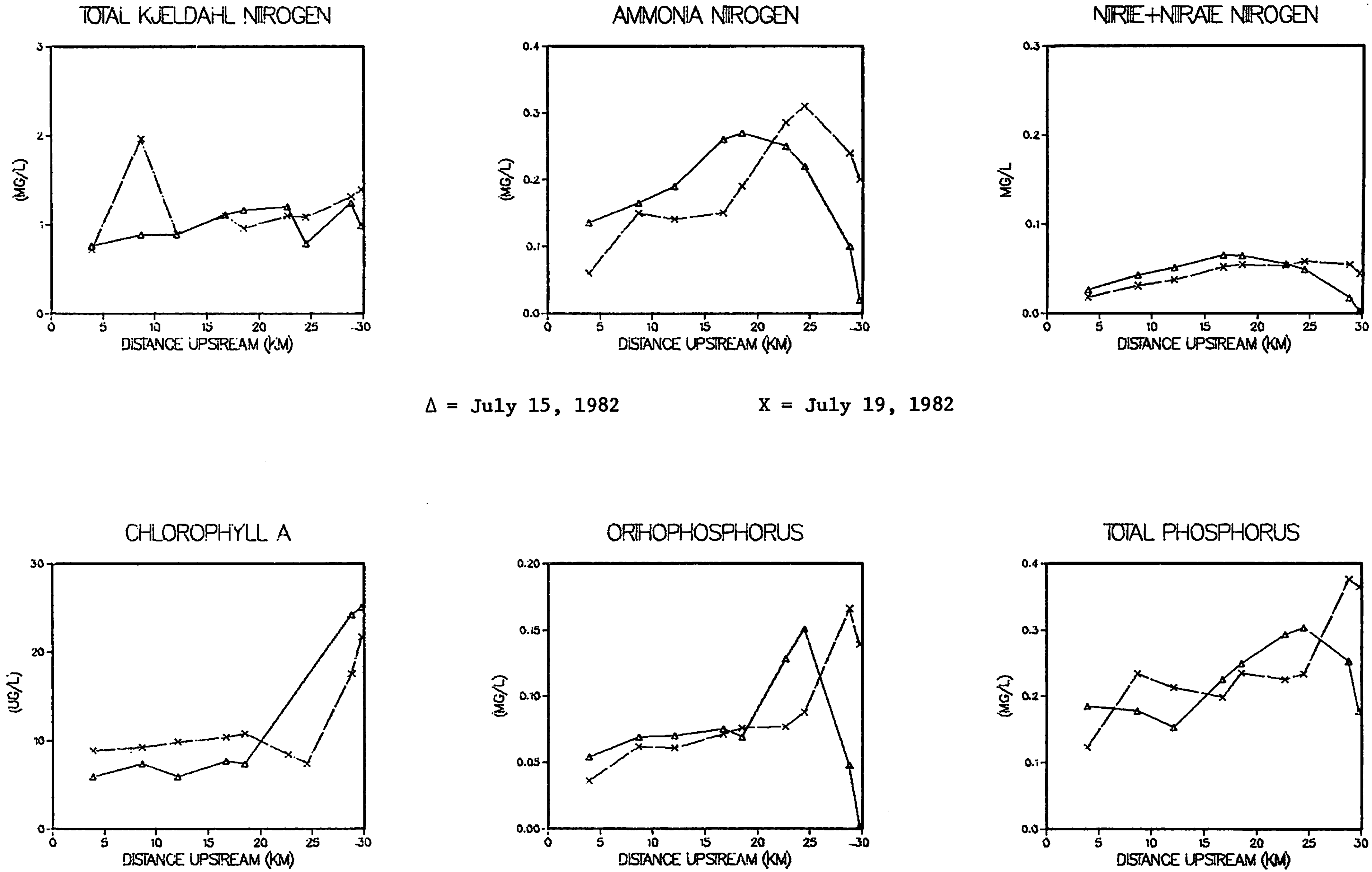


Figure 6b. July 15, 1982 low slackwater (Δ) and July 19, 1982 high slackwater (X) surveys in the Nansemond River. The first survey was conducted under "wet" conditions, the latter under "dry" conditions.

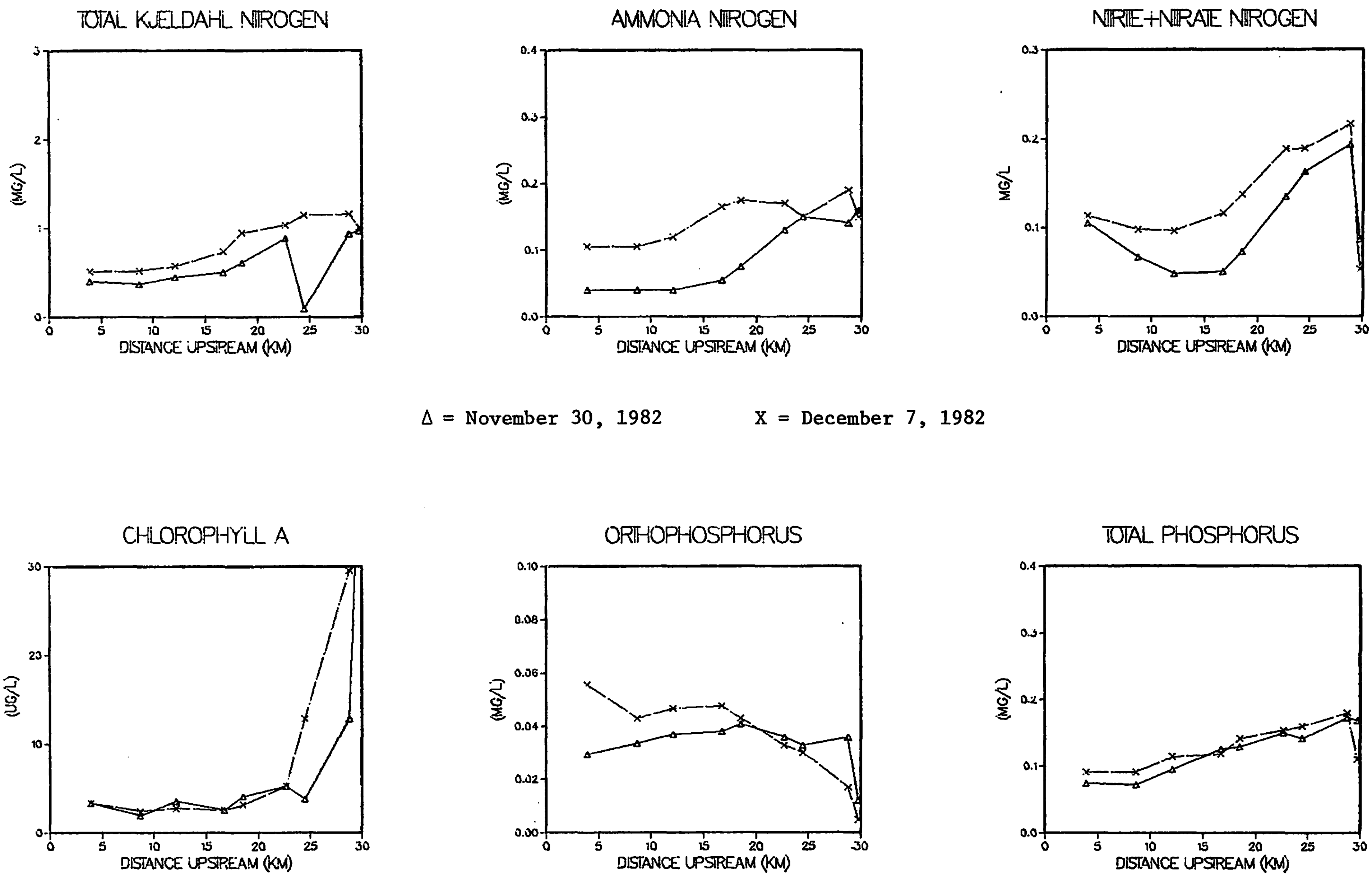
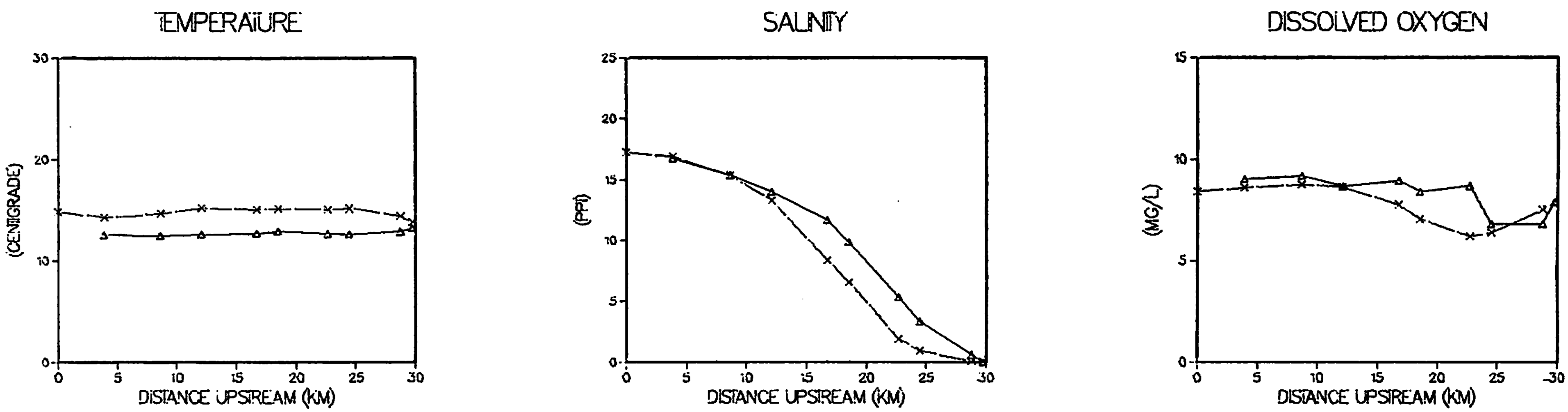


Figure 7a. November 30, 1982 high slackwater (Δ) and December 7, 1982 low slackwater (X) surveys in the Nansemond River.



Δ = November 30, 1982 X = December 7, 1982

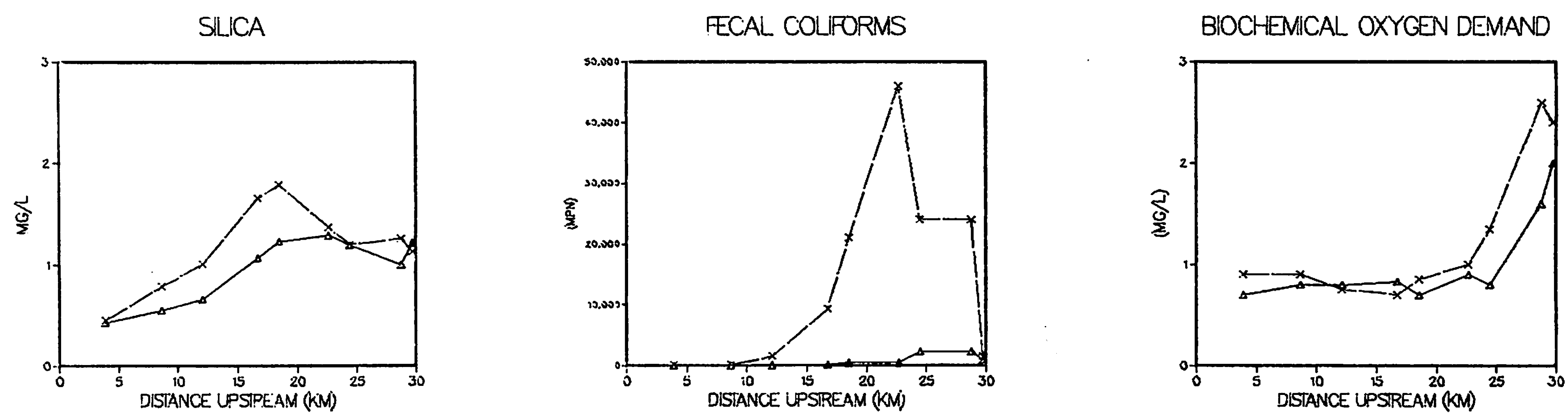


Figure 7b. November 30, 1982 high slackwater (Δ) and December 7, 1982 low slackwater (X) surveys in the Nansemond River.

CHANGES DUE TO POINT SOURCE CONTROLS

The slack water data sets for 1966-67, when major dischargers were "on line" (Table 1), and for 1982-83, when these sources were "off line" (Table 2), can be compared to examine water quality changes that have resulted. With the reduction in point source loads, one would expect improved water quality during dry periods. Figures 8-9 and Table 3 show that the April 17, 1966 and April 15, 1982 surveys can be compared. The former sampling followed 21 and the latter 17 dry days (no spillover). Similarly, the surveys on May 15, 1967 and May 20, 1982 were conducted after 49 and 52 dry days. Finally, the September 6, 1966 and September 1, 1982 surveys both followed 11 dry days.

Examination of Figures 10-12 shows that temperature and salinity distributions were roughly comparable for the three pairs of slacks. It appears that dissolved oxygen conditions have improved in terms of both absolute levels and also percent saturation. For the September and April surveys, 1982 DO levels were higher. For the April and May surveys oxygen conditions were higher in 1982 when viewed as percent of saturation levels. Additionally, Brehmer measured oxygen values less than 4.0 mg/l throughout the estuary in July 1966 (Appendix A), and at all stations 13 km or more upstream during August and September. Similar depressed oxygen levels were not observed during dry periods in 1982-83.

Although present nutrient levels are still moderately high, a distinct reduction in nutrient concentrations can be seen for both total and inorganic phosphorus. Total phosphorus levels have been reduced by a factor of 2 in the headwaters and orthophosphorus levels have decreased to an even greater degree in the most upstream segment. In 1982 phosphorus levels were fairly constant throughout the estuary whereas in 1966-67, although concentrations were comparable at the river mouth, levels increased markedly in the upriver direction.

TABLE 1 . Point Sources*
Discharging to the Nansemond River, 1976

Source	Distance from River Mouth	Model Reach Number	Flow Rate (MGD)		Waste Discharge Rate $CBOD_5$ (lbs/day)	
Louise Obici Hospital	14.1	17	.086[1]	.066[2]	21[1]	11[2]
Eberwine Brothers	2.6	33	.02		132	134[3]
Tidewater Community College	.8	35	.043	.078	5	8
Suffolk STP	18.1	3	.866	1.21	377	201
Va. Packing	17.7	5	.068		35	60[3]
Pruden Packing	17.7	5	.0001		5	
Shingle Creek STP	17.7	5	.17	.141	9	4

(1) August 1974 (from Kuo, et al., 1977)

(2) August 1976

(3) estimated

*Taken from Reference #9 - The original "208" water quality report on the Nansemond.

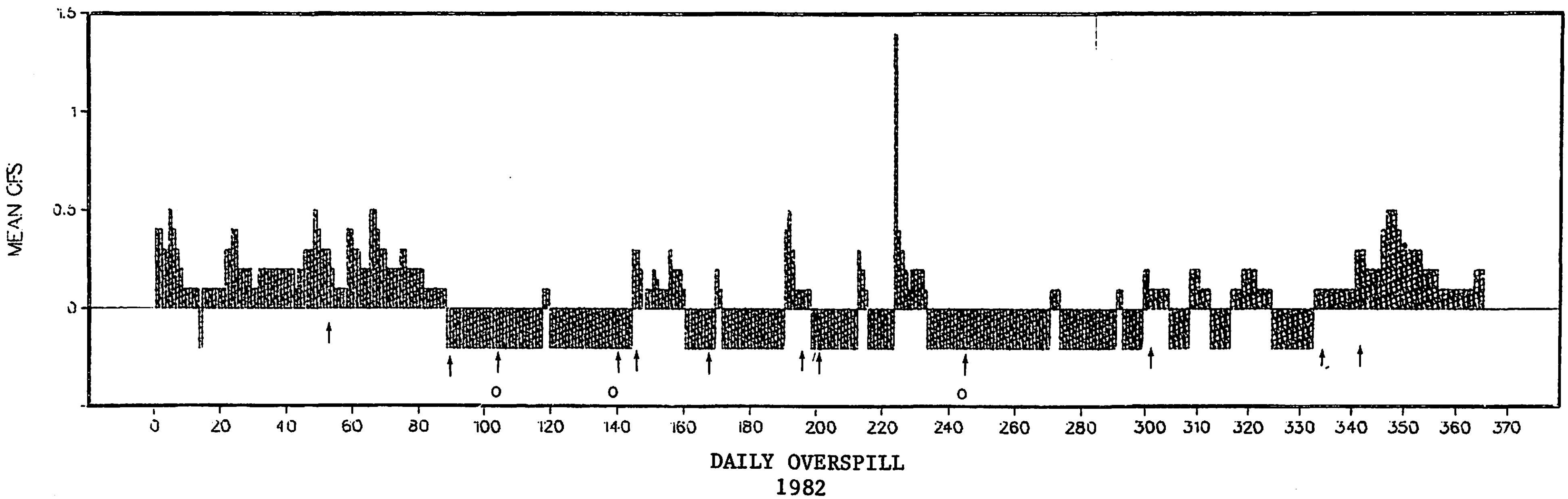
Table 2 . POINT SOURCE DISCHARGES TO THE NANSEMOND RIVER - 1982

Source	Distance from River Mouth (km)	Mean† Flow Rate (MGD)	Mean† Waste Discharge Rate ($CBOD_5$) (lbs/day)
Louise Obici Hospital	23.2	0.0563	6.850
Eberwine Brothers*	4.2	0.67	-
Tidewater Community College	1.3	0.092	20.090
Virginia Packing**	28.5	0.043	-
Wynwood Subdiv. Lagoon (Coleman Pl. Prop)	3.1	0.030	4.644
Green Pines Motel STP	25.5	0.002	0.385
Senior Citizens Village	4.3	0.01	1.687

*Average maximum flows

**Off-line in April, 1982. Data covers Jan.-April 1982.

†Data from NPDES Discharge Monitoring Reports (11)



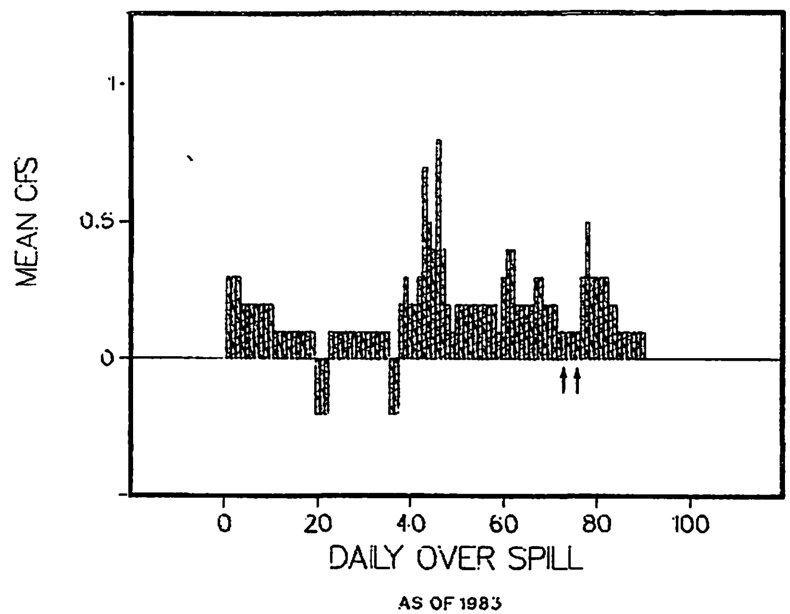
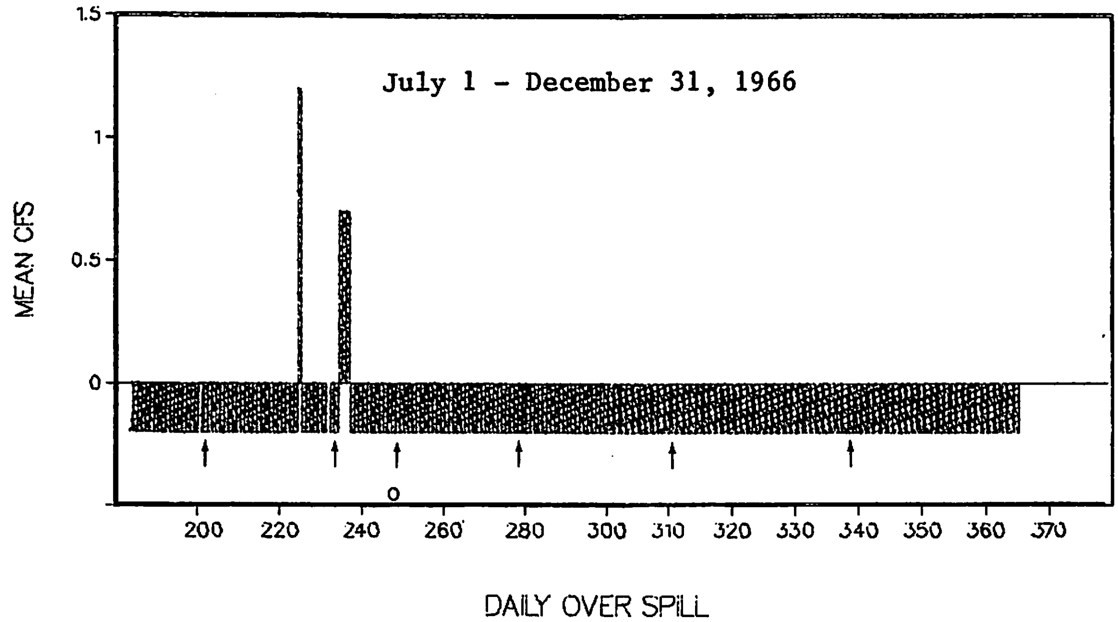


Figure 8. Spillover as measured at the Lake Meade Dam, January 1, 1982 until March 31,1983. Arrows indicate dates that slackwater surveys were conducted. Circles indicate the surveys used for point source comparisons. The shading below the zero line has no significance, but was added to give visual emphasis to period with no spillover.

WESTERN BRANCH



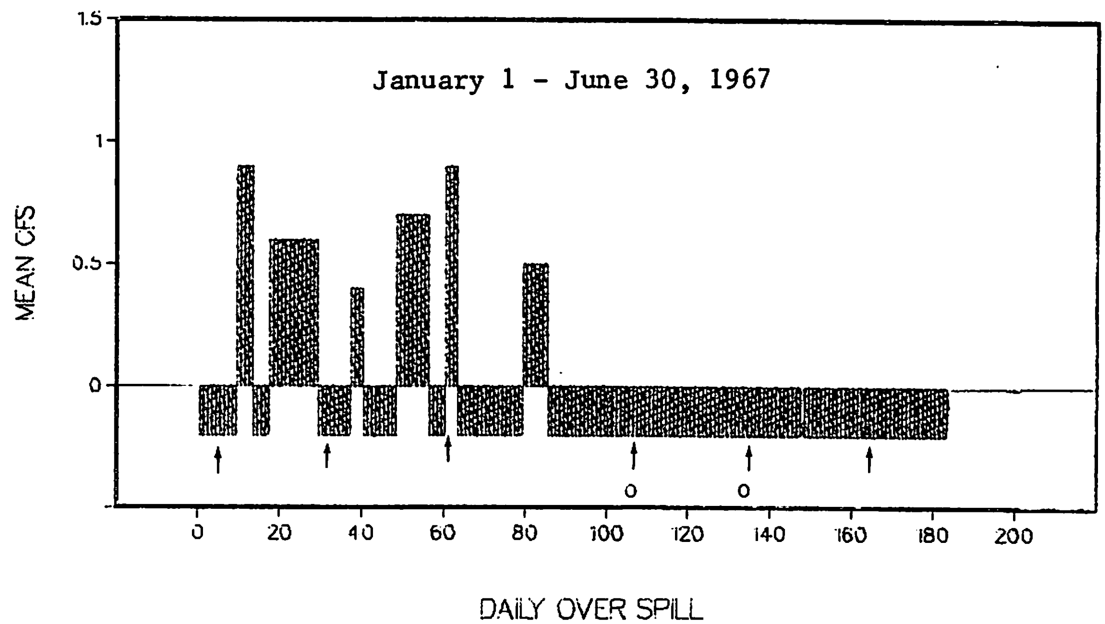


Figure 9. Spillover as measured at the Western Branch Reservoir from July 1, 1966 to June 30, 1967. Arrows indicate sampling dates. Circles indicate surveys used for point source comparisons. The shading below the zero line has no significance but was added to give visual emphasis to periods with no spillover.

Table 3 . Summary of Slackwater Dates and Water Flows Over the Reservoir Spillway at Lake Meade Dam for 1966-67 and 1982-83.

1982 - 1983 Sample Date	Tide	Prior Spillover Conditions (days)	1966 - 1967 Sample Date	Prior Spillover Conditions (days)
			Jan. 5, 1967	Dry (132)
Feb. 22, 1982	HWS	Wet (39)	Feb. 1, 1967	Dry (3)
Mar. 30, 1982	LWS	Wet (74)	Mar. 2, 1967	Wet (1)
Apr. 15, 1982	LWS	Dry (17)	Apr. 17, 1967	Dry (21)
*May 20, 1982	HWS	Dry (21)	May 15, 1967	Dry (49)
*May 26, 1982	LWS	Wet (2)		
June 17, 1982	LWS	Dry (8)	June 14, 1967	Dry (79)
*July 15, 1982	LWS	Wet (6)	July 21, 1966	Dry (21)
*July 19, 1982	HWS	Dry (2)		
			Aug. 22, 1966	Wet (8)
*Sept. 1, 1982	HWS	Dry (11)	Sept. 6, 1966	Dry (11)
*Sept. 27-28,'82	HWS/LWS	Wet (1)		
Oct. 27, 1982	LWS	Wet (2)	Oct. 6, 1966	Dry (41)
Nov. 30, 1982	HWS	Wet (2)	Nov. 7, 1966	Dry (73)
Dec. 7, 1982	LWS	Wet (9)	Dec. 5, 1966	Dry (101)
*Mar. 14, 1983	HWS	Wet (36)		
*Mar. 17, 1983	LWS	Wet (39)		

*Chuckatuck slackwater dates

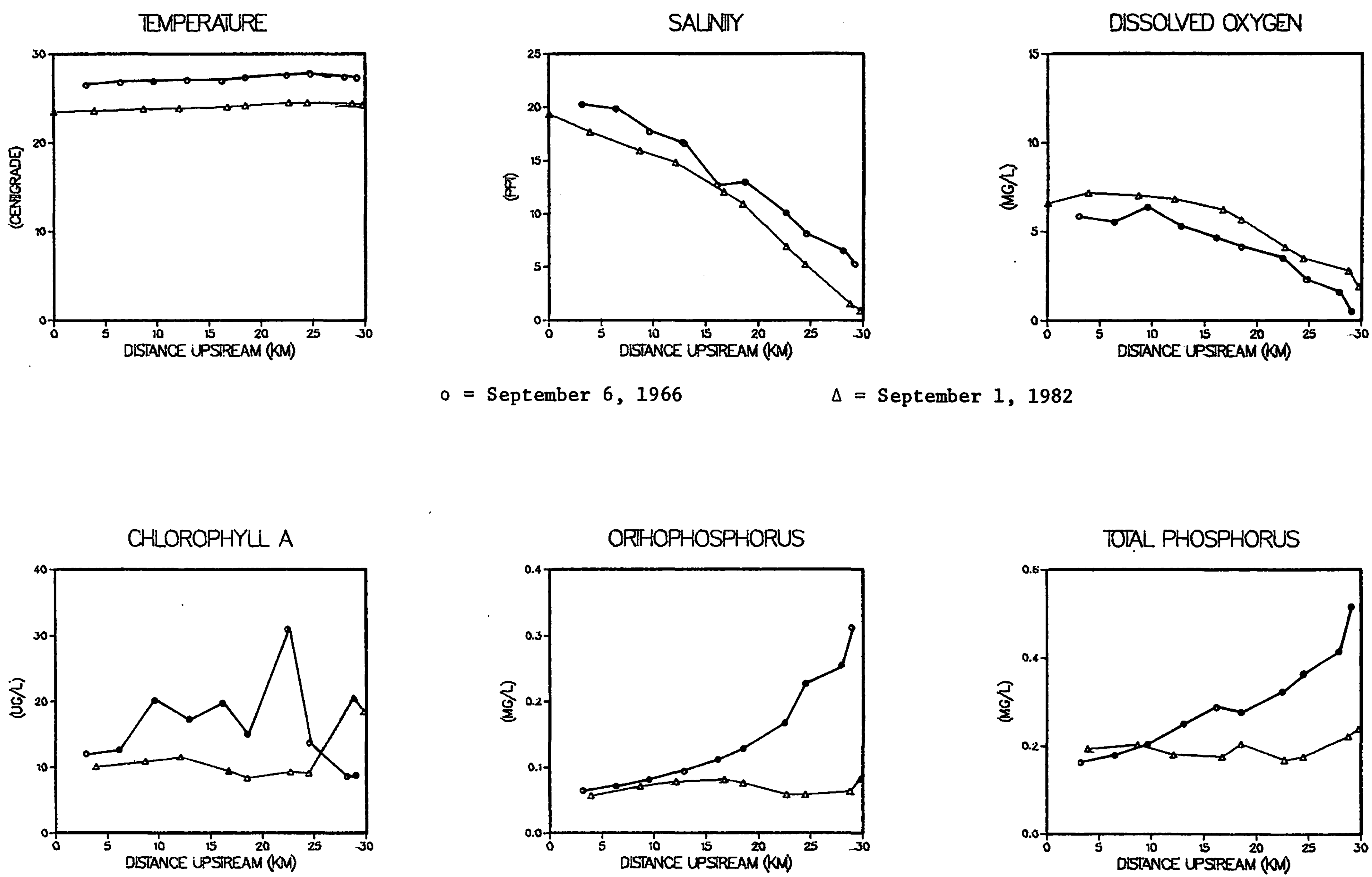


Figure 10. Comparison of Nansemond River water quality before (September 6, 1966 (o)) and after (September 1, 1982 (Δ)) removal of major point source discharges. Eleven days with no spillover from the reservoirs preceded these surveys.

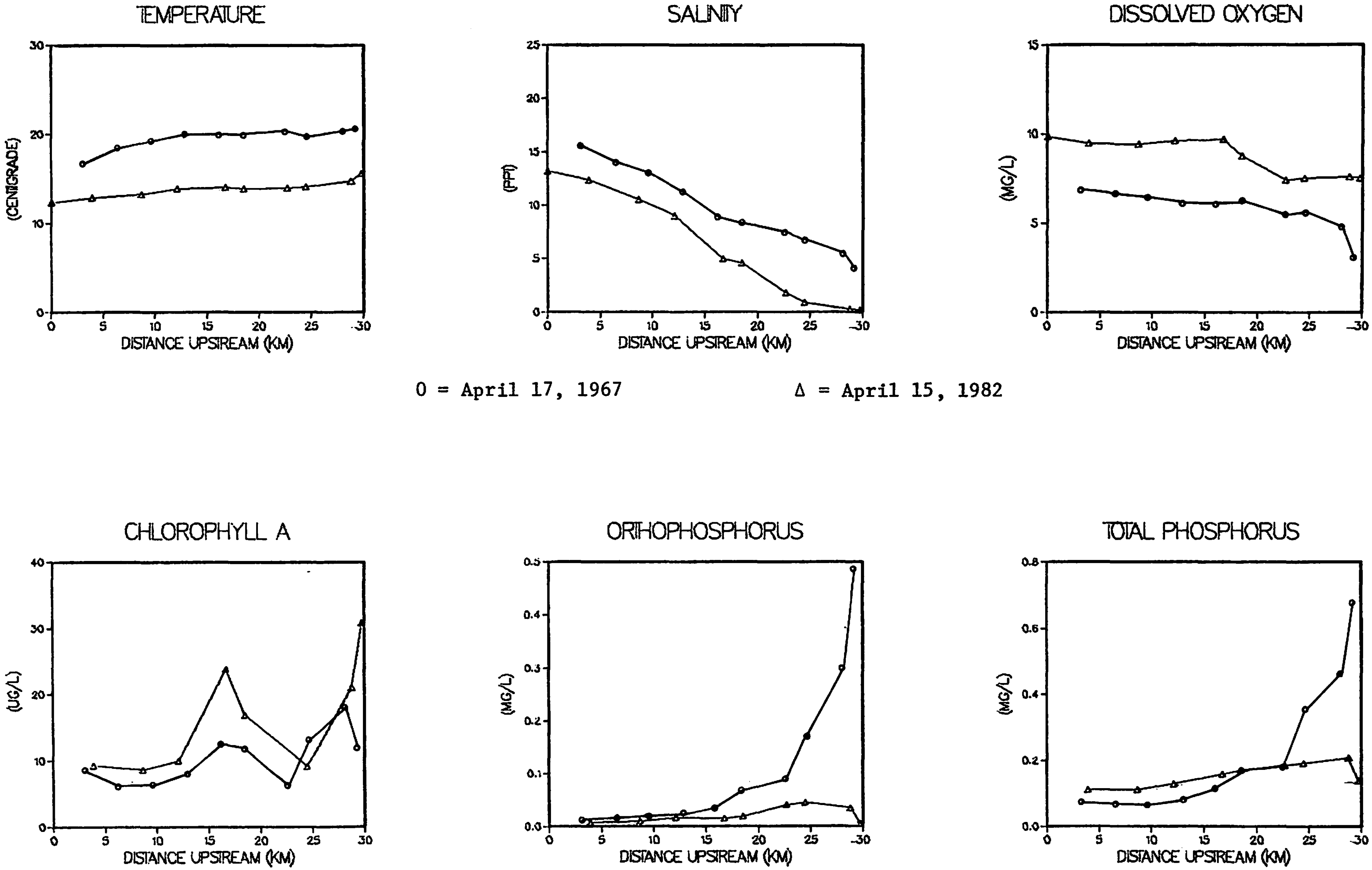


Figure 11. Comparison of Nansemond River water quality before (April 17, 1967 (o)) and after (April 15, 1982 (Δ)) removal of major point source discharges. Approximately 20 days with no spillover from the reservoirs preceded these surveys.

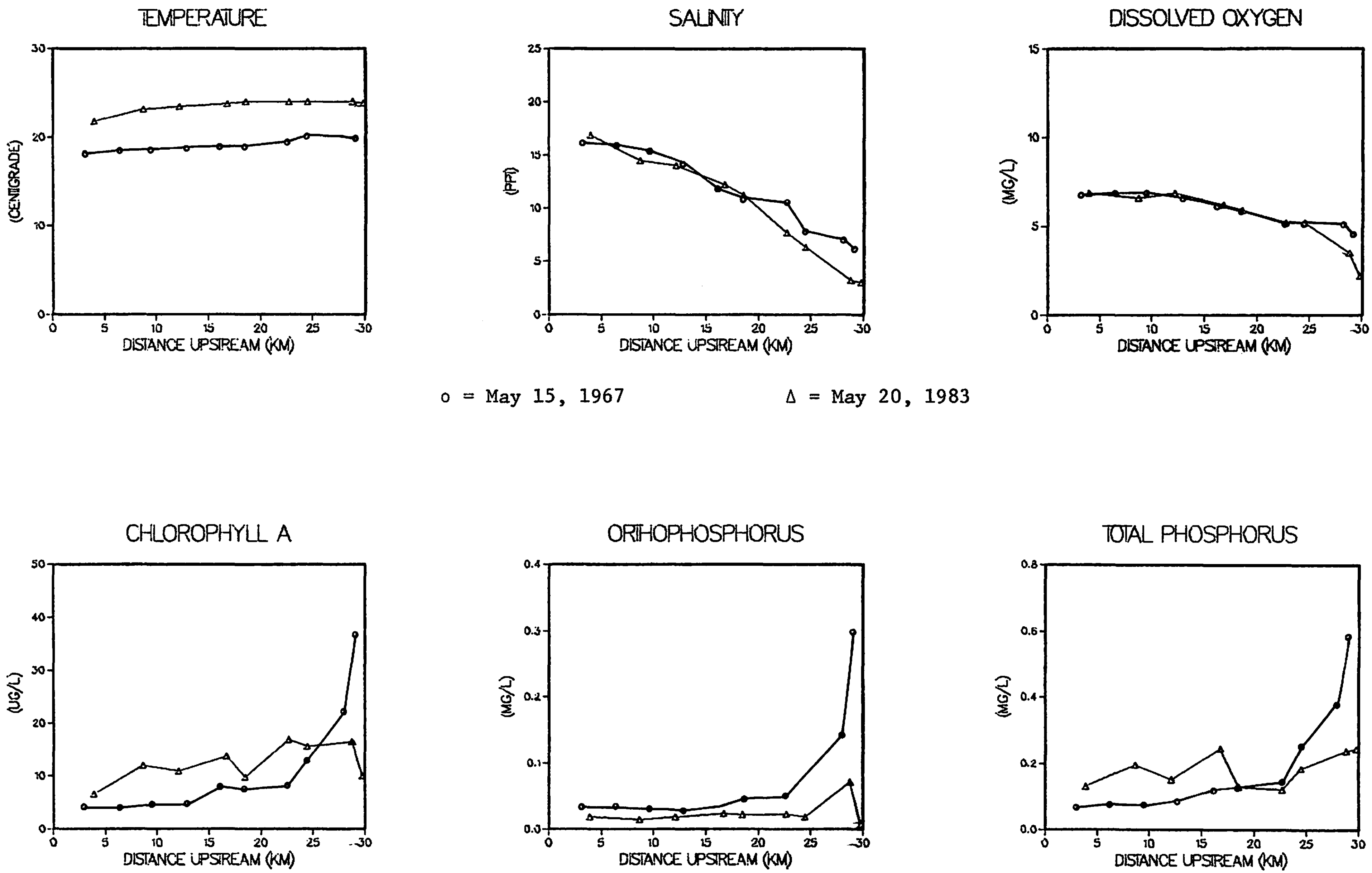


Figure 12. Comparison of Nansemond River water quality before(May 15, 1967 (o)) and after(May 20, 1982 (Δ)) removal of major point source discharges. Approximately 50 days with no spillover from the reservoirs preceded these surveys.

Average annual chlorophyll-a levels in 1982 were much lower than those recorded in 1966. Although spatial and temporal variations exist, levels did not normally exceed about 25 ug/l, whereas in 1966, measurements up to 130 ug/l were recorded.

Hence, the "then" vs. "now" comparison during dry periods reveals an encouraging trend in water quality. Dissolved oxygen levels appear to be higher and nutrient levels lower. Water quality conditions are relatively homogeneous now, but in the 1960's there was a marked longitudinal gradient. Dissolved oxygen levels at the most upstream stations are still depressed sometimes (e.g. May 1982 survey). The reasons for this are not known. It is possible that the system has not yet reached its equilibrium following the point source reductions and even further improvements might occur in future years.

WATER QUALITY DURING WET WEATHER

An "around-the-clock" intensive survey was conducted on the Nansemond River on September 27-28, 1982. This survey followed a rain event (6 cm or 2.4 inches) that caused spillover at the Lake Mead Dam, a situation which had not occurred in the previous 37 days.

During the survey, water temperatures ranged between 20 and 25 C and average salinities ranged from 18 ppt at the mouth to 5 ppt upstream. Salinity variations throughout the 24 hour period are shown in Figure 13. Longitudinal trends in nutrient concentrations, increasing upstream, were evident for total kjeldahl nitrogen, chlorophyll-a, and biochemical oxygen demand (Fig. 14). Dissolved oxygen levels declined with distance upstream. Total phosphorus and inorganic nitrogen exhibited no trend and orthophosphorus was higher near the mouth.

It is interesting to note that dissolved silica concentrations deviated

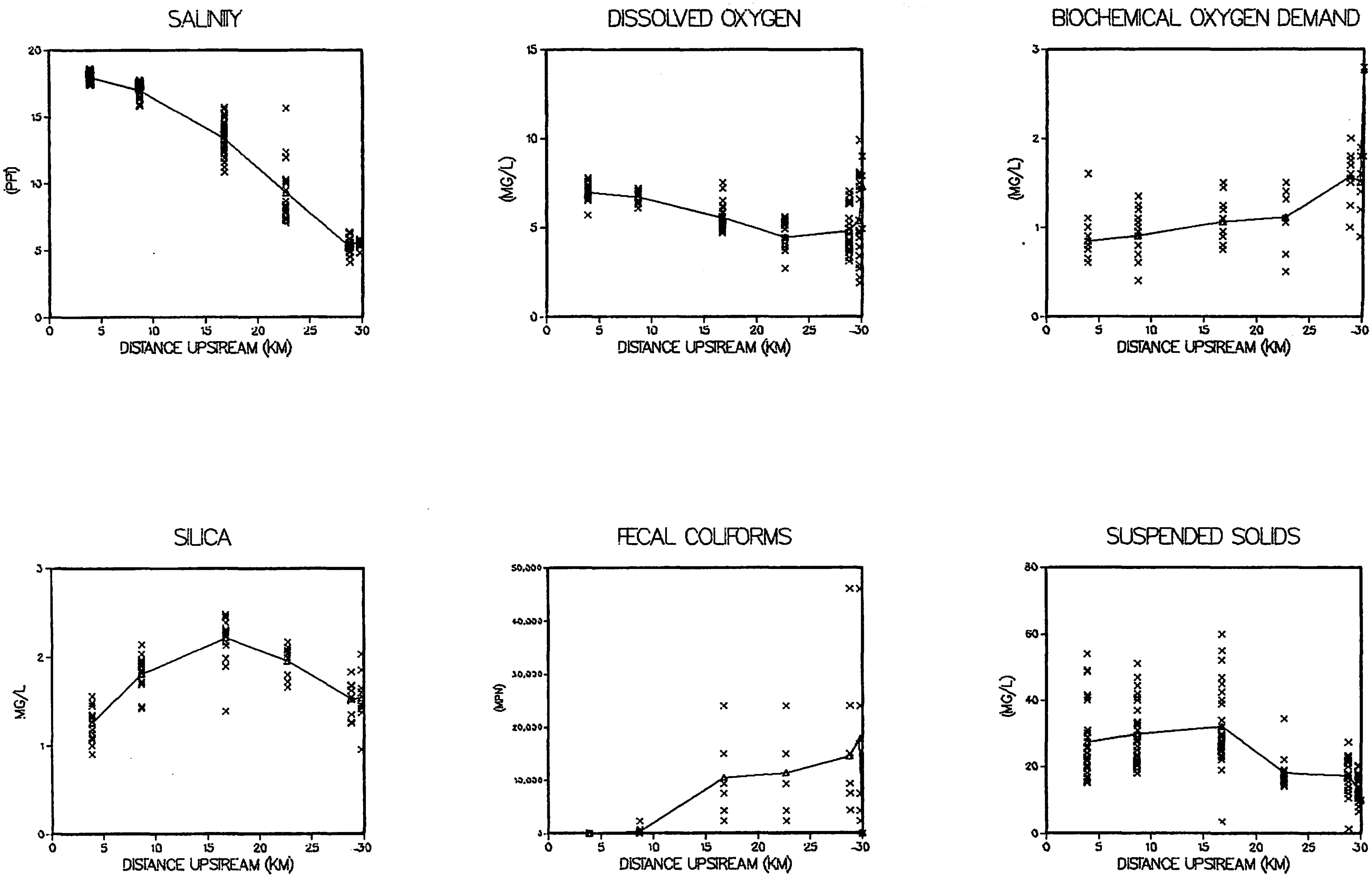


Figure 13a. Mean concentrations (Δ) and values (x) during the September 27-28, 1982 Intensive survey on the Nansemond River.

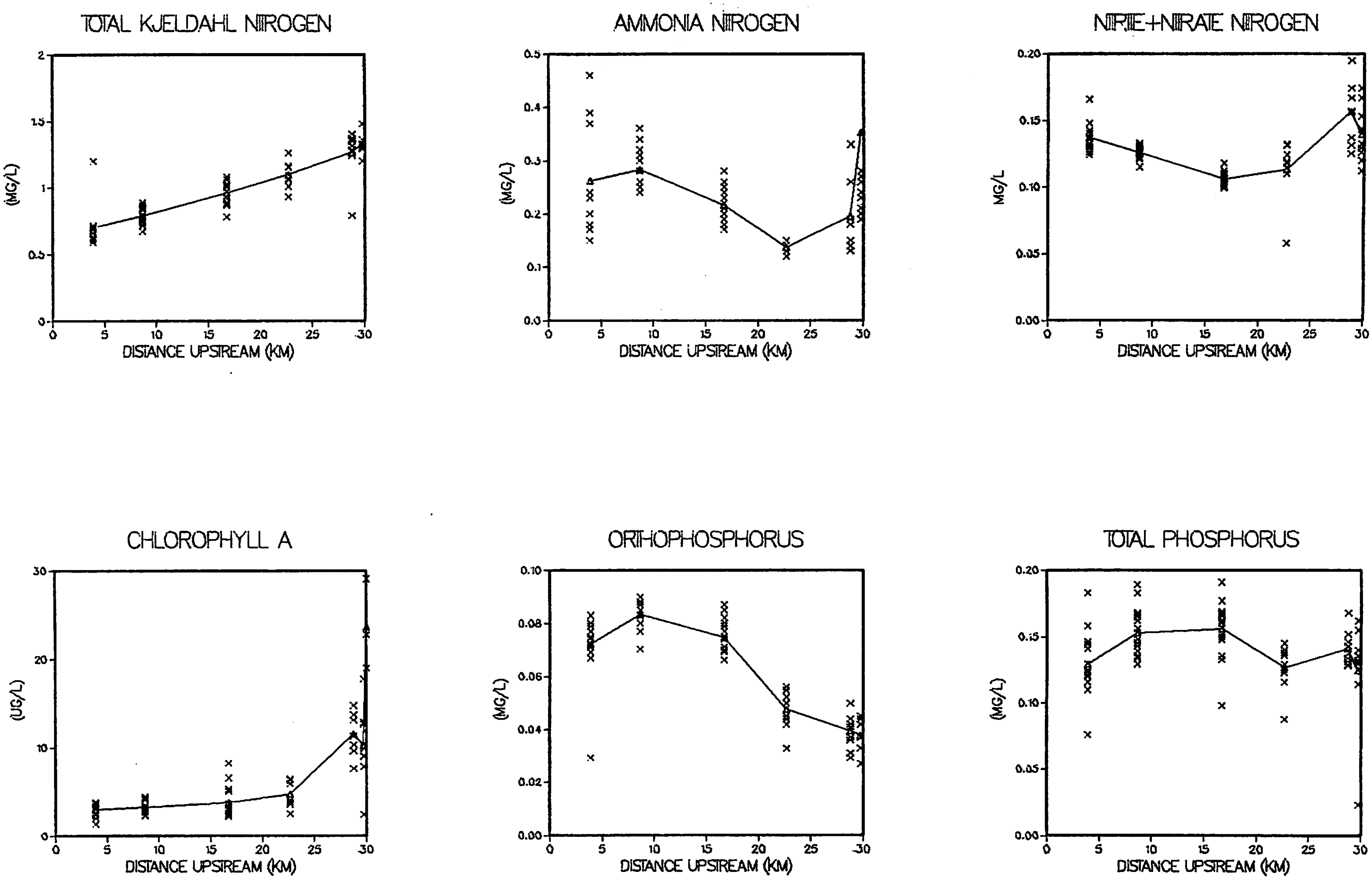


Figure 13b. Mean concentrations (Δ) and values (x) during the September 27-28, 1982 Intensive survey on the Nansemond River.

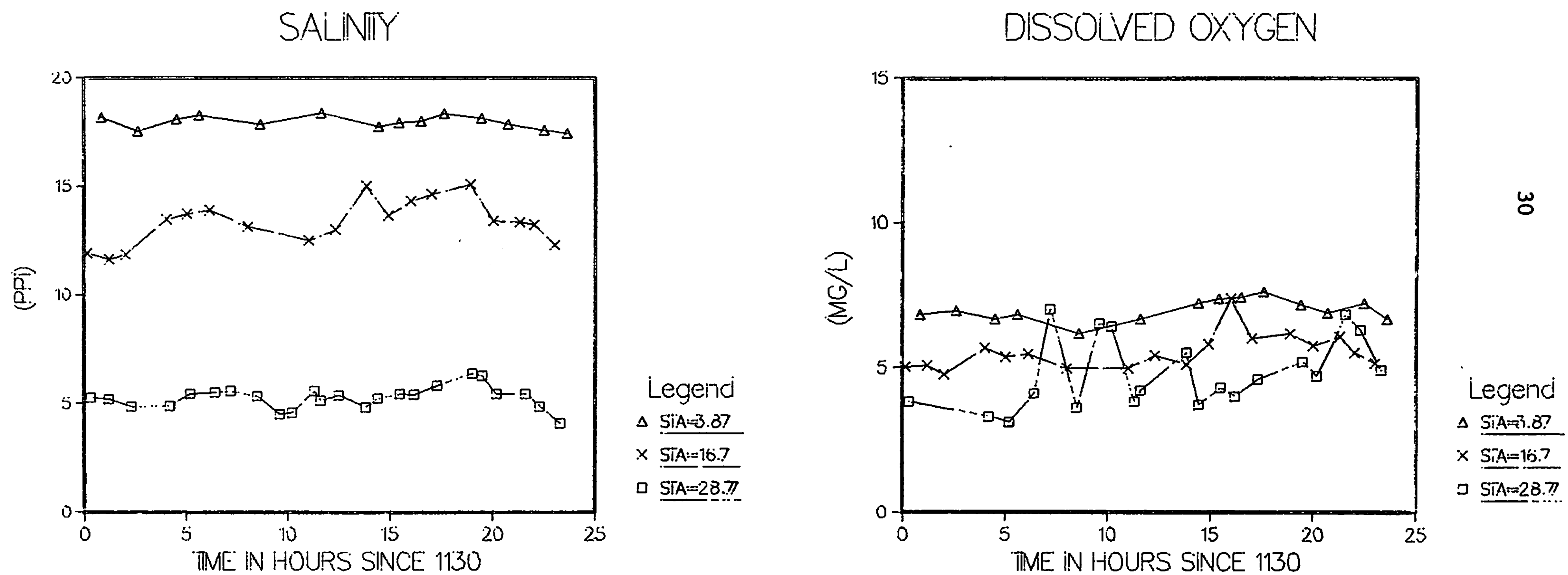


Figure 14a. Nansemond River mean concentrations at the downstream (3.87 km), mid-estuary (16.7 km), and upstream (28.77 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.

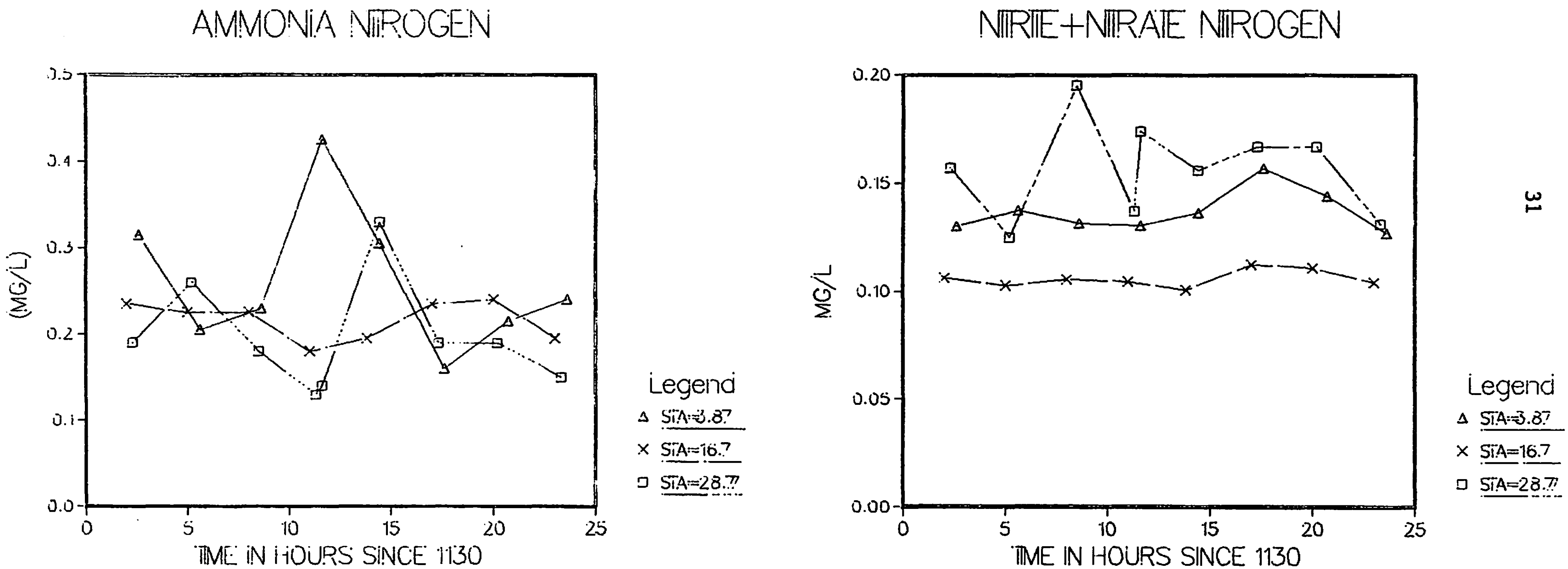


Figure 14b. Nansemond River mean concentrations at the downstream (3.87 km), mid-estuary (16.7 km), and upstream (28.77 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.

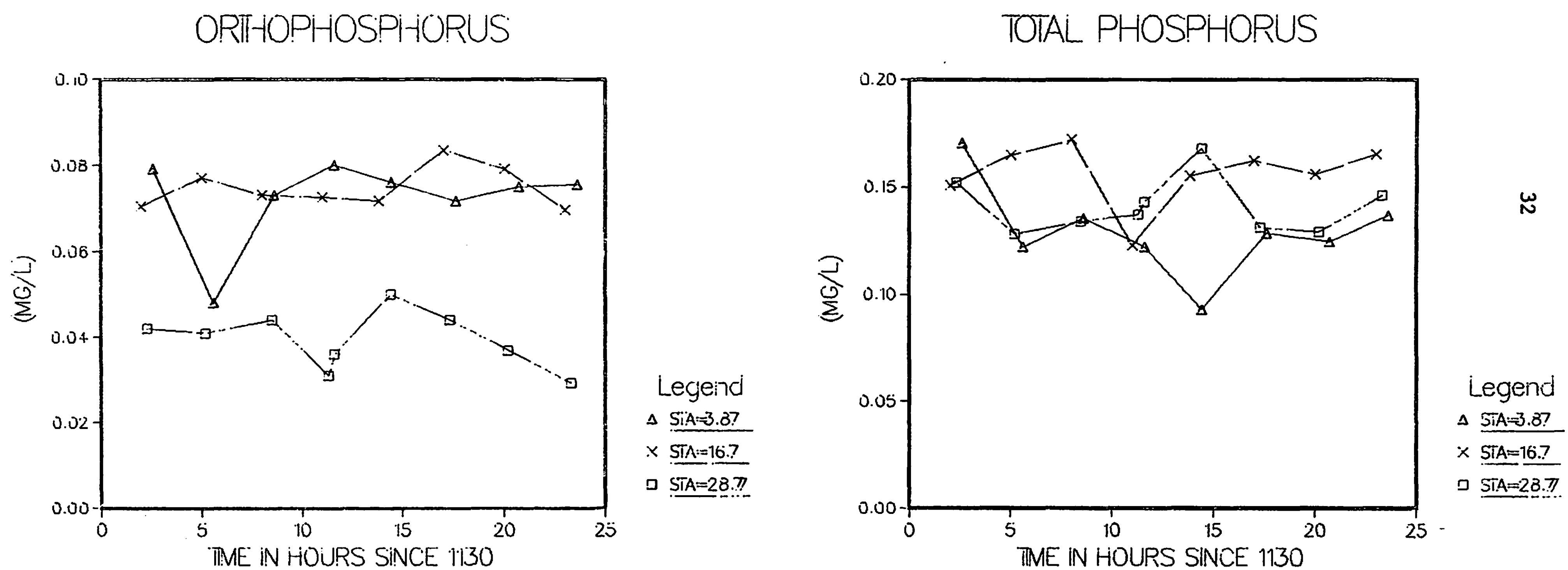
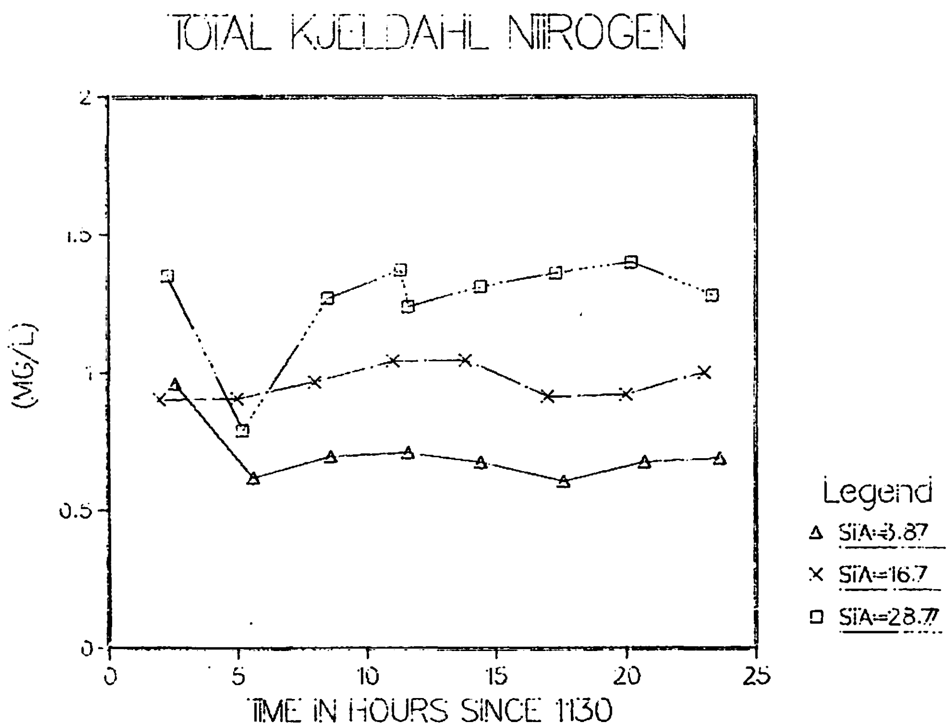


Figure 14c. Nansemond River mean concentrations at the downstream (3.87 km), mid-estuary (16.7 km), and upstream (28.77 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.



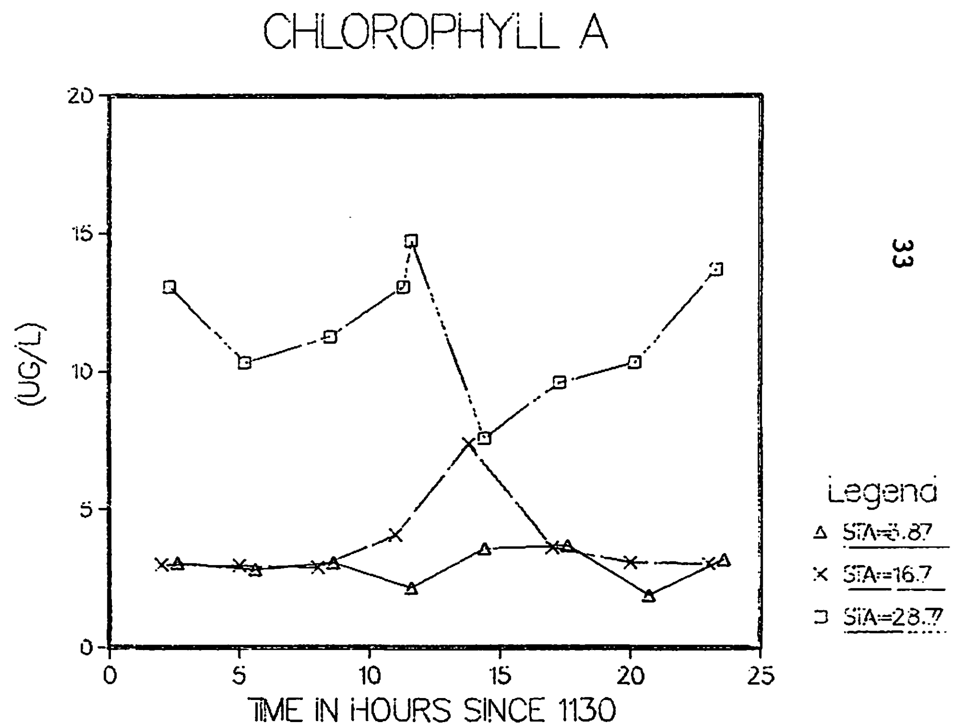


Figure 14d. Nansemond River mean concentrations at the downstream (3.87 km), mid-estuary (16.7 km), and upstream (28.77 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.

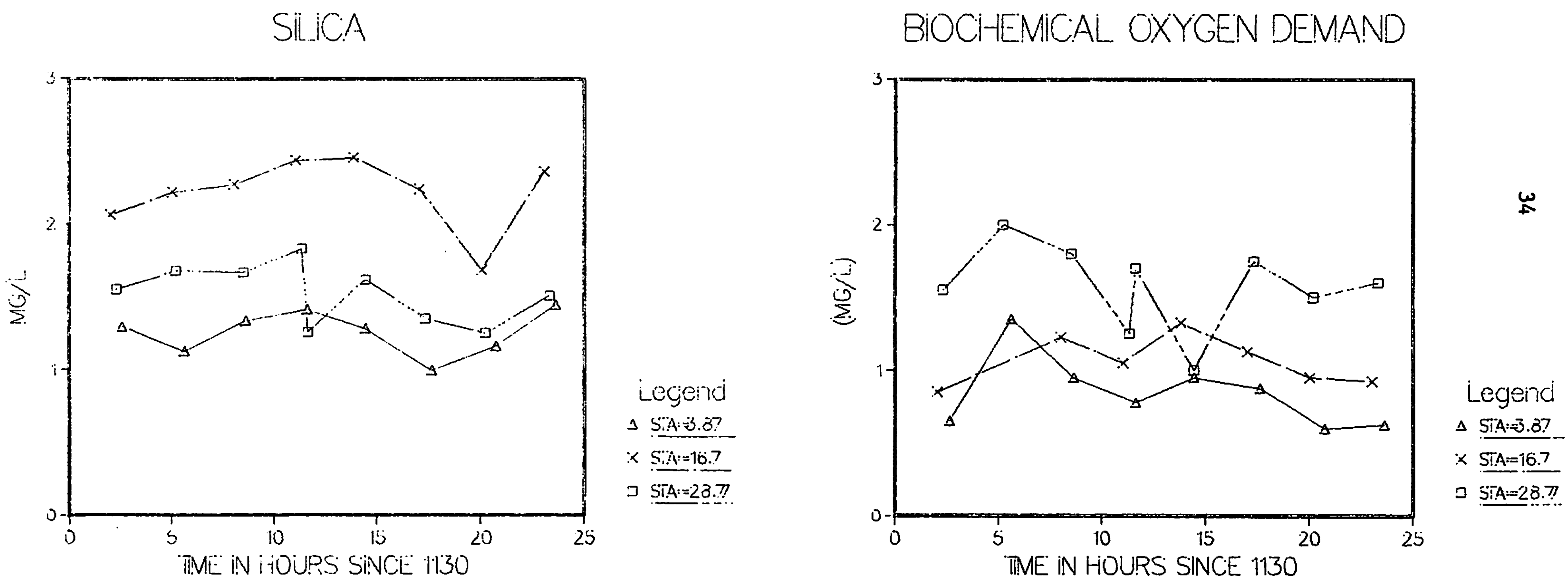


Figure 14e. Nansemond River mean concentrations at the downstream (3.87 km), mid-estuary (16.7 km), and upstream (28.77 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.

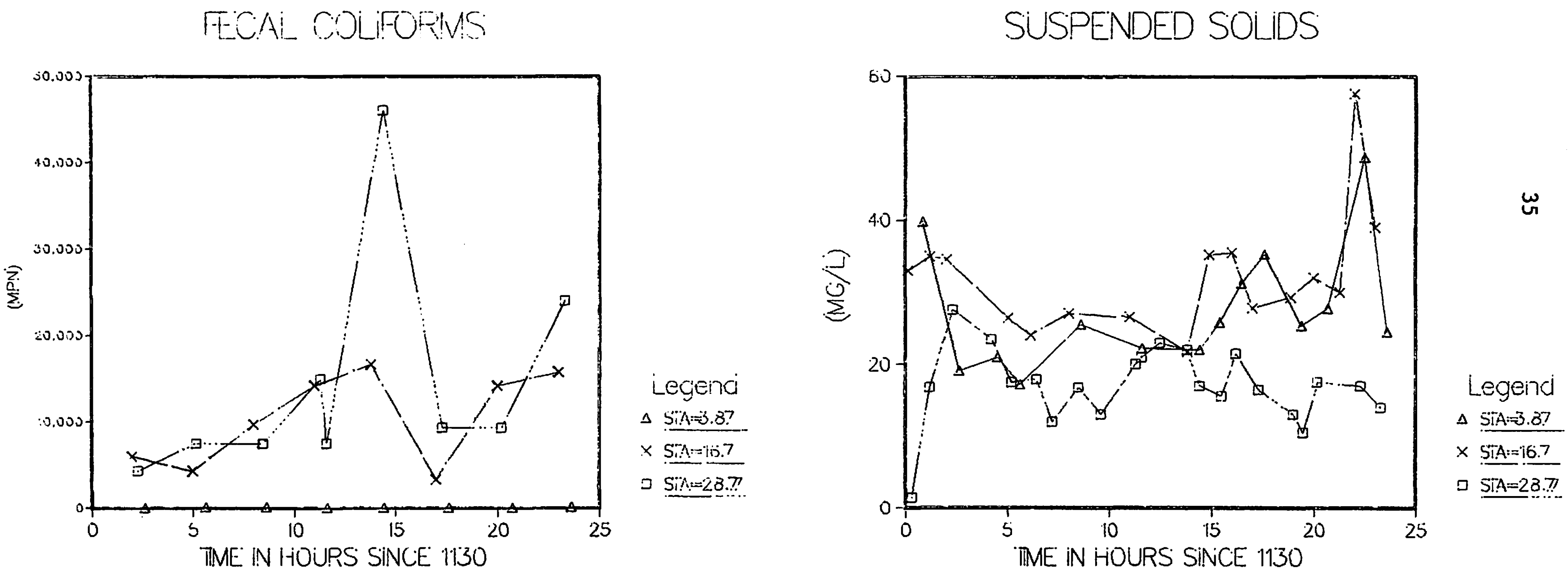


Figure 14f. Nansemond River mean concentrations at the downstream (3.87 km), mid-estuary (16.7 km), and upstream (28.77 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.

from the expected, semi-conservative pattern during both the intensive and slackwater surveys. Values were at a maximum in the mid-reach of the estuary (Fig 14), despite a longitudinal decrease in salinity. This pattern was not observed in the Chuckatuck estuary.

Tidal and diurnal influences for total kjeldahl nitrogen, ammonia nitrogen, orthophosphorus and total phosphorus were not evident. These nutrients fluctuated little throughout the period (Fig. 13). Chlorophyll-a exhibited a diurnal response at the upstream station only; levels at the mouth were fairly uniform. Upstream dissolved oxygen, biochemical oxygen demand and fecal coliform concentrations fluctuated, but the fluctuations appeared unrelated to tidal or solar influences.

During the intensive survey daily (composite) samples were collected from the Lake Meade spillover until the flow terminated three days later. Results indicated that nutrient concentrations were greatest during the first day of flow. Ammonia-nitrogen and total phosphorus concentrations of 0.35 and 0.16 mg/l respectively were measured, which was similar to concentrations present in the estuary adjacent to the dam. By the second day of spillover, ammonia-nitrogen and total phosphorus levels had dropped (Table 4). All nutrients were below detection limits on the third day, except for total phosphorus.

Also on the first day of spillover, the biochemical oxygen demand present in Lake Meade was twice as high as that present in the estuary. However, by the second day, the demand had dropped to comparable levels. Chlorophyll-a values were similarly high in the spillover (19 ug/l) when compared to the estuary (9 ug/l) as spillover commenced. Concentrations increased 65% in the following 2 days, to 29 ug/l.

Tidal influences alone can be assessed by comparing the Nov./Dec. 1982 pair of slackwater surveys (Fig. 7) and the March 1983 set (Fig. 4). All four surveys were conducted during wet weather conditions. Dissolved oxygen levels were lower at LWS than at HWS. Biochemical oxygen demand concentrations

Table 4. LAKE MEADE SPILLOVER ANALYSES

Date	Temp. °C	Dissolved Oxygen	Biochemical Oxygen Demand	Total Phosphorus	Ortho Phosphorus	Nitrite + Nitrate Nitrogen	Ammonia Nitrogen (dissolved)	Fecal Coliforms number/100 ml	Chlorophyll 'a' µg/1
		mg/1							
9/29/82	22.0	9.0	3.70	0.16	0.01	≤0.011	0.35	2.3×10^{1}	18.98
9/30/82	22.0	4.9	1.80	0.09	≤0.006	≤0.008	0.04	4.3×10^{1}	22.78
10/1/82	21.9	7.9	2.80	0.06	≤0.006	≤0.008	≤0.005	9.1×10^{0}	29.11

increased, especially in the upstream reach, during LWS. Nutrient levels tended to be greater at LWS than at HWS (Fig. 7).

Distinct responses to tidal influences were not strong in the Nansemond during the intensive survey. Dissolved oxygen and nutrient concentrations tended to fluctuate but these variations did not correspond to tidal or diurnal changes. Tidal effects during the survey may have been partially concealed by the newly introduced freshwater runoff. Also, mixing associated with the storm may have caused sediment and nutrients associated with those particles to become resuspended which would additionally cause variations not attributable to tides.

The impact of runoff also can be assessed through comparison of the May and July slackwater pairs (Figures 5 and 6 respectively). For the first pair, the initial survey occurred during dry weather but there was rainfall preceding the second survey. For the July surveys, that sequence was reversed.

Generally speaking oxygen levels were higher and BOD, nutrient, and fecal coliform levels were lower during dry weather. During the wet surveys, an oxygen sag with concentrations below 4.0 mg/l was observed in mid-estuary. Oxygen levels showed a slight increase at the two stations adjacent to the dam, perhaps due to spillover turbulence or high algae levels. However, overall oxygen levels declined and a large portion of the Nansemond failed to meet the minimum dissolved oxygen standard (4.0 mg/l). During dry periods, low dissolved oxygen occurred in the area stretching approximately 1 km downstream from the Lake Meade Dam.

Chlorophyll-a concentrations were generally between 5 and 15 ug/l, but were elevated in the upstream area especially following wet periods (Figs. 5-6). Concentrations of several nutrients (total kjeldahl nitrogen, ammonia nitrogen, total phosphorus and orthophosphorus) tended to decrease in the upstream (1 km) area following rainfall. Throughout the rest of the estuary, however, nutrient concentrations were seen to increase during wet weather periods.

Biochemical oxygen demand averaged 50% higher during wet periods than during dry surveys. This pattern was generally observed throughout the estuary (Figs. 5-6). Fecal coliform concentrations showed a distinct increase following rainfall and spillover at all stations 18 km or more from the mouth of the river.

SUMMARY

Water quality conditions in the Nansemond River show the seasonal variations typical of the region in response to the annual temperature cycle and rainfall and runoff patterns. Generally speaking the quality of the water is reasonably good throughout much of the river but conditions are less favorable at the most upstream reaches near Suffolk.

When present conditions are contrasted with those existing fifteen years earlier, one can note a marked improvement in water quality. Dissolved oxygen levels have increased either in absolute values or in terms of the percent of saturation levels. The degraded conditions previously mentioned were more severe and affected a larger portion of the river in the 1960's. Because the comparisons were made for surveys with comparable antecedent meteorological conditions, the observed changes are presumed to be due to reductions in point source loads. In other words, the river has responded to the diversion of wastewaters with generally improved water quality.

Data from the intensive survey and the slackwater surveys indicates that nonpoint source pollution remains a problem. It appears that the reservoirs trap pollutants since the quality of spillover water improves on the days following a storm. It has been mentioned previously that conditions in the most upriver reaches are often unsatisfactory. The causes for this situation are not known. However runoff from the urban developed area in and about

Suffolk is believed to be causing some of these problems. Although most of the large discharges to the river have been eliminated, some small ones still remain. Those point sources, plus any residual effects of prior conditions (for example, highly enriched sediments) also could be involved.

Overall, it can be stated that water quality in the Nansemond estuary was characterized by higher dissolved oxygen levels and lower nutrient fecal coliform and biochemical oxygen demand concentrations during dry periods. Dissolved oyxgen levels were seen to decline with a decrease in salinity. Runoff appeared to cause different responses in different parts of the river, depending on proximity to the spillover. Upstream, following runoff, a decrease in nutrient levels was detected in the area immediately adjacent to the reservoir, concomitant with an increase in oxygen levels. However, wet weather conditions tended to increase nutrient levels and decrease dissolved oxygen concentrations in an area extending 8 km further downstream. In that region, nutrient levels tended to increase and dissolved oxygen levels decreased appreciably relative to dry weather conditions.

III. WATER QUALITY IN CHUCKATUCK CREEK

The Hampton Roads Water Quality Agency contracted VIMS to collect data to document current water quality conditions in Chuckatuck Creek. In order to observe seasonal variations in water quality slackwater surveys were conducted 4 times during the year. Both low water slack (LWS) and high water slack (HWS) surveys were conducted each time. The annual ranges and variation in nutrient and bacteriological water quality are described below. Station locations are shown in Figure 15. The data from the May, July, November-December, 1982 and March 1983 slackwater surveys are plotted in Figures 16-19 respectively. In order to document both short term variations, specifically tidal and daily cycles, and runoff impacts, an intensive survey was conducted on September 27-28, 1982 following a rain event. The intensive survey data are presented in Figures 20 and 21.

SEASONAL VARIATIONS in WATER QUALITY

Observed water temperatures ranged from 11-28 C. Salinity values fluctuated between 14-19 ppt at the mouth of the estuary and between 6-16 ppt upstream. The greater variation at the upstream location shows the increased sensitivity of the headwaters to runoff.

Chlorophyll-a, organic nitrogen and organic phosphorus concentrations were highest during the summer survey and lowest in the winter. Nitrogen and phosphorus are "building block" materials of phytoplankton; it would be expected that these parameters would correlate reasonably well. The seasonal variation was most pronounced upstream. For example, chlorophyll-a concentrations varied between 2-9 ug/l downstream but between 4-17 ug/l upstream.

Orthophosphorus and total phosphorus concentrations were similarly greatest during the summer months. Levels of nitrogen species varied significantly, both seasonally and between the two surveys of the four

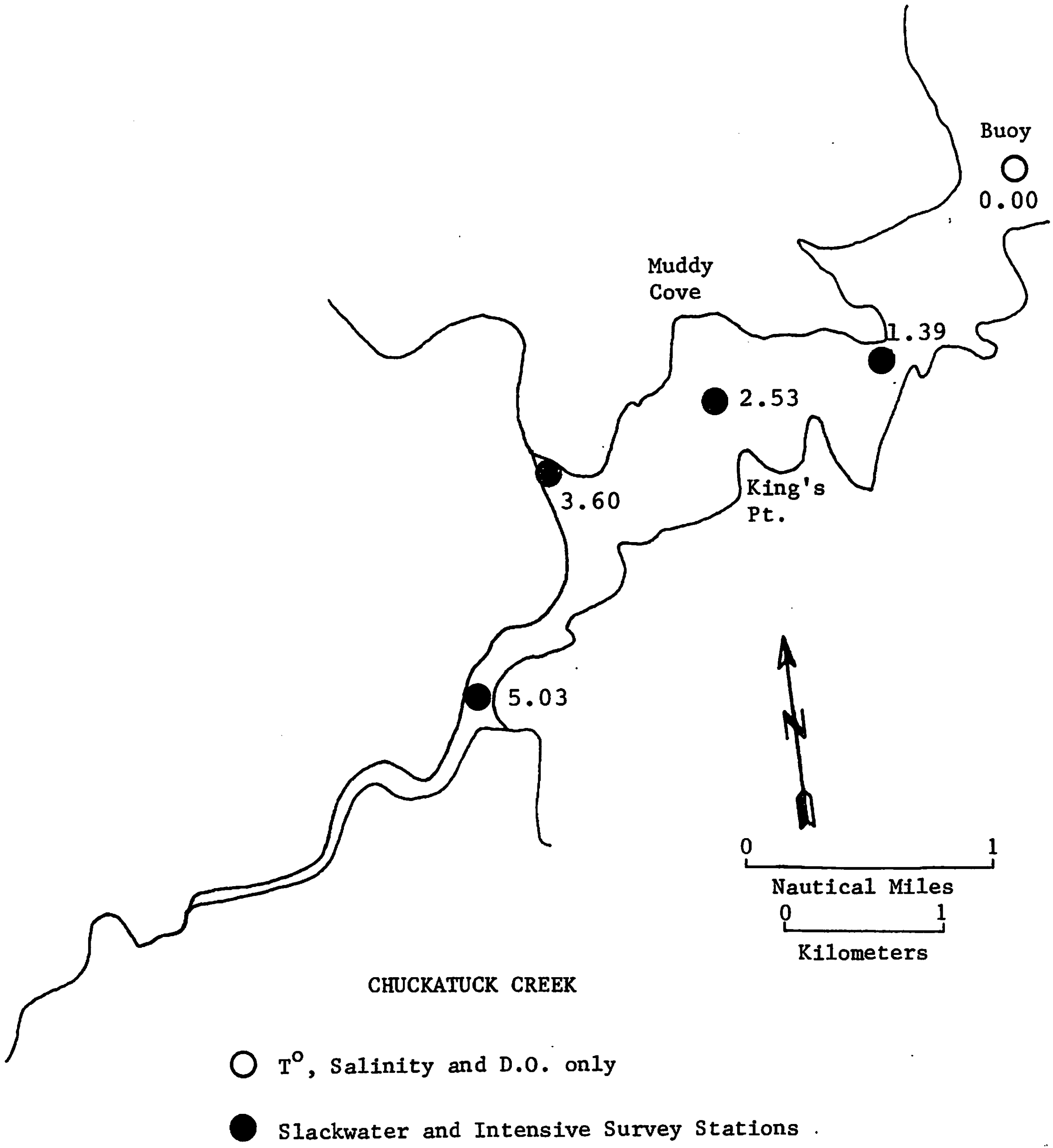


Figure 15. Station locations in Chuckatuck Creek (by kilometers).

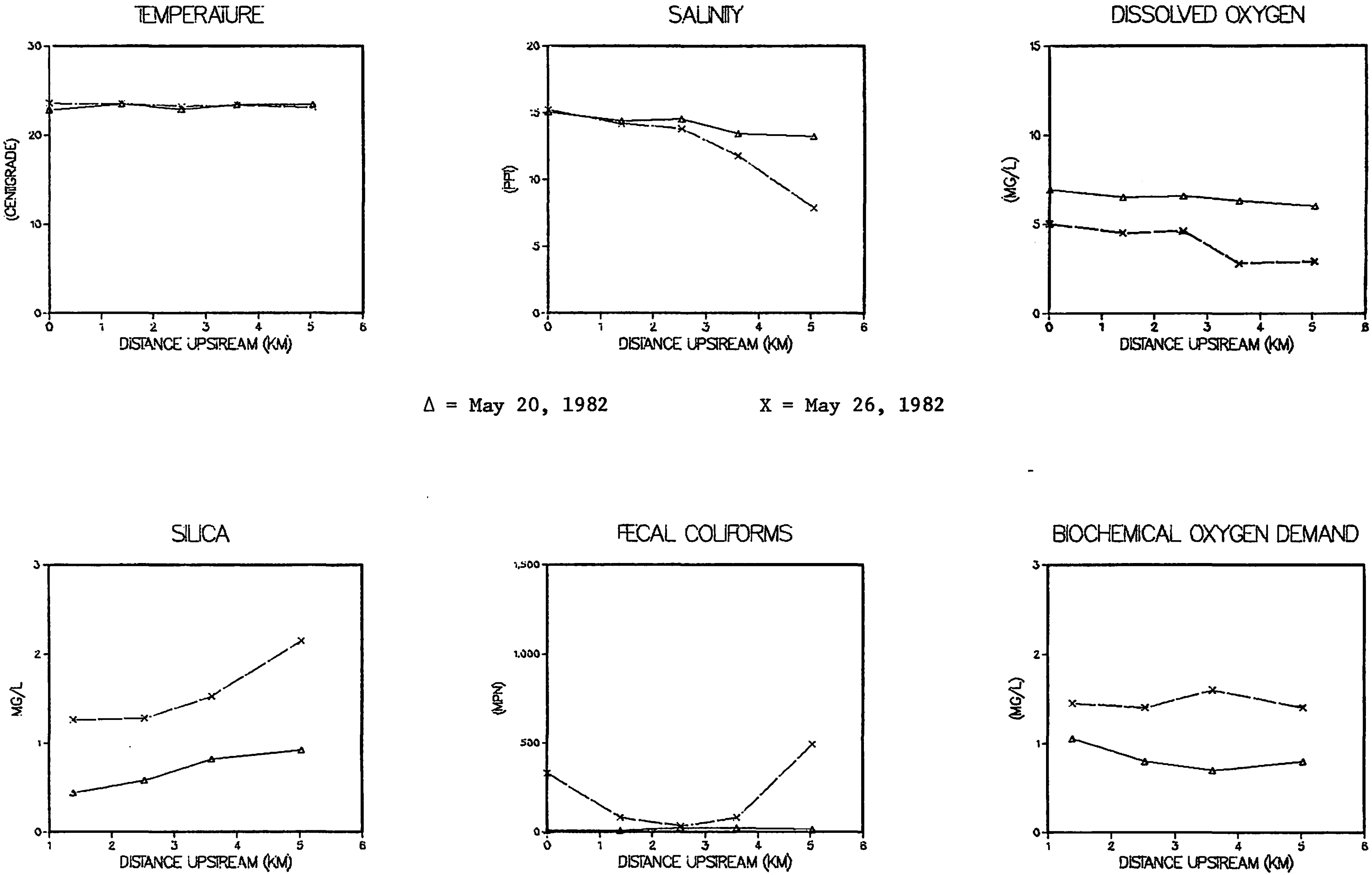


Figure 16a. May 20, 1982 high slackwater (Δ) and May 26, 1982 low slackwater (X) surveys in Chuckatuck Creek. The first survey was conducted under "dry" conditions, the latter under "wet" conditions.

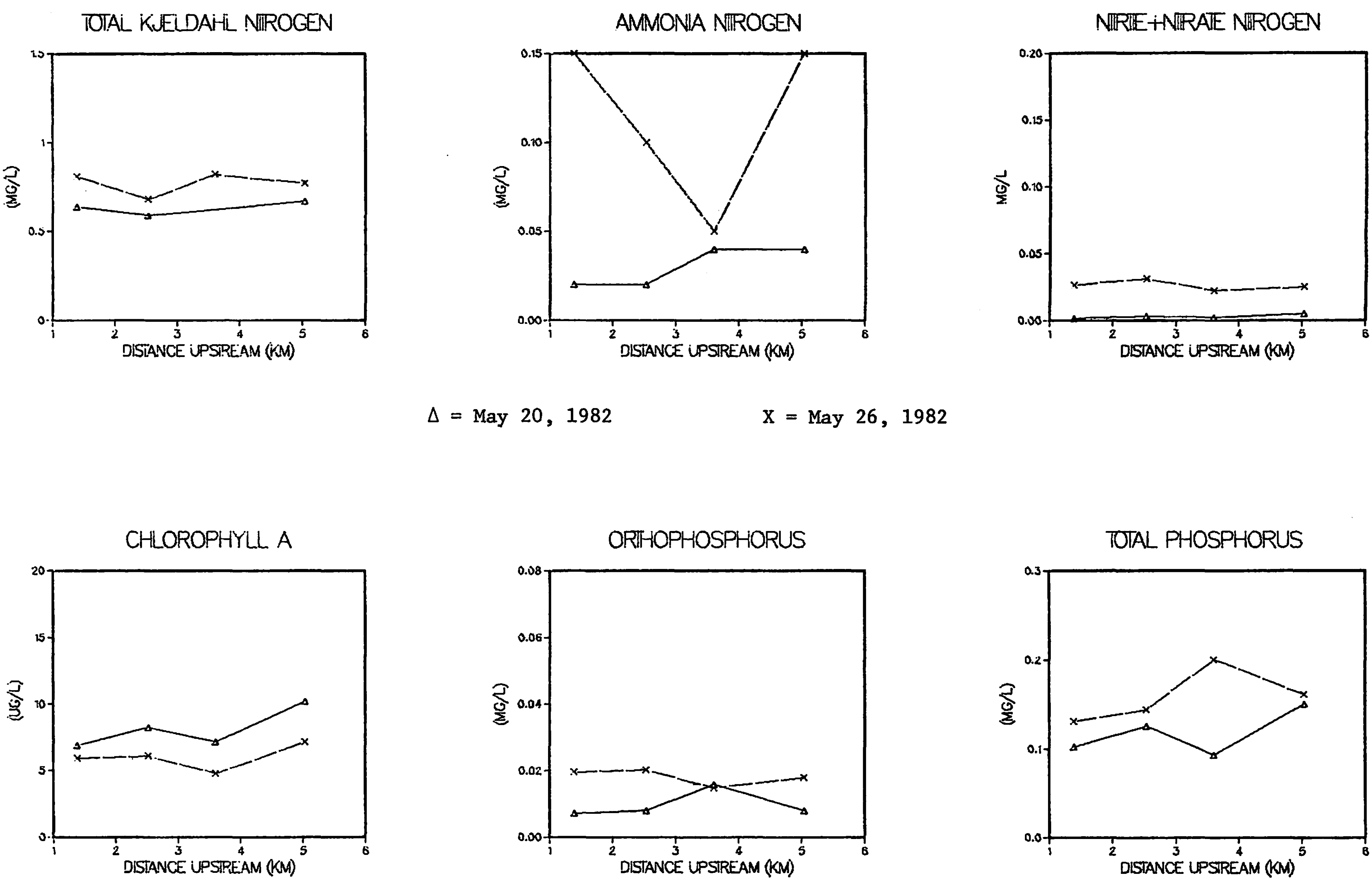


Figure 16b. May 20, 1982 high slackwater (Δ) and May 26, 1982 low slackwater (X) surveys in Chuckatuck Creek. The first survey was conducted under "dry" conditions, the latter under "wet" conditions.

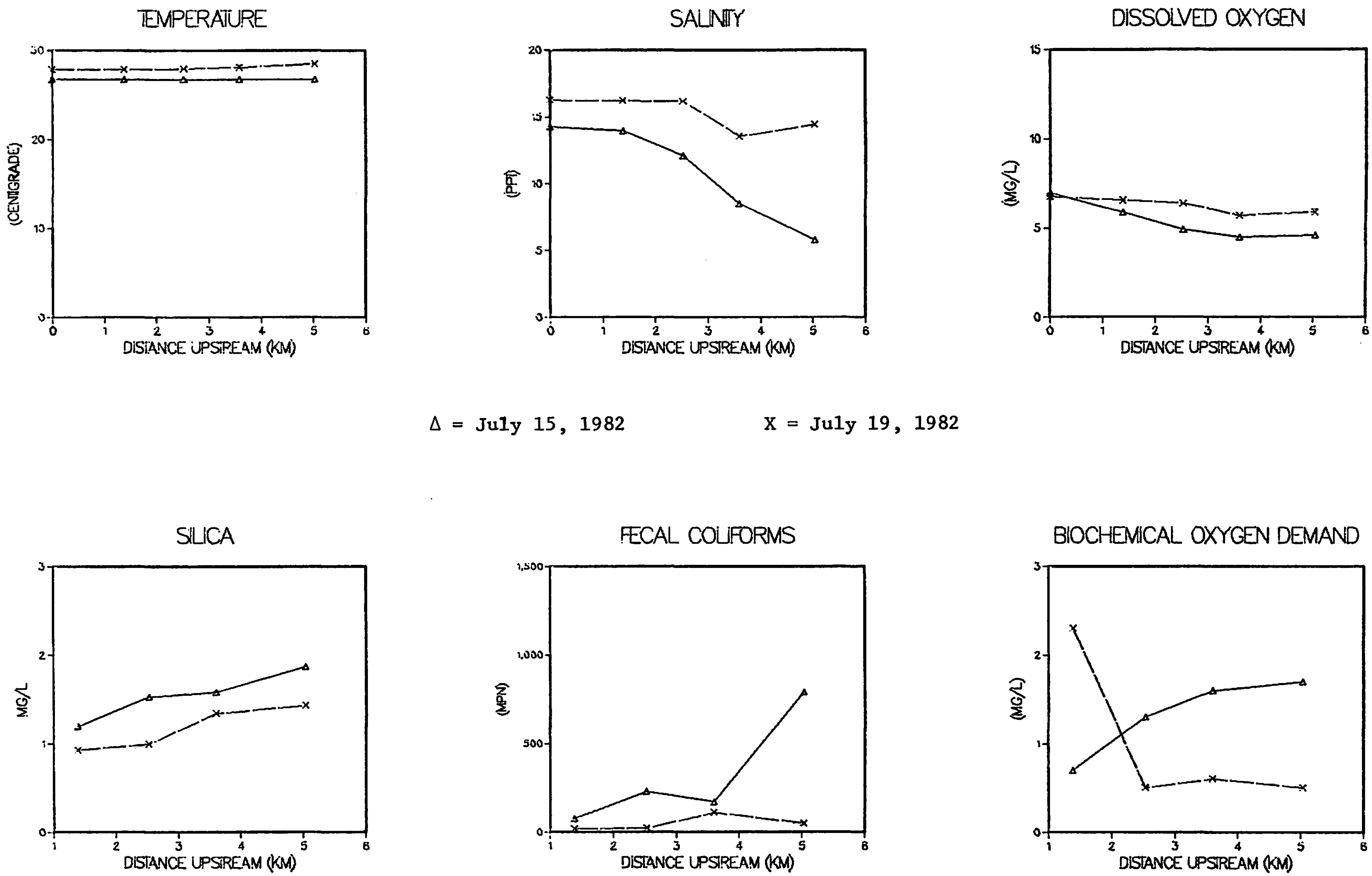


Figure 17a. July 15, 1982 low slackwater (Δ) and July 19, 1982 high slackwater (X) surveys in Chuckatuck Creek. The first survey was conducted under "wet" conditions, the latter under "dry" conditions.

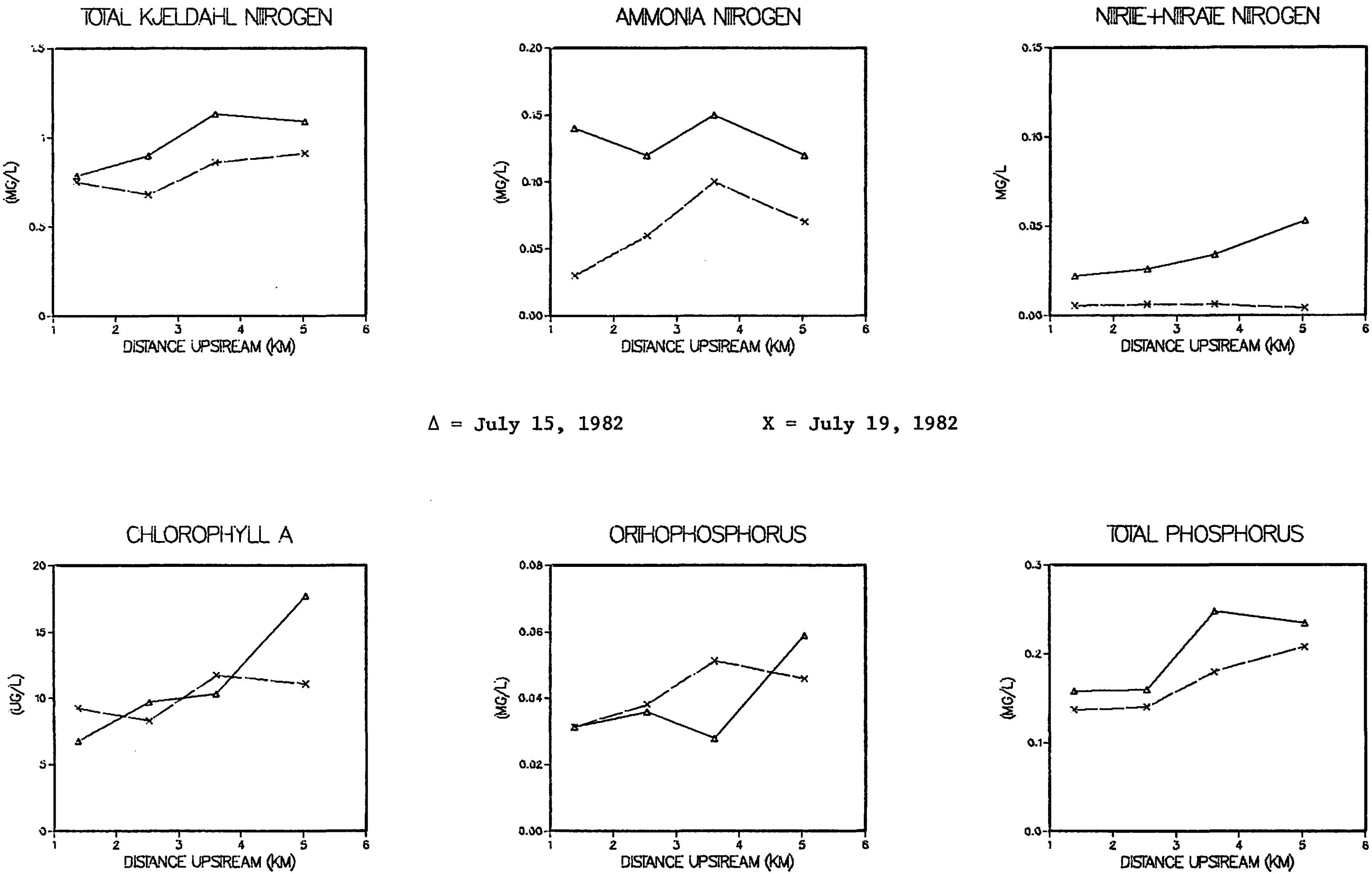


Figure 17b. July 15, 1982 low slackwater (Δ) and July 19, 1982 high slackwater (X) surveys in Chuckatuck Creek. The first survey was conducted under "wet" conditions, the latter under "dry" conditions.

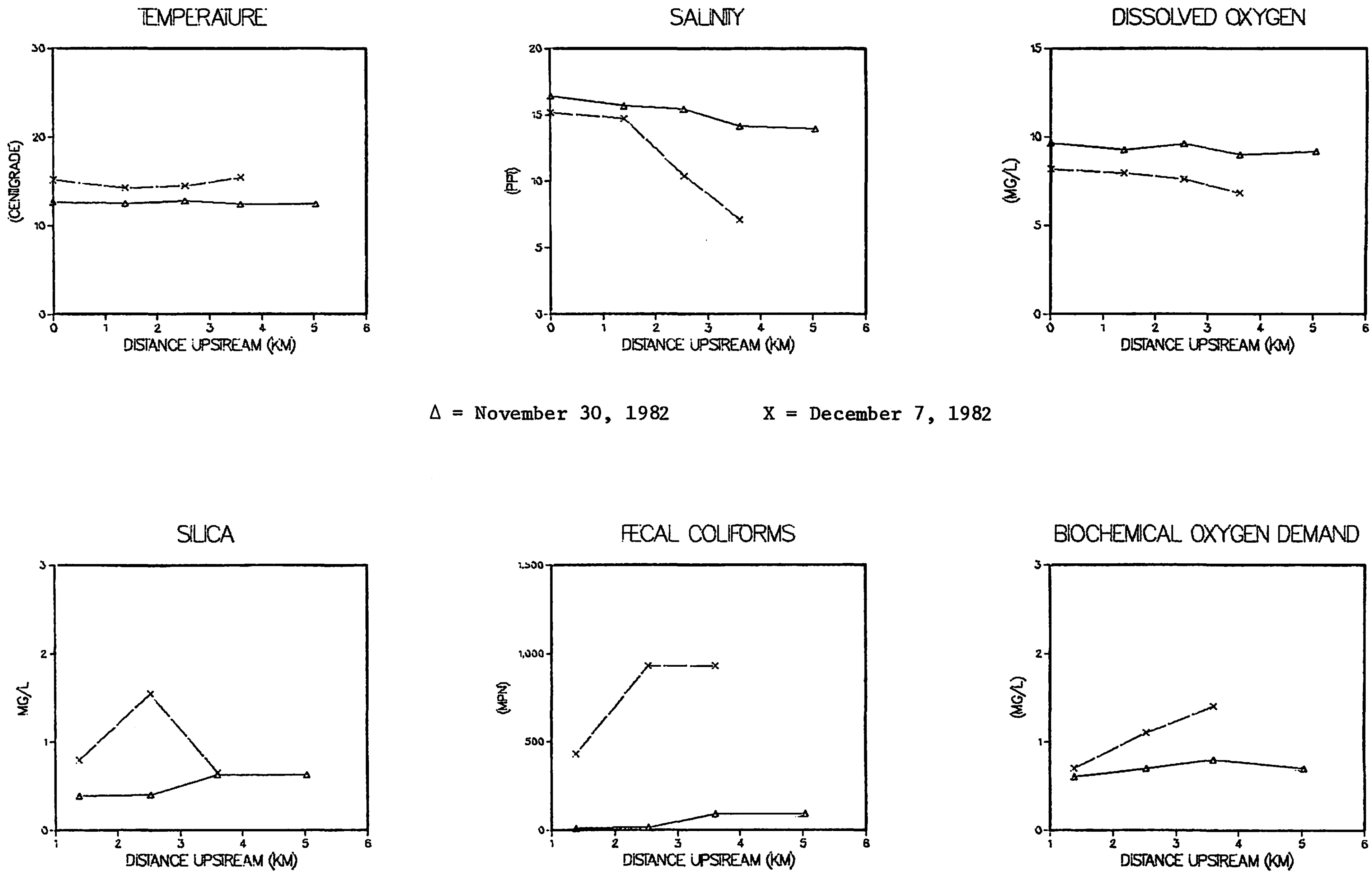
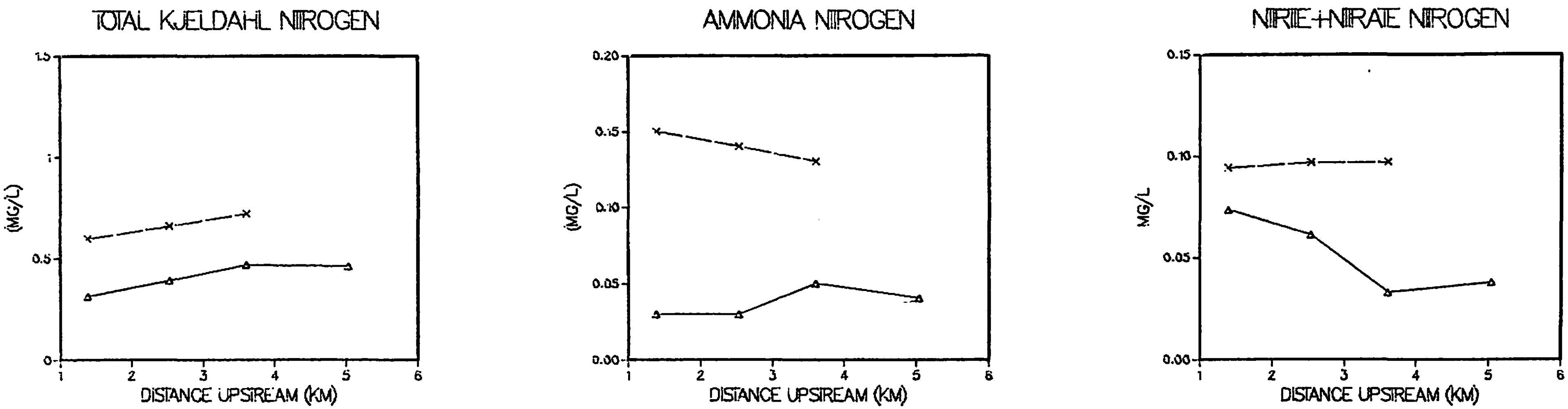


Figure 18a. November 30, 1982 high slackwater (Δ) and December 7, 1982 low slackwater (X) surveys in Chuckatuck Creek.



Δ = November 30, 1982 X = December 7, 1982

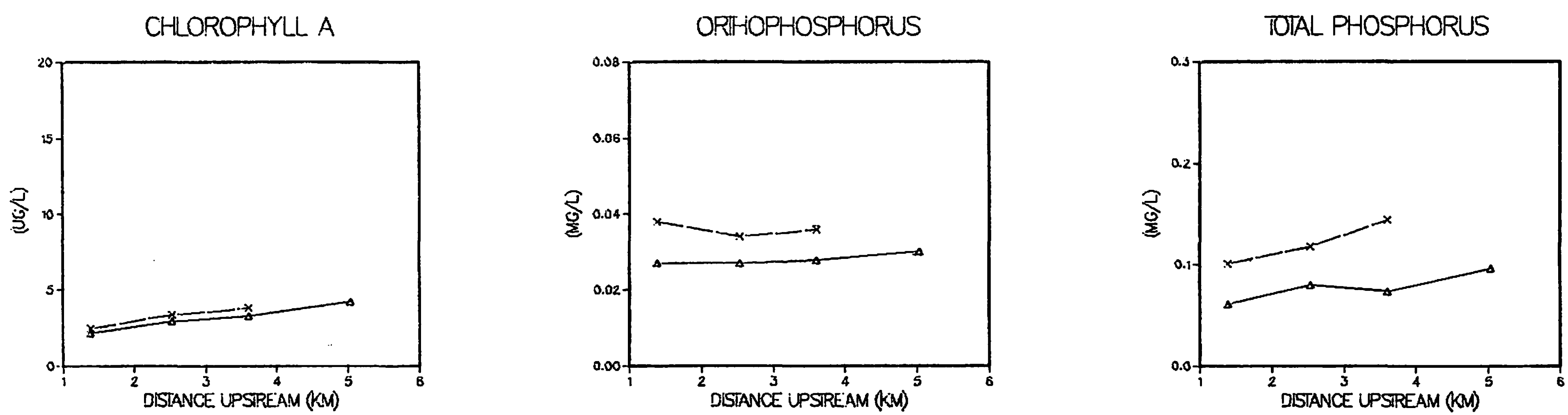


Figure 18b. November 30, 1983 high slackwater (Δ) and December 7, 1983 low slackwater (X) surveys in Chuckatuck Creek.

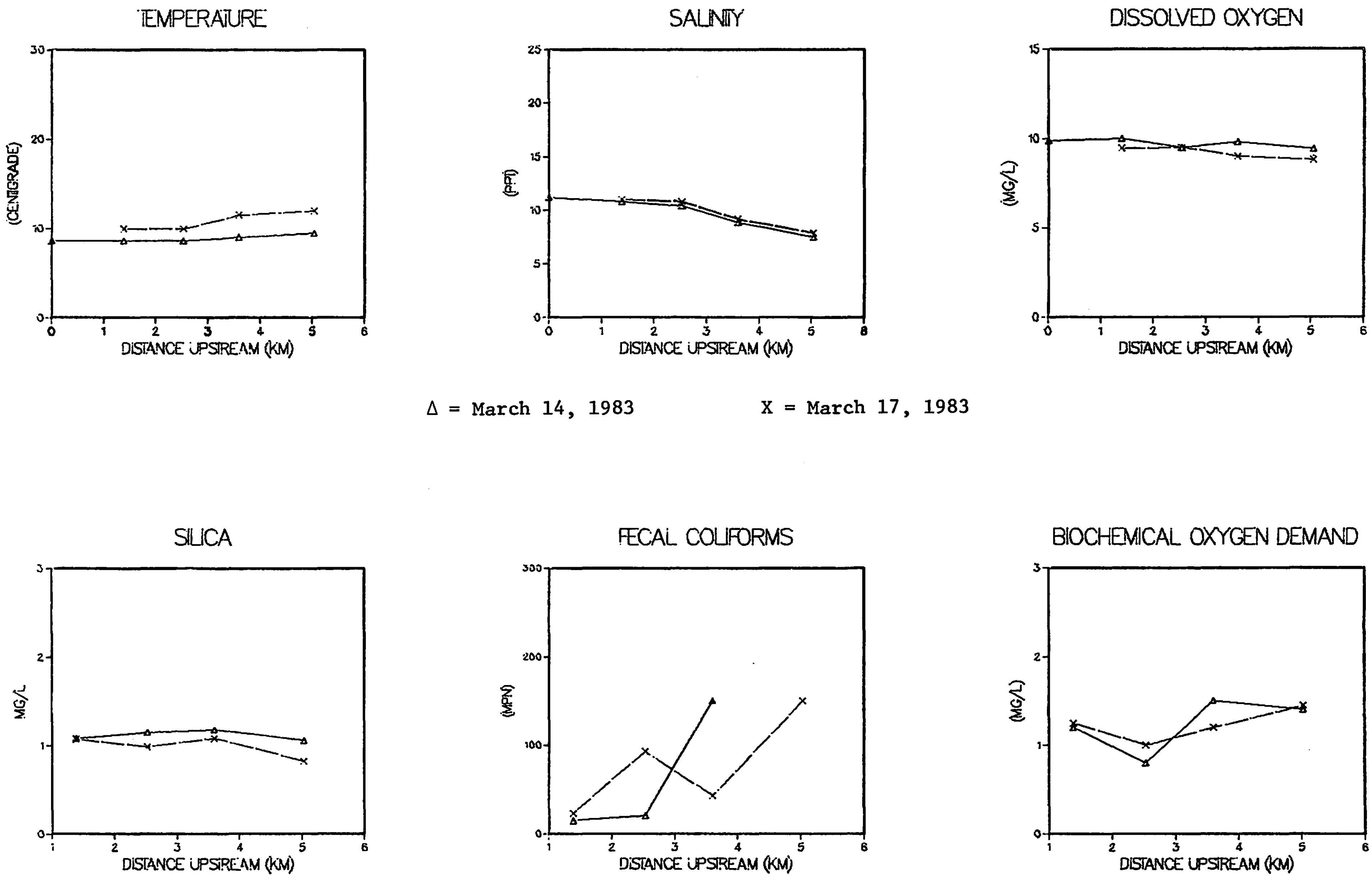


Figure 19a. March 14, 1983 high slackwater (Δ) and March 17, 1983 low slackwater (X) surveys in Chuckatuck Creek.

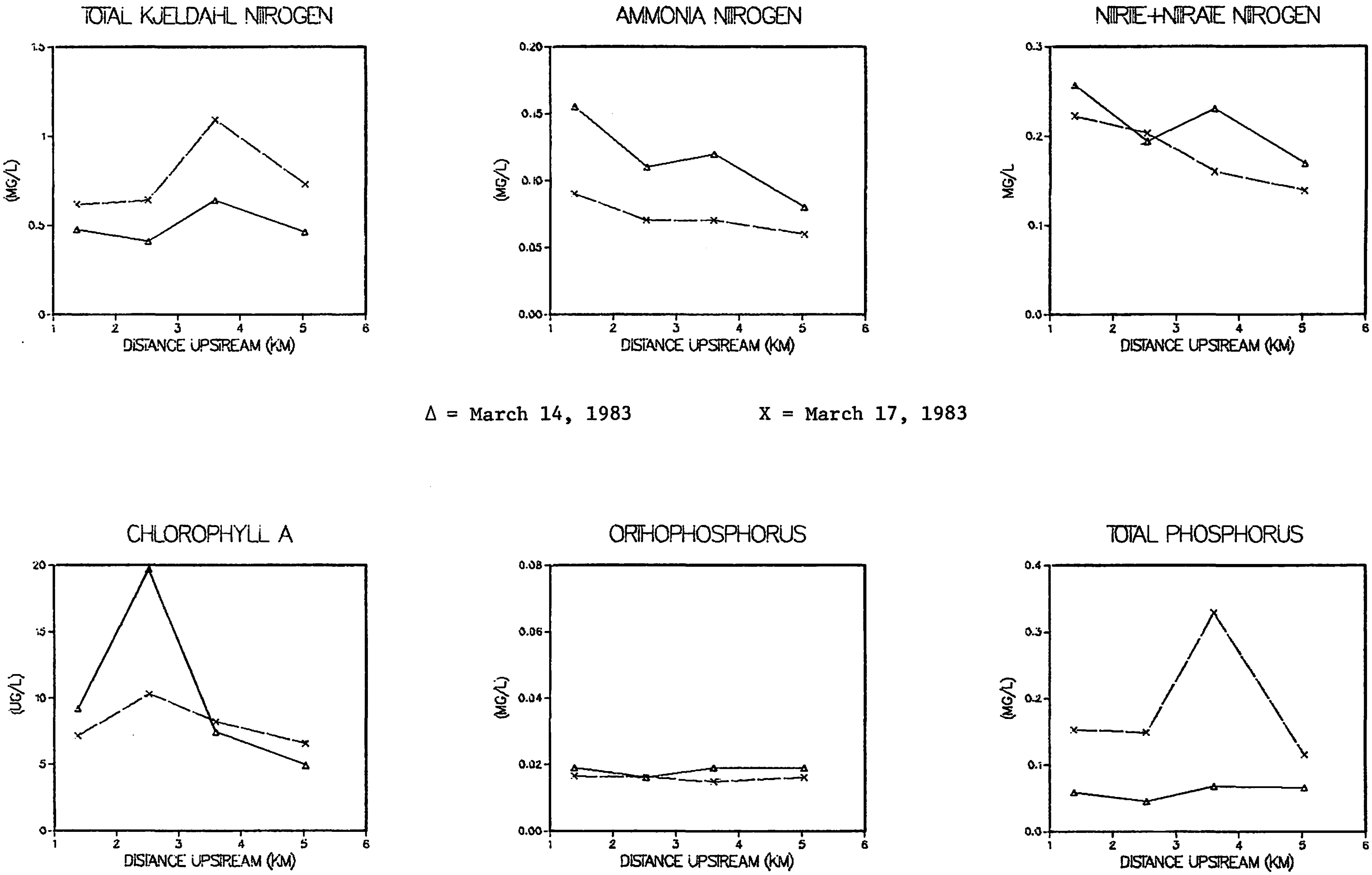


Figure 19b. March 14, 1983 high slackwater (Δ) and March 17, 1983 low slackwater (X) surveys in Chuckatuck Creek.

pairs. Nitrite- plus nitrate-nitrogen, which is generally associated with runoff, was 5 times higher in the wet spring survey in March 1983 than at other times of the year. Downstream levels were higher than upstream values, suggesting that Hampton Roads was a source of some of the nitrite-nitrate observed then in Chuckatuck Creek.

A distinct temperature dependent annual variation in dissolved oxygen levels was also observed. Oxygen saturation values were lowest in May and July (82 and 83%) and highest during the March survey (103%). In addition to temperature, this trend may also be a result of the seasonal nutrient variations. As water temperatures increase, the saturation values for oxygen in water decrease and the biological rate of decay of organic matter increases. The decreased potential for reaeration and increased consumption of dissolved oxygen results in lower oxygen levels.

Biochemical oxygen demand in the Chuckatuck was low and did not fluctuate discernably throughout the year. Values averaged less than 2 mg/l at all sample stations. Fecal coliform levels were always highest upstream, with values generally greatest at low water slack.

DAILY VARIATIONS IN WATER QUALITY

The intensive survey, conducted on the Chuckatuck Creek on September 27-28, 1982, followed a heavy (6 cm or 2.38 inch) rain event. Warm water conditions (20-25 C) prevailed throughout the estuary. Fecal coliform, dissolved oxygen, biochemical oxygen demand and nutrient samples (total Kjeldahl nitrogen, ammonia nitrogen, nitrite- plus nitrate-nitrogen, orthophosphorus, total phosphorus and silica) were collected at 4 stations in the estuary (Fig. 15).

Chuckatuck Creek is a short, mesohaline (moderate salinity, roughly half that of sea water) estuary. During the intensive survey, salinities ranged from about 18 ppt at the river mouth to 14 ppt five km upstream. The amplitudes of the tidal variation in salinity increased upstream, and ranged from a 6 ppt upstream to only a 1.5 ppt variation downstream (Fig. 21).

Temporal variations in dissolved oxygen, throughout the estuary, were about 4 mg/l during the 24 hour period. Oxygen levels decreased slightly with distance upstream (Fig. 20). Maximum concentrations appeared to be associated with HWS at all stations, but the late afternoon HWS was characterized by higher DO's. During the sampling period, oxygen levels dropped below 4 mg/l occasionally at the two upstream stations at times of LWS.

Chlorophyll-a values were on the low end of the range normally found in estuarine waters and considerably below values associated with nutrient enriched conditions. The highest observed value (10 ug/l) occurred downstream, however mean concentrations were homogeneous throughout the estuary (Fig. 20). Distinct solar or tidal influences upon chlorophyll concentrations were not evident (Fig. 21).

Average nitrite- plus nitrate-nitrogen levels were two times higher downstream (Fig. 20). Maximum values occurred near HWS. Both of these features indicate that nitrite- nitrate is being imported from Hampton Roads. Biochemical oxygen demand, as well as dissolved silica concentrations, increased with distance upstream. The remainder of the nutrients were fairly evenly distributed in the estuary, and showed neither a strong tidal nor a diurnal response during the survey.

Tidal influences alone can be analyzed by comparing data from the Nov. 30/Dec. 7, 1982 and March 14/17, 1983 slackwater sets. All four surveys were conducted during wet weather conditions. These data suggest that at a given temperature and under similar meteorological conditions, nutrient levels are generally greater at low water slack; higher dissolved oxygen levels occur at high water slack.

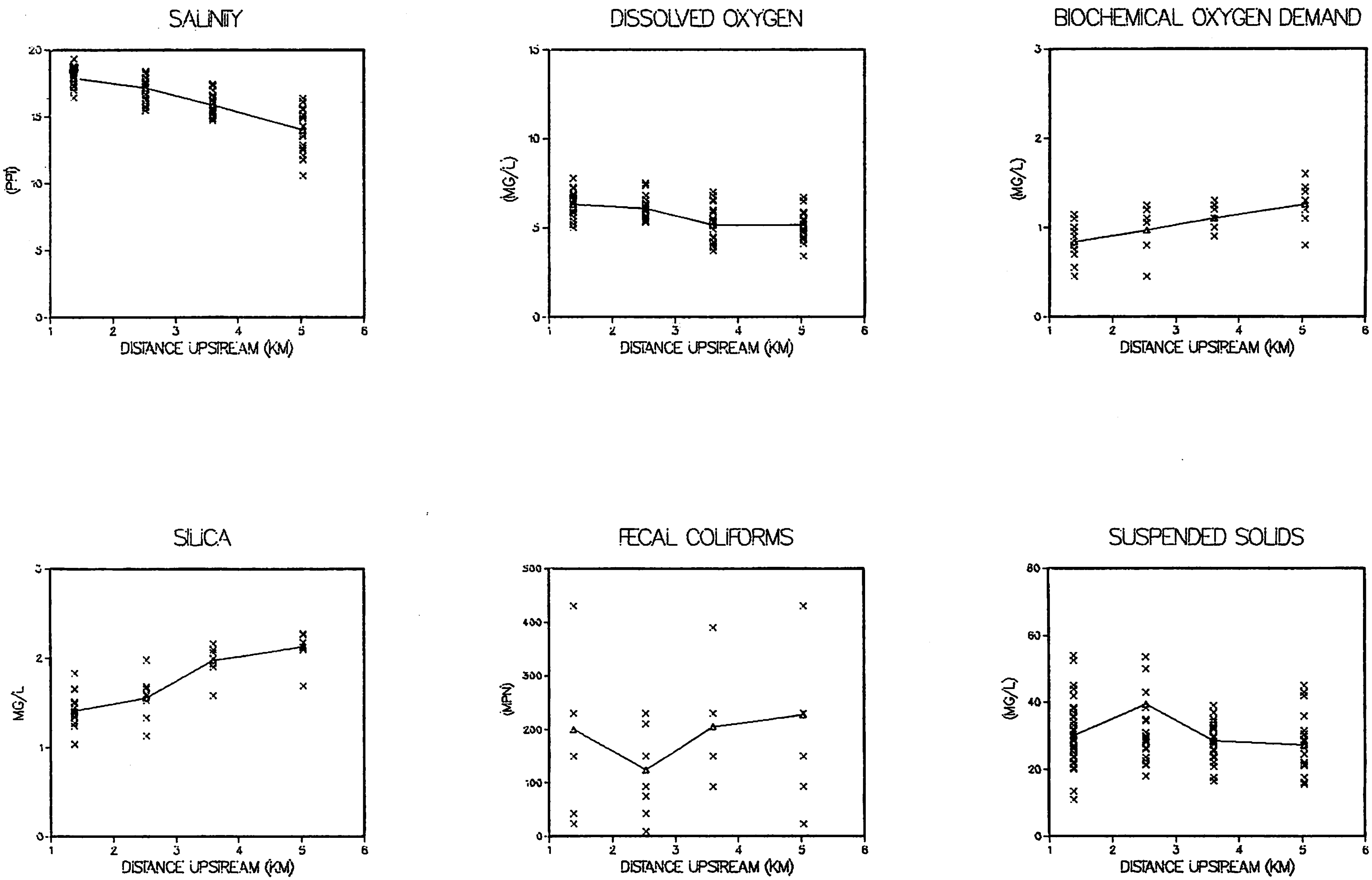


Figure 20a. Mean concentrations (Δ) and values (x) during the September 27-28, 1982 Intensive survey on Chuckatuck Creek.

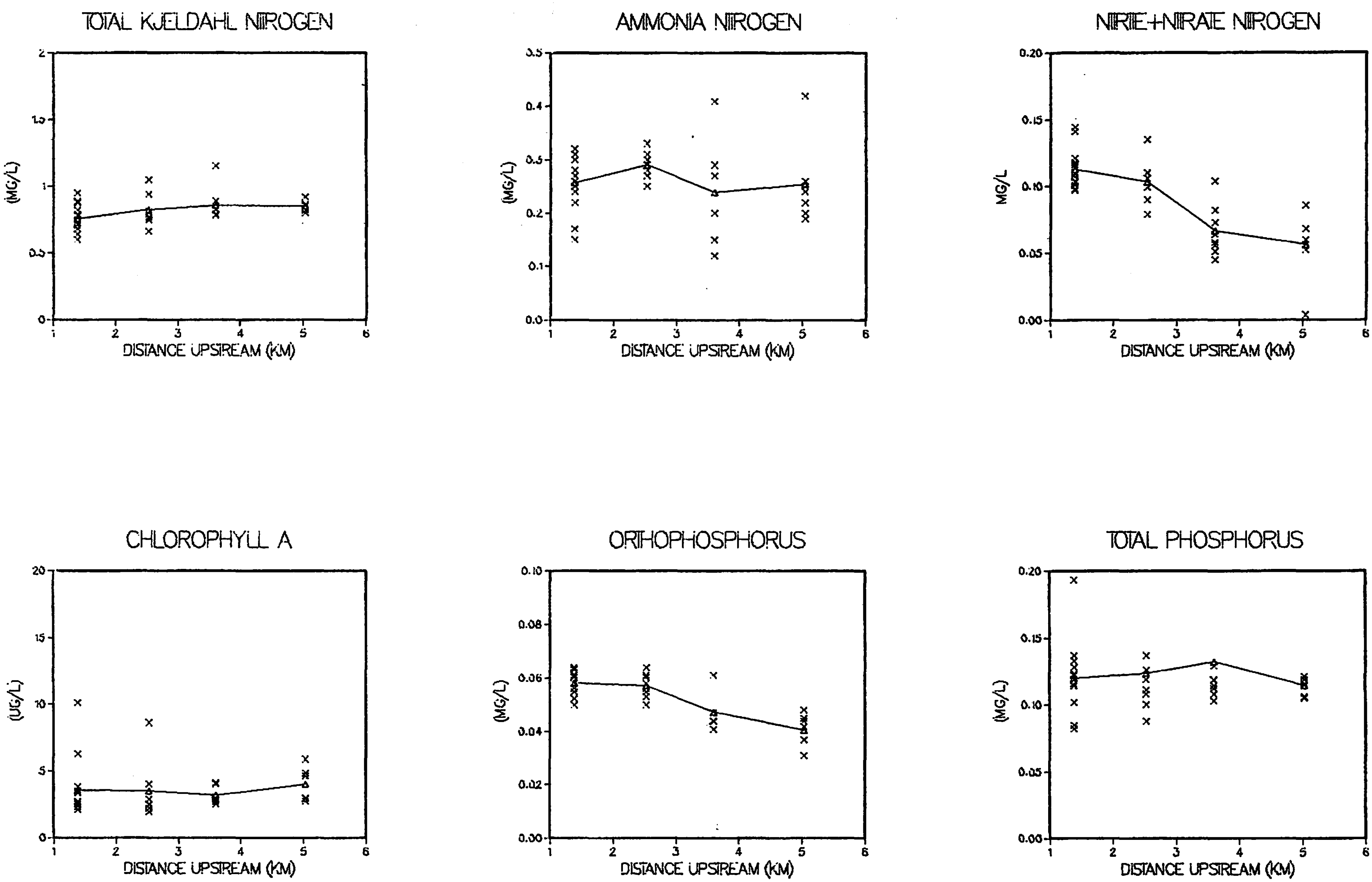


Figure 20b. Mean concentrations (Δ) and values (x) during the September 27-28, 1982 Intensive survey on Chuckatuck Creek.

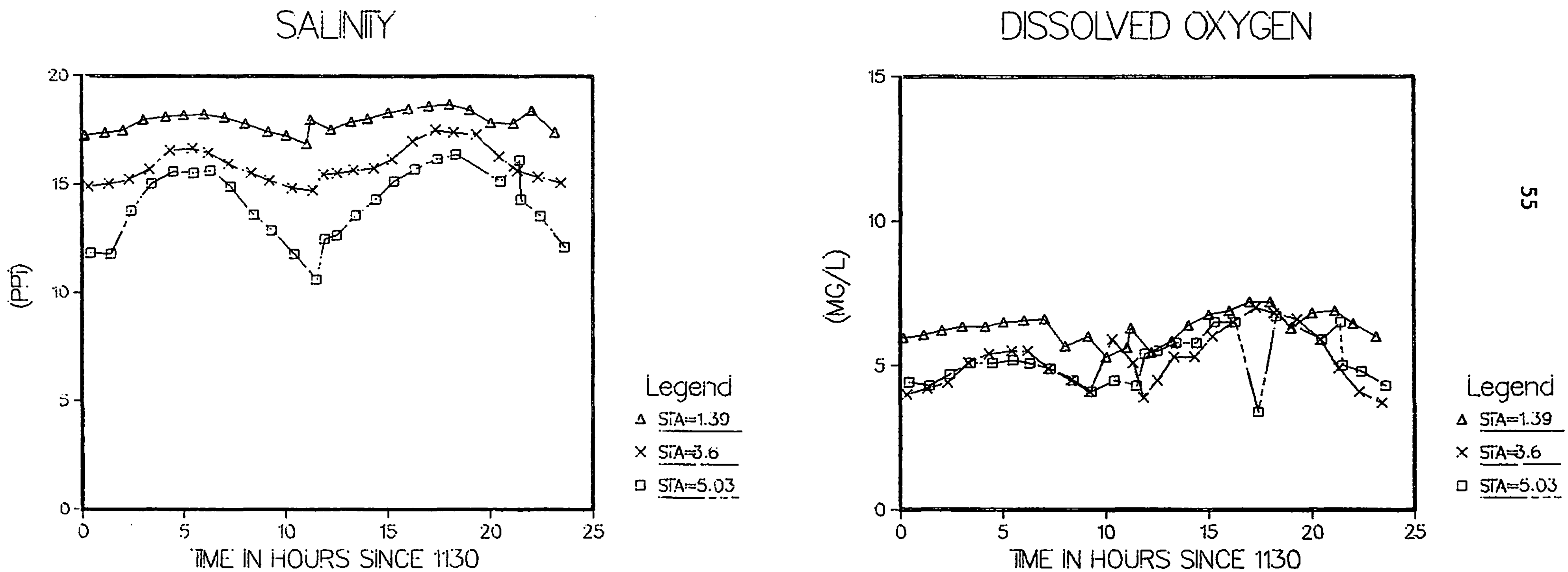


Figure 21a. Chuckatuck Creek mean concentrations at the downstream (1.39 km), mid-estuary (3.6 km), and upstream (5.03 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.

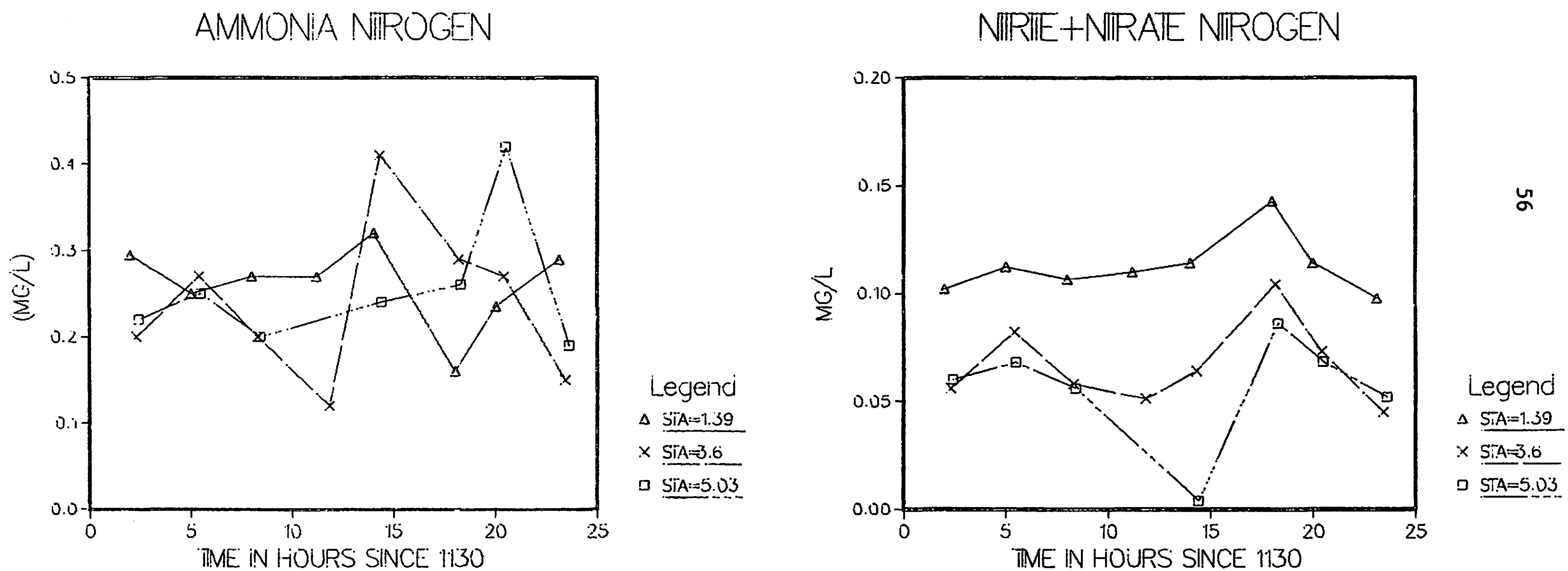


Figure 21b. Chuckatuck Creek mean concentrations at the downstream (1.39 km), mid-estuary (3.6 km), and upstream (5.03 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.

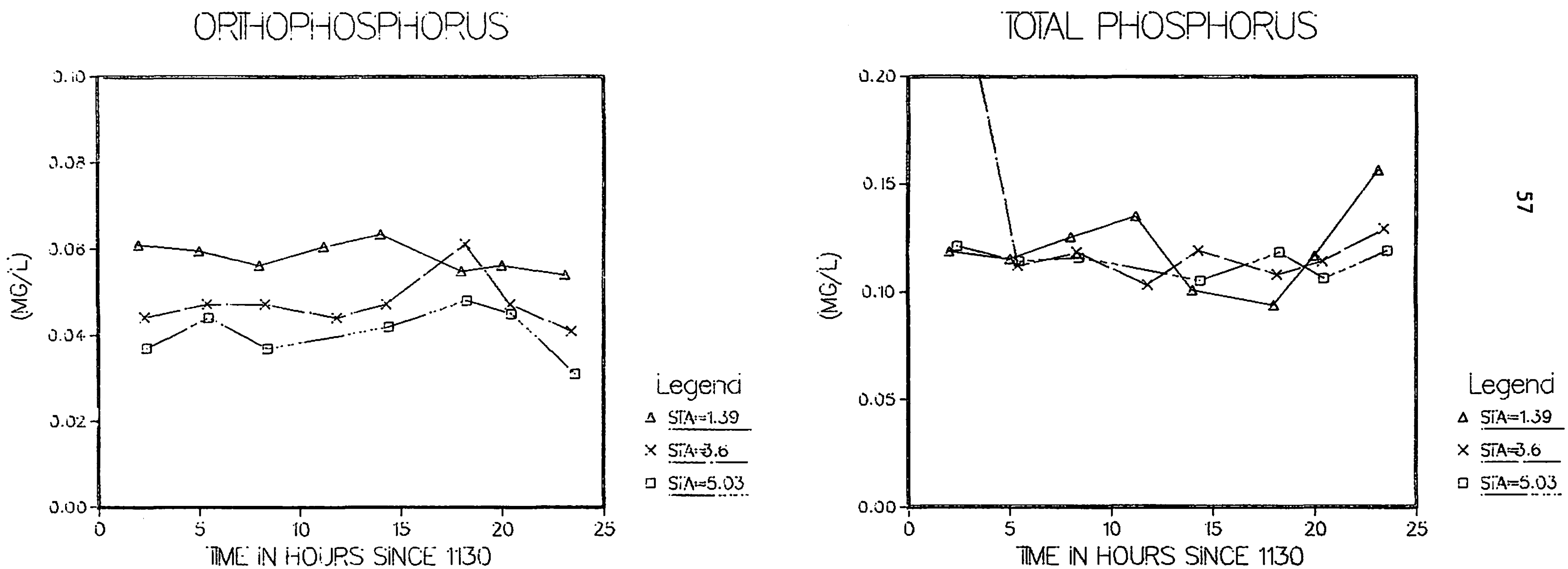
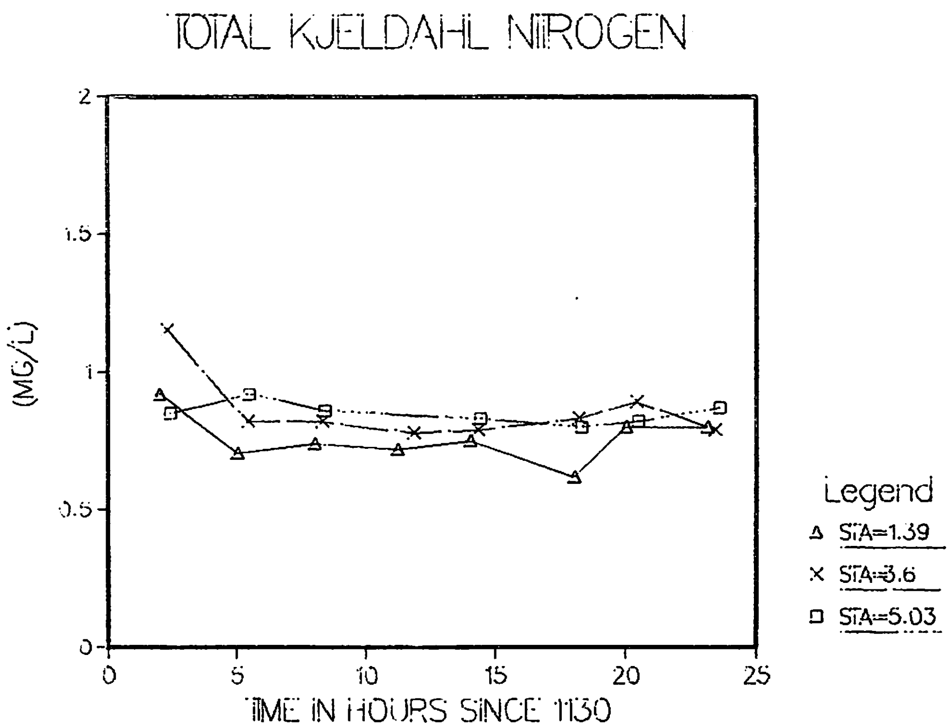


Figure 21c. Chuckatuck Creek mean concentrations at the downstream (1.39 km), mid-estuary (3.6 km), and upstream (5.03 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.



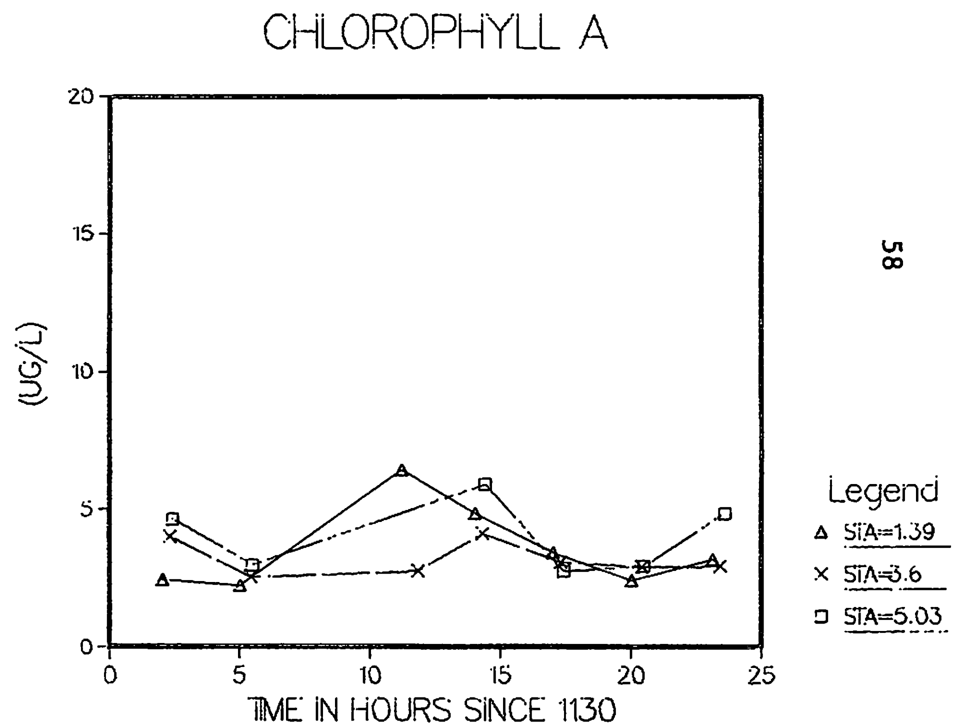


Figure 21d. Chuckatuck Creek mean concentrations at the downstream (1.39 km), mid-estuary (3.6 km), and upstream (5.03 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.

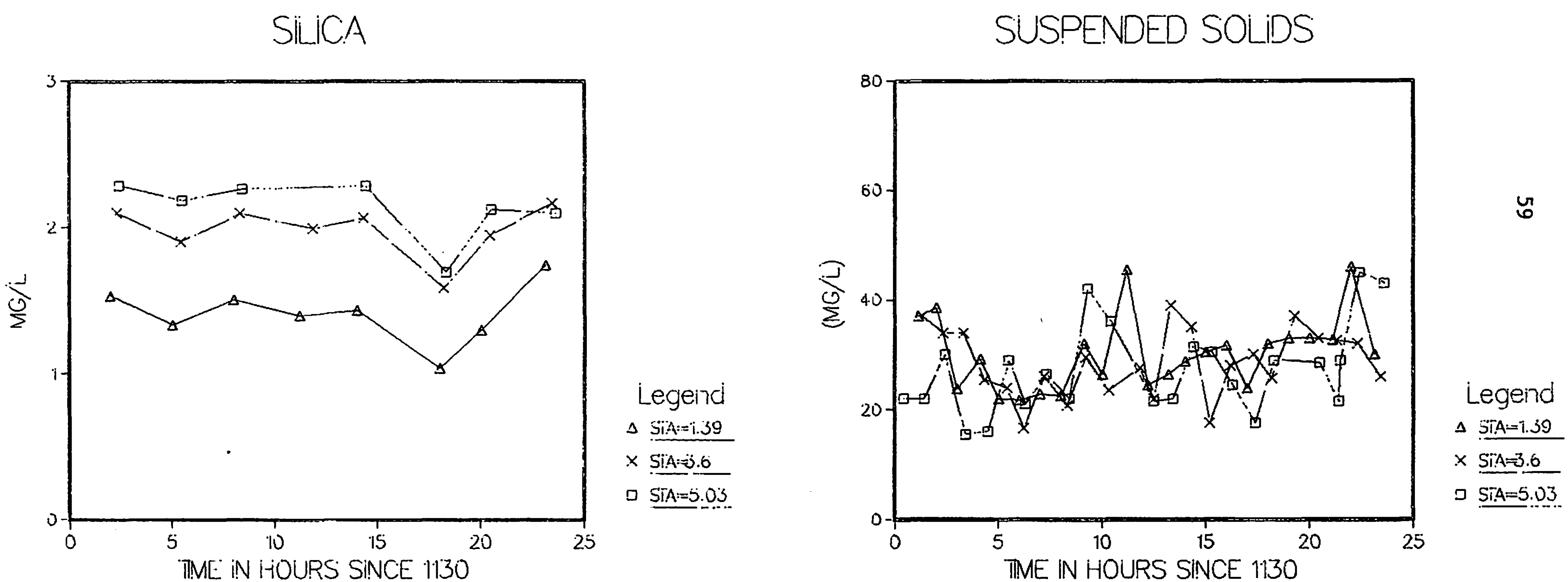


Figure 21e. Chuckatuck Creek mean concentrations at the downstream (1.39 km), mid-estuary (3.6 km), and upstream (5.03 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.

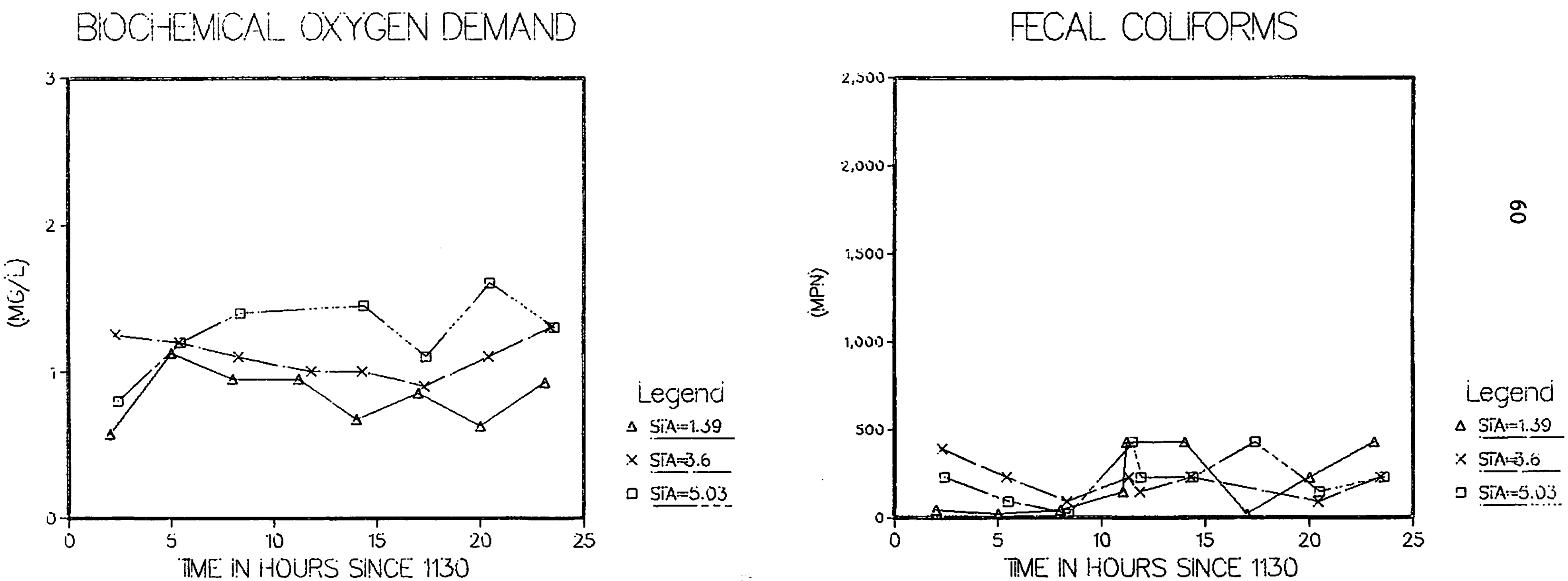


Figure 21f. Chuckatuck Creek mean concentrations at the downstream (1.39 km), mid-estuary (3.6 km), and upstream (5.03 km) stations throughout the 24-hour Intensive survey, September 27-28, 1982.

Distinct tidal effects were not observed during the intensive survey. This suggests that rain events producing significant volumes of runoff not only result in elevated nutrient concentrations but also that the effects of runoff are significant enough to override or mask variations in water quality caused by tidal and solar influences.

WET vs. DRY WEATHER CONDITIONS

The effects of runoff, or nonpoint sources of pollution (NPS), can be assessed by comparing the results from the May surveys (HWS on May 20, LWS on May 26; water temperatures 22-23 C) and the July surveys (water temperature 26-28 C). The first spring survey (HWS) was preceded by rather "dry" conditions; no rainfall had been recorded at Driver, VA (7) in the preceding 5 days. Another indication of runoff, spillover as measured at the Lake Meade Dam on the adjacent Nansemond estuary, had not occurred for 21 days prior to sampling. By the time of the second spring sampling (LWS), rainfall totalling 1.54 inches (3.9 cm) had fallen during the 4 intervening days.

Similarly, the July set of slacks can be used to examine summer NPS loadings. The first survey (LWS on July 15) followed 2 days during which 3.15 inches (8 cm) of rainfall was measured. There was no rain on the 4 days thereafter before the second survey (HWS on July 19).

The data reveal that the dry weather periods were characterized by higher oxygen levels and lower nutrient, biochemical oxygen demand and fecal coliform concentrations than wet periods (Figs. 16 & 17). Oxygen concentrations in the Chuckatuck were generally above the 5 mg/l standard. Note, however, that (Fig. 16) dissolved oxygen levels below 4.0 mg/l occurred during LWS under wet conditions at the upstream stations. Dissolved oxygen levels at the upstream stations dropped about 2 to 3 mg/l between the 20th and the 26th of May. It is not possible to separate the effects of runoff from differences due to tidal stage, but the concurrent increase in BOD levels suggests that nonpoint source pollution is responsible for most of the reduction in oxygen levels.

SUMMARY

Water quality in Chuckatuck Creek was seen to have generally acceptable nutrient levels. Concentrations were fairly homogeneous throughout the estuary, although somewhat greater levels of organic matter and chlorophyll were present upstream. This resulted in slightly higher biochemical oxygen demand and lower dissolved oxygen concentrations.

In the upstream area, nutrient levels were seen to increase following periods of runoff. This is presumably due to the oxidizable matter in runoff and the greater impact of runoff on the upstream reaches which are narrow. Similarly, nutrient levels were found to be higher at times of low water slack when dilution of land-derived flows is smallest.

Observed orthophosphorus concentrations were highest in the summer surveys, and inorganic nitrogen levels were high in December and March due to high concentrations of nitrite- and nitrate-nitrogen, presumably associated with runoff. Chlorophyll-a levels were low throughout the year. However, oxygen values below the 4.0 mg/l minimum standard were observed in the upstream area during the May 26th sampling and during the intensive survey. One must conclude that organic matter in runoff depressed oxygen levels in the estuary, especially at low water slack (when dilution is smallest) and when the water is warm (and decomposition of that material is rapid).

REFERENCES

1. Brehmer, M. L., S. O. Haltiwanger and W. I. Simmonds, 1967. "A Biological and Chemical Study of the Nansemond River, Virginia." Special Report No. 9 in Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science.

2. Commonwealth of Virginia, Department of Conservation and Economic Development, Division of Water Resources, 1971. "James River Basin Comprehensive Water Resources Plan, Volume IV. Water Resource Requirements and Problems." Planning Bulletin Number 216.

3. Commonwealth of Virginia, Department of Health, Bureau of Shellfish Sanitation, 1972-1982, Shoreline Survey Data for Shellfish Growing Areas in the Chuckatuck and Nansemond Rivers, Richmond, Va. 23230.

4. Engineering-Science Company, 1974. "Lower James River Basin Comprehensive Water Quality Management Study." Planning Bulletin Number 217-B, Final Report.

5. Kuo, A. Y. and L. R. Kilch, 1977. "Mathematical Model Studies of Water Quality of the Nansemond Estuary." Special Report No. 152 in Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science.

6. U. S. Geological Survey and Virginia State Water Control Board, Water Resources Data for Virginia, 1966-1982. Water Resources Data for Virginia. U.S.G.S. Water Data Report Series, Water Res. Div., Richmond, Va.

7. U. S. Department of Commerce, National Oceanic and Atmospheric Administration, 1982. Climatological Data for Virginia, Vol. 92, No. 1-12.

8. Virginia Institute of Marine Science, 1975. "Oceanographic Water Quality and Modelling Studies for the Outfall from a Proposed Nansemond Wastewater Treatment Plant." Special Report No. 86 in Applied Marine Science and Ocean Engineering.

9. Virginia Institute of Marine Science, 1977. "Field and Modelling Studies of Water Quality in the Nansemond River." Special Report No. 133 in Applied Marine Science and Ocean Engineering.

10. Virginia State Water Control Board, 1972-1983. No-discharge Certificates for the Chuckatuck and Nansemond Rivers. Tidewater Regional Office, Virginia Beach, Va. 23462.

11. Virginia State Water Control Board, 1982. NPDES Discharge Monitoring Reports for the Nansemond Watershed. Richmond, Va. 23230.

12. Virginia State Water Control Board, 1978. "Water Quality Inventory 305(b) Report." Information Bulletin Number 509. Report to EPA Administrator and Congress.

APPENDIX A

1966-67 Surveys in the Nansemond River

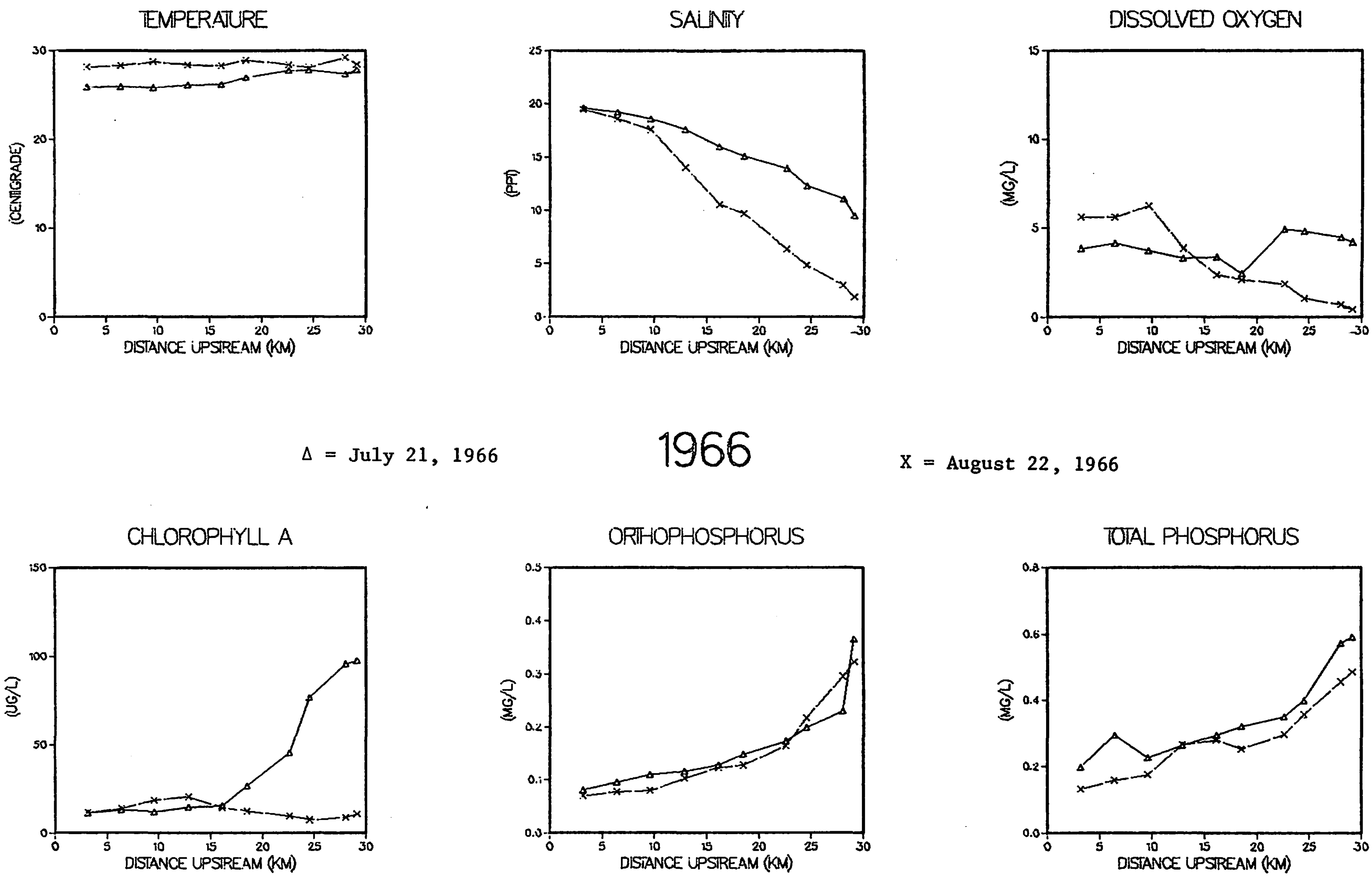


Figure A-1 July 21, 1966 (Δ) and August 22, 1966 (X) surveys in the Nansemond River.

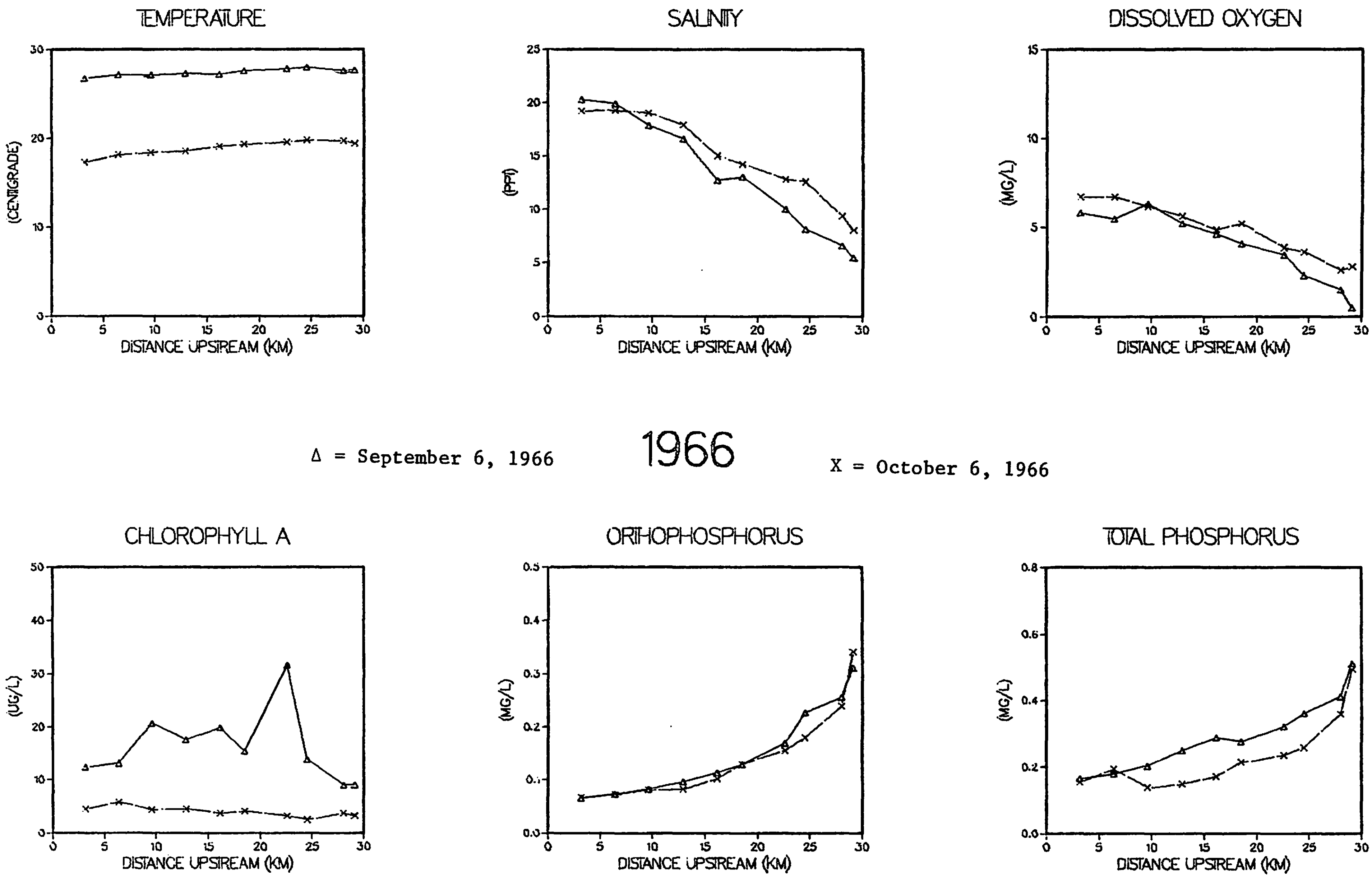


Figure A-2. September 6, 1966 (Δ) and October 6, 1966 (X) surveys in the Nansemond River.

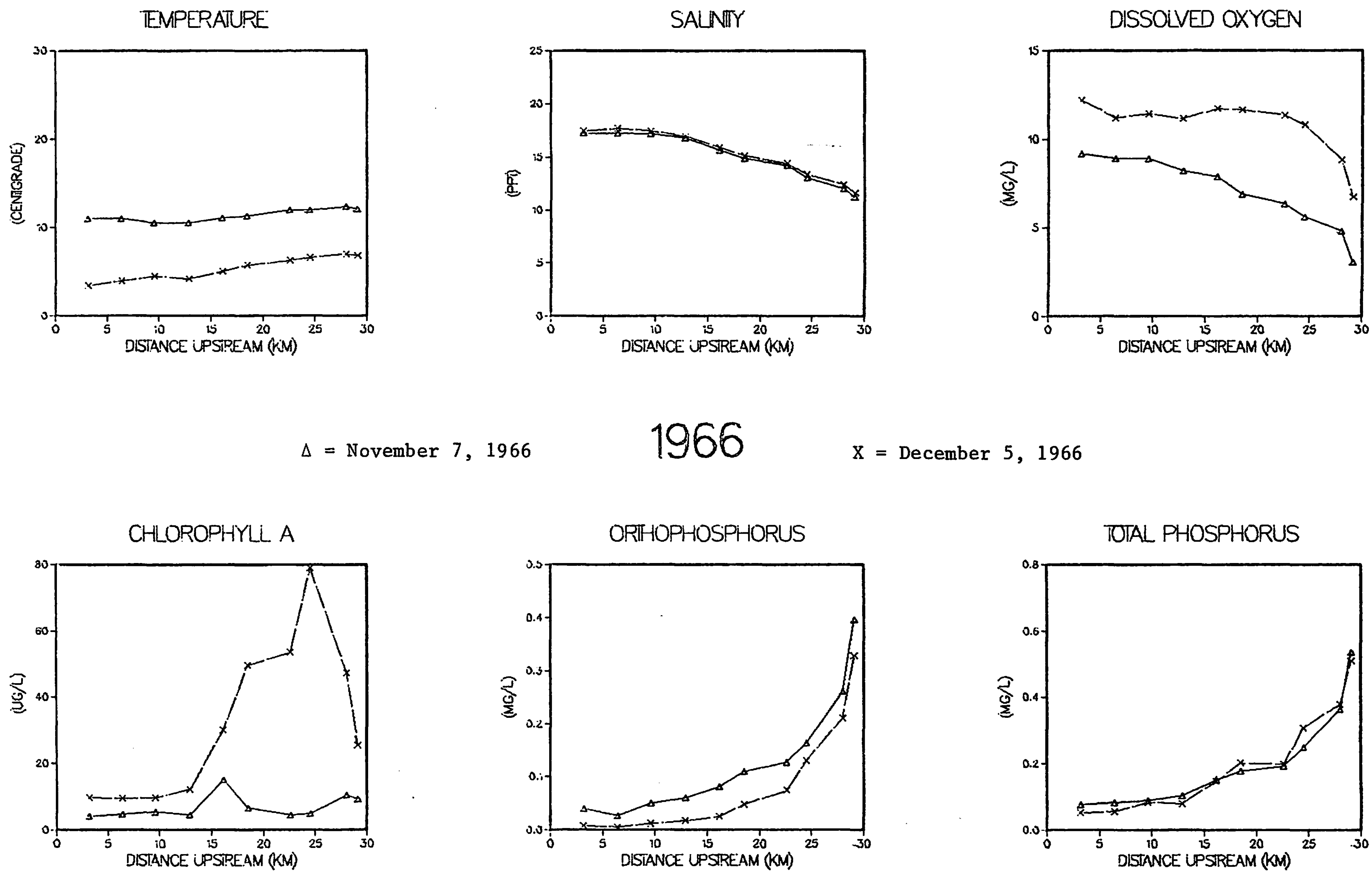


Figure A-3. November 7, 1966 (Δ) and December 5, 1966 (X) surveys in the Nansemond River.

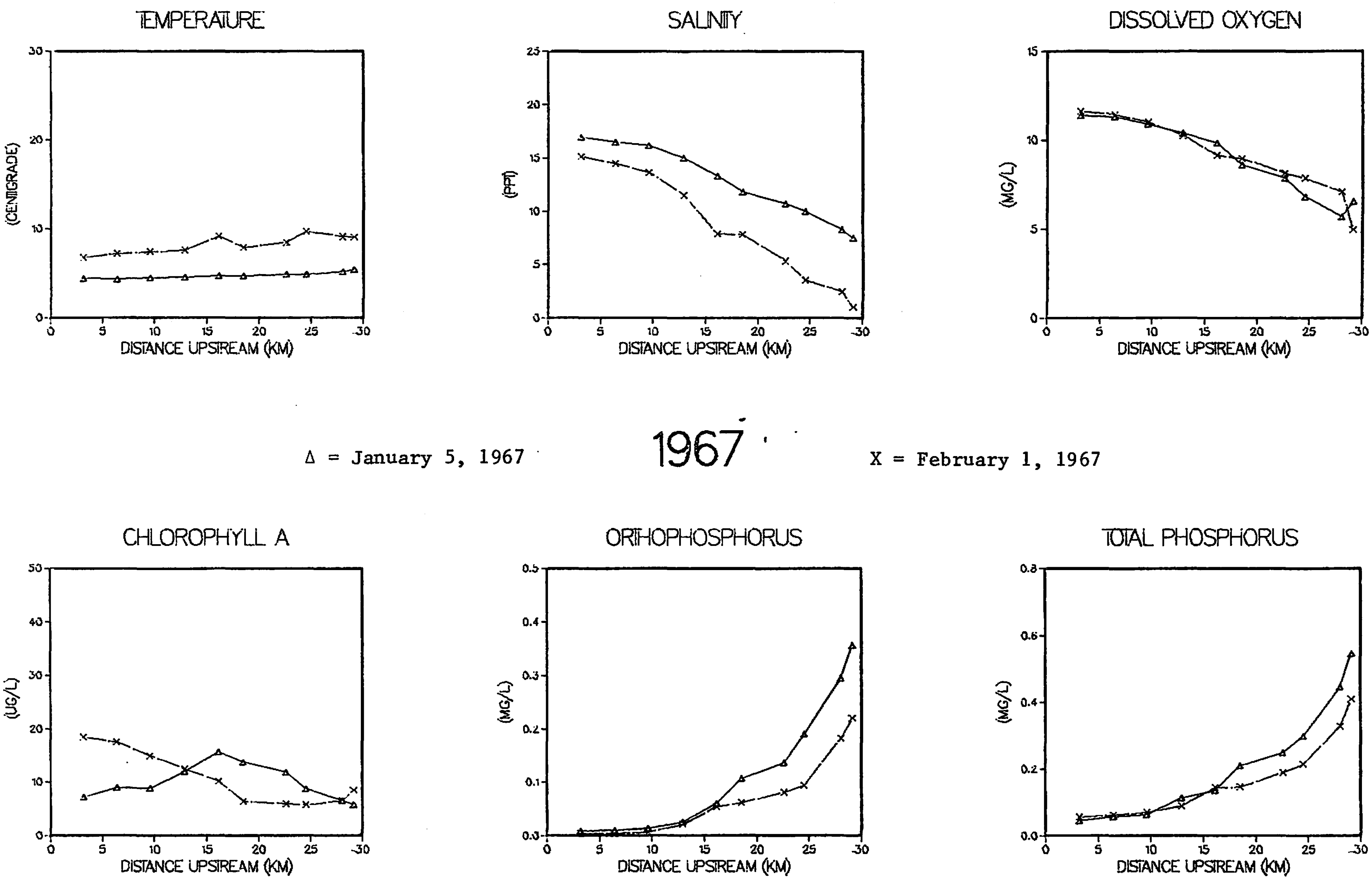


Figure A-4. January 5, 1967 (Δ) and February 1, 1967 (X) surveys in the Nansemond River.

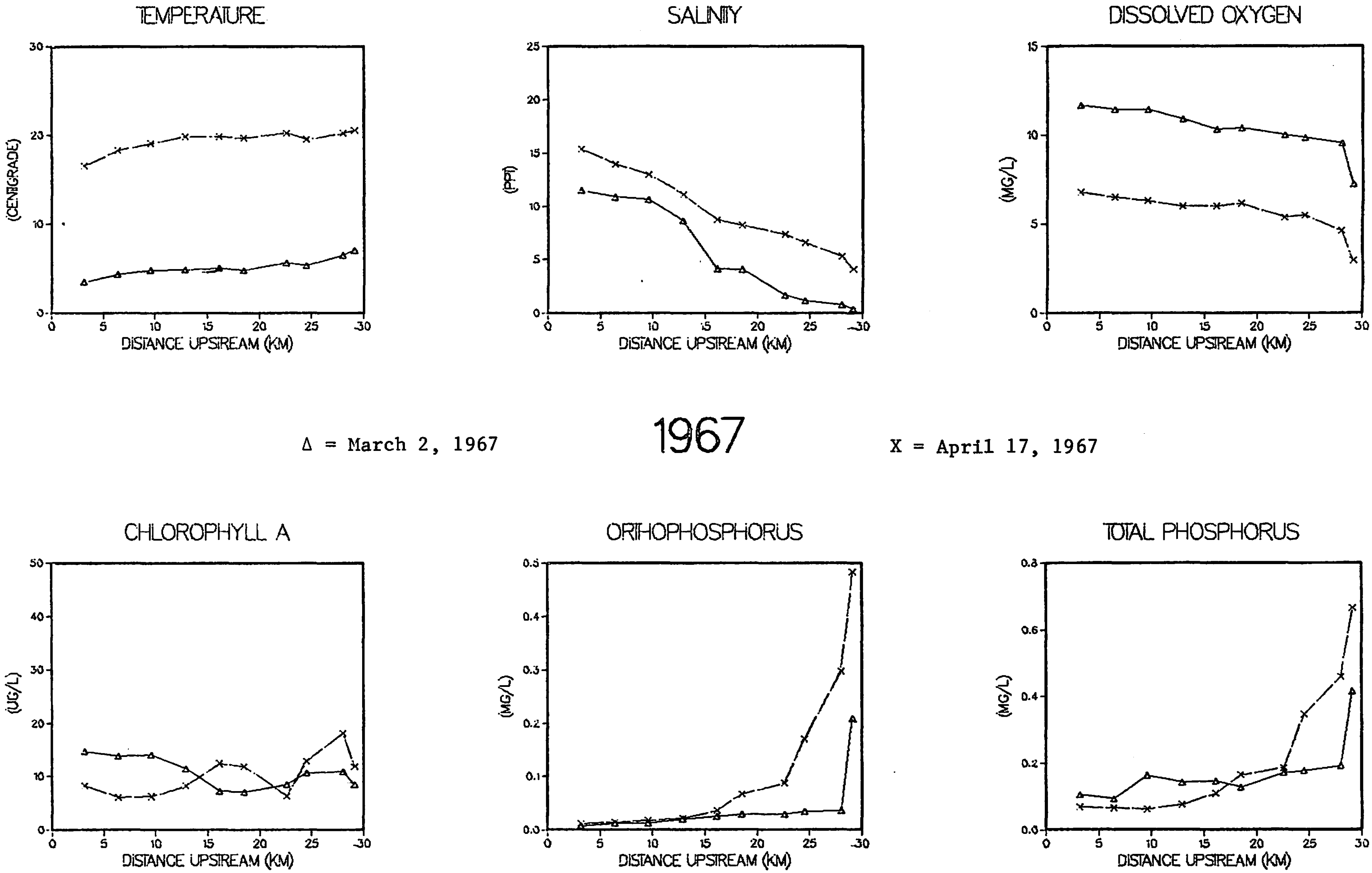


Figure A-5. March 2, 1967 (Δ) and April 17, 1967 (X) surveys in the Nansemond River.

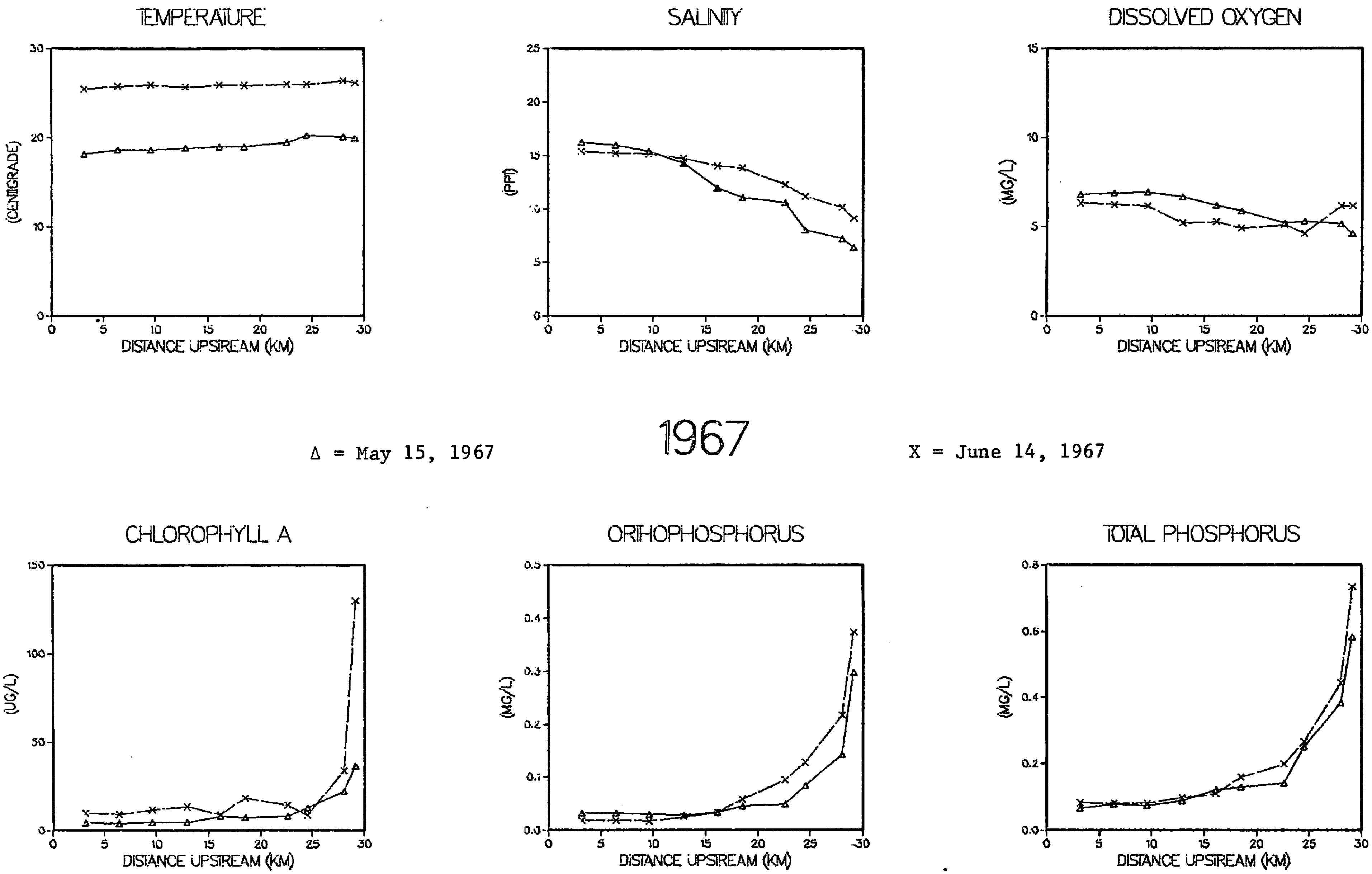


Figure A-6. May 15, 1967 (Δ) and June 14, 1967 (X) surveys in the Nansemond River.