1-1-1978

A Water Quality Study of the Estuarine James River

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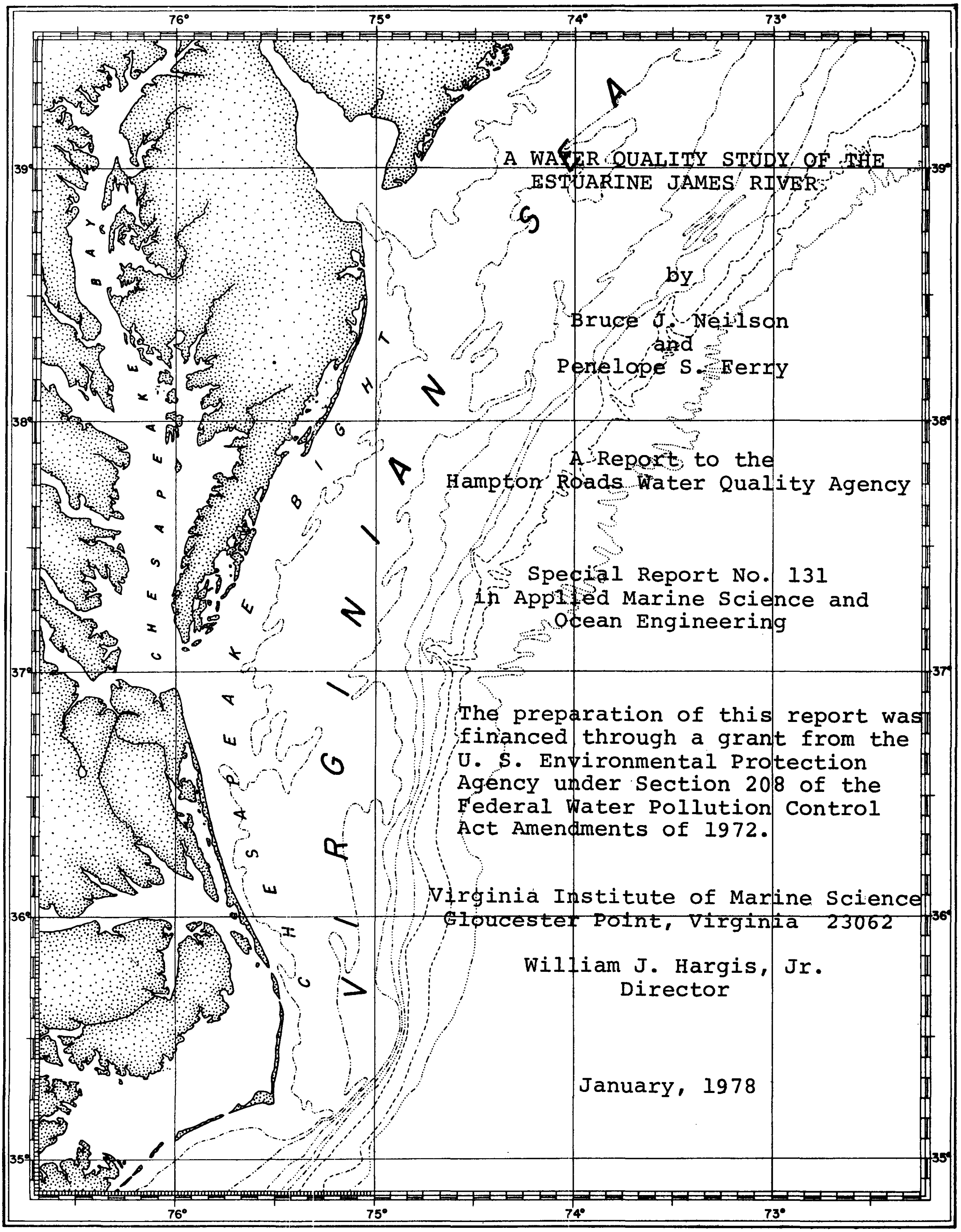
Recommended Citation
Neilson, B. J., & Ferry, P. S. (1978) A Water Quality Study of the Estuarine James River. Special Reports in Applied Marine Science and Ocean Engineering (SRAMSOE) No.131. Virginia Institute of Marine Science, College of William and Mary. https://doi.org/10.21220/V52157



A WATER QUALITY STUDY OF THE ESTUARINE JAMES RIVER

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Bruce J. Neilson
and
Penelope S. Ferry

A Report to the
Hampton Roads Water Quality Agency

Special Report No. 131
in Applied Marine Science and
Ocean Engineering

The preparation of this report was financed through a grant from the U. S. Environmental Protection Agency under Section 208 of the Federal Water Pollution Control Act Amendments of 1972.

Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

William J. Hargis, Jr.
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ACKNOWLEDGEMENTS

We would like to acknowledge the contributions of the many persons in the Virginia Institute of Marine Science's Department of Physical Oceanography and Hydraulics who conducted the field surveys, assisted with laboratory analyses and were responsible for data processing. Special thanks are due to Dr. H. S. Chen for assistance in data analysis.

The discussions, comments and general assistance of our colleagues in the Department of Estuarine Processes and Chemical Oceanography are gratefully acknowledged. We particularly want to thank Ms. Cathy Garrett for her patient typing of the manuscript.

I. DESCRIPTION OF THE STUDY AREA

The James River is the southernmost major tributary of Chesapeake Bay and the largest of the Virginia estuaries. Its total drainage basin encompasses some 26,000 square kilometres (10,000 square miles) or about one-quarter of the Commonwealth. The James is formed in Botetourt County in the Appalachian Mountains by the confluence of Jackson and Cowpasture Rivers. It then flows some 370 kilometres (230 miles) to Richmond, where it passes through the fall zone and becomes tidal. The tidal portion of the river is about 160 kilometres (100 miles) long. The long term flow (41 year average) at Richmond is 212 cubic metres per second (7483 cfs). The flow through the falls has ranged from 0.28 cms (10 cfs), excluding water diverted through the James River and Kanawha Canal, to over 9,000 cms (319,000 cfs) during the flooding produced by Hurricane Agnes in June, 1972. Gaging stations also are maintained on the Appomattox and Chickahominy Rivers, two coastal plain tributaries (see Figure 1). These rivers have long term average flows of 32.6 cms (1151 cfs) and 7.5 cms (263 cfs) respectively. If runoff to drainage area values for the gaged portion of the basin are applied to the entire basin, the average freshwater flow to the entire basin is about 300 cms (10,600 cfs).

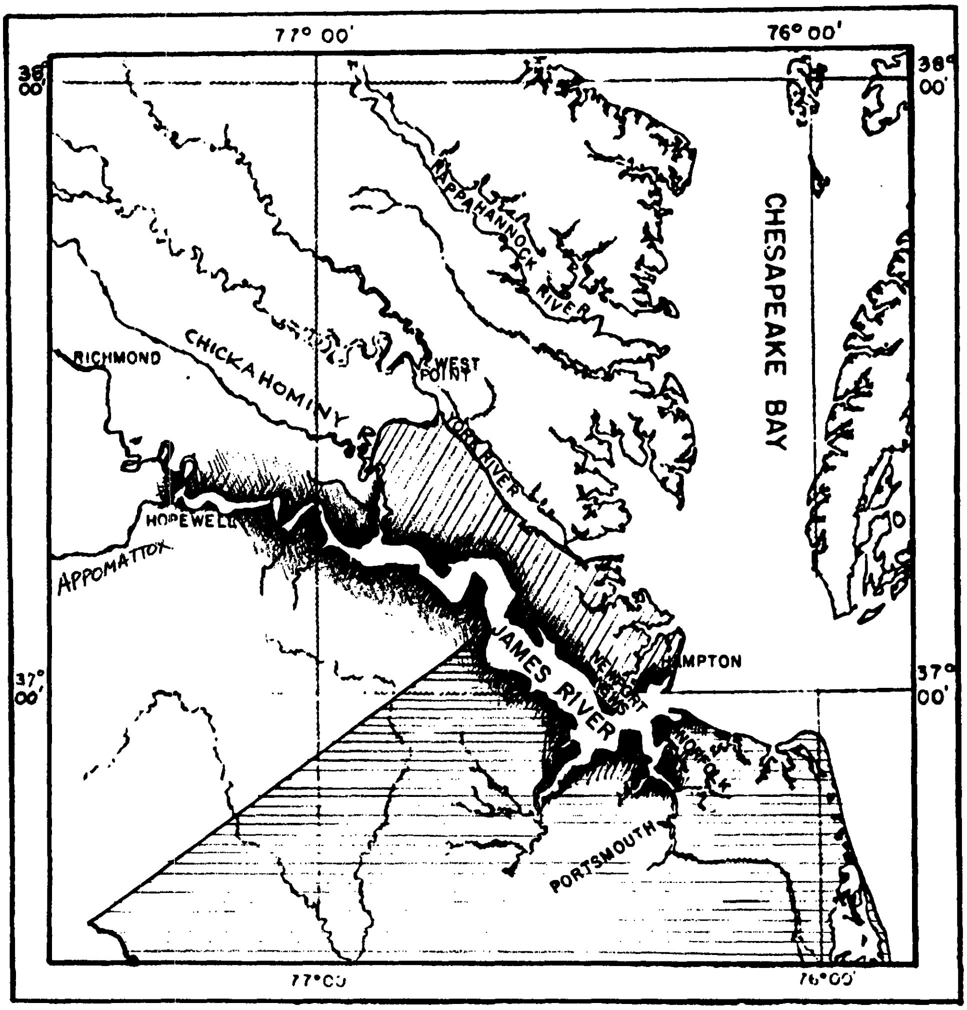


Figure 1. Tidewater Virginia showing the Hampton Roads 208 Study Area and the James River Estuary.

Below Richmond the James is tidal, although only about 50 kilometres (30 miles) of the river are brackish. The salinity intrusion normally extends upriver to the vicinity of Jamestown Island. During periods of low flow, the salt water intrusion is greater, reaching nearly to Hopewell during long, extremely dry periods. When flooding occurs, the salt water is pushed downriver by the increased freshwater flows. For example, when hurricanes produce heavy rainfall in the basin, the limit of salt water intrusion often migrates downriver to the area of the James River Bridge.

The channel is narrow (around 250 metres) and somewhat sinuous between Richmond and Hopewell, where the Appomattox River joins the James. From there to the confluence with the Chickahominy River the channel is about 1000 metres wide. Downriver of the Chickahominy, the cross section broadens even more. The average width for this segment of the river is 5.4 kilometres and in some places the James is nearly 10 kilometres wide (Cronin and Pritchard, 1975). The Hampton Roads 208 Study Area includes only this seaward, broad and mostly brackish portion of the tidal James, as can be seen in Figure 1. The water surface area of the James below the Chickahominy is 560 square kilometres (216 square miles) at mean low water. The mean low water volume is 2,400 million cubic metres (almost two-thirds of a cubic mile) which is 86% of the mean low water volume for the entire tidal James (Cronin, 1971).

Salinities are greatest near the mouth, of course, since the ocean is the source of nearly all of the salt. Near Old Point Comfort, the salinity at the surface ranges from 16 to 18 parts per thousand (ppt) in the spring to 21 or 22 ppt in late summer. Bottom salinities vary in the range 24 to 28 parts per thousand. Vertical stratification is usually reasonably strong at the mouth since the river is very deep there, around 27 metres (90 feet), and there has been little opportunity for the denser salt water to be mixed with the freshwater. Stratification throughout the rest of the estuary varies in response to freshwater runoff and tides. In the spring, when the flow at Richmond is great, often above 300 cms (10,000 cfs), the freshwater tends to flow out over the salty water, which produces strong vertical stratification. In summer and fall, the freshwater flows often are very low, around 40 cms (1400 cfs) at Richmond, and the tides are able to mix the fresh and salty waters more thoroughly. At this time, vertical salinity stratification usually is quite weak.

The climate in the area has been classified as "humid, sub-tropical". The Atlantic Ocean and Chesapeake Bay are moderating factors for the coastal areas. For example, the highest temperature recorded at the weather station at Richmond during 1976 was 37.7^{o} (100^{o} F) whereas the highest temperature recorded at Norfolk was only 35° (95° F). Similarly, the lowest temperature during 1976 was -15° (5° F) at Richmond but only -9° (16° F) at Norfolk. At Norfolk, 224 days elapsed between the last day in spring with freezing weather and the first occurrence in the fall, while the similar time interval for Richmond was 50 days shorter. Monthly average temperature ranged from 2° C in Richmond and 4° C in Norfolk in December and January to around 25° (77° F) in July and August.

Yearly precipitation is on the order of 110 cm (43 inches) with the rainfall distributed rather evenly over the year. However, significant deviations do occur because of droughts, hurricanes, and "northeasters". Much of 1976 was drier than normal: annual precipitation at Norfolk was 82 cm (32.4"), 31 cm below the normal rainfall. The 88 cm (34.8") of rain recorded at Richmond similarly was 20 cm less than the normal yearly rainfall. For both stations, April 1976 was the driest month in 1976 with only about 2.5 cm (1") recorded at either stations. July and August, the period when field surveys were conducted, also were drier than normal. The rainfall at Richmond for these two months was 10 cm (4"), 17 cm less than normal. At Norfolk, the 20 cm (8") of rain for these two months was less than normal, but the departure was only about 10 cm (4"). River flow at Richmond was only about 45 cms (1600 cfs) during August and September, versus a yearly mean flow of 188 cms (6640 cfs). That annual flow was considerably less than the mean flow of 286 cms (10,110 cfs) for water year 1975.

Nearly half of Virginia's population lives within the James River basin. The major population and/or manufacturing centers along the tidal James are the Richmond area, the Hopewell-Petersburg-Colonial Heights area and the Hampton Roads area. The domestic and industrial wastes generated in these areas at times have stressed the James and sometimes caused degraded water quality conditions. One indication of this situation is the fact that the Richmond-Crater and the Hampton Roads "208 Studies" are being conducted on the upper and lower portions of the Tidal James. This report deals primarily with estuarine portion of the James, but since wastes discharged to the James near Richmond or Hopewell eventually will be transported to the Hampton Roads area, later sections of the report will briefly discuss conditions in the tidal freshwater reaches as well.

The field survey and modelling studies of the James which were conducted for the Hampton Roads 208 Study are concerned primarily with three aspects of water quality: dissolved oxygen, eutrophication and fecal contamination. Because each of these aspects can be rather complex, because the spatial extent of the James is great and since so much information is available, each topic will be presented individually. In the following three chapters, a review of available information will be given, along with the results of the 1976 field survey and other information necessary for interpreting the data. The final chapter will include a summary of the field observations and comments on the general health of the James.

II. DISSOLVED OXYGEN

The Virginia State Water Control Board has established standards for the quality of waters within the Commonwealth. Allowable conditions vary according to water body type; estuarine systems, including the James, are in Major Class II. The minimum allowable dissolved oxygen (DO) concentration for estuaries is 4 mg/l, and the daily average value should not be below 5 mg/l. These levels have been determined to be appropriate in order to sustain a healthy aquatic community. The river supports a wide variety of life forms, ranging from microscopic plankton to large, commercially important finfish and shellfish, and most of these life forms simply cannot live in oxygen deficient waters.

Oxygen levels vary in response to natural factors as well as man's activities. The solubility of oxygen in water decreases when either the temperature or the salinity of the water is increased. For the Hampton Roads 208 study area, salinities range from close to 30 parts per thousand to near zero, while water temperatures range from around zero to about 30^{o}C. Saturation values for dissolved oxygen for these ranges of temperature and salinity are given in Table 1. One can note that saturation concentrations vary appreciably with salinity when the water is cold, but that this effect is reduced when water temperatures are elevated. The variation with temperature, however, is very strong for all salinities: saturation values for 30^{o} are only about one half the values for 0^{o}. Stated in a different manner, if the river water were completely saturated with oxygen, one

TABLE 1. Saturation Values for Dissolved Oxygen in Water of Varying Salinity and Temperature.

(DO concentrations are given in mg/l)

Water Temperature (°C)	Salinity (ppt) 0	10	20	30
0	14.6	13.7	12.8	11.7
10	11.3	10.6	10.0	9.4
20	9.2	8.7	8.2	7.8
30	7.6	7.3	6.8	6.4

would always observe a difference of one to several milligrams per litre from the mouth of the river to the freshwater portion. Similarly, DO values would vary by 5 or more milligrams per litre from winter to summer at any given station. One especially important point to note is that there is relatively little "margin for error" when temperatures are elevated: that is, the difference between saturation values and the water quality standards is only a few milligrams per litre in late summer and early fall.

Man's activities also can affect DO concentrations. Oxygen is consumed by the biochemical processes that break down the organic compounds discharged by domestic sewage treatment plants and by some industries. Of course, there are also many natural sources such as tidal marshes and the runoff from land. Biochemical Oxygen Demand (BOD) is a measure of the amount of oxygen which will be consumed by polluted water. Scientists now differentiate between the carbonaceous and nitrogenous fractions of BOD, called CBOD and NBOD for short.

Ultimate CBOD and NBOD loads in raw sewage are generated at the rate of 0.25 pound/capita-day and 0.20 pounds/capita-day respectively (Hydroscience, 1971). Treatment plants for domestic sewage traditionally have been designed to reduce these oxygen demands. Primary treatment involves physical processes (settling) and removes 25 to 40% of the CBOD, but only slightly alters the NBOD. When settling is combined with a biological process, so-called secondary treatment, 75 to 95% of the CBOD is removed. A small percentage to nearly all of the nitrogenous oxygen demand may be met in the plant depending on treatment methods used. Use of advanced waste treatment (AWT) can remove up to 98 or 99% of the CBOD (Metcalf and Eddy, 1972).

Characteristics of the bacteria which cause the decomposition result in the relatively rapid oxidation of CBOD but a delayed and slower exertion of the NBOD. Therefore, BOD values given as 5-day BOD may be assumed to be exclusively carbonaceous BOD unless otherwise specified. One of the most common tests which is performed on effluent from sewage treatment plants (STP's) and industry is the BOD test. Water samples are held at a constant temperature (usually 20^{o}C) for this test, and the amount of oxygen consumed is measured as a function of time. Usually, the results are given as 5-day BOD. As a rough "rule of thumb" the ultimate oxygen demand is one and a half times the 5-day BOD. The nitrogenous BOD values are calculated from measurements of the Total Kjeldahl Nitrogen (TKN) in the wastewater. The stoichiometry of the chemical transfer of organic nitrogen to nitrate-nitrogen indicates that 4.57 pounds of oxygen will be needed for each pound of TKN.

In the laboratory, the nitrogenous oxygen demand normally will not be exerted within the 5 day CBOD test, and it also can be inhibited by the addition of appropriate compounds. In the estuarine and tidal freshwater environment, however, it is likely that the decomposition of both the carbonaceous and nitrogenous fractions occurs simultaneously.

In a freeflowing river, BOD discharged to the waterway is carried downstream. The oxygen demand is exerted as the material is transported away from the source, resulting in decreased DO levels. Eventually, the rate of oxygen utilization decreases and natural reaeration is able to replenish the DO more rapidly than it is consumed. The result is the so called "oxygen sag" which is illustrated in Figure 2. In a tidal river or estuary, pollutants are transported upriver as well as downriver from a discharge point. Consequently, impacts are felt upriver as well as downriver of the discharge. The extent of the upriver transport increases when freshwater flows are small and tidal mixing plays a major role in dispersing the waste, as shown in Figure 3.

A. Point Sources of Pollution and Their Impact on Oxygen Values

So-called point sources (municipal sewage treatment plants and industries) tend to be clustered in distinct areas along the tidal James: the Richmond, Hopewell and Hampton Roads areas. The CBOD and NBOD loads for 1976 have been summarized for these three river segments in Table 2. Often one can note distinct zones of influence resulting from each of these discharge groups. The impact in the Richmond Area is pronounced

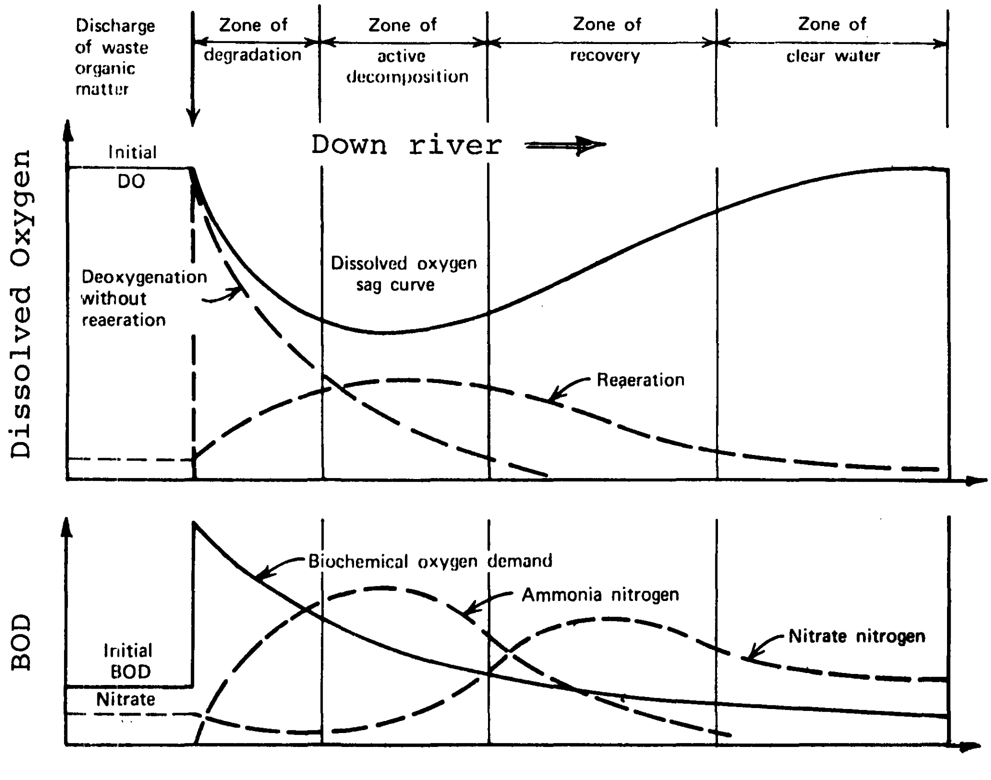


Figure 2. Generalized effects of organic pollution on a stream. (From "Water and Wastewater Technology" by Mark J. Hammer, Wiley, 1975.)

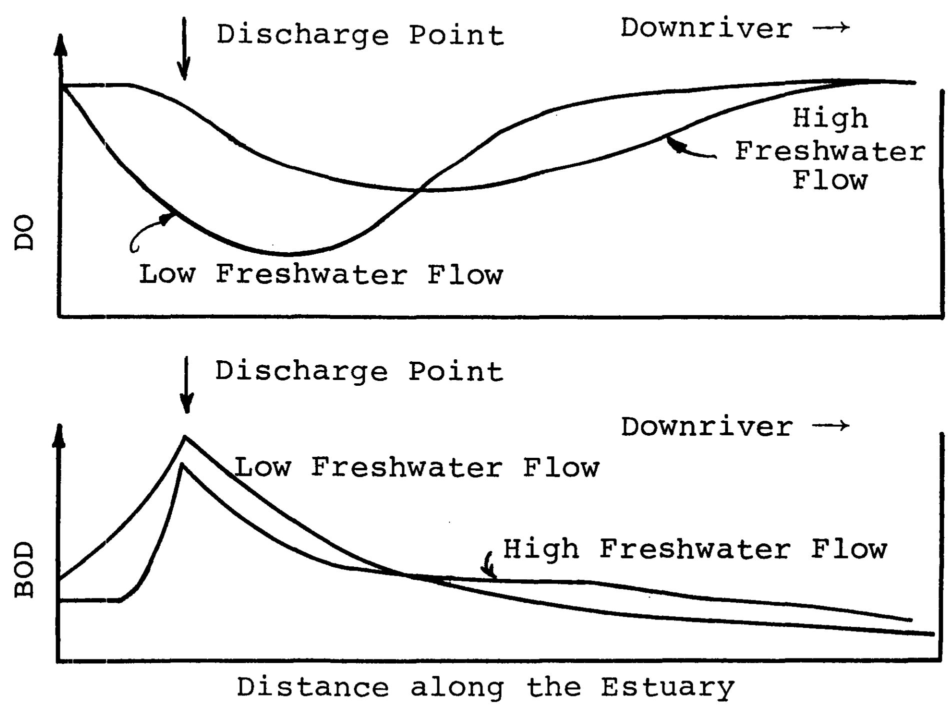


Figure 3. Hypothetical DO and BOD curves for an estuary.

TABLE 2. Point Discharges of BOD to the Tidal James.*

	Statute Miles From River Mouth	1976 Average Flow (MGD)	1976 Average CBOD5 (#/day)	July, 1976 Flow (MGD)	July, 1976 CBOD*5 (#/day)	July, 1976 NBOD (#/day)
			RICHMOND AREA			
City of Richmond STP	(98)	56.8	2750	53.3	1780	12,890
E. I. DuPont Spruance Plant	(92.7)	-	330	-	300	610
Falling Creek STP	(92.1)	4.5	470	4.1	410	3690
			HOPEWELL AREA			
Allied Chemical (Plastics)	(75)	-	8950	-	8952	56.055
Continental Can Co.	(75)	-	43,163	-	42,318	3063
Firestone Synthetic Fibers	(75)	-	1000	-	1034	187
Hercules, Inc.	(75)	-	40,970	-	33,929	840
Fort Lee	(75)	-	-	-	1500	-
City of Hopewell STP	(75)	3.05	1560	2.82	1733	3404
			BELOW CHICKAHOMINY RIVER			
HRSD - Williamsburg	(32.71)	4.7	850	5.4	811	2200
Fort Eustis	(29.40)	1.1	134	1.4	152	—
HRSD - James River	(18.24)	11.1	2060	11.2	2064	10,100
HRSD - Boat Harbor	(7.52)	20.5	24,340	21.5	28,350	18,200
Elizabeth River**	(3.55)	53.0	57,000	50.4	62,000	53,000

* Data from State Water Control Board, HRSD, and Rosenbaum, et al.

** Includes all HRSD plants, Virginia Chemicals and the City of Portsmouth - Pinners Point STP.

for several reasons. First, the river is narrow so that there is a limited volume of water into which the wastes can be dispersed. Secondly, the freshwater flow normally is quite low in late summer so that downriver transport is slow. This feature, plus elevated water temperatures, result in the near total exertion of the oxygen demand within the river reach between Richmond and Hopewell. On the other hand, when river flows are great and/or water temperatures are low, the BOD is transported far downriver and the Richmond zone of influence reaches to and beyond Hopewell. The Division of Water Resources, in its 1971 report on "Water Resource Requirements and Problems" (Bulletin 216), noted that: "The bulk of the waste load in the Richmond area is discharged below the fall line, and water quality is appreciably degraded. From the fall line to a point upstream of Bermuda Hundred (approximately 15 miles), the James River oxygen resource is severely taxed." In 1975, the State Water Control Board (SWCB) noted in their "Water Quality Inventory" that: "Mean concentrations in the Richmond area are markedly improved in the 1972-74 periods since the City's secondary treatment plant began operation." The daily 5-day BOD discharge from the Richmond STP was listed as 33,900 pounds in the 1969 introductory volume to the Comprehensive Water Resources Plan (Bulletin 213), whereas by 1976, the CBOD loads was only a few percent of the 1969 load. Note that the NBOD load remains substantial and the DO drop significant (see Figure 4).

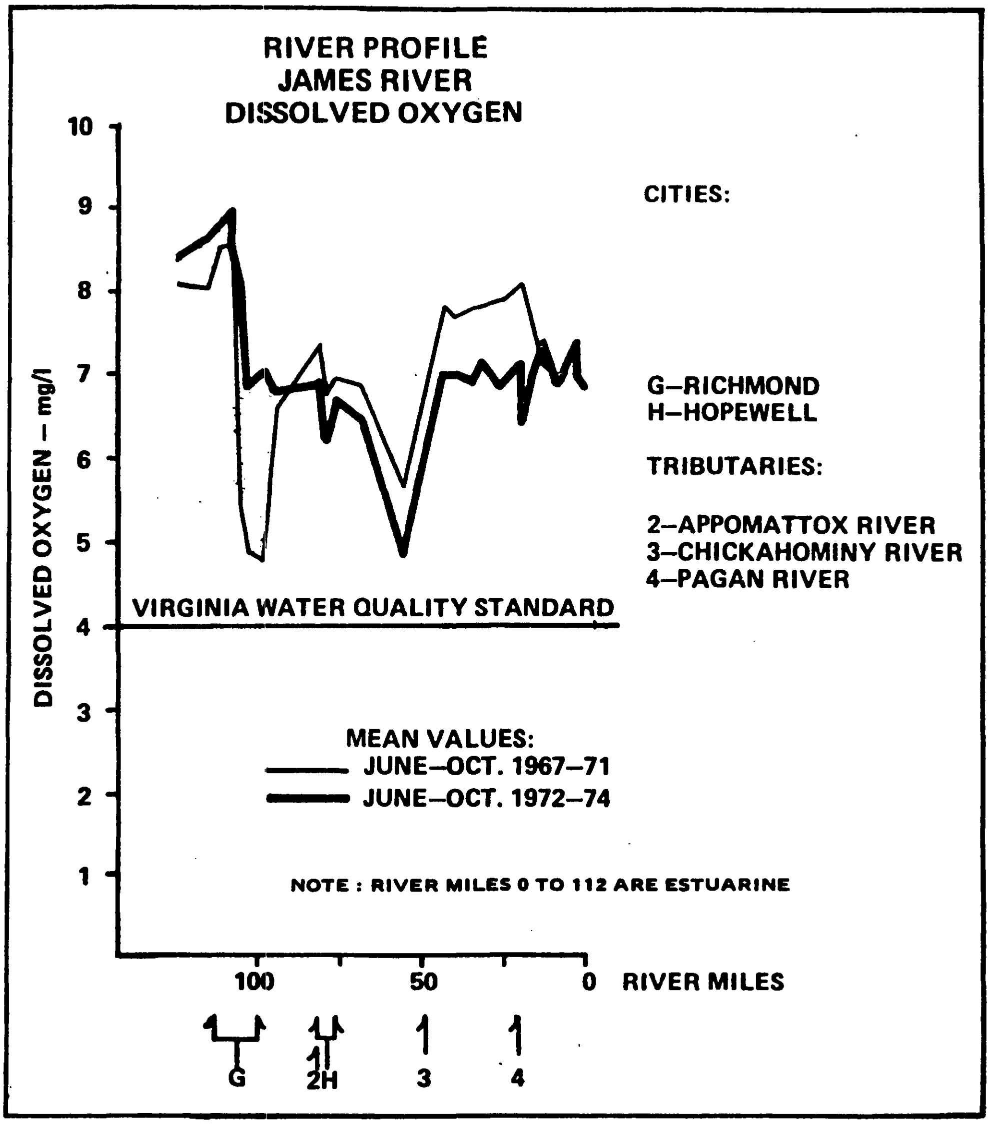


Figure 4. Average dissolved oxygen values for the Tidal James (taken from Water Quality Inventory 305(b) Report, SWCB, April, 1975).

BOD loads from the industries located near Hopewell are and have been very large. A study of "Self Purification Capacities - Lower James River - Hopewell, Virginia" was made by C. J. Velz in June, 1955. In the summary of that report, he notes the following items:

"The pollution load discharged to the James River in the Hopewell area as of July, 1953, comprises 147,000 pounds of 5-day 20°C BOD per day, of which 142,000 pounds per day is from industrial sources."

"Additional unstable organic matter in significant quantities is flushed into the James River by tide action from the extensive swamp and marsh areas."

"The James River during dry weather season arrives at Hopewell in good condition with dissolved oxygen at 85 percent of saturation and a small residual pollution load from upstream sources."

"The runoff from the James River is characterized by flashy discharge with severe droughts during the summer-fall season ... River water temperature at the peak of the warm weather approaches 30°C but the more severe droughts occur most frequently in the month of October when water temperature is lower."

Velz's conclusion was that "dissolved oxygen in the James River in the critical reach of the main channel in the vicinity of Jordan Point can be maintained above 40% of saturation as a mean through the tidal cycle, under a drought severity expected on the average in the long run once in 5 years". It should be noted that if the water temperature is 30°, 40% of saturation yields an absolute concentration of only 3 milligrams of dissolved oxygen per litre or river water, which is well below the standard.

In the 1975 inventory, the SWCB notes that "The improved dissolved oxygen concentrations (near Richmond) are negated further downstream due to the municipal and industrial complex of the Hopewell Area (Bailey Creek), and mean concentrations in the river below Hopewell to the mouth fall below those of the 1967-71 period; however, the mean dissolved oxygen levels are above 5 mg/l below Hopewell and are in the 7 mg/l range below river mile 50." In a later section they further note that the portion of the James known as Bailey's Bay has "essentially dead waters and the sludge deposits in that area are expected to continue decomposing after 'best available technology' is met." Even a brief review of the data in Table 2 shows that the BOD loads are indeed very large. When downriver transport is slow during periods of low freshwater flow, the oxygen demand has been exerted for the most part by the time the water reaches the mouth of the Chickahominy River and the Hampton Roads 208 study area.

The estuarine portion of the James has characteristics much different from the tidal riverine reaches. Tidal currents are strong and enormous volumes of water are available to dilute wastes. Consequently, DO levels usually are good even though BOD discharges can be large. In the "James River 3-C Report" (Planning Bulletin 217-B) the estuarine portion was studied in two parts. For the reach between the Chickahominy and Mulberry Island, it was noted that waste discharges were limited. However, DO sags did occur occasionally due to nonpoint loadings, with marsh inputs suspected as being the major component of these loads. Below Mulberry Island, several large waste discharges exist, but "the strength of the tidal action combined with the massive amount of dilution water available result in a rather steady DO level after the natural background variations due to changes in temperature and salinity are removed. The DO values seldom fall below 5.5 mg/l under the worst conditions and the depression of DO due to waste oxidation by river biological processes is usually less than 1.0 mg/l."

During the spring and summer of 1974, thirteen slack water surveys were made between April and September as part of an environmental study for the proposed Nansemond River waste-water treatment plant (VIMS, 1975). Seven stations in Hampton Roads and four in the lower portion of the Nansemond River were sampled on each survey. Dissolved oxygen levels generally were quite good. One sample had a DO of 3.7 mg/l and, therefore, violated the 4 mg/l standard. DO values between 4 and 5 mg/l also were observed occasionally at depths greater than 8 metres near the mouth of the river. As noted earlier, the 1975 water quality inventory states that "dissolved oxygen levels ..... are in the 7 mg/l range below river mile 50" (see Figure 4).

In summary, dissolved oxygen levels will be depressed by the input of oxygen demanding materials to the river. The spatial extent and severity of the response depends, in great part, on natural factors. When water temperatures are high and freshwater flows are low, pronounced DO sags have been observed below Richmond and also below Hopewell. Although large volumes of wastewaters are discharged to the estuarine portion of the James, the natural assimilation capacity of the river is great and dissolved oxygen values generally have been well above the water quality standards.

B. Field Survey Results

The field study for the Hampton Roads 208 program consisted of an intensive survey and two slack water surveys. Because the area to be covered was so large, the intensive survey was broken into two sections. On July 15 and 16, 1976 the upper part of the study area, from transect 2 to station 6B, was surveyed (see Figure 5). The lower portion of the study area, from station JN1 to the mouth of the James, was surveyed on July 21 and 22, 1976. A low water slack survey and a high slack survey were conducted on August 23 and 24, 1976 respectively. In addition, the Elizabeth, Nansemond and Pagan Rivers were sampled for the same slack waters. Details of the surveys are given in Appendix A and data from the intensive survey are presented in graphical form in Appendix B.

Dissolved oxygen concentrations throughout the study area generally were between 6 and 7 mg/l at the time of the intensive survey. Average values did increase slightly in the upriver direction, as shown in the slack water data presented in Figure 6. This trend probably is due to decreasing salinity and smaller BOD discharges in the upper reaches of the study area. Saturation values for this period range from 7 mg/l in Hampton Roads to 8.5 mg/l in the freshwater reaches. Some DO values were above these concentrations and a few were even above 10 mg/l. These supersaturated concentrations could result from photosynthetic oxygen production by algae. This hypothesis is reinforced by the diurnal variation which was observed at some stations. Data for station JN1 at the mouth of the Nansemond River are typical and have been graphed in Figure 7. DO values were highest in

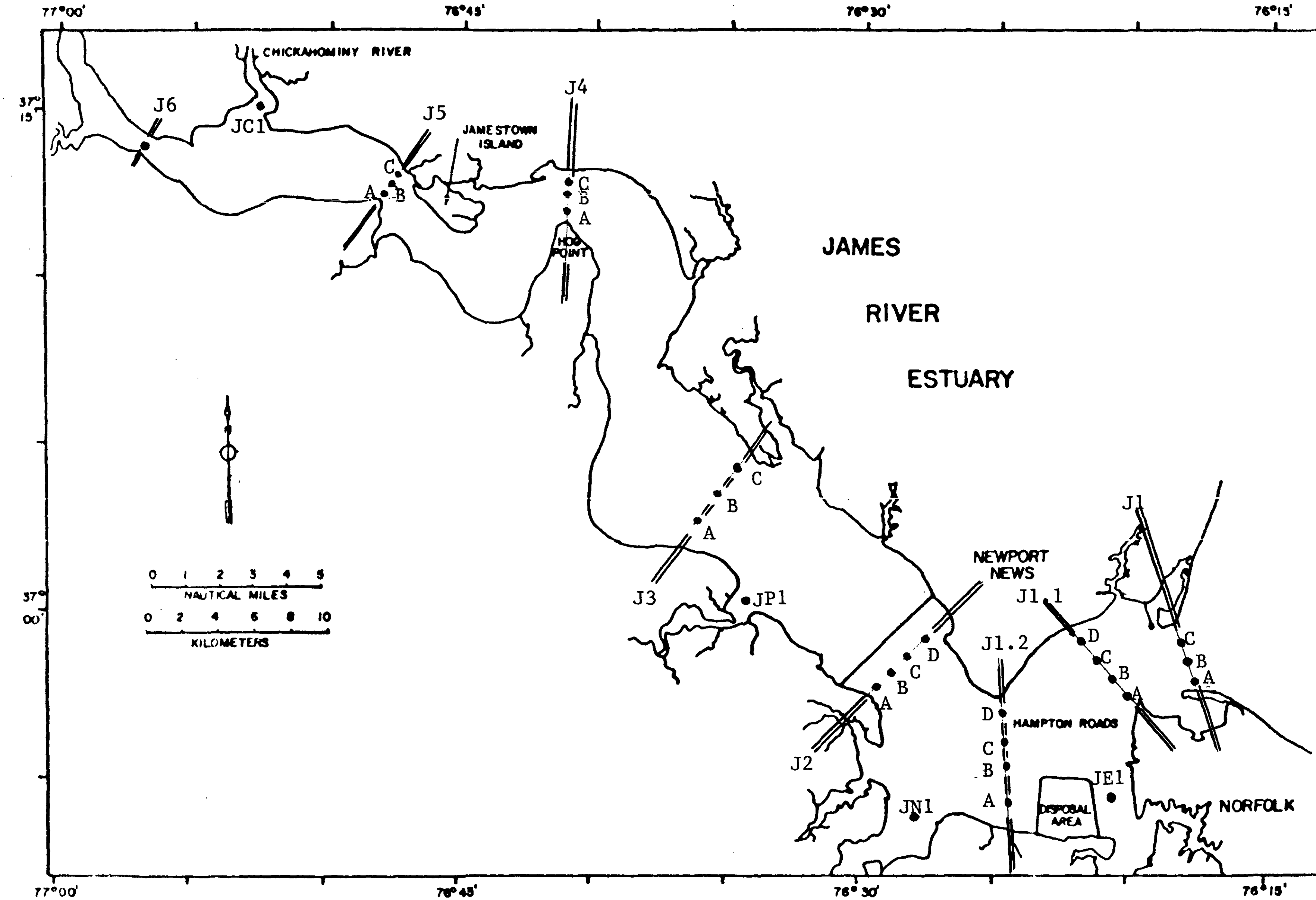


Figure 5. Intensive survey sampling stations.

JAMES RIVER
Average DO - HWS

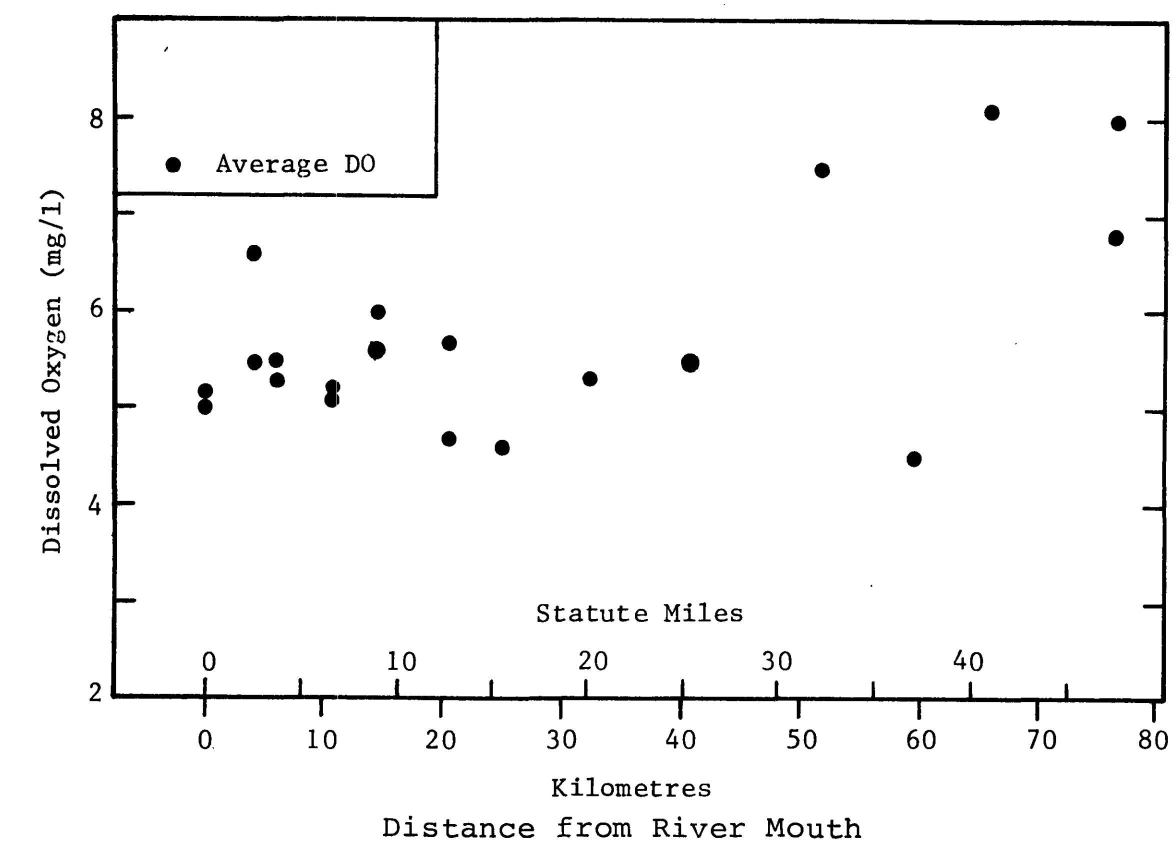


Figure 6. Dissolved oxygen values at high water slack, August 24, 1976.

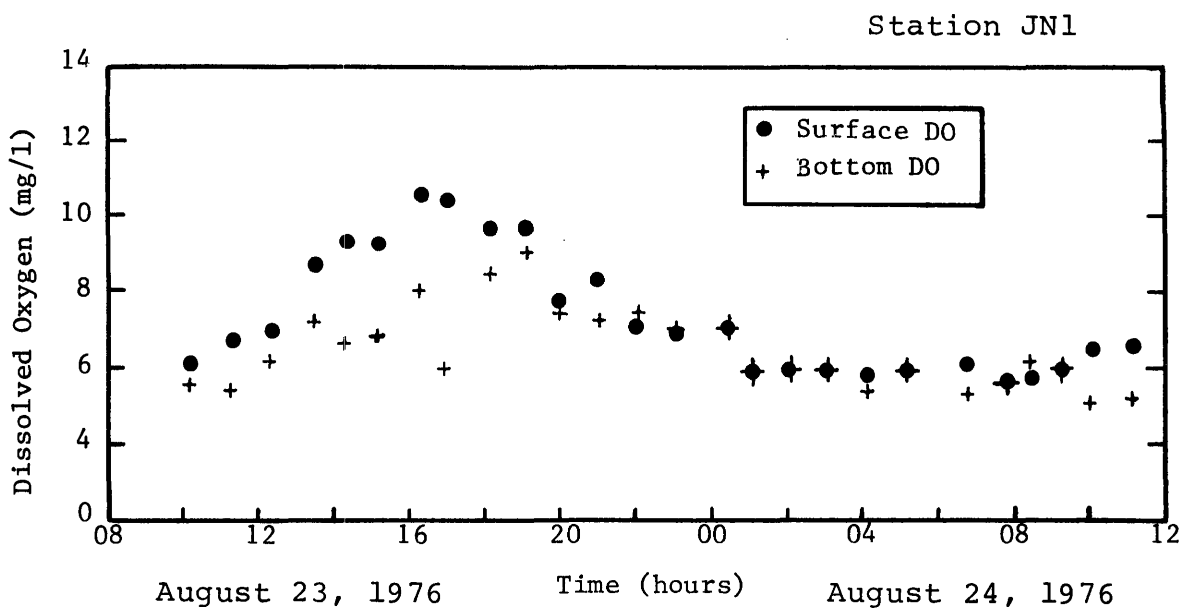


Figure 7. Dissolved oxygen variation at the mouth of the Nansemond River in August, 1976.

late afternoon, near the end of the daylight period when photosynthesis occurs. Minimum DO's occur near dawn since the phytoplankton respiration continues during the night and gradually reduces DO reserves.

A pool of water with slightly depressed DO's exists in the deep water near the mouth of the river. Dissolved oxygen concentrations between 4 and 5 mg/l frequently were observed at water depths of 10 metres or more at stations JE1 (the mouth of the Elizabeth River) J1-B and C (between Fort Wool and Old Point Comfort) and at J1.1-A and B (off Sewell's Point). Although DO's did decrease slightly with depth, DO values were almost always above 5 mg/l and usually around 6 mg/l or more at and below 10 metre's depth near Newport News Point (1.2-D) and the James River Bridge (J2-C). This pool of water with depressed DO's may be entering the James from Chesapeake Bay since values off Old Point Comfort are low throughout most of the tidal cycle. Although the poorer quality water could be coming from the Elizabeth River, DO levels at station JE1 were not consistently low. Although the origin of this water cannot be determined from the field data, it is reasonably clear that water quality was not severely degraded since the concentrations normally were above 4 mg/l, and that the deep navigation channels near the mouth of the James were the only areas affected.

CBOD (5-day) values ranged from near zero to 5.5 mg/l, with the majority of the measurements between 0.5 and 3 mg/l. UBOD (30-day) levels ranged from 3.7 to 6.2 mg/l, showing close agreement with the shorter tests. NBOD values ranged from 0.6

to 2.3 mg/l, with higher values near the upper portion of the study area and also near the mouth. Low values were observed around kilometres 29 to 39 (mile 18 to 24). This distribution shows that some unoxidized nitrogenous compounds from the Hopewell area are entering the upper end of the study area, and that additional discharges of organic nitrogen occur near the river mouth. The Boat Harbor STP and the Elizabeth River are likely sources for the slightly higher NBOD values observed in Hampton Roads. The generally low values for both CBOD and NBOD result primarily from the physical characteristics of the Lower James, namely strong tidal currents which promote mixing and dispersion and a huge tidal prism which is available to dilute waste streams.

To summarize, dissolved oxygen levels in the estuarine portion of the James were reasonably good in the summer of 1976. A few stations showed marginal levels, but this is probably due to reduced saturation values of oxygen in water that is hot (above 25^{o}C) and salty (around 25 ppt). Prior reports on the James indicate that water quality usually is good in the portion of the river between the Chickahominy and Mulberry Island. Even though there are large discharges of BOD in the Hampton Roads, DO levels there, too, usually are above the state standard. As the various portions of PL92-500, the 1972 Amendments to the Clean Water Act, are implemented, BOD loads upriver (and out of the study area) and within the study area will be reduced. Therefore, one would expect DO values to increase somewhat. This will be tested in the model studies.

III. EUTROPHICATION

Eutrophication is the natural process whereby a water body accumulates nutrients. This process can be greatly accelerated by man's activities, for example, by the discharge of treated wastewaters. In some ways, eutrophication is a beneficial thing: if nutrients were very limited in our rivers and estuaries, there would be little plant life and, therefore, little animal life as well. However, overenrichment also may have serious consequences. Increased nutrient levels are likely to stimulate additional algal growth. In some instances, the densities of algae become so great that they float in mats on the water surface. Dead plants can be washed onto the shore and decay there, causing unpleasant odors. Or the abundant plants will settle to the bottom when they die, depleting dissolved oxygen reserves.

The growth and respiration of plankton also modify the oxygen system by adding a diurnal cycle. During daylight hours, there normally is a net production of oxygen due to photosynthesis, and DO levels in the water column rise until around dusk when the sun sets. At night, there is a net loss of oxygen since the algae continue to respire but are not producing oxygen. Consequently, DO levels fall until around dawn when the sun rises again. If algal densities are great, the daily variation can be great with maximum DO values well above 10 mg/l and minimum values approaching zero. Although the daily average DO may be well above water quality standards, the values at night can be well below desired levels.

When nutrient levels increase, the species composition of the algal community also may shift. This change can be important if there is a reduction in the species preferred by shellfish or other aquatic organisms. The production of commercially important shellfish or finfish could actually decline at the same time that algae biomass was increasing.

The degree of eutrophication in an estuary is difficult to assess. There are no water quality standards for nutrient levels or algal densities. Nutrient concentrations in the water column will vary with freshwater discharge of the river, natural inputs and man's waste discharges. Frequently, large amounts of nutrients are stored in the bottom sediments and can be released when a storm causes resuspension of the fine particles. Phytoplankton growth depends on water temperature, nutrient availability and many other factors. If one essential element is lacking, growth will be inhibited. Despite all of these difficulties, it is necessary to review past and present data to see if any trends exist.

Brehmer and Haltiwanger (1966) studied the Tidal James from May, 1965 to May, 1966. They concluded that "the fresh-water tidal James River is highly enriched with phosphorus". When freshwater discharge was low, the phosphorus values decreased in the downriver direction, probably due to biological uptake and sedimentation. They noted that "during the period from July through December, 1965 the total phosphorus in the water column increased from the transition zone to the mouth. This was largely the result of an increase in SRP (Soluble

Reactive Phosphorus) form in the water column at the estuarine stations." They also studied nitrogen forms in the estuary and noted that the river was enriched with nitrogen not only from municipal treatment plant effluents but also by the industries located near Hopewell. Inorganic nitrogen concentrations were high, but were utilized by the phytoplankton in the freshwater reach below Hopewell. The freshwater plankton died when they reached saline waters, but the authors were not able to observe increased nitrogen levels downriver in the estuary, which they had presumed would result from decomposition of the plankton cells. Phytoplankton populations in the freshwater portion of the river were sufficiently high that they "adversely affected the aesthetic value of the water and produced environmental degradation". For the estuarine portion of the river, algal levels were generally quite low (Brehmer and Haltiwanger, 1966).

In the "3C Report" (Planning Bulletin 217-B) it was shown that there was a peak in organic nitrogen around river mile 45 (near the Chickahominy River mouth) with peaks for ammonia-nitrogen and nitrate-nitrogen following in the reaches slightly downriver. This occurs because organic matter is broken down into ammonia, which in turn is oxidized to nitrite and then nitrate. It is stated that "the source of nitrogen for this peak is in the vicinity of the confluence of the Appomattox and James River (RM77)." The profile for the amount of nitrogen in bottom sediments is generally similar to that for the water column. Particulate phosphorus showed a somewhat similar trend, but orthophosphate was rather uniform throughout the tidal portion of the river.

The 1975 Water Quality Inventory (SWCB) showed generally decreasing levels of nutrients, with the exception of orthophosphate, between 1967-71 and 1972-74. Total phosphorus was in the range 0.1-0.14 mg/l below Hopewell to the river mouth. Orthophosphate was on the order of 0.8 mg/l for the entire tidal portion of the river. Total Kjeldahl nitrogen showed an improving trend and ammonia showed a marked improvement for the latter period. Nitrate concentrations were at or below the "limiting algae productivity concentration level (0.3 mg/l)" except just below Hopewell.

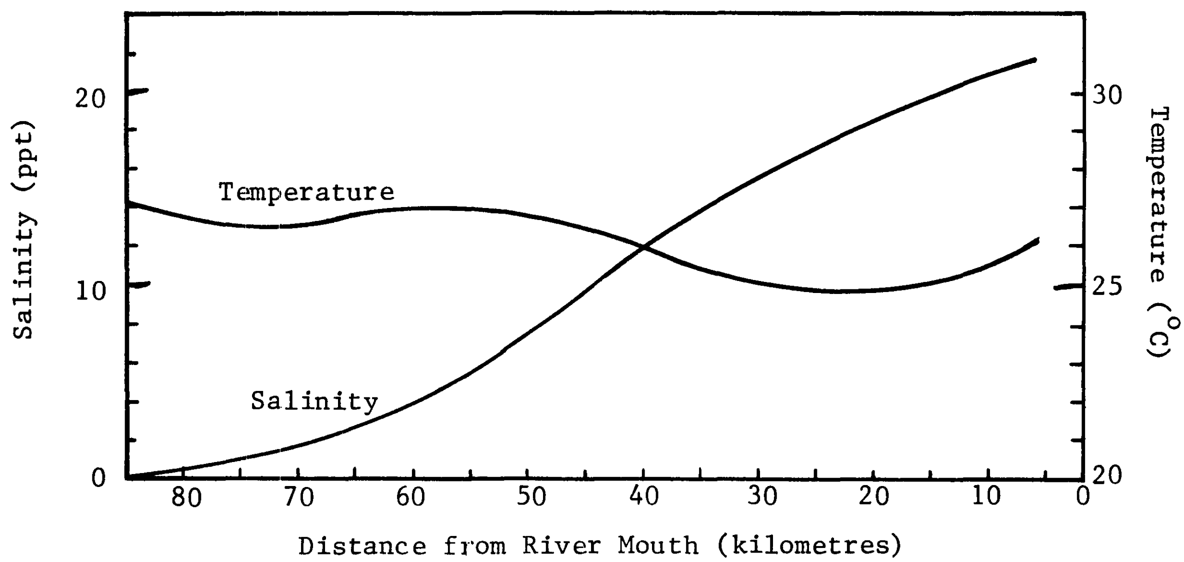
A. 208 Field Survey Results

The July, 1976 intensive survey included measurement of both nitrogen and phosphorus species as well as chlorophyll "a", one measure of phytoplankton density. Most transects included 3 or 4 stations across the width of the estuary, see Figure 5, with samples drawn from several water depths at each station. Data from the survey are presented in graphical form in Appendix B. Longitudinal profiles have been constructed for several water quality measures and are presented in the text. Data were averaged both over the depth and width of the river as well as the duration of the sampling period. These figures, therefore, show qualitative trends, and should not be used for precise quantitative analyses.

In Figure 8 one can note that virtually the entire study area had brackish water. Salinities were on the order of 0.15 parts per thousand (ppt) at stations J6 and JC1, and 1 ppt at station J5. In Hampton Roads the salinities were at or above 20 ppt. The maximum salinity observed was 29 ppt at station J1C, located at the mouth of the river, and was measured near the bottom at 17 metres.

Chlorophyll "a" concentrations were uniformly low. A very slight decrease occurred in the upper reaches of the study area. Data from a more or less concurrent study (Rosenbaum, et al., 1977) show chlorophyll "a" levels ranging between 8 and 20 μg/l in the segments around 120 kilometres above the river mouth, with values decreasing down to around 4 μg/l at kilometre 80. This decreasing trend is carried over into the 208 Study Area, where it probably is reinforced by the presence of saline waters, which would kill freshwater plankton. From transect J5 to J2 (just below the James River Bridge) values were very low (below 5 μg/l). In Hampton Roads, concentrations rose to about twice the level upriver but still were less than 10 μg/l. Values observed at the mouths of Elizabeth and Nansemond Rivers were somewhat higher, indicating that these tributaries were either more highly enriched or provided better conditions for growth than those existing in Hampton Roads.

Nitrogen and phosphorus concentrations are shown in Figure 9. The most obvious trend is that both total nitrogen and total phosphorus decrease in the downriver direction, except that there are slight increases in the Hampton Roads area.



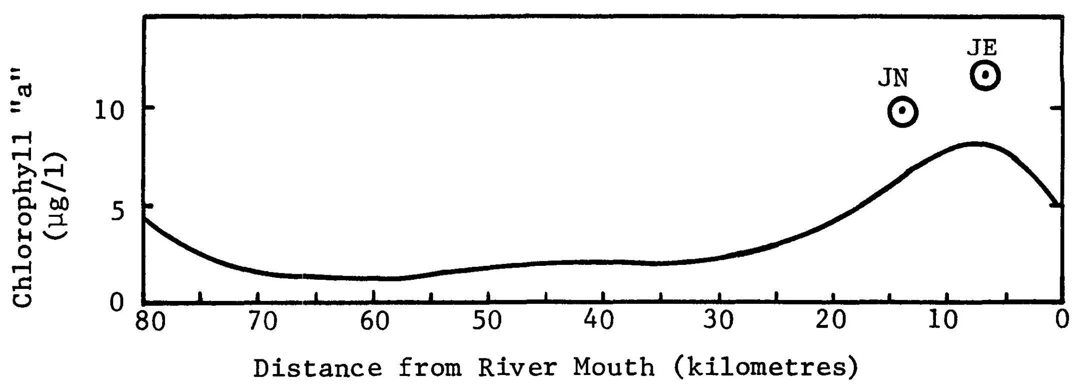


Figure 8. Temperature, salinity and chlorophyll "a" profiles for the James River.

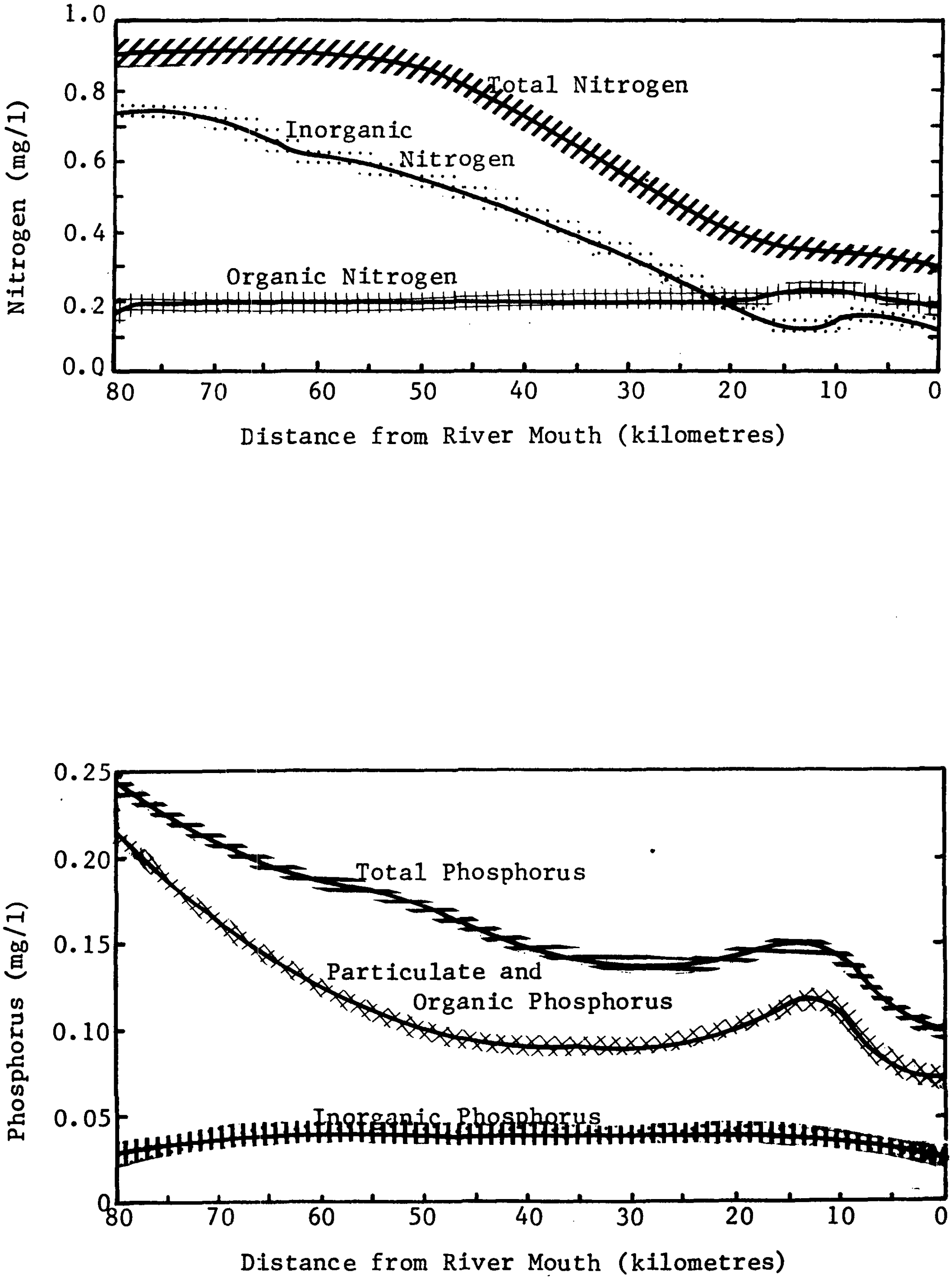


Figure 9. Longitudinal profiles for nitrogen and phosphorus species.

Total nitrogen for these calculations has been taken as the sum of Total Kjeldahl Nitrogen (TKN) plus Nitrite-nitrogen (NO_2) plus Nitrate-nitrogen (NO_3). The decrease in total nitrogen is due primarily to a decrease in inorganic forms, and specifically to nitrite and nitrate forms. Inorganic Nitrogen was calculated as the sum of ammonia-nitrogen (NH_4) plus nitrite and nitrate nitrogen. Ammonia concentrations were reasonably constant throughout the study area at about 0.1 mg/l. The high nitrite-nitrate readings at the upper end of the area indicate that the wastes from Hopewell had been nearly completely oxidized by the time they reached the Chickahominy River mouth. No definitive explanation for the decrease in nitrite and nitrate is available. It is possible that denitrification is occurring, which would result in production of nitrogen gas which could pass off into the atmosphere. Additionally, there would be some biological uptake, but probably not enough to significantly alter the concentrations since phytoplankton densities were uniformly low. Finally, dilution could be occurring since the river broadens greatly below the Chickahominy, plus "new water" enters from the Bay and travels upriver along the bottom. For the salinity stratification which existed at that time, it is likely that this upriver flow of Bay water was three or four times as great as the freshwater flow, which was about 3,000 cubic feet per second at Richmond during early July. It is likely that all these features were important in reducing the nitrite-nitrate levels, plus other factors which are not apparent from the data.

Organic nitrogen (TKN - NH_4) levels were rather constant along the river and were around 0.2 mg/l. A slight increase in the Hampton Roads area probably can be accounted for by the higher algal levels there.

Total phosphorus concentrations showed a similar downriver decline, but the impact of discharges in Hampton Roads is more obvious. Inorganic phosphorus concentrations were relatively constant at about 0.04 mg/l. The actual measurement made was for Soluble Reactive Phosphorus. The difference between the Total Phosphorus (TP) measurements and the Soluble Reactive Phosphorus (SRP) values incorporates both phosphorus included in organic matter as well as that bound to particulate matter, such as clay minerals. If we assume that the Organic Phosphorus was reasonably constant, paralleling the constant Organic Nitrogen concentrations, the decrease in total phosphorus would occur primarily due to reductions in the particulate phosphorus. This decrease could occur due to sedimentation. Suspended solids concentrations tend to be quite high in the transition zone between freshwater and saltwater, and since turbidity decreases downriver of the transition zone, some settling must be occurring. These particles probably are remove phosphorus as well.

In a study of the upper Chesapeake Bay, the Annapolis Field Office of the Environmental Protection Agency (Clark, et al, 1973) recommended that chlorophyll "a" concentrations be limited to 40 μg/l. In order to accomplish this goal, it was calculated that Total Inorganic Nitrogen and Total Inorganic Phosphorus levels should be at or below 0.8 mg-N/l and 0.04 mg-P/l respectively. Comparison of these levels with those observed in the study area show that SRP is approximately equal to the recommended upper limit all along the river. Inorganic nitrogen, on the other hand, is close to the recommended upper limit at the upper end of the study area, but decreases to much lower levels downriver. In other words, nitrogen is more likely to be limiting algal growth than is phosphorus. Since chlorophyll "a" values were far below the 40 μg/l level, it is likely that other factors, such as turbidity or grazing by zooplankton, are controlling phytoplankton growth.

To summarize, total nitrogen and phosphorus levels decrease in the 208 study area, probably due to denitrification, sedimentation and dilution. The input of these elements from the freshwater tidal portion of the James appears to be large. Nutrient concentrations near the mouth of the Chickahominy River are at levels recommended as the upper limits for the upper portion of Chesapeake Bay. Nonetheless, chlorophyll "a" levels were very low, indicating that factors other than nutrient availability are controlling growth. Despite the large volumes of dilution water available, the discharges to Hampton Roads did result in increases for several nitrogen and phosphorus species. Upgrading primary treatment plants to secondary levels is not likely to alter nutrient inputs, but some industrial loads could be reduced by implementation of "BPT" and/or "BAT" treatment practices. At present it appears that there is no reason to recommend nutrient removal since other factors (such as turbidity, mixing, zooplankton grazing, etc.) limit phytoplankton to low densities.

IV. BACTERIAL QUALITY OF THE WATER

The bacterial quality of the waters in the Commonwealth are monitored by public health agencies as well as the State Water Control Board. In general, coliform bacteria have been used as "indicator organisms" - organisms whose presence is assumed to indicate pollution of the area by fecal wastes. In recent years, there has been a trend towards use of the Fecal Coliform group of bacteria in place of the more general Total Coliform grouping, since the fecal coliforms are believed to be a better indicator of the type of pollution that is of concern. Water quality standards frequently are written with explicit levels for both total and fecal coliforms. Determinations of coliform densities involve innoculating tubes of culture media with the sample water at various dilutions. The result is the "Most Probable Number" (MPN) of bacteria existing in the water sample.

The most stringent of the bacterial standards is that set for shellfish growing areas, since shellfish tend to accumulate bacteria to levels many times in excess of that encountered in the water column. For approved growing areas Fecal Coliform counts should not exceed 14 MPN/100 ml and Total Coliform levels should be below 70 MPN/100 ml. Fecal coliform limits for primary and secondary contact recreational waters are 200 and 1000 MPN/100 ml respectively. Since the shellfish standard is more restrictive, the discussion which follows will deal primarily with this limit.

Extensive surveys of the bacterial quality of the waters in Hampton Roads have been made by state and federal agencies beginning in 1914 (Smith, 1950). Even at that time, water quality in Hampton and Mill Creeks and in the Elizabeth River was sufficiently poor to preclude direct marketing. It was concluded that shellfish could be taken safely from most of Hampton Roads, but the officials warned that additional condemnations could result if unchlorinated waste discharges were allowed to continue. Another survey in 1926 "resulted in restricting the taking of market shellfish from the entire northern section of Hampton Roads and its tributaries from Old Point Comfort to a point northwest of Hilton Village" (Smith, 1950).

Routine monitoring surveys plus the results of an extensive survey of Hampton Roads were reviewed in 1933 and 1934. The resulting report recommended that interceptor sewers and treatment plants be constructed. Several years later, the Hampton Roads Sanitation District was established by an act of the General Assembly. Progress towards implementation of the recommendations of the 1934 report both by HRSD and the City of Portsmouth were interrupted by the war. However, by the spring of 1949 the Pinners Point plant of the City of Portsmouth was in operation, as were the Boat Harbor, Army Base and Lamberts Point plants of the sanitation district. The State Department of Health and the U. S. Public Health Service conducted a major survey of the Hampton Roads area in 1949-50 to evaluate the new conditions resulting from a significant increase in sewered population as well as the operation of the treatment plants.

At the end of the 1949-50 study (Smith, 1950), it was concluded that the bacterial quality of the waters was better than it had been in 1934, despite an increase in population served. Poor water quality did exist near the eastern end of the James River Bridge due to the release of poorly treated wastewaters. Further improvements were projected when other raw discharges would be eliminated and if existing plants were carefully operated. The major unresolved hazard was the discharge of raw sewage from commercial and naval vessels in the harbor.

The 1975 water quality inventory showed that fecal coliform levels had decreased, and that the contact recreation standards were violated less frequently than in earlier years. Localized areas of poor water quality were noted for:

- the Elizabeth River
- the Nansemond River
- the Pagan River
- the James near the eastern end of the James River Bridge, due to the discharge of raw sewage from a pumping plant into "Government Ditch", with eventual discharge to the James.

A. 208 Field Survey Results

Fecal coliform analyses were made for samples collected during the intensive survey in July, 1976. In general, the bacteriological quality of the water was high. Most measurements were less than 10 Fecal coliforms per 100 millilitres of water, and many samples had counts below the detection limit (0.3 MPN/

100 ml). Counts above the shellfish standard were observed near the mouth of the Elizabeth River (stations JE1, J1.1A, B and C), near the James River Bridge (station J2B, C and D) and just above Jamestown Island (stations J5A, B and C). Most of these water samples had counts below 50 MPN/100 ml. The highest value observed was 150 MPN/100 ml.

The source of the bacteria is not known. Nonpoint sources, such as commercial freighters and pleasure craft or stormwater runoff, could be the cause of some of the higher readings. Fecal coliform levels were high also at the time of the 208 intensive survey of the Elizabeth River. The source of the contamination could not be identified which confounded modelling studies (Cerco, 1978). Additional field studies are needed to pinpoint the source(s) of the fecal wastes, assuming that similar distributions occur.

V. SUMMARY AND CONCLUSIONS

Water quality in the estuarine portion of the James River has shown signs of improvement in recent years. The intensive survey conducted in July, 1976 showed generally good quality water. Dissolved oxygen levels normally were well above the 5 mg/l standard, except for the deep waters (below 10 metres) at the mouth of the river. This pool of slightly oxygen deficient waters (DO's ranged upwards from 4 mg/l) could be coming from either the Elizabeth River or Chesapeake Bay. Nutrient loadings to the tidal freshwater reaches of the James result in high levels of nitrogen and phosphorus at the upper boundary of the Hampton Roads 208 Study area. Both total nitrogen and total phosphorus decrease toward the river mouth, with slight increases in the Hampton Roads area. This is due to reductions in nitrite and nitrate nitrogen and particulate bound phosphorus, resulting from dilution, sedimentation and denitrification. No standards for nutrient or phytoplankton concentrations are available to assess the level of nutrient enrichment. Chlorophyll "a" levels generally were low and less than 10 μg/l. Nutrient levels were rather high and sufficient to support a much denser phytoplankton population, indicating that turbidity, zooplankton, grazing, mixing or other factors are controlling algal growth.

The bacterial quality of the waters is generally good, although some samples had fecal coliform counts above the shellfish standards; this occurred near the mouth of the Elizabeth River, near the James River Bridge and just above

Jamestown Island. The maximum count observed was only 150 fecal coliforms/100 ml, which is far below levels required for recreational waters.

In general, the results of the 208 field studies show only a few minor water quality problems in the James River Estuary, at least with respect to dissolved oxygen, nutrient enrichment and bacterial levels. This contrasts with the opinions of many (scientists, conservationists, watermen, sport fishermen and others) who believe that the health of the Lower Tidal James is poor as evidenced by declining production of oysters and other commercially important species. We can only note that earlier studies have found generally good water quality too. However, another theme which was repeated in several reports is that control of toxic substances is probably the most important management need for the estuarine portion of the James. Since the Hampton Roads Water Quality Agency was not permitted to include toxic substances in its field and modelling studies, there are no new data to corroborate or disprove this latter conclusion. The generally positive findings of the 208 program do suggest that toxic substances or some other aspects of water quality are more likely causes of environmental degradation than discharges of BOD, nutrients or bacteria.

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APPENDIX A. Field Program

Sampling Station
Map of Stations
Analytical Methods

JAMES RIVER SAMPLING STATION

Parameter	Intensive Survey			2 Slack Water Surveys (22 stations)		
	Sampling Period	Sampling Frequency	Sampling Depths	Sampling Period	Sampling Frequency	Sampling Depths
Temperature	25 hrs.	hourly	T,M,B	SBE,SBF	summer	T,M,B
Salinity	25 hrs.	hourly	T,M,B	SBE,SBF	summer	T,M,B
DO	25 hrs.	hourly	T,M,B	SBE,SBF	summer	T,M,B
BOD_5	25 hrs.	every 3 hrs.	T,B*	SBE,SBF	summer	T,B**
Fecal Coliforms	25 hrs.	every 3 hrs.	T,B	SBE,SBF	summer	T,B
N	25 hrs.	every 3 hrs.	T,B	SBE,SBF	summer	T,B
Total P	25 hrs.	every 3 hrs.	T,B	SBE,SBF	summer	T,B
Chlorophyll "a"	25 hrs.	every 3 hrs.	T,B	SBE,SBF	summer	T,B
Secchi Disk	25 hrs.	every 3 hrs.	T,B	SBE,SBF	summer	T,B

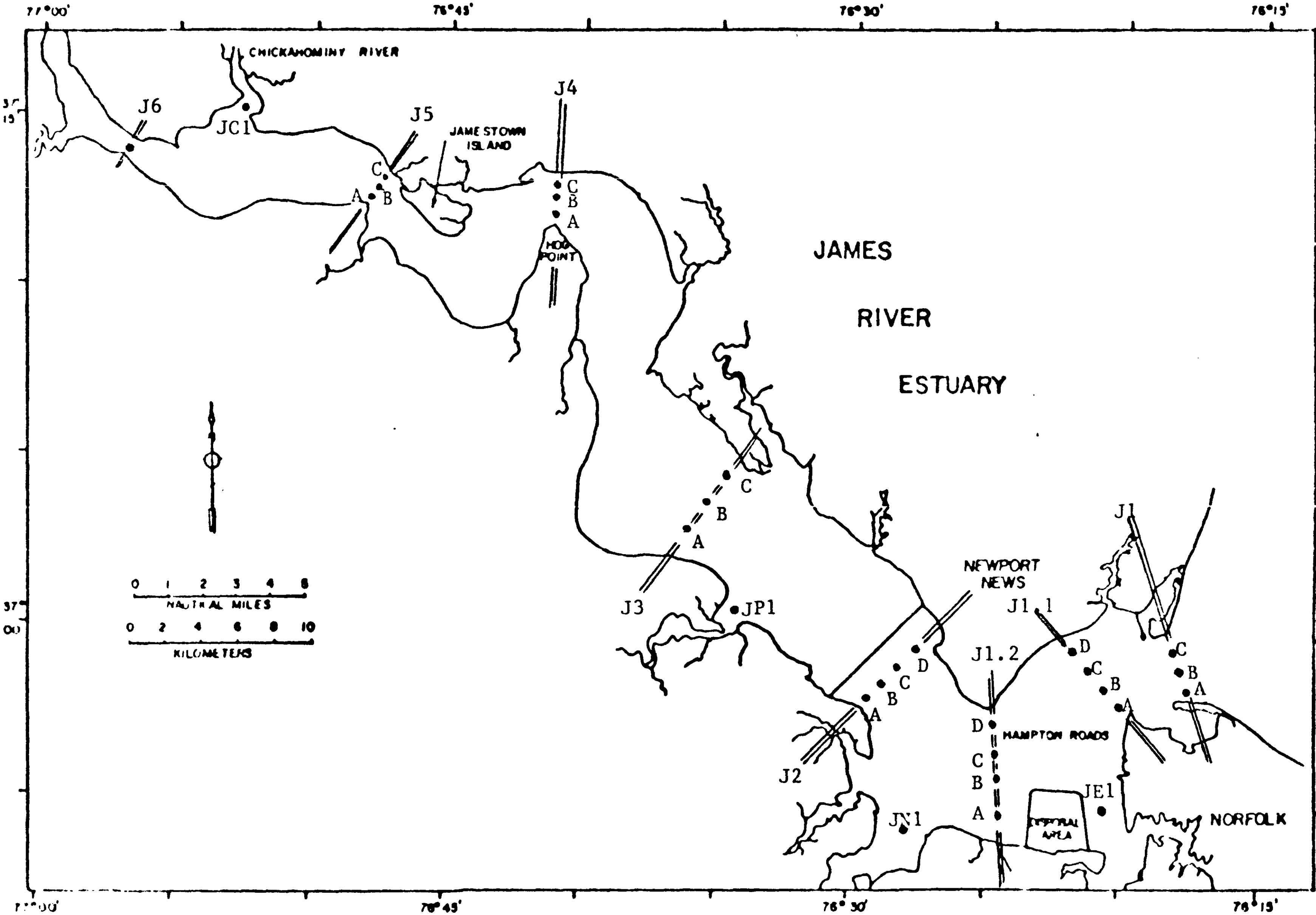
Other Measurements - 7 Stations (slack tide)

UOD	once	once	M
Benthal OD	once	once	B
Light/Dark Bottle	once	once	T

* 15 Intensive Survey Stations taken at mid-depth only
** 2 Slack Water Stations taken at mid-depth only

T = 1 meter below surface
M = mid-depth
B = 1 meter off bottom

SBE = slack water before ebb
SBF = slack water before flood



77°00'
76°45'
76°30'
76°15'
37°15'
37°00'
CHICKAHOMINY RIVER
J6
JC1
J5
JAMESTOWN ISLAND
J4
HOG POINT
JAMES RIVER ESTUARY
J3
JP1
NEWPORT NEWS
J1
J1.1
J1.2
J2
HAMPTON ROADS
JE1
JN1
NORFOLK
NAUTICAL MILES
KILOMETERS

ANALYTICAL METHODS

1) Temperature	a.	Interocean CTD Model 513/514. Accuracy $\pm 0.1^{\circ}C$. Calibrated before and after every intensive field survey.
	b.	Applied Research Austin Model ET 100 Marine. Accuracy $\pm 0.1^{\circ}C$. Calibrated before and after every intensive field survey.
2) Conductivity	a.	Interocean CTD Model 513/514. Accuracy ± 0.5 millimhos. Calibrated before and after every intensive field study.
3) Salinity	a.	Bottle grab sample analyzed in the laboratory on an Industrial Instrument Laboratory Salinometer Model RS7A. Accuracy ± 0.1 ppt. Standardized every day before using.
	b.	Interocean CTD Model 513/514. Temperature and conductivity readings used in a CBI equation to calculate salinity. Accuracy ± 0.05 ppt.
4) Dissolved oxygen	a.	Bottle grab sample pickled in the field and titrated in the laboratory using the azide modification of the Winkler method. Accuracy ± 0.1 mg/l. Standardized every day before using.
5) <u>Bacteria</u>		
Fecal coliforms		SM 908 Multiple Tube Fermentation Technic for Members of the Coliform Group. 908C - Fecal coliform MPN Procedure.

SM = Standard Methods for the Examination of Water and Wastewater, 14th Edition, 1975, APHA-AWWA-WPCF.

EPA = Methods for Chemical Analysis of Water and Wastes, 1974 U. S. EPA, National Environmental Research Center, Cincinnati, Ohio.

6) Biochemical Oxygen Demand

5-day or 30-day, 20°C, Carbonaceous BOD	SM 507 Biochemical Oxygen Demand. EPA #310 - BOD. Modified: Nitrification inhibited with pyridine.

7) Nitrogen

Ammonia-N	SM 418C Nitrogen (Ammonia)-Phenate Method. EPA #610 Automated Colorimetric Phenate Method.
Nitrate-N	SM 419C - Nitrate-Nitrogen-Cadmium Reduction Method.
Nitrite-N	SM 420 - Nitrite-Nitrogen. EPA #630 - Automated Cadmium Reduction Method for Nitrate-Nitrite Nitrogen.
Total Kjeldahl Nitrogen	SM 421 Organic Nitrogen. EPA #625 - Total Kjeldahl Nitrogen.

8) Phosphorus

Total Phosphorus	SM 425 Phosphate - Total Filtrable and non-filtrable phosphate. 425C III - Persulfate Digestion Method. EPA #665 - Total Phosphorus.
Orthophosphate	SM 425 Filtrable (dissolved) orthophosphate. EPA #671 - Dissolved ortho-phosphate.

9) Benthal Oxygen Demand

The apparatus used for determining the benthic demand consisted of a cylindrical chamber fitted with a self-contained battery-powered stirrer and a dissolved oxygen probe (YSI-15) plugged into the top of the chamber. The chamber was open at the bottom and weighted so that it settled into the sediment and effectively isolated a unit bottom area and a parcel of over-lying water. The stirrer provided gentle agitation to keep water moving past the membrane on the probe without stirring up the

9) Benthal Oxygen Demand (cont'd)

sediment. The dissolved oxygen concentration of the trapped water parcel was monitored for a sufficient length of time to obtain a dissolved oxygen versus time slope (m). The bottom oxygen demand was calculated according to the following formula:

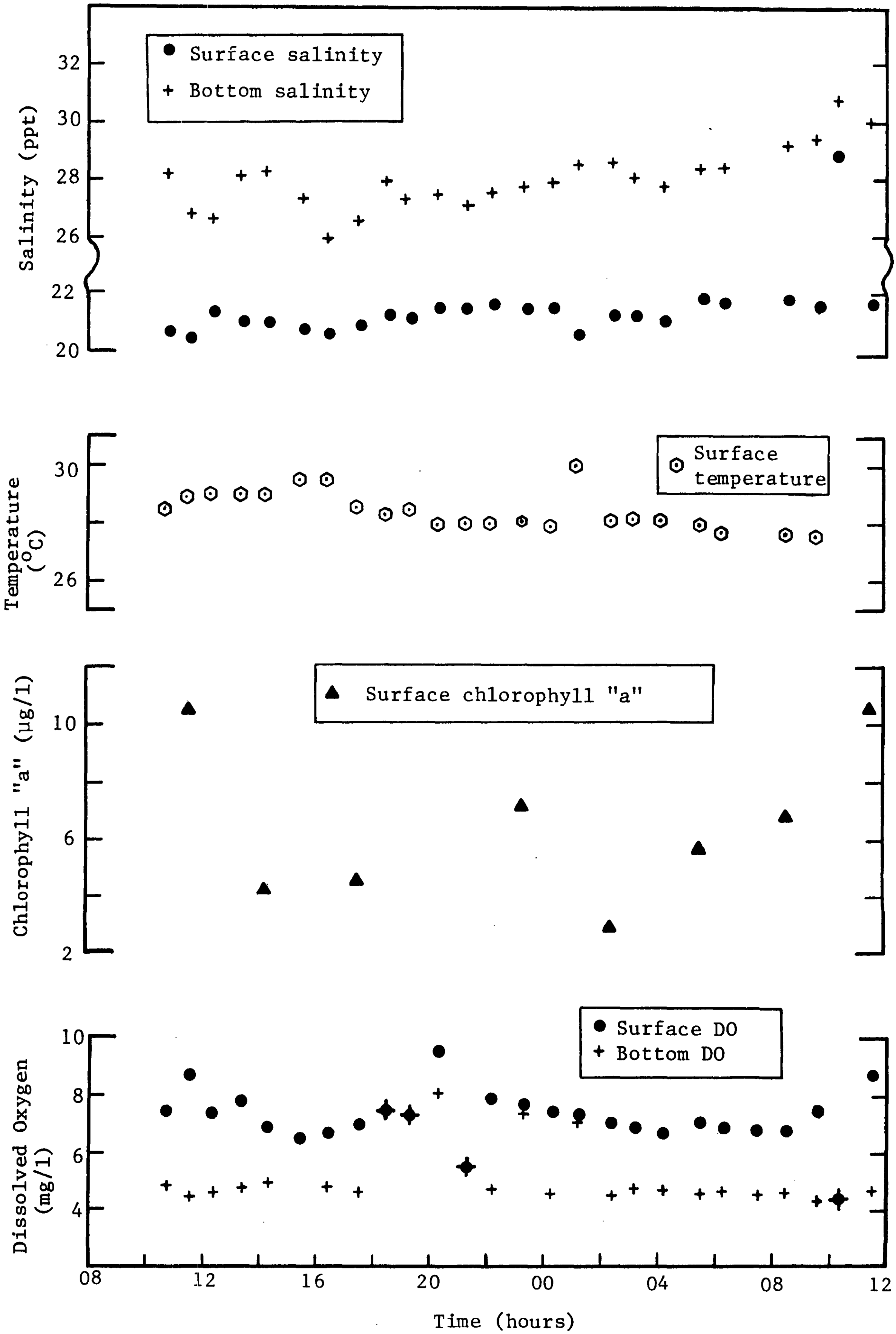
$$BD\left(\frac{gm}{m^2 \cdot day}\right) = \frac{m\left(\frac{mg}{\ell \cdot hr}\right) H \cdot 24}{10^2}, \text{ where}$$

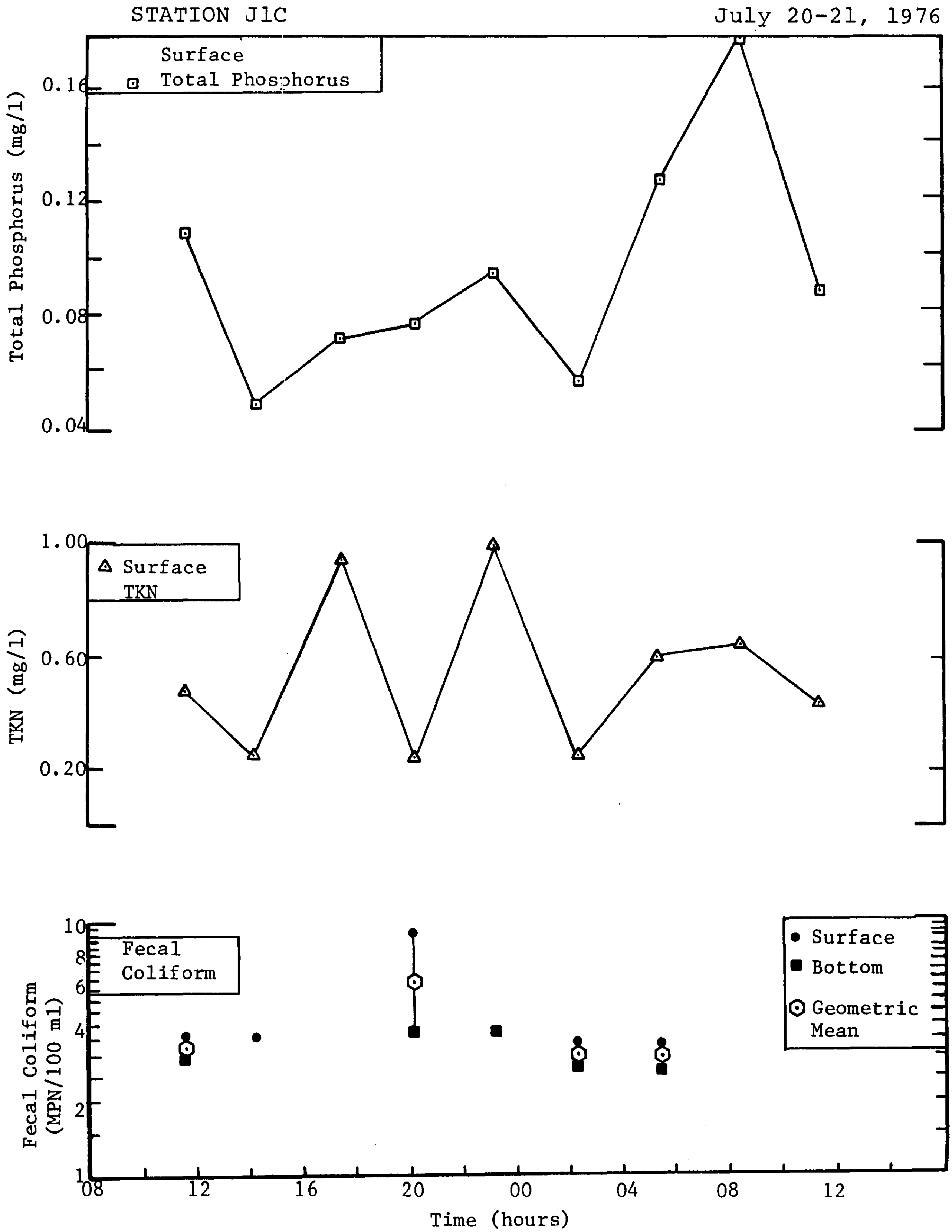
H is the mean depth of the chamber in cm., allowing for the volume displaced by the stirrer.

APPENDIX B. Intensive Survey Data for July 15-16 and July 20-21, 1976.*

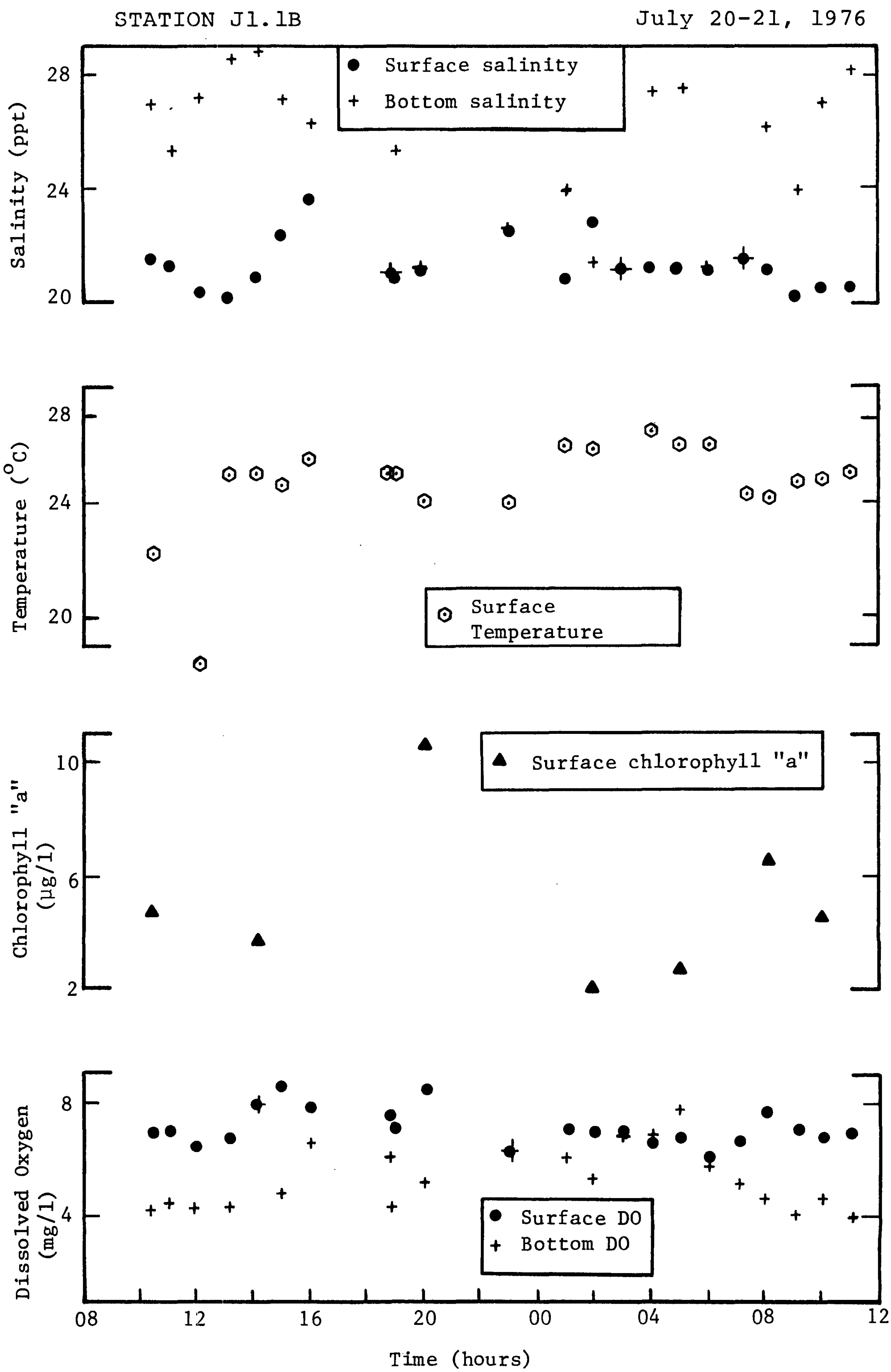
* Computer printouts of the Data for all stations are available for review and use at the Virginia Institute of Marine Science and the Hampton Roads Water Quality Agency office.

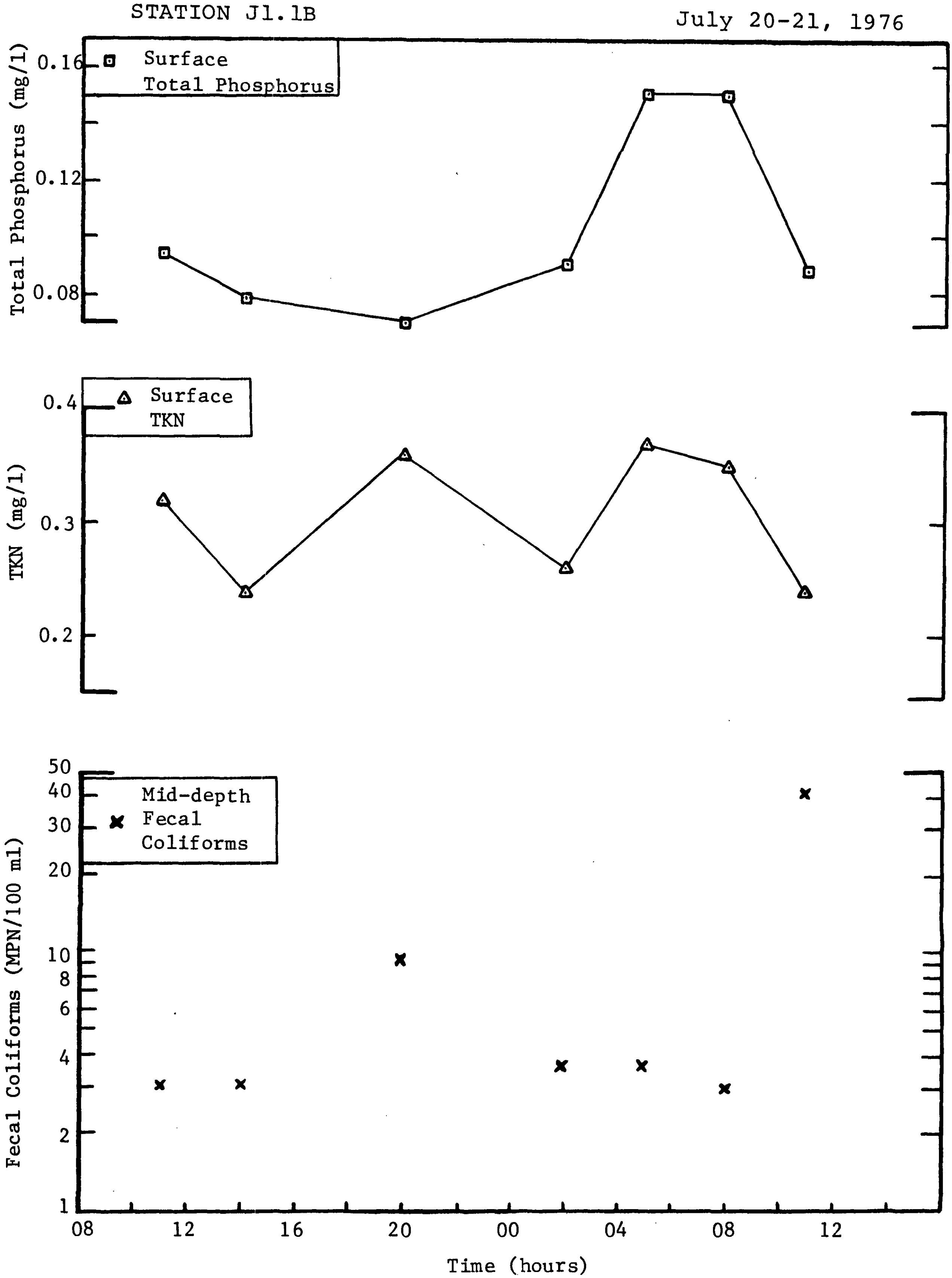
STATION J1C July 20-21, 1976

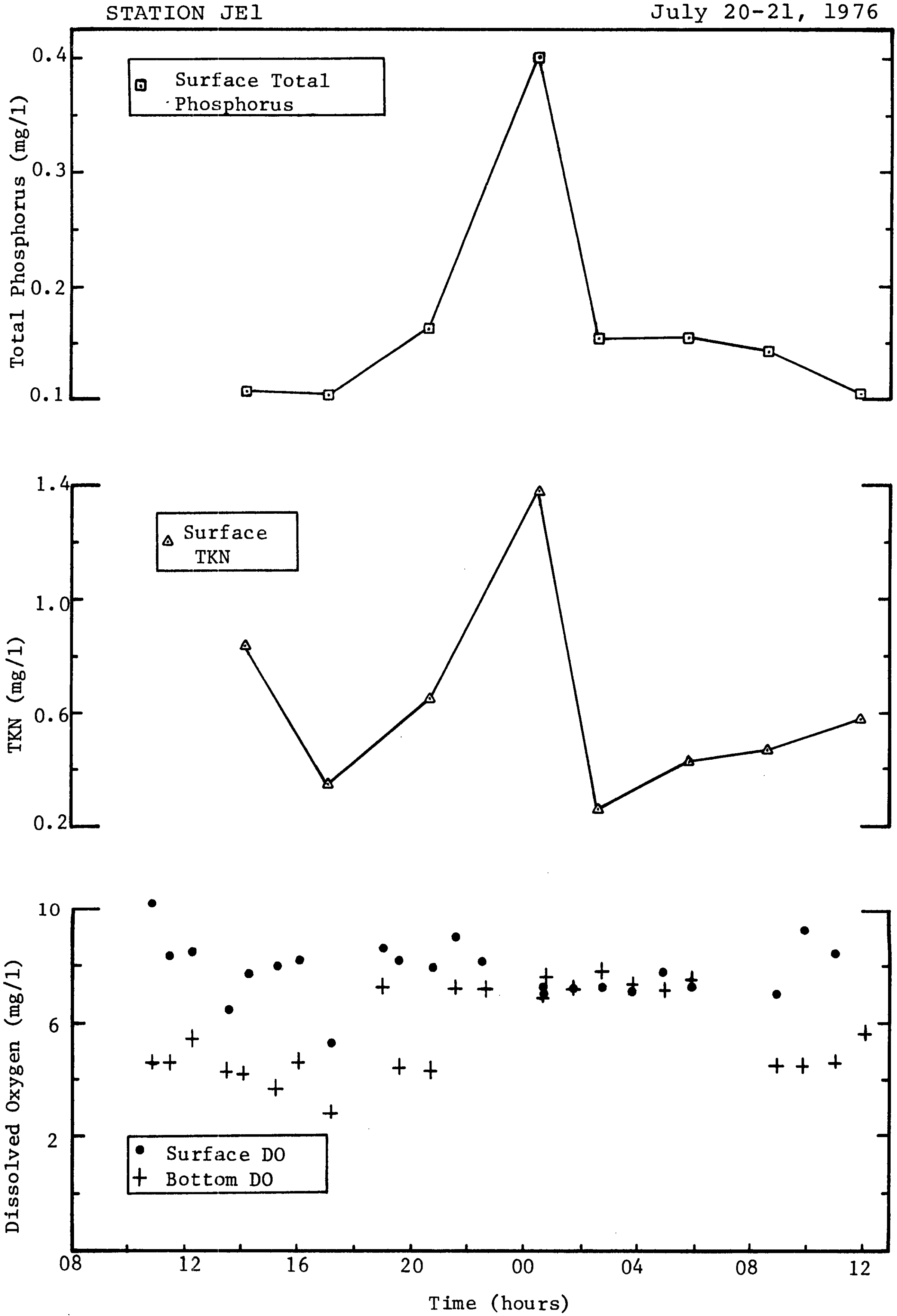


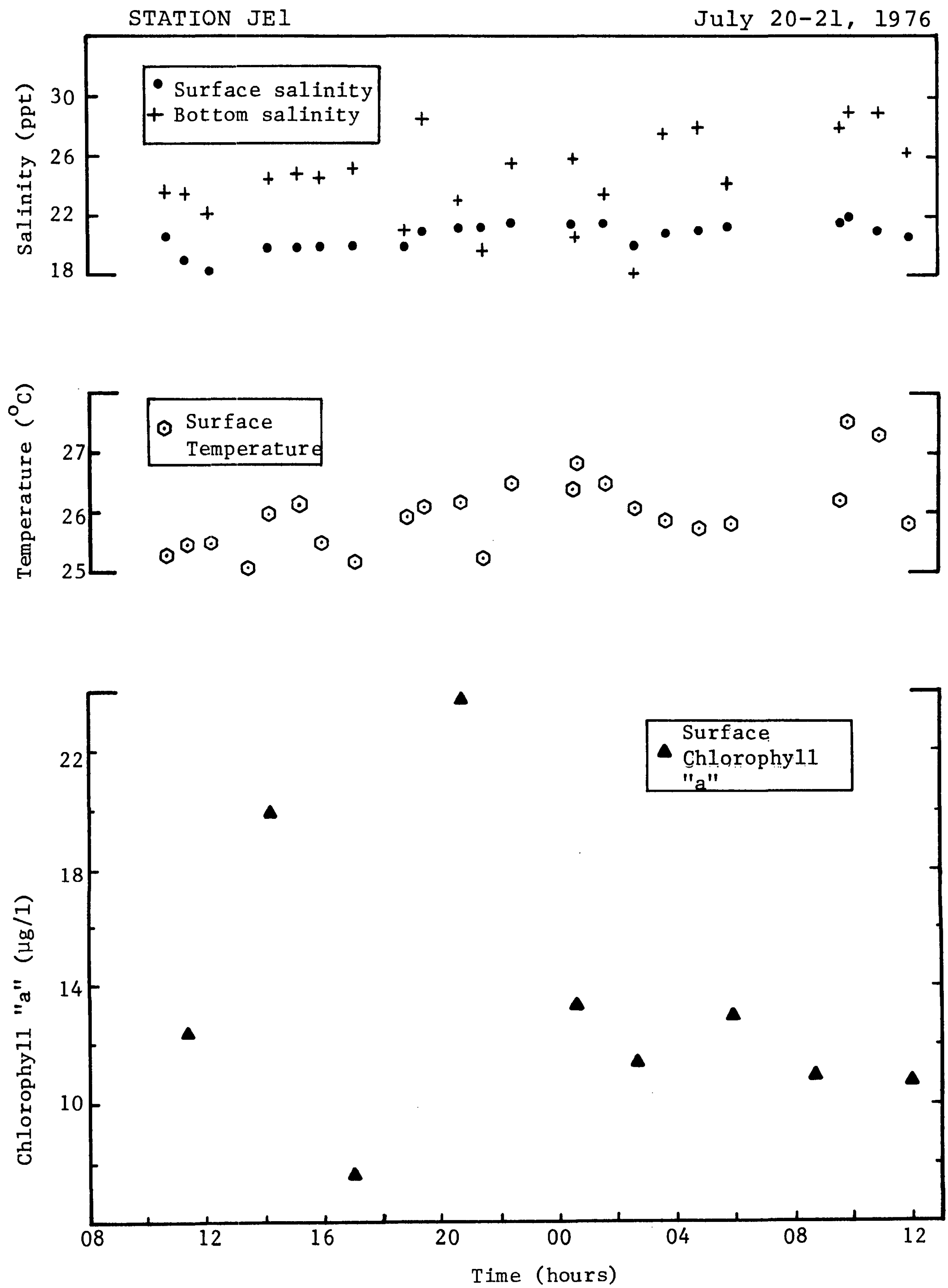


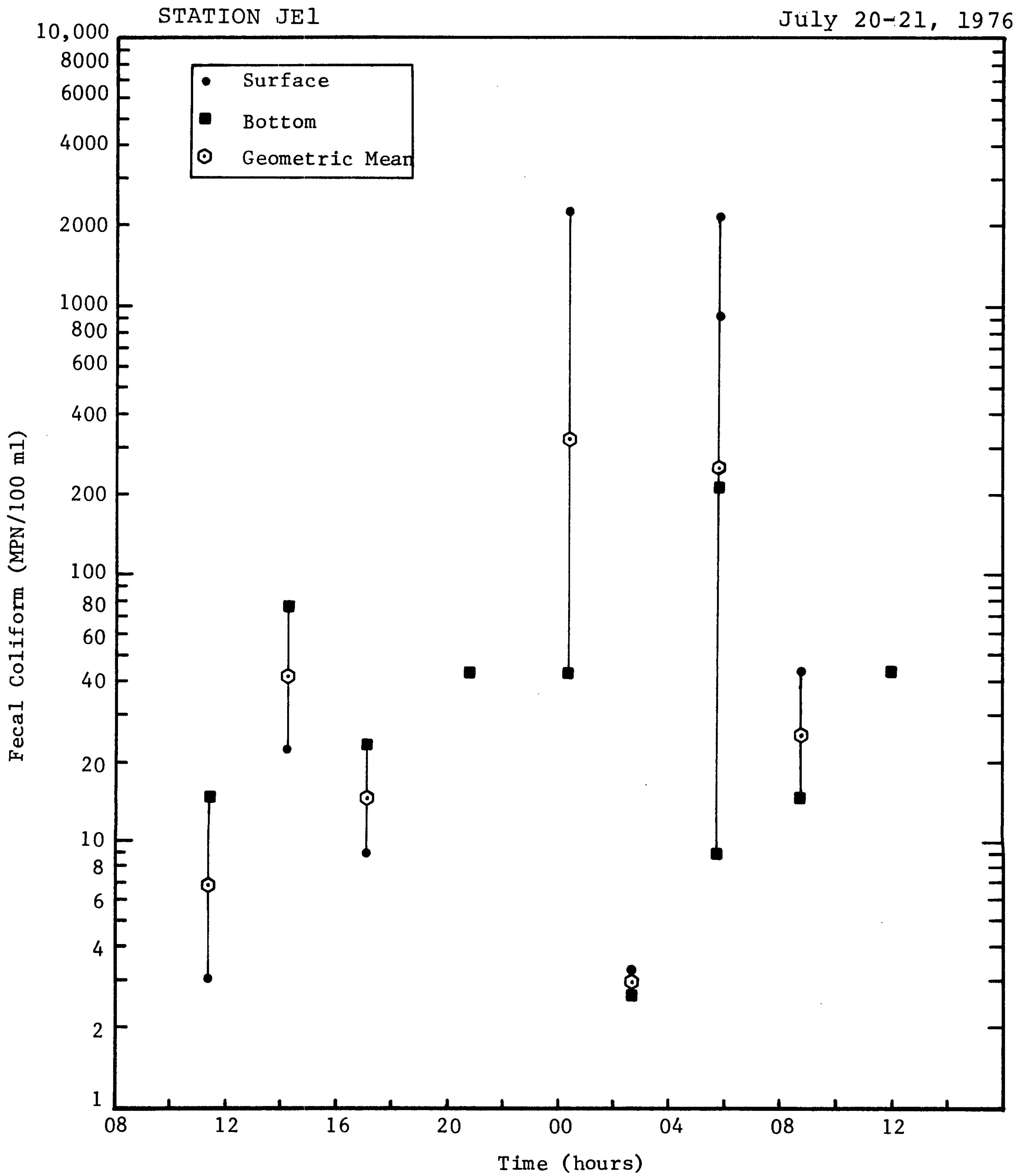
STATION J1C
July 20-21, 1976
Surface
Total Phosphorus
Total Phosphorus (mg/1)
0.16
0.12
0.08
0.04
Surface
TKN
TKN (mg/1)
1.00
0.60
0.20
Fecal
Coliform
Surface
Bottom
Geometric
Mean
Fecal Coliform
(MPN/100 ml)
10
8
6
4
2
1
08
12
16
20
00
04
08
12
Time (hours)

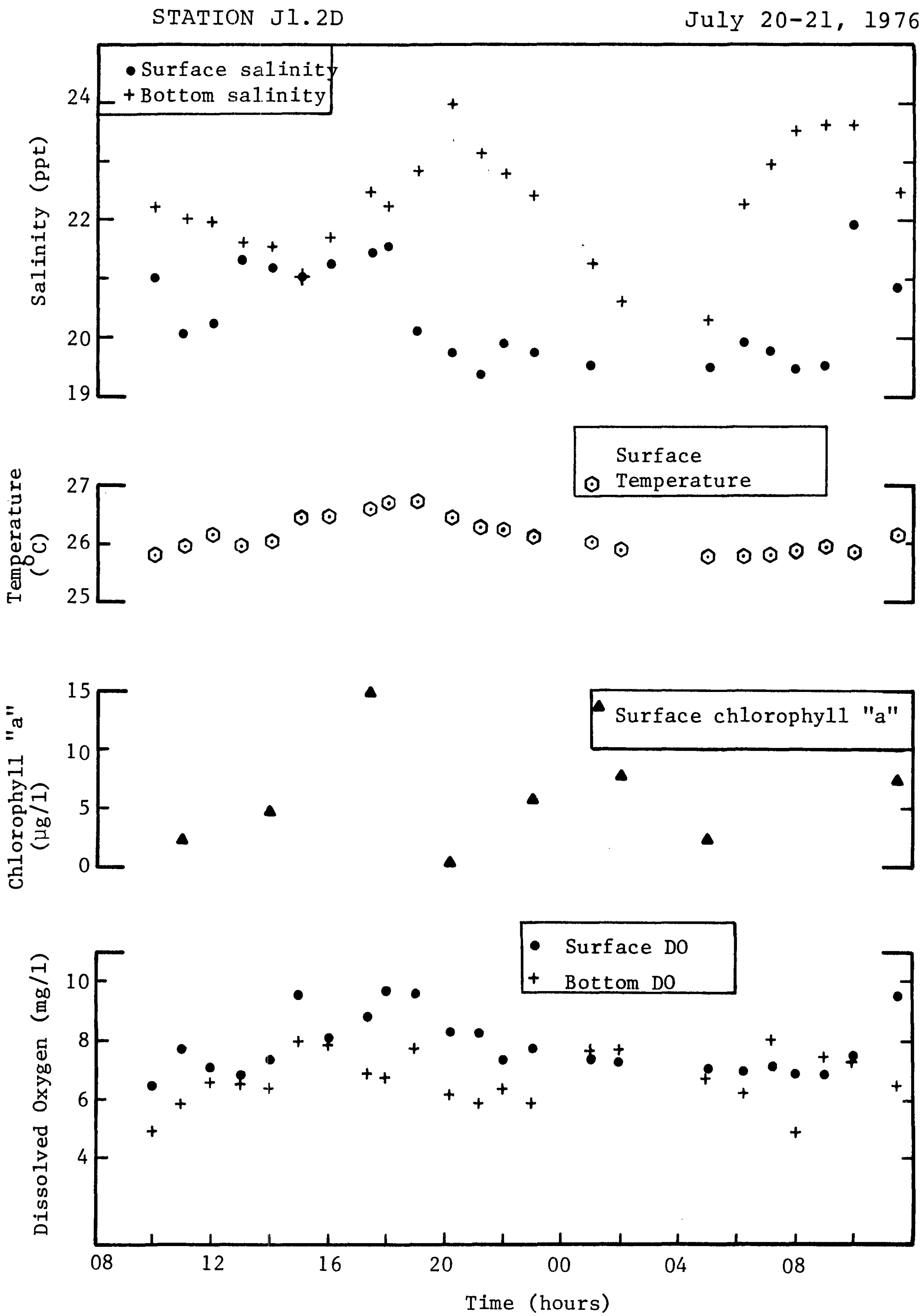

STATION J1.1B
July 20-21, 1976
Salinity (ppt)
Surface salinity
Bottom salinity
Temperature (°C)
Surface Temperature
Chlorophyll "a" (µg/l)
Surface chlorophyll "a"
Dissolved Oxygen (mg/l)
Surface DO
Bottom DO
08
12
16
20
00
04
08
12
Time (hours)


STATION J1.1B
July 20-21, 1976
Total Phosphorus (mg/l)
0.16
0.12
0.08
Surface
Total Phosphorus
TKN (mg/l)
0.4
0.3
0.2
Surface
TKN
Fecal Coliforms (MPN/100 ml)
50
40
30
20
10
8
6
4
2
1
Mid-depth
Fecal
Coliforms
08
12
16
20
00
04
08
12
Time (hours)

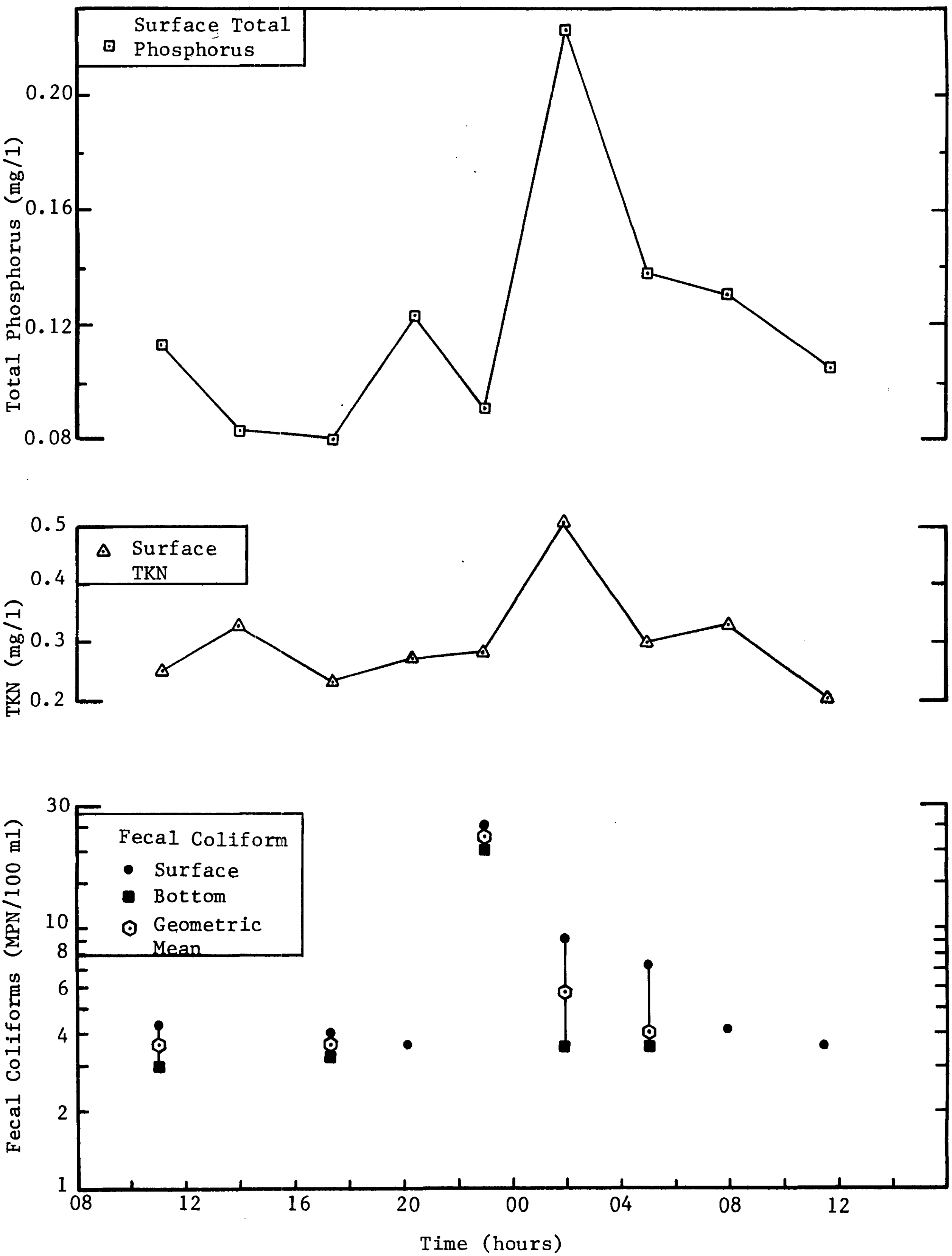

STATION JE1
July 20-21, 1976
Surface Total Phosphorus
Total Phosphorus (mg/1)
0.4
0.3
0.2
0.1
Surface TKN
TKN (mg/1)
1.4
1.0
0.6
0.2
Surface DO
Bottom DO
Dissolved Oxygen (mg/1)
10
6
2
08
12
16
20
00
04
08
12
Time (hours)


STATION JE1
July 20-21, 1976
Surface salinity
Bottom salinity
Salinity (ppt)
30
26
22
18
Surface Temperature
Temperature (°C)
27
26
25
Surface Chlorophyll "a"
Chlorophyll "a" (µg/l)
22
18
14
10
08
12
16
20
00
04
08
12
Time (hours)

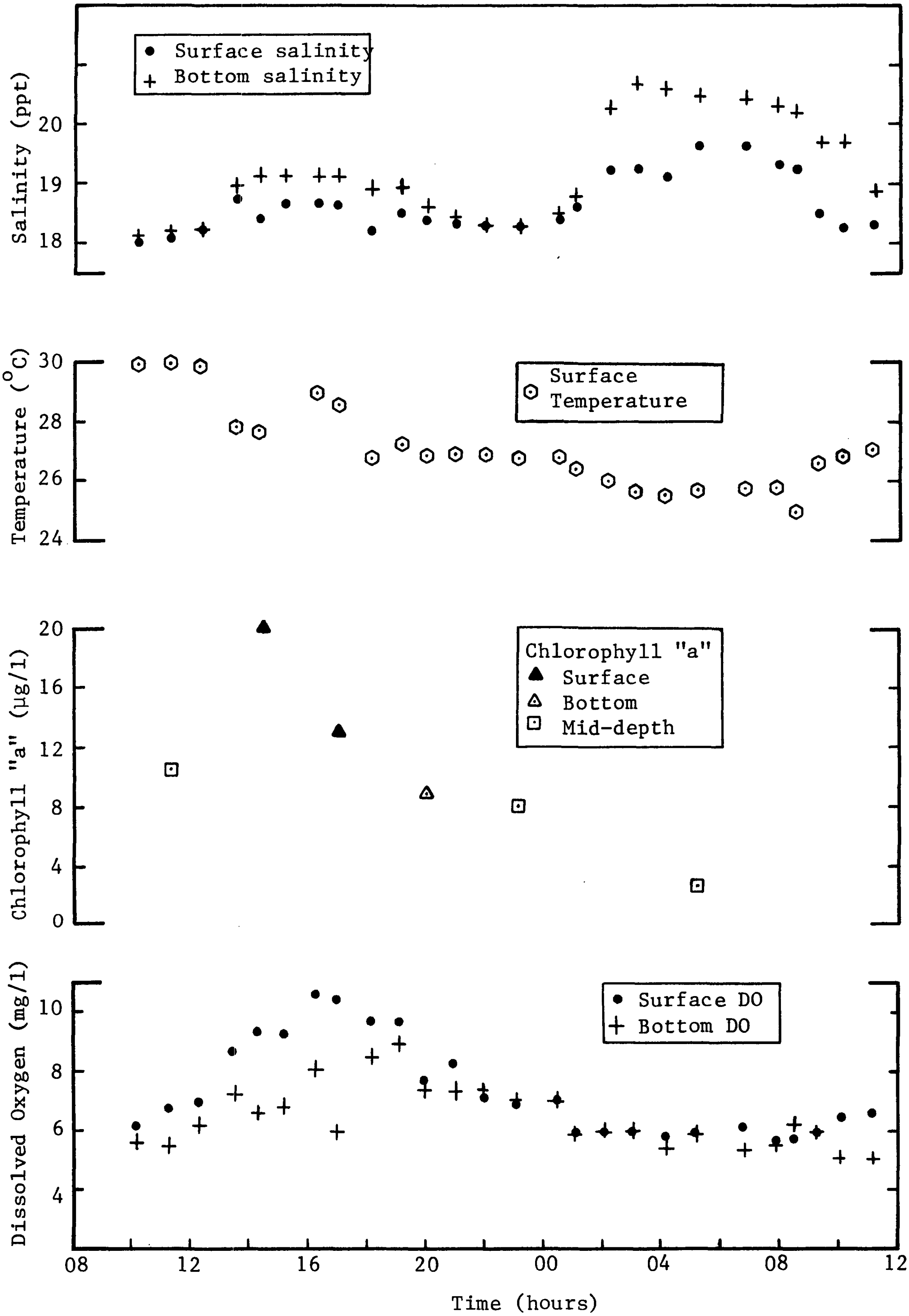

STATION JE1
July 20-21, 1976
Surface
Bottom
Geometric Mean
10,000
8000
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
8
6
4
2
1
Fecal Coliform (MPN/100 ml)
08
12
16
20
00
04
08
12
Time (hours)

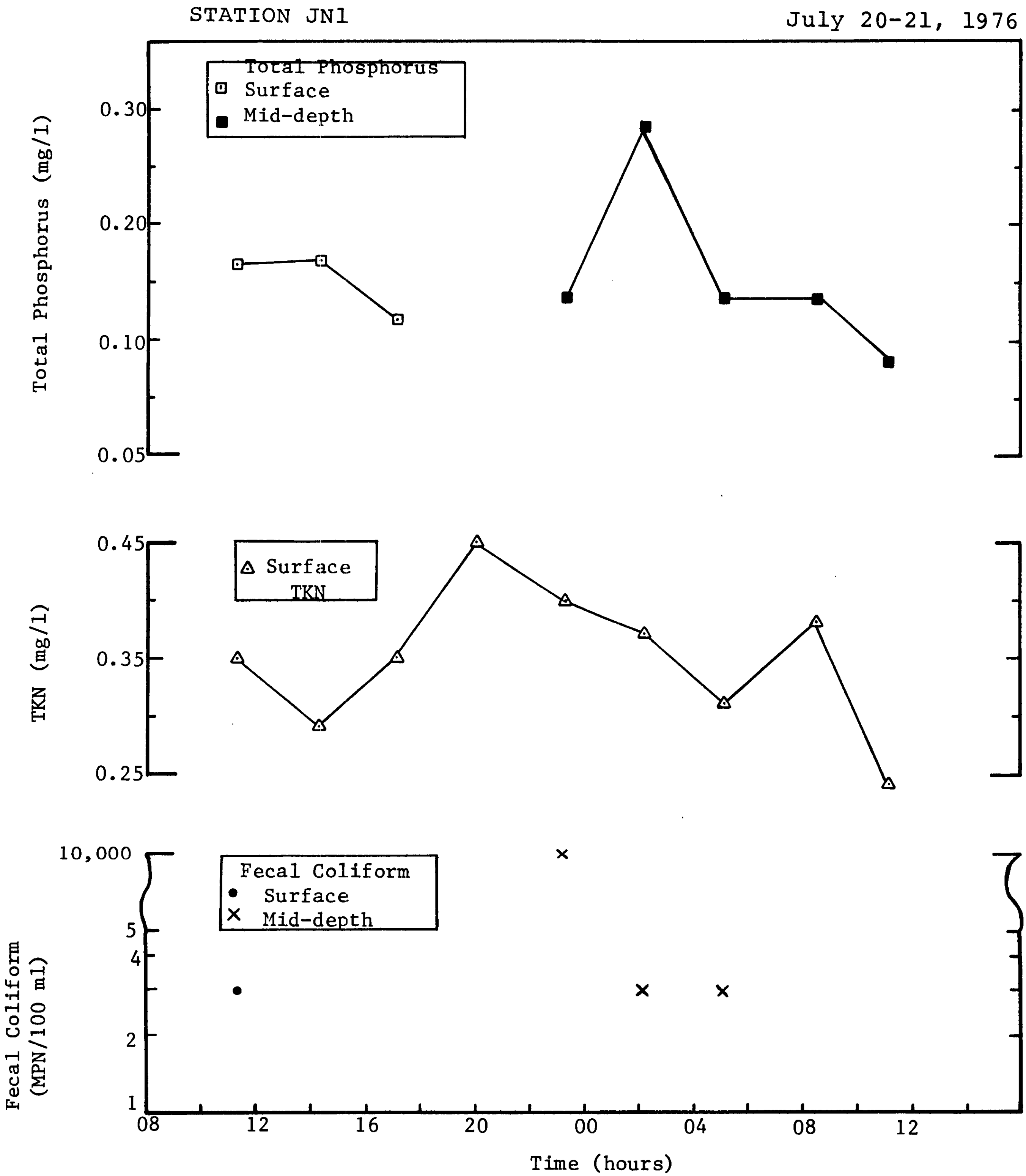

STATION J1.2D
July 20-21, 1976
Surface salinity
Bottom salinity
Salinity (ppt)
Surface Temperature
Temperature (°C)
Surface chlorophyll "a"
Chlorophyll "a" (µg/l)
Surface DO
Bottom DO
Dissolved Oxygen (mg/l)
Time (hours)

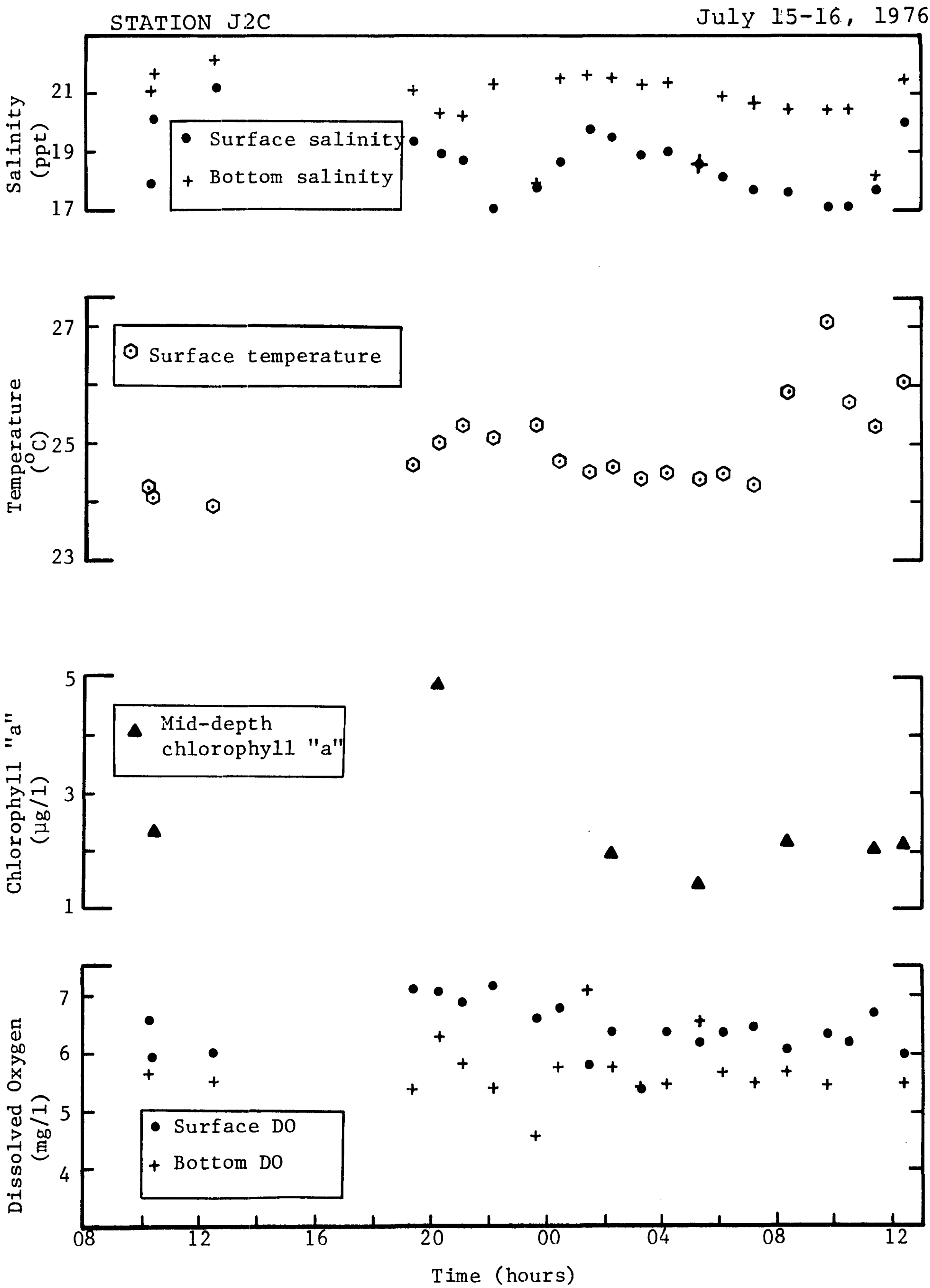
STATION J 1.2D July 20-21, 1976

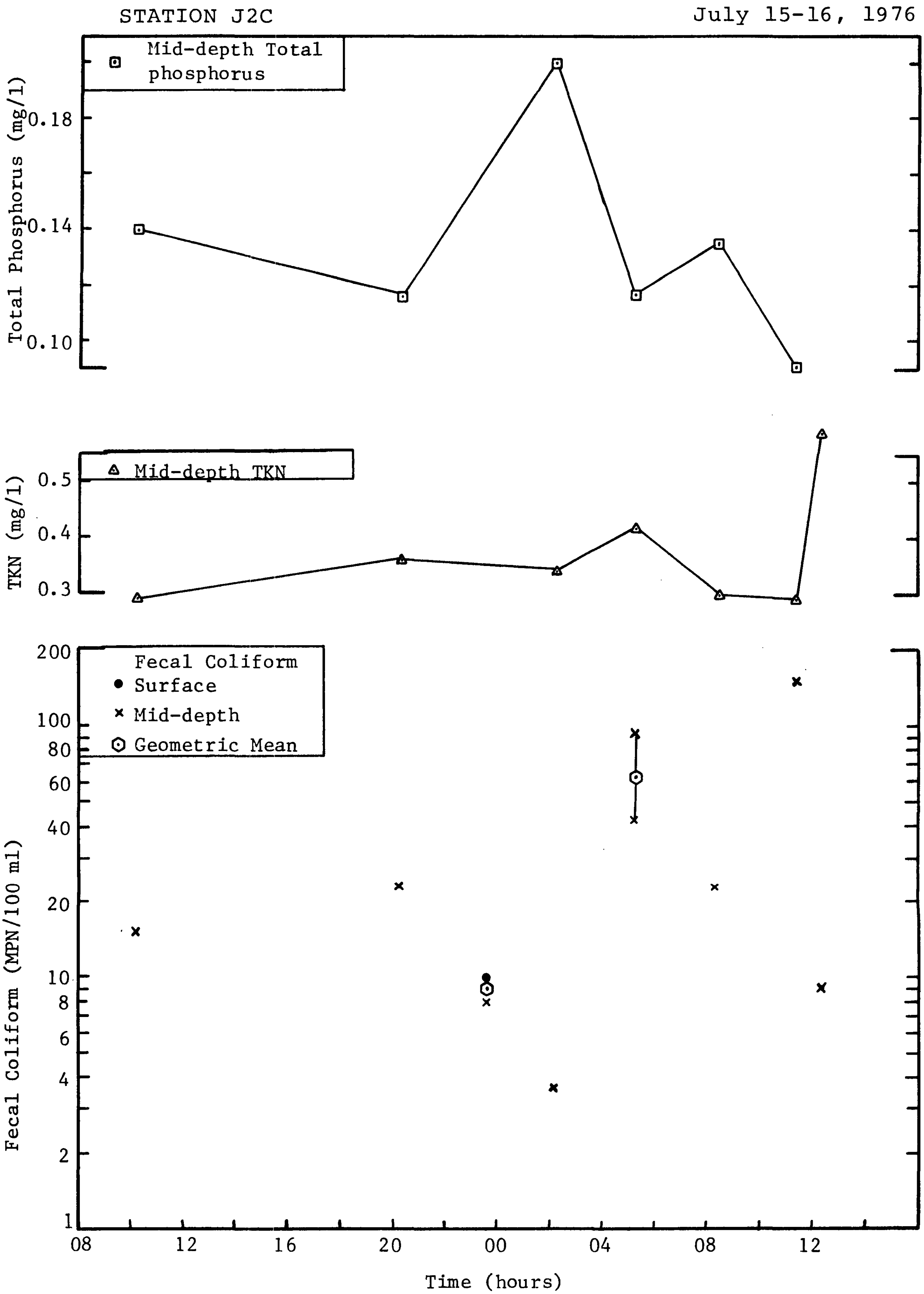


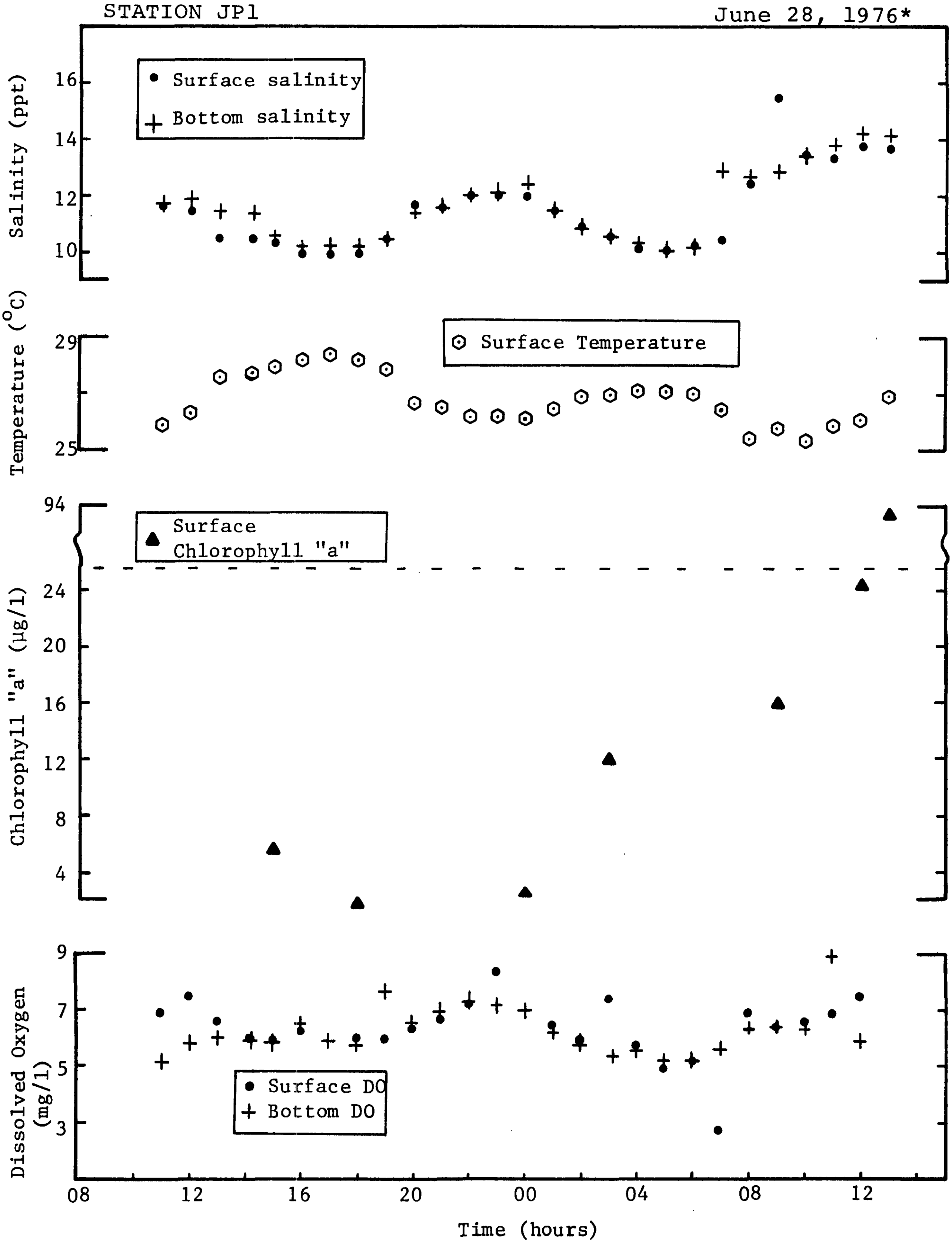
STATION JN1 July 20-21, 1976




STATION JN1
July 20-21, 1976
Total Phosphorus
Surface
Mid-depth
Total Phosphorus (mg/l)
0.30
0.20
0.10
0.05
0.45
Surface
TKN
TKN (mg/l)
0.35
0.25
10,000
Fecal Coliform
Surface
Mid-depth
Fecal Coliform
(MPN/100 ml)
5
4
2
1
08
12
16
20
00
04
08
12
Time (hours)

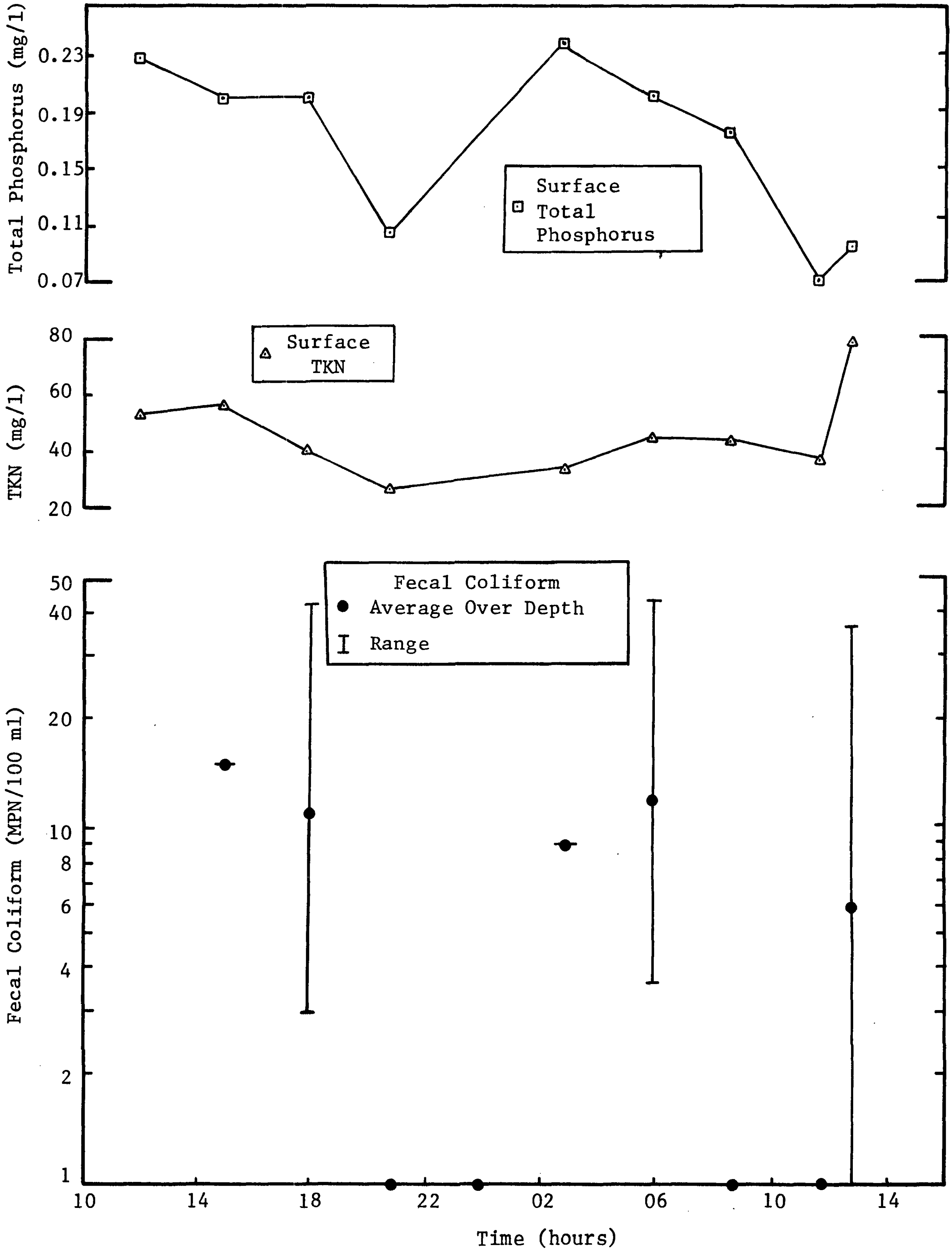

STATION J2C
July 15-16, 1976
Salinity (ppt)
17
19
21
Surface salinity
Bottom salinity
Temperature (°C)
23
25
27
Surface temperature
Chlorophyll "a" (µg/l)
1
3
5
Mid-depth chlorophyll "a"
Dissolved Oxygen (mg/l)
4
5
6
7
Surface DO
Bottom DO
08
12
16
20
00
04
08
12
Time (hours)


STATION J2C
July 15-16, 1976
Mid-depth Total phosphorus
Total Phosphorus (mg/1)
0.18
0.14
0.10
Mid-depth TKN
TKN (mg/1)
0.5
0.4
0.3
Fecal Coliform
Surface
Mid-depth
Geometric Mean
Fecal Coliform (MPN/100 ml)
200
100
80
60
40
20
10
8
6
4
2
1
08
12
16
20
00
04
08
12
Time (hours)

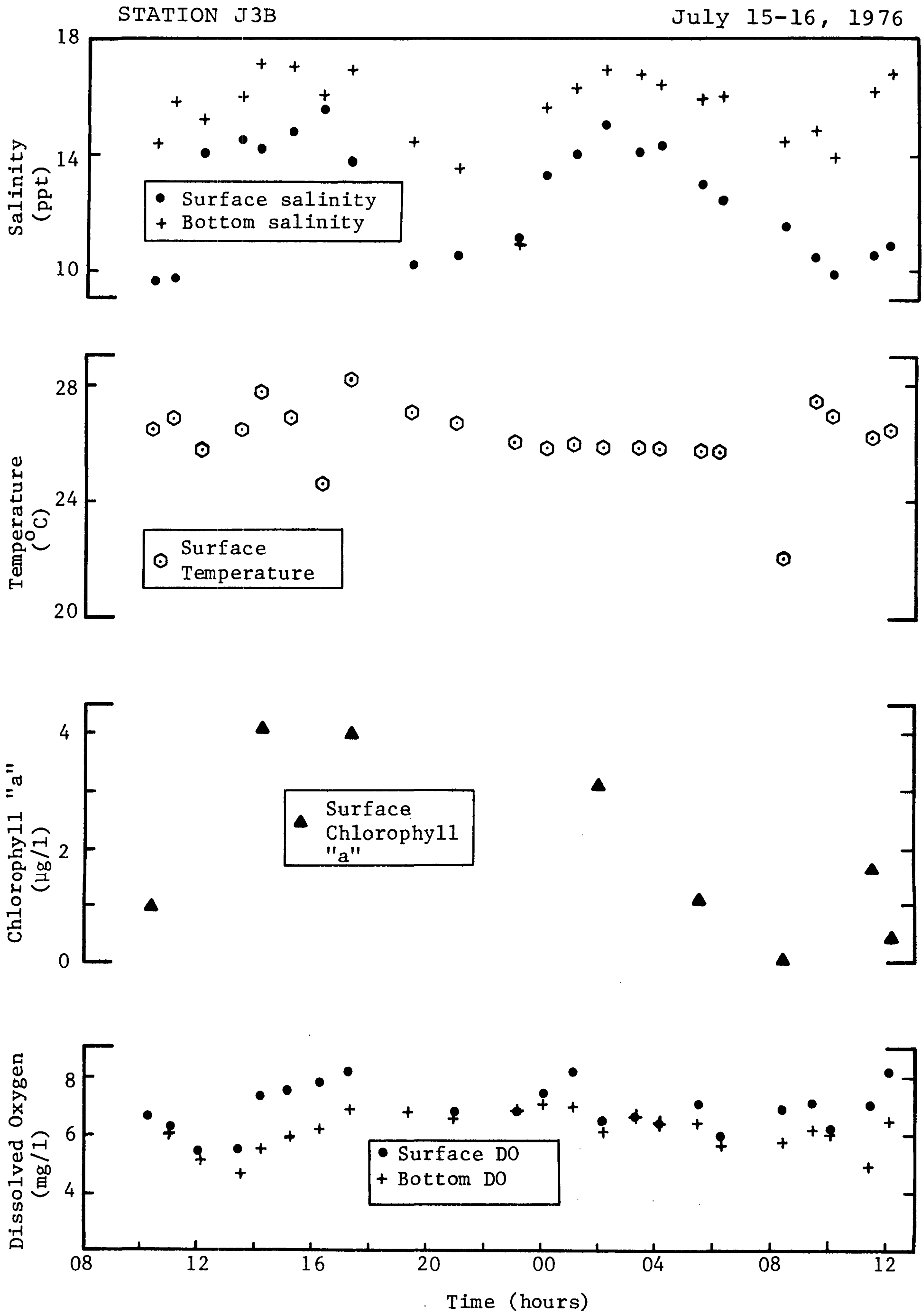


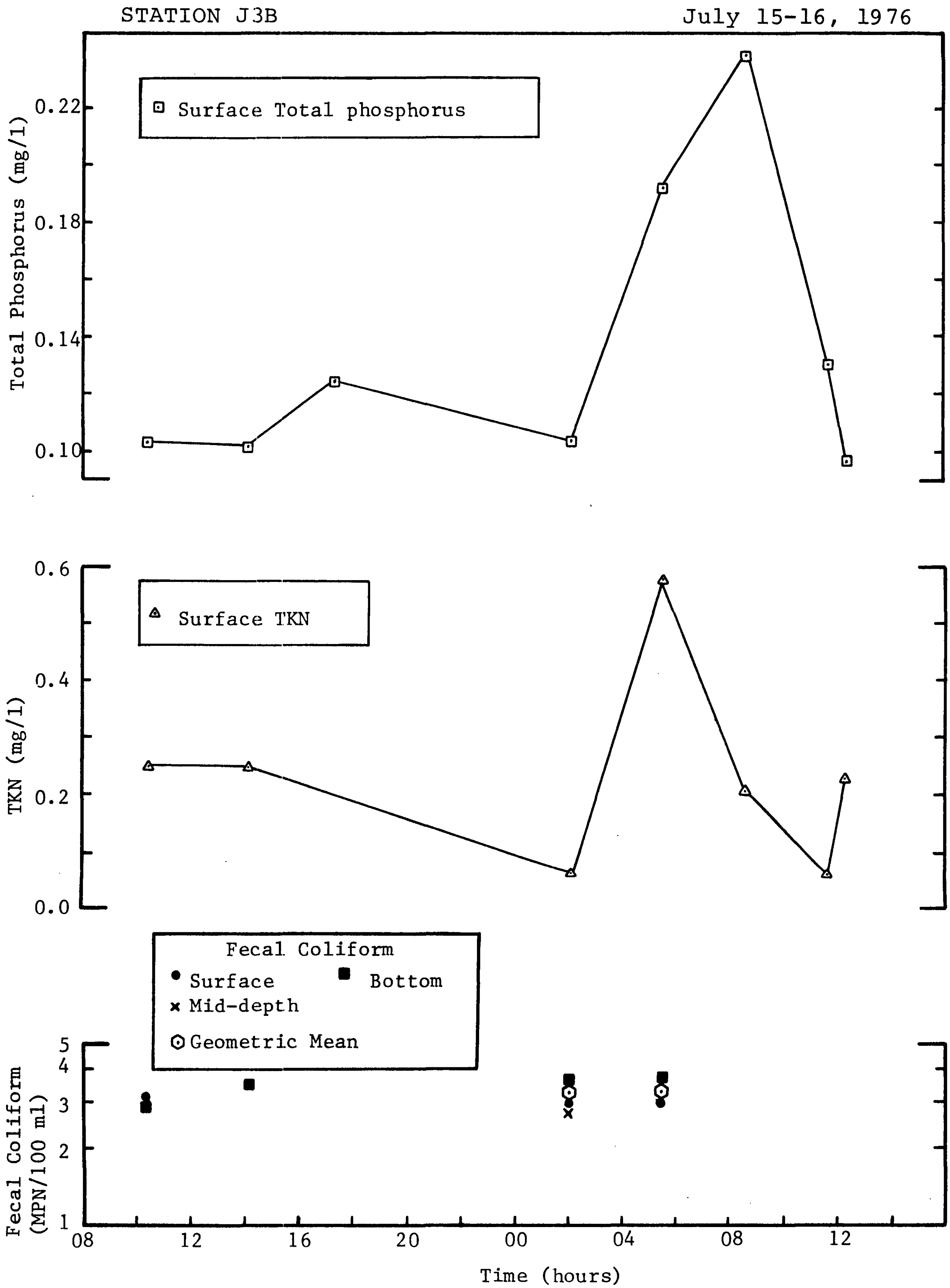
* Data from intensive study of Pagan River.

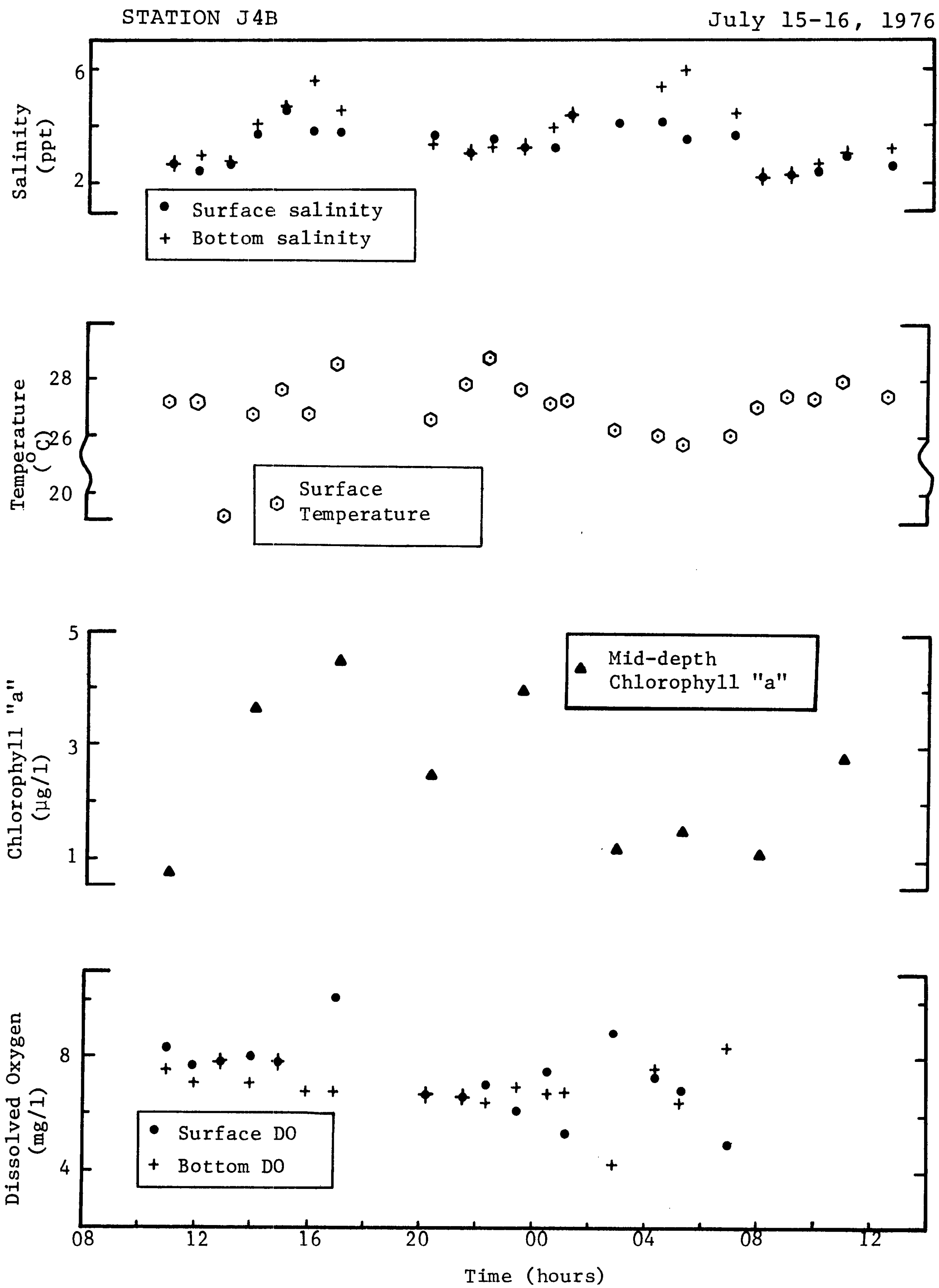
STATION JP1 June 28, 1976*

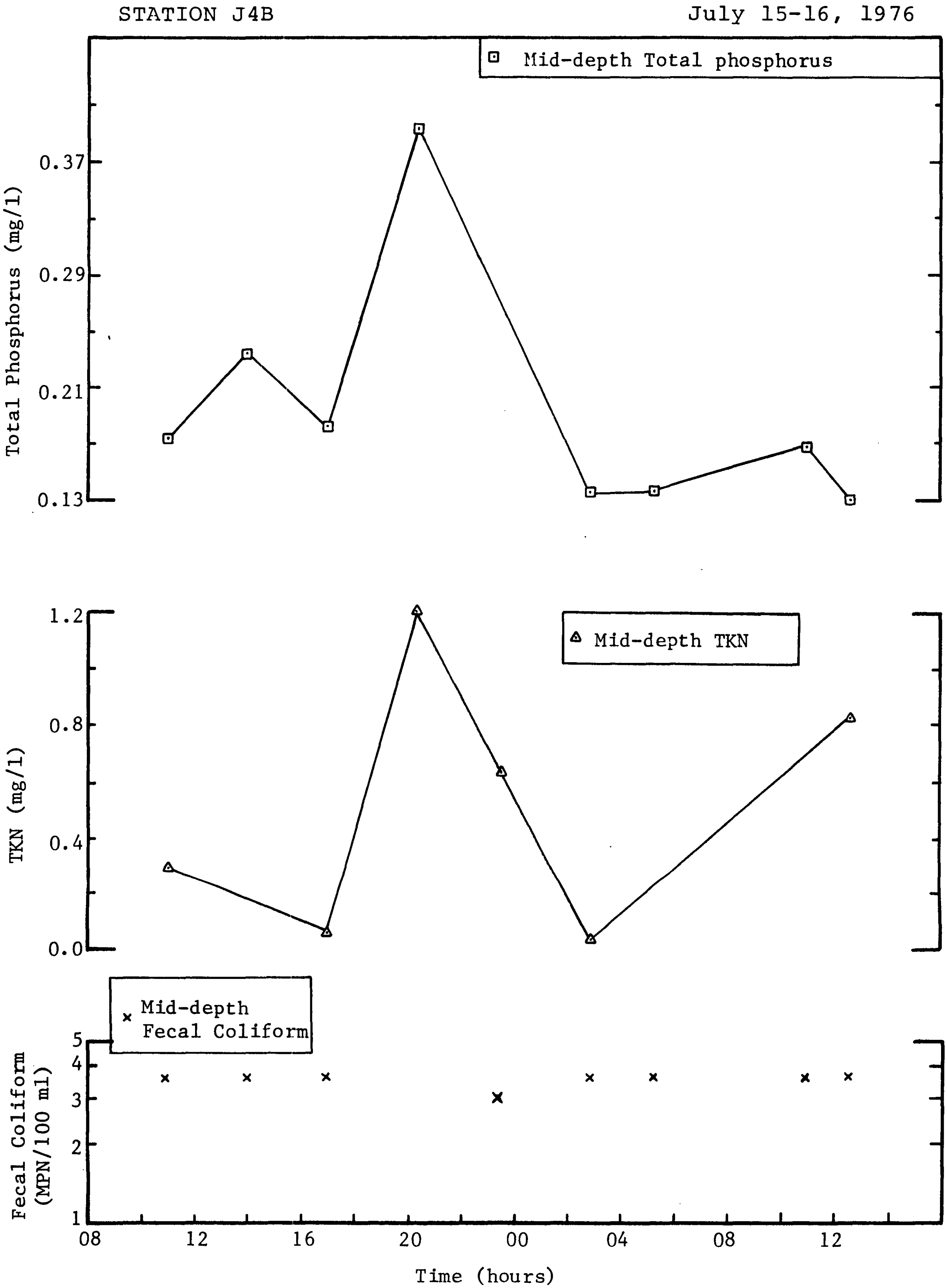


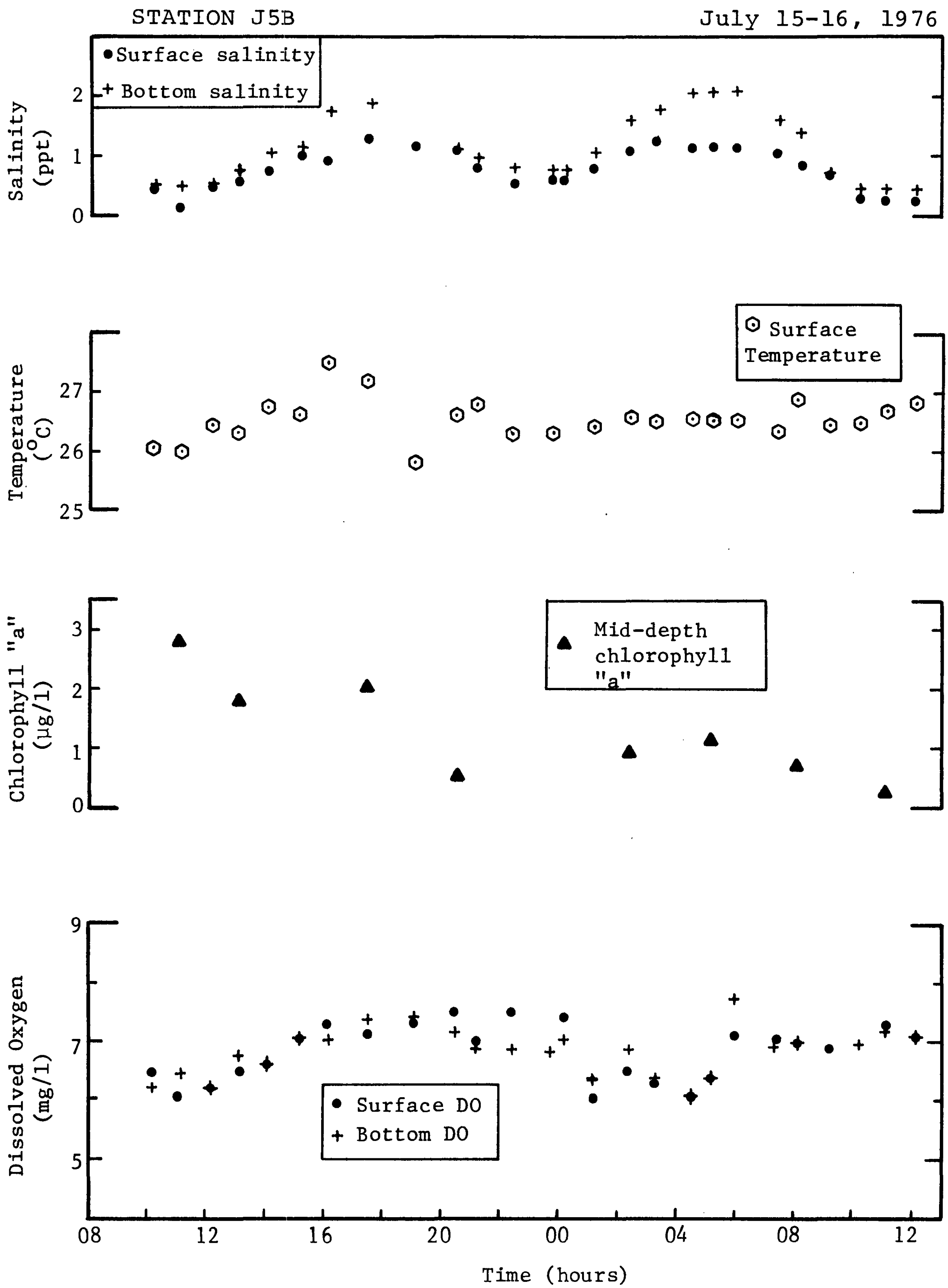
* Data from intensive survey of Pagan River.

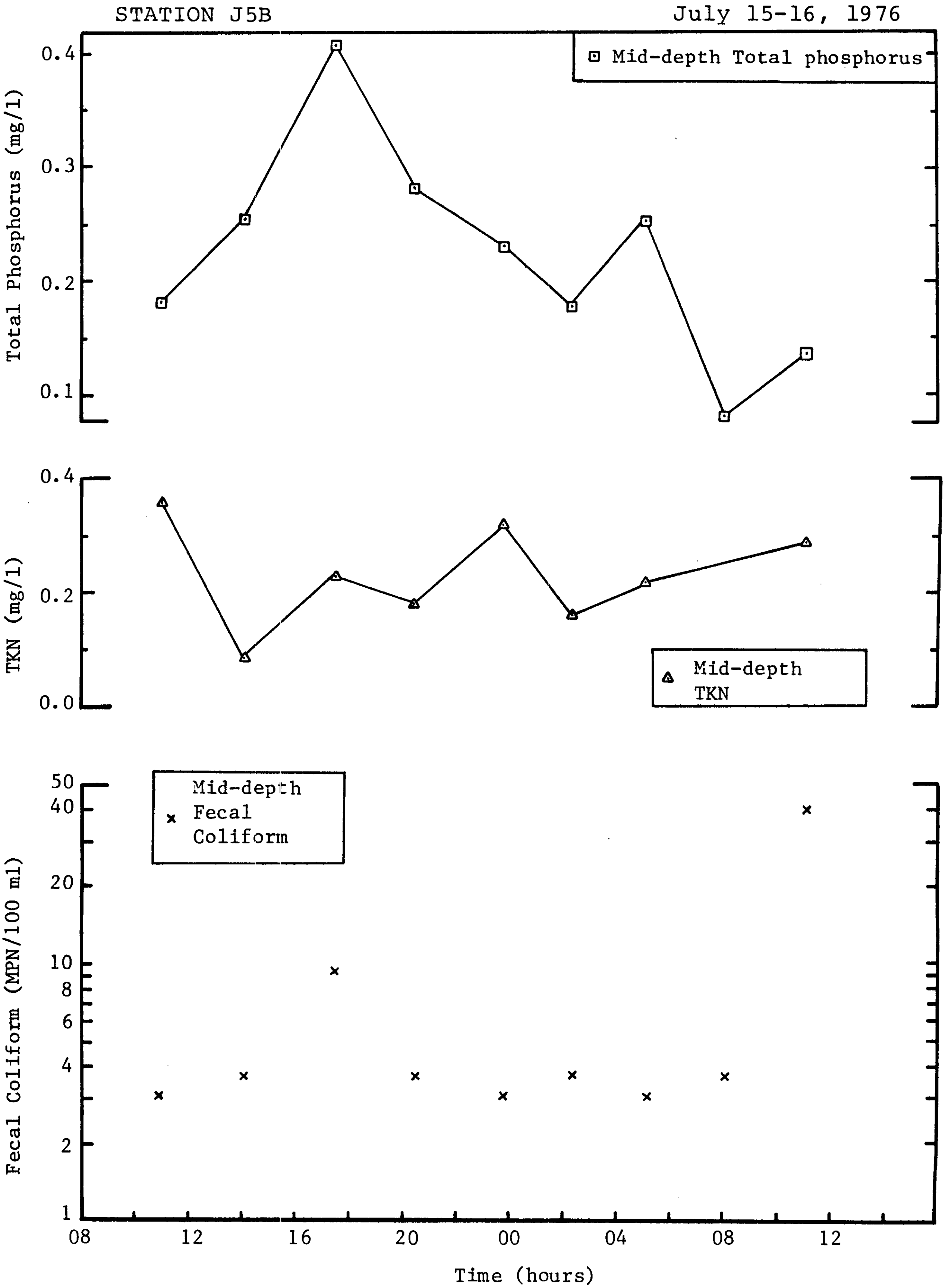

STATION J3B
July 15-16, 1976
Salinity (ppt)
18
14
10
Surface salinity
Bottom salinity
Temperature (°C)
28
24
20
Surface Temperature
Chlorophyll "a" (μg/l)
4
2
0
Surface Chlorophyll "a"
Dissolved Oxygen (mg/l)
8
6
4
Surface DO
Bottom DO
08
12
16
20
00
04
08
12
Time (hours)

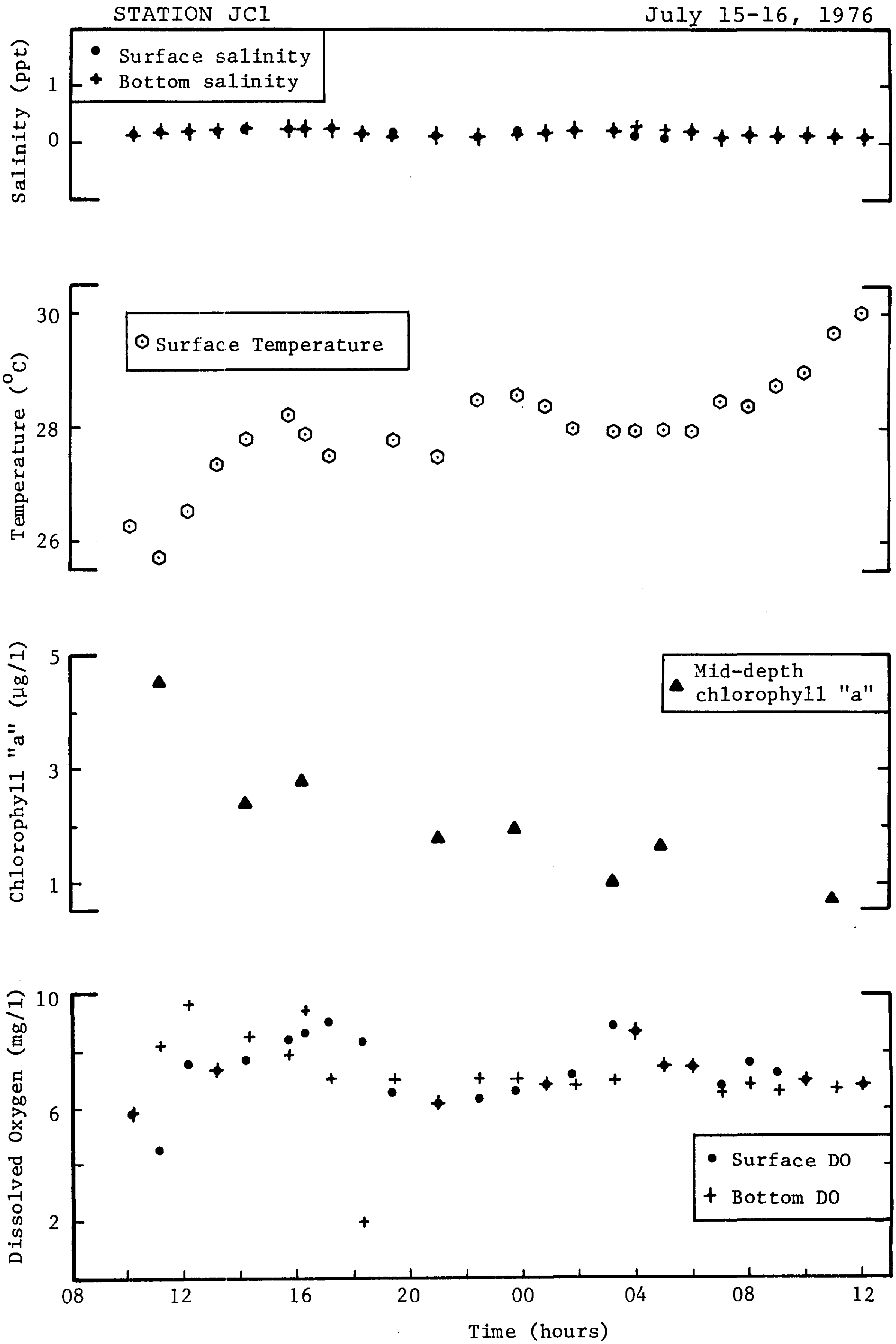

STATION J3B
July 15-16, 1976
Surface Total phosphorus
Total Phosphorus (mg/1)
0.22
0.18
0.14
0.10
Surface TKN
TKN (mg/1)
0.6
0.4
0.2
0.0
Fecal Coliform
Surface
Bottom
Mid-depth
Geometric Mean
Fecal Coliform (MPN/100 ml)
5
4
3
2
1
08
12
16
20
00
04
08
12
Time (hours)


STATION J4B
July 15-16, 1976
Salinity (ppt)
6
2
Surface salinity
Bottom salinity
Temperature (°C)
28
26
20
Surface Temperature
Chlorophyll "a" (µg/l)
5
3
1
Mid-depth Chlorophyll "a"
Dissolved Oxygen (mg/l)
8
4
Surface DO
Bottom DO
08
12
16
20
00
04
08
12
Time (hours)

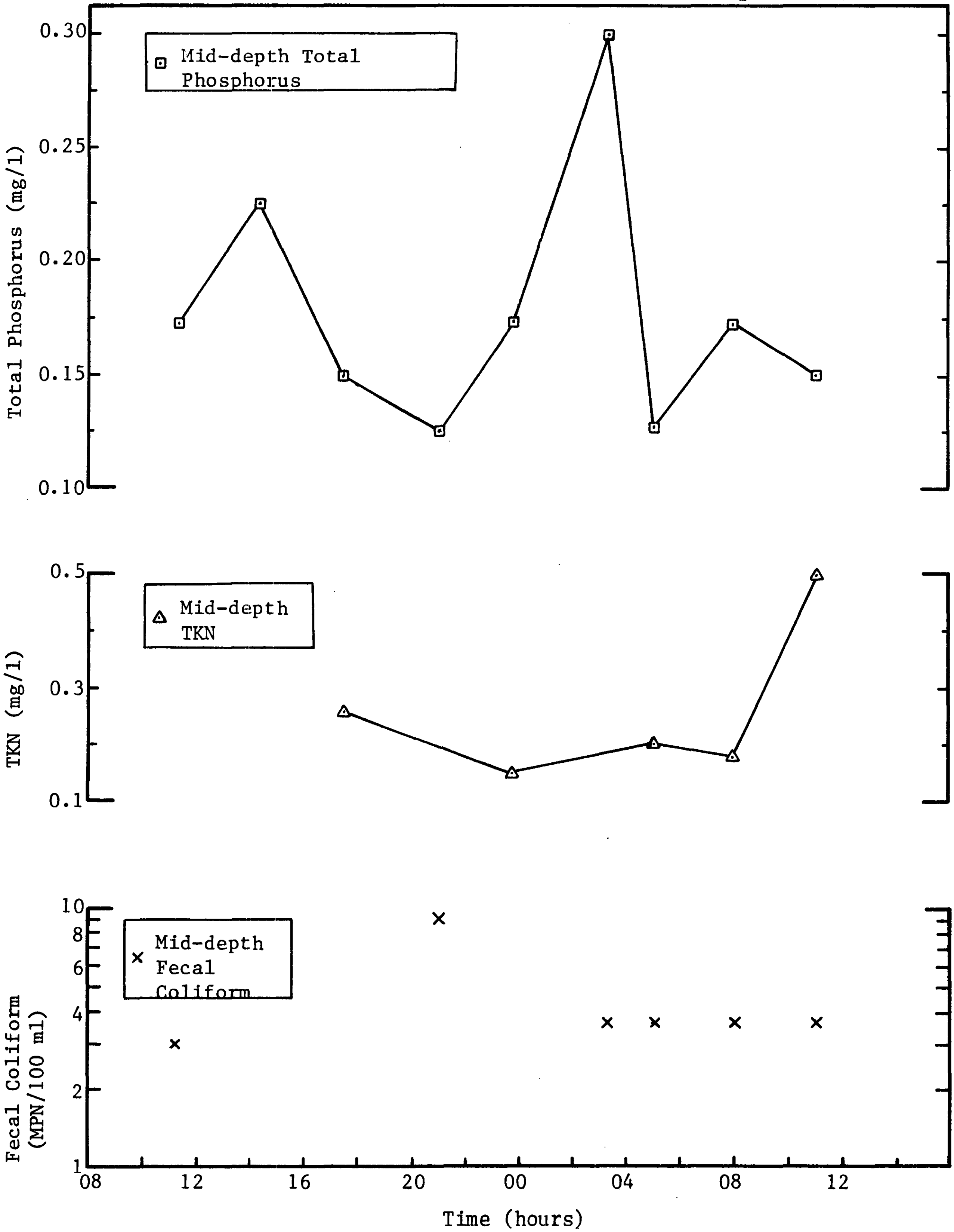

STATION J4B
July 15-16, 1976
Mid-depth Total phosphorus
Total Phosphorus (mg/1)
0.37
0.29
0.21
0.13
Mid-depth TKN
TKN (mg/1)
1.2
0.8
0.4
0.0
Mid-depth Fecal Coliform
Fecal Coliform (MPN/100 ml)
5
4
3
2
1
08
12
16
20
00
04
08
12
Time (hours)

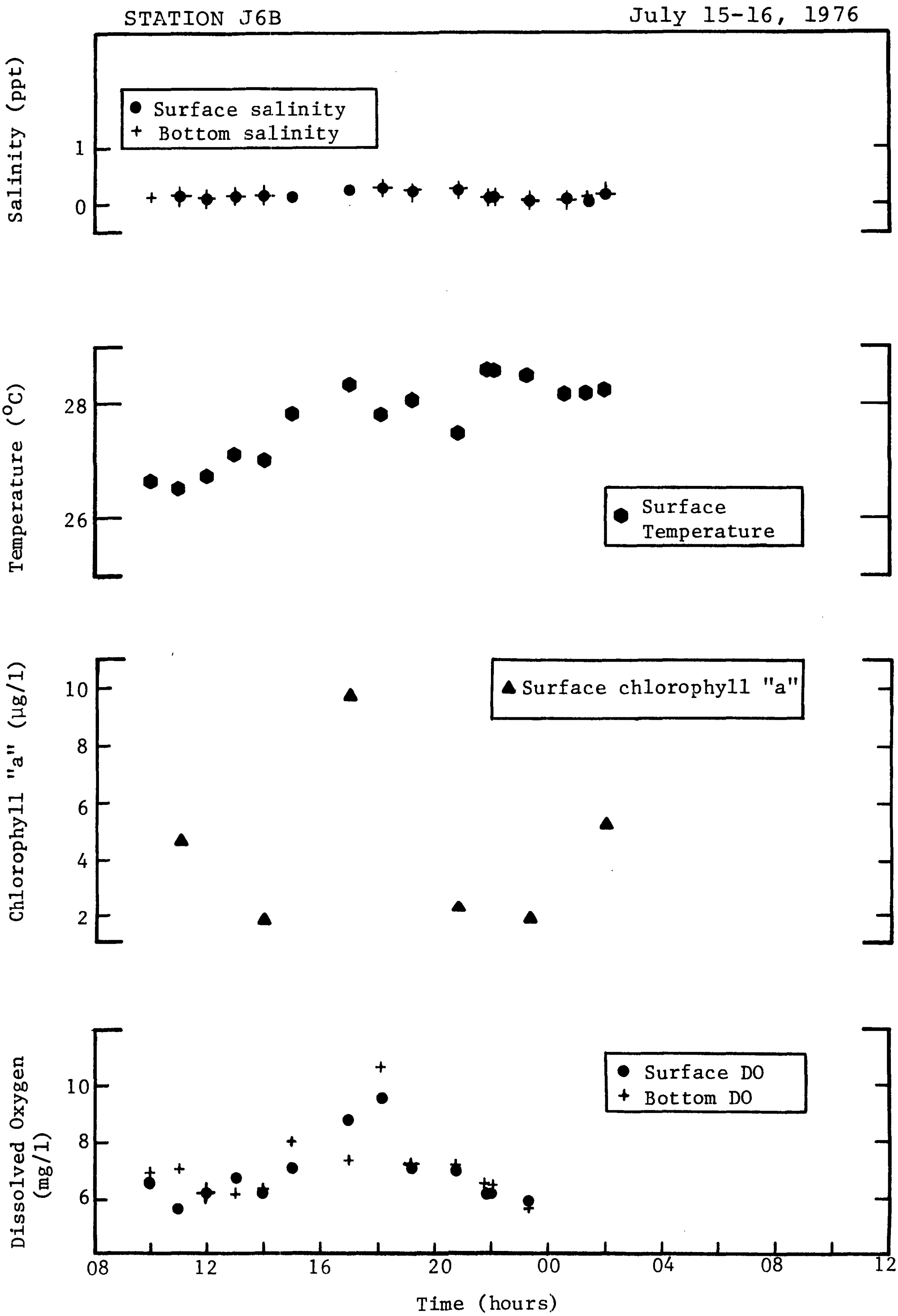

STATION J5B
July 15-16, 1976
Surface salinity
Bottom salinity
Salinity (ppt)
0
1
2
Surface Temperature
Temperature (°C)
25
26
27
Mid-depth chlorophyll "a"
Chlorophyll "a" (µg/l)
0
1
2
3
Surface DO
Bottom DO
Dissolved Oxygen (mg/l)
5
7
9
08
12
16
20
00
04
08
12
Time (hours)


STATION J5B
July 15-16, 1976
Mid-depth Total phosphorus
Total Phosphorus (mg/l)
0.4
0.3
0.2
0.1
TKN (mg/l)
0.4
0.2
0.0
Mid-depth
TKN
Fecal Coliform (MPN/100 ml)
50
40
20
10
8
6
4
2
1
Mid-depth
Fecal
Coliform
08
12
16
20
00
04
08
12
Time (hours)


STATION JC1
July 15-16, 1976
Surface salinity
Bottom salinity
Salinity (ppt)
1
0
Surface Temperature
Temperature (°C)
30
28
26
Mid-depth chlorophyll "a"
Chlorophyll "a" (μg/l)
5
3
1
Surface DO
Bottom DO
Dissolved Oxygen (mg/l)
10
6
2
08
12
16
20
00
04
08
12
Time (hours)

STATION JC1 July 15-16, 1976




STATION J6B
July 15-16, 1976
Salinity (ppt)
Surface salinity
Bottom salinity
1
0
Temperature (°C)
28
26
Surface Temperature
Chlorophyll "a" (µg/l)
10
8
6
4
2
Surface chlorophyll "a"
Dissolved Oxygen (mg/l)
10
8
6
Surface DO
Bottom DO
08
12
16
20
00
04
08
12
Time (hours)

STATION J6B July 15-16, 1976