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Elizabeth River Water Quality Report

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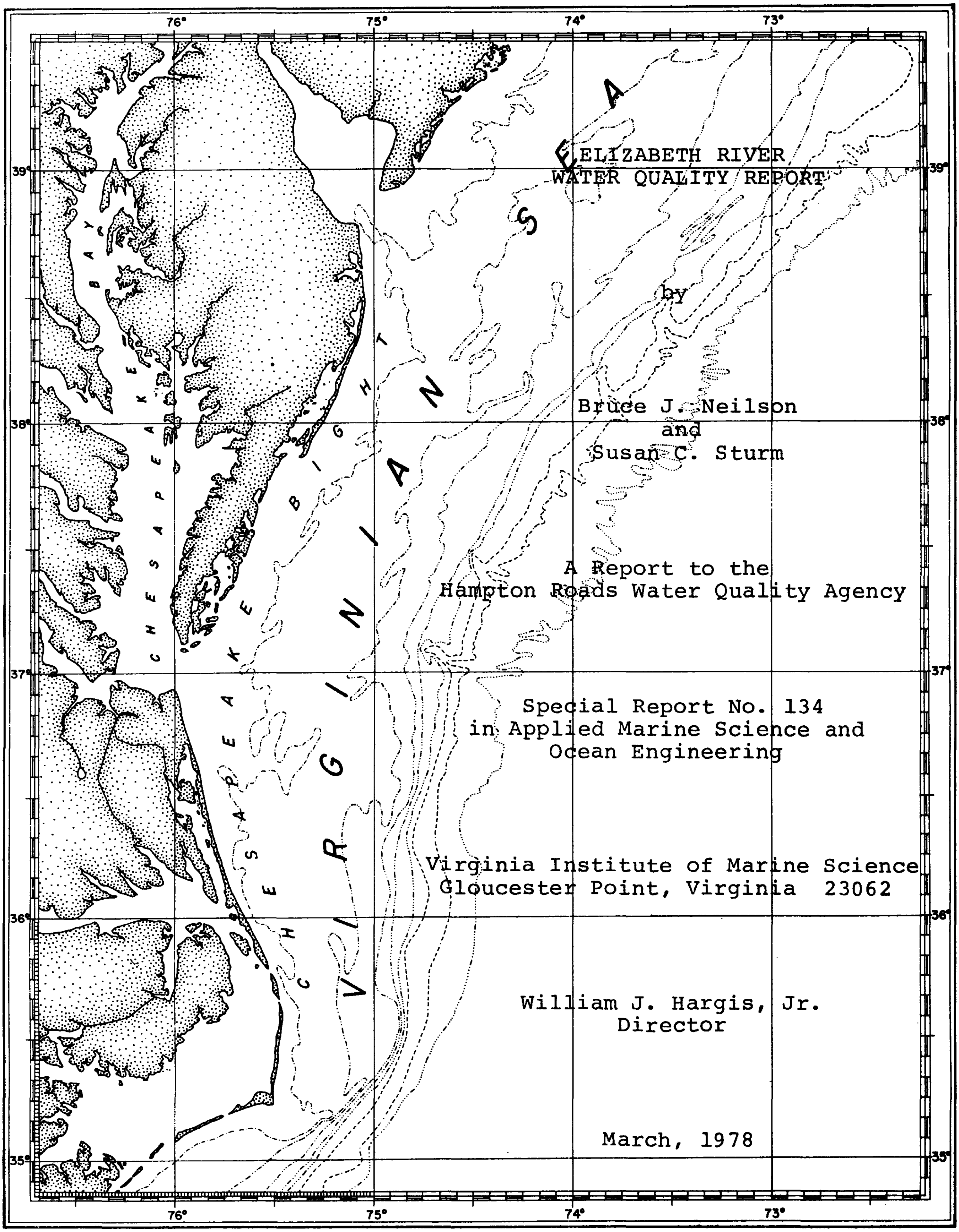

ELIZABETH RIVER WATER QUALITY REPORT

by

Bruce J. Neilson
and
Susan C. Sturm

A Report to the
Hampton Roads Water Quality Agency

Special Report No. 134
in Applied Marine Science and
Ocean Engineering

Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

William J. Hargis, Jr.
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INTRODUCTION

The Elizabeth River is the most downriver tributary of the James, debouching into Hampton Roads only a few kilometres upriver from Fort Wool and Chesapeake Bay. The Elizabeth River system is comprised of a main stem, running from Sewell's Point and Craney Island to Town and Pinner Points, plus four tributary arms: the Lafayette River and the Eastern, Western and Southern Branches. Located along the river banks and in the surrounding territory are extensive and important naval bases and docking facilities, pleasant exurbs and yacht clubs, drydocks and international shipping terminals, the commercial centers of Norfolk and Portsmouth, relatively quiet rural areas and the Great Dismal Swamp. From its earliest settlements, many of the activities of this area and a large portion of the economic base have been water-related.

The total drainage area of the Elizabeth is only slightly over 500 square kilometres (about 200 square miles) and lies entirely within the geologic coastal plains province. (See Figure 1.) The basin is seaward of the "Suffolk Scarp" and topographic relief is slight. The highest natural elevation in the area is on the order of 6 metres (20') above sea level. As a result of the basin size and characteristics, there are no free flowing streams, and therefore no gaging stations. The major source of freshwater appears to be the Great Dismal Swamp. The flow of water from Lake Drummond is regulated by the Corps of Engineers to maintain a water level in the Dismal Swamp Canal

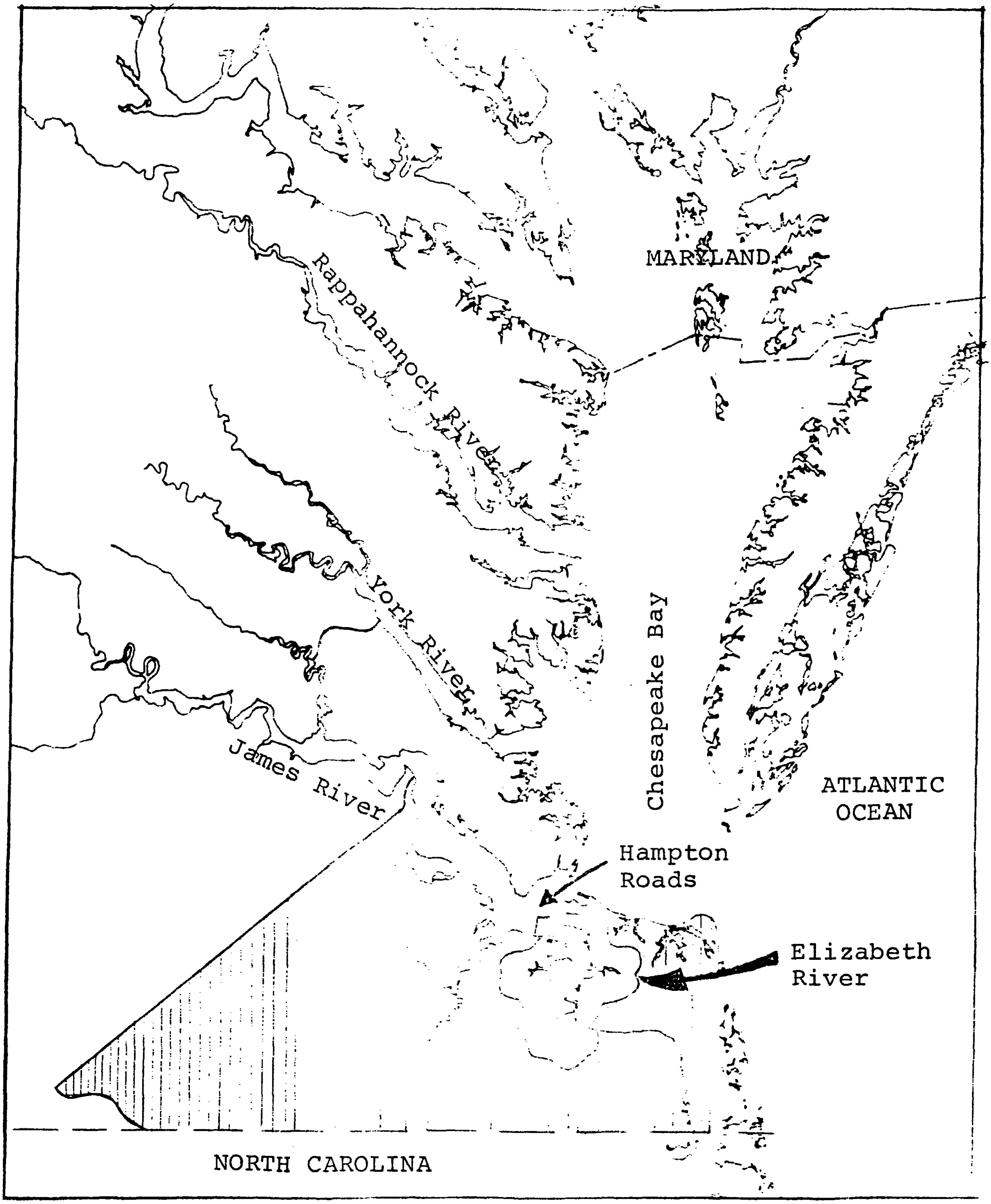


Figure 1a. 208 Study Area showing Elizabeth River drainage basin.

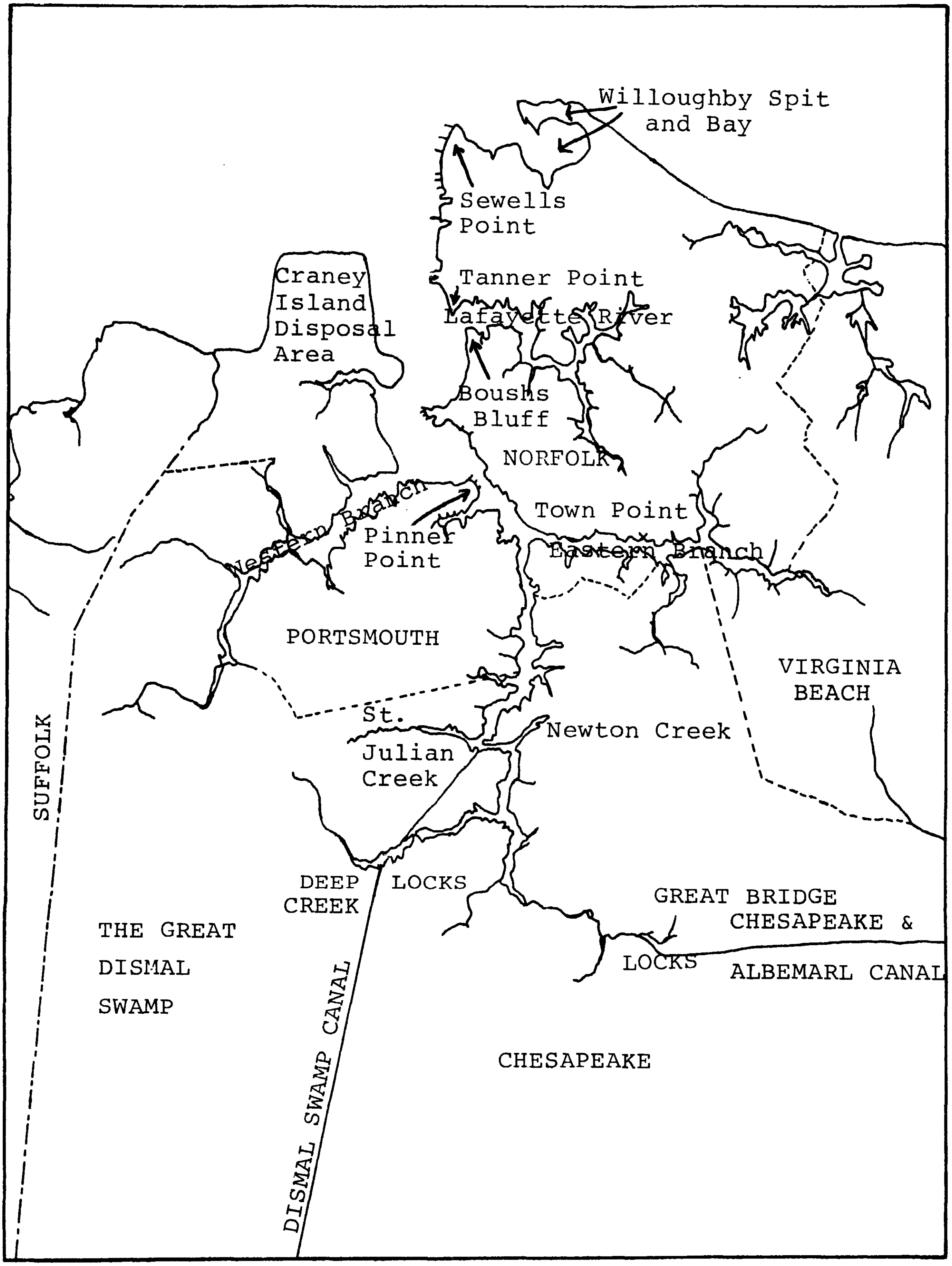


Figure 1b. Political subdivisions and reference locations in the Elizabeth River basin.

that is higher than mean sea level. During periods of heavy rainfall and light evaporation, there is a flow of water from the swamp through spillways at the Deep Creek locks. During the summer, the only flow which occurs is that due to operation of the locks, primarily for pleasure craft passing through the Intracoastal Waterway. The Elizabeth is connected to Albemarle Sound by the Chesapeake and Albemarle Canal as well. Although flow through these locks is not monitored, there could be some flux of water since the tide range in the Elizabeth is about 85 cm (2.8') and that in Albemarle Sound is less than 15 cm (0.5'). However, the flow probably is not large because of the locks and very small gradient (Corps of Engineers, 1974).

Since saline waters are able to intrude far up the tributary channels, one concludes that the freshwater flow to the various branches is small. Field observations show that freshwater is encountered in the far upriver and narrow reaches of the Lafayette River (Blair, 1975). It is likely that the situation in the other branches is similar.

Deep navigation channels are maintained from Hampton Roads up the main stem and the Southern Branch. Project depths decrease from 45 feet at the mouth to 35 feet between the Norfolk Naval Shipyard and Newton Creek. The channels in the Easter Branch, Western Branch and Lafayette River are maintained at 25 feet, 14 feet and 8 feet respectively. For more details, the reader is referred to NOS Charts 400 and 452 (12253). These charts have been used in this study for reference point locations and nomenclature.

The climate for this region has been classified as humid, sub-tropical. For the Elizabeth River area, the proximity of Chesapeake Bay and the Atlantic Ocean provide a moderating effect on temperatures. During 1976 the temperature at the Norfolk weather station ranged from 35° ($95^{\circ}F$) to -9° ($16^{\circ}F$), versus extremes of 38.3° and -26.7° for the state. Two hundred and twenty four days elapsed between the last day in spring with freezing temperatures and the first occurrence in the fall, versus only about 170 days for the Eastern Piedmont Region. Monthly average temperatures ranged from 3.8° ($38.9^{\circ}F$) in January to 25.6° ($78.2^{\circ}F$) in July, and the mean temperature for the year was 15.5° ($59.7^{\circ}F$).

There was considerably less rain in 1976 than during most years. Total rainfall at the Norfolk weather station was 82.2 cm (32.4"), 31.3 cm (12.3") below the 31 year mean. Rainfall at the Diamond Springs station, only a few kilometres away, was 94.7 cm (37.3"), 24.7 cm (9.7") less than the 68 year mean annual rainfall. The differences between the two stations demonstrate the localized nature of rain storms in this region and provide an indication of the variability in rainfall over short distances.

WATER QUALITY IN THE ELIZABETH RIVER SYSTEM

The Elizabeth River, like its neighboring estuaries, has been used for a multitude of purposes such as transportation, fisheries, recreation, wastewater disposal. Unfortunately, the consequences of some uses result in diminished usefulness for other purposes. In particular, water quality degradation resulting from the discharge of wastewaters can render a water body unsuitable for fisheries purposes. The culture of shellfish is especially vulnerable to pollution of this type.

A survey conducted by the U.S. Public Health Service in 1914 concluded that the direct taking of market shellfish was permissible in the Hampton Roads area with the exception of Mill and Hampton Creeks on the Peninsula and the Elizabeth River and its tributaries on the south shore (Public Health Bulletin 74, 1916 cited by Smith, 1950).

A second survey made by the Public Health Service in 1934 showed degraded conditions in much of Hampton Roads. Average coliform densities in the Elizabeth and Lafayette Rivers and along the shore to Sewell's Point were above 1,000 per 100 ml. Several years later, the Hampton Roads Sanitation District was established by an act of the General Assembly. Following World War II, the sanitation district built the Lambert Point treatment plant and acquired the Army Base plant from the federal government. The Pinner Point plant was built by the City of Portsmouth and began operation in the spring of 1949. As a result of these changes in wastewater treatment, the PHS in conjunction with the Virginia State Department of Health conducted a third survey of the bacterial quality of the waters in Hampton Roads. Much of the area showed improved conditions from the 1934 survey, but the Elizabeth and Lafayette Rivers continued to exhibit high levels of coliforms, as shown in Figure 2, which is taken from the report on that survey (Smith, 1950).

The degraded conditions suggested by the high bacterial levels have continued. In their 1975 inventory of water quality in the state's water bodies (the 305B Report), the State Water Control Board stated that:

> "The major water quality problems in the Hampton Roads vicinity is the Elizabeth River complex. For many years, the major use of these waters has been that of receiving wastes generated by heavy industrialization of the surrounding area. It is questionable whether or not this body of water can be restored so that it will provide for the protection and propagation of shellfish, fish and wildlife, and allow for recreational activities in and on the water by 1983 or in the foreseeable future.
>
> This body of water suffers from many problems including low dissolved oxygen values, high nutrient and sulfur-sulfite values, high bacteriological counts, high heavy metal values, oil spills, creosote leachate, and high temperature cooling water discharges. Most dischargers contribute to more than one problem area.
>
> Heavy traffic on the intercoastal waterway contributes to the fecal coliform and oil spill problems. Heavy yacht traffic, especially during the spring and fall 'migration' contributes to peaks in the fecal coliform values."

They further note that when the major treatment plants along the river are upgraded, this should "contribute to the solution of the dissolved oxygen, nutrient and high bacteriological problems". They also note problems with heavy metals, which are expected to continue in the future since bottom sediments have accumulated these compounds over the years.

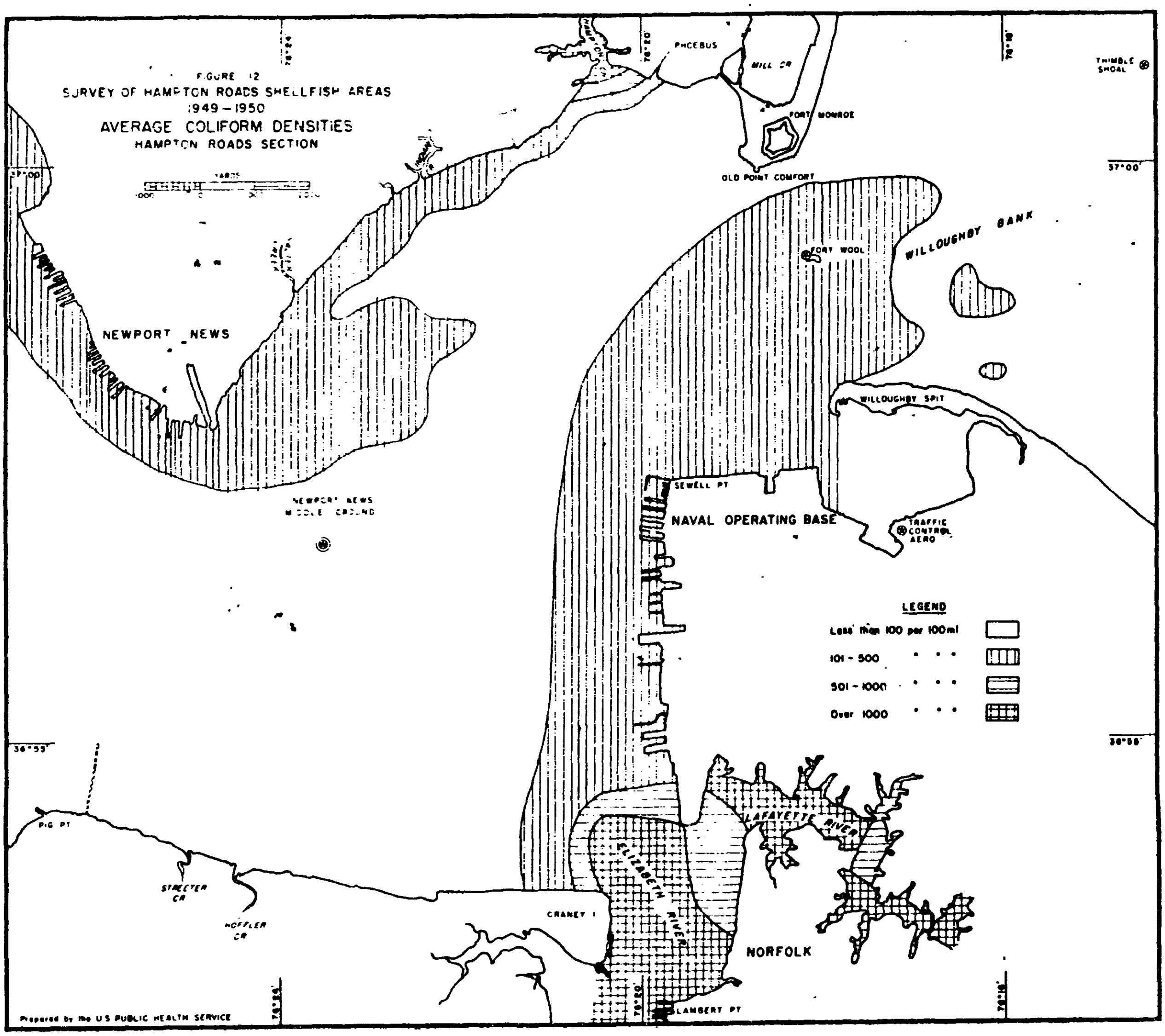


Figure 2. Average coliform densities in the eastern portion of Hampton Roads for 1949-1950 (taken from Smith, 1950).

Point Sources of Pollution

As indicated by the Water Control Board comments, large quantities of treated wastewaters are discharged to the Elizabeth River each day. At present there are three major municipal discharges and four of smaller, but significant size. These plants, the owner/operator and daily flows (in million gallons per day) for 1976 are listed below and shown in Figure 3:

Lambert Point	HRSD	26.3
Army Base	HRSD	12.0
Pinner Point	Portsmouth	10.7
Western Branch	HRSD	1.7
Deep Creek	HRSD	0.6
Washington	HRSD	0.6
Carolanne Farms	County Utilities	0.6

The combined flows from these plants is over 50 million gallons per day (MGD) which is equal to about 75 cubic feet per second or 2 cubic metres per second. If we assume that the ratio of riverflow to drainage area is the same for the Elizabeth as for the James River above Richmond, then the wastewater flow is about one third of the mean annual freshwater flow to all tributaries of the Elizabeth. During the dry summer months, the wastewater flow is several times larger than the base freshwater flow. This comparison alone would suggest that water quality could be degraded by the waste discharges.

However, conditions have changed in the recent past and are expected to improve further still in the near future. A third small treatment plant operated by HRSD near Great Bridge went off-line in October of 1975. The remaining two small plants also will be connected to the main system and go off-line in a few years. The Western Branch plant also will be eliminated when the proposed Nansemond treatment plant is constructed.

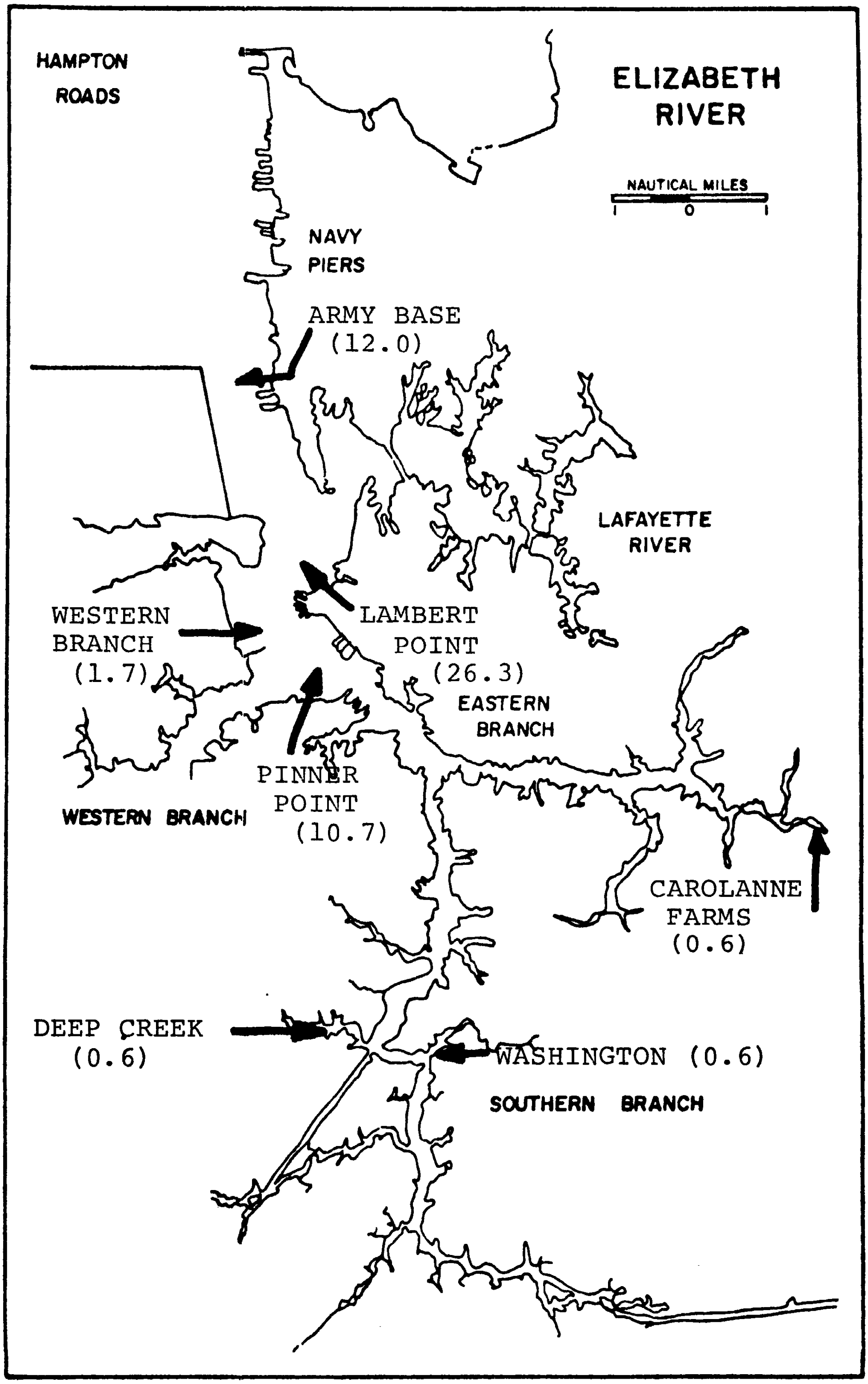


Figure 3. Location of municipal wastewater treatment plants with 1976 mean daily discharge shown in million gallons per day.

Additionally, the level of treatment will be upgraded at the remaining plants. Modifications to the Army Base and Lambert Point plants are underway, and the Pinner Point plant should be upgraded to provide secondary treatment too. At present, the combined daily load of organic matter from the plants is on the order of 60,000 pounds of 5-day BOD. BOD (Biochemical Oxygen Demand) is a measure of the oxygen which will be consumed as the organic matter in the wastewaters is decomposed. The ultimate oxygen demand is roughly one and a half times the demand measured after five days at $20^{\circ}C$. If the flow from the Western Branch plant is diverted to the James, and the remaining wastewaters are treated to secondary level, the 5-day BOD load will drop to only about 12,000 #/day when the changes are in effect.

Many industries in the area already send a portion or all of their wastewaters to the municipal systems. The only major discharger of BOD is Virginia Chemicals, which discharges about 2,000 pounds of BOD5 per day according to State Water Control Board records. Data on other constituents in the discharges from this and other industrial sources is not available. Some of these are believed to have important ecological implications. However, the 208 program was limited to consideration of oxygen demanding materials, nutrients and bacterial indicator organisms.

Nonpoint sources of pollution

Although the Elizabeth River basin is commonly perceived to be highly urbanized, and it does include densely populated areas, only about half of the basin can truly be called urban. Slightly more than 50% of the basin is either forested or is open space within urban areas. Another 9% is in tidal and freshwater marshes and 14.5% of the basin is used for cropland and pastures. The largest urban land use is residential and accounts for 28.5% of the land, when residential areas in the rural portions are included. Commercial and institutional land uses account for 9% of the area and industries occupy the remaining 8% of the basin.

Runoff from the surrounding land can bring with it large pollutant loads which may significantly alter the water quality. Runoff from the urban areas is likely to be "flashy", that is, occurring soon after rain begins and having high peak flows of short duration. Runoff from the forested and agricultural areas will be less and the response will be slower. However, when rainfall is heavy enough to produce large amounts of runoff, nutrient and BOD loads from these areas could be large. The impact from this runoff is likely to be larger than similar runoff from urban areas, since the rural areas are located along the upper reaches of the river, where flushing is poor.

Nonpoint loads from drainage canals, marshes, the Dismal Swamp, and boat traffic (recreational, military and commercial) are difficult to quantify. The data base for these inputs is extremely limited.

Residence time of pollutants

The following section is based on field and modelling studies conducted for the Hampton Roads Sanitation District (Neilson, 1975). These studies showed that a common situation in the Elizabeth was for the water mass between the Lafayette River and the Southern Branch to be nearly homogeneous. This indicated that tidal mixing was strong and that materials discharged to the river would be widely dispersed throughout the system. However, since the longitudinal salinity gradient was weak, gravitational circulation was limited and the dominant mechanism for removing material from the system was the tidal exchange. Since only a small fraction of the water is exchanged on any given tide, the residence times for the system were long.

A tidal average, mathematical model was calibrated using the results of dye studies conducted using the effluents from the Lambert Point and Army Base plants. The model was run to simulate the release and subsequent dispersion and transport of a conservative substance. The portion of the material remaining in the system was calculated and plotted as a function of time for a series of discharge points (see Figure 4.). Material discharged near the mouth of the river was removed from the system relatively rapidly. Materials discharged further up-river were dispersed relatively rapidly, but were removed from the system slowly. The further the discharge point was from the mouth, the longer it took to be flushed away.

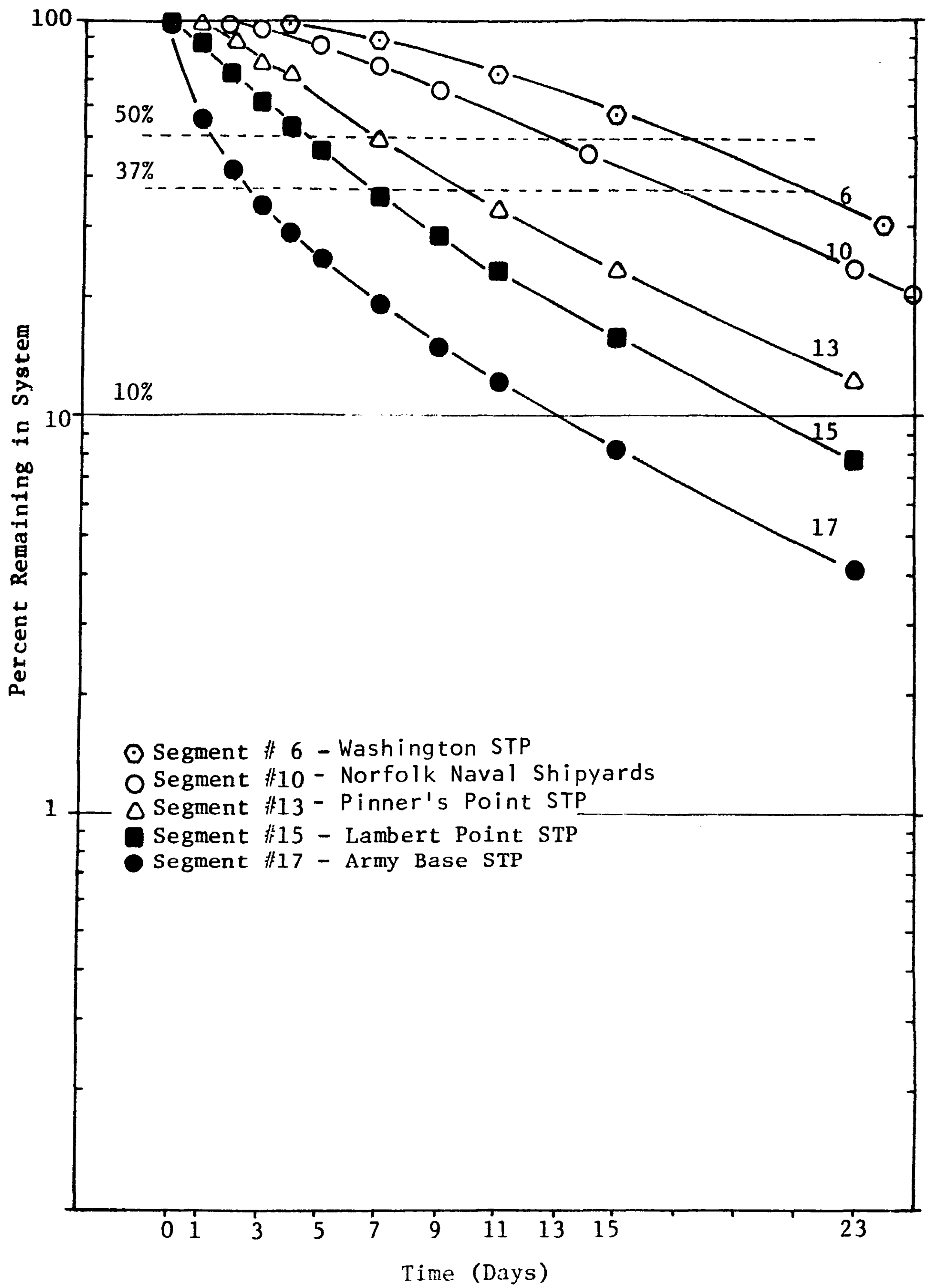


Figure 4. Residence time as illustrated by remaining portion of substance injected at various locations. (From Neilson, 1975)

One can note that for materials released in the Southern Branch, it took several days before the material had dispersed down near the mouth and began to leave the system. If the material released were not conservative, but biodegradable such as organic matter, it is clear that most of the decomposition would occur within the system. Some of the organic matter discharged near the river mouth also would be decomposed within the system but the portion would be considerably smaller.

Observations made by engineers over the years indicate that the residence time of pollutants has increased (or the flushing time has decreased) as a result of the construction of the Craney Island dredge spoil disposal area (Seufer, 1977). Since the dominant flow of the James during ebb tide is down the natural channel south of Middle Ground, it is likely that tidal exchange was greater before the dikes were built. The presence of the disposal area has in effect lengthened the river, thereby increasing the distance (and time) over which a pollutant must travel to leave the system.

Results of the 208 Field Studies

A field survey of water quality in the Elizabeth River was conducted for the Hampton Roads 208 Study from July 7 through July 9, 1976. Sampling was accomplished in two stages since a total of twenty stations were monitored. Station locations are shown in Figure 5, and details of the field study and analytical procedures are given in Appendix A. Data for representative stations are presented in graphical form in Appendix B. Two slack water surveys of the river were made on August 23 & 24, 1976 in conjunction with similar surveys of the James, Nansemond and Pagan Rivers on the same slack tides.

At the time of the intensive survey salinities ranged from about 22 parts per thousand (ppt) near the mouth to around 13 ppt near Great Bridge (station E-1). Salinities at the mouth ranged from around 21 ppt at the surface to 24 ppt near the bottom. Water temperatures showed an opposing trend with the higher temperatures (around 28^{o} C) near Great Bridge and lower values (about 23^{o}C) near the mouth.

Dissolved oxygen values ranged from good near the mouth to poor in the upper reaches of the Southern Branch and the Eastern Branch. A very strong diurnal variation was observed at station E-1 near Great Bridge, as shown in Figure 6. Concentrations ranged from around 2 mg/l to over 8 mg/l. DO's in the Eastern Branch also were below the 4 mg/l standard much of the time, but did not exhibit the diurnal trend.

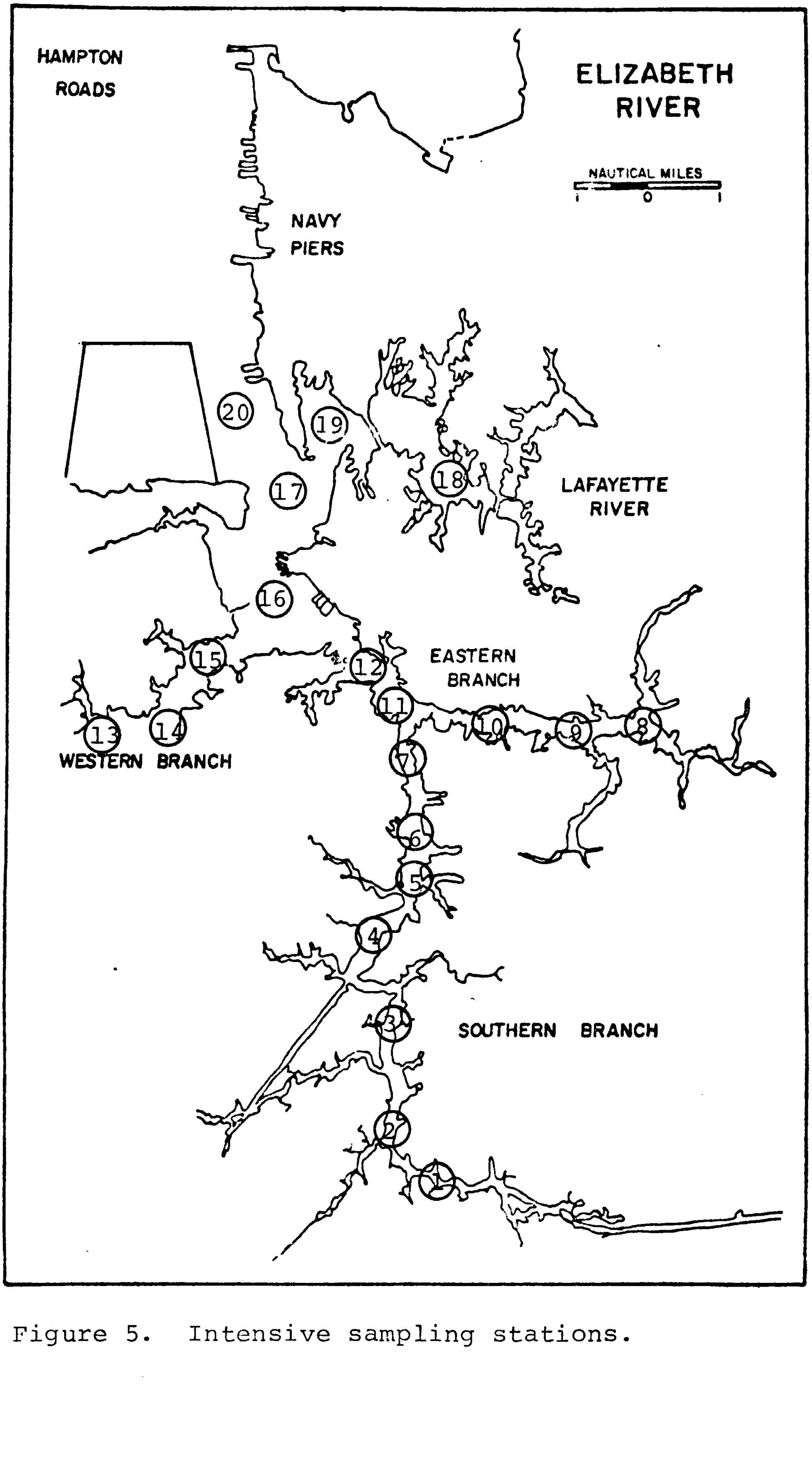


Figure 5. Intensive sampling stations.

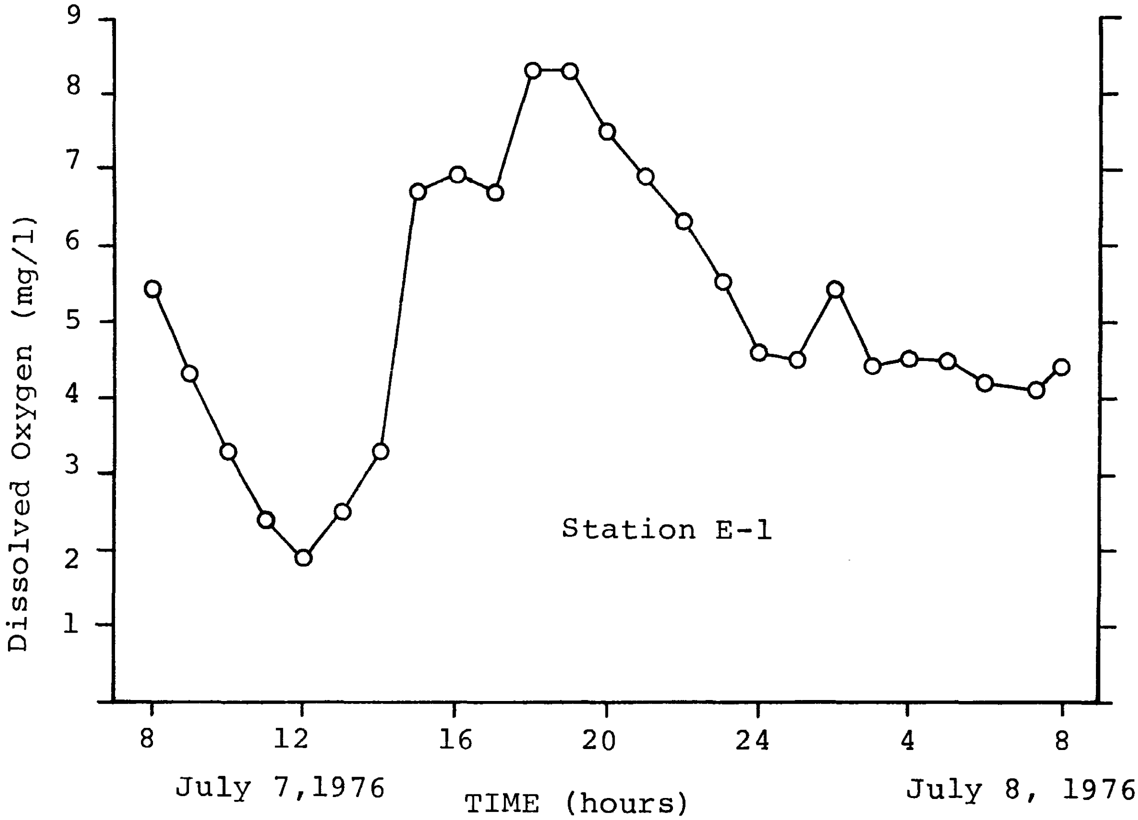


Figure 6. Variation in dissolved oxygen concentration at station E-1.

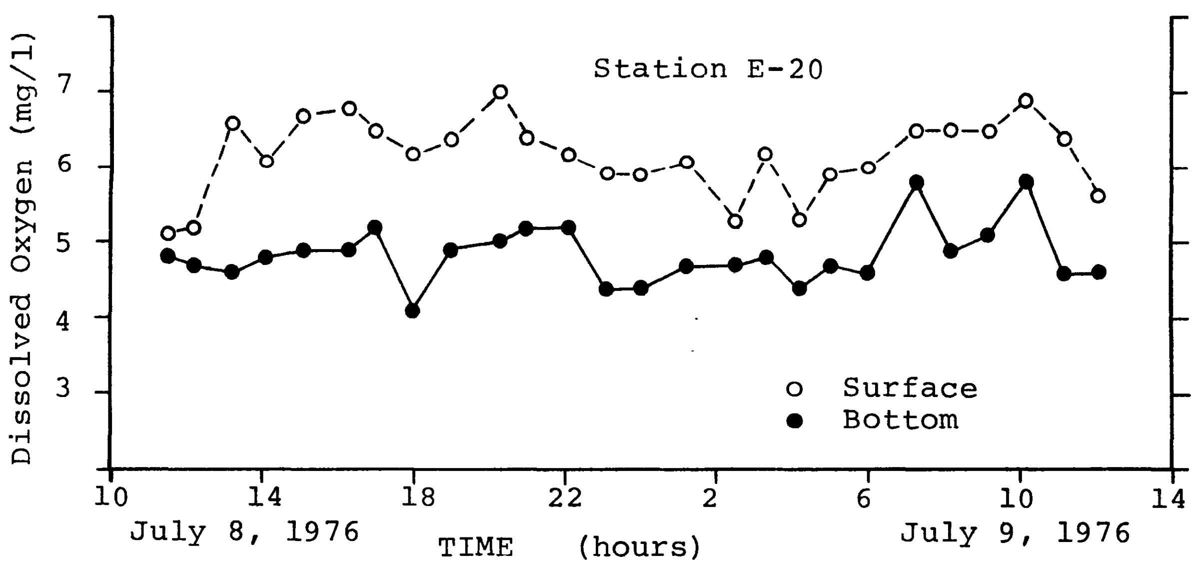


Figure 7. Variation in dissolved oxygen concentrations at station E-20 at the mouth of the river.

Dissolved oxygen concentrations below 4 mg/l were common at all stations on the Southern and Eastern Branches. The only stations which exhibited concentrations always above 4 mg/l and average values above 5 mg/l were those located on the Western Branch and the Lafayette River and station E-20 at the mouth. The data presented in Figure 7 show that although surface DO's usually were good, bottom DO's near the mouth were marginal.

The variations in DO observed at station E-16 are typical of the main stem. Concentrations near Lambert Point show a mild diurnal variation and minimum values below the 4 mg/l standard. Daily average values are only slightly above 5 mg/l. (see Figure 8) One reason why dissolved oxygen levels were depressed is that the saturation value for oxygen in water decreases as temperature and salinity increase, and for the conditions existing in the Elizabeth was about 7 mg/l. The elevated water temperatures also cause biological rates to increase, resulting in more rapid exertion of oxygen demand. These factors combined with the large BOD loads from domestic treatment plants and the long residence times result in waters with depleted oxygen reserves. Natural reaeration is limited in some reaches which have average depths ranging up to 12 metres.

Benthal oxygen demand was measured at seven locations and values ranged from 1.6 to 3.8 grams of oxygen per square metre per day. A "typical value" for other estuaries in the area is 1 gm-O_2/m^2/day. The elevated benthal demands could be responsible in part for the vertical variations in DO, since the lower values usually were observed near the river bottom.

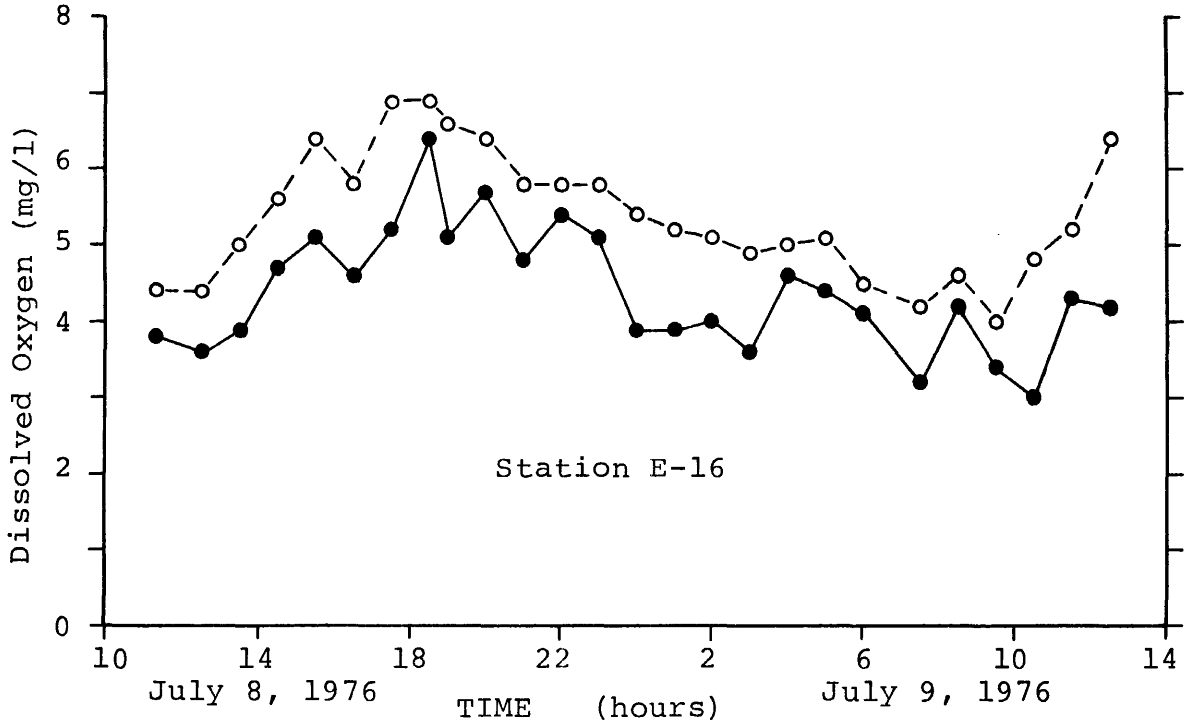
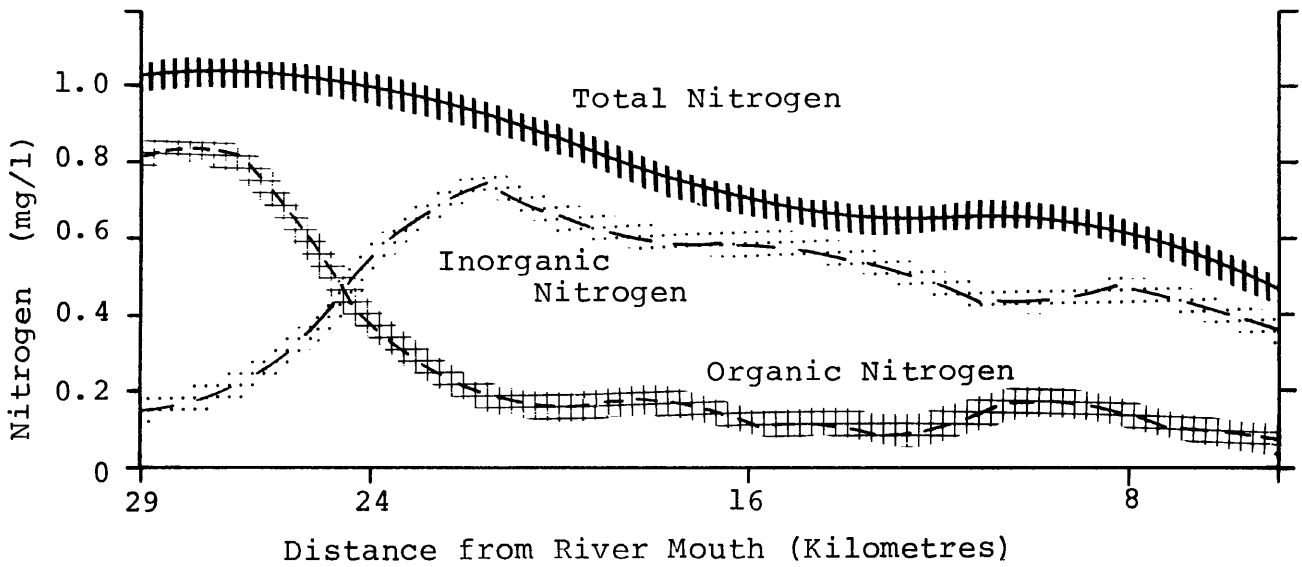


Figure 8. Dissolved oxygen variations at station E-16.

Both Total Nitrogen and Total Phosphorus concentrations decreased from the upper reaches toward the river mouth. This trend probably results from greater tidal exchange near the mouth, and therefore greater dilution towards the river mouth (Figure 9). Organic nitrogen was reasonably constant along the river with the exception of a dramatic rise in the upriver portion of the Southern Branch. There was an algal bloom occurring at stations E-1 and E-2, with observed chlorophyll "a" concentrations ranging as high as 222 ug/l. Values for all other stations along the main stem and Southern Branch were about 10 ug/l with values ranging up to about 20 ug/l (see Figure 10).

Fecal coliform counts were universally high. Readings below the shellfish growing area standard of 14 MPN/100 ml. were observed infrequently at most stations. Average values for the main stem, the Southern Branch and the Eastern Branch ranged between 100 and nearly 2000 MPN/100 ml. Bacterial counts in the Western Branch and the Lafayette River were lower, but mean values still remained above the shellfish standard. Analyses of the major treatment plant effluents at the time of the survey indicate that disinfection was good and that coliform levels in the effluent streams normally were below 20 MPN/100 ml. The increased counts observed in the river could not be accounted for by stormwater runoff (Cerco, 1978). The only remaining sources are commercial freighters, pleasure craft and wildlife. All of these pollutant sources are difficult to measure and/or quantify, but the first two could be contributing significant amounts of fecal coliforms if raw sewage is being discharged.



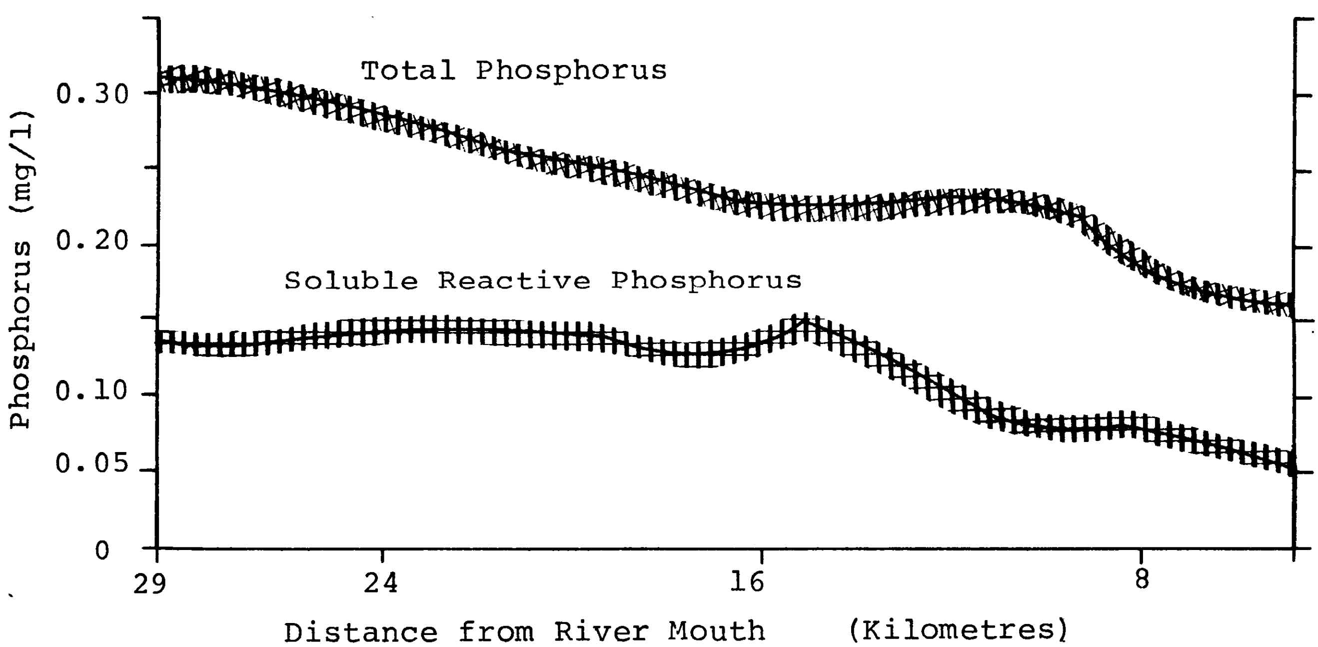


Figure 9. Variation in nutrient forms with distance from the mouth of the river.

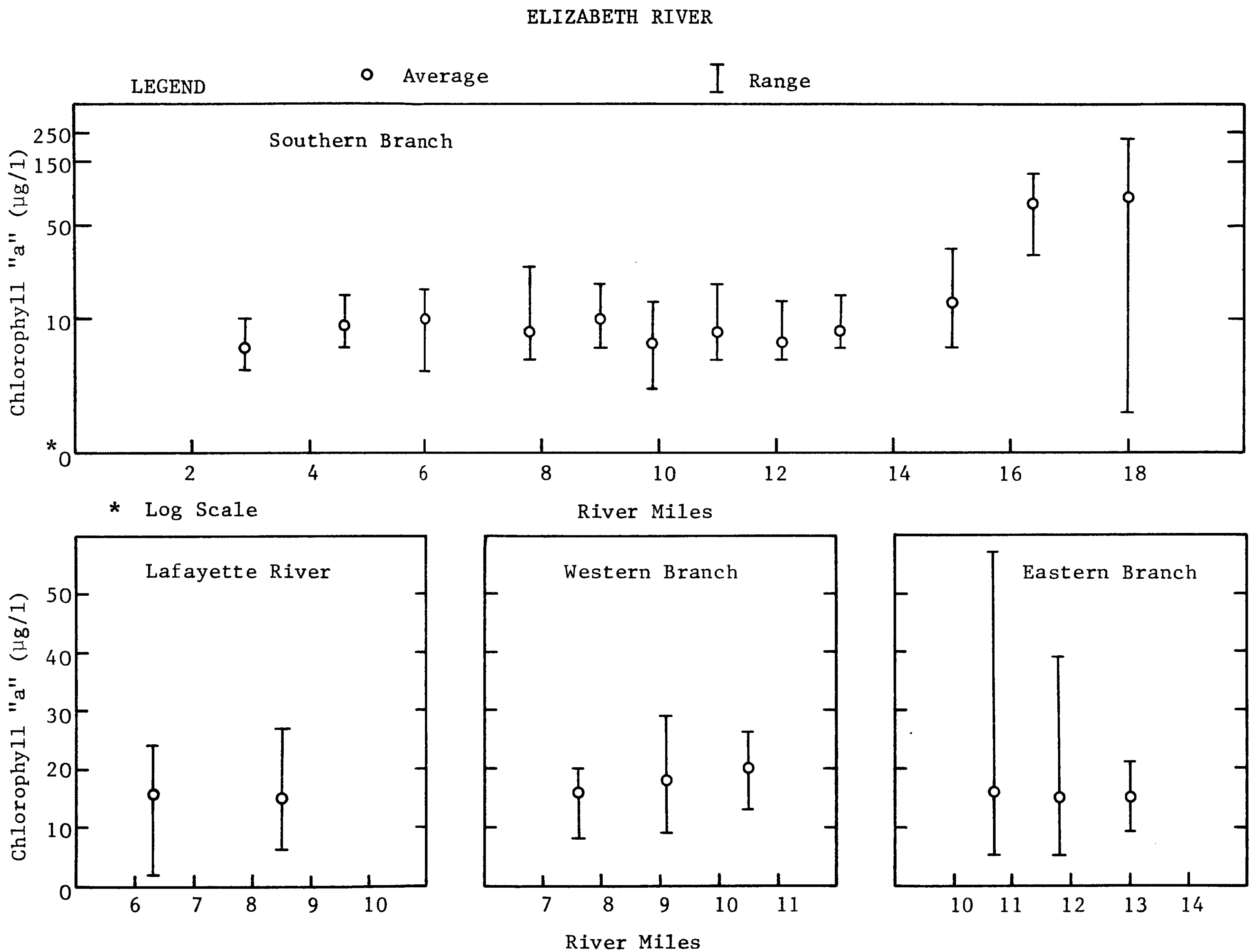


Figure 10. Variation in chlorophyll "a" levels with distance from the river mouth.

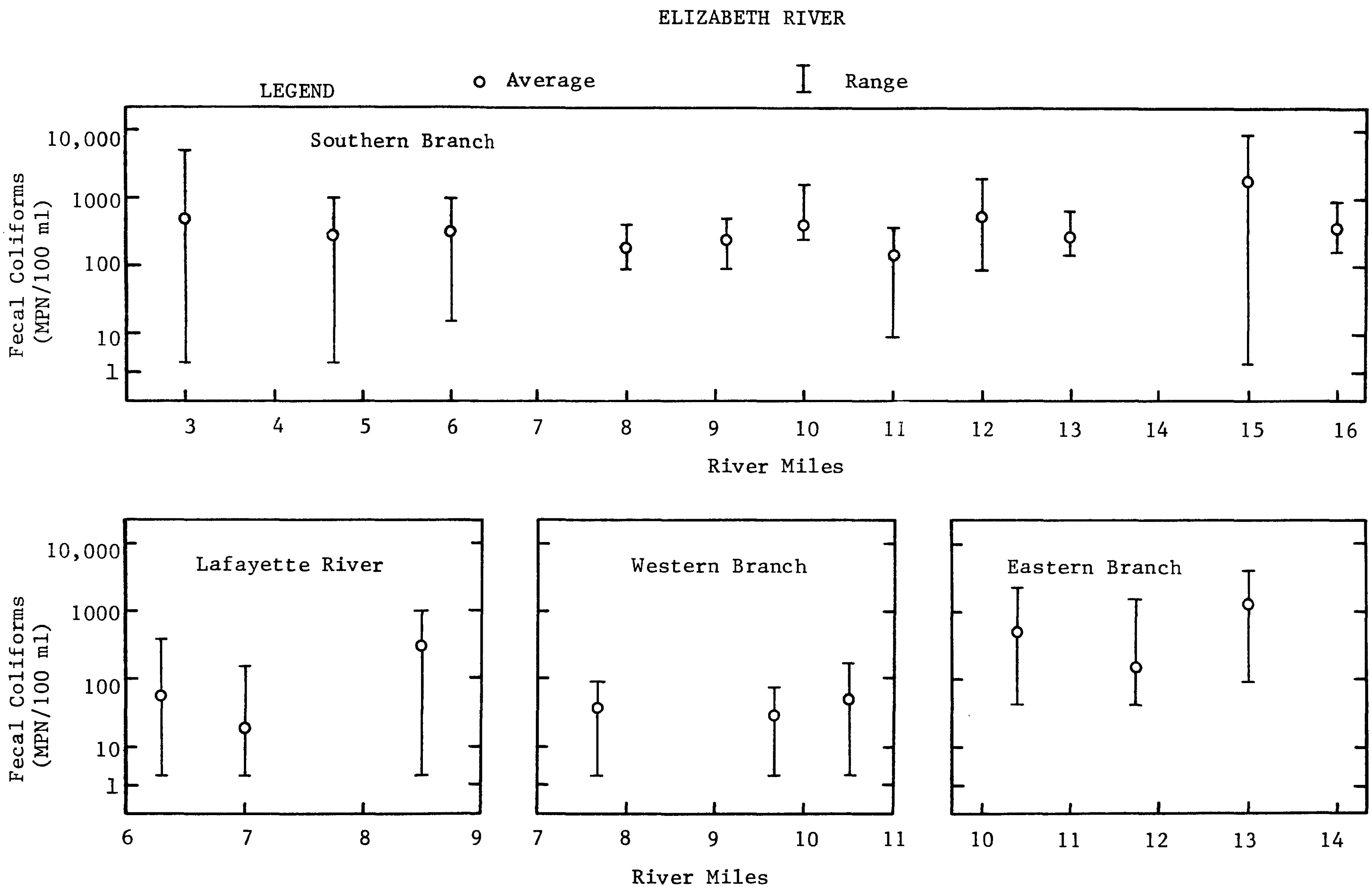


Figure 11. Fecal coliform counts in the Elizabeth River and its tributaries at the time of the intensive survey.

Data from the slack water surveys showed generally similar conditions, even though about six weeks had elapsed from the time of the intensive survey. Dissolved oxygen values were above 6 mg/l at the mouth and decreased to around 6 mg/l near Lambert Point. From Town Point to Great Bridge, DO's were variable with values up to 12.9 mg/l in the surface waters and values as low as 3.6 mg/l in the bottom waters. Values below 5 mg/l were not uncommon at depths of several metres or more, but only a few determinations were below the 4 mg/l standard. The extremely high values indicate that some other factor was at work, such as an algal bloom. Chlorophyll "a" levels were generally less than 15 µg/l with the exception of stations E-1 and E-2 near Great Bridge, where chlorophyll levels reached 85 µg/l, definitely bloom conditions.

Fecal coliform counts near the mouth were 23 MPN/100 ml or less, but for the upriver stations values tended to be in the range of 43 to 430, with one reading of 1500 MPN/100 ml. Values tended to be somewhat high at stations E-2 and E-3 (near Deep Creek) and E-16 (Lambert Point) but somewhat lower at stations E-11 (Town Point) and E-4 (near Gilmerton).

Summary

Water quality conditions in the Elizabeth River system are compromised by the large volumes of wastewaters discharged each day. The flows from sewage treatment plants probably are several times greater than the flow of freshwater to the tributaries during the dry summer months. When freshwater flow is small, tidal mixing tends to disperse wastes but also produce near homogeneity. As a result, flushing is poor and wastes discharged to the system are likely to remain there for long periods of time.

Field results show that dissolved oxygen levels are depressed below the 4 mg/l standard for much of the river. The high water temperatures and salinities reduce the saturation value to only about 7 mg/l, thereby reducing the likelihood of having DO's above the limits. The large quantities of BOD which are discharged to the river would be distributed throughout the system and the oxygen demand exerted in the river. If all major treatment plants are upgraded and smaller plants taken off-line ambient concentrations of BOD should be reduced and DO levels should increase. Additionally, benthal oxygen demand may decrease if nutrient and BOD loads are reduced, however, there have been no studies conducted to demonstrate that this will occur or to give any order of magnitude on the likely change. If land that is presently "open" is developed (say for dense residential housing or industrial activities) nonpoint pollution loads are likely to increase negating some of the benefits achieved through improved waste treatment.

Inorganic nitrogen and phosphorus levels are high relative to upper limits recommended for the upper Chesapeake Bay. However, phytoplankton levels were around 10 μg/l at most stations indicating that turbidity, predation, mixing or some other factor is limiting growth. Algal bloom conditions were observed in the most upriver segments of the Southern Branch, both during the intensive survey and during the slack water surveys. It is not clear why these conditions would exist there but not elsewhere. One possible explanation is that depths are less in this portion of the river and that tidal mixing may be dispersing the algae throughout the water column in the lower reaches.

Fecal coliform levels were far above shellfish growing standards and were approaching the limits for primary contact recreation at the time of the intensive survey. The levels were somewhat lower at the time of the slack water survey. The high levels cannot be accounted for by treatment plant effluents or stormwater runoff, and possibly could be resulting from shipping and recreational boating.

In summary, water quality in the Elizabeth River system is not good, but neither is the estuary "dead". Conditions should improve in the near future as municipal treatment plants are removed or upgraded. However, marshes, the Great Dismal Swamp, boat traffic and urban runoff contribute large and generally unknown loads. These sources must be studied further and where appropriate, controlled if water quality is to improve significantly over the long run.

REFERENCES

Blair, Carvel, 1975. Personal communication.

Cerco, Carl F., 1977. "A Water Quality Model of the Elizabeth River", Special Report No. 149 in Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science, Gloucester Point, VA 23062.

Corps of Engineers, Norfolk District, 1974. "The Dismal Swamp Canal as Related to the Great Dismal Swamp Study, P. L. 92-478." Norfolk, Virginia.

Hayes, Seay, Mattern and Mattern, 1975. "Army Base Water Pollution Control Plant Phase II Improvements", Facilities Plan, Appendix. Report to the Hampton Roads Sanitation District.

Seufer, Paul E., 1977. Personal communication.

Smith, Russell S., 1950. "Water Quality Survey of Hampton Roads Shellfish Areas 1949-1950". Division of Engineering, Virginia State Department of Health in cooperation with U. S. Public Health Service, Environmental Health Center.

Virginia State Water Control Board, 1975. "Water Quality Inventory 305(b) Report, Virginia". A Report to EPA Administrator and Congress, Information Bulletin 509, Richmond, Virginia.

APPENDIX A

Field Sampling Program

Elizabeth River Sampling Program

Parameter	Intensive Survey: Sampling Period	Intensive Survey: Sampling Frequency	Intensive Survey: Sampling Depths	1 Slack Water Survey (4 stations): Sampling Period	1 Slack Water Survey (4 stations): Sampling Frequency	1 Slack Water Survey (4 stations): 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	M†
Fecal Coliforms	25 hrs.	every 3 hrs.	T,B	SBE,SBF	summer	M
N	25 hrs.	every 3 hrs.	T,B	SBE,SBF	summer	M
Total P	25 hrs.	every 3 hrs.	T,B	SBE,SBF	summer	M
Chlorophyll "A"	25 hrs.	every 3 hrs.	T,B	SBE,SBF	summer	M

*15 Intensive Survey Stations taken at mid-depth only
†5 Slack Water Stations taken at top and bottom depths only

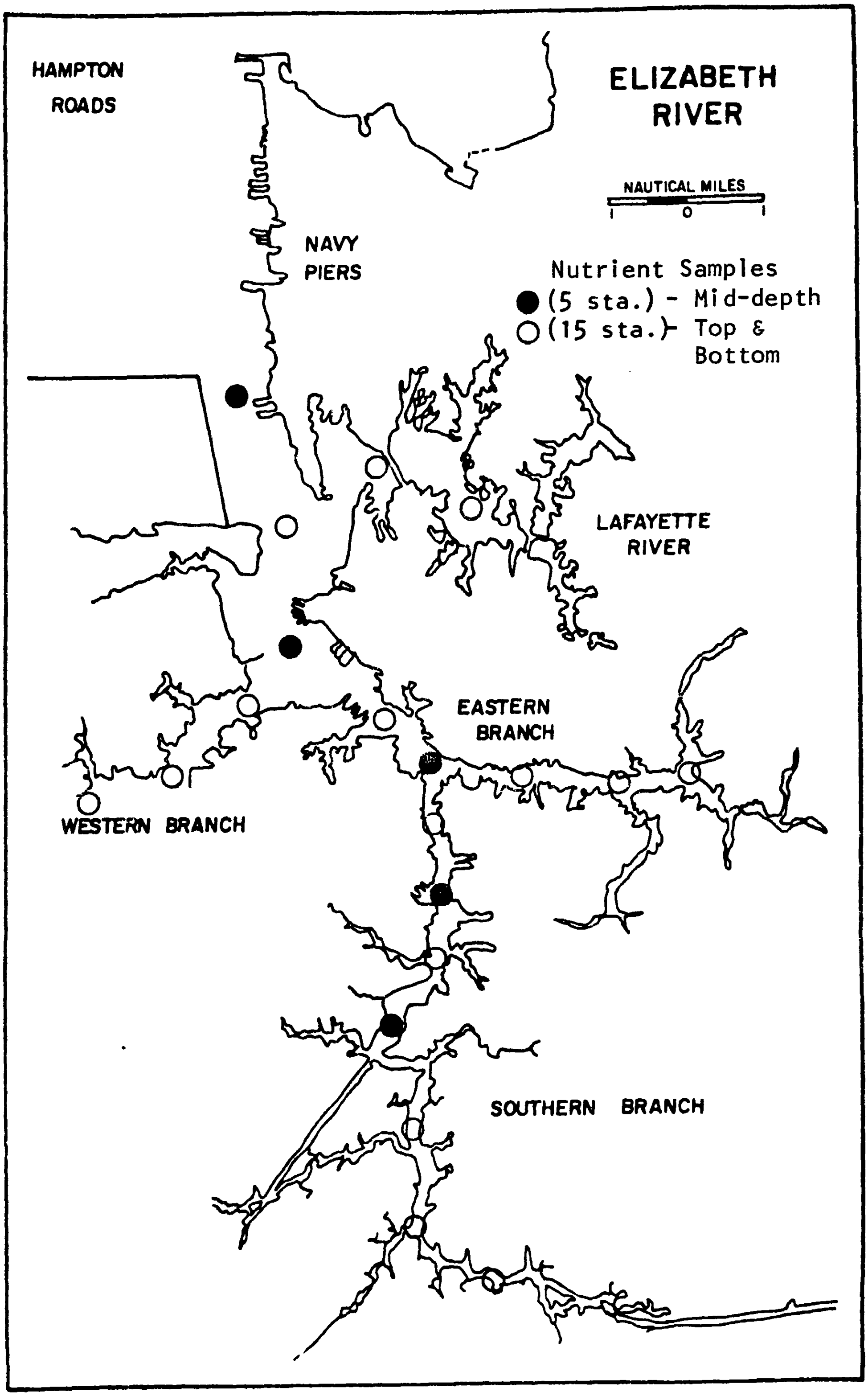
Other Measurements - 7 stations

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

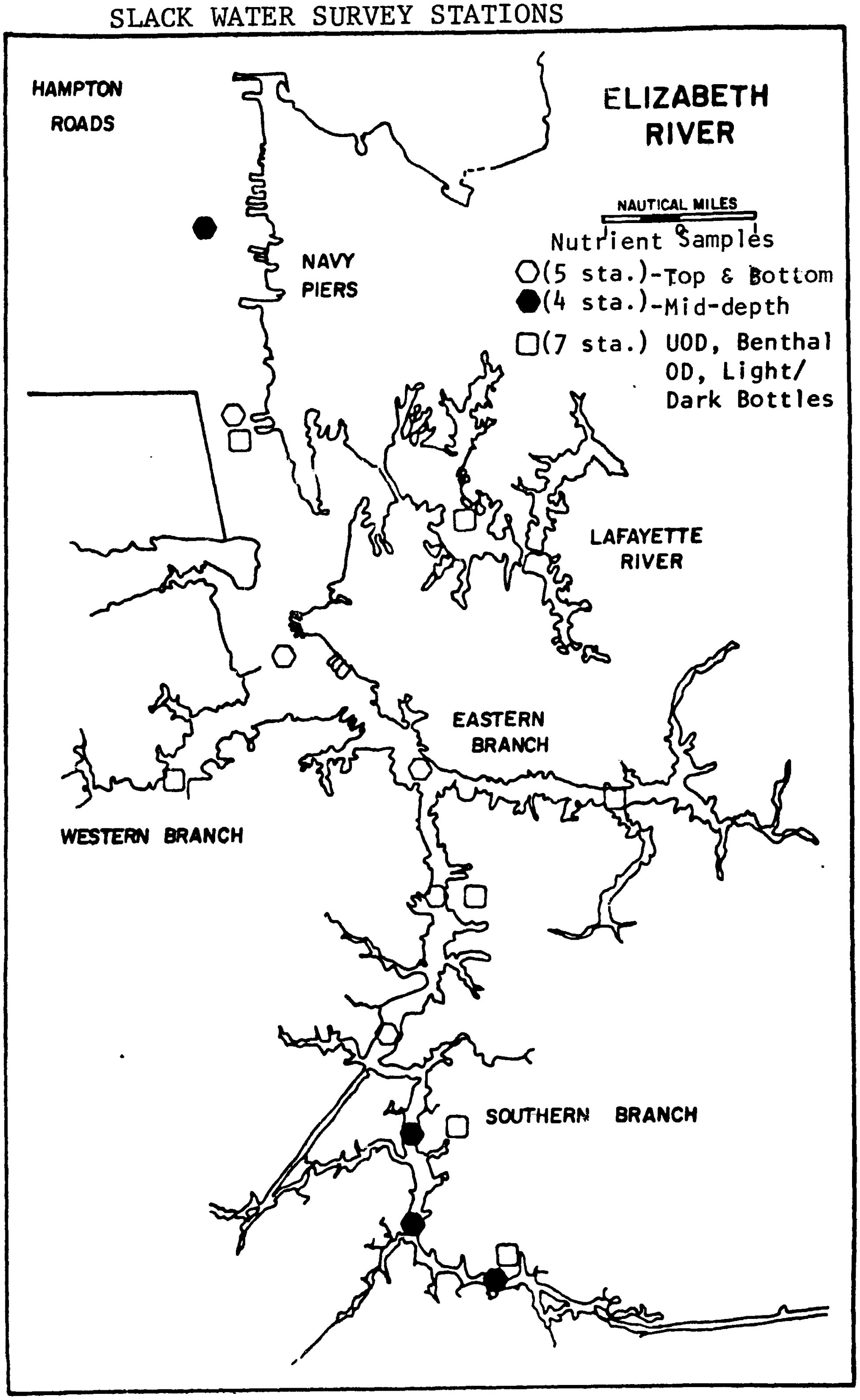
T = 1 meter below surface
M = mid-depth
B = 1 meter off bottom

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

INTENSIVE SURVEY STATIONS



SLACK WATER SURVEY STATIONS



ANALYTICAL METHODS

1) Temperature	a.	Interocean CTD Model 513/514. Accuracy ±0.1°C. Calibrated before and after every intensive field survey.
	b.	Applied Research Austin Model ET 100 Marine. Accuracy ±0.1°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) Bacteria		
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) <u>Biochemical Oxygen Demand</u>

5-day or 30-day, $20^{\circ}C$, Carbonaceous BOD	SM 507 Biochemical Oxygen Demand EPA #310 - BOD Modified: Nitrification inhibited with pyridine

7) <u>Nitrogen</u>

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) <u>Phosphorus</u>

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

9) Benthal Oxygen Demand (cont'd)

probe without stirring up the 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:

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

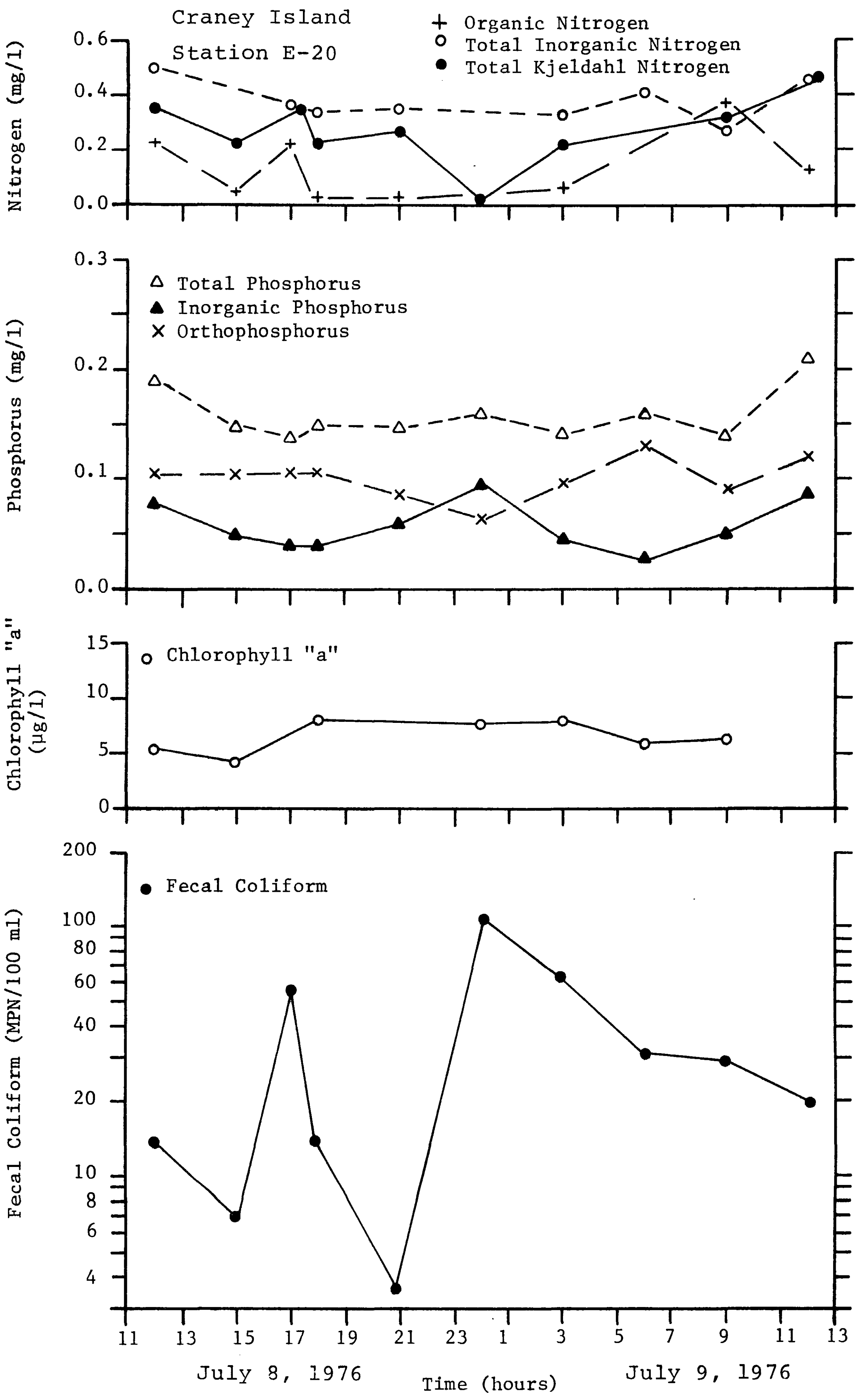
the mean depth of the chamber in cm., allowing for the volume displaced by the stirrer.

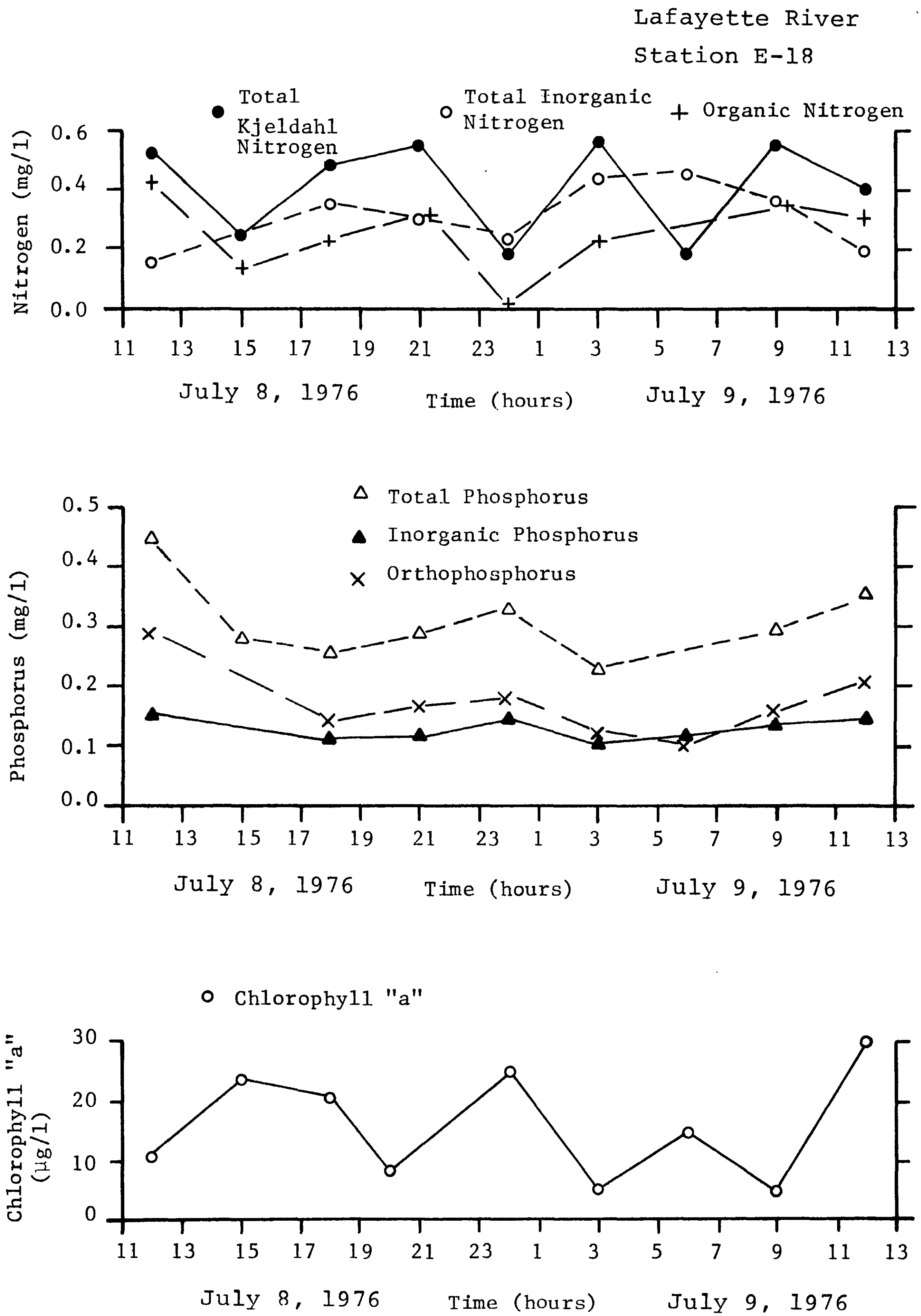
APPENDIX B

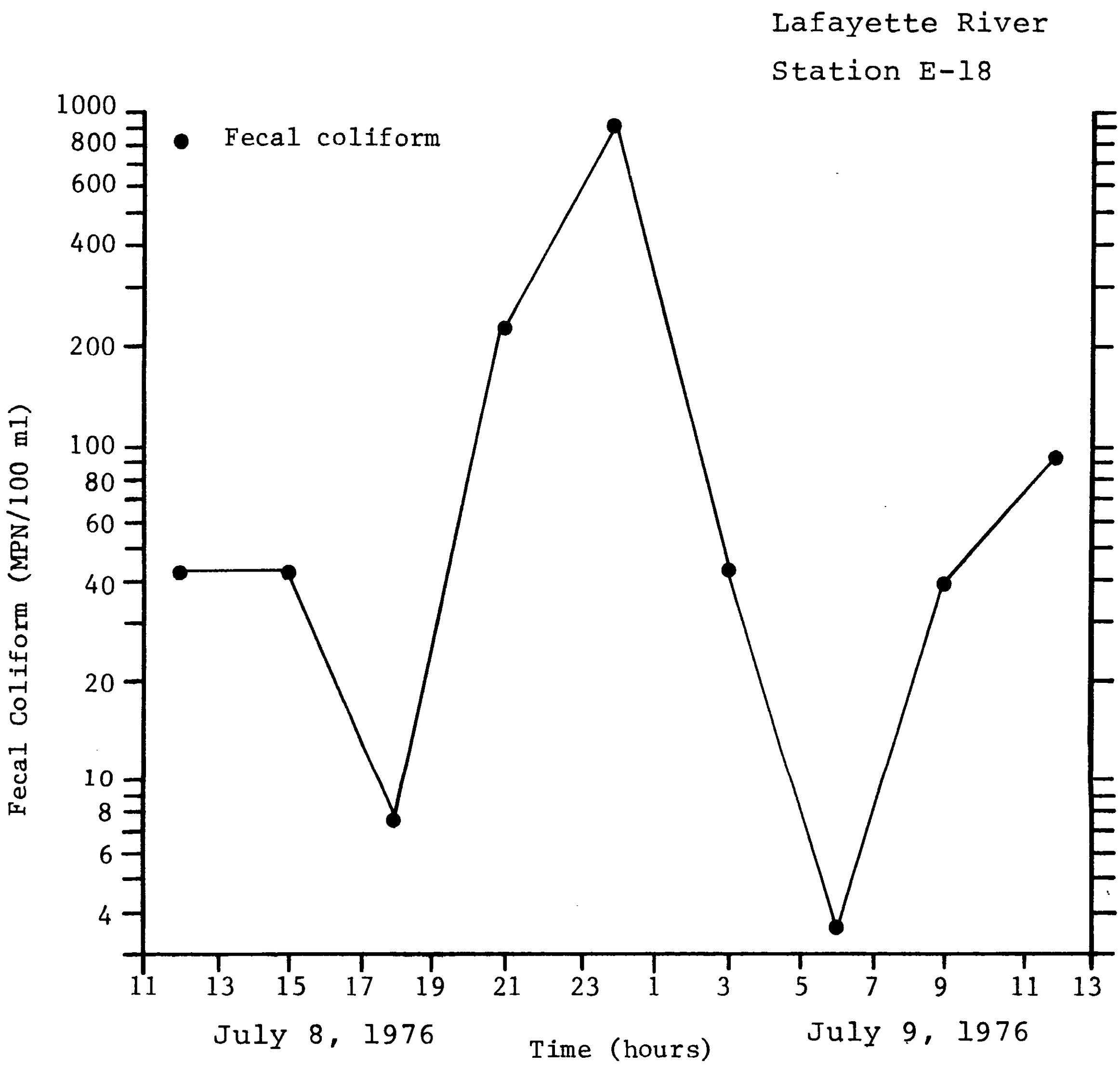
Water Quality Data from the
July 7-9, 1976 Intensive Survey

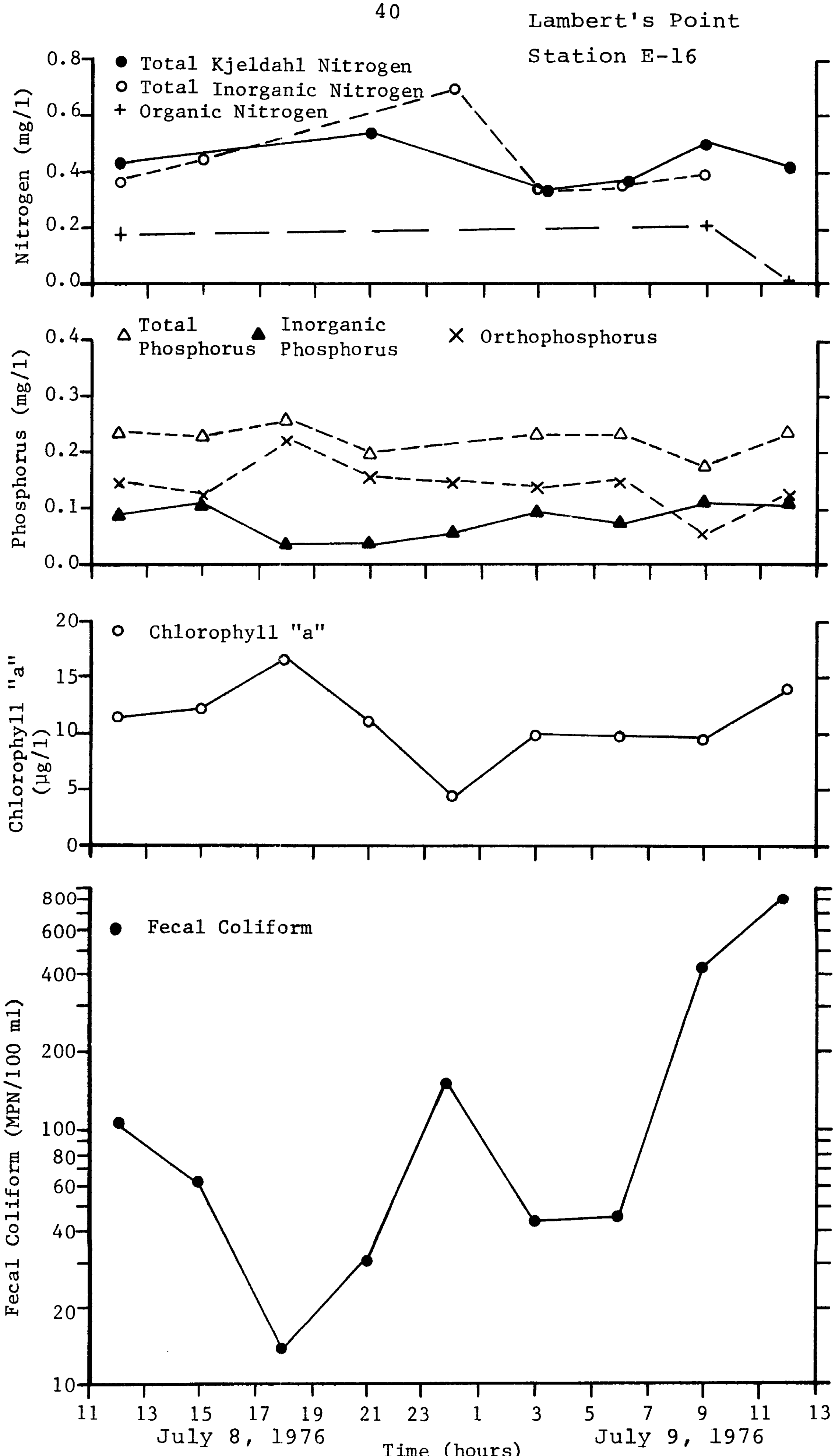
Data For selected stations is presented in graphical format (refer to Figure 5 for station locations).

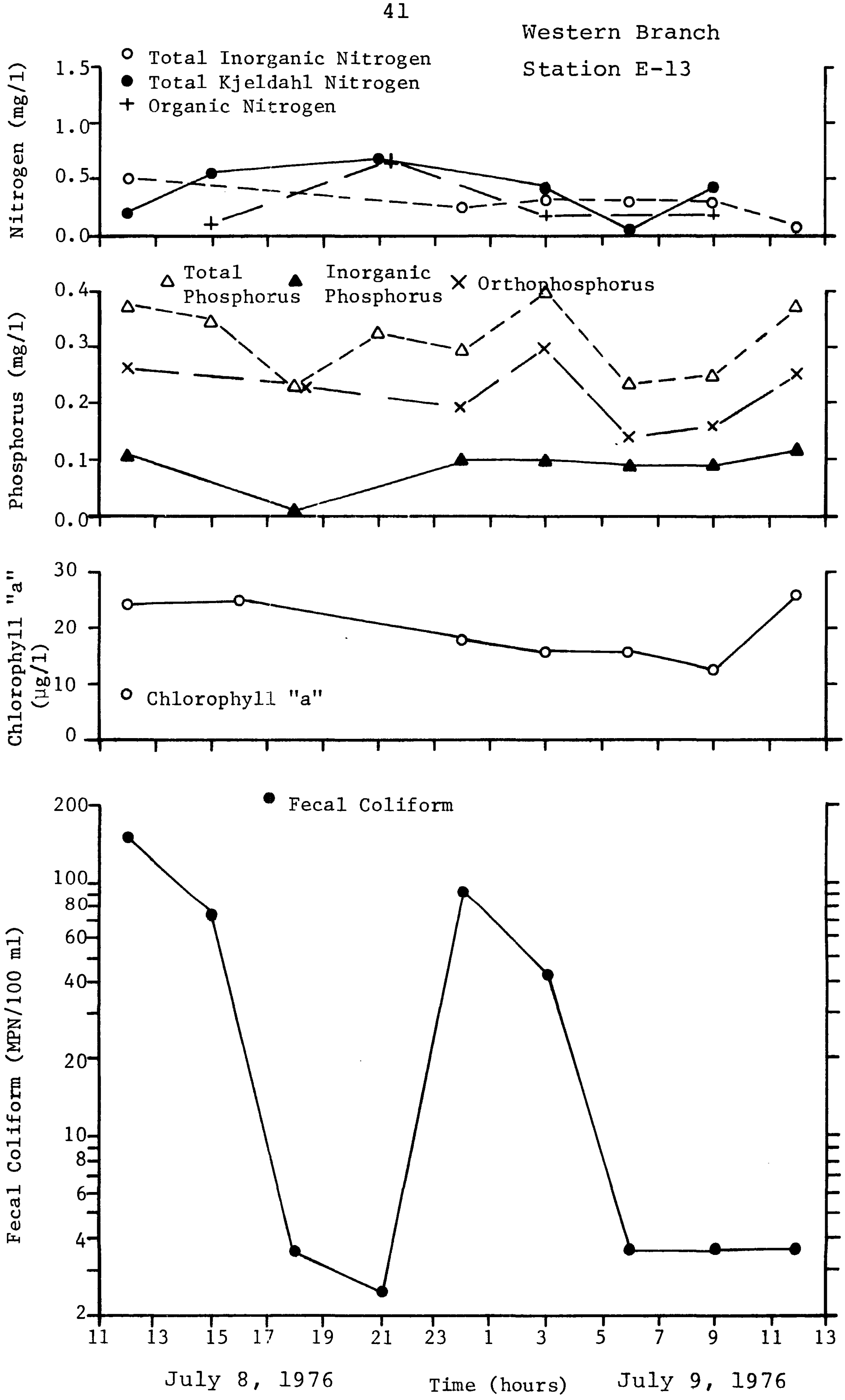
** NOTE: Computer printouts of all data for all stations are available for review and use at VIMS and the HRWQA offices.

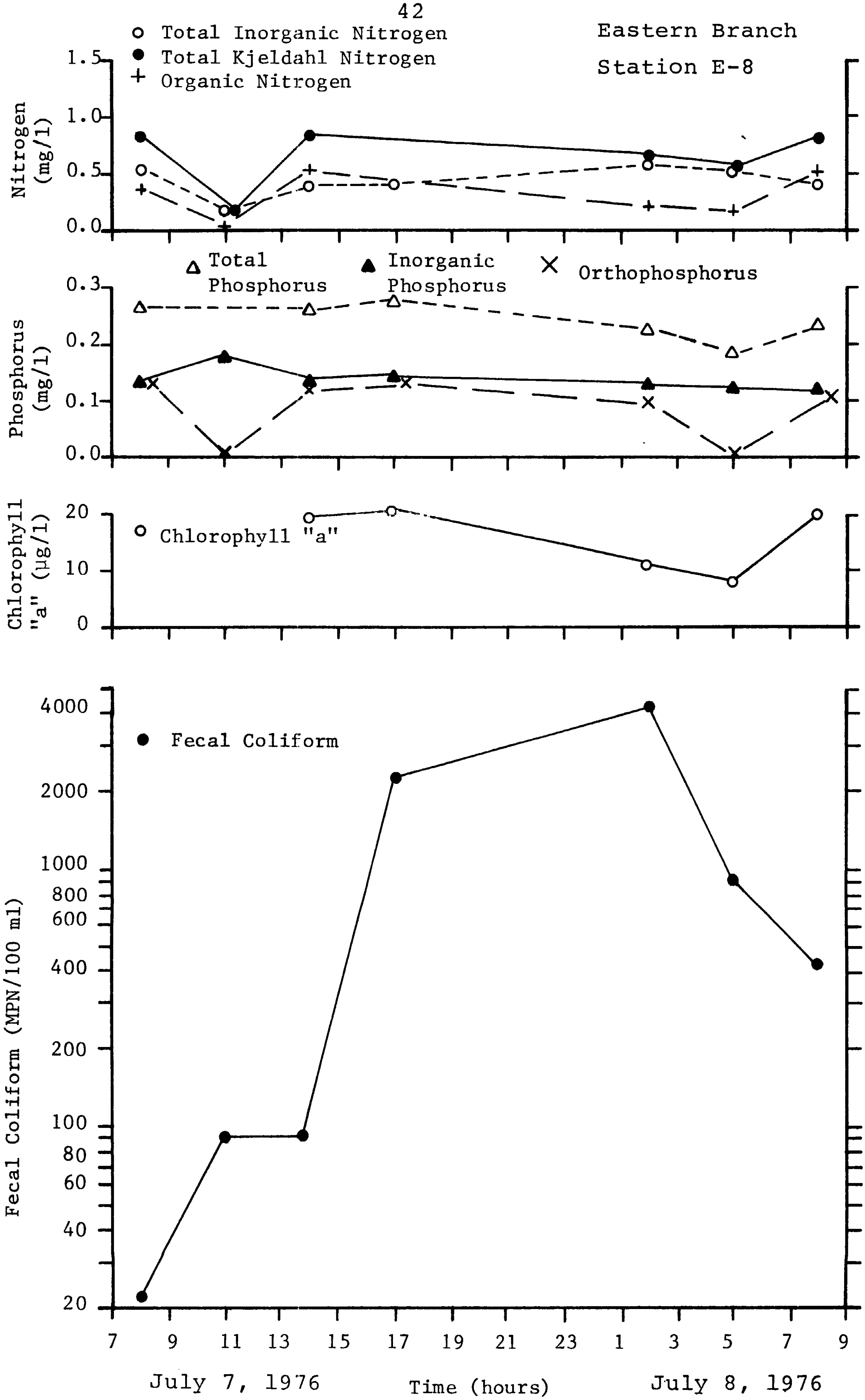

Craney Island
Station E-20
Organic Nitrogen
Total Inorganic Nitrogen
Total Kjeldahl Nitrogen
Nitrogen (mg/l)
0.6
0.4
0.2
0.0
0.3
0.2
0.1
0.0
Total Phosphorus
Inorganic Phosphorus
Orthophosphorus
Phosphorus (mg/l)
15
10
5
0
Chlorophyll "a"
Chlorophyll "a" (µg/l)
200
100
80
60
40
20
10
8
6
4
Fecal Coliform
Fecal Coliform (MPN/100 ml)
11
13
15
17
19
21
23
1
3
5
7
9
11
13
July 8, 1976
Time (hours)
July 9, 1976

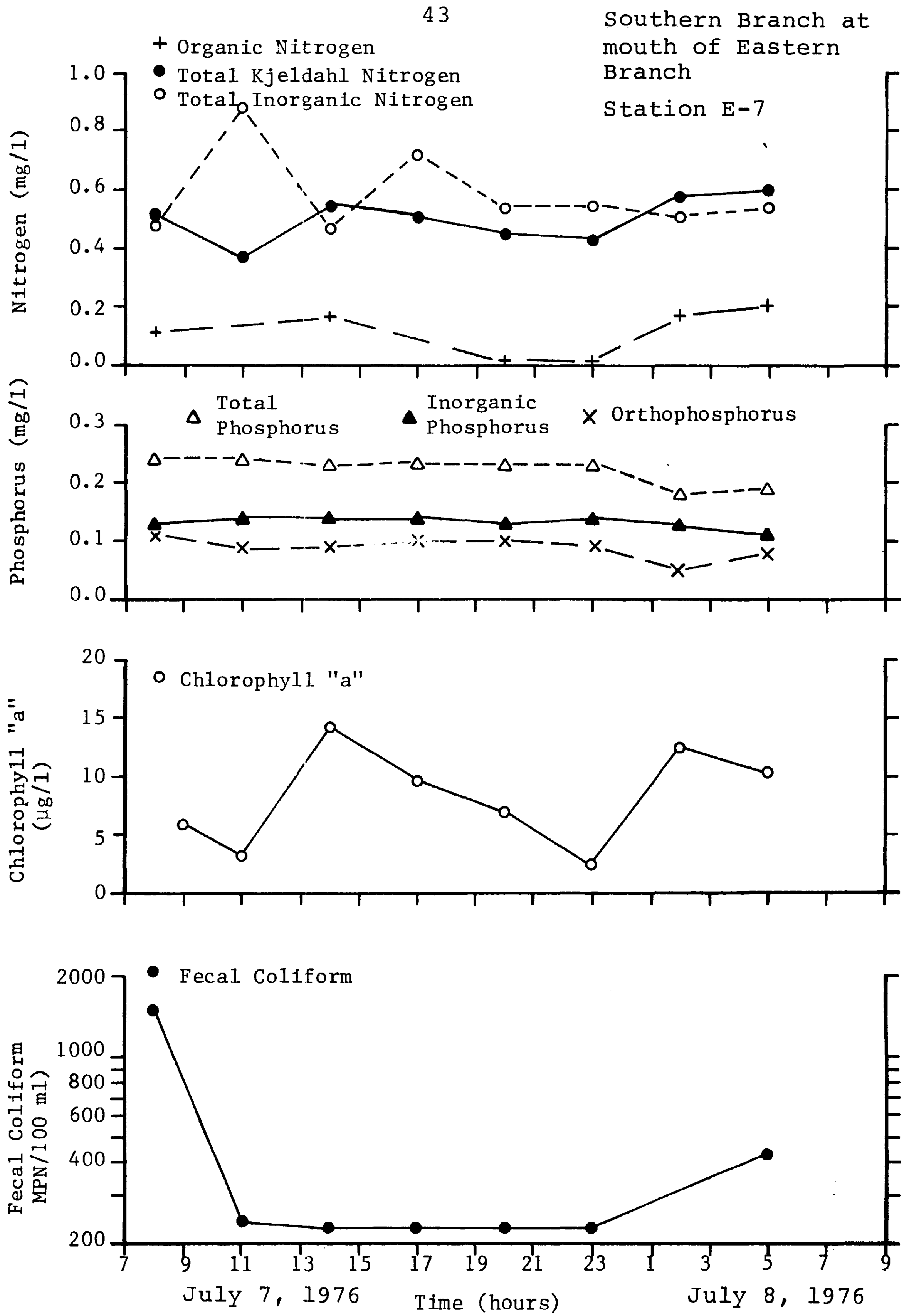

Lafayette River
Station E-18
Total Kjeldahl Nitrogen
Total Inorganic Nitrogen
Organic Nitrogen
Nitrogen (mg/l)
0.6
0.4
0.2
0.0
11 13 15 17 19 21 23 1 3 5 7 9 11 13
July 8, 1976
Time (hours)
July 9, 1976
Total Phosphorus
Inorganic Phosphorus
Orthophosphorus
Phosphorus (mg/l)
0.5
0.4
0.3
0.2
0.1
0.0
11 13 15 17 19 21 23 1 3 5 7 9 11 13
July 8, 1976
Time (hours)
July 9, 1976
Chlorophyll "a"
Chlorophyll "a" (µg/l)
30
20
10
0
11 13 15 17 19 21 23 1 3 5 7 9 11 13
July 8, 1976
Time (hours)
July 9, 1976

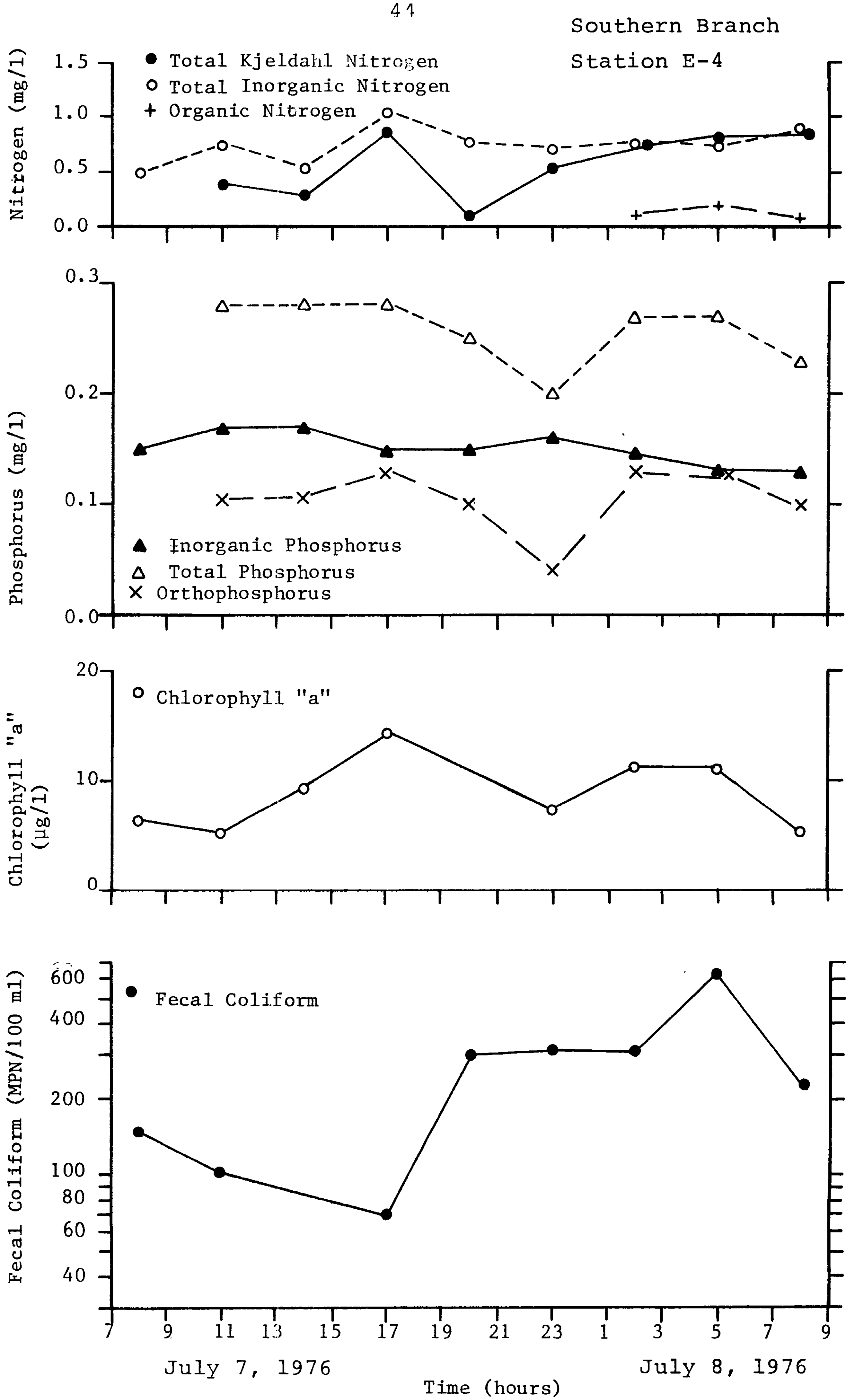

Lafayette River
Station E-18
Fecal coliform
Fecal Coliform (MPN/100 ml)
1000
800
600
400
200
100
80
60
40
20
10
8
6
4
11
13
15
17
19
21
23
1
3
5
7
9
11
13
July 8, 1976
Time (hours)
July 9, 1976

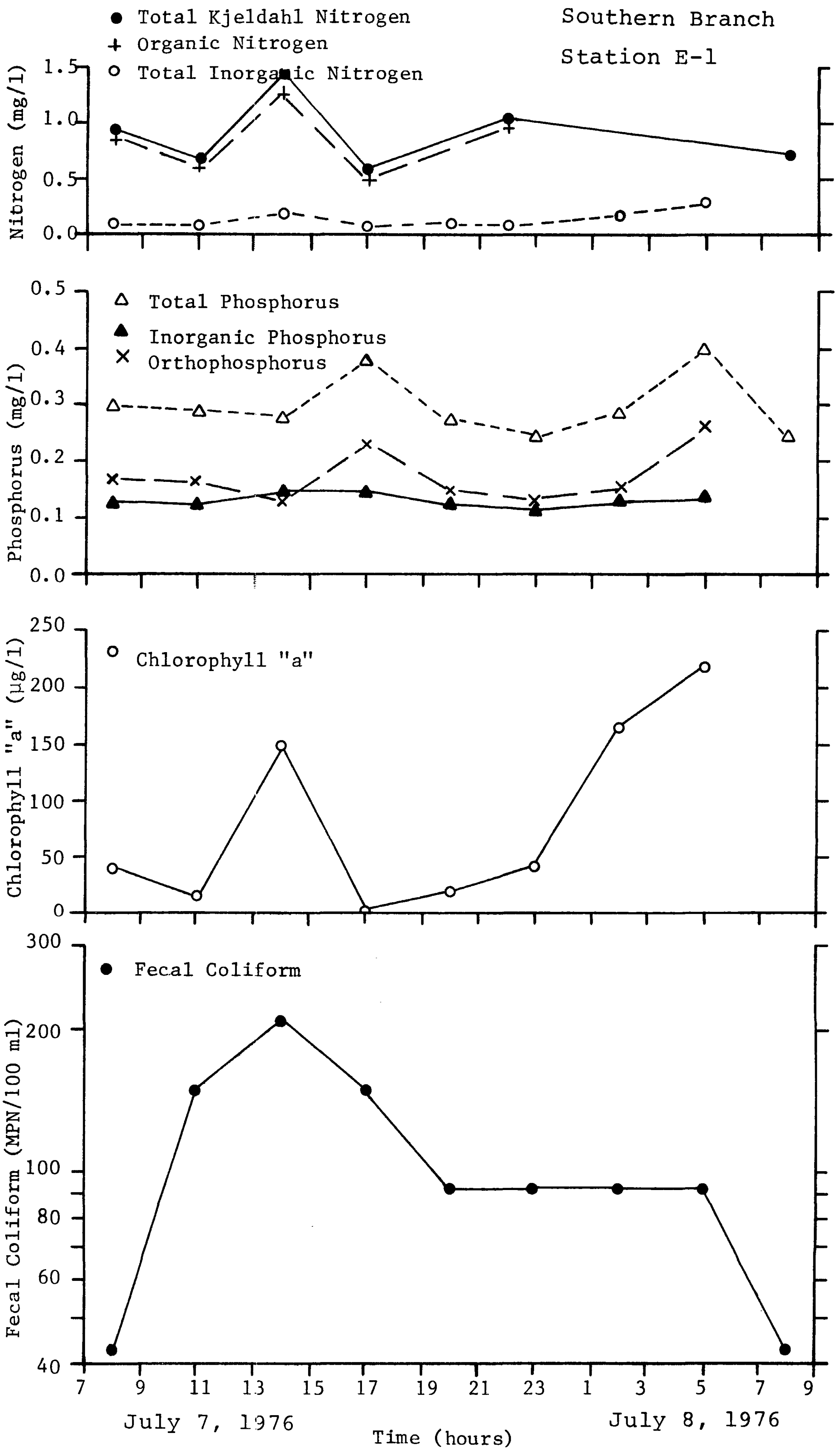

Lambert's Point
Station E-16
Total Kjeldahl Nitrogen
Total Inorganic Nitrogen
Organic Nitrogen
Nitrogen (mg/l)
0.8
0.6
0.4
0.2
0.0
Total Phosphorus
Inorganic Phosphorus
Orthophosphorus
Phosphorus (mg/l)
0.4
0.3
0.2
0.1
0.0
Chlorophyll "a"
Chlorophyll "a" (μg/l)
20
15
10
5
0
Fecal Coliform
Fecal Coliform (MPN/100 ml)
800
600
400
200
100
80
60
40
20
10
11
13
15
17
19
21
23
1
3
5
7
9
11
13
July 8, 1976
Time (hours)
July 9, 1976


Western Branch
Station E-13
Total Inorganic Nitrogen
Total Kjeldahl Nitrogen
Organic Nitrogen
Nitrogen (mg/l)
1.5
1.0
0.5
0.0
Total Phosphorus
Inorganic Phosphorus
Orthophosphorus
Phosphorus (mg/l)
0.4
0.3
0.2
0.1
0.0
Chlorophyll "a" (µg/l)
30
20
10
0
Chlorophyll "a"
Fecal Coliform
Fecal Coliform (MPN/100 ml)
200
100
80
60
40
20
10
8
6
4
2
11
13
15
17
19
21
23
1
3
5
7
9
11
13
July 8, 1976
Time (hours)
July 9, 1976


Eastern Branch
Station E-8
Total Inorganic Nitrogen
Total Kjeldahl Nitrogen
Organic Nitrogen
Nitrogen (mg/1)
1.5
1.0
0.5
0.0
Total Phosphorus
Inorganic Phosphorus
Orthophosphorus
Phosphorus (mg/1)
0.3
0.2
0.1
0.0
Chlorophyll "a"
Chlorophyll "a" (μg/1)
20
10
0
Fecal Coliform
Fecal Coliform (MPN/100 ml)
4000
2000
1000
800
600
400
200
100
80
60
40
20
7
9
11
13
15
17
19
21
23
1
3
5
7
9
July 7, 1976
Time (hours)
July 8, 1976


Southern Branch at mouth of Eastern Branch
Station E-7
+ Organic Nitrogen
● Total Kjeldahl Nitrogen
○ Total Inorganic Nitrogen
Nitrogen (mg/l)
1.0
0.8
0.6
0.4
0.2
0.0
△ Total Phosphorus
▲ Inorganic Phosphorus
× Orthophosphorus
Phosphorus (mg/l)
0.3
0.2
0.1
0.0
○ Chlorophyll "a"
Chlorophyll "a" (μg/l)
20
15
10
5
0
● Fecal Coliform
Fecal Coliform MPN/100 ml)
2000
1000
800
600
400
200
7
9
11
13
15
17
19
21
23
1
3
5
7
9
July 7, 1976
Time (hours)
July 8, 1976


Southern Branch
Station E-4
Total Kjeldahl Nitrogen
Total Inorganic Nitrogen
Organic Nitrogen
Nitrogen (mg/l)
1.5
1.0
0.5
0.0
Phosphorus (mg/l)
0.3
0.2
0.1
0.0
Inorganic Phosphorus
Total Phosphorus
Orthophosphorus
Chlorophyll "a"
Chlorophyll "a" (µg/l)
20
10
0
Fecal Coliform
Fecal Coliform (MPN/100 ml)
600
400
200
100
80
60
40
7
9
11
13
15
17
19
21
23
1
3
5
7
9
July 7, 1976
July 8, 1976
Time (hours)


Total Kjeldahl Nitrogen
Organic Nitrogen
Total Inorganic Nitrogen
Southern Branch
Station E-1
Nitrogen (mg/l)
1.5
1.0
0.5
0.0
Total Phosphorus
Inorganic Phosphorus
Orthophosphorus
Phosphorus (mg/l)
0.5
0.4
0.3
0.2
0.1
0.0
Chlorophyll "a"
Chlorophyll "a" (μg/l)
250
200
150
100
50
0
Fecal Coliform
Fecal Coliform (MPN/100 ml)
300
200
100
80
60
40
7 9 11 13 15 17 19 21 23 1 3 5 7 9
July 7, 1976
July 8, 1976
Time (hours)

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