10-1-1977

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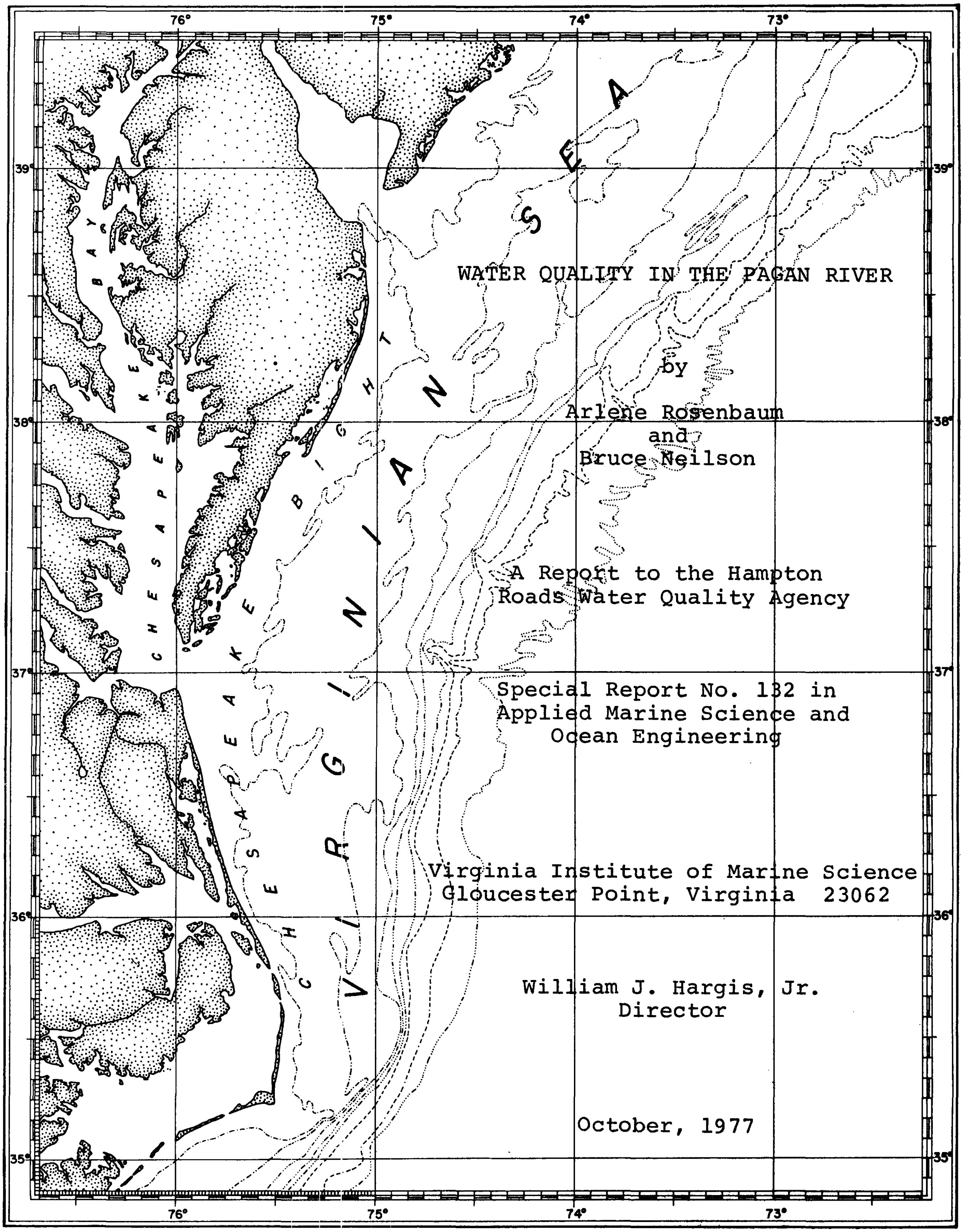
Recommended Citation

Rosenbaum, A., & Neilson, B. (1977) Water Quality in the Pagan River. Special Reports in Applied Marine Science and Ocean Engineering (SRAMSOE) No. 132. Virginia Institute of Marine Science, College of William and Mary. https://doi.org/10.21220/V5K15W



WATER QUALITY IN THE PAGAN RIVER

by

Arlene Rosenbaum
and
Bruce Neilson

A Report to the Hampton
Roads Water Quality Agency

Special Report No. 132 in
Applied Marine Science and
Ocean Engineering

Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

William J. Hargis, Jr.
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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.

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ACKNOWLEDGEMENTS

We would like to thank the entire field staff of VIMS Department of Physical Oceanography, supervised by William Matthews, and the laboratory staff supervised by Ronald Herzick, for their conscientious efforts, often under adverse circumstances. Special thanks are extended to Ms. J. C. Altemus for the extensive data compilation and editing, Ms. Linda Kilch for the preparation of the graphical data summaries, Ms. Patricia Svarney for drafting of the numerous figures, and Ms. Cathy Garrett for her noteworthy typing and report preparation.

We would also like to express our appreciation to Dr. P. V. Hyer for his design and supervision of the benthic oxygen demand survey and his helpful advice and consultation regarding the ecosystem model application, and Dr. C. S. Fang for directing the field program.

CHAPTER 1.

Introduction

The Pagan River is a small coastal plains estuary located on the south side of the James River Estuary in Isle of Wight County. The Pagan is tributary to the James, entering it some 25 kilometers (15 miles) upriver of Old Point Comfort (see Figure 1). The drainage basin contains only about 185 square kilometers (71 square miles) and most of the land uses are rural in nature. More than half the watershed is forested and slightly more than a third of the land is used for agriculture, mostly cropland with only a small portion used as pastures. There are more than 1000 hectares (2600 acres) of marsh within the basin and most of this is tidal. Residential, commercial and industrial land uses account for less than 5% of the total area.

The processing of seafood, peanuts and meat products and related activities, namely peanut farming and hog production, account for a large portion of the economic activity within the basin. Additionally there is lumbering and a variety of small industries (pulpwood paper, concrete products, truck bodies and millwork). The major population and commercial center is the town of Smithfield, which is located about 8 kilometers (5 miles) above the mouth of the river (see Figure 2).

The climate in this area can be characterized as humid, subtropical. No meteorological stations are maintained within the Pagan drainage basin, but a station is located at Wakefield slightly to the west and another at Driver, slightly to the east. The mean annual temperature at Wakefield for 1976 was 14.4^{o}C (57.9^{o}F) with monthly average temperatures ranging from 3^{o}C (38^{o}F) in January and December to 25^{o}C (77^{o}F) in July. The minimum temperature recorded in 1976 was -14^{o}C (6^{o}F) and the highest was 38^{o}C (101^{o}F).

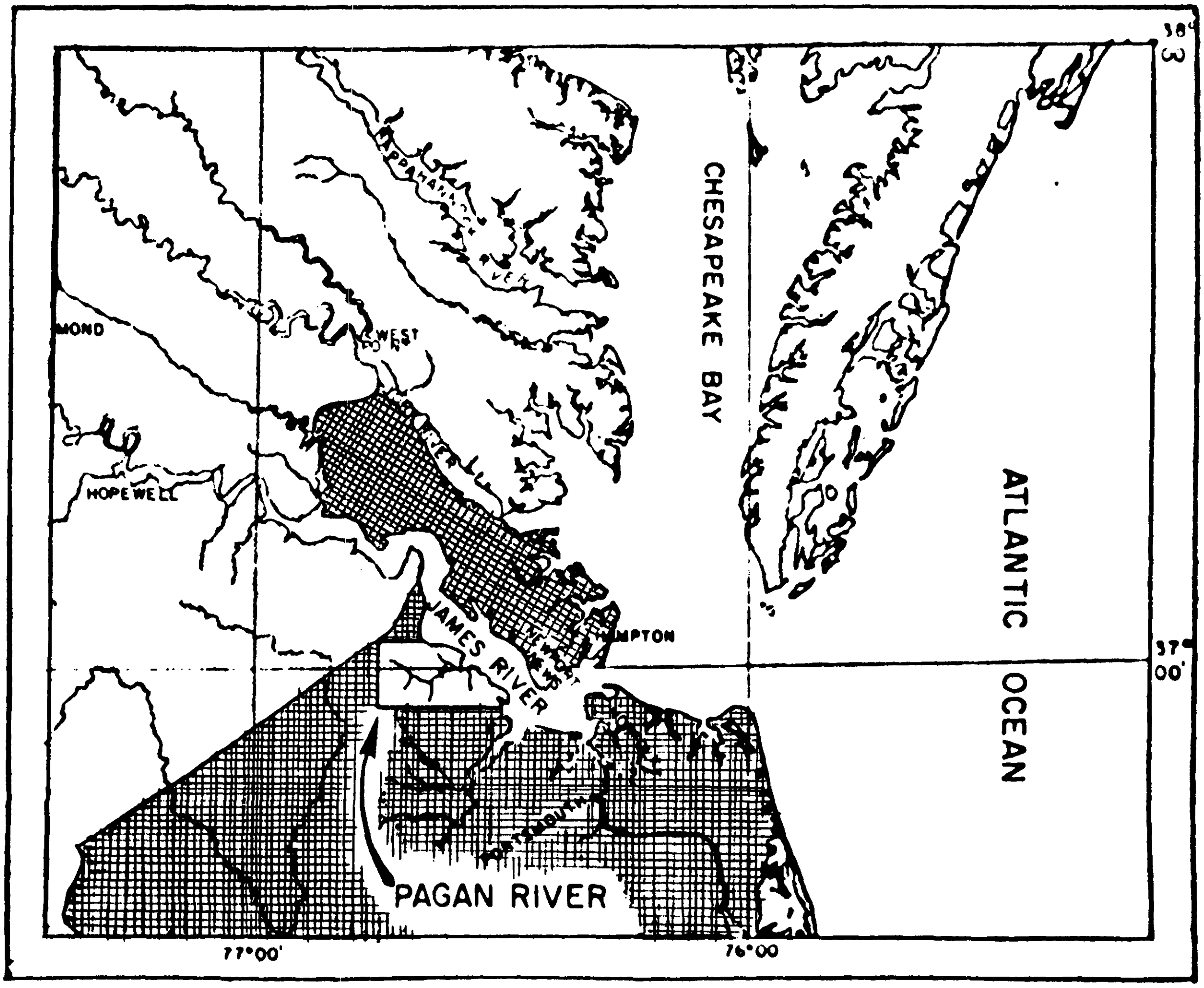


Figure 1. Location of the Hampton Roads 208 Study Area and the Pagan River.

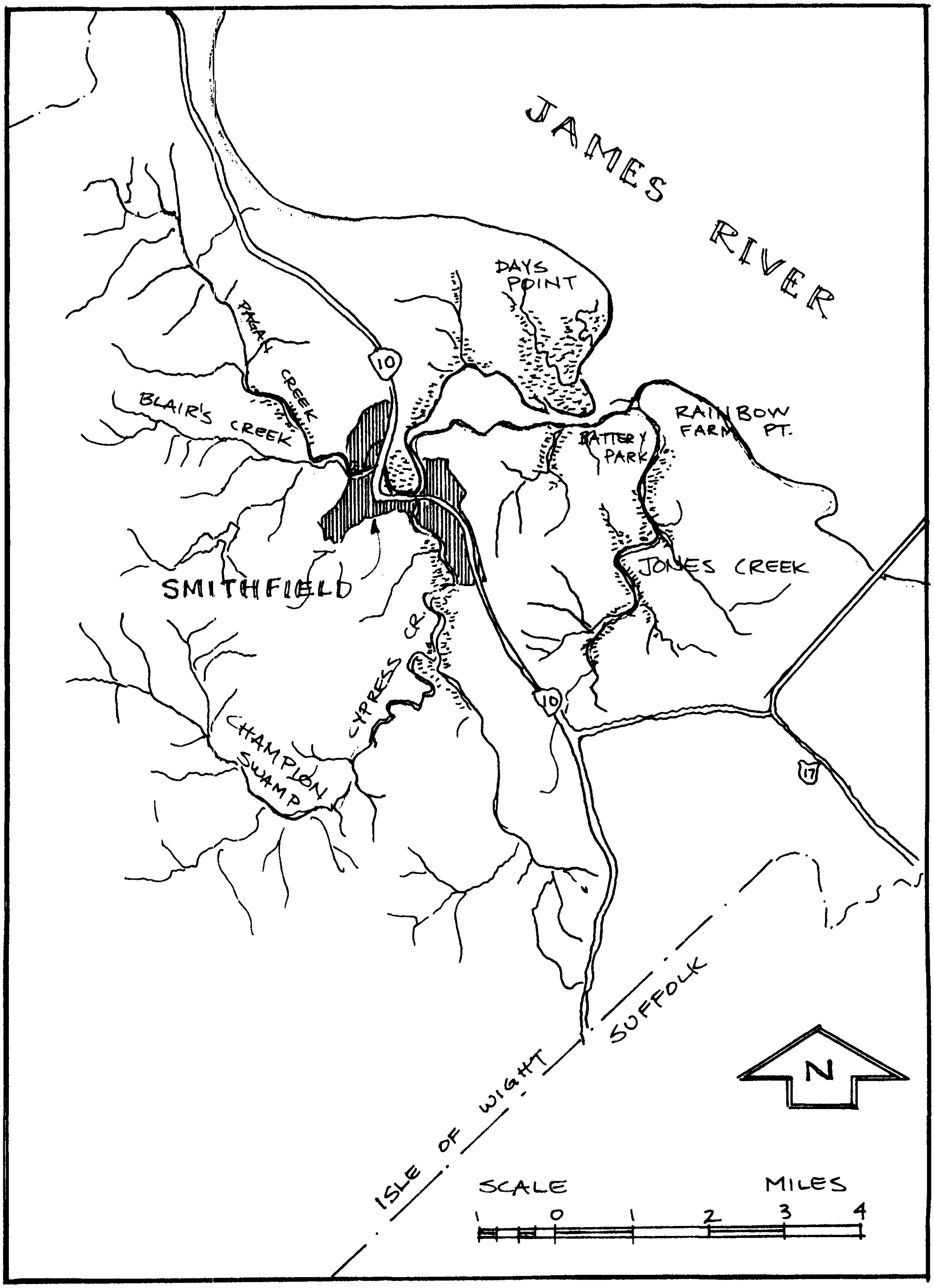


Figure 2. Pagan River drainage basin.

The yearly rainfall at Wakefield was 111 centimeters (43.6 inches) and that at Driver was 96 cm (37.7 inches), 19 cm (7.5 inches) below the long term yearly rainfall. The minimum monthly rainfall was 0.66 cm (0.26 inches) in April. However, more than 10 cm (4 inches) of rain occurred in each of the months of January, July, September, October and December.

Tidal circulation rather than freshwater runoff generally controls the physical characteristics of the river. The tide range is around 90 cm (3 feet) and tidal currents exceed 0.3 meters per second (1 foot/sec). Since the river is only about 17 kilometers (10.5 miles) long, the tidal wave propagates the length of the river in a matter of minutes.

The quality of the water in the Pagan River is often quite poor. In the Water Quality Inventory (305b) Report made by the State Water Control Board in 1975, it is stated that:

> The Pagan River water quality problems are caused by meat packing plants, poorly treated municipal waste waters, and benthic oxygen demands.

The purpose of this report is to present and summarize water quality data collected during the summer of 1976 as part of the Hampton Roads 208 Study. These data also have been used to calibrate and verify a mathematical model of water quality in the Pagan River. A description of the model and the calibration procedures are given in a separate report. A third report will present the findings of the model studies.

CHAPTER 2.

Water Quality

Several state agencies have conducted regular monitoring programs in the Pagan River. The State Water Control Board (SWCB) routinely collects samples at a number of stations within the estuary as well as monitoring the point source discharges. The Bureau of Shellfish Sanitation, Department of Health, regularly monitors the quality of the waters for the purposes of protecting the public health. The primary focus of these efforts is to determine whether pathogenic bacteria are present. The data gathered by these two agencies are useful to characterize the quality of the water in the Pagan River during recent years. As mentioned previously, a 1975 water quality inventory complied by the SWCB attributes water quality problems in the Pagan to "meat packing plants, poorly treated municipal waste waters and benthic oxygen demands". It is noted in the segment gazetteer of this report that a solution to the dissolved oxygen (DO) and nutrient problems will require a tenfold reduction in wasteload from Smithfield Packing, and that benthic oxygen demand in the vicinity of that plant and one belonging to I. T. T. Gwaltney may continue to degrade water quality. Additionally, fecal coliform problems were anticipated to continue until the sewage treatment plant for the Town of Smithfield had been upgraded, which was contingent upon the availability of funds.

Problems of fecal contamination also are evidenced by the existence of shellfish condemnation area number 64, which was enacted in September of 1972. The limits of this condemnation are shown in Figure 3.

Because of these water quality problems, the Pagan River was studied by the Water Control Board and the Virginia Institute of Marine Science in their Cooperative State Agencies Program (Kuo, Lewis and Fang,

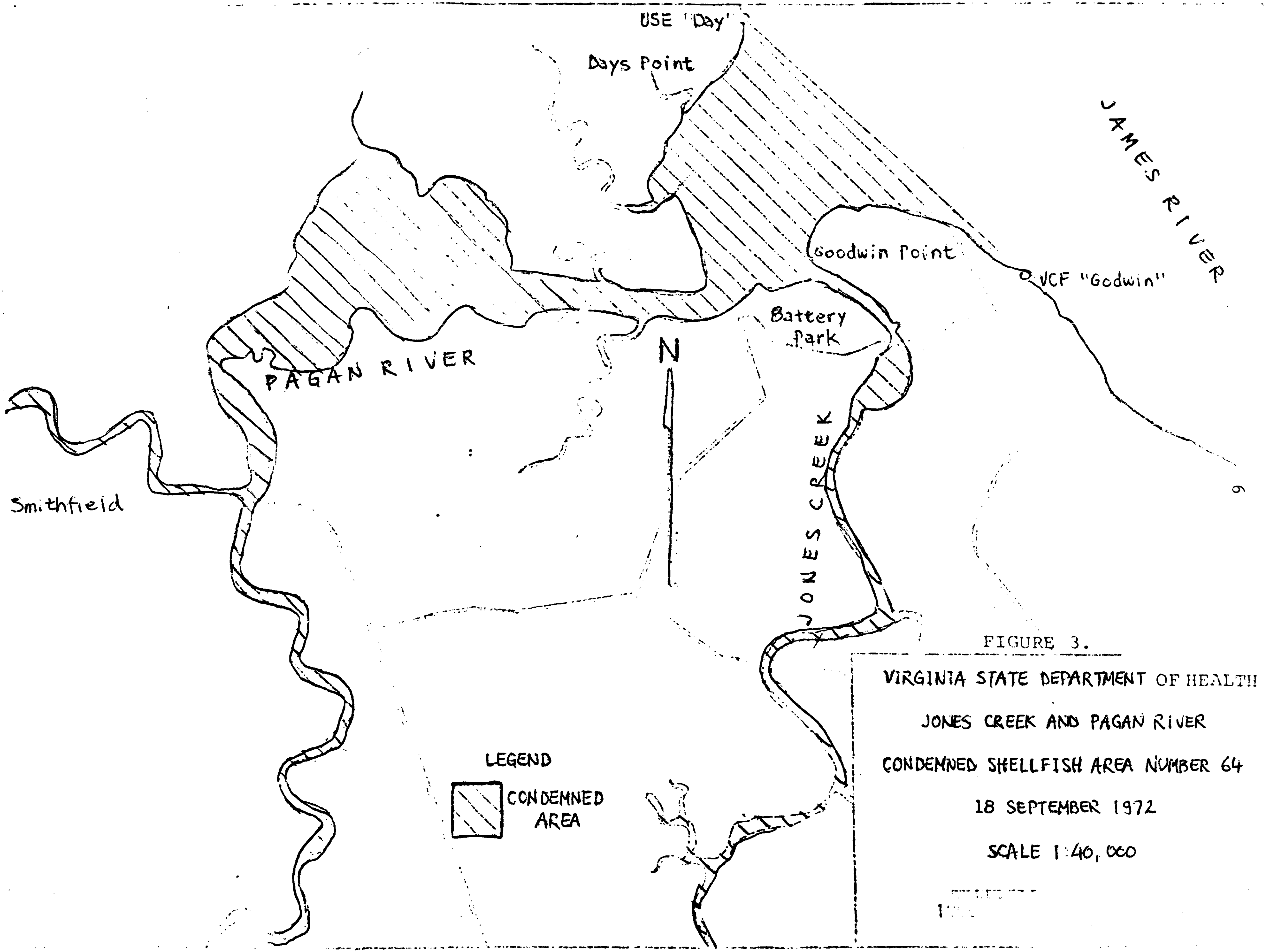


FIGURE 3.

VIRGINIA STATE DEPARTMENT OF HEALTH

JONES CREEK AND PAGAN RIVER

CONDEMNED SHELLFISH AREA NUMBER 64

18 SEPTEMBER 1972

SCALE 1:40,000

1976). This work included intensive sampling of the river in August 1974, slack water surveys in April and June of 1975, and the calibration and verification of a real time, one-dimensional mathematical model of water quality. The variables modeled were salinity (S), dissolved oxygen (DO) and both nitrogenous and carbonaceous biochemical oxygen demand (NBOD and CBOD). It was noted that a DO sag existed near the town of Smithfield and that DO values as low as 2 mg/l were observed frequently. Additionally, the existence of surface water supersaturated with dissolved oxygen was thought to indicate a phytoplankton bloom, but data were lacking to prove this.

The data contained in the CSA report only partially characterize the Smithfield and Pinewood Heights STP effluents. However, these appear to be very small compared to the discharges from the two meat packing plants owned by Smithfield Packing and I. T. T. Gwaltney. The Smithfield Packing Company is listed as discharging nearly 2000 pounds per day of 5-day carbonaceous BOD and nearly 3300 pounds per day of nitrogenous BOD. The I. T. T. Gwaltney plant discharged on a daily basis 476 pounds of CBOD5 and 2700 pounds of NBOD. The benthic oxygen demands determined in the calibration process were 1 gram of oxygen/square meter per day for the upper half portion of the river and 1.5 $gm/m^2/day$ in the lower reaches. The authors noted that since freshwater runoff was not great, tidal action dominated the flushing and dispersion of pollutants. Also no gravitational circulation to augment the flushing was observed.

CHAPTER 3.

"208" Field Studies

The studies conducted by the Water Control Board, the Bureau of Shellfish Sanitation and the Virginia Institute of Marine Science all documented water quality problems in the Pagan River. However, none of these studies was of sufficient scope to include a broad range of water quality measures and the diurnal and tidal stage variations of these measures. For these reasons, the Hampton Roads Water Quality Agency contracted VIMS to conduct a synoptic field program in order to document existing water quality fully and to provide the data necessary to calibrate and verify a mathematical model of water quality. Details of the field program design and analytical methods are given in Appendix A. and results are presented in Appendix B.

On June 28 and 29, 1976, an intensive survey was conducted. Six stations along the mid-channel of the river were monitored over two tidal cycles. At each station, samples were taken from one or more depths, depending on the total depth of the water column. Temperature, conductivity (for salinity) and dissolved oxygen were measured hourly, while nutrient, BOD, chlorophyll "a" and fecal coliform samples were collected every three hours. Secchi disk readings, benthal oxygen demand measurements and sample collection ultimate oxygen demand determinations were made periodically during the study. This type of sampling provides a comprehensive picture of water quality throughout the river and illustrates how it changes in response to sunlight and tidal oscillation. The intensive survey data are presented graphically in Appendix B.

The data from the intensive survey have been used to calibrate the mathematical model. Additional data were collected so that the model could be verified; a low water slack survey was conducted on August 23 and a high water slack survey on August 24, 1976. During same slack surveys, slack tide (either high or low) is followed as it progresses up the river. Often maximum and minimum values for water quality measures will occur at slack water. Therefore, these two surveys also provide some indication of the range over which the parameters vary.

A. Study Findings

The only observed salinity stratification (except for occasional readings) occurs at the two most downstream stations, JP1 and JP2, during a part of the tidal cycle (see Figures B 7 through B12). The data thus indicate that the cause is stratification of the water column in the James River, and that this is destroyed by tidal mixing in the inner part of the Pagan. The temporal variation of salinity shows a strong tidal periodicity. The amplitude of tidal variation in salinity increases with distance from the river mouth, with the range of variation reaching as high as 4.3 ppt at the most upstream station (mile 6.61, kilometer 10.6). This indicates that tidal mixing dominates throughout the estuary and that the estuary is essentially a well-mixed type (Cameron and Pritchard, 1963).

The observed chlorophyll "a" concentrations at all stations except JP1 are dominated by tidal fluctuations, with maximum values at low slack water (see Figures B49 through B54). The temporal variations at each station are extreme, ranging from 24 to more than 100 μg/l over the 25 hour period. The longitudinal trend of the concentrations is monotonically increasing with distance from the estuary mouth (see Figure 4). This strongly suggests a major pool of phytoplankton upstream of station JP6

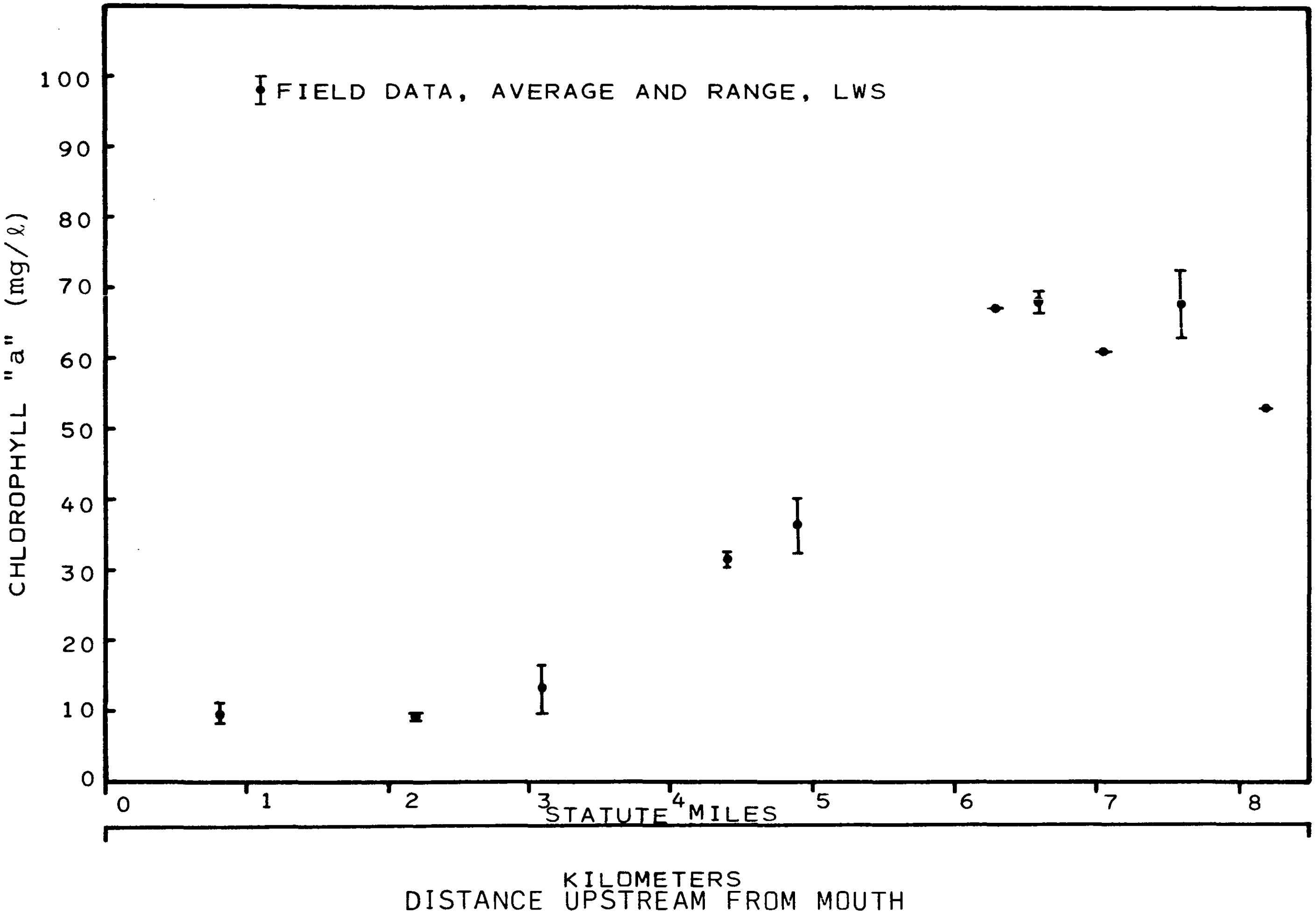


Figure 4. Chlorophyll "a" distribution, June 22, 1977.

that is transported into the study area on ebb tide. Further evidence of the existence of this pool is provided by the results of a later VIMS low slack water survey on June 22, 1977, in which stations further upstream than JP6 were sampled. Chlorophyll "a" concentrations equal to those at low slack water at JP6 were observed as far as 1.3 miles (2.1 km) upstream of that station.

The EPA has suggested, for the Potomac estuary, that 40 μg chlorophyll "a"/l indicates phytoplankton "bloom" conditions. This level is exceeded at every station in the Pagan estuary at least some time during the 25 hour sampling period on June 28-29, 1976. It was also exceeded at JP5 and JP6 during the August 23, 1976, low slack water survey and at JP6 during the June 22, 1977, low slack water survey.

The observed dissolved oxygen (DO) concentrations are in violation of the 4 mg/l water quality standard some time during the 25 hour sampling period of the intensive water quality study at every station (see Figures B55 through B60). For this parameter, too, temporal variations are large at every station, ranging from 3.5 to 8 mg/l over the 25 hour period. At the two most downstream stations, JP1 and JP2, tidal fluctuations appear to dominate. The DO level during the nighttime low slack tide was low due to phytoplankton phytosynthesis and respiration which result in increased concentrations during daylight hours and decreased levels at night. This pre-dawn low slack tide period is when the 4 mg/l standard is violated at these two stations. A similar pattern is observed for JP3 with some fluctuations during flood tide. The DO stratification is due to a combination of salinity stratification and phytoplankton activity. The DO concentration at JP6 is clearly dominated by phytoplankton activity. The stratification of DO levels during daylight hours at stations JP4 and JP5 may be due to the combined influence of phytoplankton activity, producing oxygen near the surface and benthic oxygen demand consuming it near the bottom. Moreover, these two stations are near the major waste dischargers and thus are subject to their influence as well as that of tidal mixing, phytoplankton activity, and benthic oxygen demand.

Observed fecal coliform bacteria concentrations exceeded the proposed 14 MPN/100 ml standard at every station during some portion of the 25 hour sampling period of the intensive water quality survey (see Figures B61 through B66). In fact, the entire Pagan River study area was designated on September 15, 1972, as condemned shellfish area number 64 of the Virginia State Department of Health. Moreover, the 200 MPN/100 ml primary recreation standard was exceeded at all stations but JP1 and JP2.

In general, concentrations varied significantly over a tidal cycle, with maximum values occurring at low water slack. Additionally, the bacterial counts generally increased in the upriver direction (see Figure 5). The extreme tidal variation at JP3 (over two orders of magnitude difference) indicates that the sources are upriver of that station. The more modest tidal variation at JP6 (a fivefold variation) indicates that tidal influence is weak, and the high levels (over 200 MPN/100 ml) indicate that the dominant source of bacteria is nearby. In fact, the two municipal plants and two meatpacking plants are upriver of station JP3 (see Figure 6) and the Smithfield STP is near JP6. Since no bacteriological data for this discharge is available for the period of the field survey, we can only speculate that it was the source, and note the SWCB comments in the 305b report regarding poorly treated municipal effluents.

The extreme temporal variations at each station for each parameter indicate the value of sampling over an extended time period, including a complete day-night cycle as well as a complete tidal cycle, in order to ascertain a comprehensive picture of the water quality of the estuary.

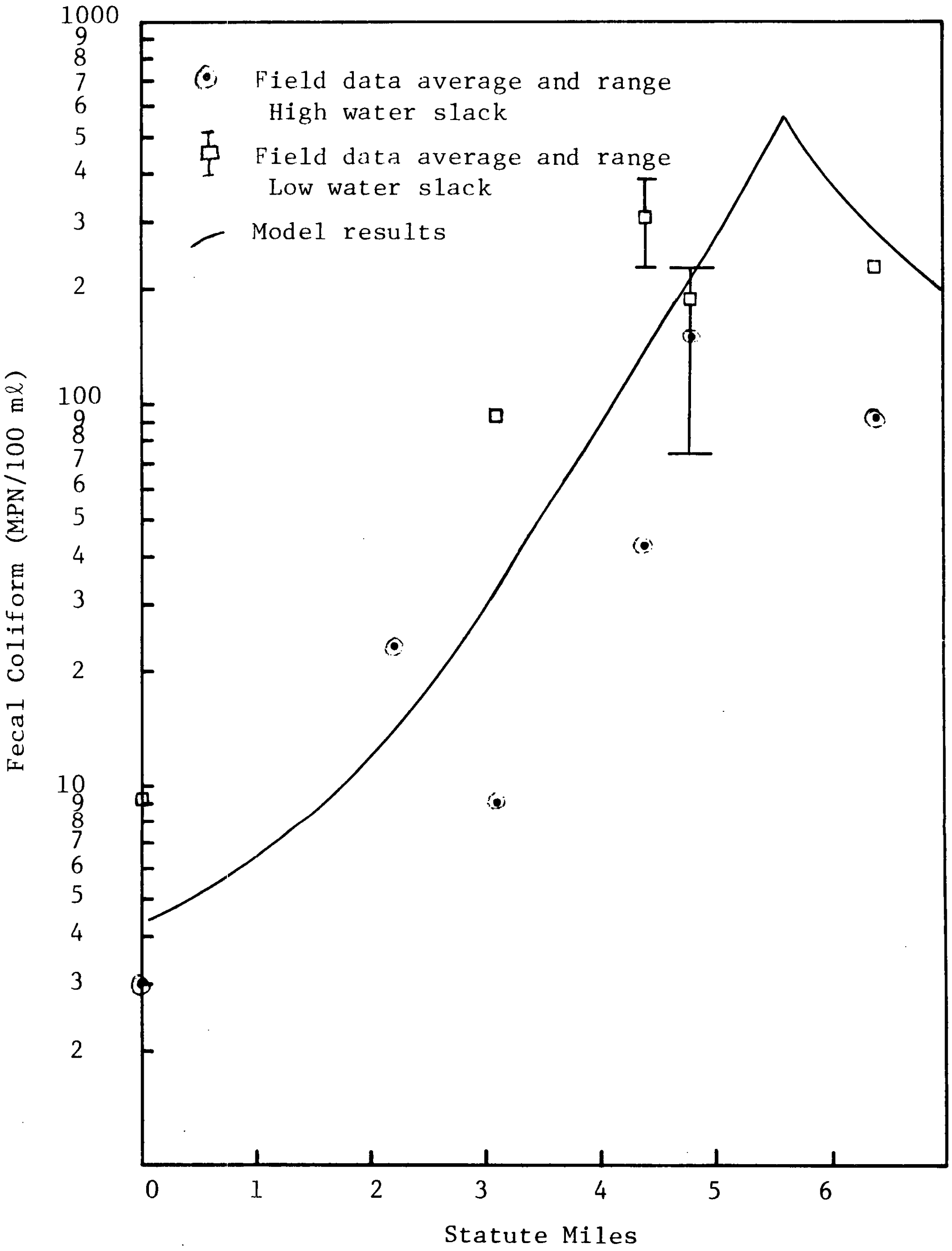


Figure 5. Comparison of computed coliform distribution with field data, August 23 and 24, 1976.

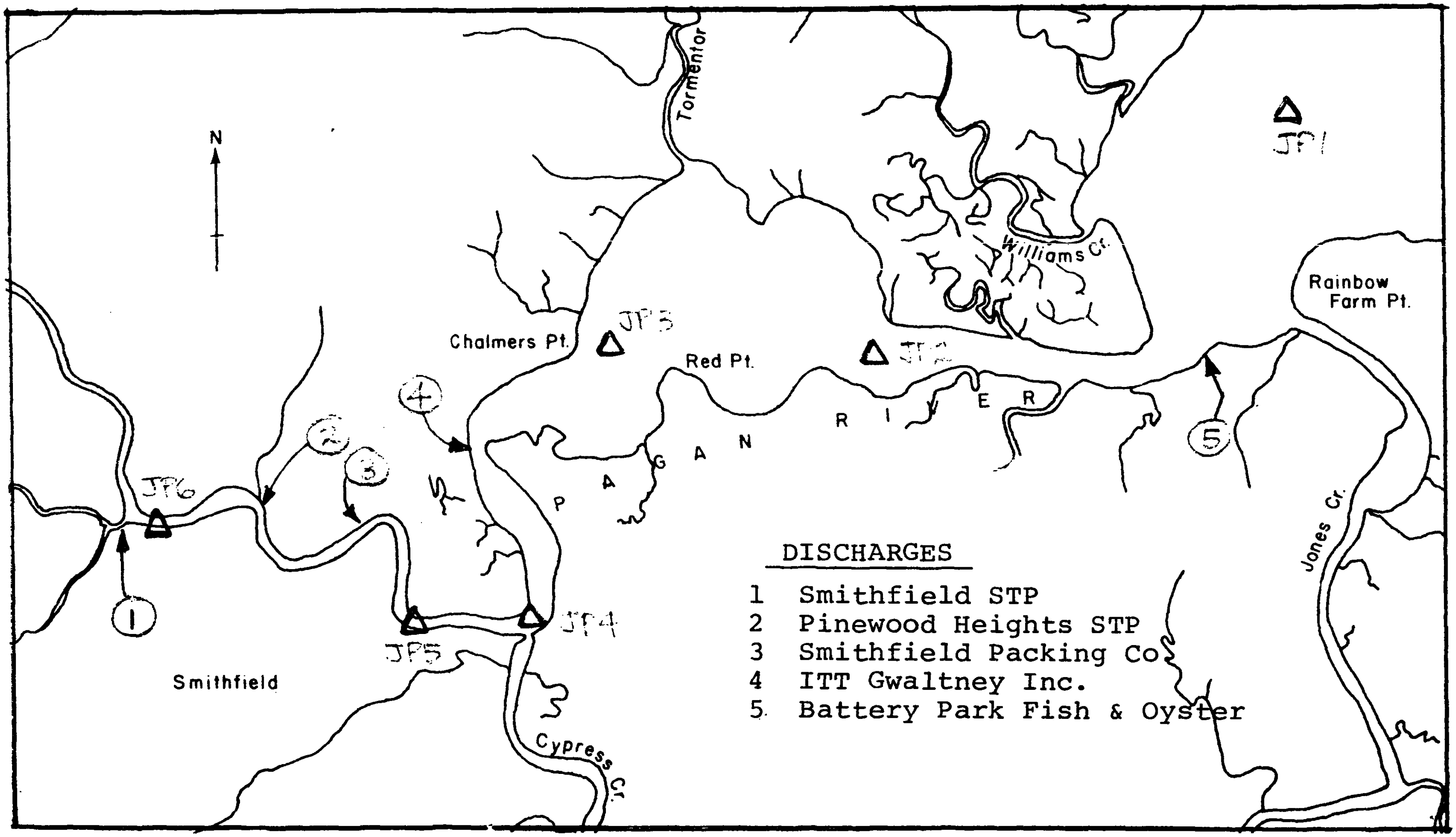


Figure 6. Locations of point sources of pollutants and intensive survey sampling stations.

CHAPTER 4.

Discussion

The data from the intensive survey provide graphic evidence of the degraded water quality in the Pagan River. The three general problem areas are: 1) eutrophication, or over enrichment of the river with the major nutrients, and the resulting algal blooms; 2) extremely low dissolved oxygen, resulting from the eutrophication and large BOD loads; and 3) fecal contamination.

It appears that these problems have arisen due to very large point and nonpoint source discharges. Fecal coliform, carbonaceous and nitrogenous BOD loads for the point sources as well as loads arising from rain events during the period of the field surveys have been listed in Table 1. The values for I. T. T. Gwaltney and Smithfield Packing are those measured by the State Water Control Board during studies of these dischargers in the spring of 1976. The values for the two treatment plants are the monthly averages for June, 1976, and that for Battery Park Fish and Oyster was supplied by Betz Engineers. The nonpoint source loads were determined by Malcolm Pirnie Engineers and supplied to VIMS for calibration of the math model. Nonpoint loads were predicted by the mathematical model of stormwater runoff, STORM, which was calibrated with field data collected in the 208 study area from March through October, 1976.

In addition to the large BOD loads, both point and nonpoint sources contribute large amounts of nutrients to the river. As a result nutrient levels are extremely high and support a large population of phytoplankton. There is no water quality standard for plankton, or more precisely, no standard for chlorophyll "a", which often is used as a measure of algal densities. However, in a study of the Upper Chesapeake Bay, the Annapolis

TABLE 1. POLLUTANT LOADINGS TO PAGAN RIVER DURING SUMMER OF 1976.

Point Sources	CBOD$_u$ (#/day)	NBOD (#/day)	Fecal Coliforms (billions/day)
I. T. T. Gwaltney	3947	2477	158
Smithfield Packing Co.	828	3432	5904
Smithfield - Cary St. Lagoon	122	(a)	(a)
Pinewood Heights STP	2	(a)	(a)
Battery Park Fish and Oyster	11	4	0.303

(a) Data not available.

Nonpoint Sources*

Date	Rainfall (inches)	CBOD$_u$ (#)	NBOD (#)	Fecal Coliforms (billions)
June 17, 1976	0.33	7,187	12,718	43,159
June 19	0.12	252	430	1,626
June 21	0.13	3,763	6,654	22,397
August 3	0.09	2,435	2,989	12,738
August 8	0.56	17,536	31,816	87,548
August 9	0.57	11,032	20,259	49.939
August 16		69	151	404

* Predicted with model "STORM".

Field Office of the Environmental Protection Agency suggested that an upper limit for plankton concentrations for that area should be 40 μg of chlorophyll "a" per liter of water (Clark, Donnelly and Villa, 1973). Clearly the levels in the upper reaches of the Pagan are well above this recommended level and probably represent bloom conditions.

Algal blooms are undesirable because they cause dissolved oxygen levels to fluctuate greatly. Plankton consume oxygen during respiration, but they also produce oxygen as a by-product of photosynthesis. Since summer days are long and nights are short, during clear weather the plankton will produce more oxygen than they consume. Consequently, DO levels will be high when plankton levels are high. In fact, in the afternoons, DO concentrations at the surface will frequently be above the saturation value. During prolonged cloudy periods, the reverse situation will hold. Oyxgen consumption will be greater than production and DO levels in the surrounding water will be depressed. If plankton concentrations are high enough and the "dark" period long enough, DO reserves can be depleted. The result can be fish kills and/or "jamborees" when blue crabs crawl onto the shore to escape the degraded water. The impact of the plankton on dissolved oxygen was observed at station JP-6, as seen in Figure 7. Chlorophyll "a" levels range from 30 to nearly 140 μg/l over a 24 hour period. Dissolved oxygen levels show a strong diurnal cycle, with maximum values of 11 mg/l in late afternoon and minimum values of less than 4 mg/l in early morning. The saturation value of oxygen in water having the same temperature and salinity as that observed in the field is about 7 mg/l.

DO levels also respond to inputs of oxygen demanding material, which is usually referred to as BOD (biochemical oxygen demand). The loads from the sewage treatment plants and the meat packing plants are large and

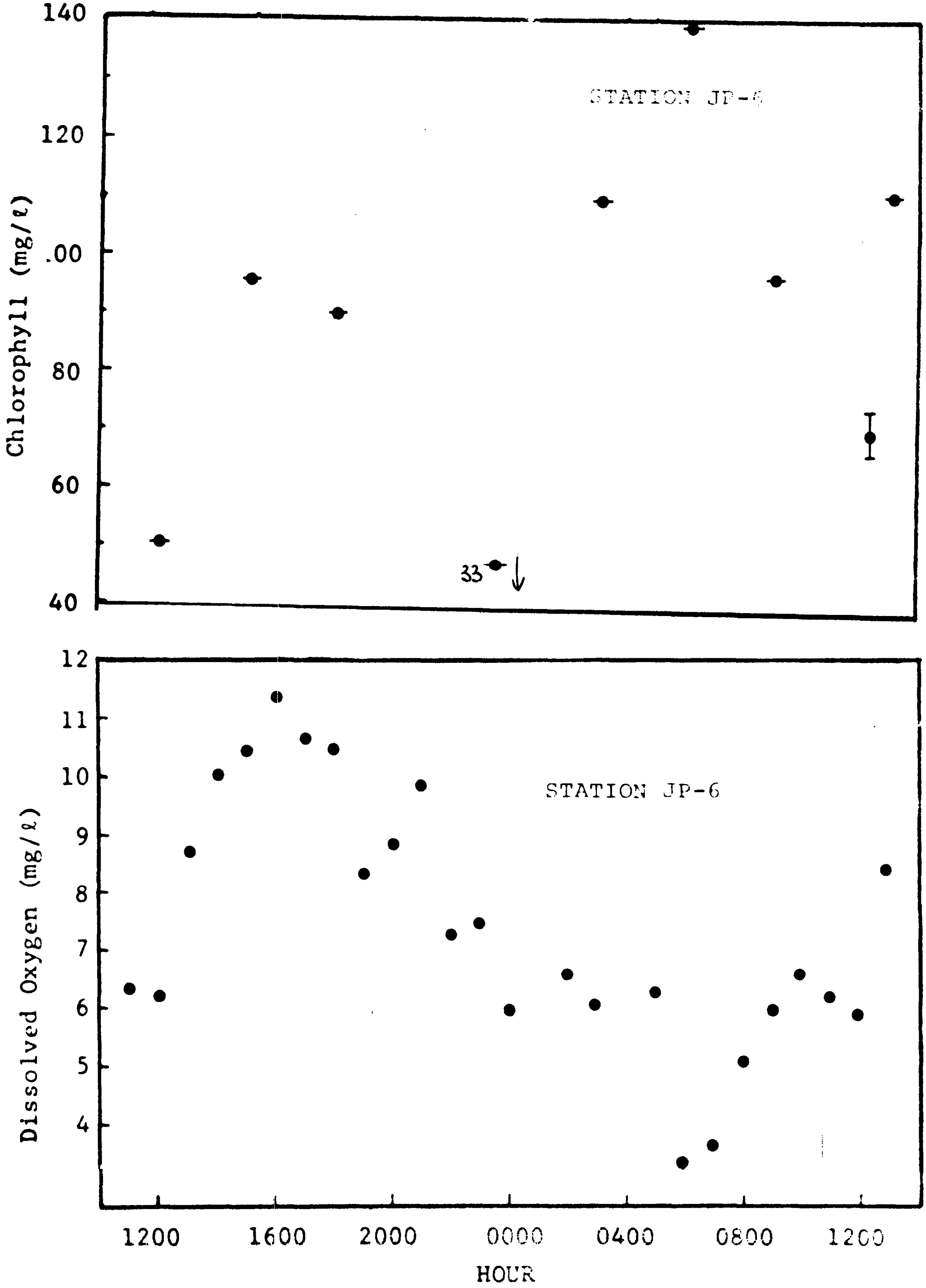


Figure 7. Chlorophyll "a" and dissolved oxygen variations at Station JP-6.

exert a significant oxygen demand on the waters of the Pagan River. Nonpoint loads, as predicted by the math model STORM, also are quite large, but occur on an intermittent basis. For all of these discharges, some portion of the BOD will be in particulate form and since tidal currents are on the order of 0.3 m/sec (1 foot/sec), it is not unreasonable to assume that settling would occur. If this were to happen, a blanket of organic material would develop on the bottom. As this material decomposed, it too would exert an oxygen demand on the overlying waters. This has been termed benthal oxygen demand.

The benthal oxygen demand was measured at three locations in the Pagan River at the time of the intensive survey, and the results were as follows:

Station	Distance from River Mouth miles (km)		Benthic Oxygen Demand $gm/m^2/day$ at 20°C and 5 mg/l DO
1	0.0	(0.0)	1.6
3	2.2	(3.5)	2.2
6	5.8	(9.3)	3.8

A "typical value" for benthal oxygen demand for estuaries would be 1 $gm/m^2/day$, or approximately the value observed near the mouth of the river. The values measured in the upper reaches of the river are high. Although the origin of the materials causing the high benthal oxygen demand is not known, the point loads and runoff from the extensive marshes are the likely sources. Dead phytoplankton also would settle to the bottom and be incorporated into the bottom sediment. Should the point and nonpoint loadings be reduced, one would expect the benthal demand to decrease over a period of years. However, so little is known about the benthic sediment/water column exchanges, the magnitude and the time scale for this change cannot even be estimated at present. The point to be noted is that the BOD loads discharged to the river have both an immediate effect and a longer term impact.

The estimates of fecal coliform loadings from the two meat packing plants are based on samples collected from these plants in the spring of 1976. The SWCB water quality inventory report refers to "poorly treated municipal waste waters". It is not known whether there has been any improvement in the quality of these effluents since 1975 when the inventory was compiled. The field data indicate that these continuous point source loadings are sufficient to warrant the condemnation of the area for shellfish harvesting. The predictions for stormwater runoff indicate that fecal coliform loadings during wet weather are very large indeed, which would exacerbate the normal situation. In short, the information gathered during the field survey and stormwater modelling support the need for a condemnation zone. Furthermore the waters in the upper segments are not suitable for primary contact recreation, since fecal coliform counts frequently exceed 200 MPN/100 ml.

A. Summary

Information in published reports concerning the Pagan River indicated that water quality in the estuary was poor. The results of the Hampton Roads 208 field studies, conducted in the summer of 1976, show that these degraded water quality conditions still exist. Both point sources loads from two meat packing plants and two small municipal wastewater treatment plants, and nonpoint loads from the surrounding land appear to be large, relative to the ability of the river to assimilate these waste products. It is believed that the base freshwater flow to the river is small so that pollutants are flushed through the system and out into the James very slowly. However, since there are no gauging stations in the Pagan drainage basin, there is no data to quantify the freshwater flow.

Nutrient levels in the river were very high and this resulted in algal populations that were substantial. Conditions in the upper several miles of the estuary would be called an algal bloom by most standards. Respiration by the phytoplankton and photosynthetic oxygen production result in a pronounced diurnal cycle to the dissolved oxygen levels, especially where chlorophyll "a" levels are high. Dissolved oxygen concentrations on the order of 2 mg/l were observed several times during the intensive survey. Modelling studies should evaluate the possibility of reducing nutrient (and therefore, plankton) levels.

A pronounced sag in dissolved oxygen levels with distance upriver from the mouth indicates that the point source loadings of BOD have an observable impact on water quality. Additionally, the point sources, marsh runoff, dead phytoplankton and perhaps other sources are thought responsible for the buildup of organic bottom deposits. These bottom sediments exert an oxygen demand which is large relative to other estuaries, and contributes to the below standard DO concentrations.

Continuous discharges of fecal coliforms are sufficient to justify a shellfish condemnation zone. Predicted nonpoint loadings indicate that runoff further degrades water quality with respect to bacterial standards. Water quality is sufficiently poor in the upper reaches of the river that primary contact recreation should not be permitted.

REFERENCES

APHA, AWWA, and WPCF, 1971. "Standard Methods for the Examination of Water and Wastewater". 13th Edition.

Cameron, W. M. and D. W. Pritchard, 1963. "'Estuaries' in the Sea" (ed. M. N. Hill), Vol. 2, John Wiley and Sons, New York, 306-324.

Clark, L. J., D. K. Donnelly and O. Villa, Jr., 1973. "Nutrient Enrichment and Control Requirements in the Upper Chesapeake Bay", Technical Report No. 56 Summary and Conclusions, Annapolis Field Office, EPA.

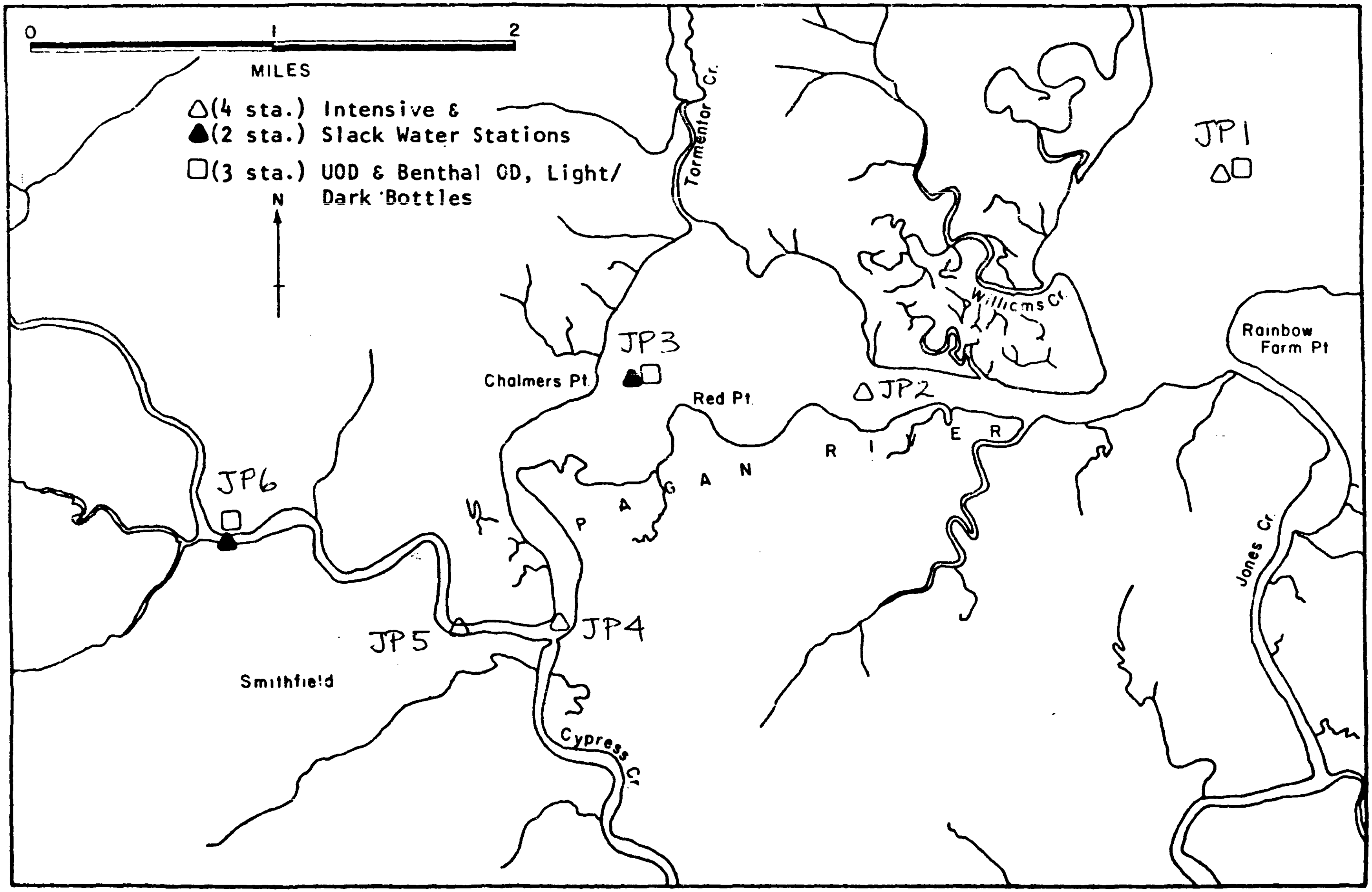
Kuo, A. Y., J. K. Lewis, and C. S. Fang, 1976. "Mathematical Model Studies of Water Quality of the Pagan Estuary". Spec. Rep. No. 107, Appl. Mar. Sci. and Ocean Eng., VIMS.

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

Owen, D. W., G. B. Williams, M. H. Peoples, C. H. Hobbs, G. L. Anderson, 1975. "Shoreline Situation Report for Isle of Wight County, Virginia". Spec. Rep. No. 97, Appl. Mar. Sci. and Ocean Eng., VIMS.

APPENDIX A.

FIELD SAMPLING PROGRAM AND ANALYTICAL METHODS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1
2
MILES
△(4 sta.) Intensive &
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☐(3 sta.) UOD & Benthal OD, Light/
Dark Bottles
N
Tormentor Cr.
Williams Cr.
JP1
Rainbow Farm Pt
JP3
Chalmers Pt.
Red Pt.
JP2
PAGAN RIVER
JP6
JP5
JP4
Smithfield
Cypress Cr.
Jones Cr.

Pagan River Sampling Program

Parameter	Intensive Survey			1 Slack Water Survey (6 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

*2 Intensive Survey Stations (depth < 5M) taken at top and bottom depth onl

**2 Intensive Survey Stations (depth < 5 M) taken at mid-depth only

Other Measurements - 3 stations (slack tide)

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

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) <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 orthophosphate
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 overlying water. The stirrer provided gentle agitation to keep water moving past the membrane on the

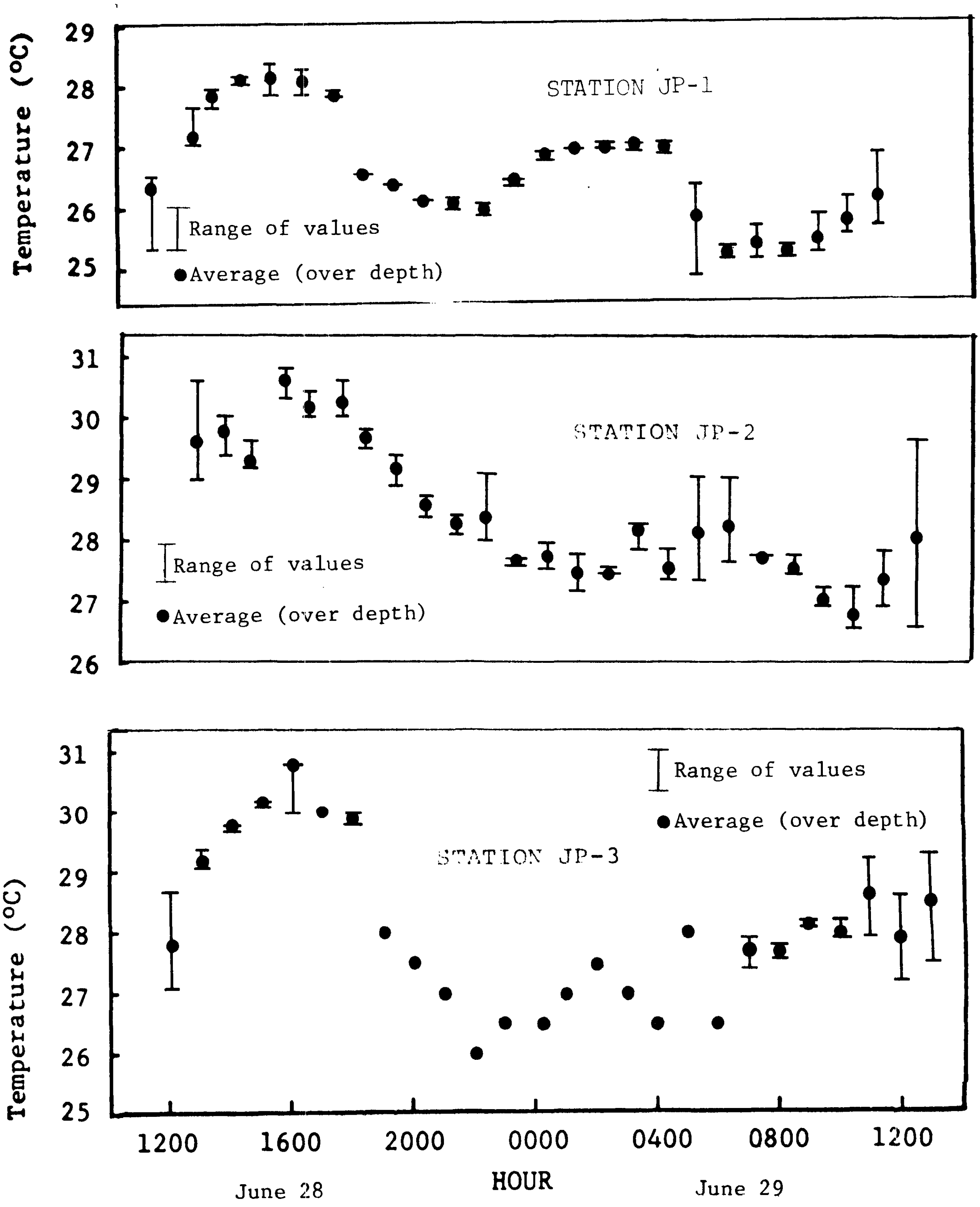
9) Benthal Oxygen Demand (cont'd)

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:

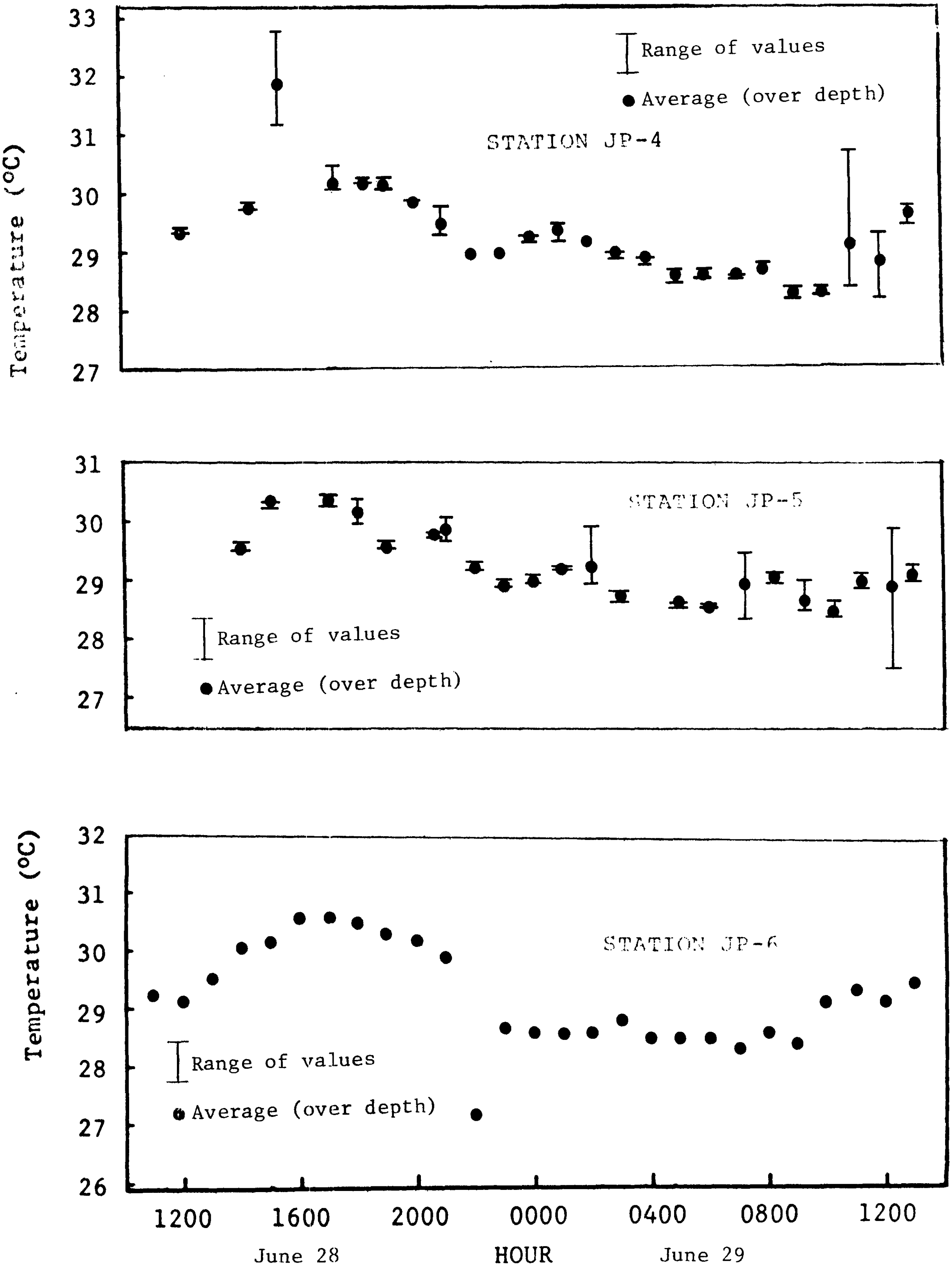
$$BD\left(\frac{gm}{m^2\cdot day}\right) = \frac{m\left(\frac{mg}{\ell\cdot hr}\right)H\cdot 24}{10^2},$$ where H is the mean depth of the chamber in cm., allowing for the volume displaced by the stirrer.

APPENDIX B.

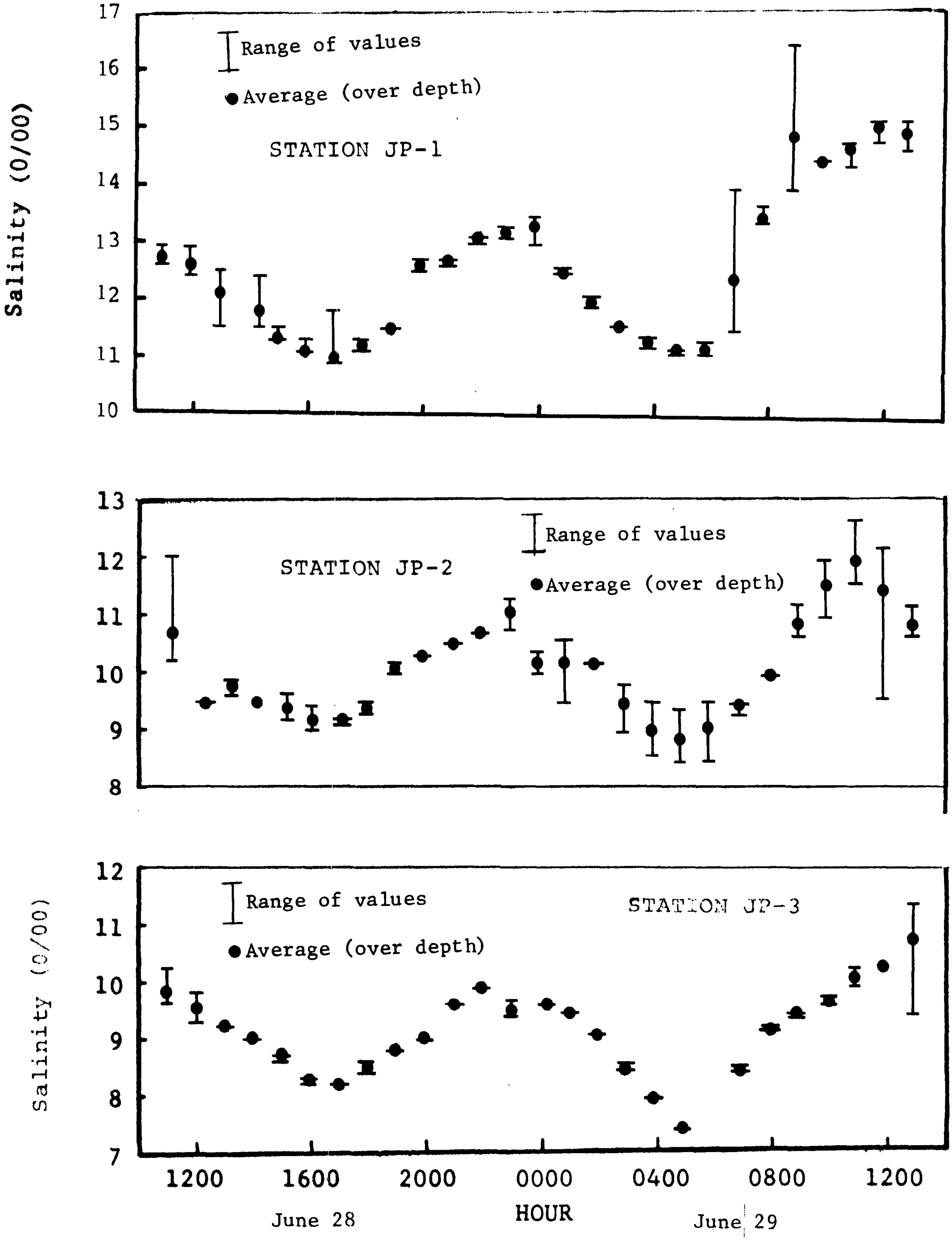
June 28-29, 1976 Intensive Water Quality Survey Data



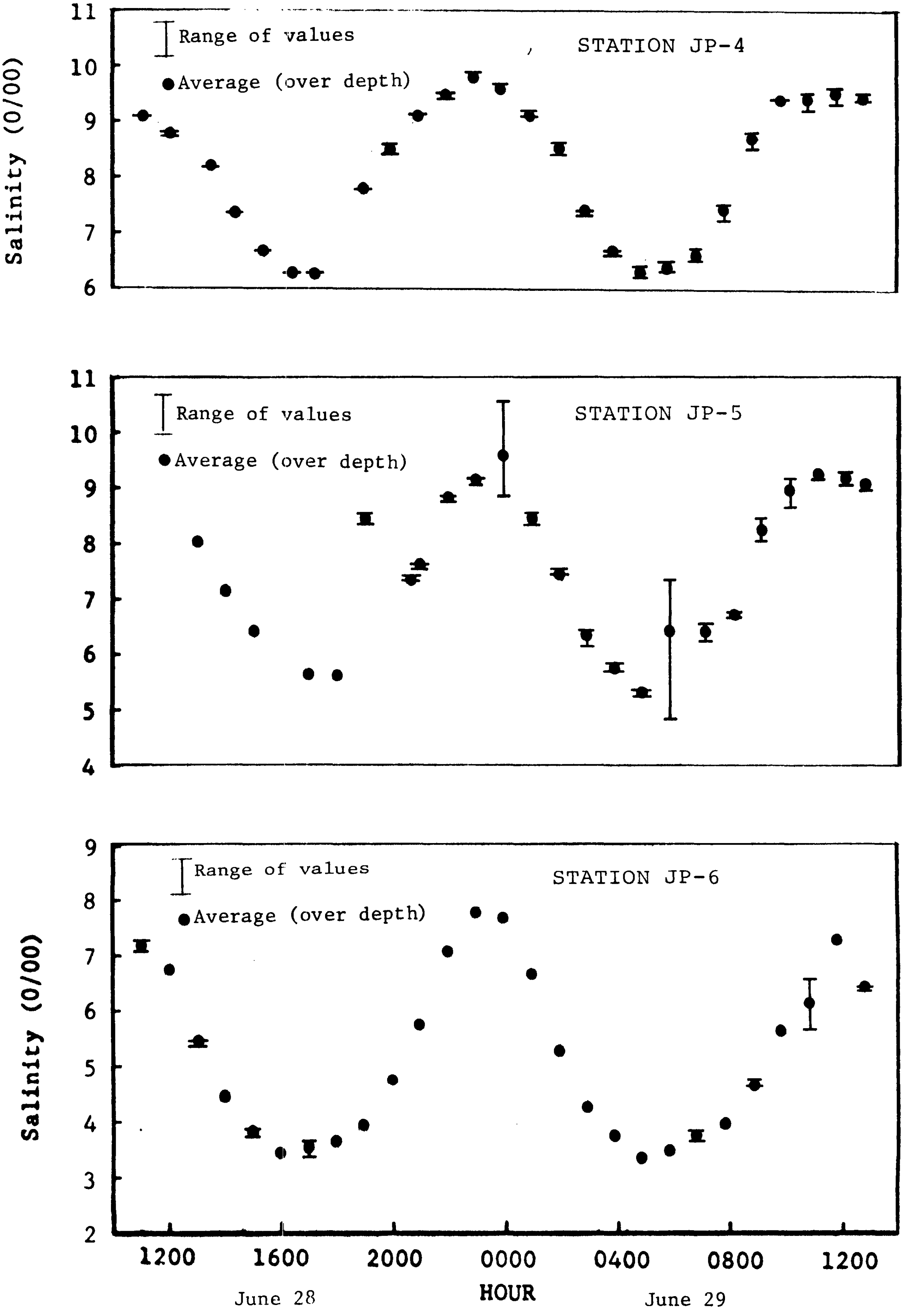
Figures B-1, B-2, B-3. Temperature for stations JP1 through JP3.



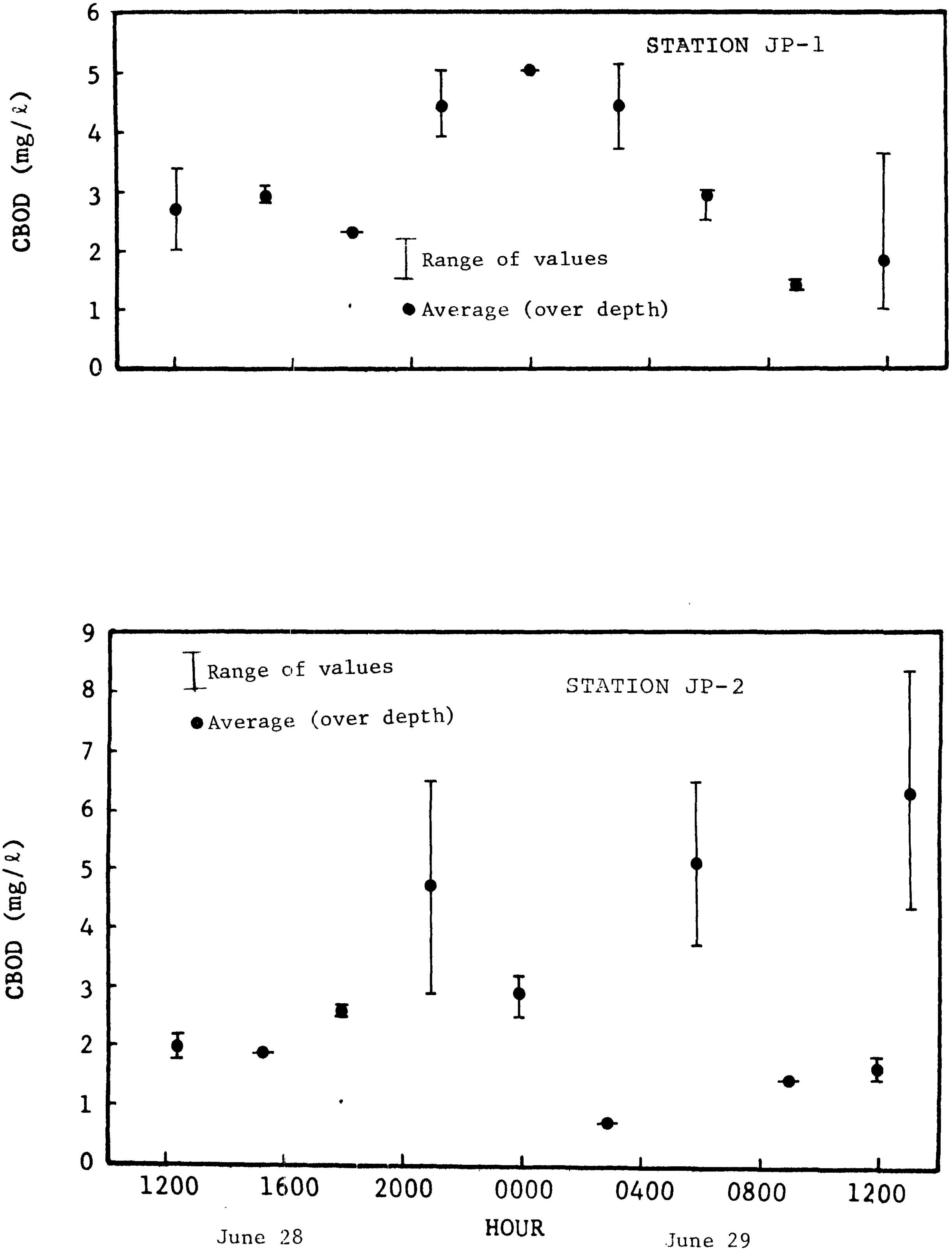
Figures B-4, B-5, B-6. Temperature for stations JP4 through JP6.



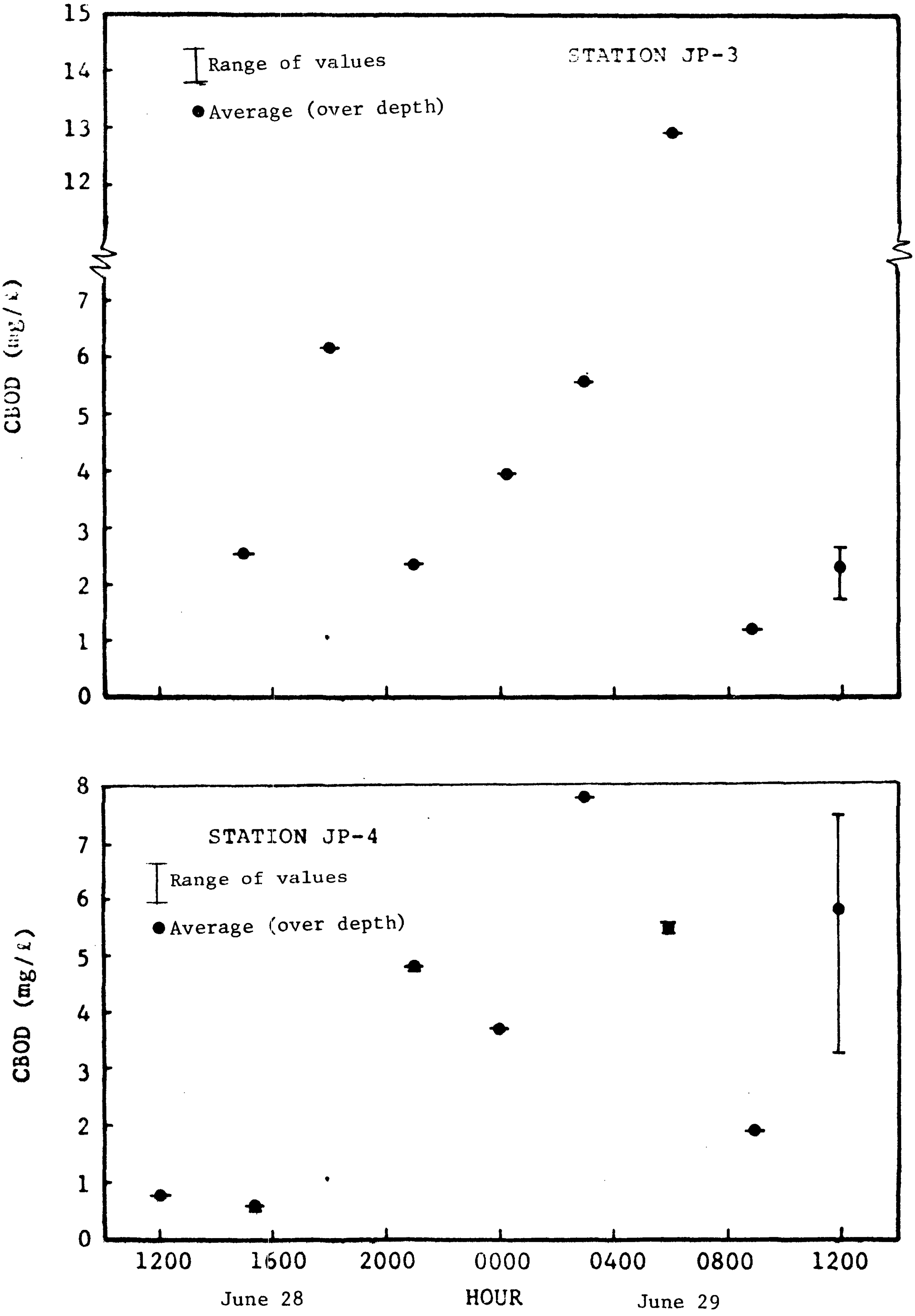
Figures B-7, B-8, B-9. Salinity for stations JP1 through JP3.



Figures B-10, B-11, B-12. Salinity for stations JP4 through JP6.



Figures B-13 and B-14. CBOD for stations JP1 and JP2.



Figures B-15 and B-16. CBOD for stations JP3 and JP4.

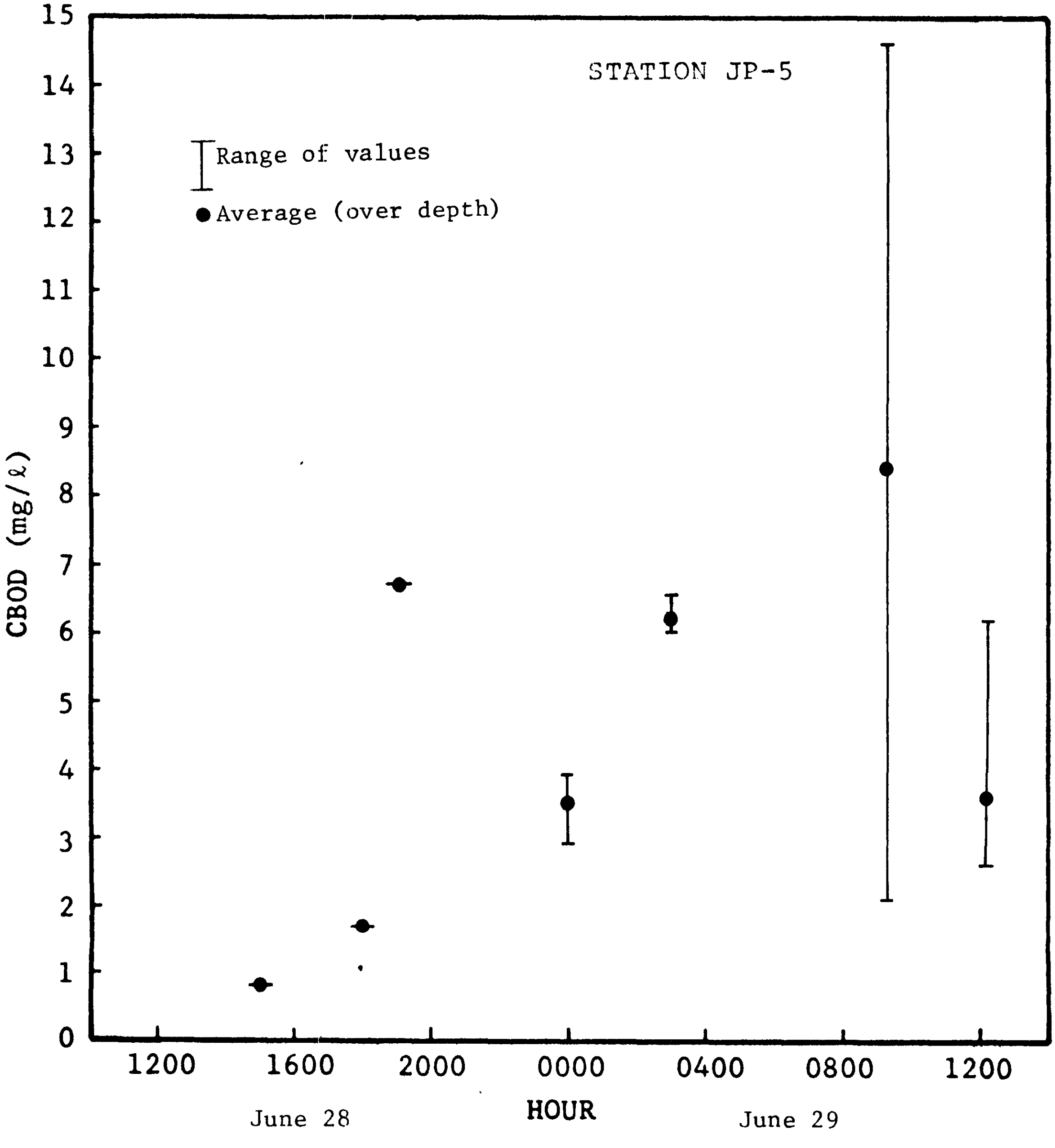


Figure B-17. CBOD for station JP5.

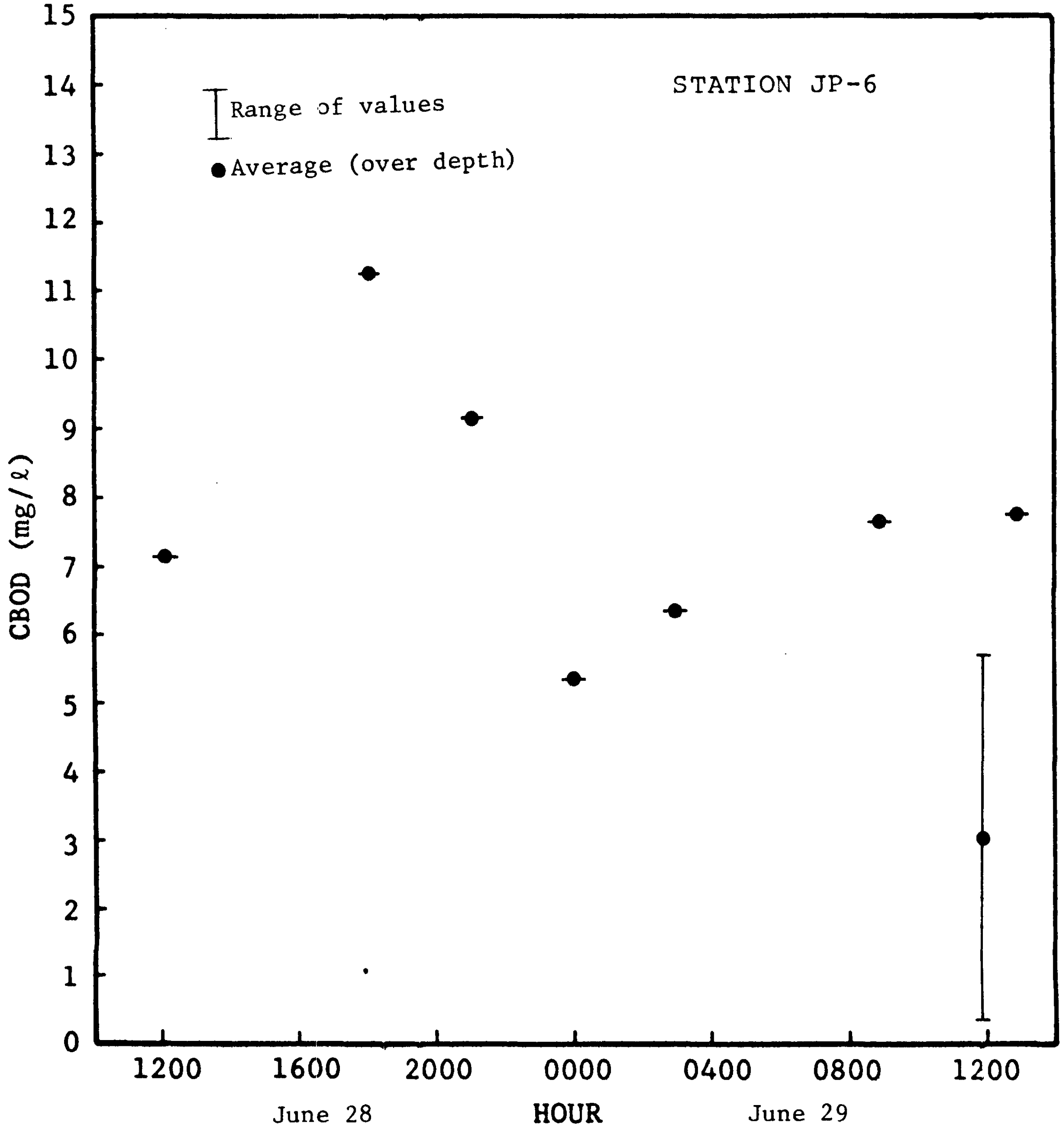
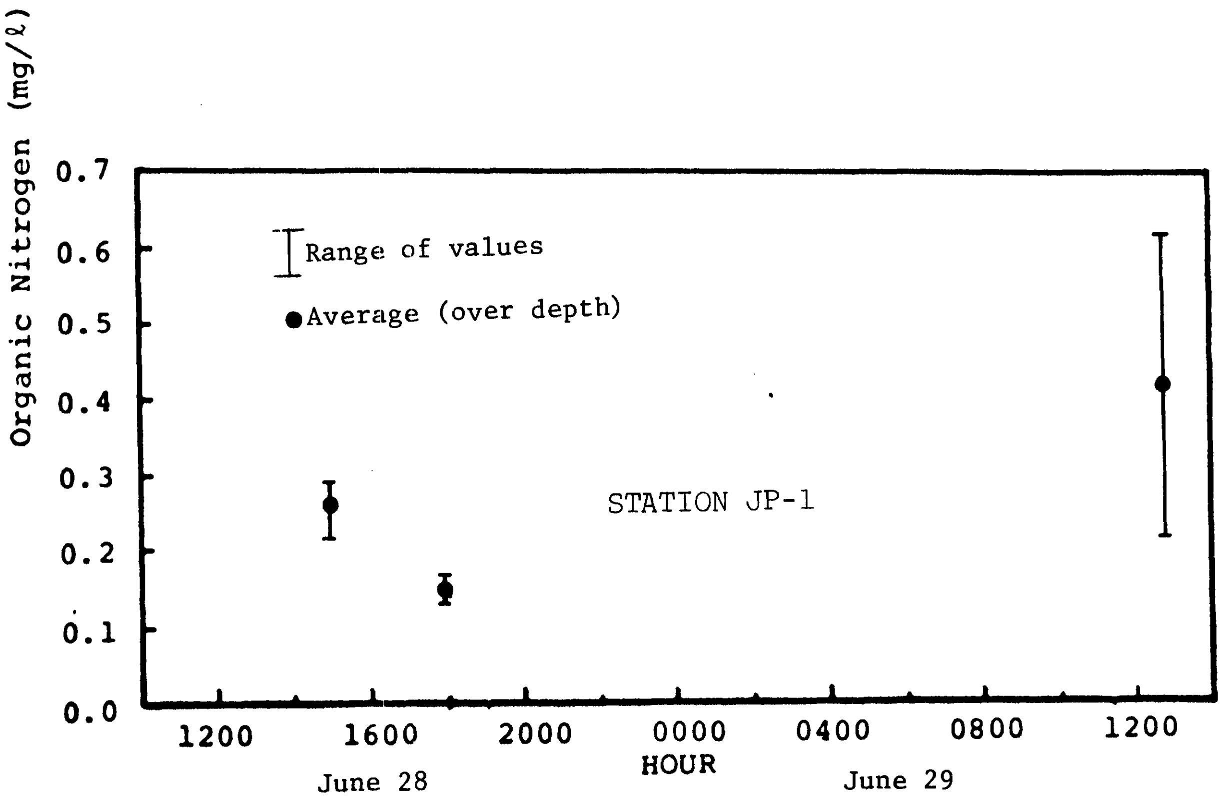
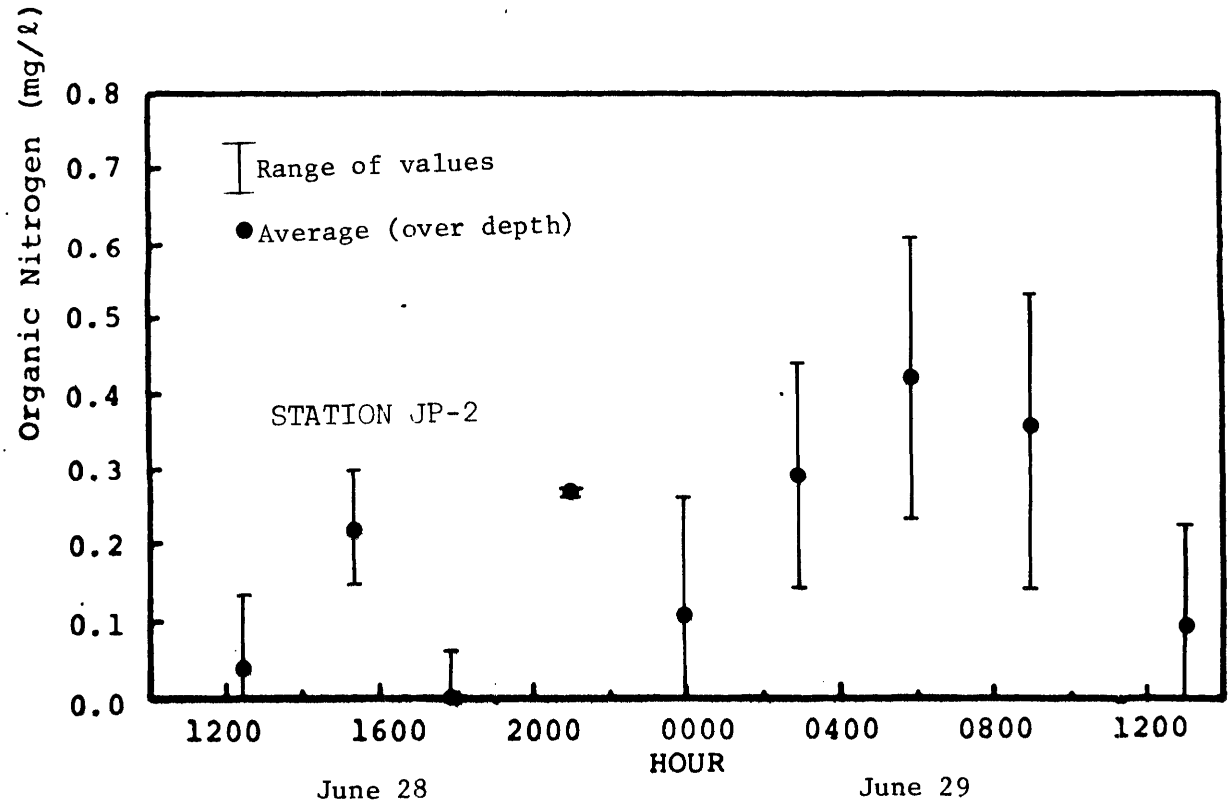
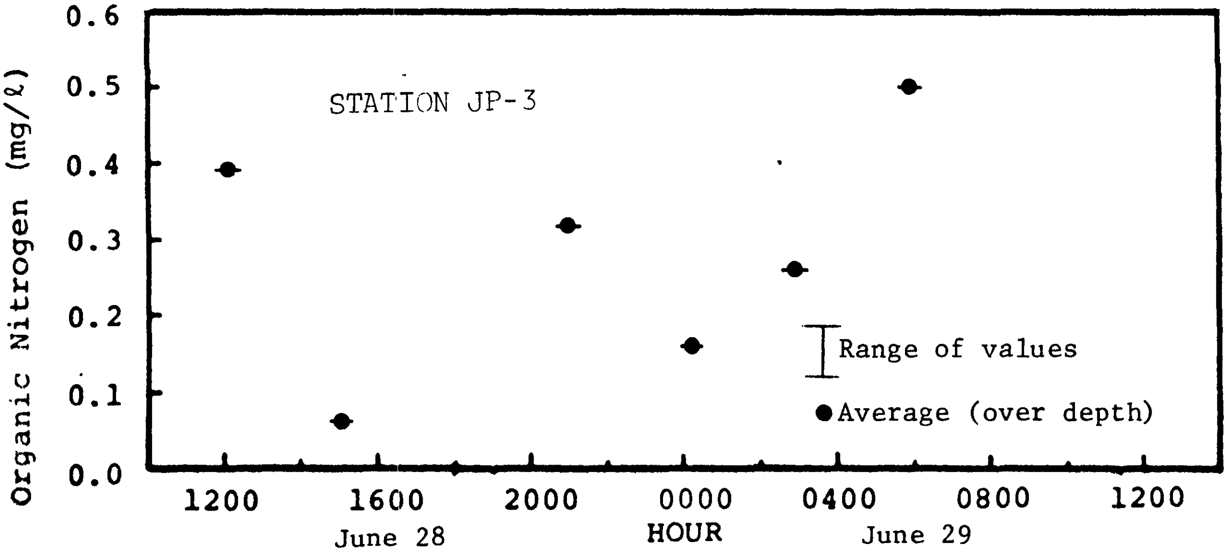


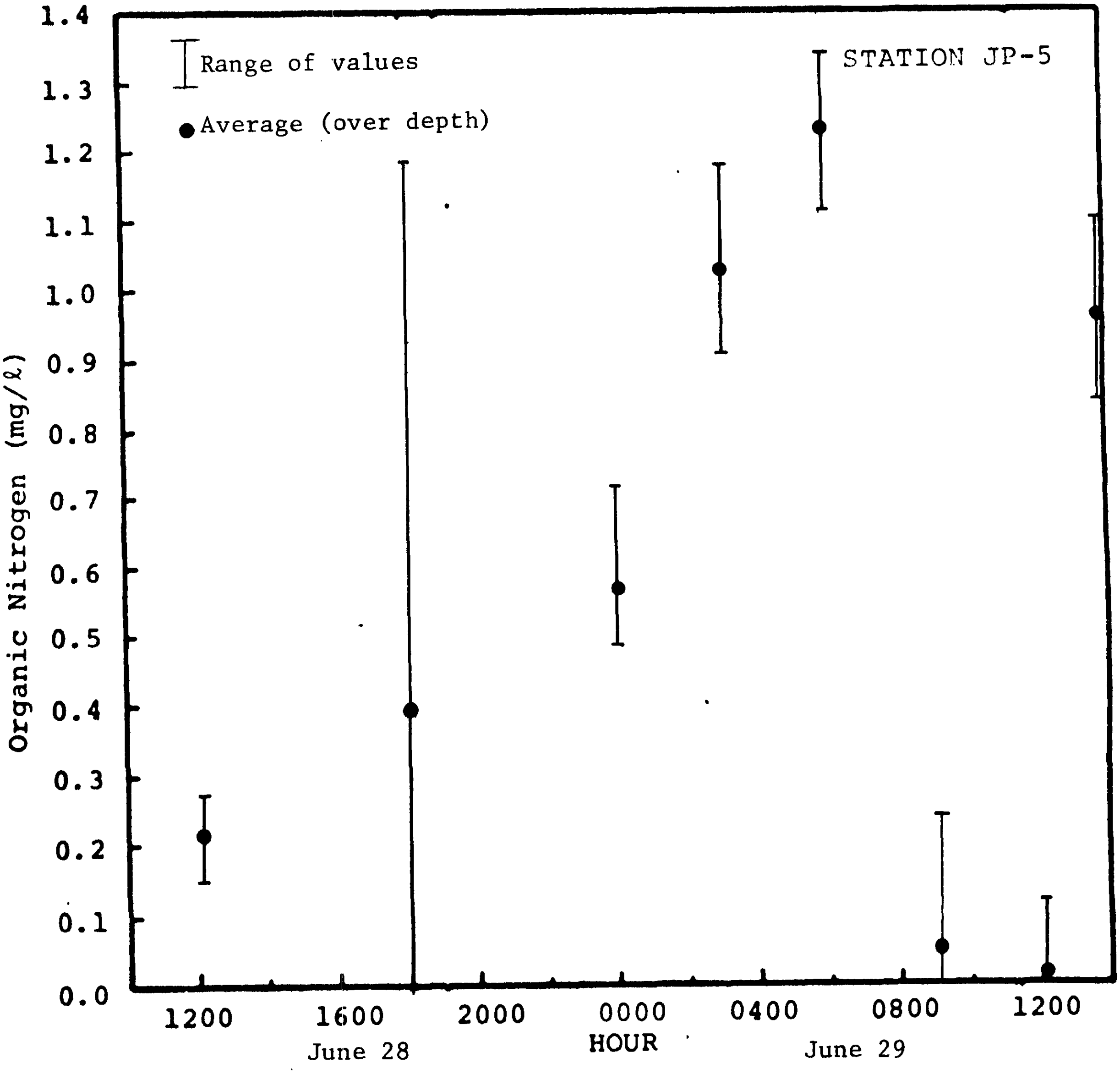
Figure B-18. CBOD for station JP6.



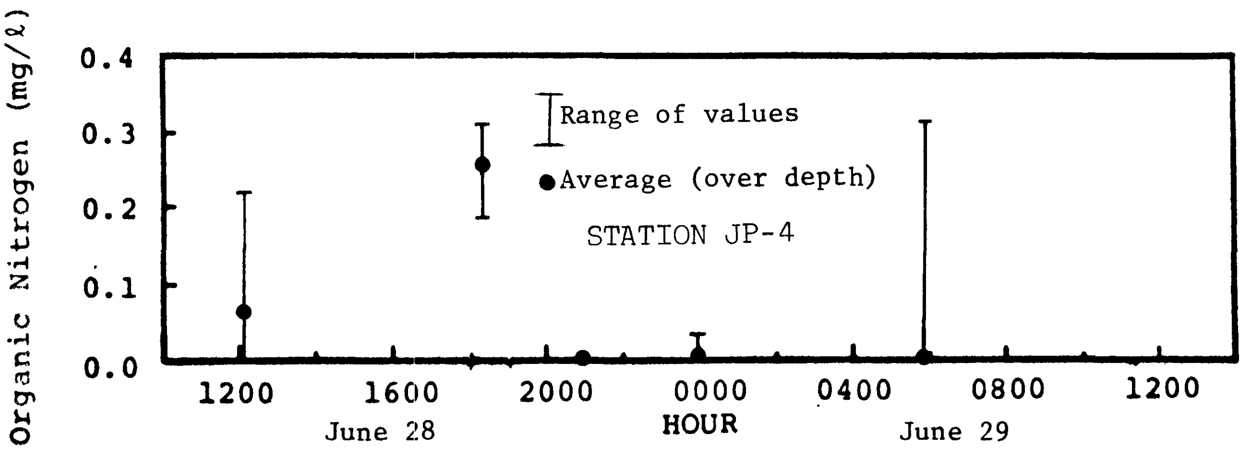


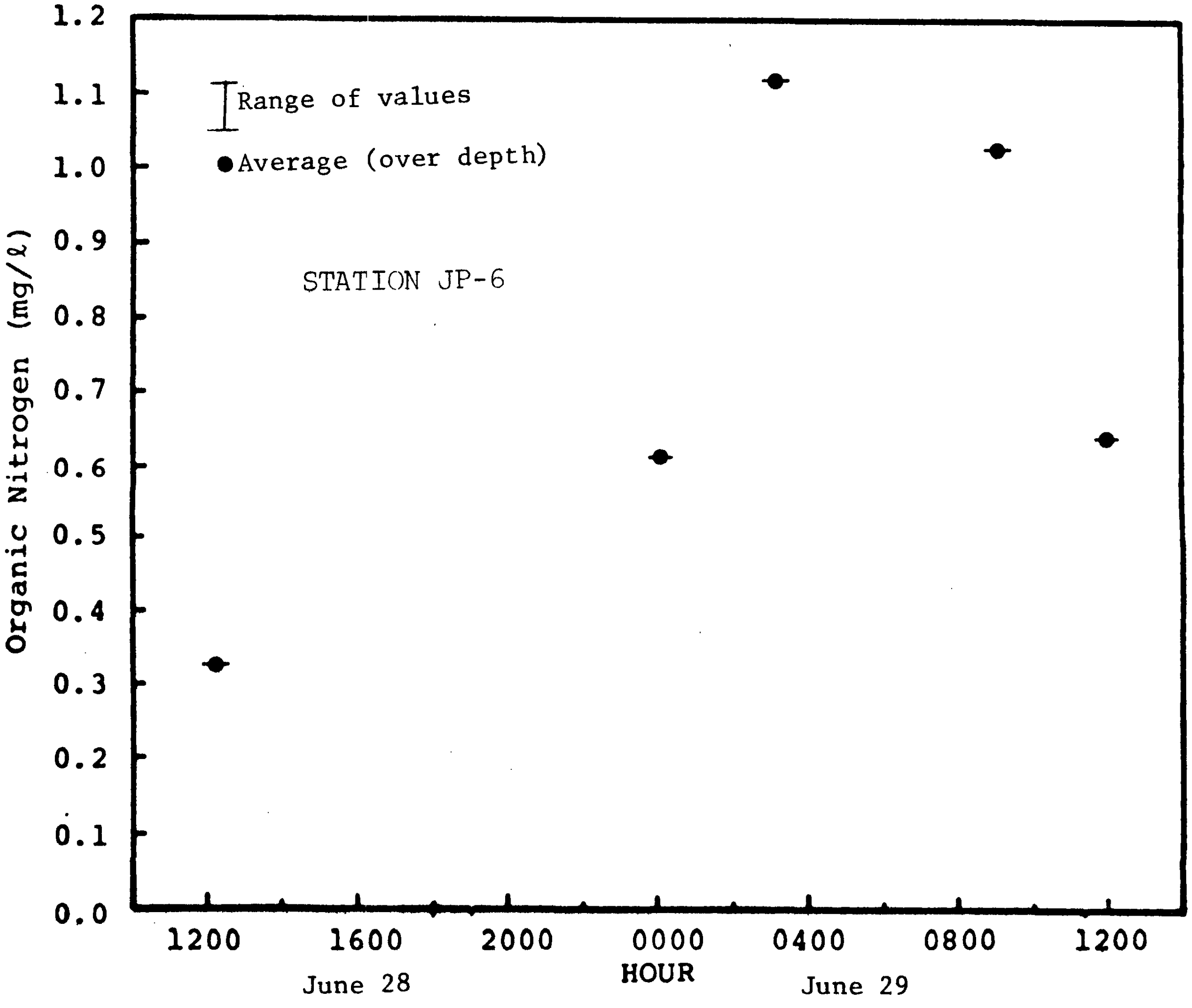
Figures B-19 and B-20. Organic nitrogen for stations JP1 and JP2.



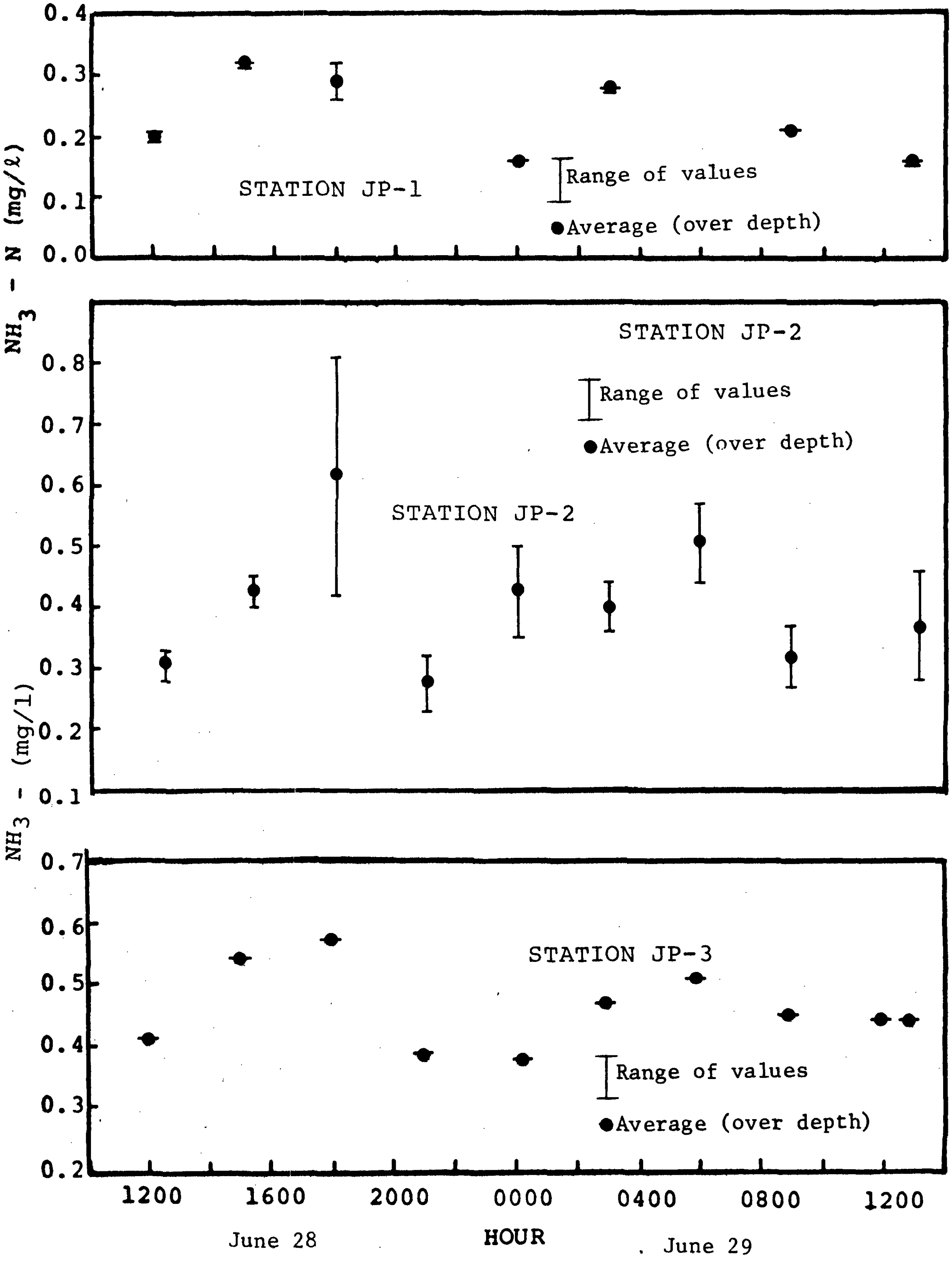


Figures B-21 and B-22. Organic nitrogen for stations JP3 and JP5.

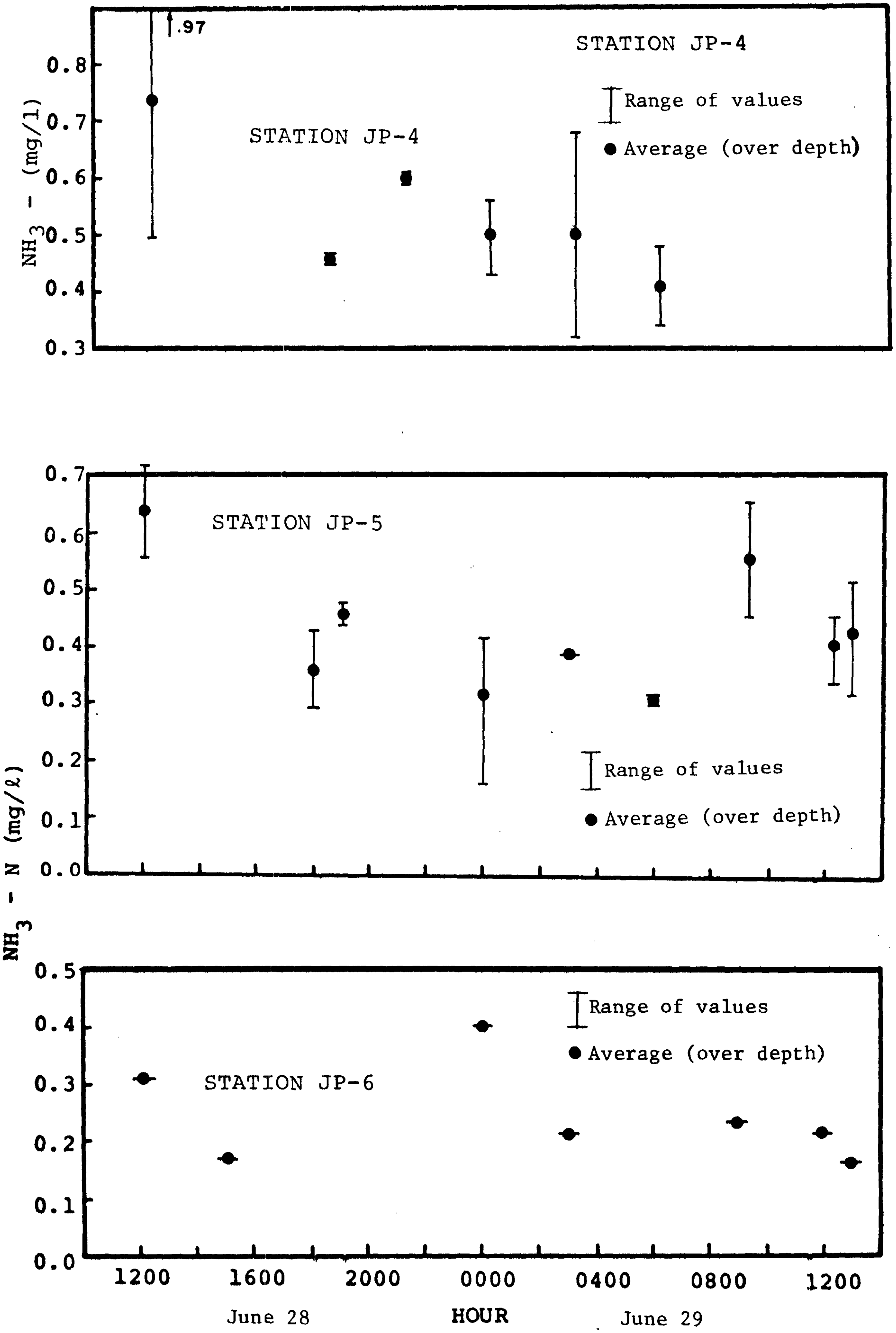




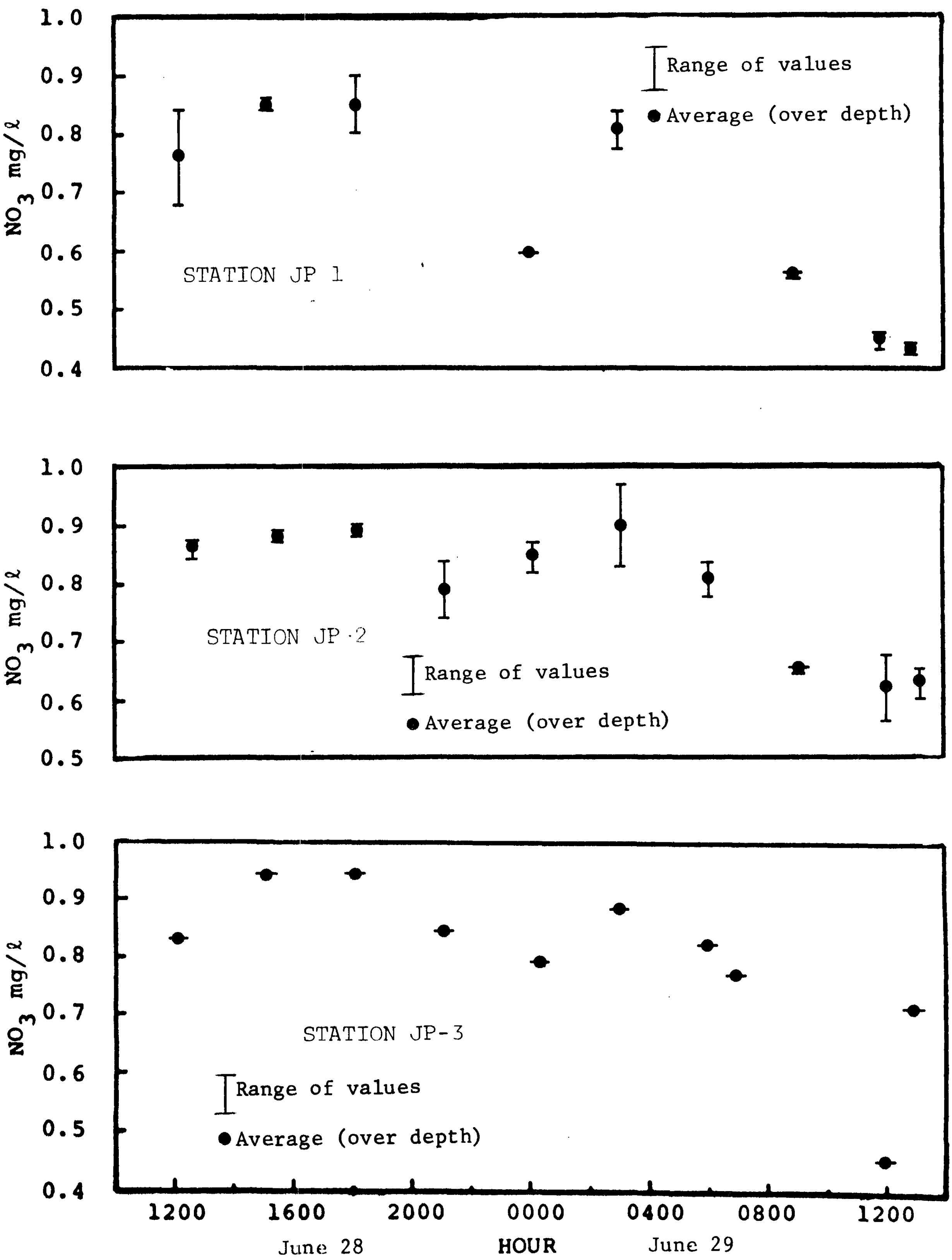
Figures B-23 and B-24. Organic nitrogen for stations JP4 and JP6.



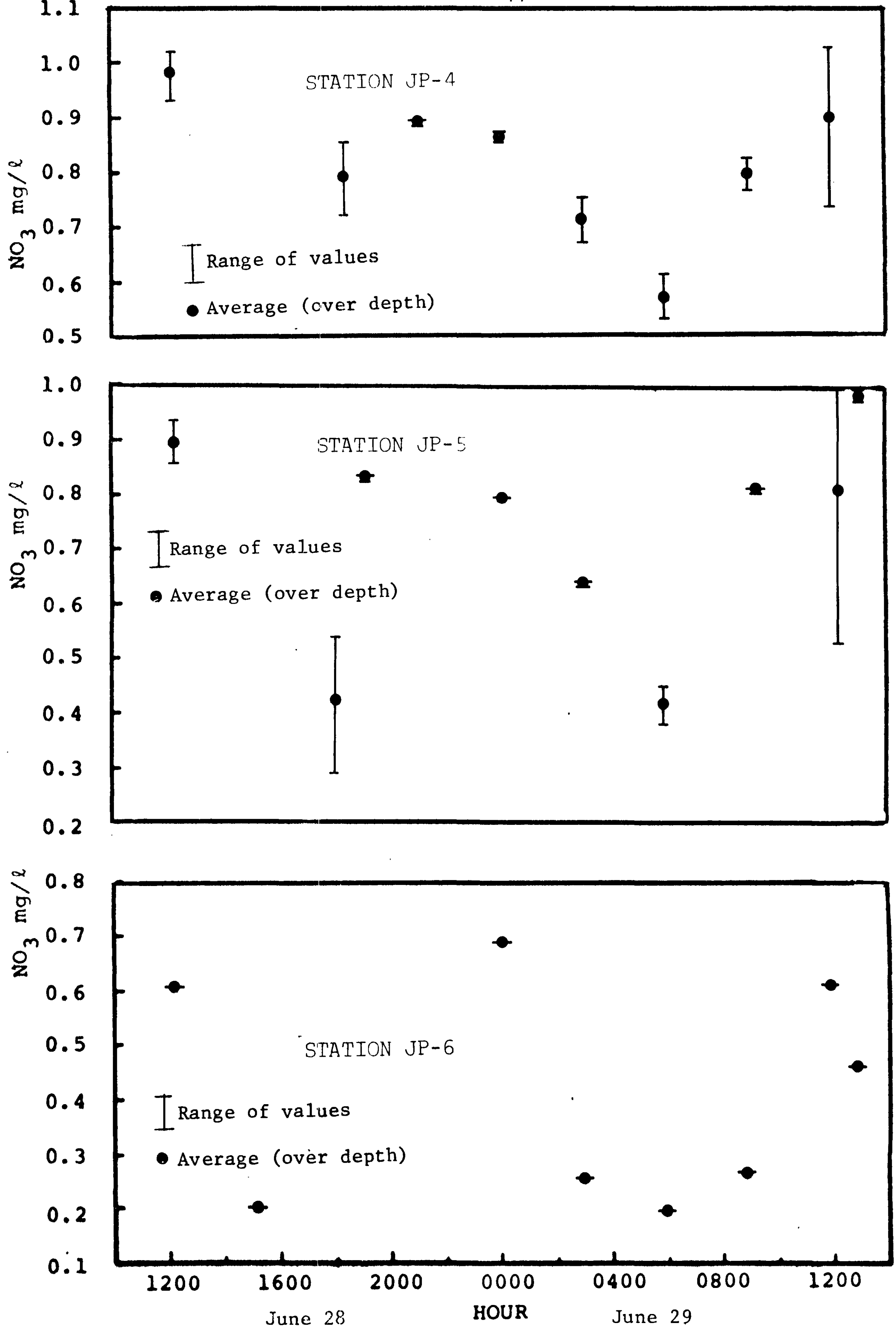
Figures B-25, B-26, B-27. Ammonia nitrogen for stations JP1 through JP3.



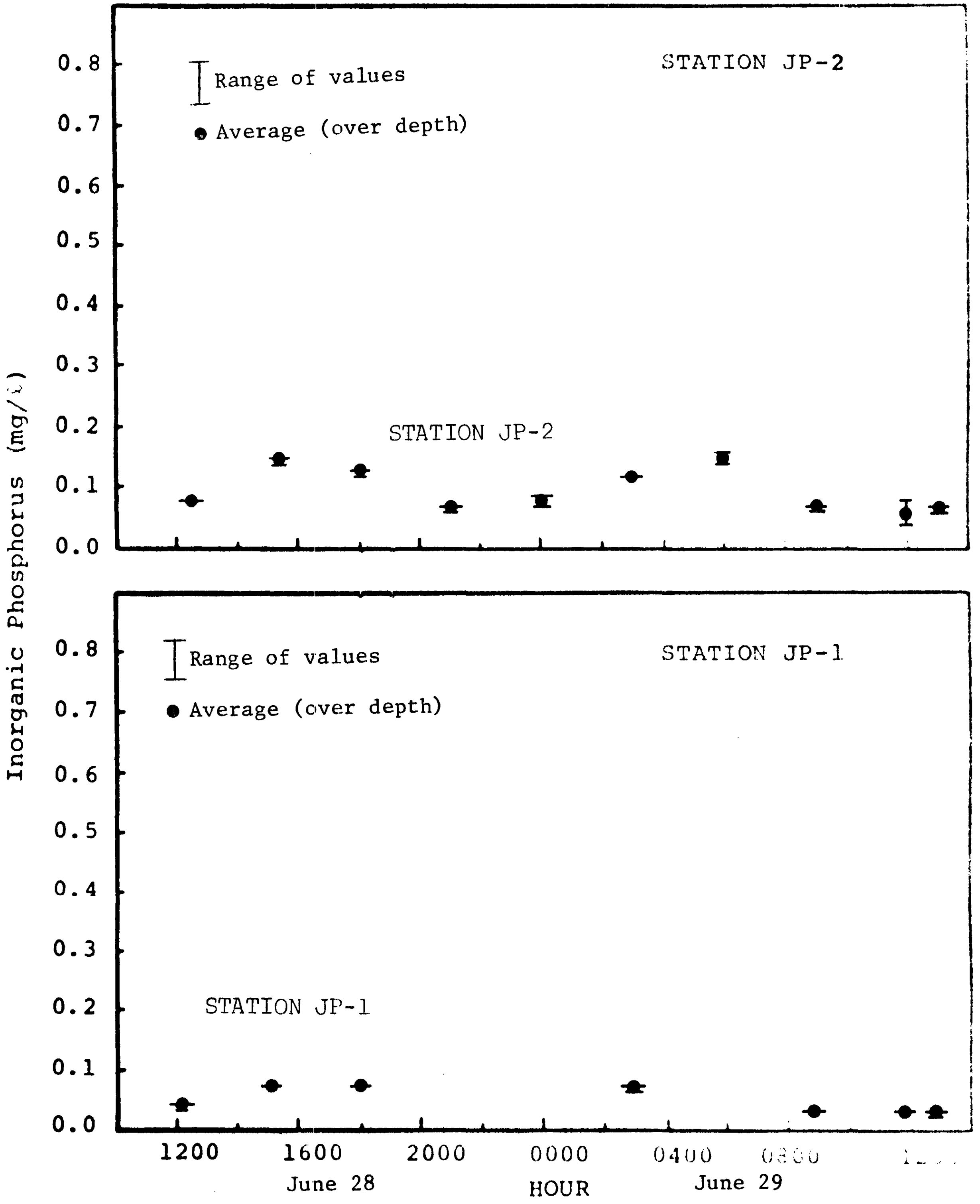
Figures B-28, B-29, B-30. Ammonia nitrogen for stations JP4 through JP6.



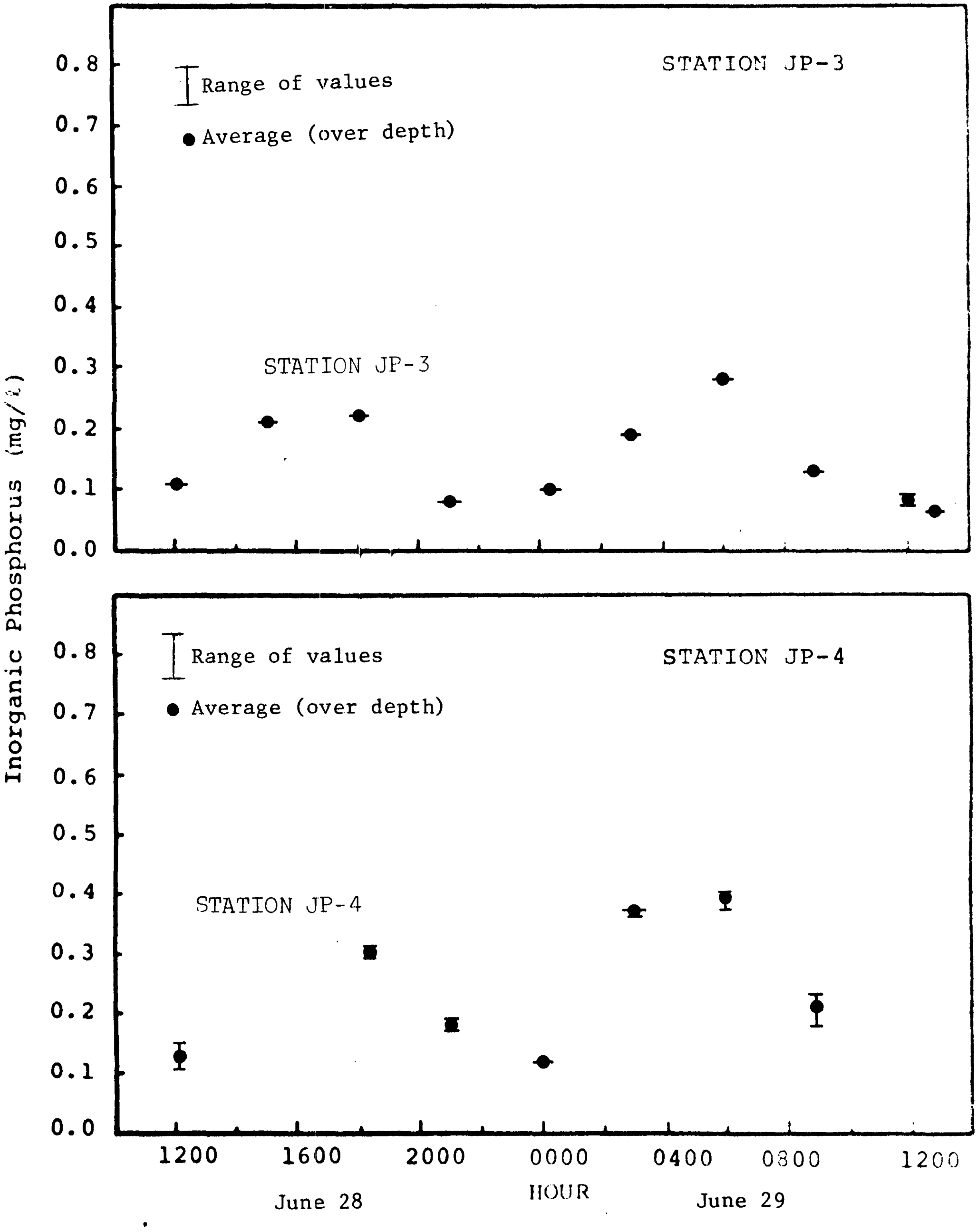
Figures B-31, B-32, B-33. Nitrate nitrogen for stations JP1 through JP3.



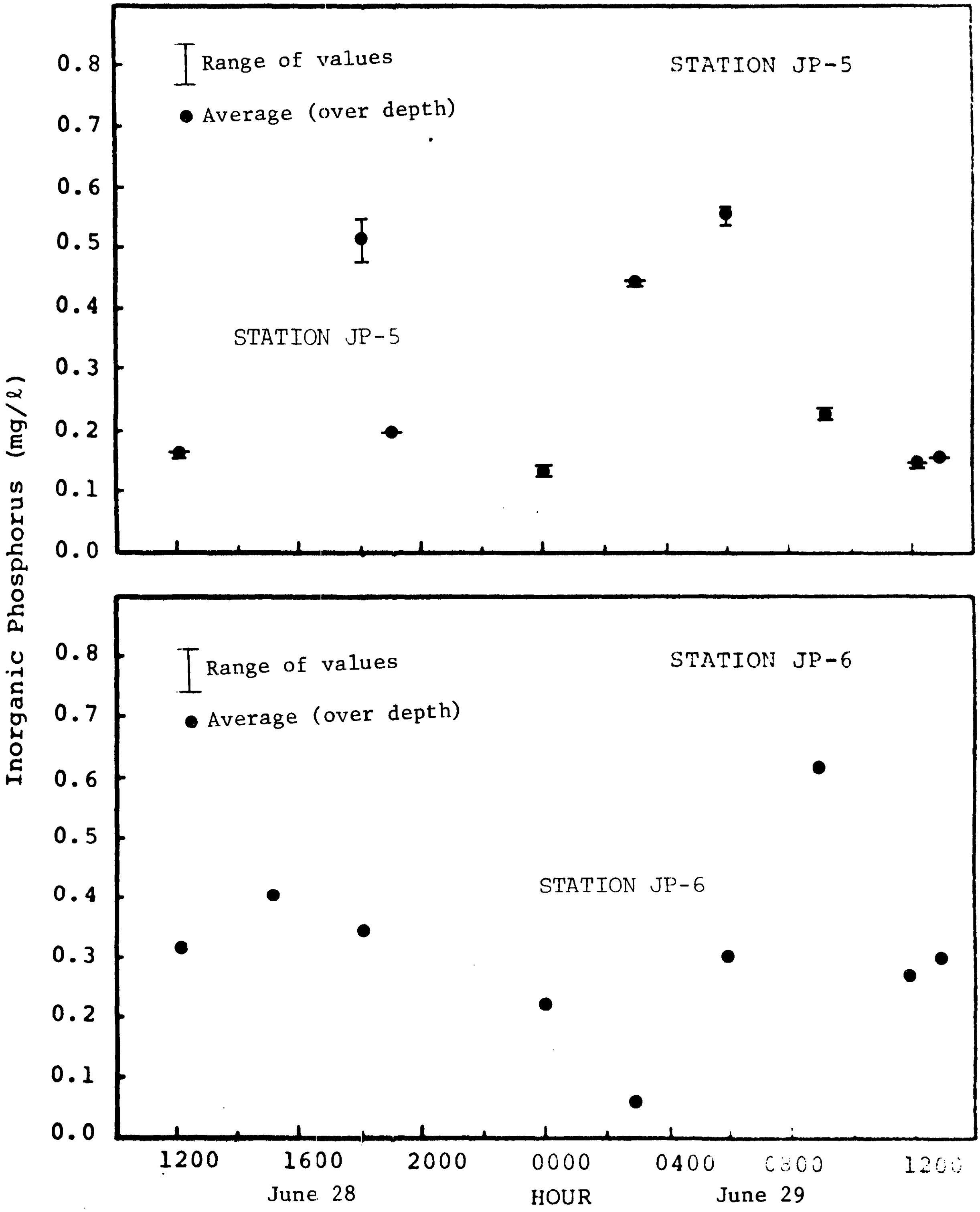
Figures B-34, B-35, B-36. Nitrate nitrogen for stations JP4 through JP6.



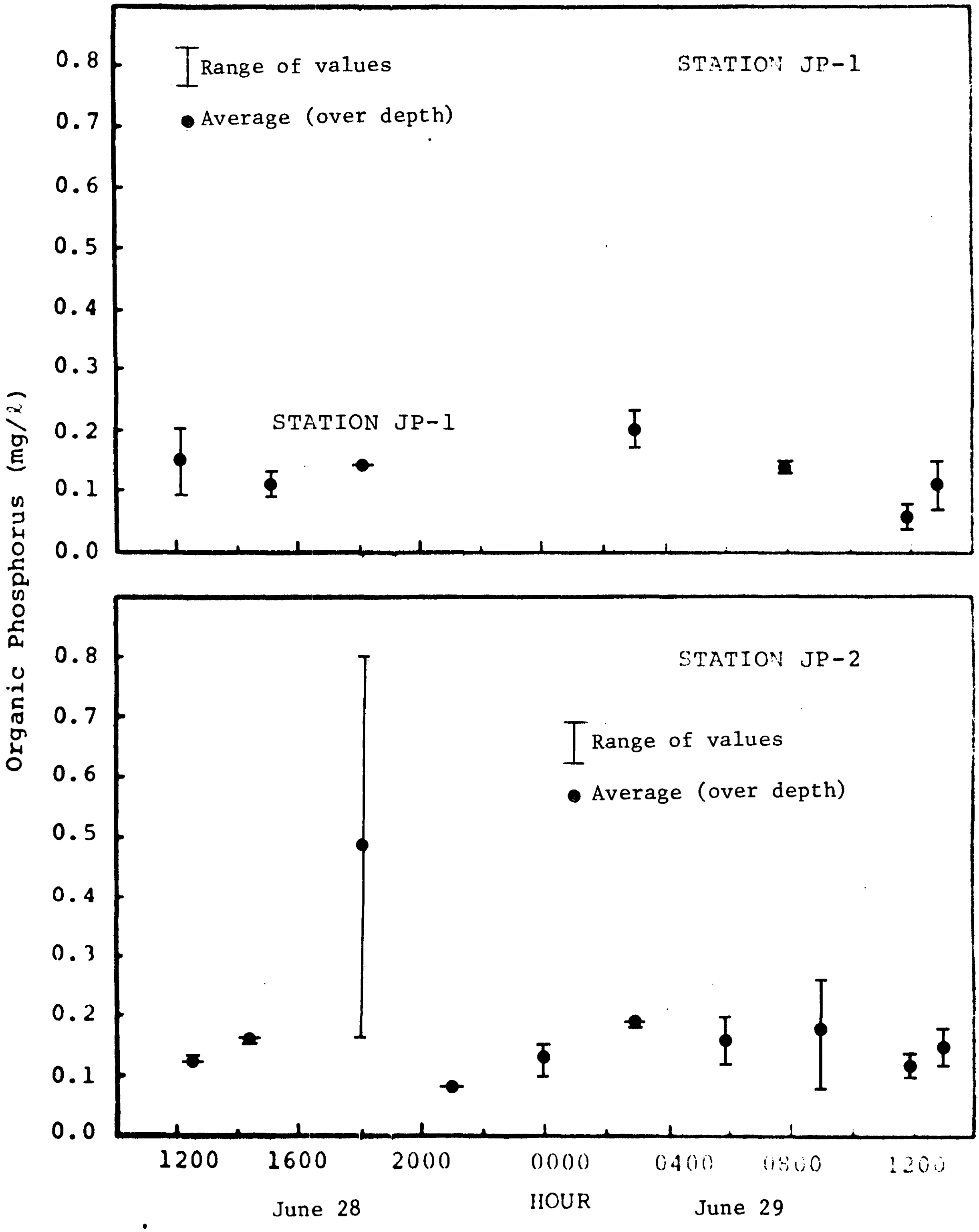
Figures B-37 and B-38. Inorganic phosphorus for stations JP1 and JP2.



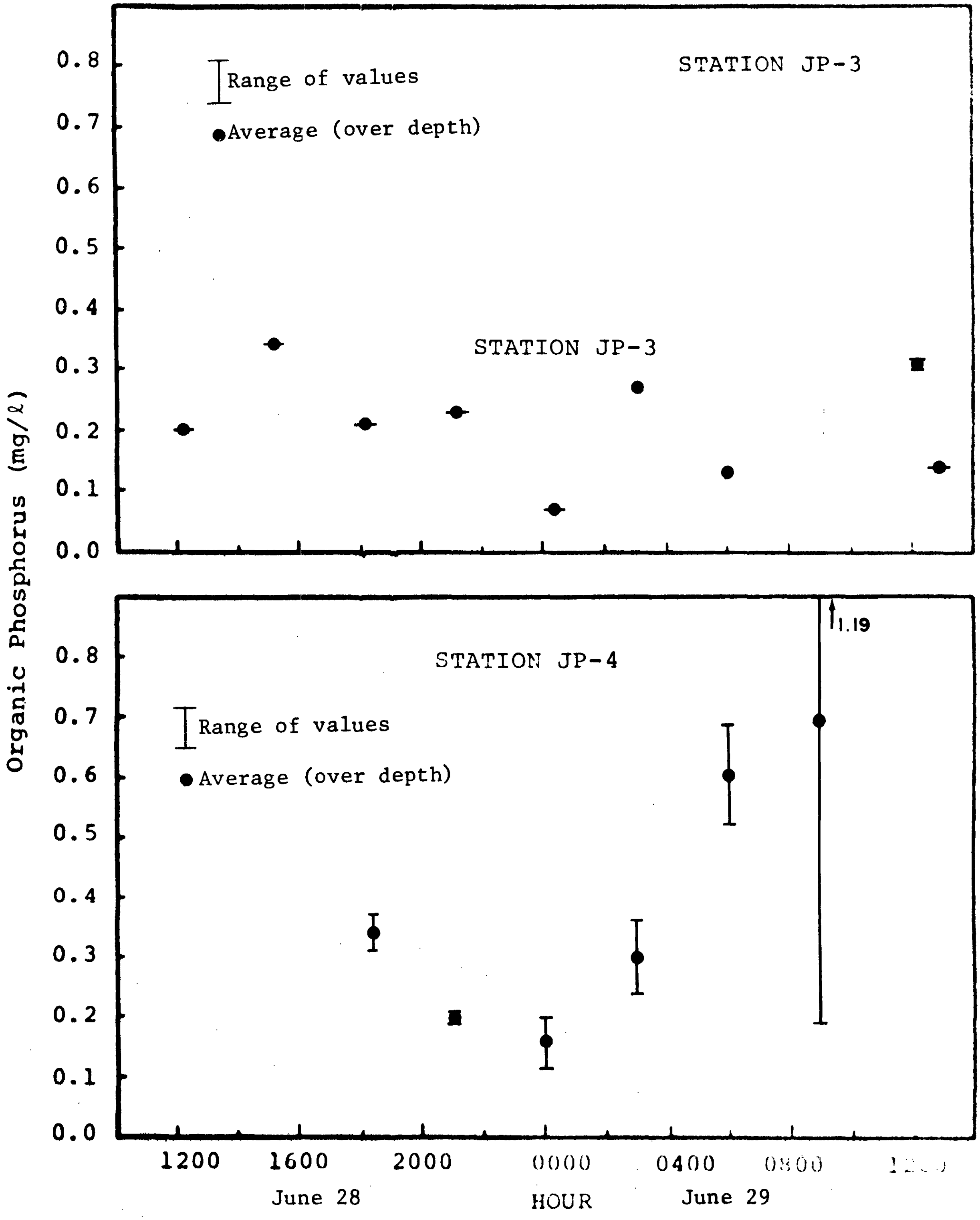
Figures B-39 and B-40. Inorganic phosphorus for stations JP3 and JP4.



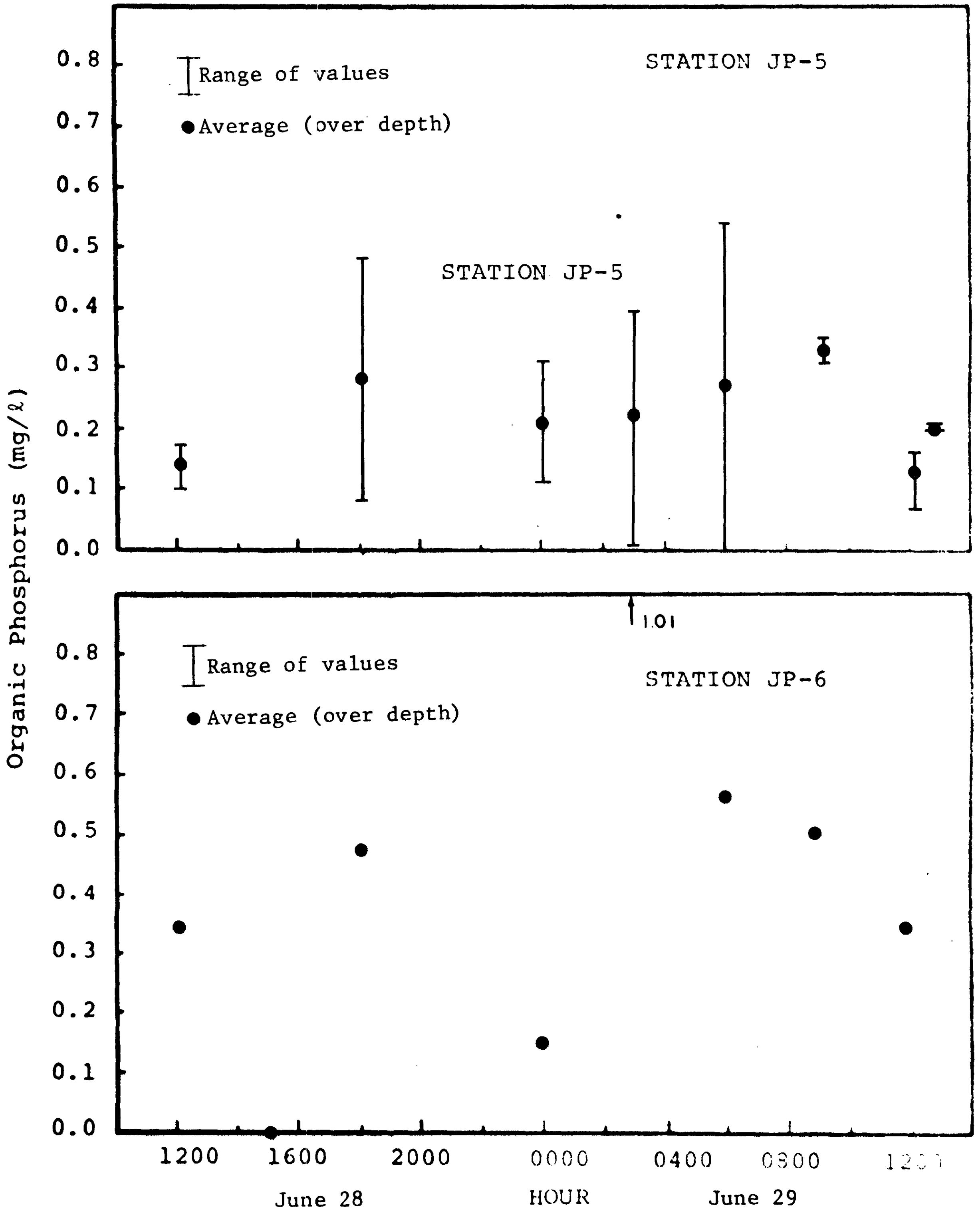
Figures B-41 and B-42. Inorganic phosphorus for stations JP5 and JP6.



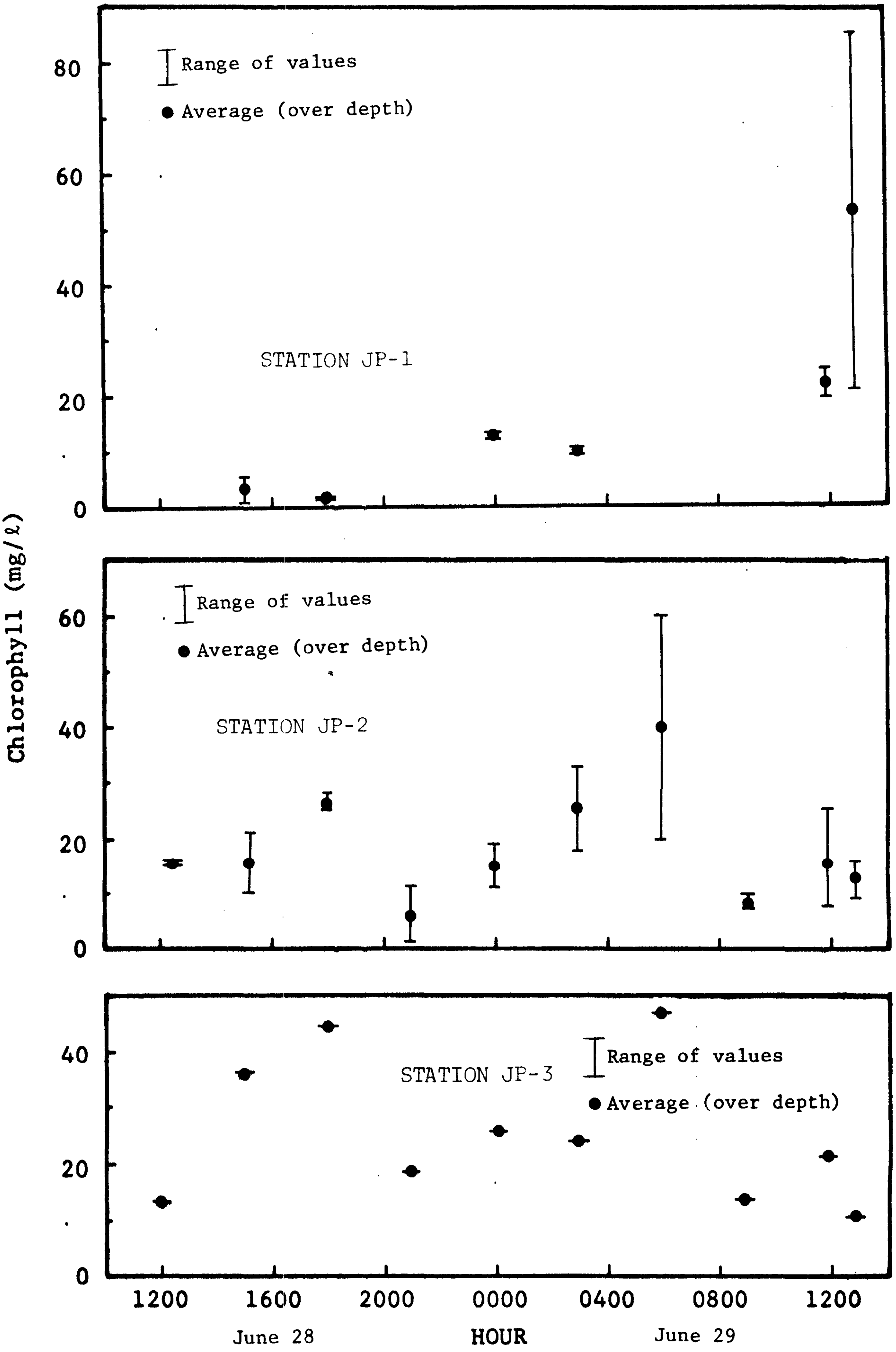
Figures B-43 and B-44. Organic phorphorus for stations JP1 and JP2.



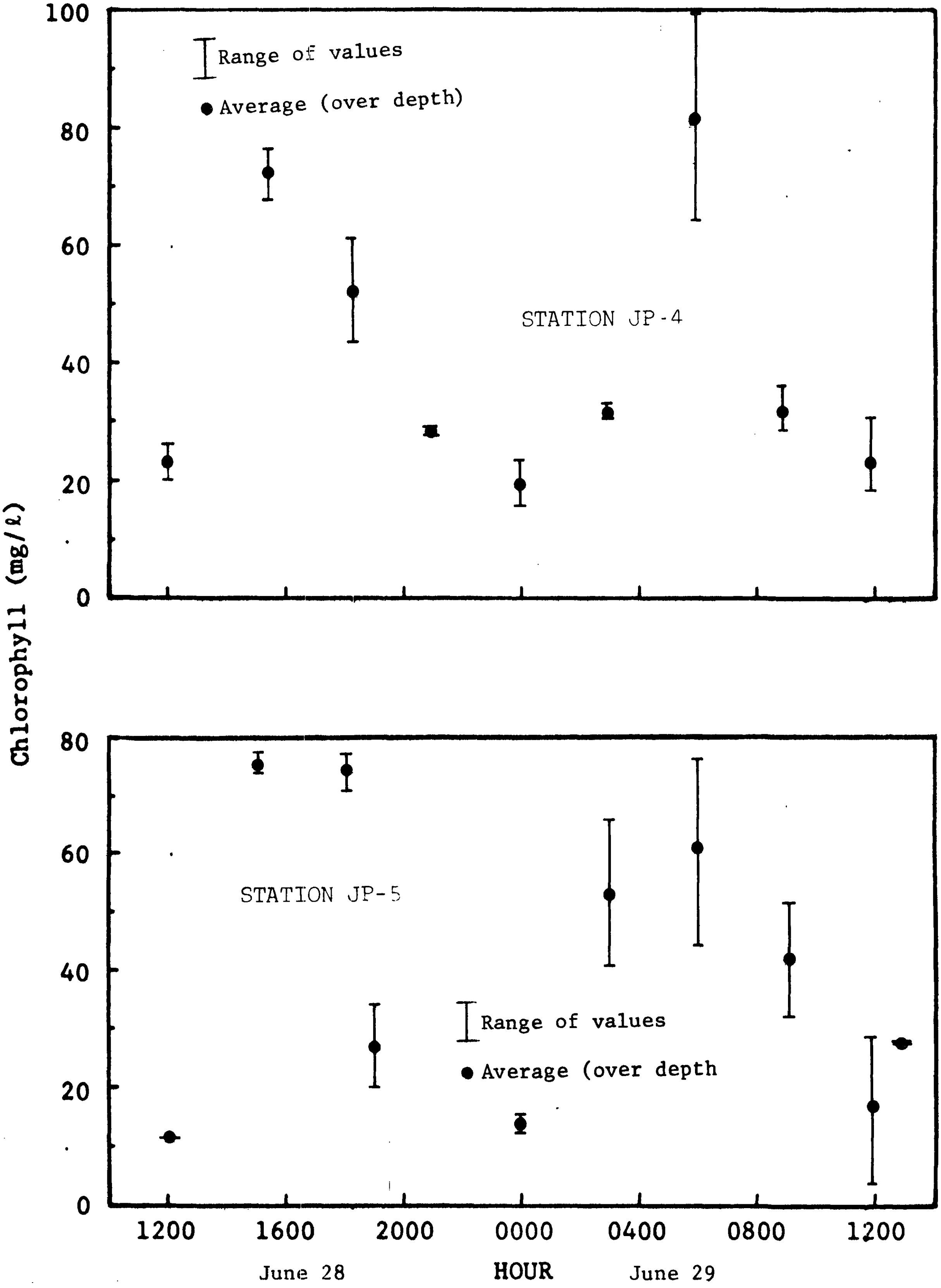
Figures B-45 and B-46. Organic phosphorus for stations JP3 and JP4.



Figures B-47 and B-48. Organic phosphorus for stations JP5 and JP6.



Figures B-49, B-50, B-51. Chlorophyll for stations JP1 through JP3.



Figures B-52 and B-53. Chlorophyll for stations JP4 and JP5.

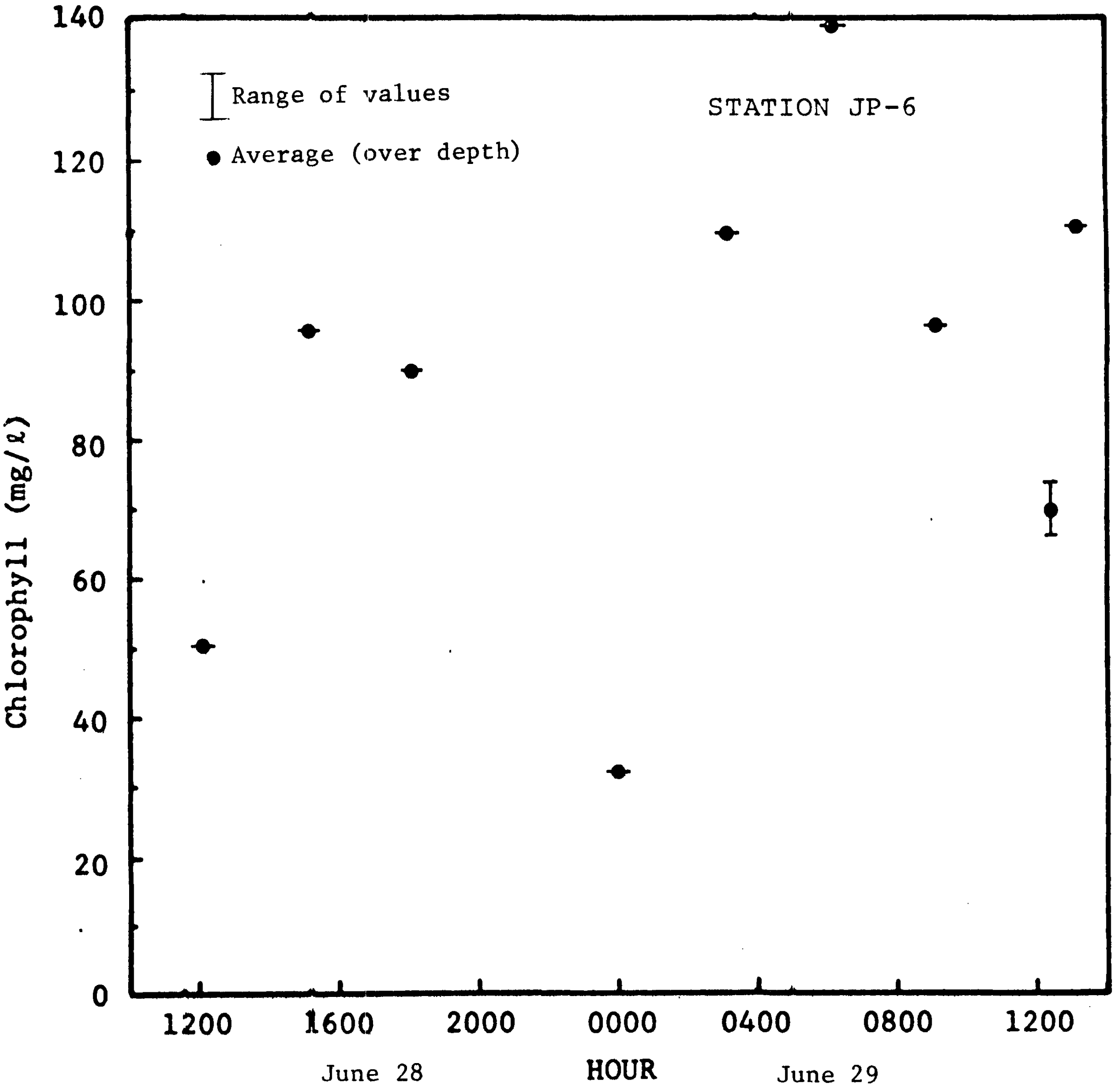
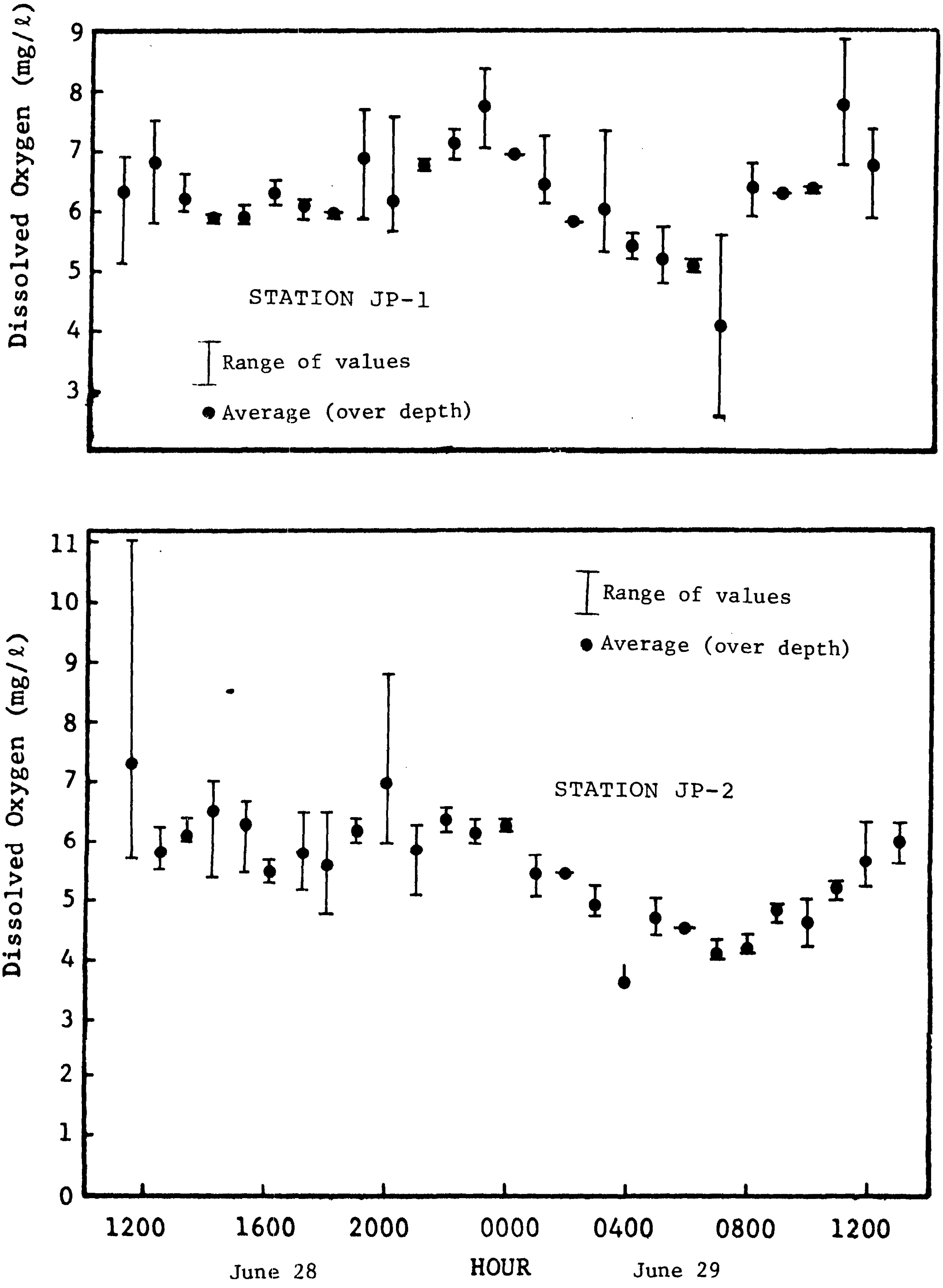
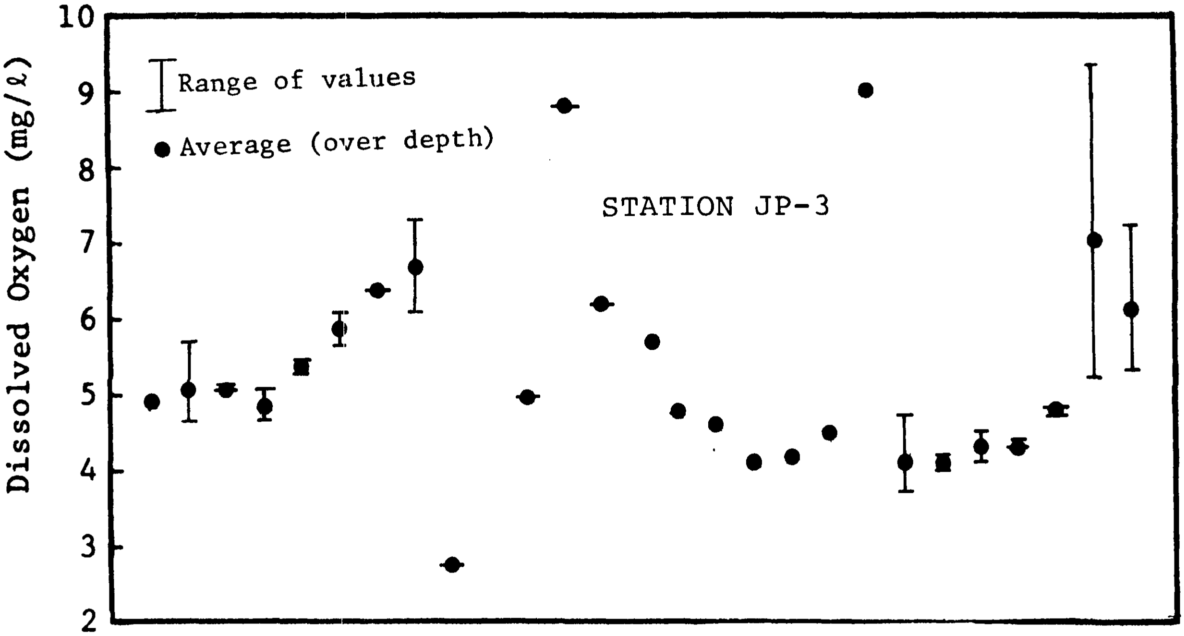
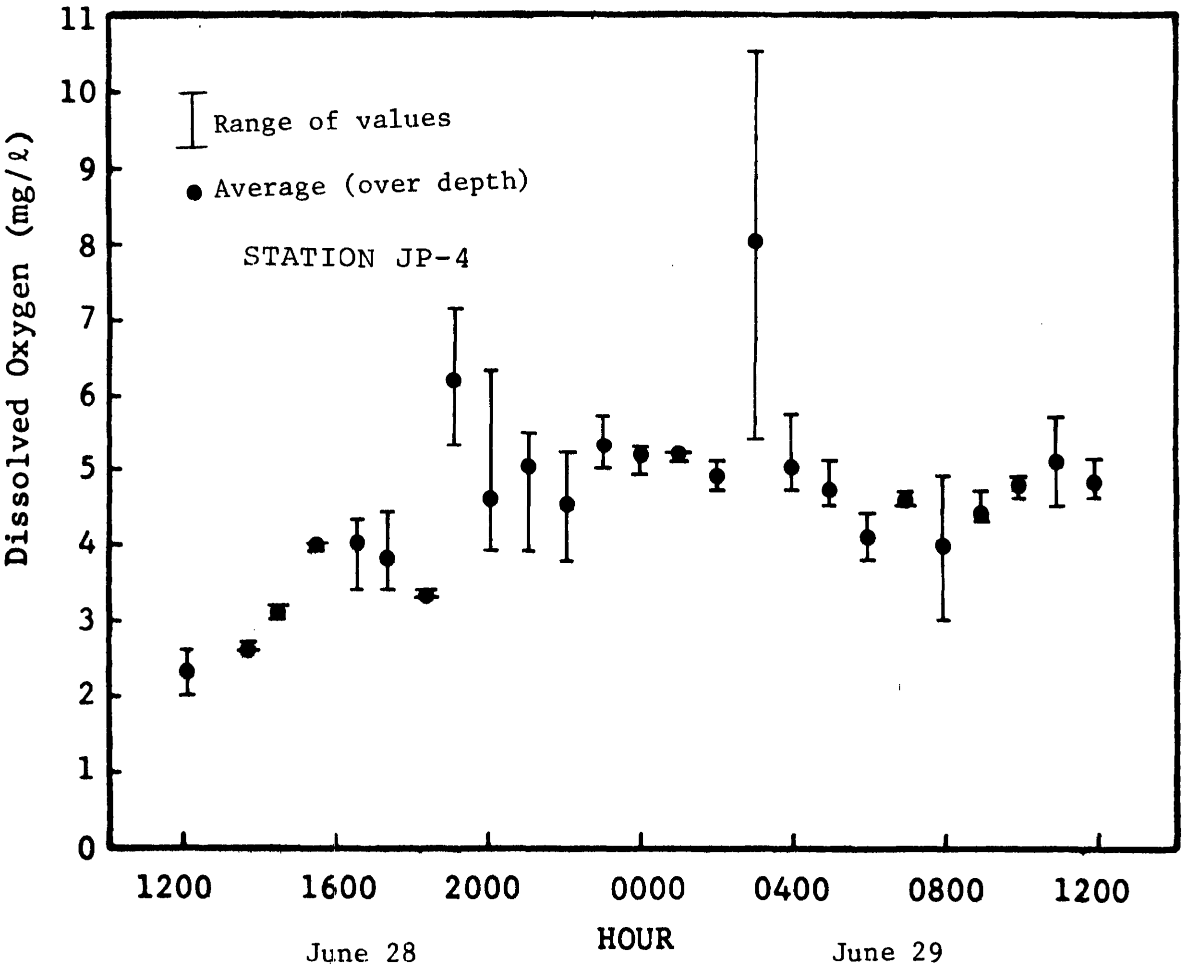


Figure B-54. Chlorophyll for station JP6.

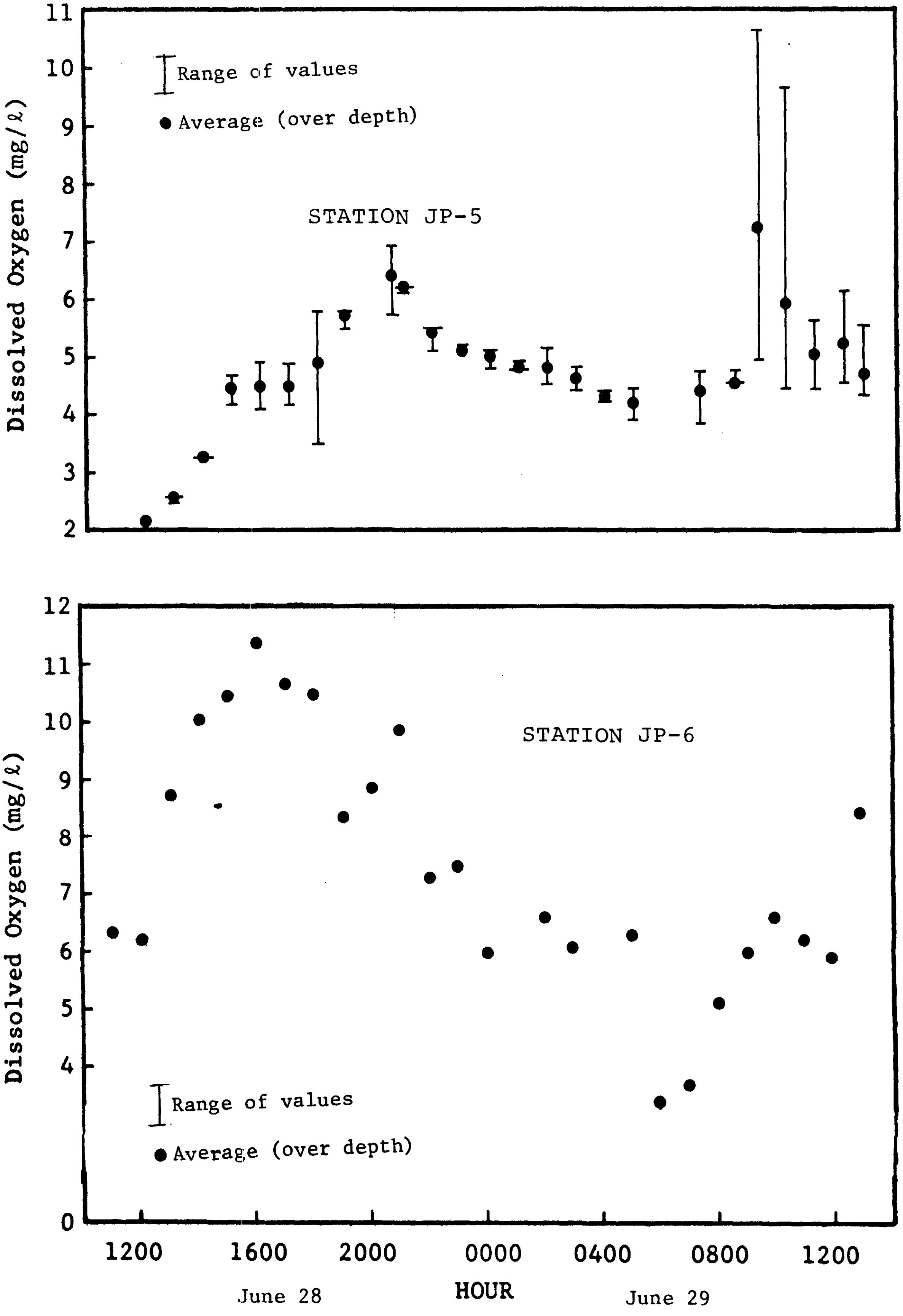


Figures B-55 and B-56. Dissolved oxygen for stations JP1 and JP2.





Figures B-57 and B-58. Dissolved oxygen for stations JP3 and JP4.



Figures B-59 and B-60. Dissolved oxygen for stations JP5 and JP6.

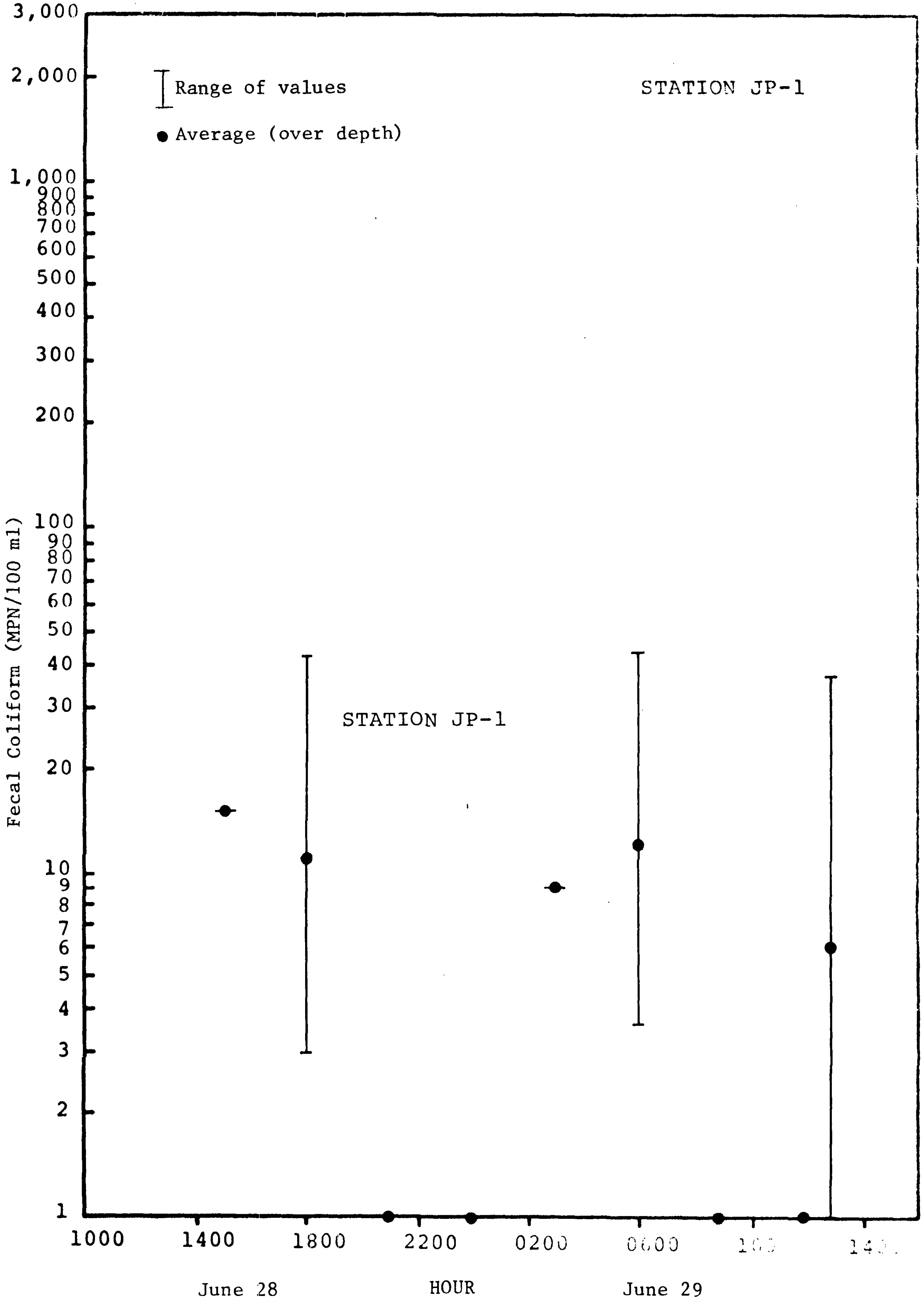


Figure B-61. Fecal coliform for station JP1.

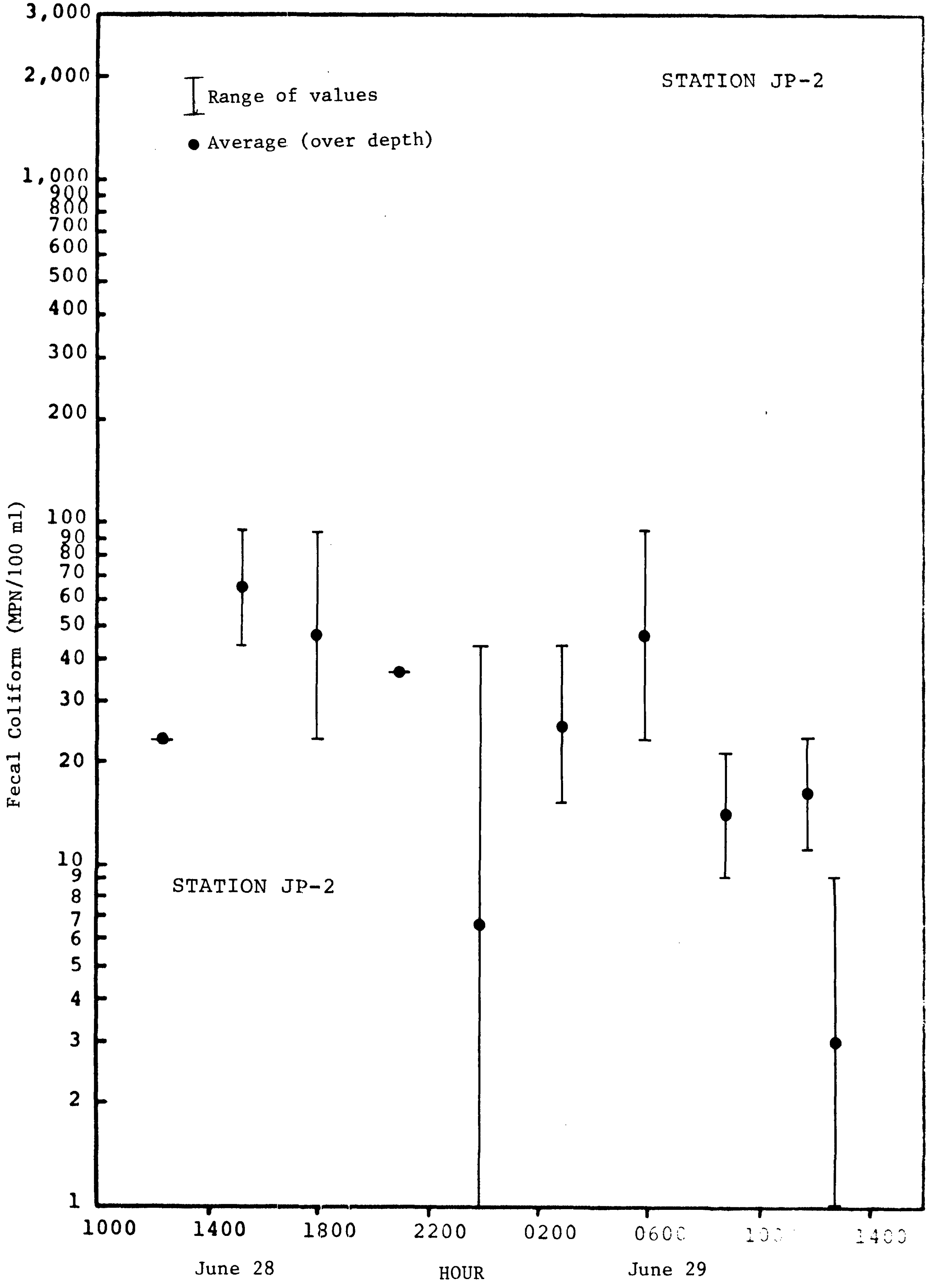


Figure B-62. Fecal coliform for station JP2.

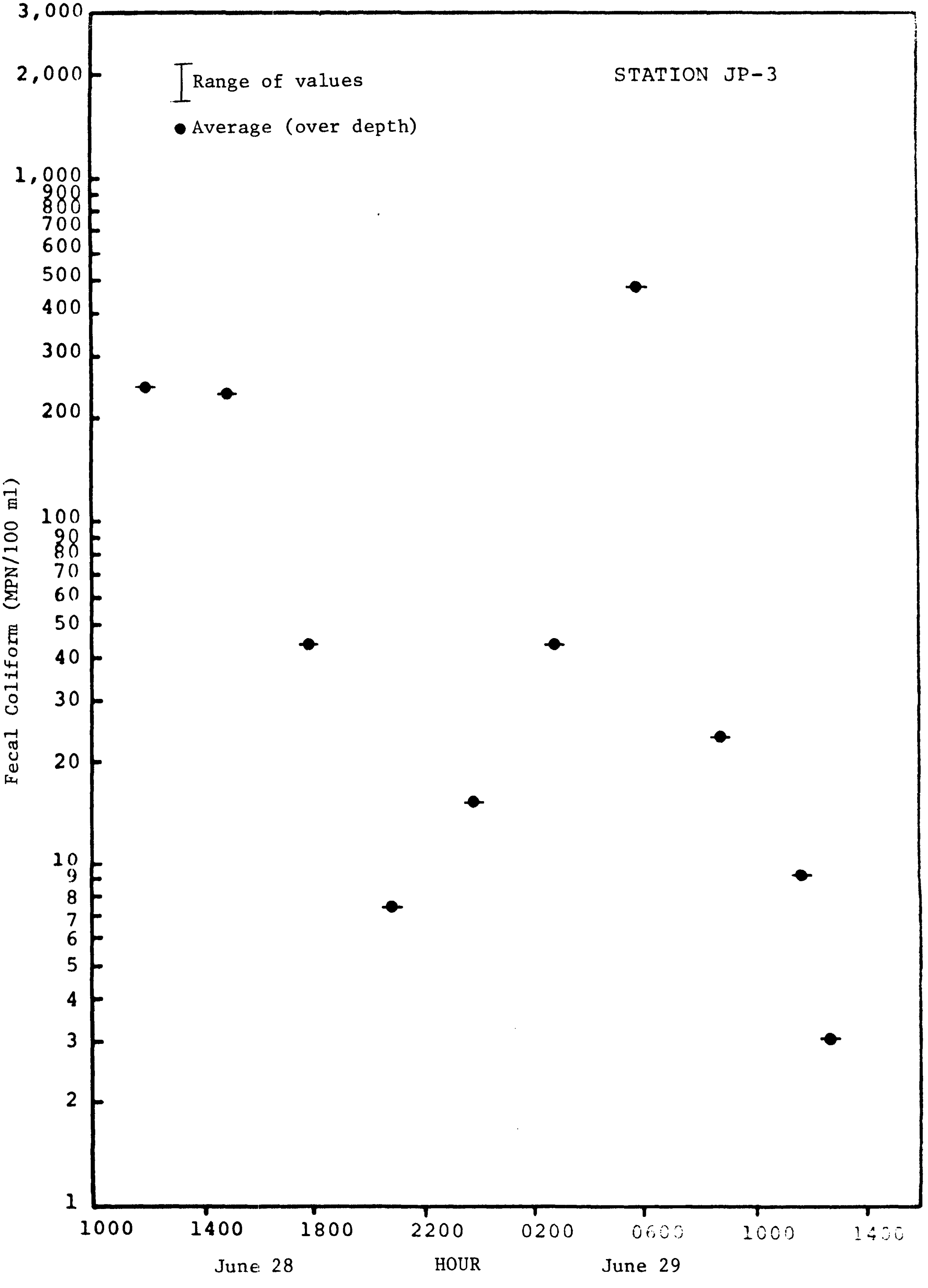


Figure B-63. Fecal coliform for station JP3.

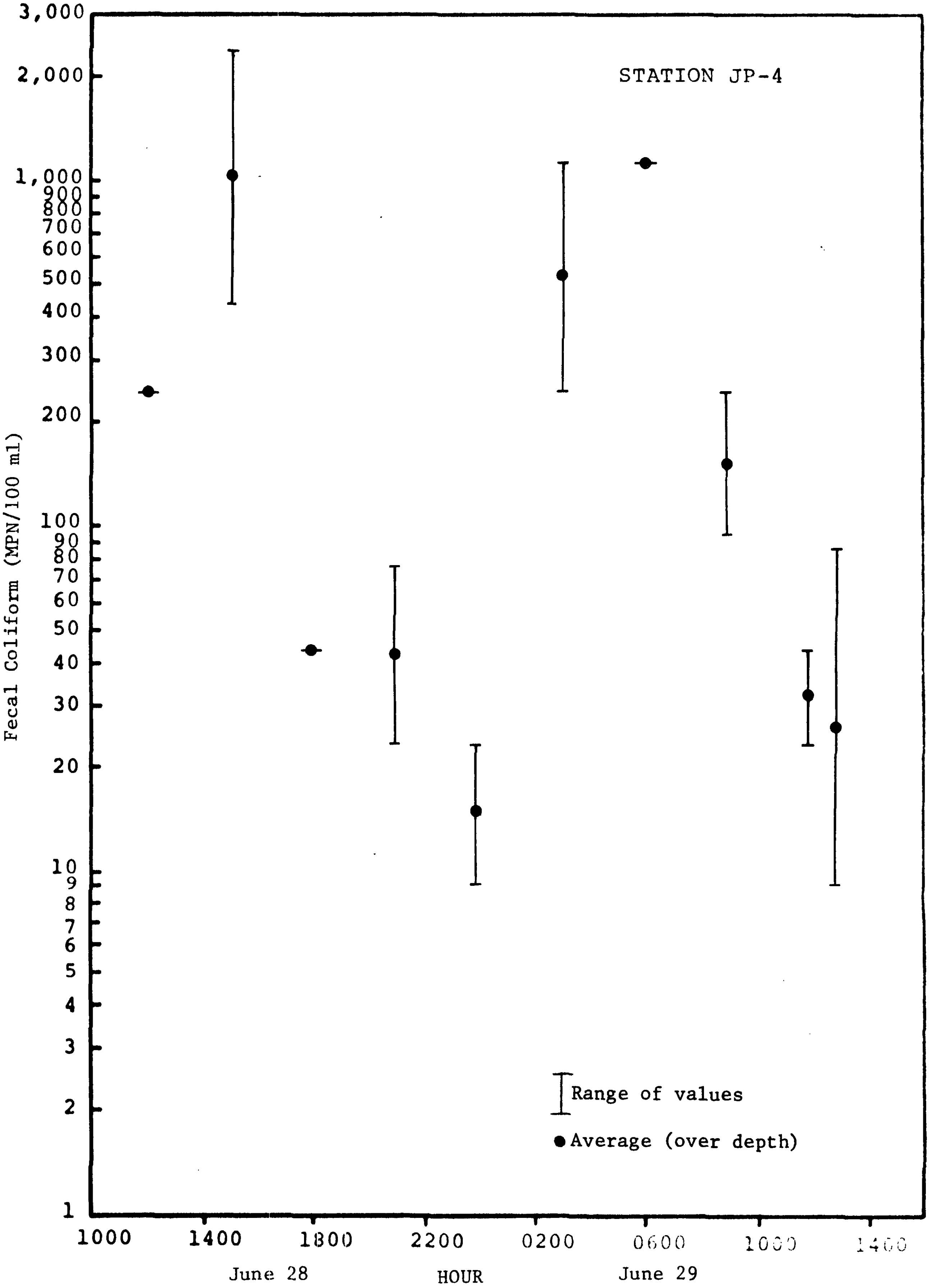


Figure B-64. Fecal coliform for station JP4.

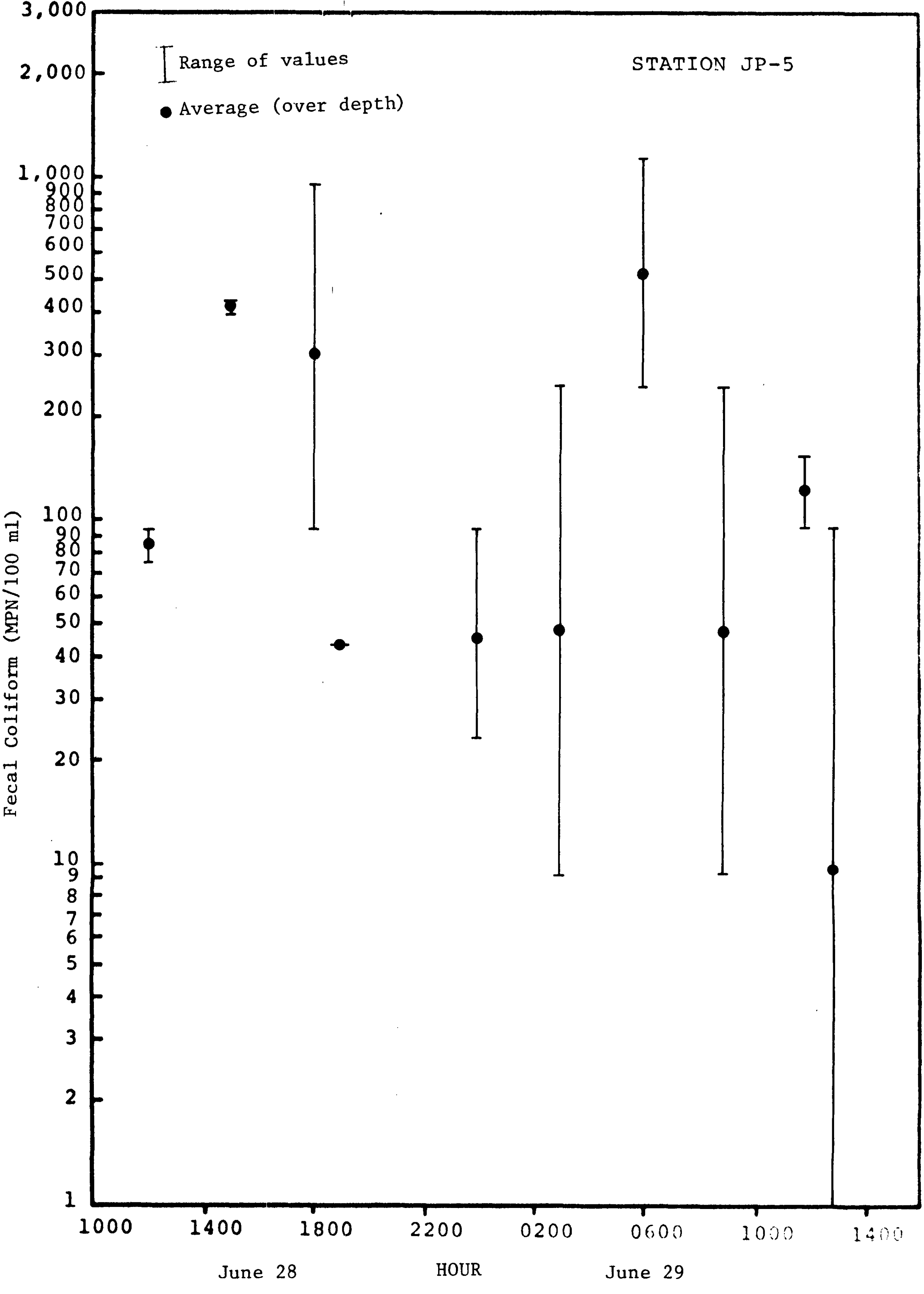


Figure B-65. Fecal coliform for station JP5.

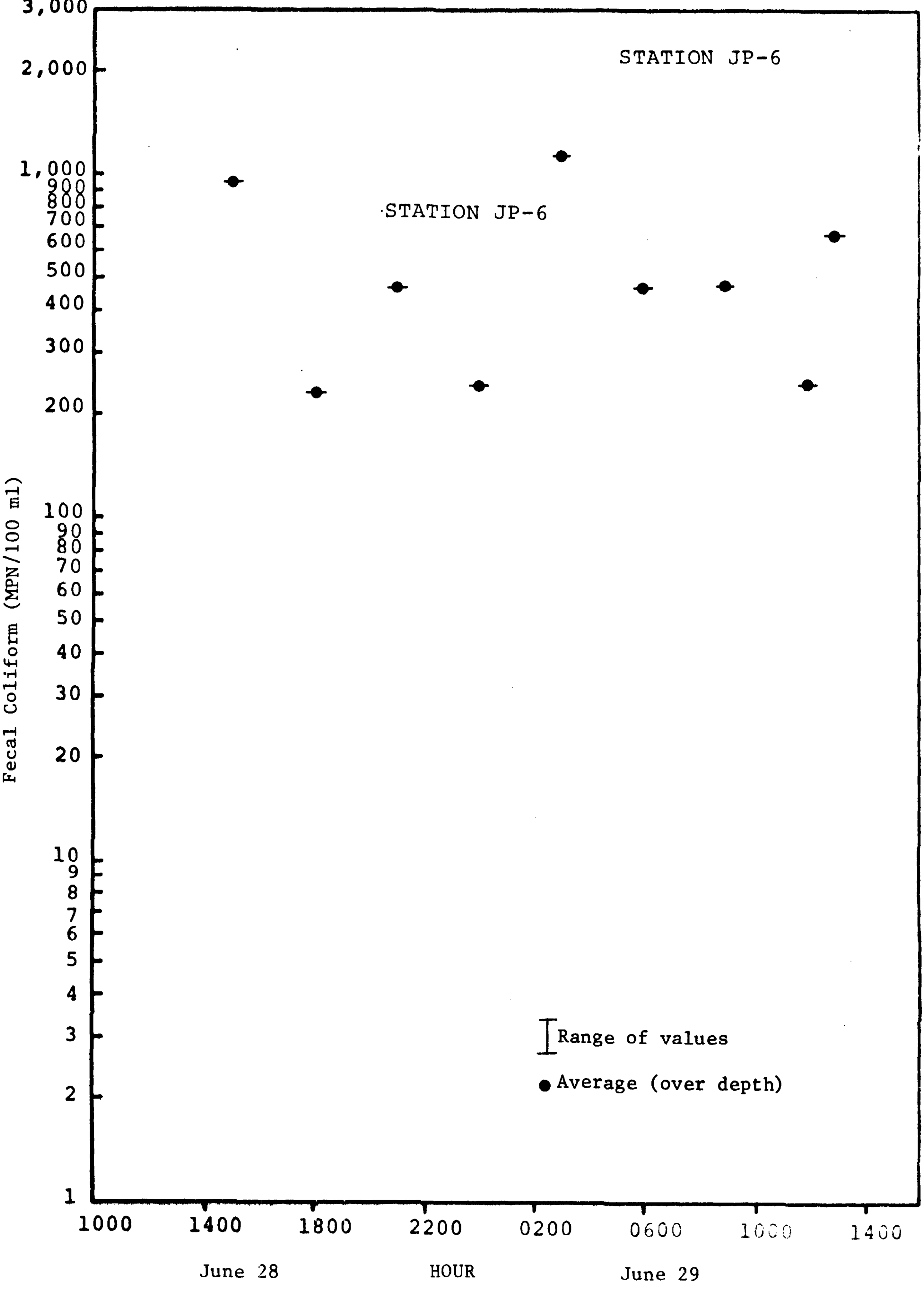


Figure B-66. Fecal coliform for station JP6.