UNITED STATES
DEPARTMENT OF THE INTERIOR
Geological Survey

TEMPERATURE AND WATER-QUALITY CONDITIONS OF THE PATUXENT RIVER ESTUARY, MARYLAND, JANUARY 1966 THROUGH DECEMBER 1967

By

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Abstract

Graphs and tables obtained from continuous from continuous records of surface-water temperature on the Patuxent River estuary from five stations for the period January 1966 through December 1967 and of surface salinity, dissolved oxygen, turbidity, tide-stage, and bottom temperature from a single station are presented herein.

The effect of powerplant cooling water in raising natural water temperatures at a location near the powerplant is clearly evident from thermograph records. Surface temperature at a station 1,000 feet downstream from the discharge canal was raised an average of about 4 degrees Celsius, and at times by as much as 8°C. Temperature rises were greatest during the winter. Infrared imagery showed that elevated surface temperatures could be detected about 3 miles upstream at flood tide. Mean annual salinity for a 5-year period (1963-1967) was highest in 1966, about 12.3 parts per thousand (ppt), and lowest in 1967, about 9.9 ppt. Dissolved oxygen values for 1966-1967 ranged from 3.2 to 15.6 milligrams/liter (mg/l), and percentage saturation ranged from 55 to 152 percent. Turbidity levels were inversely related to salinity, with the highest annual mean of 28 Jackson Candle Units (JCU) occurring in 1967, the lowest salinity year. The extreme tide range was 6.7 feet; mean water levels at the Patuxent Bridge were highest in summer and lowest in winter. Water stages are more affected by wind speed and direction than by flow in the river.

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Introduction

The Patuxent River estuary, one of the tributaries of the Chesapeake Bay estuarine system, has been under intensive biological, chemical, and physical investigation by state, federal, and private agencies since 1962. The investigation has been principally concerned with the effects of addition of heated water to the estuary by a coal-fueled, steam electric generating plant located at Chalk Point, Maryland (fig. 1). The estuarine waters are used as a heat exchanger coolant, and approximately 500,000 gallons per minute (gpm) flow through the plant.

In 1963 the U.S. Geological Survey began a program of continuously recording surface temperatures at selected sites in the estuary (fig. 1). In addition, surface and bottom temperature, conductivity, dissolved oxygen, turbidity, tide stage, wind direction, and wind velocity were obtained on a multi-channel recorder at the Patuxent River Bridge. The bridge is located in the upper middle portion of the estuary about 6.5 kilometers (3.5 nautical miles) below the powerplant's discharge point. The purpose of collection of these data is to furnish continuous environmental data that will be helpful in interpreting short-term extreme ecological changes caused by storms or anomalous meteorologic situations and to reveal long-term changes due to climatic fluctuations or due to modifications introduced by man's activities.

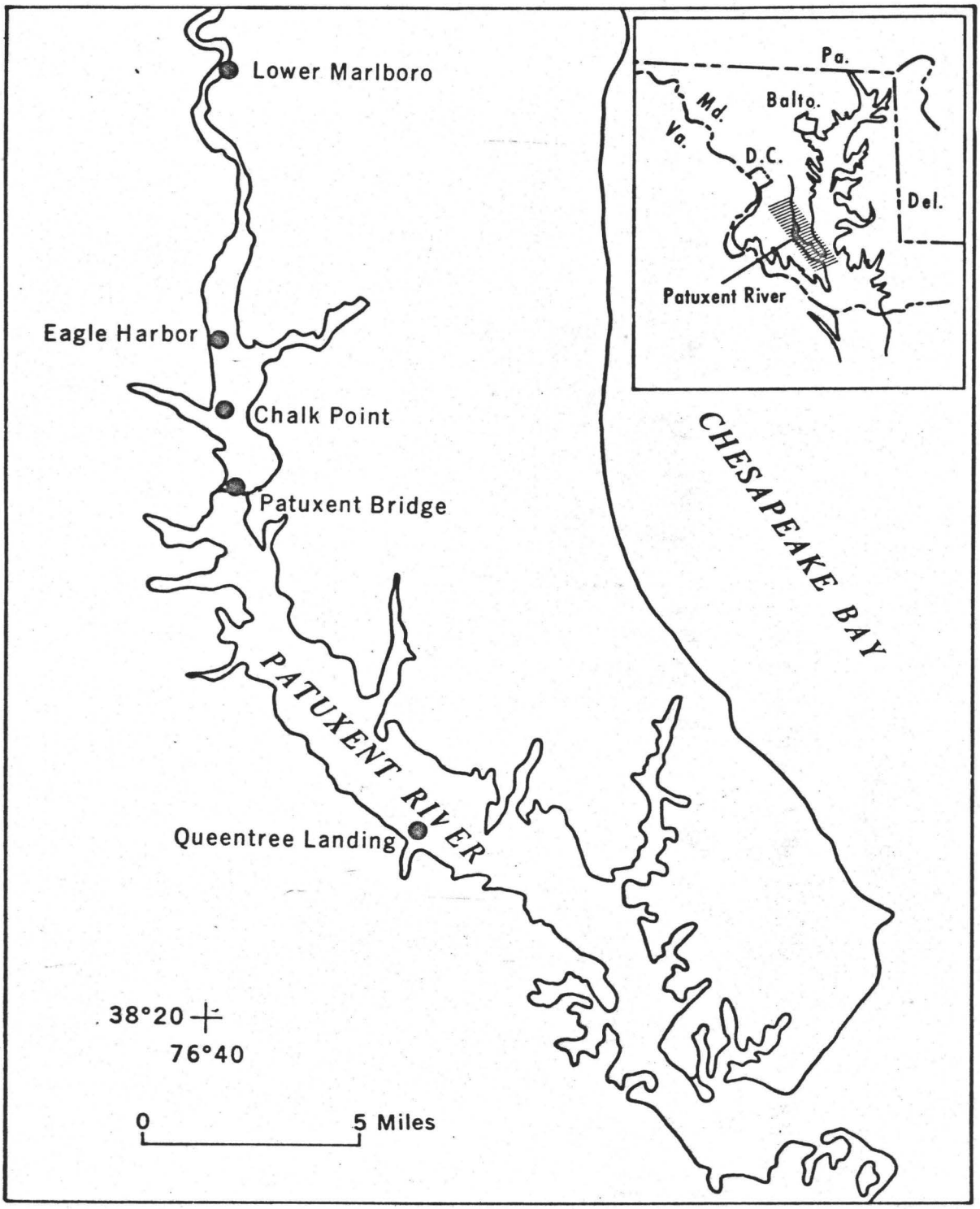

Fig. 1.--Patuxent River estuary; U.S.G.S. surface-water temperature recorders are located at each station, and a U.S.G.S. water-quality data-collection system is located at the Patuxent Bridge station.

This is the second of two U.S.G.S. Open File Reports. The first report, Cory and Nauman (1967), was released as a U.S.G.S. Open File Report in March 1967. In that report, the general conditions of temperature and water quality were described for the period July 1963 through December 1965 with little attention given to explanations of the diurnal, tidal, or storm-induced changes in the environment. This report shall describe in greater detail the cause-and-effect relations among the numerous environmental controls.

Data Collection

At four of the temperature stations, thermistor temperature sensing probes were suspended 0.1 meter below the water surface from styrofoam floats. At the bridge site, temperatures were measured by means of thermocouples, one mounted in a tank on a platform above the estuary into which water is pumped from a depth of 0.3 meter below the water's surface. The other thermocouple is permanently installed at a point 0.3 meter above the bed of the estuary.

The Queentree Landing and Lower Marlboro stations are control stations because they are representative of natural estuary water temperatures above and below the reach receiving the heated waters. The Chalk Point and Eagle Harbor stations were influenced by the heated water, with the greatest effects evident at the Eagle Harbor station which is located about 333 meters (1,000 feet) downstream

of the powerplant's discharge canal. The Chalk Point station is about 3 kilometers (3,000 yards) below the discharge canal.

During 1966, the U.S.G.S. water-quality data-collection system located at the bridge was beset with a series of equipment failures, most of which were attributable to the corrosive salt atmosphere. The salinity- (conductivity) and turbidity-sensing circuits were most affected, and data for these two parameters were collected for only 44 percent of the total recording time that year.

Daily maximum and minimum values of surface and bottom temperature, turbidity, salinity, tide stage, dissolved oxygen, and percent saturation of dissolved oxygen were tabulated from data collected, placed on IBM punchcards, and programmed for computer analysis. The results are presented in tables 1 to 5 which show weekly mean maximum, mean minimum, and weekly extreme maximum and minimum values as well as daily maximums and minimums.

Results

Temperature

Temperature is probably the most universally important environmental factor. Any changes in temperature are bound to control the many chemical processes taking place in plant or animal tissues and so affect the entire ecosystem of the estuary. In addition, many physical processes, such as viscosity, density, and the solubility of oxygen in water are directly related to temperature. In estuaries,

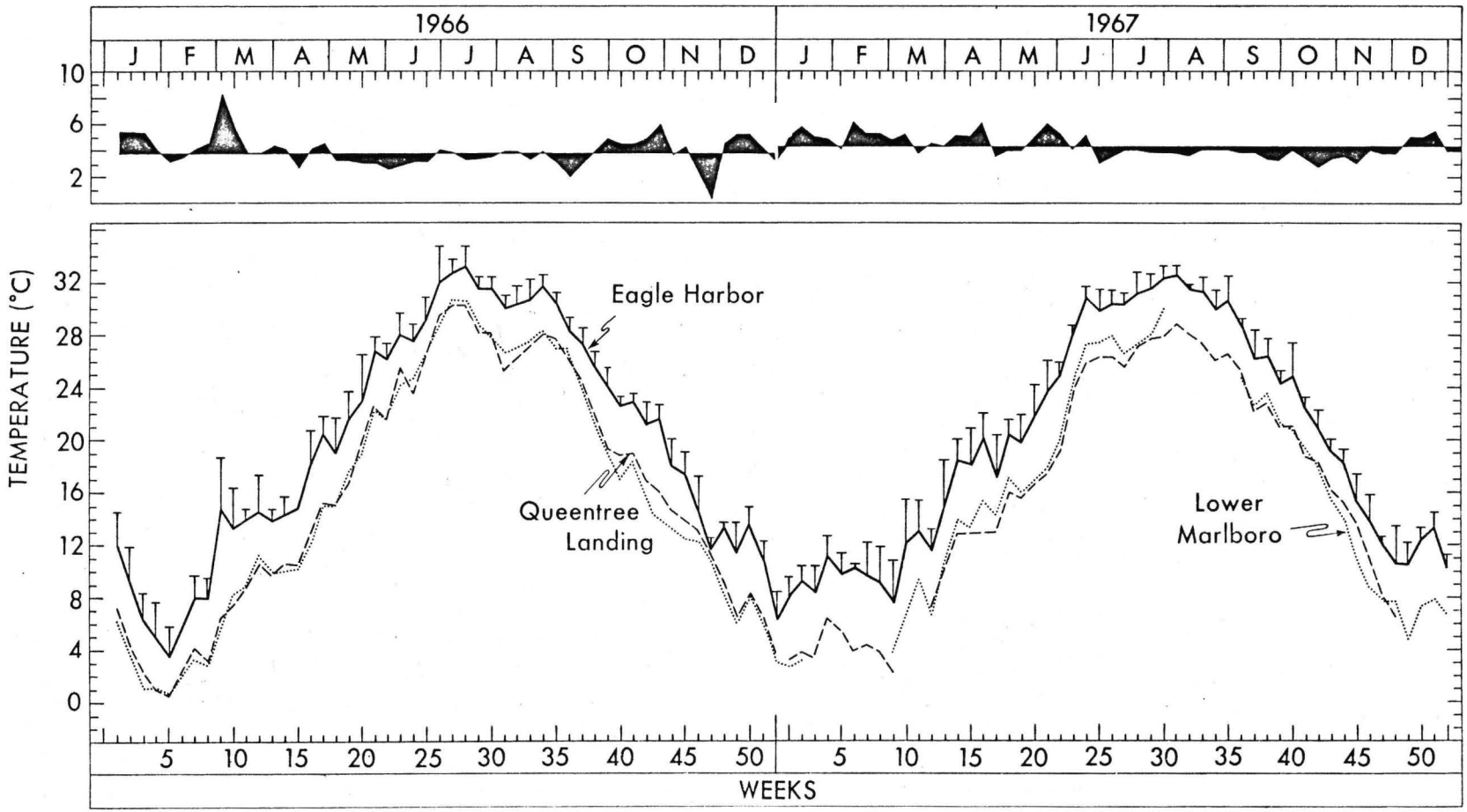

Fig. 2.--Weekly average surface-water temperatures from three locations. Stations show upstream, downstream normal temperatures and Eagle Harbor near where the Chalk Point Powerplant water is discharged. The upper graph shows the annual average (horizontal lines) degrees C above normal temperature and weekly average differences from normal at the Eagle Harbor station. Vertical bars show weekly maximum temperatures on lower graph.

the heat-storage capacity is small relative to the larger volume of the ocean so that temperature changes are closely correlated with seasonal climatic variations.

Temperatures at any location in the Patuxent estuary fluctuate annually, seasonally, diurnally, vertically, laterally, and with changes in tide. In addition to "normal" temperature variations, a portion of the estuary is subject to thermal loading stemming from heat-exchanger cooling waters which are passed through the steam-electric station (S.E.S.) discharging at Eagle Harbor. The following comments pertain to data collected from continuous recording thermographs and only give a partial picture of the thermal characteristics of the Patuxent estuary.

The weekly differences in surface temperatures caused by the S.E.S. cooling waters are best shown by comparing weekly temperature data for three locations; that is, the up-estuary station, Lower Marlboro; the S.E.S.-affected station, Eagle Harbor; and the down-estuary station, Queentree Landing (fig. 2).

The top of figure 2 shows the weekly differences of maximum temperature between the Eagle Harbor station and the natural river water temperature. The data for the figure were obtained by averaging weekly maximum temperature from ~~Eagle Harbor~~ Queentree Landing and Lower Marlboro then subtracting them from the average weekly maximum at Eagle Harbor where greatest effects of the S.E.S. were measured.

In 1966 these differences averaged 3.9°C; and in 1967, 4.3°C (horizontal line, top of fig. 2). The weekly temperature differentials ranged from 0.2°C (a return to near-natural temperature) in November 1966 to 8.5°C in March 1966. The return to near-natural temperature occurred after a four-day S.E.S. shutdown and during a period when the plant operated only three out of ten days. Based on that one observation, it would appear that it takes between three and four days for the elevated temperatures to return to normal after addition of heated water ceases.

Differences in the natural river temperature between the up- and down-estuary stations were slight, from 0 to 3°C, and in the same order of magnitude as previously observed by Nash (1947) and Cory and Nauman (1967). The more rapid response to seasonal changes observed at Lower Marlboro can be attributed to the fact that the ratio of surface area to volume increases in an upstream direction (Nash, 1947). During 1966, average weekly maximum temperatures were both higher and lower than those of 1967, ranging from an average of 0.5° to about 30.5°C as compared to a range of 2.2° to 30.0°C in 1967.

Because of its central location, the weekly surface-water temperatures at the Patuxent Bridge site (fig. 3, table 1) typify thermal patterns in the Patuxent estuary. Temperatures measured at this location over the two-year period ranged from a low of -0.7°C to

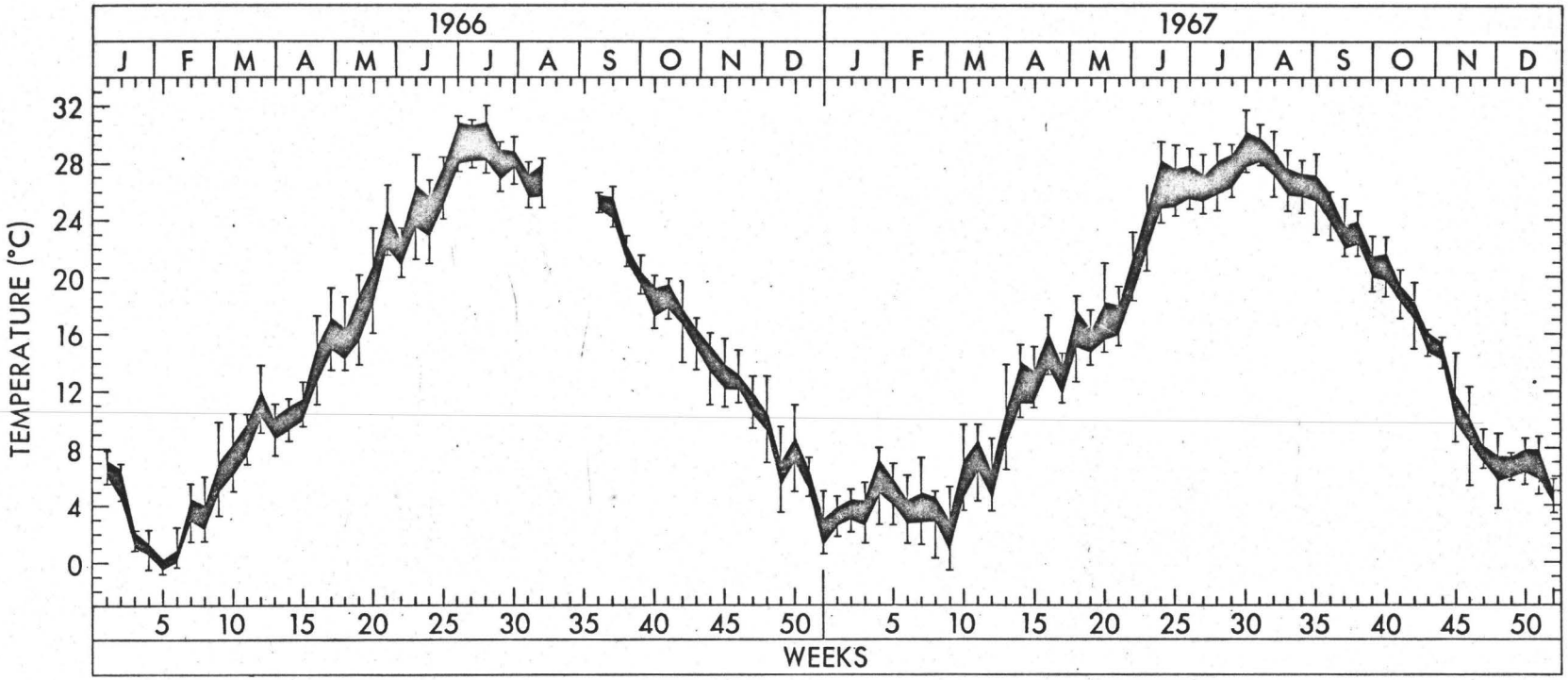

Fig. 3.--Weekly average maximum and minimum surface-water temperatures, Patuxent River Bridge. Vertical bars show weekly extreme temperatures.

a high of 32.0°C, and the largest weekly range in temperature was 7.4°C over the two-year report period.

Variations of surface temperatures due to tide and diurnal atmospheric temperature changes were slight at locations unaffected by the S.E.S. cooling waters (figs. 4 and 5). However, tidal variations and, to a lesser extent, diurnal variations of temperature are pronounced at the Eagle Harbor station where the S.E.S. cooling water causes large, rapid, temperature changes. Measurements taken at 20 minute intervals over 24-hour periods show that temperatures rise to maximum values on the outgoing tide and may return to near-natural levels at extreme high water (figs. 4 and 5). The days shown in the figures were selected because thermal patterns on February 4, 1966, represent a typical mid-winter minimum temperature condition and thermal patterns on June 30, 1966, represent mid-summer maximum temperatures observed. The daily gross generation in megawatt hours (Mwh) was about 7,500 Mwh February 4, 1966, and about 16,500 Mwh June 30, 1966.[1/] Despite the doubling of the generation output in June the temperature rise above ambient was 8.0°C in February and only 6.4°C in June. The cooling water pumping rates are purportedly reduced in winter allowing a greater increase in temperatures as they pass through the condensers. The large diurnal

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[1/] Chalk Point generation data. Unpublished. From Sheppard T. Powell Associates, Washington, D.C.

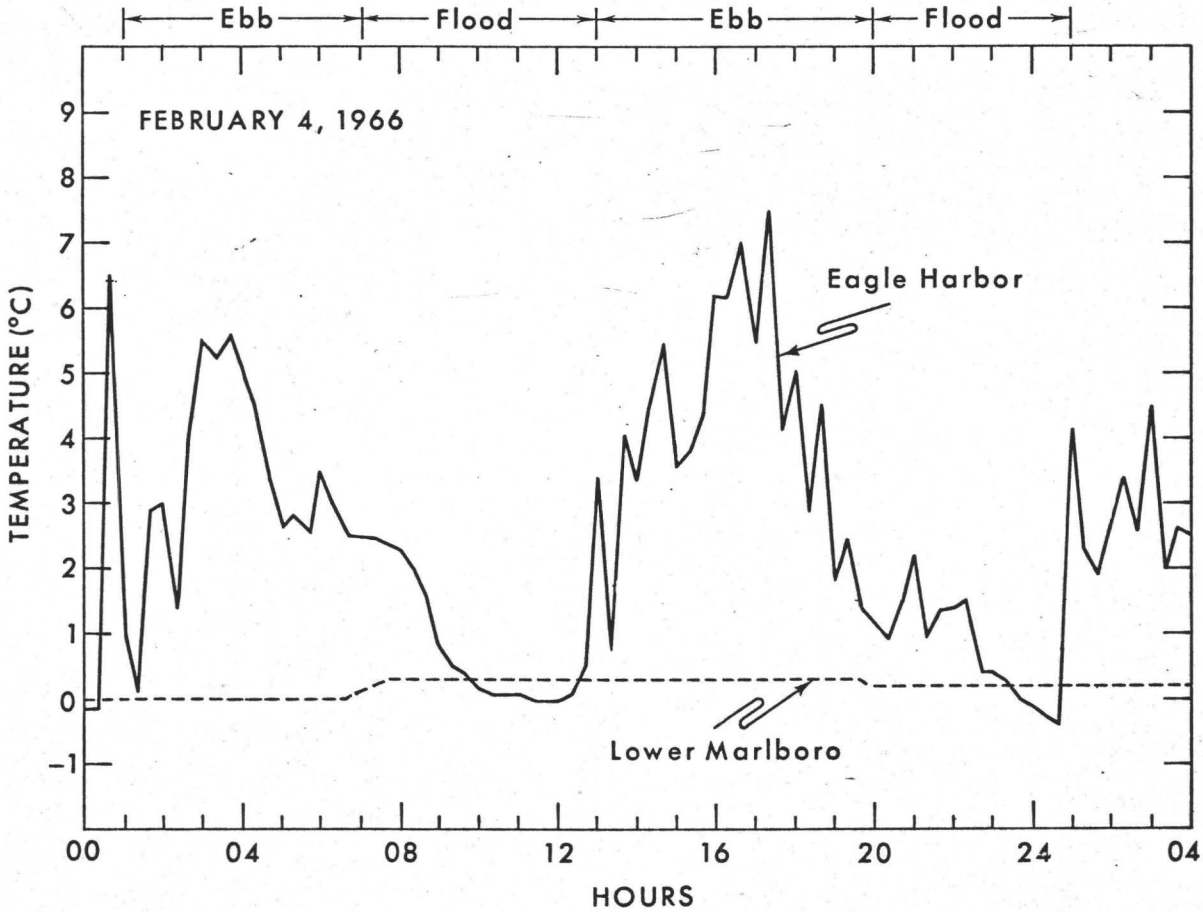

Fig. 4.--Winter surface-water temperatures from Lower Marlboro and Eagle Harbor. Ice was present during the periods of coldest temperatures at Eagle Harbor and all the time at Lower Marlboro.

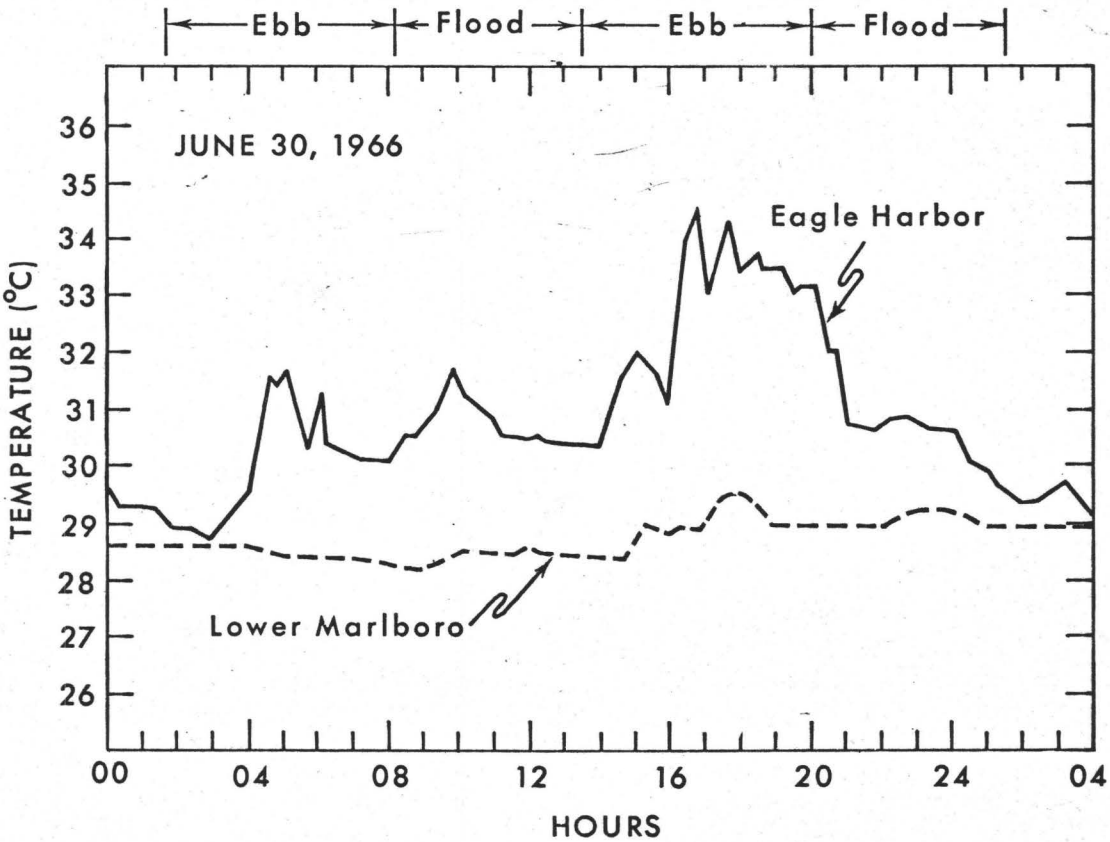

Fig. 5.--Summer surface-water temperatures from Lower Marlboro and Eagle Harbor.

temperature variation evident in the June record (fig. 5) reflects the typical summer condition when electrical demands and resultant heating of the water are highest in the late afternoon and the evening and lowest during pre-dawn hours.

A synoptic view of thermal patterns in the estuary was obtained by infrared (IR) imagery on April 10, 1967, and was furnished by the National Aeronautics and Space Administration in cooperation with the U.S. Geological Survey. The flight was made from an altitude of 3,000 feet at about 0500 hours from a plane flying downriver. Fortunately, tide stage was just before high slack water so that extreme flood tide conditions are shown. The heated water extended about three miles above the plant.

Salinity

Salinity, as temperature, is one of the most important limiting factors of biological distribution in an estuary. The brackish waters in the vicinity of the water-quality station at the Patuxent River Bridge can be classified as mesohaline (Hedgepeth, 1951). Salinities range from about 3 to 16 ppt.

Salinity of the surface waters observed at the bridge station (fig. 7, table 1) for the period January 1966 through December 1967 ranged from 15.7 ppt in January 1966 to 4 ppt in September 1967. Although a distinct seasonality with winter highs and spring lows can be observed, the record of salinity is irregular when compared to that of temperature.

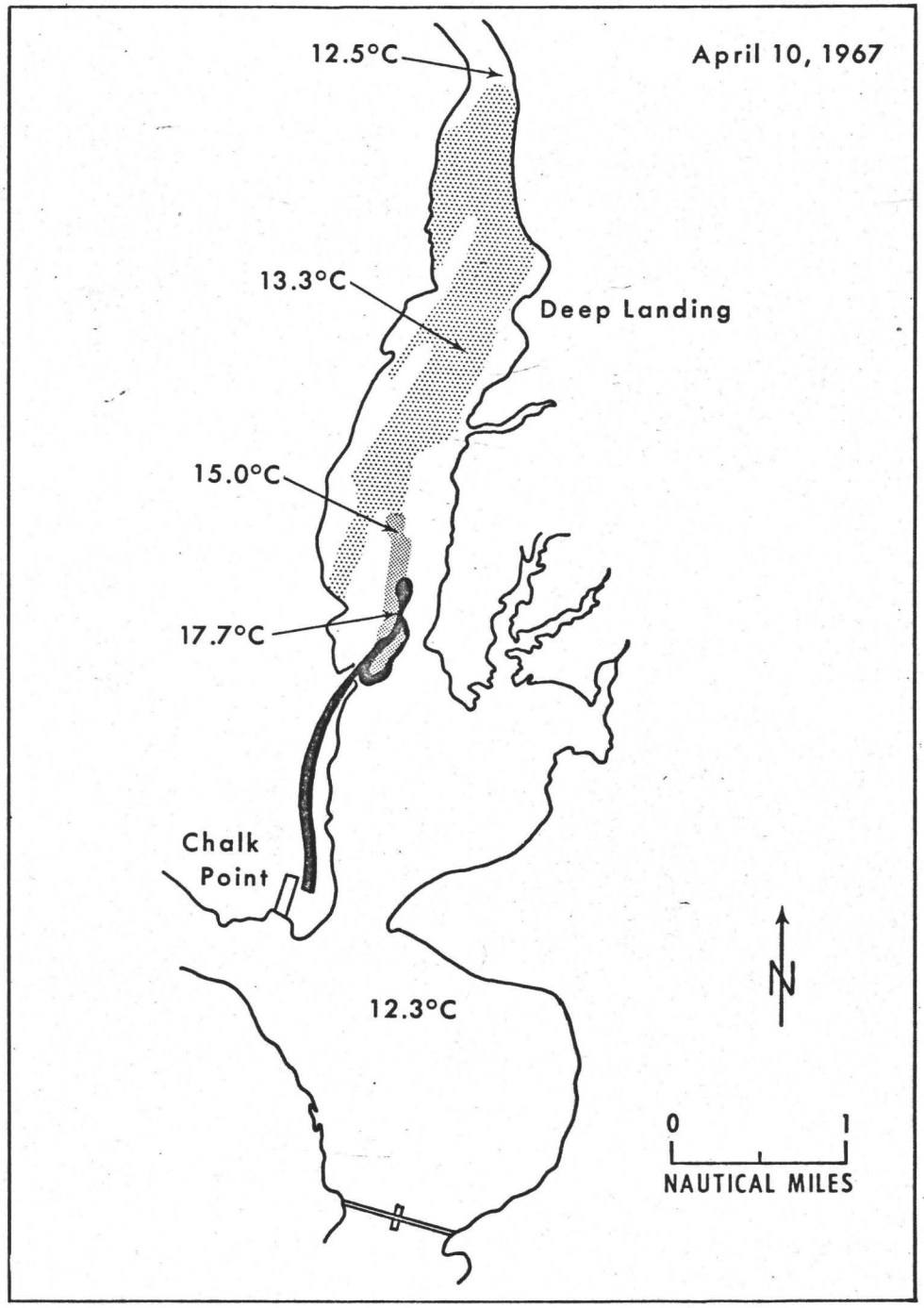

Fig. 6.--Diagram of powerplant effluent plume taken from N.A.S.A.-U.S.G.S. infrared photo. Temperatures indicated are from nearby surface temperature recorders and are estimates of true values.

To compare the years of 1966 and 1967 with each other and with the three years of record (Cory and Nauman, 1967), the annual salinity data were averaged for four periods of thirteen weeks each and compared with the average fresh water discharge measured at Guilford, Maryland (fig. 8). Discharge data from the Guilford station on the Little Patuxent were chosen because that station represented about 30 percent of the total drainage area and 33 percent of the river's total discharge (U.S. Geological Survey, 1963-1966).

During the five years of record (fig. 8), 1966 had the highest average annual salinity (12.3 ppt); and 1967, the lowest (9.9 ppt). Salinity and streamflow are inversely related with changes in salinity lagging behind streamflow by about one time interval (three to four weeks). The greatest change in a single year was observed in 1964 when quarterly averages ranged from 6.9 ppt to 14 ppt salinity in the second and fourth quarters. Extremes in runoff were also observed that year when the flow at the Guilford station ranged from about 72 cubic feet per second (cfs) to 10 cfs in the first and third quarters, respectfully.

To show the effects of salinity changes on the biota, a simple species diversity index (Menhinick, 1964) was applied to epifaunal data collected at the bridge sampling site. The highest value obtained at the bridge site, 0.38, was observed in 1966, the highest salinity year; the lowest value, 0.27, was obtained in 1967, the

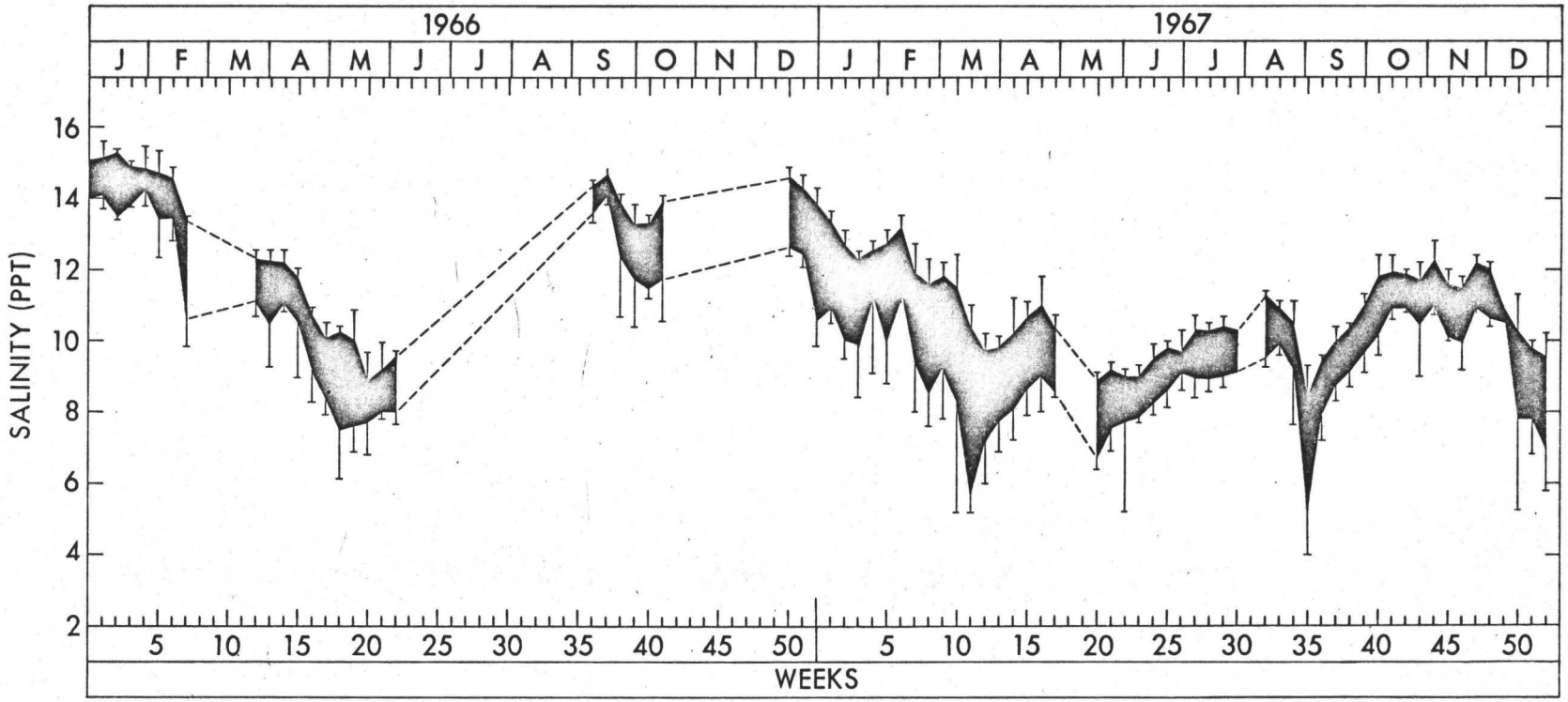

Fig. 7.--Weekly average maximum and minimum surface salinities, Patuxent River Bridge. Vertical bars show weekly extremes.

the lowest salinity year. The same index applied to other stations showed a range from 0.20 at Lower Marlboro to 0.60 at Solomons, Maryland; that is, an increase in diversity that correlates with an increase in salinity in a downstream direction. A published report on the Patuxent's epifauna (Cory, 1967) also observed that species' diversity increased in a downstream direction.

Dissolved Oxygen

In the estuarine environment, temperature and salinity greatly affect the ability of water to hold oxygen, the solubility of oxygen being increased by low temperatures and decreased by high salinities (Odum, 1959). Oxygen in water is obtained from two principal sources: 1) by diffusion from the air, and 2) by photosynthesis of aquatic plants. Dissolved oxygen is lost from the aquatic environment by respiration of both animals and plants, a process which also increases the carbon-dioxide content of the water. In a large body of water, such as the Patuxent estuary, diffusion either into or out of the water is usually slow compared to the biological effects on the amount of oxygen in the system. At night respiration of plants and animals increases the carbon-dioxide and decreases the oxygen content of the water, but during the day, production of oxygen by plants converts the carbon dioxide back into oxygen (Sargent and Hindman, 1943). These processes are also affected by the amount of sunlight available for photosynthesis, the

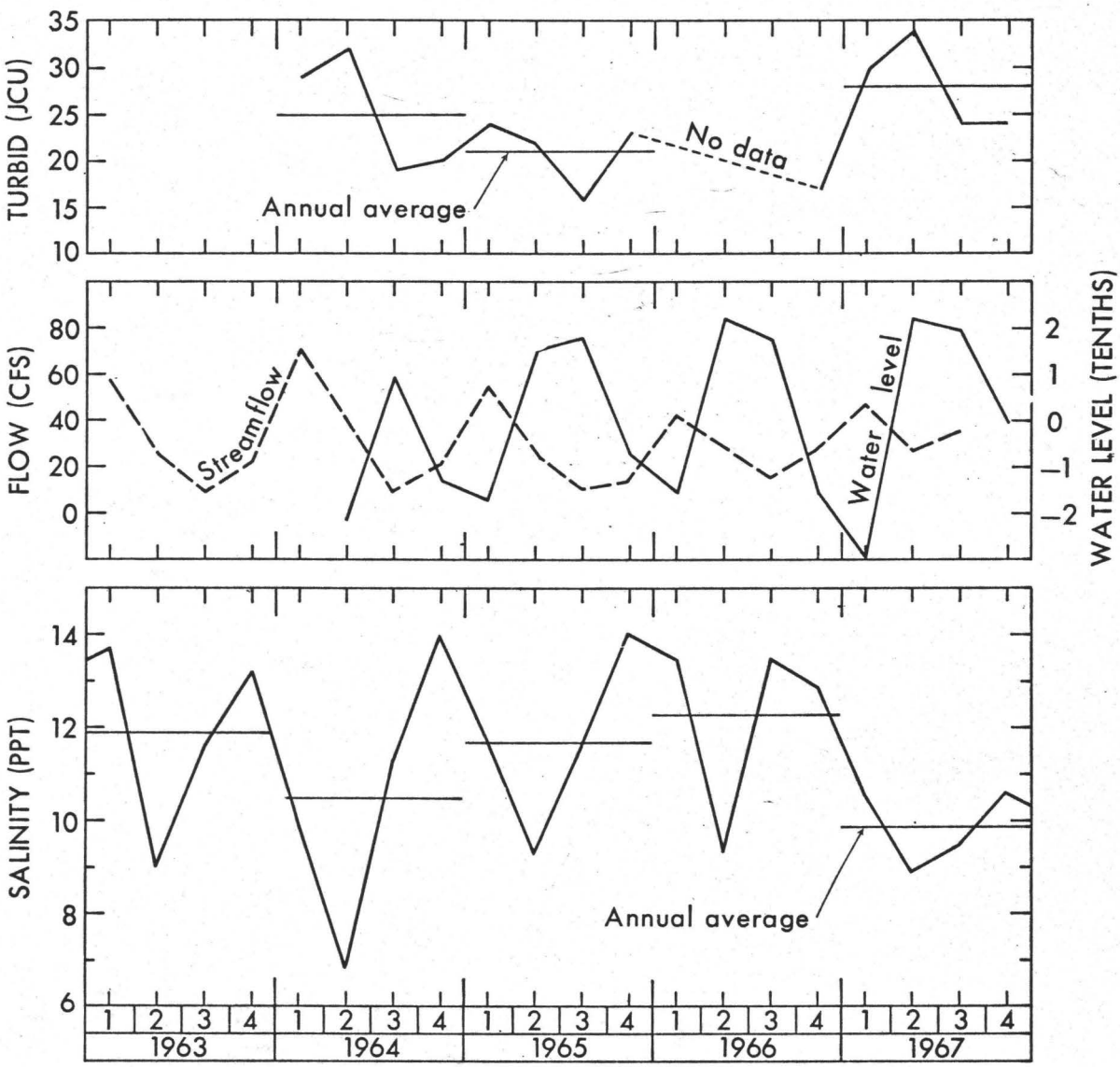

Fig. 8.--Quarterly average turbidity, streamflow, water level (in tenths of feet), and salinity at Patuxent River Bridge. Each time quarter is 13 weeks.

amount of oxydizable material in the water, and the effects of wind and tide action on the rates of oxygen diffusion into the water. Continuous records of dissolved oxygen in the water together with a record of percentage saturation help one understand the influence of some of these processes on the oxygen contained in the waters of the Patuxent estuary.

The influence of temperature and salinity on dissolved-oxygen content is best shown by the annual fluctuation of dissolved oxygen (fig. 9A, table 1). Values of dissolved oxygen ranged from a winter high of 15.6 mg/l to a summer low of 3.2 mg/l. The annual cycle of winter highs and summer lows correlates inversely with the temperature cycle. The influence of salinity, although less than that of temperature, can be observed by comparing 1967, a low salinity year, with 1966, a high salinity year. Values of dissolved oxygen were higher in 1967 than in 1966, particularly during the summer when salinity differences between the two years were greatest (fig. 9A).

Biological effects on the dissolved oxygen are best illustrated by the changing patterns in the percentage saturation curve (fig. 9A). Much of the record is missing for 1966; however, a comparison of previous records with the 1967 data indicates a rather consistent annual pattern. Percentage saturation varied from 152 percent to 55 percent for 1966 and 1967 as compared to 144 percent and 53 percent for the previous two years. The least production and consumption of

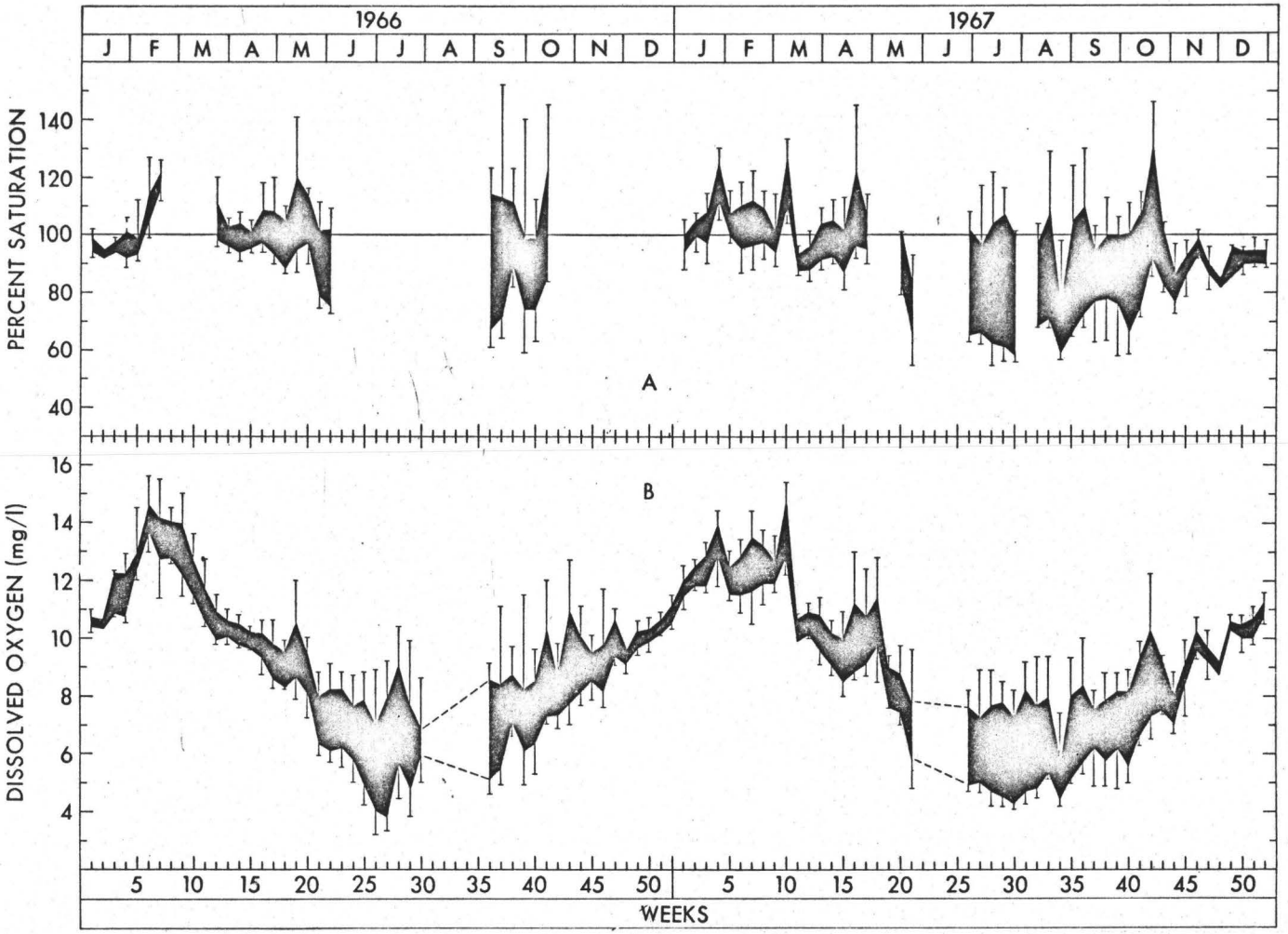

Fig. 9A.--Weekly average maximum and minimum percentage saturation of dissolved oxygen of surface waters at Patuxent River Bridge.

Fig. 9B.--Weekly average maximum and minimum dissolved oxygen. Vertical bars indicate weekly extremes.

oxygen occurred during the cold season months of November, December, and part of January when temperatures were rapidly declining and the length of days was diminished. These months also coincide with periods of reduced biological activity (Cory, 1967). Evidence of increased photosynthetic activity by phytoplankton can be seen in the rapid rise of percentage saturation in late January, March, April, and May. During the summer, when biological activity is greatest, consumption and production of oxygen produce wide variations in both the amount of dissolved oxygen and percentage of saturation (fig. 9A and B). Further evidences of biological effects on the dissolved oxygen can be seen when time series plots of the daily records are made (data to be shown in a more detailed report not yet completed). During the spring, on clear days, the photosynthetic activity produces conditions whereby the water is supersaturated both night and day. For example, dissolved oxygen plotted from a day in April ranged from 11.7 to 14.5 mg/l with percent saturation varying from 106 to 144 percent. The highest values were attained in mid-afternoon and the lowest just before dawn. A similar plot from July showed a range of 4.8 to 9.6 mg/l with percent saturation ranging from 66 to 133 percent. Except for a period of two hours during mid-afternoon, saturation remained below 100 percent the entire time.

The records of dissolved oxygen presented in this report indicate the environment is still in a healthy state. Nash (1947) reported a range in percentage saturation of Patuxent estuary surface waters of 42 to 143 percent which compares favorably with the 55 to 152 percent reported here.

Turbidity

Surface turbidity, caused by the presence of particulate matter, such as silt, clay, or finely divided organic material in the water, is measured in Jackson Candle Units (JCU) at the bridge station with a recording turbidimeter. The turbidity of the Patuxent's surface waters varies widely throughout the year and is influenced by tide, wind, fresh-water discharge, and biological activity. Turbidity is important as a limiting biological factor. Penetration of light is limited by the amount of suspended materials thus restricting the photosynthetic zone. Increases in turbidity theoretically should result in decreases in primary production of the aquatic plants.

The probable sources of turbidity materials in the Patuxent estuary are local and upstream products of erosion, river bed materials that are disturbed by tide and wind action, and plankton. The effects of erosion can be seen in the seasonal cycle of turbidity; highest average values occur during periods of high river discharge, during low-water stages, during low salinities,

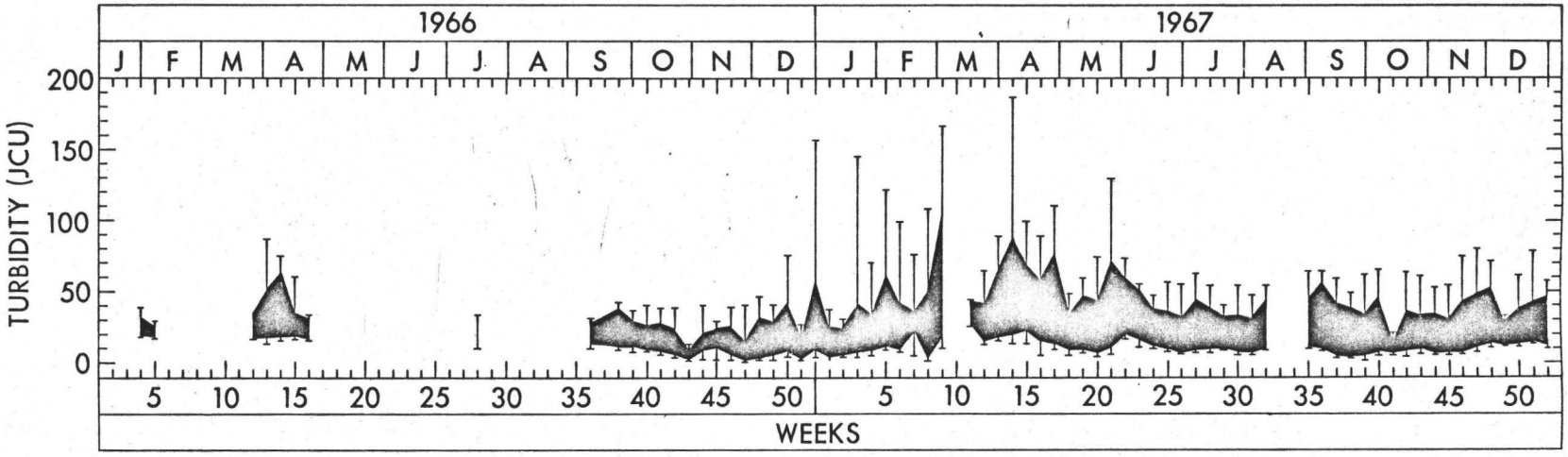

Fig. 10.--Weekly average maximum and minimum surface-water turbidity at Patuxent River Bridge.

and during the period March through June. Lowest values occur during autumn or at anytime when salinities are high, river discharge is low, and water stages are high (fig. 10).

Highest daily values of turbidity are nearly always associated with strong north or northwest winds. These winds blow parallel to the axis of the estuary and pass over a long fetch of water. Waves are generated which stir-up bottom material from the shallows. Moreover, turbid upstream waters are pushed down-channel resulting in lower water stages throughout the estuary.

Although not shown here, differences in turbidity associated with normal tide action are pronounced, exhibiting an inverse relationship to the tide stage and salinity. Except during periods when very high turbidities were recorded, the weekly average maximum and minimum turbidities reflect these tide-induced changes as illustrated by the fact that highest values of turbidity occur at low tide and lowest turbidities at high tide. The inverse relationship between salinity and turbidity was observed by Nash (1947) and Stross and Stottlemeyer (1965) who reported increases in turbidity and decreases in salinity in an upstream direction.

Turbidities averaged by quarterly increments for the years 1964, 1965, part of 1966, and 1967 (fig. 8) reflect the low-flow high salinity conditions that persisted during the years prior to 1967. Highest annual average turbidity, 28 JCU, was recorded in 1967 and the lowest annual average, 21 JCU, in 1965.

Tides and water stage

The extreme range of tides at the bridge station for the years 1966 and 1967 was 6.7 feet, or about 2 feet above mean high water and 2.5 feet below mean low water (fig. 11, table 1). The maximum weekly amplitude was about 5 feet, and the average about 2.9 feet (fig. 11). The mean range, which is the difference in height between mean high water and mean low water, was 1.9 feet.

Water stages in the Patuxent estuary are generally highest from April through September and lowest from December through February and into early March (figs. 8 and 11).

Nash (1947) observed that the increases in river level from February to April are due to higher streamflow and from April to September to the predominant southerly winds that retard the egress of water from the estuary. The decrease in water level in autumn and winter is due largely to north and northwest winds which increase the rate of egress from the estuary. He further observed that seasonal variations in wind direction and streamflow are in opposition, with streamflow increasing during periods of northerly winds and decreasing when winds are southerly. The net result is that water levels in the estuary are influenced more by the prevailing wind directions than they are by the streamflow.

Quarterly averages of water stages (fig. 8) show that water levels are, indeed, in opposition to the river's flow. Stages are

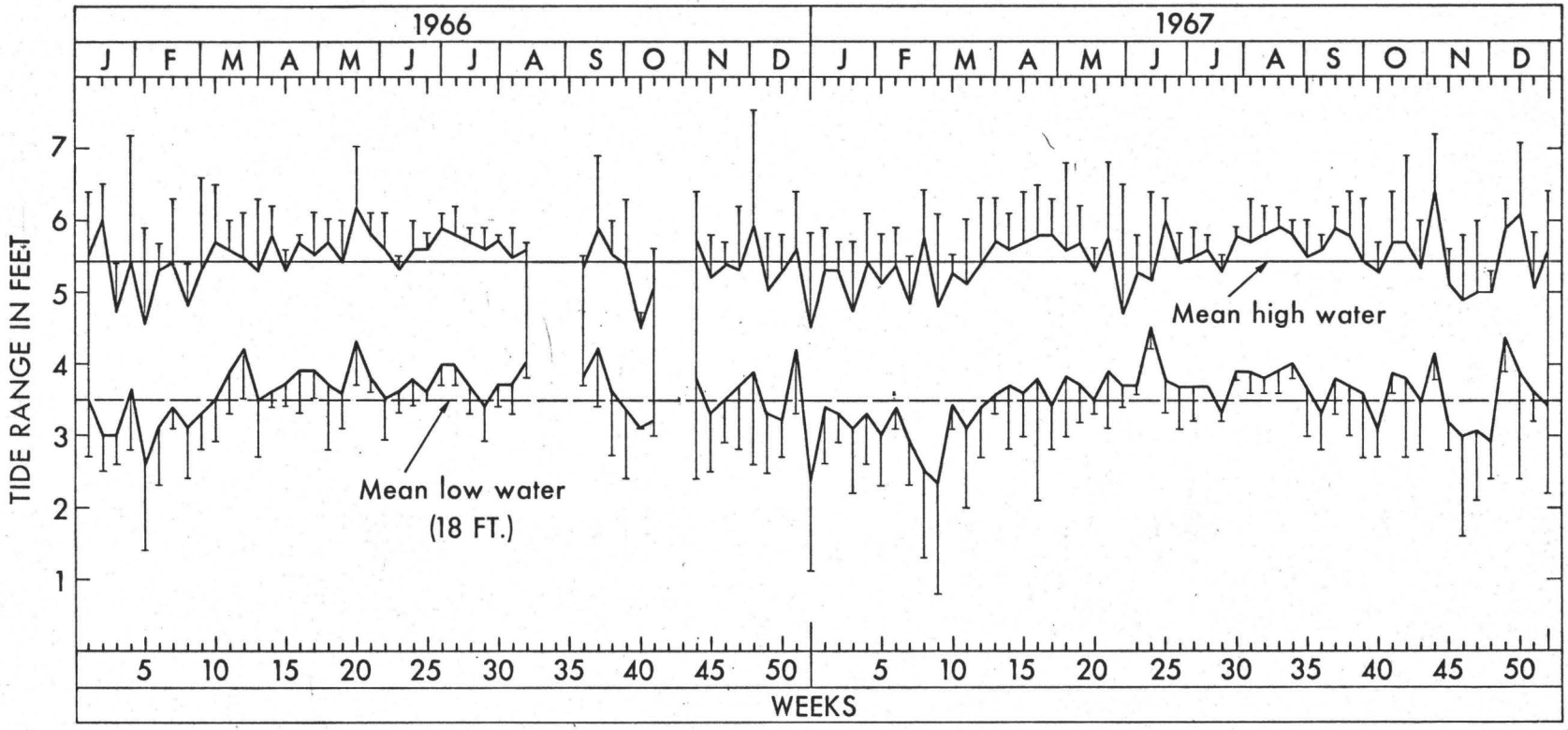

Fig. 11.--Weekly average maximum and minimum tide heights at Patuxent River Bridge station. Datum was not determined for this station; however, mean low water depth was 18 feet.

usually highest during the middle two quarters and lowest during the first and last quarters. Although this appears to be the general rule, the four-year record shows there is considerable variation between years.

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Sample sheet for table I.

PATUXENT RIVER ESTUARY, MARYLAND 38 30 45 N 76 40 14 W

		DATE	TEMPERATURE DEG C SURFACE		TEMPERATURE DEG C BOTTOM		DISSOLVED OXYGEN PPM				TURBIDITY JCU		SALINITY PPT		TIDE HEIGHT FT	
	WEEK	MO DA YR	MAX	MIN	MAX	MIN	MAX	% SAT	MIN	% SAT	MAX	MIN	MAX	MIN	MAX	MIN
	51	12 17 65	8.4	7.4	8.4	7.7	10.3	99	9.7	91	25	15	16.00	15.00	6.2	4.2
	51	12 18 65	7.9	7.1	8.0	7.3	10.3	97	9.9	92	27	16	15.90	14.70	5.5	3.5
	51	12 19 65	7.6	6.6	7.5	6.6	10.6	98	9.9	92	24	15	15.90	14.70	5.5	3.8
	51	12 20 65	6.0	5.5	7.1	6.0	10.6	96	10.2	93	26	15	16.10	14.80	5.6	3.3
	51	12 21 65	5.8	5.0	6.2	5.7	10.5	93	10.1	91	25	15	16.10	15.00	5.8	3.5
	51	12 22 65	5.6	4.5	5.9	5.2	10.5	93	10.0	87	29	16	16.00	14.60	6.0	3.3
	51	12 23 65	5.7	4.5	5.6	5.5	10.7	96	10.3	91	29	16	15.90	14.60	4.6	2.8
EXTREME			8.4	4.5	8.4	5.2	10.7	99	9.7	87	29	15	16.10	14.60	6.2	2.8
AVERAGE			6.7	5.8	6.9	6.2	10.5	96	10.0	91	26	15	15.98	14.77	5.6	3.4
	52	12 24 65	5.5	5.0	5.4	5.2	10.7	98	10.3	92	26	16	15.60	14.40	4.9	2.9
	52	12 25 65	7.0	5.4	6.7	5.4	10.5	97	10.3	93	49	1	15.70	14.70	5.8	4.0
	52	12 26 65	6.8	5.3	6.9	6.2	10.6	96	10.4	95	152	11	14.90	13.00	4.4	4.2
	52	12 27 65	5.1	3.6	6.1	4.9	11.0	95	10.3	88	267	35	15.50	13.50	6.3	2.4
	52	12 28 65	4.7	3.5	5.5	4.4	10.9	93	10.5	91	149	17	15.50	14.50	5.6	3.5
	52	12 29 65	4.6	3.5	5.3	4.6	10.9	95	10.6	92	29	17	15.50	14.60	4.8	3.5
	52	12 30 65	4.7	3.9	5.4	4.6	11.0	97	10.5	91	24	15	15.50	13.40	5.0	3.4
	52	12 31 65	5.6	4.5	5.3	4.7	10.9	97	10.5	93	25	16	15.30	14.40	5.0	3.6
EXTREME			7.0	3.5	6.9	4.4	11.0	98	10.3	88	267	1	15.70	13.00	6.3	2.4
AVERAGE			5.5	4.3	5.8	5.0	10.8	96	10.4	91	90	16	15.43	14.06	5.2	3.4
	1	1 01 66	7.3	5.5	6.8	5.4	11.0	102	10.6	98	24	15	15.10	14.50	5.4	3.7
	1	1 02 66	7.8	6.7	7.3	6.3	10.9	101	10.4	95	24	15	15.10	13.70	5.4	3.2
	1	1 03 66	7.3	6.7	7.4	6.6	10.5	98	10.2	95	23	15	15.60	14.10	5.9	4.2
	1	1 04 66	7.1	6.2	7.1	6.5	10.8	100	10.3	95	28	16	15.00	14.00	5.4	3.2
	1	1 05 66	6.7	5.7	6.8	6.3	10.8	99	10.3	93	29	16	15.10	13.80	4.8	2.7
	1	1 06 66	6.9	6.3	6.7	6.4	10.5	97	10.3	95	22	16	15.00	13.60	5.6	3.6
	1	1 07 66	6.7	6.3	6.7	6.5	10.6	97	10.2	93	24	16	15.20	14.00	6.4	4.0
EXTREME			7.8	5.5	7.4	5.4	11.0	102	10.2	93	29	15	15.60	13.60	6.4	2.7
AVERAGE			7.1	6.2	6.9	6.2	10.7	99	10.3	94	24	15	15.15	13.95	5.5	3.5