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ENVIRONMENTAL SECTION

Assessment of Thermal, Entrainment and Impingement Impacts on the Chesapeake Bay in the Vicinity of the Calvert Cliffs Nuclear Power Plant.

Prepared for

Baltimore Gas and Electric Company

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EXECUTIVE SUMMARY

Thermal plume mapping using dye tracer-temperature survey techniques under full load conditions were carried out at the Calvert Cliffs Nuclear Power Plant (CCNPP) during April and August 1979. Hydrographic conditions during these surveys were compared to ambient conditions in past years and were found to be within normal limits. The results of the eight plume mappings in April and nine in August indicated that the 6.7°C (12°F) full load plume violates no mixing zone criterion as set forth in COMAR 08.05.04.13, §E.

Field studies of the soft-shell clam, the RIS mollusc selected for study, and review of existing data on this species indicate that even though there are small, viable concentrations of healthy clams in the vicinity of CCNPP, the Calvert Cliffs area has not supported a commercial clam fishery for at least ten years. There is no evidence that the operation of CCNPP significantly affects a nursery area of consequence for soft-shell clams.

Adult blue crabs support a sizeable fishery in the vicinity of CCNPP; for this reason the blue crab was chosen as the arthropod RIS species to be studied. The results of studies using commercial crab pots, studies of the plankton in the vicinity of CCNPP and literature reviews of blue crab life history in the Chesapeake Bay region all suggest that a few or no larvae are entrained by the CCNPP during average years. While small numbers of larvae may be entrained in extremely dry years when salinities near the plant increase, it is clear that the Calvert Cliffs area is not a significant nursery area for the blue crab.

The three RIS of finfishes, bay anchovy, naked goby and spot, are all present in either egg, larval or juvenile stages in the area surrounding the CCNPP. Although significant numbers of anchovy eggs and larvae and naked goby larvae are entrained, these species reproduce and maintain extremely large populations throughout the entire Chesapeake Bay drainage system. Hence, even if 100% entrainment mortality is assumed, the effects of entrainment on the viability of the Chesapeake Bay populations of bay anchovy and naked goby are insignificant. The small number of juvenile spot entrained and the enormous size of the spot population in the Chesapeake Bay indicate that the effects of operation of the CCNPP on this species also are insignificant. Therefore, there is no evidence that the operation of the CCNPP affects a nursery area of consequence for bay anchovy, naked goby or spot.

Phytoplankton entrainment studies done during 1979-1980, when maximum ΔT approached 6.7°C, showed no substantial changes from earlier studies done at maximum ΔT's of 5.5°C. Plant effects on photosynthesis and respiration are observable most

often when water temperatures (ambient plus ΔT) exceed 30°C. Overall, there was no evidence that phytoplankton community structure or productivity was altered substantially by plant operation.

Zooplankton entrainment studies showed that plant passage produced zooplankton mortalities ranging from 12-100%, with a median mortality of 55%. The increased ΔT existing in 1979-1980 showed no independent effect on survival; however, when ambient temperatures plus plant-induced temperature elevations combined to produce water of 30°C or more, the same level which affected phytoplankton, zooplankton mortality increased.

Survival studies were carried out to estimate mortality to fish species and blue crabs as a result of impingement at CCNPP. These estimates were multiplied by the estimated total number of fish and crabs impinged and by the monetary values for each species listed in COMAR 08.02.09.01 to provide dollar values for the three full years of two unit operations at CCNPP (1977-1979). In a typical year the expected loss is $24,289 with a 95% upper confidence limit of $34,425.

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I. INTRODUCTION

The Calvert Cliffs Nuclear Power Plant (CCNPP) operates adjacent to the mesohaline segment of the Chesapeake Bay in Calvert County, Maryland. The plant maintains two generating units, each with a capacity of 815 MWe, and a once-through cooling system that uses 2700 cfs of Bay water. Unit 1 began commercial operation in May 1975 and Unit 2 in April 1977.

To comply with the State of Maryland requirements stipulated in "Water Quality Impact Assessment for Thermal Discharges" and promulgated in the Code of Maryland Regulations (COMAR) .08.05.04.13, the Baltimore Gas and Electric Company (BG&E) provided the Maryland Water Resources Administration (WRA) in November 1978 with a comprehensive study plan to evaluate the environmental impact of its Calvert Cliffs Nulear Power Plant (CCNPP). The study plan included projects designed to: (1) demonstrate that the thermal discharge mixing zone of the CCNPP complies with Maryland Water Quality Standards, according to criteria in COMAR .08.05.04.13, §E; (2) determine whether cooling water entrainment affects a spawning or nursery area of consequence for Representative Important Species (RIS) of finfish, molluscs and arthropods as defined in COMAR 08.05 .04.13, §D; and (3) determine the monetary value of impinged species destroyed by the CCNPP intake structure according to the method of estimation set forth in COMAR 08.05.04.13, §F.

After review by the WRA and revision, the study plan was accepted. Sampling and modeling plans for studying the mixing zone at Calvert Cliffs, the rationale for the selection of the RIS species bay anchovy, naked goby, spot (finfish), soft-shell clams (molluscs) and blue crabs (arthropods) for intensive study in the Calvert Cliffs area, and a sampling scheme to accurately estimate impingement losses were detailed.

Studies to estimate the effects on phytoplankton and zooplankton assemblages from entrainment through the cooling water condensers at the Calvert Cliffs plant were also conducted at the request of the WRA as a prerequisite for approval of a cross-condenser temperature increase (ΔT) at CCNPP during 1979-1980 from 5.5°C to 6.7°C. These studies were designed to assess additional detrimental effects that might result from plant operation at the increased ΔT of 6.7°C.

The following sections present in detail the results of these studies, which were designed to satisfy the relevant sections of COMAR 08.05.04.13 as they relate to CCNPP operations, as well as the additional entrainment studies requested by WRA, and conducted in 1979-1980.

II. THERMAL PLUME DYE STUDIES

AND

ANALYSIS OF PLUME SIZES

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1. INTRODUCTION

This report presents the results of two sets of field surveys of the Calvert Cliffs Nuclear Power Plant (CCNPP) plume under full plant load conditions, an analysis of the field survey data to determine plume dimensions, and a comparison of the results with the State of Maryland Water Quality Standards for estuarine thermal plume sizes at full load condenser temperature rises of 10°F (5.6°C) and 12°F (6.7°C). Results of previous plume surveys and analyses are also reviewed and compared with the present results. The general hydrographic conditions during each of the analyses are compared to time-series data of temperature, salinity, and solilunar tides for 1977 and 1978.

The CCNPP Discharge

The Calvert Cliffs Nuclear Power Plant consists of two generating units rated at 910 MWe (maximum gross generation) each. The energy source for each turbine-generator unit is provided by a pressurized water reactor. Each unit ejects approximately 1755 MWe of waste heat to Chesapeake Bay by means of six circulating water pumps in a total circulating water flow of 1,200,000 gallons per minute (gpm) (75.8 m^3/s) at a temperature rise of approximately 10°F (5.6°C).

From the forebay, the cooling water passes through the traveling screens (12 per unit), the pumps, the condensers, and thence back to the Bay through the discharge conduit. This conduit consists of four separate, horizontally arranged, 12.5-ft x 12.5-ft (3.8-m x 3.8-m) conduits and runs offshore under the natural bottom for approximately 850 ft (259 m), terminating at the (-)12-ft (3.7-m) natural contour. It is located north of, and oriented at approximately 30° from the intake channel. The bottom of the discharge conduit is at (-)19.5 ft (5.9 m) and the top at (-)6 ft (1.8 m); a discharge channel at (-)19.5 ft (5.9 m) extends another 450 ft from the end of the conduit until it intersects the (-) 19.3-ft (5.9-m) natural contour. The velocity of the cooling water at discharge is approximately 9 ft/s (2.7 m/s).

Past Studies

Three field studies of the CCNPP plume have been conducted prior to the present studies. These were (1) the Martin Marietta Laboratory (MML) surveys which are reported in MML (1976a,b) and summarized in ANSP (1979); (2) the Academy of Natural Sciences of Philadelphia (ANSP) studies reported in ANSP (1979); and, (3) the Chesapeake Bay Institute (CBI) studies in Pritchard and Rives (1979). Each of these studies was conducted during different hydrographic and plant load conditions and each had different objectives. Results from these studies aided in the design of the present surveys.

The MML Studies

The MML studies consisted of three surveys, each of one day's duration in September 1975 and March 1976, and two days' duration in November 1975. Four plumes were mapped in the September 1975 survey, seven were mapped in the November 1975 survey, and five were mapped in the March 1976 surveys.

During these surveys only one CCNPP unit was in operation. Generation output ranged from 773 MWe to 853 MWe. Condenser temperature rise ranged from 4.8°C to 5.5°C (8.6 to 9.9°F). Data from the MML one-unit surveys were used in the analyses reported in ANSP (1979).

The ANSP Studies

The ANSP studies consisted of four surveys conducted in August 1977, November 1977, April-May 1978, and August 1978. Four plumes were mapped from temperatures recorded during each survey. The ANSP studies were designed to determine the distribution of ambient temperature and to estimate the configuration and extent of the thermal plume under various hydrographic, plant operating and meteorological conditions. Ambient temperatures were estimated from data collected over a lateral and longitudinal transect at Kenwood Beach.

During the ANSP surveys, the CCNPP generation ranged from 1265 MWe to 1753 MWe when two units were operating (fifteen of the mappings) and was at 614 MWe when only one unit was operational during one mapping. The condenser temperature rise ranged from 4.2°C (7.6°F) to 5.6°C (10.0°F) during the two-unit operations.

An interpretive analysis of the survey data was performed to infer relationships between the sizes of the 2°C and 1°C isotherms and various hydrographic, plant operating, and meteorological conditions. Inferences from the data were tested using contingency analysis for qualitative assessment. The ANSP data and analysis allowed an examination of the relationship between plant capacity and plume area and between plume area and radial extent. The MML data were combined with the ANSP data to extend the analyses over a greater range of plant capacity and plume sizes.

The difficulties of basing CCNPP plume estimates on temperature measurements alone became evident during the data analysis and interpretation. Temperature readings alone provided no direct way of determining recirculation between the discharge and the intake. Recirculation is important in determining the plant discharge excess temperature (θ_o) as opposed to the plant condenser rise (ΔT). The use of distant ambient temperatures made it difficult to map nearfield (approximately 2°C and higher) isotherms, particularly under conditions of natural heating of shallow shoreline areas.

There were some limitations in the ANSP studies which would have made extrapolation of plume dimensions to maximum plant load and higher condenser temperature rise difficult. These limitations were the lack of a high plant load before and during the mappings and the fluctuation of the plant load during and between mappings. A steady plant load is required to build up background low excess temperature in the far field. The plume data from day to day inherently reflected variations in plant load over previous days which could not be factored out of the data. These limitations were accounted for in the present plume studies by maintaining a steady plant load before and during the mappings.

CBI Studies

The CBI studies were conducted in October 1977. They included extensive current meter measurements across the Bay as well as a dye dispersion study of the CCNPP discharge. The studies had three objectives. One was to obtain boundary data and verification data to be used in a three-dimensional model of a segment of the Bay extending from Kenwood Beach to Cedar Point. The second purpose was to describe the horizontal and vertical distribution of dilution and excess temperature in the near and intermediate field of the CCNPP thermal plume. The third was to evaluate the far-field dilution of the plume.

The dye release at the CCNPP discharge was made over an eight-day period. During this period there was an unusually high Susquehanna River freshwater inflow accompanied by decreasing salinities. Wind-driven circulation resulted in long periods of ebbing current near the plant. Plant heat rejection varied from 1600 MWe to 3400 MWe and the dye-release rate was paced to heat rejection.

The CBI study of the CCNPP plume primarily resulted in a description of the distribution of minimum dilution (maximum inverse dilution) for the condition of unusually strong and prolonged ebb currents. The extreme ebb-tide plume of minimum dilution was determined from repeated cross-sectional surveys over the extended period of ebb current and picking the one survey at each cross-section that had the minimum dilution. In addition, the cross-sections chosen at successive distances down the plume were not coincident in time. The plume would obviously be smaller for synoptic conditions.

Present Studies

The present plume studies were designed to be primarily near- and intermediate-field surveys at full and steady plant load. Rhodamine WT fluorescent tracer dye and temperature measurements were used to determine the background temperature toward which the plume was mixing, the build-up of low-level

excess temperature in the far field, recirculation between the discharge and intake, discharge excess temperature, and to map the excess-temperature field. Continuous-recording current meter measurements were made to determine tidal excursion distances and vertical temperature profiles were measured at fixed stations to determine stratification.

Eight plume mappings were made in April 1979 and nine plume mappings were made in August 1979. The dye release rate was proportioned to plant heat rejection, which varied very little during both surveys. Permission was obtained to increase the 10°F condenser temperature rise to 12°F as part of the studies. Plumes with a condenser ΔT greater than 11.5°F were mapped on four occasions during the August surveys.

The April study started a few days after a spring tide and ended on a neap tide. The August study was centered on a spring tide. Tidal currents were normal during both surveys with no dominant ebb- or flood-current period.

2. THERMAL PLUME FIELD STUDIES

Introduction

At Calvert Cliffs each unit draws in cooling water by means of six circulating water pumps. The cooling water from each pair of these six pumps (3 pairs in all per unit) makes a single pass through one of three separate condensers. The cooling water is then discharged to the Bay through one of the four conduits making up the discharge structure. That is, each conduit in the discharge structure serves three pumps and one and one-half condensers or accommodates approximately 25% of the total flow. In order to tag the flow in all four conduits, therefore, it was necessary to inject dye into the flow at the downstream side of four different circulating water pumps.

It can be shown from equation (II-2-7), however, that if the dye concentration, C, and the excess temperature, θ, are to be linearly related in isothermal receiving waters, then

$$\frac{\theta}{C} = \frac{Q_h}{q_d} \qquad \text{(II-2-1)}$$

where Q_h is the heat rejection rate, and

q_d is the dye injection rate.

That is, both the dye rates, q_d, and the heat rejection rate, Q_h, must be monitored continuously during the experiment and the dye injection rate adjusted to maintain a constant ratio of dye injection to heat rejection. For the April experiment a ratio of approximately 150 lb/day of dye injection to the full-load heat rejection rate (~3510 MWe) was maintained; in

August the ratio was increased to approximately 170 lb/day of dye injection to the full-level heat rejection rate to compensate for higher background fluorescence. Figures II-2-1 and II-2-2 are plots of the heat rejection rate (Δ) and the dye solution pumping rate (-) versus time. It can be seen that equation (II-2-1) was satisfied.

In addition to monitoring the dye pumping rate by frequent weighings of the four dye day-tank contents by means of beam-type scales accurate to ± 0.1 lb, dye concentration and temperatures were monitored continuously at two different circulating water pumps (one for each unit) for intake values and sequentially at approximately hourly intervals in the four discharge conduits.

The dye and temperature measurements were carried out from two Academy boats, the R/V JOSEPH LEIDY and the R/V PODON. During the April study the LEIDY sampled dye and temperature continuously at 3 depths (1, 3, and 6 m), while the PODON sampled continuously at the surface and made occasional vertical casts. During August, the LEIDY sampled continuously at 2.5 m, 4 m, and 6 m while the PODON sampled continuously at the surface (0.6 m); both made occasional vertical casts. Each run was begun upstream from the discharge at a section where excess temperatures were estimated to be less than 1°C. Both vessels then worked downstream traversing the plume in the onshore direction as far as the bathymetry and draft of the sampling vessels would permit and in the offshore direction until dye concentrations were at or near background. The runs were continued downstream until dye concentrations indicated that the maximum excess temperature in the crossing was ≤1°C.

Background fluorescence was measured in the study area for two days, 11 and 12 April, prior to dye injection and on three days, 31 July, 1, and 2 August prior to the August dye injection. An analysis of variance in background fluorescence is contained in a later section.

Three current meters were set in 42-43 ft of water approximately 1100 yd due east of the center of the curtain wall during the April study and 1310 yd east of the curtain wall during the August study. The upper meter, an Endeco Model 174, was located on the mooring 30 ft above the bottom and monitored temperature and conductivity as well as speed and direction. An Endeco Model 105 was located on the mooring at 20 ft above the bottom and a Braincon Model 1381 was placed 5 ft above the bottom. Additional information regarding the current measurements are provided in Table II-2-1 below.

Location of both vessels was determined continuously by means of Motorola Mini-Ranger III Systems. One reference station was located on the Cove Point Lighthouse and the other on Taylor's Island.

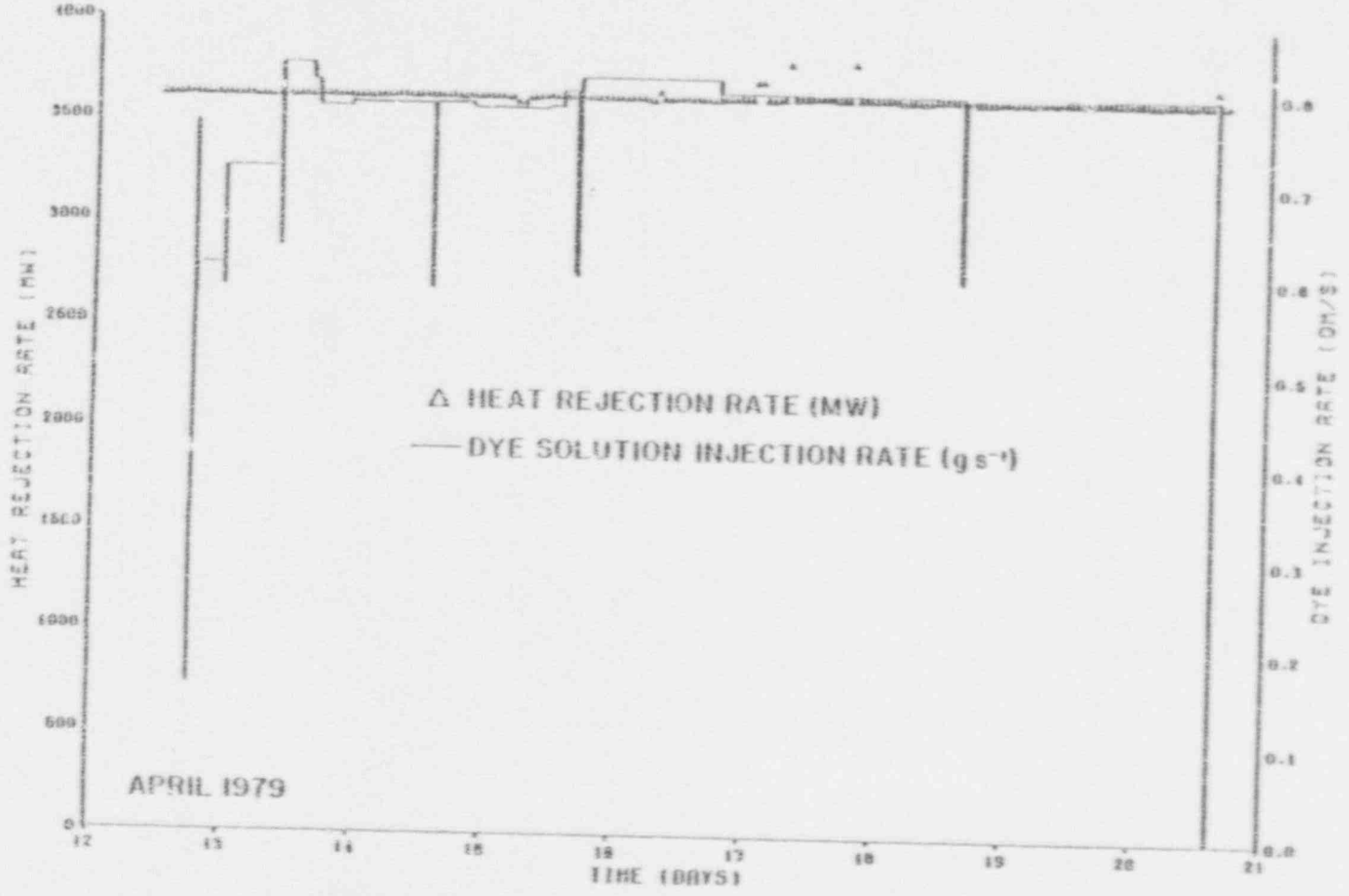


Figure II-2-1. The heat rejection rate (Δ) and dye solution injection rate (-) during the April field study.

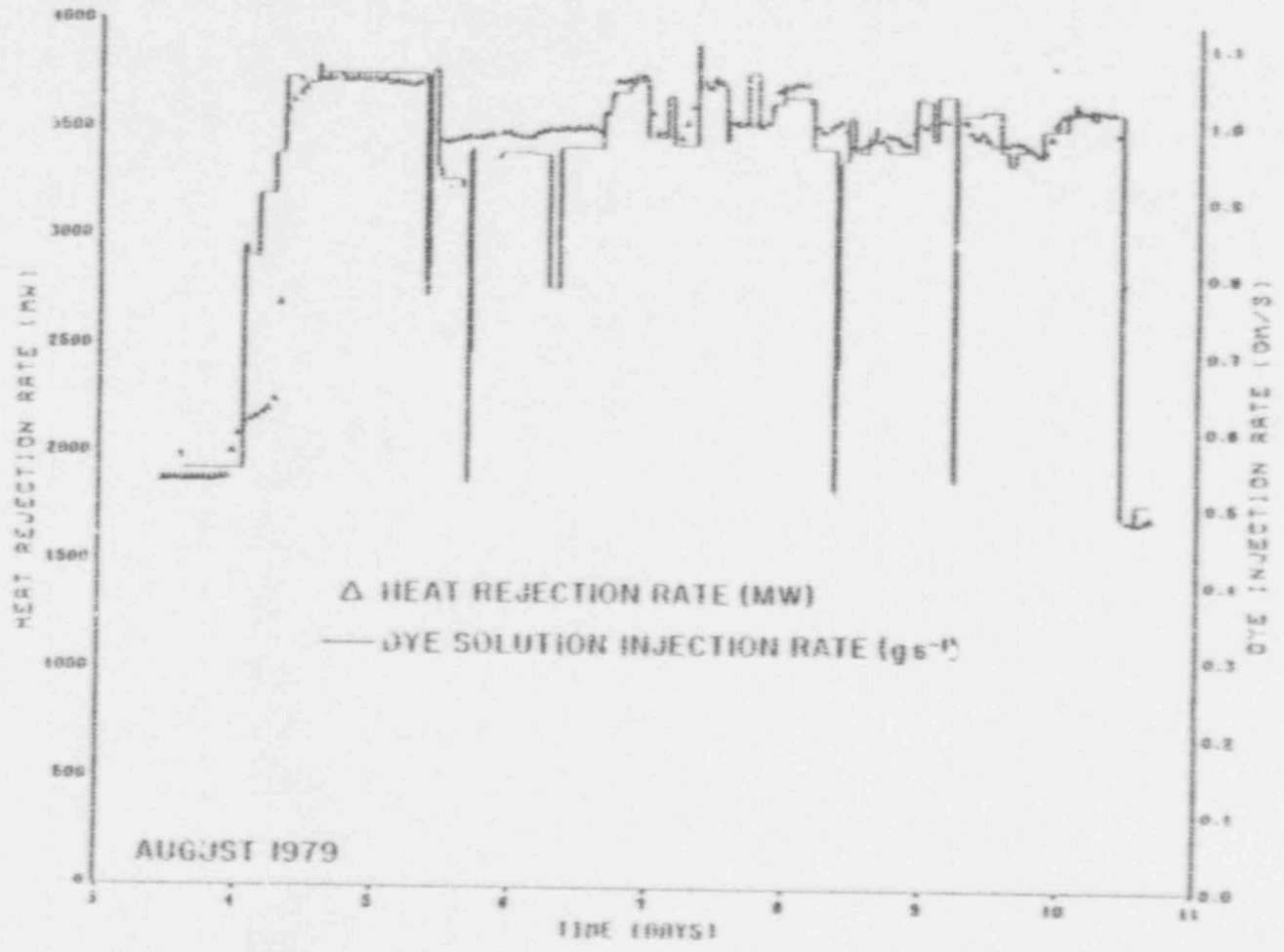


Figure II-2-2. The heat rejection rate (Δ) and dye solution injection rate (-) during the August field study.

Table II-2-1. Summary of current meter deployments

Meter #	Depth (Ft)*	Time Deployed	Time Retrieved	Comments
E174	30	1137,10 April 1979	1013,23 April 1979	
E105	20	1136,10 April 1979	1013,23 April 1979	
B1381	5	1134,10 April 1979	1014,23 April 1979	
E174	30	1347,26 July 1979	1411,10 August 1979	no record; meter flooded
E105	20	1344,26 July 1979	1413,10 August 1979	
B1381	5	1342,26 July 1979	1414,10 August 1979	short record; film jammed

*Relative to the bottom; water depth was 42-43 ft.
#E174 - Endeco Model 174 current meter.
E105 - Endeco Model 105 current meter.
B1381 - Braincon Model 1381 current meter.

The April 1979 Study

A 20% solution of Rhodamine WT dye was dispensed into the circulating water on the discharge side of four different circulating water pumps at a total average rate of 0.788 g/s (150.1 lb/day) of solution. The solution was metered into the flow by means of FMI Lab Pumps; as noted previously the pumping rate was monitored by frequent weighings of dye day-tank contents. Pumping began at 1759, April 12 and was terminated at 1431, April 20, 1979. During this period, personnel monitored the heat rejection rate, Q_h, and the dye solution pumping rate, q_d, continuously at the plant and adjusted the dye pumping rate to maintain a constant ratio of approximately 150 lb/day of dye solution to the full-load heat rejection rate (~3510 MWe) (Fig. II-2-1). Little adjustment of the dye solution injection rate was required, however, as the electrical output was maintained at or near full load during the study except for short periods of time.

The following list is a chronological summary of the sampling program:

Date	Event
5 April 1979	Maxivan departed Stony Brook, NY for Baltimore, MD with current meters; fluorometers, Motorola Mini-rangers, etc. for study.
6,7 April 1979	Calibrated current meters and thermistors at CBI, Baltimore, MD.

9 April 1979	Field parties (including R/Vs) arrived at Calvert Cliffs/Solomons Is. from CBI, MSRC, and Benedict, MD; day spent rigging boats and setting up at plant.
10 April 1979	Set current meters with R/V MAURY. Continued setting up at plant and rigging PODON and LEIDY.
11 April 1979	Continued setting up at plant. PODON and LEIDY carried out first day of background run between Kenwood Beach and Cove Point.
12 April 1979	Completed setting up at plant; started dye injection at 1759. PODON and LEIDY carried out second day of background runs.
13,14 April 1979	Dye injection and measurament program at plant carried out. No underway sampling due to rough seas and high winds. Calibrated fluorometers on 13 April.
15-20 April 1979	Dye injection and measurement programs at plant continued. Dye injection secured after underway sampling on 20 April, 1979. PODON and LEIDY underway on sampling program each day. Calibrated flurometers at plant on 19 April.
21 April 1979	Calibrated fluorometers on PODON and LEIDY. Packed equipment and departed for Baltimore/ Stony Brook/Benedict.
23 April 1979	Removed current meters.

The July/August 1979 Study

A 20% solution of Rhodamine WT dye was dispensed into the circulating water on the discharge side of four different circulating water pumps at a total average rate of 0.885 g/s (168.6 lb/day) of solution. As before, the solution was metered into the flow by means of FMI Lab Pumps and the total pumping rate adjusted to maintain a constant ratio to the heat rejection rate. Pumping was commenced at 1119, August 3, 1979 and was terminated at 1533, August 10, 1979. Plots of the heat rejection rate (Δ), Q_h, and the dye solution in pumping rate (-), q_d, versus time are shown on Figure II-2-2.

Matching dye injection to heat rejection was considerably more difficult during the August study as condenser problems frequently necessitated reducing the amount of cooling water

and hence reducing the electrical load being generated so that a ΔT of 12°F was not exceeded.

The following list is a chronological summary of the sampling program:

Date	Event
25 July 1979	Maxivan departed Stony Brook, NY for Baltimore, MD with current meters, fluorometers Motorola Mini-Ranger etc. for study.
26 July 1979	Set current meters with R/V AQUARIUS from Chesapeake Biological Laboratory (University of Maryland).
30 July 1979	Field parties (including R/Vs) arrived at Calvert Cliffs from CBI, MSRC, and Benedict, MD; day spent rigging boats and setting up at plant.
31 July 1979	Continued setting up at plant. PODON and LEIDY carried out first day of background runs between Kenwood Beach and Cove Point.
1 August 1979	Continued setting up at plant. PODON and LEIDY carried out second day of background runs between Cove Point and Kenwood Beach.
2 August 1979	PODON and LEIDY carried out third day of background runs. Completed setting up at plant.
3 August 1979	Started dye injection at 1119. Unit #2 placed in service.
4,5 August 1979	Dye injection and measurement program at plant carried out. Calibrated fluorometers.
6-10 August 1979	Dye injection and measurement programs continued at plant. Unit #1 out of service at ~1100, August 10, 1979. Dye injection secured at 1533. PODON and LEIDY underway on sampling program each day. Calibrated fluorometers at plant on 10 August. Removed current meters.
11 August 1979	Calibrated fluorometers on PODON and LEIDY. Packed equipment and departed for Baltimore/Stony Brook/Benedict.

Background Temperature Analysis

A scaling relation between dye tracer and excess temperature can be developed from simple mixing concepts as follows: The temperature under heated conditions (plant operating) at any point x,y,z and time t if we neglect surface cooling is given by

$$T_h(x,y,z,t) = \frac{T_{h,o} \times 1 + n_1 T_{n_1} + n_2 T_{n_2} + n_3 T_{n_3} + \ldots N T_N}{1 + \sum_{i=1}^{i=N} n_i} \qquad (II\text{-}2\text{-}2)$$

where $T_{h,o}$ is the temperature of the cooling water at discharge and $1 + \sum_{i=1}^{i=N} n_i$ is the volume into which a unit volume at temperature $T_{h,o}$ is considered to be mixed. T_{ni} are the temperatures of the various components of receiving water that make up the mixture.

Equation (II-2-2) may be rewritten as

$$T_h(x,y,z,t) = \frac{T_{h,o} + \bar{T}_n \sum_{i=1}^{i=N} n_i}{1 + \sum_{i=1}^{i=N} n_i} \qquad (II\text{-}2\text{-}3)$$

where

$$\bar{T}_n = \frac{\sum_{i=1}^{i=N} n_i T_{n_i}}{\sum_{i=1}^{i=N} n_i} \qquad (II\text{-}2\text{-}4)$$

For any tracer injected into the same flow and at the same state of equilibrium, we can write a similar relation, that is

$$C = \frac{C_o \times 1}{1 + \sum_{i=1}^{i=N} n_i} \qquad (II\text{-}2\text{-}5)$$

where now the contributions from the various species are zero since the background dye concentration of the receiving waters is negligibly small.

Combining (II-2-3) and (II-2-5) we have

$$T_h(x,y,z,t) - \bar{T}_n = (T_{h,o} - \bar{T}_n)\frac{C}{C_o} \qquad \text{(II-2-6)}$$

Earlier we defined the excess, θ, as the difference between T_h and the ambient or background temperature, T_a, at that same point and time. It is clear from equation (II-2-6) that a regression of T_h on C, the dye concentration, will provide information concerning $\bar{T}_n$ but not T_a. Furthermore, since all unit volumes are not necessarily exposed to the same time-temperature history after discharge, each may have its own $\bar{T}_n$, different from its neighbors or other parcels emitted at different times. As a result, T_h will not, in general, be highly correlated with C. However, if the receiving waters are well mixed as Bay waters are during the spring and fall, or if the waters above the bottom of the discharge, i.e., the upper 6 m, are well mixed, such as occurs late in the summer in the Bay, then $\bar{T}_n$ will equal T_a and equation (II-2-6) may be rewritten as

$$\theta = T_h - T_a = (T_{h,o} - T_a)\frac{C}{C_o} \qquad \text{(II-2-7)}$$

If we understand C/C_o to be measured relative to the natural or background fluorescence, then the regression of T_h on C/C_o intercepts the line $(C/C_o) = 0$ at T_a and the line $C/C_o = 1$ at $T_{h,o}$.

In the present study, we have chosen to calibrate our fluorometers in terms of C/Γ where Γ is the concentration of the original dye solution. Rewriting equation (II-2-7) accordingly, we obtain

$$T_h = T_a + (T_{h,o} - T_a)\frac{C/\Gamma}{(C/\Gamma)_o} \qquad \text{(II-2-8)}$$

To illustrate the method, data collected by the PODON on 17 April 1979 (Run #1) and by the LFIDY on 6 August 1979 (Runs 1 and 5) are plotted on figures II-2-3, II-2-4, and II-2-5 together with linear regressions of T_h on C/Γ. Table II-2-2 summarizes the results of the regression analyses for both the April and August studies, i.e., background temperature, slope, coefficient of determination, and correlation coefficient. It may be seen from Table II-2-2 that the proportion of total variation of temperature about its mean explained

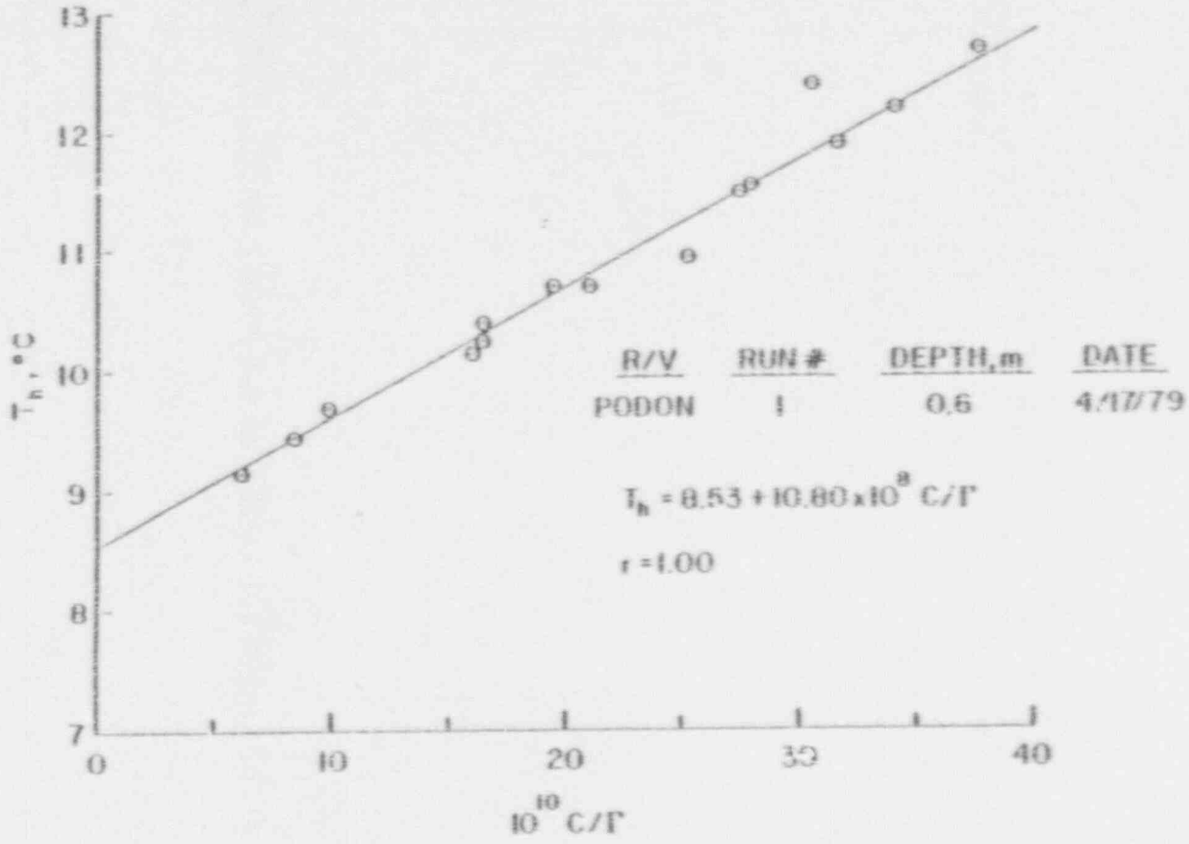


Figure II-2-3. Temperature, T_h, as a function of dye concentration, C/Γ, at 0.6 m (PODON (Run #1) on 17 April, 1979. Background fluorescence has been removed from the dye concentrations prior to plotting. The straight line is a linear regression of T_h on C/Γ.

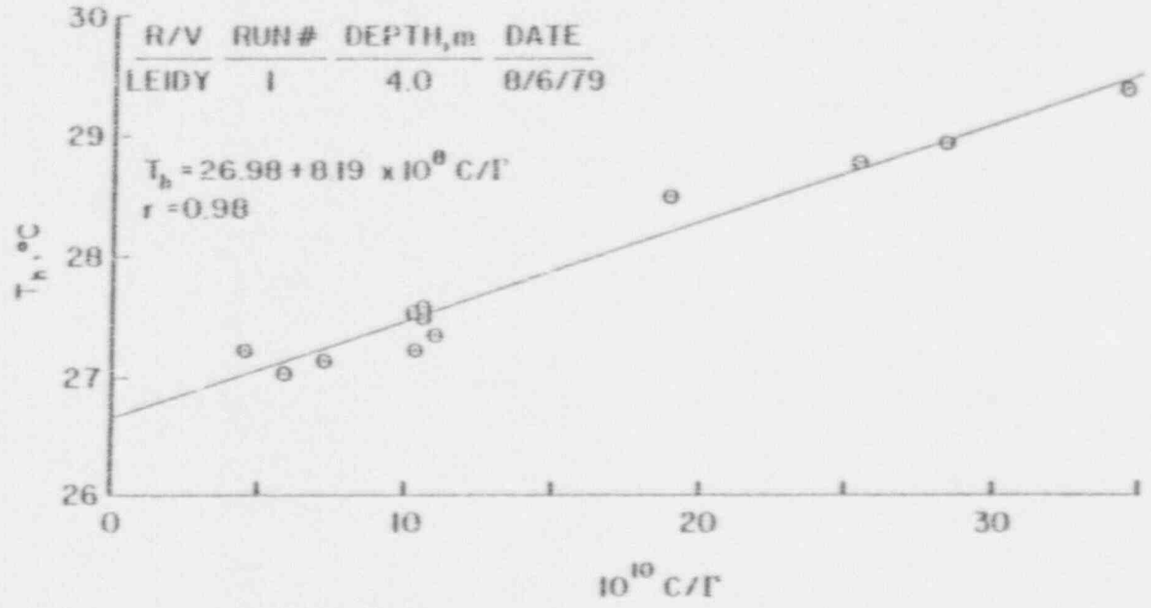


Figure II-2-4. Temperature, T_h, as a function of dye concentration, C/Γ, at 4.0 m (LEIDY (Run #1)) on 6 August 1979. Background fluorescence is included in the plotted values of C/Γ. The straight line is a linear regression of T_h on C/Γ.

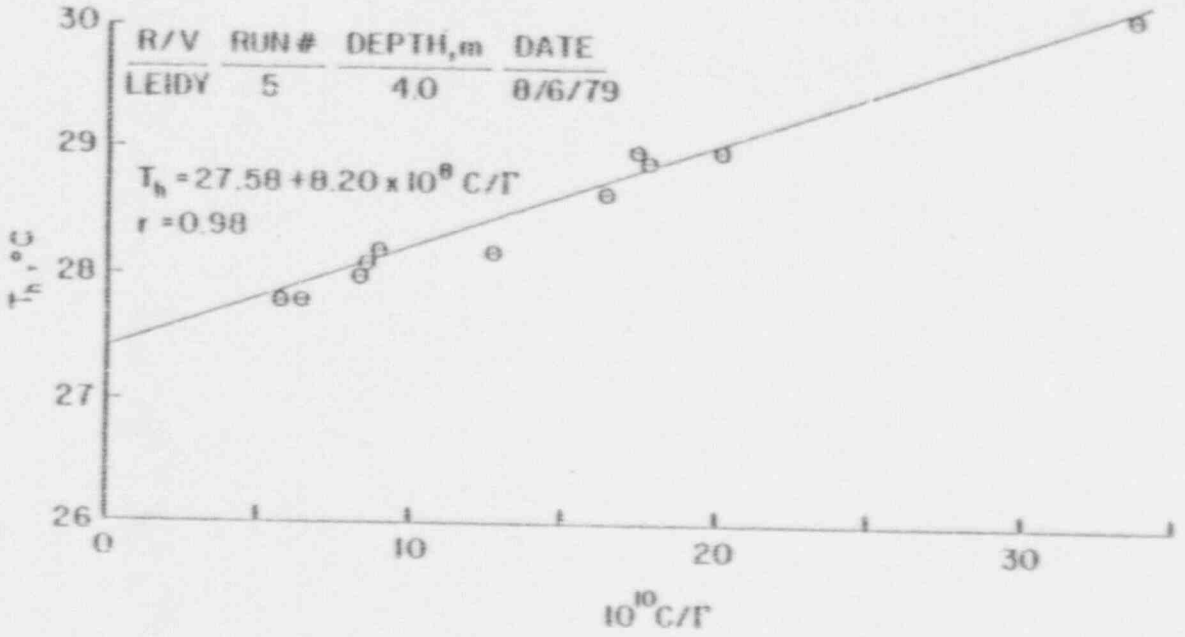


Figure II-2-5. Temperature, T_h, as a function of dye concentration, C/Γ, at 4.0 m (LEDIY (Run #5)) on 6 August 1979. Background fluorescence is included in the plotted values of C/Γ. The straight line is a linear regression of T_h on C/Γ.

Table II-2-2. Correlation statistics between dye concentration, C/Γ and temperature, T_h.

Date	Run #	R/V	Depth,m	A_0,°C	A_1 ($\times 10^{-3}$)	r^2	r
4/15/79	1	Podon	0.6	9.39	10.10	0.96	0.98
"	1	Leidy	1.0	10.01	8.51	0.96	0.98
"	1	Leidy	3.0	9.71	9.37	0.96	0.98
"	1	Leidy	6.0	9.43	10.60	0.98	0.99
"	2	Podon	0.6	10.33	6.69	0.85	0.92
"	2	Leidy	1.0	10.38	9.15	0.92	0.96
"	2	Leidy	3.0	9.90	9.97	0.98	0.99
4/15/79	2	Leidy	6.0	9.75	11.00	0.98	0.99
4/16/79	2	Podon	0.6	9.06	11.10	0.99	1.00
"	2	Leidy	1.0	9.58	10.00	0.98	0.99
"	2	"	3.0	9.44	9.16	0.98	0.99
4/16/79	2	Leidy	6.0	9.20	10.10	0.98	0.99
4/17/79	1	Podon	0.6	8.53	10.80	0.99	1.00
"	1	Leidy	1.0	9.09	12.80	0.98	0.99
"	1	"	3.0	8.82	9.85	0.98	0.99
"	1	Leidy	6.0	8.94	9.53	0.98	0.99
"	4	Podon	0.6	8.98	11.20	0.99	1.00
"	3	Leidy	1.0	9.37	9.75	0.99	1.00
"	3	"	3.0	9.11	10.40	0.98	0.99
4/17/79	3	Leidy	6.0	9.03	11.60	0.99	1.00
4/18/79	1	Podon	0.6	8.61	10.90	0.99	1.00
"	1	Leidy	1.0	9.14	10.10	0.98	0.99
"	1	"	3.0	9.01	9.55	0.99	1.00
4/18/79	1	Leidy	6.0	9.06	9.42	0.98	0.99
4/19/79	2	Podon	0.6	10.80	9.27	0.89	0.89
"	2	Leidy	1.0	10.84	8.29	0.96	0.96
"	2	"	3.0	10.47	8.72	0.96	0.96
4/19/79	2	Leidy	6.0	10.16	10.30	0.99	0.99

r^2 = Coefficient of determination

r = Correlation coefficient

$T_h = A_0 + A_1 C/\Gamma$ where A_0 is the background temperature and A_1 is the temperature-dye slope.

Table II-2-2 (continued). Correlation statistics between dye concentration, C/T, and temperature, T_h.

Date	Run #	R/V	Depth,m	A_0,°C	A_1 ($\times 10^{-3}$)	r^2	r
4/20/79	1	Podon	0.6	10.10	10.30	0.96	0.98
"	1	Leidy	1.0	10.24	10.30	0.96	0.98
"	1	"	3.0	10.24	9.74	0.98	0.99
4/20/79	1	Leidy	6.0	10.06	9.90	0.96	0.98
8/06/79	2	Podon	0.6	27.15	8.17	0.99	0.99
"	1	Leidy	2.5	27.04	8.69	0.97	0.98
"	1	"	4.0	26.98	8.19	0.96	0.98
"	1	Leidy	6.0	26.93	9.29	0.96	0.98
"	3	Podon	0.6	27.80	7.90	0.97	0.98
"	5	Leidy	2.5	27.64	8.00	0.97	0.99
"	5	"	4.0	27.58	8.20	0.97	0.98
8/06/79	5	Leidy	6.0	27.58	8.48	0.95	0.98
8/07/79	3-4	Podon	0.6	27.02	7.17	0.98	0.99
"	2	Leidy	2.5	26.91	6.68	0.98	0.99
"	2	"	4.0	26.87	7.14	0.97	0.98
"	2	Leidy	6.0	26.87	7.21	0.99	0.99
"	6-7	Podon	0.6	27.65	7.49	0.95	0.98
"	3	Leidy	2.5	27.06	7.29	0.93	0.96
"	3	"	4.0	27.16	8.00	0.96	0.98
8/07/79	3	Leidy	6.0	27.21	7.29	0.92	0.96
8/08/79	2	Podon	0.6	27.00	8.03	0.97	0.99
"	2	Leidy	2.5	26.99	6.33	0.98	0.99
"	2	"	4.0	26.98	7.47	0.99	0.99
"	2	Leidy	6.0	26.58	6.83	0.97	0.98
"	3	Podon	0.6	27.55	8.50	0.98	0.99
"	3-4	Leidy	2.5	27.54	8.18	0.99	0.99
"	3-4	"	4.0	27.31	8.15	0.97	0.98
8/08/79	3-4	Leidy	6.0	27.09	8.22	0.96	0.98

r^2 = Coefficient of determination

r = Correlation coefficient

$T_h = A_0 + A_1 C/T$ where A_0 is the background temperature and A_1 is the temperature-dye slope.

Table II-2-2 (continued). Correlation statistics between dye concentration, C/Γ, and temperature, T_h.

Date	Run #	R/V	Depth,m	A_0,°C	A_1 ($\times 10^{-9}$)	r^2	r
8/09/79	2	Podon	0.6	26.79	6.84	0.99	1.00
"	3-4	Leidy	2.5	26.79	6.50	0.99	1.00
"	3-4	"	4.0	26.78	6.89	0.99	1.00
"	3-4	Leidy	6.0	26.78	6.33	0.99	1.00
"	3-7	Podon	0.6	27.00	8.02	0.98	0.99
"	5-6	Leidy	2.5	26.99	7.57	0.98	0.99
"	5-6	"	4.0	26.98	8.63	0.99	1.00
8/09/79	5-6	Leidy	6.0	26.98	7.44	0.94	0.97
8/10/79	1-7	Podon	0.6	26.94	6.02	0.99	1.00
"	2-4	Leidy	2.5	26.94	5.38	0.90	0.95
"	2-4	"	4.0	26.93	5.44	0.99	0.99
8/10/79	1-4	Leidy	6.0	25.49	7.72	0.96	0.98

r^2 = Coefficient of determination

r = Correlation coefficient

$T_h = A_0 + A_1 C/\Gamma$ where A_0 is the background temperature and A_1 is the temperature-dye slope.

by the regression for the April runs was 96% or better for 27 of the 32 runs and 92% or better for 30 of the 32 runs. Only on 2 runs did the proportion of variation explained by the regression fall below 90%. In August, the total variation was even less with no runs below 90%.

In the event the water mixing with the plume is not well mixed, i.e., there are significant vertical and/or horizontal gradients in the ambient temperature field, then a plot of T_h versus C/Γ will not lie along a straight line but will be contained within the envelope delineated by the following points:

$(C/\Gamma)(C/\Gamma)_o$	T_a
0	$(T_a)_{min}$
0	$(T_a)_{max}$
1	$T_{h,o}$

(see Figure 7 of Carter, Pritchard and Rives, 1975). In this case, the foregoing method of determining T_a will not work; however, the absence of measurable quantitites of tracer ($C \cong o$) identifies water at ambient temperature from which the vertical and horizontal distribution of T_a may be estimated. Fortunately, in both the April and August studies T_h versus C/Γ plots were straight line, suggesting well mixed receiving waters at least to the depth of the heated plume.

Results April 1979 Study

As noted earlier, background runs were made on 11 and 12 April 1979. The fluorescence data collected on those 2 days by the PODON (1 fluorometer) and the LEIDY (3 fluorometers) were then digitized and statistically analyzed. The results are shown in Table II-2-3.

In the final column of Table II-2-3 equivalent excess temperature uncertainties are given. They were calculated as follows. Differentiating the regression equations in Table II-2-2, it may be seen that the slope, $(T_{h,o}-T_a)/(C/\Gamma)_o$ or A_1, is $d\theta/d(C/\Gamma)$. Furthermore, during the April study, $A_1 \cong 10^9$°C per 10^{-9} parts of equivalent dye or 1°C per ppb of dye. This information, together with the fluorometer calibrations (dial units versus C/Γ), was then used to convert the 90% confidence interval to C/Γ and finally to excess temperature in °C. It can be seen from Table II-2-3 that during the April study use of the underlined values for background, together with the appropriate fluorometer calibrations and regression equations, would provide estimates of the fields of excess temperature from measurements of fluorescence with an uncertainty of only

Table II-2-3. Statistical summary of background fluorescence.

Fluorometer	Date	Depth,m	Sample Size,N	Range(30 or 31.6*units)	Interval Containing 90% or greater	Median	Uncertainty $10^5 C/T$	Uncertainty θ,°C
Podon	4/11/79	1	214	8 to 16.5	9 to 13.5	10.5	± 0.050	± 0.050
"	4/12/79	1	218	5.5 to 26.0	7.5 to x'	.5	± 0.073	± 0.073
Podon	4/11-12/79	1	432	5.5 to 26.0	9 to 1^	9	± 0.056	± 0.056
Loidy	4/11/79	1	456	23 to 44	24.5 to 41	[illegible]	± 0.164	± 0.164
"	4/12/79	.	214	24 to 47.5	25 to 42	28.5	± 0.169	± 0.169
"	4/12/79	1	504	23.5 to 36	24.5 to 32.5	27.0	± 0.080	± 0.080
Loidy	4/11-12/79	1&3	1174	23 to 47.5	24.5 to 40	27.0	± 0.154	± 0.154
Loidy	4/12/79	6	566	5 to 9	5.5 to 7.5	6.5	± 0.076	± 0.076
Loidy	4/12/79	1	194	14 to 38	16.5 to 30.5	23.0	± 0.112	± 0.112
"	4/12/79	3	86	11 to 28	12.5 to 26.5	16.0	± 0.112	± 0.112
Loidy	4/12/79	1&3	280	11 to 38	13.5 to 29	20.5	± 0.128	± 0.128

NOTE: Underlined values were used as background fluorescence in subsequent analyses. 30 or 31.6 * units refers to most sensitive scale of Turner Assoc. or Turner Design Fluorometers, respectively.

0.1 to 0.2°C since errors in estimating A_1, the slope, are considered to have a negligible effect, i.e., less than 10%.

An alternative, somewhat more conservative, method of analysis was used for plotting the horizontal distributions of excess temperature, however. Background temperatures, T_a, were estimated from the regression analyses (A_o) at the 0.6-, 1-, 3-, and 6-m levels for the runs to be plotted and then compared to the temperature records for the same runs. In the event significant areas of lower temperatures were found in the records, the background temperatures were adjusted downward to eliminate these areas of negative θ. These adjusted values of T_a were then used together with the measured temperature field to calculate and plot value of θ at intervals of 1°C along the tracks of the sampling vessels plotted from the Mini-Ranger data. This information was then contoured.

Horizontal Distribution of θ

Table II-2-4 is a list of the runs which were contoured with respect to θ together with the existing hydrographic and meteorological conditions. Figures II-2-6 through 11 show selected runs for April 15, 17, and 20. The areas contained within closed isotherms were planimetered for all runs contained in Table II-2-4 and are given in Table II-2-5. Table II-2-6 lists the maximum radial extent of the excess temperature isotherms.

Vertical Distribution of θ

Table II-2-7 summarizes the vertical measurements of temperature taken during the April study. The positions of the verticals are shown in Figure II-2-12.

Recirculation

If each water molecule is "tagged" as it is drawn into a cooling water system of an estuary, after a time a certain percentage of the water molecules entering the plant intake will be ones which were previously tagged. The amount of this recirculation depends, of course, on the intake and discharge arrangement and the dynamics of the receiving waters from which the cooling water is being withdrawn. With recirculation, the concentration of dye at intake, C_i, is from simple mixing principles

$$C_i = \frac{1 \times C_o - r \times 0}{1 - r} \qquad \text{(II-2-9)}$$

Figure II-2-6. Horizontal distribution of excess temperature, θ, in °C at 0.6 m on 15 April 1979 (PODON (Run #1)).

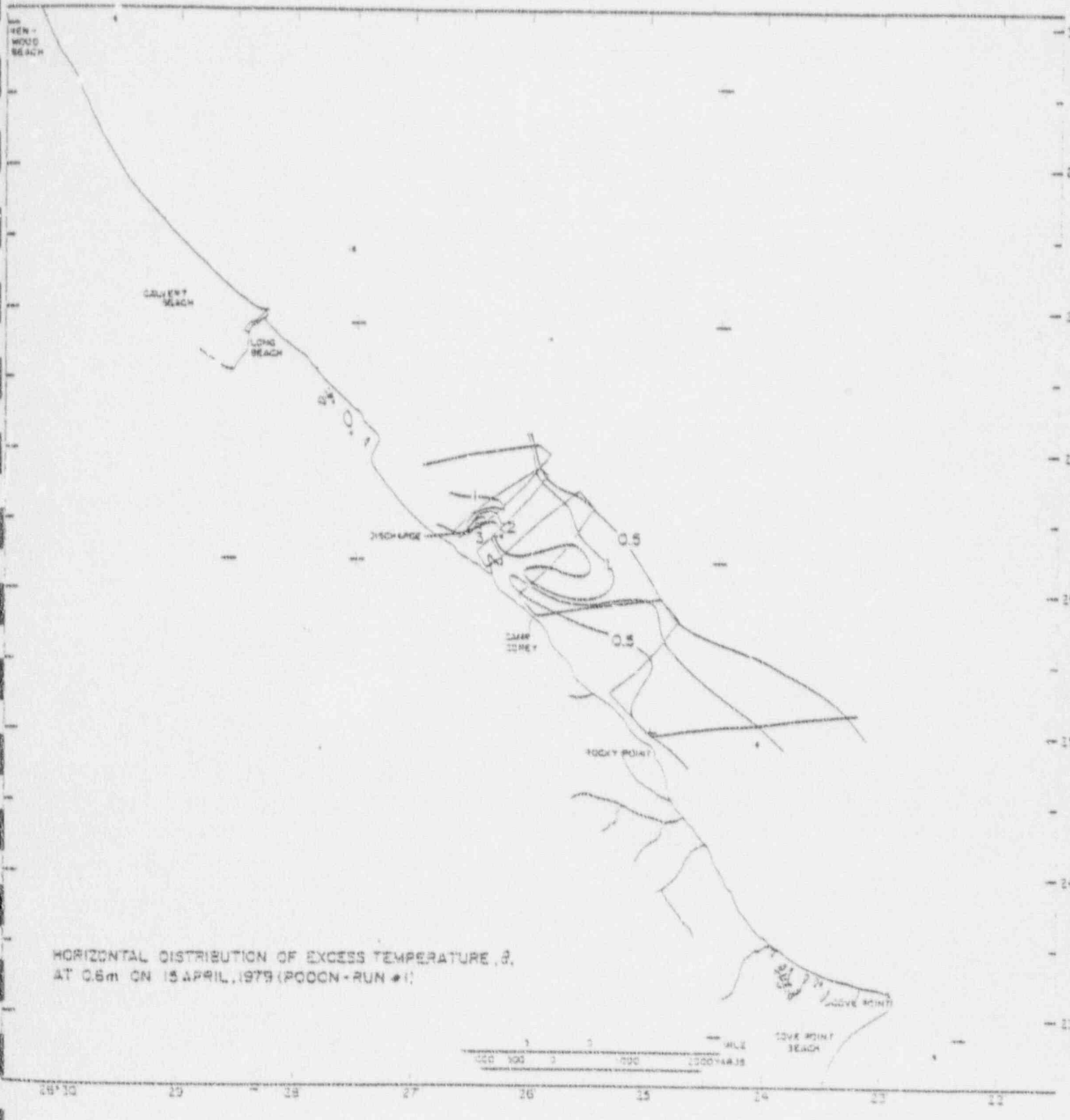
Figure II-2-7. Horizontal distribution of excess temperature, θ, in °C at 6.0 m on 15 April 1979 (LEIDY (Run #1)).

Figure II-2-8. Horizontal distribution of excess temperature, θ, in °C at 0.6 m on 17 April 1979 (PODON (Run #1)).

Figure II-2-9. Horizontal distribution of excess temperature, θ, in °C at 6.0 m on 17 April 1979 (LEIDY (Run #1)).

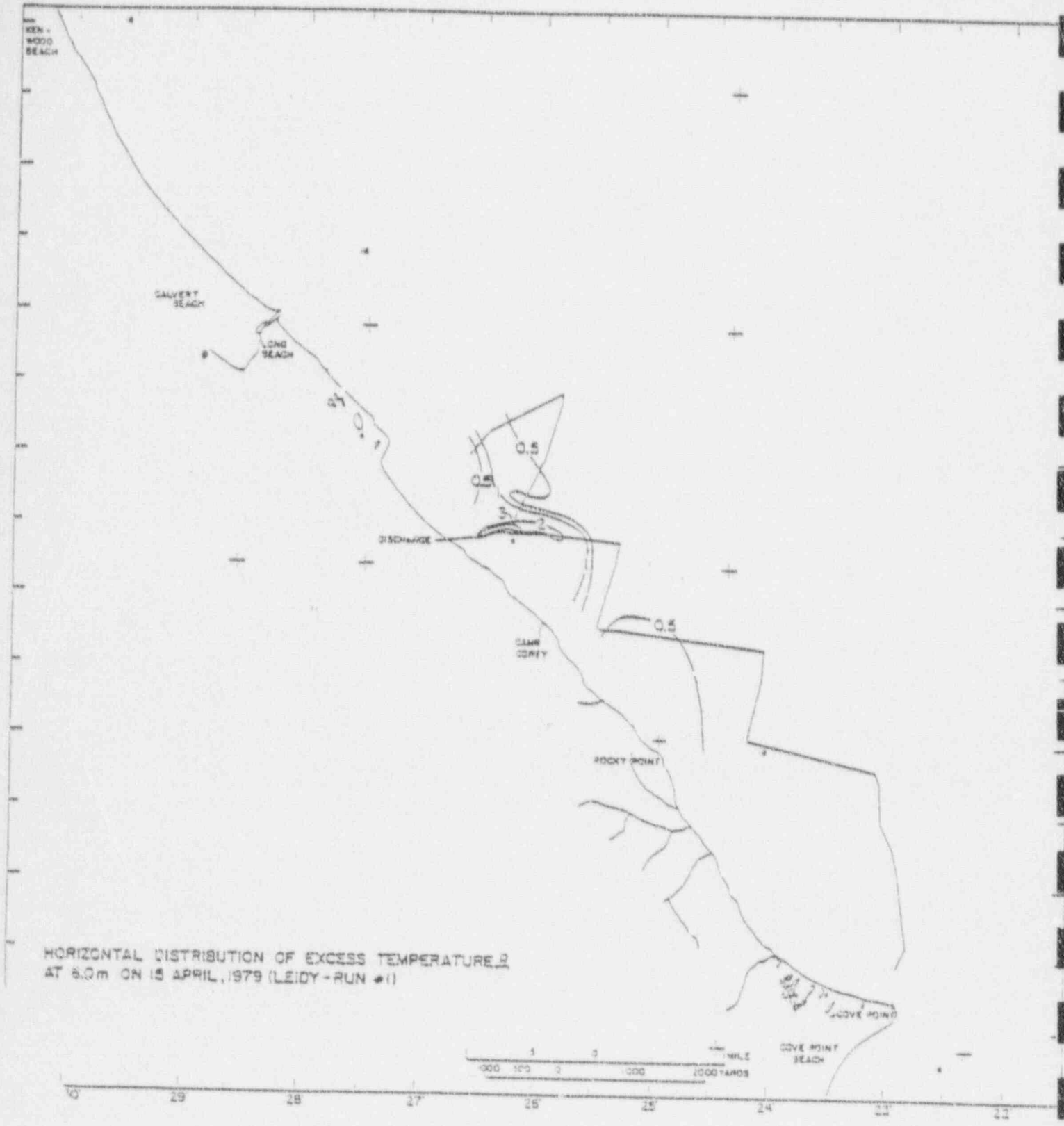
Figure II-2-10. Horizontal distribution of excess temperature, θ, in °C at 0.6 m on 20 April 1979 (PODON (Run #1)).

Figure II-2-11. Horizontal distribution of excess temperature, θ, in °C at 6.0 m on 20 April 1979 (LEIDY (Run #1)).



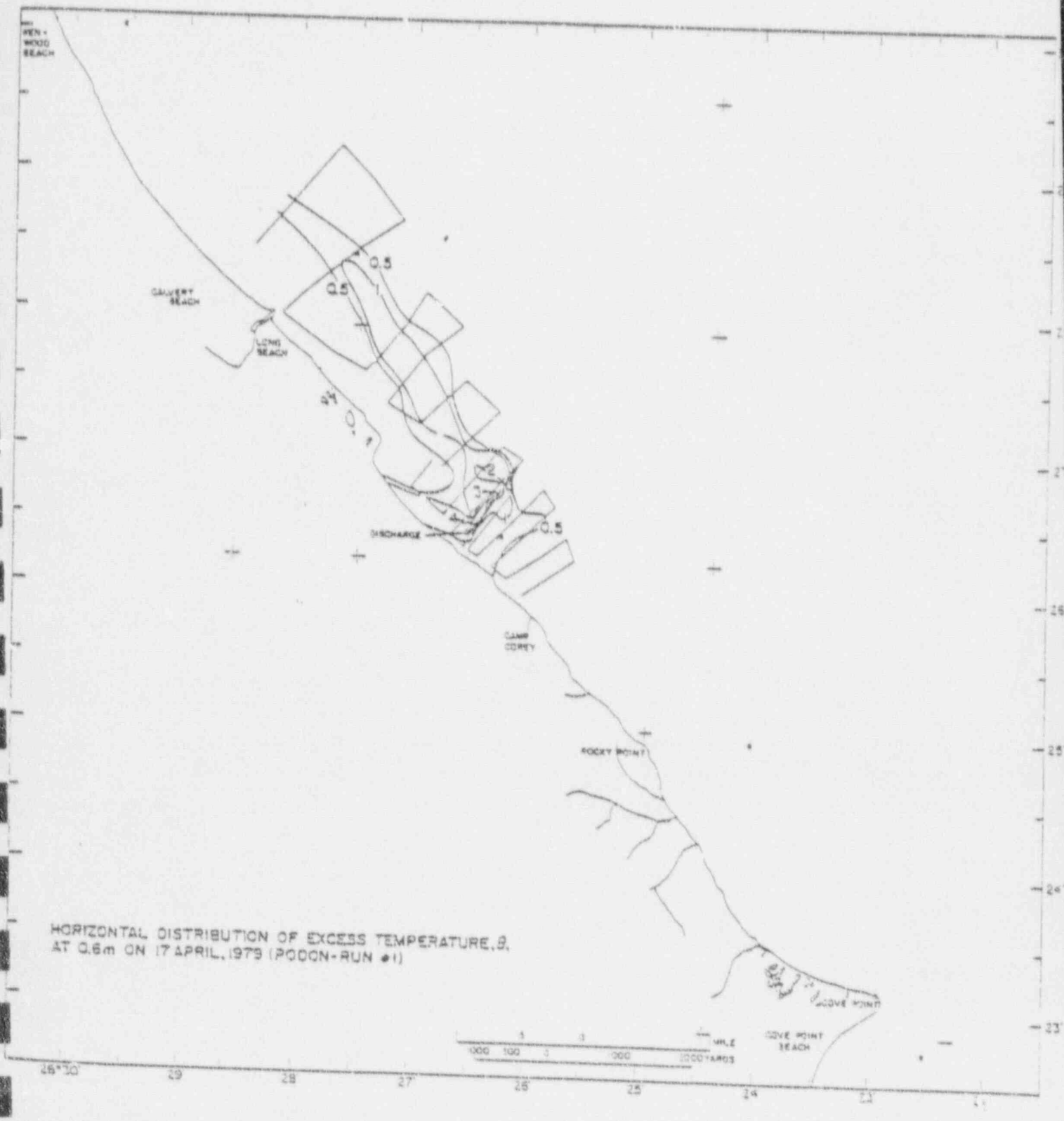
HORIZONTAL DISTRIBUTION OF EXCESS TEMPERATURE, θ,
AT 0.6m ON 15 APRIL, 1979 (POCON - RUN #1)

Figure II-2-6.



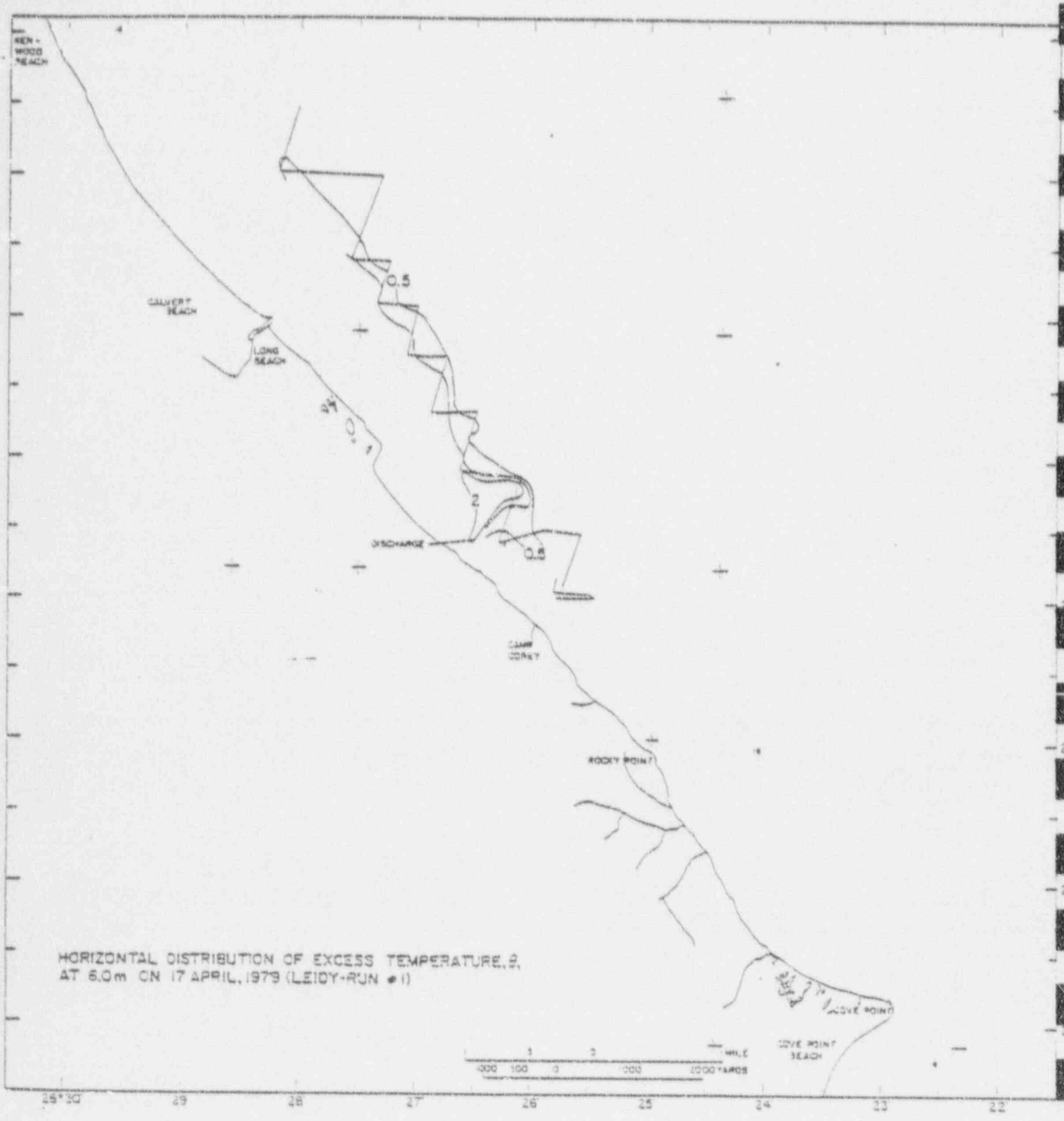
HORIZONTAL DISTRIBUTION OF EXCESS TEMPERATURE, ΔT
AT 8.0m ON 18 APRIL, 1979 (LEIDY - RUN #1)

Figure II-2-7.



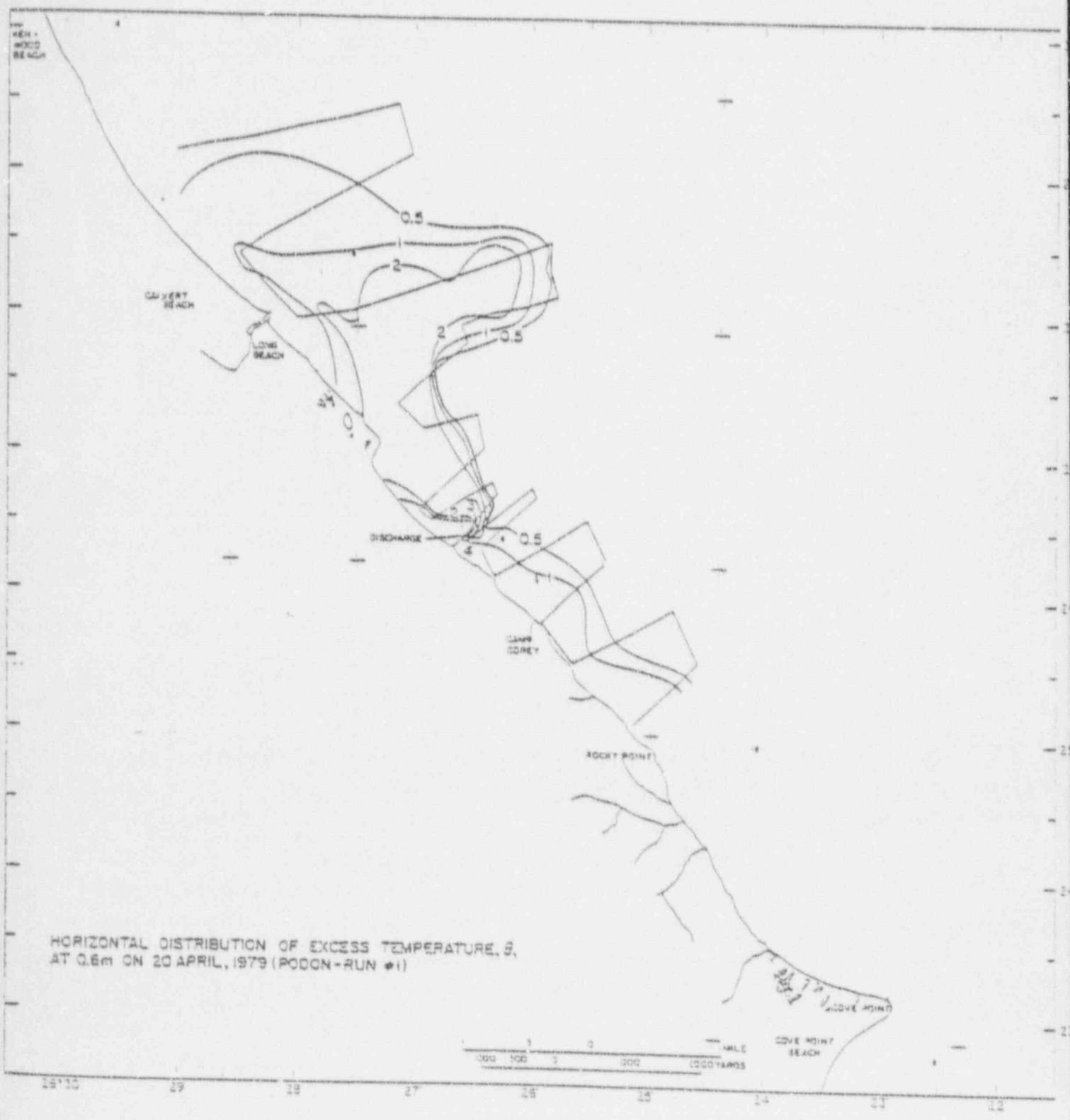
HORIZONTAL DISTRIBUTION OF EXCESS TEMPERATURE, θ, AT 0.6m ON 17 APRIL, 1979 (POOON-RUN #1)

Figure II-2-8.



HORIZONTAL DISTRIBUTION OF EXCESS TEMPERATURE, θ, AT 6.0m ON 17 APRIL, 1979 (LEIDY-RUN #1)

Figure II-2-9.



HORIZONTAL DISTRIBUTION OF EXCESS TEMPERATURE, ϑ, AT 0.6m ON 20 APRIL, 1979 (PODON-RUN #1)

Figure II-2-10.

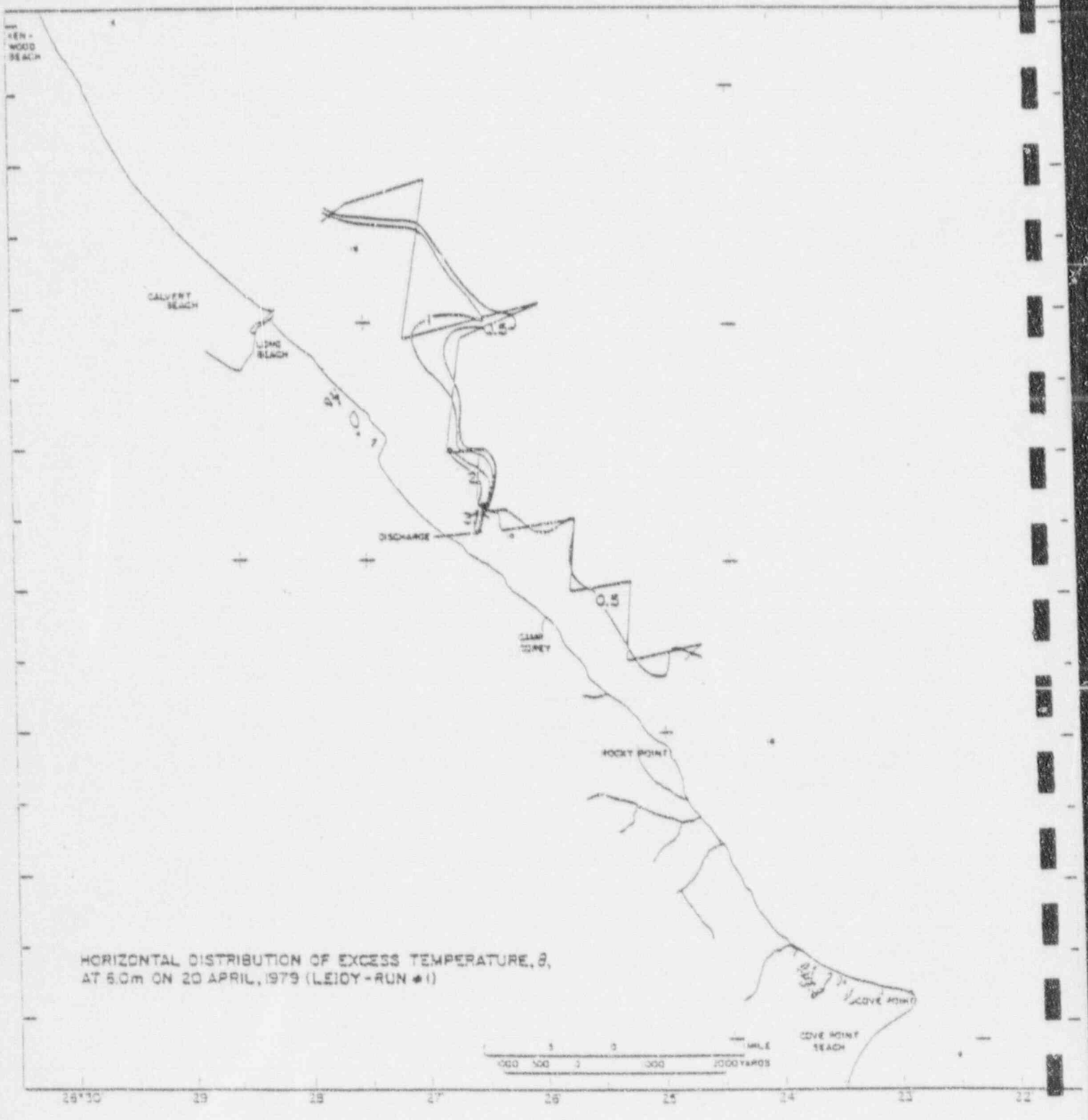


Figure II-2-11.

Table II-2-4. Hydrographic and meteorologic conditions at Calverts Cliffs during the April 1979 study period.

Date	Run #	R/V	Start Time	End Time	Wind* Speed, ms^{-1}	Wind* Direction, °M
4/15/79	1	Podon	0946	1059	3.6-5.1	266-331
"	1	Leidy	0946	1141	3.6-5.1	266-331
"	2	Podon	1430	1640	6.2-11.3	308-341
4/15/79	2	Leidy	1433	1733	6.2-11.3	308-341
4/16/79	2	Podon	1349	1514	6.2-7.2	296-297
4/16/79	2	Leidy	1338	1445	6.2-7.2	296-297
4/17/79	1	Podon	0744	0950	7.7-8.2	319-358
"	1	Leidy	0744	1019	7.7-8.2	319-358
"	4	Podon	1512	1641	3.1-10.8	345-001
4/17/79	3	Leidy	1506	1718	3.1-10.8	345-001
4/18/79	1	Podon	0854	1046	6.7-8.7	338-344
4/18/79	1	Leidy	0833	1116	6.7-8.7	338-344
4/19/79	2	Podon	1326	1513	2.6-3.1	035-054
4/19/79	2	Leidy	1324	1457	2.6-3.1	035-054
4/20/79	1	Podon	0903	1100	1.0-6.2	354-356
4/20/79	1	Leidy	0902	1117	1.0-6.2	354-356

* Wind recorded at 200-ft (61-m) level of the Calvert Cliffs microwave tower. Direction is in degrees magnetic.

Table II-2-5. Summary of areas (10^4 m^2) contained within specified excess temperature isotherms for the April 1979 surveys.

	4/15/79		4/16/79	4/17/79		4/18/79	4/19/79	4/21/79
	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #
θ	1	2	2	1	4	1	2	1
				Z = 0.5 m				
4	-	-	0.80	0.40	-	1.20	0.40	0.80
3	1.20	-	0.84	4.80	3.60	4.80	2.00	2.00
2	5.60	34.80	28.80	17.60	39.60	17.20	136.00	375.00
1	-	-	-	196.00	-	256.00	-	-
	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #
	1	2	2	1	3	1	2	1
				Z = 1 m				
4	-	-	-	-	2.00	-	-	-
3	1.60	-	2.80	-	4.40	-	4.00	4.80
2	7.60	30.40	19.60	29.60	16.00	15.20	77.20	-
				Z = 3 m				
4	-	-	-	-	1.20	-	-	-
3	3.60	-	3.20	-	5.60	-	6.40	3.20
2	9.20	34.80	13.20	12.00	22.40	13.20	44.40	18.80
				Z = 6 m				
4	-	-	-	-	1.20	-	-	-
3	3.20	-	2.80	-	6.00	-	7.20	1.60
2	14.00	26.00	17.20	28.00	16.40	16.00	66.00	12.80

Note: '(-)' indicates isotherm could not be closed.

Table II-2-6. Summary of maximum radial extent (m) of specified excess temperature isotherms for the April 1979 surveys.

	4/15/79		4/16/79	4/17/79		4/18/79	4/19/79	4/20/79
	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #
θ	1	2	2	1	4	1	2	1
				Z = 0.6 m				
4	-	-	220	160	-	280	120	180
3	360	-	260	700	580	500	340	600
2	720	1180	1020	1300	1600	1200	1060	4820
1	2400	2620	2280	4520	-	5100	-	-
	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #
	1	2	2	1	3	1	2	1
				Z = 1 m				
4	-	-	-	-	340	-	-	-
3	560	-	500	-	660	-	460	460
2	1020	1420	1220	1000	1020	1240	2680	3780
1	1240	1500	4720	-	-	-	-	-
				Z = 3 m				
4	-	-	-	-	160	-	-	-
3	800	-	460	-	560	-	640	420
2	1000	1420	980	1060	960	1000	2560	1140
1	1220	1600	-	-	-	-	-	-
				Z = 5 m				
4	-	-	-	-	180	-	-	-
3	580	-	500	-	720	-	640	420
2	1140	1440	1040	1100	1040	1000	2280	1120
1	1300	1800	-	-	-	-	-	-

Note: (-) indicates isotherm could not be closed.

Table II-2-7. Vertical distribution of temperature (^{0}C) in Chesapeake Bay near Calvert Cliffs during April 1979 surveys.

Date	R/V	Vertical # *	Time	DEPTH, m 0	1	2	3	4	5	6	7	8	9	10	11	12	13
4/11/79	Fodus	1	1046	8.90		8.45		9.22		6.14		8.36		8.30			
-	-	2	1140	9.01		8.83		8.57		8.41		8.39		8.51			
-	-	3	1325	10.44		10.06		10.19		10.20		10.50					
-	-	4	1350	10.32		10.27		9.95		9.89		9.87		9.94			
-	-	5	1357	9.65		9.55		8.99		9.04		9.05		9.04			
-	-	6	1433	9.55		9.38		8.94		8.69		8.70		8.84			
-	-	7	1419	10.36		10.17		9.98		9.70		9.68		9.67			
-	-	8	1505	9.40		9.34		9.31		9.29		9.10		8.84			
4/11/79	Fodus	9	1557	8.74		8.71		8.67		8.63		8.59		8.53			
4/12/79	Fodus	10	0944	8.83		8.76		8.61		8.58		8.71		8.71			8.57
-	-	11	0956	8.96		8.90		8.81		8.53		8.67		8.63			8.53
-	-	12	1021	9.09		9.02		8.53		8.83		8.66		8.74		8.10	7.92
-	-	13	1045	10.04		9.76		9.79		9.88							
-	-	14	1100	9.10		9.17		9.10		8.89		8.78		8.54		7.85	7.89
-	-	15	1147	9.34		9.21		9.11		9.04		8.86		8.74		7.66	7.85
-	-	16	1141	10.11		10.26		10.10	10.35								
-	-	17	1239	10.46					10.25					10.15			10.24
-	-	18	1314	10.03		9.41		9.19		9.05		9.05		8.88		8.07	
-	-	19	1336	10.80		10.32		9.64		9.23		8.92		8.85			
-	-	20	1414	9.24		9.48		9.11		9.20		9.19			8.79		
-	-	21	1508	9.30	9.54	8.71		8.55		8.52		8.86		8.75	8.83		
-	-	22	1521	9.04		9.03		8.78		8.78		8.88		9.04			
-	-	23	1551	9.53	9.38	8.64		8.51		8.50			8.56				
4/12/79	Fodus	24	1602	10.26	9.98	9.85		9.58		9.40							
4/15/79	Fodus	25	1055	10.24		10.14		9.32		9.43		9.29		9.31			9.41
-	-	26	1116	10.25		10.19		9.96		9.48		9.33					
-	-	27	1126	10.12		10.07		10.01		9.31		9.43			9.63		
-	-	28	1138	9.95		9.95		9.84		9.74		9.53			9.43		
-	-	29	1152	10.04		10.05		9.99		9.97		9.95		10.30		10.14	
4/15/79	Fodus	30	1207	9.87		9.92		9.82		9.81		9.68			9.64		

* Station locations are shown in Figure II-2-12.

Table II-2-7 (continued). Vertical distribution of temperature (°C) in Cheaspeake Bay near Calvert Cliffs during April 1979 surveys.

Date	R/V	Vertical # *	Time	D	DEPTH, m 1	2	3	4	5	6	7	8	9	10	11	12	13
4/16/79	Fishon	31	1048	9.95		9.90		9.98		9.95		9.94		10.06			
"	"	32	1532	9.05		9.08		9.08		9.02		9.07			9.35		
"	"	33	1548	8.98		8.98		8.97		8.93		8.92			8.52		
"	"	34	1559	9.70		9.68		9.59		9.56		9.11			9.02		
4/16/79	Fishon	35	1649	9.83					9.81								9.1
4/17/79	Fishon	36	2652	10.14		10.04		8.92		8.91		8.90			8.90		
"	"	37	1701	9.67		9.58		9.21		8.84		8.85			8.92		
"	"	38	1710	9.07		9.00		8.96		8.96		8.78				8.82	
"	"	39	1718	9.26		9.04		8.93		8.98		8.75			8.80		
4/17/79	Fishon	40	1728	9.58		9.10		9.05		9.05		8.99		9.00			
4/18/79	Fishon	41	1432	10.50		10.56		10.44		10.28		10.09			10.19		
"	"	42	1443	10.37		10.18		10.16		10.21		10.22		10.21			
"	"	43	1459	10.16		10.16		10.18		10.14		10.11			10.10		
"	"	44	1515	10.09		9.96		9.87		9.87		9.87		9.89			
"	"	45	1528	9.92		9.60		9.61		9.59			9.80				
"	"	46	1537	12.21		11.83		11.56		11.54			10.76				
4/18/79	Fishon	47	1543	11.19		11.20		11.16		11.06		11.14		11.02			10.9
4/19/79	Fishon	48	1609	11.01		10.89		10.88		10.87		10.91			10.07		
"	"	49	1617	12.19		10.60		10.90		11.08		11.12			9.85		
"	"	50	1630	12.54		11.42		10.70		10.81		11.64	11.65				
"	"	51	1640	11.69		9.60		9.35		9.80		10.54			9.62		
"	"	52	1651	12.41		12.00		11.08		12.00		12.20		11.23			
4/19/79	Fishon	53	1658	12.89		11.87		11.90		11.85		11.84		11.54		10.41	
4/20/79	Fishon	54	1112	10.07		9.98		9.95		10.12		10.01			9.35		
"	"	55	1131	10.70		10.58		10.54		10.46		10.41			9.43		
"	"	56	1148	10.26		10.13		10.02		10.09		10.36			9.56		
"	"	57	1152	10.31		10.17		10.01		10.05		10.13			9.59		
4/20/79	Fishon	58	1200	10.37		10.20		10.18		10.15		10.16		9.66			

* Station locations are shown in Figure II-2-12.

Figure II-2-12. Location of stations for vertical temperature measurements during the April field study. The plotted numbers correspond to Vertical #, Column 3, Table II-2-7.

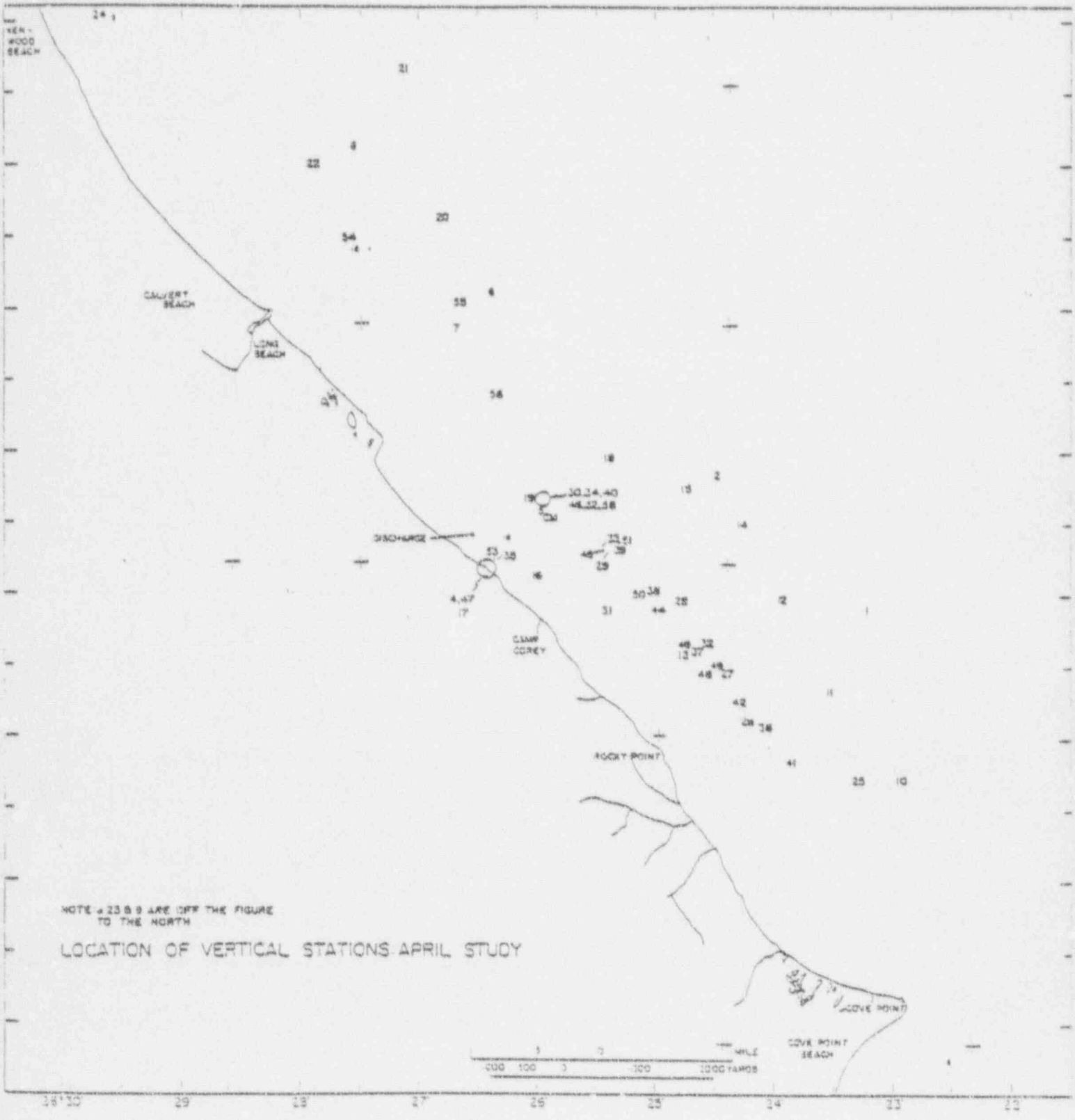


Figure II-2-12.

since the n parts of "new" water contain immeasurable tracer. Therefore, the fraction of the total flow, Q_c, that is recirculated or "old" water is

$$\frac{1}{1 - n} = \frac{C_i}{C_o} \qquad \text{(II-2-10)}$$

Using equation (II-2-10) and the inplant dye measurements the recirculation was calculated, sorted in 1% intervals and the results were plotted (Fig. II-2-13).

Figure II-2-14 shows the intake temperatures (Unit #1 - upper curve; Unit #2 - lower curve) together with wind data from the 200-ft (61-m) level of the microwave tower (wind vectors point toward the direction the wind is blowing; the line on which the wind vectors originate is oriented 315°M-135°M (magnetic), i.e., vectors pointed above the line are offshore and those below are onshore).

Currents

The location of the current meter mooring during April is shown on Figure II-2-12 as "CM". After removing errors from the current meter records, the principal direction (approximately alongshore) was determined for the record at each of the three depths by minimizing the sum of the squares of the speeds normal to the principal direction. The three records were then resolved into components parallel to (alongshore) and normal to (on/offshore) the principal directions. These records were then filtered with a low-pass filter which effectively removed from the data all periods ≤3 h to obtain noise-free versions of the data.

Data for the surface and mid-depth meters were then analyzed with respect to ebb and flood excursion lengths. That is, between all alongshore current reversals the velocity was integrated over time to determine the hypothetical distance a parcel would travel if subjected to that velocity history. These excursion data were then sorted in 1 km intervals and histograms prepared (Figs. II-2-15 and II-2-16).

Plotted on Figure II-2-17 are the low-pass filtered data for alongshore currents at the three depths (~10, 20, and 35 ft) for the period 10-23 April 1979. Figure II-2-18 shows the low-pass filtered alongshore current data at ~20 ft for the 6-day period (15-20 April) with the sampling periods indicated as cross hatched areas.

The principal flood and ebb directions as determined by the statistical method described above are indicated on Figure II-2-17. It appears that although the principal direction at 35 ft (230°M) is significantly affected by the plant intake,

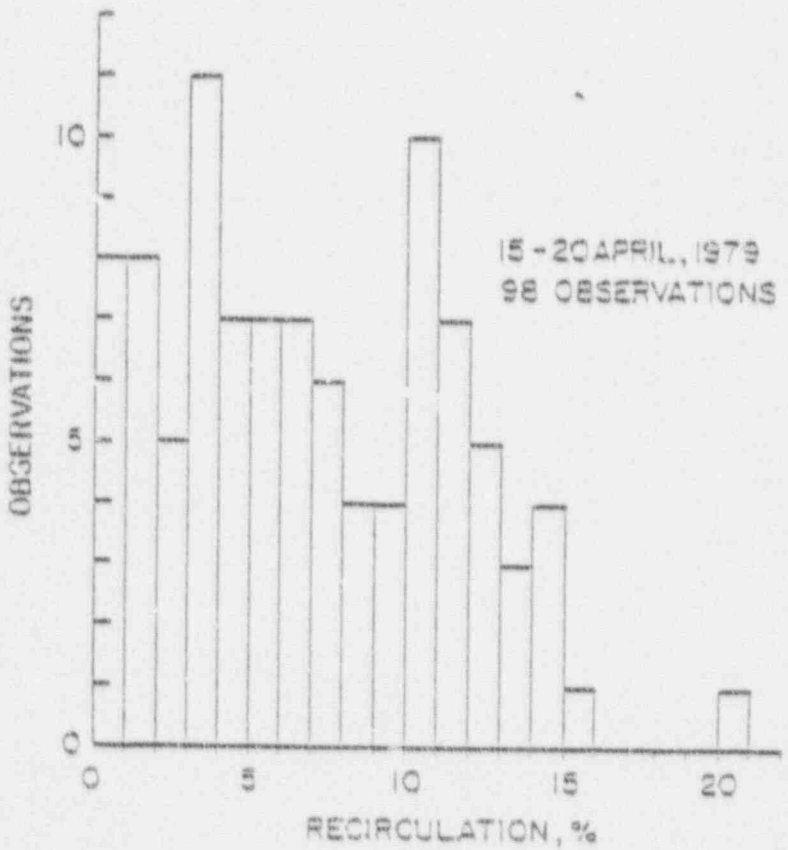


Figure II-2-13. A histogram of the distribution of recirculation observations during April 1979.

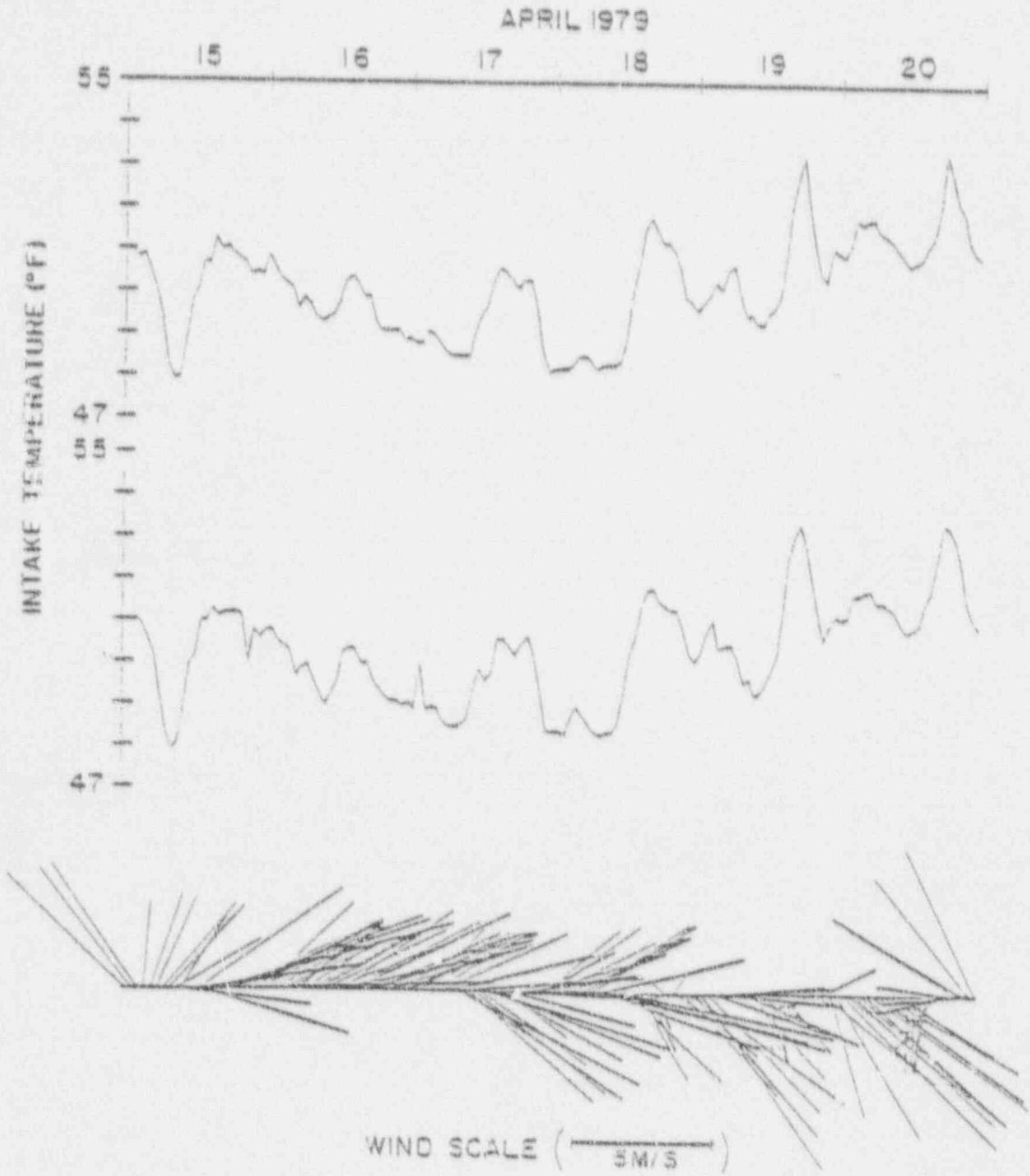


Figure II-2-14. Intake temperatures (Unit #1 - upper curve; Unit #2 - lower curve) together with wind data from the 200-ft (61-m) level of the microwave tower during the Arpil study. Wind vectors point toward the direction the wind is blowing; the line on which they originate is 315°M-135°M, i.e., approximately shore parallel at Calvert Cliffs.

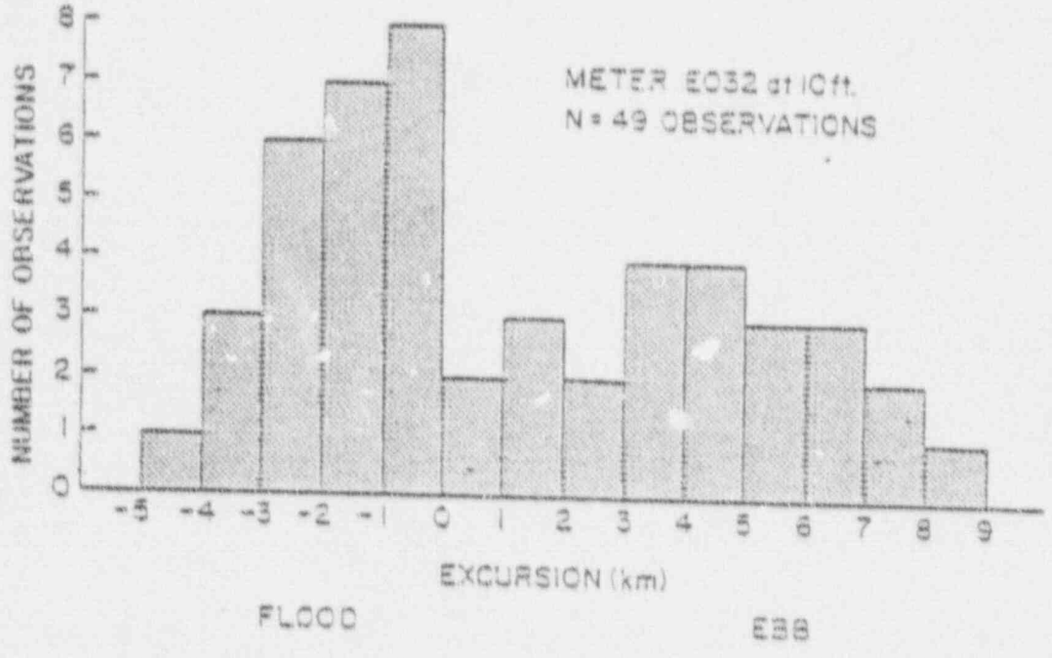


Figure II-2-15. A histogram of measurements of the flood and ebb excursions at ~10 ft (3.05 m) off Calvert Cliffs during April 1979.

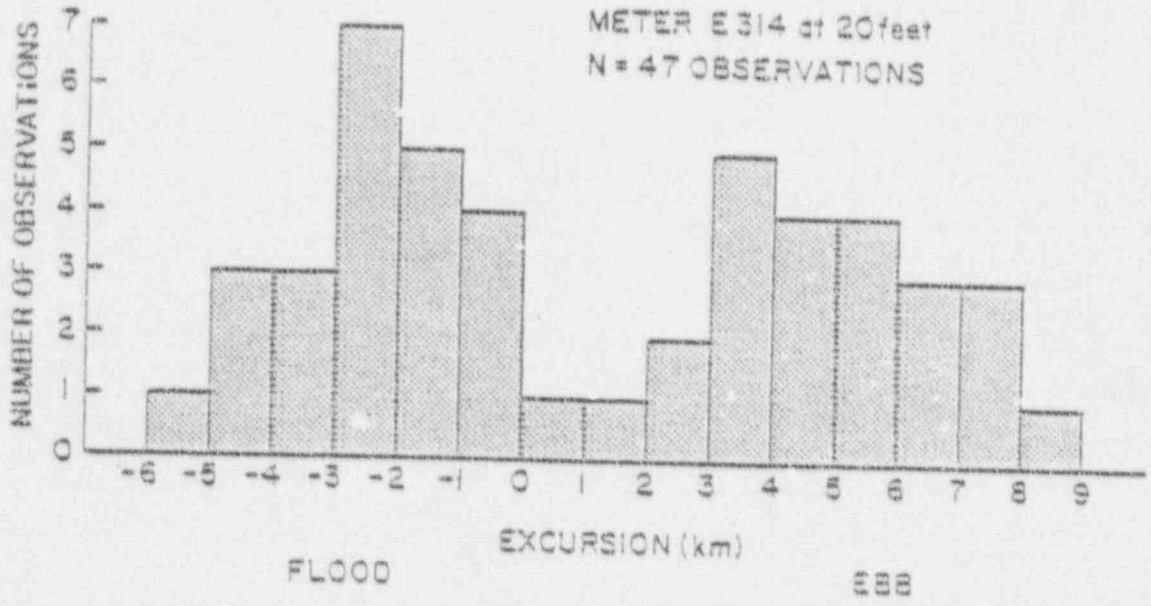


Figure II-2-16. A histogram of measurements of the flood and ebb excursions at ~20 ft (6.1 m) off Calvert Cliffs during April 1979.

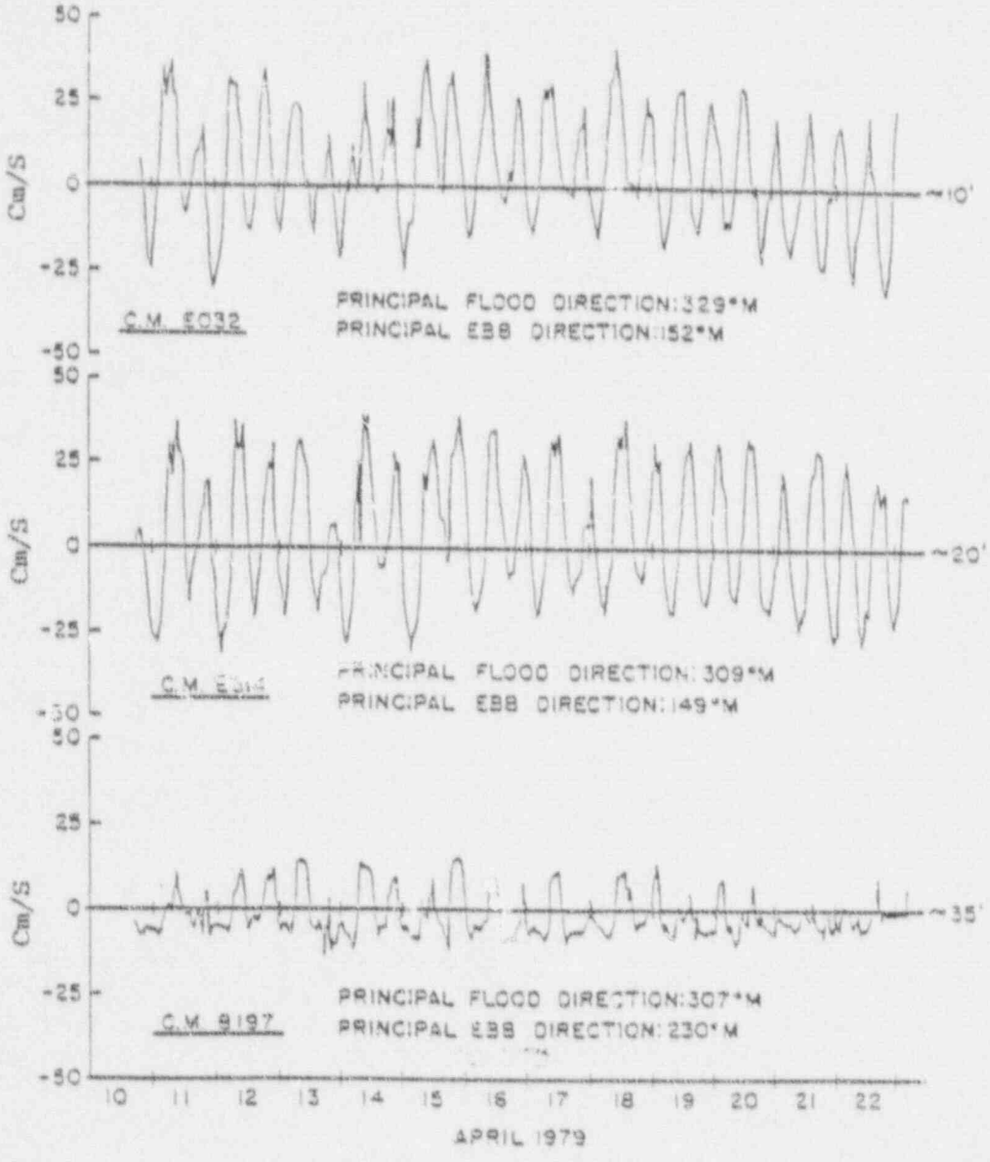


Figure II-2-17. Low-pass filtered data for alongshore currents at 10, 20, and 35 ft (3.05 m, 6.1 m, and 10.7 m) off Calvert Cliffs between 10 and 23 April 1979. Ebb tides are positive. Flood tides are negative.

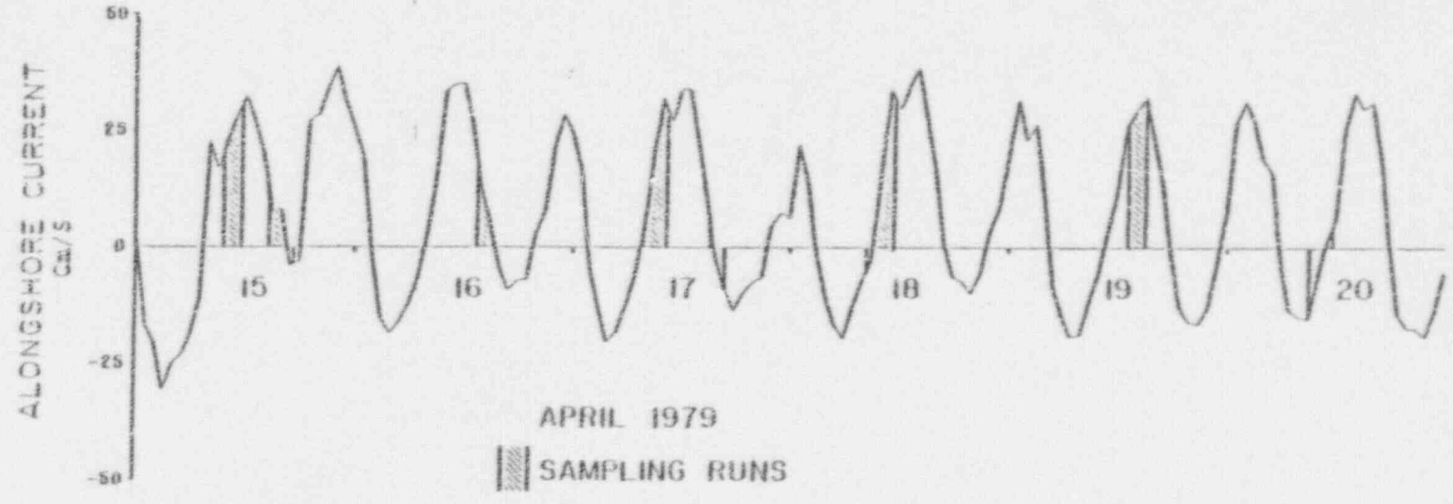


Figure II-2-18. Low-pass filtered data for alongshore currents at -20 ft (6.1 m) for the six day period (15-20 April 1979) off Calvert Cliffs. Sampling periods are indicated by cross-hatched areas. Ebb current is positive, flood is negative.

the principal directions at 20 ft (309°M/149°M) and 10 ft (329°M/ 152°M) are approximately shore parallel. These records (10 & 20 ft) should provide reliable excursion information, therefore.

Results July/August 1979 Study

During the August study, background runs were made on 31 July, 1 and 2 August 1979. The fluorescence data collected on those 3 days by the PODON (1 - fluorometer) and the LEIDY (3 - fluorometers) were then digitized and statistically analyzed. Analysis of these data was different from the April data analysis. The April data were first classified into frequency tables and medians and intervals containing 90% of the data were used for estimates of central tendency and variation, respectively, whereas means and standard deviations were calculated from unclassified August data. The results are shown in Table II-2-8. The excess temperature uncertainties in the last column are based on two standard deviations which, theoretically at least, define the interval containing 95% of the measurements. To compare the two methods of analysis, 3 of the August runs were also analyzed using the April methodology. It was found in both cases, that the medians did not differ significantly from the means and the 90% intervals were, as expected, slightly smaller than the two standard deviations.

Those statistics were then converted to relative dye concentrations, C/T, and excess temperature in °C as before. In August, however, the regression slopes are somewhat lower than in April, ~0.8×10^9 versus 10^9 °C per ppb of equivalent dye.

It is clear from Table II-2-8 that the uncertainty in excess temperature (θ) derived from background fluorescence in August was almost double that in April--between ±0.14 to ±0.35°C. That is, doubling q_d, the dye solution pumping rate, would have made the uncertainties in background fluorescence between the two studies comparable. For purposes of calculating excess temperatures from measured temperatures, therefore, background temperatures were estimated by regressing T_b on C/T for the various runs but without removing background fluorescence (Figs. II-2-4 and II-2-5, for example). The temperature records were then examined for areas of low temperature as in April. A background temperature was then selected which (1) provided a background fluorescence not significantly at variance with the appropriate mean in Table II-2-8 when used in the regression equation and (2) which minimized areas of negative θ. It was not difficult to satisfy these two conditions.

Having determined T_a, the background temperature appropriate for the desired runs, the field of excess temperature was then contoured following the procedure used for presenting the April results.

Table II-2-8. Statistical summary of background fluorescence during August 1979 surveys.

Date	Fluorometer	Depth, m	Sample Size, N	Mean (30 or 31.6* units)	σ (30 or 31.6 units)	Interval Containing 95% or greater	Uncertainty 10^9C/l	σ, °C
7/31/79	Podon	0.6	283	16.75	5.04	6.5 to 27	±0.35	±0.281
8/01/79	Podon	0.6	306	25.00	7.85	9.5 to 40.5	±0.55	±0.44
8/02/79	Podon	0.6	422	21.06	4.97	11 to 31	±0.35	±0.277
7/31/79	Leidy	2.5	550	12.51	3.07	6.5 to 18.5	±0.23	±0.185
8/01/79(AM)	"	2.5	329	19.83	5.66	8.5 to 31	±0.44	±0.349
8/01/79(PM)	"	2.5	648	19.68	4.90	10 to 29.5	±0.38	±0.302
8/02/79(AM)	"	2.5	315	18.90	4.5	10 to 28	±0.35	±0.277
8/02/79(PM)	Leidy	2.5	333	20.20	4.79	10.5 to 30	±0.37	±0.295
7/31/79(AM)	Leidy	4.0	260	22.25	4.24	14 to 30.5	±0.17	±0.139
7/31/79(PM)	"	4.0	281	21.95	4.98	12 to 32	±0.20	±0.164
8/01/79(AM)	"	4.0	304	27.10	8.27	16.5 to 43.5	±0.34	±0.272
8/01/79(PM)	"	4.0	648	22.70	5.52	11.5 to 33.5	±0.23	±0.181
8/02/79(AM)	"	4.0	316	23.42	5.66	12 to 34.5	±0.23	±0.186
8/02/79(PM)	Leidy	4.0	334	25.83	6.10	13.5 to 38	±0.25	±0.200
8/02/79(AM)	Leidy	6.0	313	3.30	3.00	0 to 6	0.25	±0.200
8/02/79(PM)	Leidy	6.0	329	5.71	4.74	0 to 15	0.194	±0.155

NOTE: 30 or 31.6 * units refers to most sensitive scale of Turner Assoc. or Turner Design Fluorometers, respectively.
σ denotes standard deviation.

Horizontal Distribution of θ

Table II-2-9 lists the runs whch were contoured with respect to θ together with the existing hydrographic and meteorological conditions. Figures II-2-19 through II-2-24 show selected runs for 6, 7, and 8 August 1979. The areas contained within closed isotherms were planimetered for all runs contained in Table II-2-9 and are given in Table II-2-10. Table II-2-11 lists the maximum radial extent of the excess temperature isotherms.

Vertical Distribution of θ

Table II-2-12 summarizes the vertical measurements of temperature taken during the August study. The positions of the verticals are shown on Figure II-2-25.

Recirculation

As a result of continuously circulating cooling water through the inplant fluorometers, a film or coating slowly built up in the cell which reduced both the excitation light and the output fluorescence. This was not discovered until the fluorometers were calibrated for the second time at the end of the experiment. This effect was not anticipated since it had not occurred during the April study or at any other power plant study conducted by CBI/MSRC investigators. The inplant dye-concentration data collected during the August study, therefore were unreliable and not amenable to analysis for recirculation as was done for the April study.

Figure II-2-26 shows the intake temperatures (Unit #1 - upper curve; Unit #2 - lower curve) together with wind data from the 200-ft (61-m) level of the microwave tower (wind vectors point toward the direction the wind is blowing; the line on which the vectors originate is oriented 315°M-135°M, i.e., approximately alongshore.

Currents

The location of the current meter mooring during July/August 1979 is shown on Figure II-2-25 as "CM". When the current meter tapes and films were retrieved, it was found that the meter at 10 ft (3.05 m) failed to provide a record because the meter had flooded through the conductivity sensor (a design deficiency since admitted and corrected by Endeco) and the meter at 35 ft (10.7 m) provided a shortened record due to film jam (~6 days).

The 20-ft (6.1-m) record and the short 35-ft (10.7-m) record were then resolved into principal directions and low-

Figure II-2-19. The horizontal distribution of excess temperature, θ, in °C at 0.6 m on 7 August 1979 (PODON (Run #s 6 & 7)).

Figure II-2-20. The horizontal distribution of excess temperature, θ, in °C at 6.0 m on 7 August 1979 (LEIDY (Run #3)).

Figure II-2-21. The horizontal distribution of excess temperature, θ, in °C at 0.6 m on 8 August 1979 (PODON (Run #2)).

Figure II-2-22. The horizontal distribution of excess temperature, θ, in °C at 4.0 m on 8 August 1979 (LEIDY (Run #2)).

Figure II-2-23. The horizontal distribution of excess temperature, θ, in °C at 0.6 m on 9 August 1979 (PODON (Run #s 3-7)).

Figure II-2-24. The horizontal distribution of excess temperature, θ, in °C at 6.0 m on 9 August 1979 (LEIDY (Run #s 5 & 6)).

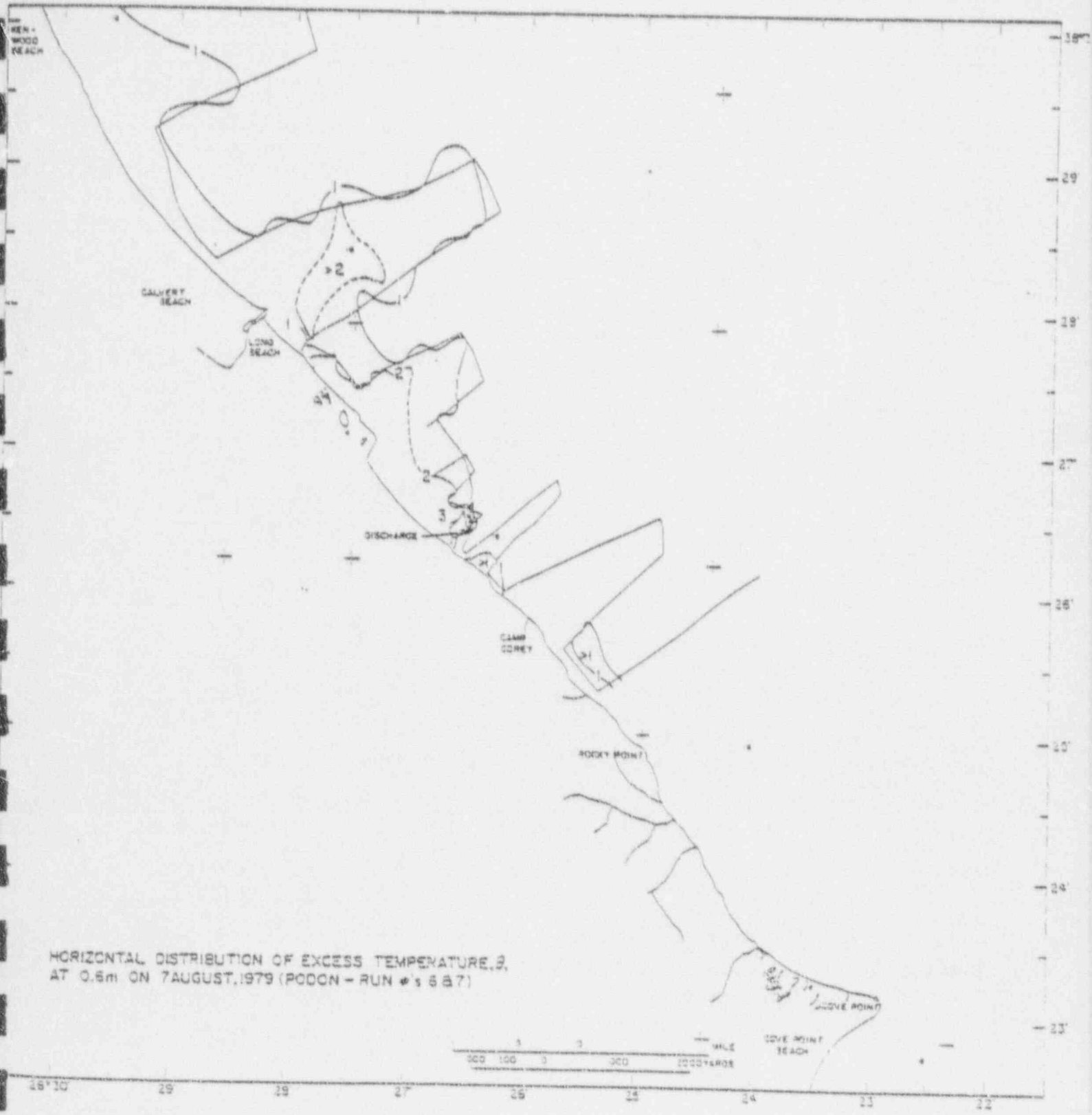


Figure II-2-19.

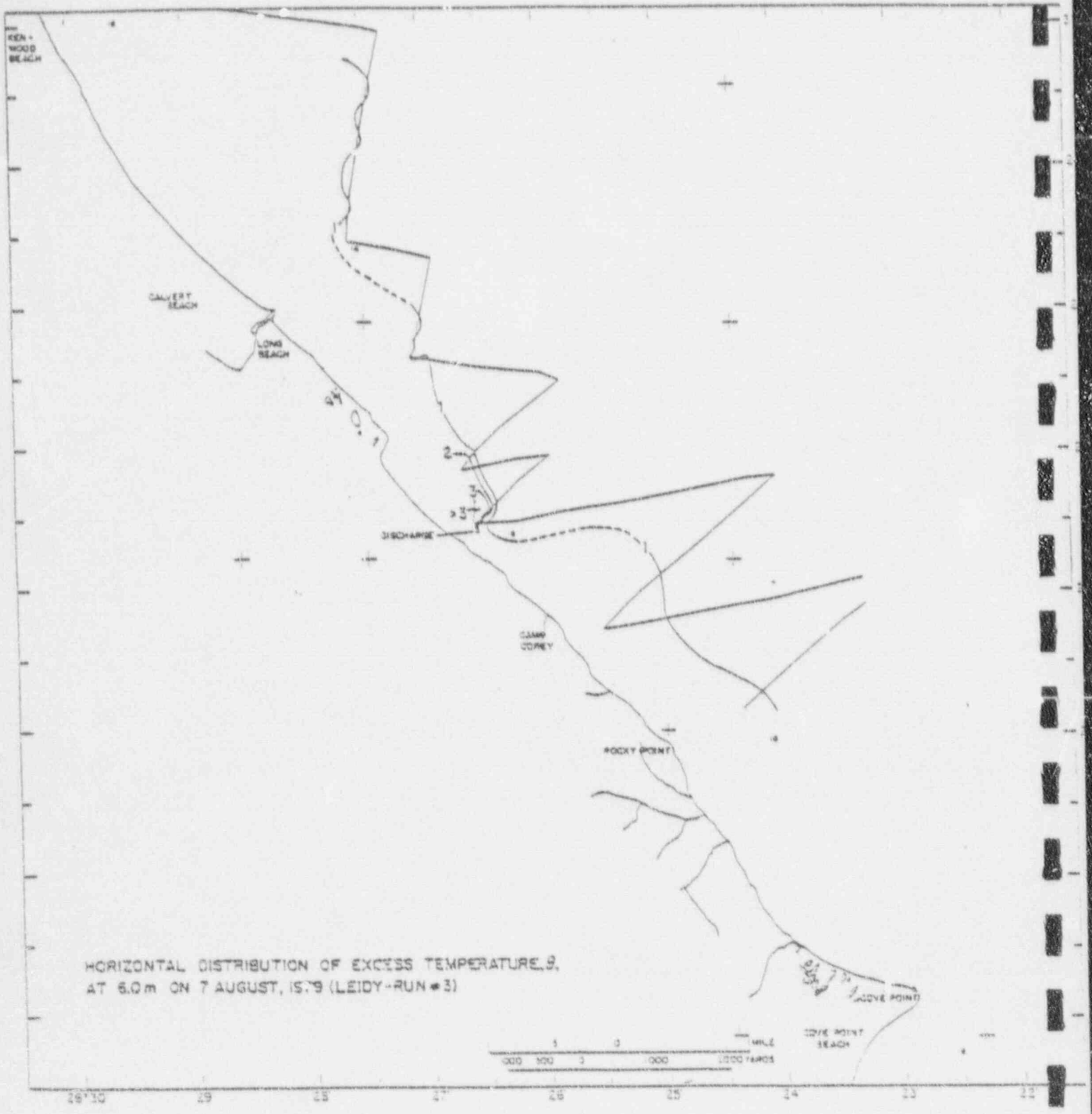
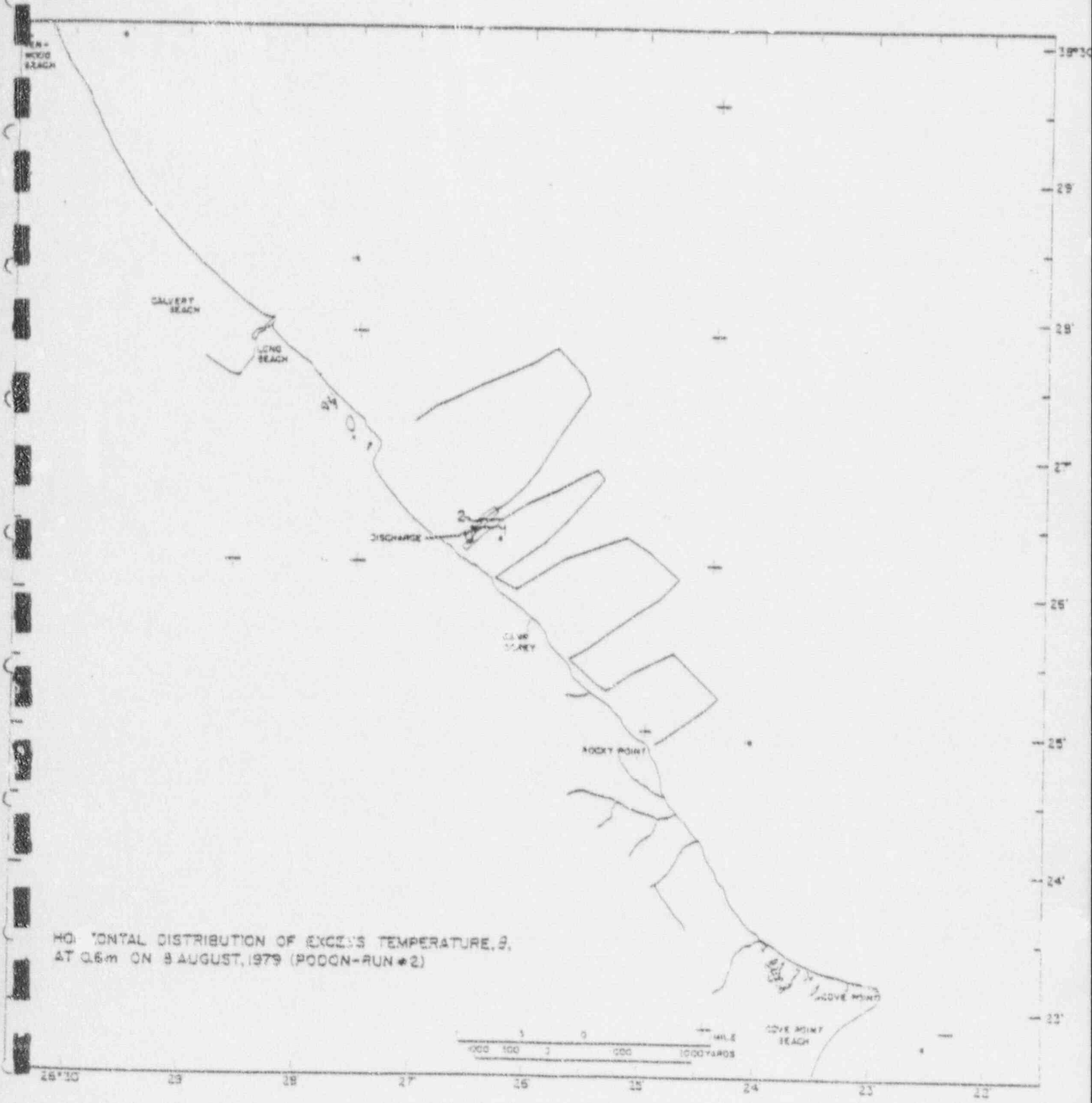


Figure II-2-20.



HORIZONTAL DISTRIBUTION OF EXCESS TEMPERATURE, θ, AT 0.6m ON 8 AUGUST, 1979 (PODDN-RUN #2)

Figure II-2-21.

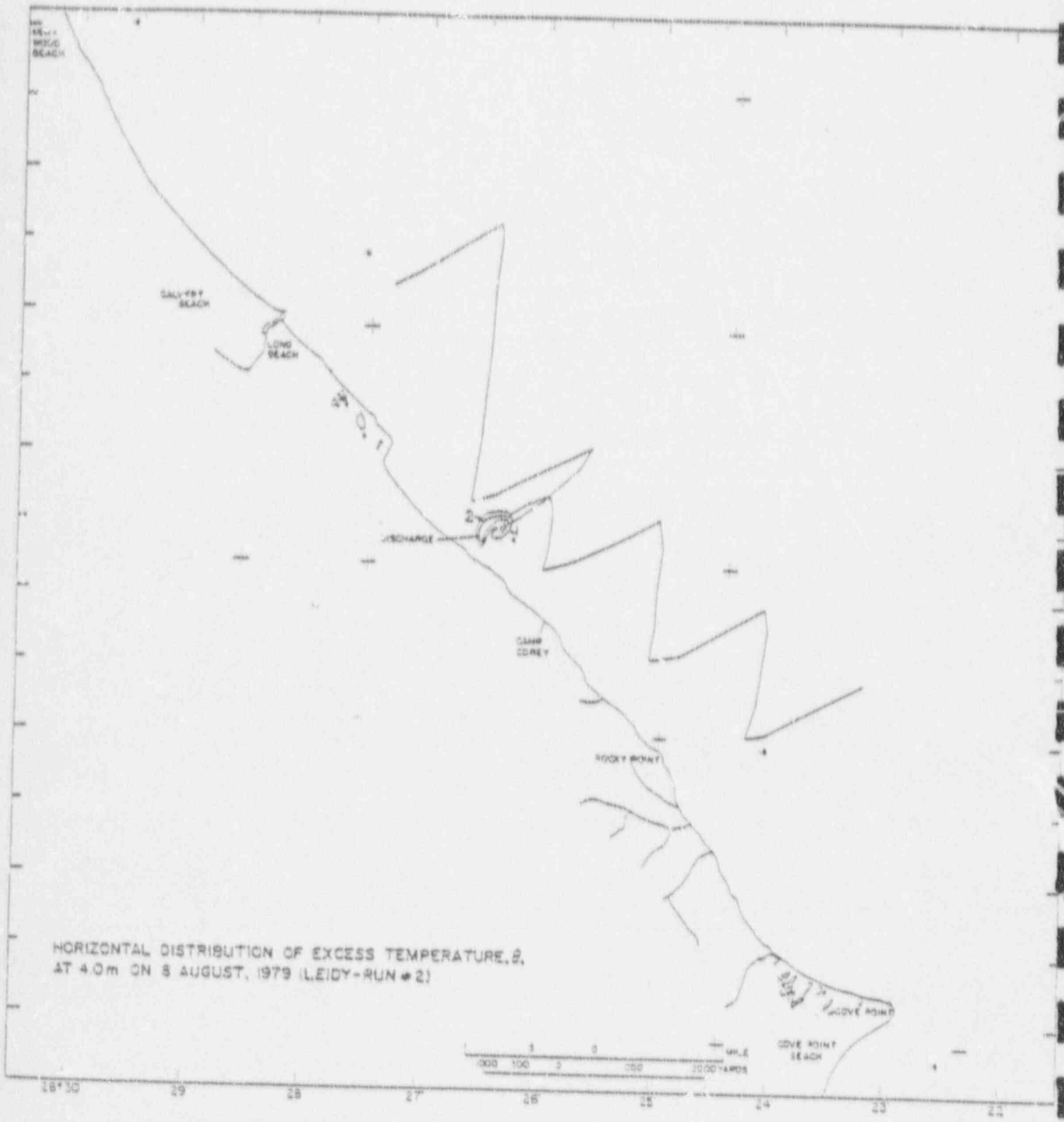
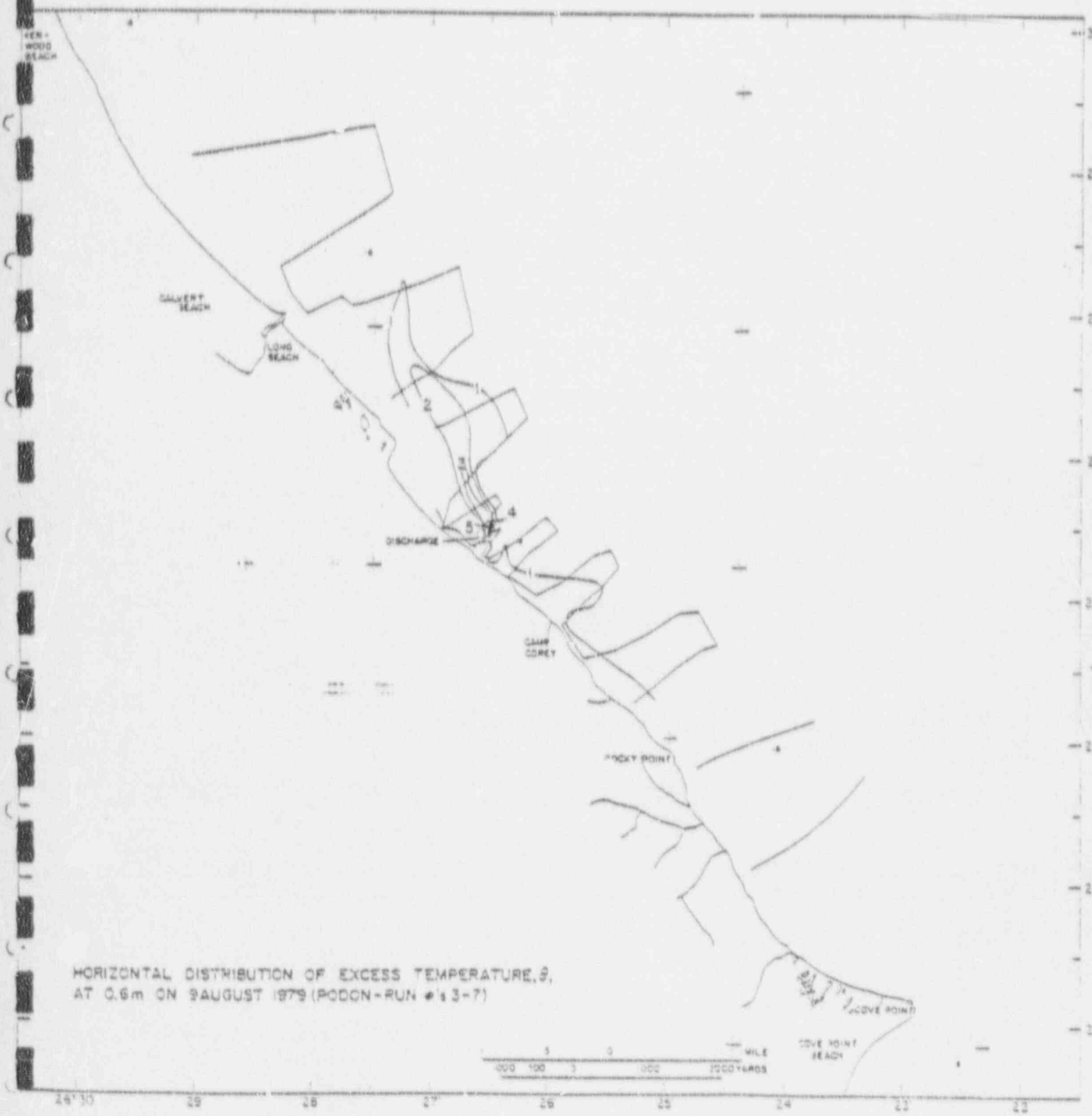


Figure II-2-22.



HORIZONTAL DISTRIBUTION OF EXCESS TEMPERATURE, ϑ, AT 0.6m ON 9AUGUST 1979 (PODDN-RUN #'s 3-7)

Figure II-2-23.

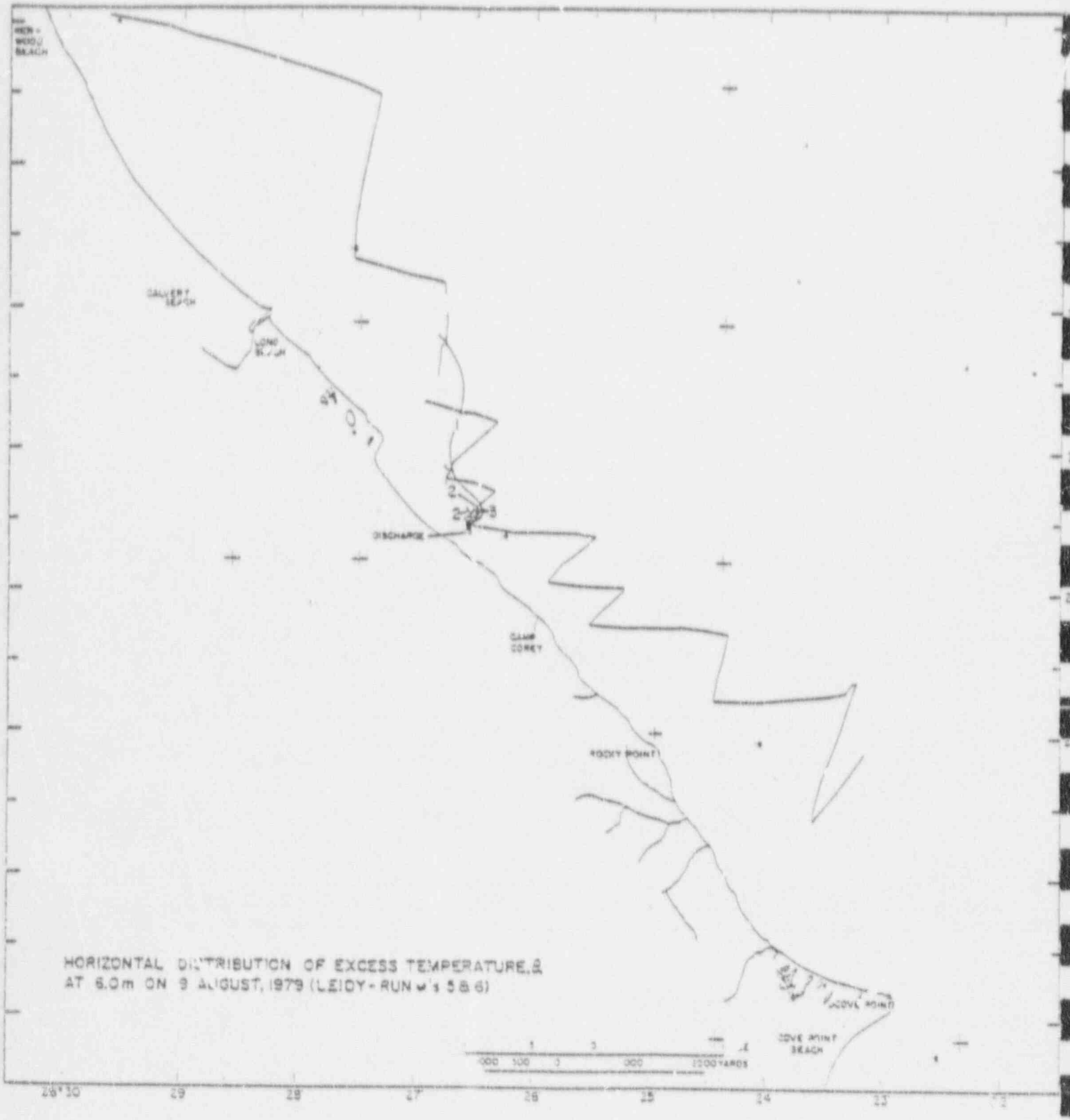


Figure II-2-24.

Table II-2-9. Hydrographic and meteorologic conditions at Calvert Cliffs during the August 1979 study period.

Date	Run #	R/V	Start Time	End Time	Wind* Speed, ms^{-1}	Wind* Direction, °M
8/06/79	2	Podon	0829	1019	3.6	290-306
"	1	Leidy	0832	1013	3.6	290-306
"	3-4	Podon	1357	1612	3.1-3.6	317-359
8/06/79	5	Leidy	1339	1601	3.1-3.6	317-359
8/07/79	1-4	Podon	1012	1137	2.7-3.6	043-061
"	2	Leidy	0853	1133	2.7-4.9	043-61
"	6-7	Podon	1420	1732	2.2-3.1	000-092
8/07/79	3	Leidy	1429	1707	2.2-3.1	000-092
8/08/79	2	Podon	0840	1020	3.6-4.0	227-237
"	2	Leidy	0832	1034	3.6-4.0	227-237
"	3-4	Podon	1233	1520	3.1-4.5	245-277
8/08/79	1-4	Leidy	1227	1605	3.1-4.5	245-277
8/09/79	2	Podon	0921	1113	4.0-4.3	334-351
"	1-4	Leidy	0901	1150	4.0-4.3	334-351
"	5-7	Podon	1248	1549	1.8-5.4	345-357
8/09/79	5-6	Leidy	1255	1617	1.8-5.4	345-357
8/10/79	1-7	Podon	0822	1140	3.1-3.6	210-239
8/10/79	1-4	Leidy	0829	1152	3.1-3.6	210-239

* Wind recorded at 200 feet (61 m) level of the microwave tower. Direction is in degrees magnetic.

Table II-2-10. Summary of areas (10 m^2) contained within specified excess temperature isotherms for August 1979 surveys.

	6/6/79		8/7/79		8/8/79		8/9/79		8/10/79
	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #
θ	2	3-4	3-4	6-7	2	3-4	2	3-7	3-7
				Z = 0.6 m					
4	0.20	-	0.64	0.32	-	0.48	0.60	0.72	-
3	2.24	0.48	11.12	-	0.16	1.60	1.68	8.08	0.16
2	39.92	7.68	49.94	-	1.20	12.96	7.20	62.56	1.04
1	106.88	574.00	-	-	4.96	-	-	-	4.50
	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #
	1	5	2	3	2	3-4	3-4	5-6	2-4
				Z = 2.5 m					
4	-	-	0.60	-	#	-	-	-	-
3	-	-	2.80	2.40	#	5.52	4.48	2.72	-
2	-	-	-	-	#	19.28	10.88	-	-
1	-	-	-	-	#	-	-	-	-
				Z = 4.0 m					
4	-	-	0.64	-	-	-	-	-	-
3	-	-	3.28	5.44	-	4.68	2.32	0.80	2.40
2	7.36	-	12.56	-	10.88	-	9.28	-	-
1	-	-	-	-	3.92	-	-	-	-
				Z = 6.0 m					
4	-	-	0.40	-	*	-	-	-	*
3	-	-	2.00	6.40	*	6.16	3.60	0.80	*
2	2.32	5.04	10.40	-	*	-	14.00	-	*
1	-	-	-	-	*	-	-	-	*

NOTE: (-) indicates isotherm could not be closed; * indicates depth not plotted; # indicates all excess temperatures < 2°C.

Table II-2-11. Summary of maximum radial extent (m) of specified excess temperature isotherms for August 1979 surveys.

	8/6/79		8/7/79		8/8/79		8/9/79		8/10/79
	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #
0	2	3-4	3-4	6-7	2	3-4	2	3-7	1-7
				Z = 0.6 m					
4	120	-	120	-	60	130	220	-	210
3	660	160	720	290	70	280	1020	86	280
2	760	680	1110	1940	300	1180	2480	320	1020
1	-	-	-	-	490	-	3550	-	-
	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #	Run #
	1	5	2	3	2	3-4	3-4	5-6	2-4
				Z = 2.5 m					
4	-	-	160	-	#	-	-	-	-
3	-	-	270	380	#	600	400	230	440
2	-	-	-	1040	#	1260	-	310	620
1	-	-	-	-	#	-	-	-	-
				Z = 4.0 m					
4	-	-	200	-	-	-	-	-	-
3	-	-	380	660	-	510	390	320	380
2	890	-	620	1040	700	1200	-	420	680
1	-	-	-	-	800	-	-	-	-
				Z = 6.0 m					
4	-	-	220	-	*	-	-	-	-
3	-	-	280	550	*	530	390	320	610
2	480	780	640	-	*	1280	-	-	930
1	-	-	-	-	*	-	-	-	-

NOTE: (-) indicates isotherm could not be closed; * indicates depth not plotted; # indicates all excess temperatures < 2°C.

Table II-2-12. Vertical distribution of temperature (°C) in Chesapeake Bay near Calvert Cliffs for August 1979 surveys.

Date	S/V	Vertical #	Time	DEPTH, m 1	2	3	4	5	6	7	8	9	10	11	12
8/01/79	Fulton	1	1039	27.30	27.00	26.95	26.80	26.70	26.65	26.40	26.10	25.65			
"	"	2	1112	27.35	27.35	27.10	27.10	27.20	27.20	27.00	26.60	26.50			
"	"	3	1142	27.60	27.45	27.20	27.05	26.90	26.85	26.80	26.35	26.65	26.30	25.30	
"	"	4	1500	27.55	27.40	27.10	26.90	26.60	26.50	26.50	26.50	26.50	26.50	26.50	26.40
8/01/79	Fulton	5	1555	27.85	27.25	26.50	26.10	26.00	25.75	25.30	25.65	25.50	25.50	25.40	25.25
8/01/79	Tolley	6	0855	-	26.94	-	26.58	-	-	26.61	-	-	-	-	23.70
"	"	7	0905	-	26.94	-	26.63	-	-	25.25	-	24.68	-	-	23.70
"	"	8	1050	27.24	-	26.98	-	26.14	26.00	25.95	-	-	24.00		
"	"	9	1124	27.24	-	27.08	-	26.44	25.98	25.88	-	-	23.90		
"	"	10	1150	27.54	-	26.93	-	27.49	27.18	26.80	-	-	23.90		
"	"	11	1540	27.64	-	27.48	-	26.56	26.20	26.18	-	-	25.00		
"	"	12	1543	27.24	-	27.08	-	26.74	26.48	25.58	-	-	24.48		
"	"	13	1612	27.64	-	27.48	-	27.24	26.58	25.98	-	-	24.68		
"	Fulton	14	0910	26.20	26.85	26.60	26.25	26.00	25.80	25.20	24.55				
"	"	15	0923	27.00	26.85	26.70	26.60	26.30	26.20	26.00	25.90	25.80	25.80		
"	"	16	0955	26.85	26.75	26.45	26.30	26.15	25.80	25.20	24.80	25.00			
"	"	17	1015	27.20	27.10	27.00	26.85	26.85	26.60	26.50	25.35	24.50	24.05		
"	"	18	1301	26.50	26.85	26.50	27.00	27.15	27.00	26.15	24.90	24.20			
"	"	19	1119	28.55	28.00	27.90	27.70	27.40	27.30	27.20	26.60	25.50	25.00	24.95	
"	"	20	1430	28.70	28.50	28.20	28.05	27.80	27.50	27.20	26.95	25.90	27.15		
8/02/79	Fulton	21	1441	28.50	28.45	28.25	28.00	27.75	27.60	27.40	27.25	27.10	27.00	25.60	
8/06/79	Tolley	22	1020	27.34	27.37	27.29	27.38	27.21	27.38	27.21	27.2.				
"	"	23	1047	27.34	27.34	27.34	27.21	27.29	27.38	27.21	27.00				
"	"	24	1104	27.94	27.89	27.84	27.83	27.70	27.58	27.59	27.40				
"	"	25	1117	27.89	27.79	27.74	27.71	27.60	27.58	27.51	27.61				
"	"	26	1135	27.64	27.64	27.54	27.48	27.48	27.41	27.40	27.53				
"	"	27	1149	27.84	27.79	27.71	27.68	27.68	27.51	27.63	27.58				
"	"	28	1610	28.29	28.15	28.06	27.79	27.78	27.61	26.78	26.28				
"	"	29	1625	28.19	28.39	28.14	28.01	28.01	27.91	27.91	27.63				
"	"	30	1636	28.94	28.74	28.56	28.61	28.68	28.53	27.98	27.78				
"	"	31	1649	28.74	28.34	28.11	27.91	27.88	27.83	27.78	27.68				
"	Tolly	32	1308	28.24	28.24	28.06	28.01	27.98	27.81	27.89	27.68				
"	Fulton	33	1616	29.20	29.10	28.65	28.55	28.70	27.95	27.90	27.70				
"	"	34	1645	29.25	29.10	29.05	28.90	28.60	28.30	28.10	27.80	26.60			
8/06/79	Fulton	35	1630	28.05	27.55	27.90	27.90	27.80	27.70	27.65	27.30	25.00			

* Station locations shown in Figure II-2-2.

Table II-2-12 (continued). Vertical distribution of temperature (°C) in Chesapeake Bay near Calvert Cliffs for August 1979 surveys.

Date	R/V	Vertical # *	Time	Depth, m 1	2	3	4	5	6	7	8	9	10	11	12
8/02/79	Lesley	36	1121	28.05	28.04	28.19	28.26	27.81	27.73	27.72	27.43	27.68	27.76		27.63
"	"	37	1152	28.04	27.99	27.91	27.89	27.90	27.80	28.00	28.01	26.68			
"	"	38	1215	28.54	28.25	27.95	27.96	27.58	27.48	27.33	27.31				
"	"	39	1240	27.65	-	27.48	-	27.41	27.28	27.21	26.38				
"	"	40	1258	28.59	-	27.38	-	-	27.06	-	26.28	-	-	24.21	
8/01/79	Lesley	41	1616	28.24	-	27.68	-	-	27.44	-	27.63	-	-	24.68	
8/08/79	Lesley	42	1036	27.19	-	27.08	-	-	27.04	-	26.36	-	-	25.08	
"	"	43	1052	27.29	-	27.18	-	-	27.16	-	26.91	-	-	24.58	
"	"	44	1108	27.64	-	27.51	-	-	27.34	-	26.28	-	-	24.48	
"	"	45	1130	27.86	-	27.38	-	-	27.36	-	25.88	-	-	24.43	
"	"	46	1441	28.29	-	27.68	-	-	27.46	-	27.33	-	-	24.53	
"	"	47	1439	28.39	-	27.30	-	-	27.92	-	26.42	-	-	24.53	
"	Lesley	48	1430	28.44	-	28.01	-	-	27.88	-	27.23	-	-	24.98	
"	Fodum	49	1020	27.50	27.30	26.95	26.98								
"	"	50	1541	27.85	27.30	27.60	27.60	27.60	27.45	27.65	27.40	27.10			
"	"	51	1547	28.65	28.95	29.00	29.00	29.05	29.12	29.00	28.95	28.35			
"	"	52	1553	28.50	28.00	27.65	27.65	27.65	27.65	27.70	27.95				
"	"	53	1601	28.35	28.05	28.00	27.95	27.95	27.80	27.70	27.50	27.20	27.00	26.00	25.90
8/08/79	Fodum	54	1612	28.60	28.60	28.40	28.35	28.00	27.95	27.80	27.50	26.60	25.50	25.30	25.20
8/09/79	Lesley	55	0913	26.65	-	26.33	-	-	26.26	-	25.30	-	-	24.68	
"	"	56	1153	26.69	-	26.83	-	-	26.36	-	27.18	-	-	24.73	
"	"	57	1207	27.07	-	27.08	-	-	27.09	-	25.43	-	-	24.58	
"	"	58	1220	27.09	-	27.06	-	-	26.99	-	27.08	-	-	24.73	
"	"	59	1425	27.44	-	27.33	27.19	-	27.15	-	-	26.88			
"	"	60	1440	27.49	-	27.38	-	-	26.99	-	27.03	-	-	24.63	
"	Lesley	61	1701	27.34	-	27.13	-	-	26.91	-	26.58	-	-	24.48	
"	Fodum	62	1127	27.25	27.25	27.25	27.25	27.25	27.25	27.25	27.25	27.20			
"	"	63	1143	27.10	27.10	27.10	27.10	27.15	27.20	27.30	27.30	27.20	27.20	27.00	
"	"	64	1150	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	26.90	26.20	25.40
"	"	65	1202	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	26.95	26.50	26.20
"	"	66	1604	27.20	27.20	27.20	27.20	27.20	27.05	26.95	26.90	25.50			
"	"	67	1611	27.20	27.20	27.20	27.20	27.20	27.00	26.20	24.80	24.80	24.80		
"	"	68	1622	28.00	27.50	27.30	27.60	27.30	27.10	27.00	26.60				
8/09/79	Fodum	69	1429	27.50	27.30	27.25	27.20	27.20	27.15	27.00	26.85				
8/10/79	Lesley	70	0956	27.44	27.44	27.40	27.19	-	25.00	24.50	-	24.68			
"	"	71	1154	26.64	-	27.10	-	27.09	26.70	26.36	-	-	24.98		
"	"	72	1205	27.01	-	27.38	-	27.14	26.62	26.68	-	-	25.48		
"	"	73	1535	28.34	-	28.13	-	27.69	27.48	27.38	-	-	25.28		
"	"	74	1545	28.24	-	28.00	-	27.66	27.33	27.28	-	-	26.38		
"	Lesley	75	1556	27.94	-	-	-	26.99	26.88	26.68	-	-	25.98		
"	Fodum	76	1149	27.20	27.40	26.90	26.75	26.65	26.45	26.20	25.95	25.80	25.65	25.30	
"	"	77	1159	27.35	27.25	27.20	27.15								
8/10/79	Fodum	78	1206	27.30	27.50	27.35	27.50	27.35	27.35	27.50					

* Station locations shown in Figure II-2-25.

Figure II-2-25. Location of stations for vertical temperature measurements during the August field study. The plotted numbers correspond to Vertical #, Column 3, Table II-2-12.

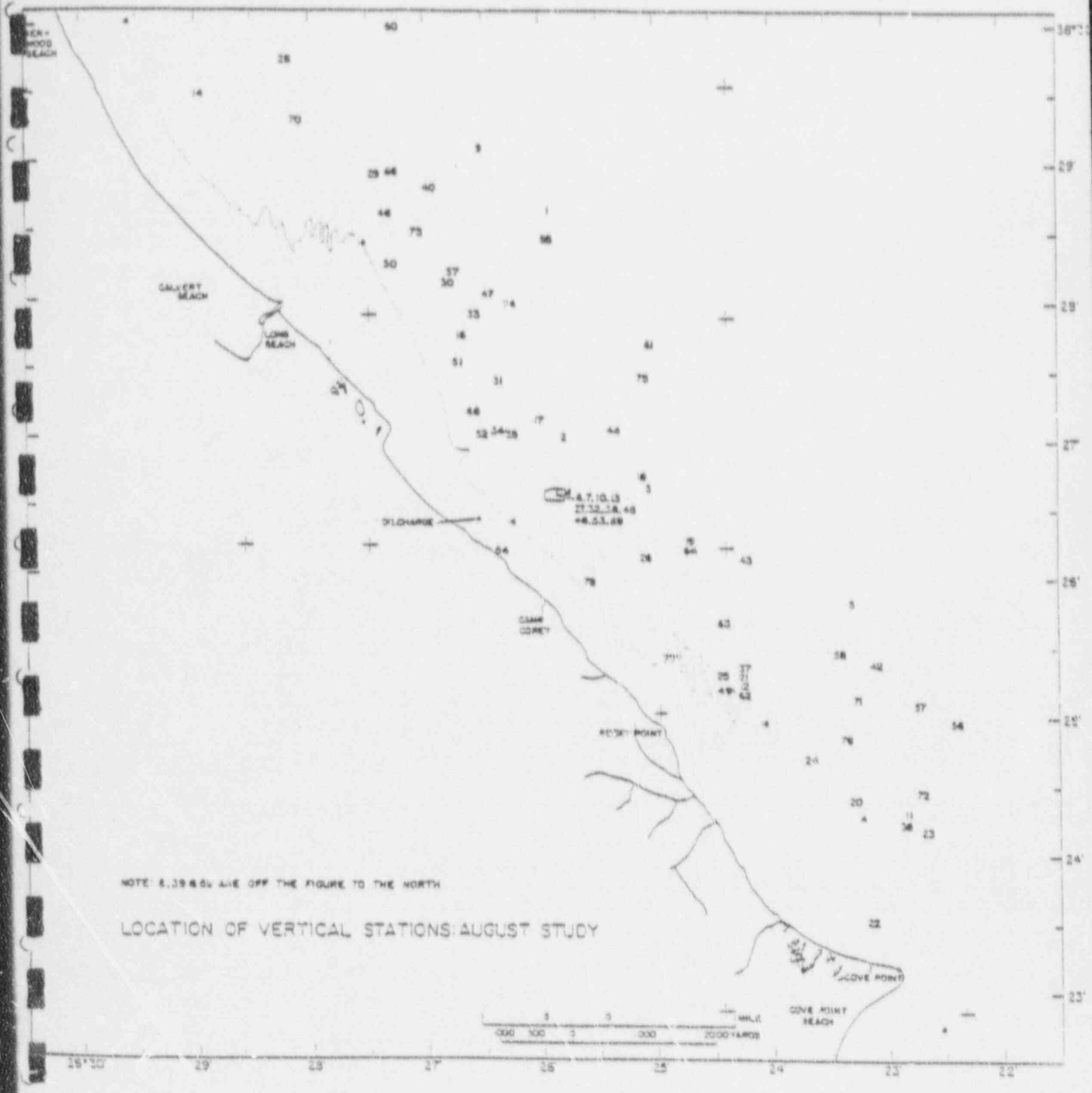


Figure II-2-25.

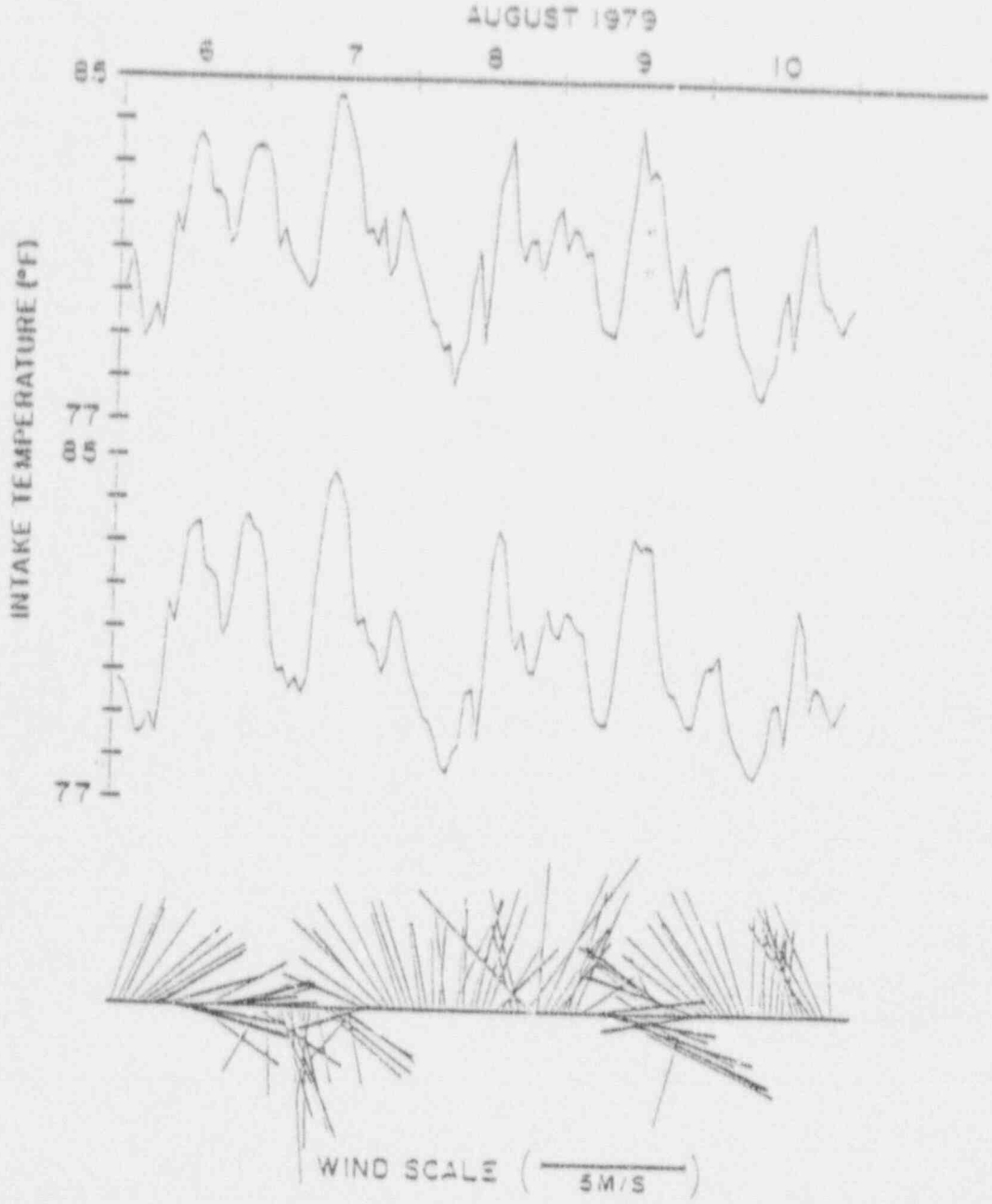


Figure II-2-26. Intake temperatures (Unit #1 - upper curve; Unit #2 - lower curve) together with wind data from the 200-ft (61-m) level of the microwave tower during the August study. Wind vectors point toward the direction the wind is blowing; the line on which they originate is 315°M-135°M, i.e., approximately shore parallel at Calvert Cliffs.

pass filtered to remove the noise. The 20-ft (6.1-m) record was then analyzed for ebb and flood excursion lengths using a procedure identical to that employed in the April analysis. Figure II-2-27 is a histogram (frequency versus excursion length) showing the results of this analysis.

Plotted on Figure II-2-28 are the low-pass filtered data for alongshore currents at the two depths (~20 and 25 ft) for the period 26 July - 10 August 1979. Figure II-2-29 shows the low-pass filtered alongshore current data at 20 ft (6.1 m) for the 5-day period (6-10 August 1979) with sampling periods indicated as cross-hatched areas.

Stratification

For the August surveys, temperature and salinity data were obtained from the floating platform vertical profiler located 300 ft (91.5 m) from the intake curtain wall in 55 ft (16.8 m) of water. Time series of isopycnal, isohaline, and isothermal profiles (prepared by the BG&E Environmental Engineering section) are given for 1 to 10 August 1979 in Figures II-2-30 to II-2-39.

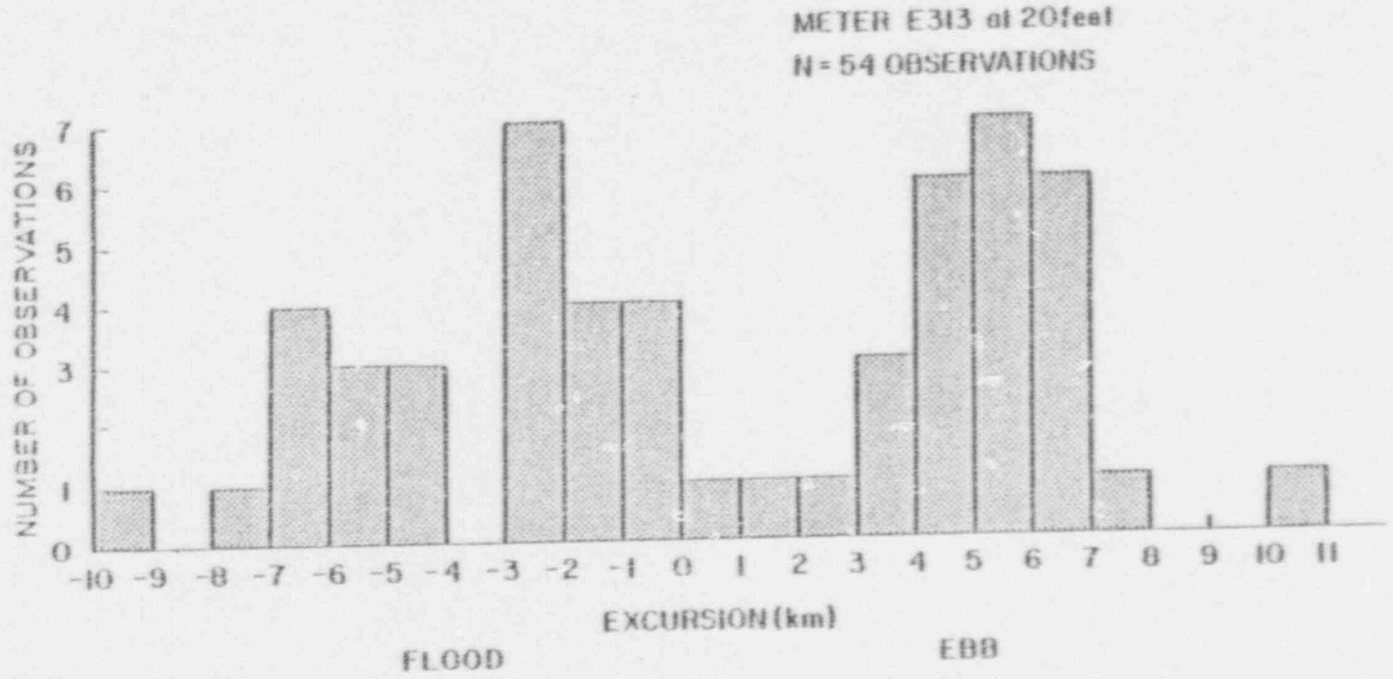


Figure II-2-27. A histogram of the measurements of the flood and ebb excursions at 20 ft (6.1 m) off Calvert Cliffs during July/August 1979.

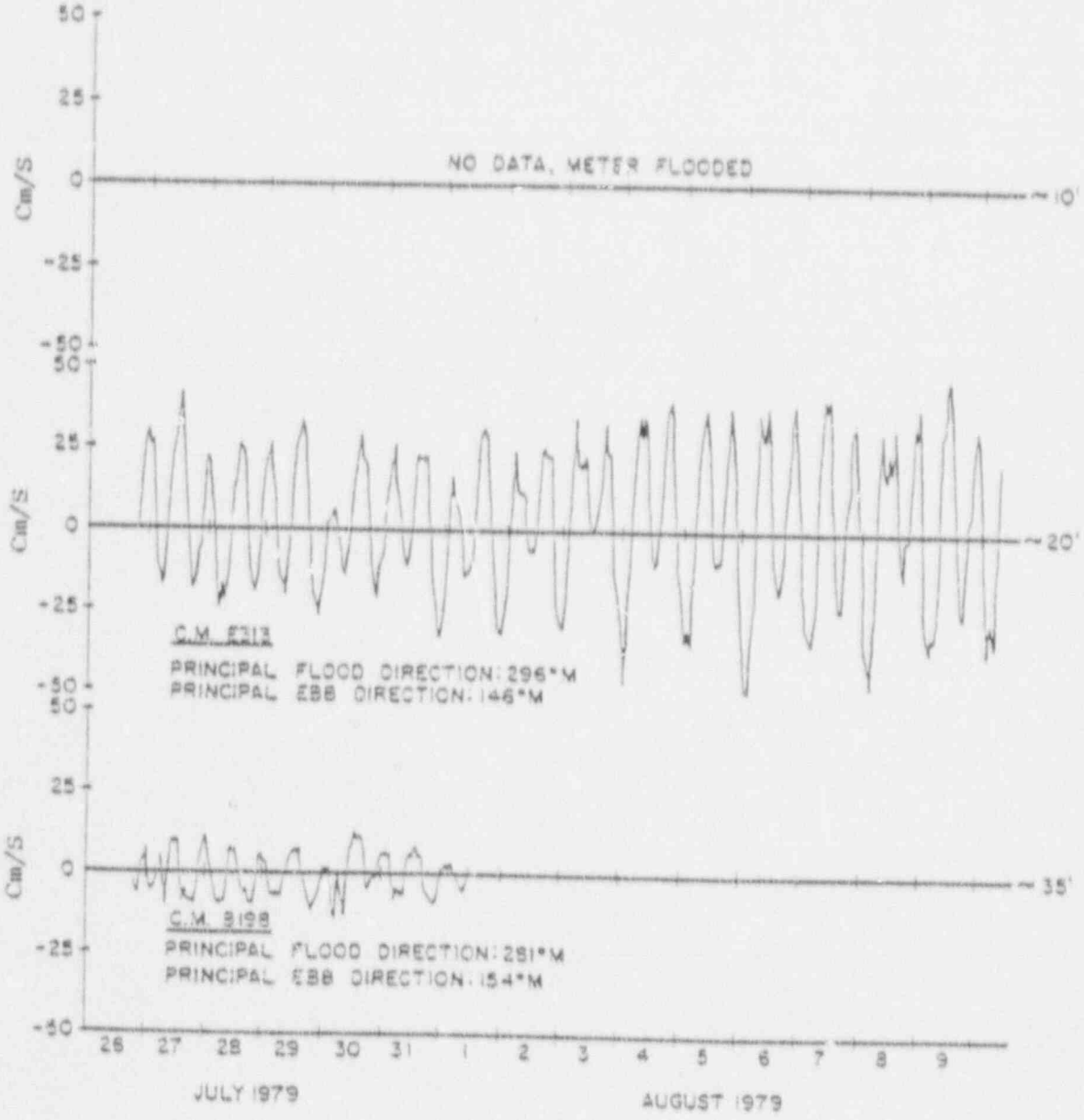


Figure II-2-28. Low-pass filtered data for alongshore currents at 20 and 35 ft (6.1 m and 10.7 m) off Calvert Cliffs between 26 July and 10 August 1979. Ebb current is positive, flood is negative.

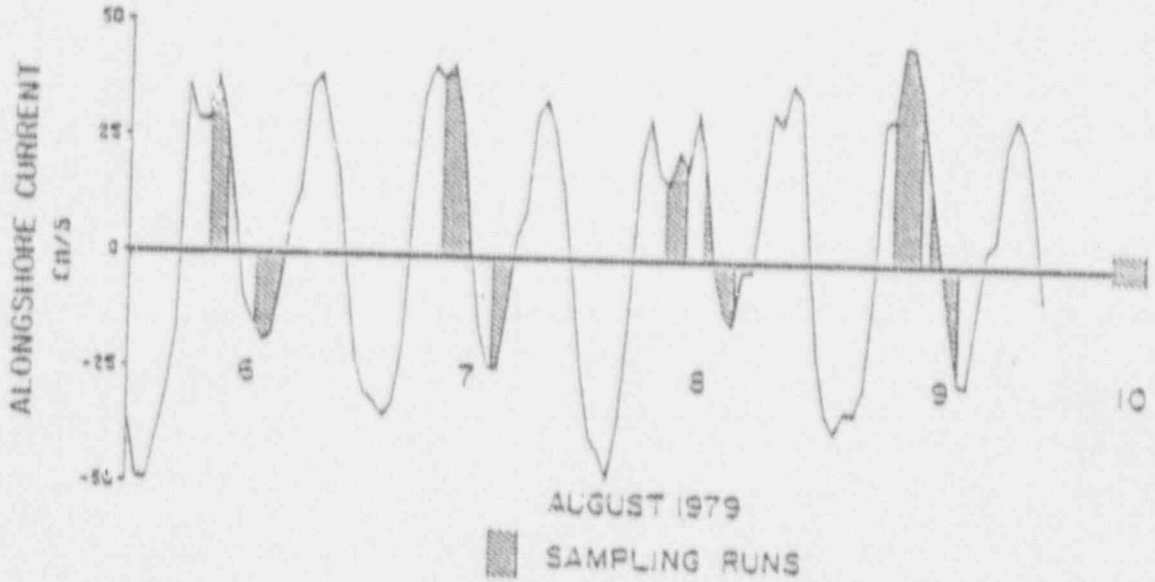


Figure II-2-29. Low-pass filtered data for alongshore currents at 20 ft (6.1 m) for the five-day period 6-10 August 1979 off Calvert Cliffs. Sampling periods are indicated on the figure as cross-hatched areas. Ebb currents are positive, flood currents are negative.

Figures II-2-30-39. Temperature, salinity and σ_t (density anomaly) at vertical profiler located off intake during the August 1979 survey. σ_t = (Density in mg/l-1)x1000.

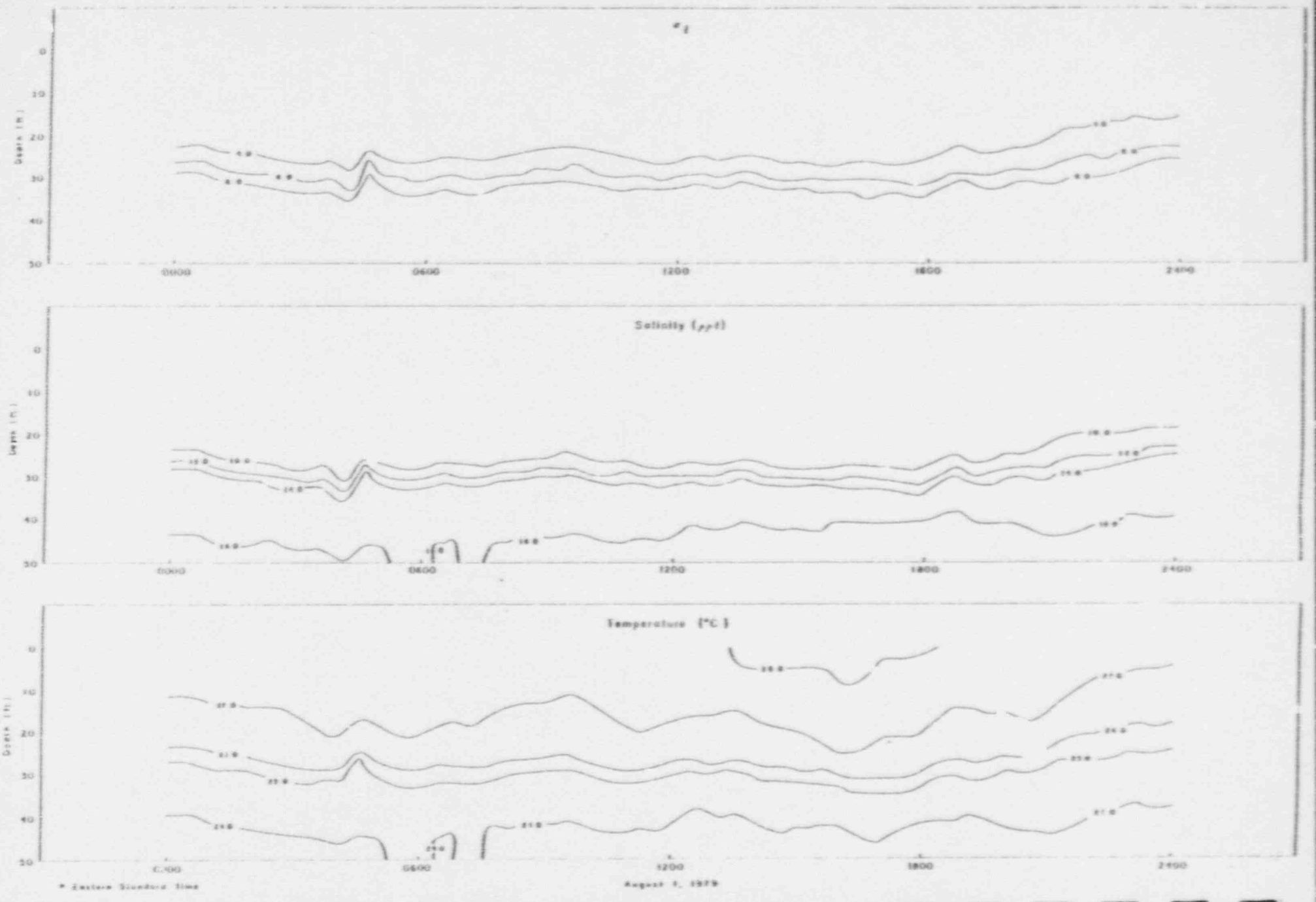

Salinity (ppt)
Temperature (°C)
Depth (ft.)
0000
0600
1200
1800
2400
August 1, 1979

Figure II-30

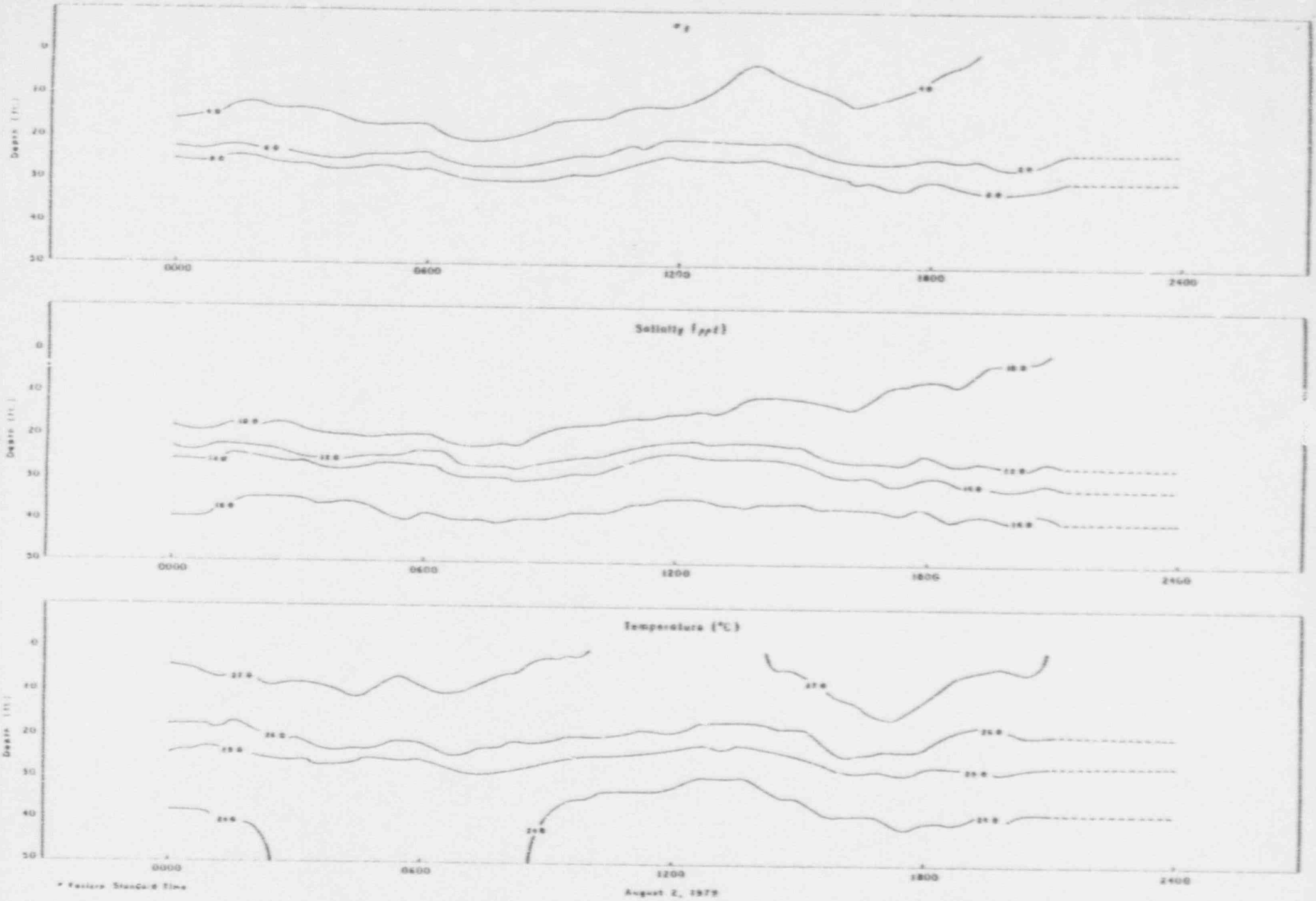


Figure II-2-31.

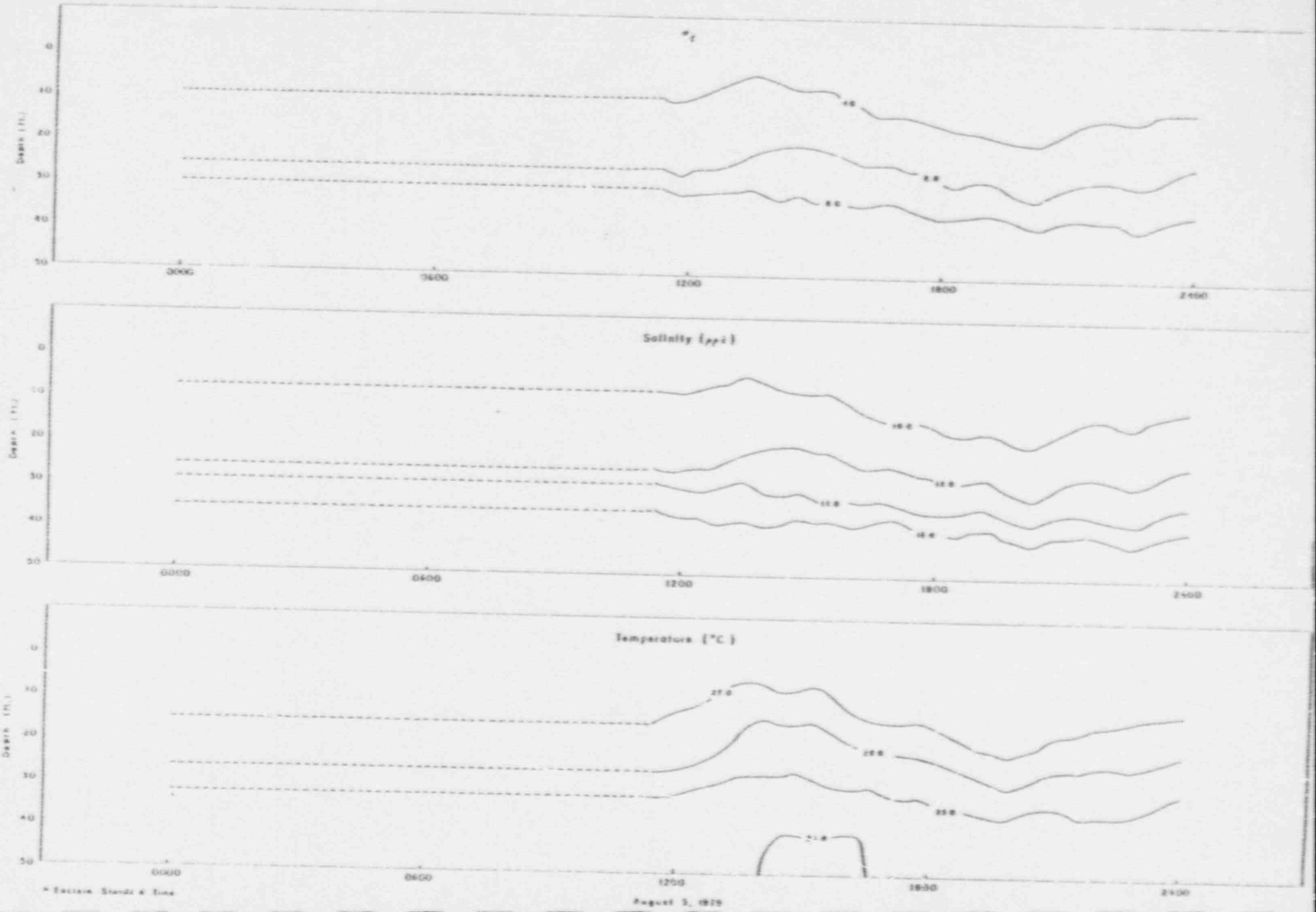


Figure 21-2-32.

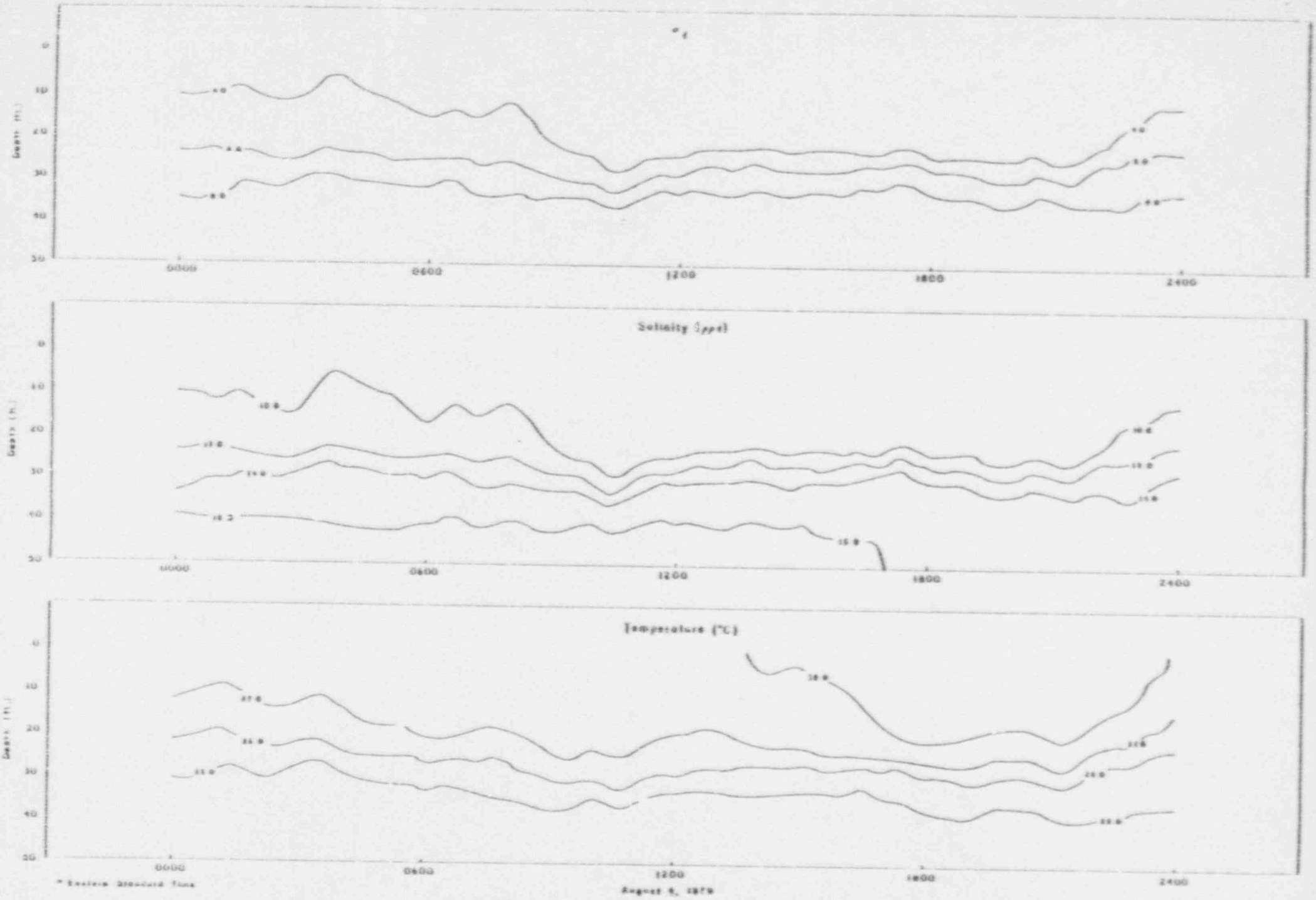


Figure II-2-33.

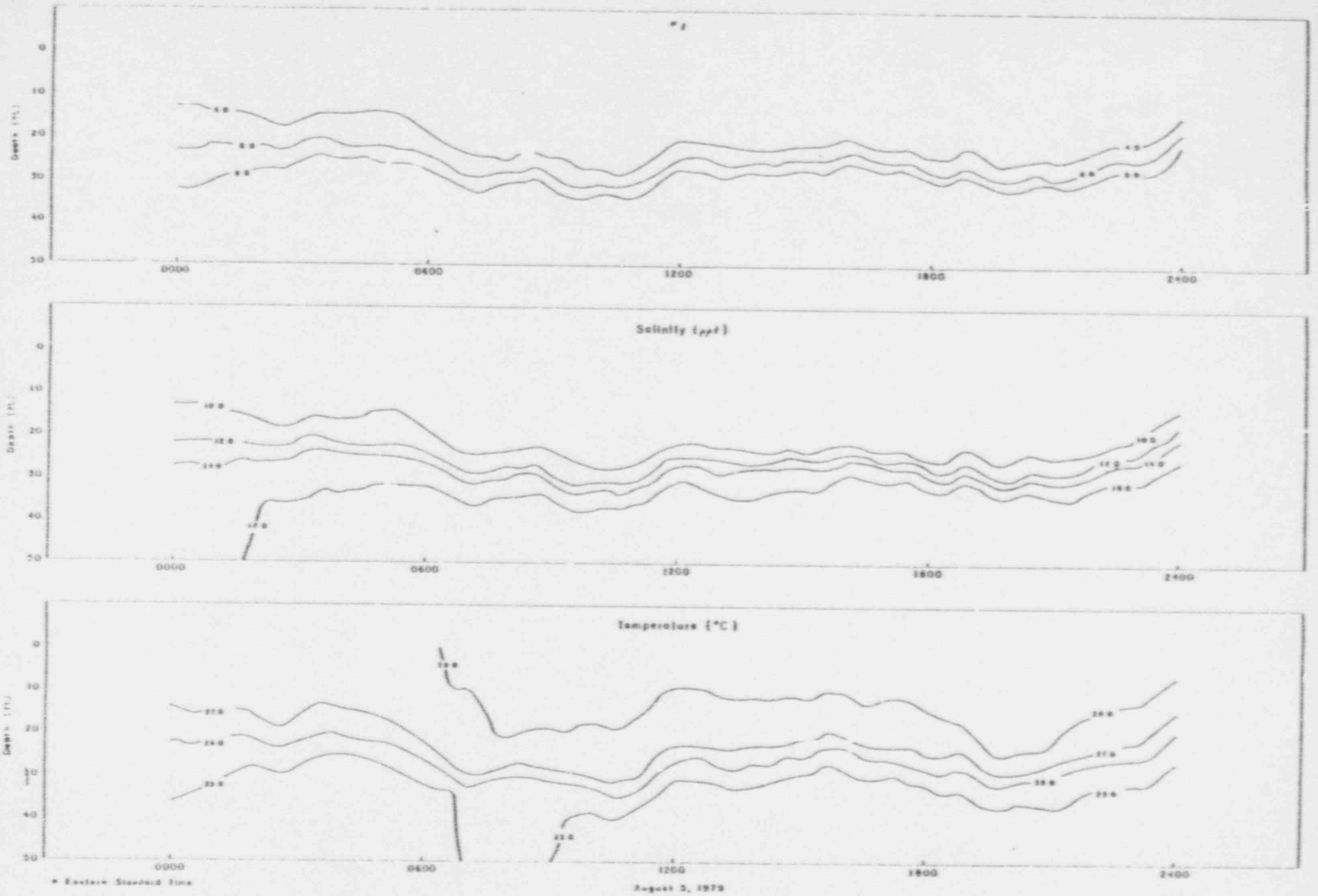


Figure II-2-34.

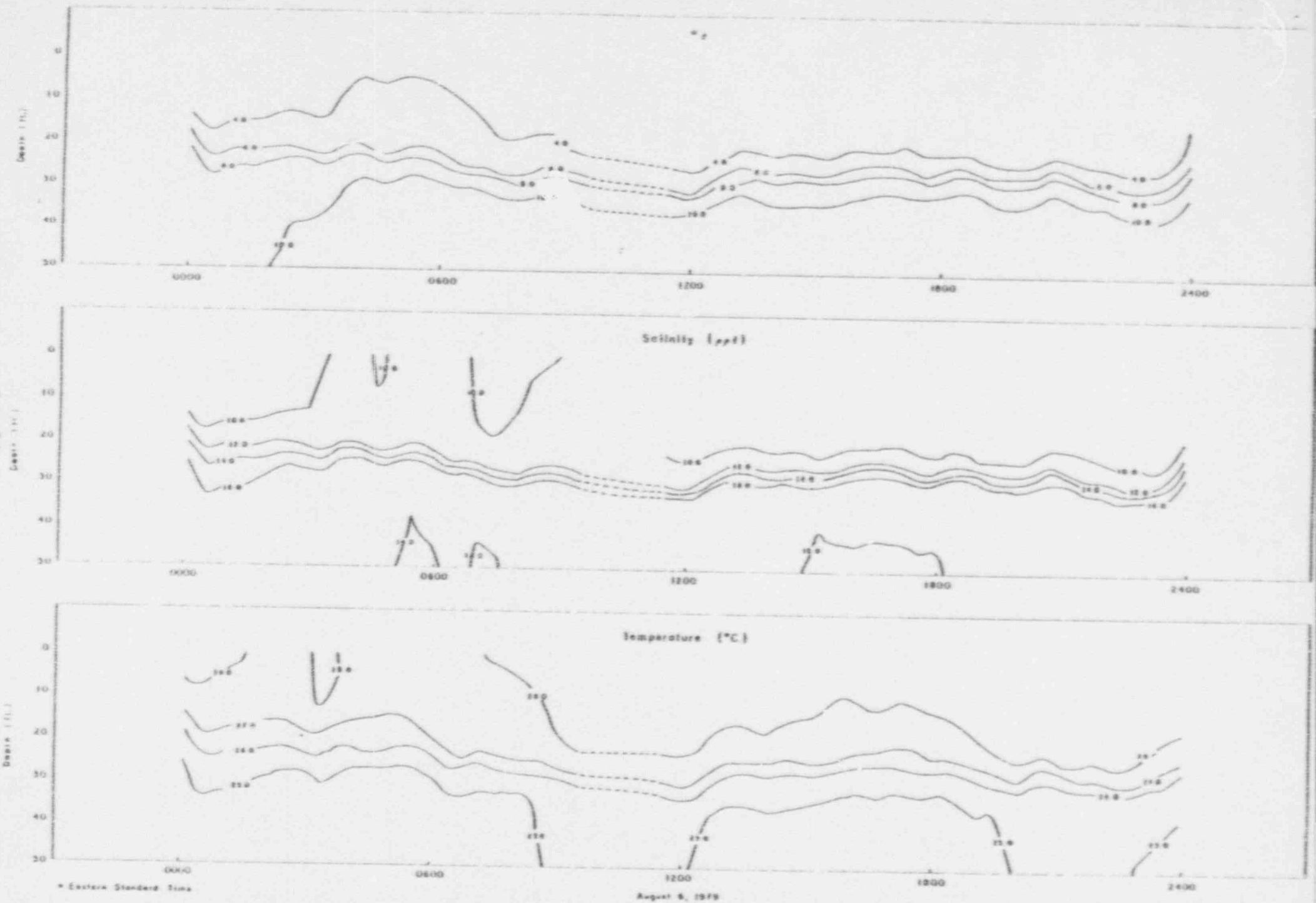


Figure II-2-35.

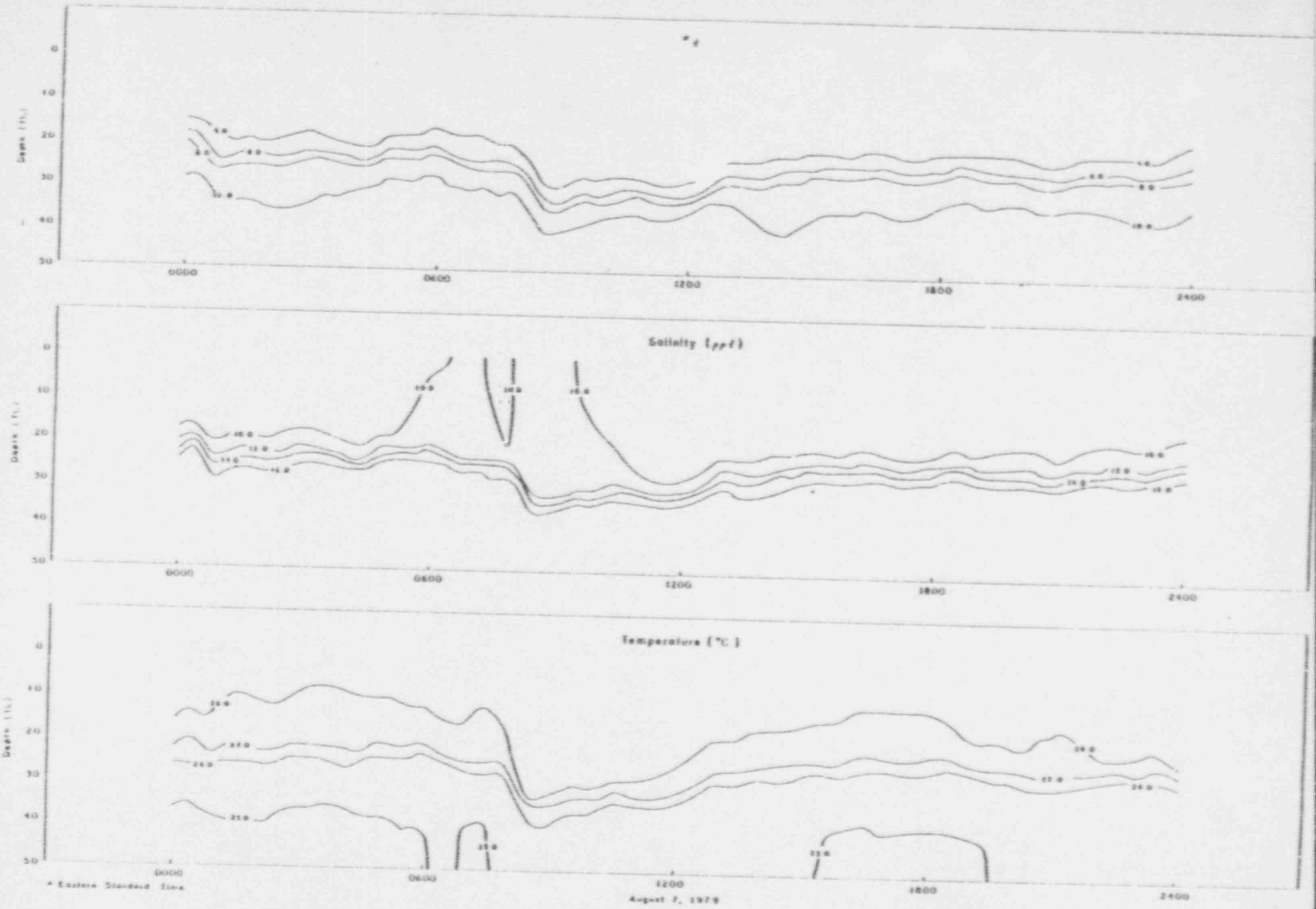


Figure II-2-36.

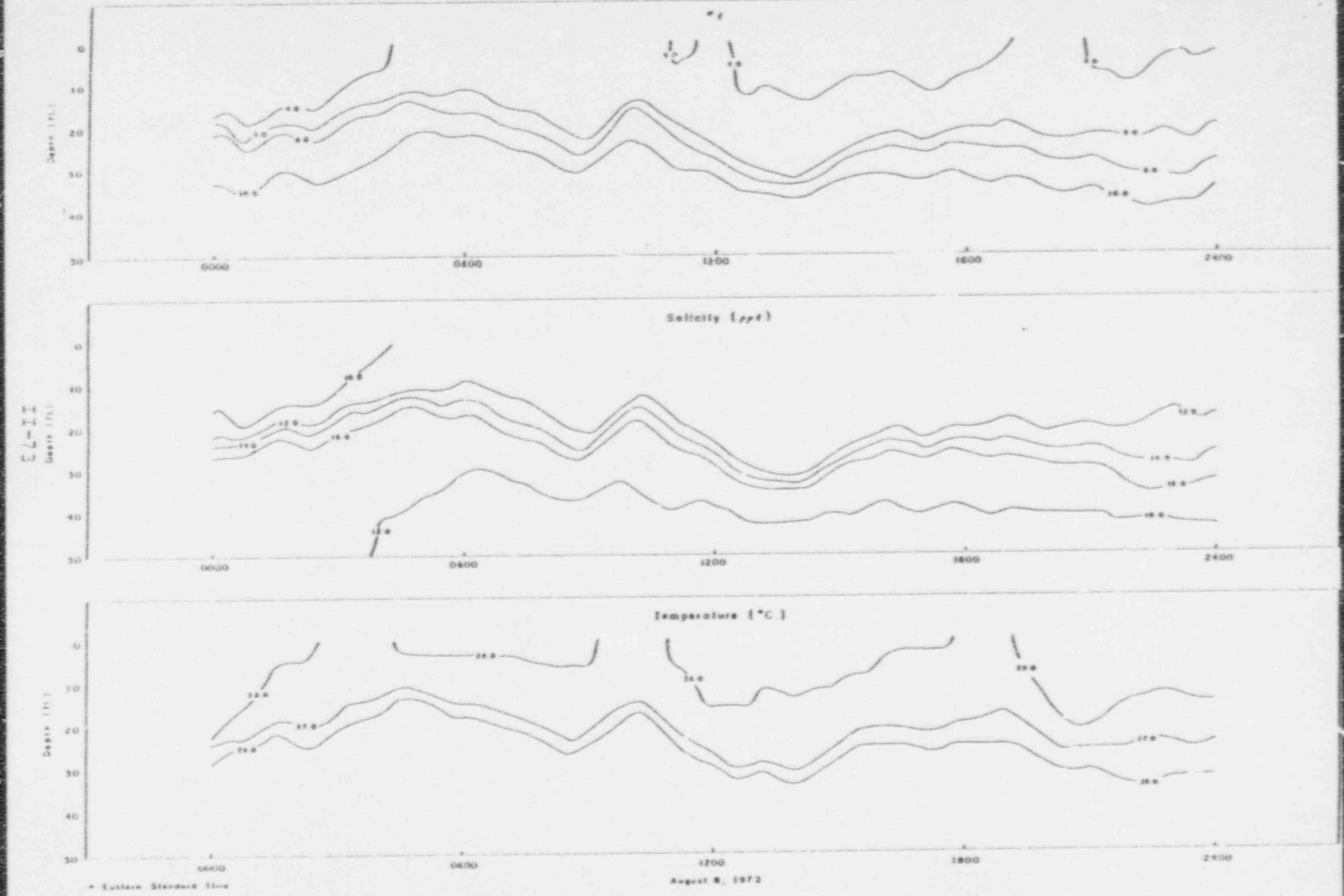


Figure II-2-37.

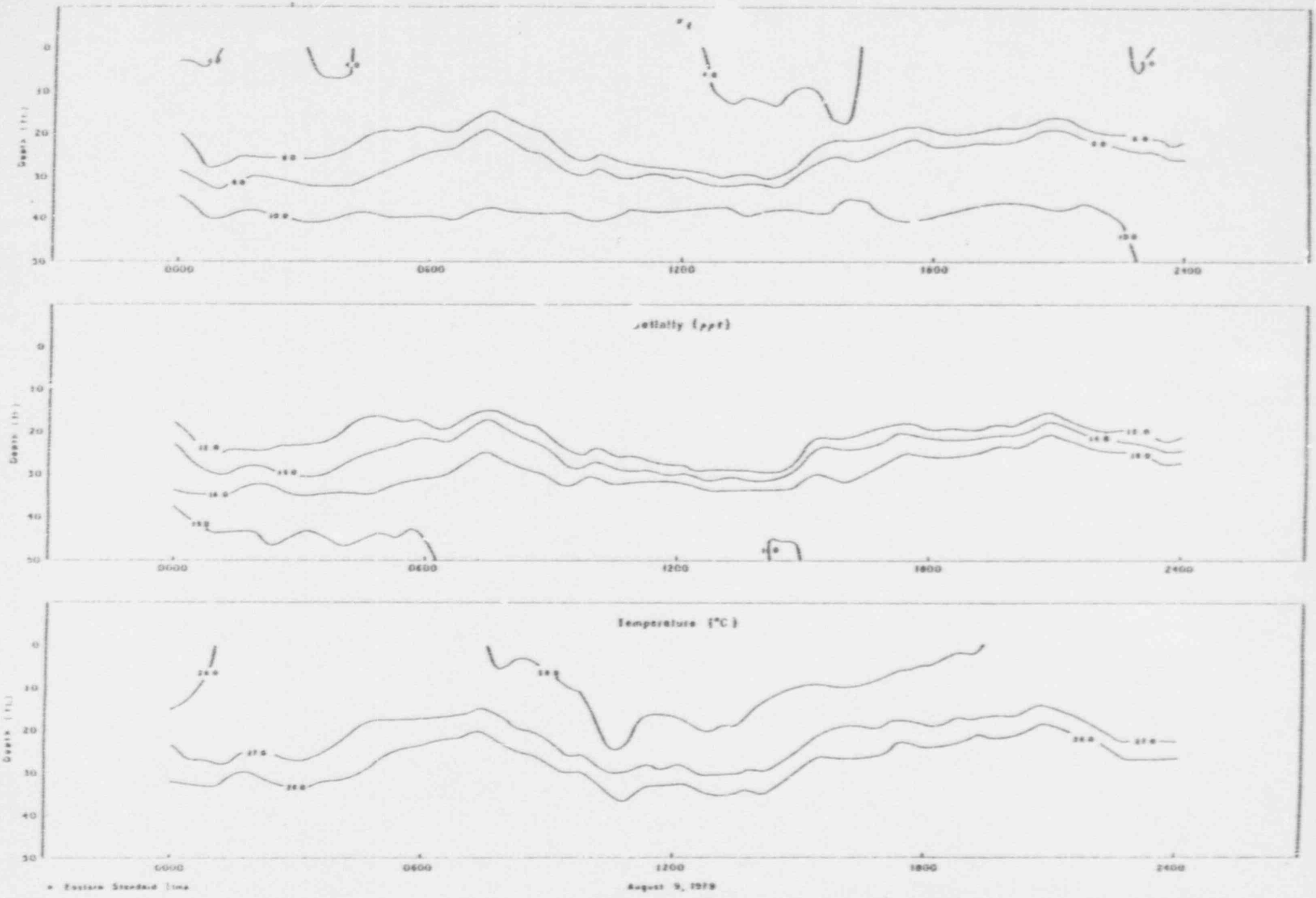


Figure II-2-38.

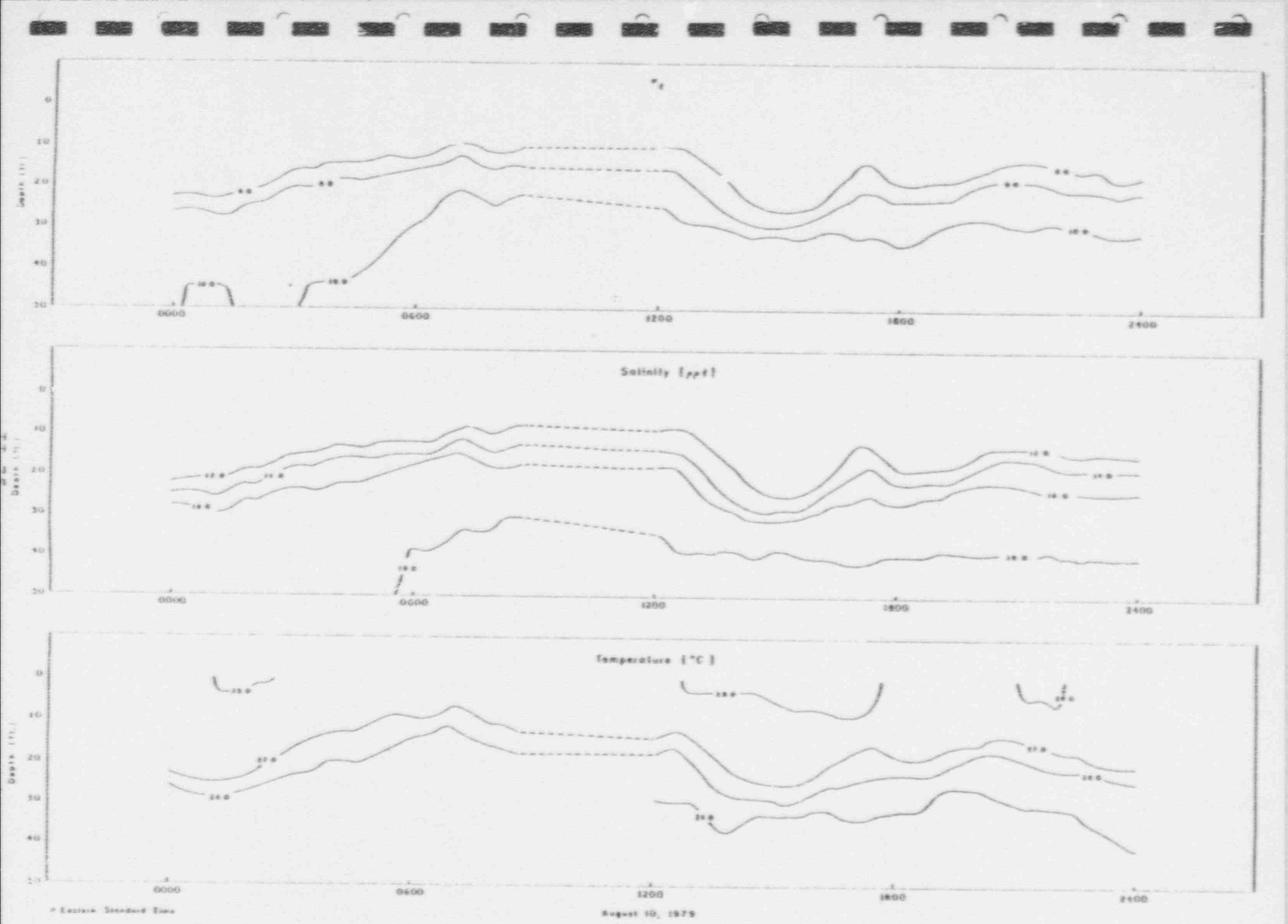


Figure II-2-39.

3. PLUME DIMENSIONAL ANALYSIS

The extensive data sets from the plume surveys were reduced and summarized to compare conditions between surveys. The plume area-excess temperature data were scaled to parameters that can be compared between surveys and to the hydrographic condition during each survey. These analyses provide relationships that can be used to estimate plume sizes relative to other conditions.

Summary Plume Data

Pertinent dimensional data for each plume mapping of the April and August surveys are summarized in Table II-3-1. These data represent individual values of parameters as they existed during the times of the mapping. Since the plume has some "memory" of antecedent conditions, the plume size may be affected by earlier values of parameters and it may be necessary to examine the detailed time-series record for interpretation.

Table II-3-1 presents summaries of data for the plume surface areas and lengths for the 4°C to 1°C isotherms shown in Tables II-2-5 and II-2-6 for the April survey and Tables II-2-10 and II-2-11 for the August survey. The plant heat rejection rates are summarized from data displayed in Figures II-2-1 and II-2-2.

Since the intake temperature is quite variable through the day, it is summarized as the daily maximum and minimum data presented in Figure II-2-14 and Figure II-2-26 and from hourly plant operating records. Figures II-2-30 to II-2-39, showing the time series of stratification near the intake, will also be used in examining intake conditions. The condenser temperature rise, ΔT, is summarized from the plant operating records.

The plume background temperature is summarized from data given in Table II-2-2. These data were determined for each plume mapping from the dye-temperature correlations, examples of which are shown in Figures II-2-3 to II-2-5.

The tidal excursion distance is identified with each plume mapping in Figure II-2-18 for the April 1979 survey and Figure II-2-29 for the August survey. The tidal excursion distance is defined as the time integral from zero crossing to zero crossing of the tidal velocity record.

The discharge excess temperature, θ_o, is defined as the sum of intake excess temperature, θ_i, and the condenser temperature rise ΔT. It is determined from the intake dye concentration measurements, from intake recirculation, or from the slope of the dye concentration-temperature relationships. During periods of thermal stratification with bottom water colder than surface water, the discharge excess temperature can

Table II-3-1. Summary of plume sizes and conditions during all plume surveys.

Date	Run	Surface Areas ($10^4 m^2$) For following Isotherms				Lengths (m) for following Isotherms				Tidal Excursion Distance
		4°C	3°C	2°C	1°C	4°C	3°C	2°C	1°C	km
4/15/79	1	-	1.20	5.60	-	-	360	720	2400	6.55
4/15/79	2	-	-	34.80	-	-	-	1180	2620	6.55
4/16/79	2	0.80	0.84	28.80	-	220	260	1020	2280	5.91
4/17/79	1	0.40	4.80	17.60	196.00	160	700	1300	4520	6.51
4/17/79	4	-	3.60	39.60	-	-	580	1600	-	-1.71
4/18/79	1	1.20	4.80	17.20	256.00	280	500	1200	5300	7.09
4/19/79	2	0.40	2.00	136.0	-	120	340	3060	-	5.00
4/20/79	1	0.80	2.00	375.0	-	180	600	4870	-	-1.92
8/06/79	2	0.20	2.24	39.92	106.88	120	660	760	-	5.85
8/06/79	3,4	-	0.48	7.68	574.00	-	160	680	-	-2.27
8/07/79	3,4	0.64	11.12	49.94	-	120	720	1380	-	6.98
8/07/79	6,7	0.32	-	-	-	-	240	3940	-	-2.60
8/08/79	2	-	0.16	1.20	4.96	60	76	300	490	6.32
8/08/79	3,4	0.40	1.60	12.96	-	130	280	1180	-	6.32
8/09/79	2	0.60	1.68	7.28	-	220	1020	2480	3550	7.60
8/09/79	3,7	0.72	8.08	62.56	-	-	84	320	-	7.60
8/10/79	1,7	-	0.16	1.04	4.00	210	280	1020	-	-2.55

Table II-?-1 (continued). Summary of plume sizes and conditions during all plume surveys.

Date	Run	Plant Heat Rejection MWT	Intake Temperature, °C Max	Intake Temperature, °C Min	Condenser Temperature Rise ΔT, °C	Ambient Temperature Ta, °C	Discharge Excess Temperature θe, °C
4/15/79	1	3520	10.6	8.9	5.72	9.39	5.72
4/15/79	2	3520	10.6	8.9	5.72	10.33	6.19
4/16/79	2	3520	10.5	9.3	5.72	9.06	6.41
4/17/79	1	3520	10.3	9.2	5.72	8.53	6.30
4/17/79	4	3520	10.3	9.2	5.72	8.98	6.68
4/18/79	1	3520	10.8	8.9	5.72	8.65	5.95
4/19/79	2	3520	11.7	9.6	5.72	10.80	5.72
4/20/79	1	3520	11.7	10.6	5.72	10.10	6.25
8/06/79	2	3520	28.6	26.1	6.0	27.15	6.78
8/06/79	3,4	3490	28.6	26.1	6.0	27.80	6.36
8/07/79	3,4	3500	29.2	26.7	6.0	27.02	6.81
8/07/79	6,7	3500	29.2	26.7	6.0	27.65	6.75
8/08/79	2	3490	28.6	25.6	6.2	27.00	5.44
8/08/79	3,4	3480	28.6	25.6	6.4	27.5?	6.94
8/09/79	2	3500	28.9	26.1	6.6	26.79	5.96
8/09/79	3,7	3480	28.6	25.6	6.4	27.00	7.66
8/10/79	1,7	3500	27.5	25.3	6.4	26.94	4.83

be less than the condenser ΔT and the difference represents the amount of condenser heat absorbed in raising the cooler intake-water temperature to the ambient surface-water temperature. During periods when there is thermal stratification with bottom water warmer than surface water supported by salinity stratification, the discharge excess temperature can be higher than the value resulting from recirculation alone (Pritchard and Rives, 1979).

Plume Area-Excess Temperature Analysis

The dilution mechanics of the CCNPP discharge and plume [illegible] been described by Pritchard and Rives (1979, pp. 152-153; [illegible] 37) as a nearfield high-momentum jet that reaches a dilu[illegible] of about 2:1 at about 900 m from the discharge orifice and a dilution of about 3:1 at 3500 m during re-entrainment on the tide reversal. The jet discharge is a rectangular structure but is hydraulically complex because it is submerged and because it expands into a dredged channel which may inhibit initial entrainment.

The CCNPP area-excess temperature data from previous surveys were examined empirically in ANSP (1979) using the relationship of:

$$A/An = (\theta/\theta_o)^{-n} (1 - \theta/\theta_c) \qquad (II\text{-}3\text{-}1)$$

which can be derived theoretically for any plume formulation described by a centerline dilution and width expansion (Edinger, Grady and Geyer, 1974). The empirical evaluations in ANSP (1979) scaled the areas to plant load and resulted in values of n=3.45 to 4.55. A simple one-dimensional high-momentum jet that expands linearly with distance and has a centerline decay of velocity of ½ gives an area-temperature relationship with n=4. It also gives the scaling area as $An=\xi_o b_o$ where ξ_o is the discharge virtual source distance and b_o is the orifice width. The virtual source distance for a one-dimensional jet is usually $4b_o$ to $10b_o$. For the CCNPP, with a width of b_o=15.2 m, the scaling area should be 930 m² to 2300 m². The scaling areas found from the data should be of this magnitude but will vary from these value because of initial vertical expansion, limitations of the discharge channel, tidal current re-entrainment, ambient stratification, and because the observations at lower excess temperature will extend beyond the end of the jet region into the far field.

The area-excess temperature data in Table II-3-1 were evaluated using Equation II-3-1 with n=4. A scaling area was calculated for each isotherm in a mapping by solving Equation II-3-1 for An, and the scaling area for the mapping was determined to be the geometric mean of the values for each isotherm. This method is used instead of least squares because there are

only two to four pairs of area-excess temperature observations per mapping, and the individual isotherm values of An give a good measure of the variation about their geometric mean. A single geometric mean An for each mapping essentially reduces the area-excess temperature data to a single value which represents the "scale" of the plume map.

The results of scaling each plume mapping to a fourth power area-excess temperature relationship are given in Figures II-3-1 and II-3-2. Shown for each plume mapping is the scaling area for that mapping and the observed A/An for the geometric mean scaling area compared to Equation II-3-1. The observed values will pass through the theoretical curve more horizontally or more vertically if their empirical power law is more than or less than n=4, respectively.

The results in Figures II-3-1 and II-3-2 show that the observed plumes generally follow the area-excess temperature scaling relationship except for the mappings of April 19 and 20. The mapping for April 20 is shown in Figures II-2-10 and II-2-11. On April 20, it appears that heat was either trapped or re-entrained along the shoreline, resulting in an ill defined 2°C isotherm.

The scaling areas in Figures II-3-1 and II-3-2 range from 200 m^2 to 7600 m^2 and the values tend to be smaller in August than in April. The observed scaling areas are within a reasonable range of the theoretical estimate for a simple one-dimensional high-momentum discharge (930 m^2 to 2300 m^2), considering all the factors affecting the real discharge that are not included in the simple jet theory.

The overall relationship between the observed area-excess temperatures and Equation II-3-1 is given in Figure II-3-3. The observed areas in each plume mapping are scaled to the geometric mean scaling area for that mapping from Figures II-3-1 and II-3-2. Figure II-3-3 shows that the present surveys resulted in data collected at higher excess temperature ratios than in the ANSP (1979) summaries. The latter were more generally far-field studies. The present data give a better fit than the ANSP (1979) results because all the plumes were measured at close to full and steady plant-load conditions while the ANSP (1979) data were scaled to heat load for comparison. Variable plant heat load is not a problem with the present data set.

At an excess-temperature ratio of 0.3 or less (an excess temperature of 1.7°C for a 10°F ΔT or 2.1°C for a 12°F ΔT), the data diverge from the theoretical relationship. This is consistent with the results of Pritchard and Rives (1979) that intermediate and far-field advective and dispersive transport processes begin beyond dilutions of 3:1.

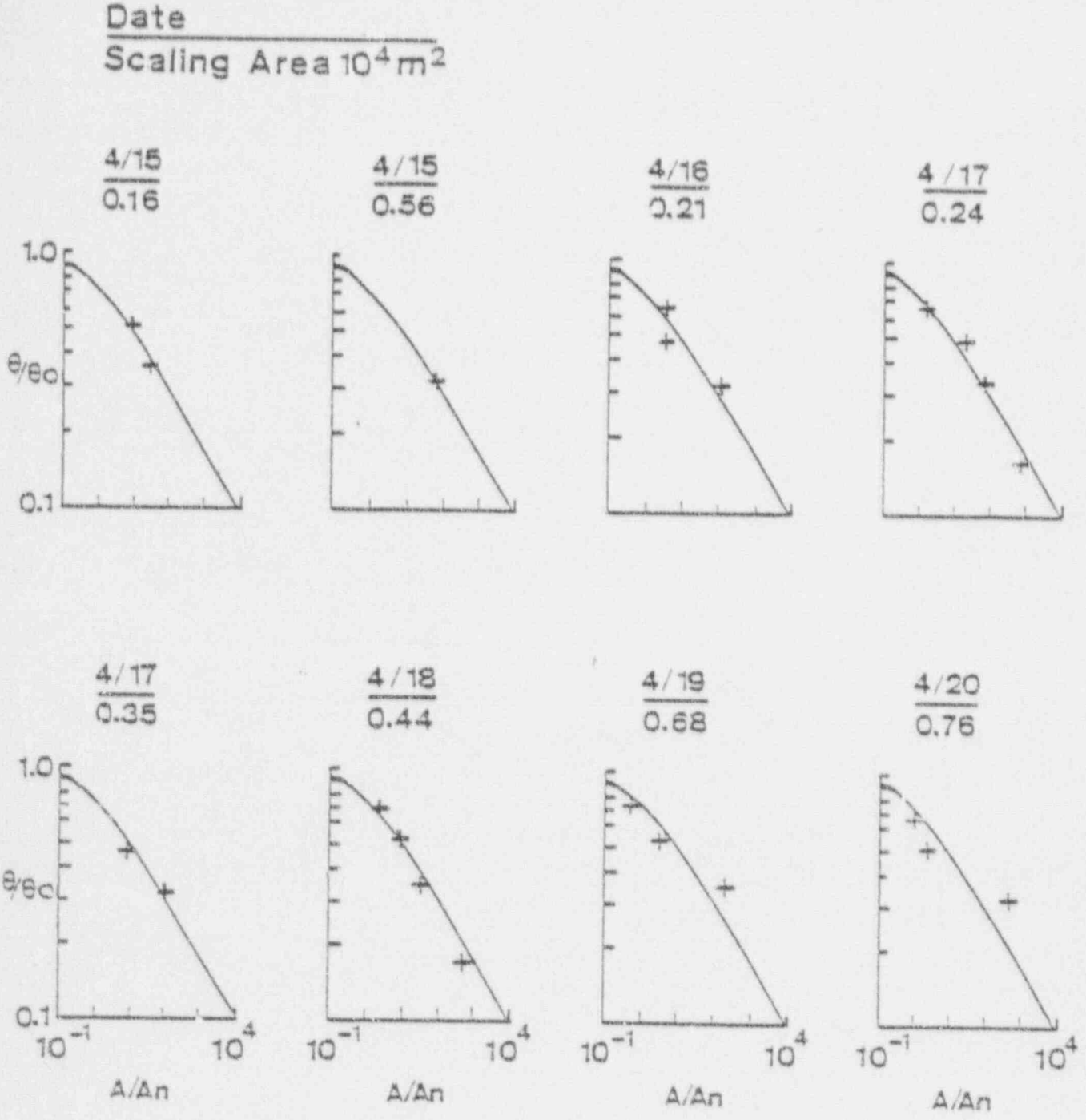


Figure II-3-1. Non-dimensional plume relations and scaling areas (10^4 m^2) for each plume survey, April 1979.

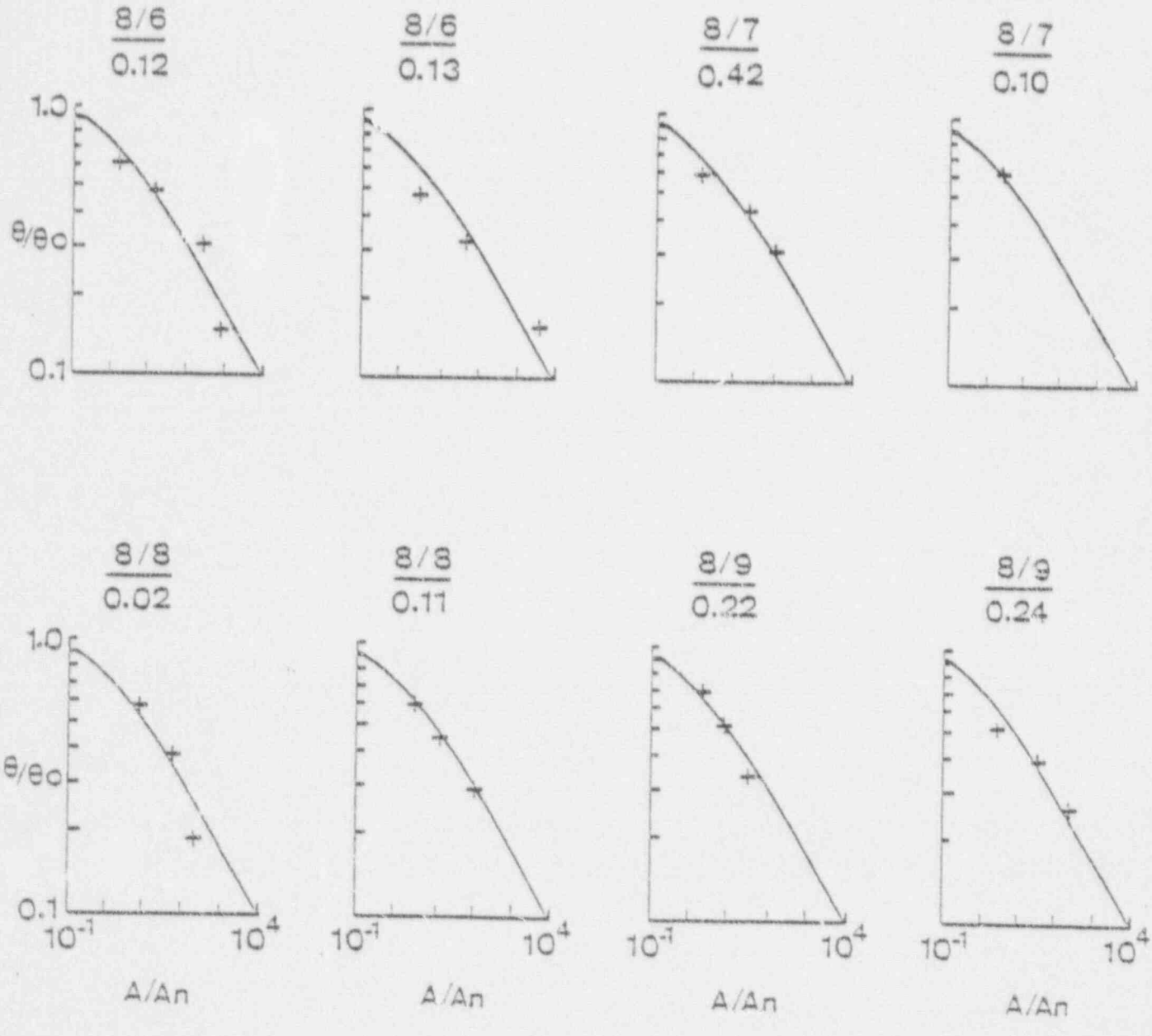


Figure II-3-2. Non-dimensional plume relations and scaling (10^4 m^2) for each plume survey, August 1979.

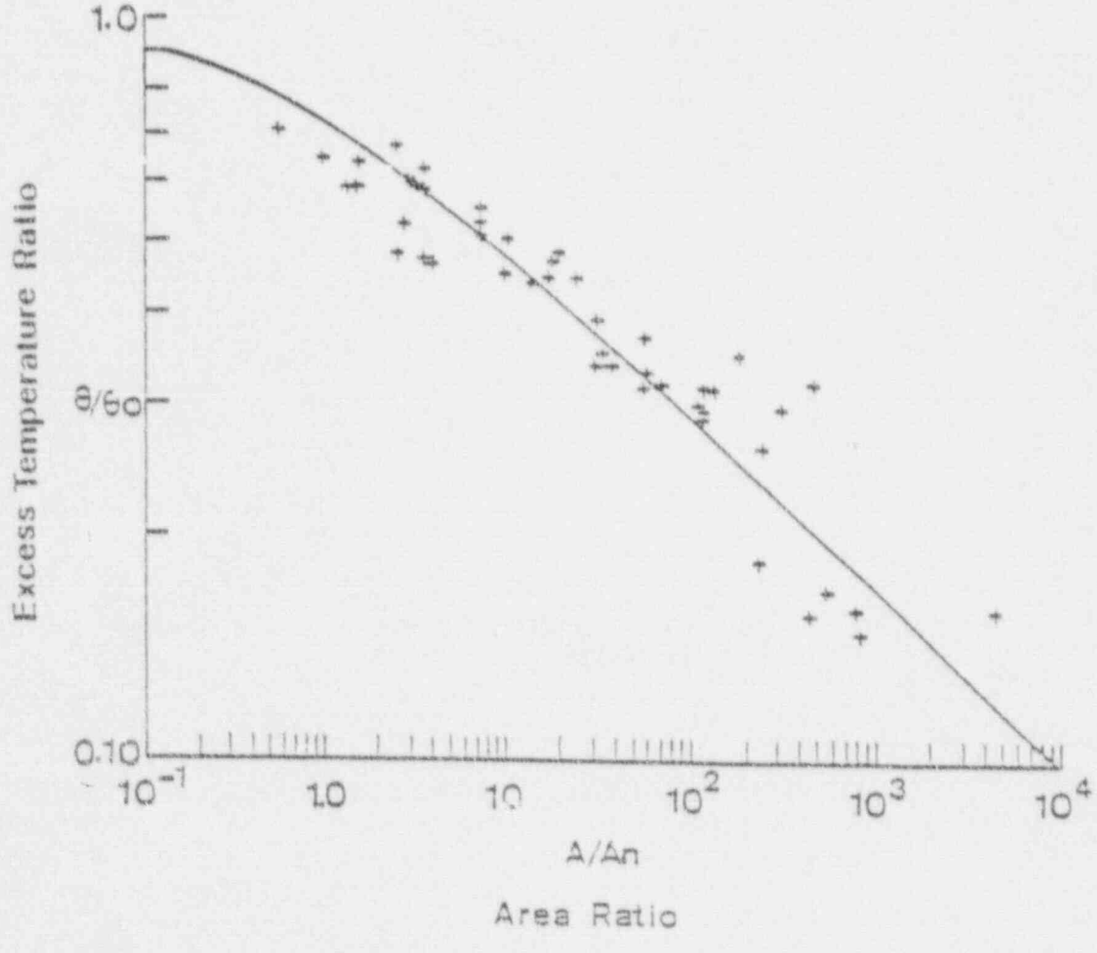


Figure II-3-3. Non-dimensional area-excess temperature relationship for all plume surveys in 1979.

The isotherm length for each observed isotherm is shown as a function of surface area in Figure II-3-4. For the present studies, isotherm length increases as the 0.51 power of area. In the ANSP (1979) studies, length increased as the 0.33 to 0.42 power of area. The present results show a greater change in length with increasing surface area than the previous results.

Scaling Area Relationships

The range of variation in scaling areas expected, at least over the range of hydrographic conditions during the 1979 plume surveys, can be estimated from the distribution of individual isotherm scaling areas. Figure II-3-5 shows the frequency distribution of the full range of observed scaling areas.

Figure II-3-5 represents the results of 48 scaled isotherms taken from 17 plume mappings on 11 separate days of surveys. During both periods of survey, Figure II-2-17 and Figure II-2-26 indicate that tidal current conditions were generally normal. There is, however, a tendency toward smaller scaling areas and smaller plumes in the August survey despite the plant operating at a higher ΔT than in April.

Using the results of Pritchard and Rives (1979), it is possible to estimate an upper bound to the scaling area. The extreme plume areas in their Table VII-16 were subjected to the same analysis as the present survey data. Plume lengths were scaled from their Figure VII-30. The result of the analysis is shown in Figure II-3-6 which gives a scaling area of 9300 m^2. The extreme plume of Pritchard and Rives was more in the far field than the jet region, and the fourth power area-excess temperature relation would be inapplicable. However, at some point, the near-field relation must scale to the far field and the 9300 m^2 can be taken as at least the matching value.

Figure II-3-5 indicates that plumes with isotherms scaled at 0.7 to 0.8 x $10^4 m^2$ were found during the present surveys and represent the lower excess-temperature isotherms of the larger April plumes. Thus, the range of scaling areas observed during the 1979 studies tend to approach the upper bound found for the October 1977 extreme plume (Pritchard and Rives, 1979) and represent a reasonable distribution of expected values under normal tidal current conditions.

Interdependence of Survey Parameters

The scaling area, An, is a single quantity representing the size of each plume. It can be used to examine the size of the plume relative to other variables. The major variables of interest along with the scaling area are the length of the 2°C isotherm, the tidal excursion length, the discharge excess

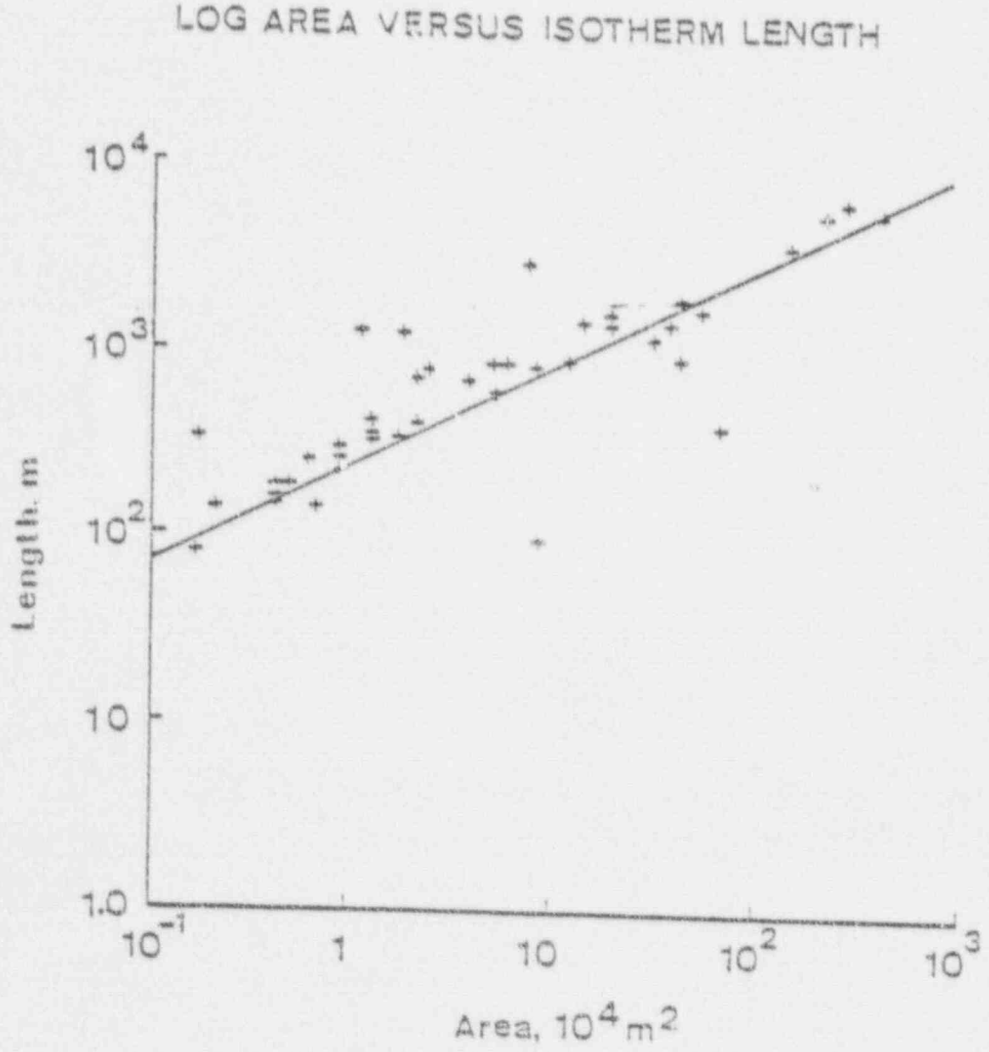


Figure II-3-4. Isotherm area-length relationships for all observed isotherms.

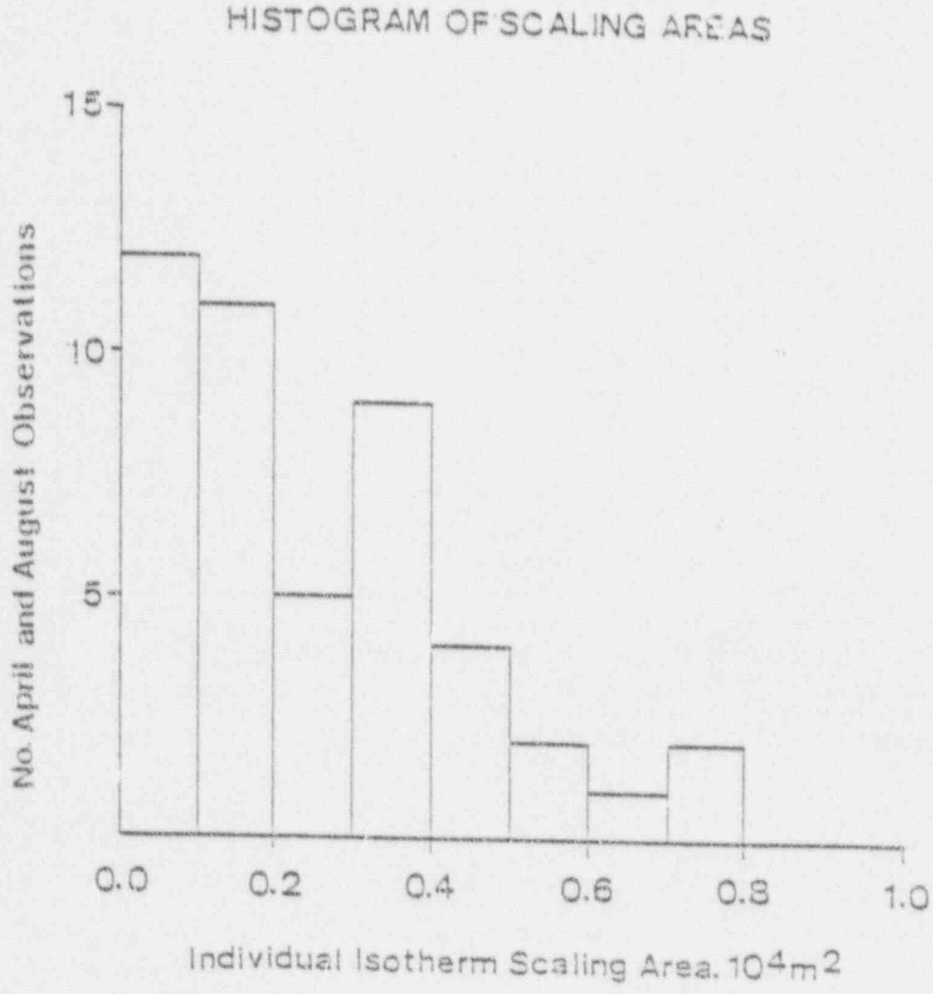


Figure II-3-5. Histogram of scaling area for all isotherms of all surveys.

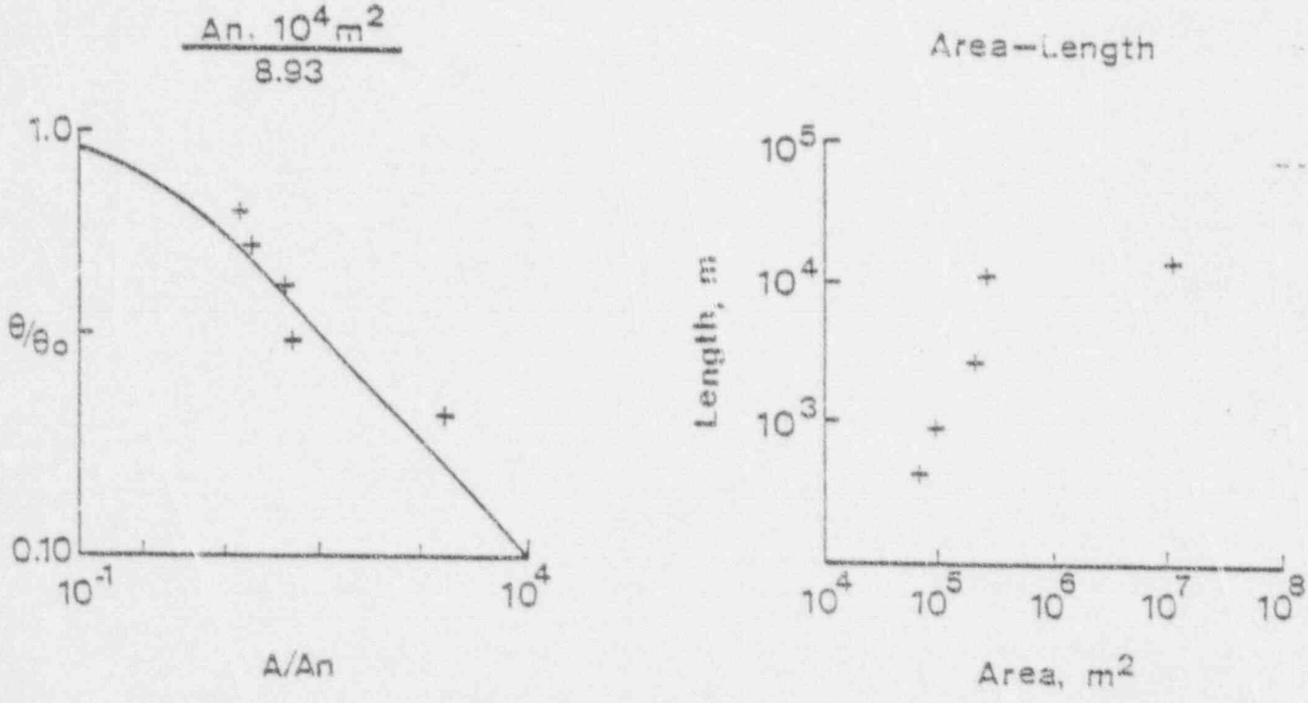


Figure II-3-6. Scaling of extreme ebb tide plume of Pritchard and Rives (1979).

temperature and the thermal stratification as measured by the difference between the surface-plume dye-study base temperature, Ta, and the intake temperature.

The partial correlation coefficients among these variables, calculated from the 17 plume-mapping data in Table II-3-1, are given in Table II-3-2. For the scaling area, the highest coefficient is with the length of the 2°C isotherm. The two, however, are not independent because of the area-length relationship (Fig. II-3-4). The next highest coefficient for scaling area is stratification; data in Table II-3-2 suggest that scaling area decreases with increasing stratification.

The relationship between scaling area and stratification is evident for the August data. The August scaling areas in Figure II-3-2 show a pattern of decreasing from the morning of August 7 to the morning of August 8 then increasing through August 9. This reflects the mappings shown in Figures II-2-20 to II-2-23 where the plume shrinks to a very small size then expands again. Examination of the intake temperatures for this period (Fig. II-2-26) shows a sharp drop of 84.5°F (29.2°C) to 78.0°F (25.5°C) from 1200 h on August 7 to 0300 h on August 8. The time-series stratification data show the pycnocline at or below the intake on August 7, rising above the intake on August 8 and falling below the intake again on August 9 (Figs. II-2-36 - II-2-38).

Along with the rise and fall of the pycnocline on August 7 to 9, Figures II-2-36 to II-2-38 show temperatures below the intake of 26 to 27°C on August 7, decreased to 25 to 26°C on August 8, and increased to 26 to 27°C on August 9. The change in discharge excess temperature (Table II-3-1) is somewhat consistent with the changes in intake temperature by having a minimum value at the time of greatest stratification.

A possible cause of the change in stratification near the plant intake is suggested by the wind data (Fig. II-2-26). For August 6 to 8, there is a pattern of offshore-onshore-offshore winds where the latter persisted through August 8 when the pycnocline was elevated and colder bottom water appeared near the intake. Such an offshore wind coupled with the stratification would tend to set up a cross bay internal seiche when surface waters moved offshore to be balanced by shoreward-moving water.

The sets of conditions occurring from August 7 to August 9 are presented in detail to illustrate a consistency between the different portions of the hydrographic data and the results of the analysis. It is interesting that like the October 1977 period analyzed by Pritchard and Rives (1979), the present August 1979 study period should have been influenced by an event with a period longer than a tidal cycle. In the present case, the event resulted in one of the smallest plumes mapped

Table II-3-2. Partial correlations between parameters of plume surveys.

	Scaling Area An	2°C Length L2c	Tidal Excursion Lta	Discharge Excess θ_o	Intake Stratification T_a-T_i
An	-	0.33	0.14	-0.16	-0.35
L_2c	-	-	-0.20	-0.10	-0.29
Lta	-	-	-	-0.21	-0.25
θ_o	-	-	-	-	0.15

at CCNPP while the October 1977 events resulted in one of the largest.

The relationship between the scaling area and stratification for all the survey data are shown in Figure II-3-7. It shows a tendency for decreasing scaling area with increased stratification but the scatter indicates that other factors also influence the size of the scaling area.

Isotherm and Tidal Excursion Lengths

The partial correlations in Table II-3-2 indicate that there is no relationship between scaling area and tidal excursion distance. Further, they indicate that there is no relation between the lengths of the 2°C isotherm and tidal excursion distance. The data in Table II-3-1 indicate there are specific short-term events when the length of the 2°C isotherm exceeds more than one-half the tidal excursion length.

With the variability in tidal excursion lengths as reflected in the frequency distributions given in Figures II-2-16 and II-2-27 and the length of an isotherm as reflected in the frequency distribution of scaling areas in Figure II-3-5, it is obvious that the two can be related only statistically. One method of comparing the two lengths is by a joint probability analysis.

The joint probability analysis is performed as follows:

(1) Asume the scaling areas have the frequency distribution given in Figure II-3-5.

(2) In each range of scaling areas, compute for a given isotherm, excess temperature and condenser temperature rise, the isotherm area using Equation II-3-1. Compute the isotherm length from the area using Figure II-3-4.

(3) Assume the ebb tide excursion lengths have a frequency distribution of that shown on Figures II-2-16 and II-2-27 combined.

(4) Assume that the ebb tide excursion length and isotherm length are independent (Table II-3-2) and that the probability of the two occurring jointly is the product of their individual frequencies.

The results of a joint probability computation for a 2°C isotherm, a 10°F condenser rise and 10% recirculation are given in Table II-3-3. It shows at each intersection of scaling area and excursion length (1) the ratio of isotherm length to excursion length and (2) the probability of the particular combination of scaling area and excursion length occurring. The

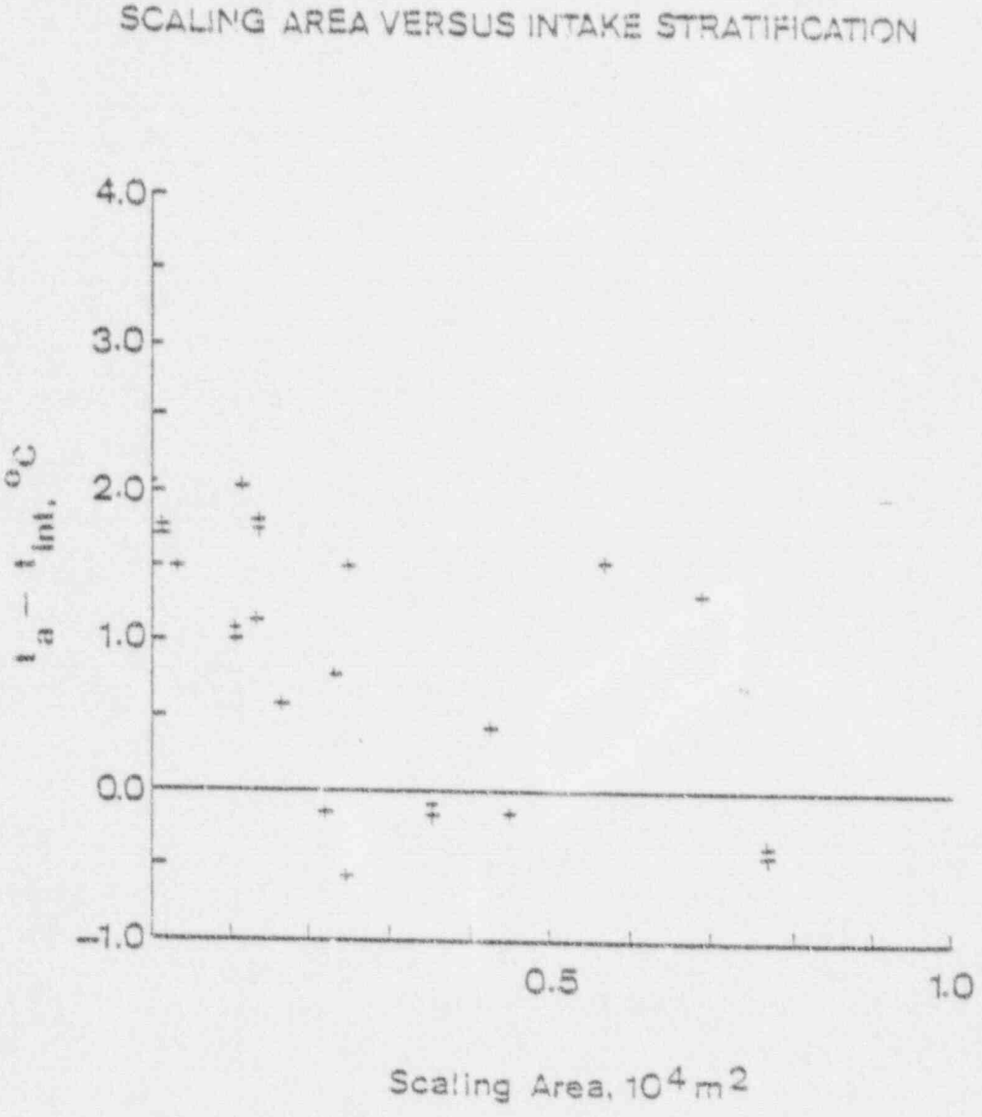


Figure II-3-7. Scaling area verrus intake stratification for all surveys.

Table II-3-3. Joint frequency distribution of 2°C isotherm length and tidal excursion distance for a 10°F condenser temperature rise at Calvert Cliffs Nuclear Power Plant. The percent of 2°C isotherm lengths exceeding one-half the tidal excursion lengths is 8.1%, mean isotherm length over all areas is 1.1 km, and mean tidal excursion length is 5.3 km.

Plume A_m 10^4 m²	P(A)	L km	Excursion lengths (km) and Frequencies (% of time observed) 0-1[1] 4.1[2]	1-2 4.2	2-3 6.1	3-4 16.3	4-5 20.4	5-6 22.4	6-7 18.4	7-8 8.2
0-1	25.3	0.5	0.5[3] 1.0[4]	0.3 1.0	0.2 1.[illegible]	0.1 4[illegible]	0.1 5.2	0.1 5.7	0.1 4.7	0.1 2.1
1-2	23.2	0.9	0.9 1.0	0.5 1.0	0.3 1.[illegible]		0.2 4.7	0.2 5.2	0.1 4.3	0.1 1.9
2-3	16.8	1.2	1.2 0.7	0.6 0.7	0.4 1.0	0.3 2.7	0.2 3.4	0.2 3.8	0.2 3.1	0.1 1.4
3-4	12.6	1.4	1.4 0.5	0.7 0.5	0.5 0.8	0.4 2.1	0.3 2.6	0.2 2.8	0.2 2.3	0.2 1.0
4-5	8.4	1.6	1.6 0.3	0.8 0.3	0.5 0.5	0.4 1.4	0.3 1.7	0.3 1.9	0.2 1.5	0.2 0.7
5-6	6.3	1.8	1.8 0.3	0.9 0.3	0.6 0.4	0.4 1.0	0.4 1.3	0.3 1.4	0.3 1.2	0.2 0.5
6-7	4.2	1.9	1.9 0.2	1.0 0.2	0.6 0.2	0.5 0.7	0.4 0.9	0.3 0.9	0.3 0.8	0.2 0.3
7-8	2.1	2.1	2.1 0.1	1.0 0.1	0.7 0.1	0.5 0.3	0.4 0.4	0.3 0.5	0.3 0.4	0.3 0.2
8-9	1.1	2.2	2.2 0.0	1.1 0.0	0.7 0.1	0.5 0.2	0.4 0.2	0.4 0.2	0.3 0.2	0.3 0.1

A_m = range of scaling area
P(A) = % of time scaling area was observed
L = calculated length (km) of 2°C isotherm for given scaling area
1/ = range of observed excursion length, km
2/ = % time excursion length
3/ = ratio of 2°C isotherm length to tidal excursion length
4/ = joint frequency of occurrence of given tidal excursion length and 2°C isotherm length

frequency with which the isotherm length exceeds one-half the ebb-tide excursion is found by summing the individual joint probabilities for which the condition occurs.

For the combination of instances of ebb tide excursion and 2°C isotherm lengths given in Table II-3-3, the mean isotherm length is 1.1 km and the mean ebb excursion length is 5.3 km. On an individual tidal excursion and plume basis, the 2°C isotherm length is more than one-half the ebb tide excursion on 8.1% of the events.

The joint probability analysis for the 2°C isotherm at a condenser rise of 12°F is given in Table II-3-4. The mean isotherm is 2.7 km. For individual events, the 2°C isotherm length is more than one-half the ebb-tide excursion on 19.5% of the events. These probabilities assume that the full plant load, the condenser ΔT and recirculation are constant over all time. Inclusion of more realistic time-varying condenser ΔT and recirculation in the analysis would reduce the percent exceedence of the short term events.

4. COMPARISON OF PAST AND PRESENT SURVEY CONDITIONS

Many of the result of the past and present plume surveys are similar yet they have been obtained under a wide range of hydrographic and meteorological conditions. In order to compare the general plant loading, hydrographic and meteorological conditions of the present studies to those of past studies and to seasonally varying conditions, time-series records have been assembled for periods in 1977 and 1978 and for portions of 1979 during the present surveys.

The ANSP and CBI studies took place in 1977 and 1978. The ANSP surveys were in August 1977, November 1977, April-May 1978, and August 1978. The CBI study was in October 1977. Values of parameters examined for April and August 1979 data are superimposed on the April and August 1977 and 1978 data. This allows direct comparison of the present survey conditions with those of the August 1977 and April 1978 studies. It also allows a comparison of survey conditions in 1979 with conditions during periods of previous years.

Plant Load

Daily plant load was obtained from hourly plant-operating records. Daily total output for 1977 and 1978 is shown in Figures II-4-1 and II-4-2. The April 1979 study period had loads higher than those in either April 1977 or April 1978. The August 1979 loads were similar to the August 1977 and 1978 loads.

Table II-3-4. Joint frequency distribution of 2°C isotherm length and tidal excursion distance for a 12°F condenser temperature rise at Calvert Cliffs Nuclear Power Plant. The percent of 2°C isotherm lengths exceeding one-half the tidal excursion lengths is 8.1%, mean isotherm length over all areas is 1.1 km, and mean tidal excursion length is 5.3 km.

Plume λ_m 10^3 m²	P(A)	L km	Excursion lengths (km) and Frequencies (% of time observed) 0-1[1] 4.1[2]	1-2 4.1	2-3 6.1	3-4 16.3	4-5 20.4	5-6 22.4	6-7 18.4	7-8 8.2
0-1	25.3	0.8	0.8[3] 1.0[4]	0.4 1.0	0.3 1.5	0.2 4.1	0.2 5.2	0.1 5.7	0.1 4.7	0.1 2.1
1-2	23.2	1.4	1.4 1.0	0.7 1.0	0.5 1.4	0.3 3.8	0.3 4.7	0.2 5.2	0.2 4.3	0.2 1.9
2-3	16.8	1.8	1.8 0.7	0.9 0.7	0.6 1.0	0.4 2.7	0.4 3.4	0.3 3.3	0.3 3.1	0.2 1.4
3-4	12.6	2.1	2.1 0.5	1.1 0.5	0.7 0.8	0.5 2.1	0.4 2.6	0.4 2.8	0.3 2.3	0.3 1.0
4-5	8.4	2.4	2.4 0.3	1.2 0.3	0.8 0.5	0.6 1.4	0.5 1.7	0.4 1.9	0.3 1.5	0.3 0.7
5-6	6.3	2.6	2.6 0.3	1.3 0.3	0.9 0.4	0.7 1.0	0.5 1.3	0.4 1.4	0.4 1.2	0.3 0.5
6-7	4.2	2.9	2.9 0.2	1.4 0.2	1.0 0.3	0.7 0.7	0.6 0.9	0.5 0.9	0.4 0.8	0.4 0.3
7-8	2.1	3.1	3.1 0.1	1.5 0.1	1.0 0.1	0.8 0.3	0.6 0.4	0.5 0.5	0.4 0.4	0.4 0.2
8-9	1.1	3.3	3.3 0.0	1.6 0.0	1.1 0.1	0.8 0.2	0.7 0.2	0.5 0.2	0.5 0.2	0.4 0.1

λ_m = range of scaling area
P(A) = % of time scaling area was observed
L = calculated length (km) of 2°C isotherm for given scaling area
1/ = range of observed excursion length, km
2/ = % of time excursion length
3/ = ratio of 2°C isotherm length to tidal excursion length
4/ = joint frequency of occurrence of given tidal excursion length and 2°C isotherm length

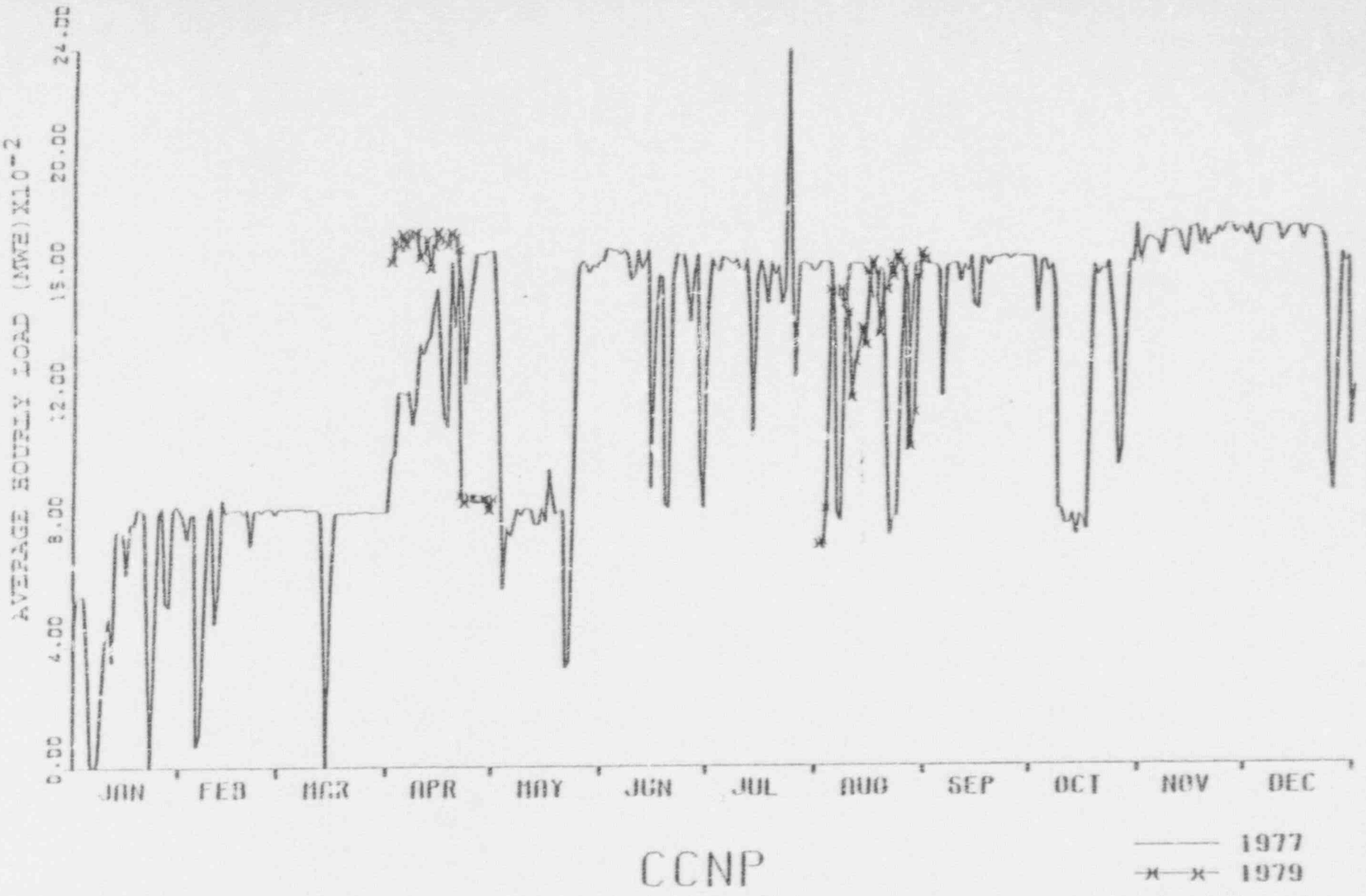


Figure II-4-1. Average hourly plant load (electrical output in megawatt hours) from plant operating records for 1977 and 1979 at Calvert Cliffs Nuclear Power Plant.

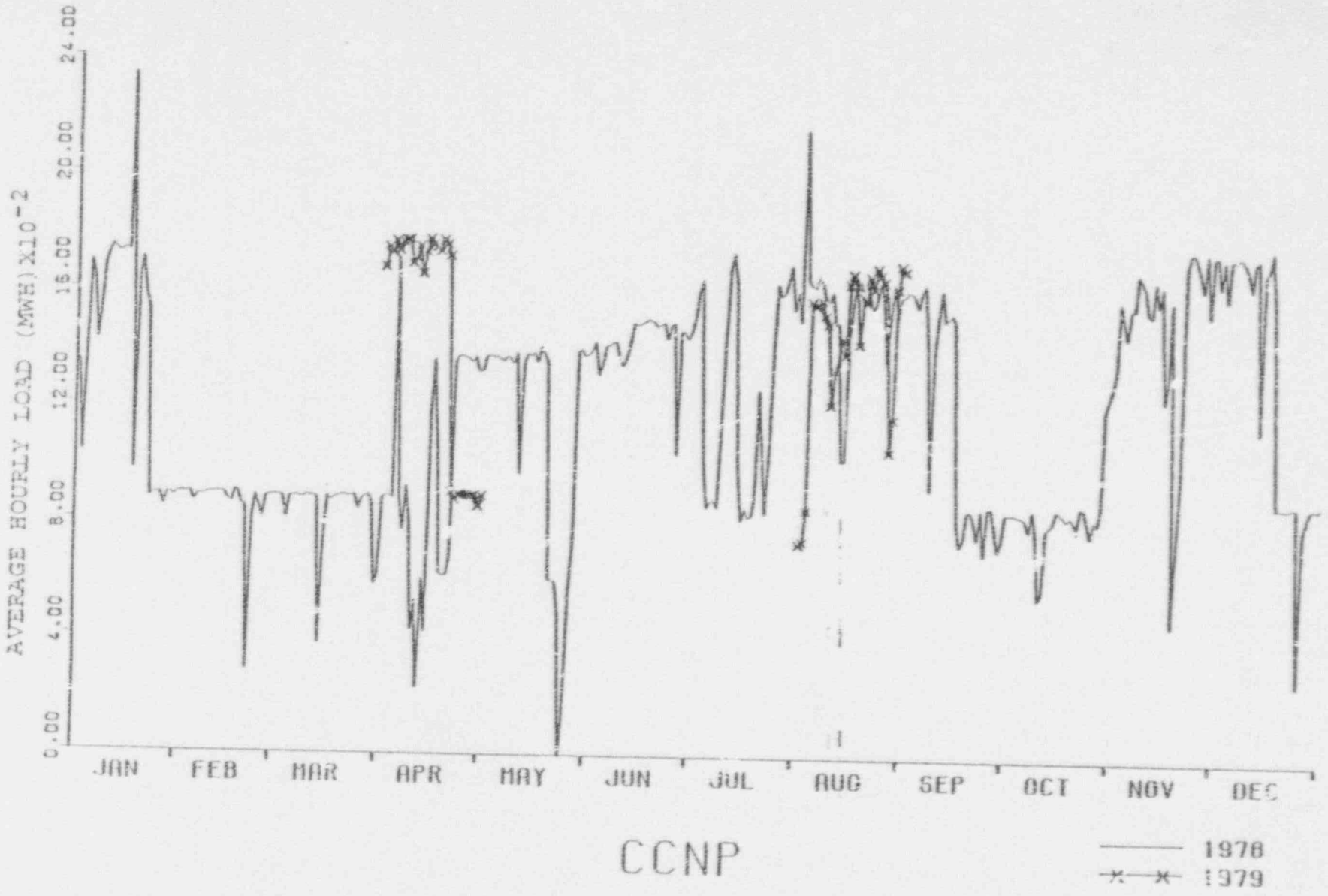


Figure II-4-2. Average hourly plant load (electrical output in megawatt hours) from plant operating records for 1978 and 1979 at Calvert Cliffs Nuclear Power Plant.

Loads preceding the CBI October 1977 surveys were near their maximum but with sharp fluctuations. During the survey period from the end of October to early November loads were steady.

Water Temperatures

Seasonal water temperatures were obtained from readings taken at the instrument platform inside the CCNPP intake forebay and from daily measurements at Solomons Island, downbay from the CCNPP site. The CCNPP records are shown in Figures II-4-3 and II-4-4, and the Solomons Island records are shown in Figures II-4-5 and II-4-6. Data for the April 1979 survey period reveal CCNPP water temperatures higher than those in April 1978 and almost identical to those of April 1977. The early August 1979 CCNPP temperatures during the study period were similar to August 1977 and higher than August 1978 temperatures. August 1979 CCNPP temperatures showed a sharp decrease after the survey period.

At Solomons Island, the April 1979 period had lower temperatures than in 1977 and had similar temperatures to those of 1978. The August 1979 temperatures were higher than the early August temperatures for both years and showed a mid-month decrease similar to that recorded at CCNPP.

Comparison of the Solomons and CCNPP 1977 and 1978 records show that the CCNPP spring-time temperatures lag the Solomons temperatures by ten to fifteen days. Both reach similar peaks and have similar fall declines.

Salinities

Salinity data were recorded from the instrument platform inside the CCNPP intake forebay and at Solomons Island. The CCNPP records are shown in Figures II-4-7 and II-4-8, and the Solomons records are shown in Figures II-4-9 and II-4-10.

At CCNPP, intake salinities for April 1979 were similar to those for April 1977 and 1978. August 1979 salinities were much lower than those for August 1977 and slightly lower than those of August 1978.

At Solomons, the April 1979 salinities were higher than they were in April 1977 and 1978. August 1979 salinities were much lower than in August 1977 and similar to those for August 1978.

Compared to 1978 and 1979, the spring and summer salinities of 1977 increased rapidly and were at higher levels throughout the summer (Figs II-4-9 and II-4-10). They had a sharp increase in September and early October, then a sharp

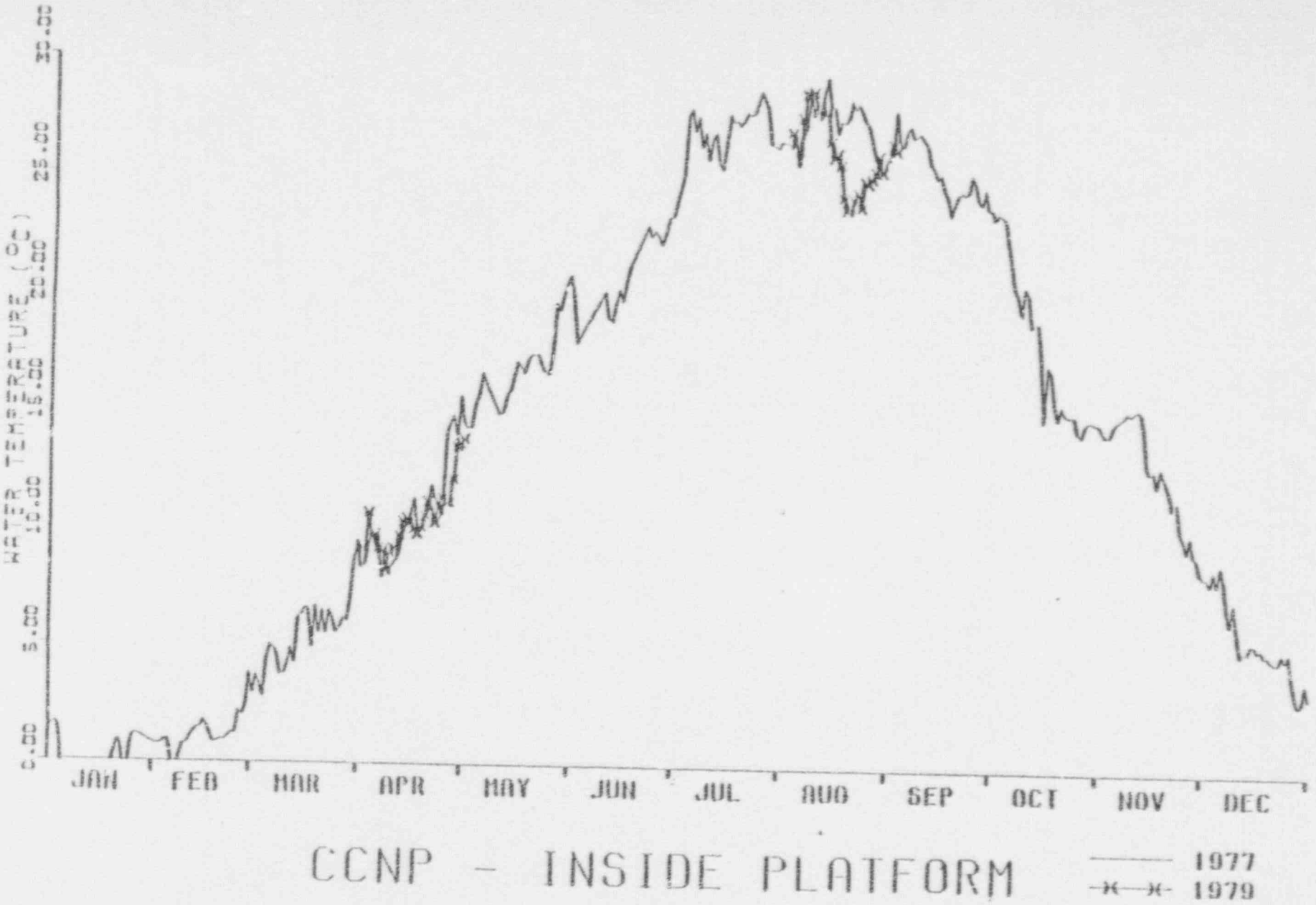


Figure II-4-3. Comparison of water temperatures recorded at monitor located inside intake bay of Calvert Cliffs Nuclear Power Plant in 1977 and during survey periods in 1979.

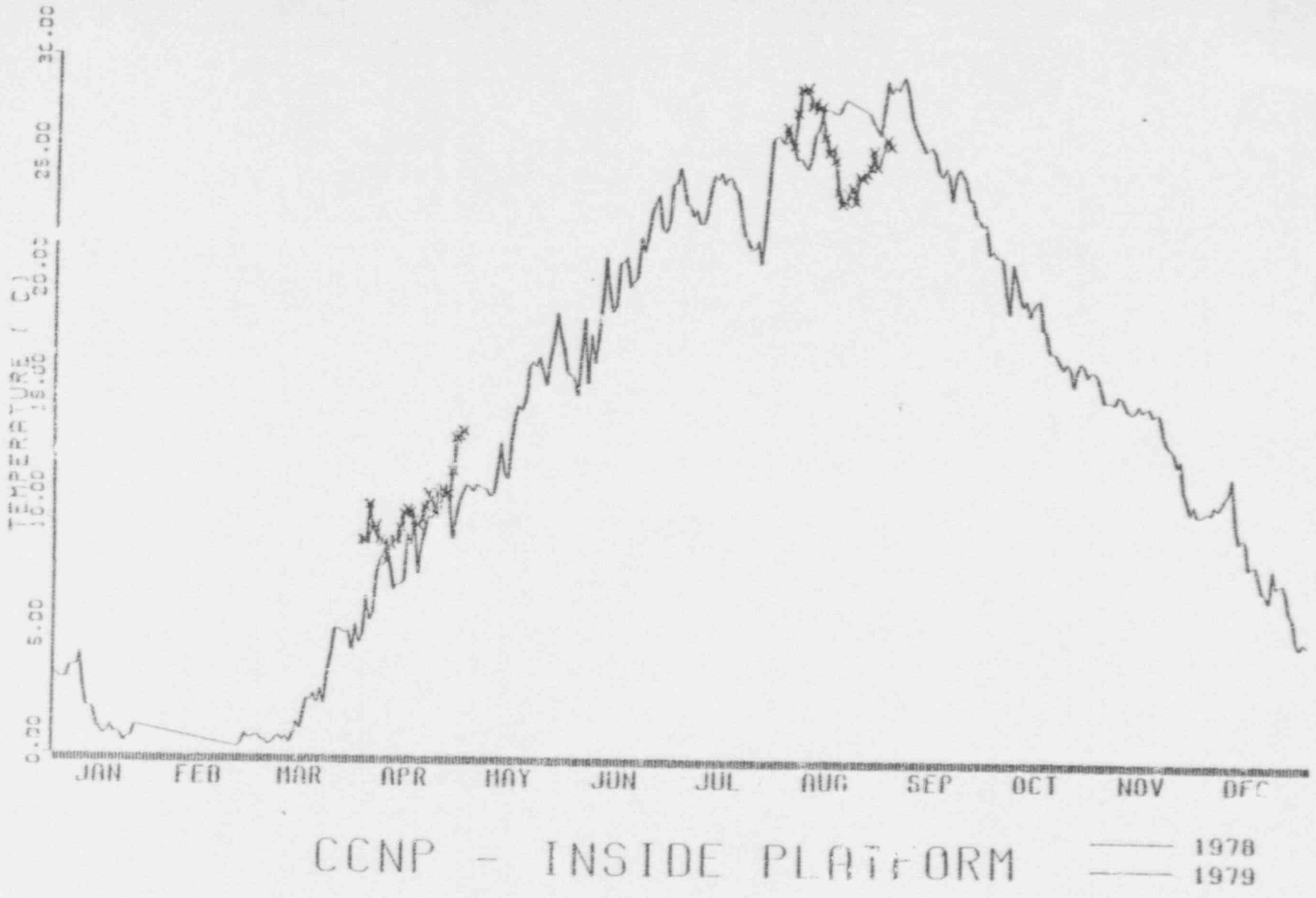


Figure II-4-4. Comparison of water temperatures recorded at monitor located inside intake bay of Calvert Cliffs Nuclear Power Plant in 1978 and during survey periods in 1979.

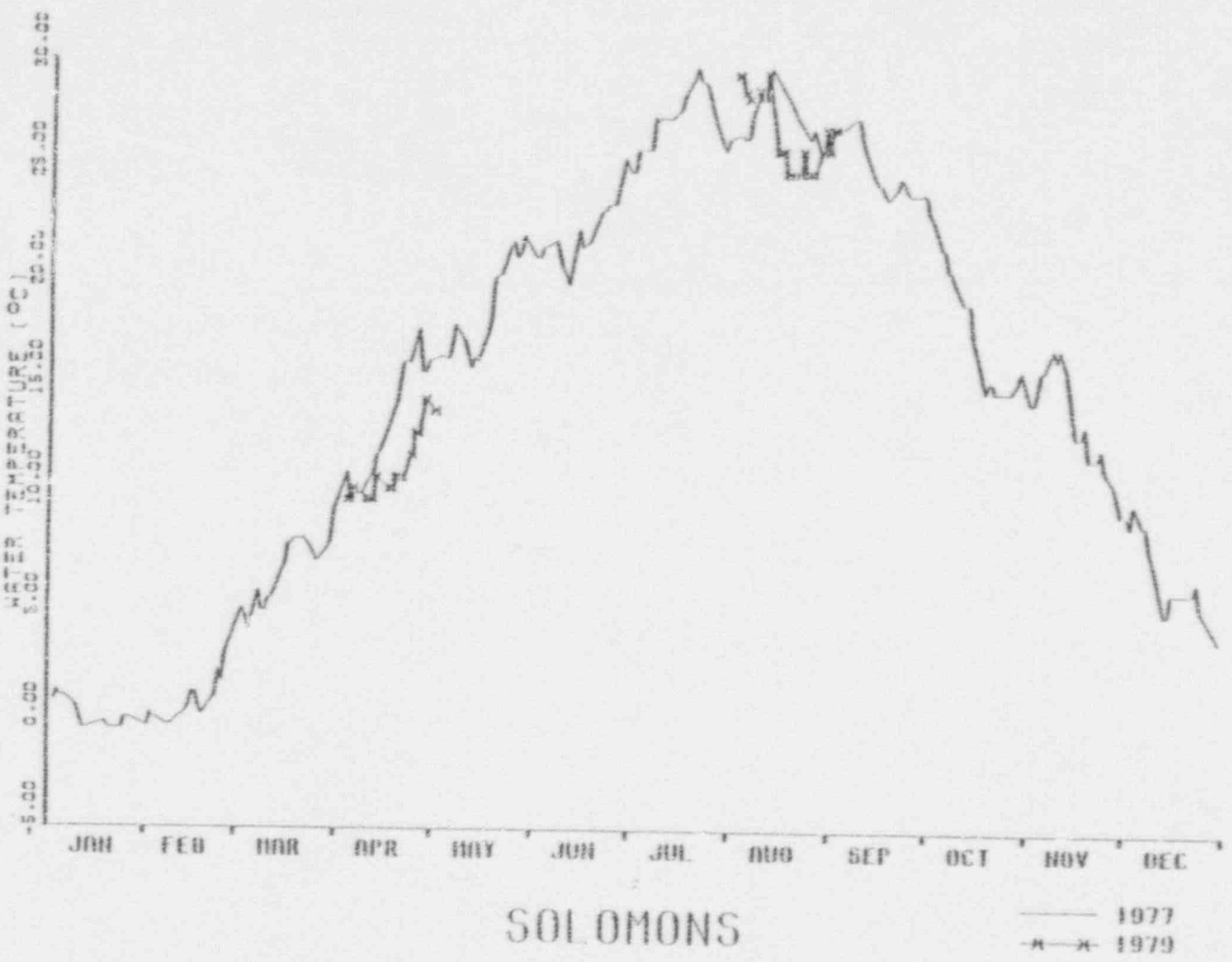


Figure II-4-5. Comparison of water temperatures recorded at Solomons Island during 1977 and for survey periods in 1979.

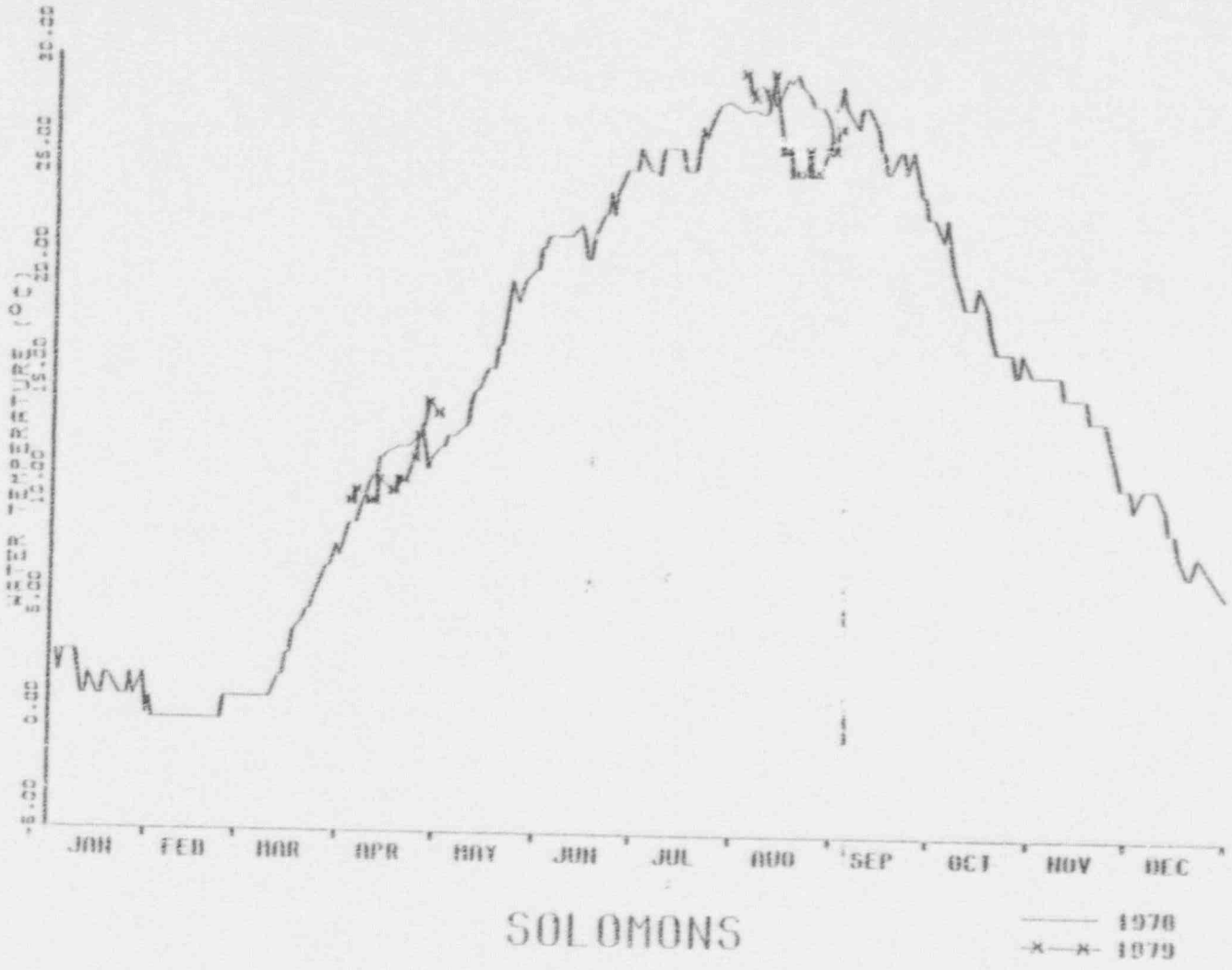


Figure II-4-6. Comparison of water temperatures recorded at Solomons Island during 1978 and for survey periods in 1979.

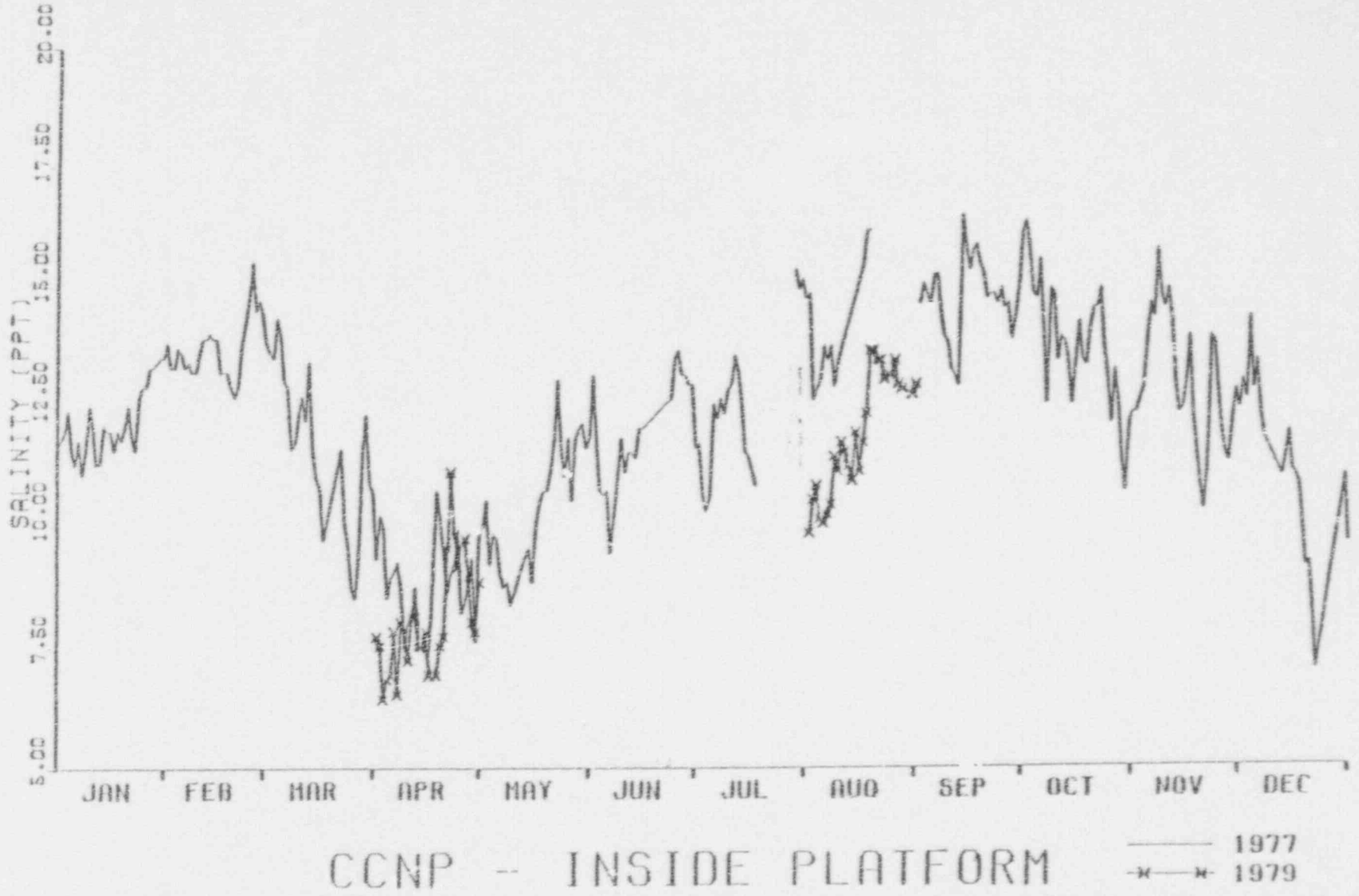


Figure II-4-7. Comparison of salinities recorded at monitor located inside intake bay of Calvert Cliffs Nuclear Power Plant in 1977 and during survey periods in 1979.

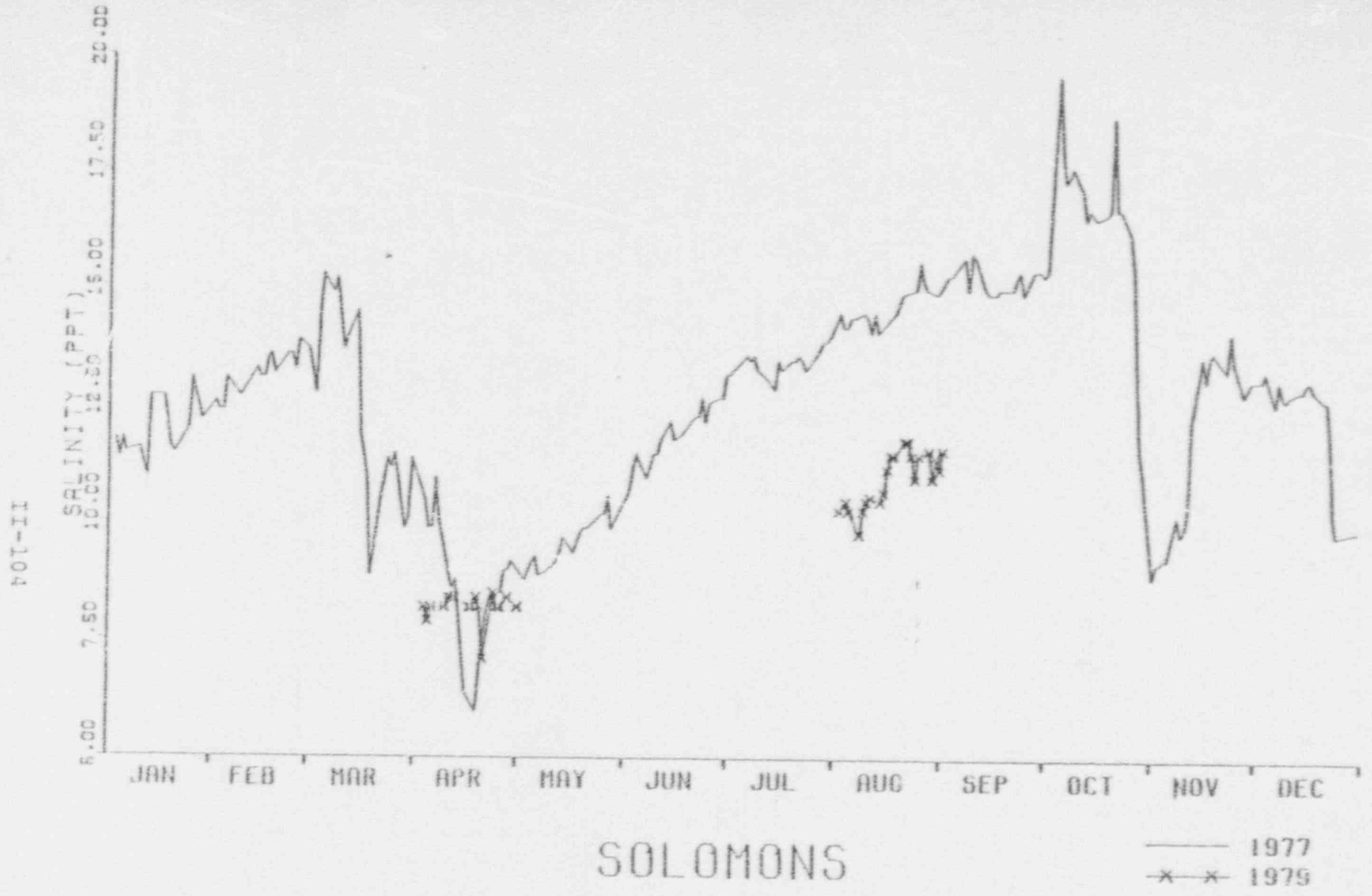


Figure II-4-9. Comparison of salinities recorded at Solomons Island during 1977 and for survey periods in 1979.

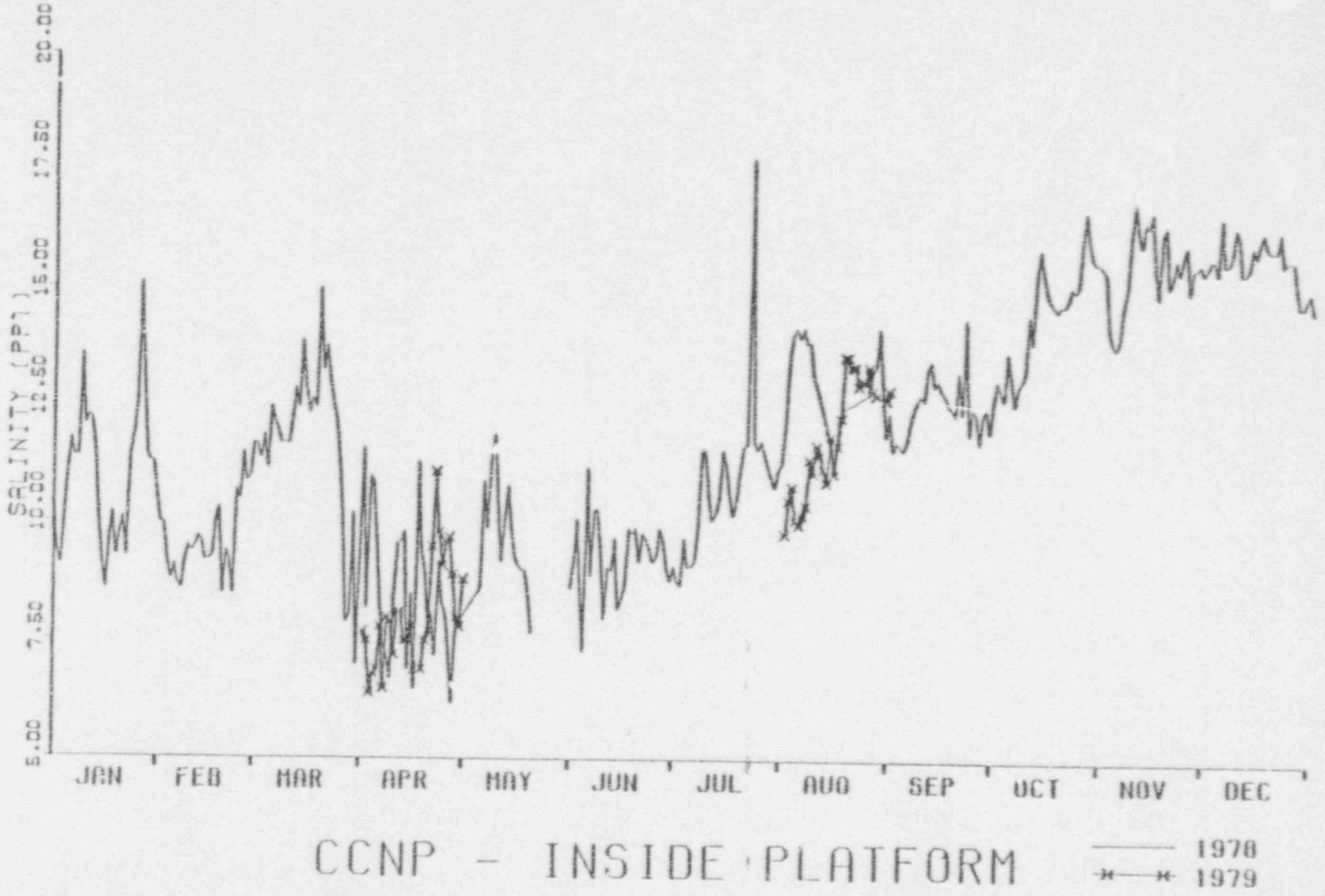


Figure II-4-8. Comparison of salinities recorded at monitor located inside intake bay of Calvert Cliffs Nuclear Power Plant in 1978 and during survey periods in 1979.

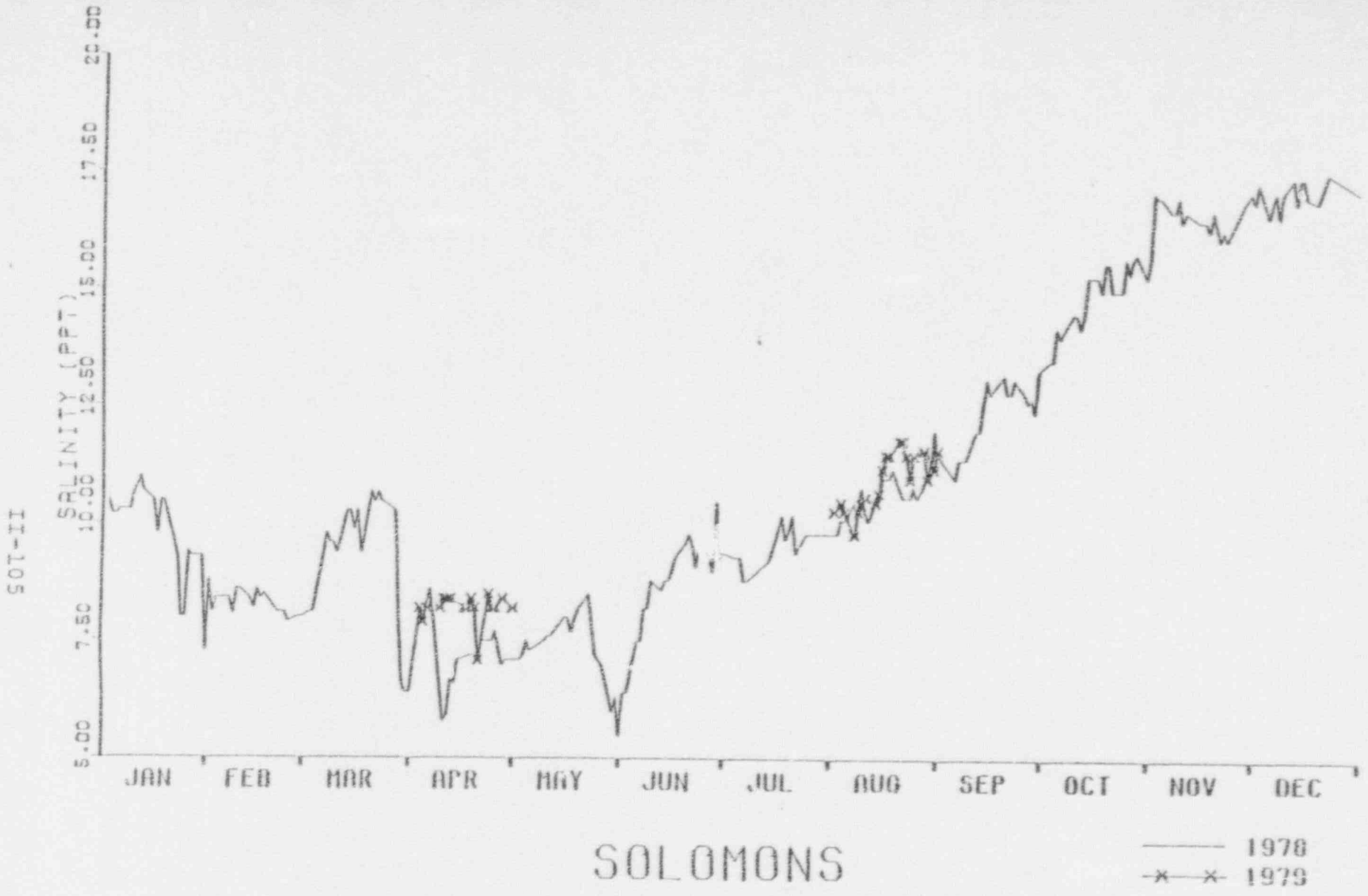


Figure II-4-10. Comparison of salinities recorded at Solomons Island during 1978 and for survey periods in 1979.

decrease in late October-early November. The CBI October 1977 survey was during the latter period.

Salinities at the CCNPP intake can be compared to the Solomons salinities to indicate downestuary salinity gradients. Since the Solomons salinity is a surface measurement and CCNPP intake withdraws from lower levels, the difference tends to indicate the presence of stratification. The sharp variations in salinity at CCNPP from day to day are also related to withdrawals from different levels. On this basis, the April 1979 survey had CCNPP salinities varying around the Solomons salinities but with Solomons salinities tending to be higher during the period of surveys reflecting a dominant longitudinal salinity gradient. During the early August 1979 survey period CCNPP salinities tended to be higher than Solomons salinities, indicating the presence of stratification in the vicinity of the plant. The stratification tends to increase through the survey period up to August 8 and then decreases. Seasonal salinity patterns follow the detailed time-varying stratification results presented in Figures II-2-30 to II-2-39. Examination of CCNPP and Solomons salinities for August 1978 (Figs. II-4-8 and II-4-10) indicates that the differences seen are similar to conditions during the 1979 survey.

Figures II-4-7 and II-4-9 show Solomons salinities during the October-November 1977 CBI study much greater than CCNPP salinities in late October, then a sharp drop in Solomons salinities to below CCNPP salinities during the latter part of the surveys. This would have coincided with the rapidly changing conditions found during the CBI studies.

River Flows

Salinity variations and the net non-tidal circulation of Chesapeake Bay near Calvert Cliffs are influenced by the freshwater inflow. The Susquehanna River is the largest source of freshwater inflow upestuary of CCNPP. The long-term mean annual flow of the Susquehanna River is 36,000 cfs. The mean annual flow for 1977 was 41,900 cfs, for 1978 was 58,900 cfs and for 1979 was 42,800 cfs. The 1977 and 1978 hydrographs are given in Figures II-4-11 and II-4-12 and include the superimposed April and August 1979 flows. River flows during the April 1979 surveys were higher than in 1977 and similar to the flows in 1978. The August 1979 survey flows were slightly higher than the 1977 flows, and crossing and lower than the 1978 flows. For both April and August 1979, however, the flows were typical of the April and August flows in 1977 and 1978.

The 1977 hydrograph, Figure II-4-11, shows in comparison to the 1978 flows, a fall period of rapidly rising flows from mid-September that is sustained through December. This period has flows as high as those that occur during the spring freshet (March-April). Within the 1977 fall high-flow period a mid-

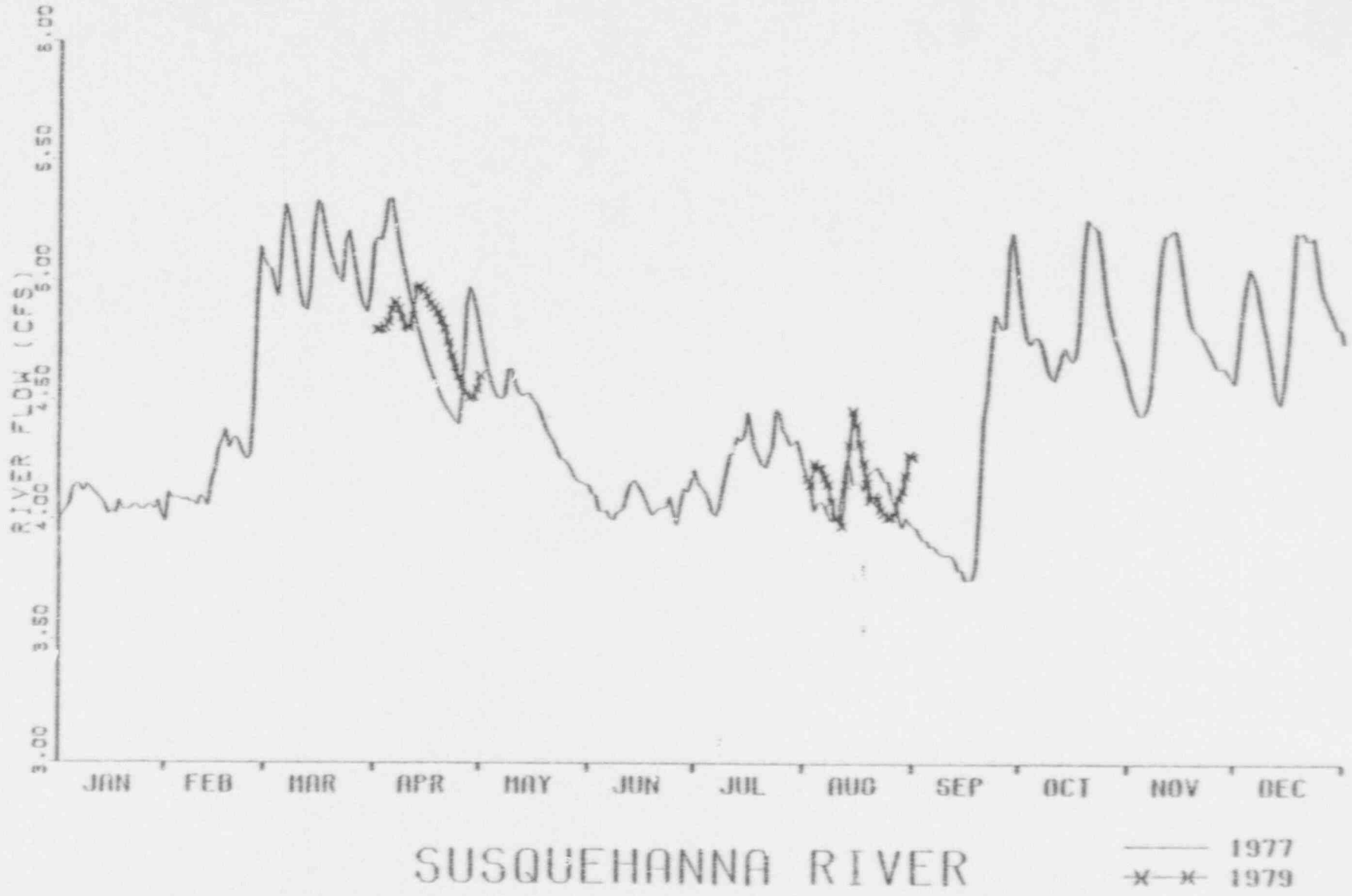


Figure II-4-11. Log values of mean daily flow (cfs) of the Susquehanna River at Marietta, Pa. in 1977 and during April and August 1979.

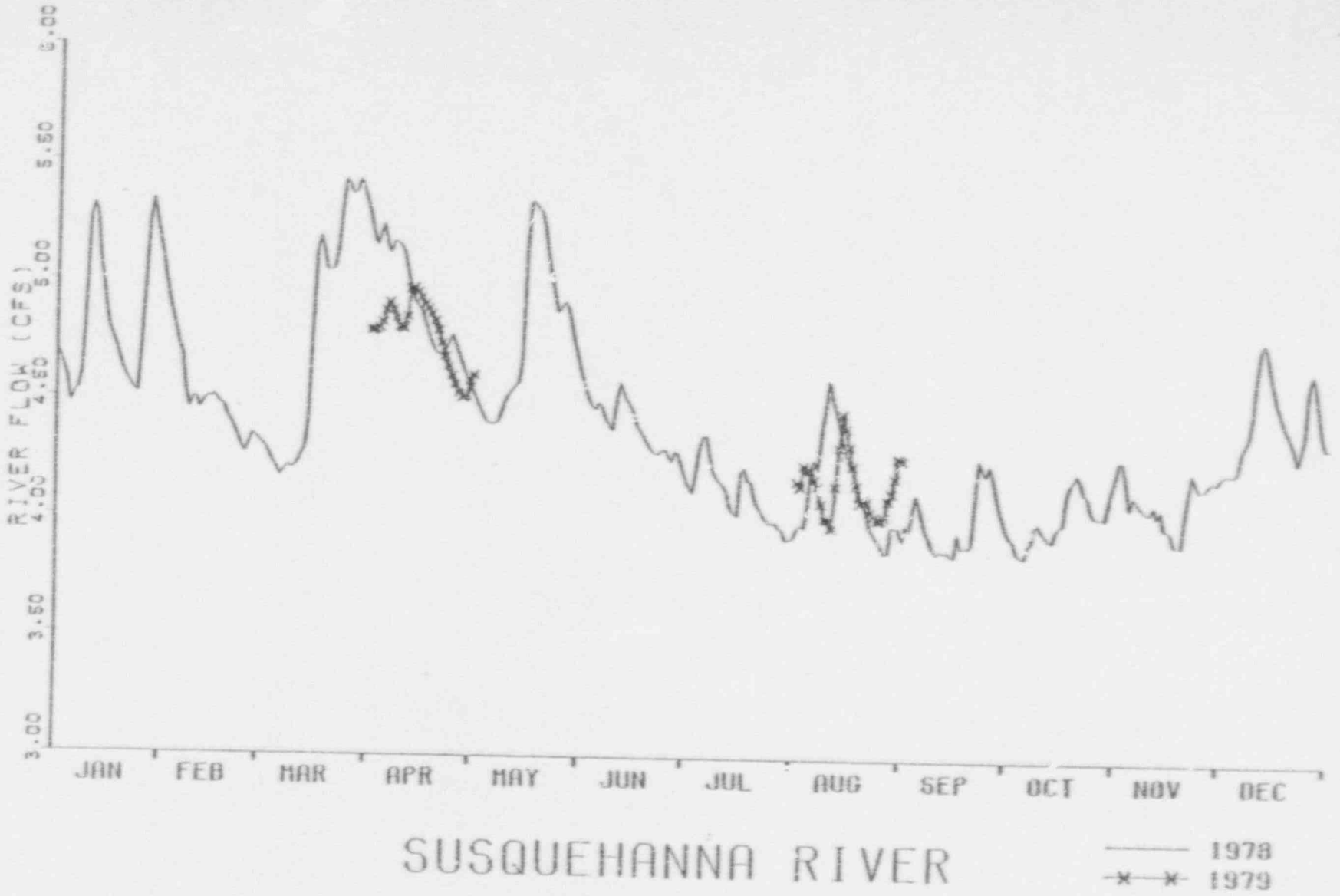


Figure II-4-12. I g values of mean daily flow (cfs) of the Susquehanna River at Marietta, Pa. in 1978 and during April and August 1979.

October peak and recession into early November occurred that coincided with the period of the 1977 CBI surveys.

The October 1977 flows also coincide with changes in salinity at Solomons Island (Fig. II-4-9) which shows a sharp drop from mid-October into November. A similar drop in salinity is found at the CCNPP intake (Fig. II-4-7); however, although the intake salinities vary widely from day to day, their seasonal trend tends to reflect the seasonal flow patterns from one year to the next. The Solomons salinities may be more responsive to local runoff and hydrographic conditions than to the Susquehanna River flow, as evidenced by the large differences in the trend of summer-time salinities between 1977 and August 1979 that are not reflected in the river flow.

Wind Speed and Direction

As discussed by Pritchard and Rives (1979) and as indicated in Section C for the 8 to 10 August 1979 plumes, wind conditions play a major role in the dynamics of Chesapeake Bay in the vicinity of CCNPP.

The 1977 and 1978 daily wind vectors from measurements taken atop the 61-m tower are shown in Figures II-4-13 and II-4-14. The wind vectors at 2-h intervals during the April and August 1979 surveys are given in Figures II-2-14 and II-2-26. The August 1979 vectors showed a persistent cross-bay wind which influenced the CCNPP intake temperatures and the size of the plume. The 1977 and 1978 daily wind vectors do not show any periodic or seasonal patterns for the cross-bay wind conditions. The conditions found during the August 1979 surveys are thus of somewhat random occurrence.

The October 1977 CBI survey was dominated by strong and persistent wind conditions that were somewhat evident as wind vectors (Pritchard and Rives, 1979; Fig. II-1A). The analysis required filtering of the downbay and cross-bay component in the time-series records to detect the contributions at different times during the 15 days of study. The October 1977 daily wind-speed vectors indicate the change in cross-wind components found during the CBI studies; this was a period of some of the strongest cross-wind components throughout the year. As indicated by Pritchard and Rives (1979), however, it would take an analysis of filtered wind-speed records to detect other differences and similarities between survey periods.

Tidal Currents

Currents measured during the April and August 1979 surveys were the result of wind, local circulation and tides. The tidal current is only one component of the locally observed current and is primarily related to solilunar conditions.

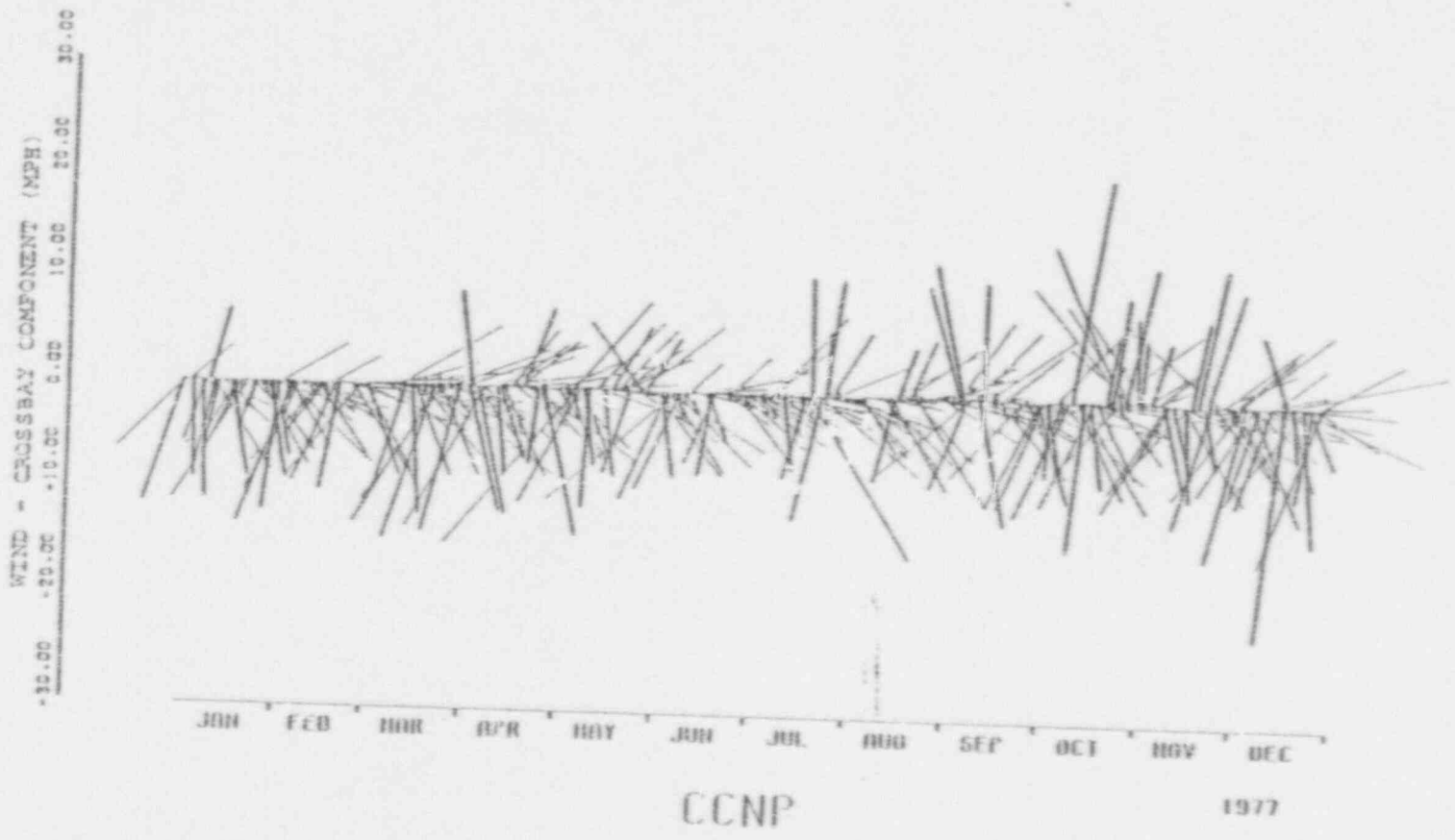


Figure II-4-13. 1977 wind vectors determined atop CCNP 61-m tower. Wind vectors point toward the direction the wind is blowing and the line on which they originate is approximately parallel to the shoreline at Calvert Cliffs.

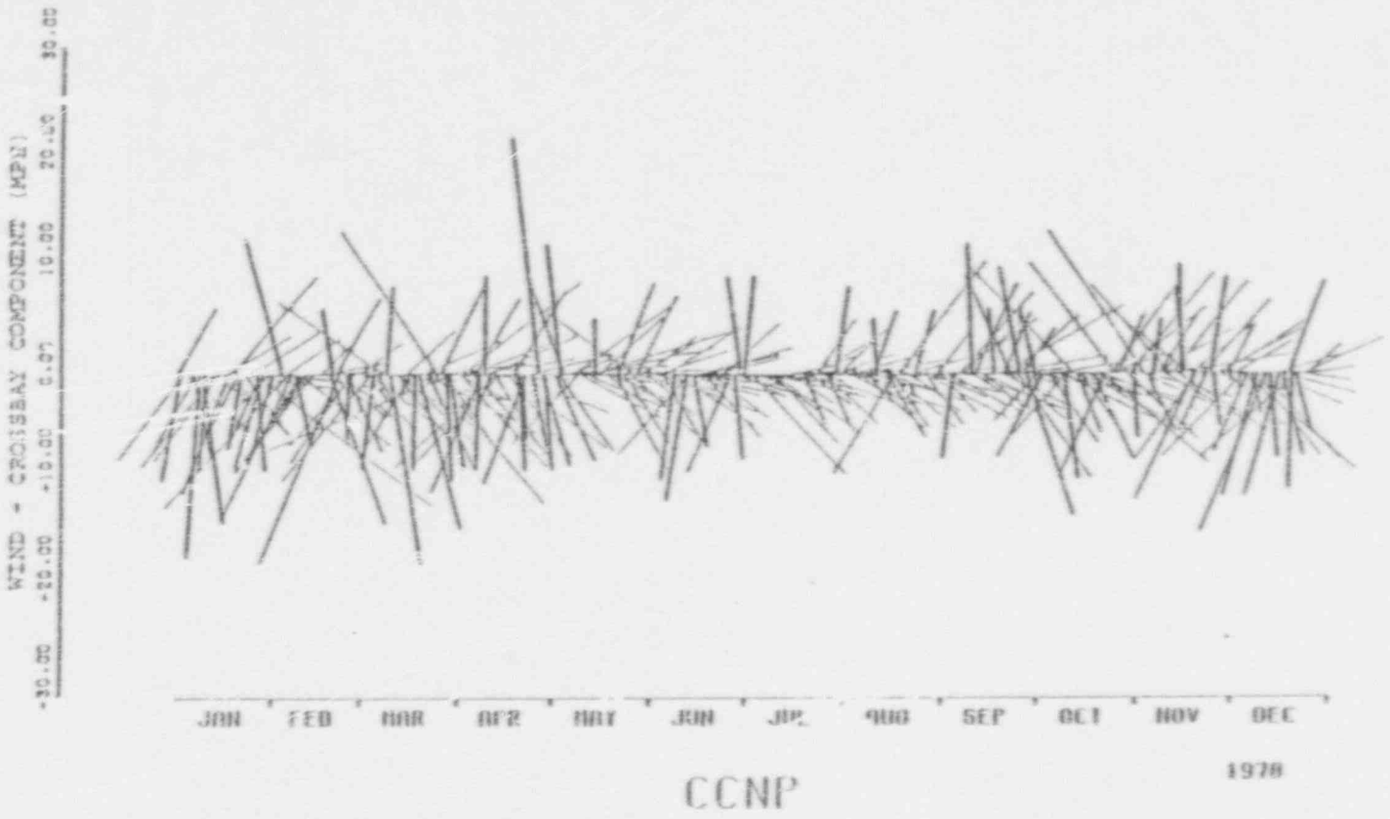


Figure II-4-14. 1978 wind vectors determined atop CCNP 61-m tower. Wind vectors point toward the direction the wind is blowing and the line on which they originate is approximately parallel to the shoreline at Calvert Cliffs.

Examination of the solilunar tidal currents during the various survey periods indicates when the surveys were made relative to spring and neap tides.

The computed USCGS tidal currents for April, August and October 1977 and 1978 are shown in Figures II-4-15 and II-4-16. The April and August 1979 tidal currents are given in Figure II-4-17. The spring tide is recognized on these diagrams as the period of large current amplitude and neap tide is the period of small current amplitude. The 15 to 20 April 1979 surveys started at the end of a spring tide and extended into a neap tide (Fig. II-4-17). The 6 to 10 August 1979 surveys are found to be centered on a period of spring tide. In comparison to past years, smaller amplitude neap tides are found in April and October 1978. Larger amplitude spring tides are found in late August 1977. The tides during the CBI 1977 studies were begun at the end of a spring tide and ended in the middle of a neap tide.

Comparative Results Summary

General hydrographic conditions during the April and August 1979 field dye studies have been compared to other periods of time and to conditions during other surveys. The comparative time-series analysis indicates that conditions during the CBI 1977 were unique relative to other periods of time. The ANSP April and August 1979 surveys were taken during periods of time with no abnormal or unique events hydrographically. The surveys were conducted during normal springtime and summer conditions, within the limits that "normal" hydrographic conditions can be identified.

5. CCNPP FULL LOAD PLUME COMPLIANCE WITH MARYLAND WATER QUALITY STANDARDS

The April and August 1979 CCNPP surveys were conducted at steady full plant load. In addition, a condenser temperature rise of 12°F was allowed during the study period. The purpose of this report section is to examine the size of the CCNPP thermal plume in relation to the mixing zone criteria used to test for compliance with Maryland Water Quality Standards. This will be done for both a 10°F ΔT and a 12°F ΔT.

Discharge Flow

The criteria require that the plant pumping rate not exceed 20 percent of the annual average net flow past the point of discharge. The maximum plant pumping rate of CCNPP is 5624 cfs. The long term freshwater inflow to Chesapeake Bay at the Susquehanna River is 36,000 cfs. In addition, the net non-tidal gravitational density circulation near Calvert Cliffs is

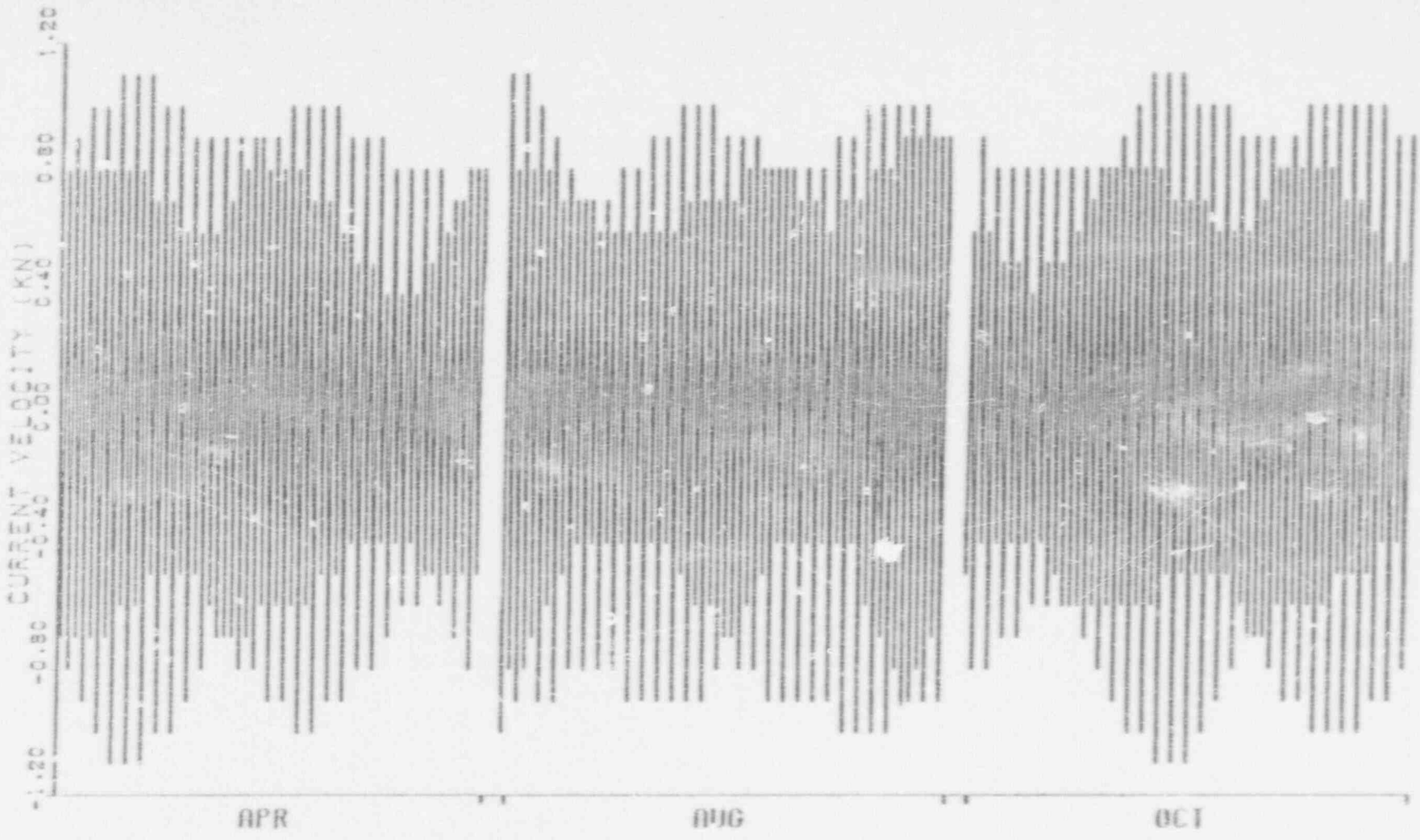


Figure II-4-15. Solilunar tidal currents near Calvert Cliffs for April, August and October 1977 from U.S. Coast Guard Survey calculations.

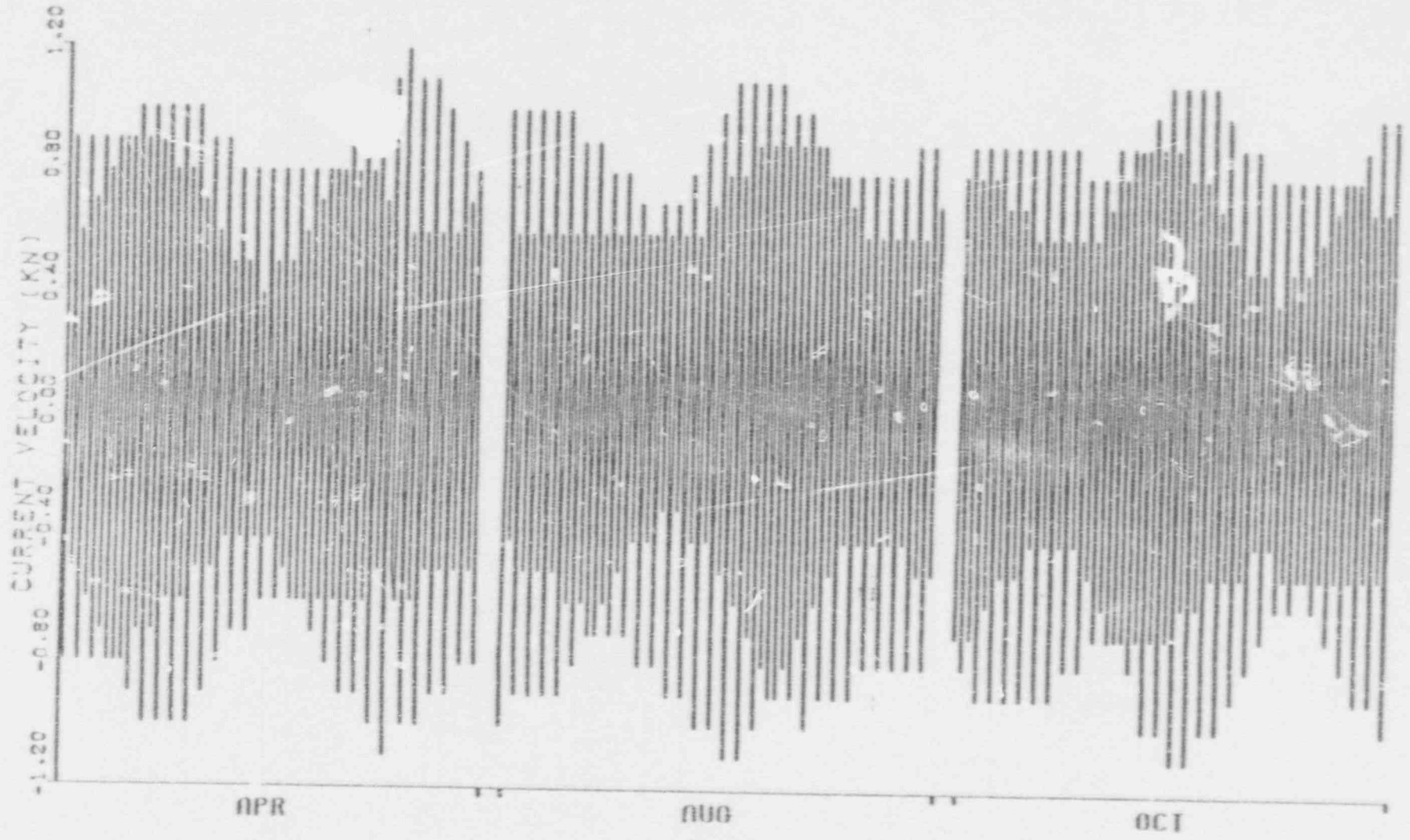


Figure II-4-16. Solilunar tidal currents near Calvert Cliffs for April, August and October 1978 from U.S. Coast Guard Survey calculations.

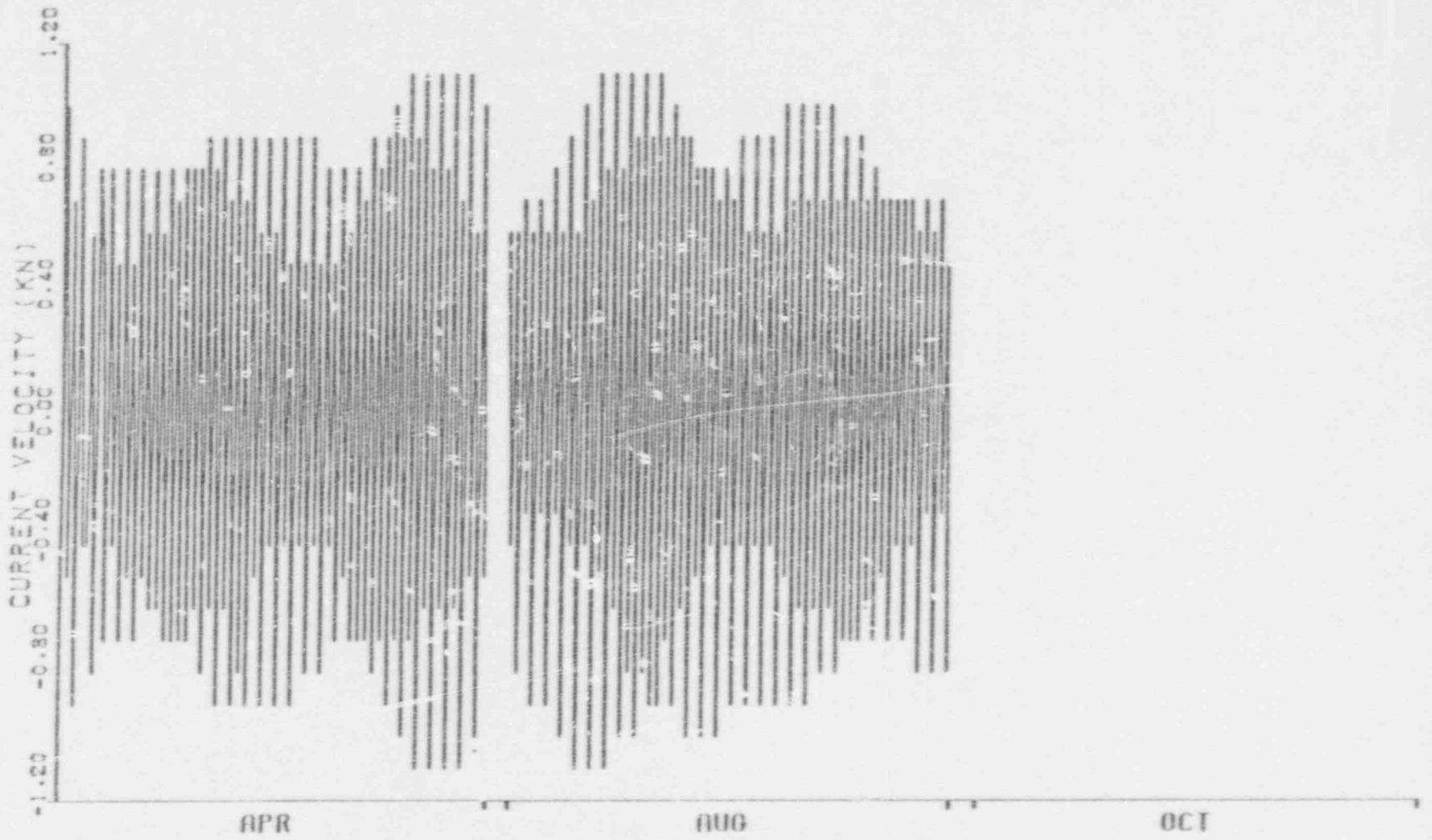


Figure II-4-17. Solinunar tidal currents near Calvert Cliffs for April and August 1979 from U.S. Coast Guard Survey calculations.

3 to 5 times the freshwater inflow based on salinity profiles given in Seitz (1971).

Based on these data the CCNPP pumping rate is less than 16 percent of the freshwater inflow and is only 2 to 6 percent of the net non-tidal surface outflow in Chesapeake Bay at Calvert Cliffs.

2°C Radial Dimension

The criteria require that the length of the full-load 2°C isotherm not exceed one-half the ebb-tide excursion. To determine compliance with this requirement two things must be established. One is the average ebb-tide excursion distance; the second is the average isotherm radial extent.

The frequency distribution of the ebb-tide excursion distance is given in Figure II-2-16 for the April period and in Figure II-2-27 for the August period. The April surveys were during a period of high freshwater inflow and the current measurements were made through a spring and neap tide. The August surveys were made during a spring tide period. There is little difference in the frequency distributions between the two periods. Combining the results of the two surveys, the mean ebb-tide excursion distance at CCNPP is 5.3 km.

The isotherm radial extent determination requires some computation based upon the results presented in Section 3. The computations are as follows: (1) select a scaling area, An, for the conditions being examined; (2) compute the isotherm area using Equation II-3-1; (3) compute the isotherm length using the relationship between length and area in Figure II-3-4. For the average radial extent, the average scaling area from all surveys is, from Figure II-3-4, $An=0.26 \times 10^4$ m^2. For a condenser temperature rise of 10°F, and assuming 10% recirculation, Equation II-3-1 gives a 2°C isotherm area of 15.2×10^4 m^2. Figure II-3-4 gives a length of 1.20 km. For a 12°F condenser temperature rise and 10% recirculation, Equation II-3-1 gives a 2°C isotherm area of 33.9×10^4 m^2 and Figure II-3-4 gives a length of 1.81 km. For both cases, the average of 2°C isotherm lengths is less than one-half the average ebb-tide excursion distance of 5.3 km.

Percent of Estuarine Cross-Section

The extreme plume developed by Pritchard and Rives (1979) shows a width from the CCNPP shoreline of 3.5 km. The width of the Bay between Kenwood Beach and Cove Point varies from 14.3 km to 9.1 km. Assuming that the extreme plume were vertically homogeneous at either of these cross-sections, it would always occupy less than 50% of the cross-section.

Percent of Average Bottom Area

The criteria require that the bottom area intercepted by the 2°C isotherm not exceed 5% of the bottom area swept by the average ebb-tide excursion. As shown previously, the ebb-tide excursion is 5.3 km and the estuary width averages 11.7 km for an ebb-tide bottom area of 62 km^2. As shown for the radial dimension computations, the full load 2°C isotherm area is 0.15 km^2 for a 10°F ΔT and is 0.34 km^2 for a 12°F ΔT. These are 0.2 and 0.5 percent, respectively, of the bottom area swept by the average ebb tide.

6. SUMMARY

The sizes of the Calvert Cliffs Nuclear Power Plant thermal plume were determined for full-load conditions using dye tracer-temperature survey techniques. One set of plume mappings was made over a five-day period in April 1979 during a neap tide and another was made in August 1979 during a spring tide. Eight plume mappings were completed in April and nine in August. Current measurements were made during both surveys to determine tidal excursion distances.

The plume-mapping data were reduced to dimensionless forms for comparison of results between mappings and survey periods and for relating plume sizes to the plant condenser temperature rise. The size of the plume could then be compared to the Maryland Water Quality Standards to determine compliance based on mixing zone criteria. It was found that for a 12°F condenser temperature rise, the CCNPP full-load plume would comply with all of the mixing zone requirements for discharges to tidal waters.

The hydrographic conditions throughout the Chesapeake Bay during the April and August 1979 surveys were compared to conditions in past years and during other surveys. It was found that relatively normal conditions existed during the two survey periods.

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R. Lassahn	Overall guidance of study requirements
E. Bauereis	

III. REPRESENTATIVE IMPORTANT SPECIES STUDIES

Table III-C-5. Density of bay anchovy eggs in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Eggs were collected from late May through August 1980. (Density expressed as organisms/100 m^3).

a. Monthly

		KS	LB	D	PSC	PS	RP
4/10/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
4/18/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
5/19/80	SURFACE	0.0	0.0	0.0	0.0	0.0	-
	MIDDLE	0.0	0.0		0.0	0.0	-
	BOTTOM	0.0	0.0	0.0	0.0	0.0	-
4/23/80	SURFACE	0.0	0.0	0.0	0.0	0.0	6.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
5/13/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
6/10/80	SURFACE	0.0	1.4	6.0	0.0	0.0	16.5
	MIDDLE	0.0	1.8		0.0	0.0	46.2
	BOTTOM	0.0	1.9	0.0	0.0	0.0	2.3
07/14/80	SURFACE	0.0	1.2	2.7	0.0	1.1	903.7
	MIDDLE	0.0	487.8		1.9	0.9	689.5
	BOTTOM	0.0	0.0	0.0	24.5	0.9	4727.6
08/25/80	SURFACE	0.0	0.0	0.0	1.3	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
07/10/80	SURFACE	0.0	0.0	0.0	0.0	0.0	-
	MIDDLE	0.0	0.0		0.0	0.0	-
	BOTTOM	0.0	0.0	0.0	0.0	0.0	-

b. Weekly

		D	PSC	PS
5/22/80	SURFACE	0.1	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	1.6	0.0	0.0
5/27/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	1.0
6/05/80	SURFACE	4.2	1.1	7.7
	MIDDLE		1.8	8.6
	BOTTOM	5.2	0.0	9.5
6/18/80	SURFACE	65.2	27.1	8.8
	MIDDLE		12.5	22.6
	BOTTOM	36.7	13.1	37.6
6/23/80	SURFACE	23.0	3.0	1.3
	MIDDLE		0.0	0.0
	BOTTOM	13.9	2.0	3.8
7/02/80	SURFACE	53.3	34.2	83.9
	MIDDLE		62.1	98.4
	BOTTOM	105.8	13.2	18.9
7/10/80	SURFACE	27.0	26.6	9.4
	MIDDLE		34.8	2.4
	BOTTOM	27.4	31.6	0.0
7/29/80	SURFACE	3.0	12.5	199.4
	MIDDLE		6.4	446.2
	BOTTOM	1.2	13.8	0.0
8/07/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
8/14/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	1.1	0.0	1.2
8/21/80	SURFACE	4.2	1.3	0.0
	MIDDLE		2.6	0.0
	BOTTOM	0.0	1.3	0.0

Table III-C-4. Density of bay anchovy eggs in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Eggs were collected from May through August 1979. (Density expressed as organisms/100 m^3).

a. Monthly

		KB	LB	B	PSC	PS	RP
4/10/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
3/19/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
4/12/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
5/02/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
6/04/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
7/09/79	SURFACE	100.0	38.7	119.8	37.7	22.6	305.2
	MIDDLE	20.2	343.1		32.2	722.8	2355.6
	BOTTOM	326.2	151.8	129.4	10.0	67.6	432.6
8/13/79	SURFACE	7.0	0.0	6.0	10.3	8.0	94.5
	MIDDLE	0.0	9.5		1.9	0.0	0.0
	BOTTOM	2.8	1.2	7.7	0.5	1.2	1.0
9/17/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
10/18/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
11/27/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
12/10/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0

b. Weekly

		B	PSC	PS
5/16/79	SURFACE	-	-	32.0
	MIDDLE		-	38.4
	BOTTOM	-	-	0.0
5/30/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
6/13/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	1.0	0.0	0.0
6/[illegible]/79	SURFACE	-	-	0.8
	MIDDLE		0.0	2.4
	BOTTOM	-	0.0	4.6
6/27/79	SURFACE	10.7	0.0	0.0
	MIDDLE		5.0	3.2
	BOTTOM	7.5	12.5	1.3
7/[illegible]/79	SURFACE	-	-	314.7
	MIDDLE		-	456.2
	BOTTOM	-	-	507.1
7/[illegible]/79	SURFACE	4.7	0.0	0.0
	MIDDLE		10.8	4.3
	BOTTOM	4.8	9.8	0.0
7/[illegible]/79	SURFACE	13.5	21.1	9.0
	MIDDLE		39.2	3.9
	BOTTOM	26.3	19.5	13.5
8/01/79	SURFACE	0.6	0.0	1.0
	MIDDLE		0.0	0.0
	BOTTOM	1.4	2.9	27.6
8/08/79	SURFACE	-	-	0.0
	MIDDLE		-	3.2
	BOTTOM	-	-	2.1
8/22/79	SURFACE	1.0	0.0	1.4
	MIDDLE		0.0	0.0
	BOTTOM	2.3	0.0	0.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	1.0

Table III C-3. Density of bay anchovy eggs in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Eggs were collected from April through September 1978. (Density expressed as organisms/100 m^3).

a. Monthly

		KB	IB	B	PSC	PS	RF
4/24/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
5/24/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	5.3	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
3/22/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
4/20/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	1.6	0.0
5/23/78	SURFACE	7.3	3.9	0.0	0.0	0.0	18.3
	MIDDLE	28.0	25.8		0.0	0.0	67.6
	BOTTOM	814.9	668.6	8.6	2.3	5.7	970.1
6/14/78	SURFACE	614.1	259.9	13.6	7.7	26.6	33.2
	MIDDLE	447.0	172.6		3.5	19.4	42.7
	BOTTOM	1168.3	660.9	0.0	6.2	427.7	1899.1
7/10/78	SURFACE	365.0	76.5	7.4	5.4	1.3	55.6
	MIDDLE	729.6	0.0		11.6	3.5	73.9
	BOTTOM	78.8	0.0	11.0	11.0	1.8	35.2
8/07/78	SURFACE	1.8	4.8	3.9	1.0	0.0	0.0
	MIDDLE	33.1	5.3		2.2	2.2	0.0
	BOTTOM	58.6	4.1	2.3	7.2	11.5	1.3
9/26/78	SURFACE	0.0	0.0	0.0	0.0	0.0	3.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
10/19/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
11/14/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
12/05/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0

b. Weekly

		B	PSC	PS
5/31/78	SURFACE	66.0	0.0	0.0
	MIDDLE		0.0	1.4
	BOTTOM	73.3	89.8	0.0
6/06/78	SURFACE	1850.6	3091.2	2327.3
	MIDDLE		5082.7	728.2
	BOTTOM	2379.6	5518.5	1683.8
6/22/78	SURFACE	3.4	0.0	9.4
	MIDDLE		0.0	17.2
	BOTTOM	1.4	5.8	9.3
6/28/78	SURFACE	0.0	3.1	11.5
	MIDDLE		2.0	17.1
	BOTTOM	3.9	0.0	8.7
7/05/78	SURFACE	23.8	21.5	7.1
	MIDDLE		28.7	18.7
	BOTTOM	26.0	33.9	80.7
7/21/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.7	0.0
	BOTTOM	0.0	13.3	0.0
7/29/78	SURFACE	0.0	0.0	1.2
	MIDDLE		0.0	12.4
	BOTTOM	1.1	2.7	575.6
8/03/78	SURFACE	1.5	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	10.6	0.0
8/15/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	25.9
8/24/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	2.6	92.5	80.1
9/01/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	1.5	0.0	0.0

Table III-C-2. Dissolved oxygen concentrations (mg/l) for sampling dates when low DO values (≤5 mg/l) were recorded or when large differences were observed within the study area during ichthyoplankton monitoring studies in Chesapeake Bay near Calvert Cliffs Nuclear Power Plant 1978-1980. (*indicates monthly six station sample collection, all other dates are weekly three station plant site collections) (S=Surface, M=Middle, B=Bottom depths)

1978

		KB	LB	D	PSC	PS	BP
7/21	S	-	-	5	5	3	-
	M	-	-		6	1	-
	B	-	-	<1	2	<1	-
7/[illegible]9	S	-	-	5	7	6	-
	M	-	-		7	6	-
	B	-	-	<1	6	4	-
8/03	S	-	-	3	6	7	-
	M	-	-		6	4	-
	B	-	-	3	1	1	-
8/07*	S	8	7	1	2	2	4
	M	7	7		1	2	4
	B	2	4	0	1	1	1

1979

		KB	LB	D	PSC	PS	BP
7/09*	S	8	7	4	5	5	7
	M	5	4		4	5	6
	B	2	2	4	4	2	3
7/18	S	-	-	6	7	9	-
	M	-	-		6	8	-
	D	-	-	5	<1	-	-
7/25	S	-	-	2	5	5	-
	M	-	-		2	2	-
	B	-	-	1	<1	<1	-
8/01,08		DO values >5					
8/13*	S	7	7	6	7	7	8
	M	7	6		6	6	7
	B	3	2	5	<1	<1	4

1980

		KB	LB	D	PSC	PS	BP
4/23*	S	14	15	12	14	14	14
	M	12	11		13	13	13
	B	5	4	10	7	5	6
5/13*	S	12	11	5	8	8	9
	M	11	11		8	1	8
	B	4	4	5	4	2	5
5/22		DO values >5					
5/27	S	-	-	8	8	9	-
	M	-	-		8	9	-
	B	-	-	8	2	8	-
6/05	S	-	-	8	10	8	-
	M	-	-		10	8	-
	B	-	-	8	1	4	-
6/10*		DO values >5					
6/18	S	-	-	6	7	9	-
	M	-	-		6	7	-
	B	-	-	6	3	4	-
6/2[illegible]	S	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	M	-	-		5	5	-
	B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1980

		KB	LB	D	PSC	PS	BP
7/02	S	-	-	6	7	8	-
	M	-	-		7	7	-
	B	-	-	6	3	4	-
7/10	S	-	-	6	8	7	5
	M	-	-		7	5	-
	B	-	-	6	6	4	-
7/14*	S	9	8	5	7	7	7
	M	8	8		7	7	6
	B	2	6	6	3	3	5
7/29		DO values >5					
8/07	S	-	-	8	8	8	-
	M	-	-		5	4	-
	B	-	-	7	3	2	-
8/[illegible]*	S	-	-	6	7	8	-
	M	-	-		6	6	-
	B	-	-	4	3	2	-
8/21		DO values >5					
8/25*	S	10	10	8	9	9	8
	M	7	6		8	6	

Dissolved oxygen data are presented in Table III-C-2. Variations in DO are important in power plant studies because fish kills are often associated with low DO episodes and because DO can influence the general distribution of fish in plant areas and their ability to avoid entrapment and impingement on intake trash racks. Table III-C-2 includes values only for sampling dates when DO concentrations were "low", i.e., when DO of 5 mg/l or below was measured at least at one location. The standard of 5 mg/l is somewhat arbitrary but is the minimum concentration recommended by the U. S. EPA (1977) to maintain "good fish populations". As a point of reference, oxygen solubility in sea water of 25°C and 10°/oo salinity--conditions typical of July and August (Table III-C-1)--is between 7 and 8 mg/l (oxygen solubility nomograph, Table XIV, Strickland and Parsons, 1972). DO concentrations for all stations and sampling dates are available in ANSP annual reports to BG&E (ANSP, 1980, 1981b; Shenker and Currence, 1979).

From the data in Table III-C-2, it appears that DO concentrations usually decrease with depth and that the water column was sometimes clearly stratified with respect to DO. This condition occurred at all six nearfield stations. When all stations are compared, however, plant site stations PS and PSC appear to have had lower oxygen values than other stations. Dissolved oxygen concentrations at Station D are assumed to reflect DO concentrations of intake source water. These data reflect a DO concentration at Station D that was usually somewhat higher than at Station PSC (bottom) which may be indicative of a mixed sample at the discharge, entrainment of upper layers of the water column at Station PSC or aeration from the turbulence at Station D.

Abundance and Distribution

Bay anchovy (*Anchoa mitchilli*)

Not all developmental stages of Bay anchovy were represented in the sample collections for these studies. Anchovy eggs and larvae were found in quantity but very few juveniles were collected.

Abundance Tables III-C-3 through III-C-5 clearly show how anchovy eggs were clumped in time and space. It is difficult to compare overall abundances between years because spawning peaks may have been missed and distribution patterns are hard to discern. In 1978, widespread spawning occurred sporadically from mid-May through August. In 1979 and 1980, spawning activity appeared to have been concentrated in June and July.

An analysis of variance was performed on anchovy egg time and space distribution (Table III-C-6a and 6b). Analysis of horizontal distributions of anchovy eggs indicates no signifi-

Table III-C-1. Temperature and salinity of plant site stations for each month during the spawning period, 1978 to 1980 compared with "ambient" nearfield measurements. "Ambient" temperature ($\bar{T}$) and salinity ($\bar{S}$) are the means of measurements at Stations KB, LB and RP. The average difference (Mean Diff.) between near-plant and near-field means is shown at the bottom of the table. Data are from ANSP ichthyoplankton monitoring studies in Chesapeake Bay near Calvert Cliffs Nuclear Power Plant.

	Surface temperature				Bottom temperature				Surface salinity				Bottom salinity			
	$\bar{T}$	PS	PSC	D	$\bar{T}$	PS	PSC	D	$\bar{S}$	PS	PSC	n	$\bar{S}$	PS	PSC	n
APR																
1978	11.7	12.0	12.0	13.0	11.5	12.0	11.5	13.5	5.7	6	6	6	6.7	7	7	7
1979	9.2	9.2	11.0	12.0	9.0	9.1	10.0	12.4	7.3	7	8	8	7.3	7	7	8
1980	14.0	14.2	14.0	15.2	11.0	10.8	11.5	15.5	7.2	8	8	8	11.2	12	12	9
MAY																
1978	18.4	19.0	19.3	19.5	15.9	16.5	16.5	18.3	5.9	5	5	5	10.0	5	6	5
1979	14.0	14.1	14.9	16.8	13.6	14.0	12.5	16.6	7.0	7	7	9	8.6	8	11	10
1980	16.7	16.4	16.9	20.8	16.3	16.2	16.5	19.5	10.0	10	10	11	11.0	11	12	11
JUN																
1978	20.2	20.2	20.0	21.0	19.6	19.8	19.9	22.0	9.0	8	8	9	11.3	10	9	9
1979	19.8	19.5	20.0	21.8	19.7	19.6	19.6	21.8	10.0	8	8	8	8.0	8	8	8
1980	20.5	20.3	20.5	22.7	20.0	19.8	20.5	22.0	12.0	11	11	11	11.3	12	12	11
JUL																
1978	25.0	26.0	25.3	26.4	23.5	24.0	24.5	25.5	8.7	9	9	9	10.6	10	10	10
1979	22.5	22.4	22.5	23.5	21.8	21.6	21.5	22.5	9.3	10	10	13.5	12.0	12	12	10.5
1980	24.7	25.8	26.0	29.4	24.2	23.6	23.6	28.6	12.0	12	12	12	13.0	14	14	12
AUG																
1978	26.8	26.5	26.0	27.8	26.1	25.3	25.5	27.4	11.3	12	12	12	12.3	13	13	12
1979	24.6	24.0	24.0	27.2	23.9	23.8	23.2	27.0	10.7	11	11	12	14.3	16	18	13
1980	26.1	25.7	26.6	28.2	25.2	24.9	25.9	26.6	12.6	14	14	14	15.6	15	19	14
SEP																
1978	23.5	24.0	23.0	25.0	22.7	23.0	24.0	25.0	11.0	12	11	11	11.0	11	11	11
1979	23.9	24.2	24.9	27.5	23.2	23.3	23.5	28.2	11.0	11	11	12	11.3	12	11	11
1980	25.2	25.2	25.6	28.0	25.5	24.9	23.8	24.0	15.0	15	15	16	15.0	15	15	16
OCT																
1978	16.7	17.5	17.5	17.5	16.7	17.0	17.0	17.5	14.7	15	15	14	15.0	15	15	14
1979	16.4	16.3	16.8	19.0	15.4	16.2	16.8	18.5	8.0	8	9	10	10.0	11	10	9
1980	18.0				18.3				16.3				18.7			
MEAN DIFF.		0.35	0.33	2.43		0.03	0.40	2.40		0.00	0.00			0.00	0.00	
		PS-T	PSC-T	D-T		PS-T	PSC-T	D-T		PS-T	PSC-T	D-T		PS-T	PSC-T	D-T

Results and Discussion

Water temperature and salinity influence fish spawning and metabolic and behavioral processes. Temperature and salinity data accompanying the biological collections for these studies are presented in Table III-C-1. (Data are presented only for those months in which juvenile anchovy, goby or spot were present.) The average temperatures and salinities recorded at non-plant-site stations (KB, LB and RP) and the individual measurements recorded at plant site stations (PS, PSC, D) are presented in Table III-C-1 for each month and year, separately for surface and bottom. The differences between individual plant-site stations and the nearfield averages were calculated for each month and averaged overall.

Summer electrical storms disrupted several weekly sampling expeditions during 1978. High winds accompanying the storms caused bottom upwelling and unusual vertical mixing of waters near the plant (Olson and Sage, 1979). The year 1979 was wetter and cooler than usual which was reflected in lower water temperatures for 1979 and, possibly, in the lower-than-usual late summer salinity records. High winds caused several incomplete sampling expeditions in 1979 as well. It was unusually dry in 1980, with a warm, protracted summer season. Water temperatures were seasonally typical for the Bay, but the salinities in Table III-C-1 do not reflect the higher values ($> 20^{0}/_{00}$) frequently recorded by others during this period (J. H. Hixson, M. M. Olson, ANSP, personal communication).

Table III-C-1 shows that plant site Stations PS and PSC were not very different from nearfield stations in temperature or salinity. Recorded temperature elevations from the heated plume at those stations rarely exceeded 1.0°C. At Station D temperature elevations were lower than the cross-condenser ΔT of 5.5-6.0°C. Mixing occurs very rapidly in the immediate area of the discharge and it is evident that both surface and bottom samples at D were mixed with unentrained Bay water. Salinity differences among stations were variable. On the bottom at Station PSC, a layer of high salinity water was occasionally encountered which seemed unrelated to water masses at other stations, e.g., August 1980 (Table III-C-1; 27 June and 18 July, 1979 (ANSP, 1980), and 27 May and 5 June, 1980 (ANSP, 1981b). This denser bottom layer may not have been drawn into the cooling system of the plant, however, for the higher salinity was not always detected at Station D on those occasions. The lower salinity at Station D may have been a sampling artifact due to the rapid mixing mentioned earlier, but it is also too simplistic to say that only bottom water is entrained. Individual panels of the curtain wall are removed during the summer to allow fish caught in the embayment area to escape which also alters the wall's function of excluding the upper water strata. Mid-depth and even surface waters may be subducted into the system, depending upon characteristics of the water column at any given moment.

vidual groups are not included in this report. Those results were preliminary in any case and the final report from EAI will include an analysis of the complete data base (EAI, in prep.).

Data Analysis

All counts were normalized to a standard volume of 100 m^3. Yolk-sac, fin-fold and post fin-fold larval stages were grouped as "larvae" for analysis and, in the case of spot, larvae and juveniles were not differentiated but grouped together.

Analyses of variance (ANOVA) (Sokal and Rohlf, 1969) were performed on log-transformed densities of groups whose persistent presence or abundance was sufficient to analyze. Analyses of the monthly data for each year included all six stations and identified differences associated with DATE, STATION, DEPTH and their interaction. Analyses of the weekly data included only Stations PS, PSC and D from late May to August for each year and examined only variation associated with DATE, STATION and their interaction. Because only two depths could be sampled at Station D, the design was unbalanced for analysis of variation by depth. Vertical distribution trends for the weekly studies were therefore inferred by inspecting the abundance tables. Numbers of spot larvae and spot and anchovy juveniles were too small for statistical analysis.

Egg and larval densities in the near field were plotted together with densities of entrained organisms (EAI, unpublished data) for visual comparison. Rigorous quantitative comparisons were not attempted because of different sampling locations, methods and schedules. The EAI data which were most comparable to the ANSP data were the means of night samples collected weekly throughout the spawning season. Means of EAI intake sample densities were plotted with ANSP densities from the bottom depth at Stations PSC and PS. Both Stations PSC and PS were included because of the patchy distribution of the study organisms in time and space and because the two stations give a better estimate of densities in the plant area. The plant is designed to preferentially draw bottom water for its cooling system and densities of entrained organisms should be most similar to densities at lower depths at these stations. Means of EAI postcondenser (TA) samples were plotted with ANSP densities in the 5-m tow at the plume (Station D). At Station D, vertical stratification was unlikely in the turbulent effluent and samples from the 5-m depth at the level of the submerged conduit terminus were assumed to be less contaminated by unentrained Bay water than surface samples.

Temperature, salinity and dissolved oxygen (DO) were measured at each station from water samples obtained with a Kemmerer sampling bottle. Temperature was measured with a hand-held thermometer, salinity was read by an A/O refractometer, and DO was determined by the Winkler titration method.

Entrainment Studies

Ecological Analysts, Inc. collected samples at CCNPP from April 1978 to September 1980. Entrainment abundance methods are described in detail in EAI reports (1979, 1980a, 1980b) and are only briefly summarized here. Pre-condenser intake (IN) samples were collected within the embayment area in front of the trash racks serving the cooling water intake system. Samples obtained between April 1978 and March 1979 were collected from in front of Unit 1. Samples obtained between March and October 1979 were collected from in front of Unit 2 and from October 1979 to September 1980 samples were again collected from Unit 1. Post-condenser samples were collected at the discharge tunnel access (TA) from appropriate conduits discharging Unit 1 or Unit 2, depending on the location of the intake sampling rig.

Samples were collected with a large volume, centrifugal trash pump. Sample water was pumped to a collecting table where the animals were sorted for abundance and viability studies. At IN, a manifold enabled the pump to draw water from surface, middle and bottom depths producing a composite sample; at TA, the sample was obtained from a single depth within the discharge conduit.

Samples were collected three times during the day and again during the night to provide diel density differences. Sampling frequency was based on anticipated periods of high density: bimonthly or weekly from April through October, monthly at other times of year.

One of the objectives of the entrainment studies conducted by EAI was to determine the viability of organisms passing through the cooling system. Both fish eggs and larvae were to be held for observation of any latent effects of entrainment. However, live eggs are transparent and difficult and time-consuming to sort. Anchovy and goby larvae are also very delicate and sampling mortality of these groups, as determined from initial precondenser mortality at IN, was very high making it difficult to evaluate the viability study results. Spot larvae and juveniles were too few to be included in the full study (EAI, 1980b). The handling time for anchovy and goby eggs was finally judged excessive by EAI and egg viability studies were abandoned. The differences in mortality between IN and TA as observed in the studies that were completed were relatively small, suggesting plant-induced mortality substantially less than 100%. However, viability data for the indi-

Channel (PSC) and the Discharge Plume (D). The channel is a deepened trench (13 m) lined with rip-rap leading from about the 10-m contour near Station PS to the intake embayment area. A curtain wall which forms the embayment extends beneath the surface to a depth of 10 m, largely excluding upper strata of the water column and permitting only bottom water from the trench to pass to the cooling system intake.

All stations were sampled monthly. During the summer spawning season (late May-August), samples were collected weekly at nearplant Stations D, PSC and PS. All sampling was conducted at night to minimize net avoidance and because some groups tend to be more abundant in the water column at night.

Sampling gear consisted of three 0.5-m diameter conical plankton nets of 223 µm mesh, equipped with General Oceanics flowmeters. The nets were gimbaled within metal rings suspended from a tow chain to fish simultaneously at surface (0 m), middle (5 m) and bottom (10 m) depths. A diving depresser to maintain depth was attached to the end of the chain below the 10-m net. The minimum vertical distance between the net and the bottom was about 35 cm, but because wave and current strength often affected towing conditions, the vertical distance between the net and the bottom was probably somewhat greater than that. Attempts to sample closer to the substrate were made during the preliminary studies in 1976-1977. Bottom-running sleds of two different designs were tried, but rip-rap and other obstacles on the Bay floor made that method ineffective. Square nets with a larger orifice fished at maximum depth were considered but these, too, could not be fished close enough to the bottom.

A single 7-min tow was taken at each station. At the nearfield stations, the nets were towed in a circular pattern to eliminate variability caused by towing with or against a current. At Station PSC, tows began at the curtain wall (13 m) and moved eastward along the intake channel. Due to the shallow depth at Station D (5 m), only surface and bottom samples were taken. A circular tow-path was impracticable because of the strength and turbulence of the discharge. Therefore at Station D nets were towed in a zig-zag pattern from the visible end of the discharge boil toward the head of the plume.

A 7-min tow filtered approximately 100 m^3 of water. After the nets were retrieved from the water and flowmeter readings recorded, the samples were hosed down into the collection cups at the cod end of the nets, then transferred to plastic gallon jugs for storage. All samples were preserved in the field with buffered formalin. In the laboratory, organisms were sorted and counted under a dissecting microscope and all organisms were identified to the lowest practical taxonomic level according to Lippson and Moran (1974). Fish larvae were separated into four developmental categories: yolk-sac, fin-fold, post-fin-fold and juvenile.

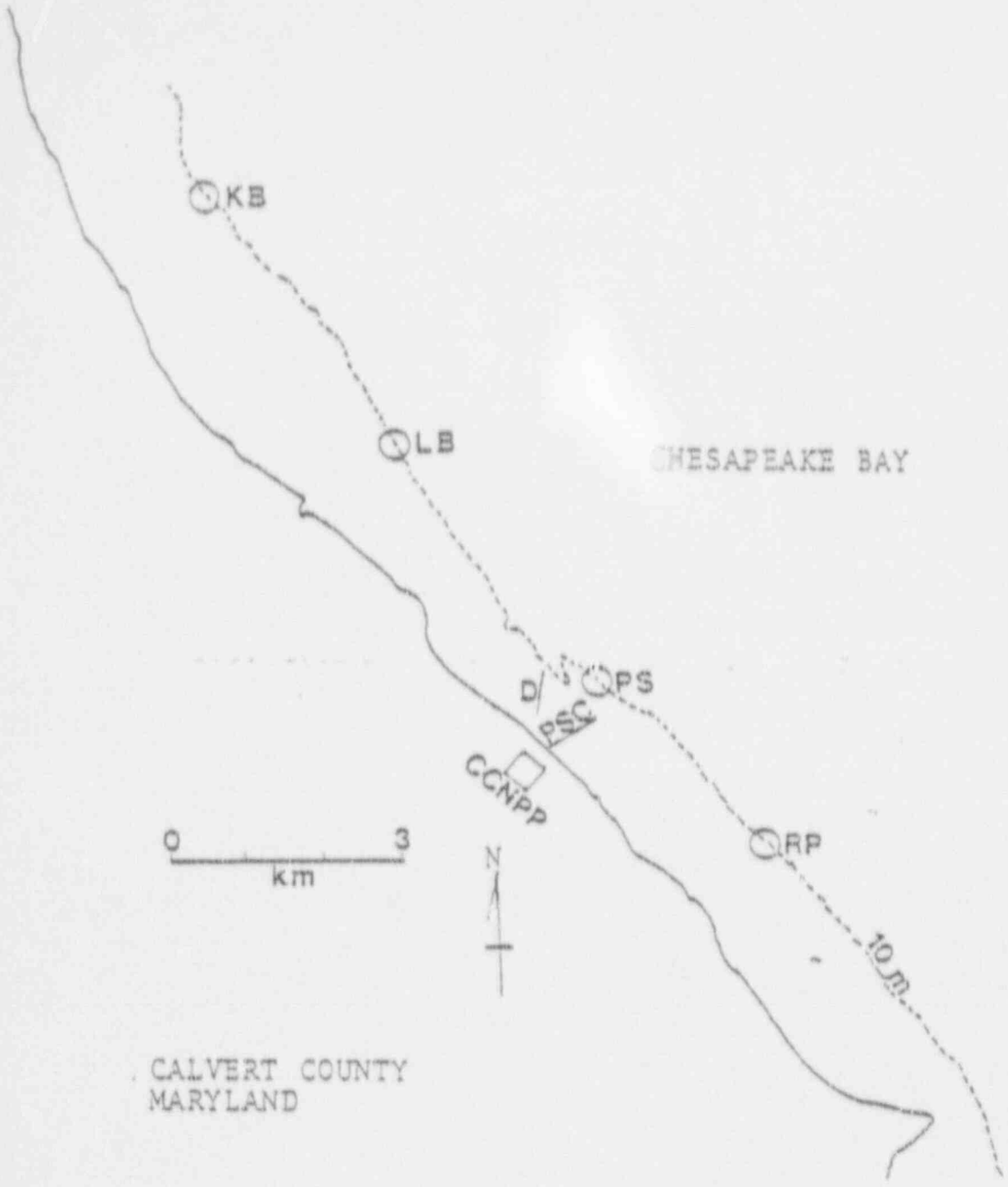


Figure III-C-1. Ichthyoplankton sampling stations, 1978-1980, in the vicinity of Calvert Cliffs Nuclear Power Plant, Maryland. KB= Kenwood Beach, LB= Long Beach D= Discharge Plume, PSC= Plant Site Channel, PS= Plant Site, RP= Rocky Point.

bottom of the Bay, the inside of empty oyster shells being a preferred habitat. Larvae are dispersed in the water column, but as they mature they take their place with adult gobies in a benthic existence among the oyster shell community. The adult goby reaches a length of about 6 cm and is not harvested commercially.

Spot (*Leiostomus xanthurus*)

Spot spawn offshore along the Atlantic coast during the late winter and early spring. It is thought that spot may spawn near the mouth of the Chesapeake Bay and by the time they swim up into the region near Calvert Cliffs and can be captured in plankton tows, the young fish have developed into late larval and juvenile stages. Nursery areas include the entire Bay; the adult range extends into fresh waters. Heavy concentrations of recently-hatched larvae may be found at the mouth of the Patuxent River and areas of the upper Bay between Baltimore Harbor and the Susquehanna River (Lippson, 1973). The adults and juveniles are bottom forage feeders and keep close to the bottom, eluding sampling gear. The adult reaches 15-30 cm in length, is the dominant species of the Bay finfish community and is a commercially-important game fish.

Materials and Methods

The present studies were developed to census macrozooplankton as well as fish eggs and juveniles. The sampling stations, methods and scheduling practices could not be specifically designed for individual groups and some aspects of the studies represent compromises to the broader objectives of the icthyo-macrozooplankton monitoring program.

Nearfield Studies

Samples were collected at stations located up- and downbay of the plant along a transect approximating the 10-m contour (Fig. III-C-1). Station designations were: Kenwood Beach (KB), Long Beach (LB), Plant Site (PS) and Rocky Point (RP). Stations PS, KB and RP coincide with fish-trawling study sites and other studies conducted by ANSP in the plant area. Station PS was defined in those studies as an impact station, while Stations KB and RP were defined as reference stations beyond thermal influence of the discharge plume. Station LB was included in the ichthyo-macrozooplankton studies as an intermediate station, potentially receiving diluted or dissipated heat from the discharge on flooding tides.

Two stations in the immediate areas of intake and discharge were sampled to obtain estimates of populations possibly entrained by the plant. Nearplant stations were: Plant Site

3) Are some life stages potentially more susceptible than others to effects of plant operations at CCNPP?

The data from these monitoring studies have been reviewed in detail in annual reports to BG&E (ANSP, 1980; Shenker and Currence, 1978, 1979; Wakefield, 1977). In this summary report, however, only quantitative studies from 1978, 1979 and 1980 have been included.

In-plant entrainment studies have been conducted for BG&E by Ecological Analysts, Inc. (EAI) of Towson, Maryland, between 1978-1980. Abundance data from their studies (EAI, 1979, 1980a, 1980b) have been integrated with ANSP data from the nearfield studies to assess the impact of the plant on these groups.

A summary and critique of these data together with the work of other investigators at the Calvert Cliffs site may be found in a comprehensive report prepared for the State of Maryland by the Martin Marietta Corporation (1980).

Representative Important Species

Bay anchovy (*Anchoa mitchilli*)

The bay anchovy is found in abundance in the Chesapeake Bay. It is a summer spawner (June-August primarily) with optimal spawning activity at salinities of 13-15 °/oo and water temperatures of 19-21°C or higher. Larvae are typically found upstream of spawning areas and concentrate in areas of lower salinity (0-6 °/oo) near the fresh/salt water interface (Lippson, 1973). Late spawn overwinter as juveniles. The adult anchovy reaches a length of about 6-9 cm and is not directly important as a source of food for man. It is, however, an important link in the food chain of many commercial and game fishes that inhabit the Bay.

Naked goby (*Gobiosoma bosci*)

Naked gobies are abundant throughout the Chesapeake Bay (Hildebrand and Schroeder, 1928; Lippson, 1973; and all phases of their life cycle are spent in these waters. It is one of the few species of fish which spawn in the vicinity of CCNPP and for this reason it is a species of particular interest in these studies.

Spawning takes place from June to October with most activity during July (Hildebrand and Schroeder, 1928). Eggs of the naked goby are difficult to census for they are not usually caught in plankton tows. The eggs are equipped with a filamentous adhesive disc which secures the egg to objects on the

C. ICHTHYOPLANKTON

Introduction

Pursuant to the Code of Maryland Regulation for thermal discharges (COMAR) 08.05.04.13 the Academy of Natural Sciences of Philadelphia (ANSP) has conducted environmental studies for the Baltimore Gas and Electric Company (BG&E) at Calvert Cliffs Nuclear Power Plant (CCNPP) on the Chesapeake Bay, Calvert Cliffs, Maryland. In compliance with COMAR 08.05.04.13 §C(2), study designs were reviewed by the State of Maryland Department of Natural Resources Power Plant Siting Program and interim annual reports have been prepared and published by the Academy and BG&E (§C(4) and (6)). This report summarizes the results and findings of studies to assess the impact of the thermal effluent and entrainment on the egg, larval and juvenile life stages of selected fish species.

Several Representative Important Species (RIS) (COMAR 08.05.04.13, §D) of Chesapeake Bay finfish pass through early developmental life stages in areas potentially affected by operations at Calvert Cliffs. Three RIS species chosen for detailed discussion are: bay anchovy (*Anchoa mitchilli*), spot (*Leiostomus xanthurus*) and naked goby (*Gobiosoma bosci*).

The pelagic eggs, and larval and juvenile life stages of these and other fishes in the vicinity of the plant have been monitored since 1976 in nearfield ichthyoplankton and macrozooplankton studies conducted by ANSP. Data from 1976 and 1977 provided general information about species diversity, and abundance and use of the plant site by juvenile fish and invertebrate groups. Subsequent studies were designed to obtain reliable quantitative information about abundance and seasonal and spatial distributions in the plant vicinity. Specific questions addressed by the ichthyoplankton studies included:

1) To what extent do these species use the Bay area in the vicinity of Calvert Cliffs as a spawning and/or nursery ground (COMAR 08.05.04.13 §C(2)b)? How do densities and periods of residence near CCNPP compare with other areas of the Bay and its tributaries?

2) How are eggs and young distributed in the surrounding area and areas immediately adjacent to the plant? Do any of these groups concentrate near the plant, attracted by warmer temperatures of the discharge or by some other desirable feature of the plant site, thereby increasing exposure of the populations to power plant effects? Are densities smaller in the plant site area, indicating avoidance of normal habitat or depletions from direct effects of power plant operation?

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ranged from 5.4°/oo to 20.2°/oo) (Abbe, 1980; G. Abbe, ANSP, unpublished data; ANSP, 1969, 1970, 1971a, 1971b, 1973, 1974; Hixson and Capizzi, 1979). Female crabs bearing eggs (sponge crabs) are seldom seen north of the Rappahannock River (approximately 80 km (50 mi) down-Bay from the CCNPP) except during dry years (Truitt, 1939). Since blue crab studies conducted by ANSP began at Calvert Cliffs in 1968, only 91 of the more than 19,400 female crabs collected were sponge crabs. Of these, 32 were taken in 1980 when extremely dry conditions often resulted in salinities of 14-18°/oo at Calvert Cliffs.

Generally, young crabs are 12-25 mm in carapace width by the time they reach the Maryland portion of the Bay (Van Engel, 1958). Although this area is still some 56 km (35 mi) down-Bay from the CCNPP, some crabs as small as 6 mm have been observed near the CCNPP (G. Abbe, ANSP, unpublished data). Cargo (1960) reported the first finding of a megalops in Maryland waters in 1957 near the mouth of the Patuxent River (12-15 km (8-9 mi) down-Bay from the CCNPP), although an occurrence of such a young stage in this area of the Bay is extremely rare. By the time blue crabs reach the CCNPP they are generally too large to be entrained through the 1-cm intake screen mesh. Nearfield zooplankton studies conducted from 1974 through 1977 (Olson and Sage, 1978a, [illegible]) detected very few decapod crustacean larvae and these belonged to the family Xanthidae (mud crabs). No commercially important species were encountered. Juvenile blue crabs were occasionally collected in macroplankton studies (23 crabs during 1980 ranging in carapace width from 11 mm to 40 mm (L. Currence, ANSP, unpublished data)), but these numbers are insignificant. Abbe (1973, 1980) has shown that the CCNPP has no observable effect on the distribution, size, weight, or sex ratio of adult crabs in this portion of the Bay.

Although more spawning of female blue crabs was in evidence near the CCNPP during 1980 than during any of the 12 previous years, and although some premature hatching might also have occurred because of the unusually high salinities, the area is nevertheless insignificant as a spawning, hatching, and nursery ground for blue crabs in Chesapeake Bay.

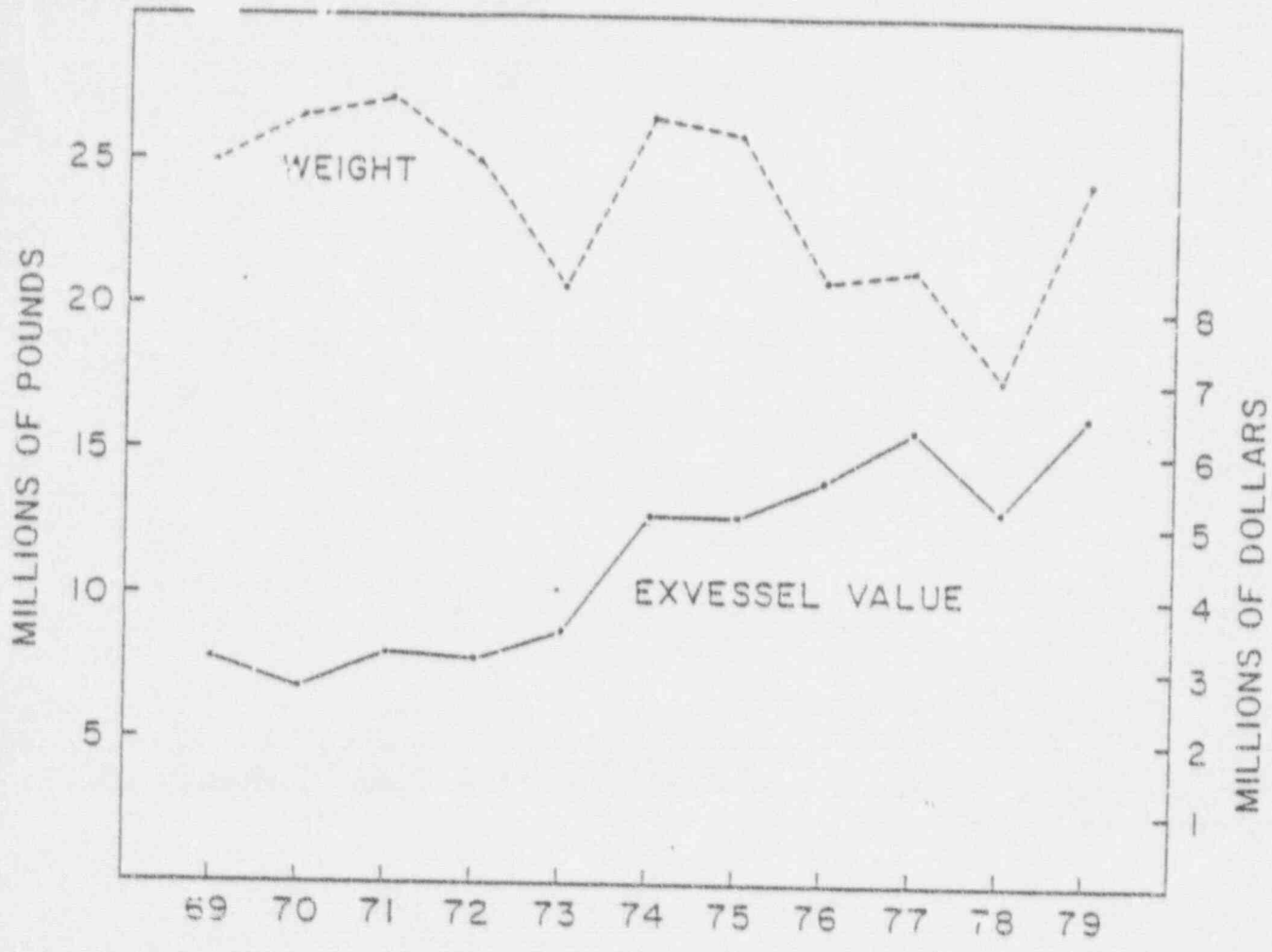


Figure III-B-1. Live weight and exvessel dollar value of Maryland blue crab landings 1969-1979. (Source: National Marine Fisheries Service, 1972-1980).

B. BLUE CRABS

The blue crab *Callinectes sapidus* Rathbun has been the basis of an important commercial fishery in Chesapeake Bay for nearly a century. In Maryland it is second only to the oyster in economic value. From 1969 through 1979 blue crab landings in Maryland have averaged 23.7 million pounds annually, valued at $4.5 million (National Marine Fisheries Service, 1972-1980). While landings have remained fairly constant since 1969 (Fig. III-B-1), exvessel value has increased from $3.1 million in 1969 to $6.5 million in 1979. The need to protect a fishery of this importance is obvious and the blue crab has therefore been designated a Representative Important Species (RIS) in the Code of Maryland Regulation (COMAR) 08.05.04.13, §D(2).

The studies reported here address COMAR 08.05.04.13, §D(3)(c), which specifies that one arthropod species from those listed as RIS be selected for intensive study in assessing impacts of thermal discharges on natural water quality. The studies are also pertinent to §C(2)(b) which requires that studies be conducted to determine whether plant cooling water entrainment affects a spawning or nursery area of consequence for RIS.

Although mating of blue crabs occurs in low and moderate salinity areas, females then migrate down-Bay to high salinity areas to spawn. The major spawning and hatching area is in the lower Bay in salinities of 23-28 °/oo (Sandoz and Rogers, 1944), an area centered about 113 km (70 mi) down-Bay from the Calvert Cliffs Nuclear Power Plant (CCNPP). After hatching the young go through two larval stages, the zoea and the megalops, before they take on the appearance of adult crabs. Sandoz and Rogers (1944) found that while nearly half of the eggs spawned at salinities of 12-13 °/oo would hatch, they hatched prematurely as prezoeae and did not survive. The first or zoea stage lasts about a month as the larva molts at least four times and grows from 0.25 mm to 1 mm in size. The megalops stage lasts only a few days, and it molts to become the first true crab, about 2.5 mm in width (Van Engel, 1958). At this point an up-Bay migration begins.

The Academy of Natural Sciences of Philadelphia (ANSP) began a series of studies of the blue crab population in the Calvert Cliffs area of Chesapeake Bay in 1968 and has conducted these studies annually since then (Abbe, 1980). These studies were designed to evaluate annual changes in the population and to determine if juvenile and adult crabs were affected by thermal discharges from the CCNPP. The fishery for adult blue crabs in the vicinity of the CCNPP is sizeable, and hundreds of crab pots are set annually in the immediate vicinity of the plant. The Calvert Cliffs area is not, however, a nursery ground for blue crab larvae because of its low salinity which averaged about 12 °/oo from 1969 through 1980 (monthly values

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Although the Calvert Cliffs area of Chesapeake Bay is a spawning and nursery area for the soft-shell clam, it does not appear to be an area of consequence. Larvae and juveniles were observed in 1979 in three separate studies discussed above, but numbers were small and it appears that 1979 was a poor recruitment year. Studies by other investigators also indicate that the numbers of early life stages of *Mya* near the CCNPP are so small that entrainment would constitute no adverse impact on the local population of this RIS. Large numbers of first-year clams have been present in the area several times during the last 10 years, but large numbers of adults have never been found. Apparently predation by fish and crabs is responsible for much of the loss of juvenile clams. It is not clear whether water temperature and wave action, in addition to predation, are responsible for controlling the size of the *Mya* population in the Calvert Cliffs area. Whatever factors are responsible, they have apparently been at work since long before the CCNPP began operation in 1975.

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lowing large catches of sublegal clams produced large catches of legal clams, and the years following small catches of sublegals produced small numbers of legal clams.

The overall productivity of the Calvert Cliffs area of the Bay in terms of commercial-size clams appears rather limited compared to other areas of the Bay where commercial activity exists. High densities of legal clams were occasionally seen, but such occasions were rare. In 1974 eight individual dredges produced 40 or more bushels/acre with a high of 61 bushels/acre (Abbe, 1974). In 1975 nine dredges at Station 13 averaged 52 bushels/acre and three of these, in 4.9 m of water, averaged 141 bushels/acre (Abbe, 1975). Unfortunately, such areas of high density proved to be very small. Average density of legal clams from 1974 through 1979 was only 5.4 bushels/acre, far below a level that could be worked profitably by commercial clammers. Ellsworth Brown, a professional clammer for over 20 years from Shady Side, Maryland, stated that he could not remember this area of the Bay being worked profitably by clammers (personal communication). Although small pockets of high density exist, it is not economically feasible for commercial clammers to work the area around Calvert Cliffs.

One such high density area was located in 4.3 m (14 ft) of water at Station 11 in 1978. One dredge (7.74 m^2) produced 90 legal clams (66 bushels/acre) (Abbe, 1979), but the entire area was probably no larger than 200 m^2. In 1979 this area was relocated and found to be still productive. In most cases where high clam densities were found, the bottom was composed of fine muddy sand with an overlying layer of shells. The shells apparently offer the clams protection from wave action and strong currents and from predators.

Conclusions

Biological productivity of the soft-shell clam, *Mya arenaria*, as measured by the abundance of legal-size clams in the Calvert Cliffs area of Chesapeake Bay has not been high enough since at least 1971 to support a commercial fishery. Although more clams were dredged per unit of effort before 1975 (when CCNPP began operating) than since that time, the reduced catches since 1975 have occurred in control areas as well as in the immediate plant vicinity. In addition, the largest station catches of the entire study period occurred in 1975 at Station 13 located within the area receiving a thermal increase from CCNPP. Thirdly, a small area of fairly high density located at Station 11 in 1978 was relocated in 1979 and appeared to be as productive as it was a year earlier. The studies, therefore, indicate no significant elimination or impairment of economic resources, especially since few if any clams have been harvested from the study area by commercial clammers in the last 10 years.

Table III-A-7. Estimated number of clams/m^2 at various depths based upon hydraulic escalator dredge collections in the study area of Chesapeake Bay, 1974-1979.

	1.2-1.8 m	2.1-2.7 m	3.0-3.7 m	4.0-4.9 m
Legal clams per square meter				
1974	1.61	2.67	3.53	*
1975	0.45	1.18	2.42	9.00
1976	0.01	0.02	0.01	*
1978	0.10	0.15	0.95	3.35
1979	0.18	0.16	0.26	0.90
Mean	0.47	0.84	1.43	4.42
Sublegal clams per square meter				
1974	2.61	2.46	2.85	*
1975	0.31	0.11	0.39	5.00
1976	0.73	0.66	0.57	*
1978	0.35	0.48	1.03	1.22
1979	0.59	0.54	0.60	0.45
Mean	0.92	0.85	1.09	2.22
Total clams caught per square meter				
1974	4.22	5.13	6.38	*
1975	0.76	1.29	2.81	14.00
1976	0.75	0.68	0.57	*
1978	0.45	0.62	1.98	4.58
1979	0.76	0.70	0.86	1.36
Mean	1.39	1.69	2.52	6.65

* Not sampled.

Table III-A-6. Density of legal-size *Mya arenaria* (clams/m^2) at 17 stations in Chesapeake Bay near the Calvert Cliffs Nuclear Power Plant, 1974-1979.

Station	1974	1975	1976	1978	1979	Mean
1	2.11	0.00	0.00	0.04	*	0.54
2	1.42	0.00	0.00	2.79	1.61	1.16
3	5.84	0.00	0.00	0.61	0.03	1.30
4	4.29	0.00	0.00	0.10	0.00	0.88
5	2.42	0.00	0.00	0.13	0.09	0.53
6	1.15	0.00	0.02	*	0.47	0.41
7	2.22	0.03	0.00	0.09	0.22	0.51
8	2.63	0.00	0.00	0.03	0.03	0.54
9	4.64	1.95	0.05	0.51	0.05	1.44
10	*	*	*	*	*	
11	0.79	0.09	0.06	2.48	0.97	0.88
12	3.08	1.53	0.01	0.63	0.23	1.10
13	0.35	10.39	0.04	0.12	0.08	2.20
14	1.31	4.10	0.00	0.26	0.03	1.14
15	1.63	1.98	0.00	0.10	0.01	0.74
16	2.10	5.25	0.00	0.14	0.33	1.56
17	5.05	3.34	0.05	0.19	0.32	1.79
18	*	*	*	1.26	0.29	0.78
Mean	2.56	1.79	0.01	0.59	0.30	1.03

* Not sampled.

Table III-A-5. Density of *Mya arenaria* (clams/m^2) at 17 stations in Chesapeake Bay near the Calvert Cliffs Nuclear Power Plant, 1974-1979.

Station	1974	1975	1976	1978	1979	Mean
1	4.76	0.00	1.09	0.24	*	1.52
2	3.18	0.00	0.78	3.39	1.98	1.87
3	8.03	0.00	0.65	0.83	0.27	1.96
4	5.48	0.00	0.78	0.35	0.20	1.36
5	3.96	0.00	0.29	0.28	0.68	1.06
6	2.73	0.00	0.15	*	1.32	1.05
7	2.86	0.03	0.32	0.18	1.14	0.91
8	5.79	0.00	0.09	0.48	0.56	1.38
9	11.33	2.11	0.58	1.99	1.11	3.42
10	*	*	*	*	*	
11	1.61	0.39	0.52	3.50	2.08	1.62
12	4.73	2.10	0.45	1.05	0.45	1.76
13	1.22	16.55	0.46	0.64	0.33	3.84
14	5.48	5.52	0.76	0.58	0.41	2.55
15	6.35	2.60	0.74	0.41	0.30	2.18
16	5.21	5.50	0.50	0.54	0.68	2.49
17	8.96	3.36	2.13	0.89	1.05	3.28
18	*	*	*	5.02	0.97	3.00
Mean	5.14	2.39	0.64	1.28	0.85	2.07

* Not sampled.

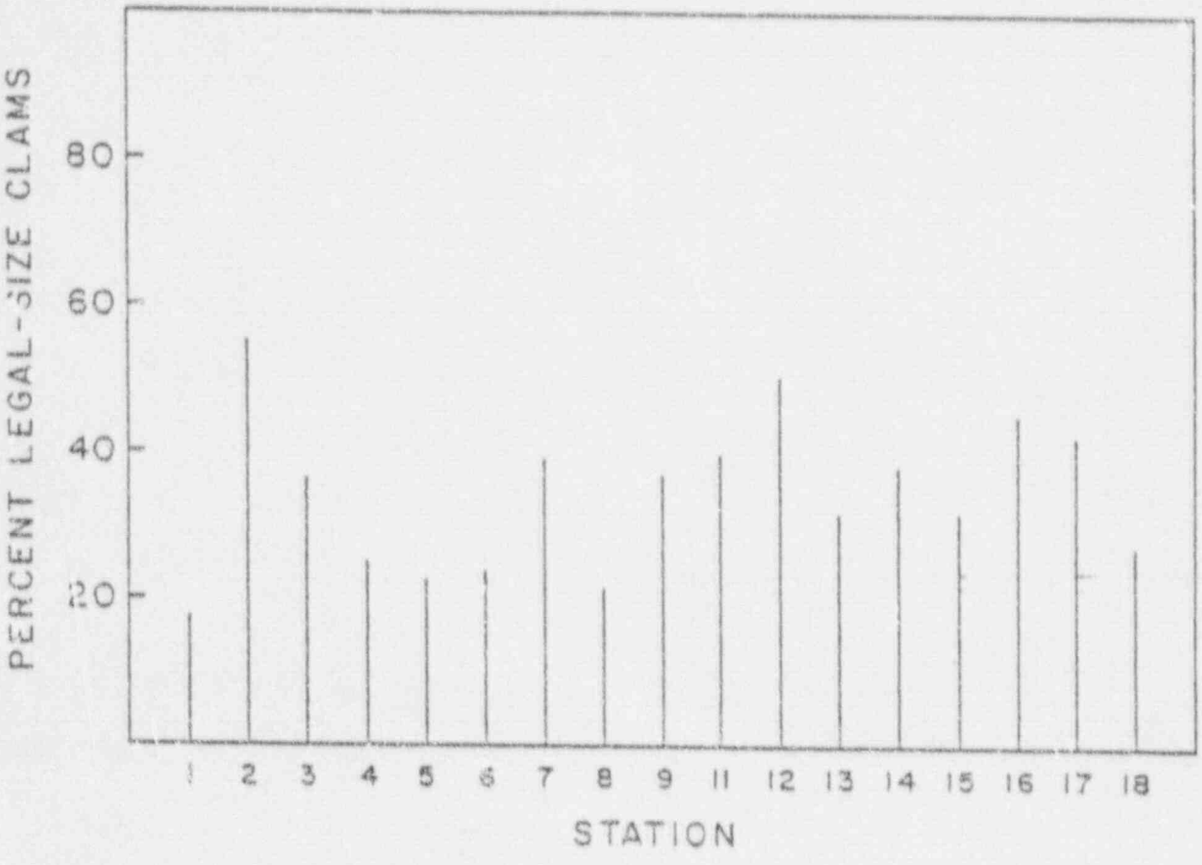


Figure III-A-6. Percent legal-size clams caught at each station averaged from 1973 through 1979, in Chesapeake Bay near the Calvert Cliffs Nuclear Power Plant.

Table III-A-4. Water depth, number of dredges made, and numbers and densities of *Mya arenaria* caught in Chesapeake Bay near the Calvert Cliffs Nuclear Power Plant, 1973-1979.

Year	Mean Water Depth (meters)	Number Dredges Made *	Legal Clams **	Sublegal Clams	Total Clams	Percent Legal	Legal Clams (Estimated Bushels/acre)	Sublegals (Estimated Clams/acre)
1973	ND	72	1,833	3,179	5,012	36.6	6-8	9,000-13,000
1974	2.4	158	3,156	3,190	6,346	49.7	12.8	10,300
1975	2.8	139	2,131	657	2,788	76.4	9.9	2,500
1976	2.4	144	16	734	750	2.1	<0.1	2,600
1978	2.7	141	538	676	1,214	44.3	2.8	2,800
1979	2.7	155	354	632	986	35.9	1.6	2,300
Total		809	8,028	9,068	17,096			
Mean	2.6					47.0	5.4***	4,100***

ND Not determined.
* In 1973 each dredge was 5 min long; thereafter each was 8.5 m long.
** Legal size was 57 mm shell length until 1975; thereafter it was reduced to 51 mm.
*** Estimates from 1973 were not included since samples were only semi-quantitative.

concentrations and predation. Holland et al. (1980) have demonstrated in cage studies at Calvert Cliffs that the *Mya* population is greatly affected by predators. Exclusion of predators such as spot (*Leiostomus xanthurus*) and blue crabs (*Callinectes sapidus*) by cages resulted in significantly increased densities of *Mya arenaria* in February, May, and November ($p<0.05$). Mortality rates are lower in fall and winter than in summer, perhaps because of the inactivity of natural predators (Brousseau, 1978). It is also possible that shifting bottom sediments could produce localized mortality, but not on the widespread scale observed over several years. It therefore appears that spot and blue crab predation is taking a heavy toll of juvenile clams during summer months regardless of the time of year these clams set.

Dredging

Out of a total of 809 dredges from 1973 through 1979, 737 were quantitative and covered 5522 m^2 producing 12,084 clams; 6,195 (51.3%) of these were of legal size (Table III-A-4). Table III-A-4 lists the effort made each year and the size of the catch. With the amount of effort remaining fairly constant from 1974 through 1979 the size of the catch has varied tremendously, from 3,156 legal clams in 1974 to 16 in 1976. In 1974 the ratio of legal clams to sublegals was nearly 1 to 1 and good catches were made at most stations (Abbe, 1974). In 1975 at the upper six stations, from which 2842 clams were taken in 1974, not a single clam was seen (Abbe, 1975). It was thought that the high winds and extremely low tides which lasted several days in April 1975 were in some way responsible for the absence of clams. As a result no legal clams were seen in that area in 1976. Figure III-A-6 illustrates the 1973-1979 average percent legal clams by station. Although there is considerable variation among stations, no overall trends are apparent.

Tables III-A-5 and III-A-6 present the density (clams/m^2) of total clams and legal clams, respectively, by station by year. These densities have ranged from 0.00 legal clams/m^2 at a number of stations during 1975 and 1976 to 10.39 legal clams/m^2 and 16.55 total clams/m^2 at Station 13 in 1975. Clam densities show no station pattern since they are not consistently higher or lower near the plant.

Densities of clams appear to increase with increasing water depth. Data from studies conducted over 5 years are presented in Table III-A-7 showing that depths of 4.0-4.9 m yield more clams than shallower depths.

Although only a very small percentage of the sublegal clams present were seen, since most went through the conveyor belt before they reached the surface, the sublegals did provide a clue as to the number of large clams that could be expected the following year. As seen in Table III-A-4, the years fol-

Table III-A-3. Number of juvenile *Mya arenaria* per 16-liter sample collected by Smith-McIntyre grab in Chesapeake Bay in the vicinity of the Calvert Cliffs Nuclear Power Plant during 1979.

	Mar.	Apr.	Jun.	Jul.	Sep.	Oct.	Dec.	Total
Flag Pond								
3 m	16	23	74	0	0	13	10	136
6 m	52	33	156	1	0	5	1	248
9 m	0	24	4	0	0	1	0	29
Control North								
3 m	51	28	17	0	0	16	1	113
6 m	129	201	72	0	0	0	0	402
9 m	3	11	12	0	0	0	0	26
Plant Site								
3 m	23	12	20	0	0	4	3	62
6 m	8	21	58	2	0	2	14	105
9 m	1	168	175	0	0	30	26	400
Dock Site								
3 m	28	26	45	0	0	5	13	117
6 m	173	94	78	0	0	16	1	371
9 m	6	5	0	0	0	1	5	17
Control South								
3 m	14	13	84	1	0	7	6	125
6 m	9	13	134	2	0	7	5	170
9 m	2	0	9	0	0	0	0	11
Total								
3 m	132	102	240	1	0	45	33	553
6 m	371	362	498	5	0	30	30	1296
9 m	12	208	200	0	0	32	31	483
	515	672	938	6	0	107	94	2332

Only one (3 mm) was taken from five bottles set in 3.0 m at CP. At Plant Site (PS), five bottles at 3.0 m yielded one 7-mm *Mya*, while six bottles at 5.5 m collected two (5 and 9 mm).

North of Cape Cod, Massachusetts, *Mya* spawns annually (Ropes and Stickney, 1965), while south of Cape Cod it may spawn semi-annually. Pfitzenmeyer (1962) observed two spawning periods from 1957 to 1959 at Solomons, Maryland but Shaw (1965) saw only a few clams in the spring of 1963 and none in the spring of 1961 or 1962. Thus, the fall set appears to be the major one, and data from bottle collections support this.

Although the number of newly set *Mya* in the Calvert Cliffs area was not large, it was comparable to numbers in many areas examined by Shaw and Hamons (1974) in the Maryland portion of Chesapeake Bay. Clams set between 29 October (when the temperature was 15.1°C) and 10 December (when the temperature was 9.2°C), but based on the size of the clams, most had set early in this period.

Benthic Sampling

Table III-A-3 lists the total number of juvenile *Mya* taken in three 16-liter grabs at each sampling station. At all stations except Plant Site, the 6-m depth produced the most clams, with very few taken in 9 m. At the Plant Site the 9-m depth yielded the most clams, followed by the 6-m depth. The 3-m depth yielded lowest densities at the Plant Site, although this was not seen at any other station; this 3-m station was closest to the discharge and the 1-3°C temperature increase may have caused avoidance since *Mya* is already near the southern end of its range. Current velocity may have also affected population density as studies by Mountford, Holland, and Mihursky (1977) indicate that sand was scoured from a 17-hectare zone in the immediate area of the CCNPP discharge. Habitat in this zone was of marginal value for infaunal organisms since they were unable to burrow into the hard bottom.

The greatest abundance of young clams was found during June, followed by April and March. Relatively few were taken in October and December, and almost none was collected in July and September. Most of the June clams were in the 1-2 mm size range, indicating that they were from an early spring spawn. The March and April clams were in the 1-2 mm and 1-4 mm size range, respectively, indicating they were from the fall spawn in 1978 since little growth occurs during the winter.

Although the absence of larvae during warm summer months is understandable, the absence of juveniles from the sediments in July and September is not. Loi (1978) observed this in 1977 when the large June population (as high as 2992/0.1 m^2) was gone by September. The mortality could be due to a number of factors, including high temperature, low dissolved oxygen

Table III-A-2. Number of newly set clams per m^2 calculated from data from bottle collectors set near the Calvert Cliffs Nuclear Power Plant and Cove Point during 1979.

	Number of weeks set	Number of bottles	Number of *Mya arenaria*
May-July			
Plant Site			
3.0 m	6	3	0
3.0 m	8	2	0
5.5 m	6	2	0
5.5 m	8	3	0
Cove Point			
3.0 m	All lost	-	-
5.5 m	6	1	0
5.5 m	8	3	0
October			
Plant Site			
3.0 m	4	5	0
5.5 m	4	6	0
Cove Point			
3.0	4	6	0
5.5	4	6	0
November-December			
Plant Site			
3.0 m	6	5	9
5.5 m	6	6	18
Cove Point			
3.0 m	6	5	11
5.5 m	6	6	37

Table III-A-1. Temperature, salinity and abundance of larval clams (Pelecypoda) per m^3 in weekly zooplankton samples in the vicinity of Calvert Cliffs Nuclear Power Plant, 12 April-25 October, 1979.

	Temperature (°C)	Salinity (‰)	Pelecypod larvae/m^3 Surface	5-m	10-m	Mean density (all depths)
Apr 12	8.9	7.8	0	0	0	0
20	10.8	7.1	0	0	0	0
27	13.0	8.0	0	22	0	7
May 2	11.7	9.5	0	0	0	0
9	16.1	10.0	0	0	0	0
16	18.5	8.2	0	0	22	7
30	19.6	9.5	20	264	88	124
Jun 4	19.8	8.7	26	20	0	15
13	21.6	9.1	0	44	253	99
18	22.8	9.0	4	31	9	15
27	21.4	8.5	18	26	26	23
Jul 5	22.0	9.0	9	0	9	6
10	22.0	10.7	740	740	423	634
18	27.1	9.5	176	88	66	110
25	25.6	11.9	15	29	0	15
Aug 1	27.0	10.8	0	0	0	0
8	27.1	10.6	0	0	0	0
13	24.5	14.3	0	0	0	0
22	24.9	12.0	0	0	0	0
30	26.6	12.5	517	198	319	345
Sep 6	26.1	12.7	209	154	66	143
12	26.0	13.3	22	88	44	51
17	24.2	11.6	106	0	0	35
26	20.8	11.4	286	374	264	308
Oct 2	21.3	10.0	198	66	330	198
8	18.6	12.0	345	705	506	519
18	15.6	9.7	0	1	0	< 1
25	15.2	10.8	88	37	0	42
Mean			99	103	87	96

From 1971 to 1975 a legal-size clam was at least 2.25 in (57 mm) in shell length. In 1976 the minimum legal size was reduced to 2.00 in (51 mm). The conveyor belt of 25.4-mm (1-in) mesh allowed most small clams to pass through it, yielding a low estimate of subiegal clams, but retained those of marketable (legal) size.

Results and Discussion

Plankton Sampling

The largest mean numbers of straight-hinge pelecypod larvae (first-shelled stage) were collected on 10 July (634/m^3), 8 October (519/m^3), and 30 August (345/m^3) (Table III-A-1). Although the larvae collected in May and September could have been *Mya*, it is unlikely that the July larvae were. July temperatures (22-27°C) were well above the 20°C at which Pfitzenmeyer (1962) found them most abundant. No larvae were collected during August. Differences in larval densities among depths were observed, but a Friedman Rank Sum test (Hollander and Wolfe, 1973) revealed no significant differences. The mean number of larvae in surface samples was 99/m^3, with 103/m^3 at the mid depth and 87/m^3 at the bottom (Table III-A-1).

The fall spawning is considered to be the primary reproductive period for *Mya* in Chesapeake Bay according to Pfitzenmeyer (1965); Shaw (1965), Chanley and Andrews (1971), and Shaw and Ramons (1974) all support this view. Few larvae were observed in late October during this study; however, the study ended at that point and therefore a portion of the spawning period in November may have been missed. In an earlier study, Ecological Analysts, Inc. (EAI) (1979) found the greatest period of entrainment of *Mya* at the CCNPP was from November 1978 to March 1979. However, this represented only a few *Mya* juveniles per 100 m^3. Subsequent studies during April 1979 through April 1980 again showed only a few *Mya* per 100 m^3 (EAI, 1980). These studies by EAI indicate that *Mya* larvae are not abundant in intake waters at CCNPP and that no significant spawning of *Mya* occurs in the area. EAI (1980) concluded from these studies that entrainment of the early life stages of *Mya* was presently at such a low level as to constitute no adverse impact on the local population of this RIS.

Bottle Collectors

The calculated density of live clams per m^2 is shown in Table III-A-2. No live *Mya* were collected from May to July or in October, but small numbers were collected at all stations during the November-December period. The largest number was found at Cove Point (CP) (5.5 m) where four *Mya* ranging in shell length from 6 to 12 mm were collected from six bottles.

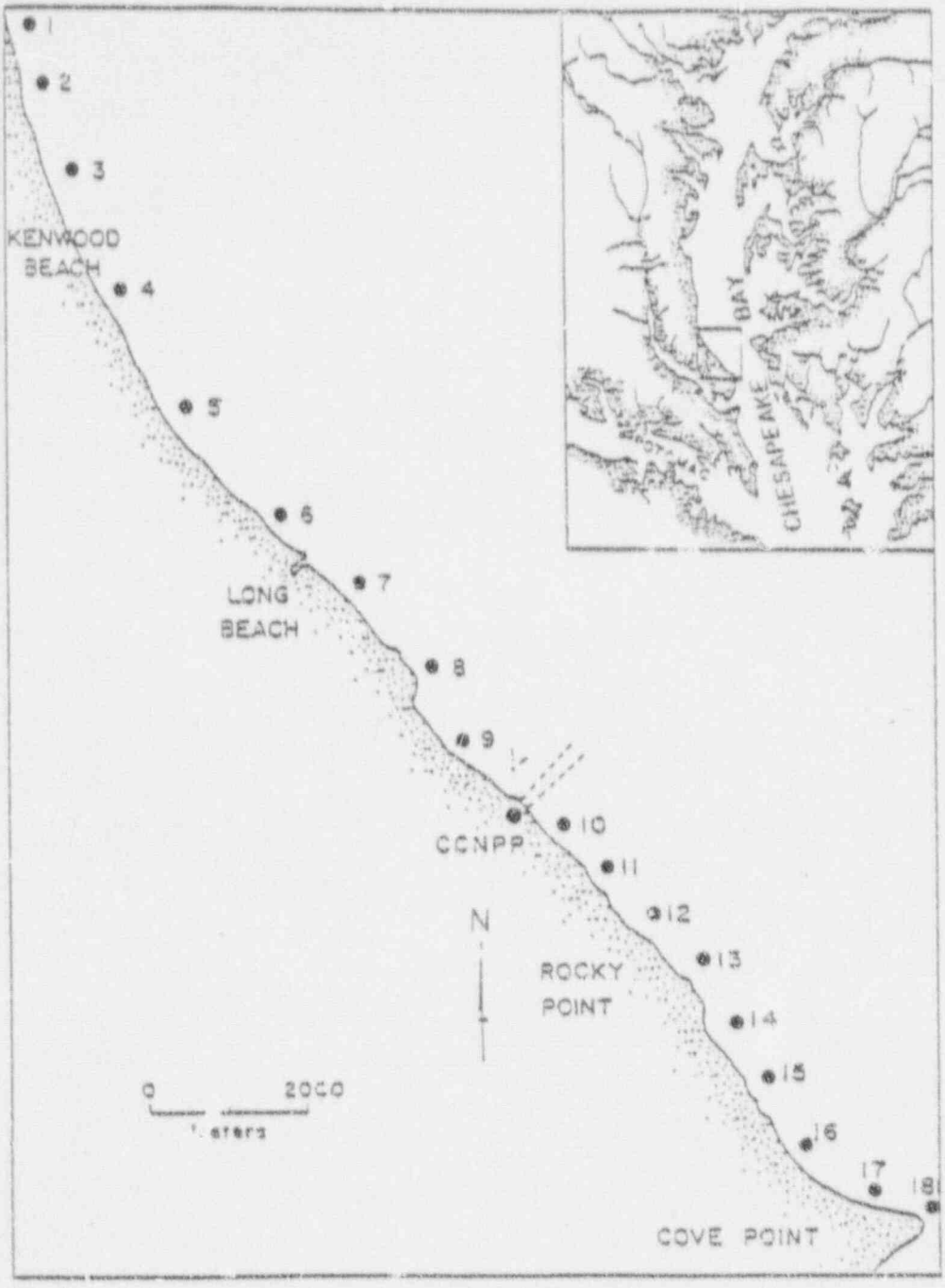


Figure III-A-5. Locations of hydraulic dredging conducted to locate soft-shell clams, *Mya arenaria*, in Chesapeake Bay near the Calvert Cliffs Nuclear Power Plant, 1971-1979.

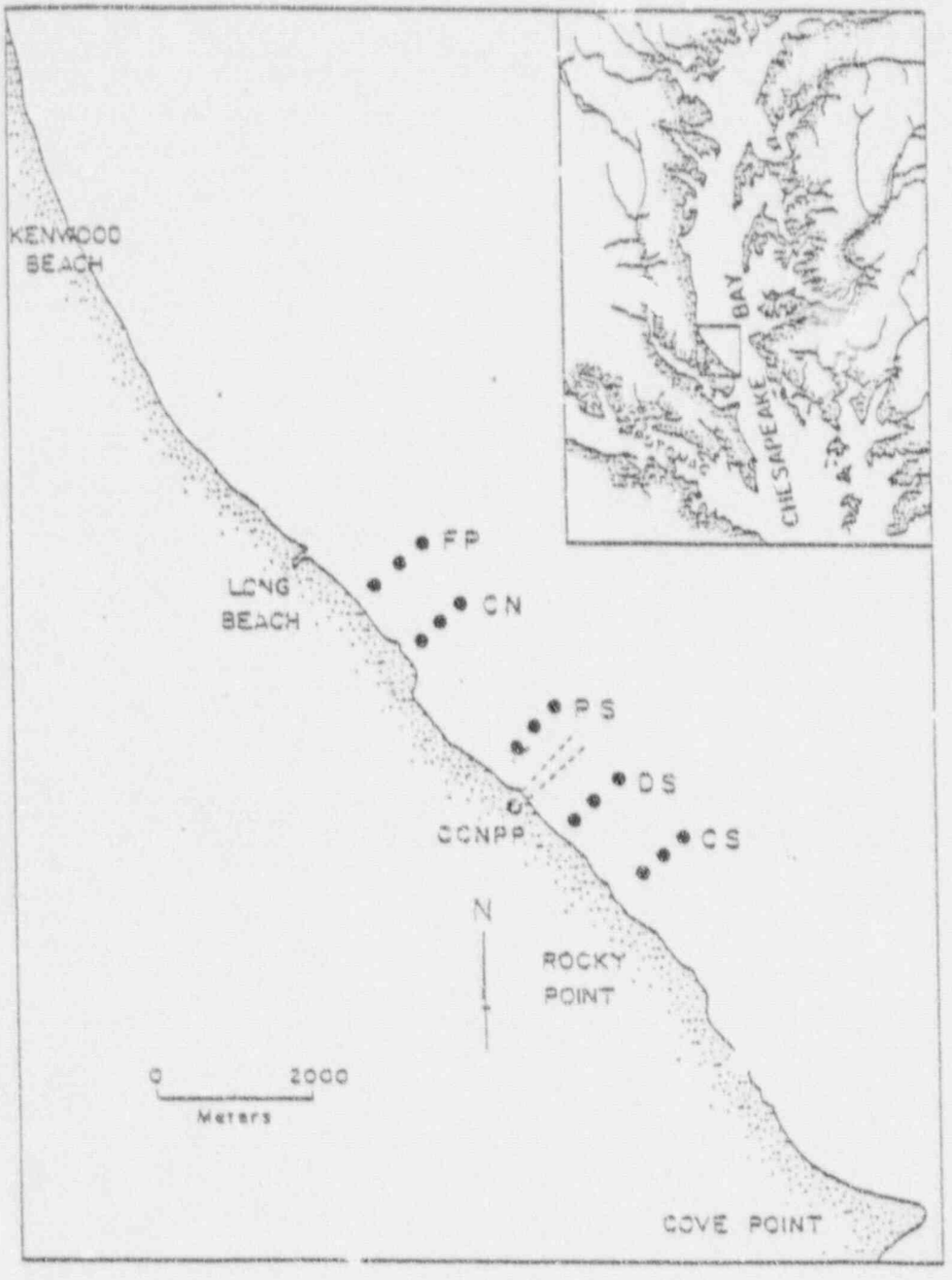


Figure III-A-4. Locations of transects at FP (Flag Pond), CN (Control North), PS (Plant Site), DS (Dock Site), and CS (Control South) where benthic grab sampling was conducted to collect *Mya arenaria* near the Calvert Cliffs Nuclear Power Plant in 1979. (The inshore station along each transect was in 3 m of water, the mid station was in 6 m, and the offshore station was in 9 m).

North (CN), Plant Site (PS), Dock Site (DS), and Control South (CS) (Fig. III-A-4). Each transect extended across sediment types (sand, sandy clay, and clay) which were previously identified by core sampling. Along each transect one station was sampled in each of the three sediment types, corresponding to 3-m, 6-m, and 9-m depths.

Sampling was conducted in March, April, June, July, September, October, and December 1979. At each of the 15 stations (three along each of five transects), three clustered samples were taken with a 0.1 m^2 Smith-McIntyre grab, which penetrated to a depth of 4 cm in packed sand (Holme and McIntyre, 1971). In softer sediments penetration was deeper and samples of up to 16 liters were taken.

Within 24 h of collection, samples were placed in a 0.5-mm mesh sieve and washed; the retained material was preserved in 10% buffered formalin-seawater with rose bengal.

In the laboratory all macro-organisms were sorted and identified. *Mya* were measured for shell length and stored in 70% alcohol. Reported abundances were normalized to 16 liters.

Escalator Dredge

During six of the seven years that dredging was conducted, a 9.75-m (32-ft) commercial hydraulic escalator dredge was used to sample the bottom from an area 1.9 km (1.2 mi) north of Kenwood Beach to Cove Point (Fig. III-A-5). During the other year (1976) a 7.92-m (26-ft) dredge, which limited the maximum depth which could be worked, was used. Eighteen stations were sampled at depths ranging from 1.2 to 4.8 m. Nine stations were north and nine were south of the CCNPP. Bottom type ranged from sandy mud to rock, but also included shell on sand, gravel on sand, and peat. Dredging was conducted once each year in mid- to late summer. Station 10 was sampled only during 1971 and 1973; because of the hard bottom at that location, which the dredge could not penetrate, it was not sampled thereafter.

The 1971 survey was qualitative in nature since no effort was made to determine the size of the area dredged. In 1973, each dredge was of 5 min duration, but since bottom type determines the distance covered in a given time, this survey was only semi-quantitative. From 1974 through 1979 each dredge sampled an area equal to the width of the dredge head (which varied from 0.81 to 0.91 m depending on year) times 8.5 m. Although the area of each dredge therefore varied from 6.88 to 7.74 m^2, the number of clams per m^2 could be accurately determined. At each station a number of dredges were made at various depths to allow comparison of clam densities with depth.

During each dredge, all live clams were picked off the dredge conveyor, sorted as legals or sublegals and counted.

rinsed and the sample concentrated to a final volume of 100 ml and preserved in 5% borax-buffered formalin. Temperature and salinity were determined at each sample depth with a Beckman RS5-3 salinometer.

In the laboratory, each sample was well mixed and an aliquot estimated to contain approximately 200 zooplankton organisms was withdrawn with a Hensen-Stempel pipette. This aliquot was transferred to a Ward counting wheel, and the life stages of various species of zooplankton were identified and counted. Because of the difficulty in making positive identification, bivalve larvae were identified only as Pelecypoda. Abundances for all collections were normalized to number per cubic meter.

Bottle Collectors

Samplers similar to those described by Shaw (1965) and Shaw and Hamons (1974) were used to collect metamorphosing clams during 1979 at the Plant Site (PS) and near Cove Point (CP) (Fig. III-A-3). Each sampler consisted of an inverted bottomless gallon bleach bottle (cross sectional area of 182 cm^2), which was suspended 0.67 m above the bottom by a midwater buoy. A second buoy marked its position at the surface and a 12-in cinder block anchored it to the bottom. As planktonic larval clams metamorphosed and settled to the bottom, some fell into the bottles where they continued their development. After a month or more, clams reached a size at which they were easily identified (Shaw, 1965).

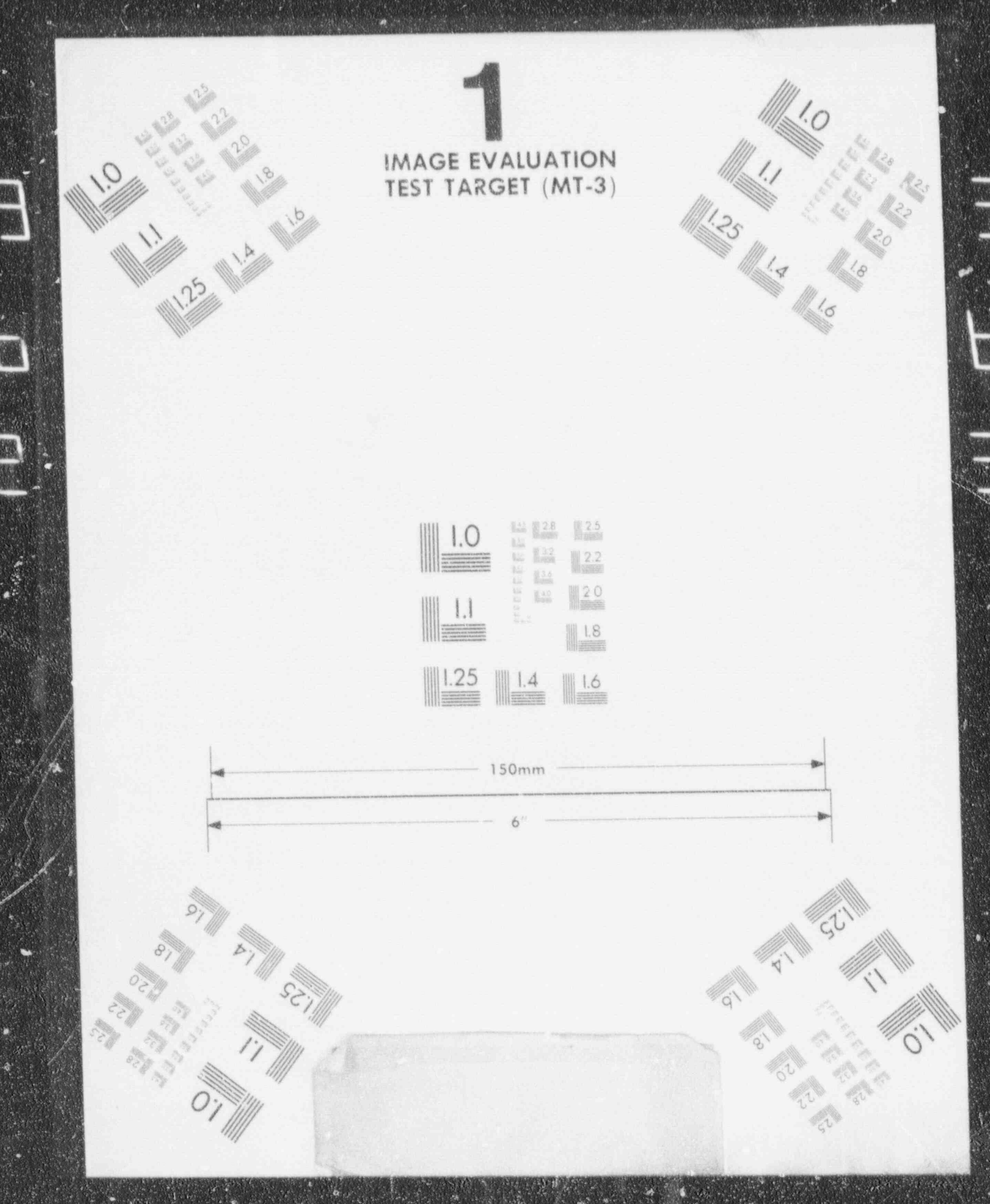
A total of 24 bottles was used, six in 3.0 m and six in 5.5 m of water at both PS and CP. They were first set out on 15 May 1979 after the temperature had reached 15°C. Many bottles were lost in a storm in late May and were replaced on 30 May. All were collected on 12 July when the temperature was well above 22°C, the upper limit for setting (Pfitzenmeyer, 1962).

In the fall, collectors were set out on 1 October as the water temperature decreased to 21°C. These were emptied and replaced on 29 October and emptied again on 10 December.

Material collected in each bottle was washed through a 212-µm sieve since *Mya* larvae metamorphose at approximately 250 µm (Pfitzenmeyer, 1962). Each sample was then preserved in 70% alcohol and returned to the laboratory where *Mya* were counted, shell length was measured and the number/m^2 was calculated.

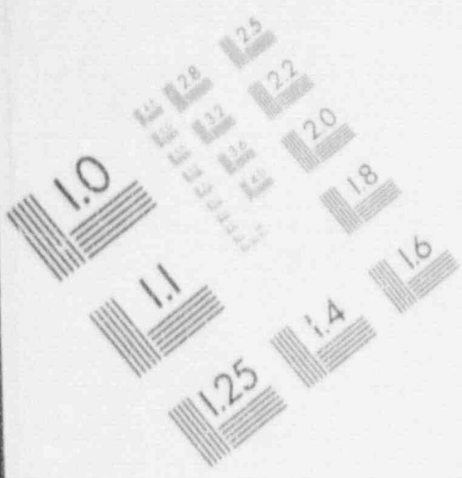
Benthic Sampling

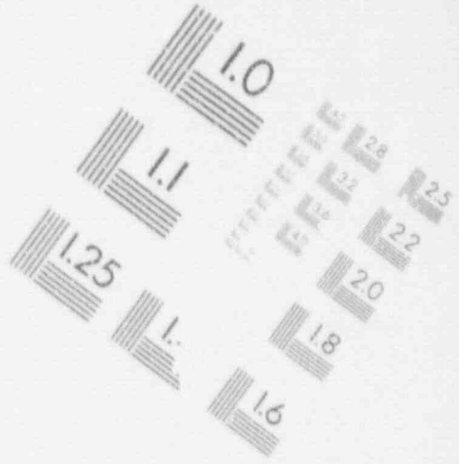
Five transects perpendicular to the shore line were established in the vicinity of the CCNPP at Flag Pond (FP), Control


1
IMAGE EVALUATION
TEST TARGET (MT-3)
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
150mm
6"

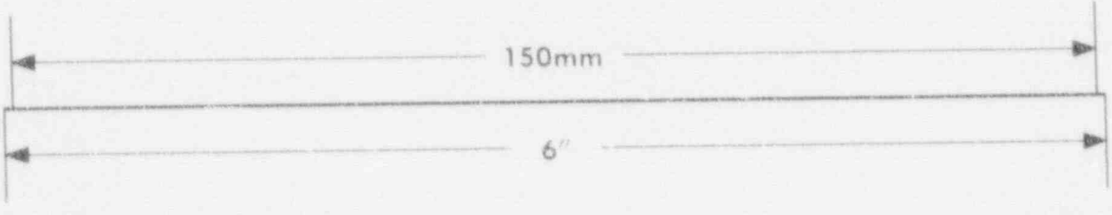
1

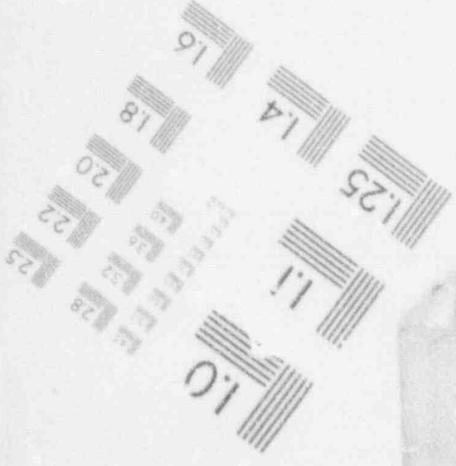
IMAGE EVALUATION TEST TARGET (MT-3)

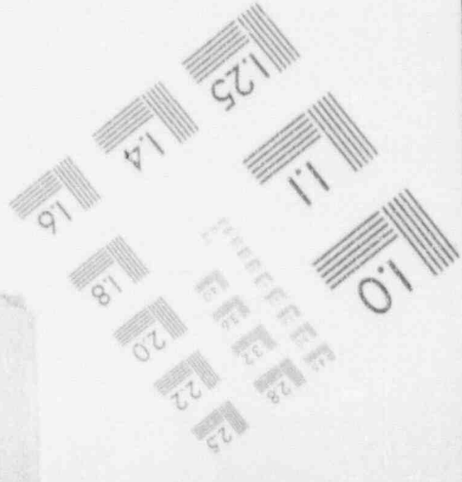












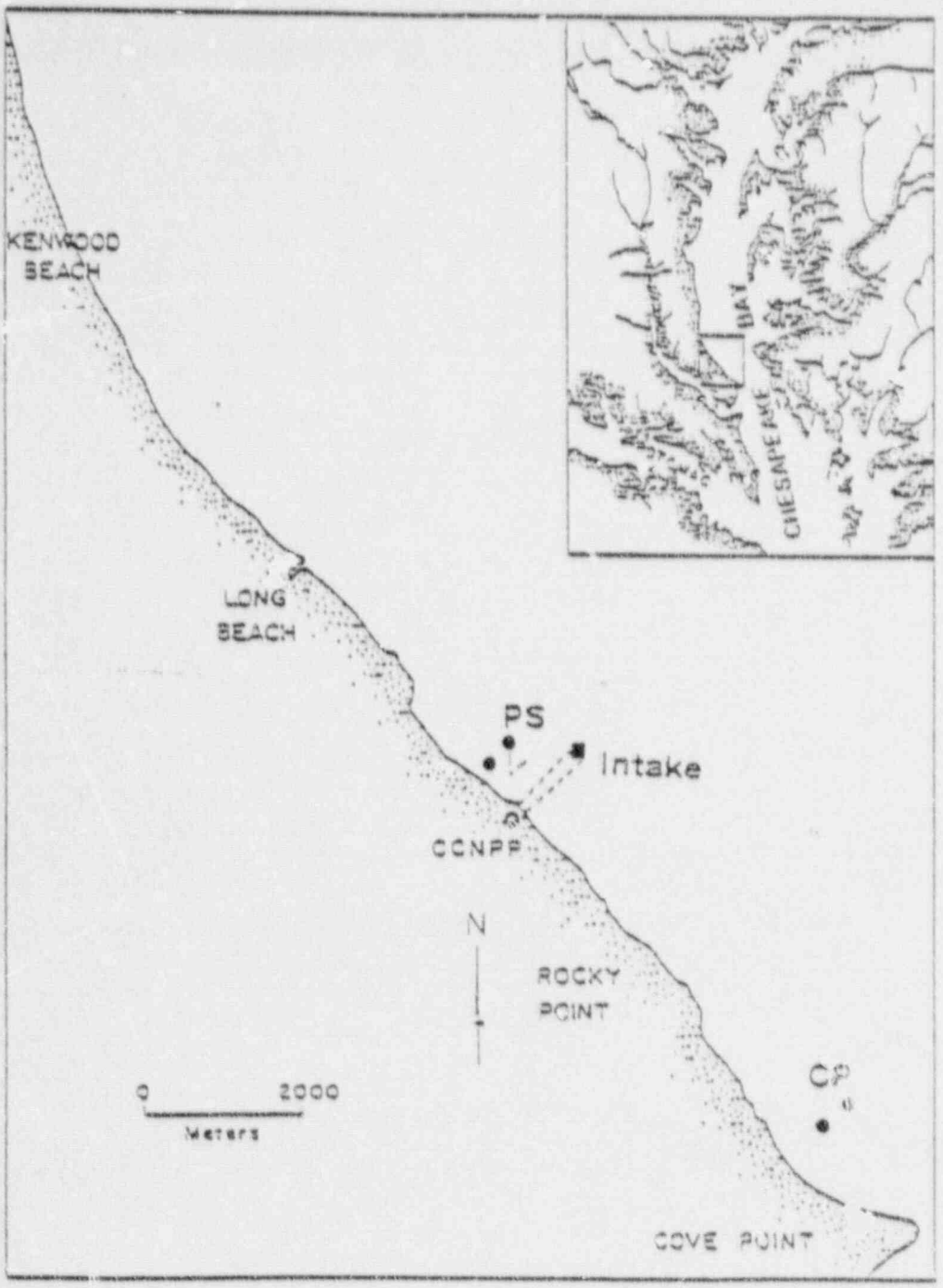


Figure III-A-3. Location of sampling areas for pumped plankton samples collected at the end of the Calvert Cliffs Nuclear Power Plant intake channel (square) and for bottle collectors set in 3.0 and 5.5 m of water near the plant discharge and near Cove Point (circles) to sample clam larvae and newly set clams during 1979.

been conducted annually since 1971 (Abbe, 1974, 1975, 1977, 1979; Abbe, D'Apolito, and Loi, 1980; ANSP, 1972, 1974). These studies therefore include preoperational (1971-74) and operational periods (1975-79) of the CCNPP. In an effort to more fully understand the dynamics of the *Mya* population in the area, the study was expanded in 1979 to estimate the abundance of all soft clam life stages near the CCNPP.

The studies reported here address COMAR 08.05.04.13, §D(3)(c) which specifies that one mollusc species from among those listed as RIS be selected for intensive study in assessing impacts of a thermal discharge on natural water quality. The studies are also pertinent to §C(2)(b) which requires that studies be conducted to determine whether plant cooling water entrainment affects a spawning or nursery area of consequence for RIS. The *Mya arenaria* population in the Calvert Cliffs area is of little commercial importance, and although some spawning and setting does occur, there are environmental factors involved which prevent this area from becoming heavily populated by legal-size clams.

Methods and Materials

Larvae were collected by pumped samples. Juveniles were sampled with bottle collectors as they metamorphosed and settled from the plankton; juveniles were also collected by benthic sampling with a Smith-McIntyre grab. Adults were taken with a commercial escalator dredge. Each of these studies is discussed in detail below and by Abbe, D'Apolito, and Loi (1980).

Plankton Sampling

Plankton sampling was conducted weekly beginning 20 April 1979, when water temperatures first reached 10°C, and continued through 25 October 1979, when temperatures dropped below 15°C. Samples were taken at the end of the intake channel, 1 km NE of the CCNPP (Fig. III-A-3), at night in about 10 m of water as part of the regular zooplankton monitoring studies (see Section IV-B). Pfitzenmeyer (1962) found the first umbone larvae at a mean temperature of 16.7°C, and found the greatest abundance at 20.2°C. Larvae were no longer observed after water temperature rose above 21.4°C. In the fall, larvae are found in the same temperature range as in spring. Pfitzenmeyer (1962) observed that most of the larvae were gone by the time the temperature fell to 13.5°C.

Three discrete, sequentially-collected 757-liter (200-gal) samples were collected at each of three depths (0, 5, and 10 m) with a 0.7 m^3/min centrifugal pump, which drew water through a 5-cm diameter plastic hose and discharged it through a volume gauge and then through a 73-µm concentrating net. The net was

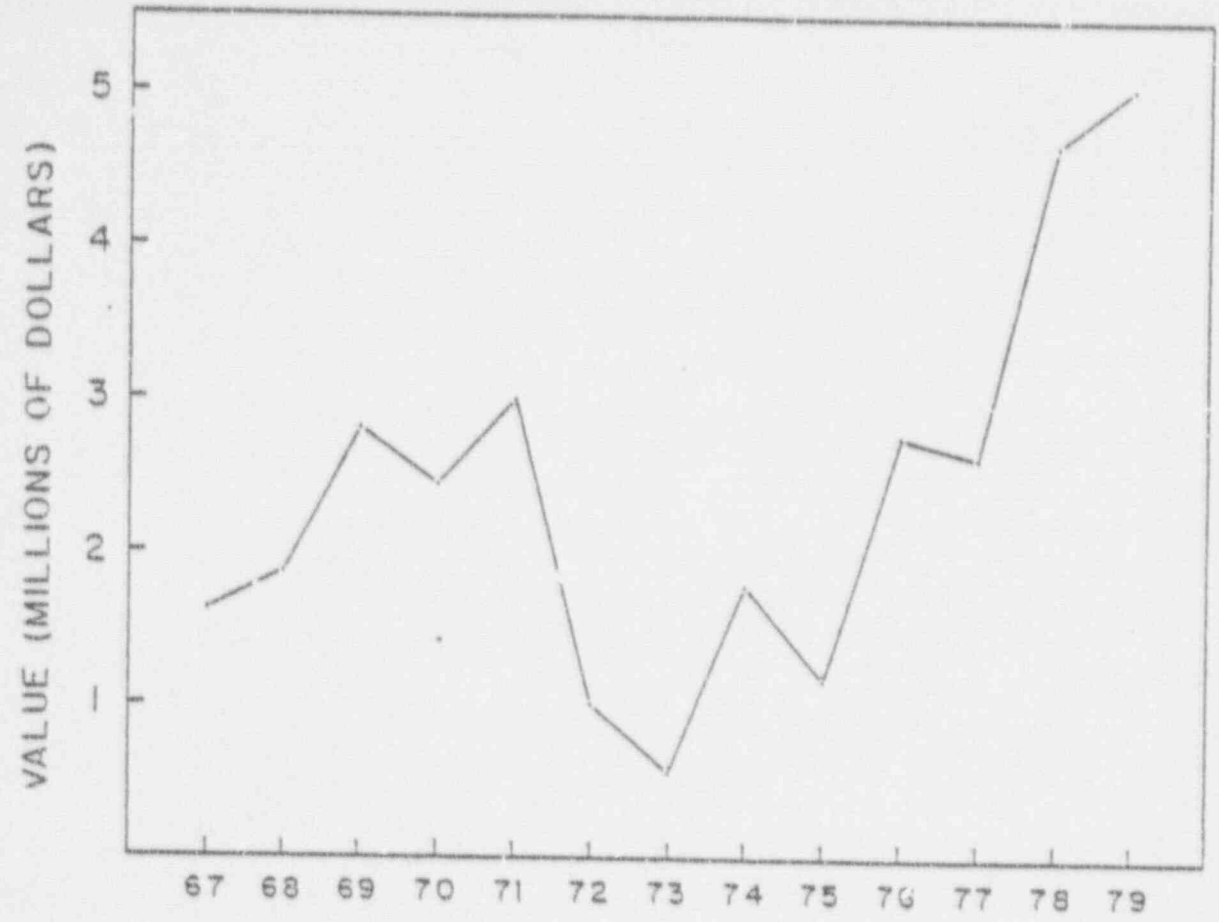


Figure III-A-2. Exvessel value of annual soft-shell clam landings in Maryland, 1967-1979 (Sources: U.S. Fish Wildl. Serv., 1969 and 1970; NMFS, 1972-1980).

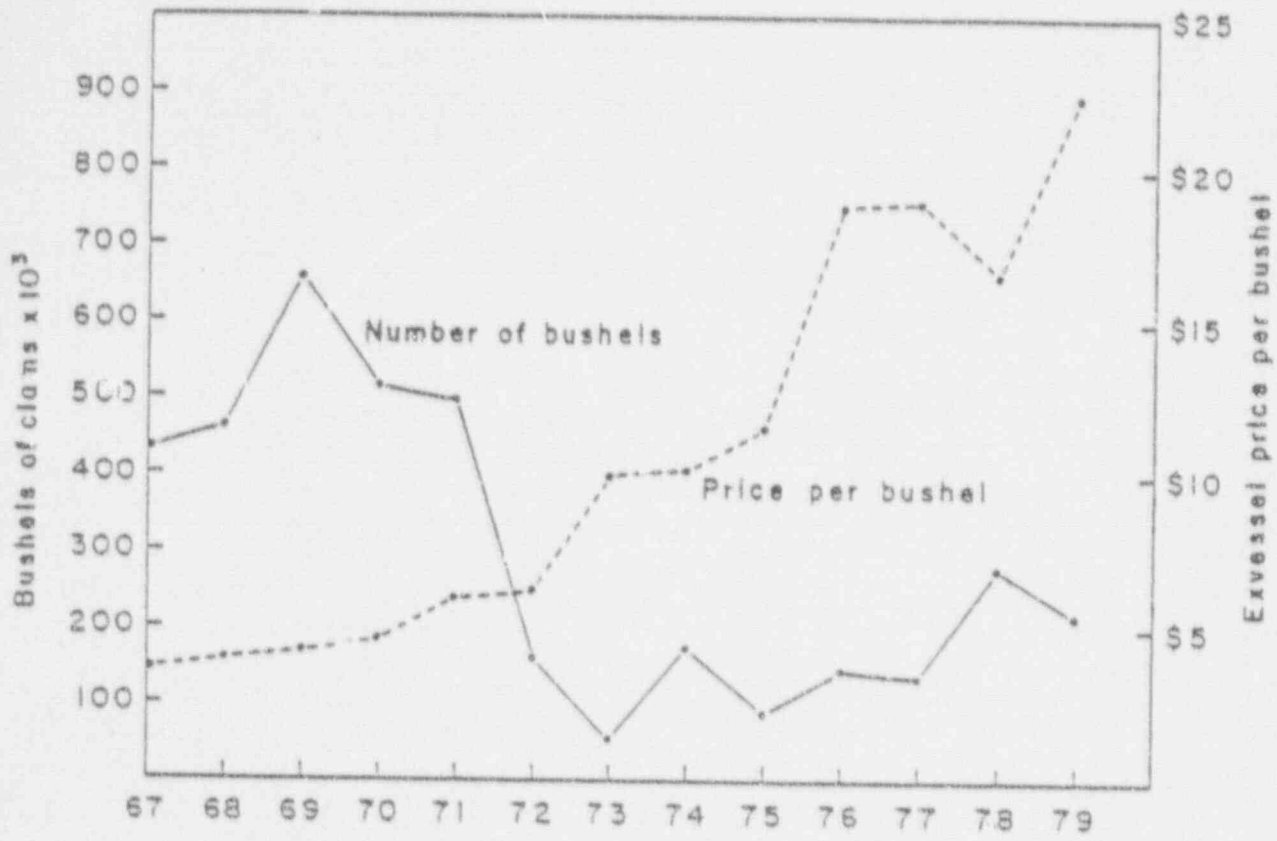


Figure III-A-1. Number of bushels and exvessel price per bushel for soft-shell clams, *Mya arenaria*, in Maryland, 1967-1979 (Sources: U.S. Fish Wildl. Serv., 1969 and 1970; NMFS, 1972-1980).

A. SOFT-SHELL CLAMS

Introduction

The fishery for the Chesapeake Bay soft-shell clam, *Mya arenaria* (Linnaeus), began in 1951 with the development of the hydraulic escalator dredge. This dredge made it possible to harvest clams that live subtidally in contrast to the New England method of hand-digging clams from temporarily-exposed tidal flats. Increasing Chesapeake Bay production surpassed decreasing New England production in the mid-1950s. The fishery in Maryland then stabilized, based upon demand for clams, most of which were shipped to New England. However, from 1969 to 1973 the annual Maryland catch declined steadily (Fig. III-A-1); much of this decline resulted from effects of Tropical Storm Agnes in 1972. Releasing a tremendous volume of fresh water into the Bay, Agnes caused prolonged low salinity which eliminated many productive clam beds. In some areas clam mortalities reached 90% (Shaw and Hamons, 1974), terminating the 1972 season and causing long-term disruption of the previously stable fishery. Clamming for human consumption was prohibited for most of the summer in 1973 because of high bacterial counts, another result of the 1972 storm. Thus, while demand for clams remained high, supplies from previously productive areas were low or nonexistent. Late in 1973, clam beds were reopened to harvesting for human consumption, but legal catch limits were reduced from earlier years. The effects of the new limits on the annual catch are evident in Figure III-A-1.

From 1972 through 1977, clam landings remained low, but in 1978 there was a large increase; the 280 thousand bushels harvested in 1978 more than doubled the 138 thousand bushels of 1977 (National Marine Fisheries Service (NMFS), 1979). Ex-vessel prices have increased sharply during the past 12 years (Fig. III-A-1), from an average of $3.71 a bushel in 1967 to over $20 a bushel in 1979 (U. S. Fish and Wildlife Service, 1969, 1970; NMFS, 1972-1980). In August and September 1979 the price reached $30 a bushel (E. Brown, professional clammer, Shady Side, Maryland, personal communication). Increased value per bushel coupled with high yields made 1979 the second year in a row for record dockside earnings for clammers. Figure III-A-2 shows the total value of soft clams landed in Maryland since 1967 and the nearly steady rise in total value since 1973.

Because of its importance in the food chain to invertebrates, fish, and waterfowl, and because of its economic value, *M. arenaria* is one of several bivalves designated as a Representative Important Species (RIS) in the Code of Maryland Regulation (COMAR) 08.05.04.13, §D(2). Excepting 1972 and 1977, a study of the adult soft-shell clam population in the vicinity of the Calvert Cliffs Nuclear Power Plant (CCNPP) has

Table III-C-6. Analysis of variance of bay anchovy egg abundance data from monthly and weekly ichthyoplankton monitoring studies conducted by ANSP in Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant, 1978-1980. (*Indicates significance at $p \leq 0.05$).

a. Monthly

Anchovy eggs — 1978

	df	SS	MS	F	PROB
DATE	3	13.26	4.42	23.57	0.0000*
STATION	4	14.86	3.72	19.81	0.0000*
DEPTH	2	3.51	1.75	9.35	0.0010*
DATE/STAT	12	8.89	0.74	3.95	0.0020*
DATE/DEPTH	6	4.55	0.76	4.04	0.0061*
STAT/DEPTH	8	1.26	0.16	0.84	0.5785
ERROR	24	4.50	0.19		

Anchovy eggs — 1979

	df	SS	MS	F	PROB
DATE	1	16.52	16.52	74.68	0.0000*
STATION	4	2.13	0.53	2.40	0.1356
DEPTH	2	0.24	0.12	0.54	0.6042
DATE/STAT	4	1.23	0.31	1.39	0.3189
DATE/DEPTH	2	1.76	0.88	3.97	0.0634
STAT/DEPTH	8	2.69	0.34	1.52	0.2839
ERROR	8	1.77	0.22		

Anchovy eggs — 1980

	df	SS	MS	F	PROB
DATE	2	7.14	3.57	13.27	0.0004*
STATION	4	12.23	3.06	11.36	0.0001*
DEPTH	2	0.18	0.09	0.34	0.7187
DATE/STAT	8	9.91	1.24	4.60	0.0046*
DATE/DEPTH	4	0.64	0.16	0.59	0.6732
STAT/DEPTH	8	1.42	0.18	0.66	0.7198
ERROR	16	4.30	0.27		

b. Weekly

Anchovy eggs — 1978

	df	SS	MS	F	PROB
DATE	13	62.01	4.77	20.27	0.0000*
STATION	2	0.37	0.19	0.79	0.4567
DATE/STAT	26	9.32	0.36	1.52	0.0853
ERROR	68	16.00	0.24		

Anchovy eggs — 1979

	df	SS	MS	F	PROB
DATE	8	20.70	2.59	20.20	0.0000*
STATION	2	0.78	0.39	3.03	0.0583
DATE/STAT	16	2.23	0.14	1.09	0.3960
ERROR	44	5.64	0.13		

Anchovy eggs — 1980

	df	SS	MS	F	PROB
DATE	12	30.01	2.50	21.56	0.0000*
STATION	2	0.28	0.14	1.22	0.3009
DATE/STAT	24	6.95	0.29	2.50	0.0019*
ERROR	65	7.54	0.12		

cant difference existed among the three near-plant Stations PS, PSC, D (Table III-C-6b). Among all stations, significant differences were found in 1978 ($p<0.0001$) and 1980 ($p=0.0001$) (Table III-C-6a) but the distribution of eggs was not consistent between years. In 1978, Stations KB, RP and, to a lesser extent, LB had much larger densities than plant site stations. In 1980, overall egg densities were down but none were collected at Station KB and only a few isolated eggs were found at the plant site stations (Table III-C-5a). A large concentration of eggs was found at Station PSC (>5000/100 m^3) and Station D (>2000/100 m^3) only once between 1978 and 1980 (on 8 June 1978, Table III-C-3b). At other times egg densities rarely exceeded 100/100 m^3. During the years of these studies, spawning in the vicinity of the plant appears to have been most active down-Bay, toward Rocky Point. The abundance and distribution of anchovy eggs in preliminary ichthyoplankton studies (Shenker and Currence, 1978) also indicated larger concentrations at Rocky Point.

Analysis of the vertical distribution of eggs in the water column yielded significant differences among depths only in 1978 ($p=0.001$) (Table III-C-6a). However, depth distributions were not consistent from station to station. In 1978, eggs were most frequently concentrated on the bottom; in following years, their distribution varied more with the largest egg concentrations found either at 5- or 10-m depths.

Anchovy egg densities at Station PSC (bottom) and PS (bottom) were plotted with EAI intake densities in Figure III-C-2a and densities at Station D (bottom) were compared with EAI's densities from TA in Figure III-C-2b. Although nearfield and in-plant samples frequently were not collected at the same time or even the same day, the plots of intake area data for 1978 agree surprisingly well, given the very patchy distribution of eggs in the study area and the very different methods of sampling. Periods of presence, abundance and fluctuations in abundance are fairly similar, suggesting that the true egg population in the plant vicinity resembled the EAI and ANSP sample populations within the general range described by the data. The 1979 and 1980 data sets fit less closely. The 1979 nearfield set lacks some data (a result of sudden storms and rough seas) and in 1980 eggs were occasionally concentrated in the upper water column at Station PS, as on 2 and 29 July 1980 (Table III-C-5) and do not appear in the plot. Using EAI data, spawning in 1979 extended from May to August, which is similar to the observed 1978 and 1980 spawning periods.

The viability of eggs following entrainment is unknown, as discussed earlier, and although a statistical analysis of intake-discharge differences has not been reported by EAI, a consistent loss of eggs between IN and TA (from mechanical maceration) is not apparent in the plots. Overall, ANSP plant site stations (including Station D) tended to have lower egg densities than those recorded at IN and TA. The differences in

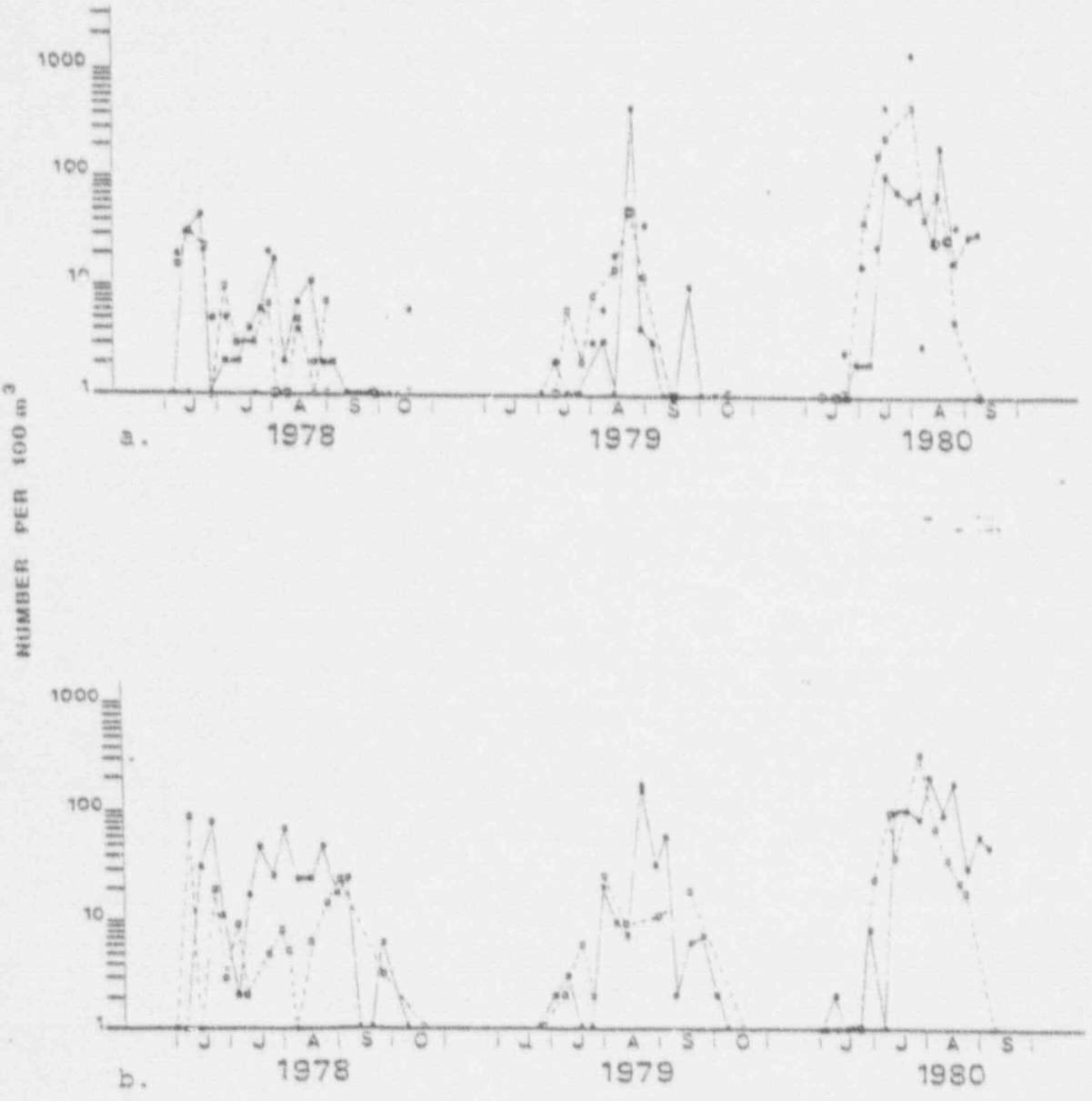


Figure III-C-2. Plots of bay anchovy egg densities entrained in the cooling system of Calvert Cliffs Nuclear Power Plant and egg densities in towed net samples from stations in Chesapeake Bay in the vicinity of the plant 1978-1980. Entrained densities are from 1978, 1979 and 1980 studies conducted by EAI. Figure III-C-2a compares entrained densities at Station IN (■) with densities at 10 m at Station PSC (□) and at Station PS (○). Figure III-C-2b compares entrained densities at Station TA (■) with densities at Station D, 5-m depth (□).

nearfield and entrained egg densities shown in the plots suggest that anchovy eggs may be susceptible to entrainment in excess of their overall population density, probably because of their aggregate distribution and a tendency for eggs to be concentrated at lower depths. Within the geographical boundaries of this six-station study, plant site stations appear to be low-density zones. However, even if the low densities around the plant were due to entrainment mortality instead of low spawning in the immediate vicinity, the loss of production to the total Bay probably would not be large. The area of Calvert Cliffs is not a major spawning area for the bay anchovy and the species spawns over its entire range in the Chesapeake Bay (Hildebrand and Schroeder, 1928; Lippson, 1973).

Anchovy larvae were found in the nearfield samples from late May through October 1978, from late June through October 1979 and from June through September, 1980 (Tables III-C-7 through III-C-9). These dates also mark the presence of entrained anchovy larvae in in-plant samples (Fig. III-C-3). Mean maximum nearfield larval densities recorded in 1978, 1979 and 1980, were 135/100 m^3 on 8 June 1978, 54/100 m^3 on 22 August 1979 and 376/100 m^3 on 29 July 1980. These densities were not consistent from one week to the next and the Bay maxima compare with consistent catches of from 200 to greater than 1000 larvae and juveniles/100 m^3 in the Patuxent River during 1978 and 1979 (ANSP, 1981). Variations in nearfield anchovy larvae populations from year to year do not correspond to variations in numbers of anchovy eggs, e.g., larval densities in 1980 (July particularly) were higher than seen in prior years while egg densities were lower. Non-correlation of nearfield anchovy egg and larvae densities may not reflect survival success of the year classes, but rather variations in the migratory patterns of the larvae. Anchovy larvae migrate to nursery areas of lower salinity upstream of spawning areas. The Calvert Cliffs area does not appear to be an important nursery area for the larvae, but may be part of a migration route up-Bay or to nearby tributaries.

Analysis of anchovy larvae's spatial distribution revealed no significant differences among the six nearfield stations (Table III-C-10a). Station differences ($D>PS\geq PSC$; $p<0.01$) indicated in the 1979 weekly studies (Table III-C-10b) suggest either that abundances were consistently underestimated at Stations PS or PSC or overestimated at D. It is noteworthy that in 1979 EAI intake densities were frequently lower than ANSP nearfield densities (Fig. III-C-3a). Densities at Station D, however, compare very well with EAI discharge data for that year (Fig. III-C-3b). The reasons for the discrepancy between intake area and discharge stations are not known.

At some power plants, the heated effluent attracts some fish species, leaving them vulnerable to thermal shock during plant shut-downs. If it is assumed that aggregations in the

Table III-C-7. Density of bay anchovy larvae in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Larvae were collected from late May through October 1978. (Density expressed as organisms/100 m^3).

a. Monthly

		RB	LB	B	PSC	PS	BP
4/24/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
5/24/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
6/22/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
7/28/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
8/23/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
9/14/78	SURFACE	1.1	3.6	30.6	33.2	2.0	0.0
	MIDDLE	6.5	1.3		66.2	18.2	17.5
	BOTTOM	56.3	2.3	0.0	29.6	0.0	3.5
10/10/78	SURFACE	0.0	0.0	2.5	0.0	3.0	0.0
	MIDDLE	1.5	0.0		0.8	1.8	3.2
	BOTTOM	0.0	0.0	1.8	3.3	1.8	0.0
11/07/78	SURFACE	0.0	0.0	3.7	15.1	2.2	5.2
	MIDDLE	53.8	10.5		0.0	2.2	0.7
	BOTTOM	4.3	14.9	6.0	0.0	0.0	0.0
12/26/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		1.3	0.0	0.0
	BOTTOM	0.0	0.0	3.3	0.0	0.0	0.0
10/17/78	SURFACE	0.0	0.0	0.0	0.0	0.0	1.7
	MIDDLE	0.0	0.0		0.0	1.4	0.0
	BOTTOM	0.0	0.0	0.0	0.0	6.4	1.1
11/14/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
12/05/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0

b. Weekly

		B	PSC	PS
5/31/78	SURFACE	0.0	0.0	2.9
	MIDDLE		0.0	4.2
	BOTTOM	0.0	0.0	0.0
6/08/78	SURFACE	40.7	61.8	740.5
	MIDDLE		53.5	57.9
	BOTTOM	90.1	15.9	19.0
6/22/78	SURFACE	3.4	1.7	6.3
	MIDDLE		14.2	21.1
	BOTTOM	19.1	23.1	21.6
6/28/78	SURFACE	13.4	1.5	0.0
	MIDDLE		6.1	24.4
	BOTTOM	2.6	0.0	5.2
7/05/78	SURFACE	1.2	1.5	0.0
	MIDDLE		11.3	1.3
	BOTTOM	8.7	10.5	5.2
7/21/78	SURFACE	7.0	0.0	3.7
	MIDDLE		2.8	7.8
	BOTTOM	5.0	3.1	0.0
7/29/78	SURFACE	14.3	4.1	1.2
	MIDDLE		9.0	10.2
	BOTTOM	7.5	7.2	20.3
8/03/78	SURFACE	2.9	19.2	7.8
	MIDDLE		7.6	0.0
	BOTTOM	4.9	0.0	0.0
8/15/78	SURFACE	0.0	3.5	0.0
	MIDDLE		8.6	3.2
	BOTTOM	5.9	4.9	4.3
8/24/78	SURFACE	23.6	2.7	0.0
	MIDDLE		29.0	15.6
	BOTTOM	14.4	1.4	1.7
9/01/78	SURFACE	28.9	1.9	4.2
	MIDDLE		2.6	24.9
	BOTTOM	23.3	7.3	0.0

Table III-C-8. Density of bay anchovy larvae in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Larvae were collected from late June through September 1979. (Density expressed as organisms/100 m^3).

a. Monthly

		KB	LB	P	PSC	PS	RP
1/10/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
3/19/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
4/12/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
5/02/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
5/04/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
7/09/79	SURFACE	0.0	0.0	1.0	1.3	0.0	1.3
	MIDDLE	2.5	0.0		2.0	2.2	2.3
	BOTTOM	1.0	0.0	2.1	0.9	1.1	2.5
8/13/79	SURFACE	0.0	1.4	8.3	2.3	1.3	0.0
	MIDDLE	7.3	32.4		5.6	13.4	6.5
	BOTTOM	12.9	6.1	9.2	13.9	18.9	4.2
9/17/79	SURFACE	0.0	0.0	1.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		3.9	2.4	0.0
	BOTTOM	1.0	0.0	17.7	0.0	0.0	1.1
10/10/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	1.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
11/27/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
12/10/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0

b. Weekly

		P	PSC	PS
5/16/79	SURFACE	-	-	0.0
	MIDDLE		-	0.0
	BOTTOM	-	-	0.0
5/30/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
6/13/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
6/18/79	SURFACE	-	-	0.0
	MIDDLE		0.0	0.0
	BOTTOM	-	0.0	0.0
6/27/79	SURFACE	0.0	0.0	0.0
	MIDDLE		1.0	0.0
	BOTTOM	0.7	0.0	0.0
7/05/79	SURFACE	-	-	2.5
	MIDDLE		-	1.9
	BOTTOM	-	-	10.5
7/18/79	SURFACE	2.3	1.7	2.1
	MIDDLE		1.8	10.3
	BOTTOM	6.4	5.3	4.0
7/25/79	SURFACE	2.9	1.2	4.4
	MIDDLE		4.6	0.0
	BOTTOM	2.3	1.8	0.0
8/01/79	SURFACE	30.5	0.0	4.1
	MIDDLE		7.4	4.9
	BOTTOM	26.0	0.0	2.5
8/08/79	SURFACE	-	-	0.0
	MIDDLE		-	14.7
	BOTTOM	-	-	6.2
8/22/79	SURFACE	104.2	8.3	29.4
	MIDDLE		13.9	21.6
	BOTTOM	150.5	47.8	53.0
8/30/79	SURFACE	21.1	0.0	4.3
	MIDDLE		2.4	3.1
	BOTTOM	10.9	11.8	36.7

Table III-C-9. Density of bay anchovy larvae in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Larvae were collected from mid June through September 1980. (Density expressed as organisms/100 m^3).

a. Monthly

		KB	LB	B	PSC	PS	RP
7/10/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
7/18/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
7/17/80	SURFACE	0.0	0.0	0.0	0.0	0.0	-
	MIDDLE	0.0	0.0		0.0	0.0	-
	BOTTOM	0.0	0.0	0.0	0.0	0.0	-
7/23/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
8/13/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
8/19/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
07/14/80	SURFACE	5.3	22.1	44.8	7.0	27.2	73.6
	MIDDLE	80.5	303.9		36.6	109.9	228.1
	BOTTOM	57.6	63.1	39.1	257.8	494.5	229.8
08/25/80	SURFACE	2.4	1.2	8.1	0.0	1.2	4.2
	MIDDLE	19.6	15.0		32.4	22.1	1.3
	BOTTOM	0.0	35.5	17.6	4.7	37.5	17.2
09/10/80	SURFACE	0.0	0.0	0.0	0.0	0.0	-
	MIDDLE	0.0	0.0		0.0	1.2	-
	BOTTOM	0.0	0.0	0.0	0.0	0.0	-

b. Weekly

		B	PSC	PS
5/22/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
5/27/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
6/05/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
6/18/80	SURFACE	0.7	0.0	0.0
	MIDDLE		1.9	1.7
	BOTTOM	0.0	0.0	0.7
6/23/80	SURFACE	0.0	2.5	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	2.5
7/02/80	SURFACE	12.8	8.5	16.8
	MIDDLE		16.7	59.1
	BOTTOM	24.0	48.6	16.4
7/10/80	SURFACE	137.9	9.6	1.2
	MIDDLE		60.8	4.8
	BOTTOM	99.9	169.6	24.7
7/29/80	SURFACE	287.8	87.3	27.8
	MIDDLE		129.1	143.8
	BOTTOM	352.8	496.4	1508.2
8/07/80	SURFACE	41.6	2.8	4.2
	MIDDLE		28.0	9.6
	BOTTOM	70.1	45.8	2.5
8/14/80	SURFACE	0.0	8.1	4.0
	MIDDLE		22.1	35.8
	BOTTOM	36.6	76.6	27.3
8/21/80	SURFACE	22.3	0.0	0.0
	MIDDLE		18.1	18.7
	BOTTOM	12.5	30.4	30.5

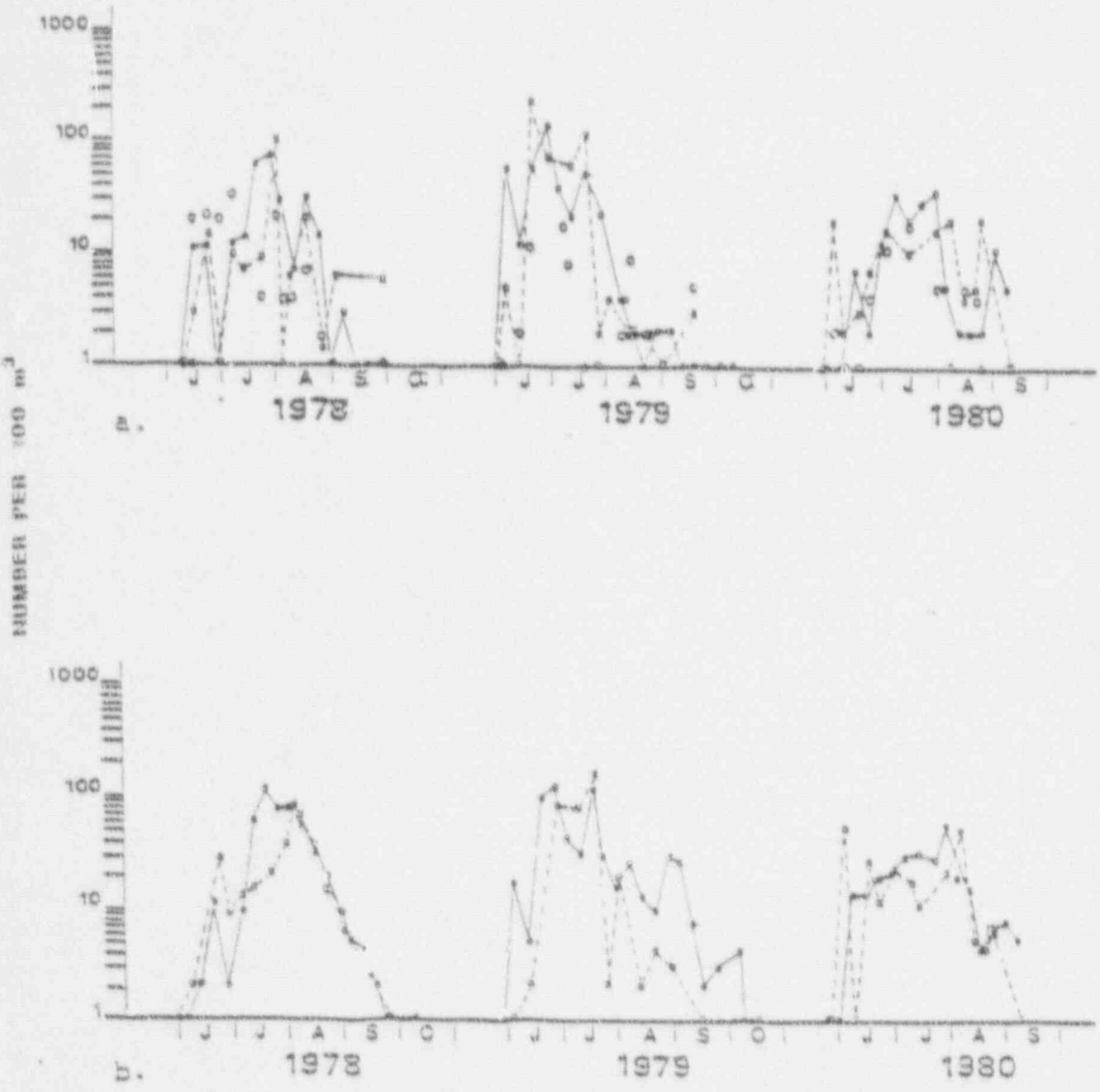


Figure III-C-3. Plots of bay anchovy larval densities entrained in the cooling system of Calvert Cliffs Nuclear Power Plant and larval densities in towed-net samples from stations in Chesapeake Bay in the vicinity of the Plant 1978-1980. Entrained densities are from 1978, 1979 and 1980 studies conducted by EAI.

Figure III-C-3a compares entrained densities at Station IN (■) with densities at 10 m at Station PSC (□) and at Station PS (○). Figure III-C-3b compares entrained densities at Station TA (■) with densities at Station D, 5-m depth (□).

Table III-C-10. Analysis of variance of bay anchovy larvae abundance data from monthly and weekly ichthyoplankton monitoring studies conducted by ANSP in Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant, 1978-1980. (*indicates significance of $p \leq 0.05$).

a. Monthly

Anchovy larvae — 1978

	df	SS	MS	F	PROB
DATE	3	4.10	1.37	8.21	0.0006*
STATION	4	0.40	0.10	0.60	0.6675
DEPTH	2	0.24	0.12	0.72	0.4972
DATE/STAT	12	3.06	0.26	1.53	0.1805
DATE/DEPTH	6	0.65	0.11	0.65	0.6885
STAT/DEPTH	8	1.05	0.13	0.79	0.6176
ERROR	24	4.00	0.17		

Anchovy larvae — 1979

	df	SS	MS	F	PROB
DATE	2	2.81	1.41	19.45	0.0001*
STATION	4	0.49	0.12	1.70	0.1584
DEPTH	2	0.88	0.44	6.12	0.0106*
DATE/STAT	8	0.89	0.11	1.54	0.2184
DATE/DEPTH	4	1.15	0.29	3.96	0.0202*
STAT/DEPTH	8	0.38	0.05	0.66	0.7193
ERROR	16	1.16	0.07		

Anchovy larvae — 1980

	df	SS	MS	F	PROB
DATE	2	17.99	9.00	60.68	0.0000*
STATION	4	0.83	0.21	1.40	0.2851
DEPTH	2	1.83	0.91	6.17	0.0120*
DATE/STAT	8	0.60	0.08	0.51	0.8323
DATE/DEPTH	4	1.69	0.42	2.84	0.0644
STAT/DEPTH	8	1.11	0.14	0.93	0.5198
ERROR	14	2.08	0.15		

b. Weekly

Anchovy larvae — 1978

	df	SS	MS	F	PROB
DATE	13	14.72	1.13	7.51	0.0000*
STATION	2	0.28	0.14	0.95	0.3928
DATE/STAT	26	3.97	0.15	1.01	0.4645
ERROR	67	10.10	0.15		

Anchovy larvae — 1979

	df	SS	MS	F	PROB
DATE	8	11.59	1.45	13.53	0.0000*
STATION	2	1.43	0.71	6.42	0.0035*
DATE/STAT	16	1.74	0.11	0.98	0.4959
ERROR	45	5.01	0.11		

Anchovy larvae — 1980

	df	SS	MS	F	PROB
DATE	10	38.36	3.84	15.91	0.0000*
STATION	2	0.24	0.12	0.50	0.6112
DATE/STAT	20	4.66	0.23	0.97	0.5132
ERROR	55	13.26	0.24		

plume at CCNPP would result in enriched samples at Station D, then densities at Station D should frequently be higher than at Station PSC, IN and particularly TA. Significant differences among near-plant stations were found for bay anchovy larvae, with Station D greater than Station PSC and PS. Because densities at Station D and at TA were very similar, aggregation or entrapment of anchovy larvae in the plume is not indicated, but cannot be ruled out. However, even assuming that anchovy larvae within the immediate area of the plant were attracted to the discharge, the concentrations at Station D were similar to larval densities at the other nearfield stations, i.e., the differences in larval abundance among all mix stations were not statistically significant.

Significant stratification of anchovy larvae by depth was indicated in 1979 ($p=0.01$) and 1980 ($p=0.012$); the abundance data for those years (Table III-C-8 and III-C-9) indicate the larvae avoided the surface while densities at 5- and 10-m depths were not consistently different from each other. Distribution of larvae within the lower water column may have been associated with DO concentrations there. A comparison of station distributions of larvae in Tables III-C-7 through III-C-9 with the distribution of available oxygen in Table III-C-2, suggests avoidance of areas where oxygen was severely limited, e.g., below 2 mg/l. On dates shown in Table III-C-2 when all DO values exceeded 3 mg/l and larval densities were large enough to detect depth differences (22 and 30 August 1979; 10, 14 and 29 July 1980; and 21 and 23 August 1980) larval densities appear to have been greater at the 10m depth. When DO values fell below 3 mg/l at the bottom, larvae seemed to concentrate at a higher depth, e.g., Station PS on 21 July 1978; Stations PS and PSC on 3 August 1978; Stations PS and PSC on 25 July 1979; Station PS on 18 July 1979; Station KB on 14 July 1980; Station PS on 7 and 14 August 1980; Stations KB and PSC on 25 August 1980. It is not a clear association, however. For instance, DO at Stations PSC (bottom) and PS (bottom) was less than 1.0 mg/l on 13 August 1979 and avoidance of the bottom was not indicated. Surface was the preferred depth of a large concentration of larvae on 8 June 1978 when all DO values exceeded 5 mg/l. There is no information in these studies on factors influencing positive kinetaxis of anchovy larvae, but positive as well as negative behavioral responses are assumed to influence their distribution.

Entrained and nearfield larval densities in Figure III-C-3 show good agreement between EAI and ANSP data sets. In 1979 and 1980, fewer larvae were probably entrained than would be expected from nearfield abundance estimates near the plant. It is possible that anchovy larvae are able to avoid entrainment despite their apparent preference for deeper water.

A few anchovy juveniles appeared in nearfield samples in April 1979. (Maximum density was 7/100 m^3 at Station D.)

These were probably carryovers from the 1978 spawn. Otherwise, juveniles were not routinely captured in net collections. However, they were found from time to time in the in-plant samples, most often in the discharge (TA). Table III-C-11 gives abundances and dates of capture of anchovy juveniles in the entrainment studies.

Depending on size (3.5-7 cm), juvenile bay anchovies may be impinged on the traveling screens in front of the plant intake rather than entrained in the cooling system. Impingement data from CCNPP (see Section V) from 1978 and 1979 indicate that, as a group, bay anchovy was the largest in numbers of individuals impinged by the screens (10 704 per total annual effort in 1978 and 10,235 in 1979). A large number of these were juveniles (J. H. Hixson, ANSP, personal communication). The impingement data are difficult to compare with the ichthyoplankton studies but the data are provided here and below for naked goby and spot larvae to serve as another relative measure of regional abundance of these groups.

Naked Goby (*Gobiosoma bosci*)

Isolated individual naked goby larvae were first caught in net tows in May and appeared in all sampling collections from mid-June through September each year. Densities in the Calvert Cliffs area varied, but were low compared to other areas of the Bay and its tributaries. Maximum densities of larvae found in isolated instances reached 130/100 m^3 in 1978, 300/100 m^3 in 1979 and 80/100 m^3 in 1980. Most other samples contained many fewer individuals (Tables III-C-12 through III-C-14). ANSP studies in the nearby Patuxent River estuary found goby larvae densities between 500 and 2000/100 m^3 (ANSP, 1981). Dovel (1971) reports the pelagic larvae are most abundant in upper regions of the Bay (salinity 1-12 °/oo) and when water temperatures are between 22 and 29°C, but does not cite comparable densities. The diminished densities in the Calvert Cliffs area in 1980 may be explained by the high salinity (8-20 °/oo) of area waters during that summer.

Analysis of naked goby larval distribution in the plant area using monthly data indicates significant differences among stations except in 1978, but not among depths (Table III-C-15a). In 1978, station differences among the six-station nearfield group were not significant, but among the plant site stations during the weekly studies, densities of goby larvae tended to be higher in the intake channel (Station PSC) than at Station PS (Table III-C-15b). In 1979 and 1980, that trend persisted; densities at Station PSC tended to be higher than at other nearfield and plant site stations. Shenker (Shenker and Currence 1979; ANSP, 1980) postulated that the rubble lining the channel and oyster beds near Station D provided desirable habitats for gobies which might explain higher densities of the goby larvae in these locations.

Table III-C-11. Mean density of bay anchovy juveniles captured in weekly nighttime collections at Calvert Cliffs Nuclear Power Plant during entrainment studies conducted by Ecological Analysts, Inc. (Density expressed as organisms/100 m^3).

	1978	
	IN	TA
4/18	0	<1
5/02	6	7
5/16	0	<1
5/23	0	2
6/20	<1	0
7/05	0	1
7/11	0	2
7/18	0	1
7/25	6	0
8/22	0	2
8/29	0	<1
9/05	0	12
9/12	0	<1
9/19	0	1
9/26	0	3
10/10	0	<1
11/14	0	2
12/15	0	6

	1979	
	IN	TA
2/06	<1	2
4/23	1	-
5/01	0	7
5/15	0	1
5/22	0	1
5/29	0	6
7/17	0	1
7/31	-	<1
8/07	0	<1
8/14	0	1
8/21	0	8
9/05	0	1
9/11	0	<1
9/18	0	3
10/02	0	2
10/09	0	1
11/13	0	3
12/18	0	<1

	1980	
	IN	TA
1/02	0	-
1/14	0	<1
2/12	0	<1
3/11	1	<1
4/25	0	1
5/05	0	1
6/02	0	2
7/14	1	5
8/18	2	0
8/25	0	1
9/02	0	2
9/08	0	1

Table III-C-12. Density of naked goby larvae in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Larvae were collected from late May through September 1978. (Density expressed as organisms/100 m^3).

a. Monthly

		KG	LB	D	PSC	PS	RP
4/24/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	6.0	0.0	0.0	0.0
5/24/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.3	0.0	0.0	0.0
6/22/78	SURFACE	0.0	0.0	0.0	0.0	3.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
7/28/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
8/23/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
9/14/78	SURFACE	0.0	0.0	0.0	2.5	0.0	0.0
	MIDDLE	2.2	0.0		1.7	0.0	1.9
	BOTTOM	0.0	1.2	0.0	3.1	0.0	0.0
10/10/78	SURFACE	0.0	0.0	12.4	4.3	3.0	3.4
	MIDDLE	4.4	5.1		0.8	14.0	3.2
	BOTTOM	3.5	1.6	14.6	6.6	21.1	1.6
11/07/78	SURFACE	7.3	2.1	173.3	43.3	4.4	1.7
	MIDDLE	24.8	10.5		2.2	4.3	1.8
	BOTTOM	3.3	21.7	64.2	6.3	3.8	0.0
12/05/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	5.8	0.0	0.0
12/19/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
1/14/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
2/03/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0

b. Weekly

		D	PSC	PS
5/31/78	SURFACE	0.0	0.0	1.5
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
6/08/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	1.1
	BOTTOM	1.8	0.0	0.0
6/22/78	SURFACE	27.3	181.1	9.4
	MIDDLE		7.1	19.8
	BOTTOM	27.3	14.5	21.6
6/28/78	SURFACE	8.9	0.0	0.0
	MIDDLE		9.2	3.7
	BOTTOM	9.2	0.0	21.6
7/05/78	SURFACE	28.8	1.5	4.2
	MIDDLE		9.6	13.4
	BOTTOM	13.0	10.5	33.8
7/21/78	SURFACE	13.9	15.7	7.3
	MIDDLE		5.5	12.4
	BOTTOM	20.6	9.2	4.2
7/29/78	SURFACE	43.0	11.0	0.0
	MIDDLE		28.9	7.9
	BOTTOM	36.5	101.3	22.1
8/03/78	SURFACE	65.6	0.5	15.6
	MIDDLE		25.0	2.3
	BOTTOM	82.3	0.0	3.5
8/15/78	SURFACE	23.8	5.3	3.3
	MIDDLE		12.3	8.1
	BOTTOM	35.2	21.4	7.2
8/24/78	SURFACE	7.9	0.0	0.0
	MIDDLE		19.3	2.4
	BOTTOM	18.3	1.4	1.7
9/01/78	SURFACE	7.5	1.9	2.1
	MIDDLE		2.6	3.6
	BOTTOM	5.8	5.5	0.0

Table III-C-13. Density of naked goby larvae in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Larvae were collected from late May through September 1979. (Density expressed as organisms/100 m^3).

a. Monthly

		RB	LB	B	PBC	PS	BP
5/10/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
5/29/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
6/12/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
6/26/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	1.0
7/04/79	SURFACE	0.0	0.0	0.0	0.0	1.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	5.4	0.0	1.4
7/09/79	SURFACE	0.0	0.0	87.0	367.8	11.3	0.0
	MIDDLE	0.0	0.0		38.1	3.3	6.9
	BOTTOM	5.8	0.0	76.8	62.5	7.6	17.7
8/13/79	SURFACE	0.0	0.0	1.2	0.0	0.0	0.0
	MIDDLE	1.2	4.1		1.9	3.0	2.3
	BOTTOM	1.8	0.0	1.5	1.9	9.4	4.2
9/17/79	SURFACE	0.0	0.0	1.0	0.0	0.0	0.0
	MIDDLE	0.0	3.7		0.0	2.4	1.2
	BOTTOM	4.1	1.2	0.0	3.4	3.6	0.0
10/16/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
11/27/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
12/10/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0

b. Weekly

		B	PBC	PS
5/16/79	SURFACE	-	-	0.0
	MIDDLE		-	0.0
	BOTTOM	-	-	0.0
5/30/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	1.4	1.0	0.0
6/13/79	SURFACE	6.2	4.3	3.5
	MIDDLE		5.2	4.4
	BOTTOM	2.1	0.0	1.9
6/18/79	SURFACE	-	-	0.0
	MIDDLE		75.2	4.6
	BOTTOM	-	236.9	11.5
6/27/79	SURFACE	95.5	27.7	0.0
	MIDDLE		31.0	9.5
	BOTTOM	84.5	76.0	13.3
7/05/79	SURFACE		-	0.8
	MIDDLE		-	1.9
	BOTTOM	-	-	18.4
7/18/79	SURFACE	51.2	9.9	0.0
	MIDDLE		175.3	7.1
	BOTTOM	154.2	120.5	0.0
7/25/79	SURFACE	1.9	0.0	0.0
	MIDDLE		1.1	10.8
	BOTTOM	2.3	1.8	0.0
8/01/79	SURFACE	10.1	2.5	1.0
	MIDDLE		2.5	1.0
	BOTTOM	16.7	3.7	6.0
8/08/79	SURFACE	-	-	2.1
	MIDDLE		-	1.1
	BOTTOM	-	-	2.1
8/22/79	SURFACE	3.8	2.4	0.0
	MIDDLE		0.0	1.2
	BOTTOM	3.5	1.8	2.4
9/30/79	SURFACE	3.7	0.0	0.0
	MIDDLE		2.8	0.0
	BOTTOM	2.9	0.0	1.0

Table III-C-14. Density of naked goby larvae in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Larvae were collected from late May through September 1980. (Density expressed as organisms/100 m^3).

a. Monthly

		KB	LB	D	PGC	PB	BF
1/10/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
2/19/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
3/19/80	SURFACE	0.0	0.0	0.0	0.0	0.0	-
	MIDDLE	0.0	0.0		0.0	0.0	-
	BOTTOM	0.0	0.0	0.0	0.0	0.0	-
4/23/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
5/13/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
6/10/80	SURFACE	0.0	0.0	1.2	0.0	0.0	0.0
	MIDDLE	1.0	0.0		0.0	1.2	0.0
	BOTTOM	0.0	0.9	0.0	2.0	0.0	0.0
7/14/80	SURFACE	0.0	0.0	13.4	4.2	2.3	0.0
	MIDDLE	4.4	0.0		7.7	4.6	6.0
	BOTTOM	1.0	1.9	9.8	9.6	17.9	1.4
8/25/80	SURFACE	0.0	0.0	3.0	1.3	0.0	0.0
	MIDDLE	0.0	0.0		11.9	2.0	0.0
	BOTTOM	0.0	1.1	4.3	19.6	0.0	2.3
9/10/80	SURFACE	0.0	0.0	0.0	0.0	1.3	-
	MIDDLE	0.0	0.0		0.0	0.0	-
	BOTTOM	0.0	0.0	2.2	0.0	0.0	-

b. Weekly

		D	PSC	PB
5/22/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.9	0.0
5/27/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
6/05/80	SURFACE	0.0	26.8	0.0
	MIDDLE		30.1	2.5
	BOTTOM	51.3	18.5	2.4
6/18/80	SURFACE	25.8	3.5	1.3
	MIDDLE		7.3	2.8
	BOTTOM	26.0	2.6	0.0
6/23/80	SURFACE	11.0	82.4	3.8
	MIDDLE		12.3	3.8
	BOTTOM	10.7	7.0	3.8
7/02/80	SURFACE	40.5	26.6	0.0
	MIDDLE		15.1	1.4
	BOTTOM	21.6	16.0	11.4
7/10/80	SURFACE	27.0	4.3	0.0
	MIDDLE		12.2	9.5
	BOTTOM	16.6	27.2	11.8
7/29/80	SURFACE	12.8	3.7	0.0
	MIDDLE		4.3	0.0
	BOTTOM	19.8	16.3	4.8
8/07/80	SURFACE	48.2	11.3	0.0
	MIDDLE		25.4	0.0
	BOTTOM	49.1	20.0	0.0
8/14/80	SURFACE	1.9	4.6	0.0
	MIDDLE		5.9	0.0
	BOTTOM	5.4	3.8	4.7
8/21/80	SURFACE	3.2	1.3	0.0
	MIDDLE		32.3	0.0
	BOTTOM	4.2	5.3	4.0

Table III-C-15. Analysis of variance of naked goby larvae abundance data from monthly and weekly ichthyoplankton monitoring studies conducted by ANSP in Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant, 1978-1980. (*indicates significance at $p \leq 0.05$).

a. Monthly

Naked Goby larvae — 1978

	df	SS	MS	F	PROB
DATE	3	2.96	0.97	19.23	0.0000*
STATION	4	0.46	0.12	2.30	0.0685
DEPTH	2	0.13	0.06	1.28	0.2954
DATE/STAT	12	1.59	0.13	2.63	0.0210*
DATE/DEPTH	6	0.55	0.09	1.84	0.1341
STAT/DEPTH	8	1.38	0.17	3.43	0.0091*
ERROR	24	1.21	0.05		

Naked Goby larvae — 1979

	df	SS	MS	F	PROB
DATE	1	1.14	1.11	9.14	0.0165*
STATION	4	3.71	0.93	7.44	0.0001*
DEPTH	2	0.46	0.23	1.83	0.2217
DATE/STAT	4	3.56	0.89	7.14	0.0005*
DATE/DEPTH	2	0.49	0.25	1.97	0.2018
STAT/DEPTH	8	0.80	0.10	0.80	0.6178
ERROR	8	1.00	0.12		

Naked Goby larvae — 1980

	df	SS	MS	F	PROB
DATE	3	1.25	0.42	10.97	0.0001*
STATION	4	1.10	0.29	7.78	0.0005*
DEPTH	2	0.11	0.05	1.39	0.2690
DATE/STAT	12	1.65	0.14	3.64	0.0042*
DATE/DEPTH	6	0.53	0.09	2.33	0.0677
STAT/DEPTH	8	0.39	0.05	1.27	0.3060
ERROR	22	0.83	0.04		

b. Weekly

Naked Goby larvae — 1978

	df	SS	MS	F	PROB
DATE	13	14.77	1.14	9.01	0.0000*
STATION	2	2.53	1.26	10.90	0.0001*
DATE/STAT	26	4.39	0.17	1.46	0.1105
ERROR	67	7.76	0.12		

Naked Goby larvae — 1979

	df	SS	MS	F	PROB
DATE	9	18.59	2.07	20.65	0.0000*
STATION	2	3.18	1.59	15.90	0.0000*
DATE/STAT	18	6.13	0.34	3.40	0.0000*
ERROR	49	4.90	0.10		

Naked Goby larvae — 1980

	df	SS	MS	F	PROB
DATE	13	14.92	1.15	11.25	0.0000*
STATION	2	6.05	3.02	29.63	0.0000*
DATE/STAT	26	6.03	0.23	2.28	0.0035*
ERROR	78	7.14	0.10		

Figure III-C-4 compares densities of goby larvae entrained in the plant with nearfield bottom densities. The plots show good agreement between data sets indicating that the larvae are entrained in densities proportional to their abundance in the intake channel. Since densities were usually higher in the intake channel than elsewhere, goby larvae populations may be more vulnerable to entrainment and its effects than expected.

Goby larvae were included in the viability and latent effects studies conducted by EAI. Goby larvae were less fragile than bay anchovy larvae, but initial precondenser mortality for gobies was also high. Results are still preliminary, but comparisons of goby larvae mortality at IN and TA indicated mortality due to entrainment substantially less than 100% (EAI, 1980a, 1980b).

Juvenile and adult gobies were not caught in net tows of the nearfield ichthyoplankton studies nor in the pumped samples of the entrainment studies. Theoretically, however, they would be susceptible to the sampling gear and to entrainment if they abandoned the benthic habitat. Apparently they do that very infrequently, for the number of naked goby impinged on the traveling screens was only one per total annual effort in 1978 and one in 1979 (see Section V).

Spot (*Leiostomus xanthurus*)

The numbers of spot larvae and juveniles collected in the nearfield studies were too small for statistical analysis. Tables III-C-16 through III-C-18 give their densities in the towed-net samples; 4, 5, and 36/100 m^3 were the maximum densities in any single location in 1978, 1979 and 1980, respectively. Similarly, low densities were found to be entrained by the plant (Fig. III-C-5). However, it is assumed that the numbers of spot larvae and juveniles in the CCNPP area were underestimated by the sampling gear employed. Some evidence of this is obtained from the impingement studies conducted at the plant (see Section V). In those studies, spot was the fourth most numerous fish species impinged on the traveling screens: 4690 individuals per total effort in 1978; 2536 per total effort in 1979 and all of these were juveniles of varying length (J. Hixson, ANSP, personal communication). Young spot were typically caught in the pumped in-plant samples in May, indicating the arrival of the first spot in the area from their spawning ground near the mouth of the Bay. The migration of the juvenile spot sometimes began a little earlier and sometimes continued into June.

Since the area surrounding Calvert Cliffs Nuclear Power Plant is neither a spawning nor nursery area for spot (Lippson, 1973), the risk to the Bay-wide population from power plant effects on the young is assumed to be minimal.

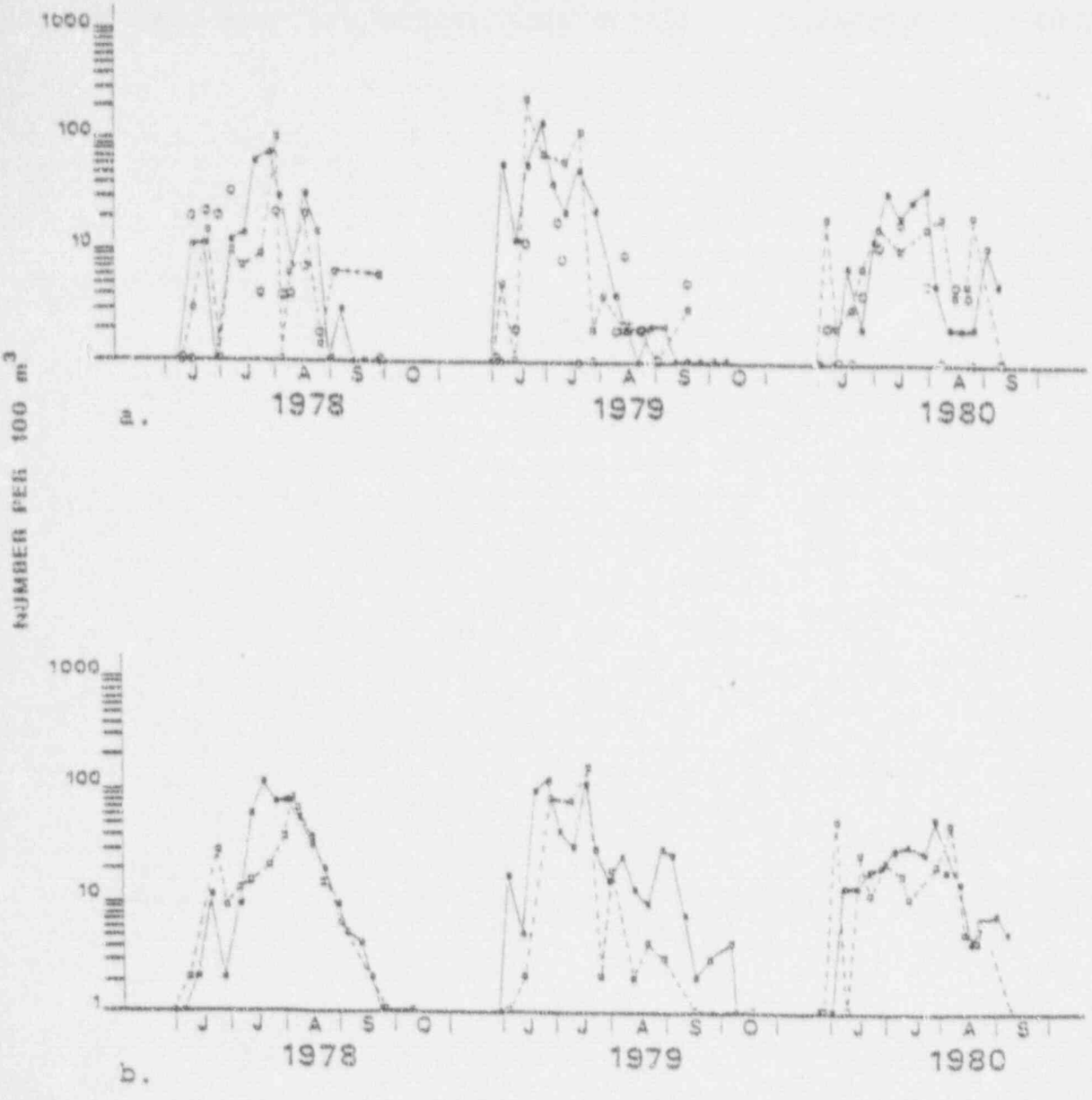


Figure III-C-4. Plots of naked goby larval densities entrained in the cooling system of Calvert Cliffs Nuclear Power Plant and larval densities in towed-net samples from stations in Chesapeake Bay in the vicinity of the plant, 1978-1980. Entrained densities are from 1978, 1979 and 1930 studies conducted by EAI.

Figure III-C-4a compares entrained densities at Station IN (■) with densities at 10 m at Station PSC (□) and at Station PS (○). Figure III-C-4b compares entrained densities at Station TA (■) with densities at Station D, 5-m depth (□).

Table III-C-16. Density of spot larvae and juveniles in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Juveniles were collected in May and June 1978. (Density expressed as organisms/100 m^3).

a. Monthly

		KB	LB	B	PSC	PS	BP
1/24/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
2/24/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
3/22/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
4/28/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
5/23/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
6/14/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	2.3	0.0
7/10/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
8/07/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
9/26/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
10/19/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
11/14/78	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0

b. Weekly

		B	PSC	PS
5/31/78	SURFACE	0.0	0.0	0.0
	MIDDLE		3.5	0.0
	BOTTOM	3.8	1.3	0.0
6/08/78	SURFACE	2.3	0.0	0.0
	MIDDLE		1.5	0.0
	BOTTOM	0.0	2.3	0.0
6/22/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
6/28/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
7/05/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
7/21/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
7/29/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
8/03/78	SURFACE	0.0	3.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
8/15/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
8/24/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
9/31/78	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0

Table III-C-17. Density of spot larvae and juveniles in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Juveniles were collected from April through early June 1979. (Density expressed as organisms/100 m^3).

a. Monthly

		KB	LB	B	PBC	PG	RP
1/10/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
3/19/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
4/12/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	1.0	0.0	0.0	0.0	5.0
5/02/79	SURFACE	0.0	0.0	1.2	0.0	0.0	0.0
	MIDDLE	1.0	0.0		0.0	0.0	2.6
	BOTTOM	0.0	1.1	2.8	4.8	3.7	0.0
6/04/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	1.0	0.0	1.7	0.0	0.0	0.0
7/09/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
8/13/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
9/17/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
10/18/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
11/27/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
12/10/79	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0

b. Weekly

		B	BC	PB
5/16/79	SURFACE	-	-	0.0
	MIDDLE		-	1.5
	BOTTOM	-	-	0.0
5/30/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	2.7	1.0	0.0
6/13/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
6/18/79	SURFACE	-	-	0.0
	MIDDLE		0.0	0.0
	BOTTOM	-	0.0	0.0
6/27/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
7/05/79	SURFACE	-	-	0.0
	MIDDLE		-	0.0
	BOTTOM	-	-	0.0
7/18/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
7/25/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
8/01/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
8/08/79	SURFACE	-	-	0.0
	MIDDLE		-	0.0
	BOTTOM	-	-	0.0
8/22/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
8/30/79	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0

Table III-C-18. Density of spot larvae and juveniles in monthly and weekly ichthyoplankton collections from the Chesapeake Bay in the vicinity of Calvert Cliffs Nuclear Power Plant. Juveniles were collected only in May 1980. (Density expressed as organisms/100 m^3).

a. Monthly

		XB	LB	D	PSC	PS	AP
1/10/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
2/18/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
3/19/80	SURFACE	0.0	0.0	0.0	0.0	0.0	-
	MIDDLE	0.0	0.0		0.0	0.0	-
	BOTTOM	0.0	0.0	0.0	0.0	0.0	-
4/23/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
5/13/80	SURFACE	0.0	2.9	8.7	2.0	20.0	1.2
	MIDDLE	0.0	1.1		6.8	5.2	3.0
	BOTTOM	0.0	0.0	36.2	5.0	0.0	1.1
6/10/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
07/14/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
08/25/80	SURFACE	0.0	0.0	0.0	0.0	0.0	0.0
	MIDDLE	0.0	0.0		0.0	0.0	0.0
	BOTTOM	0.0	0.0	0.0	0.0	0.0	0.0
09/10/80	SURFACE	0.0	0.0	0.0	0.0	0.0	-
	MIDDLE	0.0	0.0		0.0	0.0	-
	BOTTOM	0.0	0.0	0.0	0.0	0.0	-

b. Weekly

		D	PSC	PS
5/22/80	SURFACE	0.7	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	3.2	3.4	0.0
5/27/80	SURFACE	0.9	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	1.6	0.0	0.0
6/05/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
6/18/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
6/23/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
7/02/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
7/10/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
7/29/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
8/07/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
8/14/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0
8/21/80	SURFACE	0.0	0.0	0.0
	MIDDLE		0.0	0.0
	BOTTOM	0.0	0.0	0.0

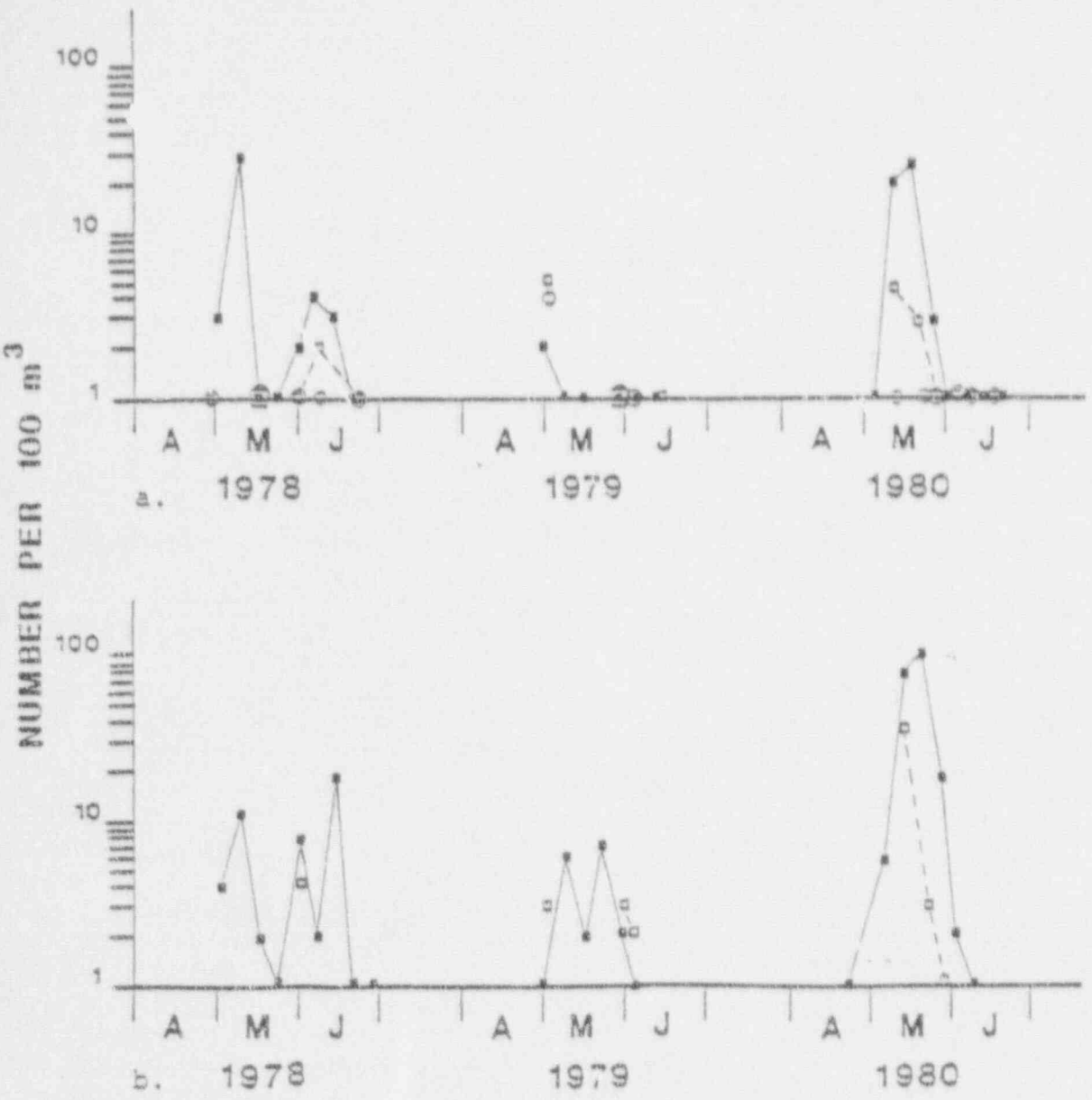


Figure III-C-5. Plots of larval and juvenile spot densities entrained in the cooling system of Calvert Cliffs Nuclear Power Plant and larval densities in towed-net samples from stations in Chesapeake Bay in the vicinity of the plant, 1978-1980. Entrained densities are from 1978, 1979 and 1980 Studies conducted by EAI.

Figure III-C-5a compares entrained densities at Station IN (■) with densities at 10 m at Station PSC (□) and at Station PS (○). Figure III-C-5b compares entrained densities at Station TA (■) with densities at Station D, 5-m depth (□).

Conclusions

The ichthyoplankton collected in the vicinity of the plant were typical estuarine spawners, not unique to this area of the Atlantic coast. Bay anchovies usually dominated the ichthyoplankton catch and naked goby larvae were common. The numbers of young spot captured in these studies were very low, but that may reflect the limitations of the sampling gear and not represent the size of the juvenile populations in the plant area. In general, the area around CCNPP is not used as a major spawning or nursery area by these groups. Goby larvae appear to be locally concentrated at near-plant stations, probably because of the desirable habitat supplied by benthic rubble in the area and lining the intake channel. Bay anchovy eggs and larvae were not so concentrated.

The thermal plume at CCNPP as represented by Station D compared to Stations PS and PSC did not appear to attract concentrations of naked goby or spot, but may be a desirable location for bay anchovy larvae. However, statistical testing did not reveal significant differences in goby, spot and bay anchovy larval densities at Station D when all six stations were compared.

Study organisms were entrained by the plant approximately in proportion to their abundance near the plant. That proportion increased or decreased by a small amount apparently related to specific characteristics of distribution, i.e., anchovy eggs may be at greater risk of entrainment because they tend to be concentrated at lower depths; anchovy larvae appear to be able to reduce risk of entrainment possibly by avoidance behavior; goby larvae may be at increased risk because of habitat preference. Juvenile spot are apparently able to avoid entrainment and sampling census as well, probably because of a strong swimming ability developed before they migrate inshore to the Calvert Cliffs area.

Ecological Analysts, Inc. has not yet completely analyzed their entrainment studies conducted at CCNPP. The effects of entrainment on anchovy eggs are unknown, but there are indications that mortality of larvae from passage through the condenser cooling system may be substantially less than 100%. Even assuming 100% mortality, however, the impact of entrainment at Calvert Cliffs on Bay-wide populations of anchovies, gobies and spot probably would be minimal.

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IV. ENTRAINMENT STUDIES

A. PHYTOPLANKTON

Introduction

Passage of estuarine water through Baltimore Gas and Electric (BG&E) Company's Calvert Cliffs Nuclear Power Plant (CCNPP) exposes the Chesapeake Bay phytoplankton community to both heat and mechanical stress. Studies elsewhere have indicated that a stimulation or a depression of phytoplankton productivity may result from thermal stress, depending upon ambient water temperature and the increase in water temperature accompanying passage through the plant. Stimulation usually occurs during the cold-water winter months, while depression has been reported during the warm-water summer months (Brooks, 1974; Smith, Brooks and Jensen, 1974).

Phytoplankton entrainment studies were initiated at CCNPP in the spring of 1976 and continued each year during the summer months from 1976 to 1980. Pigment and productivity parameters were monitored initially in 1976 and 1977. Gross and net photosynthesis, respiration, ^{14}C fixation rate, chlorophyll fluorescence, active chlorophyll *a* (chl *a*) and phaeopigment concentrations were measured at plant intake and discharge locations to assess changes in biomass (as chl *a*) and physiological activity resulting from entrainment. Cell counts by species were included in the study program to characterize the phytoplankton community in 1978 and in the years following.

Several modifications to design and purpose took place over the years. The study in 1976 focused specifically on effects from Unit #1; in 1977, data were collected from Unit #2 and compared with those from Unit #1. No differences were detected and subsequent data have been collected only from Unit #2.

The original 1976 entrainment study was designed to examine the effect of the intake curtain wall on the quantity of phytoplankton entrained in addition to effects of power plant passage during entrainment. From 1977 to 1980 studies were conducted once each month, June through September, to obtain intake-discharge comparisons over a wide range of conditions. A critical point of interest for these studies was the temperature increase (ΔT) experienced by organisms entrained by the plant cooling system. In 1976, 1977 and 1978, maximum ΔT was 5.5°C. In 1979 and 1980, maximum ΔT was provisionally raised to 6.7°C. At the request of the State of Maryland Water Resources Administration, phytoplankton entrainment studies were designed to determine changes in entrainment effects that may have resulted from the increased ΔT during 1979 and 1980.

Detailed analyses of each entrainment study have been prepared yearly for BG&E (ANSP 1978a, 1978b, 1979a, 1980a, in

prep.). This report presents and discusses the results of these studies.

Materials and Methods

The original sampling design of 1976 was substantially changed in subsequent years; thus, the sampling scheme and results of the 1976 study will be summarized separately.

1976 Studies

Studies were conducted twice in May and once in June. Samples for productivity were collected in front of and behind the traveling screens serving Unit #1, and at the terminus of the conduit discharging Unit #1 cooling water to the Bay. In front of the screens, samples were pumped from 0, 2 and 4 m depths using separate, identical diaphragm pumps. Behind the screens, samples were pumped from a single intermediate depth. At the discharge, samples were pumped from a single depth near the center of the conduit, for it was assumed that turbulence in the conduit precluded vertical gradients there.

The diaphragm pump was a 12-v PAR bilge pump with a flow rate of about 30 l/min (8 gal/min) through a 1.9-cm (0.75-in) hose suspended to the appropriate depth.

Sample collection at each location was timed in an effort to sample approximately the same water mass through the power plant. Transit time through the plant was assumed to be about 4 min.

Samples were collected 3 or 4 times per study date, usually with a 4-h interval between collection periods. Most samples were replicated: two for chlorophyll concentration and three sets (light, initial, dark) for photosynthesis estimations. A single, whole water sample was collected at each location to provide a rough estimate of phytoplankton species diversity and abundance. Temperature and salinity data were recorded for each group of replicates using a Beckman RS5-3 thermister/ salinometer. Field and laboratory procedures were the same as those detailed below.

1977-1980 Studies

Entrainment studies were scheduled to coincide with times of maximum phytoplankton abundance and maximum ambient water temperatures. Four 24-h studies were conducted each summer, one each month from June through September.

Samples were collected behind the traveling screens from the intake conduit serving Unit #2 (Station PSI) and from a

conduit discharging Unit #2 cooling water (Station PSD) (Fig. IV-A-1). Samples were collected with the low-flow diaphragm pump described above. At Station PSI, a depth-integrated sample was obtained from three hoses suspended 1, 3 and 5 m from the bottom in front of the intake circulating pump (Fig. IV-A-2). At Station PSD, samples were taken at a single depth at the center of the conduit. Sample collections at Station PSD were timed to account for the assumed 4-min transit time through the condenser cooling system. To be certain the sample at PSD was not mixed with unentrained Bay water, the temperature of the discharge water was compared to the internal conduit temperature at a discharge tunnel access port (Station DTA, Fig. IV-A-1). Samples were collected only if temperatures matched within 0.3°C

Samples for species composition determinations were collected as described below, directly from the hose of the diaphragm pump. For biomass and productivity samples, a bucket (approximately 5-liter volume) was slowly filled from the hose, over 3 min without bubbling. Subsamples were then taken from the bucket. In 1980, a procedure was added to reduce artifacts produced by oxygen supersaturation. The dissolved oxygen (DO) concentration of the bucket water was measured initially; if the water was supersaturated, nitrogen was bubbled through the sample until the DO dropped about 2 mg O_2 m^{-3} below saturation before subsamples were removed.

The table below summarizes the sampling scheme for each parameter over each 24-h study.

Measurement	Collection schedule	Replication
Species composition, abundance (not in 1977)	every hour for 24 h	none
Biomass-Chlorophyll fluorescence	every half hour for 24 h	none
Pigment extraction (fluorometer calibration)	every 4 hours for 24 h	none
Photosynthesis- ^{14}C method	every half hour daylight hours	duplicates every hour
Photosynthesis- Oxygen method	every hour daylight hours	none
Temperature and salinity	every half hour	none

Note: There was some variation in the scheme in June and July 1977 studies.

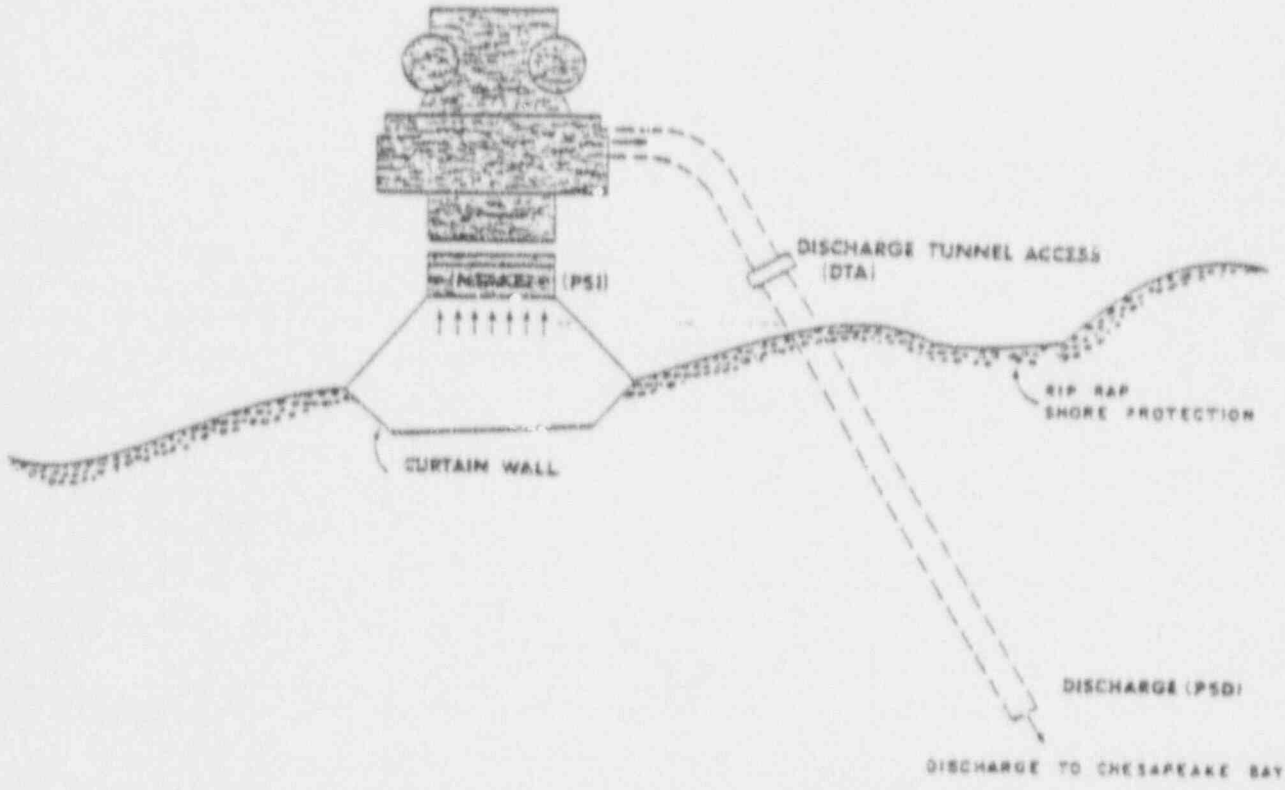


Figure IV-A-1. Phytoplankton entrainment study Stations PSI (Plant Site Intake), DTA (Discharge Tunnel Access) and PSD (Plant Site Discharge) at Calvert Cliffs Nuclear Power Plant, 1976-1980.

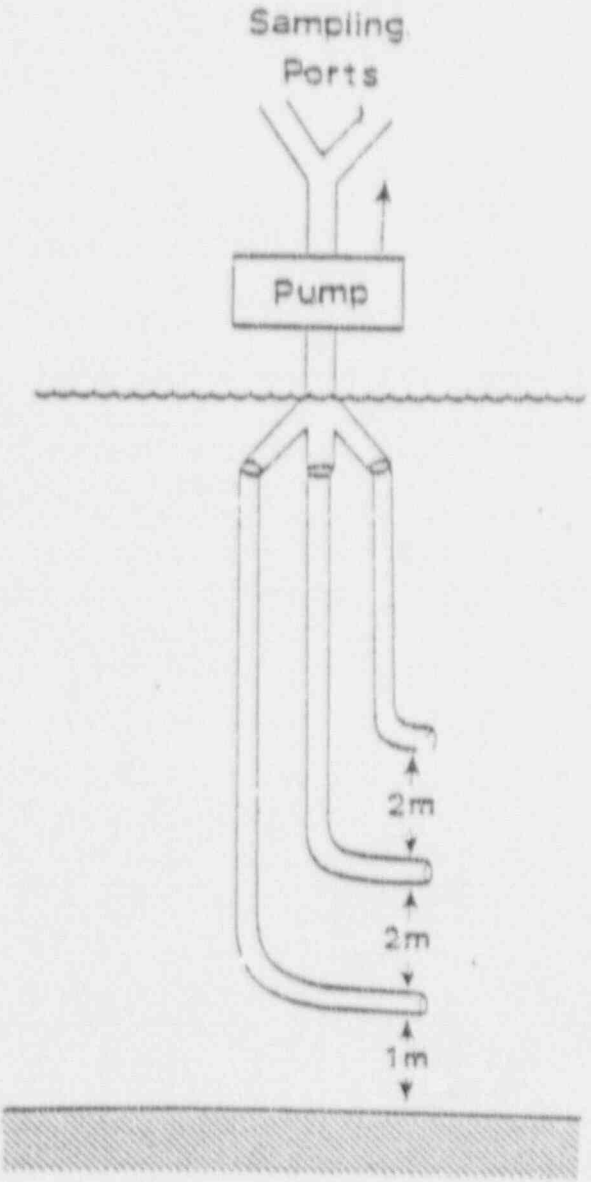


Figure IV-A-2. Schematic diagram of sampling apparatus at PSI (Plant Site Intake) for entrainment studies at Calvert Cliffs Nuclear Power Plant, 1977-1980.

Samples for species composition were collected once every hour during each 24-h study from 1978 through 1980. To minimize effects of patchiness, five 100-ml subsamples were collected at 1.5-min intervals yielding a 500-ml composite sample (total collection time 6 min). Samples were fixed immediately with 0.4 ml concentrated I_2KI solution and preserved shortly thereafter with buffered formaldehyde (final formalin concentration approximately 2.5%).

In the laboratory, samples were allowed to settle for at least 72 h, centrifuged and concentrated to a final volume of 5 ml (total concentration approximately 100:1). An aliquot of a thoroughly-mixed sample was transferred to a nanoplankton counting chamber (Palmer and Maloney, 1954) with a Pasteur pipette. All phytoplankton cells appearing in eight fields on each slide were counted and identified using a total magnification of 400x. The eight fields were arranged in a square around the center of the counting chamber to avoid massing cells that might occur at the center and near the periphery of the filled counting cell. If fewer than 250 cells were totaled in eight fields, more fields were counted until at least 250 cells had been tallied. To confirm genus and species identifications, cells were examined under oil immersion (total magnification = 1000x).

Estimates of phytoplankton biomass as chlorophyll *a* were made using a Turner Design Model 10-000R fluorometer to measure *in vivo* pigment fluorescence. Whole water samples for extracted pigment analysis were collected to calibrate fluorescence with known concentrations of chlorophyll *a*.

Phytoplankton productivity was determined using light and dark bottle techniques (Gaarder and Gran, 1927) to measure ^{14}C uptake and oxygen flux.

Uptake of ^{14}C was determined using 100-ml samples taken from the composite bucket, spiked with 1 µCi $NaH^{14}CO_3$ (8.4 mCi $mmol^{-1}$) and incubated 1.5 to 4 h at surface light intensity in a waterbath maintained at the ambient station temperature. Following incubation, samples were filtered through a 0.45 µm Millipore filter, fumed with concentrated HCl and dessicated for at least 12 h in individual scintillation vials. Scintillation fluor (1 liter scintillation grade toluene, 5 g PPO, 0.1 g dimethyl-POPOP) was added to each vial and the samples were counted in a Beckman LS-100C scintillation counter, employing external standards for efficiency calculations. Total carbonate alkalinity of whole water samples was determined by titration with 0.0199 N NCl to pH 4.5 with a Fischer Accumet Model 425 pH meter. The equations of Vollenweider (1974) were used to calculate ^{14}C fixation rates in mg C m^{-3} h^{-1}.

Oxygen flux was measured using 300-ml BOD sample bottles filled from the composite bucket. Oxygen fixation procedures, employing manganous chloride and alkaline iodide, followed

Carpenter (1965). Titration precision was ± 0.03 mg O_2 m^{-3}. Samples were incubated as described above for the ^{14}C method. Changes in oxygen concentrations (mg O_2 m^{-3} h^{-1}) in light and dark bottles represented net photosynthesis and respiration rates, respectively; the gross photosynthesis rate equalled the sum of net photosynthesis and respiration.

Temperature was measured with a hand-held thermometer, salinity was measured with a Beckman RS5-3 salinometer, and dissolved oxygen (DO) was determined from the initial oxygen bottles (1976-1979) or measured with a Yellow Springs Instrument DO meter (1980).

Data Analysis

Total cell densities and cell densities for major algal divisions were analyzed to detect changes in phytoplankton community structure resulting from passage through the plant (1978, 1979 and 1980). Estimates of cell density ratios and confidence intervals between intake and discharge were computed based on a method from Cochran (1977). The estimates and confidence intervals were computed by taking the ratio of the discharge density to the intake density. Variances of the estimate were computed using a formula based on a Taylor series expansion of the ratio, which uses the variances and the covariance of the intake and discharge series. Although estimates computed in this manner are known to be slightly biased, the bias is negligible (<1.0%). If the lower extreme of the confidence interval was greater than 1.0, a significant ($p \leq 0.05$) decrease in cell densities was indicated; if the higher end of the confidence interval were less than 1.0, a significant increase in cell densities was indicated.

Productivity parameters were analyzed for differences between stations using the paired t-test (Sokal and Rohlf, 1969). The test was applied separately to each study from 1977 through 1980. Net photosynthesis, respiration, ^{14}C fixation, fluorometric chlorophyll (flchl) and efficiency ratios (net photosyntnesis/flchl, respiration/flchl, ^{14}C/flchl) were analyzed in this way. Significance level for the differences was $\alpha=0.05$.

Because of station differences in the relationship of fluorescence to extracted chlorophyll in 1978 and 1980, efficiency ratios (photosynthesis/flchl, respiration/flchl, ^{14}C/flchl) were analyzed only for 1979. In every case, station differences in the efficiency ratios paralleled station differences in total net photosynthesis, respiration and ^{14}C fixation. It is apparent that the range of fluorometric measurements in these studies was very small compared to the range of productivity measurements, i.e., in the efficiency ratio, the denominator (fluorometric units) changed very little compared to the numerator (productivity units). The fluorometric units

acted more or less as a constant. For this reason, production and metabolic efficiencies are not emphasized in the text.

Analysis of entrainment effects on rates of gross photosynthesis was approached with another analytical technique, Hotelling's T^2-statistic (Morrison, 1967). This multivariate technique takes into account the contributions of the two components, net photosynthesis and respiration, which define gross photosynthesis. Hotelling's T^2 statistic was computed for each set of points $((NET_{PSD}-NET_{PSI}), (RESP_{PSD}-RESP_{PSI}))$ which define $(GROSS_{PSD}-GROSS_{PSI})$ for each study in 1978, 1979 and 1980. The technique tests the hypothesis that the set of points do not differ significantly from zero (0,0).

Results

1976 Studies

Studies were conducted on three dates in 1976, twice in May and once in June. The cross-condenser ΔT to which phytoplankton were exposed during the studies was well below the limit and did not exceed 3.4°C. Table IV-A-1 gives average salinity, water temperature and cross-condenser ΔT for each study in 1976. The 1976 phytoplankton cell counts (ANSP, 1978a) were not readily convertable to cell densities as measured in following years and therefore are not included in this report. Productivity was measured only at Stations PSI and PSD and productivity values as measured at Station PSI reflect the size of the phytoplankton communities on each sampling date. Average gross photosynthesis at PSI was 169, 72 and 22 mg O_2 m^{-3} h^{-1} for 14 May, 27 May and 7 June, respectively. Average respiration on these dates at Station PSI was 125, 41 and 34 mg O_2 m^{-3} h^{-1}. Concentrations of active chlorophyll *a* for periods when productivity was measured were 13, 4 and 6 mg chl *a* m^{-3} (Table IV-A-1). Carbon uptake using ^{14}C methodology was not measured in 1976.

Entrainment effects of Unit #1 on production rates and biomass (chl *a*) were variable within and between studies. Overall, biomass (chl *a*) was reduced between intake and discharge in 10 out of 11 comparisons; significant ($p<0.05$) reductions were measured four times. A significant increase was measured once. Gross photosynthesis and respiration were significantly different between stations only on 7 June. Discharge rates were greater than intake rates on that date, indicating stimulation of metabolic processes.

1977 Studies

The four entrainment studies in June, July, August and September 1977 focused on entrainment effects from Unit #2. The mean cross-condenser ΔT during these studies ranged between 3 and 5°C (Table IV-A-1), well below the present provisional

Table IV-A-1. Summary of mean values for environmental and phytoplankton community parameters measured during entrainment studies at Calvert Cliffs Nuclear Power Plant, 1976-1980. (Temperature is expressed in °C; salinity in °/₀₀; Chlorophyll *a* in mg chl m^{-3}; respiration and net and gross photosynthesis in mg O_2 m^{-3} h^{-1}; ^{14}C fixation in mg C m^{-3} h^{-1}.)

		MEAN TEMP. AT PSI	MEAN TEMP. AT PSD	MEAN ΔT	MEAN SALINITY AT PSI	MEAN TOTAL CELLS ML^{-1} AT PSI OVER 24-h	MEAN TOTAL CELLS ML^{-1} AT PSI 0700-1500 h	MEAN CHLOROPHYLL AT PSI (1)	MEAN CHLOROPHYLL AT PSI (2)	MEAN NET PHOTO. AT PSI	MEAN RESP. AT PSI	MEAN GROSS PHOTO. AT PSI	MEAN ^{14}C FIXATION AT PSI
MAY	1976a	18.2	20.2	2.0	10	-	*	13	-	44	125	169	-
MAY	1976b	19.3	22.7	3.4	10	-	*	4	-	31	41	72	-
JUN	1976	20.8	23.9	3.1	10	-	*	6	-	-12	34	22	-
	1977	21.0	24.9	3.9	12	-	-	5	*	-24	70	46	*
	1978	20.7	26.0	5.3	9	26,452	18,034	20	29	289	110	399	105
	1979	20.4	26.2	5.8	9	5,750	5,265	4	5	20	79	99	7
	1980	19.7	25.3	5.6	14	4,210	4,210	3	8	-27	153	126	19
JUL	1977	24.9	30.1	3.2	15	-	-	5	*	-19	139	120	*
	1978	24.8	30.3	5.5	9	15,832	14,332	18	-	219	68	287	53
	1979	22.2	27.8	5.6	12	3,796	3,467	6	7	108	62	170	18
	1980a	23.7	29.4	5.7	15	2,207	2,207	-	-	-	-	-	-
	1980b	24.5	30.3	5.8	14	3,967	2,658	4	5	154	53	207	28
AUG	1977	28.3	32.4	4.4	16	-	-	-	*	159	228	406	*
	1978	25.4	31.9	5.5	13	4,776	2,425	8	12	22	69	91	12
	1979	25.6	31.2	5.6	12	7,986	5,066	8	-	50	311	361	22
	1980	27.9	34.0	6.1	16	4,215	4,558	3	7	97	98	195	21
SEP	1977	25.0	29.9	4.9	17	-	-	-	*	-80	171	91	*
	1978	26.3	31.8	5.5	15	5,784	4,827	13	14	410	154	564	91
	1979	24.2	30.2	6.0	13	2,818	2,370	9	13	87	103	190	10
	1980	27.5	33.4	5.9	17	6,958	6,741	27	26	593	162	755	88

- = No data available
* = Data not available in comparable format
PSI = Plant Site Intake Station
PSD = Plant Site Discharge Station
(1) $\bar{x}$ Extracted chlorophyll *a* of 6 samples over 24-h
(2) $\bar{x}$ Fluorometric chlorophyll of 48 samples over 24-h
a = First entrainment study
b = Second entrainment study

limit of 6.7°C. The 1977 studies did not characterize the phytoplankton community by specific cell count analyses; biomass was estimated by *in vivo* fluorescence extrapolated to chl a using reference values of extracted chlorophyll. Productivity was measured using oxygen evolution methods, yielding estimates of net photosynthesis, respiration and, by addition, gross photosynthesis (Appendix A), and using ^{14}C methodology, estimates of carbon fixation (Appendix B). Carbon fixation rates were expressed in relative terms of counts per minute (cpm) and not standardized to mg C m^{-3} h^{-1}. The ^{14}C data are therefore not comparable to ^{14}C values cited for the 1978, 1979 and 1980 studies.

June 1977

Average rate of net photosynthesis by ambient phytoplankton populations, as measured at Station PSI, was -24 mg O_2 m^{-3} h^{-1}, indicating that light bottle respiration exceeded photosynthetic production, possibly a sign of metabolic stress even before condenser passage. Average respiration by dark bottle measurement was 70 mg O_2 m^{-3} h^{-1} (Table IV-A-1). The average ΔT was 3.9°C (Table IV-A-1).

Over the 24-h study, fluorometric chlorophyll was consistently lower at Station PSD, indicating a loss of biomass (Table IV-A-2). The paired t-test detected a significant reduction in net photosynthesis and significant increase in respiration at Station PSD (Table IV-A-3). Carbon fixation rates were similar at both stations.

July 1977

Average net photosynthesis in July was again negative, -19 mg O_2 m^{-3} h^{-1}, indicating oxygen demand in the pre-condenser samples at Station PSI was in excess of photosynthesis. Average respiration was 139 mg O_2 m^{-3} h^{-1}, twice the June average. The average ΔT over the day was 3.2°C; temperature of the effluent was 30.1°C (Table IV-A-1).

None of the parameters, including ^{14}C measurements, showed significant differences between stations (Tables IV-A-2 and IV-A-3).

August 1977

Photosynthesis was in excess of respiratory demand: average net photosynthesis was 159 mg O_2 m^{-3} h^{-1} and respiration was 228 mg O_2 m^{-3} h^{-1}. The ΔT was higher, 4.4°C; average effluent temperature was 32.4°C (Table IV-A-1).

In this month, fluorometric chlorophyll was consistently lower at Station PSD (Table IV-A-2) and net photosynthesis was significantly reduced at that station ($p<0.005$) (Table IV-A-3). Lower measurable photosynthesis at Station PSD may have been a result of greater respiration at Station PSD, although the

Table IV-A-2. Significant intake-discharge differences in phytoplankton community structure and metabolic parameters measured during entrainment studies at Calvert Cliffs Nuclear Power Plant, 1977 through 1980. Cell count differences were indicated when the confidence intervals for the PSD/PSI ratios did not overlap 1.0. Net photosynthesis, respiration and fluorescence chlorophyll were analyzed with the paired t-test. Gross photosynthesis was tested using Hotellings T^2- statistic. The significance level $\alpha=0.05$ was used for all tests.

		TOTAL CELLS	UNDET. MICRO.	BACIL.	CRYPTO	PYRRO.	NON-THECATE PYRRO.	NET PHOTO.	RESP.	GROSS PHOTO.	^{14}C FIXATION	FLUOR. CHL.	NET/ FLUOR.	RESP./ FLUOR.	^{14}C/ FLUOR.
JUN	77	-	-	-	-	-	-	I>D	D>I	-	-	I>D	-	-	-
	78	D>I	ns	D>I	ns	ns	ns	I>D	ns	I>D	ns	*	*	*	*
	79	I>D	I>D	ns	I>D	I>D	ns	ns	ns	D>I	D>I	I>D	ns	ns	D>I
	80	ns	D>I	ns	D>I	I>D	I>D	ns	ns	ns	ns	*	*	*	*
JUL	77	-	-	-	-	-	-	ns	ns	-	-	-	-	-	-
	78	ns	ns	ns	I>D	ns	ns	I>D	ns	I>D	I>D	>	*	*	*
	79	I>D	I>D	I>D	I>D	I>D	I>D	I>D	ns	I>D	ns	I>D	I>D	ns	ns
	80a	ns	D>I	ns	ns	ns	I>D	-	-	-	-	-	-	-	-
	80b	ns	I>D	ns	ns	ns	D>I	I>D	D>I	I>D	D>I	*	*	*	*
AUG	77	-	-	-	-	-	-	I>D	ns	-	-	I>D	-	-	-
	78	ns	ns	ns	ns	ns	ns	I>D	ns	I>D	I>D	*	*	*	*
	79	I>D	I>D	ns	I>D	I>D	I>D	ns	ns	ns	ns	-	-	-	-
	80	D>I	D>I	ns	ns	I>D	I>D	I>D	ns	I>D	ns	*	*	*	*
SEP	77	-	-	-	-	-	-	ns	ns	-	-	-	-	-	-
	78	I>D	ns	ns	I>D	I>D	I>D	I>D	ns	*	I>D	*	*	*	*
	79	ns	ns	ns	ns	I>D	ns	ns	D>I	ns	D>I	ns	ns	D>I	D>I
	80	ns	I>D	ns	ns	ns	D>I	I>D	ns	I>D	I>D	*	*	*	*

I = Plant Site Intake
D = Plant Site Discharge
ns = Not significantly different
- = No data available
> = Assumptions of test violated
a = First entrainment study
b = Second entrainment study

Table IV-A-3. Mean differences (D) and p-values from paired t-tests of station differences (PSD/PSI) in phytoplankton metabolism** measured during entrainment studies at Calvert Cliffs Nuclear Power Plant, June through September, 1977-1980.

			NET PHOTO	RESP	GROSS PHOTO	C-14 FIXATION	FLOOD	NET FLOOD	RESP. FLOOD	C-14/ FLOOD
1977	JUN	D	-52.3	50.8						
		P	<0.05	<0.01						
	JUL	D	18.4	2.4						
		P	ns	ns						
	AUG	D	+205.6	38.8						
		P	<0.005	ns						
	SEP	D	16.3	-30.8						
		P	ns	ns						
1978	JUN	D	-134.6	44.3		1.3				
		P	<0.01	ns	0.002	ns				
	JUL	D	-41.3	-24.5		-17.8				
		P	<0.01	ns	0.048	<0.005				
	AUG	D	-74.0	20.4		-9.8				
		P	<0.005	ns	0.018	<0.005				
	SEP	D	-369.3	-83.8		-102.8				
		P	<0.01	ns	*	<0.005				
1979	JUN	D	143.5	-43.3		9.7	+2.4	15.7	-2.6	1.3
		P	ns	ns	0.016	<0.005	<0.005	ns	ns	<0.005
	JUL	D	+118.0	25.7		+1.6	-0.6	+21.2	9.6	0.02
		P	<0.05	ns	0.028	ns	<0.05	<0.05	ns	ns
	AUG	D	-12.3	-29.3		-2.0				
		P	ns	ns	ns	ns				
	SEP	D	-81.0	280.9		5.0	0.1	+10.4	40.8	0.7
		P	ns	<0.05	ns	<0.005	ns	ns	<0.05	<0.005
1980	JUN	D	-0.7	-70.0		-0.14				
		P	ns	ns	ns	ns				
	JUL	D	-181.8	124.1		10.3				
		P	<0.005	<0.05	0.007	<0.05				
	AUG	D	-145.6	66.8		+2.4				
		P	<0.005	ns	0.041	ns				
	SEP	D	+414.6	41.6		+36.1				
		P	<0.005	ns	0.009	<0.005				

*Assumptions of the test were violated.

**Gross photosynthesis, which is the sum of net photosynthesis and respiration, was tested using a multiva[illegible] test of net photosynthesis and respiration simultaneously. Hotelling's T² was use[illegible] at the paired difference between PSI and PSD for each month.

intake-to-discharge increases in respiration were not significant by the paired t-test (Table IV-A-3).

September 1977

Average net photosynthesis at Station PSI was again negative, -80 mg O_2 m^{-3} h^{-1}; average dark bottle respiration was 171 mg O_2 m^{-3} h^{-1}. The ΔT was 4.9°C; average temperature at the discharge was down to 29.9°C (Table IV-A-1).

The paired t-test indicated no significant station differences for net photosynthesis and respiration (Tables IV-A-2 and IV-A-3).

Because of differences in study designs, statistical comparisons of 1976 and 1977 results from Units 1 and 2 were not undertaken. Entrainment effects attributed to each unit were variable and contradictory within units (results indicating both stimulation and depression of processes), but similar overall in the small magnitude of the observed station differences. From this evidence and from the findings of other studies of entrainable organisms at CCNPP (see Section IV-B), it was assumed that the individual units did not differ substantially in their impact on phytoplankton.

1978 Studies

Detailed analysis of phytoplankton abundance and community structure was initiated in 1978 and continued through 1980 (Appendices C through F). In the following presentation of results, characterizations of phytoplankton cell densities and physiological parameters as "high" or "low" are in comparison to values commonly observed in summer entrainment (cf. Table IV-A-1) and annual nearfield phytoplankton studies.

June 1978

Cell densities were higher in June and July of 1978 than in all subsequent entrainment studies. Total cell densities were high ($\bar{x}$ [average] at Station PSI = 23,452 cells ml^{-1}) with considerable variation over the 24-h study period (Table IV-A-1). The phytoplankton community was composed mainly of diatoms ($\bar{x}$ at Station PSI = 40%, primarily centrics), undetermined microflagellates ($\bar{x}$ at Station PSI = 35%) and dinoflagellates ($\bar{x}$ at Station PSI = 16%, principally *Prorocentrum minimum* (Pavillard) Shiller) (Table IV-A-4). A total of 33 algal taxa were counted. Total cell densities increased during the diurnal portion of the 24-h study period, at which time productivity was being measured, then declined. The average fluorometric chlorophyll was very high ($\bar{x}$ at Station PSI = 29 mg fl chl m^{-3}). Average net photosynthesis at Station PSI was 289 mg O_2 m^{-3} h^{-1}. The average ^{14}C fixation rate was 105 mg C m^{-3} h^{-1}

Table IV-A-4. Phytoplankton community composition (%) for samples collected during entrainment studies at Calvert Cliffs Nuclear Power Plant, 1978 through 1980.

1978	Jun	Jul	Aug	Sep
Undetermined microflagellates	35	32	48	48
Bacillariophyta	40	38	12	33
Cryptophyta	5	21	13	5
Pyrrophyta	16	8	24	12

1979	Jun	Jul	Aug	Sep
Undetermined microflagellates	25	42	37	24
Bacillariophyta	12	19	17	31
Cryptophyta	58	15	25	26
Pyrrophyta	2	21	16	15

1980	Jun	Jul[a]	Jul[b]	Aug	Sep
Undetermined microflagellates	16	46	51	35	52
Cyanophyta	38	9	7	< 1	2
Bacillariophyta	14	5	8	14	15
Cryptophyta	24	12	17	21	15
Pyrrophyta	7	28	17	22	12

a=First entrainment study
b=Second entrainment study

and the average respiration rate was 110 mg O_2 m^{-3} h^{-1}. Average ΔT over the study was 5.3°C; average effluent temperature was 26.0°C (Table IV-A-1).

Phytoplankton cell densities were variable, but were generally greater at Station PSD than PSI. The PSD/PSI cell density ratios were estimated to be 1.17 for total cells and 1.23 for diatoms (Table IV-A-5). Gross and net photosynthetic rates contradicted the trend in cell densities with Station PSI>PSD (gross: $p=0.002$; net: $p<0.01$) (Tables IV-A-2 and IV-A-3). ^{14}Carbon fixation rates and respiration rates were not significantly different between stations (Table IV-A-3).

July 1978

Total cell densities were substantial ($\bar{x}$ at Station PSI = 15,832 cells ml^{-1}) and variable but generally increased, peaked and declined during the 24-h study period. Undetermined microflagellates, diatoms (mainly *Chaetoceros* spp.), and cryptophytes (mainly *Cryptomonas* spp.), were the major contributors to the phytoplankton community (Table IV-A-4). Undetermined microflagellates, composing 32% of the community, were more abundant in the first 12 h, then declined steadily; diatoms, composing 38% of the community, were more abundant in the second 12 h. Cryptophytes, composing 21%, followed a diel pattern similar to that of total cells. A total of 36 algal taxa were counted. Average net photosynthesis at Station PSI was 219 mg O_2 m^{-3} h^{-1}, the average ^{14}C fixation rate was 53 mg C $m^{-3}h^{-1}$, and the average respiration rate was 68 mg O_2 m^{-3} h^{-1}. The average ΔT was 5.3°C; the discharge temperature was 30.3°C (Table IV-A-1).

No consistent differences in cell densities were observable between Stations PSI and PSD in July with the exception of the cryptophytes for which cell densities were significantly ($p\leq0.05$) greater at Station PSI than PSD (Table IV-A-2); the PSD/PSI cell density ratio for cryptophytes was estimated to be 0.34 (Table IV-A-5). Average primary productivity rates were significantly lower at Station PSD than PSI as measured by oxygen generation (gross: $p<0.05$; net: $p<0.01$) and by ^{14}C fixation ($p<0.005$), but respiration rates were not significantly different between stations (Table IV-A-3).

August 1978

Total cell densities were low ($\bar{x}$ at Station PSI = 4,776 cells ml^{-1}). Cell densities generally increased in the first half of the 24-h study period, peaked, declined then increased again. Undetermined microflagellates were the major contributors, composing 48% of the phytoplankton community (Table IV-A-4). Cell densities of cryptophytes (13%) and diatoms (12%) were low throughout the 24-h study period while dinoflagellate cell densities (24%) were low in the first half of the study but increased sharply in the second half. A total of

Table IV-A-5. Estimates and confidence intervals of phytoplankton cell density ratios (PSD/PSI) for each entrainment study at Calvert Cliffs Nuclear Power Plant, June through September, 1977-1980.

		TOTAL CELLS	UNDETERMINED MICRO-FLAGELLATES	BACILLARIO-PHYTA	CRYPTOPHYTA	PYRROPHYTA	NON-THECATE PYRROPHYTA
1978	JUN	1.17 (1.00-1.35)	1.15 (0.96-1.33)	1.23 (1.05-1.42)	1.18 (0.92-1.44)	1.16 (0.84-1.47)	1.01 (0.43-1.59)
	JUL	0.55 (0.29-1.01)	1.01 (0.91-1.11)	0.96 (0.87-1.06)	0.84 (0.73-0.95)	0.92 (0.82-1.02)	0.88 (0.77-1.00)
	AUG	0.96 (0.85-1.07)	0.94 (0.81-1.05)	1.01 (0.85-1.17)	1.01 (0.77-1.26)	0.69 (0.78-1.91)	0.91 (0.72-1.11)
	SEP	0.89 (0.82-0.97)	0.91 (0.77-1.05)	0.97 (0.85-1.09)	0.75 (0.61-0.88)	0.74 (0.63-0.85)	0.62 (0.49-0.75)
1979	JUN	0.84 (0.71-0.98)	0.72 (0.61-0.83)	1.20 (0.93-1.46)	0.83 (0.69-0.96)	0.67 (0.42-0.92)	0.63 (0.35-1.00)
	JUL	0.69 (0.61-0.77)	0.70 (0.59-0.81)	0.65 (0.56-0.74)	0.61 (0.49-0.74)	0.76 (0.65-0.86)	0.61 (0.49-0.73)
	AUG	0.67 (0.60-0.73)	0.58 (0.51-0.65)	0.92 (0.75-1.08)	0.57 (0.49-0.65)	0.71 (0.64-0.78)	0.69 (0.61-0.78)
	SEP	0.95 (0.85-1.06)	0.95 (0.84-1.06)	1.13 (0.96-1.29)	0.80 (0.71-1.02)	0.77 (0.56-0.97)	0.79 (0.56-1.02)
1980	JUN	0.99 (0.89-1.09)	1.36 (1.08-1.64)	0.54 (0.20-1.03)	1.20 (1.01-1.40)	0.82 (0.67-0.97)	0.86 (0.66-0.94)
	JUL.[1]	0.95 (0.90-1.06)	0.87 (0.78-0.97)	1.19 (0.63-1.74)	1.13 (0.92-1.33)	1.05 (0.92-1.17)	1.22 (1.02-1.42)
	JUL.[2]	1.06 (0.96-1.17)	1.19 (1.04-1.34)	0.96 (0.80-1.13)	0.85 (0.67-1.02)	0.92 (0.77-1.08)	0.66 (0.54-0.77)
	AUG	1.13 (1.04-1.21)	1.45 (1.28-1.61)	1.24 (0.98-1.49)	0.88 (0.75-1.01)	0.80 (0.66-0.93)	0.83 (0.70-0.96)
	SEP	1.01 (0.97-1.65)	0.94 (0.89-0.99)	1.07 (0.97-1.17)	1.07 (0.94-1.20)	1.05 (0.93-1.17)	1.21 (1.02-1.40)

1. First July study.
2. Second July study.

43 algal taxa were counted. Average fluorometric chlorophyll at Station PSI was 12 mg chl m^{-3}. The average daily productivity rates at Station PSI were low. Net photosynthetic rates were 22 mg O_2 m^{-3} h^{-1}. The average ^{14}C fixation rate was 12 mg C m^{-3} h^{-1}, and average respiration was 69 mg O_2 m^{-3} h^{-1}. The average ΔT was 5.5°C; the discharge temperature was 31.9°C (Table IV-A-1).

No consistent station differences were observable in total cell densities or in any major phytoplankton group or in respiration (Table IV-A-2). However, primary productivity rates were significantly lower at Station PSD than Station PSI as measured by oxygen generation (gross: $p<0.02$; net: $p<0.005$) and by ^{14}C fixation ($p<0.005$) (Table IV-A-3).

September 1978

Total cell densities were moderately low ($\bar{x}$ at Station PSI = 5,784 cells ml^{-1}). Cell densities were very low in the first few hours of the 24-h study period but increased sharply and were variable thereafter. Undetermined microflagellates and diatoms were the major contributors to the phytoplankton community, composing 48% and 33%, respectively (Table IV-A-4). A total of 36 algal taxa were counted. The average fluorometric chlorophyll at PSI was 14 mg fl chl m^{-3}. Average net photosynthesis at Station PSI was 410 mg O_2 m^{-3} h^{-1}. The average ^{14}C fixation rate was 91 mg C m^{-3} h^{-1}, and the average respiration was 154 mg O_2 m^{-3} h^{-1}. The average ΔT was again 5.5°C; the discharge temperature was 31.8°C (Table IV-A-1).

Cell densities of total cells, cryptophytes, total dinoflagellates and non-thecate dinoflagellates were significantly ($p\leq0.05$) greater at Station PSI than PSD over the 24-h period (Table IV-A-2). The PSD/PSI cell density ratios were estimated to be 0.89 for total cells, 0.75 for cryptophytes, 0.74 for total dinoflagellates and 0.62 for non-thecate dinoflagellates (Table IV-A-5). Photosynthetic rates were significantly lower at Station PSD than PSI as measured by oxygen generation (gross: see Appendix A; net: $p<0.01$) and by ^{14}C fixation ($p<0.005$), but respiration rates were not significantly different between stations (Table IV-A-3).

1979 Studies

In this year, maximum ΔT was raised from 5.5 to 6.7°C.

June 1979

Total cell densities were moderately low ($\bar{x}$ at Station PSI = 5,760 cells ml^{-1}). Cell densities were variable but were generally higher at the beginning and end of the 24-h study period. Cryptophytes, composing 58% of the phytoplankton community, were the major contributors followed by undetermined

microflagellates (25%) and diatoms (12%) (Table IV-A-4). A total of 32 algal taxa were counted. Fluorescence chlorophyll measurements were also variable but generally followed a pattern similar to that of total cell densities; average fluorescence chlorophyll at Station PSI was 5 mg fl chl m^{-3}. The productivity rates at Station PSI were low, sometimes falling below respiratory demand: average net photosynthesis was 20 mg O_2 m^{-3} h^{-1}, ^{14}C fixation was 7 mg C m^{-3} h^{-1}, and respiration was 79 mg O_2 m^{-3} h^{-1}. The average ΔT was 5.8°C; average temperature at Station PSD was 26.2°C (Table IV-A-1).

Cell densities of total cells, microflagellates, cryptophytes and dinoflagellates were significantly ($p \leq 0.05$) greater at Station PSI than PSD (Table IV-A-2). The PSD/PSI cell density ratios were estimated to be 0.84 for total cells, 0.72 for microflagellates, 0.83 for cryptophytes and 0.67 for dinoflagellates (Table IV-A-5). Fluorescence chlorophyll was greater at Station PSI than PSD ($p < 0.005$) (Table IV-A-3). Rates of net photosynthesis and respiration showed no significant station differences individually, but the increase in gross photosynthesis at Station PSD was significant ($p < 0.02$). ^{14}Carbon fixation was also greater at Station PSD than PSI ($p < 0.005$) (Table IV-A-3). Productivity, by both methods of measurement, appeared to be stimulated at Station PSD.

July 1979

Numbers of total cells were low ($\bar{x}$ at Station PSI = 3,796 cells ml^{-1}). Cell densities increased from very low levels but were variable over the day. Undetermined microflagellates were the major contributors, composing 42% of the phytoplankton community, and strongly influenced the diel pattern of total cell densities. Dinoflagellates composed 21%, diatoms 19% and cryptophytes 15% of the total phytoplankton community (Table IV-A-4). A total of 36 algal taxa were counted. Fluorescence chlorophyll ($\bar{x}$ at Station PSI = 7 mg fl chl m^{-3}) was variable and did not follow the diel pattern of total cells. The average daily productivity rates at Station PSI were 108 mg O_2 m^{-3} h^{-1} (net photosynthesis) and 18 mg C m^{-3} h^{-1} (^{14}C fixation), with the average daily respiration at 62 mg O_2 m^{-3} h^{-1}. The ΔT was 5.6°C and the discharge temperature was 27.8°C, atypically low for July (Table IV-A-1).

Total cell densities and cell densities of all major phytoplankton groups were significantly ($p \leq 0.05$) higher at Station PSI than PSD (Table IV-A-2). The PSD/PSI cell density ratios were estimated to be 0.69 for total cells, 0.70 for undetermined microflagellates, 0.65 for diatoms, 0.61 for cryptophytes, 0.76 for dinoflagellates and 0.61 for non-thecate dinoflagellates (Table IV-A-5). Fluorescence chlorophyll, gross and net photosynthesis were greater at Station PSI than PSD ($p < 0.05$, $p < 0.03$ and $p < 0.05$, respectively), but no significant station differences were demonstrated in respiration or ^{14}C fixation rates (Tables IV-A-2 and IV-A-3).

August 1979

Total cell densities were moderate but highly variable ($\bar{x}$ at Station PSI = 7,986 cells ml^{-1}). Densities declined to low levels over the first few hours but generally increased for the remainder of the 24-h study period. Undetermined microflagellates were the major contributors to the phytoplankton community, composing 37%, followed by cryptophytes (25%), diatoms (17%) and dinoflagellates (16%) (Table IV-A-4). A total of 37 algal taxa were counted. Productivity rates at Station PSI were low and variable: respiratory demand exceeded net photosynthesis for the first half of the productivity study. The average rate of net photosynthesis was 50 mg O_2 m^{-3} h^{-1}; average respiration was 311 mg O_2 m^{-3} h^{-1}. ^{14}Carbon fixation began low, but increased over the day; the average rate for the day was 22 mg O_2 m^{-3} h^{-1}. The ΔT during the study averaged 5.6°C and temperatures at the discharge averaged 31.2°C (Table IV-A-1).

Total cell densities and cell densities of undetermined microflagellates, cryptophytes, total dinoflagellates and non-thecate dinoflagellates were significantly ($p \leq 0.05$) greater at Station PSI than PSD (Table IV-A-2). The PSD/PSI cell density ratios were estimated to be 0.67 for total cells, 0.58 for undetermined microflagellates, 0.57 for cryptophytes, 0.71 for total dinoflagellates, and 0.69 for non-thecate dinoflagellates (Table IV-A-5). No significant station differences were observed in gross or net photosynthesis, ^{14}C fixation or respiration (Table IV-A-2 and IV-A-3).

September 1979

Total cell densities were low ($\bar{x}$ at Station PSI = 2,818 cells ml^{-1}). Cell densities increased over the 24-h study period, peaked and declined. The phytoplankton community was not dominated by any particular group. A total of 37 algal taxa were counted. Fluorescence chlorophyll ($\bar{x}$ at Station PSI = 13 mg fl chl m^{-3}) was variable but followed the same diel pattern as did total cell densities. Average productivity rates at Station PSI were 87 mg O_2 m^{-3} h^{-1} (net photosynthesis) and 10 mg C m^{-3} h^{-1} (^{14}C fixation); respiration at PSI averaged 103 mg O_2 m^{-3} h^{-1}. The average ΔT was 6.0°C, one of the highest in the study series; discharge temperature was 30.2°C (Table IV-A-1).

No consistent station differences were observable in total cell densities or cell densities of major phytoplankton groups except for dinoflagellates, which were significantly ($p \leq 0.05$) greater at Station PSI (Table IV-A-2); the PSD/PSI cell density ratio for dinoflagellates was 0.77 (Table IV-A-5). Fluorescence chlorophyll, gross and net photosynthesis demonstrated no significant station differences, but respiration and ^{14}C fixation rates were greater at Station PSD than PSI ($p < 0.05$ and $p < 0.005$, respectively), indicating stimulation (Tables IV-A-2 and IV-A-3).

1980 Studies

June 1980

Inclement weather caused cancellation of this study after 7 h. Total cells were moderately low ($\bar{x}$ at Station PSI = 4,210 cells ml^{-1}). In general, cell densities increased over the sampling period. Cyanophyta (blue-green algae), almost exclusively *Schizothrix calcicola* (Agardh) Gomont, was the major contributor to the phytoplankton community (38%) followed by cryptophytes (24%). A total of only 18 algal taxa were counted. Fluorescence chlorophyll ($\bar{x}$ at Station PSI = 8 mg fl chl m^{-3}) (Table IV-A-1) generally followed the same pattern as did total cell densities. Average net photosynthesis at Station PSI was -27 mg O_2 m^{-3} h^{-1} (photosynthesis was again below respiratory demand) and ^{14}C fixation was 19 mg C m^{-3} h^{-1}; respiration was 153 mg O_2 m^{-3} h^{-1}. The average ΔT over the 7-h period was 5.6°C. The average discharge temperature was 25.3°C (Table IV-A-1).

Cell densities demonstrated inconsistent station differences. Undetermined microflagellates and cryptophytes were greater at Station PSD than PSI (Table IV-A-2); PSD/PSI cell density ratio estimates for these taxa were 1.36 and 1.20, respectively (Table IV-A-5). Total dinoflagellates and non-thecate dinoflagellates were greater at Station PSI than PSD; their PSD/PSI cell density ratios were 0.82 and 0.80, respectively. Average gross and net photosynthesis, respiration and ^{14}C fixation rates demonstrated no significant station differences (Tables IV-A-2 and IV-A-3).

July 1980 (First Study)

Only samples for cell count analysis were collected during the first July entrainment study. Total cell densities were very low ($\bar{x}$ at Station PSI = 2,207 cells ml^{-1}). Although results were variable, cell densities generally declined in the early hours of the study but increased rapidly, peaked and were variable thereafter. Undetermined microflagellates (46%) and dinoflagellates (28%) were the major contributors to the phytoplankton community (Table IV-A-4) and strongly influenced the diel pattern of total cell densities. A total of 34 algal taxa were counted. The average ΔT over the 24-h was 5.7°C. The average temperature at the discharge was 29.4°C (Table IV-A-1).

Cell densities demonstrated inconsistent station differences. Densities of undetermined microflagellates were greater at Station PSI than PSD; PSD/PSI cell density ratio estimate for microflagellates was 0.87. Densities of non-thecate dinoflagellates were greater at Station PSD than PSI; their estimated PSD/PSI cell density ratio was 1.22 (Tables IV-A-2 and IV-A-5).

July 1980 (Second Study)

Total cell densities were low during the second July entrainment study ($\bar{x}$ at Station PSI = 3,067 cells ml^{-1}) and densities of total cells and all major phytoplankton groups varied bimodally over the 24 h. Undetermined microflagellates dominated the phytoplankton community (51%) (Table IV-A-4) although a total of 25 algal taxa were counted. Fluorescence chlorophyll ($\bar{x}$ at Station PSI = 5 mg fl chl m^{-3}) followed the same diel pattern as did total cell densities. The average net productivity at Station PSI was 154 mg O_2 m^{-3} h^{-1}; the average ^{14}C fixation rate was 28 mg C m^{-3} h^{-1}, while average respiration was 53 mg O_2 m^{-3} h^{-1}. The average ΔT during the study was 5.8°C, slightly higher than the previous day. The discharge temperature was also slightly higher, 30.3°C (Table IV-A-1).

Cell densities demonstrated inconsistent station differences. Cell densities of undetermined microflagellates were greater ($p \leq 0.05$) at Station PSD than PSI (Table IV-A-2), while non-thecate dinoflagellates were greater ($p \leq 0.05$) at Station PSI than PSD. The PSD/PSI cell density ratio estimates for undetermined microflagellates and for non-thecate dinoflagellates were 1.19 and 0.66, respectively (Table IV-A-5). Productivity indications were contradictory. Gross and net photosynthesis were greater at Station PSI than PSD ($p < 0.005$ and $p = 0.007$, respectively) indicating depression, while ^{14}C fixation and respiration were greater at Station PSD than PSI ($p < 0.05$ and $p < 0.05$, respectively) indicating stimulation (Tables IV-A-2 and IV-A-3).

August 1980

Total cell densities were moderately low ($\bar{x}$ at Station PSI = 4,215 cells ml^{-1}). Cell densities were variable among phytoplankton groups but generally increased rapidly, peaked and then declined. Undetermined microflagellates (35%) were the major contributors to the phytoplankton community. Dinoflagellates composed 22%, cryptophytes 21% and diatoms 14% of the total phytoplankton abundance (Table IV-A-4). A total of 26 algal taxa were counted. Fluorescence chlorophyll ($\bar{x}$ at Station PSI = 7 mg fl chl m^{-3}) followed a similar diel pattern to total cell densities. Average net photosynthesis at Station PSI was 97 mg O_2 m^{-3} h^{-1}; ^{14}C fixation was 21 mg C m^{-3} h^{-1}, and respiration 98 mg O_2 m^{-3} h^{-1}. Thermal conditions on this date were the most extreme of any during this series of studies. The ΔT was 6.1°C; average discharge temperature was 34.0°C (Table IV-A-1).

Cell densities demonstrated inconsistent station differences. Total cell densities and microflagellate densities were greater ($p \leq 0.05$) at Station PSD than PSI, but cell densities of total dinoflagellates and non-thecate dinoflagellates were greater ($p \leq 0.05$) at Station PSI than PSD (Table IV-A-2). The PSD/PSI cell density ratio estimates were 1.13 for total cells, 1.45 for microflagellates, 0.80 for total dinoflagellates and

0.83 for non-thecate dinoflagellates (Table IV-A-5). Gross and net photosynthesis were significantly greater at Station PSI than PSD ($p=0.041$ and $p<0.005$, respectively) while ^{14}C fixation and respiration rates demonstrated no significant station differences (Tables IV-A-2 and IV-A-3).

September 1980

Total cell densities were moderate ($\bar{x}$ at Station PSI = 6,958 cells ml^{-1}). Undetermined microflagellates were the major contributors to the phytoplankton community (52%) while cryptophytes (15%), diatoms (15%) and dinoflagellates (12%) contributed about equally (Table IV-A-4). A total of 43 algal taxa were counted. Cell densities were variable among phytoplankton groups but generally increased, peaked and declined over the study period. Fluorescence chlorophyll ($\bar{x}$ at Station PSI = 26 mg fl chl m^{-3}) was variable but generally followed the same diel cycle as cell densities. Average daily net photosynthesis at Station PSI was very high, 593 mg O_2 m^{-3} h^{-1}; ^{14}C fixation was 88 mg C m^{-3} h^{-1}, and respiration was 162 mg O_2 m^{-3} h^{-1}. Thermal conditions on this date were the second most extreme recorded over the five years of entrainment studies. Average ΔT was 5.9°C; average discharge temperature was 33.4°C (Table IV-A-1).

Cell densities of undetermined microflagellates were greater ($p\leq0.05$) at Station PSI than PSD (cell density ratio estimate = 0.94), and non-thecate dinoflagellate cell densities were greater ($p\leq0.05$) at Station PSD than PSI (cell density ratio estimate = 1.21) (Tables IV-A-2 and IV-A-5). Gross and net photosynthesis and ^{14}C fixation were significantly greater at Station PSI than PSD ($p<0.008$, $p<0.005$ and $p<0.005$, respectively), indicating significant depression. Respiration showed no significant station difference (Tables IV-A-2 and IV-A-3).

Discussion

Cell density data from 1978 phytoplankton entrainments indicate little if any significant reduction in cell densities. A change in the ΔT to 6.7°C was approved for 1979, but the maximum ΔT was never observed during the 1979 entrainment studies. Cell densities of most major phytoplankton groups were probably reduced by passage through the plant during the 1979 entrainment studies. The 1980 summer season provided a good opportunity to duplicate 1979 results; ambient air and water temperatures were high, ΔT's were high and weather conditions were good. But, 1980 entrainment results did not demonstrate consistent reduction in cell densities as seen in 1979. Entrainment results were highly variable; as many gains as losses in cell densities occurred during 1980 entrainment studies. On those occasions when reductions in cell densities were observed in 1978, before the increase in the ΔT, and in 1979 and 1980, the phytoplankton groups whose cell densities

were reduced by entrainment were the most delicate flagellated forms, including undetermined microflagellates, cryptophytes and dinoflagellates. However, studies of nearfield phytoplankton abundance and distribution in the vicinity of CCNPP have not detected significant depletions or other alterations of the community attributable to the plant (ANSP, 1979b; 1980b).

It is theoretically impossible for phytoplankton cell densities to increase significantly by reproduction during the 4-min passage from Station PSI to PSD. Therefore, the variable results (gains as well as losses) lead to the suggestion that consistently representative sampling of phytoplankton communities may not have been achieved. The Martin Marietta Corporation (MMC) investigated several possible sources of sampling error at CCNPP (MMC, 1980), including differences among sampling ports at intake. The MMC results showed considerable variation among intake sampling locations, but variation was random and individual stations were not significantly different from one another. Phytoplankton are horizontally patchy and also stratify vertically in the water column as a result of complex biological and hydrological factors. The only available sampling ports at Station PSI are behind the traveling screens before the circulating pumps. Sampling at a single port only permits the collection of a limited portion of intake water despite attempts to obtain a thoroughly-mixed representative sample, i.e., drawing and mixing water from three depths and compositing samples over time. Samples from Station PSD are more representative of water passing through the plant because they are thoroughly mixed from more than one intake port. Therefore, variable station-to-station results are to be expected in phytoplankton data. Salinity differences between Station PSI and PSD noted in this study also support the suggestion of nonrepresentative sampling at Station PSI.

Cross-condenser passage and other trauma of entrainment at CCNPP affect phytoplankton productivity inconsistently as measured in these studies. Between-station differences in net photosynthesis, respiration and carbon uptake vary in size and direction when individual sample pairs are examined. There are also some uninterpretable results. For example, methods which should measure approximately parallel processes (oxygen evolution and carbon uptake) sometimes contradicted one another (as they did in July 1980).

The simplified symbolic language for the statistical results (Table IV-A-2), however, reveals fairly consistent, if not predictable, trends which can be interpreted as effects of entrainment. Net photosynthesis and gross photosynthesis (as derived from measurements of net photosynthesis and respiration) at the discharge were typically depressed or, at times, similar to intake values, but rarely significantly stimulated. It does not seem that reduced photosynthesis can be attributed to increased respiration, for respiration was not typically

stimulated at the discharge. The photosynthetic processes appear to be affected. When net photosynthesis was significantly depressed, the difference appeared to be relatively large: the reductions across stations ranged from ~40% to greater than 100% of the mean daily pre-entrainment rates at Station PSI (cf. mean difference in Table IV-A-3 and mean net photosynthesis in Table IV-A-1). Depression of photosynthesis was not detectable at all times. Differences between stations were not significant when ambient rates of net photosynthesis (i.e., Station PSI values) were low or lower than respiratory demand (negative net values).

Negative values for mean net photosynthesis for the day (respiration in excess of photosynthesis) occurred at Station PSI in June 1976, June, July and September 1977, and June 1980 (Table IV-A-1). At other times, instances of "negative" photosynthesis were common in months when average photosynthetic rates were low (Appendix A). A possible explanation for these negative net photosynthetic rates may be excessive respiratory demand by all aerobic organisms in the sample bottles, not only the phytoplankton. The contribution to respiration from other sources was not directly investigated in these studies. However, zooplankton and phytoplankton samples were collected simultaneously over all years of these studies (see Section IV-B). Zooplankton densities and mortality were examined for associations with variations in respiration. No correlation was evident, indicating the numbers of zooplankton could not account for enhanced oxygen consumption and negative net photosynthesis. For example, zooplankton densities in June 1980 were atypically low (~7,000/m^3 at PSI) with relatively high pre- and post-condenser mortality. Mean respiration at PSI on that date was 153 mg O_2 m^{-3} h^{-1}. In contrast, in September 1980, phytoplankton cell densities were somewhat higher and zooplankton densities were 134,000/m^3, among the highest recorded in the series of studies. Zooplankton mortality was low. Mean dark bottle respiration at PSI in September 1980 was similar to respiration in June, 162 mg O_2 m^{-3} h^{-1}. Other possible factors causing oxygen decreases in the light bottles resulting in "negative" net photosynthesis have not been identified.

Significant depression of ^{14}C fixation occurred on four study dates, paralleling significant depression of net photosynthesis: July, August and September 1978 and September 1980 (Table IV-A-2). There were insufficient data to explain why depression of ^{14}C uptake was observed on these dates and not on other dates when photosynthesis as indicated by oxygen evolution appeared to be depressed. These four dates have in common a mean discharge temperature greater than 30°C and ΔT greater than 5.5°C. Other study dates qualifying for depressed ^{14}C fixation by those standards were: July 1980, August 1979 and 1980 and September 1979. Two of those dates (September 1979 and July 1980) were two of three observations of significant increases in ^{14}C fixation. The results for September 1979 may

be questionable, however, and no significant differences were indicated in August 1979 or 1980. August 1980 is particularly interesting in its result, for the mean ΔT during those sample collections (6.1°C; Table IV-A-1) was the highest recorded for the entire series of studies, from 1976 through 1980, and is the measured ΔT closest to the limit of 6.7°C.

^{14}Carbon fixation was significantly greater (stimulated) at the discharge a total of three times out of the 16 (Table IV-A-2), in June and September 1979 and July 1980. The July 1980 observation is problematic because significant net photosynthetic depression and increased respiration were indicated by the oxygen method. Otherwise, it may be the only reliable demonstration of stimulation of ^{14}C fixation following entrainment. The ^{14}C results from June 1979 may be an artifact of very low, variable rates of carbon uptake overall (mean ^{14}C fixation at Station PSI was 7 mg C m^{-3} h^{-1}; Table IV-A-1). The results for September 1979 may also be questionable. Carbon-uptake values at Station PSI (10 mg C m^{-3} h^{-1}) were low compared to production estimates by the oxygen methods (~35 mg C m^{-3} h^{-1}) for unknown reasons and correspondence of the two methods was variable over all sampling periods of the day. Estimates of carbon uptake (mg C m^{-3} h^{-1}) by ^{14}C and oxygen-evolution methods corresponded least well in September 1979: $C_{oxy}/^{14}C$ varied from 1.1 to 7.0 for all positive net photosynthesis/^{14}C fixation comparisons. Ratios of 1.4 to 2.2 were the average ratios for 1978 through 1980 carbon uptake estimates by the two methods indicating that, in general, O_2-flux and ^{14}C fixation were directly related and gave similar estimates of photosynthetic activity.

Respiratory rates, in general, were relatively high during the entrainment studies, but that was not unexpected for warm sampling months. Respiration may increase as a response to unspecified stress and/or to metabolic rate changes stimulated by increases in temperature, but in these studies plant-induced increases in respiration were usually small (not statistically significant). Significant stimulation of respiration was observed once in 1976 and only three times during the 1977 through 1980 series of entrainment studies: in June 1977, September 1979 and July 1980. The particular conditions supporting significant stimulation of respiration at Station PSD on those dates are not completely understood. On the latter two dates significant respiratory increases were accompanied by significant increases in ^{14}C fixation indicating stimulation of all metabolic processes.

The thermal environment and the entrainment experience in themselves do not appear to fully account for the effects observed; factors exacerbating or ameliorating the effects of heat on phytoplankton productivity were not detected by the entrainment studies. In any case, these studies probably represent maximum estimates of entrainment effects resulting from the heated discharge. Since productivity samples at

Station PSD were incubated for several hours in a water bath of circulating plume water, the study conditions of the sample phytoplankton populations were different from those experienced by natural populations. Typically, the heated discharge water mixes rapidly with unentrained Bay water such that a 2°C elevation is not detectable beyond a short distance from the discharge conduits. Entrained phytoplankton endure maximum temperature elevation for 4 min during plant passage, then within minutes resume existence in a thermal environment approximating pre-entrainment conditions. Studies by other investigators (Ecological Analysts, Inc., 1980; K. G. Sellner, ANSP, personal communication) have indicated that recovery to pre-entrainment productivity levels may be rapid and complete.

ANSP nearfield phytoplankton monitoring studies of productivity in the vicinity of CCNPP from 1974 through 1980 (ANSP, 1979b, 1980b, 1981) have not detected significant reductions in productivity at stations near the plant. Samples for nearfield studies were routinely collected within 24- to 48-h after the entrainment studies and nearfield values should generally reflect productivity of a similar phytoplankton community under similar environmental and plant operating conditions as those reflected by the entrainment results. Following the increase in maximum ΔT, productivity at stations near the plant was not significantly different from other nearfield stations, in agreement with earlier studies. There was no evidence of depression of photosynthetic activity at near-plant stations in 1980 but photosynthetic efficiency appeared to be slightly stimulated at those stations. This suggests that short-lived stimulation may follow the immediate depression of photosynthetic processes or that the diluted thermal plume may cause stimulation at stations closest to the plant. In any case, significant alteration of productivity has not been observed within the areas monitored by these studies.

Summary and Conclusions

Phytoplankton entrainment studies conducted from 1978 through 1980 included detailed abundance and community structure analyses. Fluorescence chlorophyll and cell densities followed similar patterns over the 24-h studies. Although the data were variable, 4 studies out of 13 indicated a reduction in cell densities from Station PSI to PSD as a result of entrainment of phytoplankton communities. These were September 1978, and June, July and August 1979. July and September 1978 were also characterized by reduction in net photosynthesis from Station PSI to PSD. Significant detectable reduction of cell densities did not occur consistently and is presumably dependent upon a complex of biological and hydrological variables not fully understood. The four dates on which reduction occurred were not always accompanied by particularly high ambient water temperatures or ΔT's. Entrained phytoplankton communities at CCNPP are probably reduced at given points in time; however,

there is no evidence of significant alteration of phytoplankton abundance or community structure in the nearfield as indicated by the results of nearfield phytoplankton monitoring studies conducted monthly from 1974 through 1980.

Effects of entrainment on phytoplankton photosynthesis and respiratory processes appear to be related to high ambient temperature (>30°C) and to high ΔT (≥5.5°C), as expected, but the results of the productivity studies cannot be completely explained by these factors. Effects were manifested in intake-discharge differences in net photosynthesis and respiration measured by oxygen-evolution methods and by differences in carbon fixation using ^{14}C uptake measurements.

The effect on net photosynthesis (as measured by oxygen evolution) was typically a significant reduction at the discharge, unless overall photosynthetic production was at a low level or if conditions were such that respiratory processes exceeded production. Mean daily respiration was only rarely significantly increased at the discharge. Carbon fixation (measured by ^{14}C uptake, a method believed to be more sensitive and possibly more reliable than oxygen-evolution) was significantly depressed at the discharge on 4 out of 12 study dates; stimulation was indicated reliably only once. On the other dates, station differences were either not reliable or not significant.

The relatively small and inconsistent effects on ^{14}C fixation rates were in contrast to the relatively large effects implied by rate reductions observed for net photosynthesis, but no satisfactory explanation for this discrepancy can be formulated. When it occurs, post-entrainment depression of photosynthetic processes may be short-lived. ANSP studies of productivity in Chesapeake Bay near CCNPP have not indicated significant depression. In fact, photosynthetic processes may be stimulated at stations near the plant, although increases in total productivity and photosynthetic efficiency at nearfield locations have not been demonstrated to be significant. Depression resulting from entrainment may be followed by a period of compensatory stimulation or the depressive effect may be quickly diluted at near-plant locations by low-level stimulation from the thermal plume.

Variation in study results and the implied entrainment effects observed in 1979 and 1980 could not be reliably correlated with increases in the ΔT beyond the former 5.5°C limit. It should be noted, however, that these results reflect average operating conditions (i.e., ΔT's) somewhat below the present limit of 6.7°C.

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B. ZOOPLANKTON ENTRAINMENT

Introduction

Studies to assess the effects of entrainment on zooplankton assemblages have been carried out by the Academy of Natural Sciences of Philadelphia (ANSP) at Calvert Cliffs Nuclear Power Plant (CCNPP) from 1974-1980. The effects of entrainment on zooplankton survival have generally been associated with mechanical damage (such as abrasion and hydraulic stress forces) and thermal stress (Carpenter, Peck and Anderson, 1974; Ulanowicz, 1975; Morgan et al., 1976). Power plants located on estuarine waters usually use the biocide chlorine to control fouling of the cooling system conduits; however, under certain conditions chlorine has been demonstrated to have a detrimental effect on zooplankton (Davies and Jensen, 1975; Heinle, 1976). Biocides are not presently used at CCNPP. The existance and dimensions of entrainment-related effects upon zooplankton are specific to the power plant site, plant design and mode of plant operation.

Environmental conditions such as dissolved oxygen concentration, temperature and salinity can alter zooplankton species composition as well as sex ratio and age structure of a community. In addition, these parameters also directly influence the level of tolerance of organisms to the stresses imposed upon them by entrainment (Alden, Maturo, Ingram, 1976). Entrainment studies presented here were designed to assess zooplankton survival of entrainment through CCNPP and to identify any factors affecting survival.

From 1975 through 1978, organisms transiting the once-through cooling system at CCNPP were exposed to a maximum cross-condenser temperature increase of 5.5°C. Results of entrainment studies conducted during this period have been summarized (Olson and Sage, 1979a) and include an assessment of impact resulting from the 5.5°C temperature elevation (ΔT) of the cooling water. Detailed results of these studies as well as plant site description, cooling water system configuration and detailed study methodology may be found in the semi-annual and annual reports submitted to the Baltimore Gas and Electric Company (Sage, 1975; Sage, 1976a,b; Sage and Olson, 1977; Sage and Bacheler, 1978; Olson and Sage, 1979b; Newman, Sage, and D'Apolito, 1980).

In 1979 and 1980 an increase in the cross-condenser temperature elevation (ΔT) to a maximum of 6.7°C was tested on an experimental basis. The 1979-1980 studies reported here were designed at the request of the State of Maryland Water Resources Administration to determine whether any additional impact resulted from an increase in the ΔT from 5.5°C to 6.7°C.

Materials and Methods

Prior to 1977 samples were collected each month of the year. Beginning in 1977 a new study design using time-series collection and analytical techniques was implemented to reduce variation between sample sets. Studies were conducted monthly from June through September, when the greatest impact on zooplankton survival can be anticipated (Sage, 1975; Sage, 1976a,b).

Sampling Locations

Sampling stations (Fig. IV-B-1) were located at the intake between the protective trash racks and the circulating pump serving Unit 2 (IN) and at the submerged discharge terminus (DC), 260 m offshore. Collections at IN had previously consisted of samples from a single depth but beginning in 1977 three vertical depths, 1, 2 and 3 m from the bottom, were sampled every 30 min for a 24- or 48-h period in the approach conduit at the intake station. Samples from the three depths were composited, thereby integrating any vertical density gradients. The discharge sampling location (DC) was directly in the submerged plume as it flowed from the conduits serving Unit 2. Samples were collected from a boat anchored at the discharge terminus. The discharge water at this location is turbulent and well-mixed requiring that only a single depth (~5 m) be sampled at the center of the 4-m diameter conduit. Another sampling location was established at the tunnel access (TA) which is located approximately mid-way between the condenser and the sampling location at the discharge terminus (DC). Temperature at TA and DC were compared to check that discharge sample water was not contaminated by unentrained, unheated Bay waters.

Temperature, salinity and dissolved oxygen (DO) were measured at all stations at the time of sampling. Salinity was measured with a Beckman model RS5-3 salinometer and dissolved oxygen (DO) with a Yellow Springs Instrument model 57 DO meter. Water temperature was measured by a hand-held certified thermometer calibrated in tenths of degrees.

Sampling Methods

Samples were pumped from depth using a low-volume 30.3 l/min diaphragm pump; the total volume for each sample was 20 liters. Total elapsed time in collecting each sample was approximately 6 min. Collection at DC began 4 min after IN collection, corresponding to the assumed transit time through the cooling water system. In theory, therefore, the same parcel of water was sampled at both stations.

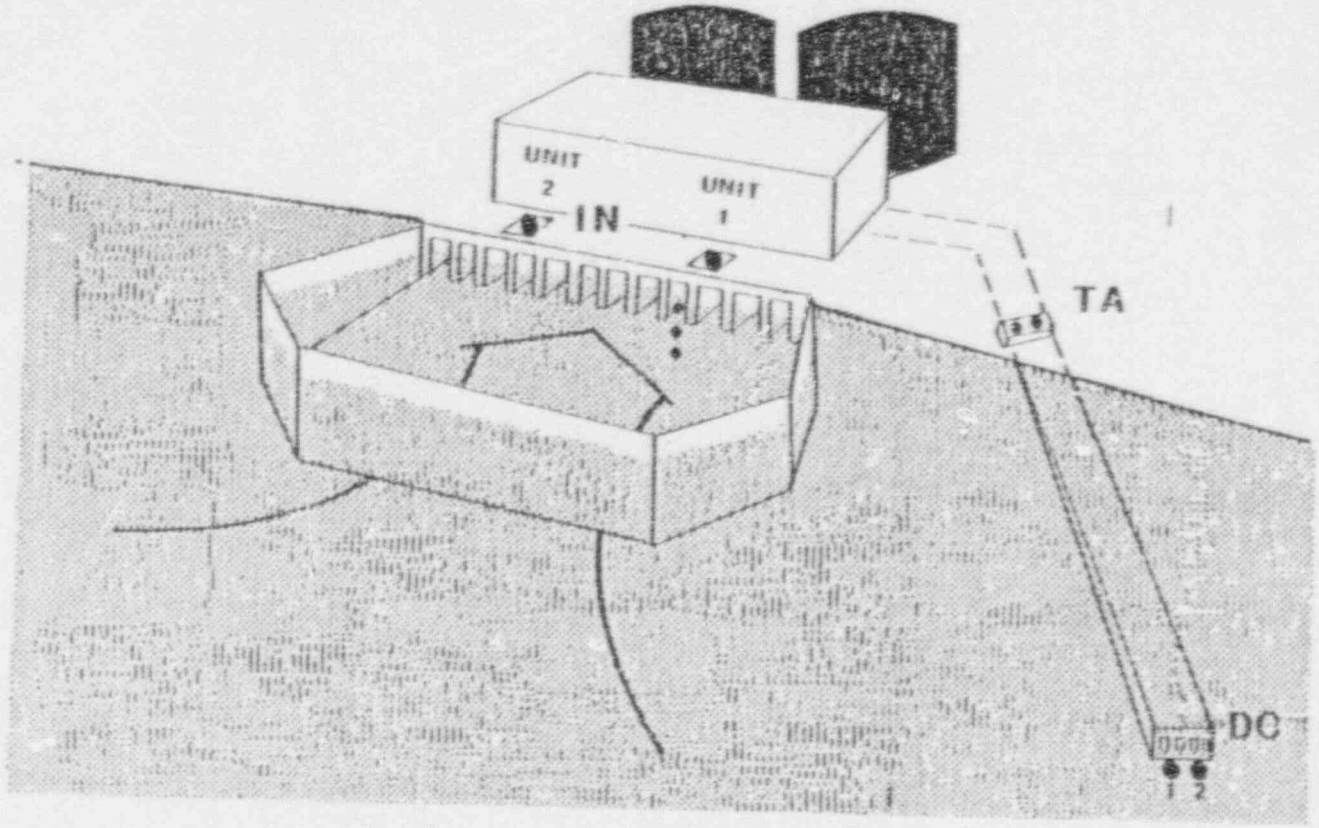


Figure IV-B-1. Schema of Calvert Cliffs Nuclear Power Plant on the Chesapeake Bay showing sampling locations for zooplankton entrainment studies, 1974-1980. IN = Intake (2 locations); TA = Tunnel Access, temperature reference station; DC = Discharge (2 locations).

After collection, neutral red vital dye (1:150,000) (Crippen and Perrier, 1974; Dressel, Heinle and Grote, 1972) was added to each sample, mixed thoroughly and the samples were incubated at least 1 h at ambient temperature in shade or darkness. Each sample was then concentrated to a final volume of 50 ml using a 73-µm mesh plankton net, acidified with 1 ml 5N acetic acid/5N sodium acetate, preserved with 5% unbuffered formalin and frozen. Color retention techniques were modified in August and September. Samples were preserved in a basic medium containing buffered formalin solution to reduce the solubility of the vital dye. However, 5N acetic acid was added to achieve the proper color just prior to analysis (Fleming and Coughlan, 1978). This method removed the need for freezing and improved handling of large numbers of samples.

Sample Analysis and Live/Dead Determination

In the laboratory, samples were thawed or acidified and an aliquot large enough to contain at least 200 organisms was withdrawn with a Hensen-Stempel pipette and transferred to a sorting wheel. Organisms were identified and counted by species and, where possible, by life stage (age class). Organisms were further designated as living or dead at the time of collection. Living dye-sensitive organisms metabolize vital dye and take on its color. Some organisms do not take up dye or do not take up dye within a practical incubation period and, therefore, vitality for those organisms cannot be consistently determined (Crippen and Perrier, 1974). In the Calvert Cliffs area, all life stages of calanoid copepods are sensitive to vital dye as are cirriped (barnacle) nauplii, annelids, flatworms and cladocerans (Crippen and Perrier, 1974).

Data Analysis

Zooplankton may be impacted in two ways when entrained through a cooling system. A decrease in total density due to physical damage sustained in transit (termed cropping) may occur and/or organisms may die when subjected to entrainment stress. The terms "% alive" and "% survival" are used in this report. "Percent alive" is defined as the percentage of the total number of organisms which are alive (dye-sensitive) in a sample. "Survival" is defined as a ratio of the number of living organisms per m^3 in a DC sample to the number of living organisms per m^3 in an IN sample, i.e., # Alive DC m^{-3}/# Alive IN m^{-3}. (The number of living organisms in discharge samples (DC) reflects plant cropping as well as mortality.) Expressed as a percent, this ratio becomes "% survival".

For the purposes of this summary, the data were analyzed using stepwise linear regression techniques (Draper and Smith, 1966). Two separate analyses were completed. In analysis I the dependent variable was the logit transformation of % sur-

vival (Cox, 1970), while independent variables were salinity, intake species densities, ambient water temperatures, and ΔT. Analysis II eliminated salinity as an independent variable, since in preliminary analyses salinity was found to be highly correlated with ambient water temperature and intake densities.

Results and Discussion

Composition and Abundance of Entrained Zooplankton

The zooplankton community as determined from the 1979-1980 entrainment samples was not unique but was common to the Bay (Heinle, 1969; Herman, Mihursky and McErlean, 1968; Olson and Sage, 1978). Community composition has been found to be stable from year to year and dominated by the calanoid copepod, *Acartia tonsa*, which is characterized by three life stages: nauplii, copepodites, and adults. *A. tonsa* nauplii account for large portions of the total zooplankton throughout most of the year.

In these studies zooplankton densities fluctuated through time with densities frequently greater at night. *A. tonsa* adults had pronounced night-time diel cycles, on occasion increasing as much as 300% in a 6-h period (Sage and Bacheler, 1978). Diel cycles may be attributed to vertical migration (Hutchinson, 1967; Bougis, 1976).

Entrainment Survival

Table IV-B-1 presents the mean total density for samples from IN and DC for each entrainment study during 1974-1980 and also indicates the % Alive at IN and DC, and % Survival.

The percent of zooplankton alive at IN was consistently high ranging from 86.6 to 99.8% with a median of 97.8%. Highest pre-entrainment mortality (~13.4%) as determined from intake samples occurred in July 1975. The percentage of living organisms was also high at DC ranging from 82.4 to 99.9% with a median of 96.2%. The greatest mortality resulting from entrainment stress occurred in August 1978 (~8%). Seasonal mortality patterns are not particularly obvious; the incidence of mortality, expected to be highest in the summer, appears to occur randomly (Table IV-B-1). The low mortality at DC relative to IN is not surprising in view of the relatively short exposure time (~4 min) and the elevation in water temperature, which in 1979-1980 was <6.7°C. Once-through cooling systems with longer exposure times and/or high elevations in water temperature (in addition to biocides) typically produce greater mortalities (Icanberry, 1974; Davies and Jensen, 1975).

Cropping (the reduction in zooplankton density from IN to DC) is the most striking effect observed. The depletion of

Table IV-B-1. Mean density (#/m^3), percent alive, mean number of living zooplankton/m^3 (excluding cirriped nauplii) in samples from intake (IN) and discharge (DC) or tunnel access (TA) stations and % surviving plant entrainment [(# alive m^{-3} at DC/# alive m^{-3} at IN) x 100] for each sampling period during zooplankton studies at Calvert Cliffs Nuclear Power Plant on the Chesapeake Bay, 1974-1980.

Date	Sta.	N/m^3	% Alive	# Alive	% Survival
10/74[4]	IN	44570	99.0	44124	94
	TA	42781	96.8	41410	
10/74[2]	IN	30580	97.9	29958	91
	TA	28026	97.5	27331	
11/74	IN	12310	99.6	12261	80
	TA	9879	98.7	9752	
1/75	IN	14078	99.6	14020	92
	DC	12946	99.4	12868	
2/75	No study				
3/75	IN	56595	98.7	55850	93
	DC	54486	94.9	51682	
4/75	IN	50716	95.4	48383	81
	DC	44170	88.7	39194	
5/75	IN	37616	96.8	36093	44
	DC	17520	90.2	15795	
6/75	IN	31387	99.3	31173	23
	DC	7539	93.6	7112	
7/75	IN	36466	86.6	31580	71
	DC	27084	82.4	22317	
8/75	IN	73855	88.3	65214	48
	DC	35093	89.2	31303	
9/75	IN	79550	93.5	72788	59
	DC	47240	91.1	43036	
10/75	IN	13400	87.9	11779	65
	DC	7998	95.1	7606	
11/75	IN	2383	76.4[1]	1820	92(100)
	DC	2608	63.9[1]	1667	
12/75	IN	6046	71.7[1]	4333	31(64)
	DC	1853	34.2[1]	1353	

Date	Sta.	N/m^3	% Alive	# Alive	% Survival
1/76	IN	9525	97.8	9320	78
	DC	7657	94.9	7270	
2/76	IN	6588	99.8	6576	96
	DC	6319	99.6	6294	
3/76	IN	24971	94.5	23704	93
	DC	22387	98.3	22001	
4/76	IN	10606	98.8	10390	42
	DC	4392	98.4	4320	
5/76	IN	1606	93.4	1500	100
	DC	1822	98.2	1789	
6/76	IN	2572	99.3	2553	100
	DC	2667	99.5	2655	
7/76	IN	3608	95.8	3458	100
	DC	6842	93.9	6428	
8/76	IN	96904	96.6	93652	12
	DC	11976	95.2	11396	
9/76	IN	62852	99.3	62442	30
	DC	19210	97.5	18723	
6/77[3]	IN	9549	98.5	9402	60
	DC	5679	99.2	5636	
6/77	IN	16020	98.9	15847	77
	DC	12348	99.3	12261	
8/77[3]	IN	44500	97.9	43561	48
	DC	21181	98.1	20782	
9/77[3]	IN	16928	99.1	16791	57
	DC	9662	98.6	9525	
6/78	IN	18966	96.4	18286	45
	DC	8829	93.6	8267	

Date	Sta.	N/m^3	% Alive	# Alive	% Survival
7/78[3]	IN	8869	99.0	8793	46
	DC	4135	97.9	4050	
7/78[2]	IN	30637	99.6	30522	44
	DC	13550	98.4	13333	
8/78[1]	IN	26867	92.3	24807	53
	DC	15552	84.3	13117	
8/78[2]	IN	47940	95.5	45773	34
	DC	17143	89.8	15389	
9/78	IN	35361	96.6	34155	36
	DC	12983	93.7	12168	
6/79	IN	24461	99.2	24263	93
	DC	22621	99.9	22601	
7/79[1]	IN	46174	97.8	45139	39
	DC	19115	91.4	17461	
7/79[2]	IN	68154	98.5	67146	26
	DC	18558	94.3	17503	
8/79[1]	IN	33492	97.6	33617	21
	DC	7445	95.0	7043	
8/79[2]	IN	101284	97.7	98894	48
	DC	49482	95.6	47296	
9/79	IN	53306	98.4	52447	26
	DC	14764	93.1	13740	
6/80	IN	7577	96.6	7322	70
	DC	5232	98.2	5139	
7/80[3]	IN	48405	95.6	46289	51
	DC	24215	97.8	23675	
8/80	IN	46902	95.5	44783	40
	DC	18439	97.9	18045	
9/80[3]	IN	129387	99.1	128183	28
	DC	37177	97.5	36238	

[1]Unreliable estimates
[4]First 24-h period in month
[2]Second 24-h period in month
[3]48-h period

densities in transit through the plant has been consistently noted over 6 yr of entrainment studies and thus does not seem to be the result of sampling bias at CCNPP. This phenomenon is attributed to physical damage incurred through mechanical abrasion and hydraulic shear forces.

The potentially non-selective capture of zooplankton, especially at the high velocity discharge, by the low-volume diaphram pump used in these studies has been suggested to induce sampling bias. Field tests by Sage and Thompson (1978) determined that there was no significant difference in captured density between a low-volume diaphragm and a high-volume vacuum pump. A more intensive investigation of this question by Bradley (1980) led to the conclusion that there was no significant difference in numbers of zooplankton collected between the low-volume diaphragm and a high-volume submersible pump. Furthermore, Bradley observed no significant difference in capture of zooplankton resulting from the orientation of the pump intake hose.

Preoperational (no thermal elevation) survival estimates were generally high, ranging from 80 to 92%, while operational estimates ranged from 12 to 100%, with a median survival of 55% for the years 1974-1980.

The cropping effect of entrainment is species and life stage selective. Calanoid copepods, dominated by all life stages of *Acartia tonsa*, are the most sensitive group. Of this group the naupliar instar stages exhibit the greatest entrainment sensitivity, followed by *A. tonsa* copepodites and to a lesser extent, adults (Table IV-B-2). This selective response has been consistent over the recent years and is believed to result from changes in the shape and rigidity of the exoskeleton of the organism. Copepod nauplii frequently molt and have a less rigid exoskeleton. Adults do not molt as frequently (relative to the nauplii) and have a thicker exoskeleton of improved structural integrity. The cylindrical shape of the adult "shell" is also thought to be more impact resistant.

Other zooplankton species, notably polychaete larvae (Fig. IV-B-2a) and the harpacticoid copepod, *Halectinosoma curticorne* (Fig. IV-B-2b), appear to be unaffected by the rigors of entrainment, and showed almost no reduction in numbers from IN to DC.

Survival estimates fluctuate monthly, daily and hourly. Prior to time-series analysis, instituted in 1977, replicate (5-7) samples were collected at 4-h intervals. Mean replicate densities varied markedly between sampling periods, though individual replicate values were close (Fig. IV-B-3). Time-series analysis revealed that densities appeared to fluctuate according to a variety of hydrodynamic processes: upwelling, tidal and diurnal cycles (Sage and Bacheler, 1978; Fig. IV-B-4). Occasionally the cropping rate was stable with IN and DC densities paralleling one another (Fig. IV-B-5).

Table IV-B-2. Percent survival (and relative abundance) of copepod nauplii, *Acartia tonsa* copepodites and *A. tonsa* adults, numerically important constituents of the Chesapeake Bay zooplankton, entrained at Calvert Cliffs Nuclear Power Plant 1976-1980. % survival: (# alive at discharge/# alive at intake) x 100; relative abundance: % of total zooplankton abundance at intake.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1976 (Unit 1)									
Copepod nauplii	66(48)	79(30)	85(46)	28(54)	100(18)	65(17)	100(37)	8(63)	25(63)
Acartia copepodites	72(17)	55(24)	100(4)	44(10)	77(19)	39(21)	100(24)	18(30)	33(31)
A. tonsa adults	76(24)	100(12)	100(9)	59(3)	87(6)	100(23)	100(16)	24(5)	62(2)
1977 (Unit 2)									
Copepod nauplii						47(29) 71(64)	78(26)	38(46)	49(31)
Acartia copepodites						51(26) 68(17)	64(43)	41(37)	46(44)
A. tonsa adults						94(2) -(0)	92(21)	82(11)	87(4)
1978 (Unit 2)									
Copepod nauplii						19(16)	[1]38(70) [2]32(57)	30(44) 22(69)	25(51)
Acartia copepodites						18(27)	[1]50(14) [2]45(29)	46(20) 38(21)	28(37)
A. tonsa adults						31(14)	[1]100(1) [2]65(4)	88(11) 100(4)	55(3)
1979 (Unit 2)									
Copepod nauplii						25(9)	[1]22(30) [2]20(61)	16(69) 43(64)	23(54)
Acartia copepodites						23(8)	[1]25(46) [2]21(22)	21(29) 40(27)	28(35)
A. tonsa adults						-(0)	[1]28(7) [2]56(4)	40(3) 100(4)	63(3)
1980 (Unit 2)									
Copepod nauplii						52(73)	24(29)	32(65)	26(76)
Acartia copepodites						85(7)	37(25)	39(25)	29(16)
A. tonsa adults						100(1)	100(18)	100(4)	69(1)

[1]First 24-h period in month.
[2]Second 24-h period in month.

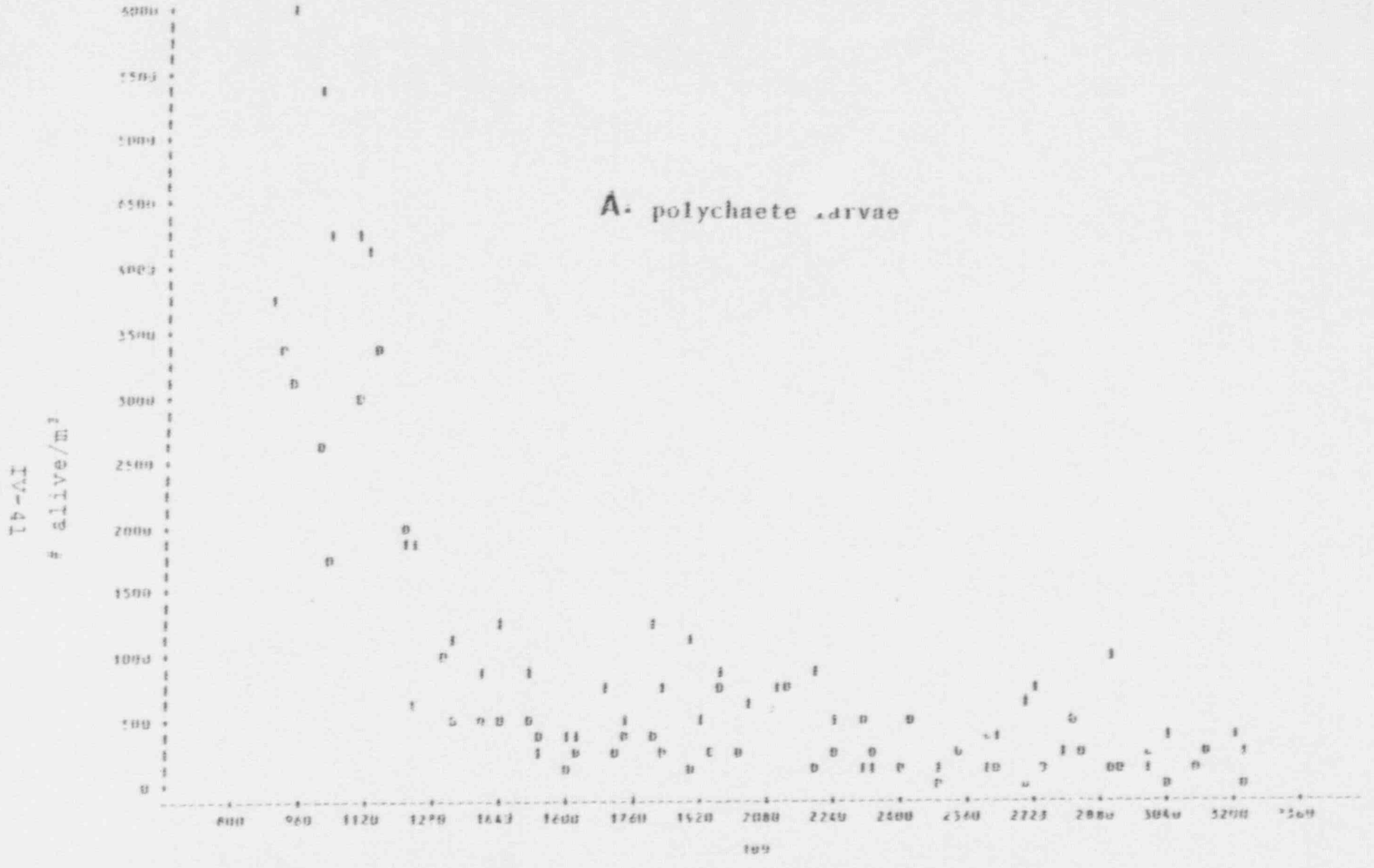


Figure IV-B-2. Density of polychaete larvae (A) and the copepod *Halectinosoma curticorne* (B) in time-series samples collected at Intake (I) and Discharge (D) of Calvert Cliffs Nuclear Power Plant during zooplankton entrainment studies, 13-14 June 1978. The figures illustrate sampling periods when densities of some organisms were greatly amplified by reproduction between Intake and Discharge stations; other species showed low survival during this study.

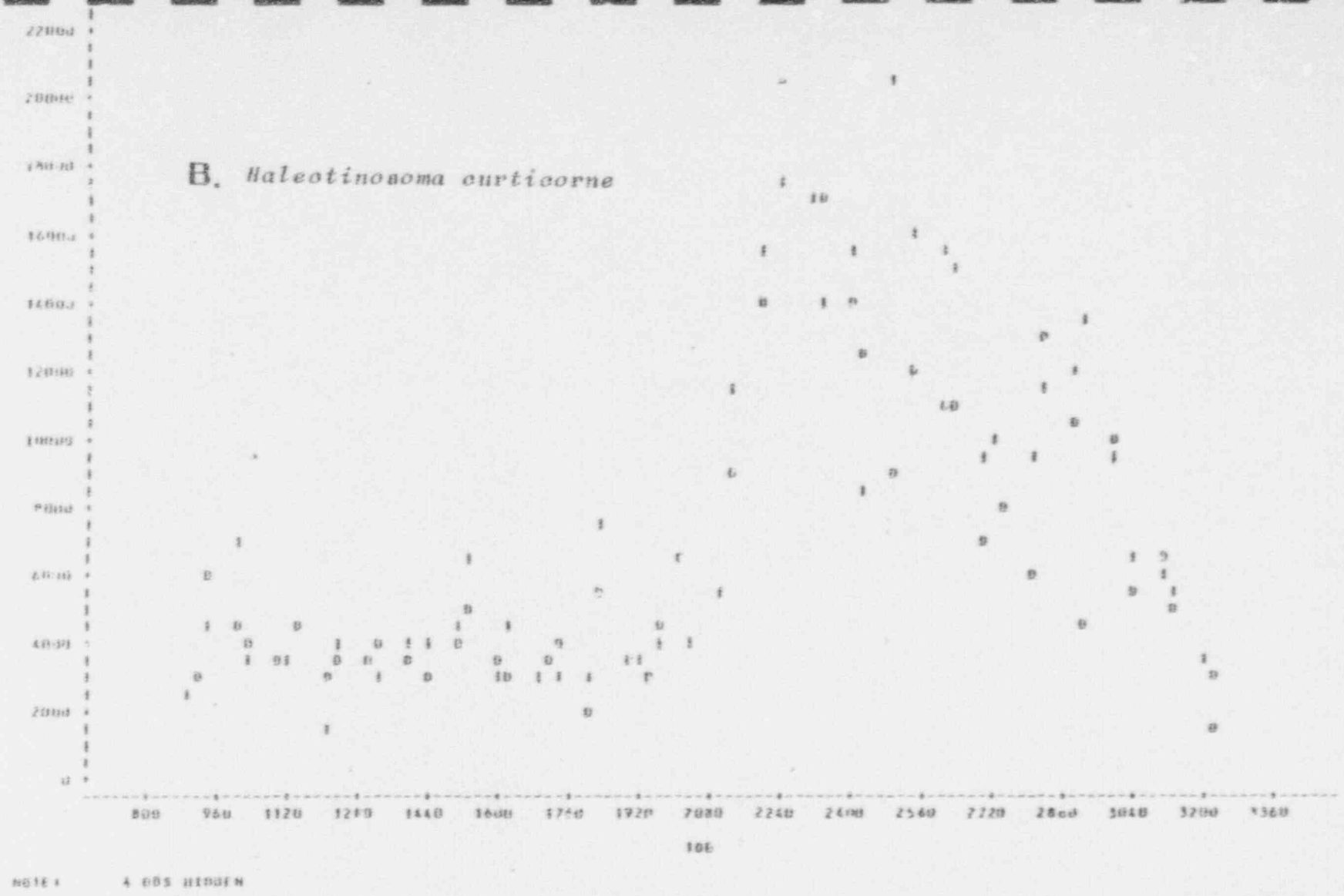


Figure IV-B-2 (continued). Density of polychaete larvae (A) and the copepod *Haleotinosoma curticorne* (B) in time-series samples collected at Intake (I) and Discharge (D) of Calvert Cliffs Nuclear Power Plant during zooplankton entrainment studies, 13-14 June 1978. The figures illustrate sampling periods when densities of some organisms were only negligibly reduced between intake and discharge stations; other species showed low survival during this study.

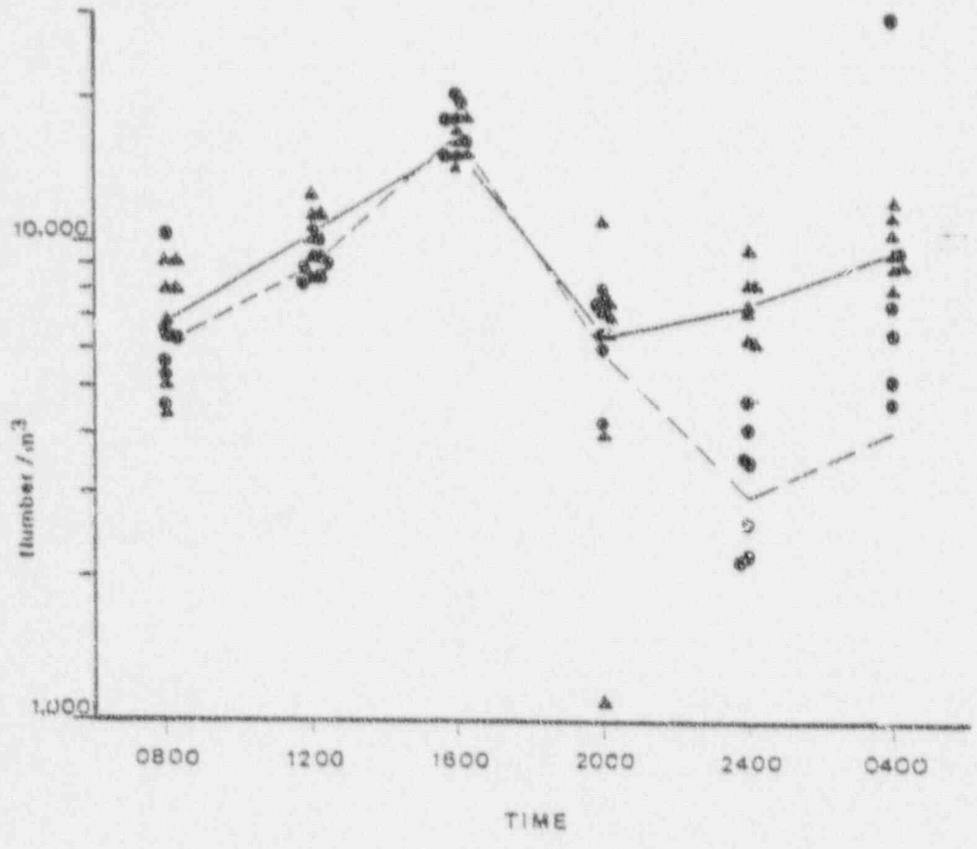


Figure IV-B-3. Total living zooplankton density (N/m^3) in replicate samples at Intake (triangles) and Discharge (circles) stations at Calvert Cliffs Nuclear Power Plant on the Chesapeake Bay at discrete sampling intervals during entrainment studies, 13-14 January 1976. Note similarity of replicates within sets, large differences between sets and short-term temporal variations in survival (variations in the magnitude of zooplankton density reduction between intake and discharge).



Figure IV-B-4. Density of *Acartia* copepodites in time-series samples collected at Intake (I) and Discharge (D) stations at Calvert Cliffs Nuclear Power Plant on the Chesapeake Bay during entrainment studies, 13-14 September 1977. Data smoothed with SAS-Tukey (Naiman et al., 1978). Note short-term variation in density and survival of entrained zooplankton.

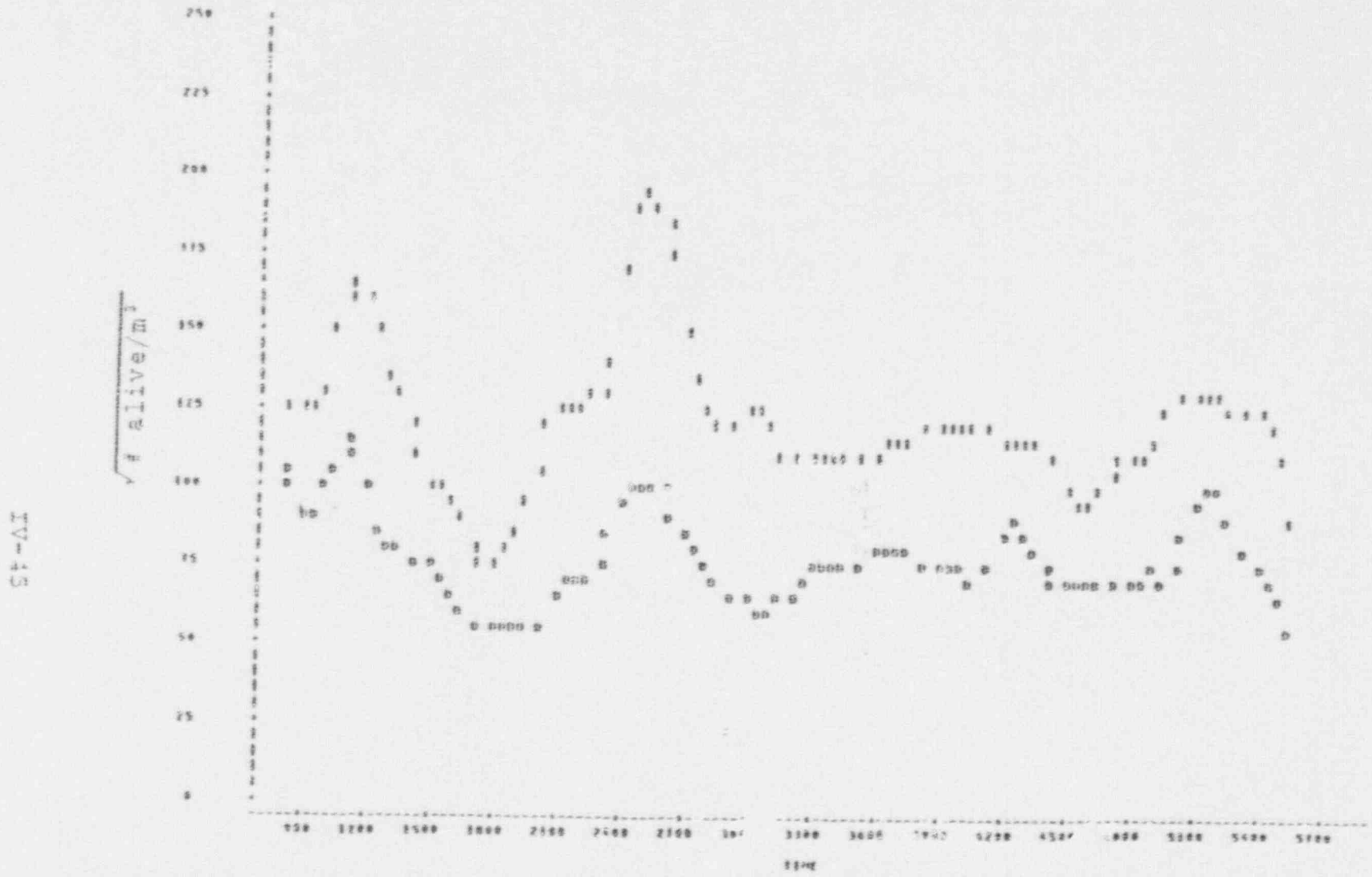


Figure IV-B-5. Density of *Acartia* copepodites in time-series samples collected at Intake (I) and Discharge (D) stations at Calvert Cliffs Nuclear Power Plant during zooplankton entrainment studies, 9-10 August 1977. Note relatively constant survival of organisms over time in contrast to variable survival shown in Fig. IV-B-4.

Ancillary hydrographic data for each year between 1977 and 1980, corresponding to the entrainment dates, are given in Table IV-B-3. In an attempt to assess the relative importance of those monitored variables, particularly an increased ΔT, a stepwise multiple linear regression analysis was employed. Results are given for copepod nauplii, *Acartia* copepodites and *Acartia tonsa* adults, the major constituents of the Bay assemblages, by year from 1977-1980 in Table IV-B-4 with emphasis on a comparison between 1977-1978 when the ΔT was a maximum of 5.5°C and 1979-1980 when the ΔT was increased.

The variable of immediate concern with respect to plant operation is the cross-condenser temperature elevation (ΔT). CCNPP was permitted to increase the amount of waste heat released on an experimental basis from 5.5°C to a maximum of 6.7°C during the summer months of both 1979 and 1980. However, the highest mean ΔT achieved for a 24-h study was 6.1°C in August 1979 and again in August 1980. The mean ΔT for the June-September study duration was 5.8°C in 1979 and 5.9°C in 1980. Thus, the focus of the study was necessarily at ΔT's <6.0°C.

Variation in ΔT was usually less than 3°C within each entrainment study. Exceptions occurred during unscheduled plant shut-downs when the temperature elevation decreased to 0°C. Temperature differential was negatively correlated with survival ($p<0.05$) for *Acartia* copepodites in 1978 (Analysis I) and was positively correlated ($p<0.05$) for copepod nauplii in 1980 (Analysis II) (Table IV-B-4). The positive correlation in 1980 was not expected as the mean ΔT for the June-September study period was 5.9°C, the highest recorded in the 6-yr study. These analyses indicate that ΔT alone at the elevations experienced to date at CCNPP does not adversely affect the survival of entrained zooplankton.

Stepwise regression (Analysis II) was used to analyze data from July 1978 and September 1979 collections when plant shut-downs occurred (Table IV-B-5). Just prior to plant shut-down ΔT averaged ~5.4°C (July) and ~6°C (September) and dropped precipitously to 0°C after plant shutdown (Olson and Sage, 1979b; Newman, Sage and D'Apolito, 1980). Results are given for copepod nauplii, *Acartia* copepodites, and *A. tonsa* adults in Table IV-B-5. The analysis shows that in July 1978 ΔT was not a significant variable contributing to survival of *A. tonsa* (all life stages), although it was a significant variable for *Acartia* copepodites in the 1978 study period overall (Table IV-B-4). Both *Acartia* copepodites and *A. tonsa* adults were significantly ($p<0.05$) affected by ΔT in September 1979. However, over the 4-mo study period in 1979, the variable ΔT was not significantly related to survival (Table IV-B-4).

To resolve these apparently conflicting results, it is necessary to understand the interaction of the independent variables in these instances. In most cases, intake density

Table IV-B-3. Mean intake [T(IN)] and discharge [T(DC)] temperatures (°C), cross-condenser temperature (°C) elevation (ΔT), salinity (°/₀₀), and range of dissolved oxygen concentrations (mg/l) during sampling periods at the Calvert Cliffs Nuclear Power Plant, 1976-1980.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1976 (Unit 1)									
T(IN)	3.1	3.0	6.4	14.6	18.7	20.6	24.9	26.0	23.7
T(DC)	8.9	6.9	11.7	19.6	23.3	24.9	29.9	30.9	29.9
ΔT	5.8	3.9	5.3	5.0	4.6	4.3	5.0	4.9	6.2
Sal	13	12	9	9	10	10	10	13	15
DO	8-12	4-12	10-13	10-11	5-9	4-9	3-6	4-7	7-8
1977 (Unit 2)									
T(IN)						22.6	26.7	28.2	24.9
T(DC)						27.0	28.8	32.6	29.4
ΔT						4.4	2.1	4.4	4.5
Sal						14	15	16	17
DO						1-4	1-7	NA	4-7
1978 (Unit 2)									
T(IN)						20.7	[1]24.8	26.4	26.3
							[2]24.1	27.5	
T(DC)						26.0	[1]30.3	31.9	31.8
							[2]29.5	32.9	
ΔT						5.3	[1]5.5	5.5	5.5
							[2]5.4	5.4	
Sal						9	[1]9	13	15
							[2]12	11	
DO						4-6	[1]6-8	1-3	1-7
							[2]4-7	1-4	
1979 (Unit 2)									
T(IN)						20.4	[1]22.2	25.6	24.2
							[2]23.6	24.1	
T(DC)						26.2	[1]27.8	31.2	30.2
							[2]29.2	30.1	
ΔT						5.8	[1]5.6	5.6	6.0
							[2]5.6	6.1	
Sal						9	[1]11	12	13
							[2]11	12	
DO						NA	[1]2-4	3-7	4-8
							[2]3-8	2-7	
1980 (Unit 2)									
T(IN)						21.5	24.0	27.9	27.3
T(DC)						27.4	29.8	24.0	33.1
ΔT						5.9	5.8	6.1	5.8
Sal						12	15	16	17
DO						3-11	1-10	1-5	4-8

[1]First 24-h period in month.
[2]Second 24-h period in month.
NA = Not available.

Table IV-B-4. Significance of independent variables used in stepwise multiple linear regression (Draper and Smith, 1966) to determine factors affecting survival of entrainment through Calvert Cliffs Nuclear Power Plant. Data used derived from 1977-1980 studies. Significant levels of the F statistic and its associated variables are enclosed in parentheses. Sign indicates a negative (-) or positive (+) regression.

	Analysis I		Analysis II*	
	Model	F	Model	F
1977 Copepod nauplii	- IN Density (0.0001) - Salinity (0.0001) + IN Temperature (0.0093)	15.70 (0.0001)	- IN Density (0.0001)	18.37 (0.0001)
Acartia copepodites	- IN Density (0.0001)	26.74 (0.0001)	- IN Density (0.0001)	26.74 (0.0001)
Acartia tonsa	- Salinity (0.0001)	24.28 (0.0001)	- IN Temperature (0.0009)	21.37 (0.0009)
1978 Copepod nauplii	- IN Density (0.0054) + IN Temperature (0.0370)	4.49 (0.0122)	- IN Density (0.0054) + IN Temperature (0.0370)	4.49 (0.012
Acartia copepodites	- ΔT (0.0001) + IN Temperature (0.0004) - IN Density (0.0552)**	9.12 (0.0001)	- ΔT (0.0001) + IN Temperature (0.0004) - IN Density (0.0552)**	9.12 (0.0001)
Acartia tonsa	+ IN Temperature (0.0099) - Salinity (0.0704)**	3.47 (0.0339)	**	**
1979 Copepod nauplii	- IN Temperature (0.0369)	4.40 (0.0369)	- IN Temperature (0.0369)	4.40 (0.0369)
Acartia copepodites	**	**	**	**
Acartia tonsa	**	**	**	**
1980 Copepod nauplii	- Salinity (0.0001)	20.50 (0.0001)	- IN Temperature (0.0013) + ΔT (0.0385)	7.73 (0.0065)
Acartia copepodites	- IN Density (0.0150) - IN Temperature (0.0208)	7.08 (0.0010)	- IN Density (0.0150) - IN Temperature (0.0208)	7.08 (0.0010)
Acartia tonsa	**	**	**	**

* Salinity removed as a variable
** NS ($p<0.05$)

Table IV-B-5. Significance of independent variables used in stepwise multiple linear regression (Draper and Smith, 1966) to determine factors affecting survival of entrainment through Calvert Cliffs Nuclear Power Plant on two occasions (July, 1978 and September, 1979) when the 5.4 or 6°C ΔT, respectively, was reduced to 0°C. Significant levels of the F statistic and its associated variables are enclosed in parentheses. Sign indicates a negative (-) or positive (+) regression.

	July 1978		September 1979	
	Model	F	Model	F
Copepod nauplii	*	*	- IN Density (0.0001)	28.19 (0.0001)
Acartia copepodites	- IN Temperature (0.0056) - ΔT (0.0631)*	9.12 (0.0002)	- IN Density (0.0001) - ΔT (0.0109)	9.82 (0.0003)
Acartia tonsa	*	*	- ΔT (0.0005)	15.08 (0.0005)

* NS ($p<0.05$)

and zooplankton survival have been negatively correlated, as have been ΔT and zooplankton survival. In analyzing the discrepancy between results of analyses of July 1978 and September 1979 data, ΔT and intake density were found to be negatively correlated with each other in July 1978. Thus the rapid decrease in ΔT during plant shutdown served to increase survival, while a concurrent increase in intake density served to decrease survival. Each of these independent variables served to mask the effect of the other, resulting in a survival rate that was relatively constant.

In contrast, ΔT is negatively correlated with survival of copepodites and adults in September 1979 and both ambient water temperature and ΔT are positively correlated with density. Thus, on this date intake density increased along with both ΔT and ambient water temperature, which collectively resulted in reducing zooplankton survival. This analysis does not reveal whether those correlations may have had a collectively additive effect on survival or whether one variable dominated, thus masking any effect of the others.

The three life stages of Acartia tonsa, nauplii, copepodites and adults, are not uniformly or consistently affected by ΔT. However, ΔT exhibited the greatest correlation with adult and copepodite survival, and therefore is deemed most important by the stepwise procedure. There is an indication that ΔT does contribute to reducing zooplankton survival, although this trend is confounded by other variables.

In combination with intake density and/or alone, ambient water temperature is the second most frequently occurring variable ($p<0.05$) negatively related to survival. The magnitude of the effect is again dependent upon species, age class and the study year. The frequency of negative correlations between ambient temperature and survival increases slightly from 1977-1980 (Table IV-B-4). Ambient temperature is more often an important variable when interacting with ΔT to increase discharge temperature to that approaching the thermal tolerance of A. tonsa (32°-35°C) (Heinle, 1969; Gonzales, 1974). Ambient temperature is more frequently negatively correlated with juvenile stages of A. tonsa. The nauplii and copepodite stages probably have a lower thermal tolerance, assuming they follow the patterns of other invertebrates in which juvenile stages are more sensitive to thermal stress (Jensen et al., 1969; Kinne, 1970).

In 1978 the usual negative association of ambient temperature and survival reversed and survival increased with ambient temperature for the June to September annual study period. This occurrence is a result of unusually low survival estimates in June 1978 (Table IV-B-2) and the coolest ambient temperatures relative to other entrainment studies in the 1978 study period (Table IV-B-3). The June estimate is sufficient to change the direction of the response of ambient temperature for

the entire study period. Another variable which is considered to be a contributor to this apparent anomaly is the low concentration of dissolved oxygen in the water column. Zooplankton may have been abnormally stressed by a hypoxic condition preceding the June sample collections; low DO is a frequently occurring summer phenomenon in this area of Chesapeake Bay (Olson and Sage, 1979b). Many zooplankton, specifically *A. tonsa*, can survive in environments with oxygen concentration as low as 1 mg/l (Bakker et al., 1977). However, the effect of imposing the additional stress of entrainment on organisms which have experienced low dissolved oxygen concentrations is not known.

Increasingly large intake densities appear to be the most significant variable, alone or interacting with other variables, associated with reduced copepod nauplii and *Acartia* copepodite survival. Survival of entrained *A. tonsa* adults does not appear to be affected by intake densities; this may be partly attributed to the stronger structural integrity of the adult carapace. Moreover, the disparate survival rates of these copepod age classes is accentuated by high ambient temperatures of the summer months.

Further examination of other variables used in the analyses, shows that the negative correlation of salinity with survival was significant ($p<0.05$) in the entrainment studies in 1977 and 1980 (Table IV-B-4). These years coincide with notably higher salinity concentrations resulting from unusually meager precipitation. Therefore, salinity concentrations increased from June to September coinciding with the normal seasonal increase in ambient water temperature and density of zooplankton.

These three variables were all highly intercorrelated, making it difficult to determine which variable causes a reduction in survival. Furthermore, higher salinity concentration has been shown to increase the tolerance of organisms to elevated temperatures (Lance, 1963; Kinne, 1970). The statistical significance of salinity on survival is probably an artifact resulting from the correlation with intake density and water temperature since the range of salinity experienced over the duration of this study was well within the established tolerance limits for the dominant zooplankton, *Acartia tonsa* (Perkins 1974; Sage, Summerfield and Olson, 1976).

Organisms physiologically adapt to natural climatic temperature changes. Temperature tolerance has been found to be related to acclimation temperatures. For instance, *Acartia tonsa* acclimated to lower temperatures is able to tolerate a 20°C temperature increase, while at higher acclimation temperatures only half (10°C) that increase is tolerated (Heinle, 1969). It can be assumed that cross-condenser temperature increases at the levels measured during these studies at CCNPP become a factor only when ambient temperatures are approaching

the annual maximum and the zooplankton community is naturally stressed (Heinle, 1969).

The effect of ΔT on zooplankton survival is, therefore, strongly influenced by ambient water temperature. Reduced survival would be expected when ΔT and ambient water temperature combine to raise the discharge temperature above 30°C at CCNPP. This relationship can be seen in Figure IV-B-6, a 3-dimensional plot of naupliar survival against ΔT and discharge temperature from 1976 through 1980. It should be noted that lower survival corresponds with higher discharge temperatures (>30°C) and not with higher ΔTs. Since zooplankton at CCNPP are only exposed for a brief (~4 min) period to elevated temperatures, mortality from heat shock is not the major problem at this site. The short exposure does not appear to be detrimental to the tolerant *A. tonsa* and other components of the community, as reflected in the low mortalities indicated by vital dye uptake. The principal effect of entrainment appears to be cropping. Affected organisms are apparently fragmented; otherwise they survive entrainment unharmed. Various species, particularly *Halectinosoma curticorne* and adult calanoid copepods, exhibit little reduction in densities, while naupliar stages are significantly reduced. The lack of cropping in the former may be the result of a more durable exoskeleton, but the reasons are not fully understood.

Summary and Conclusion

Cropping (a reduction in species density from intake to discharge) is the primary effect on entrained zooplankton observed in entrainment studies at Calvert Cliffs Nuclear Power Plant. Mortality, as indicated by the % Alive at IN and DC, is minimal. Entrained organisms apparently either maintain their structural integrity and survive passage through the plant or are fragmented from the mechanical and hydraulic shear forces and are lost.

Survival, the percent of living organisms surviving plant passage (# alive at discharge/# alive at intake), is an estimate of the effect of entrainment, reflecting both cropping and mortality. Survival estimates, which ranged from 12 to 100%, had a median of 55% and were seasonally dependent. Survival estimates were not constant but fluctuated with hourly, daily and seasonal periodicities, and involved the interaction of biological and physical factors as well as the effect of plant operations.

When the effect of a cross-condenser temperature increase (ΔT) from 5.5°C (1977-1978) to a projected 6.7°C (1979-1980) was analyzed as an independent variable in a stepwise linear regression model, results were inconclusive. There was no consistent trend in the analysis to suggest a correlation of any importance. There does appear to be an interaction between

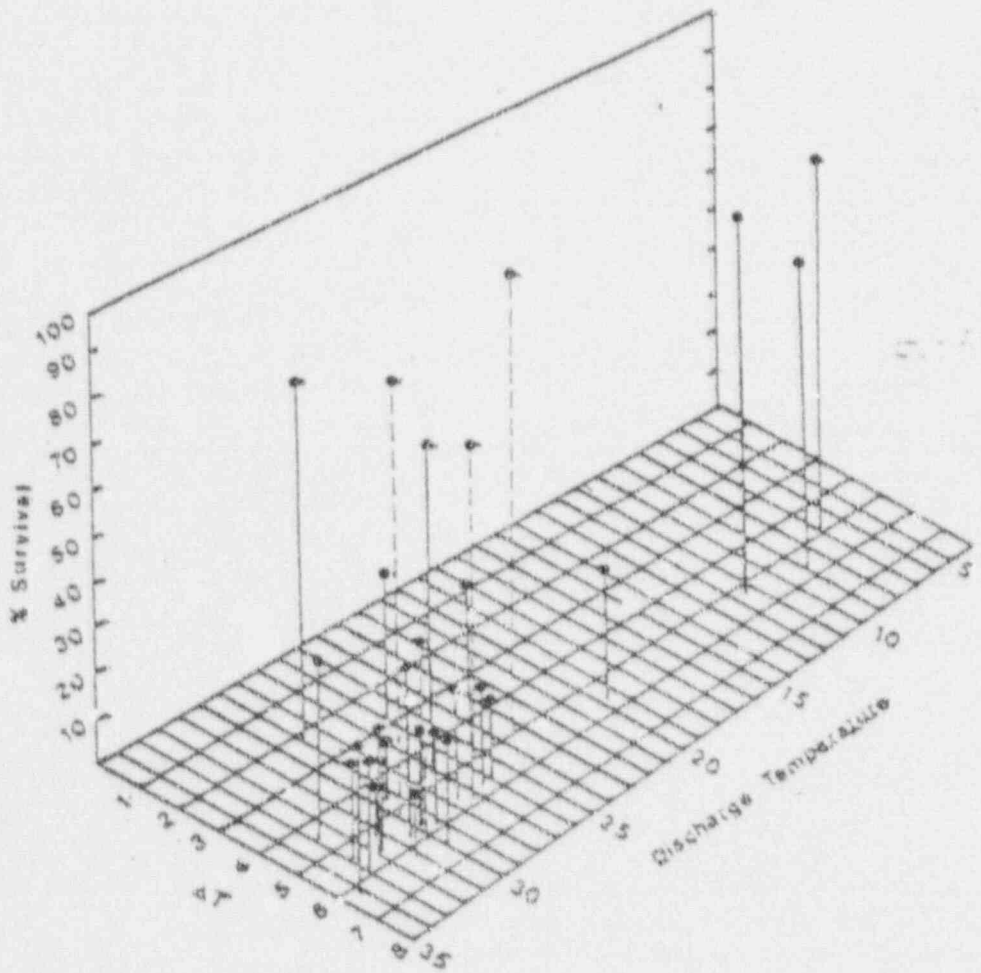


Figure IV-B-6. Three dimensional plot of copepod naupliar survival versus discharge temperature and ΔT (°C) of cooling water. Values are 24-h averages from zooplankton entrainment studies conducted at Calvert Cliffs Nuclear Power Plant from 1976 through 1980. (Dotted lines indicate questionable survival estimates).

the ΔT and high ambient water temperatures which produces a negative effect on zooplankton entrainment survival. Zooplankton exposed to high ambient water temperatures are near their upper thermal tolerance and are already thermally stressed. The ΔT's measured during studies at CCNPP were found to be instrumental in reducing zooplankton survival only when combined with ambient water temperatures which raised the discharge temperature in excess of 30°C. High ambient water temperatures usually occur during two months of the year, August and September, in this area of Chesapeake Bay.

Survival estimates for various zooplankton species were not similar. Some groups remained essentially unaffected by plant entrainment. However, calanoid copepods, the numerically dominant microzooplankton order in the Bay, appeared to have lower survival than other groups. *Acartia tonsa*, the most persistent and abundant calanoid copepod in this area of the Bay and which provided most of these entrainment data, showed age-class differences in survival as well, e.g., the naupliar stage showed lowest survival; adults showed highest survival. Maximal zooplankton densities (typically including large numbers of copepod nauplii) frequently coincide with maximum ambient water temperatures, further accentuating the effect of seasonally-reduced zooplankton survival.

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V. IMPINGEMENT

Introduction

The purpose of this report is to provide estimates of the numbers and cost of finfish and blue crabs killed by impingement on the traveling screens of the Calvert Cliffs Nuclear Power Plant. Such estimates are required by Code of Maryland Regulation (COMAR) 08.05.04.13§F(1). The results presented here are based upon collections by the Academy of Natural Sciences of Philadelphia to estimate abundances and size distributions of impinged organisms (Hirshfield, Hixson, and White, 1980; Hixson and White, 1979; Naiman, Hixson, and Wilson, 1978) and to estimate impingement-related mortality (Burton and Graves, 1979; Burton and Margrey, 1980; Hirshfield and Hixson, 1981). Detailed discussion of methods and results not presented here may be found in those reports.

In order to allow estimation of the monetary cost of finfish and blue crabs lost through impingement during a typical year at the Calvert Cliffs Nuclear Power Plant, abundance data were used from 1977, 1978, and 1979. These three were chosen because they were all years with two units in operation.

The Plant and Study Area

Calvert Cliffs Nuclear Power Plant (CCNPP) is located on the western shore of the Chesapeake Bay in Calvert County, Maryland. The plant has two units which are capable of generating net electric outputs of 850 MWe each. Both reactors are cooled by a once-through cooling system which uses approximately 9083 m^3/min of Chesapeake Bay water.

Water used for cooling purposes is drawn from the Bay under a 171-m long curtain wall, which extends below the water's surface to a depth of 8.5 m. During winter time plant operations, all removable panels in the curtain wall are left in place, providing a surface barrier (to a depth of 8.5 m) to potentially impingeable species. During summertime operations, three or four panels are removed from the curtain wall to prevent entrapment of fish species within the embayment area which may be adversely affected as a result of dissolved oxygen sags.

Water entering the embayment area under the 8.5-m deep curtain wall moves at a velocity of less than 0.15 m/sec. Cooling water travels 91.4 m from the curtain wall to the intake structure and the velocity increases from 0.15 m/sec at the curtain wall to 0.3 m/sec at the traveling screens. The 12 traveling screens (Link-belt, FMC) at each unit are designed to prevent organisms larger than 1 cm from entering the plant.

Organisms smaller than 1 cm pass through the plant's condenser system and are returned to the bay via a submerged discharge conduit.

During normal plant operations, the 12 screens (6 pumps) on each unit are sequentially operated in pairs (2 rotating screens/circulation pump) for 10 min each. Thus, in each hour of operation, all screens rotate for 10 min and are stationary for 50 min. During this rotation period, organisms that are impinged during the nonrotating periods (i.e., 50 min) are removed from the traveling screens with high-pressure water jets and returned to the bay via a storm drain system.

Methods and Materials

Abundance Estimates

The procedure for collection of samples to estimate abundances of impinged organisms was the same in 1977, 1978, and 1979 (Hirshfield, Hixson, and White, 1980; Hixson and White, 1979; Naiman, Hixson, and Wilson, 1978). A collecting net consisting of 1.27-cm stretch-mesh nylon was placed in the screen-wash discharge trough and left for approximately 1 h during each sampling period. The sampling schedule was based on a 6-day cycle in order to sample each hour of the day with equal frequency over a 365-day period. On each sampling day, 1-h collections were made at each of the two generating units; if one unit was not in operation, two consecutive samples were collected at the operating unit. The unit sampled first alternated each day. The initial 6-day sampling period, and succeeding odd-numbered 6-day periods, were scheduled as follows: the first collection began at 0000, 0400, 0800, 1200, 1600 and 2000 hours on the 1st, 2nd, 3rd, 4th, 5th and 6th days, respectively. The second collections on each day began 2 h after the first collections had begun. The second 6-day sampling period, and succeeding even-numbered sampling periods, were scheduled as follows: the first collections began at 0100, 0500, 0900, 1300, 1700 and 2100 hours on the 1st, 2nd, 3rd, 4th, 5th and 6th days, respectively. On each day the second collection began 2 h after the first had begun. Therefore, samples were taken during all hours in two 6-day sampling periods. Up to 50 individuals of any species collected were measured and examined for external injuries. A total weight for each species was also obtained. Before each sample was collected, the number of circulators operating was noted.

Mortality Estimates

Studies in 1978, 1979, and 1980 were designed to evaluate the effects of various operating procedures and other factors on the survival of impinged fishes (Burton and Graves, 1979;

Burton and Margrey, 1980; Hirshfield and Hixson, 1981). Details specific to the design of the studies may be found in those reports; procedures common to all three years are described below.

Faunal collections for the Unit I and II studies were made in animal surveillance pools (9.1 x 3.7 x 0.5 to 0.6 m). The total volume of screen wash-water was diverted into the pools by closing the storm-drain discharge flow gates and opening the gates to the pools. A collection time of 1 h ensured that all organisms impinged on all of the traveling screens of either Unit I or Unit II were taken (6 pairs x 10 min each = 60 min). If a large number of impinged organisms was collected prior to the conclusion of the 1-h sampling period, a sampling period of less than 1-h duration was used to prevent a decrease in the dissolved oxygen concentration and an accumulation of excretory products due to overcrowding in the surveillance pool. At the end of each collection period the discharge flow gate was opened and the pool gate closed. This was designated time 0 h (T_0). Collections in day-light hours were taken between 0700 and 1630 hours, while night samples were taken between 1700 and 0255 hours.

Collections were made at each unit throughout the entire year whenever plant operating conditions and weather permitted. One or two 1-h samples per unit were made on each sample date; four or five sample dates were scheduled for each week of the year. The criterion for death was failure to exhibit opercular or other overt movements whether induced spontaneously or in response to mild mechanical stimulation.

Data from a 1975 impingement survival study at Calvert Cliffs (Burton, 1976) showed survival values of 99.28% for *Trinectes maculatus* (hogchokers) and 99.54% for *Callinectes sapidus* (blue crabs) 96 h after impingement. Therefore, in the present studies these two species were not studied and were removed from the animal surveillance pools at T_0. On some occasions, impinged jellyfish were so numerous that, to avoid oxygen depletion in the pool systems, they were removed at T_0. This was accomplished through the use of dip nets.

Statistical Methods

Abundance Estimates

The mean counts of the hourly samples were calculated for each species on a monthly basis. These mean counts were multiplied by the total number of operating hours in the month to provide estimates of monthly impingement rates for each species. Yearly estimates for 1977, 1978, and 1979 were made by summing all monthly estimates.

Variance estimates are based upon procedures in Cochran (1977). The variance of each monthly estimate was calculated as:

$$\frac{N_i(N_i-n_i)}{n_i} \times var_i$$

where N_i = total number of operating hours in month i
n_i = number of hourly samples in month i
var_i = variance of the n_i samples

Variances of the yearly estimates were calculated as the sum of these monthly variances.

Survival Estimates

Previous studies (Burton and Graves 1979; Burton and Margrey, 1980; Hirshfield and Hixson, 1981) showed no substantial effects of operating conditions, seasons, temperatures, or day versus night sampling on survival rates, and no significant amount of delayed mortality for most species. Mortality estimates calculated here, therefore, used immediate mortality data from these studies. However, the large impingement episode discussed by Burton and Graves (1979) was excluded from their analyses because survival rates were abnormally low due to low dissolved oxygen levels. Survival estimates were made only for species having at least 300 individuals in survival studies collections over the three year period. The value of 300 was based upon a minimum of 10 estimates of survival using 30 fish to provide reasonable estimates of both the mean and variance of survival rates. Similarly, immediate mortality rates were used to provide more precise estimates of survival rates, since the data for delayed mortality were more limited. Ten species were so categorized: *Alosa aestivalis* (blueback herring), *Alosa pseudoharengus* (alewife), *Anchoa mitchilli* (bay anchovy), *Brevoortia tyrannus* (menhaden), *Dorosoma cepedianum* (gizzard shad), *Leiostomus xanthurus* (spot), *Menidia menidia* (Atlantic silverside), *Micropogon undulatus* (Atlantic croaker), *Paralichthys dentatus* (summer flounder), and *Pseudopleuronectes americanus* (winter flounder). A survival rate of 99.28% was used for hogchokers, and a rate of 99.54% was used for blue crabs, based on values calculated from Burton (1976).

For all other species, a mortality rate of 100% was assumed; this value is conservative, and overestimates actual mortality. These other species, with few exceptions, were impinged in low numbers during abundance studies; the effects of these exceptions are discussed below.

Estimates of survival rates for the ten abundant species were calculated using ratio-estimation techniques (Cochran, 1977). Since these techniques are based on a normal distribution approximation of the binomial distribution, sequential collections were pooled until the number of fish collected was

greater than or equal to 30 to form each datum. With these data the estimate of survival was computed as:

$$\hat{S} = \frac{\text{number of fish alive}}{\text{number of fish collected}} = \frac{\sum_{i=1}^{n} a_i}{\sum_{i=1}^{n} m_i}$$

where: $\hat{S}$ = estimated survival

m_i = number of fish collected for each datum after pooling

a_i = the associated number of fish alive for each datum after pooling

n = the number of data after pooling

The estimated variance of these ratio estimates was calculated following Cochran (1977) as:

$$\text{var}(\hat{S}) = \frac{a_i^2 - 2\hat{S}\Sigma a_i m_i + \hat{S}^2 \Sigma m_i^2}{n(n-1)(\bar{m})^2}$$

where: $\bar{m} = \frac{1}{n} \sum_{i=1}^{n} m_i$.

For all other species, the variance of the survivorship estimate was assumed equal to 0.

The estimated mortality rate ($\hat{D}$) was calculated as

$$\hat{D} = 1 - \hat{S}$$

The variance of $\hat{D}$ is equal to the variance of $\hat{S}$. The estimated number of fish killed by impingement was calculated as (D X A) where A = estimated number of individuals impinged in a year. The variance of (D X A) was calculated from Goodman (1960) as:

$$\text{var}(D \times A) = D^2 \times \text{var}(A) + A^2 \times \text{var}(D) - \text{var}(A) \times \text{var}(D).$$

Approximate 95% confidence limits for the estimated number of individuals killed by impingement were then calculated as:

$$(D \times A) \pm 1.96 \sqrt{\text{var}(D \times A)}.$$

Cost estimates

For each species, the estimated number of impinged individuals in each monthly sample was multiplied by the proportion of individuals of the actual sample of fishes that fell into the size classes designated in COMAR 08.02.09.01. For individuals longer than 12 inches, actual weights or estimates from length-weight regressions were used to estimate total weights for the estimated number of individuals. Assuming complete mortality, monetary values were obtained by multiplying the estimated number of impinged fish for each species and size category for each month by the dollar values for each species and size class listed in COMAR 08.02.09.01. Species not listed in COMAR 08.02.09.01 were considered forage fish with monetary values calculated as in the regulations. The total value for each species was then calculated as the sum of the monthly estimates for each size class. For those species with mortality estimates, the dollar value was multiplied by the mortality rate. This provided an estimate of monetary value based upon the number of fish estimated to have been killed by impingement. For all other species, a complete mortality assumption provided a conservative estimate of monetary loss.

Since the monetary values for impinged individuals differ from size class to size class, it was necessary to calculate a monetary value for an "average" individual killed by impingement in order to calculate confidence limits for monetary costs. To do this, the cost estimate assuming complete mortality for each species was divided by the estimated number impinged; this provided a weighted average monetary value for an individual of average length. All dollar values were multiplied by the 95% upper confidence limit of fish killed by impingement to provide an estimate of the 95% upper confidence limit of the monetary loss. This estimate is only approximate, since it treats the size distribution for each year as a constant.

Results and Discussion

In 1977, impingement estimates greater than 100,000 individuals were recorded for three species of finfish (bay anchovy, spot and hogchoker); these species represented 70.6% of the estimated 841,931 finfish impinged (Table V-1). Anchovy, menhaden and weakfish (*Cynoscion regalis*) were the three species with the largest estimated numbers killed by impingement. The latter species was sixth in total estimated abundance in 1977, although it was much less common in 1978 and 1979 (Tables V-2 and V-3). Since relatively few weakfish were collected for survival studies in 1978-1980, a mortality estimate of 1.00 was used. According to Burton and Margrey (1980), weakfish showed a survival rate of only 38.61%. Therefore, if 61.39% mortality was assumed instead of 100% mortality, the estimated number dead would be reduced from 34,649 to 21,271.

Table V-1. Abundance, mortality, and monetary value of finfish and blue crabs impinged at the Calvert Cliffs Nuclear Power Plant, Maryland, during 1977.

1977

SPECIES	NUMBER CAUGHT	ESTIMATED ABUNDANCE	VARIANCE OF ABUNDANCE	MORTALITY	VAR OF MORT	ESTIMATED # DEAD	VARIANCE OF # DEAD	UPPER LIMIT OF # DEAD	ESTIMATED COST	UPPER LIMIT OF COST
ALOSA AESTIVALIS	103	4529	1638385	0.47	0.0031	2035	425179	3313	228.29	358.66
ALOSA PSEUDOHARENGUS	50	2598	1330872	0.37	0.0119	958	246185	1931	177.87	358.28
ANCHOA MITCHILLI	11121	353749	9231246760	0.27	0.0016	95512	8581892?2	152938	95.88	153.39
BREVOORTIA TYRANNUS	4015	96883	1552348?4	0.40	0.0051	38753	21915971	55375	6888.44	9842.93
DOROSOMA CEPEDIANUM	17	3489	369758	0.24	0.0012	818	34726	1181	31.18	45.83
ETHOSTOMUS NIGRUM	4386	123653	6367878?7	0.13	0.0003	13582	12181187	28428	2289.51	3437.17
MENIDIA MENIDIA	136	5196	2738468	0.41	0.0102	2130	787788	3379	2.66	4.33
MICROPOGON UNDULATUS	27	842	119564	0.90	0.0012	758	97554	1378	141.32	255.32
PARALICHTHYS DENTATUS	256	8257	3658435	0.09	0.0001	743	35085	1115	435.32	714.08
PSEUDOPLEURONECTES AMERICANUS	2933	69239	422864881	0.08	0.0001	5542	3138966	9015	875.53	1456.62
TRINECTES MACULATUS	3437	117414	8154292?6	0.01	0.0000	845	42772	1248	44.52	65.85
ALOSA SCHOEPFI	2	81	3294	1.00	0.0000	81	3294	193	0.28	0.48
ANCHOA HEPSETUS	1	48	2256	1.00	0.0000	48	2256	141	0.18	0.29
ANGUILLA ROSTRATA	12	314	15863	1.00	0.0000	314	15863	543	98.86	162.18
APELTES QUADRACUS	1	21	679	1.00	0.0000	21	679	78	0.00	0.00
ASTROSCOPUS GUTTATUS	5	89	992	1.00	0.0000	89	992	151	3.20	0.34
CHASMODES BOSQUIANUS	23	436	9210	1.00	0.0002	436	9210	674	0.58	0.32
CONGER OCEANICUS	1	19	164	1.00	0.0000	19	164	44	0.00	0.00
CYNOSCION REGALIS	1831	34649	177807893	1.00	0.0000	34649	177807893	66784	8697.80	15258.49
CYPRINODON VARIEGATUS	1	19	164	1.00	0.0000	19	164	44	0.00	0.00
FUNDULUS DIAPHANUS	1	19	164	1.00	0.0000	19	164	44	0.40	0.91
FUNDULUS HETEROCLITUS	1	21	679	1.00	0.0000	21	679	78	0.50	1.45
FUNDULUS MAJALIS	1	21	679	1.00	0.0000	21	679	78	0.50	1.45
GASTEROSTEUS ACULEATUS	431	8756	4695894	1.00	0.0000	8756	4695894	13063	6.78	12.92
GOBIESOX STRUMOSUS	60	1162	26811	1.00	0.0000	1162	26811	1483	1.20	1.53
HIPPOCAMPUS ERECTUS	4	74	940	1.00	0.0000	74	940	234	0.20	0.36
MORONE AMERICANA	48	1222	74355	1.00	0.0000	1222	74355	1756	434.88	596.22
MORONE SAXATILIS	3	62	1189	1.00	0.0009	62	1189	121	77.48	158.88
OPSANUS TAU	28	674	29272	1.00	0.0000	674	29272	1889	1.08	1.58
PEPRILUS ALEPIDOTUS	18	450	18323	1.00	0.0000	450	18323	735	72.68	115.48
PEPRILUS TRIACANTHUS	2	51	1282	1.00	0.0000	51	1282	119	35.48	35.92
PERONIZON MARINUS	1	34	1895	1.68	0.0000	34	1895	99	0.18	0.29
PORICHTHYS PLECTRODON	82	1768	87142	1.00	0.0000	1768	87142	2339	2851.51	2325.93
PRIONOTUS CAROLINUS	84	2774	540545	1.00	0.0000	2774	540545	4215	4.18	6.73
SPHOEROIDES MACULATUS	1	29	801	1.00	0.0000	29	801	84	2.98	8.45
STRONGYLURA MARINA	8	145	1875	1.00	0.0000	145	1875	238	0.28	3.32
SYNGNATHUS FUSCUS	61	1618	66714	1.00	0.0000	1618	66714	2824	3.18	4.87
UROPHYCIS REGIUS	53	1773	459175	1.00	0.0000	1773	459176	3101	139.58	244.88
TOTAL FOR FINFISH	27652	841931				218834		345846	22846.22	34838.86
CALLINECTES SAPIDUS	16307	397868	1296879471	0.68	0.0000	1826	25538	2148	686.86	738.95
OVERALL TOTAL	43959	1238991				219861		347186	23453.98	35576.81

Table V-2. Abundance, mortality, and monetary value of finfish and blue crabs impinged at the Calvert Cliffs Nuclear Power Plant, Maryland, during 1978.

1978

SPECIES	NUMBER CAUGHT	ESTIMATED ABUNDANCE	VARIANCE OF ABUNDANCE	MORTALITY	VAR OF MORT	ESTIMATED # DEAD	VARIANCE OF # DEAD	UPPER LIMIT OF # DEAD	ESTIMATED COST	UPPER LIMIT OF COST
ALOSA AESTIVALIS	506	11417	4078826	0.47	0.0037	5366	1368208	7659	638.12	910.75
ALOSA PSEUDOHARENGUS	259	5455	949048	0.37	0.0119	2018	422739	3366	321.48	536.33
ANCHOA MITCHILLI	18784	362805	3262328653	5.21	0.0016	97957	443193223	139228	98.41	139.87
BREVOORTIA TYRANNUS	5786	177675	1494211064	0.40	0.0051	71078	392452163	109898	14789.91	22348.53
BROSOME CEPEDIANUM	144	3423	391359	0.24	0.0012	820	36133	1194	39.60	57.56
ETEOSTOMUS KANAWHAE	4698	159797	12786590493	0.11	0.0003	17578	1585423B9	42257	3124.88	7532.22
MENIDIA BERYLLINA	7139	169521	1985643655S	0.41	0.0102	69299	34267259J6	184034	74.17	196.97
MICROPOGON UNDULATUS	451	13971	6973772	0.98	0.0012	12574	5874573	17324	1886.88	2598.62
PARALICHTHYS DENTATUS	67	2258	134848	0.89	0.0001	283	1589	281	242.43	335.62
PSEUDOPLEURONECTES AMERICANUS	281	9563	3999674	0.06	0.0001	765	34343	1128	126.66	186.79
TRINECTES MACULATUS	4965	169897	833261221	0.81	0.0008	1223	43196	3631	65.29	87.70
ANGUILLA ROSTRATA	3	103	3352	1.00	0.0000	103	3352	216	14.10	29.63
APELTES QUADRACUS	1	35	1220	1.00	0.0000	35	1220	103	0.00	0.00
ASTROSCOPUS GUTTATUS	1	41	1667	1.00	0.0000	41	1667	121	0.00	0.24
CENTROPRISTIS STRIATA	2	65	1978	1.00	0.0000	65	1978	152	9.00	22.94
CHASMODES BOSQUIANUS	1	23	525	1.00	0.0000	23	525	68	0.02	0.06
CYNOSCION REGALIS	23	767	44512	1.00	0.0000	767	44512	1881	328.80	506.07
ETHEOSTOMA OLMSTEDI	10	289	9681	1.00	0.0000	289	9881	484	5.60	9.71
GASTEROSTEUS ACULEATUS	283	6148	663568	1.00	0.0000	6148	663568	7745	6.20	7.81
GOBIESOX STRUMOSUS	25	820	32598	1.00	0.0000	820	32598	1174	0.80	1.15
GOBIOSOMA BOSCI	1	35	1220	1.00	0.0000	35	1220	163	0.04	0.12
HYPSOLEPIS HENTZI	2	41	812	1.00	0.0000	41	812	97	0.06	0.14
LEPOMIS MACROCHIRUS	6	196	7417	1.00	0.0000	196	7417	365	63.90	114.93
MENIDIA BERYLLINA	3	101	9989	1.00	0.0000	101	9989	291	0.10	0.29
MICROPTERUS SALMOIDES	19	651	56547	1.00	0.0000	651	56947	1319	97.76	167.89
MORONE AMERICANA	45	1248	60593	1.00	0.0000	1248	60593	1730	335.80	465.62
MORONE SAXATILIS	2	47	2188	1.00	0.0000	47	2188	132	35.10	102.18
NOTEMIGONUS CRYSOLEUCAS	1	17	256	1.00	0.0000	17	256	48	0.00	0.00
OPSANUS TAU	49	1598	142279	1.00	0.0000	1598	142279	2337	2.50	3.66
PEPRILUS ALEPIDOTUS	4	80	2136	1.00	0.0000	80	2136	171	14.63	31.20
PEPRILUS TRIACANTHUS	5	173	12298	1.00	0.0000	173	12298	396	25.89	56.41
PERCA FLAVESCENS	1	33	1058	1.00	0.0000	33	1058	96	14.70	42.83
POGONIAS CROMIS	1	27	684	1.00	0.0000	27	684	78	30.67	88.90
PORICHTHYS PLECTRODON	2	63	1956	1.00	0.0000	63	1956	158	58.60	128.22
PRIONOTUS CAROLINUS	15	501	29321	1.00	0.0000	501	29321	737	0.60	1.00
SCIAENGPS OCELLATUS	3	105	3656	1.00	0.0000	105	3656	224	0.18	0.38
STRONGYLURA MARINA	6	174	6337	1.00	0.0000	174	6337	338	0.20	0.38
SYNGNATHUS FUSCUS	36	1244	76966	1.00	0.0000	1244	76966	1788	2.58	3.59
SYNODUS FOETENS	53	1872	239356	1.00	0.0000	1872	239356	2528	3.78	4.98
UROPHYCIS REGIUS	46	1564	405483	1.00	0.0000	1564	405483	2812	156.98	282.89
TOTAL FOR FINFISH	35132	1183343				296936		534864	22529.83	37379.43
CALLINECTES SAPIDUS	15227	472921	26093492B5	0.00	0.0000	2175	58982	2618	744.76	896.27
OVERALL TOTAL	50359	1576264				299111		537482	23273.79	38275.71

Table V-3. Abundance, mortality, and monetary value of finfish and blue crabs impinged at the Calvert Cliffs Nuclear Power Plant, Maryland, during 1979.

1979

SPECIES	NUMBER CAUGHT	ESTIMATED ABUNDANCE	VARIANCE OF ABUNDANCE	MORTALITY	VAR OF MORT	ESTIMATED # DEAD	VARIANCE OF # DEAD	UPPER LIMIT OF # DEAD	ESTIMATED COST	UPPER LIMIT OF COST
ALOSA AESTIVALIS	3616	133285	1432566812	0.47	0.0037	62644	376883435	190694	6300.35	10140.11
ALOSA PSEUDOHARENGUS	762	28249	42898816	0.37	0.0119	10452	17893523	18743	1839.23	3369.48
ANCHOA MITCHILLI	10735	251767	2791470562	0.27	0.0016	67977	300450447	101951	69.59	107.87
ANCYLOPSETTA TYRANNUS	2187	62930	85587788	0.40	0.0051	25112	33454491	36509	4840.55	7029.51
BAIROSOMA CEPEDIANUM	1053	38791	272267070	0.24	0.0012	9318	11161553	17429	552.77	1034.87
BRYOSTOMUS RANINUBUS	2536	56171	217299991	0.11	0.0003	6179	3518694	9851	1171.66	1788.32
MENIDIA MENIDIA	672	22008	13021258	0.41	0.0102	9055	1032430	14254	14.36	22.48
MICROPOGON UNDULATUS	1852	43869	1713193926	0.98	0.0012	39462	100492794	59130	5922.00	8869.06
PARALICHTHYS DENTATUS	168	4140	660169	0.09	0.0001	373	6998	537	204.71	294.88
PSEUDOPLEURONECTES AMERICANUS	1459	50854	389258336	0.08	0.0001	4065	2118948	7295	647.43	1169.99
TRINECTES MACULATUS	5229	142145	534609352	0.01	0.0000	1023	71711	1358	48.11	64.33
ANGUILLA ROSTRATA	2	65	1896	1.00	0.0000	65	1896	158	14.88	32.38
APELTES QUADRACUS	2	78	2362	1.00	0.0000	78	2362	165	0.00	0.00
CHASMODES BOSQUIANUS	1	39	1494	1.00	0.0000	39	1494	115	0.04	0.12
CONGER OCEANICUS	1	39	1494	1.00	0.0000	39	1494	115	0.00	0.00
CYNOSCION REGALIS	108	3458	323940	1.00	0.0000	3458	323940	4574	1845.58	1305.44
CYPRINODON VARIEGATUS	8	189	4144	1.00	0.0000	189	4144	315	1.02	0.03
ESOX NIGER	1	37	1347	1.00	0.0000	37	1347	189	19.00	55.94
FUNDULUS DIAPHANUS	9	260	12170	1.00	0.0000	260	12170	476	5.00	9.16
FUNDULUS MAJALIS	1	18	296	1.00	0.0000	18	296	52	0.00	0.00
GASTEROSTEUS ACULEATUS	784	7454	3789751	1.00	0.0000	7454	3789751	11089	7.00	10.34
GOBIOSOMA BOSCI	11	418	10174	1.00	0.0000	418	10174	616	0.00	0.00
GORTOSOMA ROSCI	1	39	1494	1.00	0.0000	39	1494	115	0.04	0.12
HYPSOPLEGIUS HENTZI	31	611	14918	1.00	0.0000	611	14918	850	0.47	0.65
ICTALURUS PUNCTATUS	1	35	1220	1.00	0.0000	35	1220	103	11.00	32.52
LEPOMIS GIBBOSUS	2	65	2130	1.00	0.0000	65	2130	155	17.00	40.66
MORONE AMERICANA	29	982	41856	1.00	0.0000	982	41856	1299	270.36	462.36
MORONE SAXATILIS	5	144	4072	1.00	0.0000	144	4072	269	126.00	235.44
OPSANUS TAU	64	1383	111551	1.00	0.0000	1383	111551	2034	2.04	3.01
PEPRILUS ALEPIDOTUS	109	3371	1259696	1.00	0.0000	3371	1259696	5597	851.14	1423.11
PEPRILUS TRIACANTHUS	13	471	99346	1.00	0.0000	471	29346	1089	137.43	194.11
PORICHTHYS POROSISSIMUS	1	20	377	1.00	0.0004	29	327	58	18.00	87.00
PRIONOTUS CAROLINUS	3	55	916	1.00	0.0000	55	916	114	29.00	58.20
SCOPHTHALMUS AQUOSUS	8	148	3427	1.00	0.0000	148	3427	263	0.00	0.00
SPHOEROIDES MACULATUS	2	44	958	1.00	0.0000	44	958	105	0.54	0.10
SYNGNATHUS FLORIDAE	1	18	296	1.00	0.0000	18	296	52	1.69	20.32
SYNGNATHUS FUSCUS	1	18	322	1.00	0.0000	18	327	53	0.00	0.00
SYNODUS FOETENS	39	912	28936	1.00	0.0000	912	28936	1245	1.04	1.42
URophycis regius	2	63	3795	1.00	0.0000	63	3795	194	0.00	0.00
	22	558	25552	1.00	0.0000	558	25552	873	44.00	60.11
TOTAL FOR FINFISH	38857	855193				256648		399897	24236.65	39841.29
CALLINECTES SAPIDUS	36829	1118499	8742497435	0.00	0.0000	5145	144991	5988	1984.28	2716.29
OVERALL TOTAL	47344	1973692				261793		405885	26220.93	42557.

An estimated total of 218,034 finfish was killed by impingement in 1977, of which 77.5% was accounted for by anchovy, menhaden and weakfish.

The estimated monetary value of finfishes killed by impingement in 1977 is $22,846; 78.2% of this figure is accounted for by weakfish, menhaden and spot. If a survival rate of 38.61% is assumed for weakfish the total would be reduced by $3,338. The approximate 95% upper confidence limit on total monetary value of finfish lost through impingement is $36,030, a value 57.7% greater than the estimated total of $22,846.

In addition to the finfish impinged in 1977, 16,307 blue crabs were collected yielding an estimate of 397,060 individual blue crabs impinged during the year (Table V-1). Of these, an estimated 1826 crabs were killed, with a monetary value of $607. The approximate 95% upper confidence limit of the number of crabs killed is 2140, with a corresponding value of $711.

Thus, in 1977, an estimated 1,238,991 individual finfish and blue crabs were impinged; an estimated 219,861 of these were killed, with an approximate 95% upper confidence limit of 347,186 individuals killed. The estimated total monetary loss in 1977 is $23,453, with an approximate 95% upper confidence limit of $36,741.

In 1978, more than 100,000 individuals from five finfish species were estimated as impinged (bay anchovy, menhaden, hogchoker, Atlantic silversides, and spot) (Table V-2). These five species represent 94.2% of the total impingement estimate of 1,103,343 finfish. Three species (anchovy, menhaden, and silversides) represent 80.3% of the estimated 296,936 finfish killed.

Monetary loss due to impinged finfish in 1978 is an estimated $22,529. Menhaden account for 65.3% of this figure, with spot and croaker representing an additional 22.2%. The approximate 95% upper confidence limit for monetary loss in 1978 is $37,379, a value 65.9% greater than the value above.

In addition to the finfish impinged in 1978, 15,227 blue crabs were collected yielding an estimate of 472,921 blue crabs impinged (Table V-2). Of these, an estimated 2175 crabs were killed with a monetary value of $745. The approximate 95% upper confidence limit of the number killed is 2618, with a corresponding value of $896.

Thus, in 1978, a total of 1,576,264 finfish and crabs was estimated an impinged; an estimated 299,111 of these were killed with an approximate 95% upper confidence limit of 537,482 individuals killed. The estimated total monetary loss in 1978 is $23,274, with an approximate 95% upper confidence limit of $38,276.

In 1979, impingement estimates for bay anchovy, hogchokers, and blueback herring were the highest of all species considered, representing 61.6% of the estimated 855,193 finfish impinged (Table V-3). The three species with the largest estimated numbers killed are bay anchovy, blueback herring and croaker; these three species represent 66.3% of the estimated total (256,640).

The estimated monetary value of finfish lost through impingement in 1979 is $24,237; three species (blueback herring, croaker and menhaden) represent 70.4% of this total. The approximate 95% upper confidence limit on the monetary loss is $38,041, a figure 57.0% greater than the value above.

In addition to the finfish impinged in 1979, 36,879 blue crabs were collected yielding an estimate of 1,118,499 individual blue crabs impinged (Table V-3). Of these, an estimated 5145 were killed with a monetary value of $1904. The approximate 95% upper confidence limit of the number killed is 5988, with a corresponding value of $2216.

Thus, an estimated 1,973,692 individual finfish and blue crabs were impinged in 1979; an estimated 261,785 of these were killed by impingement, with an approximate 95% upper confidence limit of 405,885 individuals killed. The estimated total monetary loss in 1979 is $26,141, with an approximate 95% upper confidence limit of $40,258.

The estimated yearly costs of finfish killed by impingement for the years 1977-1979 are very similar, differing by less than $2,000. Although approximately 250,000 more finfish were estimated as impinged in 1978 than in 1977 or 1979, more than half of the increase was Atlantic silversides. Since this species has a low monetary value, the cost estimate for 1978 is similar to that for the other two years.

Four species (bay anchovy, hogchoker, menhaden and spot) were ranked in the top five species in estimated abundance in all three years. Of these, only menhaden and spot contributed substantially to the monetary loss estimated for this period. Other species of substantial monetary importance (>$1,500 in one or two of the three years) include blueback herring, croaker, alewife, weakfish and bluefish.

A composite year at the CCNPP based upon three-year averages of finfish impingement values would yield 31,214 individuals collected during actual impingement samples, with a total yearly estimated impingement of 933,496 individuals. Of these, an estimated 257,204 would be killed with a monetary value of $23,204. An expected approximate 95% upper confidence limit on the number killed by impingement would be 426,602, with a monetary value of $37,150.

Similarly, inclusion of blue crabs in the totals yields an average of 54,018 individual finfish and blue crabs collected during impingement samples, with a total yearly estimated impingement of 1,596,316 individuals. Of these, an estimated 260,252 would be killed with a monetary value of $24,289. An expected approximate 95% upper confidence limit on the total number killed by impingement would be 430,184, with a monetary value of $38,425.

Conclusions

In 1977, 43,959 finfish and blue crabs were collected in impingement samples, yielding an estimate of 1,238,991 individuals impinged. Bay anchovy, spot, and hogchokers represent 70.6% of the estimated 841,931 finfish impinged. An estimated 219,861 finfish and blue crabs were killed by impingement. Anchovy, menhaden, and weakfish represent 77.5% of the estimated 218,034 finfish killed by impingement. The monetary value of finfish and blue crabs estimated as killed in 1977 is $23,453, with a 95% upper confidence limit of $36,741.

In 1978, 50,359 finfish and blue crabs were collected during impingement samples, yielding an estimate of 1,576,264 individuals impinged. Bay anchovy, menhaden, hogchoker, Atlantic silversides, and spot represent 94.2% of the estimated 1,103,343 finfish impinged. An estimated 299,111 finfish and blue crabs were killed by impingement. Anchovy, menhaden, and silversides represent 80.3% of the estimated 294 936 finfish killed by impingement. The monetary value of finfish and blue crabs estimated as killed in 1978 is $23,274, with a 95% upper confidence limit of $38,276.

In 1979, 67,736 finfish and blue crabs were collected in impingement samples, yielding an estimate of 1,973,692 individuals impinged. Bay anchovy, hogchoker, and blueback herring represent 61.6% of the estimated 855,193 finfish impinged. An estimated 231,785 finfish and blue crabs were killed by impingement. Bay anchovy, blueback herring, and croaker represent 66.3% of the estimated 256,640 killed by impingement. The monetary value of finfish and blue crabs estimated as killed in 1979 is $26,141, with a 95% upper confidence limit of $40,258.

In a composite year at the CCNPP, based on three-year averages, 54,018 finfish and blue crabs would be collected during impingement samples, with an estimated abundance of 1,596,316 individuals. Of these 260,252 would be killed with an expected approximate 95% upper confidence limit on the total number killed by impingement of 430,184.

Thus, in a typical year at the CCNPP, the expected monetary loss due to impingement of finfish and blue crabs would be $24,289, with an expected approximate 95% upper confidence limit of $34,425.

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VI. APPENDICES

Appendix A. Oxygen flux determinations of net photosynthesis, respiration and gross photosynthesis at the Calvert Cliffs Nuclear Power Plant, 1977-1980.

Table A-1. Oxygen flux (in mg O m^{-3} h^{-1}) at stations sampled during entrainment studies at Calvert Cliffs Nuclear Power Plant, June through September 1977. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

June 7, 1977				July 12, 1977				August 9, 1977				September 13, 1977			
Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI
Net Photosynthesis															
1331	-49.59	-99.17	-49.58	1145	81.82	-9.23	-91.05	1000	87.02	-189.47	-274.49	1000	-93.83	-4.92	88.91
1344	-36.68	-15.65	21.03	1150	23.17	-32.94	-56.11	1100	75.00	-88.16	-163.16	1100	-147.04	-23.72	123.32
1355	-38.53	-104.11	-65.58	1200	-38.55	48.98	87.53	1200	65.00	-49.38	-114.38	1200	-49.38	-75.00	-25.62
1510	-39.83	-88.52	-48.69	1341	-72.00	-4.88	67.12	1300	*	*		1300	-30.00	-25.21	4.79
1521	5.22	-66.95	-72.17	1347	-108.20	0.00	108.20	1400	274.58	20.08	-254.50	1400	39.67	-70.29	-109.96
1529	16.22	-82.57	-98.79	1353	0.00	-5.13	-5.13	1510	291.21	69.71	-221.50	1500	-196.64	*	
Respiration															
1331	94.21	123.97	29.76	1145	127.27	184.62	57.35	1000	370.96	257.49	-113.50	1000	217.28	108.20	-109.08
1344	47.16	104.35	57.19	1150	148.26	202.35	54.09	1100	375.00	235.10	-139.90	1100	303.56	132.81	-170.75
1355	82.57	164.38	81.81	1200	183.13	122.45	-60.68	1200	220.00	296.30	76.30	1200	98.77	185.00	86.23
1510	79.67	172.13	92.46	1341	81.60	141.46	59.85	1300	130.00	322.31	192.31	1300	130.00	206.72	76.72
1521	93.91	87.55	-6.36	1347	167.21	105.00	-62.21	1400	122.03	266.11	144.08	1400	29.75	160.67	130.92
1529	21.62	71.56	49.94	1353	126.05	92.31	-33.74	1500	156.63	224.07	73.44	1500	252.10	52.40	-199.70
Gross Photosynthesis															
1331	44.63	24.79	-19.84	1145	209.09	175.38	-33.71	1000	458.02	68.02	-390.00	1000	123.46	103.28	-20.18
1344	10.48	88.70	78.22	1150	171.43	169.41	-2.02	1100	450.00	146.94	-303.06	1100	156.52	109.09	-47.43
1355	44.04	60.27	16.23	1200	144.58	171.43	26.85	1200	285.03	246.91	-38.03	1200	49.38	110.00	60.62
1510	39.83	83.61	43.78	1341	9.60	136.59	126.99	1300	*	*		1300	100.00	181.51	81.51
1521	99.13	20.60	-78.53	1347	59.02	105.00	45.98	1400	396.61	286.19	-110.42	1400	69.42	90.38	20.96
1529	37.84	-11.61	-49.85	1353	126.05	87.18	-38.87	1500	441.84	293.78	-148.06	1500	55.46	*	

* indicates missing data

Table A-2. Oxygen flux (in mg O m^{-3} h^{-1}) at stations sampled during entrainment studies at Calvert Cliffs Nuclear Power Plant, June through September 1978. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

June 13, 1978				July 11, 1978				August 8, 1978				September 12, 1978			
Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI
Net Photosynthesis															
0800	205.2	195.6	-9.6	0800	126.5	-14.4	-140.9								
0900	242.9	164.1	-78.8	0900	281.3	81.9	-199.4	0900	77.9	-4.8	-82.7	0800	-147.5	-195.9	-48.4
1000	62.2	-351.2	-413.4	1000	275.8	105.5	-170.3	1000	-4.8	-47.8	-43.0	0900	-82.6	-58.5	-24.1
1100	410.4	384.2	-26.2	1100	234.3	106.9	-127.4	1100	-24.0	-48.6	-24.6	1000	151.0	-84.4	-245.4
1200	421.3	220.0	-201.3	1200	205.0	159.0	-46.0	1200	75.9	-84.7	-160.6	1100	878.0	43.2	-834.8
1300	308.9	237.0	-71.9	1300	196.7	-200.0	3.3	1300	15.3	-20.1	-35.4	1200	791.3	-134.4	-926.1
1400	355.4	190.2	-165.2	1400	223.7	241.0	17.3	1400	0.0	-97.2	-97.2	1300	697.0	277.7	-419.3
1500	388.0	197.5	-110.5	1500	206.0	138.8	-67.2	1500	-10.3	-85.0	-74.7	1400	473.0	174.3	-298.7
												1500	280.2	74.6	-205.6
Respiration															
0800	100.6	56.4	-44.2	0800	43.6	105.6	62.0								
0900	123.8	107.8	-16.0	0900	44.0	57.8	13.8	0900	35.0	72.0	37.0	0800	147.5	176.3	28.8
1000	261.1	609.8	348.7	1000	77.4	0.0	-77.4	1000	101.6	47.8	-53.8	0900	131.2	102.4	-28.8
1100	176.6	132.8	-43.8	1100	100.4	43.7	-56.7	1100	216.0	72.9	-143.1	1000	78.0	-285.9	-363.9
1200	53.3	100.0	46.7	1200	35.0	0.0	-35.0	1200	75.5	139.4	63.5	1100	287.8	192.0	-95.8
1300	91.1	74.1	-17.0	1300	93.4	-15.0	-108.4	1300	-10.2	50.1	60.3	1200	199.2	99.6	-99.6
1400	-5.2	63.4	68.6	1400	50.8	41.0	-9.8	1400	0.0	145.7	145.7	1300	0.0	133.9	133.9
1500	74.3	86.1	11.8	1500	183.0	99.2	3.6	1500	56.4	94.5	38.1	1400	149.4	204.1	54.7
												1500	237.6	178.0	-59.6
Gross Photosynthesis															
0800	305.8	252.0	-53.8	0800	170.2	91.2	-79.0								
0900	366.7	271.9	-94.8	0900	325.3	139.8	-185.5	0900	113.0	67.2	-45.8	0800	0.0	-19.6	19.6
1000	323.3	258.6	-64.8	1000	353.2	114.3	-238.9	1000	96.8	0.0	-96.8	0900	48.5	43.9	-4.6
1100	587.0	517.0	-70.0	1100	334.7	150.6	-184.1	1100	192.0	24.3	-167.7	1000	239.0	-370.3	-609.3
1200	474.7	320.0	-154.7	1200	240.0	169.2	-70.8	1200	151.9	54.8	-97.1	1100	1165.9	235.2	-930.7
1300	400.0	311.1	-88.9	1300	290.2	185.0	-105.2	1300	5.1	30.0	24.9	1200	990.9	-34.8	-1025.7
1400	350.2	253.7	-96.5	1400	274.6	282.1	7.5	1400	0.0	48.6	48.6	1300	697.1	411.6	-285.5
1500	382.3	283.5	-98.8	1500	309.0	238.0	-71.0	1500	46.2	0.0	-46.2	1400	622.4	378.4	-244.0
												1500	517.8	252.6	-265.2

* indicates missing data

Table A-3. Oxygen flux (in mg O m^{-3} h^{-1}) at stations sampled during entrainment studies at Calvert Cliffs Nuclear Power Plant, June through September 1979. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

June 5, 1979				July 10, 1979				August 14, 1979				September 18, 1979			
Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI
Net Photosynthesis															
0820	-82.1	-14.0	68.1	0800	0.0	-385.0	-385.0	0830	-6.5	-350.0	-343.5	†0830	22.1	-13.8	-35.9
0900	-93.2	117.6	210.8	0900	49.6	-4.0	-53.6	0930	-430.0	-263.4	166.6	0930	70.1	-78.4	-148.5
1000	-35.6	91.6	127.2	1000	128.9	10.0	-118.9	1030	-395.5	-315.0	44.5	†1030	39.3	-203.9	-243.2
1100	44.6	-19.6	-64.2	1100	199.2	65.0	-134.2	1200	-212.3	-20.0	192.3	1130	-269.8	274.3	544.1
1200	-40.5	125.0	165.5	1200	75.6	75.0	-0.6	1240	87.4	-60.0	-147.4	†1230	-50.4	50.8	101.2
1300	-15.1	645.0	660.1	1300	126.0	-25.0	-151.0	1330	160.3	-185.0	-345.3	1330	244.9	-104.6	-349.5
1420	0.0	30.0	30.0	1400	77.6	145.0	67.4	1430	110.6	242.4	131.8	†1430	138.3	81.2	-57.1
1500	15.0	-35.0	-56.6	1500	208.1	100.0	-108.1	1530	38.7	241.7	203.0	1530	331.6	-127.7	-459.3
Respiration															
0820	53.6	140.1	86.5	0800	35.0	370.0	335.0	0830	192.9	320.0	127.1	†0830	90.3	325.8	235.5
0900	97.3	39.2	-58.1	0900	74.3	115.0	41.7	0930	519.9	443.9	-76.0	0930	74.5	289.0	214.5
1000	40.7	81.9	41.2	1000	69.4	125.0	56.6	1030	485.8	470.0	-158.0	†1030	77.3	380.1	302.8
1100	74.4	276.3	101.9	1100	97.2	0.0	-97.2	1200	389.9	315.6	-74.9	1130	502.3	*	
1200	141.8	95.0	46.8	1200	65.5	5.0	-60.5	1240	164.6	275.0	90.4	†1230	206.8	228.1	21.3
1300	105.9	-500.0	-605.9	1300	30.3	135.0	104.7	1330	99.6	355.0	255.4	1330	-18.4	129.2	147.6
1420	70.0	115.0	45.0	1400	51.7	-90.0	-141.7	1430	331.8	-5.9	-337.7	†1430	16.4	341.8	325.4
1500	45.0	135.0	90.0	1500	76.3	45.0	-31.3	1530	286.5	83.3	-203.2	1530	-157.9	561.7	719.6
Gross Photosynthesis															
0820	-28.6	126.1	154.7	0800	35.0	-15.8	-50.0	0830	186.4	-30.0	-216.4	†0830	112.4	312.0	199.6
0900	0.0	156.9	156.9	0900	124.0	75.0	-49.0	0930	89.9	180.5	90.6	0930	144.6	210.6	66.0
1000	0.0	173.5	173.5	1000	198.3	135.0	-63.3	1030	126.3	155.0	28.7	†1030	146.6	176.2	59.6
1100	119.0	156.7	37.7	1100	296.4	65.0	-231.4	1200	177.6	295.0	117.4	1130	232.5	*	
1200	101.3	220.0	118.7	1200	141.2	80.0	-61.2	1240	272.1	215.0	-57.1	†1230	156.4	278.9	122.5
1300	90.8	145.0	54.2	1300	156.3	110.0	-46.3	1330	259.9	170.0	-89.9	1330	226.5	24.6	-201.9
1420	70.0	145.0	75.0	1400	129.3	55.0	-74.3	1430	442.4	236.5	-205.9	†1430	154.7	423.0	268.3
1500	60.0	100.0	40.0	1500	284.4	145.0	-139.4	1530	325.2	325.0	-0.2	1530	173.7	434.0	260.3

† indicates means of two replicates
* indicates missing data

Table A-4. Oxygen flux (in mg O m^{-3} h^{-1}) at stations sampled during entrainment studies at Calvert Cliffs Nuclear Power Plant, June through September 1980. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

June 3, 1980				July 9, 1980				August 14, 1980				September 3, 1980			
Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI
Net Photosynthesis															
0830	-137.9	-224.8	-86.9	0730	50.5	-71.8	-122.3	0730	84.8	60.3	-24.5	0800	348.4	168.0	-180.4
0930	-28.7	-39.1	-10.4	0830	52.0	-15.6	-67.6	0830	62.2	-4.8	-67.0	0900	*	-113.6	
1030	-227.0	-59.0	168.0	0930	98.1	-47.2	-145.3	0930	4.6	-19.2	-23.8	1000	*	197.5	
1130	-18.4	-54.7	-36.3	1030	224.1	-76.0	-300.1	1030	27.1	-103.0	-130.1	1100	723.9	145.8	-578.1
1230	-22.6	8.4	31.0	1130	222.4	-126.8	-349.2	1130	118.8	-160.5	-279.3	1200	736.6	286.0	-450.6
1330	-17.4	37.8	55.2	1230	180.9	24.3	-156.6	1230	126.3	-97.4	-223.7	1300	625.2	183.8	-441.4
1430	261.2	136.0	-125.2	1330	215.0	-32.3	-247.3	1330	170.8	-52.4	-223.2	1400	*	180.8	
				1430	185.6	103.3	-82.3	1430	178.5	-46.8	-225.3	1500	533.3	110.8	-422.5
Respiration															
0830	179.3	285.0	105.7	0730	50.5	173.2	122.7	0730	97.5	-60.3	-157.8	0800	96.8	177.6	80.8
0930	109.3	113.4	4.3	0830	85.5	269.7	184.2	0830	-	52.8		0900	150.6	286.4	135.8
1030	389.2	78.7	-310.5	0930	93.4	165.3	71.9	0930	129.7	134.4	4.7	1000	150.6	187.7	37.1
1130	128.6	23.5	-105.3	1030	74.7	280.0	205.3	1030	98.2	257.5	567.3	1100	257.5	136.0	-121.5
1230	94.7	58.5	-36.2	1130	31.0	-25.4	-56.4	1130	98.3	216.3	118.0	1200	209.8	275.7	65.9
1330	144.9	-14.2	-159.1	1230	39.7	352.7	313.0	1230	*	235.9		1300	186.6	156.8	-29.8
1430	24.5	35.5	11.0	1330	20.0	*		1330	60.0	219.1	159.1	1400	*	235.6	
				1430	26.5	54.1	27.6	1430	134.1	223.4	109.3	1500	80.0	203.1	123.1
Gross Photosynthesis															
0830	41.4	60.2	18.8	0730	101.0	101.4	0.4	0730	182.0	0.0	-182.0	0800	445.2	345.6	-99.6
0930	80.4	74.3	-6.1	0830	137.5	254.1	116.6	0830	*	48.0		0900	*	172.8	
1030	162.2	19.7	-142.5	0930	191.4	118.0	-73.4	0930	134.4	115.2	-19.2	1000	*	385.2	
1130	110.4	-31.3	-141.7	1030	298.8	204.0	-94.8	1030	117.3	154.5	37.2	1100	981.4	281.8	-699.6
1230	72.2	66.9	-5.3	1130	253.5	-152.1	-405.6	1130	217.1	55.8	-161.3	1200	946.3	561.7	-384.6
1330	127.5	23.6	-103.9	1230	220.6	377.0	156.4	1230	*	138.5		1300	811.8	340.5	-471.2
1430	285.7	171.4	-114.3	1330	235.0	*		1330	230.8	166.7	-64.1	1400	*	416.4	
				1430	212.2	157.4	-54.8	1430	292.6	176.5	-115.9	1500	613.3	313.9	-299.5

* indicates missing data

Appendix B. Phytoplankton production rates as measured by ^{14}C fixation at the Calvert Cliffs Nuclear Power Plant, 1978-1980.

Table B-1. Phytoplankton production rates (mg C m^{-3} h^{-1}) as measured by ^{14}C fixation during entrainment studies at Calvert Cliffs Nuclear Power Plant, June through September 1978.

June 13, 1978				July 11, 1978				August 8, 1978				September 19, 1978			
Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI
0500	107.9		-	0800	40.4	31.5	-8.9	0830	18.5	14.1	-4.4	0800	7.8	2.1	-5.7
0830	95.5	93.5	-2.0	0830	55.9	34.5	-21.4	0900	18.3	13.6	-4.7	0830	10.0	1.4	-8.6
0900	71.3	119.0	+45.7	0900	51.8	39.6	-12.3	0930	15.1	14.8	+0.8	0900	10.1	4.5	-5.8
0930	79.9	77.7	-2.2	0930	58.9	44.7	-14.2	1000	15.1	8.5	-6.6	0930	17.5	4.5	-13.0
1000	75.7	80.0	+4.3	1000	63.7	40.3	-23.4	1030	16.0	7.6	-8.4	1000	24.7	7.0	-17.7
1030	140.0	66.7	-73.3	1030	52.3	39.9	-12.4	1100	10.1	7.4	-2.7	1030	44.0	6.9	-37.1
1100	163.1	178.1	+15.0	1100	63.3	42.9	-20.4	1200	8.6	7.5	-1.1	1100	199.5	26.5	-173.0
1130	157.0	118.8	-38.2	1130	49.0	35.0	-14.0	1220	10.6	9.1	-1.5	1130	288.4	41.7	-246.7
1215	134.4	101.2	-33.2	1200	56.1	49.4	-6.7	1240	11.2	11.6	+0.4	1200	172.9	41.2	-131.7
1230	130.1	71.2	-58.9	1230	56.1	32.0	-24.1	1300	10.5	9.2	-1.3	1230	109.0	51.5	-57.5
1300		89.5	-	1300	58.1	49.4	-8.7	1330	9.7	8.8	-0.9	1300	123.2	30.8	-92.4
1330	123.0	89.1	-33.9	1330	48.1		-	1400	11.6	9.2	-2.4	1330	149.4	41.5	-107.9
1400	100.4	66.1	-34.3	1400	48.8	33.7	-15.1	1430	10.7	7.1	-3.6	1400	141.5	38.2	-103.3
1430	100.4	75.4	-25.0	1430	47.6	25.0	-22.6	1500	9.5	5.4	-4.1	1500	68.1	10.2	-57.9
1500	87.3	71.4	-15.9	1500	37.3	45.5	+8.2								

PSI = Plant Site Intake
PSD = Plant Site Discharge
(+) = stimulation
(-) = depression

Table B-2. Phytoplankton production rates (mg C m^{-3} h^{-1}) as measured by ^{14}C fixation during entrainment studies at Calvert Cliffs Nuclear Power Plant, June through September 1979.

June 5, 1979				July 10, 1979				August 14, 1979				September 19, 1979			
Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI
0820	8.90	16.56	+7.66	0800	12.88	6.21	-6.67	0830	20.65	11.67	-8.98	0830	11.66	16.96	+5.30
0840	4.61	18.29	+13.68	0830	9.39	10.01	+0.62	0900	7.65	11.24	+3.59	0900	8.64	13.64	+5.00
0900	12.82	17.26	+4.44	0900	11.06	5.77	-5.29	0930	9.55	11.89	+2.34	0930	8.69	14.18	+5.49
0930	9.19	15.40	+6.21	0930	11.04	17.92	+6.88	1000	9.16	13.00	+3.84	1000	8.41	11.72	+3.31
1000	3.45	15.44	+11.99	1000	21.12	18.40	-7.72	1030	7.08	11.17	+4.13	1030	5.81	10.53	+3.70
1030	9.79	16.18	+6.39	1030	22.13	25.57	+3.44	1100	7.75	11.82	+4.03	1130	6.32	11.81	+4.84
1100	16.48	18.66	+2.18	1100	24.30	20.60	-3.70	1200	17.10	13.32	-3.78	1130	8.06	16.92	+8.86
1130	1.57	10.43	+8.86	1130	22.57	24.17	+1.60	1220	15.84	16.08	+0.24	1200	6.53	11.29	+4.76
1200	2.93	18.95	+16.02	1200	16.28	18.32	+2.12	1240	22.22	22.84	+0.62	1230	8.96	17.04	+8.92
1230	14.02	14.88	+0.86	1230	20.59	14.11	-6.59	1300	24.96	26.28	+1.32	1300	8.80	14.54	+5.74
1306	10.18	15.78	+5.60	1300	16.55	16.99	+0.43	1330	26.78	25.55	-1.23	1330	15.67	16.92	+1.25
1400	1.74	10.44	+8.74	1330	18.45	14.58	-3.87	1400	31.29	28.94	-2.35	1400	7.58	15.97	+8.39
1420	3.59	12.86	+9.27	1400	18.80	17.67	-1.13	1430	40.63	26.10	-14.53	1430	14.14	9.72	-4.42
1440	2.85	11.39	+8.54	1430	21.10	17.59	-3.51	1500	45.39	34.09	-11.30	1500	12.45	13.43	+0.98
1500	2.51	10.17	+7.66	1500	20.99	19.11	-1.88	1530	38.93	36.40	-2.53	1530	16.97	13.18	-3.79

PSI = Plant Site Intake
PSD = Plant Site Discharge
(+) = stimulation
(-) = depression

Table B-3. Phytoplankton production rates (mg C m^{-3} h^{-1}) as measured by ^{14}C fixation during entrainment studies at Calvert Cliffs Nuclear Power Plant, June through September 1980.

June 3, 1980				July 9, 1980				August 14, 1980				September 3, 1980			
Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD PSI	Time	PSI	PSD	PSD-PSI	Time	PSI	PSD	PSD-PSI
0830	9.0	11.9	+2.9	0730	9.2	25.5	+16.3	0730	0.5	13.1	+12.6	0800	51.2	49.3	-1.9
0900	10.3	12.5	+2.2	0800	13.7	14.2	+0.5	0800	28.3	13.4	-14.9	0830	73.5	49.8	-23.7
0930	10.6	10.2	-0.4	0830	11.1	39.1	+28.0	0830	17.9	17.8	-0.1	0900	61.7	52.7	-9.0
1000	11.1	11.6	+0.5	0915	13.3	44.5	+31.2	0900	19.2	27.1	+7.9	0930	78.6	47.0	-31.6
1030	14.4	15.3	+0.9	0935	15.0	39.1	+24.1	0930	6.8	14.2	+7.4	1000	70.7	50.2	-20.5
1100	15.2	16.8	+1.6	1000	35.4	50.6	+15.2	1000	7.0	19.2	+12.2	1030	115.9	50.7	-65.2
1130	*	18.9		1030	25.0	57.0	+32.0	1030	1.4	18.4	+17.0	1100	121.6	40.7	-80.9
1200	30.8	24.4	-6.4	1100	19.9	43.7	+23.8	1100	2.5	16.4	+13.5	1130	112.1	46.9	-65.2
1230	21.7	15.1	-6.6	1130	35.7	24.9	-10.8	1130	21.1	22.9	+1.8	1200	91.2	54.4	-36.8
1300	29.6	31.8	+2.2	1200	36.8	31.5	-5.3	1200	22.0	4.0	-18.0	1230	115.6	69.1	-46.5
1330	23.4	25.0	+1.6	1230	36.4	55.0	+18.6	1230	28.2	18.8	-9.4	1300	102.4	56.3	-46.1
1400	19.3	*		1300	55.3	68.8	+13.5	1300	26.0	11.7	-14.3	1330	97.7	52.2	-45.5
1430	27.8	*		1330	39.4	47.0	+7.6	1330	37.5	29.7	-7.8	1400	83.1	58.8	-24.3
1500	21.3	*		1400	29.0	58.3	+29.3	1400	43.6	16.9	-26.7	1430	75.6	55.5	-20.1
				1430	45.9	52.6	+2.7	1430	45.2	29.4	-15.8	1500	70.2	45.3	-24.9

* indicates missing data
PSI = Plant Site Intake
PSD = Plant Site Discharge
(+) = stimulation
(-) = depression

Appendix C. Species list of phytoplankton in samples collected at Calvert Cliffs Nuclear Power Plant during entrainment studies 1978-1980.

Appendix C. Species list of phytoplankton in entrainment samples collected at Calvert Cliffs Nuclear Power Plant during June, July, August and September 1978-1980. x=present; -=absent.

TAXONOMIC GROUP	1978 J J A S	1979 J J A S	1980 J J A S
PHYLUM CYANOPHYTA			
CLASS HYPHOMYCEAE			
ORDER NOSTOCALES			
FAMILY CHROOCOCCACEAE			
MICROCYSTIS CERUGINOSA (LAGERHEIM) DEFLER	- - - x	- - - -	- - - -
FAMILY OSCILLATORIACEAE			
MERISMOPEDIA TENUISSIMA LEMMERMANN	- - - -	- - - -	x x - -
SCHIZOTHRIX CALCICOLA (AGARDH) GOMONT	x - x -	- - - -	x x x - x
SPIRULINA SUBSALSA WEBER	x - - -	- - - -	- - - -
FAMILY NOSTOCACEAE			
ANABAENA SP	- - - -	- - - -	- - - x -
PHYLUM UNDETERMINED PHYLUM			
UNDETERMINED FLAGELLATE	x x x x	x x x x	x x x x x
PHYLUM CHRYSOPHYTA			
CLASS XANTHOPHYCEAE			
ORDER HETEROCHLORIDALES			
FAMILY HETEROCHLORIDACEAE			
ELAKATOTHRIX SP	- - - -	x - - -	- - - - x
CLASS CHRYSOPHYCEAE			
ORDER CHROMULINALES			
FAMILY CHROMULINACEAE			
ERYTHROPSIDINIUM DIVALIS WOLFE	- - x -	- - - -	- - - - -
CALYCIOMONAS SP	- - - -	x - - x	- - - x -
FAMILY PEDINELLACEAE			
APEDINELLA RADIANS (LEVANDER) CAMPBELL	- - - -	- x x -	- - - - x
APEDINELLA SP	- x - -	- - - -	- - - - -
PSEUDOPEDINELLA PYRIFORME CARTER	- - x x	- - x x -	- - - - x
ORDER OCHROMONADALES			
FAMILY OCHROMONADACEAE			
OCHROMONAS SP	- - x -	x - x x	- - x x x
CLASS SILICOFLAGELLATOPHYCEAE			
ORDER SILICOFLAGELLALES			
FAMILY DICTYOCHACEAE			
DICTYOCHA FIBULA EHRENBERG	- - x -	- - x x	- - - - x
ESUVIA SUBPASTELIA (SCHIMANSKI) LEMMERMANN	x - x x	x x x x	- - x x x
PHYLUM BACILLARIOPHYTA			
CLASS BACILLARIOPHYCEAE			
ORDER GENERIC DIATOMS			
CENTRIC DIATOMS	x x x x	x x x x	x x x x x
FAMILY COSCINODISCACEAE			
COSCINODISCACEAE	x x - -	- - - -	- - - -
COSCINODISCUS SP	x x x x	x x x x	- x x -
CYCLOTELLA CRYPTICA GRUNOW	- - - -	- - - -	- x x -
CYCLOTELLA SP	- x - -	- - - -	- x x -
MELOSIRA DISTANS (EHRENBERG) KUETZING	- - - -	x - - x	- - - -
SKELETONEMA COSTATUM (GREVILLE) CLEVE	x x x x	x x x x	x x x x x
SKELETONEMA POTAMOS (WEBER) HASLE	x x x x	x x - -	- - x x
THALASSIOSIRA SP	x x - -	- - x -	x - - -
FAMILY BIDDULPHIACEAE			
BIDDULPHIA TRIDENS (EHRENBERG) GRUNOW	- - - -	- x x -	- - - -
CERATAULINA BERGONII PERAGALLO	x x - -	x x - -	- - - x
[illegible]	- - - -	x - x -	- - - x

Appendix C (continued). Species list of phytoplankton in entrainment samples collected at Calvert Cliffs Nuclear Power Plant during June, July, August and September 1978-1980. x=present; -=absent.

TAXONOMIC GROUP	1978 J J A S	1979 J J A S	1980 J J J A S
FAMILY: CHAETOCERACEAE			
CHAETOCERUS SP.	x x x x	x x x x	x x x x x
FAMILY: RHIZOSOLENIACEAE			
RHIZOSOLENIA FRAGILISSIMA BERGON	- x - -	x x x -	x - - x
RHIZOSOLENIA SP.	- - - -	- - - -	- x - x
FAMILY: LEPTOCYLINDRACEAE			
LEPTOCYLINDRUS DANICUS CLEVE	- x - x	- - - -	- - - -
LEPTOCYLINDRUS MINIMUS GRAN	- - x x	- - x -	- - - - x
ORDER: PENNATE DIATOMS			
PENNATE DIATOMS	x x x x	x x x x	x x x x x
FAMILY: FRAGILARIACEAE			
ASTERIONELLOPSIS NITZSCHIOIDES (OSTENFELD VAN GOOR)	- - x x	- - - -	- - - x -
FAMILY: NAVICULACEAE			
NAVICULACEAE	x x - -	- - - x	- - - - -
ENTOMONEIS SP.	- x - x	x - - x	- - - - -
DIPLONEIS SP.	- - - x	- x - x	- - - - -
NAVICULA SP.	- - x -	- x - -	- - x - -
FAMILY: CYMBELLACEAE			
AMPHORA SP.	- - - -	- - - x	- - x x -
CYMBELLA SP.	x - - -	- - - -	- - - - -
FAMILY: NITZSCHIACEAE			
NITZSCHIACEAE	- - - -	x - - x	- - - - -
NITZSCHIA ACICULARIS W. SMITH	x x x -	- - - -	- - - - -
NITZSCHIA CLOSTERIUM (EHRENBERG) W. SMITH	x x x x	x x x x	- x - x
NITZSCHIA SERIATA CLEVE	- - x -	- x - -	- - - - -
NITZSCHIA SPATHULATA BREBISSON	- - x x	- - x -	- - - x -
NITZSCHIA SP.	- - x -	x x - x	x x x - -
PHYLUM: CRYPTOPHYTA			
CRYPTOPHYTA	x x x x	x x x x	x x x x x
CLASS: CRYPTOPHYCEAE			
ORDER: NOT NAMED			
FAMILY: CRYPTOMONADACEAE			
CRYPTOMONAS ACUTA BUTCHER	x x x x	x x x x	x x - x x
CRYPTOMONAS OVATA EHRENBERG	x x x -	x x x x	x x - x x
PHYLUM: PYRROPHYTA			
PYRROPHYTA	- x - -	- x x -	x x x - x
CLASS: DINOPHYCEAE			
DINOPHYCEAE	x x x x	x x x x	x x x - x
ORDER: GYMNODINIALES			
GYMNODINIUM SP.	x x x x	- - - -	- - - - -
FAMILY: GYMNODINIACEAE			
AMPHIDINIUM CHOANUM LEBOUR	- - x -	- - x -	- x - - -
AMPHIDINIUM SP.	- - x -	- x x -	- - x - x
GYMNODINIUM SP.	x x - -	- - - -	- - - - -
GYMNODINIUM FUSCIANUM (STEIN)	- - x -	- x x -	- - - - x
GYMNODINIUM SIMPLEX (LOHMANN) KOFOID & SWEZY	- x - -	- - - -	- - - - -
GYMNODINIUM SPLENDENS LEBOUR	- x - x	x x x x	- x x x x
GYMNODINIUM SP.	x x x x	x x x -	x x x x x
GYMNODINIUM ESTUARIALE SUBNOV	x x x x	x x x x	- - x x x
GYMNODINIUM SP.	- x x x	- x - -	x - - - -
EUGLENOPHYTA (EUGLENOPHYCEAE)	x x x x	x x x x	x x x x
FAMILY: EUGLENACEAE			

Appendix C (continued). Species list of phytoplankton in entrainment samples collected at Calvert Cliffs Nuclear Power Plant during June, July, August and September 1978-1980. x=present; -=absent.

TAXONOMIC GROUP	1978 J J A S	1979 J J A S	1980 J J J A S
POLYKRIKOS SCHWARTZII SCHILLER	- - - -	- - - x	- x - - -
POLYKRIKOS HERDLA CHATTON	- - x x	- x x -	- - - x x
POLYKRIKOS SP.	- - - -	x - - x	- - - - -
ORDER: PERIDINIALES			
PERIDINIALES	- x - -	- - - -	- - - - -
FAMILY: GLENODINIACEAE			
GLENODINIUM HOMUNCULUS (LEBOUR) SCHILLER	- - x x	x x x -	- x - - x
GLENODINIUM SP.	x x x x	x x x x	- - - x x
HETEROCAPSA TRIQUETRA (EHRENBERG) BIEHL	- - - -	- - - -	- x - -
FAMILY: GONYAULACACEAE			
GONYAULAX DIACANTHA (MEUNIER) SCHILLER	- x - -	- - - -	- x - -
GONYAULAX DIGITALE (PIENCH)	- - x x	x - - -	- - - - x
GONYAULAX SPINIFERA (CLAPARÈDE & LACHMANN)	- - x x	x x - -	- - - - x
GONYAULAX SP.	- - - x	- - - -	x x x - x
FAMILY: PERIDINIACEAE			
PERIDINIUM DEPRESSUM BAILEY	- - - x	- - - -	- x - - x
PERIDINIUM DIVERGENS EHRENBERG	- - - -	- - - x	- - - - -
PERIDINIUM TROCHOIDEUM (STEIN) LEMMERMANN	- - x x	- x x -	- - - - x
PERIDINIUM SP.	x x x -	- x - x	- - - - x
FAMILY: CRYPTOPHYCEAE			
CRYPTOMONAS SP.	- - x x	- x x -	- x x x x
PHYLUM: EUGLENOPHYTA			
EUGLENOPHYTA	- - x x	x x x x	- - - x x
CLASS: EUGLENOPHYCEAE			
ORDER: EUGLENALES			
FAMILY: EUGLENACEAE			
EUGLENA SP.	x x - -	- - - -	- x x - -
EUTREPTIELLA SP.	- - x -	- - - x	- - - x x
PHYLUM: CHLOROPHYTA			
CHLOROPHYTA	- - - -	- - x -	x - - - -
CLASS: CHLOROPHYCEAE			
ORDER: VOLVOCALES			
FAMILY: CHLAMYDOMONADACEAE			
CARTERIA SP.	- - - -	- - - -	- x - - -
ORDER: CHROOCOCCALES			
FAMILY: ROCYSTACEAE			
ANKISTRODESMUS FALCATUS (CORDA) RALFS	- - - -	x - - -	x x - x -
ANKISTRODESMUS SPIRALIS (TURNER) LEMMERMANN	x - - -	- - - -	- - - - -
NAEGELIELLA SP.	x - - -	- - - -	- - - - -
FAMILY: SCENEDESMACEAE			
SCENEDESMUS SP.	x - - -	- x - -	- - - - -
ORDER: ZYGNEMALES			
FAMILY: DESMIDIACEAE			
COSMARIUM REGNELLI REINSCH	- - - -	- - - -	- - - - x

Appendix D. Cell densities of phytoplankton collected during entrainment studies at the Calvert Cliffs Nuclear Power Plant, 1978.

Table D-1. Total phytoplankton cell densities (cells ml^{-1}) in entrainment samples from two stations at Calvert Cliffs Nuclear Power Plant, June through September 1978. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

Time	Jun 13-14		Jul 11-12		Aug 8-9		Sep 12-13	
	PSI	PSD	PSI	PSD	PSI	PSD	PSI	PSD
0800	9,468	18,633	12,508	11,136	4,063	3,553	2,256	2,298
0900	13,602	25,421	13,834	18,415	2,576	1,837	2,518	2,068
1000	15,755	22,581	15,[illegible]19	14,170	1,948	1,397	3,291	5,227
1100	11,385	21,397	14,044	13,508	2,283	-	5,082	4,498
1200	26,652	19,9[illegible]	15,353	16,664	2,129	2,359	4,908	4,232
1300	24,386	24,285	13,081	15,431	2,946	2,698	5,852	5,604
1400	21,776	22,818	15,306	12,624	2,885	2,290	7,446	8,849
1500	21,255	24,569	12,876	15,875	2,429	1,737	6,855	5,383
1600	30,676	28,782	16,316	-	5,340	2,737	6,393	5,923
1700	23,622	24,881	16,796	14,297	6,826	2,499	5,316	5,821
1800	27,173	30,360	19,819	14,486	5,868	5,961	6,245	4,870
1900	25,942	33,516	19,851	17,326	5,521	5,472	5,237	5,378
2000	28,846	-	[illegible]076	18,052	8,576	8,481	5,115	4,757
2100	34,132	-	15,496	15,664	6,393	6,983	5,829	5,397
2200	34,085	-	16,032	13,823	8,537	8,349	6,619	5,566
2300	30,013	-	16,316	15,843	7,672	7,446	7,898	6,927
2400	38,187	-	16,727	18,683	5,622	6,739	8,243	5,858
0100	39,244	-	16,666	17,673	3,247	4,302	7,051	6,795
0200	35,852	-	19,062	16,064	4,365	4,908	6,855	5,849
0300	33,706	-	14,993	16,095	4,239	5,810	6,795	5,359
0400	28,909	-	14,896	16,979	4,332	6,431	6,074	6,211
0500	27,733	-	18,683	12,845	6,356	6,262	5,359	6,983
0600	26,518	-	12,529	12,811	6,200	6,334	8,706	9,082
0700	25,895	-	13,824	14,612	[illegible]487	7,051	8,913	6,711

- No data available

Table D-2. Cell densities (cells ml^{-1}) of undetermined microflagellates in entrainment samples from two stations at Calvert Cliffs Nuclear Power Plant, June through September 1978. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

	Jun 13-14		Jul 11-12		Aug 8-9		Sep 12-13	
Time	PSI	PSD	PSI	PSD	PSI	PSD	PSI	PSD
0800	4,285	6,362	5,839	5,982	2,437	2,128	3,245	3,845
0900	5,279	5,468	5,782	5,302	1,382	1,210	3,326	3,247
1000	6,476	8,663	7,196	7,385	1,283	870	3,307	3,328
1100	6,284	6,533	6,249	5,879	1,351	-	1,859	2,121
1200	9,989	6,187	7,838	9,310	1,181	1,335	1,890	2,347
1300	9,847	9,687	7,376	5,302	1,008	1,495	1,841	2,858
1400	7,716	8,088	6,375	5,933	1,116	1,279	3,367	2,487
1500	8,568	8,852	6,387	7,069	1,376	965	2,256	2,539
1600	10,178	9,421	7,417	-	2,576	3,542	3,535	2,581
1700	7,161	7,480	7,132	5,302	2,595	1,220	1,809	2,424
1800	6,912	9,382	6,975	5,534	2,670	1,781	3,466	2,581
1900	8,581	9,781	6,312	6,363	2,355	2,388	2,529	1,378
2000	10,983	-	5,841	5,543	4,367	4,306	1,805	2,859
2100	9,657	-	5,428	4,829	2,921	2,200	2,783	2,867
2200	10,415	-	4,366	4,229	3,291	2,670	3,291	2,200
2300	10,699	-	5,270	3,756	3,291	2,700	3,460	1,974
2400	11,644	-	2,556	4,576	2,520	1,956	3,309	2,031
0100	14,249	-	3,503	4,608	1,216	2,046	3,906	2,444
0200	13,692	-	3,913	4,418	1,866	2,181	2,670	2,695
0300	11,634	-	4,040	3,503	1,695	2,463	2,021	3,197
0400	10,415	-	3,493	3,446	1,855	3,065	2,651	2,031
0500	9,468	-	3,588	2,241	3,272	2,839	2,727	2,896
0600	10,888	-	1,799	2,289	3,686	2,998	3,969	4,458
0700	10,120	-	2,462	2,746	3,836	4,381	4,927	2,581

- No data available

Table D-3. Cell densities (cells ml^{-1}) of diatoms (Bacillariophyta) in entrainment samples from two stations at Calvert Cliffs Nuclear Power Plant, June through September 1978. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

	Jun 13-14		Jul 11-12		Aug 8-9		Sep 12-13	
Time	PSI	PSD	PSI	PSD	PSI	PSD	PSI	PSD
0800	2,627	7,839	2,619	3,861	722	591	911	995
0900	4,829	9,941	3,692	2,556	804	295	978	658
1000	5,382	9,231	3,408	3,887	361	338	3,533	1,354
1100	4,000	6,349	4,792	4,734	338	-	959	1,354
1200	8,142	6,848	5,239	4,734	414	458	2,425	888
1300	6,912	7,385	5,833	7,543	444	414	1,335	1,347
1400	9,515	8,000	5,397	4,040	421	410	2,570	1,222
1500	7,385	9,610	4,576	5,302	504	589	2,050	1,504
1600	10,746	12,734	4,197	-	677	517	2,144	2,595
1700	10,795	10,983	4,671	3,913	677	526	1,824	1,956
1800	12,971	13,255	6,249	5,239	827	1,072	1,561	1,635
1900	13,255	15,843	6,596	4,923	985	721	1,492	1,523
2000	10,730	-	5,503	6,059	926	884	1,730	1,385
2100	17,384	-	4,734	5,744	470	470	2,974	2,539
2200	16,159	-	6,438	4,387	1,109	921	1,993	2,614
2300	11,740	-	4,671	6,596	526	790	3,197	2,012
2400	15,906	-	7,637	7,637	527	527	1,991	2,576
0100	15,338	-	7,764	6,932	338	436	2,162	1,880
0200	13,886	-	9,878	6,813	404	53	2,583	2,369
0300	11,614	-	6,843	8,237	582	921	1,241	1,316
0400	11,710	-	8,458	8,629	527	620	2,476	1,523
0500	12,758	-	11,295	8,868	715	484	1,856	2,933
0600	10,509	-	7,669	7,227	414	1,834	2,990	3,629
0700	10,983	-	9,910	8,426	658	658	2,990	3,272

- No data available

Table D-4. Cell densities (cells ml^{-1}) of Cryptophyta in entrainment samples from two stations at Calvert Cliffs Nuclear Power Plant, June through September 1978. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

	Jun 13-14		Jul 11-12		Aug 8-9		Sep 12-13	
Time	PSI	PSD	PSI	PSD	PSI	PSD	PSI	PSD
0800	852	1,212	1,314	1,862	496	387	92	58
0900	1,010	1,562	2,272	1,485	501	182	85	25
1000	1,553	1,450	1,324	1,830	345	70	157	845
1100	894	2,662	2,546	2,020	287	-	508	241
1200	1,373	1,304	1,894	1,546	865	850	244	241
1300	2,589	2,795	1,988	1,578	395	235	545	432
1400	1,231	2,367	2,304	1,925	187	217	564	338
1500	1,585	1,464	2,063	2,588	248	832	602	489
1600	2,130	1,420	3,724	-	235	254	338	226
1700	1,228	947	3,566	3,251	1,598	395	263	282
1800	1,326	1,199	4,892	2,651	903	1,410	320	188
1900	1,262	1,585	5,270	4,197	849	1,260	263	150
2000	1,641	-	4,040	4,797	1,748	1,373	226	113
2100	1,752	-	3,787	3,598	921	696	263	207
2200	1,010	-	3,850	4,103	717	1,241	282	226
2300	1,383	-	4,782	4,166	1,091	1,053	545	482
2400	1,073	-	4,923	4,734	735	581	395	38
0100	1,089	-	3,945	4,797	526	551	150	150
0200	1,585	-	3,472	3,188	350	735	244	263
0300	1,262	-	2,819	2,493	491	658	226	226
0400	1,767	-	3,777	3,345	454	790	301	169
0500	1,136	-	3,030	-	639	1,166	169	282
0600	1,278	-	2,241	1,925	921	809	207	395
0700	1,251	-	2,967	2,020	696	865	150	226

- No data available

Table D-5. Cell densities (cells ml^{-1}) of dinoflagellates (Pyrrophyta) in entrainment samples from two stations at Calvert Cliffs Nuclear Power Plant, June through September 1978. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

	Jun 13-14		Jul 11-12		Aug 8-9		Sep 12-13	
Time	PSI	PSD	PSI	PSD	PSI	PSD	PSI	PSD
0800	1,562	2,849	1,041	757	561	387	92	92
0900	2,146	3,977	1,262	928	432	325	313	325
1000	1,898	2,840	1,420	978	141	333	236	338
1100	1,704	5,586	1,294	789	253	-	1,542	757
1200	6,675	3,645	978	978	316	269	1,260	707
1300	4,450	5,428	1,294	978	218	451	1,297	1,072
1400	2,698	4,308	978	663	273	309	846	884
1500	3,174	5,977	852	821	226	150	1,015	755
1600	5,491	4,308	757	-	1,053	273	263	489
1700	7,314	3,882	1,999	1,389	1,692	476	527	520
1800	5,491	5,365	1,483	978	1,260	1,072	827	432
1900	6,734	5,870	1,452	1,673	1,236	921	677	527
2000	4,101	-	1,999	1,389	1,369	1,598	1,203	621
2100	4,450	-	1,429	1,168	1,786	1,504	752	489
2200	5,491	-	1,420	978	3,178	3,159	1,015	432
2300	5,018	-	1,810	1,168	2,653	2,482	671	671
2400	7,585	-	1,357	1,420	1,749	1,448	419	376
0100	7,906	-	1,326	1,231	1,328	1,343	752	301
0200	5,491	-	1,673	1,578	1,402	1,448	564	508
0300	6,312	-	1,326	1,736	1,475	1,430	470	602
0400	4,040	-	1,105	1,515	1,216	1,656	639	370
0500	3,724	-	1,673	1,610	1,674	1,711	451	677
0600	3,219	-	789	1,389	1,205	1,297	639	489
0700	2,840	-	1,610	1,294	1,091	997	489	621

- No data available

Appendix E. Cell densities of phytoplankton collected during entrainment studies at the Calvert Cliffs Nuclear Power Plant, 1979.

Table E-1. Total phytoplankton cell densities (cells ml^{-1}) in entrainment samples from two stations at Calvert Cliffs Nuclear Power Plant, June through September 1979. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

	June 5-6		July 10-11			August 14-15		September 18-19	
Time	PSI	PSD	PSI	PSD	Time	PSI	PSD	PSI	PSD
0920/					0830			2548	2366
0900	5611	5467	1956	3189	0930	5472	2247	1372	3042
1000	6926	6474	2614	2416	1030	4062	875	2744	2764
1100	6289	6782	2783	2031	1130	3788	2999	1802	3021
1200	4695	6248	4408	1918	1300	4739	2943	2162	3114
1300	6659	8159	3281	2804	1330	2837	2990	2703	2310
1500	2692	4373	3806	3560	1430	4137	3234	3052	2929
1600	4604	5200	4759	2717	1530	7108	4648	2579	2876
1700	4640	4969	4122	2868	1630	8386	5295	3186	2121
1800	5446	3521	4468	2369	1730	6807	7860	1911	2162
1900	5133	5857	3896	2670	1830	8405	8217	2559	2651
2000	6433	5508	3660	3723	1930	9891	7277	3672	3686
2100	4859	5672	3347	2450	2030	9759	6525	4110	2846
2200	4406	2857	4576	2604	2130	7371	5415	3103	3650
2300	6453	1562	3272	2633	2230	7653	5227	4165	2826
2400	7234	1609	4388	2999	2330	7860	3941	3836	3278
0100	5323	2062	4500	2426	0030	10210	4423	3973	2846
0200	7234	3961	4513	2016	0130	7239	5434	3093	2939
0300	5467	3100	3773	1705	0230	7352	5096	3836	3216
0400	7686	5734	3748	3485	0330	10944	7164	2939	2072
0500	6309	4390	3585	3322	0430	10981	5792	2285	2733
0600	6166	6351	4337	2144	0530	9834	6638	2121	1720
0700	6001	6330	4362	2151	0630	13670	7747	1290	1310
0800	6700	5405	2686	2651	0730	10605	8368	2600	2039
					0830	12561	7315		

Table E-2. Cell densities (cells ml^{-1}) of undetermined microflagellates in entrainment samples from two stations at Calvert Cliffs Nuclear Power Plant, June through September 1979. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

	June 5-6		July 10-11			August 14-15		September 18-19	
Time	PSI	PSD	PSI	PSD		PSI	PSD	PSI	PSD
0920/					0830			730	667
0900	1891	1233	652	522	0930	2388	865	462	771
1000	1809	1315	809	921	1030	1835	353	740	956
1100	1583	1233	1081	715	1130	1327	1363	240	596
1200	1096	1192	1564	782	1300	2162	1307	723	945
1300	1315	966	1589	1386	1330	1268	1072	832	617
1400	1907	1141	1880	2196	1430	1429	1232	596	493
1500	658	1036	1730	1667	1530	2388	1564	524	514
1600	1206	1233	2271	1269	1630	3178	1895	688	444
1700	1133	1425	2121	1373	1730	2200	2332	651	650
1800	1274	891	2332	1185	1830	3140	2426	678	545
1900	1553	1377	1880	1391	1930	4156	2106	781	781
2000	1706	945	1617	1993	2030	3234	2106	767	812
2100	1261	987	1341	1006	2130	2557	1655	956	836
2200	1398	915	1567	903	2230	3272	1749	1137	668
2300	1809	458	1078	884	2330	2858	1264	1069	812
2400	2076	388	1730	1081	0030	3385	1234	987	637
0100	1315	500	1717	799	0130	2501	1730	771	627
0200	1295	927	2119	572	0230	2463	1053	712	740
0300	1089	517	1404	577	0330	3798	2144	493	575
0400	1747	1171	1554	1554	0430	4156	1536	723	688
0500	1439	871	1605	1379	0530	3573	2463	321	349
0600	1439	1336	1943	912	0630	5077	2877	57	241
0700	1500	1398	2056	918	0730	3606	2670	668	510
0800	1973	1459	978	1156	0830	5284	2144		

Table E-3. Cell densities (cells ml^{-1}) of diatoms (Bacillariophyta) in entrainment samples from two stations at Calvert Cliffs Nuclear Power Plant, June through September 1979. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

	June 5-6		July 10-11			August 14-15		September 18-19	
Time	PSI	PSD	PSI	PSD	Time	PSI	PSD	PSI	PSD
0920/0900	1028	1213	589	254	0830			853	959
1000	987	945	686	686	0930	1053	639	473	1305
1100	987	1809	545	489	1030	1068	252	1336	1192
1200	457	1644	782	301	1130	985	686	1185	1798
1300	678	1583	611	462	1300	1769	837	649	1387
1400	514	945	963	617	1330	709	837	688	633
1500	360	1299	527	539	1430	963	1128	1737	1213
1600	968	1233	602	404	1530	827	1021	935	1367
1700	968	1096	812	508	1630	1580	1113	1233	978
1800	945	849	948	536	1730	1316	1899	754	1167
1900	621	884	602	470	1830	1053	2294	853	1048
2000	617	699	1003	827	1930	1598	1692	891	918
2100	457	699	752	470	2030	1373	1636	1096	781
2200	510	709	1116	498	2130	1091	1523	442	1014
2300	740	312	577	508	2230	1166	1015	877	822
2400	719	264	689	602	2330	1391	888	781	771
0100	596	301	1003	404	0030	1636	1203	754	925
0200	904	374	614	331	0130	715	1297	668	627
0300	432	305	464	244	0230	1015	940	959	904
0400	699	617	527	351	0330	1561	1768	709	715
0500	740	543	1053	389	0430	1598	1316	641	843
0600	534	760	953	423	0530	1749	1504	814	822
0700	822	945	564	429	0630	3554	1504	694	688
0800	863	493	559	696	0730	2407	2162	1079	904
					0830	2535	2068		

Table E-4. Cell densities (cells ml^{-1}) of Cryptophyta in entrainment samples from two stations at Calvert Cliffs Nuclear Power Plant, June through September 1979. (PSI=Plant Site Intake; PSD=Plant Site Discharge).

	June 5-6		July 10-11			August 14-15		September 18-19	
Time	PSI	PSD	PSI	PSD	Time	PSI	PSD	PSI	PSD
0920/0900	2548	2816	307	169	0830			514	493
1000	3884	4008	564	376	0930	1091	273	293	791
1100	3556	3535	376	338	1030	406	150	360	390
1200	2960	3227	737	271	1130	615	338	281	421
1300	4275	5261	348	333	1300	603	414	395	637
1400	3412	2846	511	481	1330	462	508	853	543
1500	1583	1825	451	376	1430	1113	338	534	678
1600	2375	2569	677	338	1530	2332	918	637	555
1700	2448	2338	511	470	1630	1993	1083	781	403
1800	3186	1630	436	197	1730	1260	1692	349	247
1900	2685	3144	376	254	1830	2238	1843	586	730
2000	3802	3658	313	288	1930	2162	1542	1233	1521
2100	2886	3699	439	263	2030	2557	1260	1233	658
2200	2351	1202	802	263	2130	2162	1166	1202	877
2300	3658	664	777	195	2230	2238	1485	1288	1028
2400	4131	840	862	461	2330	2369	1158	1192	1038
0100	3206	1261	689	442	0030	3197	948	1507	791
0200	4645	2496	689	218	0130	2181	1297	925	987
0300	3782	2349	802	194	0230	2106	1655	959	997
0400	4850	3740	602	777	0330	3234	1692	894	436
0500	3802	2877	614	564	0430	3234	1561	534	565
0600	3864	4172	815	150	0530	2350	1091	543	260
0700	3514	3617	777	391	0630	2802	1448	200	149
0800	3329	3186	376	451	0730	1918	1674	432	329
					0830	2614	1260		