AR-1146

TO: B. W. Smith

FROM: D. A. Normandeau
C. J. Schmitt
R. L. Hogan

RE:

MERRIMACK RIVER ECOLOGICAL STUDIES:

IMPACTS NOTED TO DATE;

CURRENT STATUS AND FUTURE GOALS OF

ANADROMOUS FISH RESTORATION EFFORTS;

AND POSSIBLE INTERACTIONS BETWEEN

MERRIMACK STATION AND ANADROMOUS FISHES

Prepared By

NORMANDEAU ASSOCIATES, INC.

BEDFORD, NEW HAMPSHIRE

3 JANUARY 1975

TABLE OF CONTENTS

PAGE

I. INTRODUCTION. 1

II. SUMMARY OF IMPACTS. 4

A. PHYSICAL-CHEMICAL PARAMETERS 4

1. Temperature 4

2. Dissolved Oxygen. 5

B. BIOLOGICAL COMPONENTS 10

1. Periphyton. 10

2. Plankton 15

3. Finfish. 21

C. SUMMARY 28

III. DISCUSSION OF ANADROMOUS FISHERIES 30

A. CURRENT STATUS AND FUTURE GOALS OF MERRIMACK RIVER ANADROMOUS FISHERIES RESTORATION PROGRAM 30

1. American Shad. 30

2. Atlantic Salmon 31

B. THE HOOKSETT POND REACH OF THE MERRIMACK RIVER AS SALMON AND SHAD HABITAT AND THE LIKELY EFFECTS OF MERRIMACK STATION ON THESE FISHES 32

1. Atlantic Salmon 32

2. American Shad. 33

3. Funding. 35

C. SUMMARY AND CONCLUSIONS. 36

LITERATURE CITED. 38

APPENDIX A. 40

LIST OF FIGURES

		PAGE
1.	Map of Hooksett Pond showing new and old discharge canal configurations and sampling locations.	2
2.	Surface and bottom temperatures, 1971.	6
3.	Periphyton organisms collected per square millimeter of slide surface at two-foot depth, 1972.	12
4.	Abundance of periphyton organisms collected monthly per square millimeter of slide surface at two-foot depth, 1973.	13
5.	Number of plankton organisms per m^3 of water filtered, 1972.	18
6.	Number of plankton organisms per m^3 of water filtered, 1973.	19
7.	Number of plankton organisms per m^3 of water filtered, 1974.	20
8.	Range of daily discharge, Garvin's Falls Dam. (Based on hourly readings June 1969 to August 1972, 6-hour means August 1972 to October 1974. Vertical scale is thousands of cfs)	24
9.	Mean annual catch per unit of fyke-net effort (individuals/net-day) for the most frequently encountered Merrimack River fish species, 1967-1974 . .	26
A1.	Cross-sectional isotherms, 7 July 1972	43
A2.	Longitudinal isotherms, 7 July 1972	44
A3.	Cross-sectional isotherms, 26 September 1972	45
A4.	Longitudinal isotherms, 26 September 1972	46
A5.	Cross-sectional isotherms, 31 July 1973	47

		PAGE
A6.	Longitudinal isotherms, 31 July 1973	48
A7.	Cross-sectional isotherms, 23 August 1973	49
A8.	Longitudinal isotherms, 23 August 1973	50
A9.	Cross-sectional isotherms, 22 August 1974	51
A10.	Longitudinal isotherms, 22 August 1974	52

LIST OF TABLES

		PAGE
1.	PHYSICAL, CHEMICAL AND BIOLOGICAL PARAMETERS MONITORED IN THE MERRIMACK RIVER MONITORING PROGRAM.	3
2.	MEANS AND RANGES OF WEEKLY SURFACE DISSOLVED OXYGEN CONCENTRATIONS (ppm) BY STATION 1971-1974.	8
3.	RANGES OF DISSOLVED OXYGEN CONCENTRATIONS (ppm) RECORDED IN 1971-1974 24-HOUR DISSOLVED OXYGEN STUDIES .	9
A1.	MEAN CROSS SECTIONAL TEMPERATURES AT TRANSECT N-10 FOR EACH OF THE FIVE DATES	53
A2.	HOOKSETT POND MORPHOMETRIC PROFILES AT 5 TRANSECTS. (TOTAL CROSS-SECTIONAL AREA AND AREA BOUNDED BY GREATER THAN 5° ΔT ISOTHERMS DURING LOW FLOW AND HIGH TEMPERATURE PERIODS, 1972-1974. MEASUREMENTS IN FT^2).	54
A3.	PERCENTAGE OF TOTAL CROSS-SECTIONAL AREA BOUNDED BY ΔT'S OF 5°F OR MORE	55
A4.	MEAN CROSS-SECTIONAL TEMPERATURES AND MEAN CROSS-SECTIONAL ΔT'S.	56
A5.	PERCENTAGE OF LINEAR SURFACE DISTANCE BOUNDED BY ΔT'S OF 5°F OR MORE	57

I. INTRODUCTION

Since 1967 environmental studies have been conducted on the Hooksett Pond section of the Merrimack River near Bow, New Hampshire (Figure 1). The studies were designed to determine environmental impacts resulting from the addition of MK-II, a 350 mw generating unit, to the Merrimack Plant to supplement MK-I, a 120 mw unit already in operation. Merrimack II came on line in 1970 and, with MK-I, utilizes 444 cfs of cooling water with a resulting temperature rise of approximately 23°F. In 1971 the discharge canal configuration was changed (Figure 1) to allow greater time of travel of heated water and the placement of 56 power spray module (PSM) units to cool discharge water prior to its entry into the Merrimack River. The PSM's were activated on June 30, 1972.

Physical, chemical, and biological parameters monitored during the course of environmental studies (1967-1974) are listed in Table 1. Of the parameters studied, varying degrees of probable impacts resulting from power plant operation (thermal, mechanical, chemical) have been discerned in studies of dissolved oxygen, plankton, periphyton and localized distribution of fishes. The proposal of American shad (*Alosa sapidissima*) and Atlantic salmon (*Salmo salar*) restoration programs has brought new concerns.

The purpose of this report is to address a) the types and magnitudes of biological impacts noted in the course of the monitoring studies and b) potential problems related to the projected establishment of Merrimack River anadromous fisheries.

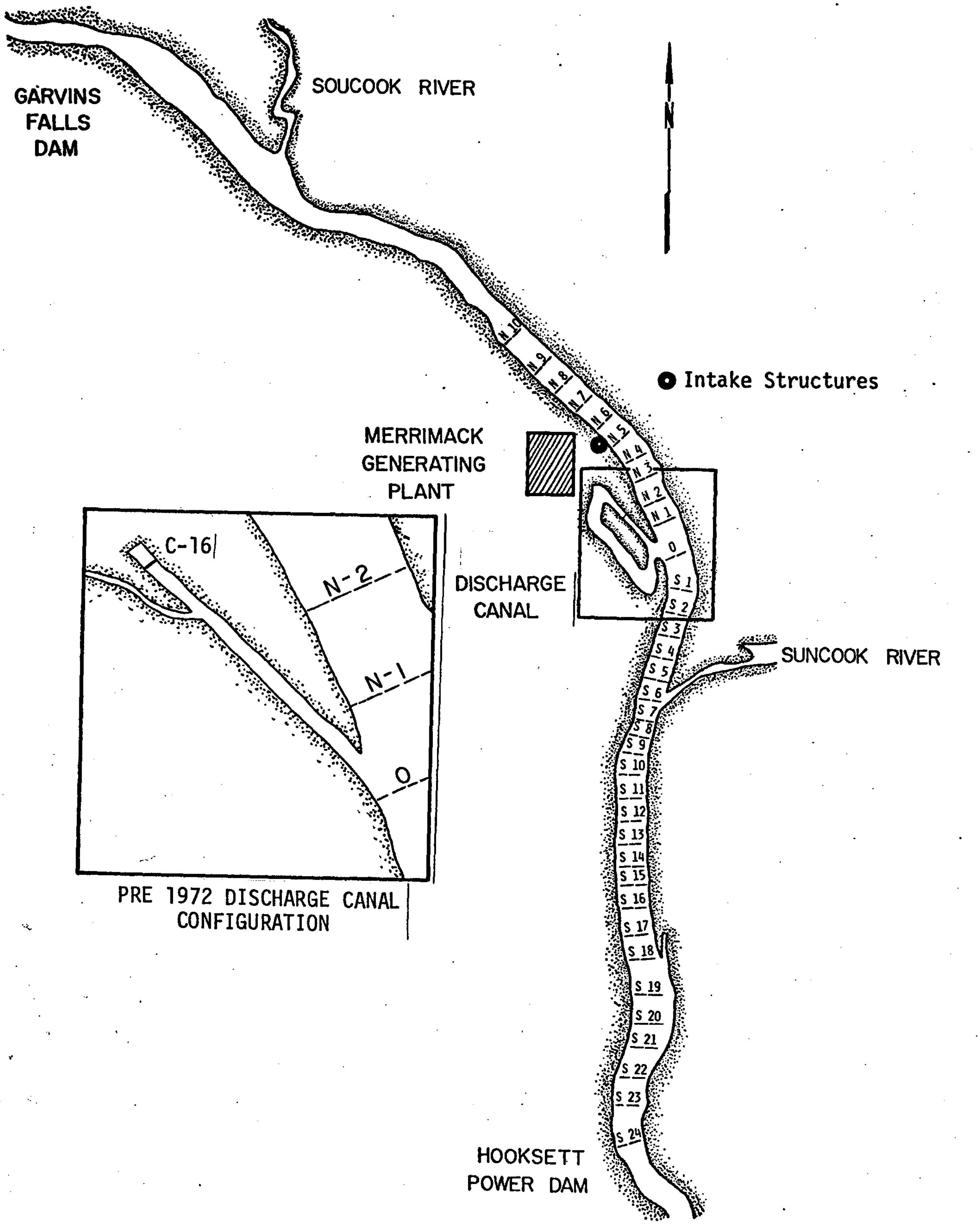


Figure 1. Map of Hooksett Pond showing new and old discharge canal configurations and sampling locations.

TABLE 1. PHYSICAL, CHEMICAL AND BIOLOGICAL PARAMETERS MONITORED IN THE MERRIMACK RIVER MONITORING PROGRAM

PHYSICAL	CHEMICAL	BIOLOGICAL
Discharge	Nitrate	Chlorophyll a
Depth of Visibility	Nitrite	Plankton
Turbidity	Total Phosphate	Periphyton
Temperature	Orthophosphate	Aquatic Plants
	Dissolved Oxygen	Aquatic Insects
	pH	Benthic Macroinvertebrates
		Finfish

II. SUMMARY OF IMPACTS

A. PHYSICAL-CHEMICAL PARAMETERS

Of all the physical and chemical parameters measured since 1967, measureable effects attributable to the operation of Merrimack Station have only been observed for temperature and dissolved oxygen. These results are summarized in the following pages.

1. Temperature

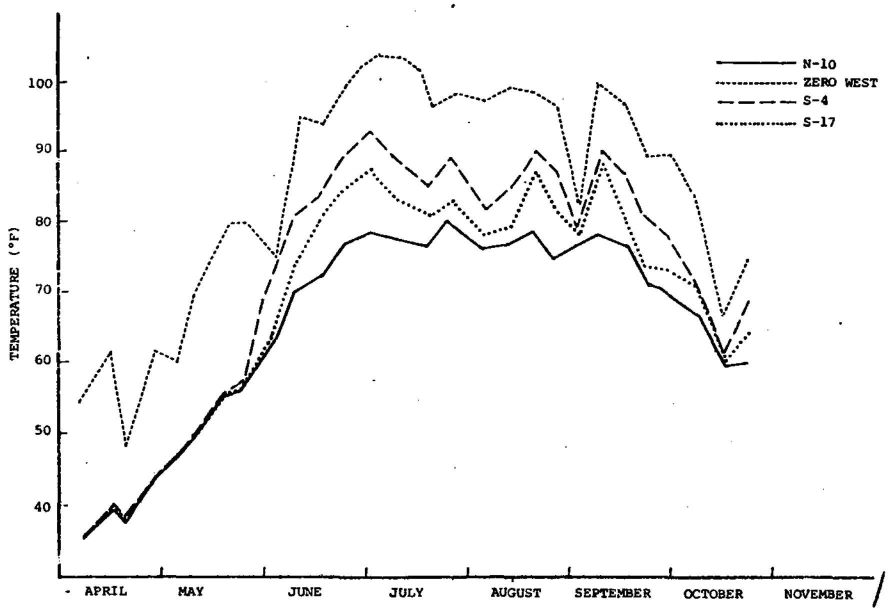
Detailed temperature investigations of Hooksett and Amoskeag Pond waters were initiated in 1967 and continued through 1968. These studies were conducted to determine the increase in thermal effects caused by MK II startup in 1968 (Normandeau, 1969). The investigations indicated that although generating capacity was increased by almost 3x, thermal effects were not substantially greater in 1968 than in 1967. This was attributed to rapid dissipation of heat to the atmosphere since stratification minimized mixing of heated water with cooler bottom waters. Effects were limited to the area of Hooksett Pond from the plant southward to Hooksett Dam. In this area intense stratification caused the heated waters to remain near the surface, coming close to the bottom only during low flow periods. Stratification was also most evident during low-flow periods. After complete mixing at Hooksett Dam, Amoskeag Pond waters were found to be a maximum of 6°F warmer than ambient waters north of Merrimack Station. Temperature investigations the following summer (NAI, 1970) yielded similar results. Additionally, it was determined that the maximum surface-bottom temperature differential was 10°F in the river itself, although the differential was as great as 29°F at the point of discharge. During 1970, MK II was down for repairs for most of the summer; results were nevertheless similar to those described for 1967-1969. Data from 1971 indicate the stratification present in Hooksett Pond prior to PSM operation; surface temperatures as far south as S-17 were generally warmer than ambient (N-10) whereas bottom temperatures differed only at Station Zero West (Figure 2). These figures typify pre-PSM annual temperature regimes for Hooksett Pond.

In June, 1972 the PSM cooling system began operation. The immediate effect of the system was a slight reduction of surface-bottom temperature differentials in the vicinity of the discharge (NAI, 1973). A lowering of maximum Zero-West temperatures occurred later in the summer. Station Zero-West Δt's were reduced from a maximum of 16°F in May to a 15°F maximum in June. The maximum for the following year (1973) was 13.9°F (NAI, 1974).

The current configuration and extent of the thermal plume is dependent upon discharge volume. Data is generally not available for high-discharge periods when the plume is probably confined to the west bank. The plume's configuration is depicted in detail for the critical periods of lowest flow and highest ambient temperature for each year since 1967 in Appendix A. Additional data pertaining to the discharge is also included in tabular form. To summarize the Appendices, the low-flow plume of Merrimack Station extends from Station N-1 southward to Hooksett Dam. The discharge extends as a lens of warm water which cools gradually as it progresses to the south. Bottom waters are affected only at Station Zero West. Complete re-mixing occurs upon passage through Hooksett Dam.

2. Dissolved Oxygen

A slight reduction in weekly surface dissolved oxygen concentrations at stations south of the discharge has been noted throughout the Merrimack River monitoring program. This reduction has remained remarkably consistent over the years and has generally ranged from a few tenths of a part



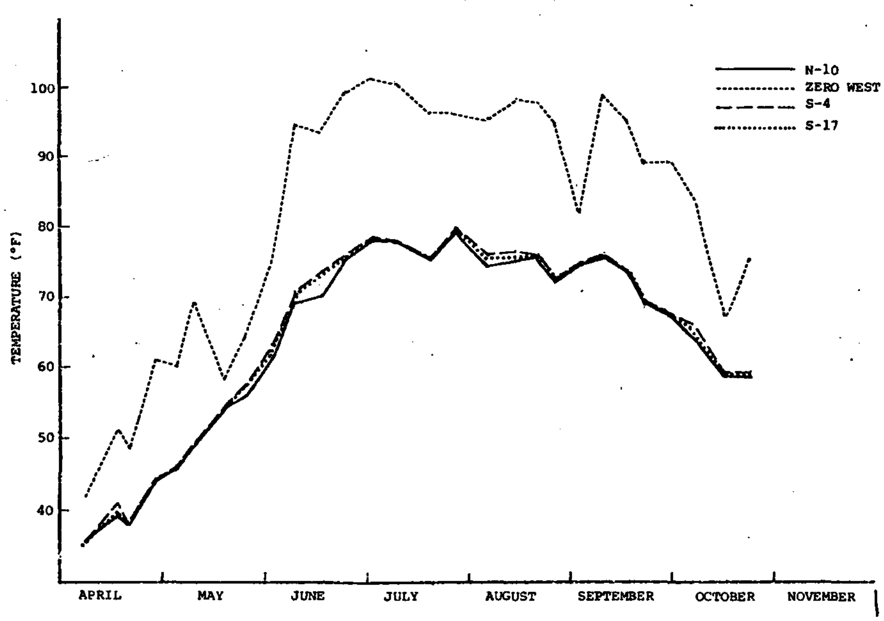


Figure 2. Surface and bottom temperatures, 1971.

per million to slightly over one part per million (Table 2). The entry of the Suncook River near Station S-6 East (Figure 1) contributes to a replentishment of dissolved oxygen concentrations at stations downstream from its confluence with the Merrimack River. The activation of the power spray modules (PSM's) in June of 1972 appeared to have had little long-term effect on river dissolved oxygen concentrations.

In 1971, 24-hour dissolved oxygen studies were initiated. Concentrations of oxygen were sampled mid-river at one-foot depth intervals every 6 hours at Stations N-10, Zero-West, S4 and S-17. In 1972 and for succeeding years stations were sampled at mid-river and at both east and west littoral zones. Ranges of dissolved oxygen concentrations recorded during the 1971-1974 studies are presented in Table 3.

As results of the weekly surface and 24-hour dissolved oxygen profile surveys demonstrate, oxygen concentrations are never critically low; only one value was reported below 5.0 ppm. This value (4.3 ppm) was recorded at Station S-4 during a 1972 24-hour survey. Although weekly surface and periodic diurnal studies are not sufficient to determine the dissolved oxygen dynamics of Hooksett Pond, they can be considered representative for the purpose of ascertaining potential biological impacts. NAI dissolved oxygen measurements have never yielded measurements of levels low enough to be considered limiting to the indigenous fauna.

TABLE 2. MEANS AND RANGES OF WEEKLY SURFACE DISSOLVED OXYGEN CONCENTRATIONS (ppm) BY STATION 1971-1974

	1971	1972	1973	1974
N-10				
R	6.4-14.8	7.6-13.7	6.8-13.3	6.7-13.8
M	9.4	9.8	9.2	9.5
O-W				
R	6.4-12.0	7.2-13.0	5.5-11.8	6.7-13.6
M	8.3	9.0	8.6	8.6
S-4				
R	5.3-13.6	7.3-13.7	6.2-13.0	7.1-13.1
M	9.3	9.4	9.0	9.2
S-17				
R	6.9-12.0	7.7-13.3	6.5-12.3	6.8-13.6
M	9.2	9.6	9.2	9.4

R = Range

M = Mean

TABLE 3. RANGES OF DISSOLVED OXYGEN CONCENTRATIONS (ppm) RECORDED IN 1971-1974 24-HOUR DISSOLVED OXYGEN STUDIES

	1971	1972	1973	1974
N-10	6.1-7.8*	6.6-8.5	6.8-7.8	7.4-9.6
Zero	5.6-7.9	5.9-8.2	6.4-7.7	6.5-9.2
S-4	5.4-8.0	4.3-7.9	6.6-8.0	6.1-9.1
S-17	5.9-7.7	5.3-8.2	6.4-8.0	6.2-8.9

* Instrumentation difficulties made it necessary to eliminate questionable data in 1971.

B. BIOLOGICAL COMPONENTS

Measurable biological impacts attributable to the operation of Merrimack Station have only been observed among periphyton, plankton, and finfish components of the Hooksett Pond biota. Other components, such as macrophytes and macrobenthos, have not been measurably affected. Observed effects are summarized in the following pages.

1. Periphyton

In 1968, the first year of periphyton studies, sampling was limited to less than one month (July 5-July 24) during the period of maximum temperatures. Sample analysis revealed differences on discharge station (Discharge Canal Station C-16) periphyton panels (glass slides) when compared to panels located north and south of the canal. Diatoms (*Chrysophyta*), green algae (*Chlorophyta*) and bluegreen algae (*Cyanophyta*) were completely absent in the discharge canal although present at Stations N-10 and S-17 in nearly equal numbers.

Station S-4 was added in 1970 and panels were exposed for one month each over a five month period (May-September). During approximately the same time period as sampled in 1968, monthly periphyton slides at Station C-16 again yielded no green algae or diatoms. Heated waters apparently reduced periphytic diatom production south of the discharge canal as well since diatoms were also less abundant at S-4 than at N-10.

During the 1971 sampling period, short and long-term effects on periphyton communities were studied using weekly accumulations, and accumulations of from 2-30 weeks respectively. Short-term effects were noted in the form of significant reductions (two way analysis of variance, angular transformation) in the percentages of green algae at Station Zero-West when compared to Stations N-10, S-4, and S-17. Differences were noted mostly from mid-June to September when Zero-West temperatures were between 90° and 100°F. No significant differences were noted among stations for bluegreen algae or diatoms. On the long-term slides both diatom and green algae production was reduced at Station Zero-West; bluegreen algae demonstrated no consistent trends. Periphyton organisms on both short and long-term slides showed signs of rapid recovery at southern stations.

During 1972 short-term (weekly) and long term (monthly) periphyton slides were examined at Stations N-10, Zero West, S-4 and S-17. Monthly slides showed reduced diatom abundance at Zero-West and southern stations (Figure 3) in all months except October. Green and bluegreen algae were not as consistent in their abundance changes as the diatoms. Weekly slides, used to "pinpoint" short-term changes in periphyton accumulations generally showed comparable results. Periphyton panels suspended at 6 ft depth (as contrasted to 2 ft normally) showed reduced numbers of diatoms and green algae at Station S-4 (June-August) when compared to N-10 panels suspended at the same depth.

Sampling procedures in 1973 were identical to those of 1972. Monthly periphyton panels failed to show any statistically significant differences in abundance or percent composition (Freidman non-parametric 2 way AOV) over the study season at the 2 or 6 ft depths. At the 2 ft depth, reductions in diatom numbers were noted for June, September and October (Figure 4). Percent composition data indicated a higher percentage of bluegreen algae at the 2 ft depth at the more southern stations than at N-10. Weekly slides showed significant differences (Freidman non-parametric 2-way AOV) in abundances among stations over the season with N-10 yielding more diatoms at the 2 ft depth than stations south of the canal. Lowest numbers were found at Zero-West. At the 6 ft depth Station N-10 had greater numbers of diatoms as well as green algae (Wilcoxon matched pairs, signed rank test). During September diatom production was strongly reduced at Station S-4 at the 6 ft depth.

Sampling procedures utilized in 1972 were again employed in 1974; results were comparable to those obtained in the previous 2 years. Diatoms were significantly less abundant ($p < 0.05$) at Station Zero-West

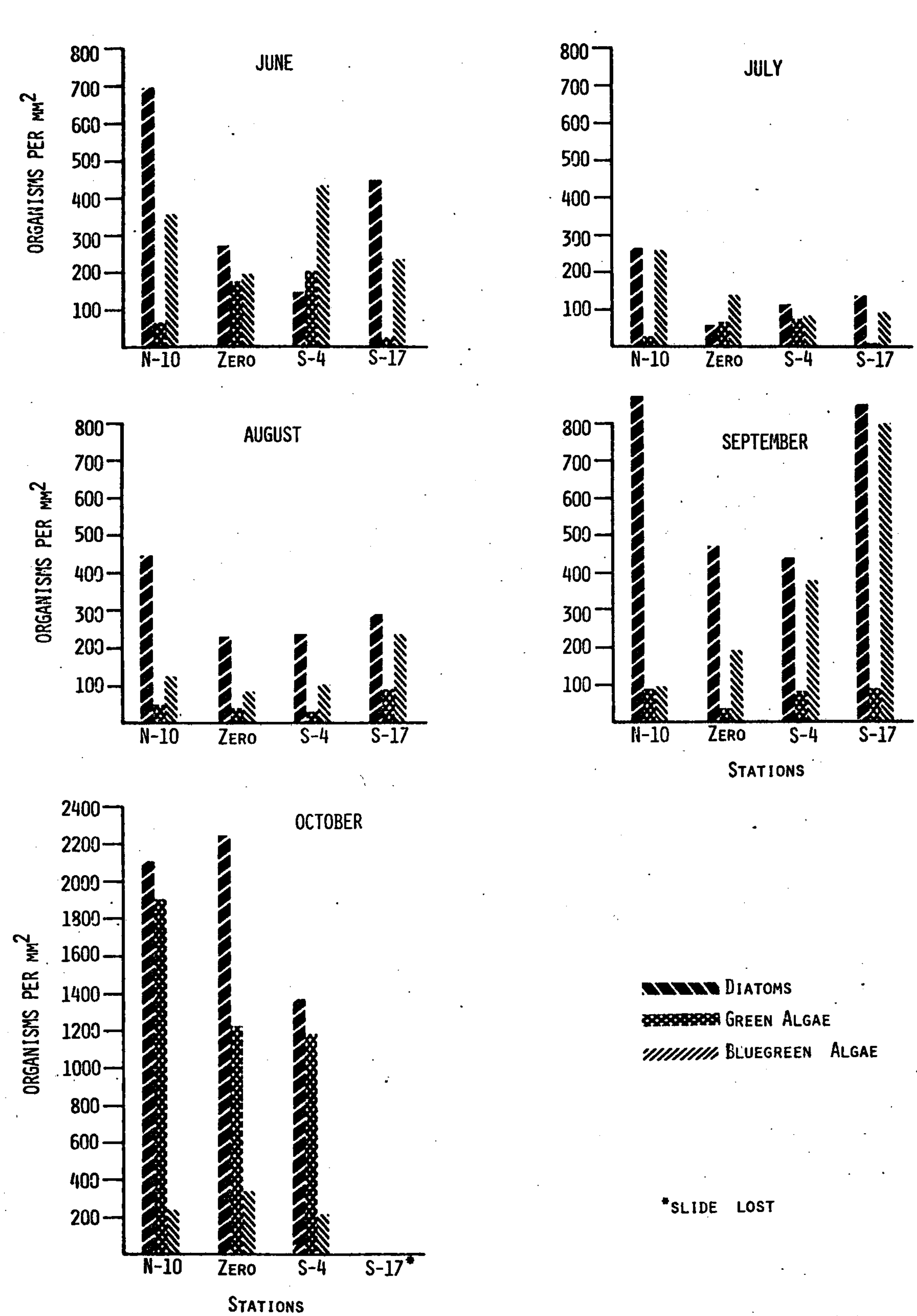


Figure 3. Periphyton organisms collected per square millimeter of slide surface at two-foot depth, 1972.

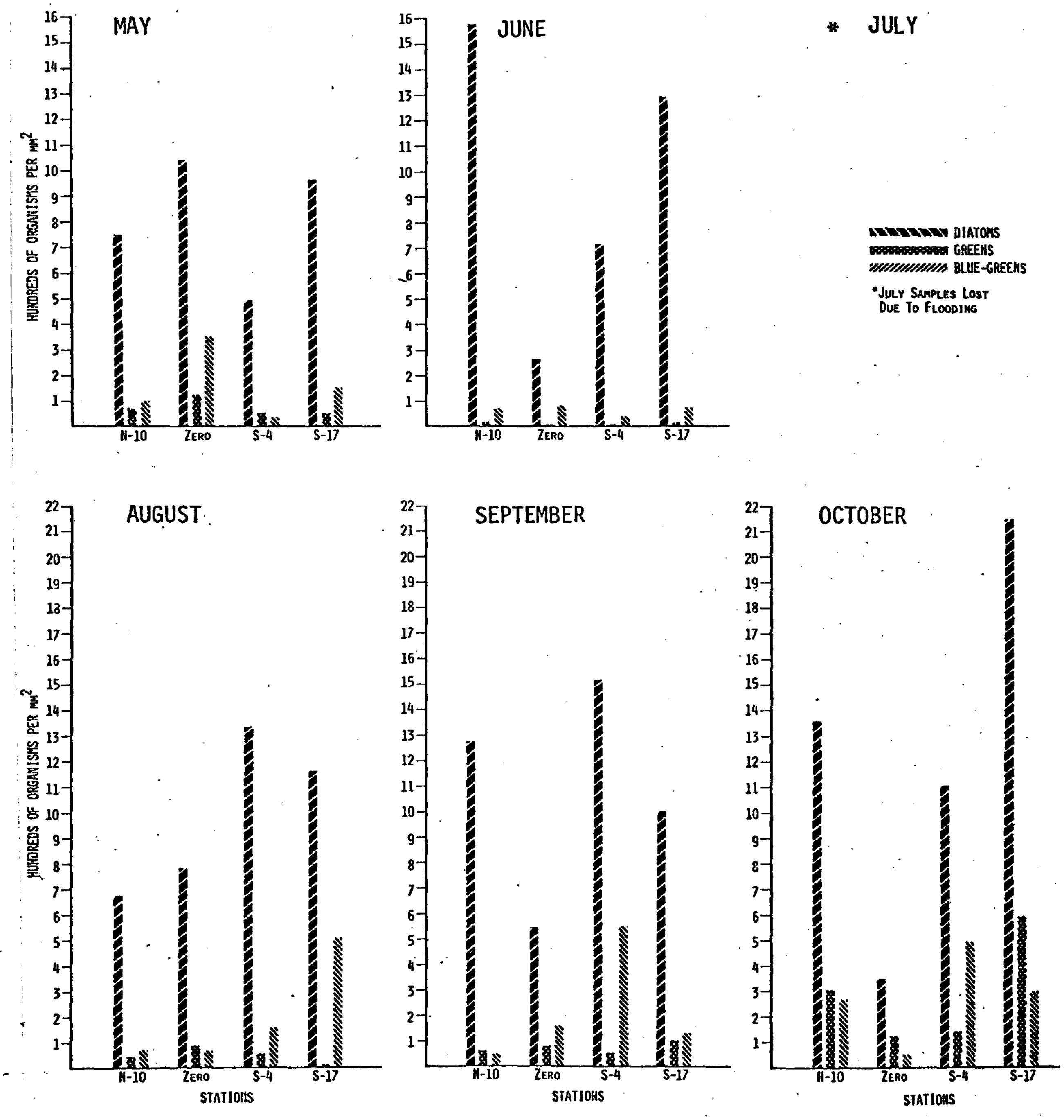


Figure 4. Abundance of periphyton organisms collected monthly per square millimeter of slide surface at two-foot depth, 1973.

than at all other stations (Tukey's Method of Multiple Comparisons). Similarly, diatoms were less abundant on monthly panels at Station S-17 than at N-10. Seasonal variation was significant ($p < 0.001$) only for green algae; the seasonal variation of diatom and bluegreen algae abundance was not significant ($p < 0.05$). The relative abundance of diatoms at Station N-10 was also revealed in monthly percent composition data; diatoms were proportionately more abundant at N-10 than at other stations. Green algae were proportionately more abundant at Station Zero-West, a trend which was not discernable as a difference in actual abundance.

As in previous years, the results of subsurface panel studies were similar to those of surface panels. Diatoms were significantly more abundant on both weekly ($p < 0.05$) and monthly ($p < 0.05$) panels at Station N-10 than at S-4. Bluegreen algae were also more abundant ($p < 0.025$) on N-10 weekly panels (parametric paired t test). Comparing surface and subsurface panels revealed significant differences only for green algae ($p < 0.01$); bluegreen algae and diatom differences were not significant ($p > 0.05$).

Two distinct trends have become apparent over the five-year study period: First, diatoms have been consistently less abundant on both long and short-term surface panels at Station Zero-West; secondly, diatoms have also been consistently less abundant at Station S-4 than at N-10 since the inception of the bottom panel program in 1972. In addition, several less distinct trends have been noted. For example, green algae were less abundant on subsurface (6 ft) than surface (2 ft) panels in both 1972 and 1974. In early studies (1970-1971) green algae were proportionately less abundant at Station C-16 (canal; 1970) and Zero-West (1971). However, in recent years either a) no significant differences were observed or b) green algae were proportionately more abundant at Zero-West (1974).

2. Plankton

During initial monitoring studies conducted in 1967-1968, plankton samples were collected at stations between N-2 and N-8, at C-16 in the discharge canal, and south of the canal at S-4, S-8, and S-20 during late spring and summer (Figure 1). Although this survey was qualitative in nature, major variations in the plankton community structure and abundance were discerned. Reduced numbers of diatoms, bluegreen algae and desmids were collected at Station C-16 (discharge site) when compared to stations north and south of the canal. The magnitude of this decrease was greatest when water temperatures exceeded 100°F.

A more comprehensive quantitative plankton program was initiated in 1970; sampling stations were established at N-6, C-16, S-4 and S-17. Analysis of variance demonstrated no significant differences ($p < 0.05$) in the abundance of either diatoms, green algae, bluegreen algae, or zooplankton between the stations monitored. In addition, fluctuations in the population obscured any seasonal trends.

In 1971 the plankton program was altered and expanded. The control station was moved from N-6 to N-10, and Station Zero became the discharge station. Subsurface (6 ft) samples were collected at N-10, S-4, and S-17. The abundance of green and bluegreen algae did not differ significantly ($p > 0.05$) among the stations during the sampling program. Green algae were more abundant during the summer at all stations. This was followed by a decrease during the fall. However, the seasonal variation was not significant. Bluegreen algae abundance was erratic over the season; these fluctuations could not be correlated with temperature or discharge. Diatoms were significantly more abundant ($p < 0.001$) at Stations N-10 and S-17 than Station Zero. Comparison of surface and subsurface data indicated no significant ($p > 0.05$) depth or station-related differences.

During the 1972 survey the subsurface station at S-17 was deleted;

all other 1971 stations remained the same. Significant seasonal variation ($p < 0.05$) in the abundance of diatoms, green algae, and zooplankton was recorded for all stations over the sampling period. This follows a trend noted in the 1971 survey wherein abundances of these groups decreased with increased temperature. Diatoms were significantly ($p < 0.005$) more abundant at Stations N-10 and S-4 than at S-17. Other pairs of stations did not show this degree of dissimilarity. General trends were partially obscured by high variability in the number of cells collected. Diatom abundance increased at the southern stations during cooler periods and decreased when temperatures rose. Green algae density was significantly higher ($p < 0.01$) at Station N-10 than at S-17 over the sampling period. Zooplankton were also found in significantly greater ($p < 0.05$) numbers at N-10 than at S-17. Differences in bluegreen algae abundance between stations was not significant. Neither were there any significant ($p > 0.05$) abundance differences between surface and subsurface samples or subsurface stations over the period covered by the survey.

In 1973 and 1974 sampling procedures and stations were the same as those used in the 1972 survey. As in 1972, significant ($p < 0.05$) abundance differences were observed between stations for diatoms and zooplankton. In addition, bluegreen algae exhibited similar significant differences in 1973. Significant seasonal differences over the year were noted for diatoms ($p < 0.005$), green algae ($p < 0.005$), and bluegreen algae ($p < 0.001$). There was no significant ($p > 0.05$) variation in the number of zooplankton over the year. Where significant variations were noted, densities were high during the spring and fall and decreased during the summer when temperatures increased. The number of diatoms at N-10 and S-4 was significantly greater than at Zero. Zooplankton followed the trend exhibited in 1972; significantly lower densities ($p < 0.05$) were observed at S-17 compared to Station N-10. Bluegreen algae at Station Zero were significantly more abundant than at Stations S-4 and S-17. There were no significant differences in green algae abundance in surface samples at the various stations. Subsurface samples indicated that green algae were significantly more abundant ($p < 0.015$) at Station N-10 than at S-4.

Samples collected during 1974 show that the abundance of diatoms, green algae, bluegreen algae, and zooplankton varied significantly ($p < 0.05$) over the sampling period. Lowest abundances occurred during periods of generally high temperatures. Densities were greatest during spring and fall. Neither diatom, green algae, nor zooplankton density varied significantly ($p > 0.05$) among stations during the 1974 study. Numbers of bluegreen algae were significantly greater ($p < 0.01$) at Station Zero than at S-17. This increase was similar to that observed in 1973.

General monthly trends for years 1972-1974 are illustrated in Figures 5-7. Significant decreases ($p < 0.05$) in abundances of various groups throughout the yearly sampling period were observed during periods of highest water temperatures (July-August). This difference was observed at all of the stations monitored. Only diatoms showed significant decreases at all stations during the summer over the three year period. The other groups effected by the seasonal temperature increases varied from year to year.

Plankton abundance differences between stations over the years studied has shown no consistent trends. Diatoms were significantly more ($p < 0.05$) abundant at N-10 than Zero during 1971 and 1973. Also during this period, stations having greater plankton abundance than Zero were S-17 (1971) and S-4 (1973). In 1972 S-4 showed a greater diatom concentration than S-17. In 1974, there was no significant ($p > 0.05$) variation in diatom concentrations by station over the sampling period.

Variation in abundance between stations for the green and bluegreen algae and zooplankton was even less consistent. Green algae concentrations were highly variable and only in 1972 were there significant among-station differences; they were more abundant at N-10 than at S-17 over the course of the 1972 sampling period. Bluegreen algae abundance was also variable. In 1973 and 1974 Station Zero had a significantly ($p < 0.05$) greater number of cells per unit volume of water than did Stations

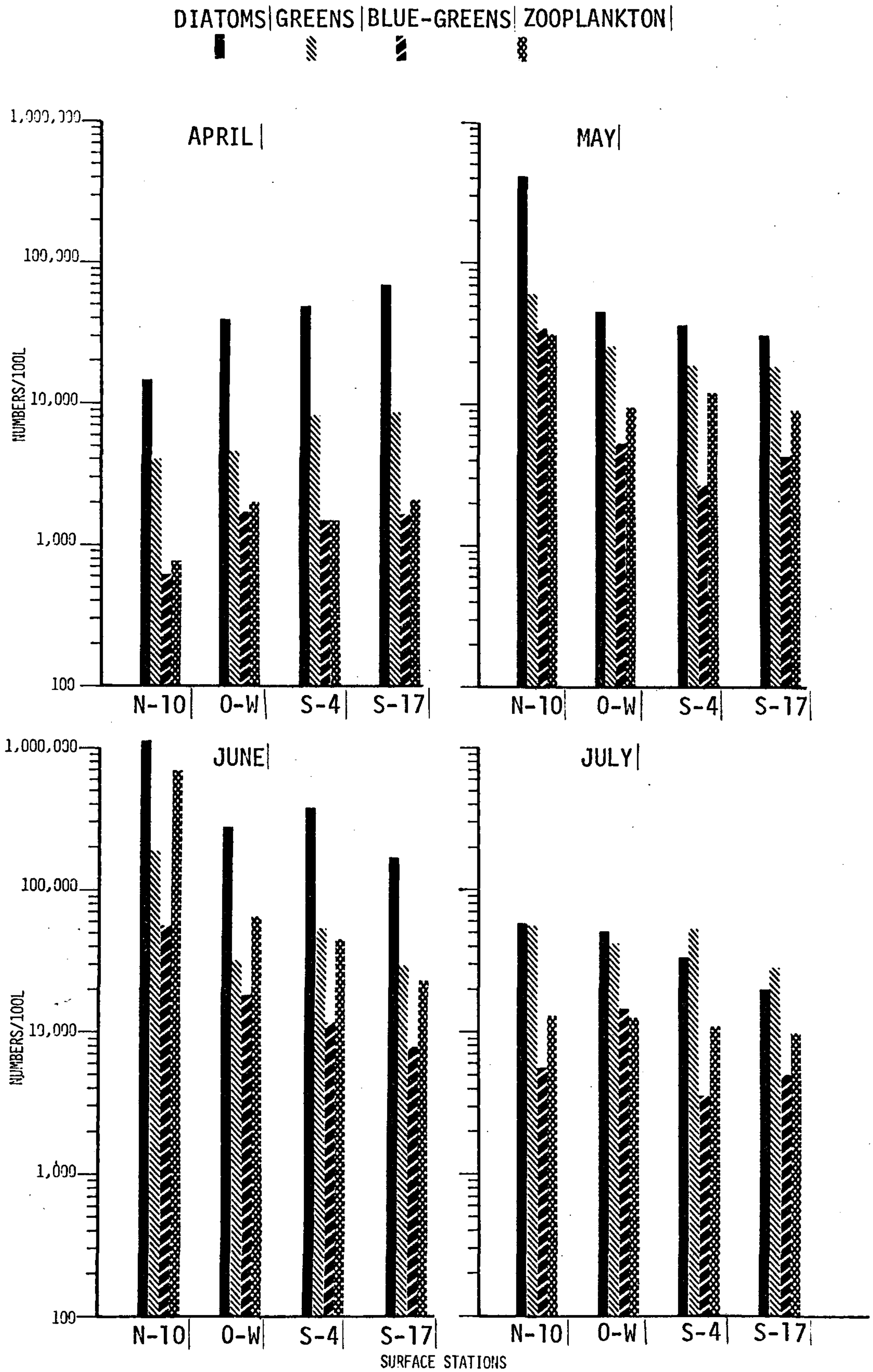


Figure 5. Numbers of plankton organisms per m^3 of water filtered, 1972.

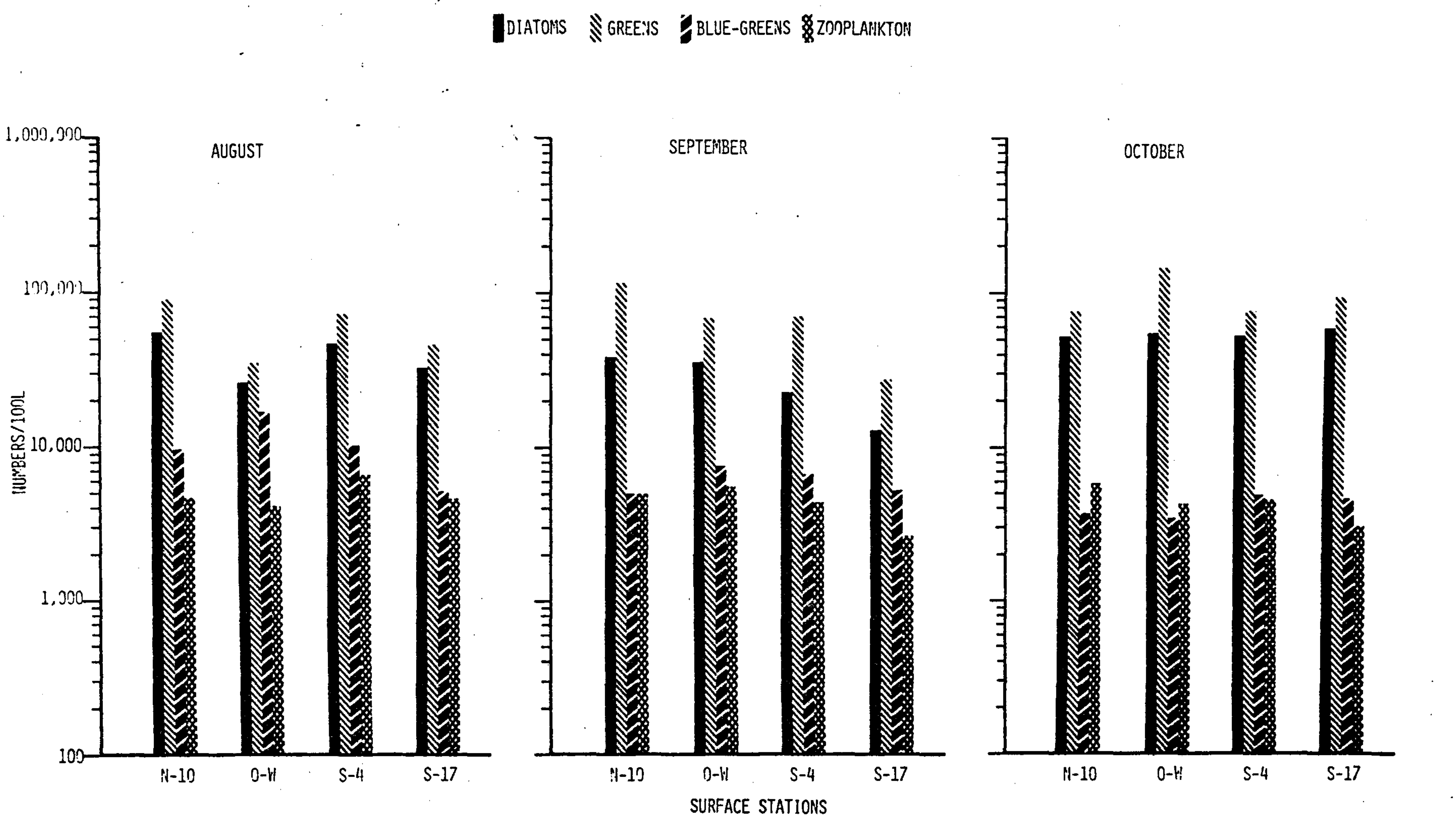


Figure 5 (continued) Numbers of plankton organisms per m^3 of water filtered, 1972.

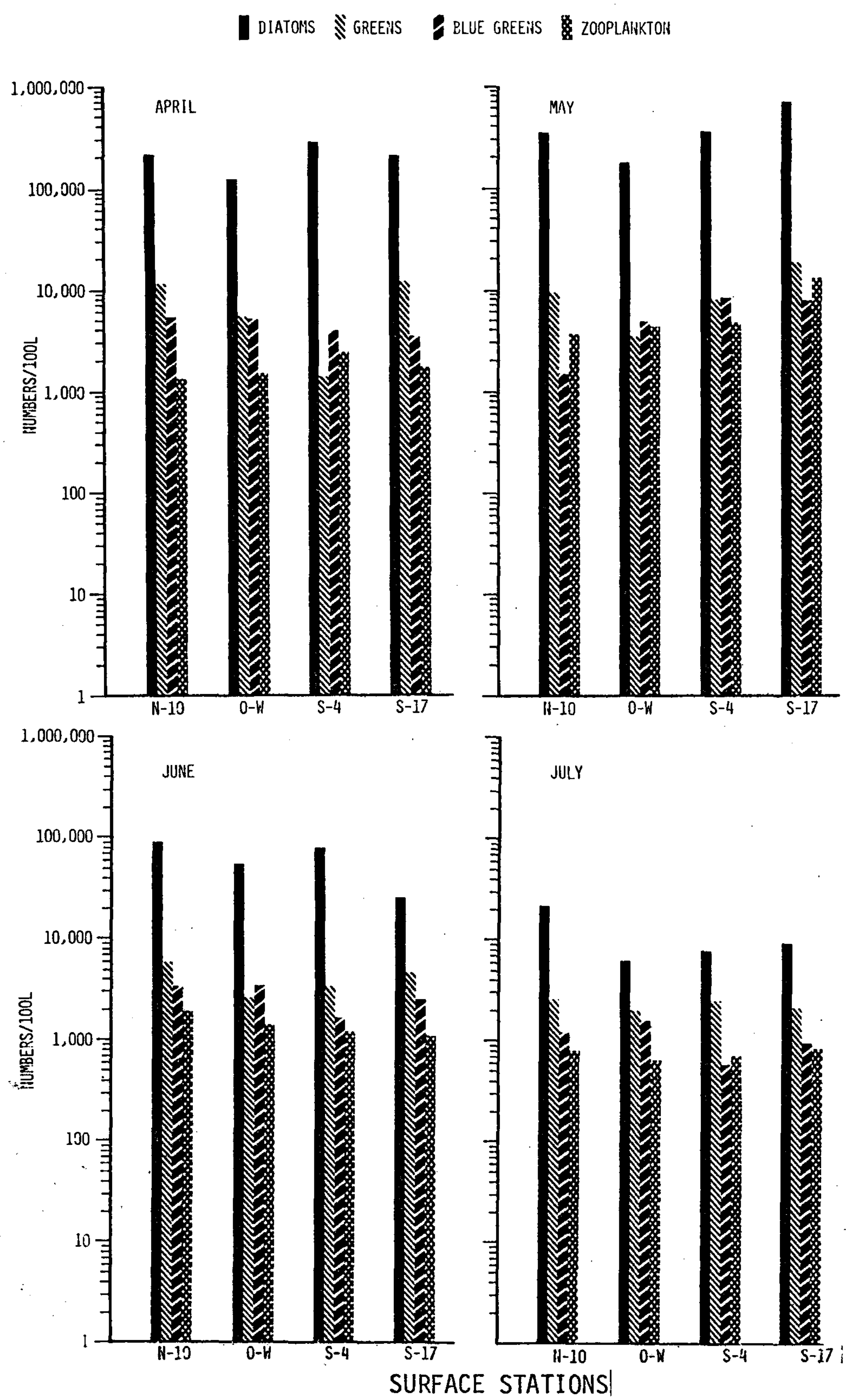


Figure 6. Numbers of plankton organisms per m^3 of water filtered, 1973.

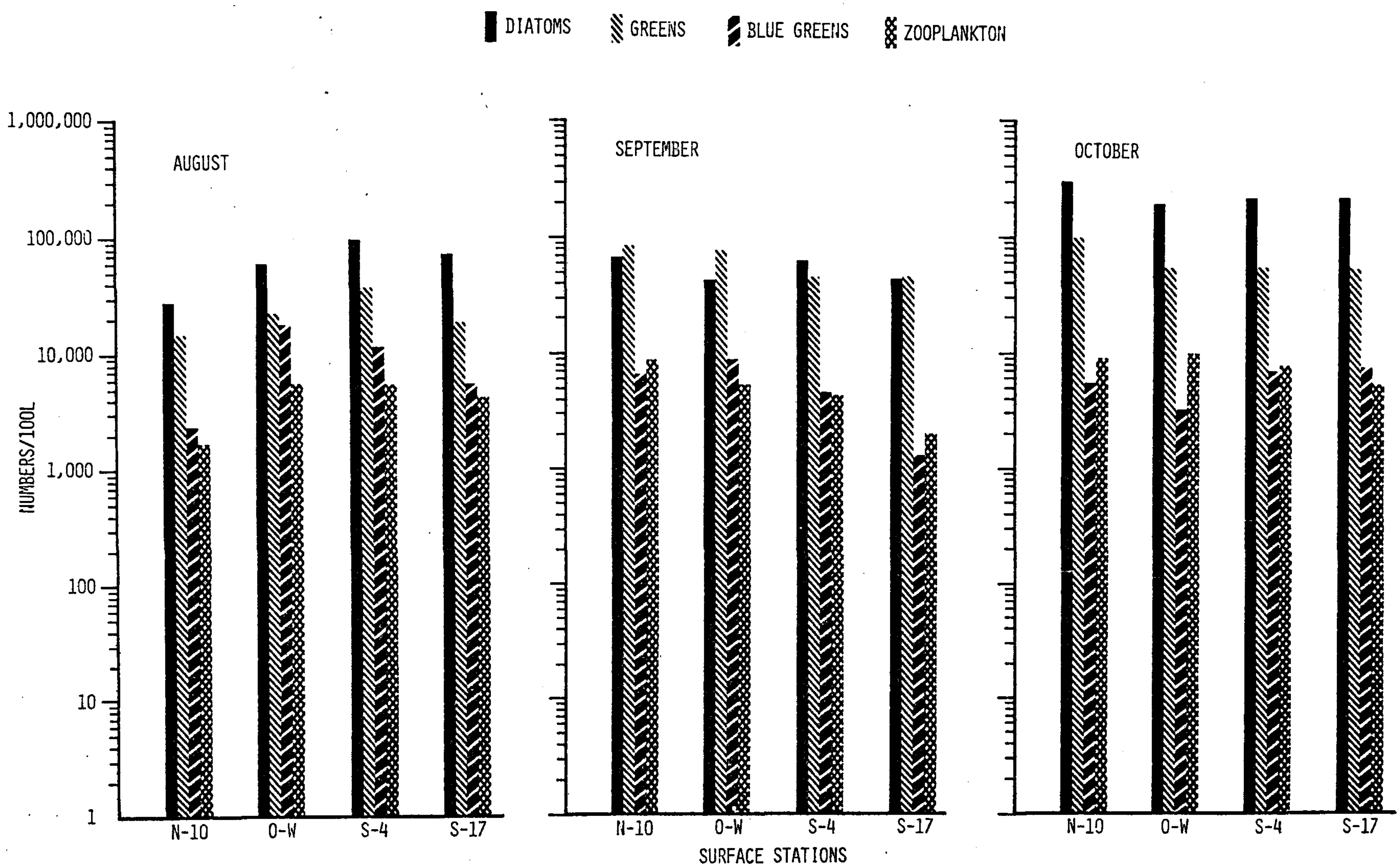


Figure 6 (continued) Numbers of plankton organisms per m^3 of water filtered, 1973.

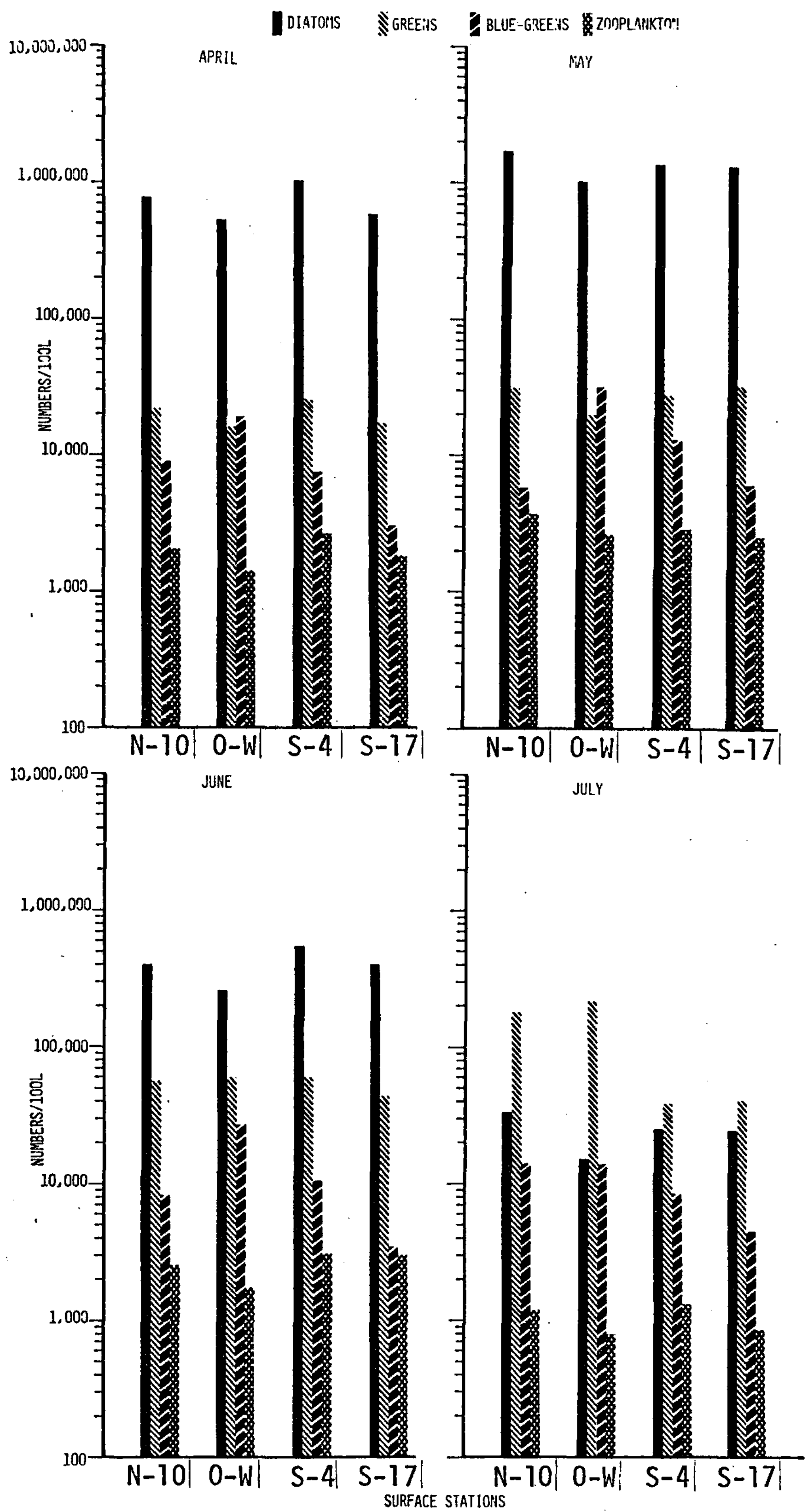


Figure 7. Numbers of plankton organisms per m^3 of water filtered, 1974.

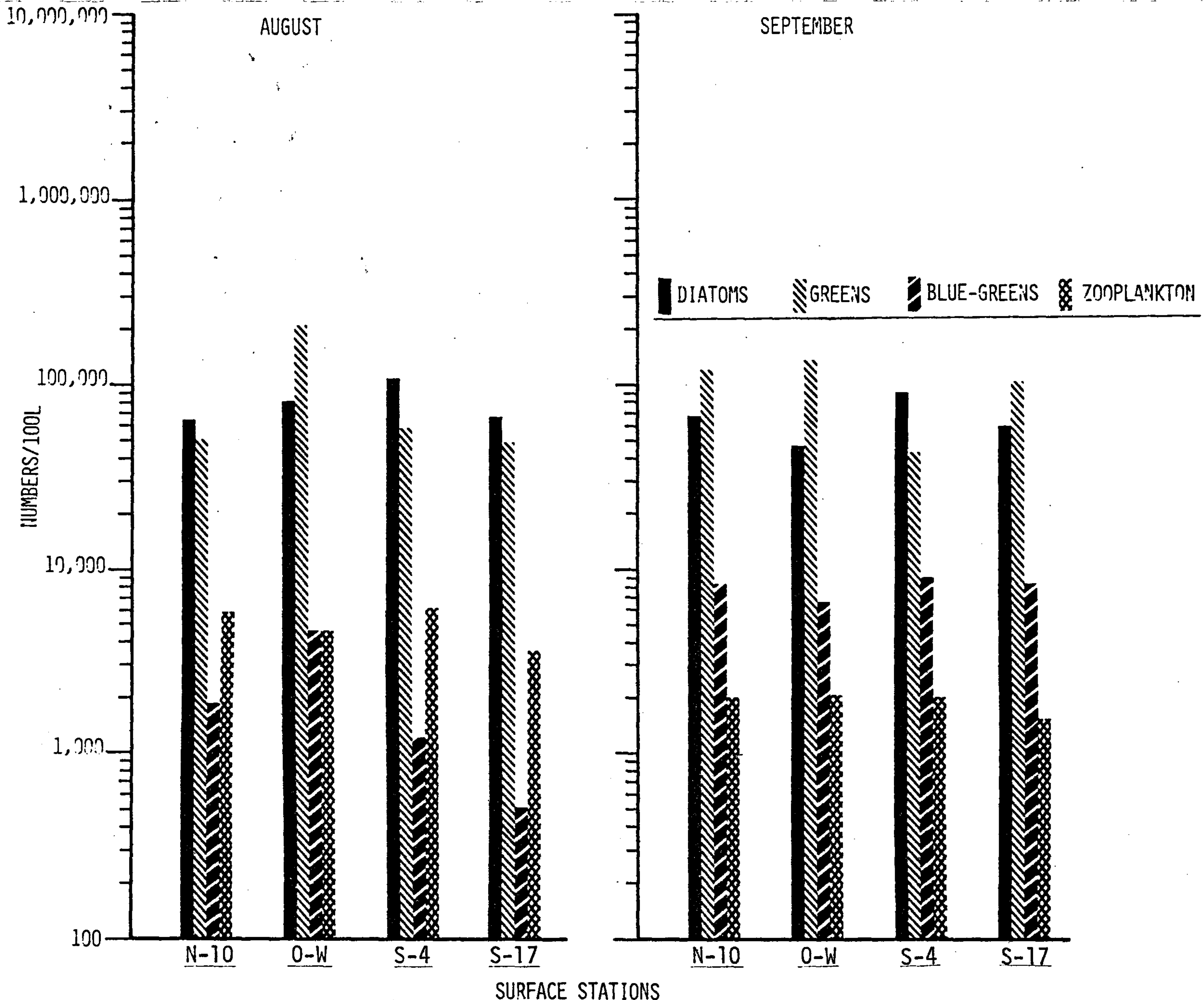


Figure 7 (continued) Numbers of plankton organisms per m^3 of water filtered, 1974.

S-4 and S-17, and S-17 respectively. Zooplankton abundances were significantly greater at N-10 than at S-17 during 1972 and 1973. This trend did not follow through into 1974.

Plankton concentrations have varied considerably between years, over the sampling periods, and between stations. In the latter two instances (over sampling periods and between stations) the differences have been significant at times. However, only one definite trend has been established over the five years this community has been monitored: Only diatom abundance differs at Station Zero with respect to N-10. Other groups indicate that the heated effluent may have little effect on the community; zooplankton and green algae show no change at Zero. The bluegreen algae sometimes increase at this station. Much of the variation observed over the years is probably related to naturally occurring fluctuations in the community and biotic and environmental variation not related to plant operation such as predation, currents, and river configuration.

3. Finfish

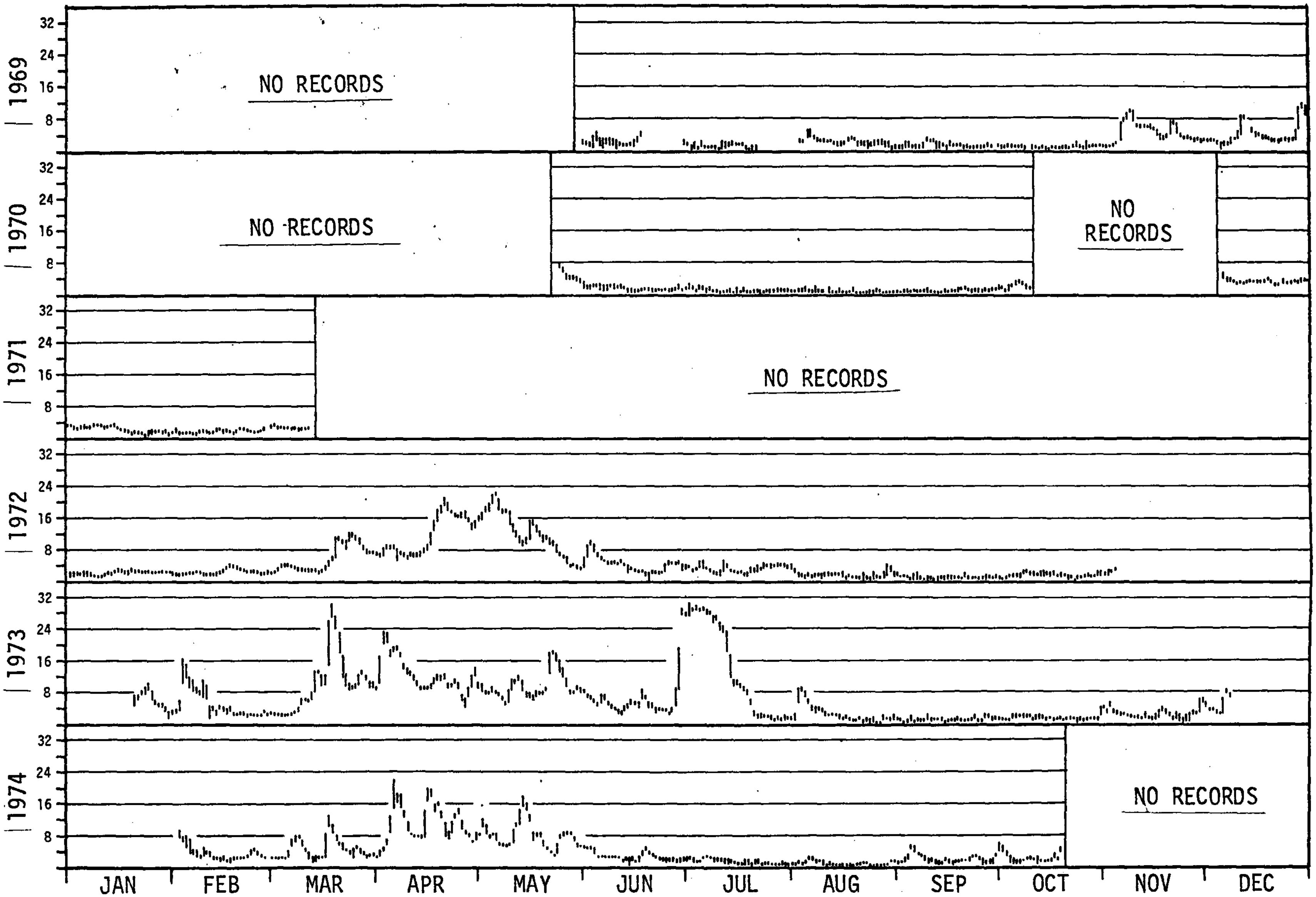
Fishery studies in the Hooksett Pond reach of the Merrimack River began with a fyke netting and electrofishing survey conducted by the New Hampshire Fish and Game Department during spring and summer 1967, 1968, and 1969. These studies were summarized by Normandeau (1969) and, in greater detail by Normandeau Associates, Inc. (NAI) (1969) and Wightman (1971a). Results indicated that nearly all species decreased in overall abundance by 40-50% from 1967 to 1968 but that populations had begun recovering by the summer of 1969. This decline and subsequent recovery was evident in all areas of Hooksett Pond, which includes river stretches above and below the power plant. Fyke net and electrofishing catches were also reduced by about 37% in the Amoskeag Pond reach downstream of Hooksett Dam. For this reason, the 1968 decline was believed to be caused by environmental conditions not related to the operation of Merrimack Station.

During the spring and summer of 1970 a survey of juvenile fish occurrence in Hooksett Pond was undertaken (NAI, 1971). Special consideration was given to possible effects of heated discharges from Merrimack Station. In addition, the spawning behavior of sunfishes (*Lepomis gibbosus* and *L. cyanellus*) was observed in the discharge canal. Juveniles were observed throughout Hooksett Pond and in the Merrimack Station discharge canal in late May, 1970 when water temperatures ranged from 58.2°F at Station N-15W to 84.8°F in the discharge canal. Juveniles persisted at all river locations until mid-summer. None were observed after June 19 within the discharge canal wherein it was concluded that water temperatures in excess of 85°F may have induced the juvenile fishes to leave the canal. During spring surveys large numbers of adult and juvenile yellow perch (*Perca flavescens*), red breasted sunfish, pumpkinseed, golden shiners (*Notemigonus crysoleucas*), brown bullheads (*Ictalurus nebulosus*), yellow bullheads (*I. natalis*), largemouth bass (*Micropterus salmoides*), and white perch (*Morone americana*) were observed in the discharge canal. No fish were observed in the discharge canal from mid-July until water temperatures fell below about 85°F in September. The nesting survey revealed that about 700 pumpkinseed nests had been constructed in the canal. These were subsequently destroyed when the water level fell, subjecting the nests to emersion. During the summer of 1970, initial dredging took place for the installation of the present power spray module cooling system.

During 1971 three electrofishing surveys were conducted in addition to a juvenile fish survey like that of 1970 (NAI, 1972). Juvenile fish were identified to the lowest possible taxon in addition to enumeration. The juvenile fish survey revealed that young-of-the-year white suckers (*Catostomus commersoni*) and common shiners (*Notropis cornutus*) were predominant through mid-July; centrarchids (*Lepomis* spp. and *Micropterus* spp.) dominated for the rest of the summer. No nests or juvenile fishes were observed in the discharge canal or at Station Zero West during 1971. This was believed to be the result of temperatures in excess of 93°F. Stations N-10, S-10, and S-18, the locations with the most habitat for young fishes (extensive littoral zone with macrophytes), were consistently richest in numbers of juvenile fishes. May, July, and October, 1971 electrofishing surveys produced similar catch/effort relationships north and south of the discharge. Station Zero West, at the discharge, produced the greatest number of species in May, when river temperatures were still cool. However, the entire area between Zero West and S-10W yielded no fish during July and only one pumpkinseed was captured at Station S-18W. East stations produced many more fish as did those north of the discharge. This pattern was repeated in August; additionally, the area on the east bank from Zero East to S-5E produced few specimens. These July and August, 1971 results indicated generally that Merrimack River fishes avoided the warm-water discharge areas when the water temperatures reached 85-90°F. However, with the exception of these seasonal attraction-avoidance reactions of juvenile and adult fishes within the thermal discharge area, seasonal trends in fish species composition were similar both north and south of the discharge.

In 1972 electrofishing surveys were supplemented by the resumption of monthly fyke netting. These aspects of the study have continued through the 1974 season with fyke nets generally being fished monthly from May through October. In addition to species composition and relative abundance data, age-and-growth analysis is performed on yellow perch, pumpkinseed, and smallmouth bass captured in the fyke net program. The juvenile fish survey was not conducted due to high water conditions (Figure 8).

Electrofishing during 1972 and 1973 essentially confirmed the results of earlier investigations (NAI, 1973, 1974). Generally, seasonal species composition and relative abundance is similar above and below the generating station with the exception of the area under direct discharge influence. This area, encompassing the old discharge canal and the portion of the river extending from N-1 to S-5, is apparently attractive to some fishes during the cooler parts of the year. During July and August, when water temperatures are highest, this area is avoided by most species. However, the zone of influence does not appar-



... daily discharge. Garvin's Falls Dam. (Based on hourly readings June 1969 to ently reach Station S-18 as it did in years before the spray module cooling system was installed. Additionally, fungus infected yellow perch were more prevalent at southern (12%) than at northern (0%) stations during the May, 1972 electrofishing samples. The increased occurrences could have been caused by transmission of the fungus among fishes attracted to the discharge in the winter and spring. However, the increased occurrence may also have been caused by a stressful environmental condition not associated with power plant operation. The phenomenon did not recur in 1973 or 1974.

Juvenile fishes were sampled with a seine during 1973. Results were similar to those obtained in earlier years; the southern stations produced greatest diversity and numbers until annual temperature maxima were reached on July 26. At this time the area under the influence of the plant discharge was devoid of juvenile fishes; northern stations yielded normal numbers.

Fyke netting results from 1972 and 1973 revealed a distribution of fishes similar to that found in earlier studies. Differences between north and south areas can be attributed to habitat availability more than the influence of the plant. Juvenile bass and sunfishes tend to congregate in the area of high macrophyte production and extensive littoral zones of Stations S-2W and S-3E. This section could be classified as a nursery for juvenile centrarchids. The mean annual catch per net-day for the major species captured by fyke netting is presented in Figure 8. Generally, catch levels vary greatly from year to year and, as in the earlier studies, "peak" years are evident (Figure 9). Since most of the major species tend to reach greatest levels in the same year, a dominant year-class effect is probably being realized. In river and stream fishes, spawning season water level stability is an important determinant of reproductive success (Starrett, 1951). Considering the tremendous variability in Merrimack River spring water levels on a year-to-year and daily basis (Figure 9), it is likely that this variation in large part determines the reproductive success and, hence, relative year-class strength of these stream fishes.

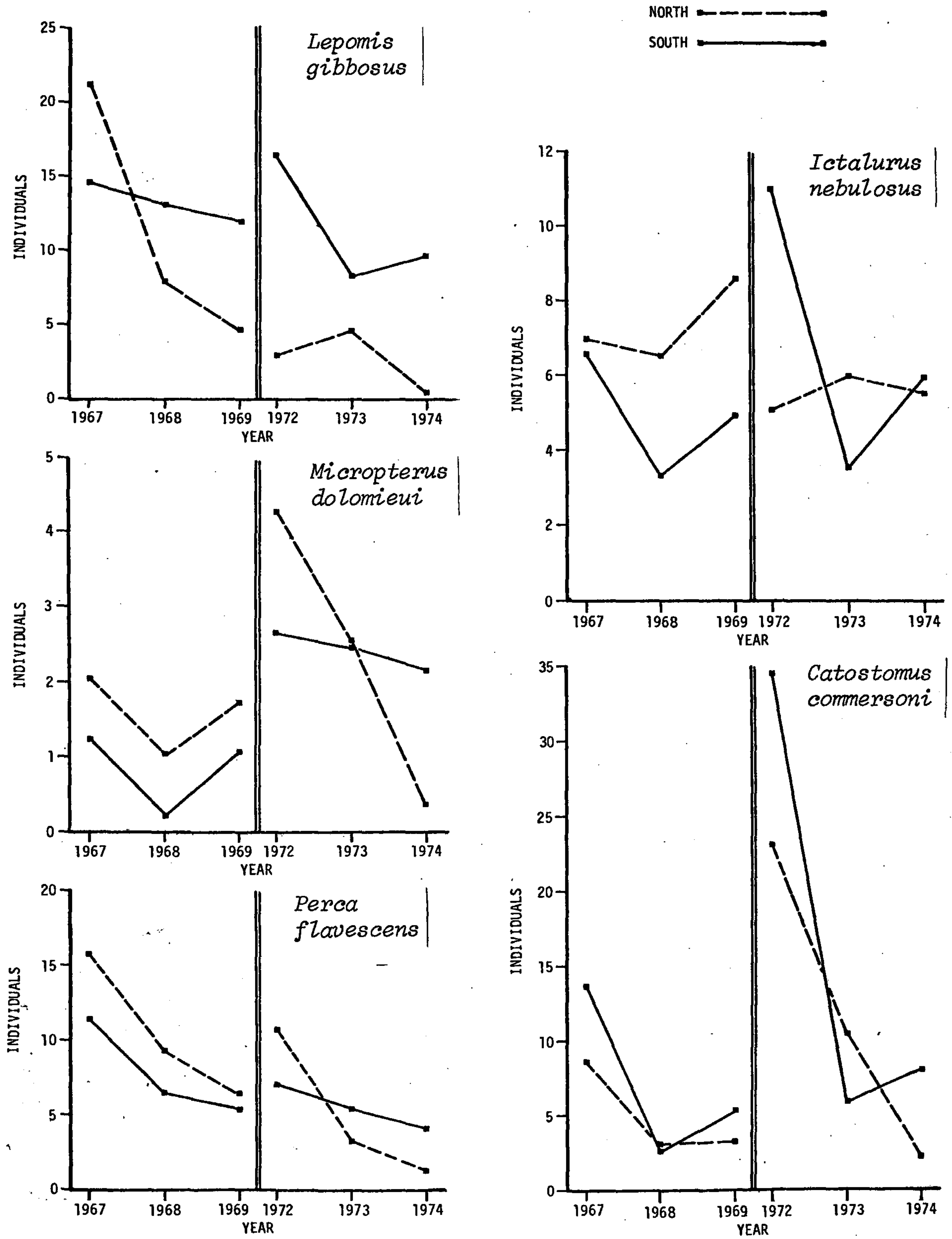


Figure 9. Mean annual catch per unit of fyke-net effort (individuals/net-day) f(the most frequently encountered Merrimack River fish species, 1967-19:

Age and growth analysis based on 1973 fyke netting data indicated that pumpkinseed and yellow perch were slightly larger at a given age south of the discharge than at the northern stations. No such differences were noted for smallmouth bass. The accretion of length and weight, as revealed by length-weight computations, was essentially identical for all three species north and south of the discharge. Generally, NAI age-and-growth findings agreed with those of Wightman (1971a) who found no substantial growth difference among Hooksett Pond pumpkinseed, yellow perch, smallmouth bass, or red-breasted sunfish although the latter has not been studied in recent years. Age and growth data from the 1974 season have not been analyzed.

In conclusion, the results of fisheries investigations conducted in the Hooksett Pond reach of the Merrimack River from 1967 through 1974 have indicated that the Merrimack Generating Station has had little measureable effect on the resident fish community. Generally, the river supports a typical balanced warm-water stream fish community characterized by the presence of many minnows (*Semotilus corporalis, Notropis* spp.), white suckers, and bullheads (principally *I. nebulosus*) and lesser numbers of game species including smallmouth bass, pumpkinseed, and yellow perch. White perch, red breasted sunfish, and chain pickerel (*Esox niger*) are also present in limited numbers. Measureable effects of the plant to date are limited to a) avoidance of the thermal plume area by all fishes during summer months; b) attraction of some species to the plume in winter and spring; c) increased size of pumpkinseed at south stations (not necessarily directly attributable to plant operation); and d) the possible spread of fungus infections in the discharge during 1972. The plant has not measureably altered the species composition of the community or age structure of any of the major fish species.

C. SUMMARY

Measurable effects of Merrimack Station which have been discerned to date through physical-chemical and biological monitoring of Hooksett Pond have been few. Temperatures in Hooksett Pond are elevated above ambient by the plant's thermal discharge. This effect is most noticeable during periods of low-flow, usually mid-to-late summer and early autumn. Passing river water through the plant's cooling system generally lowers its dissolved oxygen concentration. This is caused by a) the temperature rise through the plant, which decreases oxygen's solubility in water and, at some times, causes supersaturation; and b) the action of the PSM system, which drives off any excess (supersaturated) dissolved gasses. Generally, dissolved oxygen levels throughout Hooksett Pond are sufficiently high for the protection of the indigenous biota.

Biological effects have been noted only for plankton, periphyton, and finfish components of the Hooksett Pond biota. Only several effects can actually be related to the warm water discharge. Detectable changes in phytoplankton composition among both plankton and periphyton communities have been noted. It appears that the warm-water discharge reduces diatom production somewhat in both communities south of the plant. The ultimate effect of these reductions cannot be determined at this time. Trends among other phytoplankton phyla and the zooplankton are less clear in that changes in abundance do not occur consistently above and below the plant.

The finfish community of Hooksett Pond appears to respond behaviorally to the thermal discharge. Movement into the warm water by some species occurs during the cold months while the affected area appears to be avoided by most fishes during low flow-high temperature periods. This "behavioral thermoregulation" (Neill and Magnuson, 1974) may be potentially damaging for the following reasons:

1. Fishes may be concentrated within the plume, making them more vulnerable to predation, parasites, and pathogens.

2. Fishes within the warm plume in winter must expend large quantities of energy due to the metabolic demands of high body temperature. In the absence of extensive food supplies, weight loss and emaciation are possible.

3. Temperature-dependent reproductive cycles may be disrupted.

4. Avoidance of the area during summer further concentrates fishes in unaffected areas. The productivity of the influenced river section is thereby lost to the populations and to the community.

Only (4) and, possibly (1) have been demonstrated in Hooksett Pond. Most fish do leave the area immediately south of the plant during summer, thereby eliminating that area's productivity. In addition, the transmission of a fungal infection among yellow perch concentrated within the discharge was suspected in 1972.

Other than the slight alterations noted, no detectable changes have occurred in Hooksett Pond which can be related to the operation of Merrimack Station. It is therefore doubtful that the plant's operation has had any adverse impact on the ecology of Hooksett Pond to date.

III. DISCUSSION OF ANADROMOUS FISHERIES

A. CURRENT STATUS AND FUTURE GOALS OF MERRIMACK RIVER ANADROMOUS FISHERIES RESTORATION PROGRAM

Shad and salmon restoration programs are underway for the Merrimack River and its major tributaries. The status and future goals of these programs are outlined below (A. Knight, 1974. Pers. Com.).

1. American Shad

The American shad restoration program was initiated in 1969 with the introduction of Connecticut river eggs into most reaches of the Merrimack. Migrating adults currently ascend the fishway at Lawrence, MA and can negotiate the river as far as Lowell. These spawners are the result of propogation efforts carried out during 1969 and in subsequent years by the Merrimack River Cooperative Fishery Restoration Program (Mass. Div. Fish and Game, N. H. Fish and Game Dept., Nat. Mar. Fish. Ser., Bur. Sport Fish. and Wildl.) . However, to date no eggs, larvae, or juveniles have been taken in the lower reaches of the river despite the expenditure of considerable effort in this regard; reproductive failure to date is indicated. Runs are sustained through the continued release of Connecticut River eggs. These propagation efforts have continued; eggs have been hatched and juveniles produced in most reaches of the Merrimack River.

The goals of the shad program call for a 4-phase expansion from 1975 to 1990. Phase I calls for establishment of a spawning run (any size run) in the New Hampshire portion of the Merrimack south of Amoskeag Dam by 1978. To achieve this, propagation of juveniles via egg transport from other rivers will continue. Phase II calls for spawning runs to be extended to Franklin Falls by 1980. The magnitude of success achieved by this phase will depend upon fishway construction at Amoskeag, Hooksett, and Garvin's Falls. If a trucking program is necessary (as in the Connecticut River) the magnitude of the 1980 runs will be substantially lower than would be present if fishways are available. However, since the salmon program's success also depends on fishway construction, it is likely that construction will be pressed. Phase III calls for the expansion of Phase II programs to include major tributaries (Nashua, Souhegan, Piscataquog, Soucook, Contoocook) and the establishment of a limited sport fishery. Phase IV calls for a feasibility study and, if possible, limited commercial fishing by 1990. The magnitude of the program's success in Phase III and IV will depend on success in the tributaries; the degree to which the dams can be laddered or, if possible, breached will limit eventual productivity. Eventually, an annual run of 1 million shad is predicted.

2. Atlantic Salmon

The Merrimack River Atlantic salmon restoration program is the number three program in New England behind Penobscot and Connecticut River efforts. Merrimack River salmon restoration is scheduled to begin in 1976 with the introduction of 200,000 fingerlings into the Pemigewasset River. This figure may be revised downward to 100,000 due to difficulty in locating a Canadian egg source. The salmon program has been planned in three phases. Phase I, which will be initiated with the 1976 Pemigewasset introductions, calls for a return run of up to 200 spawning adults in 1980. Plans call for these fish to be captured in the Merrimack Estuary near Newburyport, MA and spawned artificially. The eggs will then be raised at the Milford, NH hatchery until smoltification. They will then be transferred to stockout facilities on the Pemigewasset for imprinting prior to seaward migration. The purpose of this is to develop a "Merrimack" egg source. Phase II of the program calls for the expansion of Merrimack - Pemigewasset runs so that a limited sport fishery can be sustained by 1985. Phase III calls for expanding the runs into the major tributaries with a sustained annual return of 11,000 (conservative estimate) fish by 1990 (based on habitat study by Newell and Nowell, 1963). Maximum returns will depend upon the degree to which obstructions in the tributaries are bypassed or eliminated. No hatchery propagation is planned; a naturally sustained run is hoped for because Atlantic salmon are difficult to culture and productivity is generally as high or higher under natural conditions (D. Kimball, 1974. Pers. Com.).

B. THE HOOKSETT POND REACH OF THE MERRIMACK RIVER AS SALMON AND SHAD HABITAT AND THE LIKELY EFFECTS OF MERRIMACK STATION ON THESE FISHES

Fresh water salmon and shad habitat consists only of suitable spawning and nursery areas. Extensive adult feeding areas are not necessary since seaward migration takes place long before the young reach maturity. Suitability of the Hooksett Pond reach of the Merrimack River as salmon and shad habitat in these life history phases is discussed below.

1. Atlantic Salmon

The midsummer ambient Hooksett Pond temperature maximum of about 77°F (25°C) precludes the use of this stretch of the river for breeding and nursery purposes by salmon. Hooksett Pond will only be inhabited by transient adults and smolts in April, May, and early June. During these times of year discharge is relatively high (Figure 9), which prevents heat buildup in Hooksett Pond; temperatures even at Station 0-W seldom reach the 68°F (20°C) recommended maximum (DeCola, 1970; Nat. Tech. Advisory Committee, 1968). Because of the timing of the migrations, Merrimack Station probably does not constitute a hazard either as a potentially lethal agent or as a thermal blockage to migration. Hanford

Station, on the Columbia River, has been studied extensively in this regard and no blockage of chinook salmon (*Oncohrynchus tshawytscha*) or steelhead trout (*Salmo gairdneri*) adults or smolts has been demonstrated. The ability of smolts and adults to negotiate Hooksett Pond under different conditions should be examined in great detail early in the restoration effort. Currently, there are no water quality barriers to Atlantic salmon migration in the Merrimack River mainstream (A. Knight, 1974. Pers. Com.).

2. American Shad

Hooksett Pond probably represents satisfactory habitat for all aspects of the American shad's fresh water life history. A substrate study (Normandeau, 1969) indicated that most of the Hooksett Pond bottom is of "medium" coarseness (fine sand to pebbles). Since shad prefer spawning over alluvial depositions (gravel substrates) bathed by running water (Walburg and Nichols, 1967), many places in Hooksett Pond are suitable as spawning areas. Recent *in situ* studies by Wightman (1971b) have demonstrated the hatching ability of shad eggs in the Franklin Falls section of the Merrimack. Similar experiments conducted in Hooksett Pond a year earlier failed. Nevertheless, Hooksett Pond is probably suitable for the spawning and development of shad eggs. Eggs and larvae can tolerate water temperatures up to 80°F (26.7°C) without any adverse effects (Bradford, Miller, and Buss, 1966). Hooksett Pond temperatures south of Merrimack Station generally do not reach 80°F until flow volumes decrease to summer levels in late June. The river from Station 0-W southward then warms substantially, with surface temperatures frequently exceeding 80°F. This seasonal warming corresponds to the late June-early July spawning period of Connecticut River American shad populations (Watson, 1970). However, the Merrimack Station thermal discharge is not likely to have any effect on developing shad eggs since they are semi-buoyant and remain near the bottom (Walburg and Nichols, 1967). Upon hatching, the larvae migrate vertically and seek the upper water levels. At this time they could be exposed to thermal effects from the Merrimack

Station discharge. Preliminary bioassays by Bradford *et al.* (1966) indicated that shad larvae tolerated 85°F (29.4°C) water temperatures. Other studies (Moss, 1970; Hoss, Coston, and Hettler, 1971), utilizing larvae of closely related clupeid species (menhaden, *Brevoortia tyrannus*; alewife, *Alosa pseudoharengus*; and blueback herring, *Alosa aestivalis*), have also indicated that the critical temperature for larval survival is between 28 and 30°C (83-86°F). Because Hooksett Pond surface temperatures sometimes exceed these levels by the end of July (Figure 2), some larval mortality may be attributable to Merrimack Station discharges during periods of low discharge. The magnitude of this problem, if it exists, cannot be ascertained without time-in-travel estimation. Some entrainment mortality may also occur due to the drawing of some larvae through the plant's cooling system. The magnitude of entrainment effects will also vary inversely with July discharge.

Movement of adult shad in Massachusetts portion of the Connecticut River reaches peak levels in May and June when water temperatures are between 58 and 71°F (15-22°C) (Watson, 1970). A similar late spring temperature regime exists in the New Hampshire portion of the Merrimack. Timing of spawning runs should therefore be similar or, possibly, 1-2 weeks later considering that the spawning aggregations must round Cape Cod during their spring south-to-north oceanic migration (Leggett and Whitney, 1972).

Post-larval and juvenile american shad will probably do quite well in Hooksett Pond, where there are adequate zooplankton and aquatic and terrestrial insect food sources. Like the endemic warm water fishes, the young shad will probably avoid the area of greatest thermal impact (Station N-1 to S-5) throughout most of the summer. Moss (1972) has demonstrated the ability of young shad to detect and avoid excessively warm waters. For this reason, discharge-related mortalities are unlikely. The autumn seaward migration occurs during periods of high discharge (Watson, 1970); thermal blockage is not likely. No thermal blockage of migrating adults or juveniles has been demonstrated at the Haddam Neck Connecticut Yankee Plant, on the Connecticut River. Gill net studies at this plant have shown that the young shad move downstream beneath the thermal plume.

In conclusion, the operation of Merrimack Station will probably not influence the migration of spawning Atlantic salmon or American shad in the Merrimack River. The spring concentration of migratory activities for these species generally coincides with high water levels which, in all probability, will eliminate the possibility of thermal blockage. Similarly, seaward migrations of salmon smolts (early spring) and young shad (fall) are concentrated during high water periods; adverse effects are unlikely. Shad will probably spawn in Hooksett Pond. The potential for detrimental effects to developing eggs is low because the eggs are not buoyant. Shad larvae will have the greatest potential for adverse interaction with Merrimack Station in that their pelagic nature and surface orientation may subject them to potentially lethal thermal conditions during July in low-flow years. The magnitude of this undesirable effect may, however, be ameliorated somewhat since the larvae will have to actively swim upward into the plume from below to be exposed to the high temperatures. The ability and desire to do this remains to be demonstrated. An additional potentially lethal effect exists in that some larvae may be entrained in the cooling water. Young shad will probably avoid the zone of maximum warming during July and August, eliminating the possibility of discharge-related juvenile mortalities.

3. Funding

As a co-operative effort between two states and an agency of the United States Government, nearly all activities of both the salmon and shad restoration programs are entitled to 2/3 federal funding. The only aspect of the programs not funded in this manner is Milford Hatchery operation. This is a cooperative effort between only one state and the Bureau of Sport Fisheries and Wildlife and, therefore, receives only 50% federal funding.

Department of the Interior personnel indicate that the Merrimack Connecticut, and Penobscot River anadromous fishery restoration efforts are currently a high-priority item for the Northeast region (D. Kimball, 1974. Pers. Com.). If anything, the Bureau's emphasis on anadromous fish restoration in the Northeast is expected to increase over the next decade. No budgetary estimates will be available for at least six months, however.

A study completed recently by Jason Cortell for the U. S. Army Corps of Engineers' proposed Merrimack Diversion Project has estimated the value of the expected Merrimack anadromous sport fisheries. The study estimated the shad fishery, at a 20% harvest of 1 million shad, to be worth approximately $1.4 million 1974 dollars. A 25% harvest of 11,000 Atlantic salmon is expected to yield $440,000 to $1.4 million (D. Kimball, Pers. Com.).

C. SUMMARY AND CONCLUSIONS

Hooksett Pond supports a viable, productive warm-water fish community which contains relatively high proportions of game species; its reclassification as cold-water fishery habitat is totally without biological necessity. The only cold-water fish which will occur in Hooksett Pond are transient Atlantic salmon. Because all migratory activities of this species are concentrated during relatively high discharge-low temperature periods, the likelihood of adverse interaction with Merrimack Station is very low. To classify Hooksett Pond as cold-water fishery habitat because of the American shad is equally without biological necessity since the species is not a cold-water form. To call the American shad a cold-water species is to call coastal rivers from the lower Connecticut as far southward as the St. John's River, Florida, in which shad are successful, cold-water streams. Although conditions between Merrimack Station and Hooksett Dam may, at some times, be potentially dangerous to young American shad, the enactment of cold-water stream standards for the protection of American shad in the Merrimack River is considerably more stringent than necessary for the protection of this species.

LITERATURE CITED

Bradford, A. D., J. G. Miller and K. Buss. 1966. Bio-assays on eggs and larval stages of American shad *Alosa sapidissima*. Appendix 2, pp 52-60 IN: Carlson, F. T. 1968. Suitability of the Susquehanna River for restoration of the American shad. U. S. Dept. Int., Md. Bd. Nat. Res., N. Y. Conserv. Dept., Pa. Fish. Comm.

Carlson, F. T. 1968. Suitability of the Susquehanna River for restoration of the American shad. U. S. Dept. Int., Md. Bd. Nat. Res., N. Y. Conserv. Dept., Pa. Fish Comm. 60 pp.

Hoss, D. E., L. C. Coston and W. F. Hettler. Proc. 25th Ann. Conf. S. E. Assoc. Game and Fish Comm.:635-642. 1971. Effects of increased temperatures on post-larval and juvenile estuarine fish.

Kimball, D. 1974. Personal Communication. U. S. Dept. Int., Bur. Spt. Fish. and Wildl., Div. Fed. Aid. Boston, MA.

Knight, A. 1974. Personal Communication. U. S. Dept. Int., Bur. Spt. Fish and Wildl., Div. Fish. Services. Laconia, NH.

Leggett, W. C. and R. R. Whitney. 1972. Water temperature and the migrations of American shad. Fish. Bull. 70(3):659-669.

Marcy, B. C., Jr. 1973. Vulnerability and survival of young Connecticut River fish entrained in a nuclear power plant. J. Fish. Res. Bd. Canada 30(8):1195-1203.

Moss, S. A. 1970. The responses of young American shad to rapid temperature changes. Trans. Am. Fish. Soc. 99(2):381-384.

Neill, W. and J. J. Magnuson. 1974. Distributional ecology and behavioral thermoregulation of fishes in relation to heated effluent from a power plant at Lake Monona, Wisconsin. Trans. Am. Fish. Soc. 103(4):663-710.

Newell, A. E. and H. C. Nowell, Jr. 1963. Merrimack River salmon restoration. N. H. Fish and Game Dept., Mgmt. and Res. Div. 55 pp.

Normandeau, D. 1969. The effects of thermal releases on the ecology of the Merrimack River. Inst. Res. and Services, St. Anselm's Col., Manchester, NH. 234 pp.

Normandeau Associates, Inc. 1969. The effects of thermal releases on the ecology of the Merrimack River. Supp. Rep. No. 1: Physical studies fisheries investigations, 1969. 70 pp.

__________________________. 1971. Merrimack River monitoring program. A report for the study period 1970. 117 pp.

__________________________. 1972. Merrimack River monitoring program. A report for the study period 1971. 108 pp.

__________________________. 1973. Merrimack River monitoring program. A report for the study period 1972. 91 pp.

__________________________. 1974. Merrimack River monitoring program. A report for the study period 1973. 109 pp and Appendix.

Starrett, W. C. 1951. Some factors affecting the abundance of minnows in the Des Moines River, Iowa. Ecology 32(1)13-24.

Walberg, C. and P. Nichols. 1967. Biology and management of the American shad and status of the fisheries, Atlantic coast of the United States, 1960. U. S. Fish and Wildl. Serv., Spec. Sci. Rep. Fish. No. 550. 105 pp.

Watson, J. 1970. Distribution and population dynamics of American shad *Alosa sapidissima* (Wilson), in the Connecticut River above Holyoke Dam, Mass. Ph.D. Thesis, Univ. Mass., Amherst. 105 pp.

Wightman, P. 1971a. Merrimack River thermal study. N. H. Fish and Game Dept., Div. Inland and Mar. Fish. 111 pp.

___________. 1971b. Anadromous fish restoration in the Merrimack River N. H. Fish and Game Dept., Div. Inland and Mar. Fish. Project No. AFS-10-1. July 1, 1970 to June 30, 1971.

APPENDIX A

APPENDIX A

This appendix presents data which demonstrates the manner in which the Merrimack Station cooling system effluent influences temperature distribution in the Merrimack River during periods of lowest river flow and/or highest ambient temperature. These two conditions create the greatest potential for severe thermal stress, and sometimes they occur together as is shown. The data presented herein were obtained in the summers of 1972, 1973 and 1974. The date and environmental condition (either lowest flow or highest ambient temperature) represented by each data group are as follows:

July 7, 1972	highest ambient temperature, 1972
September 26, 1972	lowest flow, 1972
July 31, 1973	highest ambient temperature, 1973
August 23, 1973	lowest river flow, 1973
August 22, 1974	highest ambient temperature and lowest river flow, 1974

Sets of six cross-sectional isotherm illustrations for each of the five dates are shown in Figures A-1, 3, 5, 7, and 9. Each set consists of cross sections at Transects N-10, Zero, S-1, S-2, S-3 and S-4. The mean cross sectional temperatures at N-10 were taken to be ambient, and Table A-1 lists these temperatures for each date. Note in the cross sections that the isotherms for a given date differ by integral numbers from the ambient temperature. This was done to facilitate computation of areas bounded by certain Δt's. These areas are presented in Table A-2 for Δt's ranging from 5°F to 17°F. Column three in Table A-2 shows the total cross sectional areas at each transect line. Table A-3 presents the information of Table A-2 as percentage of total cross sectional areas. Mean cross sectional temperatures and mean cross sectional Δt's for each transect on each date appear in Table A-4. The mean cross-sectional Δt is defined as the difference between the mean cross-sectional temperature at a given transect and the mean cross-sectional temperature at Transect N-10.

Figures A-2, 4, 6, 8, and 10 are longitudinal profiles containing isotherms at the surface, 3 ft and 6 ft depths for the stretch of river between Transect Zero and Transect S-4. Table A-5 is a listing of the percentages of linear distance along specific transect lines bounded by isotherms corresponding to a Δt of 5°F or more. Note that the ambient temperature used in these linear determinations was the mean surface temperature at Transect N-10 (rather than the cross-sectional mean used in the area computations).

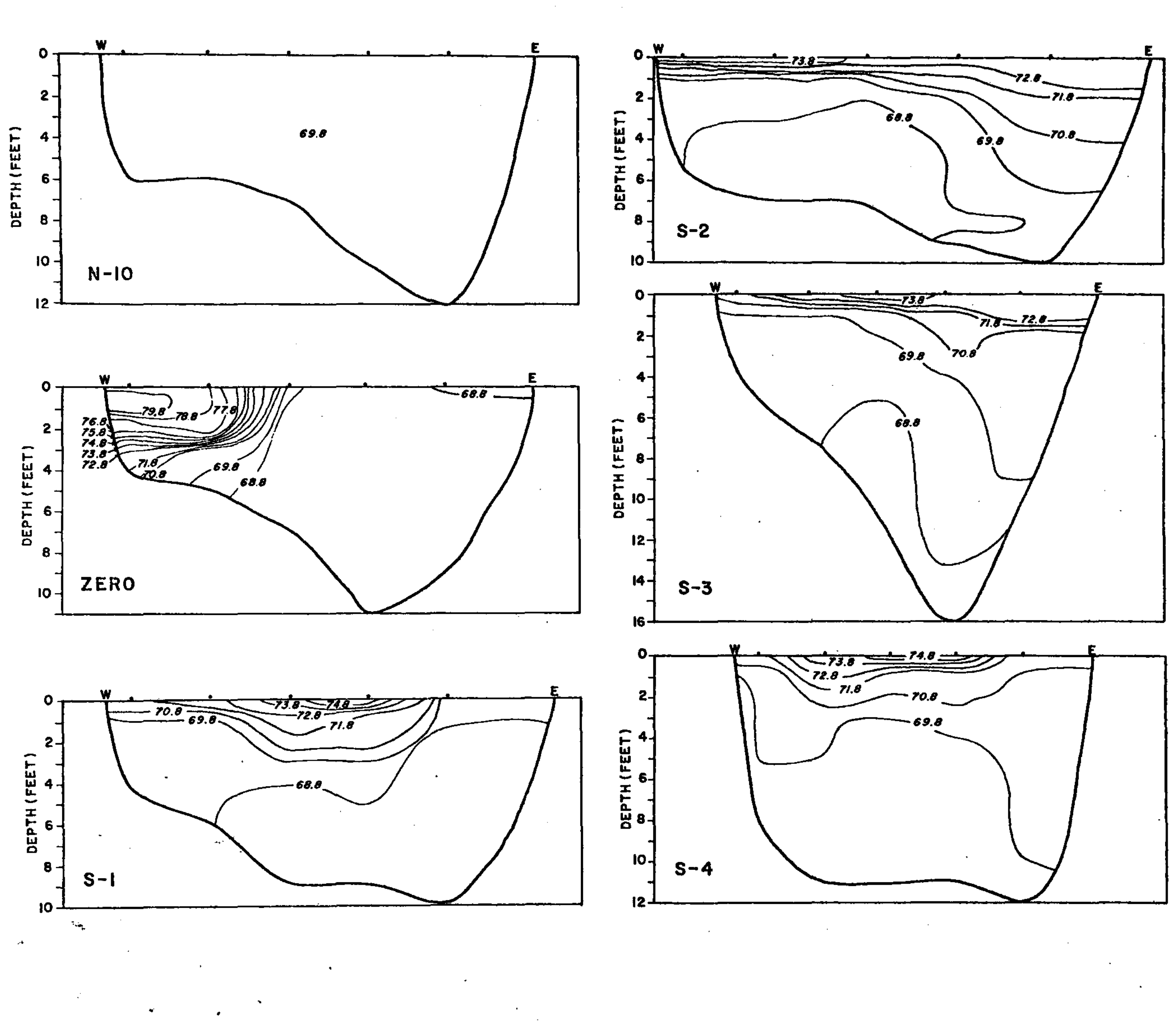


Figure A1. Cross-sectional isotherms, 7 July 1972.

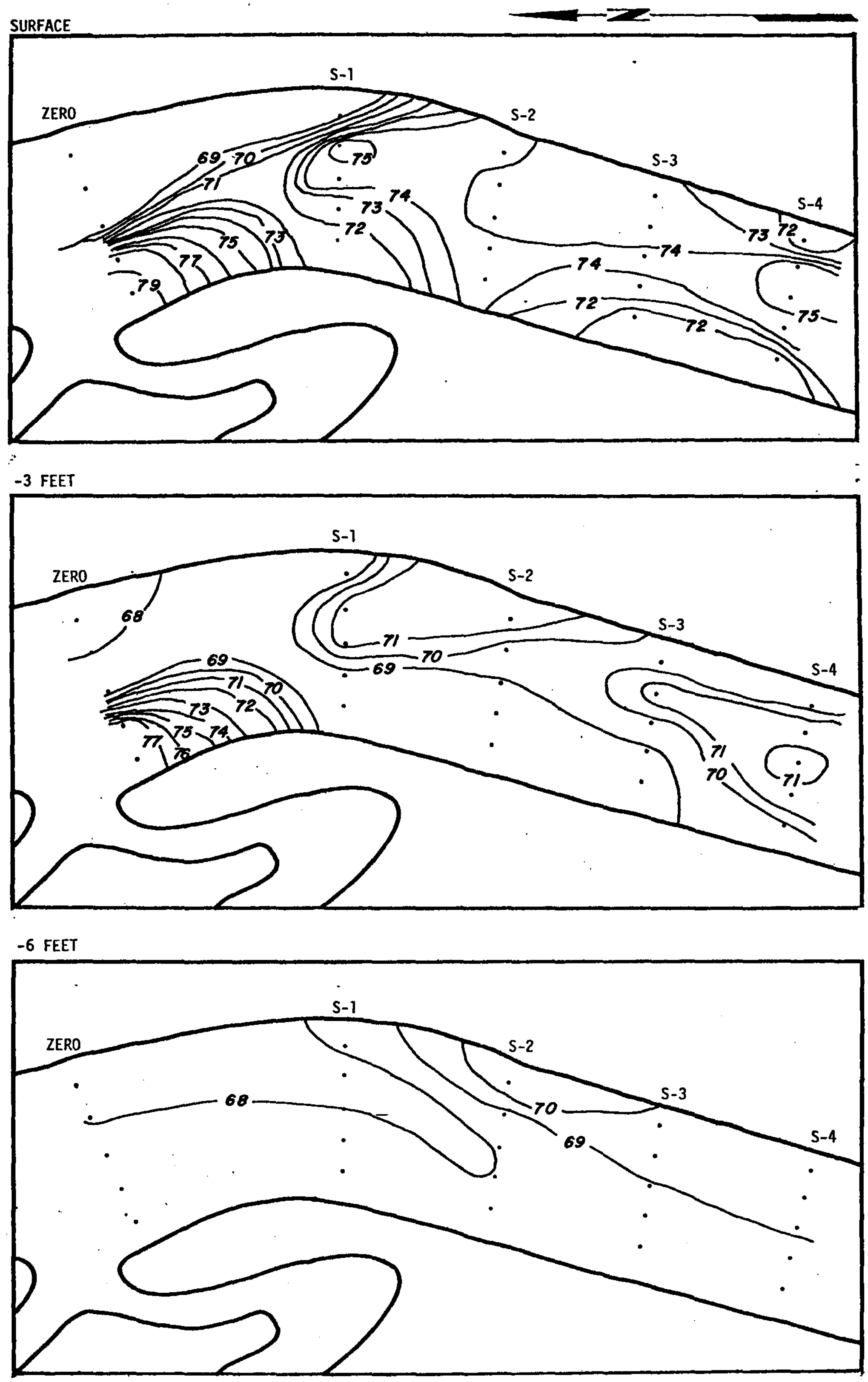


Figure A2. Longitudinal isotherms, 7 July 1972.

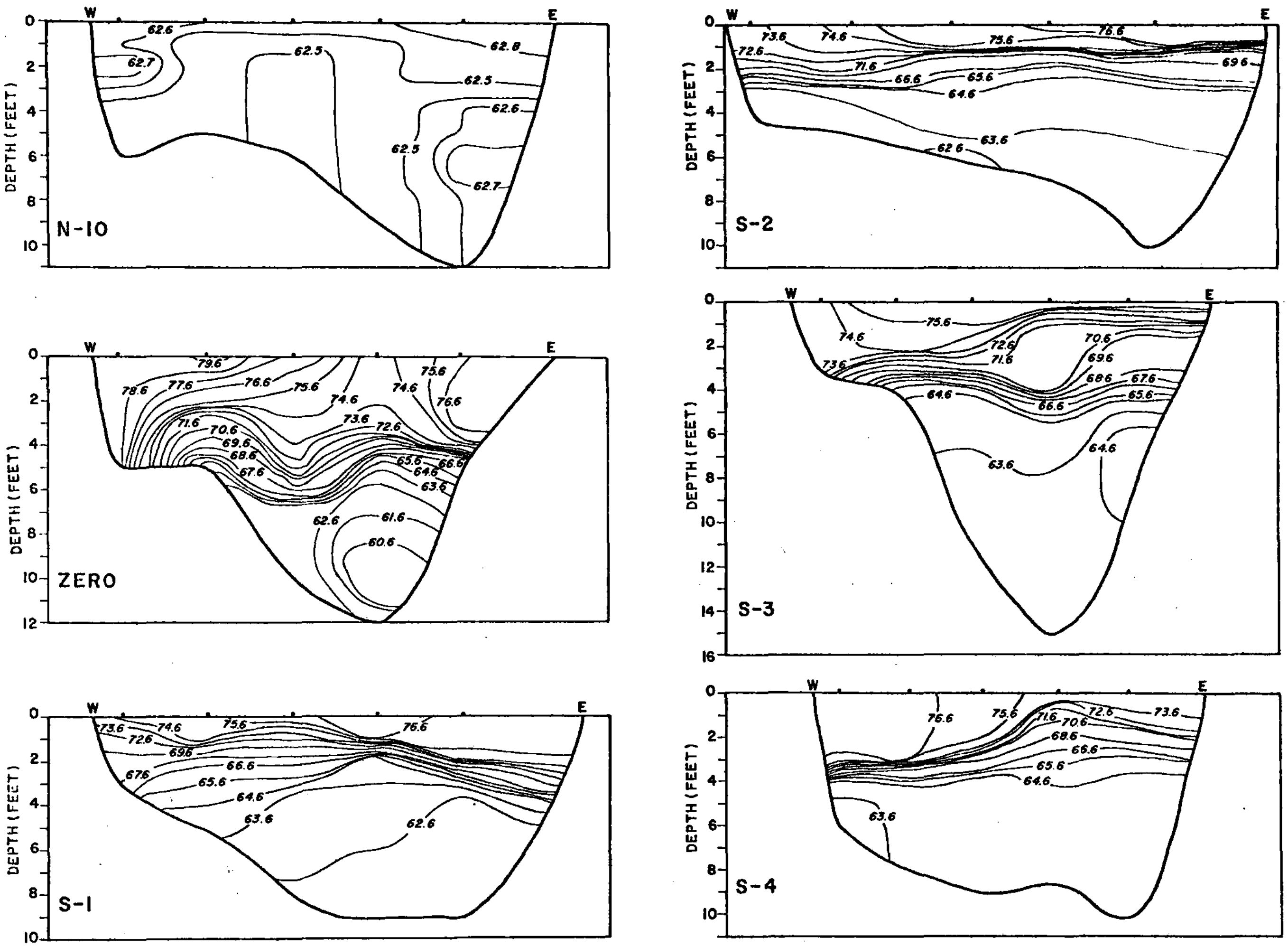


Figure A3. Cross-sectional isotherms, 26 September 1972.

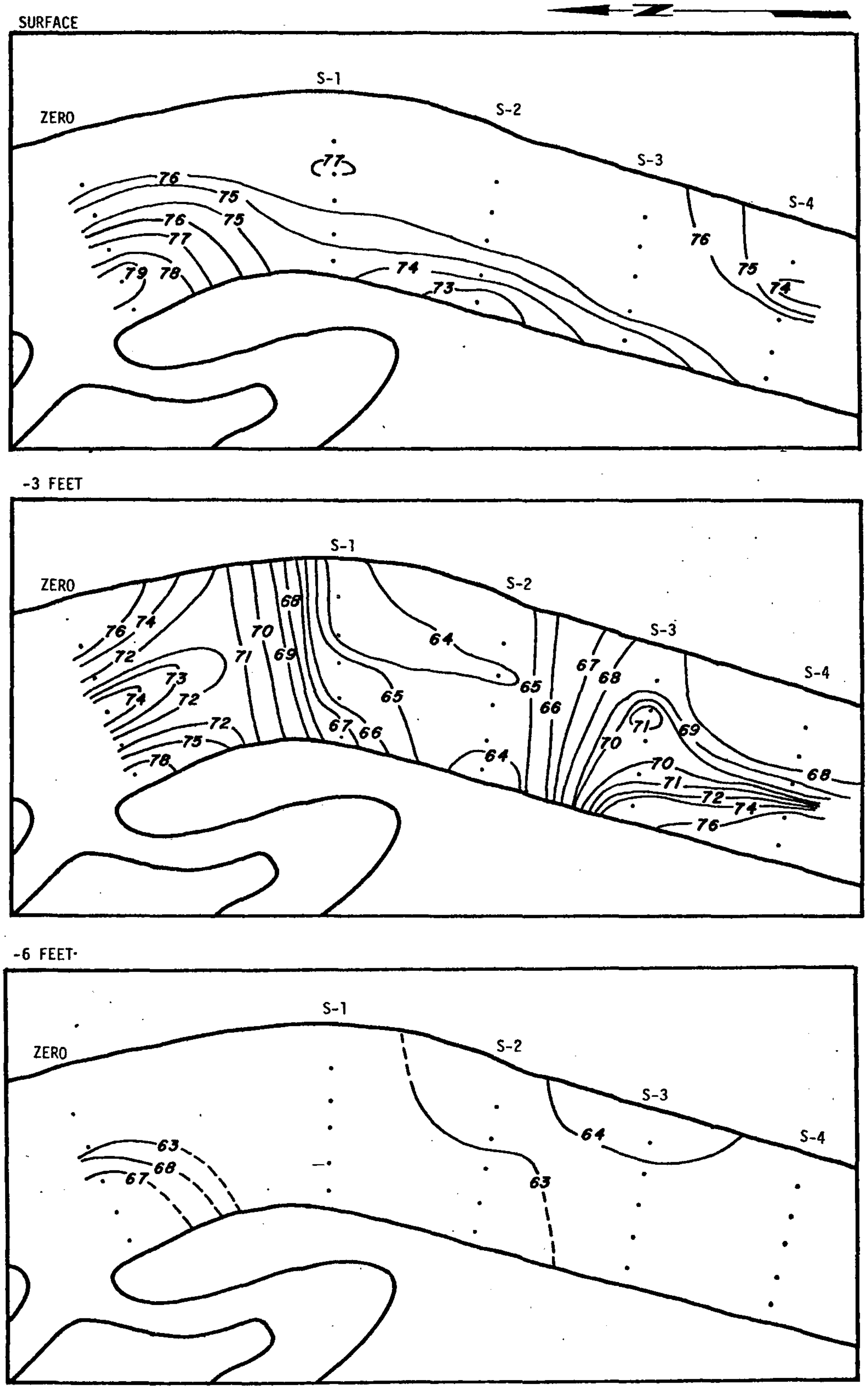


Figure A4. Longitudinal isotherms, 26 September 1972.

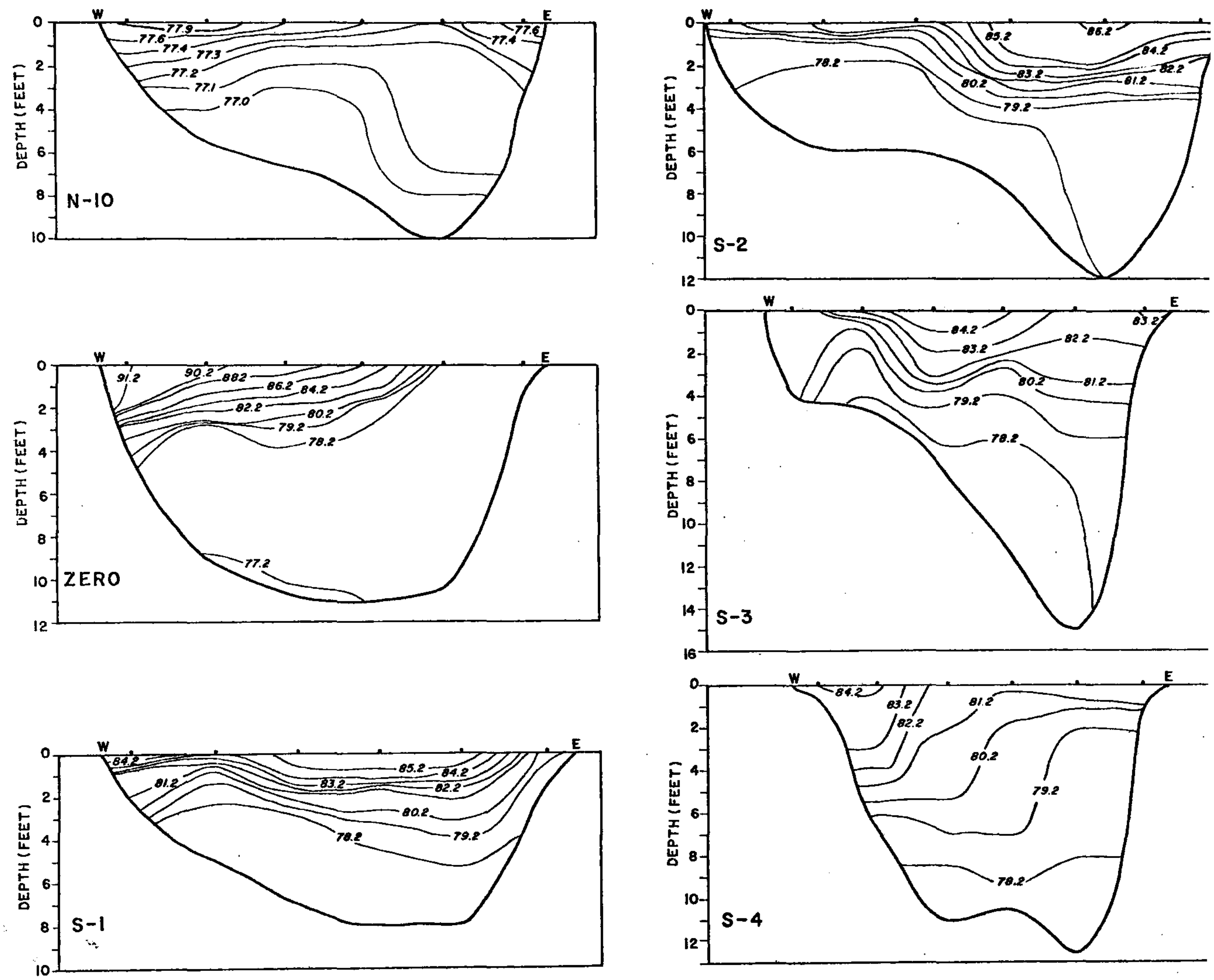


Figure A5. Cross-sectional isotherms. 31 July 1973.

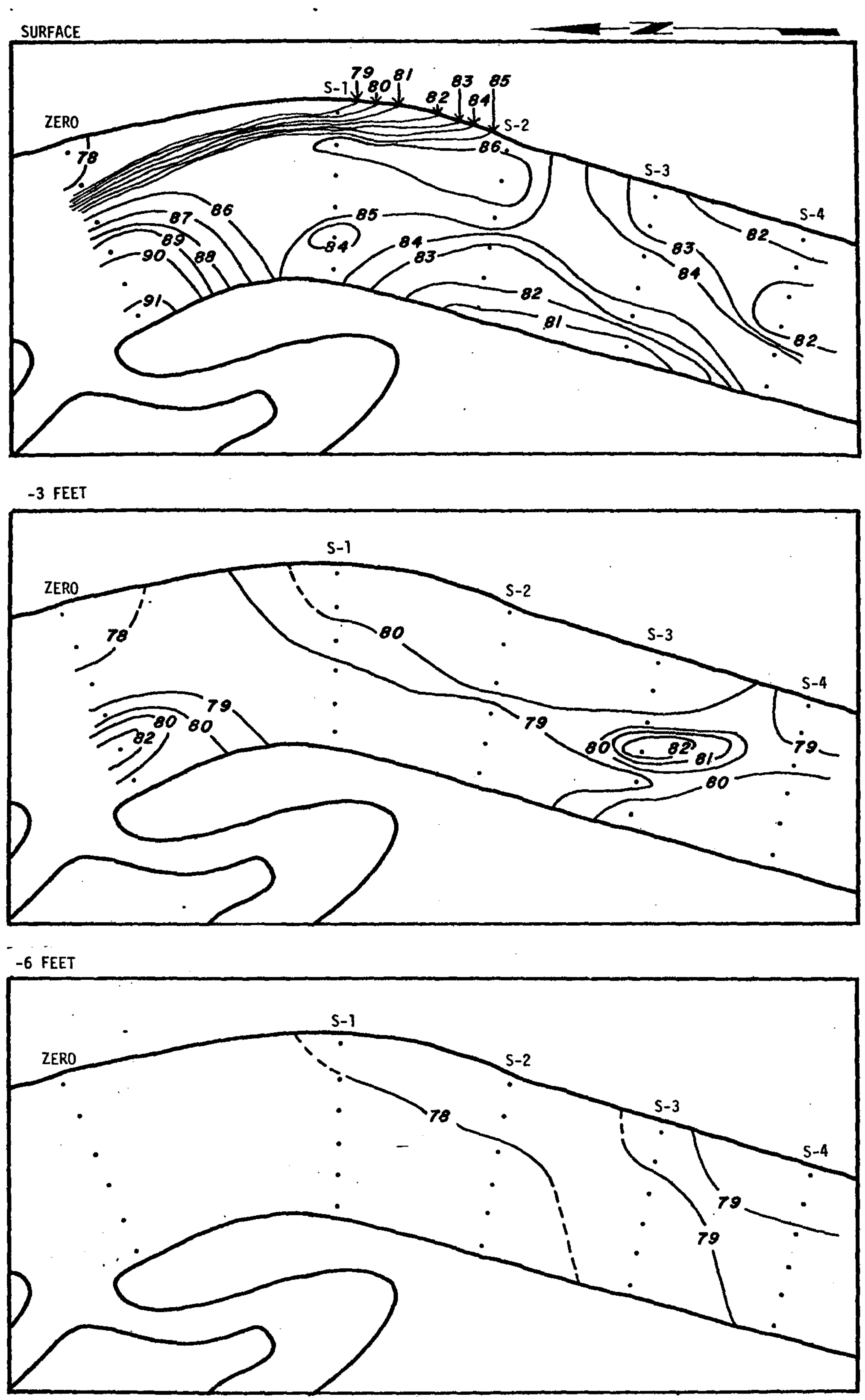


Figure A6. Longitudinal isotherms, 31 July 1973.

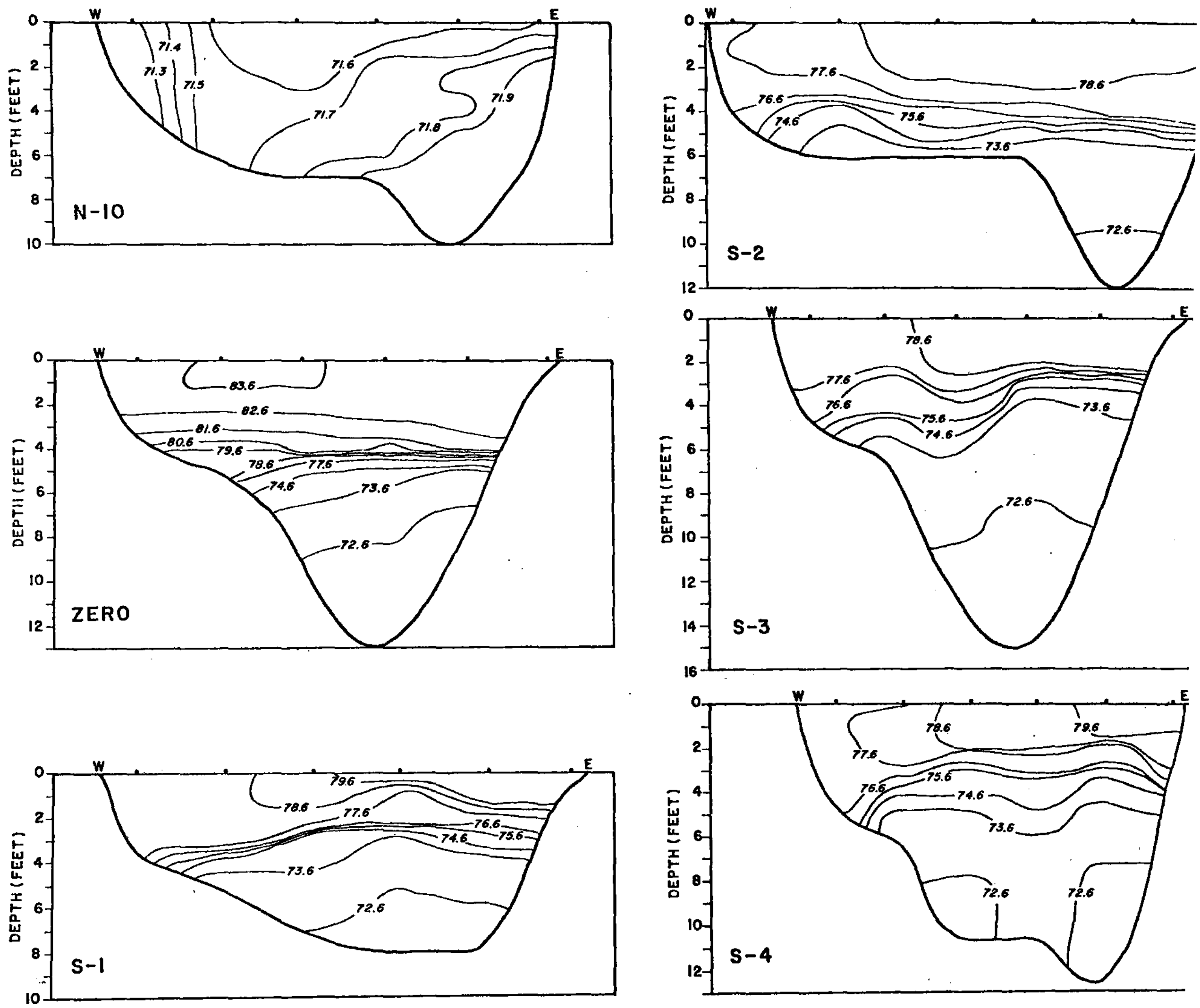


Figure A7. Cross-sectional isotherms, 23 August 1973.

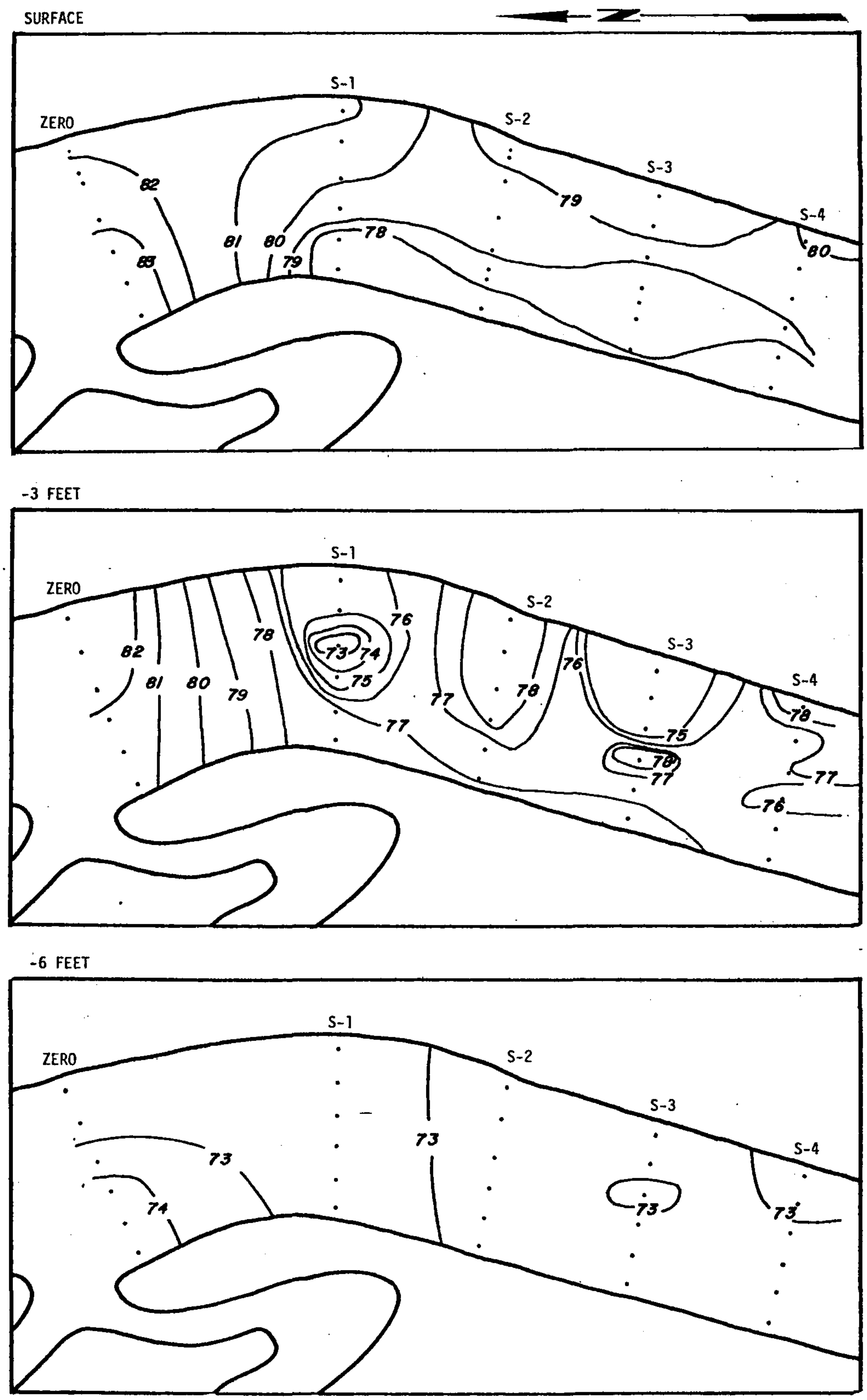


Figure A8. Longitudinal isotherms, 23 August 1973.

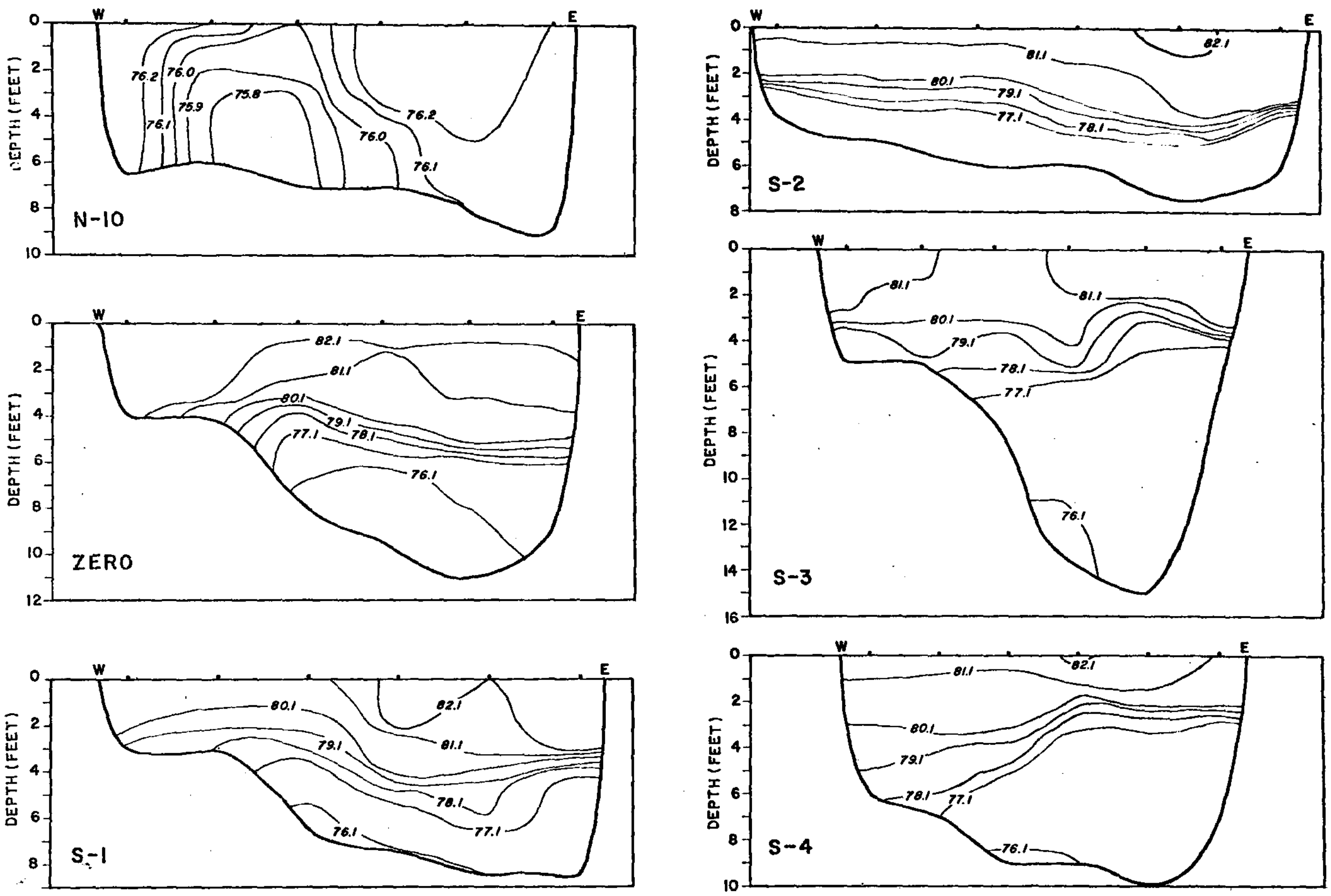


Figure A9. Cross-sectional isotherms, 22 August 1974.

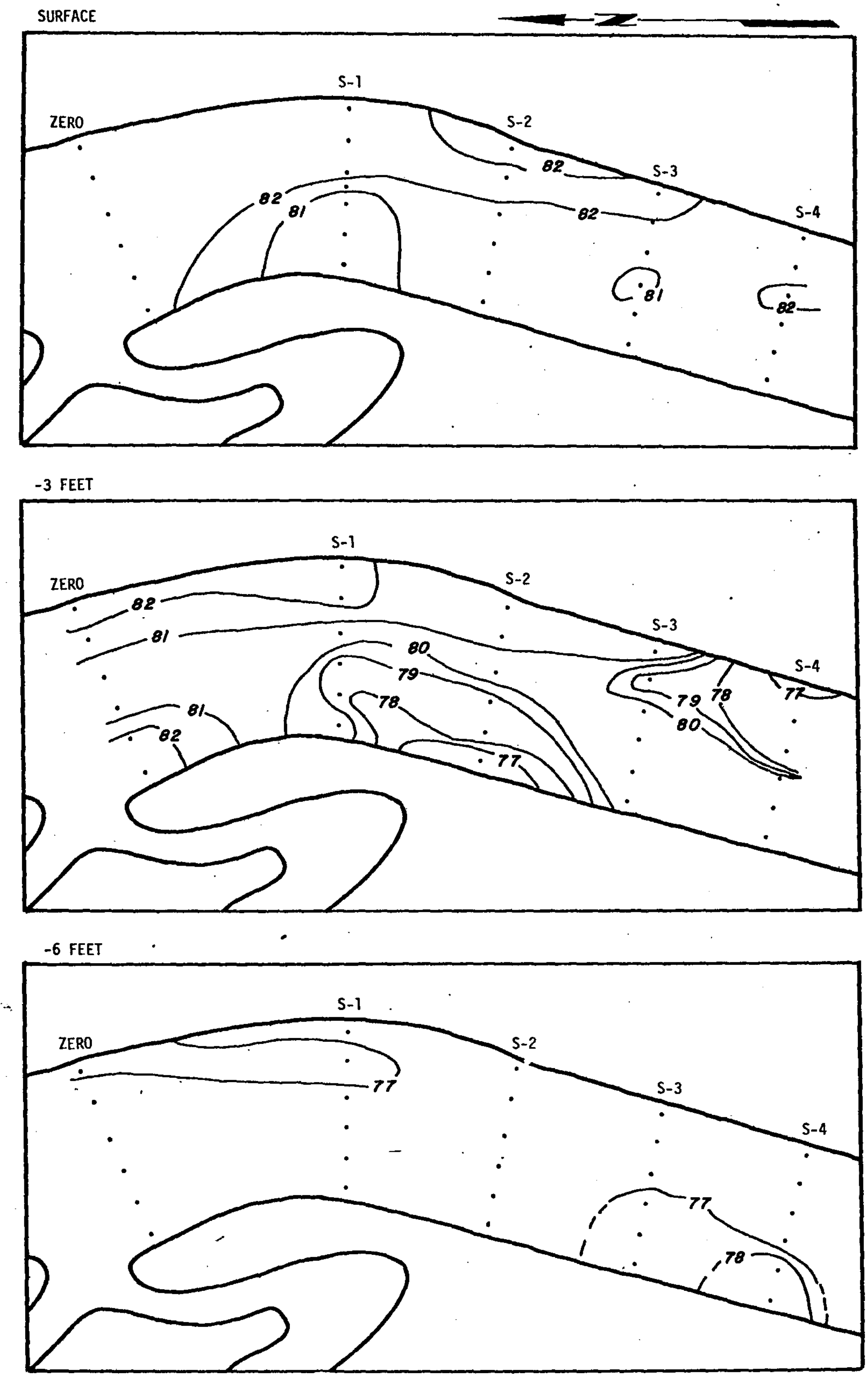


Figure A10. Longitudinal isotherms, 22 August 1974.

TABLE A1. MEAN CROSS SECTIONAL TEMPERATURES AT TRANSECT N-10 FOR EACH OF THE FIVE DATES

DATE	MEAN CROSS SECTIONAL TEMPERATURE AT N-10 (°F)*
7/7/72	69.8
9/26/72	62.6
7/31/74	77.2
8/23/74	71.6
8/22/74	76.1

* These temperatures were taken as ambient for all calculations involving cross-sections.

TABLE A2. HOOKSETT POND MORPHOMETRIC PROFILES AT 5 TRANSECTS. (TOTAL CROSS-SECTIONAL AREA AND AREA BOUNDED BY GREATER THAN 5° Δt ISOTHERMS DURING LOW FLOW AND HIGH TEMPERATURE PERIODS, 1972-1974. MEASUREMENTS IN FT^2)

DATE	TRANSECT LINE	TOTAL SECTIONAL AREA (ft^2)	≥5	≥6	≥7	≥8	≥9	≥10	≥11	≥12	≥13	≥14	≥15	≥16	≥17
7/7/72	Zero	3452	397	368	330	258	168	72							
	S-1	3904	20												
	S-2	4349													
	S-3	4194													
	S-4	3540	17												
9/26/72	Zero	3460	2192	2121	1992	1897	1798	1688	1532	1199	951	694	352	234	7
	S-1	3464	1209	1019	957	895	834	753	673	590	296	74			
	S-2	3769	1239	1169	1053	982	897	807	636	476	334	167			
	S-3	3668	1611	1492	1307	1197	894	837	691	635	205				
	S-4	3173	1243	1162	1049	988	919	848	760	606	565	361			
7/31/73	Zero	4192	658	567	505	453	374	297	218	196	155				
	S-1	2902	546	423	301	154									
	S-2	4104	773	628	453	341	16								
	S-3	3292	599	256	101										
	S-4	3376	346	227											
8/23/73	Zero	3490	2112	2062	2001	1887	1767	1609	1243	180					
	S-1	3004	1328	1146	389	226									
	S-2	4008	2281	1980	974										
	S-3	3863	1297	1140	618										
	S-4	3584	1336	817	546	152									
8/22/74	Zero	3816	1475	812											
	S-1	3220	771	459											
	S-2	3476	1000	84											
	S-3	3842	715												
	S-4	3288	388	7.5											

TABLE A3. PERCENTAGE OF TOTAL CROSS SECTIONAL AREA BOUNDED BY ΔT'S OF 5°F OR MORE

DATE	LINE	≥5	≥6	≥7	≥8	≥9	≥10	≥11	≥12	≥13	≥14	≥15	≥16	≥17
7/7/72	Zero	11.5%	10.7%	9.6%	7.5%	4.9%	2.1%							
	S-1	0.5%												
	S-2													
	S-3													
	S-4	0.5%												
9/26/72	Zero	63.4%	61.3%	57.6%	54.8%	52.0%	48.8%	44.3%	34.7%	27.5%	20.1%	10.2%	6.8%	0.2%
	S-1	34.9%	29.4%	27.6%	25.8%	24.1%	21.7%	19.4%	17.0%	8.6%	2.1%			
	S-2	32.9%	31.0%	27.9%	26.1%	23.8%	21.4%	16.9%	12.6%	8.9%	4.4%			
	S-3	43.9%	40.7%	35.6%	32.6%	24.4%	22.8%	18.8%	11.9%	5.6%				
	S-4	39.2%	36.6%	33.1%	31.1%	29.0%	26.7%	24.0%	19.1%	17.8%	11.4%			
7/31/74	Zero	15.7%	13.5%	12.0%	10.8%	8.9%	7.1%	5.2%	4.7%	3.7%				
	S-1	18.8%	14.6%	10.4%	5.3%									
	S-2	18.8%	15.3%	11.0%	8.3%	0.4%								
	S-3	18.2%	6.2%	2.5%										
	S-4	10.2%	6.7%											
8/23/74	Zero	60.5%	59.1%	57.3%	54.1%	50.1%	46.1%	35.6%	5.2%					
	S-1	44.2%	38.1%	12.9%	7.5%									
	S-2	56.9%	49.4%	24.3%										
	S-3	33.6%	29.5%	16.0%										
	S-4	37.3%	22.8%	15.2%	4.2%									
8/22/74	Zero	38.7%	21.3%											
	S-1	23.9%	14.3%											
	S-2	28.8%	2.4%											
	S-3	18.6%												
	S-4	11.8%	0.2%											

TABLE A4. MEAN CROSS SECTIONAL TEMPERATURES AND MEAN CROSS SECTIONAL ΔT'S

DATE	TRANSECT	MEAN CROSS SECTIONAL TEMPERATURE	MEAN CROSS SECTIONAL ΔT
7/7/72	N-10	69.8	---
	Zero	70.4	0.6
	S-1	69.8	0
	S-2	70.3	0.5
	S-3	70.3	0.5
	S-4	70.5	0.7
9/26/72	N-10	62.6	---
	Zero	70.8	8.2
	S-1	67.6	5.0
	S-2	67.9	5.3
	S-3	68.2	5.6
	S-4	69.8	7.2
7/31/73	N-10	77.2	---
	Zero	81.1	3.9
	S-1	80.3	3.1
	S-2	80.2	3.0
	S-3	80.1	2.9
	S-4	80.3	3.1
8/23/73	N-10	71.6	---
	Zero	83.4	11.8
	S-1	76.0	4.4
	S-2	76.9	5.3
	S-3	75.5	3.9
	S-4	75.9	4.3
8/22/74	N-10	76.1	---
	Zero	79.9	3.8
	S-1	79.7	3.6
	S-2	79.7	3.6
	S-3	79.0	2.9
	S-4	79.0	2.9

Mean cross sectional ΔT is the difference between the mean cross sectional temperature at a transect and the mean cross sectional temperature at N-10, which is considered ambient.

TABLE A5. PERCENTAGE OF LINEAR SURFACE DISTANCE BOUNDED BY ΔT'S OF 5°F OR MORE

DATE	AMBIENT TEMPERATURE	TRANSECT LINE	≥5	≥6	≥7	≥8	≥9	≥10	≥11	≥12	≥13	≥14	≥15	≥16	≥17
7/7/72	69.8	Zero	39%	37.5%	36%	34.5%	25%								
		S-1	12%												
		S-2													
		S-3													
		S-4													
9/26/72	62.8	Zero	100%	100%	100%	100%	100%	100%	100%	93%	77%	45%	35%	30%	9%
		S-1	100%	100%	100%	100%	100%	100%	100%	61%	43%	12%			
		S-2	100%	100%	100%	100%	100%	89%	85%	74%	67%	26%			
		S-3	100%	100%	100%	100%	100%	100%	100%	87%	80%				
		S-4	100%	100%	100%	100%	100%	100%	100%	54%	48%	5%			
7/31/73	77.7	Zero	69%	67%	66%	62%	55%	52%	49%	42%	20%				
		S-1	88%	76%	59%	19%									
		S-2	72%	54%	50%	45%									
		S-3	57%	39%	10%										
		S-4	31%	28.5%											
8/23/74	71.6	Zero	100%	100%	100%	100%	100%	82.5%							
		S-1	100%	100%	69%	54%	19%								
		S-2	100%	92%	63%										
		S-3	100%	100%	59%										
		S-4	100%	73%	63%	26.5%									
8/22/74	76.2	Zero	100%	82%											
		S-1	50%	26%											
		S-2	100%	9%											
		S-3	70.5%												
		S-4	91%												