**AN EVALUATION OF ENVIRONMENTAL DATA
RELATING TO SELECTED NUCLEAR POWER
PLANT SITES**

THE ZION NUCLEAR POWER STATION SITE

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MASTER

November 1976

**DIVISION OF ENVIRONMENTAL IMPACT STUDIES
ARGONNE NATIONAL LABORATORY**

Argonne, Illinois

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by

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Preface

The Office of Regulatory Research, U. S. Nuclear Regulatory Commission, is supporting a program at the Argonne National Laboratory for the evaluation of the data collected by field studies at a number of operating nuclear power plants. The objective is to analyze data from both a disciplinary and a statistical standpoint. Each of the plants chosen is required, by the terms of the licenses granted, to conduct certain monitoring programs. Some plants are running additional programs to serve their own interests. Do such programs meet the interests of ecologists concerned with the protection of biota? What is the precision and accuracy of the results? What decisions are made on the basis of the field data and how valid are such decisions? Answers to such questions would be of great value in establishing the most cost-effective programs for future plants and redesigning the programs for existing plants.

Through the cooperation of the companies operating the plants, the staff is obtaining the data from a number of installations. As the results are compiled the Laboratory prepares an informal report such as this to present the analysis pertaining to each plant chosen. A summary and inter-comparisons of data, together with the Laboratory's recommendations, will then be presented in one or more reports to the NRC.

This, the fifth of the informal reports, pertains to the Zion Nuclear Power Station.

Other reports in this series are:

ANL/EIS-1 *The Kewaunee Nuclear Power Plant Site.*

ANL/EIS-2 *The Quad-Cities Nuclear Power Station Site.*

ANL/EIS-3 *The Duane Arnold Energy Center Site.*

ANL/EIS-4 *The Three Mile Island Nuclear Station Site.*

ANL/EIS-6 *The Prairie Island Nuclear Generating Plant Site.*

ANL/EIS-7 *The Nine Mile Point Nuclear Power Station Site.*

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APPENDIX Z-2. Arithmetic and Logarithmic Plots of Monthly Abundances of Aquatic Biota, 1972-1975

<u>Organism</u>	<u>Stations</u>	<u>Plots</u>
<u>Control Stations Only</u>		
Total Phytoplankton	18 & 20	1 & 1A
	18 & 22	2 & 2A
	20 & 22	3 & 3A
	30 & 20	4 & 4A
	32 & 22	5 & 5A
	28 & 30	6 & 6A
	28 & 32	7 & 7A
	30 & 32	8 & 8A
	28 & 18	9 & 9A
<u>Control vs. Stress Stations</u>		
Total Phytoplankton	10 & 18	10 & 10A
	12 & 20	11 & 11A
	5 & 28	12 & 12A
	7 & 30	13 & 13A
	70 & 22	14 & 14A
	9 & 32	15 & 15A
<u>Stress Stations Only</u>		
Total Phytoplankton	5 & 7	16 & 16A
	5 & 9	17 & 17A
<u>Control Stations Only</u>		
Diatom Phytoplankton	18 & 20	18 & 18A
	18 & 22	19 & 19A
	20 & 22	20 & 20A
	28 & 30	21 & 21A
	28 & 32	22 & 22A
	30 & 32	23 & 23A

FIGURES

<u>Organism</u>	<u>Stations</u>	<u>Plots</u>
<u>Control vs. Stress Stations</u>		
Diatom Phytoplankton	10 & 18	24 & 24A
	12 & 20	25 & 25A
	5 & 28	26 & 26A
	7 & 30	27 & 27A
	9 & 32	28 & 28A
	70 & 22	29 & 29A
<u>Stress Stations Only</u>		
Diatom Phytoplankton	5 & 7	30 & 30A
	5 & 9	31 & 31A
	7 & 9	32 & 32A
<u>Control Stations Only</u>		
Cladocera Zooplankton	18 & 20	33 & 33A
	18 & 22	34 & 34A
	20 & 22	35 & 35A
	28 & 18	36 & 36A
	30 & 20	37 & 37A
	32 & 22	38 & 38A
	28 & 30	39 & 39A
	28 & 32	40 & 40A
	30 & 32	41 & 41A
<u>Control vs. Stress Stations</u>		
Cladocera Zooplankton	10 & 18	42 & 42A
	12 & 20	43 & 43A
	5 & 28	44 & 44A
	7 & 30	45 & 45A
	9 & 32	46 & 46A
	70 & 22	47 & 47A
<u>Stress Stations Only</u>		
Cladocera Zooplankton	5 & 7	48 & 48A
	5 & 9	49 & 49A
	7 & 9	50 & 50A
<u>Control Stations Only</u>		
Copepoda Zooplankton	18 & 20	51 & 51A
	18 & 22	52 & 52A
	20 & 22	53 & 53A
	28 & 18	54 & 54A
	30 & 20	55 & 55A
	32 & 22	56 & 56A
	28 & 30	57 & 57A
	28 & 32	58 & 58A
	30 & 32	59 & 59A

FIGURES

<u>Organism</u>	<u>Stations</u>	<u>Plots</u>
<u>Control vs. Stress Stations</u>		
Copepoda Zooplankton	10 & 18	60 & 60A
	12 & 20	61 & 61A
	5 & 28	62 & 62A
	7 & 30	63 & 63A
	9 & 32	64 & 64A
	70 & 22	65 & 65A
<u>Stress Stations Only</u>		
Copepoda Zooplankton	5 & 7	66 & 66A
	5 & 9	67 & 67A
	7 & 9	68 & 68A
<u>Control Stations Only</u>		
Crustacea Zooplankton	28 & 18	69 & 69A
	30 & 20	70 & 70A
	32 & 22	71 & 71A
	28 & 30	72 & 72A
	28 & 32	73 & 73A
	30 & 32	74 & 74A
<u>Stress and Control Stations</u>		
Crustacea Zooplankton	10 & 18	75 & 75A
	12 & 20	76 & 76A
	5 & 28	77 & 77A
	7 & 30	78 & 78A
	9 & 32	79 & 79A
	70 & 22	80 & 80A
<u>Stress Stations Only</u>		
Crustacea Zooplankton	5 & 7	81 & 81A
	5 & 9	82 & 82A
	7 & 9	83 & 83A
<u>Control Stations Only</u>		
Rotifera Zooplankton	18 & 20	84 & 84A
	18 & 22	85 & 85A
	20 & 22	86 & 86A
	28 & 18	87 & 87A
	30 & 20	88 & 88A
	32 & 22	89 & 89A
<u>Control vs. Stress Stations</u>		
Rotifera Zooplankton	10 & 18	90 & 90A
	12 & 20	91 & 91A
	5 & 28	92 & 92A
	7 & 30	93 & 93A
	9 & 32	94 & 94A
	70 & 22	95 & 95A

FIGURES

<u>Organism</u>	<u>Stations</u>	<u>Plots</u>
<u>Stress Stations Compared</u>		
Rotifera Zooplankton	5 & 7	96 & 96A
	5 & 9	97 & 97A
	7 & 9	98 & 98A
<u>Control Stations Only</u>		
Total Zooplankton	18 & 22	99 & 99A
	20 & 22	100 & 100A
	18 & 20	101 & 101A
	28 & 18	102 & 102A
	30 & 20	103 & 103A
	32 & 22	104 & 104A
	28 & 30	105 & 105A
	28 & 32	106 & 106A
	30 & 32	107 & 107A
<u>Control vs. Stress Stations</u>		
Total Zooplankton	10 & 18	108 & 108A
	12 & 20	109 & 109A
	5 & 28	110 & 110A
	7 & 30	111 & 111A
	9 & 32	112 & 112A
	70 & 22	113 & 113A
<u>Stress Stations Only</u>		
Total Zooplankton	5 & 7	114 & 114A
	5 & 9	115 & 115A
	7 & 9	116 & 116A
<u>Control Stations Only</u>		
Pontoporeia Benthos	19 & 20	117 & 117A
	19 & 21	118 & 118A
	19 & 22	119 & 119A
	18 & 28	120 & 120A
	20 & 30	121 & 121A
	32 & 22	122 & 122A
	29 & 30	123 & 123A
	29 & 31	124 & 124A
	29 & 32	125 & 125A
<u>Control vs. Stress Stations</u>		
Pontoporeia Benthos	10 & 18	126 & 126A
	19 & 11	127 & 127A
	2 & 29	128 & 128A
	12 & 20	129 & 129A
	5 & 28	130 & 130A
	21 & 13	131 & 131A
	70 & 22	132 & 132A

FIGURES

<u>Organism</u>	<u>Stations</u>	<u>Plots</u>
<u>Stress Stations Compared</u>		
Pontoporeia Benthos	2 & 4	133 & 133A
	2 & 7	134 & 134A
	2 & 9	135 & 135A
	11 & 12	136 & 136A
	11 & 13	137 & 137A
	11 & 70	138 & 138A
<u>Control Stations Only</u>		
Total Benthos	19 & 20	139 & 139A
	19 & 21	140 & 140A
	19 & 22	141 & 141A
	18 & 28	142 & 142A
	20 & 30	143 & 143A
	32 & 22	144 & 144A
	29 & 30	145 & 145A
	29 & 31	146 & 146A
	29 & 32	147 & 147A
<u>Control vs. Stress Stations</u>		
Total Benthos	10 & 18	148 & 148A
	19 & 11	149 & 149A
	2 & 29	150 & 150A
	20 & 12	151 & 151A
	5 & 28	152 & 152A
	13 & 21	153 & 153A
	70 & 22	154 & 154A
<u>Stress Stations Compared</u>		
Total Benthos	2 & 4	155 & 155A
	2 & 7	156 & 156A
	2 & 9	157 & 157A
	11 & 12	158 & 158A
	11 & 13	159 & 159A
	11 & 70	160 & 160A

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Total Phytoplankton and Diatoms, Station 9	3
Total Phytoplankton and Diatoms, Station 10	4
Total Phytoplankton and Diatoms, Station 12	5
Total Phytoplankton and Diatoms, Station 18	6
Total Phytoplankton and Diatoms, Station 20	7
Total Phytoplankton and Diatoms, Station 22	8
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Total Benthos and <i>Pontoporeia affinis</i> , Station 11	31
Total Benthos and <i>Pontoporeia affinis</i> , Station 12	32
Total Benthos and <i>Pontoporeia affinis</i> , Station 13	33
Total Benthos and <i>Pontoporeia affinis</i> , Station 18	34
Total Benthos and <i>Pontoporeia affinis</i> , Station 19	35
Total Benthos and <i>Pontoporeia affinis</i> , Station 20	36
Total Benthos and <i>Pontoporeia affinis</i> , Station 21	37
Total Benthos and <i>Pontoporeia affinis</i> , Station 22	38
Total Benthos and <i>Pontoporeia affinis</i> , Station 28	39
Total Benthos and <i>Pontoporeia affinis</i> , Station 29	40
Total Benthos and <i>Pontoporeia affinis</i> , Station 30	41
Total Benthos and <i>Pontoporeia affinis</i> , Station 31	42
Total Benthos and <i>Pontoporeia affinis</i> , Station 32	43
Total Benthos and <i>Pontoporeia affinis</i> , Station 70	44

AN EVALUATION OF ENVIRONMENTAL DATA RELATING TO SELECTED NUCLEAR POWER PLANT SITES

THE ZION NUCLEAR POWER STATION SITE

Abstract

Environmental monitoring data for the years 1972 through 1975 pertaining to the Zion Station, which began commercial operation in 1974, were analyzed by the most practical qualitative and quantitative methods. Thermal plume, water chemistry and aquatic biota data were evaluated and the results are presented in this report.

The results showed no significant immediate deleterious effects, thus confirming preoperational predictions. Although the plant has not operated long enough to reveal long-term deleterious effects, the present indications do not lead to a concerned prediction that any are developing.

The data utilized, the methods of analysis, and the results obtained are presented in detail, along with recommendations for improving monitoring techniques.

THE PLANT

LOCATION AND DESCRIPTION

The Zion Nuclear Power Station, owned and operated by Commonwealth Edison Co., is located on a 250-acre site on the western shore of Lake Michigan, in Zion Township, Lake County, Illinois (Fig. 1). It is on the extreme eastern edge of the City of Zion, Illinois. The station site is located in the far north suburban region of the Chicago metropolitan area (approximately equidistant between Chicago and Milwaukee). It is situated on a low shoreline sand dune on the Illinois shore of Lake Michigan. The terrain in the area consists of low marshlands isolated 100-2000 feet inland by the shoreline sand beaches and dunes. The presence of the intervening marshes has discouraged extensive development of the general shoreline.

Directly south of the site is the Illinois Beach State Park, which contains an approximately 1651-acre tract of nature preserve and public beaches. Immediately north of the site is a 3.2-mile long area of low sand dunes between the lake (east) and marshlands (west) extending to the Wisconsin border.

Fig. 1. Location of the Zion Nuclear Power Station.

The construction permit was issued December 26, 1968, and six years were required to build the station. There are two pressurized water reactors, which are designated as Unit 1 (southernmost) and Unit 2. The condensers are cooled by a once-through water circulation system.

Due to their size and height the major buildings of the station are the most prominent landmarks in the area--two reactor containment buildings each 147 ft in diameter and 189 ft high, and the turbine building 774 ft long and 121 ft high. These structures dominate the area and are visible from all directions. The station is a landmark for boaters as well as commuters.

The major industrial pollution loads within five miles of the station are located to the south, specifically in the Waukegan, Illinois, lakeshore industrial region where a major fossil-fueled electric generating plant is located.

INTERACTION WITH THE ENVIRONMENT

Intake and Discharge Systems

Each reactor is designed to produce a maximum of 3391 MWt at full power, of which approximately 1100 MW are converted into electric power; the balance (except for small in-plant losses) is discharged as heated water to Lake Michigan. The waste heat is released to the lake by the use of a once-through cooling system with a maximum cooling water flow of 1.75 million gallons per minute (gpm) for both units (total) of the plant. The water is taken from the lake, passed through the condensers, and returned to the lake with an average temperature increase of 20°F. At full station power operation, waste heat is discharged to the lake at a rate of 15 billion Btu per hour. The lake serves as a temporary sink for this heat, since most of it is transferred to the lake water, then to the atmosphere within a few days.

The cooling water enters the system through the intake structure (Fig. 2), which is located 2600 ft offshore. The top of the two vertical inlet pipes is about 22 ft below normal lake level. A schematic of Zion Station intake structure is given in Figure 3. Water enters vertically downward through the 16-foot steel pipes, but a "roof structure" is located above the large inlet pipes to prevent vortex formation. The intake annulus is located about 4 ft above the lake bottom. The cooling water from the intake pipes is admitted to a forebay--a rectangular concrete structure. The velocity of the water through the pipes is approximately 8.7 fps. Six centrifugal circulating water pumps draw the water from the forebay. The water passes through trash racks and through traveling screens at a velocity of 1 to 2 fps before entering the cooling system. The traveling screens are constructed of 12-gauge wire mesh with 3/8-in. square openings. As the screens move, they are cleared by high-velocity water jets. Figure 4 gives a schematic of cooling water circulation at the station. The intake structure in the lake is surrounded by a 2-in. stretch mesh net to serve as a primary barrier to stop intrusion of fish in the intake waters. The net is generally installed during April to October period each year.

The water leaves each unit through a 14-ft diameter submerged discharge pipe. Each discharge structure is located 760 ft from shore and is spaced 154 ft on either side of the center line of the intake pipes (Fig. 2). The

Fig. 2. General Layout of the Station Cooling Water Intake-Discharge System.

Fig. 3. Schematic of the Station Intake Structure.

Fig. 4. Schematic of Cooling Water Circulation at Zion Station Showing Intake/Discharge Sampling Locations.

water is discharged at an angle of 45° from the intake line and 45° away from shore. The top of the discharge opening is about 8 ft below normal lake level. At maximum power operation the average velocity of the water at the face of the outlet ports is about 9.5 fps.

By way of comparison, the flow through the cooling system at full power essentially equals that of the diversion of Lake Michigan water by metropolitan Chicago (3200 cfs), or the average input of the Grand River into Lake Michigan. The heat input of the station is equaled or surpassed by the Grand River during the summer months.

Chemical Discharges

The condensers are cleaned mechanically; consequently, the condenser water is not chlorinated. Sanitary wastes are discharged to the North Shore Sanitary District. Hence, there is no potential for direct impact on the lake or general environment due to the sanitary wastes discharged from the Zion Station.

OPERATING HISTORY

Unit 1 attained initial criticality on June 19, 1973, and began commercial operation on December 31, 1973. Unit 2 attained initial criticality on December 24, 1973, and started commercial power production on September 17, 1974. Since the plant began commercial operation, daily power generation levels have been reported to the U. S. Nuclear Regulatory Commission (NRC), formerly the U. S. Atomic Energy Commission. The data for years 1974 and 1975 (obtained from the NRC "Gray Book") for each unit are plotted in Figures 5 and 6. It is evident that the daily power generation fluctuates over the full range from zero output to the maximum level of 880 MWe (net) (the two units were restricted to 85% designed thermal power until June 25, 1976) for each unit.

This operating characteristic influences the environmental measurements and the determination of changes in the biota, water chemistry, and thermal regime in the vicinity of the station.

Fig. 5. Daily Power Generation for Zion Unit 1

Fig. 6. Daily Power Generation for Zion Unit 2.

PART I. HYDROTHERMAL ASSESSMENT

CHARACTERISTICS OF THE OUTFALL

The Zion generating station is the first large power station to use a submerged discharge for its heat-dissipation system. Two pressurized-water reactors, with a design rating of 1085 MWe each, drive the station's turbine generators. Of the 3250-MWt gross generation for each unit, approximately 2165 MWt is discharged into Lake Michigan by means of three circulating water pumps, pumping at a nominal rate of 750,000 gpm per unit. The discharge temperature is approximately 20°F above ambient at full power. The details of the discharge structure at the Zion plant are summarized in Figure I.1.

After passing through the condensers, the cooling water is returned to Lake Michigan through a submerged discharge pipe 14 feet in diameter. The two discharge structures (Fig. I.1) are rectangular boxes 30 X 75 feet located 760 feet offshore and 154 feet on either side of the intake pipes. Each structure has 14 outlet louvres, seven feet wide and three feet high, located on the offshore end and on the side away from the intake pipes. Each port has vertical guide vanes which direct the flow at an angle of 45° from the shoreline. The top of the discharge structure is approximately eight feet below normal lake level. The discharge velocity is approximately eight feet per second at full-power operation. The locations in the lake of the Zion intake and discharge are indicated in Figure I.2. Bottom contours in the area of the discharge, measured through bathymetric soundings, are presented in Figure I.3. These contours are constantly changing due to storms, littoral currents and bottom scouring by the heated discharge. The depths indicated are relative to the lake level on April 30, 1975 (580.0 IGLD 1955 Datum; + 3.2 ft above low water datum), the date these contours were measured. Depths on other dates must therefore be corrected to account for the current lake level. The contours of Figure I.3 show a rather irregular bottom with a deep area of scouring close to the discharge. Simulation of such a lake bottom in integral and phenomenological models is impossible. A bottom slope of 1:100 has usually been assumed for the region of lake bottom beyond the discharge structure at Zion; this is only a rough approximation. Notably, seasonal measurements show that the lake bottom near the discharge can change in depth by several feet due to various erosion processes; variations of a foot or more occur at distances beyond 1000 ft from the discharge structure. Hydrocon has measured these bottom contours once for each of four seasonal series of plume mappings.

PREOPERATIONAL PLUME PREDICTIONS

The Environmental Report¹ submitted by the Commonwealth Edison Company provided both analytical and hydraulic model predictions of the thermal plume from the Zion Station. The calculations were made by D. W. Pritchard of the Chesapeake Bay Institute using an integral/phenomenological model (Pritchard Model No. 1) that was calibrated with selected laboratory and field data. (The model, originally presented in Ref. 2, is summarized and critiqued in Ref. 3.) Pritchard calculated for each unit (see Table I.1) the surface areas within various isotherms under design operating conditions. No interaction

Fig. I.1. Details of the Zion Discharge.

Fig. I.2. Location of Zion Discharge and Intake and Monitoring Current Meters in Lake Michigan.

Fig. I.3. Bottom Contours in the Vicinity of the Zion Discharge.

Table I.1. Preoperational Plume Predictions
(Two Units, Full Power)

Pritchard (Model No. 1)...Stagnant Ambient Conditions

<u>°F above Ambient</u>	<u>Plume Area (acres)</u>
14	0.5
12	1.0
10	1.3
8	2.0
6	4.2
5	5.7
4	8.8
3	13.6
2	37.6
1	106

AEC Staff Predictions (Asbury-Frigo)

<u>°F above Ambient</u>	<u>Plume Area (acres)</u>
14	8
10	38
5	191
3	460

between the plumes of the two units was predicted for stagnant ambient conditions (thought to be the most critical situation). The Pritchard predictions also satisfy the U. S. EPA and State of Illinois standards; those standards required the distance to the 3°F isotherm to be less than 1000 ft or else for the 3°F isotherm to be of less area than a circle of radius 1000 ft. Pritchard predicted 27.2 acres for the two-unit plumes as compared with 71 acres maximum required by State and Federal standards (area of circle with 1000-ft radius).

Hydraulic model predictions for one operating unit were made by Alden Research Labs.⁴ In that study, the 3°F isotherm could not be closed due to the limited tank size. In fact, only isotherms above 8°F in excess temperature could be closed.

The AEC staff stated in the Environmental Impact Statement⁵ that the hydraulic model predictions prepared by Alden could not be directly related to the two-unit Pritchard predictions for two reasons: (1) the isotherms of greatest interest could not be closed in the laboratory model, and (2) only single-unit cases with cross currents were simulated in the lab model.

Based primarily on observation of other thermal discharges, the staff expected a much larger plume from the Zion Station than was predicted by either the analytical or hydraulic model. Those observations were not directly applicable, however, since the Zion discharge was unique (at that time)

in terms of its flow rate, design, and placement in the lake. Calculations were made by the staff based on the Asbury-Frigo phenomenological model⁶ to provide a conservative estimate of single unit surface isotherm areas. Table I.1 summarizes these predictions. The conservativeness attributed to the Asbury-Frigo computation is based on the fact that the Zion Station discharge structure is a high-velocity, submerged jet designed to promote rapid mixing and dilution, while the data which comprise the Asbury-Frigo correlation (37 thermal plumes from eight plants on Lake Michigan) were all taken at older plants with low velocity discharges and ostensibly less efficient dilution capability.

The staff concluded that the only totally reliable way to obtain definitive information on plume size is an operational field program. Commonwealth Edison was therefore required⁷ to conduct detailed measurements of the thermal plume under various meteorological, lake current, and operating conditions as part of the technical specifications.

During the licensing hearings, Pritchard⁸ presented revised calculations of the plume characteristics at Zion. The results were a little less optimistic but indicated (according to Pritchard) that the plume from the Zion discharges still would satisfy the mixing zone standard set by the State of Illinois and the U. S. EPA. This second set of calculations was based on a different model of completely phenomenological origin. Only this latter model will be compared with operational measurements.

The model is simply a series of empirical correlations developed from six sources of data:⁸

- (1) Twenty-five hydraulic model studies conducted by Stolzenbach and Harleman at MIT.
- (2) Three hydraulic model studies conducted by the Corps of Engineers at Vicksburg, Mississippi.
- (3) Four field surveys of the thermal plume at the Waukegan Power Station made by the Industrial Bio-Test Company.
- (4) A field survey of the plume at Turkey Point, Biscayne Bay, Florida.
- (5) Two field surveys of the plume at Ginna Nuclear Power Station, Lake Ontario.

The three basic formulas used to interpret the data are

$$S_{\theta} = n \sqrt{h_0 b_0} (\theta/\theta_0)^{-\beta},$$

$$b_{\theta} = b_0 + m S_{\theta}, \text{ and}$$

$$A_{\theta} = 0.86 b_{\theta} S_{\theta}.$$

Here, S_{θ} is the centerline distance to temperature θ , b_{θ} is the maximum width of isotherm θ , and A_{θ} is the area of isotherm θ . Also, n , m , and β are empirical

coefficients dependent on whether the calculations indicate that the plume is

- a) unbent but not depth limited
- b) unbent and depth limited
- c) bent but not depth limited
- d) bent and depth limited

Correlations for n , m , β under these conditions are given in Table I.2. Surface heat transfer is handled by applying corrective factors to the plume parameters calculated using the correlations. The plume depth is assumed to grow linearly with slope dh/dx (see Table I.2) until the critical-mixing depth $h_{\frac{1}{2}}$ is reached.

The genesis of the model is Pritchard's observation that, when data for excess temperature ratio are plotted versus centerline position on a log-log scale, the resulting pattern may be closely approximated by a series of connected line segments. Pritchard further observed that the slopes of these segments depend on whether the plume interacts with the bottom, and on the outfall and ambient conditions. Pritchard then attempted to correlate these slopes with certain physically measurable parameters. He further observed that from a plot of the maximum isotherm width versus centerline position on a linear scale, the maximum width can also be approximated by connected line segments. Accordingly, Pritchard derived correlations for these slopes in terms of measurable parameters. In some cases, the correlations can be written in an explicit, computable form, though in other cases, numerical values must be obtained from a table by interpolation.

After the length and maximum width of a given isotherm are computed using the appropriate correlations, areas are calculated (see Table I.2) and then corrected for surface cooling following essentially the same procedure as given in Pritchard's first model.^{2,3} Further details of the Pritchard Models No. 1 and 2 appear in Refs. 2 and 3 and an evaluation of the models for heated surface discharges appears in Ref. 3.

A serious question arises concerning the applicability of a surface-discharge model, since the Zion discharge is submerged in 12 feet of water. Pritchard notes that the effluent from either unit forms a long slot discharging at high velocity (IF_0 varies 30-60 depending upon environmental conditions). A high-velocity discharge in shallow water is assumed by Pritchard to provide essentially the same plume independent of the vertical location of the outfall. We expect that this is probably a reasonable assumption because the jet is of high velocity and is discharged into a shallow ambient receiving body. A fully-mixed plume should result independent of the location of the jet in the vertical water column.

OPERATIONAL MONITORING

Objectives

The objective of the operational monitoring program as set up in the Environmental Technical Specifications was to determine the characteristics of

Table I.2. Correlations for Pritchard Model No. 2

Basic Definitions:

$$IF_o = q_o / [g h_o (\Delta \rho / \rho)]^{1/2}$$

$$Ar = b_o / h_o$$

$$R = q_o / U_a$$

$$\beta^1 = 1 + (3.684 / IF_o) + (6.524 / IF_o^2) + (5.84 / IF_o^3)$$

$$f_1 = \begin{cases} 3 / (IF_o + 15) & Ar < 1 \\ 1.5 / (IF_o + 15) & Ar > 1 \end{cases}$$

Critical Mixing Depth

$$h_{1/2} = 0.3 \sqrt{h_o b_o} (Ar)^{1/4} IF_o^{3/4}$$

Rate of Vertical Growth

$$\frac{dh}{dx} = 0.4 (Ar)^{1/8} \exp (-6.4 IF_o^{-0.4})$$

a. Unbent, but not Depth-Limited Plume

$$n_U = 7.57 - 3.638 IF_o^{-0.245}$$

$$m_U = n_U^{-1} [1.152 + 3.945 \exp (-0.1 IF_o) - 2.999 \exp (-0.2 IF_o) - 1.933 \exp (-0.3 IF_o)]$$

$$\beta_U = \beta' (Ar)^{-f_1}$$

b. Unbent, Depth-Limited Plume

$$n_L = n_U (1 - 0.340 [1 - \exp (-0.0135 / S_x)] [1 - IF_o^{-1}])$$

$$m_L = m_U (0.4 + 0.6 \exp (-0.0196 / S_x))$$

$$\beta_L = \beta_U ([1 - 1.15 \exp (-0.0135 / S_x)] [1 - IF_o^{-1}] + 1)$$

c. Bent, but Not Depth-Limited Plume

$$n_{BU} = n_U [1 - 0.333 \exp (-0.05 R)]$$

$$m_{BU} = m_U [1 - 0.333 \exp (-0.05 R)]$$

$$\beta_{BU} = \begin{cases} 4 & R \leq 6.5 \\ \beta' \cdot (\text{value interpolated from table below}) & R > 6.5 \end{cases}$$

	7.0	8.0	9.0	10.0	12.0	15.0	20.0	∞
1.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1.5	1.726	1.680	1.565	1.495	1.426	1.346	1.207	1.000
2.0	1.940	1.781	1.602	1.533	1.450	1.371	1.219	1.000
3.0	2.137	1.838	1.640	1.565	1.480	1.395	1.232	1.000
4.0	2.249	1.874	1.659	1.591	1.498	1.408	1.244	1.000
5.0	2.300	1.910	1.690	1.610	1.510	1.420	1.250	1.000
6.0	2.300	1.910	1.690	1.610	1.510	1.420	1.250	1.000
7.0	2.300	1.910	1.690	1.610	1.510	1.420	1.250	1.000
8.0	2.300	1.910	1.690	1.610	1.510	1.420	1.250	1.000
9.0	2.300	1.910	1.690	1.610	1.510	1.420	1.250	1.000
10.0	2.300	1.910	1.690	1.610	1.510	1.420	1.250	1.000
12.0	2.300	1.910	1.690	1.610	1.510	1.420	1.250	1.000
15.0	2.300	1.910	1.690	1.610	1.510	1.420	1.250	1.000
20.0	2.300	1.910	1.690	1.610	1.510	1.420	1.250	1.000
-	2.300	1.910	1.690	1.610	1.510	1.420	1.250	1.000

d. Bent, Depth-Limited Plume (R < 10 Only)

$$n_{BL} = \begin{cases} 2.08 (Ar)^{-1/2} & \theta / \theta_o \geq 0.429 \\ 11.3 (Ar)^{-1/2} & \theta / \theta_o < 0.429 \end{cases}$$

$$m_{BL} = m_U [\text{value interpolated from table below}]$$

R	1.0	2.0	4.0	6.0	8.0	10.0
	0.250	0.237	0.221	0.212	0.230	0.265

$$\beta_{BL} = \begin{cases} 4 & 1 \geq \theta / \theta_o \geq 0.429 \\ 2 & \theta / \theta_o < 0.429 \end{cases}$$

the thermal plume under widely differing environmental conditions. More specifically, the applicant was required to measure parameters such as centerline temperature decay, plume depth, and plume width. The effect of ambient currents on the location of the plume centerline was also to be studied. Furthermore, the monitoring program was to be carried out in a manner that would allow an assessment of the variation of plume characteristics with season. Accordingly, the program was divided into four separate study periods:

1. Fall: Nov. 1 - Dec. 1; actual measurements made Dec. 5 - Dec. 9, 1973.⁹⁻¹²
2. Summer: June 15 - Sept. 15; actual measurements were made July 22 - 28, 1974.¹¹⁻¹³
3. Winter: Feb. 15 - Mar. 15; actual measurements were made to determine the sinking plume effect from Feb. 22 - 28, 1975.^{11,12,14}
4. Spring: Apr. 15 - May 15; actual measurements were made to determine the interaction of the plume with the thermal bar from April 25 - 29, 1975.^{11,15}

Table I.3 lists the dates that plumes were measured by Hydrocon of Baltimore, Md. for the Commonwealth Edison Co. The dates of plume measurements by Frigo et al.^{16,17} at Argonne National Laboratory are also listed in the table. A comparison and discussion of data acquired by the two groups, Hydrocon and Argonne, is provided later. First, a brief discussion of Hydrocon instrumentation and measurement procedure will be given.

Hydrocon Instrumentation and Plume-Monitoring Procedure

Hydrocon normally uses a tracer dye to help delineate the plume boundaries and define temperatures. The tracer dye, Rhodamine WT, is pumped continuously into the cooling-water discharge during the days on which individual plume maps are taken. An instrumented boat moves along a serpentine path simultaneously measuring the dye and temperature distribution in the receiving waters. For unstratified conditions, the dye concentrations are scaled to temperatures using a general scaling relation between the temperature and dye concentration developed from simple mixing concepts.

The dye serves two purposes. First, it allows the boat operator to distinguish between the plume and the ambient waters. The dye is especially helpful in this regard when the ambient waters are stratified (ambient temperature is variable) since the distinction between plume and ambient water is often a very cloudy one at the lower temperature excesses. Hydrocon also found dye to be useful in unstratified conditions as an auxiliary measure of plume and ambient temperature. The advantages of the dye stem from its low background level and the high resolution with which dye concentrations can be measured. A practical problem faced by any monitoring program is to identify heated water returning to the region of the discharge during a current reversal. This warm water can significantly increase the plume areas within isotherms below 2°C excess temperature. Dye can be of considerable help in identifying such situations owing to its low and relatively constant background concentration. Returning heated water is most easily identified by tracer methods.

Table I.3. Dates of Plume Data Acquired at Zion

			Operating Power Level, MWe	
			Unit 1	Unit 2
Hydrocon Data:				
Dec. 5, 1973	D	U	-	0
Dec. 7, 1973	T,D	U	574	0
Dec. 8, 1973	T,D	U	687	0
Dec. 9, 1973	T,D	U	625	0
July 25, 1974 (1528-1655)	T,D	S	860	0
July 26, 1974 (1005-1143)	T,D	S	861	0
July 27, 1974 (1315-1440)	T,D	S	857	0
July 28, 1974 (1205-1312)	T,D	S	854	0
Feb. 25, 1975	T,D	U	33	602
Feb. 26, 1975	T,D	U	0	631
Feb. 27, 1975	T,D	U	0	777
Feb. 28, 1975	T,D	U	0	848
April 25, 1975 (Run 1)	T,D	S	610	843
April 25, 1975 (Run 2)	T,D	S	610	843
April 27, 1975	T,D	S	891	879
April 29, 1975	T,D	S	894	856
Argonne Data:				
Sept. 9, 1973 (1041-1212)	T	S	450	0
Sept. 9, 1973 (1320-1357)	T	S	450	0
Oct. 9, 1973 (1227-1303)	T	S	0 ^a	0
Oct. 10, 1973 (1070-1237)	T	S	432-443 ^a	0
Oct. 10, 1973 (1528-1632)	T	S	432-435 ^a	0
Oct. 11, 1973 (1020-115)	T	S	342-439 ^a	0
May 1, 1975 (1010-1300)	T	S	885	890
May 1, 1975	T	S	894	892
July 9, 1975	T	S	0	864
July 10, 1975	T	S	0	883
July 11, 1975 (1003-1219)	T	S	312	865

^aOnly 2 of 3 pumps for the unit were in operation.

D - Dye plume measured

T - Temperature plume measured

S - Stratified ambient conditions

U - Unstratified ambient conditions

The Hydrocon dye and temperature sampling program was carried out with two boats; one sampled continuously at the near surface (0.5 m), while the other made vertical profiles at fixed locations in the lake. The boat position was obtained using a Motorola Mini-Ranger, an electronic positioning system, to a typical accuracy of about ± 3 meters. The fluorometer, a Turner Model III, was adjusted to provide a precision of ± 0.005 ppb; the accuracy of a given measurement was, however, considerably less due to background variations and calibration limitations (of the order of ± 0.03 ppb). Temperature was measured with a single YSI thermistor of time constant less than one second; its accuracy was $\pm 0.02^\circ\text{C}$. Temperature and fluorescence in the plant intake and discharge were monitored continuously for the purpose of detecting recirculation. This point will be discussed in more detail later.

Figure I.4 presents the results of a sample plume measured under unstratified conditions showing the dye and temperature plumes. Figure I.5 shows the locations at which the second boat measured vertical profiles and Figure I.6 illustrates typical profiles obtained. Note the almost fully mixed character of the plume. This is typical of measurements made at all power levels even when both units are operational.

Data Analysis and Interpretation

The analysis of the plume data carried out by Hydrocon depended on whether the lake was stratified or not. For unstratified conditions, Carter et al. of Hydrocon use a scaling relationship between dye and temperature which is given by

$$T_h(x,y,z,t) = T_a + \theta_o \frac{C_d}{(C_d)_o}, \quad (1)$$

where T_h is the local plume temperature, C_d is the dye concentration at the same point, T_a is the (uniform) ambient temperature, and θ_o is the difference between outfall and ambient temperatures. The more constant the plant power level (outfall temperature) and ambient conditions, and the more synoptic the data, then the greater the resulting correlation between dye and temperature. Only when the receiving waters are approximately isothermal would the correlation between tracer concentrations and temperature be high enough to permit utilization of Eq. 1 for scaling tracer concentrations to excess temperatures and for determining background temperature.

An example of the Hydrocon analysis appears in Figure I.7; the correlation between temperature and dye measurements is shown. This corresponds to the plume measured on December 9, 1973, from 0929 to 1135 during the fall study. Selected temperature and tracer data are plotted here. A regression line of T_h on $C_d/(C_d)_o$ was computed and the intercepts calculated as $T_a = 4.93^\circ\text{C}$ (ambient temperature) and $T_{h,o} = 11.99^\circ\text{C}$ (outfall temperature). The data from 2m, 4m, and 6m were similarly treated. The results are tabulated in Table I.4 together with r , the correlation coefficients. Dye concentrations in the form $C_d/(C_d)_o$, were then scaled to excess temperature using Eq. 1; also the concurrently measured temperature field was converted to a field of excess temperatures by subtracting $\bar{T}_n$, the average ambient temperature over space (since T_a and $C_d/(C_d)_o$ are highly correlated, $\bar{T}_n \approx T_a$). The result is two separate realizations of the excess temperature, one based on measured dye concentrations (Fig. I.4 top) and the other on the measured temperature field (Fig. I.4

Fig. I.4. Comparison of Isolines of Constant Temperature and Dye Concentration for Unstratified Conditions, December 9, 1973.

Fig. I.5. Location of Vertical Stations for the Plume Survey of December 9, 1973 (unstratified conditions).

Fig. I.6. Selected Vertical Distribution of Excess Temperature, θ , Scaled from the Temperature (•) and Scaled from the Dye Field (x), December 9, 1973 (unstratified conditions).

Fig. I.7. Correlation of Dye and Temperature Measurements for Unstratified Ambient Conditions of December 9, 1973.

Table I.4. Slope, θ_o , and Intercepts, $\bar{T}_n$, and $T_{h,o}$ for December 9, 1973 (unstratified conditions)

Depth	$T_{h,o}$ (°C)	$\bar{T}_n$ (°C)	θ_o (°C)	r
Surface	11.99	4.93	7.06	0.89
2	11.91	4.63	7.27	0.99
4	12.50	4.63	7.87	0.96
6	11.48	4.76	6.72	0.93
Average	11.97	4.74	7.23	

bottom). The field of excess temperature based on the measured temperature field depends primarily on the estimation of $\bar{T}_n$, the T_h intercept, whereas the field of excess temperature based on dye tracer depends on $T_{h,o} - \bar{T}_n$, the slope of the regression line. As a result of surface cooling, the excess temperature probably decays faster than the dye concentration; that is, the method produces an estimate of $\bar{T}_n$ or T_a that is too low and θ_o that is too high. As a result, both fields will be too large (or conservative) for a given isotherm or concentration. The realization derived from the measured temperatures and $\bar{T}_n$ is probably the more nearly correct since it includes, at least to the first order, the effect of surface cooling.

In the case of a stratified ambient lake, the results are quite different. First, the plume as determined from the dye concentration is quite different from that determined by the temperature field. For example, consider the dye and temperature plume measured from 1315-1440 on July 27, 1974, and shown in Figure I.8. The two isotherm or contour patterns are quite different. On this date there was a small offshore temperature gradient at the surface, as shown in Figure I.9. A significant vertical stratification also existed on that date as represented in Figure I.10. The lack of coherence between the temperature and dye results is due to the variable background "concentrations" for temperature. Excess temperature is plotted against dye concentration in Figure I.11. The correlation is obviously poor. In these stratified ambient cases, dye can only be used to indicate the boundary of the thermal plume; the absence of a measurable quantity of tracer is indicative of water at the background temperature for that time and place. Boat transects made outside the region of measurable dye concentration provide measurements of the ambient temperature. The ambient temperature was a slowly varying function of time, but we hope it did not change appreciably during the time required to measure the plume; i.e., approximately 1-2 hours.

In order to calculate the excess temperature at the surface, each temperature measurement was reduced by a surface ambient temperature according to distance offshore. A regression fit to the data of Figure I.9 gives (see Figure I.9),

$$T_a = 19.60 + 1.2083 \times 10^{-3}y, \quad (2)$$

Fig. I.8. Comparison of Isolines of Constant Temperature and Dye Concentration for Stratified Conditions, July 27, 1974 (Run 2).

Fig. I.9. Background Temperature as a Function of Distance Offshore for Stratified Conditions, July 27, 1974 (Run 2).

Fig. I.10. Background Temperature as a Function of Depth for Stratified Conditions, July 27, 1974.

Fig. I.11. Plot of Temperature as a Function of Dye Concentration at the Surface for Stratified Conditions, July 27, 1974 (Run 2).

where y is in meters, and T_a is in $^{\circ}\text{F}$. Figure I.8 (top) shows the horizontal distribution of $(C_d)_0/C_d$ at the surface. Figure I.8 shows the excess temperature field determined in that way. Note the negative excess temperatures from Figure I.8 (bottom). These negative values result from colder bottom water being mixed into the surface layers. Quite a different interpretation would have resulted if one had referenced temperature to the lowest value measured in the vicinity of the plume, a customary way to choose ambient temperature. We feel that the Hydrocon method of choosing ambient temperature is more instructive and realistic.

The vertical distribution of temperature was determined differently. The vertical profiles taken outside the plume ($C_d \approx 0$) revealed that the background temperature, T_a , decreased with depth but that all temperature measurements at four meters or below (measured at different horizontal ambient locations) were essentially independent of position (alongshore or offshore) for a given run. For each run, therefore, all measurements of temperature, T_a , with corresponding values of $C_d \approx 0$ and taken at depths z equal to or greater than four meters, were combined and the regression of T_a on depth z computed. T_a at two meters was estimated by linear interpolation between four meters and surface values appropriate to the position. The excess temperature, θ , at any depth then was, of course, simply the difference between the measured temperature, T_h , and the value of T_a estimated as described above. Although not shown, the vertical distribution of θ so obtained indicated excess temperatures at or near the bottom to be 2 to 3°C higher than corresponding surface values. This is not a surprising result since the cooling water was discharged as a bottom jet and the local ambient temperature was 2 to 3°C lower at the bottom. We support the Hydrocon method of defining plume excess temperatures below the surface but we also note that a linear interpolation between ambient temperatures at four-meter depth and the surface can be dangerous since the temperature profile is not usually linear.

Perhaps the best illustration of the need for an additional tracer to help monitor the plume under stratified conditions is given in Figure I.12. This figure shows the temperature (upper) and dye (lower) records made at the surface during a plume transect on July 27, 1974 (one leg of Run 2). From the temperature figure alone it appears that the transect might be in ambient water. From the dye measurements it is clear that colder bottom water has been mixed into the surface layers in sufficient quantities that the temperature of the mixture on the plume periphery is lower than the local ambient.

Monitoring of Outlet Conditions

It is imperative for any serious model validation effort to obtain accurate measurements of the outfall flow rate, outfall temperature, and intake temperature (optional). Originally, for the winter survey, measurements made by plant personnel were used to define temperatures within the plant system itself at various locations along the intake/discharge system for Unit 1. The inlet and outlet temperature system unfortunately was yielding inaccurate results since it was noticed that outlet temperatures were $1\text{--}2^{\circ}\text{F}$ lower than the inlet temperatures with no heat being rejected (0% generation). (In-plant temperature measuring systems are very often inaccurate since careful calibrations are seldom made.)

Fig. I.12. Surface Dye Concentration (lower) and Temperature (upper) Records during a Plume Transect for Stratified Conditions, July 27, 1974 (Run 2).

Calibration of the inlet and outlet thermistors was attempted on February 25, 1973, approximately six months after the study began. The readings of the thermistors were compared with a specially calibrated recording thermometer and the difference in readings was taken to be a constant calibration error. Pritchard¹⁸ notes that this is not totally satisfactory since it is not clear if the plant thermistors maintained the same amount of miscalibration over the six-month period. Moreover, the comparison was made at a temperature different from that measured during the winter survey. Based upon the probability that these thermistor readings were unreliable, the outfall temperatures for the fall survey were obtained from Figure I.7 through a temperature/dye correlation. This is obviously not as good as accurate time-averaged measurements. Future surveys by Hydrocon were made with outlet and inlet temperatures determined using their own calibrated thermistors installed in the intake/outfall line. The Argonne data from 1973 (Table I.3) is based on the uncalibrated thermistor readings for outlet and intake temperatures. Following the Hydrocon⁸ discovery of the inadequacy of the plant's temperature measuring system, the Argonne group set up its own outlet and intake temperature measuring system. Unfortunately, although accurate outfall measurements were obtained in 1975, the intake forebay, which has spatially-variable temperatures in most seasons, was used for the measurement of intake temperature providing a non-representative value.

In each of the four study periods, Hydrocon undertook to measure the flow rate from the operating unit(s) of the Zion discharge using the dye tracer. The flow rate can vary from the nominal rate whenever the pumps are operated away from the design curve. The test consisted of discharging Rhodamine WT dye at a known rate into the discharge side of one of the circulating water pumps and measuring its concentration, also measuring it at the valve house (as far from the point of injection as possible but still in the discharge line), and in the intake water just upstream from the dye injection point. From the measurements of intake and outlet dye concentration, as well as the known dye injection rate, the flow rate of the operating pumps is determined. This procedure is repeated with different pumps (three per unit) running to allow calculation of the flow rate of each of the pumps. Hydrocon found it necessary to recalibrate before each study since plant flow rate values might have changed due to different plant operating procedures. The flow rates for the different studies are:

fall (Unit 1): 1677 cfs
 summer (Unit 1): 1573 cfs
 winter (Unit 1): 2115 cfs; (Unit 2): 2299 cfs
 spring (Unit 1): 2041 cfs; (Unit 2): not measured

The Argonne group used the Hydrocon measurements of flow rate since they did not themselves measure the flows. This procedure can lead to errors since the flow rates could easily have shifted between the time the flows were measured and the time the plumes were measured. We feel that the plant flow rate should always be checked independently; plant values should not be accepted *a priori* as correct.

Examples of plant measurements during the spring study period appear in Figures I.13-I.15. In these figures current meter measurements for the study periods are included as well as the results of a simple semi-empirical model for current prediction based on seasonal data.

Fig. I.13. Current Meter Measurements at Station C (top) and Plant Statistics (bottom) during the Fall 1973 Hydrocon Plume Survey.

Fig. I.14. Current Meter Measurements at Stations B and C (top) and Plant Statistics (bottom) during the Summer 1974 Hydrocon Plume Survey.

Fig. I.15. Current Meter Measurements at Station C (top) and Plant Statistics (bottom) during the Spring 1975 Hydrocon Plume Survey.

Evaluation of Data Taken by Hydrocon

We attempted to make an evaluation of the quality of the data obtained by Hydrocon. First, a comparison of the Hydrocon and Argonne measuring systems and procedure is given in Table I.5. Our feeling is that the Hydrocon data are quite good. Our major concern is that the data for each plume study were taken over a two-hour period which raises questions on the synoptic nature of such data in the face of ever-changing environmental conditions. Also, the fact that vertical profiles were taken by a second boat can lead to incompatible results between the surface and profiling measurements. If the purpose of the profiling were solely to provide some plume depth information rather than to compensate for the lack of a multidepth sensor system on the first boat, then the dual-boat measurements may be satisfactory. Clearly, the Argonne system is superior in terms of obtaining synoptic measurements (except that it did not provide measurements below three-meter depth). The Hydrocon group has clearly taken the measurement of outlet and ambient conditions more seriously and as a result, their data are more appropriate for model validation.

Hydrocon data from all seasons is compared in Figure I.16. In total, the data taken under stratified ambient conditions yields the smallest surface areas since the intake temperature is substantially below the surface ambient (the reference temperature for surface measurements). As a result, the smallest plume occurs under stratified conditions with the most critical situation being the unstratified case. A comparison of area data taken from temperature and dye measurements for unstratified conditions appears in Figures I.17 and I.18. Clearly, the dye-measured areas provide a good second estimate on isotherm areas; the trend in areas from dye follows well the trend in isotherm areas.

A comparison of Hydrocon and Argonne data for single-unit operation appears in Figure I.19. Here data from all surveys are plotted together. The data are spanned by the Hydrocon measurements of stratified and unstratified conditions and cover at least three orders of magnitude. The Argonne data are more plentiful at the higher isotherms while the Hydrocon data are more plentiful at the lower isotherms. To see whether the single-unit plume is satisfying preoperational State and Federal mixing-zone standards, the lower isotherms areas ($\Delta T/\Delta T_0 \approx 0.3$ for stratified conditions (80% power) and ≈ 0.23 for unstratified conditions (60% power)) need to be compared to the maximum permissible mixing zone area of $3.14 \times 10^6 \text{ ft}^2$. In either case a single unit operating alone will satisfy the standards (see Fig. I.13). For two-unit operation (80% power on each), Figure I.20 shows that plume areas will generally exceed standards, except for strongly stratified conditions. The large scatter in the data is most likely due to varying environmental conditions during each plume observation and to a lesser extent on the difference in plant power levels. Keep in mind that the following outlet and ambient data remain questionable (see Table I.5):

- (a) Hydrocon outfall temperature for the fall survey
- (b) Argonne outfall temperature for all the 1973 dates
- (c) Argonne ambient temperature measurements for all 1973 and 1975 dates where stratified ambient conditions are present.

Table I.5. Comparison of Hydrocon and Argonne Systems Used
for Plume Measurement at Zion

Boat Instrumentation: The Argonne system is more sophisticated in terms of on-board equipment. It has the capability of measuring at multiple depths simultaneously avoiding the use of two boats, one for profiling. This cuts down on plume-measurement time making a more synoptic study. During the Zion studies, the Argonne 3-m depth boom was used which cannot sense plume activity below that shallow depth; this loses much depth and profile information. The Argonne towed thermistor chain for profiling to any depth was not yet ready for use.

Outfall and Intake Temperature: Hydrocon had its measuring system installed in the plant to obtain these measurements. Argonne, in its 1973 measurements, used plant measurements for these quantities. Hydrocon found such plant values inaccurate even after "calibration" done several months later by Zion plant personnel. Based upon Hydrocon's success, Argonne placed its own measurement system directly in the plant cooling water for their 1975 measurements. Their intake thermistor was unfortunately placed in the forebay where temperature was probably nonuniform.

Plant Flow Rate: Hydrocon measured the plant discharge rate with an in-plant dye tracer technique before each week-long survey. Results indicated a flow rate range from 1741 to 2299 cfs during different survey periods. Argonne relied on previous Hydrocon measurements which can lead to errors since flow rate changes can occur due to change in the plant operating conditions.

Ambient Temperature: Hydrocon's dye-temperature combination is a more reliable procedure for estimating the ambient temperature distribution. It is certainly an improvement over the traditional method of eyeballing a single value from a time and space variable distribution.

Ambient Current Data: The Hydrocon system of 4 *in situ* current meters stations is satisfactory. For nearly every plume configuration, one station should be reading ambient values. The 1973 Argonne current measurements were made by profiling once before and once after the plume survey. Such measurements are indicative only of the times measured and not of times in between; large errors can occur. The Argonne 1975 current meter measurements were satisfactory, since an instrument package was placed upstream to record continuously during the plume mapping.

Conclusion: The Hydrocon system was more reliable for determining flow rate, ambient, and intake temperatures but the Argonne system provided more synoptic plume temperatures. Both systems should have provided reasonable measurement of the high temperature isotherms but the lower isotherms could only have been accurately determined by the Hydrocon methodology.

Fig. I.16. Surface Area Measurements within Isotherms Determined by Hydrocon for the Fall, Summer, Spring, and Winter Surveys.

Fig. I.17. Comparison of Surface Areas Contained within Isolines of Constant Temperature and Dye Concentration for the Fall Surveys (Unstratified Conditions).

Fig. I.18. Hydrocon Surface Area Data Measured by Dye and Temperature Under Unstratified Conditions.

Fig. I.19. Aggregate Comparison of Hydrocon and Argonne Plume Surface Area Data for Similar Power Levels and Single Unit Operation.

Fig. I.20. Aggregate Comparison of Hydrocon and Argonne Plume Surface Area Data for Similar Power Levels and Double Unit Operation.

COMPARISON OF PREOPERATIONAL PREDICTIONS WITH OPERATIONAL MONITORING DATA

The Pritchard Model (No. 2) employed for preoperational predictions was described in an earlier section. When Pritchard made his own comparisons with the Hydrocon field data, several inadequacies appeared in the model.

1. The use by Pritchard of an effective orifice width of 60 feet and a resulting discharge velocity of 9.3 fps was in error. Pritchard should have used the actual width of 74 ft and the full flow speed of 7.84 fps (nominal). The confusion resulted from the examination of hydraulic model results⁴ which gave the impression that the louvres blocked the flow, reducing the effective discharge width. In reality, the flows from the 14 jets combine a few feet from the discharge structure into a single-slot jet that is 74 feet wide. This error is quite significant and resulted in greatly optimistic plume predictions.
2. The assumption was made in the preoperational predictions that the thermal plume would extend in an offshore direction and not be significantly bent in a direction parallel to the shoreline by the ambient currents. This is an important assumption, since an offshore-directed plume will reach a point at which the depth of water becomes greater than the vertical thickness of the plume. Beyond that point, the plume can entrain water from below as well as along the sides as it is no longer depth limited. The excess temperature decreases at a faster rate than if the plume were everywhere bottom limited. In the presence of ambient currents, which appeared for all surveys, the plume was found to be depth-limited at all locations measured. Thus, the preoperational model would clearly be optimistic in all cases from this point of view.
3. The assumption was made that all the dilution water entrained into the plume had zero excess temperature. In 80 percent of the plumes measured, this was found to be untrue. In these cases, the effects of periods of reversing currents at Zion were still present, bringing back warm water to the plant site for reentrainment. Such periods are anticipated by examining current meter records for periods of reversing currents for a 48-hour period before the survey. The measurement of dye entering the discharge region from upcurrent areas was the final clue. Such addition of reheated water to the plume area greatly increases the areas of the lower plume isotherms. This was not anticipated from preoperational plume calculations.
4. The assumption was made in the preoperational predictions that none of the heated water discharged from Zion is recirculated back into the intake. This assumption was nearly always violated since dye was commonly noticed in the intake water. In the two-unit operation at Zion, a recirculation of 24 percent was observed during a two-day period of plume mapping. This assumption of no recirculation is easy to correct in the model if one has an independent estimate of the recirculation temperature.
5. The preoperational model assumed unstratified ambient conditions in all seasons. Large regions of negative excess temperature were apparent from the measurements during stratified ambient conditions. This was undoubtedly caused by the mixing of colder subsurface water with the plume. In

essence, the average temperature of ambient water mixing with the plume was somewhat below what was usually considered to be the surface ambient temperature.

Realizing the above difficulties, Pritchard modified the model used to provide preoperational predictions in the following way to handle those effects. These changes are listed in the order corresponding to the given above:

1. Use of 74 ft as the Zion discharge width instead of 60 ft.
2. The assumption of a depth-limited plume for all cases.
3. Use of (80% of the time depending upon current history and dye measurements) a reentrainment excess temperature above zero. Typically, this value was between 0° and 1°F. The reentrainment excess temperature was not determinable from the field measurements and had to be estimated and tested against the data through model predictions. This does not make the improved Pritchard model objective.
4. Allowance for recirculation into the intake which creates a higher outfall temperature. The recirculation excess temperature is estimated from the dye concentration measured in the intake and is not easily estimated *a priori*.
5. The treatment of stratified ambient conditions is more complicated. First, the offshore and vertical temperature gradients are chosen based on measured ambient conditions, such as in Figures I.9 and I.10 (see also Table I.6). Next the effective entrainment temperature is assumed to be equal to the ambient temperature at the depth $z = \epsilon h_{\frac{1}{2}}$ where ϵ is some value less than unity (assumed *a priori* for that plume) that is constant for that plume. The next step is to apply the model to the case under study (assuming no stratification), the model will provide the centerline distance ξ_{D_j} to isotherms, written in terms of dilutions D_j . The plume trajectory taken from the actual plume measurements is taken. On that trajectory, for each distance ξ_{D_j} there corresponds an offshore distance y_j . An ambient temperature, $(\bar{T}_n)_j$, is calculated from the y_j and the corresponding $z = \epsilon h_{\frac{1}{2}}$ for that point. Pritchard hypothesizes that even though the effective mean entrainment temperature may vary with distance along the trajectory of the plume, $\bar{T}_n$ can be considered to be constant over a sufficiently short interval along the centerline of the plume, say over the distance between successive isotherms.

Thus if $(T_n)_j$ defines the j th isoline of actual surface temperature along the centerline of the plume, $j = 1, 2, \dots$, then we have an effective mean entrainment temperature $(\bar{T}_n)_j$ which can be used with the dilution ratio given by the thermal model to determine $(T_n)_j$. The dilution ratio D_j is defined as

$$D_j = \frac{(T_n)_j - (\bar{T}_n)_j}{T_{h,o} - (\bar{T}_n)_j}, \quad (3)$$

Table I.6. Empirical Expressions for the Offshore and Vertical Stratification in the Ambient Lake during the Hydrocon Summer Plume Survey

Background Temperature, T_a , as a Function of y , z , and t

25 July 1974 (1528-1655)

Surface: $T_a = 4.194 \times 10^{-4}y + 66.38$

2 meters: By interpolation

4-9 meters: $T_a = -1.512z + 70.65$

$r = -0.95$

26 July 1974 (1005-1143)

Surface: $T_a = 2.250 \times 10^{-4}y + 66.20$

2 meters: By interpolation

4-11 meters: $T_z = -1.764z + 71.40$

$r = -0.92$

27 July 1974 (1315-1440)

Surface: $T_a = 2.178 \times 10^{-3}y + 67.28$

2 meters: By interpolation

4-7 meters: $T_a = -1.224z + 65.98$

$r = -1.00$

28 July 1974 (1205-1312)

Surface: $T_a = 8.100 \times 10^{-4}y + 68.74$

2 meters: By interpolation

4-8 meters: $T_a = -1.908z + 73.13$

$z = -0.79$

Note: T_a in $^{\circ}\text{F}$; y and z in meters.

where $T_{h,o}$ is the outfall temperature. Writing the same expression for the adjacent higher isotherm along the plume centerline $(T_n)_{j-1}$, yields

$$D_{j-1} = \frac{(T_n)_{j-1} - (\bar{T}_n)_{j-1}}{T_{h,o} - (\bar{T}_n)_{j-1}} \quad (4)$$

Taking the ratio of the two equations and solving for $(T_n)_j$ gives

$$(T_n)_j \approx \frac{D_j}{D_{j-1}} \left[(T_n)_{j-1} - (\bar{T}_n)_{j-1} \right] + (\bar{T}_n)_j \quad (5)$$

It was assumed in deriving the above equation that

$$\frac{(T_{h,o} - (\bar{T}_n)_{j-1})}{(T_{h,o} - (T_n)_j)} \approx 1. \quad (6)$$

The correction on the plume predictions for an unstratified ambient due to the presence of this stratification can now continue. This is done as follows: starting with the innermost value of D_j , i.e., $j = 1$, we note that $(D_j/D_{j-1}) = D_1/D_0 = D_1$ since $D_0 = 1.0$ and that $(T_n)_{j-1} = T_{h,o}$ which is known. Since ξ_{D_j} , D_j , and ϵ are known, Eq. 5 is used to calculate the new values of the temperatures at each isotherm in this corrective procedure. Pritchard makes the final assumption that once the values $(T_n)_j$, and consequently θ_j at the distance ξ_{D_j} are determined, then the width and area of the surface plume enclosed by the excess temperature isotherms are obtained from the relationships given by the preoperational thermal plume model.

With these changes noted, Figures I.21, I.27-I.35 show the comparisons of the preoperational and improved models with the field data with respect to plume surface areas. Each comparison will now be discussed individually.

December 7, 1973--unstratified--(Figs. I.13, I.21-I.23): In this case the southward lake current was sufficiently strong to bend the plume in the longshore direction so that it was bottom-limited at all distances from the outfall of Unit 1. The plume traveled approximately parallel to shore in the south direction. The preoperational model does poorly, due in part to the error of assuming an outfall width of 60 ft. rather than 74 ft. With this error corrected, the model is slightly conservative for $\Delta T/\Delta T_0 > 0.20$ ($\Delta T > 3.5^\circ\text{F}$). Below that temperature the measured areas become much larger than the predictions. The model can be made to match the data only if it is assumed that the plume remains bottom limited at all distances from the outfall, if there is a recirculation through the intake of 0.6°F above ambient, and if the dilution water entrained into the plume has a background excess temperature of about 0.15°F . This latter number was obtained through numerical experimentation not from the field data. Examining Figure I.13, it appears that the current was moving southward for a 24-hour period before the plume study was made; it is not clear that a 0.15°F reentrainment excess temperature is realistic.

Fig. I.21. Surface Distribution of Dilution for the Hydrocon Plume Studies of December 7, 8 and 9, 1973.

Fig. I.22. Surface Distribution of Temperature for the Hydrocon Plume Studies of December 7, 8, and 9, 1973.

Fig. I.23. Comparison of Pritchard Model Predictions to Surface Area Data for December 7, 1973--Unstratified Conditions.

An examination of the measured plume dye and temperature distribution, together with the computed temperature rise across the condensers (based on the measured plant flow rate and heat rejection rate) indicated that there was indeed recirculation through the intake on all three days (Dec. 7, 8, 9) with intake temperature above ambient between 0.3-0.7°F.

December 8, 1973--unstratified--(Figs. I.13, I.21, I.22, I.24): Sometime between the 7th and 8th of December the ambient current changed direction from south to north. Significant reentrainment undoubtedly occurred for some period of time. The reentrainment would be felt mostly by the lower isotherms. Pritchard's preoperational (corrected) predictions were conservative for $\Delta T/\Delta T_o > 0.45$ ($\Delta T > 5.6^\circ\text{F}$). Agreement at lower isotherms was obtained only by assuming a completely bottom-limited plume with a recirculation temperature excess of 0.3°F and a reentrainment temperature excess of about 0.6°F.

December 9, 1973--unstratified--(Figs. I.13, I.21, I.22, I.25): This is the only case in which the preoperational (corrected) Pritchard model compares favorably with the data. No special modifications were needed except, of course, for the corrected outfall width. Pritchard notes that this plume was directed north for 48 hours before measurements were made, removing the possibility of any reentrainment of old plume water. Moreover, the plume was not depth limited for temperatures below 2.5°F, allowing vertical entrainment there. Cases I and II plotted in Figure I.25 do well in replicating the data; Case II allows for some recirculation actually observed on that date. This Dec. 9 case best replicates the idealized conditions set forth in the preoperational model.

July 25, 1974--stratified--(Figs. I.14, I.26-I.28): In this case, the plume was headed south for nearly a 24-hour period; current speeds were quite small. The preoperational model was modified to handle stratification (see Table I.6) with ϵ varied from 0.65, 0.75, and 0.85. The ϵ value of 0.75 best replicated the data. The preoperational uncorrected model did quite well in fact, but only in this case.

July 26, 1974--stratified--(Figs. I.14, I.26, I.27, I.29): The plume was again headed south with a nearly 48-hour southerly persistence in lake current. The results with the best fit ϵ of 0.85 is plotted in Figure I.29. The uncorrected preoperational model did not perform as well here.

July 27, 1974--stratified--(Figs. I.14, I.26, I.27, I.30): The plume has apparently just begun to reentrain due to a sudden current reversal. The model corrected for stratification does rather poorly here; corrections for reentrainment and recirculation, if made, would exacerbate the problem. An ϵ of 0.85 provided the best results. The uncorrected preoperational model performed quite poorly.

July 28, 1974--stratified--(Figs. I.14, I.26, I.27, I.31): Here the plume is headed north and has been in that direction for 24 hours. Plume water is apparently both north and south of the plant. A simple correction due to stratification does not succeed ($\epsilon = 0.65$ is the best of the three ϵ values tested). Undoubtedly, considerable reentrainment is occurring. It should be noted that for the four dates in July that plume surveys were made, a small amount of recirculation into the intake was observed,

Fig. I.24. Comparison of Pritchard Model Predictions to Surface Area Data for December 8, 1973--Unstratified Conditions.

Fig. I.25. Comparison of Pritchard Model Predictions to Surface Area Data for December 9, 1973--Unstratified Conditions.

Fig. I.26. Surface Distribution of Dilution for the Hydrocon Plume Studies of July 25-28, 1974.

Fig. I.27. Surface Distribution of Temperature for the Hydrocon Studies of July 25-28, 1974.

Fig. I.28. Comparison of Pritchard Model Predictions to Surface Area Data for July 25, 1974 (1528-1655)--Stratified Conditions.

Fig. I.29. Comparison of Pritchard Model Predictions to Surface Area Data for July 26, 1974 (1005-1143)--Stratified Conditions.

Fig. I.30. Comparison of Pritchard Model Predictions to Surface Area for July 27, 1974 (1315-1440)--Stratified Conditions.

Fig. I.31. Comparison of Pritchard Model Predictions to Surface Area Data for July 28, 1974 (1205-1312)--Stratified Conditions.

especially for July 28 and 29. The preoperational model again does poorly, providing an incorrect trend.

April 25, 1975 (Runs 1 & 2)--stratified--(Figs. I.15, I.32-I.34): For these runs the current was directed south with no apparent current reversal affecting the plume size. Dye was injected, for these April dates, in the discharge of Unit 1 only, to allow the location of the furthest reaches of the plume downcurrent. No dilution maps are presented because there were large quantities of untagged excess heat in the receiving waters. The offshore temperature gradient was approximated by

$$T_a(y,t) = 46.17 - 2.981 \times 10^{-4}y$$

Here again no significant vertical stratification existed. The preoperational (uncorrected) model again is inaccurate with an incorrect trend.

April 27, 1975--stratified--(Figs. I.15, I.32, I.35): For this run, the ambient current was reversing from south to north. The field of background temperature was still able to be determined by analyzing the field of temperature from transects made well upstream to the north, where no measurable quantities of dye were observed. The offshore temperature gradient was determined and approximated by:

$$T_a(y,t) = 45.8 - 3.132 \times 10^{-4}y$$

No significant vertical stratifications existed. The preoperational (uncorrected) model is again inaccurate.

April 29, 1975--stratified--(Figs. I.15, I.32): The lake current reversal on April 27 from south to north caused significant quantities of old Zion plume water (or Waukegan plume water with the Waukegan plant 6000 m south) to reach the Zion discharge area. Hydrocon could not make any reliable estimate of background temperature. No further study was done with that plume.

CONCLUSIONS

1. The Pritchard model as developed and used for preoperational predictions gives satisfactory forecasts in only about 20 percent of the cases (single unit only). Additional factors such as reentrainment of plume water, recirculation of plume water into the intake, and the effects of stratification are not modeled although they appear to be significant factors. In short, the Pritchard model, as developed for preoperational predictions, gives good predictions only for unstratified ambient conditions with no recirculation and no reentrainment. Even then, the actual outfall slot width, 74 ft, must be used instead of an "effective" width. The use of the effective width as in preoperational calculations yields optimistic predictions of plume areas. Thus, the preoperational model (corrected for the proper outfall width) performs very well in that 20 percent of the cases when the model assumptions were most nearly correct, but very poorly otherwise; e.g., stratified conditions, cases with significant reentrainment of already heated water, two-unit operation, etc. Surface area predictions, optimistic by an order of magnitude, were not uncommon in those cases.

Fig. I.32. Surface Distribution of Temperature for the Hydrocon Plume Studies of April 25, 27, 29, 1975.

Fig. I.33. Comparison of Pritchard Model Predictions to Surface Area for April 25, 1975 (Run 1)--Stratified Conditions, Two Unit Operation.

Fig. I.34. Comparison of Pritchard Model Predictions to Surface Area for April 25, 1975 (Run 2)--Stratified Conditions, Two Unit Operation.

Fig. I.35. Comparison of Pritchard Model Predictions to Surface Area for April 27, 1975--Stratified Conditions, Two Unit Operation.

2. The Pritchard model in its post-operational form is not a predictive model. Some input quantities needed by the model use the plume data themselves or else require some model-data fitting. These required quantities are:
 - a) an excess temperature of reentraining water
 - b) a temperature for recirculation into the intake
 - c) the parameter ϵ used in determining the level below the surface of effective temperature for entrainment (stratified conditions).
 - d) the plume trajectory for cases when the plume is discharged under stratified ambient conditions.
3. The hydraulic model⁴ of the Unit 1 discharge was grossly inadequate for predicting the plume from the Zion plant. Most significantly, the tank used was much too small causing significant reentrainment effects; in fact, only the 8°F excess temperature isotherm could be closed in the laboratory model. Further, it ignored the presence of the second unit and double-plume interaction that would occur for the cases where long-shore ambient currents existed. Although unrealistic temperature fields resulted from the lab model, the hydraulic study did indicate that there would be no significant problem (in the very near field) with passing ships and surface elevation changes in the region of plume and free surface interaction. This was borne out from field observations.
4. The Hydrocon plume data was of generally good quality. The data themselves could have been more synoptic with depth measurements taken simultaneously. The most important improvement that would help the measurement system is the use of a multidepth probe rather than a single-depth measure. The Hydrocon measurement techniques for outfall temperature, intake temperature, ambient temperature, and plant flow rate were well developed. Measurement of these quantities is imperative for model validation, yet it is not taken seriously by most other groups taking field data at power plants. The use of an additional tracer whose background level is low (dye in this case) is necessary for the proper delineation of the plume from large plants under stratified ambient conditions. This is most important for the delineation of the lower isotherms, especially the 3°F isotherm in this case, where mixing zone standards were set.
5. No plume measurements were made during the period when the plume is expected to be the largest, i.e., during the winter de-icing mode. During such periods of the winter, the discharge flow of heated water is approximately 1400 cfs per unit with an excess temperature at discharge of about 26°F. Operation of the de-icing mode encompasses about 1-2 months of the year in total. Recent Pritchard predictions under the deicing mode for the Zion two-unit thermal plume showed an area of the 3°F isotherm of about 1990 acres.¹⁸ This is the largest area predicted by Pritchard in his recent recalculations¹⁸ for the Zion double-unit plume. These recent recalculations are based on a further developed version of the above-described Pritchard Model No. 2.

6. Perhaps the most significant conclusion from the Zion plume study, from the standpoint of thermal plume research in the past few years, is that it is unacceptable to ignore ambient motions--ambient current history, current reversals, ambient stratification effects, plume recirculation into intake, wind-induced effects on the current, etc.--in predicting the plume on a particular date. These factors are often as important as the characteristics of the outfall design in defining the lower isotherms. Pritchard's position is even stronger; he states¹⁸ that it is impossible to predict accurately the plume characteristics on a particular date largely because of these unpredictable ambient factors. He states that only limiting cases or statistical predictions can be made, i.e., a particular prediction can be said to occur x% of the time but it cannot be determined beforehand on which days it will occur. There is much to be said for that point of view.

References for Part I

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14. Hydrocon, Inc. "The Distribution of Excess Temperature from the Zion Generating Station on Lake Michigan Winter (Sinking Plume) Study Period (February 1975)," Ref. No. 120. Baltimore, Maryland. September 1975.
15. Hydrocon, Inc. "The Distribution of Excess Temperature From the Zion Generating Station on Lake Michigan Spring (Thermal Bar) Study Period (April 1975)," Ref. No. 121. Baltimore, Maryland. October 1975.
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17. A. A. Frigo, R. A. Paddock, and D. McCown, Unpublished work. Energy and Environmental Systems Division. Argonne National Laboratory, Argonne, Illinois.
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PART II. CHEMICAL ASSESSMENT

PREDICTED IMPACTS

No analytically detectable concentrations of chemicals were expected in the plant discharge.¹ Nevertheless, about 50 chemical and physical parameters of water quality have been monitored at the plant intake, discharge, and selected sampling points in Lake Michigan. The quantities of chemicals used in the operation of the Zion Station and their expected concentrations in the discharge are shown in Table II.1. As can be seen from the table, the principal source of chemical discharge to the lake from the plant is demineralizer regeneration. After dilution with the cooling water stream the concentration of sodium sulphate, the product of the regenerate neutralization, increases by about 0.023 mg/l, as compared with the lake sulphate concentration of about 23 mg/l.

Since December 1974, discharges of chemicals have been subject to limitations of a National Pollution Discharge Elimination System (NPDES) permit. This permit controls the concentrations and total amounts of dissolved and suspended solids released and the pH in demineralizer wastes before they are diluted with the cooling water discharge. Conditions of the NPDES permit are given in Table II.2. If the conditions of the permit are satisfied, increments of dissolved and suspended solids in the discharge are expected to be undetectable.

OBSERVED IMPACTS

As stated above, the amount of chemicals added is so small and the dilution so great that it was predicted incremental changes in water quality could not be analytically detected and that no measurable chemical effects would result from plant operation. For this report available monitoring records were examined to test the validity of this prediction--i.e. to determine whether any unpredicted changes in water quality parameters have been detected by monitoring efforts. It was assumed that any direct short-term change would be so small, and chemical fluctuations at field points so large, that an incremental change could only be detected by a direct comparison of samples from the intake and discharges. Changes other than those of temperature and oxygen could not be detected at field points in the lake.

Water quality data contained in the semiannual and annual reports were examined for the period January 1974 to December 1975, covering the time of commercial operation of Units 1 and 2. Generally, the chemical measurements were made on either 24-hour composite water samples or grab water samples taken from the intake bay and the two discharges. The grab samples were taken both before and during the discharge of the neutralizer (demineralizer wastes) tank in an effort to determine the chemical changes caused by the demineralizer wastes. The composite samples were taken at times that included waste tank discharges. All waste tank discharges were through the Unit 1 discharge.

Table II.1. Estimated Chemical Usage Zion Units 1 & 2^a

Name	Amount Used, lb/yr	Releases		Comments
		lb/yr	PPM Conc.	
Chlorides	None	None	0.006 ^b	See sodium hypochlorite
Boric Acid	1,000	None	None	Losses are buried offsite
Sodium hypo- chlorite	8,000	8,000	0.032 ^c	
Lithium hydroxide	9 ^d	None	None	Removed and retained by demineralizer
Hydrazine	30,000 ^d	None	None	Break down to make hydrogen, nitrogen, and ammonia and released to the stack
Morpholine	5,220 ^d	None	None	
Sodium hydroxide	84,000	None	None	See sodium sulphate
Sulfuric acid	90,000	None	None	See sodium sulphate
Sodium sulphate	None	132,000	0.023	Products of regenerate neutralization
Resins - CVS demineralizer	15,700	None	None	Resin filters in effluent discharges
Alum	9,840	9,840	0.0015	
Detergents	2,000	1,455	0.002	
Organic solids	900	None	None	Kept in liquid radwaste
Phosphates	500	None	None	Removed and retained by the demineralizer

Table II.1. Continued

Name	Amount Used, lb/yr	Releases		Comments
		lb/yr	PPM Conc.	
Boron	630	630 ^e	0.003 ^e	Boron and phosphate will be released from the plant during intermittent periods corresponding to primary-to-secondary steam generator leakage
Phosphates	1,500	1,500 ^e	0.006 ^e	

^aThis table was taken from Table D-1.1 of Supplement IV of the applicant's Environmental Report for Zion Units 1 & 2. Modification has been in the chlorides, sodium hypochlorite, sodium sulfate, boron, and phosphate concentrations to show the actual concentrations expected during periods of addition of chemicals, rather than the average for the entire year.

^bThe chloride produced by reduction of some hypochlorite, an unknown additional small amount will be produced before discharge. The concentration is an estimated for periods of addition of sodium hypochlorite.

^cThe sum of the free and combined chloride residual. An unknown amount will be transformed to chloride ion before discharge. The concentrations are those calculated for periods of addition of sodium hypochlorite.

^dLargely in primary and secondary systems.

^eThe applicant's figures were reduced by a factor of 2 to reflect the staff's estimate of the actual releases and concentrations.

Table II.2. Conditions of Zion NPDES Permit

Filter Backwash:

Prior to June 30, 1977--Suspended solids, 1000 mg/l, average

After June 30, 1977 to October 1, 1979--suspended solids 15 mg/l, maximum

Neutralizing Tank Effluent:

Prior to June 30, 1977--Sodium sulfate, 168 kg/day, daily average, 1590 kg/day, daily maximum

After June 30, 1977 to October 1, 1979--Total dissolved solids, 3500 mg/l, maximum

Radwaste System:

Until October 1, 1979--Suspended solids, 15 mg/l, maximum; oil and grease, 15 mg/l, maximum

All discharges shall have pH between 6.0 and 9.0 and there shall be no discharge of floating solids or foam other than in trace amounts.

Of the 50 water quality chemical species reported, nine were selected for a more detailed evaluation. These were cadmium, trivalent chromium, magnesium, total phosphorus, sulfate, boron, iron, dissolved oxygen, and ammonium ion. For each selected parameter, the two years of available data were tabulated. The range of values for some chemical species was very large but not untypical of the lake. The results were examined to see if differences in means between any pair were caused by a few extreme values. Also, for each chemical species, individual pairs of intake discharge values were examined. Such an examination revealed no systematic difference between the intake and discharge concentrations.

All the chemical species studied, except for oxygen, are listed in Table II.3. The table shows the average values for the individual parameters in the intake, Units 1 and 2 discharges, and in some cases the root mean square differences of duplicate analyses of each sample. For comparison, the means and ranges of values obtained at the Lake County Water Pumping Station during 1972 preoperational period and Illinois Pollution Control Board criteria for aquatic life are also shown. Table II.3 also contains short comments on the results.

Effects on oxygen concentrations as a result of passage of water through the plant are plotted in Figures II.1 and II.2. Figure II.1 shows changes in dissolved oxygen as a function of the temperature difference between intake and discharge, and Figure II.2 shows the change in the dissolved oxygen (discharge-intake) as a function of dissolved oxygen in the intake. Also shown are the zero horizontal axes and linear regression lines for each figure. The estimated regression equations are given in the figures. The linear regressions explain a relatively small amount (less than 50% in each case) of variation in the data, leaving a large amount of scatter about the lines (Figs. II.1 and II.2). Figure II.2 has seven points designated with pluses that were obtained while the plant was not operating. These are not representative of plant operation and were not used in computing the regression line.

As indicated by the values of the water quality measurements given in Table II.3, there is no evidence of increased concentrations of chemicals; in fact, some concentrations were decreased. With the exception of a single large value for cadmium, intake concentration values were within ranges found at various Lake Michigan shore points.² The single large cadmium value was rejected by the utility's consultant when computing averages and was presumed to be an artifact.

There is at least one possible explanation for the in-plant decreases of some of the parameters. Because the samples are not filtered before analysis, it is probable that the "dissolved" solids contained some slowly settleable or colloidal particulate matter. These could absorb normally soluble ionic substances and a decrease of the absorbed material would then also be observed if the suspended material was deposited within the plant. Since the settleable material behaved in a highly erratic manner, detection of small amounts of material added in the plant would be extremely difficult.

As expected, dissolved oxygen in the cooling water has been changed by passage through the plant. The regression lines of Figures II.1 and Figure II.2 indicate, within very broad limits, that the oxygen loss is proportional to temperature increases, and that oxygen loss is also proportional to the initial

Table II.3. Comparison of Intake and Discharge Water Quality Parameters

	Water Stream		
	Intake	Unit 1 Discharge	Unit 2 Discharge
<u>Ammonia</u> (Grab)			
Average value	0.04 mg/l	0.04	0.05
Range	<0.01-0.12	<0.01-0.22	<0.01-0.17
Lake County Water Plant	Mean 0.04	Range 0.01-0.10	
Illinois Water Standard	0.02 mg/l		

Comment: There is no evidence of station induced changes.

Magnesium (Grab)

Average value	11.9 mg/l	12.0	12.0
Range	10.4-14.8	10.9-21.5	11.1-14.5
Lake County Water Plant	Mean 11.7 mg/l	Range 10.6-13.2	
Illinois Water Standard	NA		

Comment: A single sample of the Unit 1 discharge contained 7 mg/l above the intake prior to tank discharge and 1 mg/l during tank discharge. No explanation was given. Other values apparently randomly distributed above and below the intake.

Average value	0.1 mg/l	0.04 mg/l	0.05 mg/l
Range	0.004-0.26	0.001-0.17	0.01-0.24
Lake County Water Plant	Mean 0.027 mg/l	Range 0.006-0.099	
Illinois Water Standard	0.007 mg/l		

Comment: The mean intake value is well above the preoperation value and state standard: Very high values (0.25 mg/l, maximum) occurred sporadically in the intake; however, such levels are not uncommon at shore points on Lake Michigan. The larger values of total phosphorus generally dropped sharply in transit through the plant. The erratic nature of the intake phosphorus precluded determination of any incremental phosphorus from the plant.

Table II.3. Continued

	Water Stream		
	Intake	Unit 1 Discharge	Unit 2 Discharge
<u>Cadmium (Composite)</u>			
Average value	0.00076 mg/l	0.00062 mg/l	0.00031 mg/l
Range	0.00006-0.0058	0.00002-0.0056	0.00002-0.0012
Lake County Water Plant	Mean 0.0002	Range .001-.0011	
Illinois Water Standard	0.01 mg/l	RMS = 0.00026	

Comment: A single very large (0.11 mg/l) value from December 1974 in the intake and both discharges was excluded by the operator from calculation. This value was 50 times larger than the next largest figure. A number of high values in the intake sharply decreased in passage through the system. Lower values of the intake appeared to result in discharge values randomly scattering above and below the intake.

Trivalent Chromium (Composite)

Average value	0.011 mg/l	0.0042 mg/l	0.0025 mg/l
Range	0.0014-0.033	0.0012-0.0066	0.0008-0.011
Lake County Water Plant	(Total) Mean 0.0033 mg/l	Range 0.001-.008	
Illinois Water Standard	1.0 mg/l	RMS - .0008	

Comment: As with a number of other substances, large values of chromium occurred in the intake and were reduced in the system. The erratic nature of the intake values preclude any determination as to whether chromium is added in the plant.

Iron (Composite)

Average value	0.6 (1.6) mg/l	0.3 mg/l	0.2 mg/l
Range	0.0014-0.033	0.0012-0.0066	0.0008-0.011
Lake County Water Plant	Mean 0.35 mg/l, large	Range .001-0.026 mg/l	
Illinois Water Standard	0.3 mg/l		

Comment: Large values of iron (9 mg/l) occurred in the intake during a construction period in July and August 1974. The average including the high values is shown in parenthesis above. Large values for iron in the intake also sharply decreased in passing through the plant. Increases occurred for smaller intake values but not in a consistent manner.

Table II.3. Continued

	Water Stream		
	Intake	Unit 1 Discharge	Unit 2 Discharge
<u>Sulfate (Grab)</u>			
Average value	20 mg/l	19 mg/l	19 mg/l
Range	10-26	10-26	10-26
Lake County Water Plant	Mean 19.6	Range 17.4-24.1	
Illinois Water Standard	24		
Comment: All pairs were within experimental error and there is no measurable effect.			
<u>Boron (Grab)</u>			
Average value	0.03 mg/l	0.03	0.04
Range	0.01-0.09	0.01-0.1	0.01-0.09
Lake County Water Plant	Mean 0.06	Range 0.02-0.22	
Illinois Water Standard	1.0 mg/l		
Comment: In one instance, Unit 1 discharge contained 0.06 mg/l above the intake prior to waste discharge, which dropped to 0.03 mg/l during discharge. All other results were within 0.02 mg/l of the intake and apparently random above and below.

Fig. II.1. Variation in Dissolved Oxygen in Discharge Water as a Function of Temperature Change (discharge-intake).

Fig. II.2. Variation in Dissolved Oxygen in Discharge Water as a Function of Dissolved Oxygen in the Intake Water.

dissolved oxygen, with an intercept at about 5 mg/l. The Illinois Pollution Control Board requires a minimum of 5 mg/l of oxygen, so the curve shows that it is unlikely that plant operations can decrease oxygen below the state limit.

CRITIQUE, CONCLUSION AND RECOMMENDATION

The monitoring program has confirmed the predictions made in the FES that no changes in water quality parameters as a result of station operation could be detected. The very small amounts of material added, the large dilution, and the erratic fluctuation of concentrations of substances that could not conceivably be results of plant operations, precluded detection of small changes. Since changes were small or negative on a direct comparison between intake and discharge measurements, plant-related chemical effects at field points in the lake would certainly be undetectable since the effects could not be larger than at the discharge and since the fluctuations are subject to a wider variety of influences in the open lake. As a consequence, it is concluded that the present monitoring program has served its purpose.

It is our belief that the only type of program that can provide useful information is one that either directly determines the contents of any waste stream (as the NPDES program) or one that monitors inventory and losses of any material that may be discharged into the lake. Phosphate and boron should be monitored by direct analyses of discharge streams if possible, or by inventory control and loss evaluation. Since no detectable chemical effects should occur in the final discharge during normal plant operation (other than changes in oxygen concentration), the purpose of the monitoring program would be precautionary and preventative. This program would be expected to record the evidence that no significant deviations have occurred.

References for Part II

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PART III. AQUATIC ASSESSMENT

POTENTIAL AND PREDICTED ECOLOGICAL IMPACTS

The entrainment of planktonic organisms and fish in condenser cooling water and the discharge of waste heat into Lake Michigan are the major sources of potential impact on the aquatic ecosystem. All aquatic life present in the lake water drawn into the intake will pass through submerged pipes into the station forebay. Larger organisms, principally adult and juvenile fish, will become trapped in the forebay and/or killed by impingement on the traveling screens. An unknown but seasonably variable number of adult and juvenile fish, fish eggs, and larvae are expected to be killed by the station operation.

On the basis of knowledge of the life history of Lake Michigan fishes, the staff expected that the 2600-ft offshore location of the station intake would significantly reduce entrainment of fry and juveniles of most species in comparison with that which would occur if the intake were located nearer the shore (FES, P. V-6).^{1*}

The well-known "rheotactic" behavior of many fishes (in which a fish maintains or controls its position in a current, compensating by swimming upstream) is known to depend primarily on the fish's visual cues and occasional mechanical contacts with fixed objects, (e.g., the bottom), rather than on lateral line receptors. The staff anticipated the possibility of increased relative rates of fish entrainment at the intake during the night and at frequent times of high turbidity in Zion waters when visual cues are absent or reduced. This would be influenced by diurnal and seasonal variations in local fish densities due to inshore migrations, the condition and effectiveness of the intake exclusion nets, and other factors (FES, P. V-8), but the staff did not have sufficient information to make reasonably quantitative estimates of fish entrainment at the intake (FES, P. V-6).

The staff also expected that a significant fraction of organisms small enough to pass through the 3/8-in. mesh traveling screens (e.g. phytoplankton, zooplankton, fish eggs and larvae, and benthic forms such as *Pontoporeia* and *Mysis*) would be killed. The quantity and character of such kills were predicted to be highly variable, due to seasonal differences in entrained species, age, composition and abundance, as well as seasonal variations in ambient (acclimation) temperatures. The condenser-pass kill (mechanical and thermal) also was difficult to predict because of the variation in the size of plankton (FES, p. V-9).

*Hereinafter references to the Final Environmental Statement will be cited as FES, with specific section and page numbers, in parentheses.

Thermal damage to phytoplankton as a consequence of condenser passage should primarily involve the diatoms. Condenser-passage effects at the Zion Station were not expected to have an important impact on Lake Michigan phytoplankton, zooplankton, or benthic populations (FES, pp. V-8 through V-11). Even if condenser passage were to be lethal to most planktonic organisms, there are other factors to consider. First, because only a small fraction of the lake water and plankton pass through the station, the numbers of organisms affected would have little direct impact on lake populations. In addition, many of the species have a short generation time (a few hours to a few weeks) and remaining organisms should be capable of replenishing the area. Second, it is doubtful that inshore waters at Zion are important spawning waters for any fish species other than perhaps alewives and smelt. Moreover, the important species of fish have demersal (bottom or attached) eggs, which can become planktonic (and entrainable) only transiently.

Within the mixing zone of the thermal plume, especially close to the diffuser ports, organisms are subjected to thermal stress and turbulence. Regarding direct lethality, it was expected that whether acclimated to low or high ambient water temperatures, almost all plankton and fish would survive brief exposures of this type, since residence times in the higher excess isotherms would be short (measured in minutes) due to rapid dilution with lake water.

Fish may be attracted to the heated plume during the cooler months. These fish will probably attempt to follow a temperature gradient and select their preferred environmental conditions. A small number of fish may be killed by thermal (cold) shock during infrequent periods of reactor shutdown. However, to minimize cold shock impacts the reactor shutdown schedules provide for a gradual, controlled reduction of heat in the condensers. In most months, due to its lower density heated plume water will rise and spread.

Benthic organisms in the immediate area of the discharge are not numerous and probably would not be affected by sinking plumes during the winter months. The sinking plume phenomenon should occur at some distance from the discharge structure, and consequently, the plume and bottom temperatures would differ only by a few degrees or less. Under most conditions, the heated plume will not affect the benthos beyond the immediate vicinity of the diffuser (FES, pp. V-11 and 12).

Wave action, turbidity, nature of the bottom sediments, and lack of tributaries emptying into the lake near Zion argue against the presence of important spawning grounds for most fishes. Moreover, most schooling of young fish was expected to occur in water shallower than the depth of the intake and discharge. In addition, since the intake and discharge pipes are buried in the lake bottom, interference with fish schooling and migrations was expected to be less than it would be if the pipes were resting on the bottom (FES, pp. V-25 and 26).

It was not expected that the heated discharge would have an important effect on commercial or sport fish populations in the lake. Adult whitefish are deepwater fish which migrate from deeper to shallower waters for spawning in the fall, but this species has been distributed primarily in the northernmost parts of the lake. Cisco and lake trout inhabit deep waters during most of the year. Several salmonid species are maintained in the lake primarily by hatchery propagation and planting (essentially on a "put-and-take" basis).

The thermal plume may produce some local adverse effects on smelt (common near the station) when they move inshore for spring spawning. There is active sport fishing during smelt runs in April and May. Juvenile perch, and possibly some whitefish and cisco, school in appreciable numbers in inshore waters off Zion and will be subject to discharge effects. This hazard is reduced by the offshore placement of the diffusers, but juveniles swept into the plume would be stressed.

The chemical wastes of biological concern include chlorine, sulfate, phosphate, morpholine, and hydrazine. As a result of the use of mechanical condenser cleaning (AMERTAP) at the station, the only chlorine in the effluent is that originating from plant service water chlorination which is intermittently discharged with the condenser cooling water at a concentration of less than 0.03 ppm. These discharges were scheduled to occur three times a day for a period of 15 minutes each.

The inexactness of the station plume model made it difficult to estimate the chlorine and chloramine residence time and concentration in the lake near the station, but the concentrations are diluted during and after discharge. The chlorine residual is further reduced rapidly by the chlorine demand of the lake water, but the chloramines are reduced less quickly and may persist for days. Several considerations suggested that the quantities of chlorine released into the lake by the Zion station would not be hazardous to the biota (FES, pp V-16 through 10; III-26 and 27).

OBSERVED IMPACTS

Methods of Analysis

An analysis was made of nonradiological aquatic biology data obtained during the period 1972 through 1975. The major biological groups (phytoplankton, zooplankton, benthos, and fish) and various subgroups were selected for this evaluation on the basis of their abundance and persistence throughout the seasons, availability of sampling data, and specific biological characteristics, i.e. life history, sessile or planktonic, etc. The subgroup Bacillariophyceae (diatoms) in phytoplankton, subgroups Crustacea, Rotifera, Cladocera, and Copepoda in the zooplankton, and subgroup *Pontoporeia affinis* in the benthos, were examined in this detailed evaluation of the possible effects of Zion plant operation on these biotic groups. Fish impingement was studied in considerable detail and fish abundance data were utilized in conjunction with the evaluation. "Reference" and "stress" stations in the Zion study area were selected by examining the measured thermal plume configurations. These stations located within 2°C ΔT isotherm of any plume configurations were designated as "stress" stations. The north control stations were considered as primary "reference" stations. The Dead River stations were also used as "reference" for comparisons.

By nature, environmental data occur in the form of a time series. Sampling a time series and estimating the nature and magnitude of change requires proper statistical treatment of the data. It is important to recognize that the classical statistical procedures, such as the t test, have played an important role in estimating and testing for differences in mean values. Such tests ordinarily carry underlying assumptions of a normal probability density

function, independence of observations, and homogeneity of variance. Time-series data do not require these assumptions. In addition, strong seasonal component and nonstationary elements are present in these data. The mathematical functions representing this type of behavior combine past history and elements of discrete responses. It is also conceivable that the parameters, or even the joint distribution itself, may depend upon particular points in time. Thus the values of the random variable observed in time sequence are not always independent and identically distributed.

In an undisturbed environment, the measured changes and variations of an indicator characteristic (response variable) are natural and follow probability laws. Assumptions concerning probability models have led to estimates of the parameters of these distributions. When disturbances resulting from perturbations of the ecosystem are introduced, it is common to expect changes to occur in the response variable. The magnitude and extent of the changes are generally unknown, *a priori*. Thus, to estimate these changes one must be able to measure responses to the added causal factors. It is appropriate to consider the types of disturbances that may affect the response variable.

For simplicity, assume a time-variable phenomenon. A pulse of some magnitude is added to the otherwise constant response function (see Fig. III.1). The effect of this pulse disturbance may be (a) an exponential decay with total recovery to the original condition; (b) no lasting change in response, that is, an immediate and complete recovery; (c) more subtle conditions may prevail where the effect of the pulse undergoes a very gradual and slow recovery; or (d) no recovery at all. Less likely cases include the situation where the effect may be an intensification resulting in a long-term increasing impact, or an exponential decay to a new steady-state value (see Figs. III.1e and III.1f).

The task of measuring such responses becomes more complicated when we consider continuous pollution! The responses to a steadily added pollutant may be (a) a cumulative long-term impact, (b) a short-term adjustment to a new level of behavior, (c) a long-term slow recovery, (d) a short-term fast recovery, or (e) a long-term slow destruction with no recovery at all. Of course, there are a number of possibilities for mixed responses.

Two classes of statistical methods seem logically attractive for use in environmental impact analysis. With a considerable overlap in the final estimation method (i.e., least squares analysis), the basic model considerations and accompanying assumptions are different. In the general linear model approach (variance-components analysis), variations in the response variable measured over time and space are decomposed into assignable sources of such variations and are assumed to be additive. The unexplained part (i.e., residual error) is then assumed to be independently, identically, and normally distributed with unknown common variance. The effects of power plant operation are postulated to be fixed and of constant but unknown magnitude and the same for all stressed locations.

In the time-series analysis approach, the response variable correlation to past observations is taken into consideration. The responses to power plant operation are assumed to be functions (linear or nonlinear) which can vary in time and space. The residuals could be correlated and may be heterogeneous in variance.

(a)

(b)

(c)

(d)

(e)

(f)

Fig. III.1. Possible Responses to a Disturbance in a Time Series.

A discussion of each class of methods is given in order to summarize the details.

Time Series Analysis

Since extensive time-series analysis was not carried out on the Zion environmental data, only a brief discussion on the method is given here.

In a time-series approach, the basic analysis model for environmental variables consists of the following:

$$Y = S_i + A_j + \text{lagged terms} + \text{operational effects function} + \text{random error term},$$

where: S_i is the seasonal effect, A_j is a deterministic component independent of season, lagged terms are to represent the autoregressive behavior, and the random error term is a white noise component assumed to be normally, independently, and identically distributed with mean zero and unknown variance σ^2 . The white noise can also be represented by a moving average representation.

The observations (data) have a time-series dependence; seasonal, annual, and spatial values are likely to be highly correlated. When a power plant begins operation, the change in the stochastic process is probably not that of an immediate discrete change with no change thereafter. It is more likely that a lagged response will occur and the function describing the time-dependent response will be something other than a horizontal straight line. Examples of possible responses are shown in Figure III.1. Under such conditions, we must consider the use of time-series analysis methods, especially the method referred to as "intervention analysis."² A systematic time sampling with evenly spaced observations simplifies the mathematics of this analysis.

A deviation from Box-Tiao's method (intervention analysis) can be suitably applied, and such an approach will relax the systematic, evenly spaced data requirements. The procedure is to examine the data in the frequency domain rather than in the time domain. Suppose that the response values are adequately modeled by "k" harmonics; then:

$$y_t = \delta + \sum_{j=1}^k (A_j \sin \alpha_j t + B_j \cos \alpha_j t) + f(t) + u_t$$

where: δ , A_j , B_j are regression coefficients, and u_t is random error assumed to be normally distributed with mean zero and unknown variance σ_u^2 .

The function of interest for environmental impact determination is $f(t)$. If $f(t)$ is a linear or an intrinsic linear function, then ordinary least squares will provide the estimates for all coefficients in the model. Depending on the shape and the values of the coefficients, inferences about the nature and extent of the impacts can be drawn. Uses of all these time-series approaches can be accomplished if the data collected samples the stochastic process fairly intensively.

General Linear Models (Variance-Components) Analysis

The general statistical approach taken under this class of methods, as applied to the environmental data analysis, is to consider the spatial and temporal distributions of the biotic groups as a sum of fixed responses due to assignable sources of factor levels. Time, space, and sampling locations, together with replicates, are taken to form a factorial experimental design. Natural logarithmic transformation for variance reduction is used before carrying out the general linear regressions.

Because biological and physical-chemical data are expected to be correlated, we can take advantage of this relationship in detecting an impact by carrying out multivariate and covariance analyses. However, because of the unavailability of simultaneous covariable measurements, we did not carry out such analyses. Rather, we restricted the analyses to a univariate variance-components form.

Preoperational studies were carried out during the construction period. Testing of the operability of the equipment and other construction-related environmental stresses were reflected in the data collected. It is not clear whether the data collection schemes were designed to either circumvent the contamination or to take into account such perturbations in the analysis of the data for estimating and testing of impact hypotheses.

Faced with the type of data available from Zion, we are left to make the best analysis we can. So the analytical framework was set to use general linear regression analysis in a univariate manner. The independent variables are dummy variables, taking a value of zero or one depending on the absence or presence of the factor-level effect. The decision to use a linear model in a variance-components form was dictated by the post-hoc analysis that made sense. Logarithmic transformations were made before obtaining the general regressions.

The two general linear models used in these studies are the following:

$$\text{Model 1: } \ln y = \alpha + \begin{matrix} \text{stations'} \\ \text{effects} \end{matrix} + \begin{matrix} \text{months'} \\ \text{effects} \end{matrix} + \begin{matrix} \text{stations'} \\ \times \text{ months'} \\ \text{effects} \end{matrix} + \text{random error}$$

$$\begin{aligned} \text{Model 2: } \ln y = \alpha + \begin{matrix} \text{years'} \\ \text{effects} \end{matrix} + \begin{matrix} \text{stations'} \\ \text{effects} \end{matrix} + \begin{matrix} \text{months'} \\ \text{effects} \end{matrix} + \begin{matrix} \text{years'} \\ \times \text{ stations'} \\ \text{effects} \end{matrix} \\ + \begin{matrix} \text{years'} \times \\ \text{months'} \\ \text{effects} \end{matrix} + \begin{matrix} \text{stations'} \\ \times \text{ months'} \\ \text{effects} \end{matrix} + \begin{matrix} \text{years'} \times \\ \text{stations'} \times \\ \text{months'} \text{ effects} \end{matrix} + \text{random error} \end{aligned}$$

where y's are the observed values of the dependent variable (benthic densities, phytoplankton densities, and zooplankton densities).

The various additive effects are estimated by a number of dummy variables. The number of such dummy variables depended on the number of levels of

each factor present for a particular set of data values. The error terms are assumed to be normally, identically and independently distributed with mean zero and unknown constant variance.

Residuals from the fitted models were examined to be aware of special data points problems. Particular attention was given to extreme values and outliers. Presence of such incidences was only used to carry out proper interpretations of the data.

Model 1 was used to analyze year-by-year data and Model 2 was used to analyze the preoperation-operation combined-years data. Effective interpretation with such an approach was to examine the nested variance components analysis with nesting occurring within the year factor.

From the analysis of variance associated with these general linear regressions, individual comparisons were made using either the least significant difference method, or by single degrees of freedom sum of squares computations. Because of the unbalanced, missing cells, and outliers types of conditions of the data, such an approach provided the most reasonable analysis for estimating and testing the hypotheses.

Some of the indicator organisms used in this study are euplankton species. These include phytoplankton (diatoms and total phytoplankton), zooplankton (total zooplankton, Rotifera, Cladocera, and Copepoda), and benthos (*Pontoporeia affinis* and total benthos). Because of insufficient data, fish were not analyzed except in the impingement studies discussed later in this report. This diverse array includes several trophic levels -- both free-floating and sessile organisms. In the plankton and benthos the subgroups represent the major portion of the biomass.

In the case of the Zion plant, 1972 and 1973 were preoperational years and 1974 and 1975 were operational years. In making comparisons between the preoperational and operational distributions of the organisms, one must assume that the comparison provides a true estimate of the plant operational impact and not the natural changes between the years.

Intrayear station comparisons consisted of month, station, and station $\times$ month interactions while interyear comparisons were for month, station, year, station $\times$ month, and station $\times$ year interactions.

Interyear comparisons were made between stations. Data for all years at each station were compiled and the means computed for each station. The means for selected station pairs were then compared and their statistical significance computed.

In many station comparisons, arithmetic data and logarithmic transformation of the data were plotted against time. Statistical results and arithmetic and logarithmic graphs of paired stations (where the monthly mean densities of organisms are plotted against time) are presented in Appendix Z-1, Tables 1-4; and Appendix Z-2, Plots 1-9, respectively. The contents are compiled in the following order: phytoplankton, zooplankton, and benthos. Tables of raw data compiled for the statistical analyses are given in Appendix Z-3 and are in the same order as in Appendix Z2.

Spatial and temporal comparisons of means and their statistical differences only confirm the knowledge that if biological measurements are made at various points in time, the observations are expected to differ in values. Therefore, such statistical comparisons are of confirmatory nature and reveal very little about the nature and extent of environmental changes due to power plant operation. However, the understanding and appreciation of these inherent differences provide an objective basis for determining environmental effects. The final hypothesis of interest (about the magnitude of environmental change due to power plant operation) is tested in the significance of the interaction effect in a two-way layout. The basic experimental design for the determination of environmental changes is the following:

	Reference	Stress
Before	M_{11}	M_{12}
After	M_{21}	M_{22}

The interaction comparison of interest is formulated as $D = (M_{11} + M_{22} - M_{21} - M_{12})$ and the single degree of freedom test is performed to determine first the statistical significance and then the biological interpretation of the significance to the local environment.

Thus, the tables are prepared to determine first the station and sampling period differences by comparing stressed and reference locations chosen with biological questions in mind; final testing and conclusions are then obtained by interpreting the interaction effect in the two-way design.

Selected Data Analysis

For the Zion plant, most of the biotic groups were sampled every month, thus providing a large data set subject for a variety of analytical techniques. We chose total phytoplankton and total zooplankton biotic groups for two types of detailed analysis given in this section. For each of the two groups the data consist of 12 monthly observations per year throughout four years. The Zion plant began operation during August, 1973, and therefore there were 19 months of data for the preoperational period and 29 months of data for the operational period.

The purpose of this examination was to explore methods of analyzing these types of data so that questions such as the following could be answered in a satisfactory manner:

"For what time period should the environmental variables be sampled both before and during the plant operation?" and,

"Can adjustments for seasonality in the data be made so that impact of plant operation can be more easily assessed?"

Accordingly the analysis and discussion in this section are exploratory in nature.

Adjustment for Seasonal Effect

The first task attempted in this set of analyses was to make an adjustment for the seasonal differences in species abundances observed in the biotic communities. The plots of various stations over time show that the data are highly seasonal but the yearly peak level does not occur during the same month each year. For illustration Figure III.2, the plot of total phytoplankton for Station 28, shows the peak month for 1972 through 1975 as June, May, May, and March, respectively. In addition, the level of the yearly peak month is quite different from year to year. Thus, a monthly adjustment to reduce the seasonal effect based on the average monthly level for four or five years might be quite misleading. In Figure III.2 a five-point moving average curve is also shown to represent the smoothing of the data for the station.

Having observed the differences in the occurrence of peak abundances over the years, we proceeded with the idea that pairing of control and stress stations according to geographical similarities would be beneficial in addressing the seasonality question. A selected number of such station pairs were plotted for phytoplankton and zooplankton data. These plots are given in Figures III.3 through III-5. The figures indicated that the station pairs tracked each other quite well and reach their yearly peak values in approximately the same month. In addition to plots of paired stations we also plotted data levels at different depths for the same station. As an example, Figures III.6 and III.7 represent the plots for total phytoplankton and total zooplankton densities for the north control stations at depths of three and 18 meters. The plots indicate that the agreement between three- and 18-meter biotic densities at the same zone may not be quite as good as between different stations at the same depth.

To further show the relationship between different depths and stations, Table III.1 presents the correlations of total phytoplankton and total zooplankton densities computed using the time data by depth and station. The table shows that in both of the biotic groups the correlations generally are higher between stations at the same depth than between depths at the same zone. In addition to correlations for the arithmetic data, Table III.2 presents the correlations of the naturally logarithmic total phytoplankton and total zooplankton data by depth and station. In general Table III.2 indicates the same patterns as Table III.1. However, the correlations for the log data are higher, especially for different depths at the same transect for total zooplankton levels.

After the plots and the correlations between depths and locations were examined, an attempt was made to adjust for seasonal effects by taking the difference between the log levels of paired control and stress locations. The log transformation was used to help stabilize the variance, which quite often increases with mean level for each station. In addition, the log transformation tends to reduce the effect of high peaks on the mean level over various time periods. Figures III.8, III.9, and III.10 present plots over time for log differences between stations for phytoplankton and zooplankton densities. These plots indicate that the paired difference may have taken care of the large seasonal trends seen in the individual raw data plots.

Fig. III.2. Plot of Total Phytoplankton Levels and Five-Point Moving Average Line from May 1972 through December 1975 at the North Control Station (28) at Three Meter Depth.

Fig. III.3. Plot of Total Phytoplankton Levels from January 1972 through December 1975 at North Control and North Zion Stations at Three-Meter Depth.

Fig. III.4. Plot of Total Zooplankton Levels from January 1972 through December 1975 at North Control and North Zion, Stations, at Three-Meter Depth.

Fig. III.5. Plot of Total Zooplankton Levels from January 1972 through December 1975 at South Zion and Dead River Stations, Depth = 3 meters

Fig. III.6. Plot of Total Phytoplankton Levels at Three and 18 Meter Depths from May 1972 through December 1975 at North Control Station.

Fig. III.7. Plot of Total Zooplankton Levels from April 1972 through December 1975 at North Central Station.

Table III.1 Correlations of Total Phytoplankton and Total Zooplankton Levels over Time by Depth and Station, from January 1972 through December 1975

Total Phytoplankton (sample size = 48 months) ^{1/}

	Depth in Meters	North Zion			South Zion			North Control			Dead River		
		3	9	18	3	9	18	3	9	18	3	9	18
North Zion	3	1.0	.79	.75	.96	.84	.74	.91	.81	.61	.94	.81	.73
	9		1.0	.88	.77	.93	.86	.74	.87	.67	.77	.89	.86
	18			1.0	.76	.91	.98	.84	.92	.75	.74	.89	.88
South Zion	3				1.0	.85	.74	.88	.81	.63	.97	.84	.75
	9					1.0	.88	.80	.88	.67	.83	.93	.89
	18						1.0	.85	.93	.79	.73	.87	.87
North Control	3							1.0	.90	.72	.89	.79	.73
	9								1.0	.70	.79	.90	.85
	18									1.0	.65	.66	.79
Dead River	3										1.0	.82	.73
	9											1.0	.88
	18												1.0

^{1/} Average correlation between stations at same depth = .89
Average correlation between depths at same zone = .81

Total Zooplankton (sample size = 48 months) ^{2/}

	Depth in Meters	North Zion			South Zion			North Control			Dead River		
		3	9	18	3	9	18	3	9	18	3	9	18
North Zion	3	1.0	.30	.65	.66	.32	.65	.80	.41	.62	.78	.26	.64
	9		1.0	.61	.31	.99	.48	.09	.97	.48	.09	.99	.48
	18			1.0	.69	.65	.97	.45	.71	.94	.54	.57	.91
South Zion	3				1.0	.32	.78	.42	.45	.60	.69	.26	.56
	9					1.0	.53	.13	.98	.53	.11	.98	.54
	18						1.0	.48	.60	.93	.58	.43	.91
North Control	3							1.0	.24	.49	.54	.07	.54
	9								1.0	.59	.20	.96	.59
	18									1.0	.46	.45	.96
Dead River	3										1.0	.04	.48
	9											1.0	.44
	18												1.0

^{2/} Average correlation between stations at same depth = .85
Average correlation between depths at same zone = .46

Table III.2. Correlations of Log Total Phytoplankton and Zooplankton Levels Over Time by Depth and Station, from January 1972 through December 1975

Log Total Phytoplankton (sample size = 48 months) ^{1/}													
	Depth in Meters	North Zion			South Zion			North Control			Dead River		
		3	9	18	3	9	18	3	9	18	3	9	18
North Zion	3	1.0	.85	.84	.92	.83	.85	.94	.84	.80	.92	.83	.82
	9		1.0	.90	.81	.93	.88	.83	.93	.86	.83	.90	.90
	18			1.0	.81	.90	.98	.87	.91	.90	.82	.90	.94
South Zion	3				1.0	.84	.79	.92	.84	.77	.96	.86	.81
	9					1.0	.89	.83	.94	.86	.85	.93	.91
	18						1.0	.89	.91	.90	.83	.88	.93
North Control	3							1.0	.88	.79	.91	.82	.83
	9								1.0	.85	.86	.93	.90
	18									1.0	.79	.84	.92
Dead River	3										1.0	.86	.83
	9											1.0	.92
	18												1.0

^{1/} Average correlation between stations at same depth = .93
Average correlation between depths at same zone = .85

Log Total Zooplankton (sample size = 48 months) ^{2/}													
	Depth in Meters	North Zion			South Zion			North Control			Dead River		
		3	9	18	3	9	18	3	9	18	3	9	18
North Zion	3	1.0	.83	.81	.92	.85	.68	.90	.86	.80	.91	.85	.83
	9		1.0	.89	.86	.97	.70	.79	.95	.85	.79	.97	.87
	18			1.0	.79	.90	.78	.75	.90	.96	.83	.91	.96
South Zion	3				1.0	.87	.68	.83	.88	.80	.68	.84	.80
	9					1.0	.72	.78	.97	.88	.81	.96	.90
	18						1.0	.59	.72	.76	.72	.72	.78
North Control	3							1.0	.82	.74	.85	.79	.78
	9								1.0	.88	.81	.96	.91
	18									1.0	.81	.88	.97
Dead River	3										1.0	.81	.84
	9											1.0	.91
	18												1.0

^{2/} Average correlation between stations at same depth = .90
Average correlation between depths at same zone = .82

Fig. III.8 Plot of Log Differences between North Zion and North Control Total Phytoplankton Levels at Three-Meter Depth from May 1972 through December 1975.

Fig. III.9 Plot of Log Differences between North Zion and North Control Total Zooplankton Levels at Three-Meter Depth from April 1972 through December 1975.

Fig. III.10 Plot of Log Differences between South Zion and Dead River Total Zooplankton Levels at Three-Meter Depth from January 1972 through December 1975.

Further investigation of the log difference adjustment for seasonality and its success was verified by computing several correlograms before and after taking log differences of control and stress locations. These correlograms are presented in Figures III.11 through III.14 for three- and nine-meter depths and for total phytoplankton and total zooplankton densities. The correlograms all exhibit the same basic patterns for the two biotic groups. That is, for the log levels of a stress location, the autocorrelation for various lags has a cyclic pattern as k (lag value) increases from one to 12 months with the largest positive autocorrelations at lags of one and 12 months and the largest negative autocorrelations at lag six months. On the other hand, the autocorrelations for the various lags for the log-differenced variable are usually relatively small with no particular pattern as k increases. In fact, tests of significance of the log difference autocorrelations shown that in almost all cases the autocorrelations are not significantly different from zero. Thus, it would appear that taking the difference between log levels of stress and control stations in a paired way would effectively eliminate seasonal trends for the Zion data.

Test of Impact Assuming Independence of Data Over Time

Having adjusted for seasonal trends by taking the paired differences, we proceeded with the problem of testing the impact of plant operation on total phytoplankton and total zooplankton levels. In this effort two testing procedures were used: 1) assume that the differences of the logs between stations are independent over time and perform an analysis of variance on these differences; 2) assume that an integrated moving average process fits the differences of the logs between stations and test the change in the level of this time series by the analytical technique provided by Box and Tiao. We first explored the approach under the first assumption.

For the analyses of variance approach let the following model describe the difference of the logs between a stress and a control station at one time period and one depth.

$$d_{kit} = \mu + BA_k + S_i + T_{t(k)} + (BA \times S)_{ki} + e_{kit} \quad (1)$$

where:

$i = 1, 2, \dots, s$ (stations)

$k = 1, 2$ (1 = before plant on, 2 = after plant on)

$t = \begin{cases} 1, \dots, n_b & \text{(before plant on)} \\ 1, \dots, n_a & \text{(after plant on)} \end{cases}$

BA_k = fixed effect of impact of turning plant on

S_i = random effect between paired stations differences
 $[Var(S_i) = \sigma_s^2]$

$T_{t(k)}$ = random time effect within BA_k $[Var(T_t) = \sigma_t^2]$

Fig.III.11 Correlograms of Log Total Phytoplankton Levels.

Fig. III.12 Correlograms of Log Total Zooplankton Levels.

Fig. III.13 Correlograms of Log Total Phytoplankton Levels.

Fig. III.14 Correlograms of Log Total Zooplankton Levels.

$(BA \times S)_{ki}$ = interaction between BA_k and S_i [$\text{Var}(BA \times S) = \sigma_{bas}^2$]

e_{kit} = interaction between T_t and S_i [$\text{Var}(e_{kit}) = \sigma_e^2$]

Thus, the variance of d_{kit} is given by:

$$\text{Var}(d_{kit}) = \sigma_s^2 + \sigma_t^2 + \sigma_{bas}^2 + \sigma_e^2 \quad (2)$$

A schematic of the d_{kit} 's for TP and TZ levels is as follows:

Paired Station Differences	Before Plant on (k=1) Time (Months)			After Plant on (k=2) Time (Months)		
	1	...	n_b	1	...	n_a
1	d_{111}	...	d_{11n_b}	d_{211}	...	d_{21n_a}
2						
.						
.						
s	d_{1s1}	...	d_{1sn_b}	d_{2s1}	...	d_{2sn_a}

To test impact using the model in Eq. 1, the following ANOVA may be run:

Source	df	EMS
BA	1	$\sigma_e^2 + k_1 \sigma_{bas}^2 + \sigma_t^2 + s k_1 (\Sigma BA_k^2)$
Time/BA	$n_b + n_a - 2$	$\sigma_e^2 + \sigma_t^2$
Station	$s - 1$	$\sigma_e^2 + (n_a + n_b) \sigma_s^2$
BA $\times$ X	$s - 1$	$\sigma_e^2 + k_1 \sigma_{bas}^2$
T $\times$ S = error	$(s - 1)(n_b + n_a - 2)$	σ_c^2
TOTAL	$s(n_a + n_b) - 1$	

Thus, if $\sigma_{bas}^2 = 0$ the test of impact is:

$$F_{1, n_b + n_a - 2} = MS(BA) / MS(\text{time/BA}) \quad (3)$$

i.e., Eq. 3 tests $H_0: BA_1 = BA_2$.

$$^+k_1 = (n_a + n_b) - (n_a^2 + n_b^2) / (n_a + n_b)$$

The F-test given in Eq. 3 is the same as the following t-test:

$$t_{n_b+n_a-2} = \frac{\bar{d}_{1..} - \bar{d}_{2..}}{[\text{Var}(\bar{d}_{1..} - \bar{d}_{2..})]^{1/2}} \quad (4)$$

where: $\text{Var}(\bar{d}_{1..} - \bar{d}_{2..}) = \sigma_t^2 \left(\frac{1}{n_b} + \frac{1}{n_a} \right) + \frac{\sigma_e^2}{s} \left(\frac{1}{n_b} + \frac{1}{n_a} \right)$

Note that the ANOVA can also be used to estimate the variance components σ_e^2 , σ_{bas}^2 , σ_s^2 , and σ_t^2 .

Using the model given in Eq. 1, we ran ANOVA's for TP and TZ levels at depths of three and nine meters. The results for TP are given in Table III.3.

Table III.3. ANOVA for TP Levels

Source	df	TP 3 Meters			TP 9 Meters		
		SS	MS	F	SS	MS	F
BA	1	0.0013	0.0013	n.s.	0.0325	0.0325	n.s.
Time/BA	42	2.3248	0.0554	n.s.	3.0235	0.0720	n.s.
Station	1	0.4572	0.4572	sig(.01)	0.1911	0.1911	sig(.10)
BA × S	1	0.0062	0.0062	n.s.	0.1149	0.1149	n.s.
Error	42	2.0753	0.0494		2.4048	0.0573	
TOTAL	87						

The corresponding estimates of the variance components are:

	TP 3 Meters	TP 9 Meters
$\hat{\sigma}_e^2 =$	0.0494	0.0573
$\hat{\sigma}_{bas}^2 =$	0.0	0.0029
$\hat{\sigma}_s^2 =$	0.0093	0.0030
$\hat{\sigma}_t^2 =$	0.0030	0.0074

Thus, for TP levels at three and nine meters there was no indication that the operation of the plant had any impact. Also, note that the differences between station pairs are significant at both three and nine meters but that time/BA and BA $\times$ S are not significant.

Table III.4 gives the ANOVA results for TZ levels.

Table III.4. ANOVA for TZ Levels

Source	df	TZ 3 Meters			TZ 9 Meters		
		SS	MS	F	SS	MS	F
BA	1	0.3081	0.3081	n.s.	0.2391	0.2391	n.s.
Time/BA	43	24.3400	0.5660	sig(.05)	6.5391	0.1520	n.s.
Station	1	1.6662	1.6662	sig(.05)	0.0091	0.0091	n.s.
BA $\times$ S	1	3.3350	3.3350	sig(.01)	0.0297	0.0297	n.s.
Error	43	13.163	0.3061		10.3953	0.2418	
TOTAL	89						

The corresponding estimates of the variance components are:

	<u>TZ 3 Meters</u>	<u>TZ 9 Meters</u>
$\hat{\sigma}_e^2 =$	0.3061	0.2418
$\hat{\sigma}_{bas}^2 =$	0.1469	0.0
$\hat{\sigma}_s^2 =$	0.0302	0.0
$\hat{\sigma}_t^2 =$	0.1300	0.0

The most interesting result in Table III.4 is the presence of an interaction between BA and stations at three meters. To investigate this interaction further, Table III.5 gives the TZ sample means used to compute the three-meter BA $\times$ S interaction (the nine-meter means are also given for comparison purposes).

Table III.5 clearly shows the presence of a BA $\times$ S interaction at three meters and indicates that $\ln SZ - \ln DR$ has a much larger change in magnitude from before to after plant operation than does $\ln NZ - \ln NC$. Accordingly, we also tested before versus after means for each station pair for three-meter TZ levels using a two-tailed t-test (again nine-meter t-tests are also given for comparison purposes).

Table III.5. Sample Means of TZ 3 and 9 Meter Levels
for the BA $\times$ S Interaction

Paired Station Difference	Before Plant On		After Plant On	
	3 Meters	9 Meters	3 Meters	9 Meters
Station 1 = ln NZ - ln NC	.09	-.15	-.19	-.08
Station 2 = ln SZ - ln DR	-.16	-.18	.36	-.03

The results were as follows:

Paired Station Difference	TZ 3 Meters	TZ 9 Meters
ln NZ ln NC	t = 1.41(sig 0.17)	t = 0.46(n.s.)
ln SZ ln DR	t = 2.47(sig 0.05)	t = 1.17(n.s.)

Thus, for TZ three-meter levels, ln SZ - ln DR shows a positive impact (after > before) as a result of power plant operation (probability level is 0.05) while ln NZ - ln NC shows a small negative impact (probability level is 0.17). Figure III.15 illustrates this further. In the figure the differences of the logs between the two station pairs are relatively similar until approximately February 1975 when ln SZ - ln DR becomes relatively large. This pattern can also be seen in Figure III.10 and somewhat in Figure III.5. Finally, Table III.6 gives sample means of three- and nine-meter log TZ levels for the four sampling stations before and after the plant was turned on and the difference between the before and after means.

Table III.6. Sample Means of Log TZ Levels by Station
Before and After Plant Operation

Station	3 Meters			9 Meters		
	Before	After	After-Before	Before	After	After-Before
ln NC	9.64	10.29	+0.65	9.86	10.15	+0.29
ln NZ	9.73	10.09	+0.36	9.71	10.08	+0.37
ln SZ	9.68	10.09	+0.41	9.74	10.13	+0.39
ln DR	9.84	9.73	-0.11	9.92	10.16	+0.24

Table III.6 shows that at three meters water depth the Dead River station is the only one whose average values (of log levels) decreased after operations began. However, at nine meters the averages of all stations increased after

Fig. III.15. Plot of Total Zooplankton Levels at Three Meter Depth from January 1972 through December 1975.

operation. Thus, the decrease in three-meter ln DR levels is probably the cause of the significant t-test for ln SZ - ln DR.

Test of Impact Assuming an Integrated Moving Average Process

The second approach for testing impact is to consider that the log differences are time series instead of an independent series over time. Accordingly, we attempted to analyze two paired-difference series in order to fit the integrated moving average process given by Box and Tiao.³ In brief, the model for this process is:

$$(\ln NZ - \ln NC)_t = d_t = L + \gamma_0 \sum_{j=1}^{t-1} a_{t-j} + a_t, \quad t = 1, \dots, n_b \quad (5)$$

where: L is a location parameter,

γ_0 is a parameter which depends upon the interdependency of the observations of the time-series ($0 \leq \gamma_0 \leq 2$), and

a_t is a random normal variable with mean 0 and variance σ^2 .

Equation 5 describes the n_b observations prior to starting the power plant. The n_a observations following the start-up of the plant differ from Eq. 5 only in that an impact, δ , is present, i.e.,

$$d_t = L + \gamma_0 \sum_{j=1}^{t-1} a_{t-j} + a_t + \delta, \quad t = n_b+1 \dots n_a + n_b \quad (6)$$

The parameter δ measures impact and is assumed to produce an immediate and constant effect upon the time-series. The use of this model formulation only relaxes the restriction on independence of the error term. The model formulation, including the impact parameter otherwise remains the same. Further work and investigation are needed to model the impact function to provide a more realistic form of the model in Eq. 6.

The model given in Eqs. 5 and 6 has been found to provide a reasonable fit to many time series. The model regards the system as being subjected to periodic random shocks, a_t . Furthermore, a proportion of each shock is assumed to remain in the system. Note that the integrated moving average model is nonstationary, except when $\gamma_0 = 0$.

Assuming that Eqs. 5 and 6 fit the TP and TZ data, the objective of this subsection is then to test whether the impact, δ , is significantly different from zero. To do this, Box and Tiao have shown that

$$\frac{\hat{\delta}}{S\sqrt{\gamma_0(2 - \gamma_0)}} \text{ is distributed as } t \text{ with } (n_a + n_b - 2) \text{ degrees of freedom,} \quad (7)$$

where

$$\hat{\delta} = \gamma_0 \left[\sum_{s=1}^{n_a} (1 - \gamma_0)^{s-1} d_{n_b+s} - \sum_{s=1}^{n_b} (1 - \gamma_0)^{(n_b-s)} d_s \right].$$

(the formula for S is rather complicated and is not given here; see Box and Tiao³).

However, before using Eq. 7 on the current data, we first checked the appropriateness of the model given in Eqs. 5 and 6 and also estimated the parameter γ_0 which is assumed to be known when using Eq. 7 to test δ (note, in this subsection only three-meter data is examined). To check the appropriateness of the model, we examined $\ln SZ - \ln DR$ and $\ln NZ - \ln NC$ to determine whether these series had the following properties of an integrated moving average model: (i) the time series should have no cycles in its graph and no sustained drifts in one direction from a baseline, (ii) the correlogram of the time series should be free of cycles and have random fluctuation around a baseline, and (iii) the correlogram of the differences between successive observations in the time series ($d_t - d_{t-1}$) should have a lag-1 autocorrelation equal to

$$\rho_1 = \frac{-(1 - \gamma_0)}{1 + (1 - \gamma_0)^2} \quad (8)$$

and all higher lag correlations near zero.

Regarding (i), Figures III.8, III.9, and III.10 show that at three meters the differences of logs between stations of TP and TZ levels appear to have an absence of cycles and no sustained one-directional drifts from the baselines. For (ii), Figures III.11 and III.12 indicate correlograms which appear to be no more than a random array of nonsignificant autocorrelations. (Note: In general, for judging the fit of the model, it would be more satisfactory to compute correlograms before and after the power plant begins operation. However, because of the limited sample sizes (e.g., $n_b = 19$) in the present case, the before and after operation data were combined in estimating the correlograms.) Finally regarding (iii), we computed the correlograms of $d_t - d_{t-1}$ and found that the autocorrelations greater than lag-1 were relatively small. Figure III.16 presents these correlograms for TP levels for lags up to five. In addition, after estimating γ_0 (as described below) the expected (assuming models 5 and 6) lag-1 autocorrelation of each of the $d_t - d_{t-1}$ series were compared to the observed autocorrelation. The results are given in Table III.7 and show close agreement between the observed and expected lag-1 autocorrelations. Thus, the TP and TZ series at three meters, based on the differences of the log levels between paired stations, gave no evidence of not satisfying the integrated moving average process given in Eqs. 5 and 6. However, at this point it is important to note, since the estimates of γ_0 given in Table III.7 are relatively close to zero, that it would also appear reasonable to treat the two series as having independent observations over time. In fact, for a series with $\gamma_0 = 0$, Eq. 8 shows that

Fig. III.16. Correlogram of the First Difference of Total Phytoplankton Levels at Three Meter Depth.

Table III.7. Comparison of Expected and Observed Lag 1 Autocorrelations

Paired Station Differences	"Max. Likelihood Estimate" of γ_0	Expected Lag-1 Autocorrelation of $d_t - d_{t-1}$ ^a	Observed Lag 1 Autocorrelation of $d_t - d_{t-1}$
<u>TP Levels</u>			
ln NZ - ln NC	.1	-.497	-.498
ln SZ - ln DR	.2	-.488	-.536
<u>TZ Levels</u>			
ln NZ - ln NC	.05	-.50	-.486
ln SZ - ln DR	.2	-.488	-.539

^aExpected lag 1 autocorrelation for a series fitting model (5) and (6) is given in Equation (8).

the lag-1 autocorrelation of $d_t - d_{t-1}$ is equal to -0.50 which is also very close to the observed autocorrelations given in Table III.7.

In order to estimate γ_0 from the available d_t data for each time series, we computed the "likelihood distribution" of γ_0 , denoted by $h(\gamma_0|d_t)$ (see Ref. 3). That is, we computed

$$h(\gamma_0|d_t) = \frac{\gamma_0(2 - \gamma_0)(S^2)^{-1/2}(n_a + n_b - 2)}{[(1 - (1 - \gamma_0)^{2n_b})(1 - (1 - \gamma_0)^{2n_a})]^{1/2}} \quad (9)$$

for each time series at three meters. Figure III.17 plots adjusted $h(\gamma_0|d_t)$'s versus γ_0 for the two TP series. The estimate of γ_0 was then taken at the peak of $h(\gamma_0|d_t)$ and the results of this "maximum likelihood" estimation for each of the four time series under study are given in Table III.7.

Accordingly, having examined the appropriateness of the model given in Eqs. 5 and 6 for the series under study and having estimated γ_0 for each series, we then computed the t-test given in Eq. 7. The results were as follows:

Three-Meter Data

TP Levels	t-Value	TZ Levels	t-Value
ln NZ - ln NC	0.385 (n.s.)	ln NZ - ln NC	-0.998 (n.s.)
ln SZ - ln DR	-0.415 (n.s.)	ln SZ - DR	0.555 (n.s.)

Fig. III.17. Adjusted Likelihood Distribution Plots for Total Phytoplankton Levels at Three-Meter Depth.

Thus, none of the four t-tests was significant. A closer examination of $\hat{\delta}$, given in Eq. 7, indicates why the t-test for $\ln(\text{SZ}) - \ln(\text{DR})$ TZ levels was not significant using the integrated moving approach. Equation 7 shows that $\hat{\delta}$ is simply the difference between two exponentially weighted averages, one having maximum weight immediately prior to plant operation and the other having maximum weight immediately after plant operation begins. However, an examination of Figure III.15 shows that $\ln \text{SZ} - \ln \text{DR}$ does not become relatively large until approximately February 1975 (recall that the Zion plant became operational during August 1973). Thus, one could argue that the impact of the plant on $\ln \text{SZ} - \ln \text{DR}$ did not occur until February 1975. That is, the impact, $\hat{\delta}$, was not immediate. To examine this hypothesis, we also applied the t-test in Eq. 7 to the $\ln(\text{NZ}) - \ln(\text{NC})$ and $\ln(\text{SZ}) - \ln(\text{DR})$ TZ levels assuming that $n_b = \text{January 1975}$ instead of July 1973. The results of these t-tests were

3 Meter Data	
TZ Levels	t Value
$\ln \text{NZ} - \ln \text{NC}$	1.00 (n.s.)
$\ln \text{SZ} - \ln \text{DR}$	1.44 (sig. at 0.10 level for one-tailed test)

Thus, the t-tests give some indication for $\ln \text{SZ} - \ln \text{DR}$ that there has been an impact after January 1975.

The nonsignificance of the t-test for $\ln \text{SZ} - \ln \text{DR}$ when $n_b = \text{July 1973}$ points out the necessity to develop not only models for the random portion of the time series (i.e., the $\gamma_0 \sum a_{t-j}$ term in Eq. 5 but also models for the deterministic component due to the impact of the power plant (i.e., the δ in Eq. 6). As discussed by Murarka⁴ and Box and Tiao² this impact component, if present, may take a variety of forms; therefore, an iterative model building approach is necessary to determine its shape.

Determining Sample Size Assuming Independence over Time

One of the objectives in analyzing the Zion data was to examine the sample sizes (number of months and stations) necessary to detect impacts of various magnitudes. The analysis of variance given in Tables III.3 and III.4 indicates that due to the significant differences between station pairs and the interaction between them for three-meter total zooplankton levels at the three-meter depth, a minimum of two pairs of the stations should be sampled at each depth. For total zooplankton densities it would seem reasonable to have more than two station pairs to determine whether the different effluent impacts detected for South Zion and Dead River zones are typical. If detected impacts between other station pairs are similar, such differences may be due to the presence of outliers. In general, if there is a significant station interaction, it would appear worthwhile to sample several station pairs so that the response surface for a particular depth can be examined. However, if no interaction is present, then only two or three station pairs are sufficient. First, by using the total phytoplankton data at three and nine meters and carrying out the t-test given in Eq. 4, we calculate the sample sizes

required to detect various magnitudes of impact. The classical formula for determining sample sizes based on the t-test is given as Eq. 10.

$$\frac{(t_{\alpha} + t_{\beta})^2}{d^2} = \frac{1}{\text{Var}(\bar{d}_{1..} - \bar{d}_{2..})} \quad (10)$$

where: t_{α} = value of t-distribution at desired significance level α
 t_{β} = value of t-distribution at desired power β
 d = difference to be detected.

In carrying out these calculations it is assumed that $N_a = n_b = n/2$. This assumption gives the minimum sample size necessary to satisfy Eq. 10. In addition, σ_{bas}^2 was assumed to be zero. Using the model in Eq. 1 with these assumptions, Eq. 10 becomes Eq. 11 shown below:

$$\frac{2(t_{\alpha} + t_{\beta})^2}{d^2} = \frac{ns}{s_e^2 + ss_t^2} \quad (11)$$

In the absence of a cost model for n and s we assume values for n and solve Eq. 11 for s . The values for d were determined by assuming that it was desired to detect certain ratios of the geometric means of the station pairs before and after the power plant was turned on. That is, let Z_{kit} be the ratio of total phytoplankton levels between the stress and control station at one time period and one depth. It was assumed that the following ratio was equal to some value D :

$$\frac{\left(\begin{matrix} s & n \\ II & II \\ i=1 & t=1 \end{matrix} Z_{1it} \right) \frac{1}{sn}}{\left(\begin{matrix} s & n \\ II & II \\ i=1 & t=1 \end{matrix} Z_{2it} \right) \frac{1}{sn}} = D \quad \text{i.e., the ratio of geometric means of } Z_{kit} \text{ before and after plant is turned on equals } D.$$

Taking logs of both sides gives

$$\frac{1}{sn} \sum_i \sum_t d_{1it} - \frac{1}{sn} \sum_i \sum_t d_{2it} = \bar{d}_{1..} - \bar{d}_{2..} = d$$

where $d_{1it} = \log Z_{1it}$ and $d = \log D$. Recall d_{kit} was defined in Eq. 1.

The results of using Eq. 11 for various values of n , α , β , D and the estimated variance components in Table III.3 are given in Table III.8.

Table III.8 Number of Paired Stations Necessary for Given n (months)
to Detect Differences D for Given α and β , Results for
Total Phytoplankton Levels†

One-Tailed Tests					
n = Months	D = Ratio of G.M.'s Before & After	3 Meters		9 Meters	
		$\alpha = .05$ $\beta = .10$	$\alpha = .10$ $\beta = .10$	$\alpha = .05$ $\beta = .10$	$\alpha = .10$ $\beta = .10$
12	1.1	17	12	>100	>100
	1.2	3	2	5	3
	1.5	1	1	1	1
	2.0	1	1	1	1
24	1.1	6	4	12	7
	1.2	2	1	2	2
	1.5	1	1	1	1
	2.0	1	1	1	1

† $n = n_a = n_b$, d in Eq. 11 = log D, G.M. = geometric mean.

Even though Table III.8 indicates that for D = 1.5 and 2.0 one station pair is sufficient, it would seem better to always sample at least two station pairs because of the relatively large differences between stations and the possibility of a BA by station interaction.

For TZ levels, the presence of the large interaction between BA and stations at three meters greatly increases the number of station pairs necessary to detect impact when using the t-test in Eq. 4. The reason for the increase in this case is

$$\text{Var}(\bar{d}_{1..} - \bar{d}_{2..}) = 2 \left(\frac{\sigma_e^2}{sn} + \frac{\sigma_{bas}^2}{s} + \frac{\sigma_t^2}{n} \right). \quad (12)$$

Thus, the d.f. for the t-test is quite small since the estimate of σ_{bas}^2 is based on a mean square with only s-1 d.f. (see Table III.4). Conversely, when σ_{bas}^2 is assumed to be 0 (as for TP levels) the d.f. for the t-test is equal to 2n - 2. Using Eq. 10 and the variance components given in Table III.4 to estimate the variance given in Eq. 12, for TZ levels at three meters we would require (i) 15 station pairs to detect a difference of D = 1.5 when n = 24 months, and $\alpha = \beta = 0.10$ and (ii) four station pairs when D = 2.0, n = 24 months, and $\alpha = \beta = 0.10$. This compares with a requirement of only one station pair for TP levels (see Table III.8).

In addition to the above, we ignored the ln NZ - ln NC data computed the number of months required to detect given D's for ln (SZ) -ln (DR) TZ levels

at three and nine meters. These sample sizes were computed using the formula shown in Eq. 13.

$$\frac{2(t_{\alpha} + t_{\beta})^2 \hat{\sigma}_t^2}{d^2} = n \quad (d = \log D) \quad (13)$$

where $\hat{\sigma}_t^2$ is an estimate of the variance component between times within BA_k for $\ln SZ - \ln DR$ only (i.e., the data for $\ln NZ - \ln NC$ were dropped for these calculations, and therefore no $BA \times S$ component was considered). The results, given in Table III.9, show that the TZ data requires larger sample sizes than the TP data to detect differences of size D.

Table III.9. Months of Sample Size^a Needed for Detecting Change in Zooplankton Levels

One-tailed Test		
	3 meters	9 meters
D=Ratio of G.M. Before & After	$\alpha=.10$ $\beta=.10$	$\alpha=.10$ $\beta=.10$
1.2	>100	63
1.5	38	13
2.0	14	5

^aBased on data for SZ and DR Zones, $n=n_a=n_b$.

General Analysis of All Biotic Groups

Linear-Models Analysis

In addition to analyzing the fate of selected aquatic organisms, the staff investigated, by detailed linear-model analyses, various groups of organisms that were monitored in the Zion area. A summary of year-by-year linear comparisons of total phytoplankton, diatoms, total zooplankton, rotifers, copepods, cladocerans, crustaceans, total benthos, and the amphipod *Pontoporeia affinis* are given in Appendix Table Z-1.2. In general, the comparisons of the mean annual densities of these groups were made for selected locations, depths, and zones. These tests were made to establish the statistical significance of the changes that may have occurred between the pre-operational (1972 and 1973) and operational years (1974 and 1975). Statistical testing was supplemented by observation of abundance patterns for the selected taxonomic groups for the period 1972 through 1975. Inconsistencies in behavior patterns were noted for interpretational use. Special attention was centered on changes occurring after the beginning of operation of the facility (August 1973), relative to the period prior to this date. The summary of observations made as a result of these analyses follows.

Phytoplankton. Total phytoplankton and diatoms consistently showed higher inshore densities compared to the offshore densities in the study area in 1972-1975. No preoperational versus operational differences could be found. A comparison between stations suggested that there is considerable variation; however, no significant differences in abundance were observed in 1973-1975 for total phytoplankton and in 1972-1973 for diatoms (Table III.10; Appendix Tables Z-1.2 and Z-1.6). The diatoms showed abundance differences early in the study followed by a more homogenous distribution in operational years. Little alongshore variation was indicated by the analyses, suggesting that the phytoplankton are quite uniform at selected depth contours north, south, and adjacent to the generating station.

Table III.10. Zion Nuclear Station Biological Monitoring Results
for 1972 through 1975
(1972 and 1973 Preoperational, 1974 and 1975 Operational)

Parameters Analyzed	Phytoplankton		Zooplankton					Benthos	
	Total Phytoplankton	Diatoms	Rotifera	Cladocera	Copepoda	Crustacea	Total Zooplankton	Pontoporeia	Total Benthos
Comparison of annual mean density at selected depth contours; each contour includes both stress and reference areas.	Essentially all depth comparisons show inshore > offshore patterns in 72-75.	Stress and reference areas show inshore > offshore abundance pattern for 72-75.	Evidence of inshore > offshore variability except in 74. Inshore areas are similar (3 & 9m).	Random distribution with some evidence of inshore > offshore abundance pattern.	Inshore < offshore pattern in 72 & 73; not evident in 74 but some evidence again in 75.	Inshore < offshore distribution of crustacea in all years except 1974.	Patchy distribution; no pattern.	Inshore < offshore distribution, 72-75; more random in 75.	Inshore < offshore distribution in 72-75, except 73 which had random distribution.
Comparison of annual mean density at the 4 designated sampling zones perpendicular to the shore, (NC, NZ, SZ, DR).	No consistent pattern between zones; uniform distribution in stress and reference areas.	Uniform horizontal distribution 72-75.	Random variation in stress and reference areas 72-75.	Uniform horizontal distribution in 72-75. Some random variation evident.	Random distribution 72-75.	Random differences evident in preop. and operational years.	No horizontal pattern in 72-74. In 75 stress areas had higher densities.	Similar patterns in preoperational and operational years.	Random variation in 72-75.
Selected depth comparisons at specific stations on different transects.	Uniform distribution; no differences 72-75.	No depth specific horizontal variation in reference or stress zones in 72-75.	Uniform distribution; no difference 72-75.	Uniform distribution in preoperational & operational data; some random variation evident.	No horizontal variation evident in 72-75.	Uniform distribution 72-75. No pattern observed.	No pattern in depth distribution during 72-75.	Uniform distribution 72-75. No pattern observed.	No consistent pattern or change from preoperational to operational.
Selected depth comparisons at specific stations on the same transects.	Consistent inshore > offshore abundance pattern in stress and reference areas.	Inshore > offshore abundance pattern consistent in stress and reference areas.	In 72-73 northern zones show inshore > offshore differences. In 74 distribution was uniform. Some evidence of inshore > offshore in 75.	Inshore > offshore variation in 72-73, 75; 74 showed no inshore-offshore pattern.	Evidence of inshore < offshore densities in 72-73 but not in 74, 75.	No pattern of distribution during 72-74. In 75 there was a shift to inshore > offshore.	No set abundance pattern in 72-75.	Inshore < offshore density patterns in 72-75.	Inshore < offshore abundance pattern except in 74 when inshore > offshore.

Zooplankton. Zooplankton abundance and distribution varied between taxonomic groups. As a whole, variation between months, depths (which corresponds to increasing distance offshore), and month $\times$ depth interaction showed significant differences in 1972-1975, while stations, month $\times$ station and depth $\times$ station terms were not significantly different (Appendix Table Z-1.1). This pattern is consistent with the expected distribution of the organisms in Lake Michigan.⁵

For any selected depth contour, the density of rotifers, cladocerns, copepods, and crustaceans varied without showing a north-south distribution pattern. But the abundance of these zooplankton increases as one moves from offshore locations to inshore areas.⁵ This pattern was present for all stations for preoperational and operational periods (Appendix Tables Z-1.1 through Z-1.3). Total zooplankton distribution showed no recognizable patterns. The differences in mean densities were random.

After careful examination of the preoperational and operational zooplankton data, it was found that the patterns which were seen in the preoperational period (1972 and 1973) persisted through the operational period (1974 and 1975) (Appendix Table Z-1.1). Within the framework of the data, it is concluded that the Zion plant operation did not induce a distinguishable effect on the local zooplankton as indicated in Table III.10 and summarized in Table III.11.

Benthos. The distribution of *Pontoporeia affinis* was variable, showing significant differences between months, depths, stations, month $\times$ depth, depth $\times$ station, and half of the month $\times$ station terms. The abundance of these organisms declined with nearness to shore. This observation is consistent with ecological data on the distribution of this amphipod in an environment of increasing depth, such as the sloping floor of a littoral zone. In addition, *Pontoporeia affinis* is a cold stenothermic organism preferring temperatures of less than 10-15°C and light intensity of low levels. These criteria would be more closely met at depths offshore.

Similar results, observed for total benthos, were expected since *Pontoporeia affinis* comprises a large proportion of the benthos and is the most abundant benthic invertebrate of the upper Great Lakes.^{6,7}

All distribution patterns of *Pontoporeia affinis* both parallel and perpendicular to shore were observed in preoperational and operational years in both stress and reference areas. These results indicate that plant operation made no significant changes in abundance or distribution patterns. Thus, no detectable impact occurred in these groups of organisms (Tables III.10 and III.11).

Graphical Time Series Analysis

Both the numbers and natural logarithmic values of benthic, zooplankton, and phytoplankton organisms were plotted by group for selected station pairs from 1972 through 1975. The plots are shown in Appendix Z-2. Results of graphical analyses augmented by the parametric tests are summarized in Tables III.12-III.15. Various stress station pairs were plotted to obtain a visual support for the similarity/dissimilarity in the time pattern of the

Table III.11. Annual Average Organism Densities¹ for Various Biotic Groups at Zion Station

STRESS AREAS*

North Zion and South Zion Transects (Zones)

Year	Total Phytoplankton	Diatoms	Total Zooplankton	Total Crustacea	Copepoda	Cladocera	Rotifera	Total Benthos	<i>Pontoporeia affinis</i>
1972	1800	1545	53813	44627	17560	27067	9184	3471	2168
1973	2282	1922	41164	28364	16455	11905	10633	5231	3816
1974	2755	2527	32597	23497	18061	5436	8947	4395	2590
1975	2159	2009	118438	76098	38963	37134	42462	4496	2765

REFERENCE AREAS

North Control Zone⁺

Year	Total Phytoplankton	Diatoms	Total Zooplankton	Total Crustacea	Copepoda	Cladocera	Rotifera	Total Benthos	<i>Pontoporeia affinis</i>
1972	1366	935	66772	50177	19969	30208	16600	2909	2171
1973	2531	2200	46124	34985	22233	12753	7590	3656	2836
1974	2737	2481	46175	34172	21833	12340	11994	4328	2353
1975	2220	2079	84279	61352	41998	19354	26806	3435	2429

Dead River Control Zone**

Year	Total Phytoplankton	Diatoms	Total Zooplankton	Total Crustacea	Copepoda	Cladocera	Rotifera	Total Benthos	<i>Pontoporeia affinis</i>
1972	1944	1692	61824	52392	19665	32728	9458	5345	2252
1973	2230	1875	36409	26739	16700	10031	9651	5593	2579
1974	2738	2507	30727	21871	17239	4633	10231	4193	1757
1975	2193	2048	172894	162391	80351	02040	10445	6234	2192

* Means of stations 5, 7, 10, 12

+ Means of stations 28, 30

** Means of stations 18, 20

¹Total Phytoplankton and Diatoms as Mean Numbers Per Milliliter. All Others are Mean Numbers Per Cubic Meter.

Table III.12. Summary of Plots for Zion Plankton¹ 1972-1975

	Stress Stations						Reference Stations					
	5	7	9	10	12	70 13a	18	20	22	28	30	32
Stress Stations	5	<div style="border: 1px solid black; padding: 2px; display: inline-block;"> $i > 0$ $P \cdot \Delta Z \uparrow$ </div>		<div style="border: 1px solid black; padding: 2px; display: inline-block;"> $i > 0$ $P; Z = *$ </div>								
	7		<div style="border: 1px solid black; padding: 2px; display: inline-block;"> $i > 0$ $\Delta Z \uparrow$ </div>									
	9											
Reference Stations	18				<div style="border: 1px solid black; padding: 2px; display: inline-block;"> $P = *$ $\Delta R \uparrow$ </div>			-	*	-		
	20				<div style="border: 1px solid black; padding: 2px; display: inline-block;"> $P = *$ $\Delta R \uparrow$ </div>				-		-	
	22					*						-
	28	*									-	<div style="border: 1px solid black; padding: 2px; display: inline-block;"> $i > 0$ $P \& Z$ </div>
	30	<div style="border: 1px solid black; padding: 2px; display: inline-block;"> $P \& Z$ $\uparrow \Delta$ </div>										<div style="border: 1px solid black; padding: 2px; display: inline-block;"> $i > 0$ $P \& Z$ </div>
	32			<div style="border: 1px solid black; padding: 2px; display: inline-block;"> $\Delta P \uparrow$ $Z = *$ </div>								

¹ Plankton = Total Phytoplankton and Diatoms: Total Zooplankton, Rotifera, Cladocera, Copepoda, Crustacea

↑ = Population increase in 1974 and/or 1975

- = No Zion impact

$i > 0$ = Inshore > Offshore

$0 > i$ = Offshore > Inshore

P = Phytoplankton

Z = Zooplankton

R = Rotifera

Δ = Potential Zion Station Impact

* = No differences of importance

Table III.13. Station Pairs* Compared with Arithmetic and Logarithmic Plots for Total Phytoplankton, Diatoms, Cladocera, Copepoda, Crustacea and Total Zooplankton from 1972-1975 at Zion Generating Station

<u>Stress Station vs. Stress Station</u>	<u>Reference Station vs. Reference Station</u>	<u>Stress Station vs. Reference Station</u>
5-9	30-32	70 (13a)-22
7-9	28-32	9-32
5-7	30-20	7-30
	28-18	5-28
	32-22	10-18
	28-30	12-20
	18-20	70-22
	18-22	
	20-22	
	30-32	

* See Figure III.18.

Table III.14. Summary of Plots for Zion Benthos

	Stress Stations										Reference Stations						
	2	4	5	7	9	10	11	12	13	70 13a	20	21	22	28	30	31	32
Reference Stations	18								TB+					*			
	19								r>s		*	*	*				
	20								*						*		
	21								*								
	22									*							-
	28			*													
	29	*													0>i	-	*

	Stress Stations									
	2	4	5	7	9	10	11	12	13	70 13a
Stress Stations	2	*		*	i<0					
	5									
	7									
	9									
	11							i<0	i<0	i<0; p+

- p = Pontoporeia
 TB = Total benthos
 + = Population depression in 1974 and/or 1975
 0>i = Offshore > inshore
 * = No important difference between stations
 i<0 = Inshore less than offshore
 - = No Zion impact
 r>s = Density higher in reference than in Stress Station

Table III.15. Station Pairs* Compared with Arithmetic and Logarithmic Plots for Total Benthos and Pontoporeia from 1972-1975 at Zion Generating Station

Stress Station vs. Stress Station	Reference Station vs. Reference Station	Stress Station vs. Reference Station
2-4	19-20	10-18
2-7	19-21	11-19
2-9	19-22	2-29
11-12	18-28	12-20
11-13	20-30	5-28
11 70 (13a)	32-22	13-21
	29-30	70 (13a)-22
	20-31	

* See Figure III.19

distribution of the different groups of organisms. Similar paired plots were made for reference locations and reference-stressed station pairs.

This ordering facilitates the evaluation of alterations in cyclic or acyclic patterns or time trends, periods of stimulation or depression, and peculiarities which are valuable for impact assessment. All stress stations refer to any sampling location which, in particular, is within the $\Delta T = 2^\circ\text{C}$ isotherm. Reference locations are likewise well outside of the designated area, viz., the North Control zone and Dead River control zone (Figs. III.5 and III.6).

Phytoplankton and Zooplankton. For stress station pairs in general, the planktonic groups analyzed by plotting abundances over time showed cyclic patterns throughout the 1972 to 1975 time period. These patterns are consistent with all of the statistical treatments and mean comparisons which were used to determine inshore-offshore and alongshore variability. However, some individual comparisons, i.e., station 5 (inshore) vs. station 7 (offshore) (Fig. III.18) suggest a slight stimulation of zooplankton populations in the offshore location (station 7) relative to inshore (station 5) in August, 1975. Although much natural variability is present in inshore-offshore patterns between zooplankton subgroups, the evidence of stimulated abundances may be inferred as the influence of the Zion warm water discharge. Tables III.12 and III.13 show that inshore plankton counts were greater than those offshore as seen particularly at stress station comparisons 5 and 7, 5 and 9, and 7 and 9.

For reference station pairs, similar results are seen for comparisons of stations 28 and 32, and 30 and 32 (Table III.2). Impacts due to the operation of the Zion plant were not detected at the reference locations, but inshore plankton densities were higher than those farther offshore (see comparison of stations 28 and 32, and 30 and 32). The cyclic abundance and distributional patterns for all planktonic groups were observed in both north and south reference areas.

Fig. Ill.18. Field Sampling Locations for Plankton and Water Chemistry, Southwestern Lake Michigan near Zion and Waukegan, Illinois.

For stress-reference station pairs, slightly higher peaks were observed at station 7 (stress) over station 30 (reference) in 1975 for total phytoplankton, rotifers, cladocerans, crustaceans, and total zooplankton. This trend was also evident at station 12 (stress) vs. 20 (reference) where rotifers were more abundant at station 12 (Table III.2). Since both stations 7 and 12 are within the $\Delta T = 2^\circ\text{C}$ isotherm (Fig. III.18) one might suspect a stimulation in the discharge area. This increase is consistent with that discussed in the preceding paragraphs comparing stations 5 and 7. It should be noted that the relatively equal abundances observed between stress station 5 and reference station 28 complicate a conclusion that there is an impact due to operation of the power plant.

Benthos. The three combinations of sampling stations compared for benthos were the same as those for plankton (Table III.14).

The plots of stress station pairs show a normal abundance and distributional pattern for 1972-1975, indicating little nuclear plant effect. The only exception is a depression of the population of the amphipod *Pontoporeia affinis* at station 13 relative to station 11 (Fig. III.19), but it is accompanied by much variability in the remaining comparisons and is therefore not considered significant.

A comparison of stress (only) stations showed no important differences between two of the station pairs. There was a drop in *Pontoporeia affinis* at offshore station 70 (13a), and a general inshore-offshore gradient at the remainder of the stress stations that were compared (Table III.14). Since *Pontoporeia affinis* are deep, cold water (stenothermic) amphipods, a higher density would be expected offshore particularly in the warmer months and in areas that are artificially warmed.

In the group of paired reference stations, no detectable impact was seen and there were usually no important differences (Plots in Appendix Z-2, Table III.14, Fig. III.19). However, we observed offshore benthos densities greater than those farther inshore. This was expected since *Pontoporeia affinis* makes up the greatest part of the benthos.

Most comparisons of the stress and reference stations showed no important differences and no observable impact (Table III.14) from operation of the Zion plant. However, the density of benthos was lower at station 11 (stress) than at station 19 (reference) and the total benthos were depressed at station 10 (stress) relative to its corresponding station 18 (reference).

All plotted data in both of the latter station categories suggest that there is a considerable amount of variability in the distribution and density of benthos of the region, and that in stress and reference areas, no abnormal pattern alteration or specific occurrences of significance were evident. This is consistent with linear comparisons made in an effort to detect inshore-offshore patterns and alongshore variability.

Fig. III.19. Benthos Sampling Locations in Southwestern Lake Michigan near Zion and Waukegan, Illinois.

Discussion

Phytoplankton

Total phytoplankton and diatoms show an inshore to offshore decrease with no alongshore pattern of distribution in the area of the Zion generating station. This is a typical configuration found for most of Lake Michigan in both the northern and southern basins.⁸ No systematic differences were observed between the Zion station stress and reference areas, and operational data collected in the study area adjacent to the facility showed little difference from that recorded for the preoperational period. Arithmetic value plots of the 1972-1975 data suggest a slight stimulation of phytoplankton in the area of station 7 in 1975. This is the result of higher total phytoplankton counts, but it is not considered important because there was no change in diatoms, the main component of the phytoplankton in Lake Michigan. The rise in numbers of total phytoplankton may be the result of stimulation of a green, bluegreen, or other taxonomic group not specifically studied in this evaluation.

All linear comparisons show that the variability and similarity of the phytoplankton distributions during the preoperational and operational periods between the stressed and reference locations remain nearly the same. This leads to a conclusion that, at least in the short term, there is no discernable impact of Zion plant operation on the phytoplankton component of the biota. This is in agreement with Glooschenko⁹ and Griffith,¹⁰ that temperature *per se* does not appear to control phytoplankton biomass.

Zooplankton

Linear comparisons for months, depths, stations, and their corresponding interactions indicate that, like the phytoplankton component, zooplankton show a distribution of organisms which can commonly be expected in this section of Lake Michigan. The subgroups Cladocera, Copepoda, Rotifera, and Crustacea show alongshore homogeneity but diverse patterns of inshore-offshore abundances. The total zooplankton category was very patchy, showing no recognizable distributional patterns. Slightly higher peaks were evident for the rotifers, cladocerans, crustaceans, and total zooplankton in the discharge area in 1975. This increase may have been the result of the added impact of Unit 2, which was put into commercial operation in September 1974. Also, it may have resulted from an accumulation of zooplankton organisms in the region due to an additive effect of entrained organisms which were not completely dispersed after passing through the condensers. This phenomenon is also observed in some of the benthic organisms and is discussed further in the section on benthos, specifically, that segment of the amphipod *Pontoporeia affinis*.

Our results suggest that the Zion generating station had little effect on the distribution of zooplankton. This is consistent with the findings of Beeton and Barker¹¹ who showed that the primary variable affecting the distribution of zooplankton adjacent to a power station near Milwaukee, Wisconsin, was the distance from shore. They also present strong evidence that the thermal discharge had little or no effect on zooplankton distribution.

Benthos

All patterns of benthic abundance and distribution alongshore and perpendicular to the shore (inshore-offshore), in stress and reference areas, preoperational and operational periods, remained essentially unchanged from 1972-1975. The numerical plots suggest considerable variability in the density of the benthic organisms with somewhat cyclic periods of abundance. Rather wide variability in the nearshore benthos is characteristic of the Great Lakes benthic communities.⁷

The utility's consultant indicates that higher numbers of the amphipod *Pontoporeia affinis* were observed at stations 6, 7, 11, and 12 in 1975. All of these sampling stations are adjacent to the discharge and are subject to perturbation by the facility. The consultant, however, suggests that this rise can be attributed to the gradual accumulation of animals which became entrained and passed through the condensers. Since the generating plant was in a higher mode of operation in 1975 than at any other time, this seems to be a logical explanation. The analyses at Argonne did not show an increase in this period, therefore, it is our observation that this may not be an important event. *Pontoporeia* are extremely mobile, migrating great distances in vertical and horizontal patterns,^{5,12} thus making them difficult to study. The amphipod is considered a vital link in the food web of Lake Michigan.

An evaluation of the benthic data and intensive analysis showed no detectable induced change due to operation of the Zion station. If one assigns an impact status to the accumulation of organisms due to either the additive effect of entrained organisms in the area of the discharge, or to some other reason,* then the Zion generating station has produced such an impact. This is an extremely local phenomenon which may be beneficial since the higher trophic level animals would find an increased food supply in the region of the discharge. Studies have revealed that the majority of those organisms entrained in a generating station are transported unharmed to the discharge.¹³⁻¹⁵ If this is the case at the Zion facility, the staff does not feel it to be detrimental to the biota.

Fish data were not analyzed because of the lack of population estimates necessary for impact assessments. Most of the species which are found in the area of the plant, i.e., alewife, smelt, trout, and salmon, are transient. Smelt and alewives are in the littoral regions of Lake Michigan during short periods of spawning but not throughout the entire year. Salmon and trout species migrate to the northern portions of the lake during warmer summer months; when the water temperature in the southern basin is higher. Although some trout and salmon return in the fall, the populations are transient and only small numbers of perch and chubs can be found throughout most of the year. The staff feels that an intensive investigation would be necessary in order to evaluate the potential impact of the Zion generating station on endemic fish species.

Analyses of available biological and thermal data collected at the Zion generating station indicate that little plant-induced effect can be detected.

*Other causes might be increases due to a more rapid rate of reproduction, and/or accumulations resulting from the elevation of water temperature in the area.

More intensive investigations of specific taxonomic groups may illustrate species-specific problems; however, under the present guidelines requiring more general studies, a potential ecological consequence is not observed.

CRITIQUE, CONCLUSION, AND RECOMMENDATION

The collection of data on the distribution of organisms in the major biological groups (phytoplankton, zooplankton, benthos and fish) follows a grid pattern at the Zion site with emphasis on depth effects. Such a monitoring scheme may be unnecessarily emphasizing the sampling intensity in the space factor, while inadequately examining the time responses. The need for stronger assumptions in the analysis of the data results in the basic problem of the dilution of the power of the tests. Emphasis should be placed on collecting data from multiple stations located in the maximum anticipated stress areas. Such stations are distinctly lacking in the Zion site sampling program.

It is easy to show that the testing power for detecting a modest plant-induced change is acceptably enhanced with a lesser amount of data collection when the design considerations are properly formulated.

Some relevant criticism of the existing programs is in order here.

1. Depth effects on the distribution of biotic organisms are the major factor in the sampling program. We, *a priori*, know that the water column characteristics have a major role in determining the distribution patterns of the organisms. Unless we can formulate a hypothesis of differential plant impact in the depth direction, use of several levels of depth factor are unnecessary.
2. The present program needs improvement in the pairing and location of stations in reference and stress areas. Changes should be made with extreme care, relative to variables such as depth, bottom type, temperature differences, lake currents, etc.
3. More sampling stations in the stressed area (the part of the water body likely to be most affected by the plant operation) will be needed to obtain the estimate of the plant's effect on the biota. This can be done at the expense of stations which are located at various depths and which do not provide information on the plant effects.
4. The short-term (immediate) responses to plant operation are examined without considering a lag response. It is our view that the proper analytical approach would be to design a sampling scheme suitable for estimating a lagged response to the power plant intervention effect. The effect in itself is likely to be a time-varying function of perhaps a non-linear form. From the analysis of Zion data, it is clear that an increasing intensity of impact may occur, but it may only be detectable in a long-term manner.
5. In the Zion plant case, the selection of the south control zone as a reference condition is rather questionable because of the strong possibility that the Zion and/or Waukegan thermal plumes may both be present in this area at certain times of the year.

6. The data on estimates of local adult, juvenile and larval fishes do not have the needed sensitivity to allow detection and subsequent interpretation of the plant-caused losses in the local fishery resources.

7. The trawling times were of varying lengths and thereby introduced a large error. Such a sampling approach has resulted in reducing the precision in detecting impacts.

8. It appears that benthic, phytoplankton, and zooplankton groups of organisms do not show impacts due to the power plant operation. Because of the constraint of the given data, it is not possible to show a high degree of confidence in detecting effects.

9. At Zion, it is not essential that the organisms, with the exception of fish, be identified to the species level, although classifying organisms into major subgroups at a genus level is necessary for any meaningful analysis. If an impact is detected within a specific group, however, it may be necessary to identify species in order to aid evaluation of the change.

10. More emphasis needs to be placed upon both the analysis and the assumptions for analysis of the data. One point that can be emphasized here is that in further analyses of these types of data, the differences of the log densities between control and stress stations, or some equivalent transformation should be analyzed instead of the raw data. The use of differencing and transforming, not only seems to remove seasonality, but also appears to remove serial correlations over time. Hence, it would be reasonable to rely on classical techniques of testing the presence of an intervention, when the model only considers a fixed magnitude response of the intervention.

11. One of the more important aspects which needs research and further investigation is the examination of various impact functions modeling the effect of intervention. A mixture of time-series and classical statistical methods may have to be utilized to model the biotic distribution and the power plant's effect on the biota.

12. Murarka¹⁶ suggests a regression approach for the determination of effects from the operation of power plants. In brief, the approach uses the following regression model to relate density of organisms of control (x_{it}) and stress (y_{it}) stations at time point (t) before the plant is operational:

$$y_{it} = A + \sum_{i=1}^s B_i (x_{it} - \bar{x}_{it}) + e_{it} \quad (14)$$

where A is intercept constant

s = number of control stations

B_i = regression coefficients relating the reference to stress stations.

The estimates of B_i coefficients are obtained by the least squares method using the preoperational data. Using the preoperational estimates and the

observed x_{it} , values for the operational period, a prediction of y_{it} is obtained, i.e.,

$$\hat{y}_{it} = \hat{A} + \sum_{i=1}^S \hat{B}_i \left(x_{it} - \bar{x}_i \right). \quad (15)$$

A comparison of $\hat{y}_{it}$ with y_{it} during operational period can be made to determine whether an impact of statistical significance has occurred.

A principal drawback of this procedure is that the independent variables are also measured with errors as large as those of the dependent variables. This may restrict the sensitivity of the method in detecting impacts of smaller magnitude. Little effort was vested in attempting to use this approach for Zion data; therefore, it is not possible to comment on the suitability of this analysis in the case of Zion. It would be beneficial to carry out a complete analysis under this approach.

13. From our experience in analyzing data from various power plants, we find that it is very difficult to find evidence of an impact, because of the number of sampling locations involved and the tendency for time interactions to be significant. These interactions are not necessarily caused by the plant operation. Thus, methods for combining the results from several sampling locations and then testing them for impact need to be examined. Table III.16 combines data for station pairs and depths for an ANOVA to test impact hypotheses (here $n_a = n_b = n$).

Table III.16. Analysis of the Variance Table and Expected Mean Squares

Source	df	EMS
BA	1	$\sigma_e^2 + s\sigma_{bad}^2 + d\sigma_{bas}^2 + sd\sigma_t^2 + sdn(\Sigma BA_k^2)$
Time/BA	$2n-2$	$\sigma_e^2 + sd\sigma_t^2$
Station (S)	$s-1$	$\sigma_e^2 + 2n\sigma_{sd}^2 + 2nd\sigma_s^2$
Depth (D)	$d-1$	$\sigma_e^2 + 2n\sigma_{sd}^2 + 2ns\sigma_d^2$
BA $\times$ S	$s-1$	$\sigma_e^2 + d\sigma_{bas}^2$
BA $\times$ D	$d-1$	$\sigma_e^2 + s\sigma_{bad}^2$
S $\times$ D	$(s-1)(d-1)$	$\sigma_e^2 + 2n\sigma_{sd}^2$
Error	$(sd-1)(2n-2) + (s-1)(d-1)$	σ_e^2
TOTAL	$sd(2n) - 1$	

As in Table III.3, the overall test of impact using the ANOVA in Table III.16 is $F = MS(BA)/MS(Time/BA)$ if there are no $BA \times S$ and $BA \times D$ interactions. However, if either $BA \times S$ or $BA \times D$ are significant then the results are not so clear cut and it may be necessary to examine impact by depth and/or station pairs as was done for the TZ data. Note that if the $BA \times D$ interaction is not significant, it may be an indication that samples only need be taken at one or two depths.

It should be pointed out here that the ANOVA given in Table III.16 may not be the most appropriate method for including depth in the analysis. Instead of treating depth as another factor in an ANOVA, it may be more reasonable, since the data at different depths are highly correlated (see Table III.1), to treat the data at the same time point at each of the three depths as a multivariate observation. One could then perform a multivariate analysis of variance (MANOVA) analogous to the ANOVA which was performed (Tables III.3 and III.4) for one depth. This approach would involve fewer assumptions than treating depth as another factor in the ANOVA. The MANOVA would, in effect, test the simultaneous effect of the intervention at the three depths of measurement.

Another technique for combining data over depths and stations that might prove useful is to use a response surface approach. In the example below, consider depths as the X axis and distance to the various stations as the Y axis.

Thus, for each month (t) there are 12 observations for the various (X, Y) coordinates. The following model may then be fit over time for a particular variable (e.g., TP):

$$TP_t = \alpha + B_1 X_t + B_2 X_t^2 + B_3 Y_t + B_4 Y_t^2 + B_5 (XY)_t + e_t \quad (16)$$

where: α and $B_1, \dots, B_5$ are regression coefficients and e is a random error which is assumed to be $NID(0, \sigma^2)$.

Equation (16) can be fit before and after plant operation begins to determine whether the shape of the response surface has changed. For example, before plant operation, the coefficient B_5 on the $(XY)_t$ term in Eq. 16 may not be significantly different from zero. However, during plant operation, the coefficient B_5 may become significant due to an impact on the stress stations

NZ and SZ. In addition, the model given in Eq. 16 might be used to help determine where to put sampling stations, e.g., should several depths be sampled or are one or two depths sufficient?

We used an integrated moving average process to separately fit the time series $\ln SZ - \ln DR$ and $\ln NZ - \ln NC$ at three-meter depth. However, no attempt was made to combine the data from the two time series. In the future, if the time series approach is used, some thought should be given to how the data from several station pairs can be combined, and an overall test of impact performed. (As an aside, a procedure to determining sample size when using the time series approach should also be considered.)

14. For the present report, we investigated the following null hypotheses: $H_0 \mu_{\text{before}} = \mu_{\text{after}}$ (when assuming $\ln NZ - \ln NC$ observations were over time) and $H_0 \delta = 0$ (when using the integrated moving average time series approach). Obviously, these are only two of a multitude of null hypotheses and models that could be tested. For example, for $\ln(SZ) - \ln(DR)$ TZ levels, the following model for impact was also briefly considered:

i.e., the impact, δ , does not occur immediately with plant operation (August, 1973) but only after a time period (February, 1975). Certainly, additional hypotheses and models will have to be examined. In determining these hypotheses and models, assistance should be solicited from knowledgeable sources (e.g., aquatic biologists) to determine the possible impacts of environmental variables on nuclear power plants. For example, (1) are the before and after overall phytoplankton averages what really should be tested or would it be more reasonable to only test the peak phytoplankton levels during the years before and after plant operation? and (2) is the impact likely to be a sudden jump in level δ , a slow increase over several years, or will only the yearly peak levels be effected?

Since one can never be sure when the effect of the intervention starts, it seems reasonable to analyze the differences in the log levels between stations over time and use spline regression methods. In this way one would allow the data to have one slope before the intervention, another slope

between the onset of intervention and the time a maximum effect is realized, and a third slope after the maximum effect occurs. The spline regression analyses would also allow one to estimate the time of maximum effect. Since the analyses in the current report indicate that the data are basically independent over time (i.e., the differences of the logs), the assumptions underlying classical spline regression should be satisfied.

15. In conclusion, a need clearly exists for the development of sampling designs and data-analysis methods most appropriate to the determination of environmental impacts.

FISH IMPINGEMENT

Potential and Predicted Impacts

One of the most visible effects of power plant operation is the fish kills that occur at the cooling water intakes. The losses of various species of fish in varying quantities are assumed to have an effect on the fisheries of the water body. Although the nature and extent of the losses can be measured, the resulting stresses on the fisheries are not well understood and the effects are variable from one aquatic system to another. As a result, it is difficult to define a "significant" fish kill and its effect on local fisheries. Case by case analysis may be needed to determine the effects of losses due to impingement on the fisheries of the region. Because fish kills are observed, it is assumed that a reduction of fisheries resources does occur, and therefore such kills are a potential ecological impact in a long term. The number of fish killed during any short period has little significance except as it relates to the dynamics of the fish population in the natural water body.

Fish impingement predictions made at the time the Final Environmental Statement was prepared were not quantitative. It was recognized that the fish impingement would occur and that alewives, yellow perch, salmonids, smelt and shiners would be the species most likely to be affected. Many other species may be impinged, but in very small numbers. It was recognized that only impingement data obtained during actual station operation would provide an adequate basis for quantitative assessment. Therefore, intensive monitoring of the traveling screen and forebay for impinged fish was required, especially during the first year of station operation.

Observed Fish Impingement

During the years 1973 through 1975, fish impingement was monitored at the Zion power plant. Only intermittent operation in 1973 occurred before Zion Unit 1 went into commercial operation in January 1974. The commercial operation of Unit 2 began in September 1974. Power production was to reach a maximum of 85% of the dependable capacity. During 1975 both units were in operation. Throughout the monitoring period, kills of various species of fish were observed. Figures III.20-III.22 show the observed daily fish kills for the period 1973-1975. The values are the natural logarithmic transformation plotted against time. Table III.17 summarizes the fish impingement data for the years 1973 to 1975. The two dominant species impinged are alewives and rainbow smelt. In examining the plots of these two species and the total impingement rates at Zion power plant, we can see that there is a distinct

Fig. III.20. Plot Showing the Transformed Total Impingement Values for 1973, 1974, and 1975.

Fig. III.21. Plot Showing the Transformed Alewife Impingement Values for 1973, 1974, and 1975.

Fig. III.22 Plot Showing the Transformed Rainbow Smelt Impingement Values for 1973, 1974, and 1975.

Table III.17. Summary of Fish Impingement Data for Years 1973-1975

MONTH	DAY	YEAR	IN_TEMP	TOTIMP	ALEWIFE	SMELT	FLOW
9	9	73	51.8	13	6	7	250
9	11	73	51.8	37	19	18	500
9	13	73	59.9	100	46	48	500
9	14	73	53.6	74	36	30	560
9	15	73	50.0	101	56	45	500
9	16	73	59.9	0	0	0	500
9	18	73	62.6	349	54	273	560
9	19	73	62.6	220	67	135	800
9	20	73	59.9	632	180	432	580
9	21	73	59.9	2218	147	2022	580
9	24	73	58.1	279	102	162	250
9	25	73	58.1	469	129	321	250
9	26	73	54.5	548	168	330	250
9	27	73	53.6	10	1	4	66
9	28	73	58.1	4	0	0	66
9	29	73	59.0	3	2	0	250
9	30	73	59.0	170	87	65	500
10	1	73	60.8	61	35	18	500
10	2	73	60.8	53	36	15	500
10	3	73	60.8	286	171	105	750
10	4	73	60.8	115	65	44	750
10	5	73	59.9	372	287	72	750
10	6	73	60.8	215	102	107	500
10	7	73	60.8	75	61	14	750
10	8	73	58.1	2515	2354	144	500
10	9	73	58.1	200	79	118	750
10	10	73	59.0	200	169	21	750
10	11	73	59.0	1435	1333	93	750
10	12	73	57.2	798	694	93	60
10	13	73	53.6	3774	3643	127	60
10	14	73	50.0	1909	1863	39	60
10	15	73	48.2	9574	9505	60	490
10	16	73	48.2	0	0	0	500
10	17	73	50.0	12105	12094	8	750
10	18	73	53.6	15900	15863	37	750
10	19	73	58.1	4458	4343	107	500
10	20	73	58.1	0	0	0	500
10	21	73	58.1	484	423	56	500
10	22	73	54.5	2	2	0	250
10	23	73	58.1	167	95	65	284
10	24	73	51.8	0	0	0	40
10	25	73	51.8	1081	943	132	240
10	26	73	48.2	67	49	16	240
10	28	73	48.2	111	81	18	40
10	29	73	48.2	297	271	20	250
10	30	73	51.8	78	52	14	240
10	31	73	51.8	26	21	4	240
11	2	73	54.5	0	0	0	500
11	3	73	56.3	0	0	0	490
11	5	73	52.7	0	0	0	500
11	7	73	52.7	984	915	60	468
11	8	73	52.7	1167	1034	128	500
11	9	73	50.0	178	131	40	680
11	10	73	50.0	393	376	15	500
11	11	73	50.0	2378	1897	480	700

Table III.17. Continued

MONTH	DAY	YEAR	IN_TEMP	TOTIMP	ALEWIFE	SMELT	FLOW
11	12	73	49.1	4169	4012	148	700
11	28	73	45.5	65	30	30	460
11	29	73	40.1	726	690	30	460
11	30	73	41.9	1584	1494	75	225
12	1	73	42.8	2153	2077	55	225
12	2	73	42.8	736	644	87	500
12	3	73	43.7	2197	2166	26	500
12	5	73	43.7	6405	5502	627	900
12	6	73	42.8	438	415	16	500
2	28	74	34.0	21	0	10	680
3	2	74	34.0	111	0	38	680
3	3	74	34.0	31	0	30	852
3	4	74	36.0	425	0	372	568
3	5	74	37.0	60	0	40	568
3	6	74	37.0	205	0	163	852
3	7	74	37.9	161	0	102	852
3	8	74	37.0	2245	0	2142	284
3	9	74	37.0	153	0	138	60
3	10	74	37.0	560	0	497	568
3	11	74	37.0	202	0	188	568
3	12	74	36.0	1055	1	1029	568
3	13	74	36.0	1872	0	1840	852
3	14	74	40.1	4111	0	4049	568
3	15	74	41.0	2020	1	1987	568
3	18	74	36.0	3089	6	3053	568
3	19	74	37.0	2211	4	2156	568
3	20	74	37.0	9187	14	9068	1136
3	21	74	39.0	3893	16	3826	1136
3	22	74	38.0	966	13	903	1136
3	23	74	37.0	554	3	544	1136
3	26	74	34.9	1366	20	1296	852
3	27	74	38.1	3812	77	3680	1136
3	28	74	38.1	1178	35	1022	1136
3	29	74	37.0	1114	6	1105	852
3	30	74	34.9	2966	4	2911	852
4	1	74	37.0	4159	18	4090	852
4	2	74	36.0	6120	64	6026	852
4	3	74	36.0	1973	14	1944	852
4	4	74	39.0	705	1	688	852
4	5	74	41.9	2060	821	1175	852
4	6	74	37.0	3296	940	2346	568
4	7	74	41.0	1322	219	1082	852
4	8	74	37.0	2715	594	2085	568
4	9	74	39.0	2189	1216	937	284
4	10	74	42.1	1410	815	577	204
4	11	74	45.0	412	190	204	284
4	12	74	49.1	706	306	372	284
4	13	74	42.1	419	219	185	284
4	15	74	42.1	3426	1850	1448	852
4	16	74	44.1	4573	1663	2855	1136
4	17	74	43.0	15943	12969	2819	1420
4	18	74	44.1	4552	3540	935	1136
4	19	74	44.1	4958	3922	993	852
4	20	74	44.1	9992	9208	732	852
4	21	74	45.0	1998	981	972	852

Table III.17. Continued

MONTH	DAY	YEAR	IN_TEMP	TOTIMP	ALEWIFE	SMELT	FLOW
4	22	74	49.1	2421	830	1576	852
4	23	74	45.0	2714	624	2063	852
4	24	74	44.1	2427	1032	1286	852
4	25	74	46.0	3586	1273	2094	852
4	26	74	45.0	2666	800	1771	852
4	27	74	47.1	344	44	259	852
4	29	74	45.0	9640	4769	4455	852
4	30	74	43.0	2609	1354	1187	852
5	1	74	45.0	1942	848	974	568
5	2	74	46.0	4880	2231	2369	852
5	3	74	45.0	3488	1979	1319	852
5	4	74	45.0	2960	1566	1279	1136
5	5	74	47.1	717	380	315	1136
5	6	74	48.0	5348	3089	2153	1136
5	7	74	46.0	11041	7780	3036	1136
5	8	74	48.0	18016	12679	5291	1136
5	9	74	49.1	97756	90223	7442	1136
5	10	74	50.0	91154	89676	1407	852
5	11	74	49.1	33985	32879	1058	852
5	12	74	46.9	30661	30629	30	852
5	17	74	48.0	3226	3216	10	852
5	18	74	48.0	4509	4462	30	852
5	19	74	48.0	6119	4553	1554	852
5	20	74	49.1	2351	2251	97	852
5	21	74	49.1	1307	1297	5	852
5	22	74	49.1	1421	972	443	852
5	23	74	47.1	6335	5595	727	568
5	24	74	47.1	7240	6507	725	568
5	25	74	47.1	2109	2095	14	568
5	26	74	47.1	874	869	3	284
5	27	74	48.0	572	436	132	66
5	28	74	48.0	562	365	185	66
5	29	74	47.1	2364	2295	57	66
5	30	74	47.1	2788	2060	722	568
5	31	74	47.1	4999	4455	540	568
6	1	74	50.0	4994	4973	13	568
6	2	74	50.0	5531	5484	39	568
6	3	74	52.0	11098	10817	275	568
6	4	74	52.0	9616	9595	8	1136
6	5	74	49.1	11711	11073	632	1136
6	6	74	48.0	14967	14951	10	1136
6	7	74	47.1	14222	14207	10	1136
6	8	74	50.9	8627	8589	32	1136
6	9	74	50.0	17233	17231	0	1136
6	10	74	46.0	7633	7575	42	852
6	11	74	46.0	11933	11908	20	852
6	12	74	48.0	12359	12343	14	852
6	13	74	47.1	6270	6244	17	852
6	14	74	46.0	6635	6604	18	852
6	15	74	47.1	9608	9589	10	852
6	16	74	45.0	13096	13062	18	852
6	17	74	48.0	4913	4881	25	852
6	18	74	49.1	4332	4295	28	852
6	19	74	50.0	3970	3942	20	852
6	20	74	51.1	3104	3080	20	852

Table III.17. Continued

MONTH	DAY	YEAR	IN_TEMP	TOTIMP	ALEWIFE	SMELT	FLOW
6	21	74	50.0	5054	5024	26	852
6	22	74	51.1	12622	12571	31	852
6	23	74	54.0	9046	9028	14	852
6	24	74	54.0	22971	18495	4410	852
6	25	74	54.0	9238	5351	3828	852
6	26	74	55.0	5741	5459	276	852
6	27	74	55.0	7279	7235	25	852
6	28	74	54.0	5552	5489	52	852
6	29	74	55.0	4328	4321	3	852
6	30	74	52.5	10772	10690	71	852
7	1	74	52.5	6837	6783	47	852
7	2	74	53.5	2539	2516	17	852
7	3	74	53.5	5151	5146	2	852
7	4	74	52.0	5993	5974	10	710
7	5	74	51.5	11174	11151	13	710
7	6	74	53.5	5163	5046	11	852
7	7	74	52.5	12539	12289	242	852
7	8	74	52.5	20697	20685	8	852
7	9	74	52.0	23152	23126	22	852
7	10	74	52.5	15485	15442	41	852
7	11	74	57.5	12529	12503	25	852
7	12	74	62.0	15636	15604	30	852
7	13	74	61.5	16357	16329	24	852
7	14	74	61.0	21087	20777	301	852
7	15	74	61.5	23462	23435	27	852
7	16	74	63.5	22487	22455	32	852
7	17	74	63.0	20376	20305	66	852
7	18	74	54.5	21934	21885	47	852
7	19	74	50.0	4900	4898	1	852
7	20	74	59.0	6247	6234	12	852
7	21	74	66.0	5368	5331	34	852
7	22	74	56.0	5175	5151	23	852
7	23	74	61.0	4624	4603	20	852
7	24	74	64.0	3716	3677	36	852
7	25	74	62.0	1863	1848	14	852
7	26	74	61.5	4921	4879	40	852
7	27	74	61.5	4494	4475	19	852
7	28	74	61.0	1817	1783	34	852
7	29	74	59.0	6383	6353	29	852
7	31	74	65.5	9872	9822	48	852
8	1	74	64.5	13925	13749	173	852
8	2	74	64.0	12651	12610	40	852
8	3	74	56.0	17106	17064	42	852
8	4	74	47.5	17171	17531	138	852
8	5	74	48.0	10305	10260	45	852
8	6	74	48.5	11045	10862	183	852
8	7	74	51.0	3360	3333	30	999
8	8	74	58.5	2722	2689	30	994
8	9	74	60.0	2743	2710	33	994
8	10	74	54.5	12330	12281	34	852
8	11	74	49.0	13375	13310	41	852
8	12	74	52.5	1190	1175	15	1086
8	16	74	53.0	800	800	0	1278
8	17	74	54.5	258	236	22	1136
8	19	74	53.5	183	172	11	1470

Table III.17. Continued

MONTH	DAY	YEAR	IN_TEMP	TOTIMP	ALEWIFE	SMELT	FLOW
8	20	74	50.5	1292	1262	30	1136
8	21	74	47.5	2495	2447	40	1136
8	22	74	52.5	2271	1846	411	1278
8	23	74	59.0	6150	6115	34	1420
8	26	74	52.0	758	741	17	994
8	27	74	56.0	60	30	30	568
8	28	74	62.5	65	30	30	568
8	29	74	67.0	65	30	30	568
9	1	74	64.5	2154	2122	30	1136
9	2	74	64.5	3637	3607	30	1562
9	3	74	64.0	3170	3140	30	1278
9	4	74	64.0	6857	5766	1091	1278
9	5	74	65.0	5249	5201	42	1278
9	6	74	64.5	1962	1610	358	1136
9	7	74	59.0	1448	1421	27	1278
9	9	74	55.5	2845	1193	1652	1420
9	10	74	54.0	7360	7100	256	1420
9	11	74	49.5	3464	3360	99	1420
9	12	74	49.5	5485	3323	2154	1420
9	13	74	51.1	3178	2990	185	1562
9	14	74	60.1	4123	3971	149	1704
9	15	74	58.0	2463	1663	800	1704
9	16	74	57.5	3496	3179	317	1704
9	18	74	55.5	10686	4780	5906	1704
9	18	74	56.0	1461	1095	366	1704
9	19	74	56.0	2692	2391	301	1562
9	20	74	55.0	5162	4892	264	1420
9	21	74	56.5	1090	1062	26	1562
9	22	74	57.5	6491	4755	1672	1562
9	23	74	56.5	1226	1096	129	1562
9	24	74	56.0	3727	1224	2500	1704
9	25	74	55.5	3636	3500	126	1704
9	26	74	56.0	6937	4656	2264	1704
9	27	74	56.0	5120	4738	366	1704
9	28	74	51.0	13543	13333	207	1704
9	29	74	49.5	6614	6432	178	1704
9	30	74	52.0	27171	26549	618	1704
10	2	74	52.5	6627	4347	2226	1704
10	3	74	51.5	7184	6612	559	1704
10	4	74	51.5	5270	5134	130	1704
10	5	74	52.0	4059	3468	564	1704
10	29	74	50.0	1719	1714	3	1420
10	30	74	50.5	1739	1739	0	1420
10	31	74	51.0	9423	9387	23	1562
11	1	74	53.0	1298	1280	15	1704
11	2	74	53.0	620	641	12	1704
11	3	74	49.5	8271	8250	15	1704
11	4	74	48.5	231	221	10	1704
11	5	74	48.0	263	253	0	1704
11	6	74	48.5	41075	38973	2081	1278
11	7	74	48.5	82	63	17	852
11	8	74	48.0	114	97	16	852
11	9	74	48.0	14	10	4	852
11	10	74	48.5	14	10	3	852
11	11	74	48.5	376	364	7	1136

Table III.17. Continued

MONTH	DAY	YEAR	IN_TEMP	TOTIMP	ALEWIFE	SMELT	FLOW
11	12	74	48.0	0	0	0	1562
11	13	74	49.0	1480	1458	10	1704
11	14	74	48.5	250	127	123	1704
11	15	74	46.5	0	0	0	1704
11	26	74	44.5	1280	1220	53	1704
11	27	74	44.5	9508	6881	2621	1704
11	28	74	43.5	1067	960	107	1704
11	29	74	42.5	27	18	7	1704
11	30	74	40.0	281	281	0	1420
12	1	74	38.0	20	10	7	1136
12	3	74	38.0	372	372	0	852
12	4	74	37.5	938	912	25	852
12	5	74	39.5	1026	1000	18	852
12	6	74	42.0	97	90	5	852
12	7	74	41.0	218	134	81	852
12	8	74	38.5	148	132	16	852
12	9	74	37.5	140	140	0	852
12	10	74	37.0	26	25	0	994
12	11	74	37.5	10	6	2	1278
12	12	74	38.0	5153	4530	585	1420
12	14	74	40.0	832	577	238	1420
12	16	74	38.5	1043	923	85	1704
12	17	74	40.0	13333	1239	89	1704
12	18	74	39.0	1611	1448	149	1704
12	19	74	39.0	44	0	30	1704
12	20	74	39.0	9	0	3	1704
12	22	74	38.0	97	30	30	1704
12	23	74	37.5	144	30	30	1704
12	24	74	37.0	127	74	30	1704
12	27	74	36.5	54	25	0	1704
12	28	74	38.0	22	10	1	1704
12	29	74	39.5	45	30	5	1704
12	30	74	39.0	52	26	9	1704
12	31	74	38.1	56	30	14	1704
1	2	75	36.2	63	30	30	852
1	6	75	33.4	48	14	30	1136
1	17	75	36.0	97	11	30	1704
1	20	75	32.0	98	5	29	1420
1	24	75	32.0	42	0	27	1704
1	27	75	34.5	23	0	15	1704
1	31	75	32.9	27	6	10	1704
2	3	75	34.5	38	0	30	1136
2	11	75	34.0	46	0	30	1704
2	14	75	33.5	75	19	30	1704
2	17	75	33.6	50	0	30	1704
2	21	75	33.8	55	0	55	852
2	25	75	34.2	12	0	10	1704
3	5	75	32.4	697	1	668	852
3	9	75	33.8	210	0	198	852
3	13	75	35.6	0	0	20	852
3	17	75	34.9	15	0	10	852
3	22	75	36.7	17	0	13	0
3	25	75	38.5	65	18	30	1136
3	29	75	38.9	5168	2491	2662	1704
4	15	75	37.6	2620	2057	549	1420

Table III.17. Continued

MONTH	DAY	YEAR	IN_TEMP	TOTIMP	ALEWIFE	SMELT	FLOW
4	21	75	43.9	2063	2044	13	1704
4	25	75	46.5	14580	14563	8	1704
4	29	75	46.6	58198	58182	16	1704
5	3	75	47.1	2832	2832	0	1704
5	7	75	47.1	276497	276497	0	1704
5	10	75	48.0	1045800	1045800	0	1704
5	14	75	46.0	2863500	2863500	0	1704
5	18	75	45.8	107196	107196	0	1704
5	22	75	45.1	419580	419580	0	1704
5	26	75	43.5	11650	11650	0	852
5	30	75	51.4	1951	1951	0	852
6	3	75	49.8	2779	2779	0	852
6	11	75	55.4	638	638	0	568
6	15	75	51.8	3357	3357	0	568
6	19	75	51.8	8037	8037	0	284
6	23	75	57.2	3176	3176	0	568
6	30	75	68.0	4532	4532	0	568
7	8	75	52.0	1239	1239	0	1136
7	12	75	57.4	1087	1087	0	1704
7	16	75	44.2	1107	1103	0	1704
7	20	75	37.8	2272	2229	30	1704
7	24	75	38.3	685	682	2	1704
7	28	75	37.6	491	491	0	1704
8	1	75	51.8	601	591	7	1704
8	5	75	46.4	400	399	0	1704
8	9	75	47.7	729	729	0	1420
8	13	75	47.5	140	137	2	1704
8	17	75	61.5	619	619	0	1704
8	25	75	42.4	561	541	18	1704
9	2	75	55.0	585	580	0	852
9	6	75	55.9	153	152	0	1136
9	10	75	54.7	221	219	0	1136
9	14	75	53.1	382	375	6	852
9	18	75	53.1	618	615	2	1420
9	22	75	35.2	287	274	7	1136
9	26	75	43.5	687	667	10	1136
9	30	75	50.0	2344	2333	9	1704
10	4	75	45.5	736	727	7	1704
10	8	75	46.0	4138	4138	0	1704
10	12	75	46.0	1000	988	9	1704
10	16	75	45.0	486	468	11	1704
10	20	75	43.9	177	160	10	1420
10	24	75	44.1	524	505	18	1704
10	28	75	42.4	379	370	8	1704
11	1	75	40.5	65	61	3	1704
11	5	75	39.4	393	386	5	1704
11	9	75	36.9	183	178	4	1704
11	13	75	36.1	355	252	68	1704
11	17	75	38.7	323	257	56	1704
11	21	75	34.7	229	176	53	1704
11	25	75	31.1	422	286	136	1704
11	29	75	31.6	135	126	9	1704
12	3	75	33.1	15	6	4	1704
12	7	75	32.4	64	7	56	1704
12	11	75	30.6	88	24	58	1704

Table III.17. Continued

MONTH	DAY	YEAR	IN_TEMP	TOTIMP	ALEWIFE	SMELT	FLOW
12	15	75	32.4	535	10	522	1704
12	19	75	29.1	2604	61	2504	1704
12	23	75	25.3	600	0	588	1704
12	27	75	23.5	77	15	53	1704
12	31	75	23.5	186	0	181	1704

seasonality in the dominant fish kills. The alewife impingement rate rises in the spring and reaches a stable rate in the summer before declining rapidly to a low value in the winter. There is a natural die-off period for Alewives in winter. However, fish impingement does not appear to have been affected by this phenomenon.

Rainbow smelt impingement rates are at the maximum during the winter period, but reduce to a low rate during most of the summer. As a result of this functionally inverse behavior of the two dominant fish species impinged at the Zion intakes, the total fish impingement shows a non-zero fish kill rate at all times. From a census type sampling, i.e., recording fish kills for every day throughout the year, an estimate of total fish kills by species is provided on a yearly basis. If there is interest in the daily impingement rate, a time-dependent function for expected daily fish kills can be estimated by using these data. In the case of Zion, it is apparent that for a daily impingement rate at various times of the year, an annual average number is not a proper statistic. As a matter of fact, the total impingement rate follows an approximate function which has varying coefficient values in the various segments. In this case, two linear curves and a third constant value function may suffice to represent the expected impingement rates at various times throughout the year.

The fish impingement data for 1974 and 1975 were analyzed statistically. Multiple regressions using quadratic order variables in time and temperature, together with a linear part due to the flow variation, were used as the independent variables, and logarithmically transformed alewife and rainbow smelt were used as the dependent variables. As a first approximation, this particular function was selected after a careful study of several other simple regression models.

Because of the absence of a protective net around the intake structure in the lake in May 1975 there were a few days when exceptionally high impingements of alewives were recorded. This was an unusual condition, so it was treated as an extreme values (outliers) problem. Regressions were fitted where these outlier points were included for testing the effect of these data points on the fitted function. But the regressions which discarded these data points in the estimation of the coefficients are considered to be the appropriate fitted models. Results of all these analyses are given in Table III.18. Figures III.23-III.26 provide the fitted line and the data scatter.

A study of the regressions reveals that the 1974 and 1975 impingement rates are nearly the same (as seen by comparing the regression Models II, III and IV). The coefficients are very stable and consistent. The linear parts show that there is an overall increasing trend in fish impingement rates within the year. This trend is modified by the strong quadratic part becoming dominant as time value is increased.

Even though an apparently satisfactory regression model has been found, there are a number of deficiencies in this model. This work should be considered as only a beginning of an effort which probably will give rise to more satisfactory methodology. Efforts are underway to abstract time-dependent and environmental variable-dependent functions from presently available data and to obtain generalized results on the dynamics of fish impingement.

Table III.18. Regression Analysis Results for Alewife Impingement at the Zion Nuclear Power Plant

Model	Regression Equation	R ²
Model I	$y^a = -18.989988 + 0.079994 * \text{Time} - 0.000196 * \text{Time}^2 + 0.68233 * \text{Temperature} - 0.006336 * \text{Temperature}^2 + 0.0011797 * \text{Flow}$ <p>(2.76)^b (0.0096) (0.000023) (0.1253) (0.00124) (0.00029) (for time period 1974 and 1975, n = 326)</p>	0.61
Model II	$y^a = -13.0783659 + 0.0445 * \text{Time} - 0.0001009 * \text{Time}^2 + 0.50223 * \text{Temperature} - 0.00424 * \text{Temperature}^2 + 0.00074 * \text{Flow}$ <p>(4.30)^b (0.0137) (0.000037) (0.209) (0.0022) (0.00055) (for time period 1975 only without outliers, n = 74)</p>	0.67
Model III	$y^a = -18.798776 + 0.135475 * \text{Time} - 0.000317 * \text{Time}^2 + 0.5594 * \text{Temperature} - 0.005933 * \text{Temperature}^2 + 0.000655 * \text{Flow}$ <p>(4.89)^b (0.019) (0.000044) (0.232) (0.0022) (0.00039) (for time period 1974 only, n = 245)</p>	0.64
Model IV	$y^a = -15.70851 + 0.05952 * \text{Time} - 0.000152 * \text{Time}^2 + 0.5353 * \text{Temperature} - 0.004585 * \text{Temperature}^2 + 0.00212618 * \text{Flow}$ <p>(5.68)^b (0.018) (0.000048) (0.2772) (0.0029) (0.00069) (for time period 1975 only, n = 81)</p>	0.61
Model V	$y^a = -17.29029 + 0.07586 * \text{Time} - 0.0001836 * \text{Time}^2 + 0.62866 * \text{Temperature} - 0.005733 * \text{Temperature}^2 + 0.000606 * \text{Flow}$ <p>(2.62)^b (0.009) (0.000022) (0.1187) (0.00113) (0.00029) (for time period 1974 and 1975 without outliers for 1975, n = 319)</p>	0.63

a - Where $y = \ln$ (Daily alewife impingement + 1.0).

b - The values in the parentheses are the standard errors of the coefficients.

Fig. III.23. Plot Showing the Transformed Data and the Regression Fits
Using Model III for 1974 and Model IV for 1975.

Fig. III.24. Plot Showing the Transformed Data and the Fitted Regressions Using Model III for 1974 and Model II for 1975.

Fig. III.25. Plot Showing the Transformed Data and the Regression Fit Using Model I Fitted to All Data Combined for Years 1974 and 1975.

Fig. III.26. Plot Showing the Transformed Data and the Regression Fit
Using Model V Fitted to Combined Data for 1974 and 1975.

The alewife impingement values for 1974 were compared with those for 1975 by fitting the quadratic function. This comparison demonstrates the effect of the absence of the net during the month of May, 1975. It also indicates that the alewife impingements during 1975 were very much the same as those in 1974 except during the month of May. The comparison implies that only a nominal increase in fish impingement occurred, indicating that even with two units in operation in 1975, the fish impingement rate at Zion did not increase in proportion to the doubled generating capacity and additional water intake. A cautionary theory, however, is that the fish abundance in the intake area for 1975 might have been low, thereby keeping total impingement for 1975 about the same as that for 1974.

To get an approximate estimate of fish abundance in the Zion intake area, trawl data were collected (as number of fish per minute of effort) for various depths of water. Figures III.27 and III.28 give the alewife and rainbow smelt results obtained for 1974 and 1975. From an examination of the catch-effort data for the 12- and 18-ft depths (these depths correspond to the location of Zion intake crib), it is observed that the abundance of alewives and rainbow smelt were considerably less in 1975 than in 1974. This may explain the near equal impingement in 1975 as compared to 1974, even though both units were in operation in 1975 but only one during 1974.

Critique, Conclusion and Recommendation

Fish impingement rates can be estimated by means of a function of time and plant-related environmental variables if concurrent observations of the variables are made. Daily observations for all the days of the year are not needed to make a high precision estimation. Adequate sampling frequency will vary from site to site because of differences in the site-specific, time-dependent fish impingement rate function. Once the deterministic part has been functionally represented and the residual (stochastic part) is obtained, a sample size determination can be made. The staff of Argonne is endeavoring to develop the full details on sampling designs, estimation methods and the computer software need to perform the analyses. The work is expected to be completed by the end of fiscal year 1977.

Fig. III.27. Average Number of Alewife Collected by Trawl per Minute of Effort in the Zion Zone from April 1974 to December 1975.

Fig. III.28. Average Number of Smelt Collected by Trawl per Minute of Effort in the Zion Zone from January 1974 to December 1975.

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APPENDIX Z-1

STATISTICAL COMPARISONS OF MONTH, DEPTH, AND STATION EFFECTS

ON THE DISTRIBUTION OF SELECTED GROUPS OF ORGANISMS

Table

Zooplankton, Statistical Analysis, 1972-1975	Z-1.1
Benthos and Phytoplankton, Statistical Analysis, 1972-1975	Z-1.2
Phytoplankton and Zooplankton Comparisons	Z-1.3
Benthos Comparisons	Z-1.4

Appendix Z-1.1. Statistical Analysis of Significance between Station Criteria for Zooplankton

	Total Zooplankton				Rotifera				Crustacea			
	72	73	74	75	72	73	74	75	72	73	74	75
	α	α	α	α	α	α	α	α	α	α	α	α
Month	.0001	.0001	.0001	.0001	.0001	.001	.0001	.0001	.0001	.0001	.0001	.0001
Depth	.0101	.0011	.0693	.0001	.0721	.0035	<u>.3653</u>	.0073	.0049	.1594	.0095	.0034
Station	<u>.6729</u>	<u>.2931</u>	.0165	<u>.5335</u>	<u>.2628</u>	<u>.2278</u>	<u>.2990</u>	<u>.3312</u>	<u>.5816</u>	<u>.5137</u>	.0068	<u>.5448</u>
Month $\times$ Depth	.0005	.0001	.0195	.0001	.0101	.0001	.0067	.0001	.0004	.0001	.0013	.0001
Month $\times$ Station	<u>.8060</u>	.0012	.1730	<u>.5723</u>	<u>.2931</u>	.0019	<u>.6219</u>	<u>.3751</u>	<u>.5584</u>	<u>.7825</u>	.0808	<u>.6019</u>
Depth $\times$ Station	<u>.4048</u>	<u>.3215</u>	.0282	<u>.3800</u>	<u>.5806</u>	<u>.6655</u>	<u>.4322</u>	<u>.3999</u>	<u>.3788</u>	<u>.5223</u>	.0422	<u>.3960</u>
	Copepoda				Cladocera							
	72	73	74	75	72	73	74	75				
	α	α	α	α	α	α	α	α				
Month	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001				
Depth	.0596	<u>.5069</u>	.0001	.0010	.0011	.0001	<u>.2883</u>	.0134				
Station	<u>.5858</u>	<u>.5807</u>	<u>.2144</u>	<u>.5273</u>	<u>.5591</u>	<u>.5965</u>	.0013	<u>.5877</u>				
Month $\times$ Depth	.0001	.0008	.0001	.0001	.0005	.0001	.0115	.0001				
Month $\times$ Station	<u>.7805</u>	<u>.8656</u>	<u>.8761</u>	<u>.6016</u>	<u>.7788</u>	<u>.9963</u>	.0053	<u>.6203</u>				
Depth $\times$ Station	<u>.9651</u>	<u>.3073</u>	.0368	<u>.3924</u>	<u>.3449</u>	<u>.6902</u>	<u>.3229</u>	<u>.5640</u>				

If $\alpha > .2000$, there is no significant difference (these figures are underlined).

Appendix Z-1.2. Statistical Analysis of Significance Between Zion Station
Criteria for Benthos and Phytoplankton.

	Total Benthos				<i>Pontoporeia</i>				Total Phytoplankton				Diatoms			
	72 <u>a</u>	73 <u>a</u>	74 <u>a</u>	75 <u>a</u>	72 <u>a</u>	73 <u>a</u>	74 <u>a</u>	75 <u>a</u>	72 <u>a</u>	73 <u>a</u>	74 <u>a</u>	75 <u>a</u>	72 <u>a</u>	73 <u>a</u>	74 <u>a</u>	75 <u>a</u>
Month	0.0001	.0001	.0001	.0005	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
Depth	0.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0002	.0001	.0001	.0001	.0001	.0001	.0001	.0001
Station	0.0001	.0001	.0001	.0054	<u>.3127</u>	.0399	.0001	.0099	.0284	<u>.3479</u>	<u>.5050</u>	<u>.6370</u>	.0004	.0870	<u>.3412</u>	<u>.6556</u>
Month * Depth	0.0487	.0070	<u>.4603</u>	<u>.8790</u>	.0001	.0182	.0001	.0004	.0080	.0001	.0001	.0001	.0001	.0001	.0001	.0001
Month * Station	0.1505	.1617	<u>.6160</u>	<u>.4666</u>	.0611	<u>.2035</u>	<u>.5372</u>	.1535	.0032	.0001	<u>.9746</u>	.0003	.0001	.0001	<u>.8990</u>	.0002
Depth * Station	0.0134	.0001	.0001	<u>.2288</u>	.0324	.0002	.0001	.0006	<u>.5017</u>	.0305	.1370	.0768	<u>.3633</u>	.0887	.0705	.0724

If $\alpha > .2000$, there is no significant difference (these figures are underlined).

Appendix Z-1.3. Phytoplankton and Zooplankton Comparisons at Zion Nuclear Power Station

Comparison of Annual Mean Density at Selected Depth Contours; Each Contour Includes Both Stress and Reference Areas	Comparison of Annual Mean Density at the 4 Designated Sampling Zones Perpendicular to the Shore, (NC,NZ,SZ,DR).	Selected Depth Comparisons in Meters at Specific Stations on Different Transects.*†	Selected Depth Comparisons in Meters at Specific Stations on the Same Transects.*†
3-9 m 3-18 9-18	DR-NC DR-SZ NZ-SZ SZ-NC NZ-DR	NZ(3)-NC(3) SZ(3)-DR(3) SZ(3)-NZ(3) NZ(9)-NC(9) SZ(9)-DR(9) SZ(9)-NZ(9) NZ(18)-NC(18) SZ(18)-DR(18) SZ(18)-NZ(18)	NC(3)-NC(9) NC(9)-NC(18) NC(3)-NC(18) NZ(3)-NZ(9) NZ(9)-NZ(18) SZ(3)-SZ(9) SZ(9)-SZ(18) SZ(3)-SZ(18) DR(3)-DR(9) DR(9)-DR(18) DR(3)-DR(18)

* DR = Dead River Control Zone
 NC = North Control Zone
 SZ = South Zion Zone
 NZ = North Zion Zone

† See Fig. III.18 in text.

Appendix Z-1.4. Benthos Comparisons at Zion Nuclear Power Station

Comparison of Annual Mean Density at Selected Depth Contours; Each Contour Includes Both Stress and Reference Areas.	Comparison of Annual Mean Density at the 4 Designated Sampling Zones Perpendicular to the Shore, (NC,NZ,SZ,DR). *†	Selected Depth Comparisons in Meters at Specific Stations on Different Transects.*†	Selected Depth Comparisons in Meters at Specific Stations on the Same Transects.*†
3-6 m	DR-NC	NZ(3)-NC(3)	NC(3)-NC(6)
3-9	DR-SZ	SZ(3)-DR(3)	NC(6)-NC(9)
3-12	NZ-SZ	SZ(3)-NZ(3)	NC(9)-NC(12)
6-9	SZ-NC	NZ(6)-NC(6)	NC(3)-NC(9)
6-12	NZ-DR	SZ(6)-DR(6)	(NC(6)-NC(12)
9-12		SZ(6)-NZ(6)	NC(3)-NC(12)
		NZ(9)-NC(9)	NZ(3)-NZ(6)
		SZ(9)-DR(9)	NZ(6)-NZ(9)
		SZ(9)-NZ(9)	NZ(9)-NZ(12)
		SZ(12)-NC(12)	NZ(3)-NZ(9)
		SZ(12)-DR(12)	NZ(6)-NZ(12)
		SZ(12)-NZ(12)	NZ(3)-NZ(12)
			SZ(3)-SZ(6)
			SZ(6)-SZ(9)
			SZ(9)-SZ(12)
			SZ(3)-SZ(9)
			SZ(6)-SZ(12)
			SZ(3)-SZ(12)
			DR(3)-DR(6)
			DR(6)-DR(9)
			DR(9)-DR(12)
			DR(3)-DR(9)
			DR(6)-DR(12)
			DR(3)-DR(12)

* DR = Dead River Control Zone
NC = North Control Zone
SZ = South Zion Zone
NZ = North Zion Zone

† *See Fig. III.19 in text.

APPENDIX Z-2
ARITHMETIC AND LOGARITHMIC PLOTS OF MONTHLY ABUNDANCES
OF AQUATIC BIOTA, 1972-1975

<u>Organism</u>	<u>Stations</u>	<u>Plots</u>
<u>Control Stations Only</u>		
Total Phytoplankton	18 & 20	1 & 1A
	18 & 22	2 & 2A
	20 & 22	3 & 3A
	30 & 20	4 & 4A
	32 & 22	5 & 5A
	28 & 30	6 & 6A
	28 & 32	7 & 7A
	30 & 32	8 & 8A
	28 & 18	9 & 9A
<u>Control vs. Stress Stations</u>		
Total Phytoplankton	10 & 18	10 & 10A
	12 & 20	11 & 11A
	5 & 28	12 & 12A
	7 & 30	13 & 13A
	70 & 22	14 & 14A
	9 & 32	15 & 15A
<u>Stress Stations Only</u>		
Total Phytoplankton	5 & 7	16 & 16A
	5 & 9	17 & 17A
<u>Control Stations Only</u>		
Diatom Phytoplankton	18 & 20	18 & 18A
	18 & 22	19 & 19A
	20 & 22	20 & 20A
	28 & 30	21 & 21A
	28 & 32	22 & 22A
	30 & 32	23 & 23A
<u>Control vs. Stress Stations</u>		
Diatom Phytoplankton	10 & 18	24 & 24A
	12 & 20	25 & 25A
	5 & 28	26 & 26A
	7 & 30	27 & 27A
	9 & 32	28 & 28A
	70 & 22	29 & 29A
<u>Stress Stations Only</u>		
Diatom Phytoplankton	5 & 7	30 & 30A
	5 & 9	31 & 31A
	7 & 9	32 & 32A

APPENDIX Z-2 Continued

<u>Organism</u>	<u>Stations</u>	<u>Plots</u>
<u>Control Stations Only</u>		
Cladocera Zooplankton	18 & 20	33 & 33A
	18 & 22	34 & 34A
	20 & 22	35 & 35A
	28 & 18	36 & 36A
	30 & 20	37 & 37A
	32 & 22	38 & 38A
	28 & 30	39 & 39A
	28 & 32	40 & 40A
	30 & 32	41 & 41A
<u>Control vs. Stress Stations</u>		
Cladocera Zooplankton	10 & 18	42 & 42A
	12 & 20	43 & 43A
	5 & 28	44 & 44A
	7 & 30	45 & 45A
	9 & 32	46 & 46A
	70 & 22	47 & 47A
<u>Stress Stations Only</u>		
Cladocera Zooplankton	5 & 7	48 & 48A
	5 & 9	49 & 49A
	7 & 9	50 & 50A
<u>Control Stations Only</u>		
Copepoda Zooplankton	18 & 20	51 & 51A
	18 & 22	52 & 52A
	20 & 22	53 & 53A
	28 & 18	54 & 54A
	30 & 20	55 & 55A
	32 & 22	56 & 56A
	28 & 30	57 & 57A
	28 & 32	58 & 58A
	30 & 32	59 & 59A
<u>Control vs. Stress Stations</u>		
Copepoda Zooplankton	10 & 18	60 & 60A
	12 & 20	61 & 61A
	5 & 28	62 & 62A
	7 & 30	63 & 63A
	9 & 32	64 & 64A
	70 & 22	65 & 65A
<u>Stress Stations Only</u>		
Copepoda Zooplankton	5 & 7	66 & 66A
	5 & 9	67 & 67A
	7 & 9	68 & 68A

APPENDIX Z-2 Continued

<u>Organism</u>	<u>Stations</u>	<u>Plots</u>
<u>Control Stations Only</u>		
Crustacea Zooplankton	28 & 18	69 & 69A
	30 & 20	70 & 70A
	32 & 22	71 & 71A
	28 & 30	72 & 72A
	28 & 32	73 & 73A
	30 & 32	74 & 74A
<u>Stress and Control Stations</u>		
Crustacea Zooplankton	10 & 18	75 & 75A
	12 & 20	76 & 76A
	5 & 28	77 & 77A
	7 & 30	78 & 78A
	9 & 32	79 & 79A
	70 & 22	80 & 80A
<u>Stress Stations Only</u>		
Crustacea Zooplankton	5 & 7	81 & 81A
	5 & 9	82 & 82A
	7 & 9	83 & 83A
<u>Control Stations Only</u>		
Rotifera Zooplankton	18 & 20	84 & 84A
	18 & 22	85 & 85A
	20 & 22	86 & 86A
	28 & 18	87 & 87A
	30 & 20	88 & 88A
	32 & 22	89 & 89A
<u>Control vs. Stress Stations</u>		
Rotifera Zooplankton	10 & 18	90 & 90A
	12 & 20	91 & 91A
	5 & 28	92 & 92A
	7 & 30	93 & 93A
	9 & 32	94 & 94A
	70 & 22	95 & 95A
<u>Stress Stations Compared</u>		
Rotifera Zooplankton	5 & 7	96 & 96A
	5 & 9	97 & 97A
	7 & 9	98 & 98A
<u>Control Stations Only</u>		
Total Zooplankton	18 & 22	99 & 99A
	20 & 22	100 & 100A
	18 & 20	101 & 101A
	28 & 18	102 & 102A
	30 & 20	103 & 103A
	32 & 22	104 & 104A

APPENDIX Z-2 Continued

<u>Organism</u>	<u>Stations</u>	<u>Plots</u>
<u>Control Stations Only</u>		
Total Zooplankton (cont.)	28 & 30	105 & 105A
	28 & 32	106 & 106A
	30 & 32	107 & 107A
<u>Control vs. Stress Stations</u>		
Total Zooplankton	10 & 18	108 & 108A
	12 & 20	109 & 109A
	5 & 28	110 & 110A
	7 & 30	111 & 111A
	9 & 32	112 & 112A
	70 & 22	113 & 113A
<u>Stress Stations Only</u>		
Total Zooplankton	5 & 7	114 & 114A
	5 & 9	115 & 115A
	7 & 9	116 & 116A
<u>Control Stations Only</u>		
Pontoporeia Benthos	19 & 20	117 & 117A
	19 & 21	118 & 118A
	19 & 22	119 & 119A
	18 & 28	120 & 120A
	20 & 30	121 & 121A
	32 & 22	122 & 122A
	29 & 30	123 & 123A
	29 & 31	124 & 124A
	29 & 32	125 & 125A
<u>Control vs. Stress Stations</u>		
Pontoporeia Benthos	10 & 18	126 & 126A
	19 & 11	127 & 127A
	2 & 29	128 & 128A
	12 & 20	129 & 129A
	5 & 28	130 & 130A
	21 & 13	131 & 131A
	70 & 22	132 & 132A
<u>Stress Stations Compared</u>		
Pontoporeia Benthos	2 & 4	133 & 133A
	2 & 7	134 & 134A
	2 & 9	135 & 135A
	11 & 12	136 & 136A
	11 & 13	137 & 137A
	11 & 70	138 & 138A
<u>Control Stations Only</u>		
Total Benthos	19 & 20	139 & 139A
	19 & 21	140 & 140A
	19 & 22	141 & 141A

APPENDIX Z-2 Continued

<u>Organism</u>	<u>Stations</u>	<u>Plots</u>
<u>Control Stations Only</u>		
Total Benthos (cont.)	18 & 28	142 & 142A
	20 & 30	143 & 143A
	32 & 22	144 & 144A
	29 & 30	145 & 145A
	29 & 31	146 & 146A
	29 & 32	147 & 147A
<u>Control vs. Stress Stations</u>		
Total Benthos	10 & 18	148 & 148A
	19 & 11	149 & 149A
	2 & 29	150 & 150A
	20 & 12	151 & 151A
	5 & 28	152 & 152A
	13 & 21	153 & 153A
	70 & 22	154 & 154A
<u>Stress Stations Compared</u>		
Total Benthos	2 & 4	155 & 155A
	2 & 7	156 & 156A
	2 & 9	157 & 157A
	11 & 12	158 & 158A
	11 & 13	159 & 159A
	11 & 70	160 & 160A

APPENDIX Z-3
SUMMARY TABLES OF DATA USED FOR THE
EVALUATION OF VARIOUS BIOTIC GROUPS

Z-3 Table

Total Phytoplankton and Diatoms, Station 5	1
Total Phytoplankton and Diatoms, Station 7	2
Total Phytoplankton and Diatoms, Station 9	3
Total Phytoplankton and Diatoms, Station 10	4
Total Phytoplankton and Diatoms, Station 12	5
Total Phytoplankton and Diatoms, Station 18	6
Total Phytoplankton and Diatoms, Station 20	7
Total Phytoplankton and Diatoms, Station 22	8
Total Phytoplankton and Diatoms, Station 28	9
Total Phytoplankton and Diatoms, Station 30	10
Total Phytoplankton and Diatoms, Station 32	11
Total Phytoplankton and Diatoms, Station 70	12
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 5	13
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 7	14
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 9	15
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 10	16
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 12	17
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 18	18
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 20	19
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 22	20
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 28	21
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 30	22
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 32	23
Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 70	24
Total Benthos and Pontoporeia affinis, Station 2	25
Total Benthos and Pontoporeia affinis, Station 4	26
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Table Z-3.1. Total Phytoplankton and Diatoms, Station 5

DATE	# OSSV	TOTAL PHYTOPLANKTON (#/BL)	DIATOMS (#/BL)
JAN 1972	1	1019	877
FEB 1972	1	4149	3984
MAR 1972	1	1744	1707
APR 1972	1	1816	1744
MAY 1972	1	4807	4656
JUN 1972	1	1870	1644
JUL 1972	1	1192	972
AUG 1972	1	688	583
SEP 1972	1	1397	477
OCT 1972	1	1276	639
NOV 1972	1	814	519
DEC 1972	1	1308	1171
JAN 1973	1	1351	1176
FEB 1973	1	1649	1569
MAR 1973	1	2859	2762
APR 1973	1	3974	3912
MAY 1973	1	7082	7028
JUN 1973	1	1762	1622
JUL 1973	1	4410	1182
AUG 1973	1	1138	1077
SEP 1973	1	1755	1622
OCT 1973	1	818	599
NOV 1973	1	1279	997
DEC 1973	1	2507	2290
JAN 1974	1	1759	1324
FEB 1974	1	4018	3930
MAR 1974	1	4457	4153
APR 1974	1	5807	5751
MAY 1974	1	4793	4643
JUN 1974	1	1642	1400
JUL 1974	1	3165	3039
AUG 1974	1	1673	1541
SEP 1974	1	719	347
OCT 1974	1	1256	1052
NOV 1974	1	1427	1282
DEC 1974	1	4496	3783
JAN 1975	1	2638	2529
FEB 1975	1	2920	2827
MAR 1975	1	14096	13826
APR 1975	1	2885	2535
MAY 1975	1	606	534
JUN 1975	1	1285	1152
JUL 1975	1	638	442
AUG 1975	1	1177	975
SEP 1975	1	783	654
OCT 1975	1	852	715
NOV 1975	1	1080	914
DEC 1975	1	3226	3018

Table Z-3.2. Total Phytoplankton and Diatoms, Station 7

DATE	# OBS	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
JAN 1972	1	1429	1314
FEB 1972	1	3960	3837
MAR 1972	1	1872	1778
APR 1972	1	3093	2987
MAY 1972	1	4006	3881
JUN 1972	1	1519	1350
JUL 1972	1	1316	1004
AUG 1972	1	602	411
SEP 1972	1	1070	264
OCT 1972	1	1168	914
NOV 1972	1	1021	702
DEC 1972	1	1064	859
JAN 1973	1	1122	1001
FEB 1973	1	2041	1981
MAR 1973	1	2062	1940
APR 1973	1	3355	3304
MAY 1973	1	4369	4307
JUN 1973	1	2024	1860
JUL 1973	1	2299	501
AUG 1973	1	323	221
SEP 1973	1	1086	1012
OCT 1973	1	753	499
NOV 1973	1	784	655
DEC 1973	1	2128	1858
JAN 1974	1	1814	1864
FEB 1974	1	3660	3477
MAR 1974	1	3388	3130
APR 1974	1	5089	4988
MAY 1974	1	3697	3503
JUN 1974	1	1336	1217
JUL 1974	1	2177	2014
AUG 1974	1	1334	1255
SEP 1974	1	381	196
OCT 1974	1	961	793
NOV 1974	1	949	818
DEC 1974	1	6845	5844
JAN 1975	1	1150	1059
FEB 1975	1	2434	2357
MAR 1975	1	5184	5098
APR 1975	1	1436	1266
MAY 1975	1	1237	1183
JUN 1975	1	777	640
JUL 1975	1	626	425
AUG 1975	1	1071	839
SEP 1975	1	1214	997
OCT 1975	1	1011	827
NOV 1975	1	862	627
DEC 1975	1	1614	1391

Table Z-3.3. Total Phytoplankton and Diatoms, Station 9

DATE	# OBS	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
JAN 1972	1	1292	1209
FEB 1972	1	1459	1337
MAR 1972	1	1920	1886
APR 1972	1	1090	1051
MAY 1972	1	1873	1689
JUN 1972	1	1516	1369
JUL 1972	1	966	543
AUG 1972	1	375	227
SEP 1972	1	1394	151
OCT 1972	1	824	639
NOV 1972	1	512	384
DEC 1972	1	912	814
JAN 1973	1	1087	998
FEB 1973	1	2053	2019
MAR 1973	1	2267	2185
APR 1973	1	3116	3028
MAY 1973	1	4619	4588
JUN 1973	1	1065	904
JUL 1973	1	2981	508
AUG 1973	1	225	129
SEP 1973	1	1281	1068
OCT 1973	1	611	471
NOV 1973	1	575	375
DEC 1973	1	1383	1227
JAN 1974	1	1609	1498
FEB 1974	1	2852	2677
MAR 1974	1	2357	2219
APR 1974	1	2792	2690
MAY 1974	1	3319	2930
JUN 1974	1	1007	882
JUL 1974	1	2140	2014
AUG 1974	1	1341	1260
SEP 1974	1	185	58
OCT 1974	1	787	646
NOV 1974	1	974	799
DEC 1974	1	5502	4886
JAN 1975	1	1580	1505
FEB 1975	1	2181	2133
MAR 1975	1	3719	3666
APR 1975	1	1227	1138
MAY 1975	1	953	824
JUN 1975	1	833	766
JUL 1975	1	403	292
AUG 1975	1	699	604
SEP 1975	1	528	397
OCT 1975	1	526	435
NOV 1975	1	647	477
DEC 1975	1	1086	995

Table Z-3.4. Total Phytoplankton and Diatoms, Station 10

DATE	# OBSN	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
JAN 1972	1	1236	1108
FEB 1972	1	1498	1246
MAR 1972	1	1650	1574
APR 1972	1	2495	2456
MAY 1972	1	7074	6969
JUN 1972	1	3177	3019
JUL 1972	1	924	819
AUG 1972	1	530	419
SEP 1972	1	1353	275
OCT 1972	1	1237	706
NOV 1972	1	1072	721
DEC 1972	1	954	828
JAN 1973	1	1179	1018
FEB 1973	1	2088	2029
MAR 1973	1	2152	2089
APR 1973	1	3978	3905
MAY 1973	1	7800	7707
JUN 1973	1	3240	3058
JUL 1973	1	5969	1788
AUG 1973	1	1286	1180
SEP 1973	1	1260	1157
OCT 1973	1	668	490
NOV 1973	1	1968	1723
DEC 1973	1	2232	2051
JAN 1974	1	1862	1321
FEB 1974	1	4468	4377
MAR 1974	1	4889	4508
APR 1974	1	5826	5772
MAY 1974	1	4996	4816
JUN 1974	1	1133	947
JUL 1974	1	2746	2545
AUG 1974	1	1698	1658
SEP 1974	1	681	393
OCT 1974	1	1174	1001
NOV 1974	1	1445	1280
DEC 1974	1	5739	5076
JAN 1975	1	3789	3662
FEB 1975	1	2541	2458
MAR 1975	1	14605	14426
APR 1975	1	2957	2732
MAY 1975	1	797	717
JUN 1975	1	1322	1215
JUL 1975	1	452	251
AUG 1975	1	1111	929
SEP 1975	1	1551	1389
OCT 1975	1	1017	897
NOV 1975	1	1346	1167
DEC 1975	1	2895	2679

Table Z-3.5. Total Phytoplankton and Diatoms, Station 12

DATE	# OBS	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
JAN 1972	1	1366	1250
FEB 1972	1	1366	1245
MAR 1972	1	1455	1391
APR 1972	1	2939	2905
MAY 1972	1	3317	3223
JUN 1972	1	1819	1433
JUL 1972	1	1037	713
AUG 1972	1	582	477
SEP 1972	1	1322	219
OCT 1972	1	1249	960
NOV 1972	1	1398	1067
DEC 1972	1	1162	859
JAN 1973	1	1302	1182
FEB 1973	1	1961	1939
MAR 1973	1	2794	2649
APR 1973	1	3563	3501
MAY 1973	1	4051	3999
JUN 1973	1	1545	1407
JUL 1973	1	2806	506
AUG 1973	1	277	164
SEP 1973	1	1340	1184
OCT 1973	1	565	417
NOV 1973	1	872	693
DEC 1973	1	1715	1449
JAN 1974	1	1727	1514
FEB 1974	1	3633	3479
MAR 1974	1	2722	2556
APR 1974	1	4843	4730
MAY 1974	1	3891	3757
JUN 1974	1	787	721
JUL 1974	1	2122	1957
AUG 1974	1	1160	1125
SEP 1974	1	465	243
OCT 1974	1	951	806
NOV 1974	1	957	867
DEC 1974	1	5669	4892
JAN 1975	1	1275	1201
FEB 1975	1	2721	2641
MAR 1975	1	5965	5882
APR 1975	1	1377	1167
MAY 1975	1	1048	944
JUN 1975	1	809	619
JUL 1975	1	472	339
AUG 1975	1	435	343
SEP 1975	1	1071	1014
OCT 1975	1	1078	939
NOV 1975	1	758	672
DEC 1975	1	1444	1295

Table Z-3.6. Total Phytoplankton and Diatoms, Station 18

DATE	# OBS	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
JAN 1972	1	1957	1829
FEB 1972	1	1745	1635
MAR 1972	1	1963	1927
APR 1972	1	2822	2772
MAY 1972	1	7616	7530
JUN 1972	1	3372	3109
JUL 1972	1	932	684
AUG 1972	1	590	454
SEP 1972	1	1147	391
OCT 1972	1	1326	738
NOV 1972	1	1328	859
DEC 1972	1	1055	871
JAN 1973	1	1143	1089
FEB 1973	1	1786	1741
MAR 1973	1	2573	2516
APR 1973	1	3849	3753
MAY 1973	1	8474	8410
JUN 1973	1	2160	2006
JUL 1973	1	3420	818
AUG 1973	1	1119	1048
SEP 1973	1	1031	975
OCT 1973	1	678	410
NOV 1973	1	1879	1654
DEC 1973	1	2195	1965
JAN 1974	1	1666	1260
FEB 1974	1	4651	4540
MAR 1974	1	3733	3405
APR 1974	1	4593	4545
MAY 1974	1	3721	3587
JUN 1974	1	1623	1508
JUL 1974	1	2251	2066
AUG 1974	1	1665	1593
SEP 1974	1	553	244
OCT 1974	1	1170	1023
NOV 1974	1	1351	1198
DEC 1974	1	5867	5062
JAN 1975	1	3789	3661
FEB 1975	1	2160	2080
MAR 1975	1	14227	14087
APR 1975	1	3186	2912
MAY 1975	1	855	785
JUN 1975	1	1633	1454
JUL 1975	1	522	329
AUG 1975	1	1131	905
SEP 1975	1	875	806
OCT 1975	1	847	747
NOV 1975	1	1365	1187
DEC 1975	1	2652	2309

Table Z-3.7. Total Phytoplankton and Diatoms, Station 20

DATE	# OBS	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
JAN 1972	1	1521	1341
FEB 1972	1	1716	1637
MAR 1972	1	1959	1899
APR 1972	1	1507	1447
MAY 1972	1	3539	3469
JUN 1972	1	4059	3954
JUL 1972	1	947	533
AUG 1972	1	442	311
SEP 1972	1	1237	395
OCT 1972	1	1394	885
NOV 1972	1	1455	1114
DEC 1972	1	1016	818
JAN 1973	1	1248	1057
FEB 1973	1	2007	1949
MAR 1973	1	2224	2118
APR 1973	1	3001	2939
MAY 1973	1	3925	3836
JUN 1973	1	1241	1019
JUL 1973	1	3528	630
AUG 1973	1	296	186
SEP 1973	1	1556	1420
OCT 1973	1	600	462
NOV 1973	1	1809	1522
DEC 1973	1	1770	1488
JAN 1974	1	1757	1423
FEB 1974	1	3991	3914
MAR 1974	1	3870	3597
APR 1974	1	4790	4675
MAY 1974	1	3313	3142
JUN 1974	1	1205	1130
JUL 1974	1	2654	2516
AUG 1974	1	1494	1452
SEP 1974	1	535	251
OCT 1974	1	981	764
NOV 1974	1	1028	865
DEC 1974	1	7253	6415
JAN 1975	1	1282	1199
FEB 1975	1	2382	2315
MAR 1975	1	6594	6483
APR 1975	1	1674	1432
MAY 1975	1	1147	1092
JUN 1975	1	606	494
JUL 1975	1	450	273
AUG 1975	1	799	672
SEP 1975	1	1174	1078
OCT 1975	1	961	837
NOV 1975	1	973	746
DEC 1975	1	1350	1260

Table Z-3.8. Total Phytoplankton and Diatoms, Station 22

DATE	# OBS	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
JAN 1972	1	1716	1605
FEB 1972	1	2199	2081
MAR 1972	1	1446	1377
APR 1972	1	2057	2022
MAY 1972	1	2966	2889
JUN 1972	1	3112	2802
JUL 1972	1	888	395
AUG 1972	1	500	339
SEP 1972	1	1581	158
OCT 1972	1	839	504
NOV 1972	1	952	798
DEC 1972	1	704	602
JAN 1973	1	1068	938
FEB 1973	1	1944	1918
MAR 1973	1	2713	2643
APR 1973	1	3104	3010
MAY 1973	1	3335	3278
JUN 1973	1	947	778
JUL 1973	1	2547	585
AUG 1973	1	248	134
SEP 1973	1	1268	1153
OCT 1973	1	587	439
NOV 1973	1	736	472
DEC 1973	1	1397	1160
JAN 1974	1	2107	1808
FEB 1974	1	2072	2718
MAR 1974	1	2767	2526
APR 1974	1	3415	3338
MAY 1974	1	3542	3244
JUN 1974	1	958	884
JUL 1974	1	2185	2072
AUG 1974	1	1017	972
SEP 1974	1	261	84
OCT 1974	1	745	648
NOV 1974	1	1203	893
DEC 1974	1	3561	5004
JAN 1975	1	1625	1552
FEB 1975	1	1652	1604
MAR 1975	1	2286	3195
APR 1975	1	1856	1744
MAY 1975	1	1226	1137
JUN 1975	1	558	480
JUL 1975	1	335	198
AUG 1975	1	610	495
SEP 1975	1	524	449
OCT 1975	1	556	440
NOV 1975	1	685	538
DEC 1975	1	1183	1114

Table Z-3.9. Total Phytoplankton and Diatoms, Station 28

DATE	# OBS	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
APR 1972	1	240	170
MAY 1972	1	2333	2249
JUN 1972	1	3425	1271
JUL 1972	1	1352	1183
AUG 1972	1	936	737
SEP 1972	1	1447	369
OCT 1972	1	1431	798
NOV 1972	1	972	671
DEC 1972	1	1115	923
JAN 1973	1	1147	1067
FEB 1973	1	1700	1602
MAR 1973	1	3621	3456
APR 1973	1	4488	4445
MAY 1973	1	10954	10875
JUN 1973	1	2273	2139
JUL 1973	1	4210	1217
AUG 1973	1	950	841
SEP 1973	1	1584	1529
OCT 1973	1	987	715
NOV 1973	1	1612	1175
DEC 1973	1	2787	2406
JAN 1974	1	2190	1576
FEB 1974	1	2997	2933
MAR 1974	1	3988	3765
APR 1974	1	4592	4547
MAY 1974	1	5244	5043
JUN 1974	1	1703	1517
JUL 1974	1	3010	2799
AUG 1974	1	1810	1760
SEP 1974	1	783	532
OCT 1974	1	1582	1335
NOV 1974	1	2166	1698
DEC 1974	1	6242	5428
JAN 1975	1	3987	3886
FEB 1975	1	3881	3795
MAR 1975	1	11884	11796
APR 1975	1	3301	3032
MAY 1975	1	724	633
JUN 1975	1	2046	1875
JUL 1975	1	944	653
AUG 1975	1	1176	1010
SEP 1975	1	1253	1165
OCT 1975	1	597	493
NOV 1975	1	1340	1131
DEC 1975	1	3118	2841

Table Z-3.10. Total Phytoplankton and Diatoms, Station 30

DATE	# OBSN	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
APR 1972	1	227	175
MAY 1972	1	1732	1679
JUN 1972	1	2961	1854
JUL 1972	1	1493	1329
AUG 1972	1	591	415
SEP 1972	1	883	338
OCT 1972	1	952	724
NOV 1972	1	1283	1006
DEC 1972	1	1124	934
JAN 1973	1	1285	1142
FEB 1973	1	1406	1374
MAR 1973	1	2811	2743
APR 1973	1	3627	3596
MAY 1973	1	6302	6236
JUN 1973	1	1625	1505
JUL 1973	1	2296	561
AUG 1973	1	289	239
SEP 1973	1	957	912
OCT 1973	1	796	588
NOV 1973	1	1301	1054
DEC 1973	1	1732	1390
JAN 1974	1	1819	1455
FEB 1974	1	3535	3452
MAR 1974	1	3852	3484
APR 1974	1	4392	4266
MAY 1974	1	3464	3124
JUN 1974	1	996	860
JUL 1974	1	1673	1554
AUG 1974	1	1529	1486
SEP 1974	1	321	86
OCT 1974	1	1061	795
NOV 1974	1	1050	892
DEC 1974	1	5688	5163
JAN 1975	1	1967	1881
FEB 1975	1	2454	2401
MAR 1975	1	5452	5371
APR 1975	1	1448	1245
MAY 1975	1	1003	910
JUN 1975	1	790	737
JUL 1975	1	485	364
AUG 1975	1	573	534
SEP 1975	1	1305	1211
OCT 1975	1	1029	899
NOV 1975	1	871	674
DEC 1975	1	1652	1361

Table Z-3.11. Total Phytoplankton and Diatoms, Station 32

DATE	# OBSN	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
APR 1972	1	59	45
MAY 1972	1	3338	1317
JUN 1972	1	2650	1289
JUL 1972	1	522	406
AUG 1972	1	578	482
SEP 1972	1	1157	158
OCT 1972	1	661	524
NOV 1972	1	448	350
DEC 1972	1	1045	861
JAN 1973	1	830	690
FEB 1973	1	1284	1274
MAR 1973	1	1387	1334
APR 1973	1	2930	2864
MAY 1973	1	6011	5975
JUN 1973	1	839	739
JUL 1973	1	1320	418
AUG 1973	1	175	101
SEP 1973	1	931	726
OCT 1973	1	590	414
NOV 1973	1	370	263
DEC 1973	1	1008	914
JAN 1974	1	1619	1414
FEB 1974	1	2594	2493
MAR 1974	1	2187	2095
APR 1974	1	3077	3030
MAY 1974	1	2015	1767
JUN 1974	1	1066	968
JUL 1974	1	2149	2014
AUG 1974	1	937	835
SEP 1974	1	251	93
OCT 1974	1	893	646
NOV 1974	1	1155	969
DEC 1974	1	1883	2668
JAN 1975	1	1418	1341
FEB 1975	1	1670	1645
MAR 1975	1	1753	1722
APR 1975	1	1257	1187
MAY 1975	1	733	668
JUN 1975	1	472	433
JUL 1975	1	226	165
AUG 1975	1	430	346
SEP 1975	1	483	439
OCT 1975	1	613	462
NOV 1975	1	456	371
DEC 1975	1	915	842

Table Z-3.12. Total Phytoplankton and Diatoms, Station 70

DATE	# OBS	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
JAN 1972	1	1496	1381
FEB 1972	1	1563	1454
MAR 1972	1	2098	1938
APR 1972	1	1155	1079
MAY 1972	1	1699	1597
JUN 1972	1	1622	1315
JUL 1972	1	867	421
AUG 1972	1	461	349
SEP 1972	1	1114	303
OCT 1972	1	746	573
NOV 1972	1	550	415
DEC 1972	1	853	719
JAN 1973	1	1119	971
FEB 1973	1	1226	1180
MAR 1973	1	2426	2342
APR 1973	1	3474	3420
MAY 1973	1	5109	5017
JUN 1973	1	1154	1011
JUL 1973	1	2806	478
AUG 1973	1	232	123
SEP 1973	1	1247	1058
OCT 1973	1	587	428
NOV 1973	1	572	421
DEC 1973	1	1384	1256
JAN 1974	1	1665	1498
FEB 1974	1	2711	2581
MAR 1974	1	2491	2307
APR 1974	1	2768	2703
MAY 1974	1	2903	2614
JUN 1974	1	962	870
JUL 1974	1	2483	2369
AUG 1974	1	1095	1038
SEP 1974	1	198	80
OCT 1974	1	752	549
NOV 1974	1	1147	887
DEC 1974	1	5234	4810
JAN 1975	1	1490	1361
FEB 1975	1	1708	1666
MAR 1975	1	3449	1288
APR 1975	1	1224	1110
MAY 1975	1	781	690
JUN 1975	1	892	844
JUL 1975	1	462	276
AUG 1975	1	498	427
SEP 1975	1	324	285
OCT 1975	1	576	476
NOV 1975	1	615	514
DEC 1975	1	1160	1061

Table Z-3.13. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 5

DATE	# OBS	TOTAL ZOOPLANKTON (#/M**3)	CRUSTACEA (#/M**3)	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
JAN 1972	1	5765	4951	4908	43	816
FEB 1972	1	4181	3057	3051	6	1124
MAR 1972	1	1500	1467	1467	0	33
APR 1972	1	780	762	762	0	18
MAY 1972	1	9502	6716	6449	267	2735
JUN 1972	1	53919	8687	8514	173	45232
JUL 1972	1	19911	3575	2521	1054	16336
AUG 1972	1	119215	96202	52629	43573	23013
SEP 1972	1	177353	162105	51285	110820	15248
OCT 1972	1	189220	188159	37846	150313	1061
NOV 1972	1	32825	32550	15449	17101	275
DEC 1972	1	19368	18739	16792	1947	629
JAN 1973	1	3067	2615	2458	157	451
FEB 1973	1	8214	7786	7783	3	428
MAR 1973	1	592	530	526	4	62
APR 1973	1	9455	4616	4419	197	4839
MAY 1973	1	17302	6431	5903	528	10862
JUN 1973	1	18140	11844	9362	2482	6296
JUL 1973	1	43212	13398	7150	6248	29814
AUG 1973	1	52401	21599	4018	17581	30802
SEP 1973	1	112216	106507	103252	3255	5702
OCT 1973	1	37116	35487	12495	22992	1629
NOV 1973	1	32707	31420	17910	13510	1287
DEC 1973	1	8605	8445	7383	1062	160
JAN 1974	1	13702	13331	13207	124	371
FEB 1974	1	12742	12653	12643	10	89
MAR 1974	1	3082	3000	2990	10	32
APR 1974	1	3840	3704	3701	3	136
MAY 1974	1	17145	6503	6442	61	10642
JUN 1974	1	54621	9256	8851	405	45365
JUL 1974	1	43963	15914	11958	3956	28049
AUG 1974	1	96802	66143	50427	15716	30659
SEP 1974	1	37727	24700	18775	5925	13027
OCT 1974	1	67915	62665	30980	31685	5250
NOV 1974	1	28616	25456	16908	8548	3160
DEC 1974	1	51128	40939	38618	2321	10189
JAN 1975	1	31653	23486	22338	148	8147
FEB 1975	1	10454	7816	7801	15	2638
MAR 1975	1	22305	17919	17875	44	4386
APR 1975	1	1072	1043	1040	3	29
MAY 1975	1	7374	6937	6627	310	437
JUN 1975	1	7728	3131	3098	33	4597
JUL 1975	1	94011	29020	6774	22246	64991
AUG 1975	1	96974	46376	35501	10875	50598
SEP 1975	1	86004	75453	44152	31301	10551
OCT 1975	1	54756	42072	36208	25864	3692
NOV 1975	1	24482	23275	9827	13448	1207
DEC 1975	1	15765	15362	13612	1750	403

Table Z-3.14. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 7

DATE	# OBS	TOTAL ZOOPLANKTON (#/M**3)	CRUSTACEA (#/M**3)	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
JAN 1972	1	10222	9231	9158	73	991
FEB 1972	1	4476	3233	3230	3	1243
MAR 1972	1	3576	3561	3561	0	15
APR 1972	1	2158	2150	2150	0	8
MAY 1972	1	3001	2411	2205	206	589
JUN 1972	1	11191	5038	4888	150	6153
JUL 1972	1	69658	22069	17588	4481	47589
AUG 1972	1	225414	209616	54839	154777	15798
SEP 1972	1	126071	108466	33406	75060	17605
OCT 1972	1	67280	66808	34661	32147	472
NOV 1972	1	43978	39262	31076	8186	4716
DEC 1972	1	5019	4213	3682	531	806
JAN 1973	1	5034	4649	4625	24	385
FEB 1973	1	3770	3532	3522	10	248
MAR 1973	1	1026	927	927	0	99
APR 1973	1	11877	9793	9675	118	2202
MAY 1973	1	8331	5821	5728	93	2516
JUN 1973	1	29609	25384	24733	651	4225
JUL 1973	1	246753	171025	44172	126853	75728
AUG 1973	1	91659	32290	6334	25952	59369
SEP 1973	1	38073	36819	35811	1008	1254
OCT 1973	1	32345	31247	23572	7675	1098
NOV 1973	1	40006	38485	20487	17998	1521
DEC 1973	1	22031	21107	18246	2861	924
JAN 1974	1	3111	2969	2958	11	142
FEB 1974	1	6607	6547	6542	5	60
MAR 1974	1	4133	4120	4120	0	13
APR 1974	1	2452	2354	2353	1	98
MAY 1974	1	22817	16950	16875	75	5867
JUN 1974	1	49206	21228	20903	325	27978
JUL 1974	1	13341	9036	8392	644	4305
AUG 1974	1	87248	67854	32349	15505	19384
SEP 1974	1	40767	29683	11288	8401	11084
OCT 1974	1	59043	53617	36285	17332	5426
NOV 1974	1	18503	16389	15171	1218	2114
DEC 1974	1	41267	25930	22893	3037	15337
JAN 1975	1	12273	8898	8850	48	3375
FEB 1975	1	15918	13906	13847	59	2012
MAR 1975	1	16034	14776	14776	0	1288
APR 1975	1	1109	1092	1090	2	16
MAY 1975	1	7661	1194	1026	168	1294
JUN 1975	1	13437	4800	4567	233	8637
JUL 1975	1	175071	98441	23737	74704	76630
AUG 1975	1	2087482	1106616	629152	477464	980866
SEP 1975	1	62620	52296	34402	17894	10324
OCT 1975	1	51558	48195	33220	14975	3363
NOV 1975	1	27426	26648	13346	13302	778
DEC 1975	1	13452	12846	11419	1427	606

Table Z-3.15. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 9

DATE	# OBS#	TOTAL ZOOPLANKTON (#/M ³)	CRUSTACEA (#/M ³)	COPEPODA (#/M ³)	CLADOCERA (#/M ³)	ROTIFERA (#/M ³)
JAN 1972	1	3418	2945	2900	37	473
FEB 1972	1	3438	2953	2951	2	485
MAR 1972	1	2764	2751	2751	0	13
APR 1972	1	3449	3445	3445	0	4
MAY 1972	1	8441	7897	7225	172	542
JUN 1972	1	20174	11215	11097	118	8999
JUL 1972	1	111717	55105	34827	20273	5612
AUG 1972	1	170868	156873	38356	118522	13990
SEP 1972	1	49666	48094	27461	20633	1572
OCT 1972	1	117163	112395	72572	39823	4768
NOV 1972	1	25910	25202	22224	2978	708
DEC 1972	1	12576	11609	11077	532	967
JAN 1973	1	8740	8314	8255	59	426
FEB 1973	1	3594	3576	3576	0	18
MAR 1973	1	1734	1613	1613	0	120
APR 1973	1	15230	11983	11889	94	3247
MAY 1973	1	15540	14119	14050	69	1421
JUN 1973	1	39537	37739	36962	777	2575
JUL 1973	1	106105	64016	50773	13243	42089
AUG 1973	1	141313	66818	19729	47089	74495
SEP 1973	1	24807	23553	21606	1947	1254
OCT 1973	1	33934	31952	26584	5368	1982
NOV 1973	1	39359	37981	25371	12610	1378
DEC 1973	1	23187	22862	21697	1165	325
JAN 1974	1	5150	5068	5050	18	82
FEB 1974	1	4860	4792	4787	5	68
MAR 1974	1	4211	4193	4193	0	18
APR 1974	1	4906	4682	4682	0	224
MAY 1974	1	21780	16625	16537	88	5155
JUN 1974	1	41773	22607	22534	73	19172
JUL 1974	1	32772	20512	15723	4789	12260
AUG 1974	1	122002	94016	63879	30137	27986
SEP 1974	1	74309	68529	54852	12677	5780
OCT 1974	1	101070	90222	62722	27500	10848
NOV 1974	1	30688	26768	24026	2742	3920
DEC 1974	1	37985	20491	19192	1299	17494
JAN 1975	1	10072	9166	9146	20	906
FEB 1975	1	9757	8464	8459	5	1293
MAR 1975	1	5488	5126	5126	0	362
APR 1975	1	4602	4589	4504	5	13
MAY 1975	1	4423	4253	4028	225	170
JUN 1975	1	28909	10415	9695	720	18494
JUL 1975	1	119345	76629	14265	62364	42716
AUG 1975	1	205866	161412	74123	87289	84454
SEP 1975	1	59771	52597	39398	13199	7174
OCT 1975	1	30853	29535	22265	7270	1318
NOV 1975	1	8382	7260	6428	832	5122
DEC 1975	1	4036	3904	3871	33	132

Table Z-3.16. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 10

DATE	# OBS	TOTAL ZOOPLANKTON (#/M**3)	CRUSTACEA (#/M**3)	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
JAN 1972	1	15847	14718	14688	34	1129
FEB 1972	1	9162	7347	7336	11	1815
MAR 1972	1	1734	1723	1721	2	11
APR 1972	1	1243	1243	1243	0	0
MAY 1972	1	5621	3885	3814	471	1735
JUN 1972	1	69147	8491	7750	741	60656
JUL 1972	1	10941	2358	1192	1166	8583
AUG 1972	1	432195	384331	104926	279405	47864
SEP 1972	1	87246	76459	42975	33484	10787
OCT 1972	1	186273	185565	33483	152082	708
NOV 1972	1	40982	40275	12545	27730	707
DEC 1972	1	6953	6558	5195	1363	395
JAN 1973	1	3112	2623	2476	147	458
FEB 1973	1	5403	5055	5055	0	348
MAR 1973	1	524	496	492	4	27
APR 1973	1	8309	5479	5401	78	2830
MAY 1973	1	15158	5203	4641	562	9977
JUN 1973	1	17348	8523	6878	1645	8825
JUL 1973	1	90818	44525	15970	28555	46293
AUG 1973	1	45537	23472	5324	18148	22115
SEP 1973	1	62559	59586	57910	1676	2973
OCT 1973	1	45075	43549	9534	34015	1526
NOV 1973	1	61996	58688	19207	39081	3308
DEC 1973	1	24322	24250	20904	3346	72
JAN 1974	1	9337	8877	8797	80	460
FEB 1974	1	18222	18167	18167	0	55
MAR 1974	1	2479	2431	2429	2	48
APR 1974	1	2748	2674	2672	2	74
MAY 1974	1	14436	6888	6843	45	7548
JUN 1974	1	28237	12228	11896	332	16009
JUL 1974	1	12411	5109	3653	1456	7302
AUG 1974	1	26493	18167	12633	5534	8326
SEP 1974	1	79421	44143	30113	19056	31052
OCT 1974	1	73131	69296	37758	31538	3835
NOV 1974	1	23629	20434	11567	8867	3195
DEC 1974	1	47157	35992	33537	2455	11165
JAN 1975	1	49210	25220	24580	650	14046
FEB 1975	1	13068	10865	10836	29	2203
MAR 1975	1	7860	3970	3470	8	3892
APR 1975	1	558	525	523	2	32
MAY 1975	1	7088	5719	5218	501	1369
JUN 1975	1	12916	10718	10315	403	2198
JUL 1975	1	335625	230015	13794	216221	105610
AUG 1975	1	150201	64303	43149	21154	85988
SEP 1975	1	86773	69501	36313	33188	17272
OCT 1975	1	115364	108291	36208	72083	7073
NOV 1975	1	29230	27123	12769	14354	2107
DEC 1975	1	16971	16273	13855	2418	698

Table Z-3.17. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 12

DATE	# OBS	TOTAL ZOOPLANKTON (#/M**3)	CRUSTACEA (#/M**3)	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
JAN 1972	1	8981	7212	7119	93	1769
FEB 1972	1	3810	2858	2855	3	952
MAR 1972	1	2432	2427	2427	0	5
APR 1972	1	857	845	845	0	12
MAY 1972	1	4369	3454	3128	326	914
JUN 1972	1	26869	8394	8186	208	18470
JUL 1972	1	52959	25490	17213	8277	27469
AUG 1972	1	215206	185891	58162	127729	29395
SEP 1972	1	60958	47793	19260	28533	13165
OCT 1972	1	73176	72390	47632	24758	786
NOV 1972	1	54350	43975	32646	11329	10375
DEC 1972	1	6028	5394	4818	576	634
JAN 1973	1	4330	4068	4037	31	262
FEB 1973	1	4045	3746	3744	2	299
MAR 1973	1	1068	959	958	1	109
APR 1973	1	12605	9888	9802	86	2803
MAY 1973	1	8943	6529	6454	75	2414
JUN 1973	1	37825	34631	31051	3580	3194
JUL 1973	1	356190	186939	65391	121548	104808
AUG 1973	1	102736	31045	4442	26603	49635
SEP 1973	1	74859	68256	61084	7172	2162
OCT 1973	1	35203	31768	26269	5499	773
NOV 1973	1	54920	47787	22448	25339	2359
DEC 1973	1	29439	22653	20065	2588	914
JAN 1974	1	3073	2426	2413	13	93
FEB 1974	1	8167	6805	6805	0	44
MAR 1974	1	3594	2959	2956	3	31
APR 1974	1	4229	3726	3725	1	234
MAY 1974	1	25791	14132	14017	115	10120
JUN 1974	1	54606	24051	23771	280	27736
JUL 1974	1	15328	9506	8243	1263	5822
AUG 1974	1	151796	125446	82030	43416	26350
SEP 1974	1	53442	43507	32334	11173	9935
OCT 1974	1	70976	65403	48573	16830	5573
NOV 1974	1	16910	14532	13766	766	2378
DEC 1974	1	39047	25772	23404	2368	13275
JAN 1975	1	10844	8154	8082	72	2690
FEB 1975	1	16335	13585	13542	43	2750
MAR 1975	1	8207	6935	6930	5	1272
APR 1975	1	934	925	924	1	9
MAY 1975	1	5308	4676	4508	168	632
JUN 1975	1	28150	15664	15271	393	12486
JUL 1975	1	101744	45233	15131	30102	56511
AUG 1975	1	1602551	1137662	492005	645657	464889
SEP 1975	1	73254	64897	42523	22374	8157
OCT 1975	1	44007	40939	33069	7870	3068
NOV 1975	1	19042	17607	10079	7528	1435
DEC 1975	1	12992	12244	11359	905	728

Table Z-3.18. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 18

DATE	# OBS	TOTAL ZOOPLANKTON (#/M**3)	CRUSTACEA (#/M**3)	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
JAN 1972	1	2684	2531	2508	23	153
FEB 1972	1	1483	1239	1237	2	244
MAR 1972	1	1017	1017	1017	0	0
APR 1972	1	1591	1561	1559	2	30
MAY 1972	1	6772	4744	4214	530	2027
JUN 1972	1	42963	5119	4843	276	37844
JUL 1972	1	40481	11514	8529	2985	28967
AUG 1972	1	324157	305589	61235	244354	18568
SEP 1972	1	189440	172463	95259	77204	16977
OCT 1972	1	301573	299922	53291	246631	1651
NOV 1972	1	31455	29244	15154	14090	2211
DEC 1972	1	12526	11974	9051	2123	552
JAN 1973	1	3293	2571	2517	54	722
FEB 1973	1	4239	4032	4032	0	207
MAR 1973	1	676	620	617	3	55
APR 1973	1	1249	1148	3786	368	2101
MAY 1973	1	22156	4305	3838	467	17031
JUN 1973	1	19403	12066	6767	5299	7337
JUL 1973	1	59446	52115	9786	42329	7331
AUG 1973	1	58775	23289	5109	18100	35486
SEP 1973	1	35065	32281	31361	920	2784
OCT 1973	1	26477	25565	9755	15810	912
NOV 1973	1	28527	27460	13188	14272	1067
DEC 1973	1	31486	31350	25910	5440	136
JAN 1974	1	8189	7897	7791	106	292
FEB 1974	1	10902	10808	10803	5	94
MAR 1974	1	1281	1263	1261	2	18
APR 1974	1	1675	1580	1526	2	147
MAY 1974	1	13173	7332	7288	44	6041
JUN 1974	1	62988	23004	21840	1184	42988
JUL 1974	1	8841	14066	13390	676	4775
AUG 1974	1	46425	20873	22194	4679	15552
SEP 1974	1	60116	40264	24230	16034	19852
OCT 1974	1	42920	38732	19602	19130	4188
NOV 1974	1	24430	21645	12884	8761	2785
DEC 1974	1	43172	29334	27720	1614	13838
JAN 1975	1	53719	37345	36680	665	16374
FEB 1975	1	1426	620	619	1	806
MAR 1975	1	16147	12410	12386	24	1737
APR 1975	1	744	717	712	5	28
MAY 1975	1	2131	1606	1537	69	525
JUN 1975	1	8655	6950	5666	1284	1705
JUL 1975	1	63328	28066	8110	19948	35262
AUG 1975	1	33951	18203	16628	1575	15748
SEP 1975	1	285540	251704	44903	104801	33836
OCT 1975	1	23785	18590	11030	7560	5195
NOV 1975	1	12061	10668	5121	5547	1393
DEC 1975	1	13975	13316	11251	2065	659

Table Z-3.19. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 20

DATE	# OBS	TOTAL ZOOPLANKTON (#/M**3)	CRUSTACEA (#/M**3)	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
JAN 1972	1	3504	3421	3340	81	83
FEB 1972	1	2583	2426	2424	2	157
MAR 1972	1	1564	1554	1554	0	10
APR 1972	1	2183	2154	2153	1	29
MAY 1972	1	7450	5009	4656	353	2440
JUN 1972	1	12316	3651	3555	96	8665
JUL 1972	1	106515	49974	33201	16773	56541
AUG 1972	1	162695	140217	64091	76126	22478
SEP 1972	1	85753	73413	19180	54233	12340
OCT 1972	1	83941	82998	41027	41971	943
NOV 1972	1	51060	37384	30147	7237	13676
DEC 1972	1	8066	8300	7929	371	403
JAN 1973	1	6040	5587	5555	32	453
FEB 1973	1	4747	4356	4354	2	391
MAR 1973	1	1356	1185	1185	0	171
APR 1973	1	15906	13016	13664	152	2242
MAY 1973	1	10291	6291	6146	145	4000
JUN 1973	1	49687	41618	37688	3930	8069
JUL 1973	1	245140	141866	82409	59457	103274
AUG 1973	1	78107	46665	3289	43376	30742
SEP 1973	1	74760	72410	67815	4595	2260
OCT 1973	1	41553	40934	32767	8167	619
NOV 1973	1	29503	28281	13601	14680	1222
DEC 1973	1	19932	18732	15585	3147	1200
JAN 1974	1	6012	5836	5809	27	176
FEB 1974	1	10872	10738	10738	0	134
MAR 1974	1	3978	3957	3957	0	21
APR 1974	1	3103	2857	2856	1	246
MAY 1974	1	21591	13180	13126	54	8411
JUN 1974	1	60620	30433	30182	251	30187
JUL 1974	1	32616	19272	15165	4107	13344
AUG 1974	1	81798	59780	49994	9786	22018
SEP 1974	1	77669	61605	37965	23640	16064
OCT 1974	1	54413	47071	35929	11142	7342
NOV 1974	1	20321	17843	14502	3341	2478
DEC 1974	1	40137	25587	22973	2614	14550
JAN 1975	1	12205	8861	8801	60	3344
FEB 1975	1	15090	12358	12321	29	2780
MAR 1975	1	9628	7485	7480	5	2143
APR 1975	1	871	854	851	3	16
MAY 1975	1	5748	5085	4945	140	663
JUN 1975	1	14074	8189	7947	242	5885
JUL 1975	1	177273	119819	20082	99737	57454
AUG 1975	1	3225536	3173937	1587891	1586046	51599
SEP 1975	1	80930	71184	48810	22374	8357
OCT 1975	1	65672	62663	33778	28885	3009
NOV 1975	1	21065	19571	14069	5502	1494
DEC 1975	1	7891	7192	6704	398	699

Table Z-3.20. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 22

DATE	# OBSV	TOTAL ZOOPLANKTON (#/M ³)	CRUSTACEA (#/M ³)	COPEPODA (#/M ³)	CLADOCERA (#/M ³)	ROTIFERA (#/M ³)
JAN 1972	1	1867	1782	1763	19	85
FEB 1972	1	3837	3614	3611	3	223
MAR 1972	1	3030	3030	3030	0	0
APR 1972	1	3462	3424	3424	0	38
MAY 1972	1	5874	5176	4838	336	697
JUN 1972	1	71996	43576	43512	64	28420
JUL 1972	1	103983	56826	41971	14855	47157
AUG 1972	1	109408	102596	46844	55752	6812
SEP 1972	1	56093	54835	27292	27543	1258
OCT 1972	1	76160	73959	50851	23108	2201
NOV 1972	1	56762	44312	35633	8679	12450
DEC 1972	1	8993	8124	7820	504	671
JAN 1973	1	10117	9701	9629	72	414
FEB 1973	1	3900	3876	3826	0	74
MAR 1973	1	3023	2797	2797	0	226
APR 1973	1	12594	10619	10490	129	1975
MAY 1973	1	11157	9286	9266	20	1871
JUN 1973	1	49801	45802	43945	1857	5856
JUL 1973	1	117108	65352	47786	17566	51756
AUG 1973	1	77160	54883	28379	26504	22269
SEP 1973	1	44753	42853	38176	4659	1918
OCT 1973	1	38141	35982	26806	9176	2159
NOV 1973	1	27356	26119	16235	9884	1239
DEC 1973	1	22039	20844	19266	1578	1195
JAN 1974	1	6496	6315	6285	30	181
FEB 1974	1	7123	7016	7016	0	94
MAR 1974	1	3772	3739	3739	0	33
APR 1974	1	4063	3781	3977	4	282
MAY 1974	1	25859	17503	17366	137	8356
JUN 1974	1	41917	22340	22281	59	19577
JUL 1974	1	30875	16229	14743	2486	14646
AUG 1974	1	139619	93669	83706	9963	45950
SEP 1974	1	99386	88333	69212	18981	11053
OCT 1974	1	106934	95909	76191	19718	11025
NOV 1974	1	37849	33323	26587	6736	4526
DEC 1974	1	40518	18352	17156	1196	22166
JAN 1975	1	13018	10864	10839	25	2154
FEB 1975	1	10278	8356	8341	15	1922
MAR 1975	1	6703	6332	6332	0	371
APR 1975	1	2442	2423	2419	4	19
MAY 1975	1	6881	5935	5614	321	946
JUN 1975	1	30201	18018	17577	441	12183
JUL 1975	1	77143	40163	25505	14658	36980
AUG 1975	1	136162	80803	45535	35268	55360
SEP 1975	1	60130	50860	39822	11038	9270
OCT 1975	1	37142	34723	28081	6642	2419
NOV 1975	1	11763	10480	9212	1268	1283
DEC 1975	1	4374	4077	4035	42	297

Table Z-3.21. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 28

DATE	# OBSV	TOTAL ZOOPLANKTON (#/M**3)	CRUSTACEA (#/M**3)	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
APR 1972	1	2138	2138	2138	0	0
MAY 1972	1	6392	5835	5208	187	957
JUN 1972	1	6692	2356	2258	98	8036
JUL 1972	1	62360	17404	12751	4653	44956
AUG 1972	1	124576	95574	55097	40477	29002
SEP 1972	1	167265	136318	48780	87538	30947
OCT 1972	1	159393	157506	28531	128975	1887
NOV 1972	1	38670	38576	19101	19475	94
DEC 1972	1	12582	12287	11367	920	295
JAN 1973	1	884	739	718	21	145
FEB 1973	1	5157	5116	5116	0	41
MAR 1973	1	907	899	897	2	7
APR 1973	1	18291	10346	10199	147	7945
MAY 1973	1	8587	2291	2219	72	6296
JUN 1973	1	30897	18667	15510	2157	12230
JUL 1973	1	52631	28196	10728	17468	24435
AUG 1973	1	35571	21816	3911	17905	13755
SEP 1973	1	296481	281979	267972	14007	14502
OCT 1973	1	47211	44213	10228	33985	2998
NOV 1973	1	33387	32119	12441	19678	1268
DEC 1973	1	22451	22291	20710	1581	160
JAN 1974	1	26834	26374	26304	70	460
FEB 1974	1	7826	7806	7791	15	20
MAR 1974	1	6014	5998	5998	0	16
APR 1974	1	2112	2091	2089	2	21
MAY 1974	1	21676	9381	9273	108	12295
JUN 1974	1	46373	5958	5227	731	40415
JUL 1974	1	40636	16349	12686	3663	24287
AUG 1974	1	163005	132660	93022	39638	30345
SEP 1974	1	49962	32100	18009	14091	17862
OCT 1974	1	173220	163698	61866	101832	9522
NOV 1974	1	72812	66729	36618	30111	6083
DEC 1974	1	49782	37999	34705	3294	11783
JAN 1975	1	74816	52709	51764	945	22107
FEB 1975	1	4960	99296	99223	73	4960
MAR 1975	1	21290	19610	19610	0	1680
APR 1975	1	743	717	715	2	26
MAY 1975	1	8034	5647	3971	1676	2387
JUN 1975	1	12095	6299	6261	38	5796
JUL 1975	1	73726	15772	1960	13812	50754
AUG 1975	1	57098	31941	25530	6411	25157
SEP 1975	1	119310	103570	48513	55057	15740
OCT 1975	1	66443	58731	26282	32449	7912
NOV 1975	1	30893	29707	11979	17728	1186
DEC 1975	1	31700	31326	27798	3528	374

Table Z-3.22. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 30

DATE	# OBS	TOTAL ZOOPLANKTON (#/M ³)	CRUSTACEA (#/M ³)	COPEPODA (#/M ³)	CLADOCERA (#/M ³)	ROTIFERA (#/M ³)
APR 1972	1	1321	1321	1321	0	0
MAY 1972	1	7840	5803	5415	388	2036
JUN 1972	1	29308	9448	9165	283	19860
JUL 1972	1	68164	22028	17705	4323	46136
AUG 1972	1	310294	217631	45744	171887	92663
SEP 1972	1	83146	61029	35277	25752	22117
OCT 1972	1	83788	83080	40951	42129	708
NOV 1972	1	30782	28770	12453	16317	2012
DEC 1972	1	7182	6482	6142	340	700
JAN 1973	1	3507	3116	3040	76	388
FEB 1973	1	5572	5487	5487	0	85
MAR 1973	1	1708	1697	1685	12	11
APR 1973	1	14404	12177	12157	20	2247
MAY 1973	1	10608	7316	7216	100	3292
JUN 1973	1	34774	30322	29818	504	4452
JUL 1973	1	180747	124744	14697	110072	52996
AUG 1973	1	59148	34252	8175	26077	24869
SEP 1973	1	151299	46755	35259	11496	4544
OCT 1973	1	38532	35127	23713	11414	3405
NOV 1973	1	32672	30727	12081	18656	1935
DEC 1973	1	21529	39222	19611	19611	158
JAN 1974	1	3441	3298	3280	18	143
FEB 1974	1	7063	7003	6998	5	60
MAR 1974	1	3503	3492	3489	3	11
APR 1974	1	4557	3999	3999	0	362
MAY 1974	1	24449	15138	15050	88	9311
JUN 1974	1	37979	13358	13052	305	24621
JUL 1974	1	25238	14103	12777	1528	11133
AUG 1974	1	178470	113950	64463	49487	64520
SEP 1974	1	58154	48279	25672	22607	9875
OCT 1974	1	51232	48105	23169	24926	3127
NOV 1974	1	25564	23149	20859	2290	2417
DEC 1974	1	28287	10110	17762	1328	9177
JAN 1975	1	30267	22886	22597	289	7381
FEB 1975	1	19411	16087	16000	87	3324
MAR 1975	1	10018	8734	8734	0	1284
APR 1975	1	1035	1019	1017	2	15
MAY 1975	1	4868	4220	4053	167	648
JUN 1975	1	37554	17992	17735	257	19562
JUL 1975	1	172636	129643	10336	119307	42993
AUG 1975	1	1119705	712070	536804	175266	407635
SEP 1975	1	65366	48235	29030	19205	18131
OCT 1975	1	32836	29712	16389	13323	3124
NOV 1975	1	15854	15234	11500	3734	620
DEC 1975	1	11843	11285	10130	1125	558

Table Z-3.23. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 32

DATE	# OBS	TOTAL ZOOPLANKTON (#/M**3)	CRUSTACEA (#/M**3)	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
APR 1972	1	2452	2452	2452	0	0
MAY 1972	1	10443	9460	9352	108	982
JUN 1972	1	47465	33153	32940	213	14312
JUL 1972	1	89569	37578	28995	8583	51991
AUG 1972	1	97254	87927	32804	55123	9327
SEP 1972	1	42636	41085	23016	18069	1551
OCT 1972	1	84728	78597	63112	15485	6131
NOV 1972	1	49049	48148	40831	7337	881
DEC 1972	1	11539	10556	10111	445	983
JAN 1973	1	10278	10202	10172	30	76
FEB 1973	1	4068	4056	4056	0	12
MAR 1973	1	5041	4988	4988	0	63
APR 1973	1	9921	8431	8357	74	1490
MAY 1973	1	22030	20910	20771	139	1120
JUN 1973	1	66387	58791	58555	236	7832
JUL 1973	1	99103	39448	28995	10453	38669
AUG 1973	1	111415	62386	32804	29582	59144
SEP 1973	1	33442	26305	23016	3289	621
OCT 1973	1	44272	74706	63112	11594	1533
NOV 1973	1	26735	45503	40831	4672	884
DEC 1973	1	27931	11011	10111	900	458
JAN 1974	1	9341	9257	9231	26	84
FEB 1974	1	8723	8671	8668	3	52
MAR 1974	1	5046	5033	5033	0	15
APR 1974	1	5190	4928	4926	2	262
MAY 1974	1	20377	14686	14639	47	5551
JUN 1974	1	51594	32569	32547	22	19025
JUL 1974	1	45969	27615	21500	6115	18354
AUG 1974	1	124823	119892	63568	56324	22931
SEP 1974	1	94497	86124	66876	19248	8373
OCT 1974	1	98861	91371	71357	20014	7490
NOV 1974	1	35139	29640	25557	4083	5499
DEC 1974	1	28743	18677	17953	724	10066
JAN 1975	1	14658	13513	13493	20	1165
FEB 1975	1	12304	11152	11152	0	1152
MAR 1975	1	5159	5136	5136	0	23
APR 1975	1	4252	4210	4208	2	42
MAY 1975	1	4753	4726	4684	42	27
JUN 1975	1	13143	8968	8703	265	4175
JUL 1975	1	115933	64178	24211	39967	51755
AUG 1975	1	135919	117694	62580	55114	18225
SEP 1975	1	71167	61897	38382	23515	9270
OCT 1975	1	40186	37670	26764	10906	2516
NOV 1975	1	8794	8047	7210	837	747
DEC 1975	1	4624	4528	4460	68	96

Table Z-3.24. Total Zooplankton, Crustacea, Copepoda, Cladocera, and Rotifera, Station 70

DATE	# OBSV	TOTAL ZOOPLANKTON (#/M**3)	CRUSTACEA (#/M**3)	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
JAN 1972	1	2759	2338	2321	17	416
FEB 1972	1	2959	2027	2025	2	932
MAR 1972	1	3433	3430	3430	0	3
APR 1972	1	2876	2870	2870	0	6
MAY 1972	1	7296	6798	6510	288	497
JUN 1972	1	17782	10025	9871	154	7757
JUL 1972	1	102192	58273	39771	18502	43919
AUG 1972	1	185645	173384	37729	135655	12261
SEP 1972	1	49002	46408	20941	25467	2594
OCT 1972	1	107648	94878	69480	24994	8174
NOV 1972	1	46847	44646	36501	8145	2201
DEC 1972	1	12306	11469	10584	885	837
JAN 1973	1	10500	10077	10031	46	423
FEB 1973	1	3210	3180	3180	0	30
MAR 1973	1	1669	1572	1572	0	97
APR 1973	1	14016	11190	11067	133	2026
MAY 1973	1	15732	14120	14050	70	1612
JUN 1973	1	39445	37529	36291	1238	3154
JUL 1973	1	134390	62247	48414	13833	72151
AUG 1973	1	110938	68313	25179	43134	42625
SEP 1973	1	30313	28941	25858	3083	1372
OCT 1973	1	29405	27820	22790	5030	1585
NOV 1973	1	33276	31964	21016	10948	1312
DEC 1973	1	24206	23614	22655	959	592
JAN 1974	1	4195	4109	4101	8	86
FEB 1974	1	6821	6762	6762	0	59
MAR 1974	1	0	0	0	0	0
APR 1974	1	4897	4619	4619	0	278
MAY 1974	1	24591	18355	18277	78	6236
JUN 1974	1	37579	21030	20927	103	16549
JUL 1974	1	35182	20358	16755	3602	14924
AUG 1974	1	99700	71257	58618	12438	28443
SEP 1974	1	80883	74632	61394	13236	6251
OCT 1974	1	106375	95085	68382	26703	11290
NOV 1974	1	29595	24834	22622	2212	4761
DEC 1974	1	33956	16065	14516	1549	17891
JAN 1975	1	12477	11173	11108	65	1304
FEB 1975	1	9063	7420	7410	10	1643
MAR 1975	1	4429	4187	4187	0	242
APR 1975	1	3811	3791	3785	6	20
MAY 1975	1	4996	4772	4550	222	224
JUN 1975	1	26348	9161	8755	406	17187
JUL 1975	1	150982	116359	21260	95099	34623
AUG 1975	1	148373	104130	57080	47058	42441
SEP 1975	1	61865	54921	36810	18111	6944
OCT 1975	1	35041	32838	25056	7782	2203
NOV 1975	1	8572	7631	6771	860	941
DEC 1975	1	3970	3863	3844	39	87

Table Z-3.25. Total Benthos and Pontoporeia affinis, Station 2

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1972	1	1304	921
APR	1972	1	1427	860
JUN	1972	1	6516	4895
AUG	1972	1	8425	7683
OCT	1972	1	3728	3454
DEC	1972	1	1394	1120
FEB	1973	1	558	321
APR	1973	1	4319	3586
JUN	1973	1	3686	3298
AUG	1973	1	9015	7012
OCT	1973	1	8600	6081
DEC	1973	1	2051	1621
FEB	1974	1	713	473
APR	1974	1	1677	765
JUN	1974	1	6213	5358
AUG	1974	1	11496	5599
OCT	1974	1	5146	3789
DEC	1974	1	2183	1465
FEB	1975	1	1446	799
APR	1975	1	3610	2660
JUN	1975	1	6138	5330
AUG	1975	1	7900	6865
OCT	1975	1	10155	8174
DEC	1975	1	3533	2074

Table Z-3.26. Total Benthos and Pontoporeia affinis, Station 4

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1972	1	3114	1451
APR	1972	1	3265	1588
JUN	1972	1	9639	7503
AUG	1972	1	10712	6473
OCT	1972	1	5103	4134
DEC	1972	1	7825	5287
FEB	1973	1	2386	1077
APR	1973	1	15418	6884
JUN	1973	1	5982	4990
AUG	1973	1	27320	18281
OCT	1973	1	23880	17161
DEC	1973	1	10348	6478
FEB	1974	1	5873	3875
APR	1974	1	5486	3142
JUN	1974	1	11066	7815
AUG	1974	1	8207	5917
OCT	1974	1	14468	6530
DEC	1974	1	7541	3747
FEB	1975	1	4810	1512
APR	1975	1	4484	855
JUN	1975	1	8666	5831
AUG	1975	1	11042	8170
OCT	1975	1	9241	4451
DEC	1975	1	6928	3445

Table Z-3.27. Total Benthos and Pontoporeia affinis, Station 5

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1972	1	539	95
APR	1972	1	2556	161
JUN	1972	1	2277	1172
AUG	1972	1	1668	515
OCT	1972	1	756	364
DEC	1972	1	643	435
FEB	1973	1	57	38
APR	1973	1	90	14
JUN	1973	1	161	128
AUG	1973	1	1262	855
OCT	1973	1	1838	666
DEC	1973	1	718	553
FEB	1974	1	945	260
APR	1974	1	149	85
JUN	1974	1	529	326
AUG	1974	1	4163	709
OCT	1974	1	1507	595
DEC	1974	1	643	340
FEB	1975	1	335	246
APR	1975	1	1077	959
JUN	1975	1	1370	1229
AUG	1975	1	2059	1120
OCT	1975	1	3480	1191
DEC	1975	1	1008	846

Table Z-3.28. Total Benthos and Pontoporeia affinis, Station 7

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. APPINIS (#/M**2)
FEB	1972	1	2896	1635
APR	1972	1	3303	1304
JUN	1972	1	4290	3648
AUG	1972	1	8647	6724
OCT	1972	1	8987	6185
DEC	1972	1	4394	2844
FEB	1973	1	1710	501
APR	1973	1	10045	7447
JUN	1973	1	5396	4782
AUG	1973	1	10655	6577
OCT	1973	1	18451	14118
DEC	1973	1	3813	2674
FEB	1974	1	4295	2003
APR	1974	1	2112	1162
JUN	1974	1	8812	7239
AUG	1974	1	13154	9025
OCT	1974	1	12403	7409
DEC	1974	1	3232	2372
FEB	1975	1	1507	671
APR	1975	1	1644	926
JUN	1975	1	9871	8174
AUG	1975	1	11941	9063
OCT	1975	1	11192	7853
DEC	1975	1	3568	1852

Table Z-3.29. Total Benthos and Pontoporeia affinis, Station 9

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1973	1	7040	269
APR	1973	1	22156	4942
JUN	1973	1	6544	1559
AUG	1973	1	21664	4418
OCT	1973	1	19963	4328
DEC	1973	1	10834	3303
FEB	1974	1	17861	3076
APR	1974	1	9100	902
JUN	1974	1	11066	7815
AUG	1974	1	15786	3756
OCT	1974	1	21357	3237
DEC	1974	1	25794	1819
FEB	1975	1	14841	1177
APR	1975	1	9573	449
JUN	1975	1	19344	3043
AUG	1975	1	16353	4947
OCT	1975	1	10811	1810
DEC	1975	1	14468	3421

Table Z-3.30. Total Benthos and Pontoporeia affinis, Station 10

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1972	1	222	43
APR	1972	1	2197	676
JUN	1972	1	1025	227
AUG	1972	1	2433	2022
OCT	1972	1	912	888
DEC	1972	1	383	841
FEB	1973	1	76	43
APR	1973	1	988	676
JUN	1973	1	255	227
AUG	1973	1	2221	2022
OCT	1973	1	1219	888
DEC	1973	1	936	841
FEB	1974	1	260	213
APR	1974	1	421	364
JUN	1974	1	586	548
AUG	1974	1	3893	624
OCT	1974	1	1871	926
DEC	1974	1	1040	624
FEB	1975	1	633	236
APR	1975	1	1039	888
JUN	1975	1	2429	2211
AUG	1975	1	2030	1271
OCT	1975	1	1951	4952
DEC	1975	1	1185	846

Table Z-3.31. Total Benthos and Pontoporeia affinis, Station 11

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1972	1	666	576
APR	1972	1	1663	1002
JUN	1972	1	1139	1102
AUG	1972	1	5906	5694
OCT	1972	1	4763	4597
DEC	1972	1	1271	954
FEB	1973	1	246	170
APR	1973	1	4933	3978
JUN	1973	1	2755	2722
AUG	1973	1	4508	4224
OCT	1973	1	5226	4522
DEC	1973	1	2211	2122
FEB	1974	1	213	180
APR	1974	1	406	335
JUN	1974	1	5349	4999
AUG	1974	1	5906	3898
OCT	1974	1	4579	3676
DEC	1974	1	2296	1881
FEB	1975	1	1153	898
APR	1975	1	3856	3756
JUN	1975	1	5561	4810
AUG	1975	1	5879	4857
OCT	1975	1	8694	6199
DEC	1975	1	2131	1309

Table Z-3.32. Total Benthos and Pontoporeia affinis, Station 12

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1972	1	1578	567
APR	1972	1	2674	1021
JUN	1972	1	4895	3634
AUG	1972	1	9119	6464
OCT	1972	1	10584	7125
DEC	1972	1	6327	3411
FEB	1973	1	2977	780
APR	1973	1	4990	2594
JUN	1973	1	5089	4144
AUG	1973	1	23412	19585
OCT	1973	1	22108	16778
DEC	1973	1	7069	4569
FEB	1974	1	3569	2358
APR	1974	1	3052	1469
JUN	1974	1	7829	6057
AUG	1974	1	12989	8064
OCT	1974	1	11912	6133
DEC	1974	1	6105	3265
FEB	1975	1	2391	7
APR	1975	1	1890	0
JUN	1975	1	12403	179
AUG	1975	1	14890	11269
OCT	1975	1	13167	7763
DEC	1975	1	4849	2603

Table Z-3.33. Total Benthos and Pontoporeia affinis, Station 13

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1972	1	3908	1257
APR	1972	1	5193	1167
JUN	1972	1	4026	2320
AUG	1972	1	11165	1095
OCT	1972	1	10012	5561
DEC	1972	1	8940	3652
FEB	1973	1	2684	529
APR	1973	1	15696	6265
JUN	1973	1	9540	6719
AUG	1973	1	24674	11902
OCT	1973	1	22878	14903
DEC	1973	1	12502	6549
FEB	1974	1	5944	3274
APR	1974	1	6421	2608
JUN	1974	1	11538	6832
AUG	1974	1	8226	5202
OCT	1974	1	14681	6861
DEC	1974	1	8760	3071
FEB	1975	1	4441	10
APR	1975	1	3322	13
JUN	1975	1	10400	151
AUG	1975	1	14326	8595
OCT	1975	1	11293	2882
DEC	1975	1	11997	4271

Table Z-3.34. Total Benthos and Pontoporeia affinis, Station 18

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1972	1	340	302
APR	1972	1	227	113
JUN	1972	1	2878	2429
AUG	1972	1	643	534
OCT	1972	1	1914	1852
DEC	1972	1	954	869
FEB	1973	1	71	33
APR	1973	1	463	364
JUN	1973	1	846	775
AUG	1973	1	4101	2670
OCT	1973	1	1777	1219
DEC	1973	1	2254	1280
FEB	1974	1	302	189
APR	1974	1	751	184
JUN	1974	1	822	747
AUG	1974	1	4512	1054
OCT	1974	1	2051	1063
DEC	1974	1	2145	1384
FEB	1975	1	822	293
APR	1975	1	2084	1644
JUN	1975	1	6393	5736
AUG	1975	1	5641	1427
OCT	1975	1	6558	2377
DEC	1975	1	2329	387

Table Z-3.35. Total Benthos and Pontoporeia affinis, Station 19

DATE	# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB 1972	1	728	369
APR 1972	1	1351	463
JUN 1972	1	10428	9029
AUG 1972	1	9001	8028
OCT 1972	1	10367	7513
DEC 1972	1	2443	1521
FEB 1973	1	964	506
APR 1973	1	5283	3941
JUN 1973	1	2561	2353
AUG 1973	1	11950	10003
OCT 1973	1	10617	7858
DEC 1973	1	2707	1748
FEB 1974	1	614	439
APR 1974	1	1796	1143
JUN 1974	1	10145	4588
AUG 1974	1	7881	5283
OCT 1974	1	9152	6213
DEC 1974	1	1833	1337
FEB 1975	1	1252	7
APR 1975	1	2282	27
JUN 1975	1	18210	121
AUG 1975	1	11392	9270
OCT 1975	1	11913	8462
DEC 1975	1	3212	1692

Table Z-3.36. Total Benthos and Pontoporeia affinis, Station 20

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1972	1	860	132
APR	1972	1	5868	1418
JUN	1972	1	14076	7810
AUG	1972	1	20431	4961
OCT	1972	1	6332	3482
DEC	1972	1	9615	3119
FEB	1973	1	5287	572
APR	1973	1	10338	3582
JUN	1973	1	6317	3870
AUG	1973	1	15640	8056
OCT	1973	1	12639	5798
DEC	1973	1	7380	2731
FEB	1974	1	3879	902
APR	1974	1	1847	501
JUN	1974	1	10579	5703
AUG	1974	1	5268	2981
OCT	1974	1	11501	4371
DEC	1974	1	6653	2008
FEB	1975	1	4881	13
APR	1975	1	2693	0
JUN	1975	1	13443	251
AUG	1975	1	11567	7149
OCT	1975	1	14118	5670
DEC	1975	1	4276	1356

Table Z-3.37. Total Benthos and Pontoporeia affinis, Station 21

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1972	1	4915	586
APR	1972	1	16566	586
JUN	1972	1	15120	3964
AUG	1972	1	22831	3256
OCT	1972	1	10371	3709
DEC	1972	1	9672	2377
FEB	1973	1	7168	1181
APR	1973	1	16566	4777
JUN	1973	1	6521	2873
AUG	1973	1	16188	5826
OCT	1973	1	20842	5576
DEC	1973	1	6658	2849
FEB	1974	1	4286	1408
APR	1974	1	3827	808
JUN	1974	1	6771	2731
AUG	1974	1	6705	1833
OCT	1974	1	18616	2736
DEC	1974	1	7943	884
FEB	1975	1	3747	6
APR	1975	1	7938	11
JUN	1975	1	12219	151
AUG	1975	1	15043	4356
OCT	1975	1	17147	1361
DEC	1975	1	8859	2254

Table Z-3.38. Total Benthos and Pontoporeia affinis, Station 22

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1973	1	51082	241
APR	1973	1	76129	132
JUN	1973	1	40498	335
AUG	1973	1	45299	1186
OCT	1973	1	34932	1016
DEC	1973	1	35674	203
FEB	1974	1	49097	236
APR	1974	1	33448	118
JUN	1974	1	54092	123
AUG	1974	1	52717	71
OCT	1974	1	50179	90
DEC	1974	1	24990	90
FEB	1975	1	1652	1604
APR	1975	1	1856	1744
JUN	1975	1	558	480
AUG	1975	1	68342	0
OCT	1975	1	66225	661
DEC	1975	1	45842	170

Table Z-3.39. Total Benthos and Pontoporeia affinis, Station 28

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1972	1	0	0
APR	1972	1	624	9
JUN	1972	1	2419	1640
AUG	1972	1	2835	1295
OCT	1972	1	1777	1370
DEC	1972	1	643	515
FEB	1973	1	208	151
APR	1973	1	227	43
JUN	1973	1	76	19
AUG	1973	1	1077	657
OCT	1973	1	1947	369
DEC	1973	1	321	194
FEB	1974	1	888	265
APR	1974	1	14	9
JUN	1974	1	198	137
AUG	1974	1	3973	180
OCT	1974	1	4573	402
DEC	1974	1	713	312
FEB	1975	1	1677	146
APR	1975	1	331	123
JUN	1975	1	260	165
AUG	1975	1	2499	709
OCT	1975	1	2426	723
DEC	1975	1	1060	619

Table Z-3.40. Total Benthos and Pontoporeia affinis, Station 29

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
APR	1972	1	1550	926
JUN	1972	1	9729	7985
AUG	1972	1	7763	7220
OCT	1972	1	5174	4947
DEC	1972	1	1517	1366
FEB	1973	1	770	510
APR	1973	1	2018	435
JUN	1973	1	3133	2977
AUG	1973	1	2930	2580
OCT	1973	1	4768	3586
DEC	1973	1	3137	1871
FEB	1974	1	605	406
APR	1974	1	921	529
JUN	1974	1	3789	3081
AUG	1974	1	7362	2542
OCT	1974	1	4621	3090
DEC	1974	1	2263	1701
FEB	1975	1	1304	775
APR	1975	1	265	137
JUN	1975	1	9478	8510
AUG	1975	1	5641	4394
OCT	1975	1	6558	5221
DEC	1975	1	2329	1710

Table Z-3.41. Total Benthos and Pontoporeia affinis, Station 30

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
APR	1972	1	1814	1115
JUN	1972	1	5590	5146
AUG	1972	1	7262	5155
OCT	1972	1	5987	4876
DEC	1972	1	3043	2764
FEB	1973	1	1418	988
APR	1973	1	7258	6265
JUN	1973	1	9672	9119
AUG	1973	1	6596	4682
OCT	1973	1	11127	8746
DEC	1973	1	3941	2802
FEB	1974	1	2204	1701
APR	1974	1	2509	1247
JUN	1974	1	9771	8472
AUG	1974	1	10962	8571
OCT	1974	1	12880	4271
DEC	1974	1	3246	2665
FEB	1975	1	1318	723
APR	1975	1	638	491
JUN	1975	1	10513	9559
AUG	1975	1	9015	7947
OCT	1975	1	8802	5816
DEC	1975	1	2679	2122

Table Z-3.42. Total Benthos and Pontoporeia affinis, Station 31

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
APR	1972	1	10584	397
JUN	1972	1	3133	1455
AUG	1972	1	3818	2707
OCT	1972	1	4626	2632
DEC	1972	1	9200	6780
FEB	1973	1	1021	43
APR	1973	1	865	4158
JUN	1973	1	2405	255
AUG	1973	1	7579	5330
OCT	1973	1	11529	10112
DEC	1973	1	9398	6265
FEB	1974	1	2878	633
APR	1974	1	780	57
JUN	1974	1	1210	884
AUG	1974	1	4716	2211
OCT	1974	1	6341	3152
DEC	1974	1	6105	2514
FEB	1975	1	728	208
APR	1975	1	808	468
JUN	1975	1	2301	1177
AUG	1975	1	5775	3284
OCT	1975	1	5702	1356
DEC	1975	1	5292	4111

Table Z-3.43. Total Benthos and Pontoporeia affinis, Station 32

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1973	1	8359	4791
APR	1973	1	11118	6525
JUN	1973	1	12587	8084
AUG	1973	1	6152	2263
OCT	1973	1	32352	19670
DEC	1973	1	7867	4475
FEB	1974	1	9592	7248
APR	1974	1	10669	2088
JUN	1974	1	12994	7579
AUG	1974	1	17138	7121
OCT	1974	1	14676	9630
DEC	1974	1	5953	4163
FEB	1975	1	7513	1866
APR	1975	1	3553	1720
JUN	1975	1	19944	8803
AUG	1975	1	14582	9252
OCT	1975	1	14311	5613
DEC	1975	1	12829	7792

Table Z-3.44. Total Benthos and Pontoporeia affinis, Station 70

DATE		# OBSN	TOTAL BENTHOS (#/M**2)	P. AFFINIS (#/M**2)
FEB	1973	1	18168	241
APR	1973	1	95625	1725
JUN	1973	1	35253	1739
AUG	1973	1	66821	4626
OCT	1973	1	67497	3241
DEC	1973	1	16764	1805
FEB	1974	1	14619	902
APR	1974	1	49400	543
JUN	1974	1	33051	1167
AUG	1974	1	25165	1748
OCT	1974	1	54819	1980
DEC	1974	1	8760	3071
FEB	1975	1	26526	8
APR	1975	1	25005	2
JUN	1975	1	47165	27
AUG	1975	1	24951	2178
OCT	1975	1	31068	1200
DEC	1975	1	16719	1635