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

THE KEWAUNEE NUCLEAR POWER PLANT SITE

by

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August 1976

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

Argonne, Illinois

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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 plans to prepare 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 first of the informal reports, pertains to the Kewaunee Nuclear Power Plant. Similar reports pertaining to the sites of the Zion, Prairie Island, Three Mile Island, Duane Arnold, Quad Cities, and Nine Mile Point plants are envisaged.

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Diatoms	2 & 11	2 & 2A
Phytoplankton	11 & 7	3 & 3A
Diatoms	11 & 7	4 & 4A
Phytoplankton	11 & 12	5 & 5A

FIGURES

<u>Organisms</u>	<u>Stations</u>	<u>K2 Plots</u>
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Phytoplankton	11 & 14	7 & 7A
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Phytoplankton	11 & 16	9 & 9A
Diatoms	11 & 16	10 & 10A
Phytoplankton	12 & 7	11 & 11A
Diatoms	12 & 7	12 & 12A
Phytoplankton	12 & 16	13 & 13A
Diatoms	12 & 16	14 & 14A
Rotifera	2 & 11	15 & 15A
Rotifera	11 & 12	16 & 16A
Rotifera	11 & 13	17 & 17A
Cladocera	2 & 11	18 & 18A
Cladocera	11 & 12	19 & 19A
Cladocera	11 & 13	20 & 20A
Copepoda	2 & 11	21 & 21A
Copepoda	11 & 12	22 & 22A
Copepoda	11 & 13	23 & 23A
Chironomidae	11 & 3	24 & 24A
Chironomidae	11 & 12	25 & 25A
Chironomidae	11 & 13	26 & 26A
Chironomidae	3 & 12	27 & 27A
Chironomidae	12 & 7	28 & 28A
Chironomidae	12 & 16	29 & 29A
Naididae	11 & 3	30 & 30A
Naididae	11 & 12	31 & 31A
Naididae	11 & 13	32 & 32A
Naididae	3 & 12	33 & 33A
Naididae	12 & 7	34 & 34A
Naididae	12 & 16	35 & 35A
Total Benthos	11 & 3	36 & 36A
Total Benthos	11 & 12	37 & 37A
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AN EVALUATION OF ENVIRONMENTAL DATA RELATING
TO SELECTED NUCLEAR POWER PLANT SITES

THE KEWAUNEE NUCLEAR POWER PLANT SITE

Abstract

Environmental monitoring data for the years 1973, 1974 and 1975 pertaining to the Kewaunee Plant, which began operation in mid-1974, were analyzed by the most practical qualitative and quantitative methods. 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 cumulative effects of multiple lakeshore plants are not considered in this effort.

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

The primary purpose of biological monitoring of power plants is to detect any significant impacts of plant operation on the overall aquatic ecosystem, or on any of its component parts, i.e., fish, zooplankton, benthos, phytoplankton, and their subcategories. A significant detrimental impact is one that adversely changes the populations in such a way that the lost or impaired individual organisms are either not replaced or that the replacement is delayed too long (e.g., a year or two) and the ecosystem balance is upset.

Regulatory measures are based on the concept that various environmental balances must be maintained or restored. Monitoring is the means of detecting detrimental impacts that can lead to loss of environmental balances. Hence, monitoring is done to determine whether a given activity significantly impairs the biological balance and violates regulatory measures.

Certain nonradiological monitoring data from the Kewaunee Nuclear Power Plant were evaluated to determine the effectiveness of the surveillance requirements set forth in the license. Incidental to this undertaking is the development of an understanding of the nature and extent of environmental changes occurring in locales disturbed by the effluents from the plant. Hypotheses regarding short-term changes under the constraints of given data were tested by quantitative and qualitative analytical methods.

For this particular report, the matters considered are those relating to the monitoring of phytoplankton, zooplankton and benthos in Lake Michigan near the plant. Studies of the thermal plume measurements and models for making predictions for the Kewaunee Plant have also been evaluated and the results are presented in this report.

THE PLANT

LOCATION

The Kewaunee Nuclear Power Plant is located in east-central Wisconsin at the eastern edge of the territory served by the Wisconsin Power Pool. The site is on the west-central shore of Lake Michigan in a predominantly rural area between the lakeside towns of Kewaunee (eight miles to the north) and Two Rivers (13 miles to the south), see Figure 1. Prior to construction of the plant, the 908 acres comprising the site were used solely for farming, so the region is predominantly rural. Land use is agricultural, related principally to livestock and poultry.

The site occupies an area of rolling farmland bordered on the east by flat beaches adjoining Lake Michigan. Maximum relief between the rolling terrain and the beaches is on the order of 100 feet.

Ground surface elevations on the site range from 590 to 700 IGLD (International Great Lakes Datum). The rolling topography at the site represents part of a glacial end moraine deposited along the Lake Michigan shoreline during the most recent period of glaciation.

The shoreline along most of the site is characterized by steep, unstable bluffs. A short stretch of coastline with moderately flat, stable slopes near the center of the site is protected from active erosion by a promontory extending into the lake.

INTERACTION WITH THE ENVIRONMENT

The plant has a single pressurized-water reactor system and a turbine-generator system, both supplied by the Westinghouse Electric Corporation. Lake Michigan water is used for once-through cooling of the condenser. The licensed power level is 1650 MWt (535 MWe net). Non-radioactive systems, their wastes, and the effluent waste streams are as follows:

	<u>System</u>	<u>Effluent Discharged to Environment</u>
1)	Secondary coolant, conditioning chemicals	Boiler blowdown discharged to lake via circulating-water discharges
2)	Condenser circulating-water system, intermittent addition of hypochlorite solution	Circulating-water discharged to lake

The boiler blowdown (Item 1 above) contains the three chemicals added as conditioners in the secondary-coolant system: hydrazine, N_2H_4 ; morpholine,

Fig. 1. Location of the Kewaunee Nuclear Power Plant.

$C_4H_{10}NO$; and phosphate, PO_4 . Hydrazine decomposes into gas at elevated temperatures; morpholine is present at a lower concentration than the phosphate. The latter is present at a normal maximum concentration of 5 ppm in the coolant. The normal blowdown, based on an estimated average primary-to-secondary leak rate of 20 gal/day, will be two 5-min periods at a rate of 50 gpm. At this rate, dilution of the phosphate waste by the 413,000 gpm (summer) circulating-water coolant discharge will give an incremental increase in phosphate concentration of 6×10^{-4} ppm in the effluent at the time of blowdown. It can be expected that there will be infrequent periods of leakage of circulating-water into the condenser. During such periods, phosphates will be added to the secondary water to control hardness at levels up to perhaps 60 ppm. At this concentration, and at the expected increased blowdown rate of 125 ppm, the phosphate content of the circulating-water effluent would be increased by about 0.02 ppm.

Based on a system capacity of 108,000 gallons before periodic regeneration, the total amounts of chemicals added to the circulating-water discharge are 4.6 lb/day for the clarifier 268 lb/day for demineralizer regeneration (including neutralizing). These daily quantities, if discharged into the 413,000 gpm circulating-water system over a period of two hours, are calculated to increase the dissolved solids content (normally 135 ppm) by 0.7 ppm.

The circulating-water system provides once-through cooling of the main condenser of the steam-electric system. The normal flow rate through the condenser is 413,000 gpm (or 918 cfs) during periods other than winter. The water temperature is increased an average of 20°F in passing through the plant. This heat exchange amounts to 4.1 billion British thermal units per hour. In winter, the lower temperature of the lake water allows a reduced-flow operation, such that only about 287,000 gpm passes through the condenser, with an average temperature rise of 28°F.¹

The intake structure is located approximately 1600 ft from the shore at a point where the lake depth is 15 ft (Fig. 2). The inlet structure is three inverted cones with 22-ft-diameter openings at 1 ft above the lake bottom. At full flow, the velocity at the intake mouth is about 0.9 feet per second (fps). Intake is conducted in the main 10-ft-diameter pipe to the forebay at the screenhouse on the shore. The forebay water passes through four traveling screens (in parallel) with a mesh size of 3/8 in. The screens are provided with automatic water backwashing.

OPERATING HISTORY

The single pressurized water reactor in the Kewaunee Nuclear Power Plant produces a net output of 540 MWe. On August 6, 1968, the USAEC issued a provisional construction permit for this plant and construction was about 94% complete by September 1, 1972. Initial criticality was achieved on March 7, 1974, and commercial operation began in June 1974.

Since the reactor went critical daily power generation levels have been reported by the utility to NRC. We obtained these data from the NRC "Gray Book" and made the plot of power generation on a daily basis for the 1974-1975 time period (Fig. 3). From this plot it is evident that daily power generation fluctuates over the full range from no output to the maximum level of 540 MWe.

Fig. 2. Arrangement of the Plant Structures.

Fig. 3. Daily Power Generation at the Kewaunee Plant for 1974 and 1975.

Such an operation characteristic influences the environmental measurements and the biota, water chemistry and thermal plume in the vicinity of the plant.

PART I. AQUATIC ASSESSMENT

PLANT-SPECIFIC POTENTIAL IMPACTS

Since the intake structure is located in the shallow inshore region, which at times is biologically the most productive region of the lake, the organisms in the immediate vicinity could be entrained in the intake and suffer high mortality in passing through the plant. Plankton entrainment in the thermal plume from the surface discharge may also result in an impact on the local plankton community. The benthic organisms are relatively free from thermal impact since the plume tends to rise in the summer; however, during the winter a sinking plume may have an effect on local benthic organisms.

Thermal additions may affect fish in several ways: (1) by thermal shock due to relatively sudden increases or decreases in temperature, (2) by influencing species composition in the area through differences in thermal preference and the possibility of increased or decreased food supply, (3) by influencing spawning times of fish, (4) by influencing the survival of eggs and young spawned in the area because of the direct thermal effects or changes in predation rates, and (5) by influencing migration routes.

The maximum allowable chlorine residual in discharge water is 0.1 mg/l for 30 minutes per day.² If the level of chlorination of the circulating-water system necessary to control slime is such that the maximum allowable level in the discharge is surpassed, there is a potential for a biological impact.

PREDICTED IMPACTS

Effects of Intake and Entrainment

A number of predicted impacts were extrapolated from data collected at the nearby Point Beach Nuclear Plant, which is assumed to have similar ecological conditions.

Plankton

Damage to plankton may result from the stresses they encounter in passing through the plant. These stresses are caused by chemical additives (if present), turbulence, elevated temperatures, and pressure changes as the plankton pass through the pumps, condenser, various pipes, and the thermal plume.

In general, mechanical and pressure damage to organisms cannot be distinguished from thermal or chemical effects. Phytoplankton as well as the zooplankton are likely to be affected. Damage to the phytoplankton is not considered as critical as damage to other biological forms for two reasons:

(1) regeneration of the phytoplankton population lost in the plant occurs rapidly in the plume and surrounding waters because of the short life cycles; and (2) phytoplankton damaged in the plant are still available as food to other organisms after being discharged. Ichthyoplankton, including fish eggs and sac fry, are the important forms considered here since their development is slower and they produce the future standing fish crop for the area.

Fish Eggs and Larvae

Some increase in the mortality rate of fish eggs and larvae due to entrainment is expected at Kewaunee. For example, some eggs and larvae of alewife, whitefish, and perch, which are shallow, warmwater spawners, will be drawn into the plant. Some limited mortality is also expected of alewife, smelt, sculpin, and the larvae of shiners (Cyprinidae) as a result of their entrainment in the intake water.³

Fish

Even fully formed fish that enter the intake stream may be unable to swim free. At the mouths of the three intake cones the velocity is approximately 1 fps and most fish, especially the larger ones, could escape with a short burst of speed. But if they do not they are soon trapped in a velocity of approximately 11 fps⁴ from which it is unlikely that many will escape. Most will be impinged on the screens where they are killed and eventually removed with the trash accumulated by the rotating screens. Some such killing of young and adult fish is predicted.

Effects of Thermal Discharge on Biota

Plankton

The discharge of heated water into the lake will have some local effects on the viability, reproduction, food-web relationships, and growth of aquatic animals as well as the photosynthetic capacity of algae.⁵

Studies at the nearby Point Beach Nuclear Plant showed that during plant operation periphyton growth was significantly greater at the three testing stations nearest the discharge. Growth at all other stations was similar to that in the control areas. Such localized increase in periphyton growth may not be detrimental; it is only when the periphyton growth exceeds the rate at which fish and invertebrates can assimilate the organisms into the normal food chain that such growth becomes a nuisance. Excessive growth can create problems, both esthetically and practically, as when the filamentous algae break away, float onto beaches, and decay, but excessive growth of periphyton is not expected to occur at the Kewaunee Plant.⁵

Benthos

The population of benthic organisms in the Kewaunee area is sparse because of the rocky nature of the lake bottom. It is assumed that the elevated temperature of the effluent water will cause minimal damage.⁶ This appraisal is supported by the fact that the discharged water will be warmer and more buoyant (in the summer) than the receiving waters, so that under most conditions the plume will not come into contact with the benthos. A possible exception exists in the winter when a sinking plume may occur.

Fish

Effects of Temperature Increases. The potential effects of thermal additions on fish are listed in the earlier subsection entitled, "Plant-Specific Potential Impacts". Such effects at the Kewaunee Plant are expected to be

minimal, based on information gathered from the nearby Point Beach Nuclear Station.

It is unlikely that juvenile or adult fish will voluntarily enter the parts of the thermal plume that are too hot; fish are known to have definite temperature preferences and tend to move to and stay in waters of these preferred temperatures, if available. Although it is possible that fish wandering into the plume could experience temperature changes up to 20°F in summer and 28°F in winter, there are no strong currents or physical obstructions in the plant area that would force the fish to swim through heated water or to remain there for a period long enough to damage them.⁷ Therefore, it is unlikely that juvenile or adult fish life will be killed by high-temperature shock, and it is not expected that the heated discharge will have a measurable (or detectable) effect on the important fish species.

Effects of Temperature Decreases. Fish that become adjusted to plume temperatures may experience a cold shock when there is a sudden stoppage of heated effluent as in the case of a plant shutdown. At such times, temperatures may drop to near ambient conditions within a few hours.

In the Kewaunee Plant area, inshore water temperatures in the summer vary because of natural causes by as much as 19°F within three days.⁸ It is not known whether fish exposed to such change stay within the area or move to minimize the extent of change. During winter, ambient water temperature is near freezing and there are no natural sudden changes in water temperature. Sudden chilling of the plume by a shutdown of the plant, if one occurs, may have adverse effects. These will depend upon the rate of the shutdown and the temperature differential. A rapid shutdown is unlikely. However, during the colder months when fish may concentrate in large numbers in the warmer water, they conceivably could be subjected to a near 28°F decrease in temperature within a short period. This extreme shock would probably be fatal to most Great Lakes fishes and benthic organisms. However, juvenile and adult fish are capable of moving rapidly with a shift in direction of a thermal plume or a reduction in its size. Because of this, they can usually avoid damage due to shifts in the thermal plume or nonscram shutdowns. Because of the thermal sensitivity of fish and some other organisms, sudden plant shutdowns must be avoided when possible, especially during the colder months.

Effects of Chemical Releases. Since fish are attracted to the warm waters of the mixing zone, the addition of toxic substances such as chlorine to the discharge water must be very carefully controlled. The warmed effluent tends to lower the pH, which increases the toxicity of chlorine. Thus, the use of chlorine as a biocide could entail considerable risk to fish attracted to the thermal plume. The potential impact of free and combined chlorine (total residual) could conceivably be much greater than the thermal effects alone. This complicates the regulatory problem involving thermal discharges by introducing a second, less well-defined parameter as a potential undesirable impact. In the absence of precise data on the effects of total residual chlorine in the plant effluent, monitoring is required during and following chlorination.

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 and benthos) 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. "Reference" and "stress" stations in the Kewaunee study area were selected by examining a composite of five thermal plume configurations measured during the period June–November 1974.⁹ Those stations located within the 2°C isotherm of any given plume configuration were designated as "stress" stations, while those entirely outside the plume were established as "reference" stations (Fig. 4).

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 a change in mean values of two independent samples. Such tests ordinarily carry underlying assumptions of a normal probability density function, independence of observations and homogeneity of variance. Time-series data do not meet these assumptions. In addition, a strong seasonal component and nonstationary elements are present in these data.

In fact, time series observations are jointly distributed random variables; i.e., they constitute a stochastic process. 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, observations in time sequence do not always present random, independent observations from the same distribution.

The sampling design and data collection scheme must then incorporate probability sampling required by the stochastic process. Mathematical formulation that will invoke the insight of environmental-variable relationships will employ sophisticated stochastic dynamic models.

The Nature of Impacts

In an undisturbed environment, the changes and variations measured in an indicator characteristic (response variable) are natural and follow unknown 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. 5). The effect of this pulse may be (a) an exponential decay resulting in total recovery to the original condition; (b) no effect at all on the behavior, thus showing an immediate and complete recovery; (c) more subtle conditions may prevail where the effect of the pulse may be a very gradual and slow recovery; (d) or yet another possibility of no recovery at all. Less likely cases include the

Fig. 4. Location of the Sampling Stations near the Kewaunee Plant. The semicircle indicates the approximate location of the 2°C AT surface isotherm.

(a)

(b)

(c)

(d)

(e)

(f)

Fig. 5. Possible Responses to a Pulse Disturbance in a Stable Time Series.

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 Fig. 5(e) and 5(f)].

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

Time-Series Analysis

If we opt for a time-series analysis, then the basic analysis model consists of the following:

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

where: S_i is the seasonal effect,

A_j is a deterministic part 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 .

Confounding of effects, non-homogeneous variance, non-normal probability models, and the stochastic nature of the process were all given very little thought. The complex biological-environmental relationships are only grossly understood. The inherent variability, mixing of statistical populations and limitations on the measurement methods all work against the attempts to measure minor changes which may result from operation of a nuclear facility. Quantitative estimation of magnitudes of nuclear power plant induced impacts are very difficult unless a very careful effort is made in designing the data collection scheme. Surveys of the general nature under a host of unspecified assumptions stand in the way of making a meaningful analysis for inference about the impacts in the biological systems.

Most of the objectives of the Kewaunee monitoring program were very broadly defined. No specific impact hypotheses were asked or posed before a monitoring program was designed which would either provide an affirmative answer to the occurrence of an impact or negate the postulate of the impact. Such an approach, by nature, does not take into account confounding with simultaneous other changes in the environment, and sample size necessary to obtain needed precision.

Univariate analyses have been generally attempted. No covariable adjustments are recognized. For instance, between the various times of the year, water temperatures change quite markedly. These natural environmental conditions have a dominant role in determining the biotic distribution in the lake. In analyzing and planning for the data collection this should be considered, perhaps by way of "analysis of covariance" methods.

Systematic sampling to obtain an observation set will simplify the mathematical procedure in estimating the parameters, but further work is needed to generalize the model and to get explicit results that will be of direct use in the environmental impact analysis and monitoring data evaluations.

Such observations (data) have a time-series dependence; seasonal, annual, and spatial values are likely to be highly correlated. At the start of a power plant perhaps the change in the stochastic process is not that of an immediate discrete change and 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 5. With this type of setup, we must consider the use of time-series analysis methods, especially the method referred to as "intervention analysis."

To make use of such a technique, the data should be gathered more frequently and they should be evenly spaced in time. Due to the seasonal components, which may be multiplicative, additive, or a mixture of both, such adjustments must be incorporated in the basic ARIMA model. An added term or function, which represents an expected response to the operation of the nuclear plant, will be part of such a model. Simultaneous estimation of the parameters in the "nonlinear" time-series model gives an estimate on the behavior of the changes in the response variable.

The use of this method cannot be demonstrated for the Kewaunee data, where the time-series measurements are very few and operational data are limited to one year. An anticipated problem may arise if the series is nonstationary in the variance. The nonstationary condition in the mean will be much easier to take care of by differencing, but the variance problem may be a little harder issue to resolve.

A deviation from Box-Tiao's method¹⁰ (intervention analysis) can be suitably applied, and such an approach will relax the systematic, evenly spaced data requirements. The procedure is that which examines 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: S , 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 the 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.

Variance Components Analysis

The general statistical approach taken is that of applying analysis of variance in a designed experimental context. Time, space, and sampling locations, together with possible replicates, are considered as forming a factorial experimental design. Seldom if ever were underlying assumptions about the time-series and correlated data structure previously considered either in designing or in analyzing the data obtained from the monitoring studies (with the exception of transformation for reduction in variance and perhaps meeting of normality assumption).

The biological and physical-chemical data should be correlated. To take advantage of such a correlation and perhaps to improve the possibilities of detecting an impact (when present), multivariate analysis of variance could be considered. Unfortunately, the data for a multi-variate response measurement are not coordinated. Simultaneous measurements on a number of biological and physical-chemical variables are lacking.

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 situation with the given data from Kewaunee Plant, we are left with the alternative of making the best analysis we can. So the analytical framework is set to use general linear regression analysis in a univariate manner. The independent variables are dummy variables taking a value of 0 or 1 depending on the absence or presence of the factor-level effect. The decision to use a linear model in a variance-components form to analyze the data was dictated by the post-hoc analysis that made some sense. Logarithmic transformations were carried out before obtaining the general regressions.

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

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

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

$$\begin{matrix} \text{years'} \times & \text{stations'} & \text{years'} \times \\ + \text{months'} & + \times \text{ months'} & + \text{stations'} \times \\ \text{effects} & \text{effects} & \text{months'} \text{ effects} \end{matrix} + \begin{matrix} \text{random} \\ \text{error} \end{matrix}$$

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 quantity.

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 with the data, such an approach was taken and provided the reasonably best analysis for estimation and testing of hypotheses.

Some of the indicator organisms used in this evaluation study are the euplankton species. These include the phytoplankton (diatoms and total phytoplankton), and zooplankton (Rotifera, Cladocera, and Copepoda). The benthos component included the Naididae, Chironomidae and total benthos. Because of insufficient data, fish were not analyzed. The fish data were qualitative, but not sufficiently quantitative to yield good statistical results. This diverse array includes several trophic levels and both free floating and sessile organisms. In the plankton the subgroups represent the major portion of the biomass while in the benthos they are those organisms which did not exhibit large natural fluctuations in density yet are representative of the types of organisms present in the community. In addition, the Naididae are sessile organisms and the Chironomidae have emergent stages in their cycle (see Fig. 4 for sampling stations).

Since there was only one year (1973) of preoperational data and one year (1975) of operational data, the effects of years are totally confounded with the operational changes in the biota. The presence of "main" effects confounding is the highest order problem in these data. One must make a very strong assumption. Two possibilities exist. One, that there is no natural difference between the two years. The other, that any change between the years is due to the plant operation. Either is a very strong assumption.

Intra-year station comparisons consisted of month, station, and station*month interactions. Inter-year (1973 preoperational, 1975 operational) components were month, station, and year, and station*month and station*year interactions.

Inter-year (1973*1975) comparisons were made between stations; data for both 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 versus time. These graphic representations are given in Appendix K2 and are referred to in the text.

Statistical results and arithmetic and logarithmic graphs of paired stations (where the monthly mean density of organisms are plotted versus time) are presented in Appendix K1 tables and Appendix K2 graphs. 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 K3 and are in the same order as Appendix K1.

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 plant operation. However, the understanding and the appreciation of these inherent differences provide an objective basis for a determination of environmental effects. The final hypothesis of interest (about the magnitude of environmental change due to 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 first determine 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 digesting and interpreting the interaction effect in the two-way design.

Almost all the initial comparisons made within a year showed that the mean densities of organisms in the various biotic groups were statistically different between stations, months, and interactions between stations and months. These results were obtained for the total phytoplankton, diatoms, Rotifera, Cladocera, Copepoda, Chironomidae, Naididae, and total benthos. Appendix K1, Tables 1-6; 14-25; 31-42 summarize the statistics obtained and the various comparisons made.

From all these comparisons and thorough examination of the biological events in the environment, the following conclusions are drawn regarding the nature and magnitude of the immediate environmental changes which are the result of Kewaunee Plant operation.

1. Total phytoplankton and diatoms showed normal spatial and temporal variation in the inshore waters (App. K1, Tables 1-4, 7-13A) as found in the intra-year stations comparisons. The preoperational vs. operational comparison showed a slight enhancement of phytoplankton groups in the immediate plant discharge area (text Fig. 4 and Table 1).

Table 1. Statistical Comparison of Preoperational (1973) and Operational (1975) Population Densities at the Same Sampling Stations

1973 VS 1975 Station	<u>Phytoplankton</u>		<u>Zooplankton</u>			<u>Benthos</u>		
	Diatoms	Total Phytoplankton	Cladocera	Copepoda	Rotifera +	Naididae	Chironomidae	Total Benthos
2	0	0	*↓	0	**↑			
3			*↓	**↑	**↑	*↓	0	0
4			**↓	0	**↑			
6			*↓	0	**↑	*↓	**↓	**↓
7	**↑	*↑	0	0	**↑	*↓	0	0
8			0	*↑	**↑	**↓	0	0
11	**↑	*↑	0	0	**↑	0	0	**↓
12	**↑	*↑	0	0	**↑	0	0	0
13			*↓	0	**↑	**↓	*↓	**↓
14	**↑	*↑						
15			0	0	**↑			
16	**↑	*↑	*↓	0	**↑	0	0	0
17			**↓	0	**↑	*↓	0	*↓
20	*↑	0	**↓	0	**↑			
21			**↓	0	**↑			
22			**↓	0	**↑			
24	0	0						

0 No significant difference

* Significant difference (0.05)

** Significant difference (0.01)

↓ Annual mean density of 1975 < 1973

↑ Annual mean density of 1975 > 1973

+ Net size change from 120 μ m to 64 μ m in 1974

As such, this could be interpreted as an impact due to the facility operation. If there is a lagged response which may appear in a long term, such a response cannot be determined through the present analysis.

2. The random differences observed in zooplankton groups for intra-year comparisons suggest normal distribution patterns in the study area (App. K1, Tables 14-16; 18-20; 22-24; 26, 27, 27A). These random differences are probably due to the patchy nature of this group in a large body of water.

Preoperational vs. operational comparisons showed no unusual spatial or temporal pattern for the Copepoda (App. K1, Table 25). However, Cladocera were stimulated in the immediate area of the plant discharge (text Fig. 4, and Table 1). This may be a result of an enhancement of phytoplankton groups, a food source for the Cladocera, possibly coupled to a direct thermal enhancement. Although the Rotifera showed a significant increase in abundance in 1975, any real change is probably masked by the effect of a reduction in the mesh size of the collecting net in 1974.

3. The benthos showed normal temporal and spatial distribution patterns in intra-year comparisons (App. K1, Tables 8, 9; 31-33; 35-37; 39-41). Alterations of this pattern are consistent with the modification of environmental parameters and characteristics associated with a large volume discharge and subsequent change to the lake bottom configuration at the onset of facility operation.

Fluctuations in chironomid numbers during the study period at the Kewaunee Plant showed little periodicity, and peak heights were variable from 1973 (preoperational) to 1975 (operational). In the operational period from July 1974 through 1975, a decrease in the numbers of midges was observed (text Table 1; App. K2, Plot 26). Same station comparisons for 1973 and 1975 indicate that no significant difference is evident in chironomids between the preoperational and operational years at specific stations. No consistent pattern of change is indicated for the Chironomidae, or numbers of total benthos. No upward trends occurred. A cautious (guarded) conclusion based on the analyses is that the discharge area has a local small reduction in Chironomidae densities as an immediate effect due to plant operation.

Benthic organisms are useful as indicators of a point stress since most of them are sessile and must either survive in a modified physiological state or perish. However, unless a good sampling program is established to determine any induced effect, an evaluation is extremely difficult. The substrate at the Kewaunee Stations 6 and 11 (Fig. 4) is sand, and for most of the remaining stations it is primarily rock of varying sizes. The quantitative sampling of benthic populations is very difficult in the latter. Any apparent differences between years and/or stations may be a result of extremely difficult sampling conditions.

DISCUSSION

Phytoplankton

Inshore phytoplankton abundance ($\#/m^3$) in the vicinity of the Kewaunee Plant shows spring and autumn peaks of both diatoms and total phytoplankton. This pattern was observed in both preoperational (1972, 1973) and operational (1975) years in all stations analyzed 2, 7, 11, 12, 14, and 16 (Fig. 4). Station 2 is a designated reference station and Station 11 is located at the discharge (Fig. 4), yet both had strong phytoplankton bimodal periodicity. In addition, the height of the spring peaks for 1973, 1974, and 1975 at these stations increased $\sim 47\%$ between 1974 and 1975. It may appear that this increase is the result of a plant induced stimulation of the phytoplankton (since the remaining stations did not show this dramatic increase). Such an inference is challenged because of an observed increase in excess of 400% between 1973 and 1974, a preoperational period. The obvious question arises as to whether this increase is a natural acceleration in population reproduction or partly natural and partly due to the plant operation. One immediate conclusion is to recognize the limiting nature of the data and not assign the observed change to any particular cause. Another cautious approach would be to assign all the changes either to plant operation or to natural causes.

Based on limited data that are available, it appears that the warmwater discharge of the Kewaunee Plant has stimulated the phytoplankton abundances within the area enclosed by the 2°C isotherm, at least in 1975 (Fig. 4, Table 1). The magnitude and extent of the increase cannot be separated from the year to year natural changes. Methodology using time-series "intervention analysis" have to be developed to attempt estimation under such conditions.

Zooplankton

Rotifera

Zooplankton occupy the second trophic level in the food chain of most aquatic ecosystems. The three taxonomic groups, Rotifera, Cladocera, and Copepoda, represent the greatest contribution to the zooplankton biomass in most lakes including Lake Michigan. The zooplankton densities ($\#/m^3$) vs. time plots show annual peaks which occurred in July for 1973, 1974, and 1975. These peaks represent a lag of 1-2 months from those of the phytoplankton bloom as would be expected in Lake Michigan. The seasonal pattern observed for the phytoplankton was also observed for rotifers. Each succeeding peak, beginning in 1973 and finishing in 1975, is greater at Stations 11 and 2 (Fig. 4). This pattern can be recognized in all the stations plotted; however, the peak height at Station 11 (discharge) is higher than any other station. The seasonal periodicity, although observed at Stations 2, 12, and 13, was not as obvious as at Station 11. The only observable difference between 1973 and 1975 was an increase in the density of the zooplankton organisms during a bloom. No change in occurrence of the pulse was noted after plant operation began.

The results from intra-year station comparisons of 1975 data show that the annual mean density at Station 11 (closest to the discharge) is higher and significantly different from Stations 2 (reference station), 12 and 13 [which are within the plume ($\Delta T = 2^\circ\text{C}$) and are farther offshore relative to the discharge]. In addition, the 1973 and 1975 comparisons at the same station (Table 1)

suggest a significant increase in the number of rotifers at all stations in the study area (Table 1, Fig. 4). However, a substantial portion of this increase, and possibly all of it is the result of a reduction in the size of the net mesh. The applicant's consultant changed the net size from a #12 (120 μm) to a #25 (64 μm) in 1974.^{11,12} This resulted in a higher rotifera count without a real change in the abundances.* However, a real population increase may also have occurred, as periodic cycles of rotifer abundance are common. It appears, superficially, that the 1973-1975 Kewaunee upward trend is a natural and widespread phenomenon, unrelated to thermal input from the Kewaunee Plant. The increases at the control stations, similar to those in the plume areas, would tend to support this interpretation. However, these "results" would be expected following a switch to a smaller net mesh size.

A real population increase in rotifers could result from an increase in phytoplankton growth or from the warmer waters in the plume, or both. Phytoplankton and phytodetritus are a food source for rotifers. Thus, a rotifer population increase may be a result of more food organisms (diatoms and other phytoplankton) being available; the phytoplankton were stimulated in 1975, and this may have been due to plant thermal input.

Cladocera

The Cladocera follow the same seasonal abundance pattern as the rotifers with peaks in July for 1973, 74 and 75.** It is interesting to note that as the phytoplankton peak density rose 47% in 1975 relative to that of 1973, the cladoceran peak height increased by 56%. This may be the direct result of a cause and effect relationship between phytoplankton and this zooplankton group. In the years 1973 to 1974, the annual mean density of cladocerans at Stations 11 and 12 were not significantly different; however, in 1975 Station 11 had a significantly higher density.

If the apparent correlation between higher numbers of phytoplankton and cladocerans is real, the stimulation of phytoplankton has probably induced a greater abundance of cladocerans. It is likely that the rise in cladocerans and possibly rotifers is partly the result of an increased food supply, and the increase in temperature. Under these possibilities it is not prudent to eliminate a synergistic effect of increased food and elevated temperatures on the reproduction of these organisms.

The Cladocera in Lake Michigan are most abundant during the warm summer months when surface temperatures are elevated. A localized area of elevated temperature might not increase the cladoceran biomass at any given time, but may lengthen the productive period in such a way as to increase the annual mean

*The length range for the Phylum Rotatoria is from about 40 to 2500 μm , but the great majority of rotifers are between 100 and 500 μm long. [R. W. Pennak, "Freshwater Invertebrates of the United States." Ronald Press Co., N. Y. 1953) p. 159.]

**The Cladocera range in size from about 200 to 18,000 μm and it is assumed that the change in net size (from 120 μm to 64 μm) by the applicant in 1974 did not significantly affect the cladoceran counts. Ibid. (Pennak), p. 323. However, the net efficiency may have been reduced by this size change (reduction), and this may have resulted in abnormally lower counts of cladocerans and copepods.

density. More sophisticated research is necessary to further clarify these observations.

Copepoda

The copepods account for the largest fraction of zooplankton biomass in Lake Michigan during most of the year. Evidence of seasonal peaks of abundance in spring (March) and late summer (July) can be seen in 1974 but not in 1973 or 1975. The body length of the copepoda species ranges from 300 to 3200 μm .¹³ Although immature forms are smaller, it is assumed that the change in net mesh size, made by the applicant in 1974 (from 120 μm to 64 μm) had little effect on the copepod counts. If the change in mesh size reduced the net efficiency, fewer copepods would have been collected with the same effort; this may have happened. Graphic representation of $\#/m^3$ vs. time indicates that the fall peak was present in 1973, 1974, and 1975 with no apparent shift in time of occurrence during preoperational or operational periods.

The mean annual density of copepods in 1975 was not significantly different from that of 1973 in all but 2 of 15 sampling stations (Table 1). No evidence of the Kewaunee Plant impact on these zooplanktonic organisms was seen.

Comparisons between stations in the same year, different stations in different years and between the same station in preoperational (1973) and the operational year (1975) indicate that no significant difference can be detected in the copepod densities in most comparisons. The mean abundances at several places were found to be significant, however, and this is probably due to the patchy distribution of the organisms within the study area.

We can find no evidence of plant-induced enhancement or depression of the copepod population in the data available. Without systematic preoperation data (preferably for at least three years), natural oscillations in biological populations cannot be well defined in the study area. Assignment of an impact or lack of one without such data may be at best arbitrary under strong assumptions.

Benthos

Comparison of data for the years 1973 and 1975 at the same benthos station indicate that when a significant difference in the population density occurred, it was the result of a lower average population density in 1975 (Table 1).

The temporal pattern of total benthos abundance oscillated during the study period. Stations 12 and 3 showed no apparent periodicity; however, the population density at Station 11 was depressed following the onset of plant operation in 1974. This decrease is also evident at Station 13. The total benthos near the discharge in 1973 was significantly higher than in 1975, which indicated that the population had decreased sometime after the plant went into operation in 1974 (Table 1). This decrease may be the result of either a natural decline, since it is rather scattered in occurrence, or a plant-induced depression of the benthic organisms. Since a large significant decline in Chironomidae or Naididae is not evident, the significant decrease in total benthos must be the result of a large decline in a group not studied or an accumulation of a number of small declines in specific groups. It is

probably the latter (e.g., for Station 11, see Table 2). An apparent inconsistency which is suggested by no significant decrease in the numbers of Naididae or Chironomidae at Station 11 but a significant (0.01 level) decrease in total benthos (Table 1) is important to address. The annual mean chironomid population remained essentially the same [1973 (5176 per $1/8 \text{ m}^2$), 1975 (5059 per $1/8 \text{ m}^2$)] (Tables 2 and 3), but the percentage composition increased (Table 4). The Naididae population decreased from an average of 3539 per $1/8 \text{ m}^2$ in 1973 (Table 2) to 214 per $1/8 \text{ m}^2$ in 1975 (Table 3) and the percentage composition decreased from 10% to 5% (Table 4). Computations limited to this group indicate a nonsignificant 1973 to 1975 difference (Table 1). This inconsistency may be partially due to a very high variance among months and a low variance within months of the successive years. In 1973 a sharp increase in the number of Naididae was observed in September and remained until November while in 1975 this rise was not apparent. Several other 1973 benthic populations were also depressed somewhat in 1975, and this was sufficient to account for the significant drop in total benthos in 1975 (Tables 1-3; App. K2, Plots 36-41A).

If the Naididae are stimulated or depressed by elevated temperatures during certain ambient temperature regimes, one might expect an increase or decrease due to warm discharge water. Elevated temperatures were present at Station 11 in 1975 due to plant operation but not in 1973, which was a pre-operational year. These 1975 conditions may have resulted in the equivalent of a "seasonal differential effect" in the heated discharge. The physiology of many invertebrate forms is sketchy, and additional information is necessary to substantiate this hypothesis.

The substrate at Kewaunee Stations 6 and 11 is sand, and for most of the remaining stations it is primarily rock of varying sizes. The quantitative sampling of benthic populations is very difficult in the latter. Any apparent differences between years and/or stations may be a result of extremely difficult sampling conditions.

CONCLUSIONS

The restricted analysis of biological data from Kewaunee Nuclear Power Plant does not show an immediate significant effect on the biota of Lake Michigan. Local stimulation of certain phytoplankton groups and subsequent relative* enhancement of the Cladocera in the discharge area (Table 1; Fig. 4) is noted but a significance cannot be assigned regarding the effect on lakewide community. Damage to the benthic community by dredging, the discharge, Δt effects, and velocity are considered acceptable adverse impacts and an inevitable result of power generation.

It is recognized that our conclusions are based on a data set that contains insufficient preoperational data and inconsistent sampling; we observe that an immediate widespread damage to the biota is not evidenced in the Kewaunee Plant vicinity. If one must consider the cumulative effect of multiple use of Lake Michigan, a different analytical and philosophical approach is necessary. This may, by necessity, include an interdisciplinary cooperation between various agencies and research groups actively working on Lake Michigan. This approach is certainly not within the scope of the present study.

*Relative to the 1975 decline at stations outside of the thermal plume.

Table 2. Benthic Data (mean number per 1/8 square meter) from Kewauue Station 11 in 1975.
Differences from corresponding stations in 1973 are also shown.

Benthic Group	Sampling Date					Total	1973 minus 1975 Difference	
	4/23	5/21	7/22	9/26	11/18			
Total Nematoda	107	472	24	16	21	640	2613	↓*
Total tubificids	101	600	64	323	1029	2117	1534	↑
Total Naididae	44	8	24	61	77	214	3325	↓
Total Oligochaeta	170	835	88	387	1125	2605	2226	↓
Total Chironomidae	881	2964	144	131	939	5059	117	↓
Total Ostracoda	44	437	59	3	117	660	2455	↓
Total benthos	1271	5222	323	579	2408	9803	8460	↓
Other	69	514	8	42	206	839	1049	↓

*Arrows pointing down indicate the mean number in 1975 is less than that for 1973; up arrows indicate 1975 mean is greater than that for 1973.

Table 3. Benthic Data (mean number per 1/8 square meter)
from Kewaunee Station 11 in 1973

Benthic Group	Sampling Date					Total
	4/13	5/22	7/24	9/29	11/16	
Total Nematoda	40	56	483	1925	749	3,253
Total tubificids	106	108	8	27	334	583
Total Naididae	59	19	46	349	3,066	3,539
Total Oligochaeta	271	295	83	390	3,792	4,831
Total Chironomidae	821	626	134	656	2,939	5,176
Total Ostracoda	1109	51	147	123	1,685	3,115
Total benthos	2593	1232	935	3273	10,230	18,263
Other	352	204	88	179	1,065	1,888

Table 4. Percent Composition of 1973 and 1975 Benthic Organisms at the Kewaunee Effluent Sampling Station Number 11

Benthic Groups at Station Number 11	Sampling Dates										Annual Average % Composition	
	April		May		July		September		November			
	13th 1973	23rd 1975	22nd 1973	21st 1975	24th 1973	22nd 1975	29th 1973	26th 1975	16th 1973	18th 1975	1973	1975
Total Naididae	2.28	3.5	1.54	0.0	4.92	7.4	10.65	10.6	29.97	3.2	9.87	4.94
Total Tubificidae	4.09	7.9	8.77	4.0	0.86	19.8	0.82	55.8	3.25	42.7	3.56	26.04
Total Oligochaeta	10.45	13.4	23.94	4.0	8.88	27.2	11.92	66.8	37.07	46.7	18.45	31.62
Total Ostracoda	42.77	3.5	4.14	1.2	15.72	18.3	3.75	0.5	16.47	4.9	16.57	5.68
Total Chironomidae	31.66	69.3	50.81	78.3	14.33	44.6	20.00	22.6	28.73	39.0	29.11	50.76
Total Nematoda	1.54	8.4	4.55	14.4	51.66	7.4	58.81	2.8	7.32	0.9	24.78	6.78

Present Limitations of Monitoring Data

With the present monitoring approach, it is difficult or impossible to detect a number of man-made impacts and/or natural biological perturbations in the aquatic environment and to differentiate one from the other. Better monitoring designs, methods, and longer range planning are needed. The best of current state-of-the-art methodology and equipment should be used initially in a given monitoring program and not changed in type, location, timing intervals, or in method of use. Erratic changes in the program may result in preoperational data which cannot be properly compared with operational data. If new procedures or equipment are introduced, concurrent samples should be taken with both old and new methods for a year. Today, serious deficiencies often occur in monitoring programs at nuclear power facilities because of inconsistency in sampling.

Monitoring Critique

1. Ideally, the minimal requirement is a good basic over-all aquatic monitoring plan designed for the statistical analysis of data in each major biological group (phytoplankton, zooplankton, benthos, and fish).
2. Presently, there is a wide spectrum of difference in the quality and quantity of data collected at operating nuclear power facilities. There are numerous reasons for this, many of which can be explained by the developing state-of-the-art in equipment for ecological monitoring. Also, shortages of available trained personnel have been a factor. However, if aquatic ecologists in general will standardize monitoring procedures where possible, much more can be learned through comparative analyses.
3. The inadequate aspects of the aquatic monitoring programs that we have found are listed below with recommendations for improvement:

a) Preoperational monitoring has been inadequate. More than one year of complete preoperational monitoring should be obtained, with the basic statistical design included initially, followed by adequate data sampling for all four major groups (phytoplankton, zooplankton, benthos, fish, including ichthyoplankton). At least one year of monitoring data should be obtained prior to the start of construction.

b) Field equipment, particularly the sampling gear, should be carefully selected from generally accepted state-of-the-art supplies. Changes in type of sampling gear, net sizes, etc., should not ordinarily be made after the monitoring program has officially begun. If changes in gear are made, duplicate samples using both old and new equipment should be obtained for at least one year. Gear types, net sizes, etc. should be clearly stated, and written on tables and figures.

c) Sampling stations should be carefully located on the basis of statistical, biological, and physical parameters. Insofar as possible, the same general station locations or areas should be used for all biotic groups. After the monitoring program has officially begun, these stations should not be changed or deleted throughout preoperational, construction, and operational studies.

d) All stations should be monitored in a consistent manner (time frequency technique, etc.) according to the initial basic statistical, physical and biological planning. If bad weather interferes, the first possible day thereafter should be substituted, and no exceptions should be made.

e) Insofar as possible, the same well-trained and experienced personnel should remain on the project. Training programs for personnel new to the project should be integrated under close supervision.

f) The raw data should be computerized and presented in a clearly uniform and consistent manner with a view toward having a ten-year set of data, rather than two, three or a few years of data. This will make it easier to observe natural vs. plant-induced changes when they occur. All raw sampling data (c.g., duplicate, triplicate, quadruplicate) should be presented, rather than just the means or averages.

g) Data from site-specific projects should be made available for possible incorporation into the monitoring program to answer ecological questions unique to each generating station.

h) A more coordinated effort should be made between groups mapping thermal plumes and those doing ecological monitoring. This is extremely important when determining the location of biological sampling stations.

References for Part I

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PART II. HYDROTHERMAL ASSESSMENT

The thermal discharge at Kewaunee is at the surface from an open channel at the shoreline. Although a surface discharge, the Kewaunee outfall is a more modern design in which the effluent leaves the channel as a high-velocity jet. A high efflux velocity (large initial densimetric Froude number) is expected to enhance mixing of the heated effluent with the ambient water and thus provide a rapidly diluted plume. In contrast, the other older power plants on the Great Lakes have low-velocity discharges that result in highly buoyant plumes.

The completely semi-empirical Pritchard Model No. 2 was used to provide preoperational predictions. Subsequent to the commencement of plant operation, plume data from Kewaunee were used to test the model and then to improve the predictions where discrepancies were found. The field data and modeling efforts¹⁻⁶ are critically evaluated (reviewed) below.

CHARACTERISTICS OF THE OUTFALL

The plant is located on a small promontory jutting into Lake Michigan. Figure 6 illustrates the location of the plant on its promontory on the western shore of the Lake. The discharge channel is 40 ft wide at its entrance to the lake and has a depth of 5 ft when the mean lake level is 577 ft (IGLD); the elevation of the lake bottom at the canal entrance to the Lake is 572 ft. The discharge is made 130 ft from the shoreline.

The lake bottom in this area has a gradual slope of about 1:100. The bottom of the lake just outside the point of discharge was dredged to provide more entrainment water for the plume. This area is still rather shallow, however. Figure 7 provides a sketch of the discharge structure itself and the specially dredged outlet basin. The discharged water enters its special outlet basin through a submerged 10-ft-diameter concrete pipe which connects through a concrete transition piece to an open basin 40 ft wide, constructed of sheet-piling sides and riprap bottom. The bottom of the basin slopes upward to meet the natural sand bottom of the Lake. At the mouth of the basin, sheet-metal piling fans out to protect the adjacent shoreline. The total length of the transition piece and basin is about 130 ft. The maximum distance at which the discharge facility has affected the lake bottom configuration through dredging is about 500 ft from the shore. Note from Figure 7 that at the mouth of the discharge basin, the discharge structure pilings diverge from the 40-foot wide channel. The pilings open into the lake at a wider angle than the initial spreading of the jet (not shown) and consequently is expected to have little effect on the thermal plume.

Although the Lake Michigan lake level varies very slowly in time, low and high water extremes were noted over the two-year period of plume monitoring (1974-1975). The lake level directly affects the jet discharge parameters through its effect on the jet depth at the outfall. For the mean lake level of 577 ft, the initial jet depth is 5 ft; for high-water level of 581.9 ft (IGLD), it is 9.9 ft; for the low-water level of 575.4 ft (IGLD), it is 3.4 ft. By continuity, the initial jet velocities are affected, assuming a constant plant flow rate of 918 cfs.

Fig. 6. Location of the Kewaunee Discharge on the Promontory on the Western Shoreline of Lake Michigan.

Fig. 7. Sketch of Kewaunee Discharge Configuration.

The nominal exit velocity will be 4.7 fps--when the lake is at its mean level of 577 ft (IGLD). At the low-water level of 575.4 ft (IGLD), the discharge velocity would be 6.9 fps and at the high-water level of 581.9 ft (IGLD), it would be 2.4 fps. These initial depth and velocity changes in turn affect the usual nondimensional initial jet parameters such as densimetric Froude number, aspect ratio, and jet-to-ambient current velocity ratio. These differences can conceivably cause a significant variation in plume dimensions. This was not expected before the operation of the plant. This will be discussed later.

The major characteristics of the Kewaunee bottom topography are illustrated in measurements made in a preoperational survey made on May 29, 1974 (see Fig. 8). Here it was seen that the lake bottom near the plant is very irregular with numerous ridges and troughs extending north and south. The bottom slope is approximately 1:100 from the shoreline to the 20-ft contour, and a slope of 1:300 from the 20-ft contour to the 30-ft contour. A major feature of the bottom topography is the promontory whose submerged portion extends 2500 ft into the Lake and is 1500-ft wide. The end of this promontory is marked by a steep slope between the 20-ft and 30-ft contours. This section of the nearshore zone is an extension of the promontory on which the plant is located.

A larger scale drawing of the bottom contours for the immediate vicinity of the discharge, mapped during the operational period, is given in Figure 9. These depth measurements indicate a deep depression immediately in front of the discharge outlet. This depression is mostly the result of bottom scouring just off the end of the discharge canal. The measurements revealed a small mound (see Fig. 9) just north of the discharge outlet and offshore of the depression, defined by the 7-ft contour. The depression was probably built by sediment depositing from both scouring and diversion of alongshore sediment transport. These distinctive nearshore bottom characteristics were not noticed in a bottom survey made just three months earlier (August 28, 1974) after the plant had been off line for about one month. This should indicate the level of scouring potential the Kewaunee discharge has in the near region of the channel. We may conclude from all the preoperational and operational bottom contour measurements made that (1) scouring of the lake bottom takes place within 50 to 100 ft from the discharge inlet, and (2) the sediment transported offshore is apparently being deposited within 150 ft to 300 ft from the discharge outlet. This scouring does affect bottom depths which in turn does affect plume dispersion; however, this is difficult to anticipate preoperationally or operationally due to the many complex factors which affect it (plume dispersal, littoral currents, storms, etc.).

PREOPERATIONAL PLUME PREDICTIONS

At the time preoperational Kewaunee plume predictions were made (1970-1972), the state-of-the-art of plume modeling was in its infancy. Predictions were based on grossly conservative assumptions and/or models that were entirely unverified. Predictions were also made by extrapolating limited data from similar sites or laboratory data. Much of the predictive capability was qualitative. The Kewaunee preoperational predictions were no exception.

Table 5 lists the models (mathematical and otherwise) that were used to predict the Kewaunee thermal plume (quantitatively or otherwise). The first model applied to Kewaunee was the Ho model.^{1,7} This model was highly idealized,

Fig. 8. Preoperational Survey of Bottom Topography at the Kewaunee Plant, May 29, 1974.

Fig. 9. Operational Survey of Bottom Topography in the Immediate Vicinity of the Discharge Outlet at Kewaunee Plant on Lake Michigan, November 12, 1974.

Table 5. Predictive Methods Used for the Kewaunee Thermal Plume

Preoperational

Applicant:

Ho model^{1,7} -- highly idealized model assuming dispersion by surface heat loss only.

Pritchard Model (No. 2)^{3,11,12} -- completely phenomenological approach developed from quantitative analysis of 50 sets of laboratory and field data.

AEC Staff:

Asbury-Frigo Model^{2,8} -- correlation of area data from 6 power plants having surface discharges into large lakes.

Laboratory study of Wiegel Mobarek-Jen^{2,9} -- hydraulic model study of heated surface discharges into a stagnant ambient waterbody with a sloping bottom.

Measurements at the Point Beach Plant^{2,10} -- qualitative extension of field measurements at a similar plant 4.5 miles south of Kewaunee.

Operational

Applicant:

Model of the Pritchard No. 2 model to affect better comparisons of the preoperational model to the operational plume data -- done by P. P. Pailly of NALCO Environmental Services.⁵

assumed no lake current, and had unknown values for a number of important parameters. Ho made the conservative assumption that surface-heat loss was the predominant mode of heat dissipation. The shape of the predicted isotherms were oval, with their short axis coinciding with the centerline of the discharge. The model predicted that for some assumed typical conditions that the 3°F isotherm (above ambient) would extend 7000 ft from the discharge structure and that the area within the 3°F isotherm would be about 1000 acres. Subsequent laboratory and field data showed that the model assumptions were inaccurate and the model therefore was not validated for use. The Ho predictions are compared with improved applicant predictions, AEC Staff estimates and thermal plume measurements made during plant operations. This discussion is to follow.

The AEC staff² used three approaches to check Ho model predictions

- a) comparison with the Asbury-Frigo⁸ correlation on surface isotherm areas for heated surface discharges
- b) comparison to the generic laboratory model study on surface discharges by Mobarek, Wiegel, and Jen.⁹
- c) comparison with plumes at the nearby Point Beach site.¹⁰

Each approach will now be reviewed.

The Asbury-Frigo model is actually a correlation of surface area data from six power plants having surface discharges into large lakes. A total of 23 thermal plumes were included in the correlation. The estimated areas within specific isotherms projected for the Kewaunee plume are listed in Table 6. Use of the correlation requires only the nominal Kewaunee flow rate (918 cfs) and the nominal outfall temperature rise (20°F). From the result of Table 6, the AEC staff concluded that the applicant's estimate of 1000 acres within the 3°F isotherm was very conservative. The Asbury-Frigo predictions themselves were thought to be conservative since the Kewaunee discharge is of a high-velocity type and should therefore produce faster dilution than the low-velocity discharges of the older plants used in developing the Asbury-Frigo correlation. The very shallow bottom in the immediate vicinity of the Kewaunee discharge would inhibit rapid mixing to some degree, but still, the dilution should be more rapid with the newer design.

No model predictions were also compared with data from a laboratory study made by Mobarek, Wiegel, and Jen.⁹ In that study, the effect of varying the bottom slopes was studied under stagnant ambient conditions. The most pertinent tests were for a 1:10 nozzle (aspect ratio) mounted in a rectangular channel cut into a 1:100 slope "beach." This case is the most geometrically and dynamically similar to the Kewaunee situation. Table 6 compares the flow parameters for this lab case with the actual flow condition at Kewaunee. Predictions of centerline temperature decay based on the lab data are also given in Table 7.

A third prediction of Kewaunee plumes was based on measurements on Point Beach Unit 1. Table 8 compares the Kewaunee and Point Beach Unit 1 plants. The Point Beach Plant is roughly 4.5 miles south of Kewaunee. The AEC staff presented several plumes measured at Point Beach Unit 1 (before the operation of Unit 2). The implication is that the isotherm patterns observed at Point Beach should be similar to those expected at Kewaunee. Environmental conditions are probably quite similar. Although the power level is higher at Kewaunee (1650 MWt compared to 1518 MWt for each of the two Point Beach units), the larger initial densimetric Froude number of the Kewaunee discharge should produce better mixing. As noted earlier, the larger mixing at Kewaunee is somewhat offset by the shallow bottom at the Kewaunee site.

Table 6. Asbury-Frigo Predictions of Surface Areas of the Kewaunee Plume^{2,8}

Temperatures above Ambient	Area
15°F	3.2 acres
10	25.3
5	129
3	254

Table 7. Comparison of Flow Parameters in the Laboratory Model and the Kewaunee Plant Discharge, and Resulting Projections on Centerline Temperature Decay

Parameter	Value	
	Wiegel Tests	Kewaunee Plant
Discharge aspect ratio	1:10	1:8
Bottom slope	1:100	~1:100
Densimetric Froude number, F_o	$5 < F_o < 50$	6.3
Discharge Reynolds number, R_c	$700 < R_e < 9000$	3.6×10^6
Centerline Excess Temperature	Distance from Discharge	
20°F	264 ft	
15	440	
10	685	
5	1760	
3	3600	

Note: The predictions are based on relating centerline distances to particular measured isotherms to the number of equivalent diameters. The flow development region is observed in the lab study to be approximately 30 equivalent diameters downstream. This flow-established region is the distance before the centerline temperature and velocity begin to decay.

Table 8. Comparison of Kewaunee and Point Beach Plants

	Point Beach Unit 1	Kewaunee
Reactor type	PWR	PWR
Thermal power, MWt	1518	1650
Net power, MWe	497	540
Condenser flow, cfs	783	918
Coolant ΔT , °F	19	20
Discharge dimensions, ft	13.3 D $\times$ 35 W	5 D $\times$ 40 W
Discharge velocity, fps	1.65	4.6
Densimetric Froude No.	3.1	6.3

The AEC staff argued that the Kewaunee plume would be significantly distorted by the promontory just south of the plant. The staff commented that they expected that this promontory would cause major differences between Point Beach and Kewaunee plumes. The reasoning was that with a north-flowing lake current, the promontory would induce additional mixing in the nearfield region of the Kewaunee plume but might also hold some of the warm water against the northern shoreline in the vicinity of the plant causing reentrainment and higher plume temperatures.

The AEC staff speculated that the Kewaunee plume would contact the lake bottom in the region surrounding the dredged discharge canal. Beyond that point, where the lake bottom gradually slopes off (beyond 530 ft from the discharge), the AEC staff thought that the plume would follow the bottom contour for a short distance before separating and stratifying at the surface. The Point Beach experiences was used as a basis for those remarks. Also, it was expected that the typical Point Beach plume depth of 6 ft and bottom separation at 600 ft from the outfall would characterize the Kewaunee case too.

The final point of interest in the preoperational study was an estimate of the effect of the Point Beach plume on the Kewaunee plume. The AEC staff presented an infrared image of a northerly-directed plume from Point Beach Unit 1. A slight trace of the Point Beach plume was seen in the area of the Kewaunee Plant. Boat data taken just before and after the infrared data indicated that the plume temperature dropped to roughly 1°F above the ambient lake temperature at approximately one mile north of the Point Beach discharge. The AEC staff thus estimated that the influence of Kewaunee, at a distance of 4.5 miles, would only be a fraction of a degree. Operation of the second unit at Point Beach along with the first was expected to somewhat increase the effect of the Point Beach plume for northerly-directed currents but this effect should be less than or equal to 1°F.

After the EIS was published, Wisconsin Public Service Corporation through its consultant Bio-Test Laboratories (now NALCO Environmental Services) published a recalculation of the thermal plume predictions using Pritchard's Model No. 2.^{11,12} The model, although having only very limited validation, was thought to be an improvement over the analysis previously made by Ho. The computer code for the model had been written by ANL, and was transmitted to NALCO at their request for these calculations.

The Pritchard Model No. 2 has a completely phenomenological base, i.e., is nothing more than a series of empirical correlations developed from six sources of data. These data are¹¹:

- (1) Twenty-five hydraulic model studies of heated surface discharges conducted by Stolzenbach and Harleman.
- (2) Seventeen hydraulic model studies of crossflow interaction of heated plumes conducted by H. H. Carter at the Chesapeake Bay Institute.
- (3) Three hydraulic model studies conducted by the Corps of Engineers at Vicksburg, Mississippi.

- (4) Four field surveys of the thermal plume at the Waukegan Power Station made by NALCO.
- (5) A field survey of the plume at the Turkey Point Power Station, Biscayne Bay, Florida.
- (6) Two field surveys of the plume at Ginna Nuclear Power Station, Lake Ontario.

The model relies on three basic formulas

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

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

$$A_{\theta} = 0.86 b_0 S_{\theta}.$$

In the above equations, 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 . The symbols n , m , and β are empirical coefficients whose values are dependent on whether calculations indicate that the plume is

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

Pritchard defines the plume to be depth limited when its local half-depth, estimated assuming no bottom interaction, is greater than the actual local bottom depth. Correlations for n , m , β under these conditions are given in Table 9. Further corrections on the numbers calculated with these correlations are made to handle surface heat transfer. The depth of the plume is assumed to be linear ($dh/dx \dots$ See Table 9) until a special critical-mixing depth h_c is reached (See Table 9); from that point on, the plume depth is assumed to be constant. The model treats crossflow and bottom effects in a very simplified manner.

The genesis of the model came from Pritchard's observation that, when data for normalized temperature excesses (above ambient) are plotted versus centerline position on a log-log scale, the resulting pattern of data may be closely approximated by a series of connected straight-line segments. This is the motivation for the correlations on centerline temperature decay. Pritchard further observed that the slopes of the segments depend on whether the plume is interacting with the bottom of the lake, as well as on the usual outfall and ambient conditions. He has in this model attempted to correlate these slopes with certain physically measurable parameters. Pritchard further observed that a plot of the maximum isotherm width versus centerline position on a linear scale can also be approximated by connected line segments. He has also derived correlations for these slopes in terms of measurable parameters. In some cases, the correlations of the model can be written in an explicit, computable form, though in other cases, numerical values must be obtained from a table.

When the length and maximum width of a given isotherm have been computed using the appropriate correlation, areas are calculated (See Table 9) and then corrected for surface cooling following essentially the same procedure as given

Table 9. Correlations for Pritchard Model No. 2

Basic Definitions:

$$\begin{aligned}
 IF_o &= q_o / [g h_o (\Delta \rho / \rho)]^{1/2} \\
 Ar &= b_o / h_o \\
 R &= q_o / U_a \\
 \beta^1 &= 1 + (3.684 / IF_o) + (6.524 / IF_o^2) + (5.84 / IF_o^3) \\
 f_1 &= \begin{cases} 3 / (IF_o + 15) & Ar < 1 \\ 1.5 / (IF_o + 15) & Ar > 1 \end{cases}
 \end{aligned}$$

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

$$\begin{aligned}
 n_U &= 7.57 - 3.638 IF_o^{-0.245} \\
 m_U &= n_U^{-1} [1.152 + 3.945 \exp(-0.1 IF_o) - 2.999 \exp(-0.2 IF_o) \\
 &\quad - 1.933 \exp(-0.3 IF_o)] \\
 \beta_U &= \beta' (Ar)^{-f_1}
 \end{aligned}$$

b. Unbent, Depth-Limited Plume

$$\begin{aligned}
 n_L &= n_U (1 - 0.340 [1 - \exp(-0.0135/S_x)] [1 - IF_o^{-1}]) \\
 m_L &= m_U (0.4 + 0.6 \exp(-0.0196/S_x)) \\
 \beta_L &= \beta_U ([1 - 1.15 \exp(-0.0135/S_x)] [1 - IF_o^{-1}] + 1)
 \end{aligned}$$

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

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

in an earlier model developed by Pritchard.¹³ Further details of the model appear in Refs. 11 and 12 and a separate evaluation of the model for heated surface discharges appears in Ref. 12.

NALCO used the Pritchard Model No. 2 for a wide range of expected outfall and ambient conditions in an attempt to assess the range in plume parameters possible over a yearly period. The results are summarized in Table 10 with respect to the 3°F isotherm (excess temperature above ambient). As can be seen, predictions vary widely with plant operating conditions (100%, 80%, 50% power) and seasonal environmental conditions. Among the major conclusions drawn from these comparisons were (as projected for the Kewaunee plume by NALCO):

- (1) The bottom slope at Kewaunee (1:100) will cause the plume to interact with the bottom (i.e., be depth limited) to about 1300 feet offshore; i.e., to a temperature excess of 7.7°F).
- (2) The Point Beach plume will occasionally affect (overlap) the Kewaunee plume. The influence at the Point Beach plume will be to slightly decrease the areas within isotherms of excess temperature at Kewaunee but to increase the areas within water temperature isotherms (due to a higher ambient temperature).
- (3) The surface isotherm areas will increase from spring to summer and decrease from summer to fall. The size may increase from fall to early winter, decreasing again in late winter during minimum lake temperature. This prediction was made assuming uniform ambient temperature for all seasons.
- (4) Summer thermal stratification will be a significant factor in increasing the plume surface area.
- (5) Ambient currents will be significant in increasing the plume surface area. (The Pritchard Model No. 2 indicates that the ambient current causes the plume to bend along the shallower lake bottom contours and be depth limited for relatively long distances).
- (6) The winter sinking plume will decrease the surface area and increase the affected bottom from early to late winter.
- (7) A reduction in plant power level will reduce the plume surface area.
- (8) Recirculation will probably occur during periods of low or zero ambient current whenever the ambient current causes the plume to bend towards the lake.
- (9) Based on previous limited experience with the Pritchard Model No. 2 applied to laboratory and field data, the predicted areas were expected to be optimistic (smaller) within a distance of 30 discharge widths from the discharge structure (which was the longitudinal distance that those generic model-data comparisons were made) or about 1200 ft at Kewaunee and then conservative thereafter.

Table 10. Preoperational Predictions over a Range of Possible Plant and Environmental Conditions at Kewaunee³ (Predictions made by Computer Simulation using Pritchard Model No. 2)³

Run	Centerline Distance to 3°F Isotherm, feet	SINK Maximum Width of 3°F Isotherm, feet	Surface Area of 3°F Isotherm, acres
1	8,241	2664	434
2	3,441	1230	81
3	5,304	1827	191
4	4,784	1618	153
5	2,650	719	38
6	5,304	1827	191
7	7,878	2863	445
8	7,472	2657	392
9	2,538	663	33
10	3,824	1055	80
11	18,390	CENTER LINE 3321	1206
12	17,629	3126	1088
13	7,158	1166	165
14	5,304	1827	191
15	4,006	1273	101
16	1,954	375	15
17	5,681	2037	229
18	6,208	2206	271
19	7,143	901	127
Baseline Conditions			
Discharge flow rate (Q_o)		918 cfs	
Depth of discharge (h_o)		5.0 ft	
Width of discharge (b_o)		40.0 ft	
Heat rejection rate (Q_H)		4.12×10^9 Btu/hr	
Initial temperature rise (θ_o)		20.0°F	
Depth of water at discharge ($(D_w)_o$)		5.0 ft	
Bottom slope (S_x)		0.01	
Ambient current speed (U_a)		0.0 fps	
Ambient temperature (T_a)		55.0°F	
Intake temperature (T_i)		55.0°F	
Wind speed (W)		0.0 mph	
Key to Individual Computer Runs			
1 - Bottom slope = 1/200 ($S_x = 0.005$)			
2 - Bottom slope = 2/100 ($S_x = 0.002$)			
3 - Bottom slope = 1/100, baseline case			
4 - Point Beach influence ($T_a = 56.8^\circ\text{F}$, 1.8°F warmer than baseline ambient; $\theta_o = 18.2^\circ\text{F}$)			
5 - Spring conditions ($T_a = T_i = 44.0^\circ\text{F}$)			
6 - Summer conditions, baseline case			
7 - Winter conditions - Low Froude number ($Q_o = 655$ cfs, $\theta_o = 28.0^\circ\text{F}$, $T_a = T_i = 37.0^\circ\text{F}$)			
8 - Winter conditions - High Froude number ($Q_o = 655$ cfs, $\theta_o = 28.0^\circ\text{F}$, $T_a = T_i = 34.0^\circ\text{F}$)			
9 - Strong thermal stratification ($\theta_o = 12.0^\circ\text{F}$, $T_i = 47.0^\circ\text{F}$)			
10 - Weak thermal stratification ($\theta_o = 16.0^\circ\text{F}$, $T_a = 45^\circ\text{F}$, $T_i = 41.0^\circ\text{F}$)			
11 - Low ambient current ($U_a = 0.25$ fps, $W = 12.0$ mph)			
12 - High ambient current ($U_a = 0.40$ fps, $W = 20$ mph)			
13 - Low ambient current - Strong stratification ($\theta_o = 12.0^\circ\text{F}$, $U_a = 0.25$ fps, $T_i = 47.0^\circ\text{F}$, $W = 12.0$ mph)			
14 - 100% power output, baseline case			
15 - 80% power output ($\theta_o = 16.0^\circ\text{F}$; $Q_H = 3.3 \times 10^9$ Btu/hr)			
16 - 50% power output ($\theta_o = 10.0^\circ\text{F}$; $Q_H = 2.06 \times 10^9$ Btu/hr)			
17 - 80% discharge flow rate ($Q_o = 734$ cfs, $Q_H = 3.3 \times 10^9$ Btu/hr)			
18 - Recirculation ($\theta_o = 22.5^\circ\text{F}$; $T_i = 57.5^\circ\text{F}$, a recirculation through the intake of 2.5°F)			
19 - Point Beach plant summer case ($Q_o = 872$ cfs, $h_o = 13.8$ ft, $b_o = 35.1$ ft, $Q_H = 2.58 \times 10^8$ Btu/hr, $\theta_o = 13.1^\circ\text{F}$, $(D_w)_o = 13.8$ ft, $S_x = 0.01$, $U_a = 0.22$ fps, $T_a = 55.4^\circ\text{F}$, $T_i = 55.4^\circ\text{F}$, $W = 3.4$ mph)			

- (10) The model could not treat the situation of a northward current flowing past the submerged promontory although it was expected qualitatively that the ambient temperature would be locally increased due to reentrainment on the lee side of the plume. The influence of this reentrainment could not be successfully modeled.

The Environmental Tech Specs for the plant call for plume surveys to determine the seasonal changes in plume characteristics--centerline temperature decay, plume width, and surface areas--and the development of a mathematical model that could properly simulate the Kewaunee plumes.

OPERATIONAL FIELD MEASUREMENTS ON THE PLUME

Thermal plume surveys were conducted at the Kewaunee Plant in June, July, October, and November 1974; and April through November 1975. A total of thirty plume surveys have been made to define plume characteristics. A summary of the most pertinent outfall and ambient conditions measured during the 1975 surveys is given in Table 11.

During each survey, a boat equipped with navigation and temperature measuring systems traversed the study area on several transects in order to define ambient water temperature and the surface extent of the thermal plume. The navigation system was a Motorola Mini-Ranger accurate to ± 3 m at 20 nautical miles; the temperature measuring system was accurate to $\pm 0.05^\circ\text{C}$. A single temperature sensor was mounted on the boat for plume measurements at a depth of 0.5 meter from the water surface. While the boat was underway, temperature and position were digitally recorded at approximately one second intervals.

Following the survey of the surface plume, vertical temperature profiles were measured at locations within and outside of the plume. At each location, position was recorded and temperature was measured at 1-m depth intervals.

Currents in the study area were continuously monitored with four in situ ENDECO Type 105 recording current meters. Temperatures in the study area were continuously monitored with four ENDECO Type 109 recording thermographs. Figure 10 shows the location of the in situ current meters and thermographs. Continuous wind speed and direction and air temperature were recorded by an MRI Mechanical Weather Station which was located on shore approximately 75 ft above water level. Auxiliary meteorological data were recorded periodically on the survey boat.

For analysis of the thermal plume data, position and surface temperature data (0.5-m depth actually) were plotted using a Cal-Comp plotter and digital computer. Isotherms were contoured by hand at 1°C intervals.* Vertical

*NALCO has chosen to mix English and metric units in their presentation of plume measurements. For example, plant flow rate is given in ft^3/sec while isotherms are contoured in $^\circ\text{C}$. We have kept to this hybrid presentation to allow continuity between their work and ours. The only troublesome point comes in the determination of say the area of the 3°F isotherm, which must be calculated by interpolation between measurements of the 2°C and 1°C isotherm.

Table 11. Meteorological and Ambient Temperature and Current Conditions for the Thermal Plumes Surveyed at the Kewaunee Plant during 1975

Date of Survey	Time (hours)	Wind		Ambient Temp.		Current		2° AT				Half-Depth ^a (m)
		Speed (mph)	Direction (from)	Air (°C)	Lake (°C)	Speed (fps)	Direction (towards)	Temp (°C)	Centerline (ft)	Width (ft)	Area (acres)	
22 April	1327-1510	10	SSE	b	7.8	0.42	N	9.8	4649	1339	170	2.2
20 May	1130-1300	8-10	SE	15.0	8.2	0.29	NNE	10.2	3476	2216	104	2.0
24 June	1220-1520	6-7	NE	18.7	9.6	0.19	SW	11.6	b	b	b	1.5
22 July	1400-1815	6-9	W	27.5	8.8	0.25	ENE	10.8	b	b	b	2.0
26 August	1200-1445	calm-26	W	27.2	17.2	0.24	S	19.2	2061	581	19	1.0
23 September	1140-1420	calm	-	15.0	8.6	0.06	E	10.6	1690	1005	19	2.5
21 October	1125-1438	8-12	WSW	12.8	8.9	0.11	S	10.9	4062	1670	117	2.5
18 November	2027-2220	5-8	S	5.8	6.2	0.06	ESE	8.2	6581	3800	404	b
28 November	1000-1440	6-10	W	-6.8	5.8	0.19	NE	7.8	2750	790	28	2.5
7 August	1056-1400	18-24	SE	21.0	18.0	0.36	NNE	20.0	5519	1232	83	1.5
7 August	1604-1741	20-22	SE	21.0	18.8	0.58	NNE	20.7	2499	642	26	1.5
8 August	0939-1109	15-30	SSE	22.0	18.1	0.37	NNE	20.1	2502	1044	46	1.7
9 August	1018-1300	18-22	W	26.7	18.1	0.16	SE	20.2	2645	515	21	0.9
9 August	1900-2037	7	SE	21.0	14.3	0.56	NE	16.4	b	b	b	2.3
10 August	1425-1638	10	SW	26.0	11.6	0.33	N	13.6	b	b	b	1.9
11 August	1115-1402	0-1	NE	23.0	11.0	0.15	SSE	13.1	2606	858	24	2.2
11 August	1610-1842	calm	-	21.0	12.3	0.12	WSW	14.3	b	b	b	1.5

a = Half-depth is the depth at which the excess temperature is one-half the value at the surface.

b = missing data

Fig. 10. Location of Ambient Current and Thermograph Mooring Locations in Lake Michigan near the Kewaunee Plant.

temperature profiles were also plotted and contoured in 1°C intervals. Mean wind and current speeds and direction were calculated for the hours during the thermal plume surveys.

The area within each contoured isotherm was measured with a planimeter. The centerline was traced as a smooth curve from the discharge outlet through the maximum extent of each isotherm. The centerline distance to each isotherm was measured and the maximum width perpendicular to the centerline was determined. From the vertical temperature section nearest the centerline, the half-depth of the plume was determined as the average depth at which the excess temperature at the surface decreased to one half its value. However, in order to properly define the excess temperature at the surface (actually 0.5-m depth), the ambient temperature had to be specified. This was done by subjective analysis of the temperature profile upstream of the plume, the temperature profiles near the boundary of the plume, as well as thermograph and current meter records. Once the ambient temperature was specified, the excess temperature of each contoured isotherm within the plume was determined by subtracting the ambient temperature from the measured temperature.

All measured parameters were tabulated and the area and centerline distance of each isotherm was plotted versus the temperature concentration, θ/θ_0 , where θ = excess temperature of each isotherm and θ_0 = excess temperature at the discharge outlet, all above ambient.

On a number of occasions (Nov. 1974 and Aug. 1975), a dye tracer study was made simultaneously with the temperature survey in order to better define plume properties. A fluorescent dye (Rhodamine WT) was injected into the condenser cooling water flow prior to its discharge into the receiving waters and then the subsequent horizontal and vertical distribution of the dye in the receiving waters was ascertained. Aside from cooling by direct transfer of heat to the atmosphere, both excess heat and dye are thought to be subject to the same physical processes of advection and turbulent diffusion for unstratified ambient conditions. Based on this philosophy, dye would provide a means for determining the amount of true dilution that has occurred free of surface heat loss.

The dye measuring equipment (fluorometers) were calibrated before and after the two extensive dye surveys. All thermistors were calibrated prior to each field expedition.

A Turner Model 111 fluorometer was used to determine the fluorescence of the water. Since Rhodamine WT is a fluorescent dye and fluorescence is proportional to dye concentration, this procedure measured the distribution of dye concentration in the water.

The fluorescence of Rhodamine WT dye is temperature dependent. It decreases approximately 2.7% for each degree centigrade increase in temperature. Thus, in order to correct for this effect when calculating the dye concentration from fluorescence, the temperature was measured simultaneously with fluorescence.

A 20% solution of fluorescent Rhodamine WT dye with a specific gravity of 1.20 was continuously injected into the plant's cooling water at an average rate of 14.1 ml/min. The dye was injected at a vent on the outlet side of the plant's circulating water pump No. 1B. Injection at this point ensured that,

after passage through the plant's condensers, the dye would be completely mixed with the cooling water.

The fluorescence of the intake water was monitored at a vent on the outlet side of circulating water pump No. 1A and the fluorescence of the discharge water was monitored at a vent on a 10-inch recirculating water pipe. The outputs of the fluorometer and thermistor along with the time marks were recorded on chart paper. Intake and discharge fluorescence were monitored alternately each hour during the surveys and, since the system was unattended, discharge fluorescence only was monitored throughout the evenings of the surveys.

The first plume survey began approximately 42 hours after the start of dye injection. This was considered to be a reasonable amount of time for the dye to mix thoroughly with the plume and for initial transients in the dye concentration to smooth out. Two boats were used to obtain a synoptic survey of the temperatures and fluorescence of the plume. Each boat was equipped with a temperature measuring system, a fluorometer and a Motorola Mini-Ranger navigation system. For the surface plume surveys, one boat traversed the area on several transects and pumped water from 0.5 meter depth, through a fluorometer, past a thermistor and back over the side. The simultaneous outputs of the fluorometer, the thermistor, a digital clock and the Mini-Ranger were digitally recorded at approximately 1-sec intervals. The second boat measured vertical profiles of fluorescence and temperature at an average of 25 locations. These vertical profiles were obtained by lowering a sampling tube to a number of known depths and holding it there until a stable temperature and fluorometer reading were obtained. These readings along with time and location were digitally recorded.

During the intensive November 1974 surveys for example, two complete plume surveys were conducted each day. Each survey required 2 to 3 hours with a period of 1 to 2 hours between surveys. Continuous current and meteorological data were also obtained during these dye/temperature surveys.

Analysis identical to that discussed above for plumes defined by only temperature measurements was also carried out for the temperature and dye plumes from those studies. However, it was first necessary to convert fluorescence data into dye concentrations. This was accomplished by correcting the fluorescence to a standard temperature (20°C) and using the calibration curves to calculate the dye concentration. In order to determine which isopleths of dye concentration were to be contoured, the fractional decrease in excess temperature or temperature concentration, θ/θ_0 was calculated for each isotherm. The inverse (i.e., θ_0/θ) is often referred to as the dilution factor. The dye concentrations with dilution factors equal to those of the isotherms were chosen to be contoured. However, the calculation of a dilution factor also required that the background dye concentration be specified. In every case, the background concentration was chosen to be zero. It is also assumed that the background fluorescence remained zero throughout the several day period of the two dye/temperature studies.

Auxiliary measurements were made occasionally to better define quantities of interest to biologists. To this end, time-temperature and velocity measurements were obtained several times during the study periods by repeatedly placing a drogue equipped with a continuous recording temperature system into

the discharge and tracking it with shore-based transits. With this method, the decay of both temperature and velocity along the paths taken by the released drogues was determined. The temperature system was estimated to be accurate to within 0.5°C . Occasionally, additional drogues without recording systems were used to further define the velocity structure within the plume. An abbreviated survey of the thermal plume was conducted before and after each drogue study.

The time-temperature profiles were plotted and the drogue speed and direction were tabulated. The plume configuration before and after each set of drogue measurements was plotted along with the drogue trajectories.

ANALYSIS OF FIELD DATA

Thermal plumes were mapped monthly during June through November of 1974 and April through November of 1975 (except for August and September of 1974 when the plant was out of service); the majority of the plumes were mapped in 1975. A list of some of the pertinent parameters measured in the 1975 surveys is given in Table 11. The plant was operating at approximately 50% power during the 1974 plume surveys (918 cfs) and at approximately 100% power during the 1975 plume surveys (918 cfs). In addition to the effects of power level differences, considerable variation was found in the centerline lengths, maximum widths, and areas of plume isotherms due to variations in the ambient current, wind, and lake conditions. A plot of the combined measurements of all surveys during 1974 and 1975 in terms of centerline temperature decay, width, and area is presented in Figure 11. The legend for these graphs is given in Table 12. The scatter is obviously wide (large). NALCO attempted to explain some of the scatter by separating the plumes (1975 plumes examined only; full power at Kewaunee) into three distinct groups according to environmental conditions. These groupings are illustrated for the 1975 data in Table 13. The groupings are quite arbitrary but were chosen to try to distinguish plumes with similar plume characteristics. Here, plumes are categorized as either 1) headed northwardly, 2) headed lakewardly, or 3) headed southwardly. Each of these groups was then subdivided into four categories according to wind and current speed. Table 13 lists the centerline length, maximum width, and area of the 2°C excess temperature isotherm and plume half-depth for each category. The distinguishing characteristics of each group will now be briefly summarized.

Northward Plumes

Northward flowing plumes generally fit into Category I (see Table 13) with wind speeds greater than 8 mph and current speeds higher than 0.2 ft/sec. Category I plumes generally had large areas and long centerline lengths and widths averaging 96 acres, 4036 ft, and 1357 ft, respectively. A good example of a Group I plume is the April 22, 1975, plume presented in Figure 12 and Table 14. The strong winds and currents pushed this plume against the shoreline causing a decrease in inshore entrainment of ambient water. The usually sharp-edged sides of the plume were obscured on the inshore side by reentrainment of plume water due to the confining boundary of the inshore region as well as the usual ambient temperature gradients. The vertical structure of the plume showed high temperature gradients on the lakeward edge of the plume and vertically well-mixed water on the inshore side. Near the centerline, the plume half-depth ranged from 2.0 to 2.2 m. The 2°C excess temperature isotherm was

Fig. 11. Combined Plot of Plume Measurements of Centerline Temperature Decay, Maximum Plume Width, and Surface Areas for All Plumes Mapped at Kewaunee during 1974, 1975.

Table 12. Legend for Plots of Plume Characteristics for the Thermal Plumes Mapped during 1974 and 1975 at Kewaunee

Symbol	Plume Date			Time	Plume Direction
A	25	June	1974	1030-1400 hrs.	Southward
B	23	July	1974	1600-1730 hrs.	Northward
C	23	Oct.	1974	1200-1400 hrs.	Southward
D	12	Nov.	1974	1030-1400 hrs.	Lakeward
E	16	Nov.	1974	0900-1200 hrs.	Lakeward
F	16	Nov.	1974	1300-1500 hrs.	Lakeward
G	17	Nov.	1974	0900-1200 hrs.	Northward
H	17	Nov.	1974	1300-1600 hrs.	Northward
I	18	Nov.	1974	0845-1100 hrs.	Lakeward
J	18	Nov.	1974	1300-1500 hrs.	Lakeward
K	19	Nov.	1974	1000-1200 hrs.	Northward
L	19	Nov.	1974	1300-1500 hrs.	Northward
M	20	Nov.	1974	0900-1200 hrs.	Southward
N	20	Nov.	1974	1300-1500 hrs.	Southward
O	22	Nov.	1974		Northward
P	22	April	1975	1327-1510 hrs.	Northward
Q	20	May	1975	1130-1300 hrs.	Northward
R	24	June	1975	1220-1520 hrs.	Southward
S	22	July	1975	1400-1815 hrs.	Lakeward
T	7	Aug.	1975	1056-1400 hrs.	Northward
U	7	Aug.	1975	1604-1741 hrs.	Northward
V	8	Aug.	1975	0930-1136 hrs.	Lakeward
W	9	Aug.	1975	1018-1300 hrs.	Lakeward
X	9	Aug.	1975	1900-2037 hrs.	Northward
Y	10	Aug.	1975	1425-1638 hrs.	Southward
Z	11	Aug.	1975	1115-1420 hrs.	Southward
1	11	Aug.	1975	1610-1824 hrs.	Lakeward
2	26	Aug.	1975	1200-1445 hrs.	Lakeward
3	23	Sept.	1975	1140-1420 hrs.	Lakeward
4	21	Oct.	1975	1125-1438 hrs.	Lakeward
5	18	Nov.	1975	2027-2220 hrs.	Lakeward
6	28	Nov.	1975	1000-1440 hrs.	Lakeward

Table 13. Classification of Thermal Plumes by Wind Speed, Current Speed and Current Direction,
Measured in Lake Michigan near the Kewaunee Plant during 1975

Date of Survey	Time (Hours)	Category I (Winds > 8 mph) (Current > 0.20 ft/s)				Category II (Winds > 8 mph) (Current < 0.20 ft/s)				Category III (Winds < 8 mph) (Current > 0.20 ft/s)				Category IV (Winds < 8 mph) (Current < 0.20 ft/s)			
		CL	W	A	HD	CL	W	A	HD	CL	W	A	HD	CL	W	A	HD
Group #1 <u>Northward Plumes</u>																	
22 April	1327-1510	4649	1339	170	2.2												
20 May	1130-1300	3476	2216	104	2.0												
7 Aug.	1056-1400	5519	1232	83	1.5												
7 Aug.	1604-1741	2499	642	26	1.5												
9 Aug.	1900-2037					-	-	-	2.3								
Average		4036	1357	96	1.8												
Group #2 <u>Lakeward Plumes</u>																	
22 July	1400-1815																2.0
26 Aug.	1200-1445	2061	581	19	1.0												
23 Sept.	1140-1420													1690	1005	19	2.5
21 Oct.	1125-1438					4062	1670	117	2.5								
18 Nov.	2027-2220													6581	3800	404	-
28 Nov.	1000-1440	2752	790	28	2.5												
8 Aug.	0930-1136	2502	1044	46	1.7												
9 Aug.	1018-1300					2645	515	21	0.9								
10 Aug.	1425-1638	-	-	-	1.9												
Average		2432	805	31	1.8	3354	1093	69	1.7					4095	2403	212	2.3
Group #3 <u>Southward Plumes</u>																	
24 June	1220-1520																1.5
11 Aug.	1115-1420													2606	858	24	2.2
11 Aug.	1610-1824																1.5
Average														2606	858	24	1.7

- Missing Data

CL=2CAT isotherm centerline length (ft).

W= 2CAT isotherm maximum width measured perpendicular to the centerline (ft).

A= 2CAT isotherm area (acres).

HD=Plume Half-Depth, the depth at which the surface excess temperature decreases by one half, (meters).

Fig. 12. Isotherms (degrees centigrade) of Excess Temperature for the North-Directed Thermal Plume at Kewaunee, April 22, 1975.

Table 14. Environmental and Plant Operating Conditions during Three Thermal Plume Surveys at Kewaunee Nuclear Power Plant

	25 Jun 1975	18 Nov 1975	22 Apr 1975
Discharge Rate (cfs)	918	918	918
Temperature (°C)			
Ambient	12.6	6.0	7.8
Intake	12.8	6.5	8.1
Discharge	23.3	12.4	18.3
Ambient Current			
Speed (fps)	0.17	0.11	0.42
Direction	SSW	NE	N
Wind			
Speed (mph)	2.5	13	10
Direction	SW	S	SSE

in contact with the lake bottom at a depth of 4 m approximately 1000 ft north of the discharge outlet.

Lakeward Plumes

An example of one of the lakeward-directed plumes is the study of November 18, 1975 (see Fig. 13 and Table 14). The lakeward plumes of Category I were on the average smaller than northward plumes of Category I. The confining boundary effect and the lee-side reentrainment seen in the northward plumes did not generally occur for the plumes directed lakeward. However, comparing the plume characteristics between Categories I, II and III of the lakeward set yields wide variations between such plumes observed. The centerline length and maximum width of the 2°C excess temperature isotherm for the nine lakeward plumes of 1975 ranged from 1690 ft to 6581 ft and 581 ft to 3800 ft respectively. Plume half-depths determined near the plume centerline ranged from 0.9 to 2.5 m. The 2°C excess temperature isotherm was in contact with the lake bottom at depths between 3 m and 5 m approximately 900 to 1700 m from the discharge outlet. The surface area of the 2°C isotherm ranged from 19 to 404 acres. Comparing Categories I, II, and IV of the lakeward plumes (Group II) indicates that the size of the plume increased as the wind and current speeds decreased. Vertical temperature decay was more rapid for plumes with smaller currents and winds. Large currents and winds apparently increase vertical mixing and dilution. The NALCO group emphasized their difficulty in determining a single value for ambient temperature during summer stratified periods when offshore and vertical temperature gradients were present. They found that the characteristics of the 2°C isotherm were highly dependent on the value chosen for ambient temperature.

Southward Plumes

Two of the three southward flowing plumes reported in Table 13 were not sufficiently defined to close the 2°C isotherm. The third plume (June 25, 1975,

Fig. 13. Isotherms (degrees centigrade) of Excess Temperature for the Lakeward-Directed Thermal Plume at Kewaunee, November 18, 1974.

Fig. 14 and Table 14) was measured under changing environmental conditions. Consequently, the choice of ambient temperature was difficult. The apparent effect of the promontory south of the discharge was to deflect the plume to the southeast until offshore currents turned it southward. The absence of confining boundaries made these plumes the most rapidly diluting of the three groups. Sharp vertical temperature gradients within 2500 ft of the discharge and near the plume centerline were characteristic of the southward plumes. Half-depths ranged from 1.5 m to 2.2 m for the June 25 case and the 2°C isotherm made contact with the lake bottom at a maximum distance of 1100 ft south of the discharge outlet. Based only on the limited mappings carried out, it appears that the smallest surface plumes are those directed southward. Their small size is perhaps the result of minimal boundary interference and an ample supply of dilution water brought in by the southwardly directed ambient current.

An interesting sketch of the generic location of the 2°C isotherm was made by NALCO for the Kewaunee 316a demonstration for the U. S. EPA. According to the U. S. EPA September 1974 Draft Guidelines for a 316(a) Demonstration, the Discharge Zone for a power plant is

"that portion of the receiving waters which falls within the 2°C excess temperature isotherm 30% or more of the time, as defined by data representing a period of at least a few months and preferably indicative of a complete cycle"

NALCO attempted an estimate of this discharge zone by drawing the smallest curve which encloses the furthest extent of the 2°C surface isotherms for all plumes mapped from June 1974 - June 1975. The same was done for the 2°C isotherm on bottom of the lake. The results appear in Figure 15. This definition of the discharge zone was found to include 985.3 acres at the surface and 94.5 acres at the bottom. In Appendix 1 to Public Service Notice 4WI-0515B issued by the State of Wisconsin Department of Natural Resources on August 28, 1975, the mixing zone as of July 1, 1979, is defined as "The area within the perimeter of a rectangular figure extending 1250 feet in both directions along the shoreline and 1250 into the lake." This region which encompasses 71.74 acres is shown in Figure 15. The discharge zone of the Kewaunee Plant exceeds this limitation.

A study of the data themselves shows them to be quite consistent from 1974 to 1975 (see Fig. 16). Although the power levels are different (50% in 1974 and 100% in 1975) the normalization θ/θ_0 apparently does the trick to relate areas between the 1974 and 1975 plumes (see Fig. 16). The conglomerate of 1974 and 1975 data are plotted in Figure 11 for centerline temperature, maximum plume width, and surface areas. A large amount of scatter exists at the lower isotherms; largely variable ambient conditions are considered responsible. Surprisingly, the plume direction (northward, southward, and lakeward) is a significant but not the major cause of differences between plumes. It is the ambient current and wind speed causing more or less dilution in the far field once the plume is no longer depth limited and free to entrain vertically as well as laterally. Greater winds and currents caused greater mixing and reduced temperature.

The Asbury-Frigo curve along with the envelope of the data used to construct it is plotted along with the data in Figure 12. It is revealing that better than expected predictions (in terms of expectations from this curve)

Fig. 14. Isotherms (degrees centigrade) of Excess Temperature for the South-Directed Thermal Plume at Kewaunee, June 25, 1975.

Fig. 15. Configuration Area of the Surface and Bottom Thermal Discharge Zone at Kewaunee. Solid and open circles represent furthest extents of $\Delta T = 2^{\circ}\text{C}$ isotherms at the surface and bottom, respectively, for plumes surveyed June 1974-June 1975.

are achieved by the Kewaunee plumes. This is probably due to the Kewaunee jet being of high velocity which allows it to mix much better with ambient water than the low velocity discharges whose plumes were used to set up the Asbury-Frigo correlation. The shallowness of the bottom does reduce the dilution capability and consequently the improvement with respect to the Asbury-Frigo curve is not a major one.

Figure 17 plots together measurements made by dye and temperature for the same plumes. In the figure, all open symbols represent temperature measurements; the same symbol but closed represents the corresponding dye measurement. All temperature/dye plumes are included in that graph. It appears that the dye is a good second measure of plume characteristics for unstratified lake conditions (fall and winter), but is not adequate during stratified conditions (late spring and summer); the dye was useful under these stratified conditions solely to help determine the location of the plume in the lake and better define ambient temperatures. The success of dye as a second measure of temperature under unstratified ambient conditions is illustrated in Figures 18 and 19 for plumes in November 1974.

The possibilities of eddy circulation due to the presence of the promontory were studied on four dates in 1974. As many as 10 drogues were set out near the promontory and tracked for several hours. Drogue trajectories were plotted and drogue speeds and directions were tabulated. The drogue trajectories were used as an estimate of current patterns near the promontory. Figure 20 shows a generalized picture of the results of a northward and southward ambient current. Apparently a weak eddy current is present for north currents of magnitude about 0.3 fps; the eddy is noticed by a turning of the drogues northward towards the shore; for a measured current of 0.42 fps, a significant eddy current was noticed. This eddy was observed to have a radius of approximately 1200 ft including an area of about 104 acres. Drogues within 1600 ft from shore were affected by this eddy while drogues further offshore followed the ambient current. Clearly, eddy size is dependent upon current speed. For an observed southward current of 0.25 fps, drogue trajectories indicated that the current is deflected by the promontory towards the southeast. No evidence of eddy circulation on the south side of the promontory was found. Apparently, only the larger northward currents are affected by an eddy circulation. Such cases would imply a significant reentrainment of plume water on the lee side only in those cases.

Additional auxiliary data were taken to help interpret the nature of the thermal plumes at Kewaunee. A secondary purpose was to provide data often required by biologists studying the thermal impact of the plume on aquatic biota. The first are plume velocity measurements made by drogues.

A sample of the surface velocity distribution along the centerline of the plume is presented in Figure 21. These data were measured for an offshore directed plume on November 15, 1974. The drogues were released within 108 feet of the outfall structure and allowed to drift with the current. The exit velocity (3.1 fps) was calculated from the volume discharge rate (918 fps) and the outlet area (312 ft²) for a lake elevation of 579 ft.

Time-temperature studies were also carried out during 1974 and 1975. These data were collected by means of a drogue outfitted with a strip-chart recorder and a thermistor located at a depth of 1.6 ft. The drogue, simulating

Fig. 17. Plume Characteristics as Determined Simultaneously from Temperature and Dye Measurements: (top) center-line decay, (middle) maximum plume width, (bottom) surface areas.

Fig. 18. Fractional Decrease in Excess Temperature and Dye Concentration with Centerline Distance for Thermal Plumes at Kewaunee, November 16-22, 1974.

Fig. 19. Variations of Surface Area with Excess Temperature and the Equivalent Dye Concentration for Plumes Surveyed at the Kewaunee Plant, November 16-22, 1974. The excess temperature and equivalent dye concentration are expressed as a fraction, $\Delta T / \Delta T_0$, of the excess temperature or dye concentration at the discharge outlet.

Fig. 20. Schematic Illustration of: (left) Eddy Circulation Associated with Northward Currents in Lake Michigan near the Kewaunee Plant, (right) the Deflection of Southward Currents in Lake Michigan by the Promontory near the Kewaunee Plant.

Fig. 21. Plume Velocity Versus Distance from the Discharge Canal Outlet for a Thermal Plume at Kewaunee. Measurements were made by tracking two drogues released near the outlet.

a drifting organism was allowed to follow the current while simultaneously recording temperature. Time-temperature relationships are presented in Figure 22. The initial portion of each curve is based upon estimates of the travel time from the intake to the point of efflux. The central portion of the curves were derived from seven time-temperature profiles for four thermal plumes surveyed on Nov. 15, 1974, Nov. 22, 1974, May 20, 1975, and July 21, 1975. Each curve was extrapolated to ambient temperature based on 1) the location of the drogue when retrieved, 2) ambient current, and 3) extent of the thermal plume. The average time-temperature relationship shown in Figure 22 is the mean of the seven measured profiles. The two extreme cases were considered best and worst cases based on time required to return to ambient.

The reduction in excess temperature within 50 to 75 minutes travel time from the outfall was found to range from 55% for the worst case to 90% for the best case. The worst case shows a significant increase in excess temperature for travel times longer than 60-75 minutes. NALCO believes that this was a result of a changing plume configuration during measurements.

It should be noted that the plumes used in the above averaging did not have similar plume characteristics because the time-temperature studies were done on dates chosen only through convenience. Details on the specific conditions of each drogue study as well as the precise drogue paths are to be found in the source references.

COMPARISON OF PREOPERATIONAL MODEL AND OPERATIONAL DATA

We restrict our attention to the evaluation of the Pritchard Model No. 2 which was used by the applicant before the plant was operational. A lake level of 577 ft (IGLD) was always used by NALCO for preoperational calculations. Consequently, we first ran the computer code for that lake level for all 1974 and 1975 thermal plumes in spite of sometimes significant lake level variations. We consider that those runs represent preoperational predictions, since the model was used in that mode before the plant was operational. We call these runs Version 1 of the Pritchard Model No. 2. As noted above, the NALCO group did not consider lake level variations at all perhaps expecting them to have an insignificant effect on plume dispersion.

We also, for each plume survey in 1974 and 1975, had the Pritchard Model No. 2 rerun a second time but this time using the correct lake level for the plume survey tested. These calculations better test the accuracy of the model, since we are supplying it the most accurate input conditions for the particular data comparison. As mentioned above, lake level was apparently an important parameter at Kewaunee (during 1974 and 1975) because it affected the depth of the discharge and the exit velocity. At low water level of 575.8 ft, the initial discharge velocity would be 6.9 ft/sec (for 918 cfs) and a lake level range 581.4-579.4 ft, the initial discharge velocity ranges from 2.5 ft/sec - 2.3 ft/sec. For one-pump operation (December-April) the most usual lake level range is 579.4 ft to 578.8 ft yielding an initial jet velocity of 2.2-2.5 ft/sec. These changes appear to be significant and, under ordinary circumstances (with no bottom interference), would reflect directly on the dilution capability of the jet. The lower the lake level, the higher the discharge velocity and initial densimetric Froude number implying more dilution. On the other hand, the lower the lake level, the thinner the surface jet and the reduced quantity of entrainment water available for mixing. The close

Fig. 22. Time-Temperature Profiles for the Thermal Plume at Kewaunee. Profiles are plotted as thermal plume excess temperature versus time of travel from the discharge canal outlet. The first three minutes are travel time from the intake to the outlet. The dashed line indicates extrapolation.

proximity of the lake bottom in these cases will work against better dilution. Whether those opposing influences compensate for one another could not be assumed a priori. We call the application of the Pritchard model with the correct lake level, Version 2.

The third version tested against the field data was the NALCO modification (by P. P. Pailly) of the Pritchard No. 2 Model. Tech Specs required the utility to develop a model that satisfactorily predicts plumes at Kewaunee. The improvements were made by NALCO after they tested the original (preoperational) Pritchard Model No. 2 with the 1974-1975 Kewaunee plume data. NALCO modified some of the correlations for plume half-depth, centerline temperature decay and maximum plume width, but not the basic philosophy of the model. The changes are listed in Table 15. All these changes are empirical and were obtained from data to which the corrected model was fitted again.

Table 15. NALCO Modifications of Pritchard Model No. 2

1. Half-depth:

$$h_{\frac{1}{2}} = 0.3 (h_o b_o)^{\frac{1}{2}} (Ar)^{\frac{1}{4}} (F_o)^{3/4} [1 - 1/(F_o)^{\frac{1}{2}}]$$

2. Centerline Distance:

$$S_{\theta} = 2.91 (b_o) (\theta/\theta_o)^{-4}, \text{ for } (\theta/\theta_o) \geq 0.6$$

$$S_{\theta} = 10.43 (b_o) (\theta/\theta_o)^{-3/2}, \text{ for } 0.6 \geq (\theta/\theta_o) \geq 0.2$$

$$S_{\theta} = 23.32 (b_o) (\theta/\theta_o)^{-1}, \text{ for } (\theta/\theta_o) \leq 0.2$$

3. Maximum Plume Width:

$$b_{\theta} = b_o + m_1 \epsilon, \text{ for } (\theta/\theta_o) \geq 0.6$$

$$b_{\theta} = b_o + m_2 \epsilon, \text{ for } 0.6 \geq (\theta/\theta_o) > 0.2$$

$$b_{\theta} = b_o (1 - 61.4 m_1) + m_2 \epsilon, \text{ for } (\theta/\theta_o) \leq 0.2$$

4. Plume Surface Area:

$$A = 0.86 \epsilon b_{\theta}$$

Note: All other correlations and calculations remain the same as in Pritchard Model No. 2.

Although we compared the predictions of all three models with each of the 28 thermal plumes mapped by NALCO, only 12 comparisons are presented here. We have divided the 12 into the following groups: 4 plumes directed northward (Figs. 23-27), 4 plumes directed lakeward (Figs. 28-32), and 4 plumes directed southward (Figs. 33-37). The actual isotherm maps (derived from measurements at 0.5 m) are presented in Figures 23, 28, and 33. Conglomerate plots of predictions versus measurements for the three codes (in terms of centerline temperature decay, maximum plume width, and surface areas) are presented in Figures 38-40. Conclusions based on our analysis are as follows:

1. The predictions of the Pritchard Model No. 2 (nominal lake level), Pritchard Model No. 2 (actual lake level), and the NALCO modification of the Pritchard Model No. 2 are successively better in terms of their overall descriptive capability. These models will be referred to as Versions 1, 2, and 3, respectively in the discussion. In each version, the plumes predicted are narrow, cool, and deep compared to the measured plumes. This statement applies to isotherms in which $\theta/\theta_0 > 0.2$. A drastic increase in maximum plume width, distance to an isotherm and surface isotherm areas occurs in Versions 1 and 2 for $\theta/\theta_0 \leq 0.2$, implying a corresponding reduction in plume depth over the same region. This result reflects poorly on the turbulent diffusion portion of the Pritchard Model No. 2; it was changed in Version 3 and separately by Pritchard himself (not shown).¹⁴ Version 3 of the model corrects this gross overprediction for $\theta/\theta_0 > 0.2$ quite well, but does so empirically based on the Kewaunee data itself through a fitting procedure.

2. The original preoperational model (Version 1) has the following characteristics.

- a. Predictions of the half-depth of the plume are too large generally by a factor or two.

- b. The centerline distance to those excess temperatures greater than 20% of the initial excess temperature is predicted within a factor of three.

- c. The maximum width of those excess temperatures greater than 20% of the initial excess temperature is predicted within a factor of 2.0.

- d. The area of those excess temperatures greater than 20% of the initial excess temperature is predicted within a factor of five.

- e. The model underestimates the amount of mixing when the excess temperature is less than 20% of the initial excess temperature and therefore overestimates the size of the plume at these temperatures.

3. The discrepancy between each version of the model and the data does not seem to be explained by either season or direction of the plume (northward, southward, or lakeward) at least in the near field. This is probably due mostly to the bottom-limited nature of the plume during all these situations. The far-field data show changes due to ambient current (in the data primarily and only secondarily in the model) due to wind (data only)--larger values cause more mixing and consequently smaller plumes. Predictions do not show significant changes in the far field.

4. Version 3 of the code replicates within a factor of 2 the half-depth, centerline distance, maximum width and surface areas.

Fig. 23. Surface Isotherm Maps (0.5-m depth) for Four Selected Thermal Plumes Directed Northward.

KEWAUNEE NUCLEAR POWER PLANT - 17 NOV 1974 0900-1200.

Fig. 24. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the North-Directed Thermal Plume of November 17, 1974 (0900-1200 hrs).

KEWAUNEE NUCLEAR POWER PLANT--19 NOV 1974, 0900-1100

Fig. 25. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the North-Directed Thermal Plume of November 19, 1974 (0900-1100 hrs).

KEWAUNEE NUCLEAR POWER PLANT — 22 APRIL 1975

Fig. 26. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the North-Directed Thermal Plume of April 22, 1975.

KEWAUNEE NUCLEAR POWER PLANT 9 AUGUST 1975 1900-2087

Fig. 27. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the North-Directed Thermal Plume of August 9, 1975 (1900-2037 hrs).

Isotherms at 0.5 meter depth for the thermal plume at Kewaunee Nuclear Power Plant on Lake Michigan, 17 November 1974, 1300-1600 hours.

Isotermis of 0.5 meter depth for the thermal plume at
Kewaunee Nuclear Power Plant on Lake Michigan.
18 November 1974, 0845-1100 hours.

1 Isotherms at 0.5 meter depth at the Kewaunee Nuclear Power Plant on Lake Michigan, 8 August 1975, 0937 -1107 hours.

Isotherms at 0.5 meter depth for the thermal plume at the Kewaunee Nuclear Power Plant on Lake Michigan, 18 November 1975, 2027-2220 hours.

Fig. 28. Surface Isotherm Maps (0.5-m depth) for Four Selected Thermal Plumes Directed Lakeward.

KEWAUNEE NUCLEAR POWER PLANT — 17 NOV 1974, 1300-1600

Fig. 29. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the Lakeward-Directed Thermal Plume of November 17, 1974 (1300-1600 hrs).

KEWAUNEE NUCLEAR POWER PLANT--18 NOV 1974, 0845-1100

Fig. 30. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the Lakeward-Directed Thermal Plume of November 18, 1974 (0845-100 hrs).

KEWAUNEE NUCLEAR POWER PLANT 8 AUGUST 1975 0939-1109

Fig. 31. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the Lakeward-Directed Thermal Plume of August 8, 1975 (0930-1109 hrs).

KEWAUNEE NUCLEAR POWER PLANT -- 18 NOVEMBER 1975

Fig. 32. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the Lakeward-Directed Thermal Plume of November 18, 1975.

Fig. 33. Surface Isotherm Maps (0.5-m depth) for Four Selected Thermal Plumes Directed Southward.

KEWAUNEE NUCLEAR POWER PLANT -- 25 JUNE 1974

Fig. 34. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the South-Directed Thermal Plume of June 25, 1974.

KEWAUNEE NUCLEAR POWER PLANT--20 NOV 1974, 1300-1500

Fig. 35. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the South-Directed Thermal Plume of November 20, 1974 (1300-1500 hrs).

KEWAUNEE NUCLEAR POWER PLANT -- 24 JUNE 1975

Fig. 36. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the South-Directed Thermal Plume of June 24, 1975.

KEWAUNEE NUCLEAR POWER PLANT 11 AUG. 1975 1115-1402

Fig. 37. Model-Data Comparisons for Centerline Temperature Decay, Maximum Plume Width, and Surface Isotherm Areas for the South-Directed Thermal Plume of August 11, 1975 (1115-1402 hrs).

Fig. 38. Conglomerate Plot of Model-Data Comparisons of Centerline Temperature Decay for Versions 1, 2, and 3 (left, middle, right, respectively).

Fig. 39. Conglomerate Plot of Model-Data Comparisons of Maximum Plume Width for Versions 1, 2, and 3 (left, middle, right, respectively).

Fig. 40. Conglomerate Plot of Model-Data Comparisons of Surface Isotherm Areas for Versions 1, 2, and 3 (left, middle, right, respectively).

DISCUSSION OF PLUME DATA AND MODEL VALIDATION

We feel that the plume data acquired by NALCO were certainly of good quality for the higher isotherms. Under unstratified ambient conditions, if no reentrainment of previously discharged plume water existed; i.e., the ambient current persistent in one direction for a long period of time (~ 2 days), then a choice of ambient temperature would be greatly simplified and the data-taking procedure would be most accurate. Limitations on the data-gathering procedure are the following:

1. The total time necessary to carry out a plume survey varied from 2-4 hours which is quite long compared with about $\frac{1}{2}$ -1 hour using state of the art techniques employing a single boat with multiple thermistors. In some cases, under transient ambient conditions, their technique led NALCO to difficulties in determining a synoptic plume. The validity of the data is open to question for these cases. The use of a single sensor at 0.5 m depth and not a multidepth, multisensor apparatus forced NALCO to use two boats--one to determine a horizontal plume map and the second to provide vertical profiles. This indeed was quite cumbersome and led to problems when conditions were not fairly steady.
2. The use of dye in the November 1974 surveys was helpful in providing an additional measure of the plume temperature field; this was for unstratified conditions. Here the dye helped to define ambient temperature as well. The use of dye under stratified conditions was helpful only in that it allowed a better determination of the ambient condition; i.e., it helped distinguish the ambient from the plume. There is no scaling possible between dye and temperature under stratified conditions (due to a nonuniform background for the temperature field) and consequently dye measurements in those cases should not be used in validating models. We feel that the dye tracer could have been used more effectively for all plume mappings, and not just for selected field surveys.
3. Outlet conditions could have been more carefully studied. NALCO relied solely upon the plant measurements for flow rate; in actuality, experience has shown that the proper flow rate can easily vary by 15% of the nominal rate for the plant. Such a difference could be significant for a model validation effort. The determination of the correctness and constancy of that flow rate could have been evaluated by making occasional careful vertical and horizontal profiles of the jet velocity at the discharge outlet. Perhaps a better method would be to employ a tracer to check the flow rate inside the plant as done by Hydrocon at the Zion plant.¹⁵ NALCO did, however, measure the outlet temperature by moving their boat up to the point of discharge--as best they could considering they had to move against a large velocity.
4. The choice of ambient temperature for unstratified conditions was generally satisfactory. A problem exists in requiring oneself to choose a single number to represent an ambient waterbody, stratified in the offshore and vertical direction. We feel it would be more appropriate to relate each plume temperature to an ambient temperature chosen from the best information available--a combination of offshore and vertical temperature gradients.¹⁵

For a point y offshore and z below the surface, the plume excess temperature would then be the measured plume temperature minus the offshore ambient at the y distance offshore--that quantity attenuated by a fraction between 0

and 1 taken from the corresponding point in the normalized ambient vertical profile.

Limitations on the NALCO plume prediction and modeling effort are as follows:

1. Preoperational predictions should have been carried out examining possible lake level variations since the lake level has a large effect on initial discharge parameters such as initial densimetric Froude number (through initial velocity and channel depth), aspect ratio (through channel depth), and ambient current-to-discharge velocity ratio. Significantly different plumes are "theoretically" possible over the range of lake levels observed. The effect of the shallower bottom probably mitigated somewhat those effects. However, that was not known a priori.

2. The NALCO modification of the Pritchard Model No. 2 removed some of the sharp discrepancies in predictive trends shown in the model-data comparisons but did not make the model wholly satisfactory. The major improvement NALCO effected was in the predictions for plume areas. A sharp improvement is seen upon analysis of Figure 40. However, the changes made in the Pritchard Model No. 2 were not significant enough to correct the underprediction of plume length and maximum isotherm width in the near field ($\theta/\theta_0 > 0.2$). Improvements were indeed effected (See Figs. 38 and 39) but are only a start. The major improvement made was in correcting the over-prediction of surface plume size by allowing more mixing to take place for $\theta/\theta_0 < 0.2$. Pritchard had assumed simple turbulent diffusion operational in the far-field temperature region. Only recently has Pritchard made a modification¹⁴ himself in that region. He did this by matching the preoperational Pritchard Model No. 2 with a point source diffusion model (the plant as a point source in a uniform current) at some calculated distance in the far field (this distance is calculated by setting the two temperature distributions equal) and using the point source model from there on. Our major point here is that NALCO did indeed improve the Pritchard model for Kewaunee applications but did not improve it to the point that all plume characteristics were satisfactorily modeled. We believe this to be a limitation not so much of the NALCO work but of the basic formulation of the Pritchard model which is too over-simplified to encompass all the major plume dispersive phenomena. The Pritchard phenomenological model was developed from data that were too idealized (mostly laboratory data) to handle the rigors and complexity of the Kewaunee site (wind effects, highly irregular bottom profile, transient effects). The quantity of good quality data (laboratory and field) that are available for the development of a good phenomenological model is still limited.

CONCLUSIONS

1. The NALCO plume mapping studies at Kewaunee were generally adequate to define the surface temperatures for the higher isotherms under stratified conditions and the complete set of isotherms (down to 2°C) for unstratified conditions. At times, the surveys were not synoptic due to the long survey times (2-4 hours). The dye tracer Rhodamine WT could have been used more effectively in defining plume characteristics and excess temperatures for all surveys. Careful measurements of outfall conditions are very necessary for the model validation portion of their program; actual measurements of the plant flow rate (and hence initial jet velocity) should have been made to verify the nominal value.

2. No surveys were carried out during the winter-spring period when the operating policy of the plant was significantly different. For this period only one of the two pumps operates, requiring a 28°F ΔT across the condensers (larger than the nominal $\Delta T = 20^{\circ}\text{F}$). We expect these plumes to be larger than the one measured. It is unfortunate that no such plumes were ever measured; they could very well have provided the most extreme temperature conditions. Winter sinking plumes were also not measured. The bottom area affected by the Kewaunee plume would be expected to be maximal under such winter sinking conditions. In addition, the possible Point Beach plume interaction on the Kewaunee plume was not studied; we do not consider this as significant an omission, however, since such interaction is expected to occur only seldom and be rather inconsequential.

3. The Kewaunee plume characteristics show a wide scatter due to different outfall and ambient conditions present during the surveys. Plumes are significantly affected by their direction (northward, lakeward, southward). The distribution of plume characteristics within each of the above three groups seems to be determined from the magnitude of the ambient current and wind. More specifically the far-field characteristics of plumes within a group depend mostly on current speed and wind speed: the greater these quantities, the smaller the surface plume size (of course, more vertical mixing and an increased vertical depth results). The time history of ambient current and wind speed are undoubtedly important also in their effects on plume reentrainment. This, however, was not studied. The Wisconsin state requirement of the area of the 2°C isotherm to be less than 72 acres is probably always violated; the measured values (for 100% plant power level) range from 100-300 acres. The earlier 1972 State of Wisconsin regulation of a 3°F (1.7°C) mixing zone of 1000 ft (31 acres) was always violated when that isotherm (actually 1°C) could be closed.

4. The application of the preoperational model to the plume data indicates a sharp underprediction of plume characteristics for $\theta/\theta_0 > 0.20$ and a sharp overprediction for $\theta/\theta_0 < 0.20$. This value of $\theta/\theta_0 = 0.20$ typically involves areas of about 100 acres. The application of the model with actual lake level variation included performed slightly better than with a fixed average lake level [577 ft (IGLD)], as was used in all preoperational calculations. Both versions of the preoperational model were not satisfactory in terms of being able to predict the trends in plume characteristics. The NALCO modification of the Pritchard Model No. 2 provided a significant improvement over the preoperational model in terms of being able to replicate the field data yet still needs more work in terms of replicating plume lengths and widths (total area predictions are satisfactory). It should be noted that the NALCO modification of Pritchard's Model No. 2 was developed from the fitting of existing plume data at Kewaunee and has no theoretical basis. It has never been tested to determine its predictive capability against new Kewaunee data. In this sense, the NALCO modification is a model for past Kewaunee plumes and not necessarily for future plumes; at least, the model has not been validated with plume data that it was not developed with. The NALCO model is very site specific and use at other sites also requires extensive validation before doing so.

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APPENDIX K1

STATISTICAL COMPARISONS OF MONTH AND STATION

EFFECTS ON THE DISTRIBUTION OF SELECTED GROUPS OF ORGANISMS

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KEWAUNEE

Phytoplankton and Diatoms

1972 Total Phytoplankton

1.	Source	F	α	Statistical Significance
	Month	10.0867	0.0006	SD
	Station	3.3843	0.0204	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	SD (.05)
	11	vs	14	SD (.05)
3.	Stations in order of decreasing means: 2, 11, 14			

DIATOMS

1.	Source	F	α	Statistical Significance
	Month	7.0121	0.0028	SD
	Station	6.1556	0.0015	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	SD (.05)
	11	vs	14	SD (.01)
	12	vs	16	SD (.05)
3.	Stations in order of decreasing means: 2, 16, 11, 12, 14			

KEWAUNEE

1973 Total Phytoplankton

1.	Source	F	α	Statistical Significance
	Month	8.5299	0.0001	SD
	Station	5.3999	0.0002	SD

DIATOMS

1.	Source	F	α	Statistical Significance
	Month	17.4390	0.0001	SD
	Station	6.1547	0.0001	SD
2.	Station Comparisons (Diatoms and Total Phytoplankton):			Stat. Sig.
	2	vs	11	NSD
	11	vs	12	SD (.05)
	11	vs	7	SD (.01)
	11	vs	14	SD (.01)
	11	vs	16	SD (.01)
3.	Stations in order of decreasing means (Diatoms and Total Phytoplankton):			
	11, 2, 12, 7, 16, 14			

KEWAUNEE

1974 Total Phytoplankton

1.	Source	F	α	Statistical Significance
	Month	12.6636	0.0001	SD
	Station	8.5173	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	11	vs	7	SD (.10)
	11	vs	14	SD (.01)
	2	vs	11	NSD
	11	vs	12	NSD
	11	vs	16	NSD
3.	Stations in order of decreasing means: 11, 2, 16, 7, 14			

DIATOMS

1.	Source	F	α	Statistical Significance
	Month	11.4909	0.0001	SD
	Station	8.9431	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	11	vs	7	SD (.10)
	11	vs	14	SD (.01)
	2	vs	11	NSD
	11	vs	12	NSD
	11	vs	16	NSD
3.	Stations in order of decreasing means: 11, 2, 16, 12, 14			

KEWAUNEE

1975 Total Phytoplankton

1.	Source	F	α	Statistical Significance
	Month	15.2937	0.0001	SD
	Station	6.2258	0.0001	SD
2.	Station Comparisons:			Statistical Significance
		12	vs 11	SD (.05)
		11	vs 7, 2,14,16	SD (.01)
3.	Stations in order of decreasing means: 11, 12, 2, 7, 16, 14			

DIATOMS

1.	Source	F	α	Statistical Significance
	Month	15.4115	.0001	SD
	Station	7.2032	.0001	SD
2.	Station Comparisons:			Statistical Significance
		12	vs 11	SD (.05)
		11	vs 7, 2,14,16	SD (.01)
3.	Stations in order of decreasing means: 11, 12, 2, 7, 16, 14			

KEWAUNEE

1973, 1975 Preoperational, Operational

Total Phytoplankton

1.	Source	F	α	Statistical Significance
	Month	11.2641	0.0001	SD
	Station	9.6327	0.0001	SD
	Station vs month	0.7339	0.8587	NSD
	Year	13.7364	0.0005	SD
	Station vs Year	0.4097	0.8918	NSD
	Month vs Year	9.0897	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	SD (.01)
	11	vs	7	SD (.01)
	11	vs	12	SD (.01)
	11	vs	14	SD (.01)
	12	vs	14	SD (.01)
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means:			
	11, 2, 20, 12, 7, 16, 24, 14			

KEWAUNEE

1973, 1975 Preoperational, OperationalDIATOMS

1.	Source	F	α	Statistical Significance
	Month	16.7982	0.0001	SD
	Station	11.1297	0.0001	SD
	Station vs Month	0.7749	0.8124	NSD
	Year	29.1502	0.0001	SD
	Station vs Year	0.5651	0.7818	NSD
	Month vs Year	12.6636	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	SD (.01)
	11	vs	7	SD (.01)
	11	vs	12	SD (.01)
	11	vs	14	SD (.01)
	12	vs	14	SD (.01)
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means: 11, 2, 20, 12, 7, 16, 24, 14			

KEWAUNEE GENERATING STATION

Statistical Comparisons

<u>Intra-Year 1972</u>		
<u>Month</u>	<u>Station</u>	<u>Sta. * Mo.</u>
<u>Phytoplankton</u>		
Diatoms	*	*
Total Phyto.	*	*

O No Significant Difference

* Significant Difference

KEWAUNEE GENERATING STATION

Statistical Comparisons

	Intra-Year 1973			Inter-Year 1973, 1975					
	Month	Station	Sta. * Mo.	Month	Station	Year	Sta. * Mo.	Sta. * Yr.	Mo. * Yr.
<u>Phytoplankton</u>									
Diatoms	*	*	-	*	*	*	0	0	*
Total Phyto.	*	*	-	*	*	*	0	0	*
<u>Zooplankton</u>									
Cladocera	*	*	*	*	*	*	*	*	-
Copepoda	*	*	*	*	*	*	*	*	-
Rotifera	*	*	*	*	*	*	*	*	-
<u>Benthos</u>									
Naididae	*	*	*	*	*	*	*	*	-
Chironomidae	*	*	*	*	*	*	*	*	-
Total benthos	*	*	*	*	*	*	*	*	-

0 No Significant Difference

* Significant Difference

- No Data

KEWAUNEE GENERATING STATION

Statistical Comparisons

	Intra-Year 1974			Intra-Year 1975		
	<u>Month</u>	<u>Station</u>	<u>Sta. * Mo.</u>	<u>Month</u>	<u>Station</u>	<u>Sta. * Mo.</u>
<u>Phytoplankton</u>						
Diatoms	*	*	-	*	*	-
Total Phyto.	*	*	-	*	*	-
<u>Zooplankton</u>						
Cladocera	*	*	*	*	*	*
Copepoda	*	*	*	*	*	*
Rotifera	*	*	*	*	*	*
<u>Benthos</u>						
Naididae	*	*	*	*	*	*
Chironomidae	*	*	*	*	*	*
Total benthos	*	*	*	*	*	*

O No Significant Difference

* Significant Difference

- No Data

Kewaunee Generating Station - Statistical Analysis

TOTAL PHYTOPLANKTON

Intra-Year Sampling Station Comparisons (1972)

Stations	2	3	6	7	8	11	12	13	14	16	17
2						*					
3											
6											
7											
8											
11									*		
12											
13											
14											
16											
17											

DIATOMS

Intra-Year Sampling Station Comparisons (1972)

Table 10 A

Stations	2	3	6	7	8	11	12	13	14	16	17
2						*					
3											
6											
7											
8											
11									**		
12										*	
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

TOTAL PHYTOPLANKTON

Intra-Year Sampling Station Comparisons (1973)

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11				*			*		*	*	
12											
13											
14											
16											
17											

DIATOMS

Intra-Year Sampling Station Comparisons (1973)

Table 11A

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11				*			*		*	*	
12											
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

TOTAL PHYTOPLANKTON

Intra-Year Sampling Station Comparisons (1974)

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11				*			0		*	0	
12											
13											
14											
16											
17											

DIATOMS

Intra-Year Sampling Station Comparisons (1974)

Table 12A

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11				*			0		*	0	
12											
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

TOTAL PHYTOPLANKTON

Intra-Year Sampling Station Comparisons (1975)

Stations	2	3	6	7	8	11	12	13	14	16	17
2						**					
3											
6											
7						**					
8											
11				*			*		*	*	
12											
13											
14											
16											
17											

DIATOM

Intra-Year Sampling Station Comparisons (1975)

Table 13A

Stations	2	3	6	7	8	11	12	13	14	16	17
2						**					
3											
6											
7						**					
8											
11				*			*		*	*	
12											
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

TOTAL PHYTOPLANKTON

Inter-Year Sampling Station Comparisons (1973, 1975)											Table 13B
Stations	2	3	6	7	8	11	12	13	14	16	17
2						**					
3											
6											
7											
8											
11				**			**		**		
12				0					**	0	
13											
14											
16											
17											

DIATOMS

Inter-Year Sampling Station Comparisons (1973, 1975)											Table 13C
Stations	2	3	6	7	8	11	12	13	14	16	17
2						**					
3											
6											
7											
8											
11				**			**		**		
12				0					**	0	
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

KEWAUNEE

1973 Rotifera

1.	Source	F	α	Statistical Significance
	Month	562.9673	0.0001	SD
	Station	11.2938	0.0001	SD
	Sta. * Mo.	6.9801	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	SD (.05)
	11	vs	12	NSD
	11	vs	13	NSD
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means: 7, 16, 12, 11, 13, 2			

KEWAUNEE

1974 Rotifera

1.	Source	F	α	Statistical Significance
	Month	61.9864	0.0001	SD
	Station	5.8915	0.0001	SD
	Sta. * Mo.	2.0129	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	NSD
	11	vs	12	NSD
	11	vs	13	SD (.05)
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means: 11, 16, 7, 2, 12, 13			

KEWAUNEE

1975 Rotifera

1.	Source	F	α	Statistical Significance
	Month	1701.1190	0.0001	SD
	Station	94.5576	0.0001	SD
	Sta. * Mo.	17.6314	0.0001	SD
2.	Stations Comparison:			Statistical Significance
	2	vs	11	SD (.05)
	11	vs	12	SD (.01)
	11	vs	13	SD (.01)
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means: 11, 2, 12, 7, 16, 13			

KEWAUNEE

1973, 1975 Preoperational, OperationalRotifera

1.	Source	F	α	Statistical Significance
	Station	5.5848	0.0001	SD
	Month	186.3261	0.0001	SD
	Year	3271.7334	0.0001	SD
	Sta. * Mo.	1.1768	0.0001	SD
	Sta. * Yr.	3.3516	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	SD (.05)
	11	vs	12	NSD
	11	vs	13	SD (.01)
	11	vs	6	NSD
	11	vs	7	NSD
	11	vs	8	SD (.01)
	11	vs	17	SD (.01)
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means:			
	11, 6, 7, 12, 16, 2, 13, 8, 17			

KEWAUNEE

1973 Cladocera

1.	Source	F	α	Statistical Significance
	Month	3115.8076	0.0001	SD
	Station	25.7409	0.0001	SD
	Sta. * Mo.	18.8010	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	NSD
	11	vs	12	NSD
	11	vs	13	NSD
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means: 2, 7, 11, 13, 16, 12			

KEWAUNEE

1974 Cladocera

1.	Sources	F	α	Statistical Significance
	Month	969.1495	0.0001	SD
	Station	27.6995	0.0001	SD
	Sta. * Mo.	21.5469	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	NSD
	11	vs	12	SD (.05)
	11	vs	13	NSD
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means: 11, 7, 2, 13, 12, 16			

KEWAUNEE

1975 Cladocera

1.	Source	F	α	Statistical Significance
	Month	1510.8786	0.0001	SD
	Station	20.2075	0.0001	SD
	Sta. * Mo.	11.5810	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	NSD
	11	vs	12	NSD
	11	vs	13	NSD
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means: 11, 2, 12, 7, 13, 16			

KEWAUNEE

1973, 1975 Preoperational OperationalCladocera

1.	Source	F	α	Statistical Significance
	Station	4.4539	0.0001	SD
	Month	983.1328	0.0001	SD
	Year	280.8445	0.0001	SD
	Sta. * Mo.	4.6471	0.0001	SD
	Sta. * Yr.	4.99406	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	NSD
	11	vs	12	NSD
	11	vs	13	NSD
	11	vs	6	NSD
	11	vs	7	NSD
	11	vs	8	NSD
	11	vs	17	SD (.01)
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means:			
	11, 2, 6, 7, 12, 13, 16, 8, 17			

KEWAUNEE

1973 Copepoda

1.	Source	F	α	Statistical Significance
	Month	876.0704	0.0001	SD
	Station	40.6769	0.0001	SD
	Sta. * Mo.	25.5439	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	NSD
	11	vs	12	NSD
	11	vs	13	NSD
	12	vs	16	NSD
	12	vs	7	NSD
3.	Stations in order of decreasing means:			
	17, 8, 7, 6, 13, 12, 11, 2, 16			

KEWAUNEE

1974 Copepoda

1.	Source	F	α	Statistical Significance
	Month	572.5330	0.0001	SD
	Station	32.9334	0.0001	SD
	Sta. * Mo.	13.2347	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	NSD
	11	vs	12	NSD
	11	vs	13	SD (.05)
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means: 13, 16, 2, 12, 7, 11			

KEWAUNEE

1975 Copepoda

1.	Sources	F	α	Statistical Significance
	Month	2337.1132	0.0001	SD
	Station	42.2790	0.0001	SD
	Sta. * Mo.	19.3258	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	NSD
	11	vs	12	NSD
	11	vs	13	NSD
	11	vs	7	NSD
	11	vs	16	NSD
3.	Stations in order of decreasing means:			
	8, 13, 11, 17, 2, 7, 6, 16, 12			

KEWAUNEE

1973, 1975 Preoperational, OperationalCopepoda

1.	Sources	F	α	Statistical Significance
	Station	3.2725	0.0001	SD
	Month	79.8627	0.0001	SD
	Year	15.1427	0.0001	SD
	Sta. * Mo.	1.4275	0.0063	SD
	Sta. * Yr.	1.5820	0.0781	SD
2.	Station Comparisons:			Statistical Significance
	2	vs	11	NSD
	11	vs	12	NSD
	11	vs	13	NSD
	11	vs	6	NSD
	11	vs	7	NSD
	11	vs	8	NSD
	11	vs	17	NSD
	12	vs	7	NSD
	12	vs	16	NSD
3.	Stations in order of decreasing means:			
	8, 13, 17, 7, 11, 6, 2, 12, 16			

Kewaunee Generating Station - Statistical Analysis

ROTIFERA

Intra-Year Sampling Station Comparisons (1973)

Stations	2	3	6	7	8	11	12	13	14	16	17
2						*					
3											
6											
7											
8											
11				0			0	0		0	
12											
13											
14											
16											
17											

ROTIFERA

Inter-Year Sampling Station Comparisons (1973, 1975)

Table 26A

Stations	2	3	6	7	8	11	12	13	14	16	17
2						*					
3											
6											
7											
8											
11			0	0	**		0	*			**
12				0						0	
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

ROTIFERA

Intra-Year Sampling Station Comparisons (1974)

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11							0	*			
12				0						0	
13											
14											
16											
17											

ROTIFERA

Intra-Year Sampling Station Comparisons (1975)

Table 27A

Stations	2	3	6	7	8	11	12	13	14	16	17
2						*					
3											
6											
7											
8											
11							**	**			
12				0						0	
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

CLADOCERA

Intra-Year Sampling Station Comparisons (1973)

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11							0	0			
12				0						0	
13											
14											
16											
17											

CLADOCERA

Inter-Year Sampling Station Comparisons (1973, 1975)

Table 28A

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11			0	0	0		0	0			*
12				0						0	
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

CLADOCERA

Intra-Year Sampling Station Comparisons (1974)

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11							*				
12				0						0	
13											
14											
16											
17											

CLADOCERA

Intra-Year Sampling Station Comparisons (1975)

Table 29A

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11							0	0			
12				0						0	
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

COPEPODA

Intra-Year Sampling Station Comparisons (1973)

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11							0	0			
12				0						0	
13											
14											
16											
17											

COPEPODA

Inter-Year Sampling Station Comparisons (1973, 1975)

Table 30A

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11			0	0	0		0	0			0
12				0						0	
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

COPEPODA

Intra-Year Sampling Station Comparisons (1974)											Table 30B
Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11							0	*			
12				0						0	
13											
14											
16											
17											

COPEPODA

Intra-Year Sampling Station Comparisons (1975)											Table 30C
Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3											
6											
7											
8											
11				0			0	0		0	
12											
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

KEWAUNEE

1973 Chironomidae

1.	Sources	F	α	Statistical Significance
	Month	18.1850	0.0001	SD
	Station	6.3344	0.0001	SD
	Sta. * Mo.	1.3947	0.1127	SD
2.	Station Comparisons:			Statistical Significance
	11	vs	12	SD (.01)
	11	vs	13	SD (.01)
	3	vs	12	NSD
	3	vs	11	SD (.01)
	12	vs	16	NSD
	12	vs	7	SD (.05)
3.	Stations in order of decreasing means: 13, 3, 16, 12, 11, 7			

KEWAUNEE

1974 Chironomidae

1.	Sources	F	α	Statistical Significance
	Month	11.5988	0.0001	SD
	Station	10.9750	0.0001	SD
	Sta. * Mo.	4.0460	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	11	vs	12	SD (.01)
	11	vs	13	NSD
	3	vs	12	NSD
	3	vs	11	SD (.01)
	12	vs	16	NSD
	12	vs	7	SD (.05)
3.	Stations in order of decreasing means: 16, 12, 3, 13, 7, 11			

KEWAUNEE

1975 Chironomidae

1.	Sources	F	α	Statistical Significance
	Month	67.6154	0.0001	SD
	Station	49.7103	0.0001	SD
	Station * Month	7.7688	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	11	vs	12	SD (.01)
	11	vs	13	SD (.01)
	3	vs	12	NSD
	3	vs	11	SD (.01)
	12	vs	16	NSD
	12	vs	7	NSD
3.	Stations in order of decreasing means: 3, 7, 16, 12, 13, 11			

KEWAUNEE

1973, 1975 Preoperational, Operational

Chironomidae

1.	Sources	F	α	Statistical Significance
	Month	16.2143	0.0001	SD
	Station	17.1375	0.0001	SD
	Station * Month	2.2412	0.0005	SD
	Year	11.5507	0.0008	SD
	Sta. * Year	3.0093	0.0035	SD
2.	Station Comparisons:			Statistical Significance
	3	vs	11	SD (.01)
	3	vs	12	NSD
	3	vs	13	NSD
	11	vs	16	SD (.01)
	11	vs	17	SD (.01)
	12	vs	16	NSD
	13	vs	16	NSD
	13	vs	8	NSD
3.	Stations in order of decreasing means:			
	3, 16, 8, 12, 13, 17, 7, 11, 6			

KEWAUNEE

1973 Naididae

1.	Sources	F	α	Statistical Significance
	Month	99.5928	0.0001	SD
	Station	8.2660	0.0001	SD
	Sta. * Mo.	3.2313	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	11	vs	12	SD (.05)
	11	vs	13	SD (.01)
	3	vs	12	NSD
	3	vs	11	NSD
	12	vs	16	NSD
	12	vs	7	NSD
3.	Stations in order of decreasing means: 13, 16, 12, 7, 3, 11			

KEWAUNEE

1974 Naididae

1.	Sources	F	α	Statistical Significance
	Month	173.3224	0.0001	SD
	Station	9.0502	0.0001	SD
	Sta. * Mo.	8.5678	0.0001	SD
2.	Station Comparisons:			
	11	vs	12	NSD
	11	vs	13	NSD
	3	vs	12	NSD
	3	vs	11	NSD
	12	vs	16	NSD
	12	vs	7	NSD
3.	Stations in order of decreasing means:			
	16, 11, 12, 13, 3, 7			

KEWAUNEE

1975 Naididae

1.	Sources	F	α	Statistical Significance
	Month	34.0590	0.0001	SD
	Station	7.7025	0.0001	SD
	Station * Month	2.7864	0.0004	SD
2.	Station Comparisons:			Statistical Significance
	11	vs	12	SD (.01)
	11	vs	13	NSD
	3	vs	12	SD (.05)
	3	vs	11	NSD
	12	vs	16	NSD
	12	vs	7	NSD
3.	Stations in order of decreasing means: 16, 12, 7, 3, 13, 11			

KEWAUNEE

1973, 1975 Preoperational, OperationalNaididae

1.	Sources	F	α	Statistical Significance
	Station	7.1656	0.0001	SD
	Month	62.6779	0.0001	SD
	Year	118.4884	0.0001	SD
	Station * Month	2.5882	0.0001	SD
	Station * Year	1.3652	0.2131	SD
2.	Station Comparisons:			Statistical Significance
	11	vs	12	SD (.01)
	11	vs	13	SD (.05)
	3	vs	12	SD (.05)
	3	vs	11	SD (.05)
	12	vs	16	NSD
	12	vs	7	NSD
3.	Stations in order of decreasing means: 16, 12, 13, 7, 3, 11			

KEWAUNEE

1973 Total Benthos

1.	Sources	F	α	Statistical Significance
	Month	40.6030	0.0001	SD
	Station	8.8405	0.0001	SD
	Sta. * Mo.	2.7537	0.0003	SD
2.	Station Comparisons:			Statistical Significance
	11	vs	12	SD (.01)
	11	vs	13	SD (.01)
	3	vs	12	NSD
	3	vs	11	NSD
	12	vs	16	NSD
	12	vs	7	NSD
3.	Stations in order of decreasing means: 13, 12, 16, 7, 3, 11			

KEWAUNEE

1974 Total Benthos

1.	Source	F	α	Statistical Significance
	Month	12.4236	0.0001	SD
	Station	22.6552	0.0001	SD
	Sta. * Mo.	4.5644	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	11	vs	12	SD (.01)
	11	vs	13	SD (.05)
	3	vs	12	NSD
	3	vs	11	SD (.01)
	12	vs	16	NSD
	12	vs	7	SD (.05)
3.	Stations in order of decreasing means: 16, 12, 3, 13, 7, 11			

KEWAUNEE

1975 Total Benthos

1.	Source	F	α	Statistical Significance
	Month	67.0894	0.0001	SD
	Station	148.4546	0.0001	SD
	Station * Month	12.7397	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	11	vs	12	SD (.01)
	11	vs	13	SD (.01)
	3	vs	12	NSD
	3	vs	11	SD (.01)
	12	vs	16	NSD
	12	vs	7	NSD
3.	Stations in order of decreasing means: 16, 12, 7, 3, 13, 11			

KEWAUNEE

1973, 1975 Preoperational, OperationalTotal Benthos

1.	Source	F	α	Statistical Significance
	Month	29.6663	0.0001	SD
	Station	24.1885	0.0001	SD
	Station-Month	1.8376	0.0063	SD
	Year	45.8898	0.0001	SD
	Sta. * Yr.	5.1632	0.0001	SD
2.	Station Comparisons:			Statistical Significance
	3	vs	7	NSD
	3	vs	11	SD (.01)
	3	vs	12	NSD
	3	vs	13	NSD
	11	vs	16	SD (.01)
	11	vs	17	SD (.01)
	12	vs	16	NSD
	13	vs	16	NSD
	13	vs	8	NSD
3.	Stations in order of decreasing means:			
	13, 8, 16, 17, 12, 7, 3, 6, 11			

Kewaunee Generating Station - Statistical Analysis

CHIRONOMIDAE

Intra-Year Sampling Station Comparisons (1973)

Stations	2	3	6	7	8	11	12	13	14	16	17
2											
3						**	0				
6											
7											
8											
11							**	**			
12				*						0	
13											
14											
16											
17											

CHIRONOMIDAE

Inter-Year Sampling Station Comparisons (1973, 1975)

Table 43A

Stations	2	3	6	7	8	11	12	13	14	16	17
2											
3						**	0	0			
6											
7											
8											
11										**	**
12										0	
13					0					0	
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

CHIRONOMIDAE

Intra-Year Sampling Station Comparisons (1974)

Stations	2	3	6	7	8	11	12	13	14	16	17
2											
3						**	0				
6											
7											
8											
11							**	0			
12				*						0	
13											
14											
16											
17											

CHIRONOMIDAE

Intra-Year Sampling Station Comparisons (1975)

Table 44A

Stations	2	3	6	7	8	11	12	13	14	16	17
2											
3						**	0				
6											
7											
8											
11							**	**			
12				0						0	
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

NAIDIDAE

Intra-Year Sampling Station Comparisons (1973)

Stations	2	3	6	7	8	11	12	13	14	16	17
2											
3						0	0				
6											
7											
8											
11							*	**			
12				0						0	
13											
14											
16											
17											

NAIDIDAE

Inter-Year Sampling Station Comparisons (1973, 1975)

Table 45A

Stations	2	3	6	7	8	11	12	13	14	16	17
2											
3						*	*				
6											
7											
8											
11							**	*			
12				0						0	
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

NAIDIDAE

Intra-Year Sampling Station Comparisons (1974)

Stations	2	3	6	7	8	11	12	13	14	16	17
2											
3						0	0				
6											
7											
8											
11							0	0			
12				0						0	
13											
14											
16											
17											

NAIDIDAE

Intra-Year Sampling Station Comparisons (1975)

Table 46A

Stations	2	3	6	7	8	11	12	13	14	16	17
2											
3						0	*				
6											
7											
8											
11							**	0			
12				0						0	
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

TOTAL BENTHOS

Intra-Year Sampling Station Comparisons (1973)

Stations	2	3	6	7	8	11	12	13	14	16	17
2						0					
3						0	0				
6											
7											
8											
11							**	**			
12				0						0	
13											
14											
16											
17											

TOTAL BENTHOS

Inter-Year Sampling Station Comparisons (1973, 1975)

Table 47A

Stations	2	3	6	7	8	11	12	13	14	16	17
2											
3				0		**	0	0			
6											
7											
8											
11										**	**
12										0	
13					0					0	
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

Kewaunee Generating Station - Statistical Analysis

TOTAL BENTHOS

Intra-Year Sampling Station Comparisons (1974)

Stations	2	3	6	7	8	11	12	13	14	16	17
2											
3						**	0				
6											
7											
8											
11							**	*			
12				0						0	
13											
14											
16											
17											

TOTAL BENTHOS

Intra-Year Sampling Station Comparisons (1975)

Table 48A

Stations	2	3	6	7	8	11	12	13	14	16	17
2											
3						**	0				
6											
7											
8											
11							**	**			
12				0						0	
13											
14											
16											
17											

0 - No Significant Difference

* - Significant Difference (.05)

** - Significant Difference (.01)

APPENDIX K2

ARITHMETIC AND LOG PLOTS OF MONTHLY ABUNDANCES OF AQUATIC BIOTA

DETERMINED DURING 1972-1975 AT VARIOUS STATIONS

<u>Organisms</u>	<u>Stations</u>	<u>K2 Plots</u>
Phytoplankton	2 & 11	1 & 1A
Diatoms	2 & 11	2 & 2A
Phytoplankton	11 & 7	3 & 3A
Diatoms	11 & 7	4 & 4A
Phytoplankton	11 & 12	5 & 5A
Diatoms	11 & 12	6 & 6A
Phytoplankton	11 & 14	7 & 7A
Diatoms	11 & 14	8 & 8A
Phytoplankton	11 & 16	9 & 9A
Diatoms	11 & 16	10 & 10A
Phytoplankton	12 & 7	11 & 11A
Diatoms	12 & 7	12 & 12A
Phytoplankton	12 & 16	13 & 13A
Diatoms	12 & 16	14 & 14A
Rotifera	2 & 11	15 & 15A
Rotifera	11 & 12	16 & 16A
Rotifera	11 & 13	17 & 17A
Cladocera	2 & 11	18 & 18A
Cladocera	11 & 12	19 & 19A
Cladocera	11 & 13	20 & 20A
Copepoda	2 & 11	21 & 21A
Copepoda	11 & 12	22 & 22A
Copepoda	11 & 13	23 & 23A
Chironomidae	11 & 3	24 & 24A
Chironomidae	11 & 12	25 & 25A
Chironomidae	11 & 13	26 & 26A
Chironomidae	3 & 12	27 & 27A
Chironomidae	12 & 7	28 & 28A
Chironomidae	12 & 16	29 & 29A
Naididae	11 & 3	30 & 30A
Naididae	11 & 12	31 & 31A
Naididae	11 & 13	32 & 32A
Naididae	3 & 12	33 & 33A
Naididae	12 & 7	34 & 34A
Naididae	12 & 16	35 & 35A
Total Benthos	11 & 3	36 & 36A
Total Benthos	11 & 12	37 & 37A
Total Benthos	11 & 13	38 & 38A
Total Benthos	3 & 12	39 & 39A
Total Benthos	12 & 7	40 & 40A
Total Benthos	12 & 16	41 & 41A

APPENDIX K3

SUMMARY TABLES OF DATA USED FOR THE EVALUATION OF VARIOUS BIOTIC GROUPS

K3 Table

Plankton and Diatoms, Station 2	1
Plankton and Diatoms, Station 7	2
Plankton and Diatoms, Station 11	3
Plankton and Diatoms, Station 12	4
Plankton and Diatoms, Station 14	5
Plankton and Diatoms, Station 16	6
Plankton and Diatoms, Station 20	7
Plankton and Diatoms, Station 24	8
Copepoda, Cladocera and Rotifera, Station 2	9
Copepoda, Cladocera and Rotifera, Station 3	10
Copepoda, Cladocera and Rotifera, Station 4	11
Copepoda, Cladocera and Rotifera, Station 6	12
Copepoda, Cladocera and Rotifera, Station 7	13
Copepoda, Cladocera and Rotifera, Station 8	14
Copepoda, Cladocera and Rotifera, Station 11	15
Copepoda, Cladocera and Rotifera, Station 12	16
Copepoda, Cladocera and Rotifera, Station 13	17
Copepoda, Cladocera and Rotifera, Station 15	18
Copepoda, Cladocera and Rotifera, Station 16	19
Copepoda, Cladocera and Rotifera, Station 17	20
Copepoda, Cladocera and Rotifera, Station 20	21
Copepoda, Cladocera and Rotifera, Station 21	22
Copepoda, Cladocera and Rotifera, Station 22	23
Total Benthos, Chironomidae and Naididae, Station 3	24
Total Benthos, Chironomidae and Naididae, Station 6	25
Total Benthos, Chironomidae and Naididae, Station 7	26
Total Benthos, Chironomidae and Naididae, Station 8	27
Total Benthos, Chironomidae and Naididae, Station 11	28
Total Benthos, Chironomidae and Naididae, Station 12	29
Total Benthos, Chironomidae and Naididae, Station 13	30
Total Benthos, Chironomidae and Naididae, Station 16	31
Total Benthos, Chironomidae and Naididae, Station 17	32

SUMMARY STATISTICS TABLE
FOR STATION 2
KEWAUNEE NUCLEAR POWER PLANT

DATE		# OBSN	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
MAY	1972	4	950 (398.2)	440 (199.0)
AUG	1972	4	2488 (1723.1)	1076 (819.6)
SEP	1972	4	7363 (2495.2)	3592 (1219.4)
NOV	1972	4	2859 (1476.9)	1290 (784.7)
APR	1973	1	2307	2203
MAY	1973	1	2220	2220
JUN	1973	1	1034	1034
JUL	1973	1	964	878
AUG	1973	1	1004	296
SEP	1973	1	2649	2496
OCT	1973	1	781	585
NOV	1973	1	3517	3306
APR	1974	1	5809	5622
MAY	1974	1	2092	1977
JUN	1974	1	1614	1530
JUL	1974	1	2381	2303
AUG	1974	1	2557	2338
SEP	1974	1	6178	5610
OCT	1974	1	1838	1712
NOV	1974	1	1993	1884
APR	1975	1	1970	1772
MAY	1975	1	2881	2772
JUN	1975	1	648	527
JUL	1975	1	1702	1510
AUG	1975	1	1929	1073
SEP	1975	1	892	785
OCT	1975	1	2026	1843
NOV	1975	1	2067	1947

SUMMARY STATISTICS TABLE
FOR STATION 7
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
MAY 1972	4	567 (81.6)	254 (39.1)
AUG 1972	4	1578 (292.7)	565 (109.5)
SEP 1972	4	1443 (605.7)	602 (300.6)
NOV 1972	4	895 (366.8)	347 (190.5)
APR 1973	1	2037	1050
MAY 1973	1	1355	1355
JUN 1973	1	1523	1523
JUL 1973	1	547	453
AUG 1973	1	1739	469
SEP 1973	1	1066	890
OCT 1973	1	823	683
NOV 1973	1	867	714
APR 1974	1	3579	3421
MAY 1974	1	1918	1784
JUN 1974	1	2019	1909
JUL 1974	1	1955	1860
AUG 1974	1	935	769
SEP 1974	1	2339	1910
OCT 1974	1	1900	1807
NOV 1974	1	2091	1977
APR 1975	1	1992	1785
MAY 1975	1	3475	3159
JUN 1975	1	707	626
JUL 1975	1	1378	1305
AUG 1975	1	2077	1134
SEP 1975	1	1351	1173
OCT 1975	1	931	790
NOV 1975	1	2024	1956

SUMMARY STATISTICS TABLE
FOR STATION 11
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
MAY 1972	4	719 (100.2)	322 (65.1)
AUG 1972	4	2504 (785.2)	1025 (336.6)
SEP 1972	4	2705 (228.0)	1232 (117.8)
NOV 1972	4	1070 (372.1)	386 (167.9)
APR 1973	1	1894	1728
MAY 1973	1	1353	1353
JUN 1973	1	1760	1760
JUL 1973	1	1187	1103
AUG 1973	1	2079	937
SEP 1973	1	3373	3076
OCT 1973	1	1625	1429
NOV 1973	1	1366	1176
APR 1974	1	9484	9366
MAY 1974	1	2206	2052
JUN 1974	1	2066	1973
JUL 1974	1	2664	2574
AUG 1974	1	2714	2523
SEP 1974	1	3893	3458
OCT 1974	1	1620	1467
NOV 1974	1	1920	1830
APR 1975	1	2595	2384
MAY 1975	1	14032	12543
JUN 1975	1	714	692
JUL 1975	1	2944	2809
AUG 1975	1	2174	1750
SEP 1975	1	974	831
OCT 1975	1	2799	2624
NOV 1975	1	2382	2242

SUMMARY STATISTICS TABLE
FOR STATION 12
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
MAY 1972	4	822 (85.4)	366 (57.0)
AUG 1972	4	1961 (359.9)	562 (68.4)
SEP 1972	4	1445 (305.2)	368 (141.3)
NOV 1972	4	1009 (405.3)	396 (232.8)
APR 1973	1	1768	1685
MAY 1973	1	1382	1382
JUN 1973	1	1709	1709
JUL 1973	1	753	672
AUG 1973	1	1461	455
SEP 1973	1	1205	896
OCT 1973	1	946	826
NOV 1973	1	1001	858
APR 1974	1	3384	3195
MAY 1974	1	2088	1932
JUN 1974	1	1686	1618
JUL 1974	1	2104	2043
AUG 1974	1	936	813
SEP 1974	1	2121	1670
OCT 1974	1	3094	2988
NOV 1974	1	2798	2639
APR 1975	1	1876	1663
MAY 1975	1	2126	1982
JUN 1975	1	818	763
JUL 1975	1	2800	2582
AUG 1975	1	1989	1661
SEP 1975	1	1266	1123
OCT 1975	1	1593	1449
NOV 1975	1	1560	1502

SUMMARY STATISTICS TABLE
FOR STATION 14
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
MAY 1972	4	1005 (72.4)	281 (216.7)
JUG 1972	4	1054 (132.7)	409 (40.3)
SEP 1972	4	857 (134.7)	227 (90.7)
NOV 1972	4	791 (103.0)	199 (140.1)
APR 1973	1	2291	2181
MAY 1973	1	1219	1219
JUN 1973	1	802	802
JUL 1973	1	332	260
AUG 1973	1	741	202
SEP 1973	1	733	532
OCT 1973	1	539	366
NOV 1973	1	540	373
APR 1974	1	3059	2779
MAY 1974	1	1938	1814
JUN 1974	1	1037	899
JUL 1974	1	773	717
AUG 1974	1	413	276
SEP 1974	1	1306	871
OCT 1974	1	492	448
NOV 1974	1	1426	1357
APR 1975	1	1654	1567
MAY 1975	1	1339	1280
JUN 1975	1	550	510
JUL 1975	1	1352	1225
AUG 1975	1	1233	746
SEP 1975	1	819	560
OCT 1975	1	767	632
NOV 1975	1	992	944

SUMMARY STATISTICS TABLE
FOR STATION 16
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
MAY 1972	4	963 (90.5)	487 (90.4)
AUG 1972	4	1564 (513.9)	634 (272.9)
SEP 1972	4	2520 (594.8)	1127 (287.7)
NOV 1972	4	1305 (385.3)	566 (191.0)
APR 1973	1	1931	1801
MAY 1973	1	1243	1243
JUN 1973	1	2452	2452
JUL 1973	1	592	512
AUG 1973	1	1187	261
SEP 1973	1	849	658
OCT 1973	1	680	510
NOV 1973	1	958	663
APR 1974	1	3798	3653
MAY 1974	1	2654	2527
JUN 1974	1	1885	1675
JUL 1974	1	2515	2029
AUG 1974	1	1380	1264
SEP 1974	1	3186	2664
OCT 1974	1	1836	1721
NOV 1974	1	2605	2487
APR 1975	1	2268	1913
MAY 1975	1	1626	1416
JUN 1975	1	801	766
JUL 1975	1	1214	1079
AUG 1975	1	1930	1254
SEP 1975	1	1085	1014
OCT 1975	1	1216	1144
NOV 1975	1	2344	2192

SUMMARY STATISTICS TABLE
FOR STATION 20
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
MAY 1972	4	787 (90.9)	338 (35.7)
AUG 1972	4	2500 (1032.5)	1111 (378.1)
SEP 1972	4	2081 (240.0)	963 (90.6)
NOV 1972	4	2129 (863.5)	977 (442.4)
APR 1973	1	1343	1243
MAY 1973	1	2313	2313
JUN 1973	1	1478	1478
JUL 1973	1	851	799
AUG 1973	1	1173	412
SEP 1973	1	2630	2425
OCT 1973	1	1078	905
NOV 1973	1	1033	826
APR 1974	1	5269	5176
MAY 1974	1	1780	1617
JUN 1974	1	1782	1677
JUL 1974	1	1548	1408
AUG 1974	1	589	483
SEP 1974	1	6078	5429
OCT 1974	1	1629	1523
NOV 1974	1	5874	5696
APR 1975	1	2525	2170
MAY 1975	1	4331	3956
JUN 1975	1	814	742
JUL 1975	1	1794	1643
AUG 1975	1	1714	1353
SEP 1975	1	605	563
OCT 1975	1	1631	1572
NOV 1975	1	2050	1940

SUMMARY STATISTICS TABLE
FOR STATION 24
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL PHYTOPLANKTON (#/ML)	DIATOMS (#/ML)
APR 1973	1	2009	1925
MAY 1973	1	1586	1586
JUN 1973	1	708	708
JUL 1973	1	624	492
AUG 1973	1	883	217
SEP 1973	1	1024	813
OCT 1973	1	440	316
NOV 1973	1	871	663
APR 1974	1	2727	2620
MAY 1974	1	1828	1685
JUN 1974	1	958	837
JUL 1974	1	1403	1264
AUG 1974	1	518	406
SEP 1974	1	1649	1075
OCT 1974	1	484	376
NOV 1974	1	1118	995
APR 1975	1	1540	1351
MAY 1975	1	1613	1329
JUN 1975	1	849	717
JUL 1975	1	1184	1043
AUG 1975	1	1183	828
SEP 1975	1	697	627
OCT 1975	1	724	613
NOV 1975	1	782	715

SUMMARY STATISTICS TABLE
FOR STATION 2
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
MAY 1973	4	5743 (251.9)	356 (160.8)	13487 (3340.7)
JUN 1973	4	1597 (1016.6)	431 (333.2)	319 (286.4)
JUL 1973	4	8804 (400.8)	67219 (2640.9)	28923 (6112.6)
AUG 1973	4	30367 (3169.7)	13892 (2888.1)	2555 (597.1)
OCT 1973	3	4916 (1255.4)	7755 (2042.6)	52 (52.5)
NOV 1973	4	27661 (3546.4)	5488 (940.0)	693 (348.1)
APR 1974	4	5540 (1565.9)	23 (13.0)	91131 (15329.3)
MAY 1974	4	27492 (7448.9)	55 (14.2)	54631 (10523.2)
JUN 1974	4	4248 (1565.2)	1105 (157.5)	54868 (12214.3)
JUL 1974	4	7539 (2464.7)	1687 (694.5)	155045 (19712.3)
AUG 1974	4	16093 (3614.9)	26208 (2204.4)	193990 (44621.6)
SEP 1974	4	10592 (1884.3)	42417 (4896.6)	101606 (26264.5)
OCT 1974	4	8623 (340.1)	13806 (3397.0)	22952 (4772.1)
NOV 1974	4	11246 (892.9)	2702 (587.6)	49741 (3744.4)
APR 1975	4	7468 (541.8)	56 (25.5)	31278 (8491.7)
MAY 1975	4	17877 (3544.0)	190 (76.5)	57855 (12666.9)
JUN 1975	4	5604 (1521.4)	35 (41.2)	92988 (15779.2)
JUL 1975	4	87931 (4955.9)	47467 (7397.3)	629261 (55464.0)
AUG 1975	4	38641 (7473.9)	65756 (10169.0)	401188 (64685.7)
SEP 1975	4	59000 (8582.4)	32768 (6494.6)	39388 (3518.9)
OCT 1975	4	5589 (1732.0)	34785 (4403.8)	39774 (7106.3)
NOV 1975	4	2506 (551.3)	1026 (337.6)	21419 (6590.6)

SUMMARY STATISTICS TABLE
FOR STATION 3
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
MAY 1973	4	9478 (767.3)	472 (47.1)	23210 (2880.0)
JUN 1973	4	2001 (838.1)	350 (153.9)	190 (165.4)
JUL 1973	4	3979 (983.5)	44092 (6777.2)	11111 (2922.0)
AUG 1973	4	29149 (6136.5)	13558 (4216.6)	1916 (954.7)
SEP 1973	4	25754 (4590.6)	12366 (3194.7)	1749 (296.6)
OCT 1973	4	1580 (999.3)	1380 (474.3)	74 (51.0)
NOV 1973	4	46672 (3815.1)	3479 (427.7)	899 (398.0)
APR 1974	4	7392 (1186.6)	25 (18.2)	64192 (5526.0)
MAY 1974	4	23807 (6455.9)	48 (19.4)	46258 (2561.5)
JUN 1974	4	9556 (1426.5)	1432 (561.7)	46179 (11764.5)
JUL 1974	4	4462 (2042.1)	5238 (1869.6)	136983 (55457.7)
AUG 1974	4	11227 (2701.6)	10533 (5717.5)	115086 (22428.0)
SEP 1974	4	12442 (3341.4)	16204 (4754.8)	61786 (15000.5)
OCT 1974	4	10530 (1990.3)	11909 (1189.3)	25131 (2683.4)
NOV 1974	4	11422 (1872.9)	2270 (690.5)	38401 (7320.9)
APR 1975	4	7439 (950.4)	15 (5.8)	39032 (5350.8)
MAY 1975	4	16517 (2727.3)	137 (34.0)	69718 (6816.1)
JUN 1975	4	11498 (1542.7)	190 (69.5)	177088 (18434.3)
JUL 1975	4	108695 (12051.8)	28255 (5307.4)	488683 (44463.4)
AUG 1975	4	55582 (9353.2)	23922 (7552.7)	182143 (39445.9)
SEP 1975	4	52197 (5160.3)	28090 (3213.0)	27409 (4858.9)
OCT 1975	4	5521 (836.5)	6637 (941.0)	21008 (4074.6)
NOV 1975	4	2930 (879.7)	298 (146.6)	11107 (4023.4)

SUMMARY STATISTICS TABLE
FOR STATION 4
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/d**3)
MAY 1973	4	8655 (476.5)	475 (138.3)	21607 (3593.7)
JUN 1973	4	5983 (1888.1)	1100 (312.5)	1493 (671.0)
JUL 1973	4	7309 (1342.8)	43227 (11027.8)	11750 (5401.8)
AUG 1973	4	44407 (10125.7)	20488 (3535.5)	2174 (582.8)
SEP 1973	4	30457 (3033.8)	16295 (3386.1)	2188 (419.9)
OCT 1973	4	7146 (1333.5)	4696 (1235.5)	112 (94.0)
NOV 1973	4	31674 (3575.2)	3145 (516.9)	826 (330.5)
APR 1974	4	8919 (401.2)	13 (10.6)	60667 (9344.1)
MAY 1974	4	13764 (2790.8)	14 (4.8)	28412 (4360.8)
JUN 1974	4	6638 (808.0)	1909 (263.9)	42624 (7365.0)
JUL 1974	4	6037 (307.5)	3674 (644.4)	191056 (67660.0)
AUG 1974	4	42563 (2012.1)	33329 (3502.4)	113854 (15903.4)
SEP 1974	4	9744 (1584.3)	9527 (1901.8)	33459 (9436.4)
OCT 1974	4	8570 (1890.7)	3502 (430.2)	14308 (1231.4)
NOV 1974	4	12922 (1193.4)	1287 (210.1)	32213 (3968.2)
APR 1975	4	7583 (568.2)	11 (7.0)	27278 (5151.3)
MAY 1975	4	13322 (1213.3)	227 (159.1)	64296 (6741.0)
JUN 1975	4	18618 (2675.2)	102 (10.8)	128969 (17814.0)
JUL 1975	4	112969 (8263.9)	17271 (6748.8)	280387 (59699.4)
AUG 1975	4	30407 (7445.2)	14303 (4200.6)	92692 (26853.9)
SEP 1975	4	42053 (11102.7)	9933 (3184.0)	17173 (3769.6)
OCT 1975	4	20703 (4033.1)	17517 (4123.4)	15632 (3010.3)
NOV 1975	4	4489 (737.5)	248 (132.9)	11350 (3346.1)

SUMMARY STATISTICS TABLE
FOR STATION 6
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
APR 1973	4	10442 (1000.9)	325 (107.6)	2633 (437.8)
MAY 1973	4	4908 (841.5)	523 (135.2)	14714 (11093.5)
JUN 1973	4	6230 (1388.3)	929 (354.2)	1019 (146.0)
JUL 1973	4	3047 (1062.3)	56726 (5783.7)	36570 (21309.7)
AUG 1973	4	44623 (6736.6)	31143 (5751.0)	5070 (636.7)
SEP 1973	4	59771 (3939.4)	14976 (1772.6)	2181 (589.2)
OCT 1973	4	10983 (1674.0)	12189 (6056.9)	354 (110.2)
NOV 1973	4	21811 (5139.2)	4923 (1010.1)	575 (147.0)
APR 1974	4	4914 (537.8)	67 (28.5)	82714 (9374.8)
MAY 1974	4	12956 (1405.3)	46 (5.7)	69438 (3335.7)
JUN 1974	4	1005 (92.4)	962 (109.3)	152529 (34955.3)
JUL 1974	4	5800 (1746.8)	5666 (1020.8)	276428 (56302.3)
AUG 1974	4	28312 (5830.4)	12827 (1193.0)	175104 (42372.1)
SEP 1974	4	19312 (4921.9)	50328 (14582.6)	142021 (59772.3)
OCT 1974	4	9541 (2086.7)	16588 (2990.2)	23741 (5766.0)
NOV 1974	4	9489 (2234.2)	4716 (622.4)	55921 (9901.6)
APR 1975	4	5740 (1248.8)	19 (27.9)	42220 (15731.5)
MAY 1975	4	11674 (1615.0)	66 (31.0)	61363 (6106.8)
JUN 1975	4	7636 (507.0)	55 (20.7)	255030 (7562.0)
JUL 1975	4	87493 (10471.0)	19296 (4176.6)	592011 (48135.4)
AUG 1975	4	62576 (31125.3)	26603 (7638.9)	439738 (26228.8)
SEP 1975	4	66887 (17534.8)	24953 (6083.6)	23081 (6029.4)
OCT 1975	4	4630 (797.8)	16284 (3457.5)	40688 (10559.0)
NOV 1975	4	948 (335.8)	15776 (2500.6)	19540 (4855.9)

SUMMARY STATISTICS TABLE
FOR STATION 7
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
APR 1973	4	8204 (586.6)	236 (48.0)	1975 (430.4)
MAY 1973	4	6722 (709.6)	494 (38.6)	17544 (2022.1)
JUN 1973	4	11350 (1331.2)	1029 (164.0)	1809 (314.5)
JUL 1973	4	3242 (1442.4)	61069 (15720.2)	31097 (6964.3)
AUG 1973	4	53170 (4283.8)	27646 (3325.3)	4834 (971.8)
SEP 1973	4	36940 (2062.9)	10714 (1570.6)	2437 (111.3)
OCT 1973	4	9743 (1716.9)	8238 (1236.8)	386 (183.1)
NOV 1973	4	25230 (5650.9)	3139 (364.4)	1002 (300.8)
APR 1974	4	4347 (510.5)	22 (14.0)	78917 (17425.0)
MAY 1974	4	14062 (3469.9)	56 (16.9)	62675 (6850.8)
JUN 1974	4	2499 (1906.4)	685 (376.2)	53688 (18037.2)
JUL 1974	4	3499 (579.9)	5878 (1325.0)	149732 (37796.8)
AUG 1974	4	41947 (8478.1)	28955 (11991.4)	153307 (21648.1)
SEP 1974	4	16841 (1517.3)	21976 (7507.7)	86967 (22516.3)
OCT 1974	4	13284 (3069.9)	19551 (3954.6)	31104 (2313.1)
NOV 1974	4	7275 (1047.2)	3517 (911.6)	55708 (6821.7)
APR 1975	4	6990 (1336.5)	27 (16.6)	28685 (3447.2)
MAY 1975	4	10013 (1666.4)	128 (20.4)	77219 (6673.7)
JUN 1975	4	4341 (925.1)	114 (44.4)	126578 (11873.6)
JUL 1975	4	84787 (10456.0)	23473 (4417.4)	395312 (37396.8)
AUG 1975	4	45046 (7355.7)	24065 (5652.4)	260601 (26312.1)
SEP 1975	4	47612 (6147.6)	43711 (7405.9)	29647 (5606.8)
OCT 1975	4	5888 (1029.5)	13016 (1768.6)	27203 (6268.5)
NOV 1975	4	2613 (455.4)	1762 (384.7)	18966 (2991.8)

SUMMARY STATISTICS TABLE
FOR STATION 9
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBS	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
APR 1973	4	4337 (197.1)	368 (81.8)	3254 (437.1)
MAY 1973	4	9366 (498.5)	340 (110.8)	12913 (2468.0)
JUN 1973	4	14913 (1506.8)	1179 (233.7)	3085 (653.1)
JUL 1973	4	6759 (1837.3)	95572 (5148.2)	9314 (2555.3)
AUG 1973	4	40058 (3991.7)	15143 (405.7)	2646 (386.2)
SEP 1973	4	33190 (303.3)	11311 (1567.0)	2555 (1360.8)
OCT 1973	4	4585 (1493.0)	6013 (788.4)	190 (132.8)
NOV 1973	4	42344 (8085.7)	4421 (718.4)	354 (208.1)
APR 1974	4	6014 (1244.8)	23 (6.7)	73424 (5668.7)
MAY 1974	4	34086 (10068.3)	11 (7.5)	21142 (3819.2)
JUN 1974	4	14139 (1700.1)	2341 (438.5)	66911 (9940.4)
JUL 1974	4	8293 (1769.0)	10421 (1043.5)	160073 (34756.7)
AUG 1974	4	40757 (6545.0)	27798 (10006.1)	66540 (13239.9)
SEP 1974	4	24380 (5598.8)	29823 (6420.9)	74437 (11074.1)
OCT 1974	4	9411 (1641.8)	5889 (467.6)	17866 (767.4)
NOV 1974	4	11103 (2506.3)	3199 (451.3)	54408 (4330.6)
APR 1975	4	8088 (736.2)	37 (22.4)	4320 (758.0)
MAY 1975	4	13858 (1448.1)	46 (18.7)	76335 (3493.8)
JUN 1975	4	23815 (1107.0)	5207 (10183.4)	227385 (26499.2)
JUL 1975	4	75913 (3621.2)	19414 (4187.8)	146068 (22609.7)
AUG 1975	4	44171 (12642.9)	9313 (5725.1)	95611 (23784.5)
SEP 1975	4	31575 (4166.4)	6667 (5690.0)	14765 (2470.1)
OCT 1975	4	29581 (3390.4)	11448 (7781.4)	21229 (6128.3)
NOV 1975	4	4280 (521.0)	470 (229.6)	10127 (503.8)

SUMMARY STATISTICS TABLE
FOR STATION 11
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
APR 1973	4	9125 (587.2)	330 (89.8)	3011 (258.4)
MAY 1973	4	4045 (200.5)	158 (66.8)	4897 (1359.6)
JUN 1973	4	4571 (2119.0)	988 (445.5)	1276 (705.6)
JUL 1973	4	3832 (752.2)	25171 (2337.4)	16545 (10011.4)
AUG 1973	4	31418 (3348.8)	36821 (1199.9)	4048 (437.7)
SEP 1973	4	38079 (2563.0)	15540 (2667.4)	2004 (585.7)
OCT 1973	4	10616 (833.9)	15680 (3332.4)	1893 (321.6)
NOV 1973	4	19202 (3032.3)	4009 (258.5)	752 (386.0)
APR 1974	4	4115 (872.8)	67 (52.6)	81959 (15385.2)
MAY 1974	4	9183 (2111.0)	187 (82.9)	128243 (41015.7)
JUN 1974	4	1666 (693.9)	540 (171.7)	70239 (18042.3)
JUL 1974	4	7962 (1244.7)	10487 (1775.3)	483645 (84016.7)
AUG 1974	4	14329 (1522.6)	13613 (8803.4)	91389 (25291.3)
SEP 1974	4	19856 (5924.0)	26615 (5610.9)	102762 (28387.1)
OCT 1974	4	8251 (1063.8)	20844 (7503.9)	24170 (4720.3)
NOV 1974	4	7880 (2664.7)	3361 (824.1)	52069 (22466.9)
APR 1975	4	10209 (1806.6)	125 (38.7)	72791 (17016.4)
MAY 1975	4	11844 (2432.9)	429 (83.6)	105890 (11139.8)
JUN 1975	4	9452 (3002.6)	39 (47.1)	144930 (42578.9)
JUL 1975	4	73551 (7578.3)	29436 (7505.2)	737254 (93021.5)
AUG 1975	4	76941 (50333.0)	72026 (2197.4)	530419 (313378.8)
SEP 1975	4	57417 (3227.3)	48231 (4091.7)	40626 (4732.7)
OCT 1975	4	5298 (870.6)	16549 (1877.0)	157992 (18282.4)
NOV 1975	4	1932 (651.3)	5379 (538.5)	26496 (7185.4)

SUMMARY STATISTICS TABLE
FOR STATION 12
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
APR 1973	4	7725 (313.4)	315 (52.8)	2127 (518.1)
MAY 1973	4	3291 (441.0)	140 (56.1)	8938 (2160.6)
JUN 1973	4	15369 (4244.8)	1210 (198.0)	2368 (977.6)
JUL 1973	4	5865 (1060.9)	42854 (7908.1)	23697 (10280.7)
AUG 1973	4	37491 (14029.6)	18716 (5324.4)	2859 (878.9)
SEP 1973	4	25446 (6366.9)	10225 (1654.8)	4716 (1865.5)
OCT 1973	4	6894 (2554.7)	7158 (2263.5)	548 (77.2)
NOV 1973	4	13435 (5336.1)	2889 (894.4)	428 (154.7)
APR 1974	4	4152 (664.3)	12 (10.0)	57543 (12903.2)
MAY 1974	4	14592 (5956.4)	115 (38.5)	66374 (26944.6)
JUN 1974	4	2018 (847.7)	496 (36.0)	58156 (14028.1)
JUL 1974	4	5777 (1240.0)	6670 (5167.1)	320255 (258538.0)
AUG 1974	4	42507 (6549.8)	18 (20.2)	218242 (48021.6)
SEP 1974	4	18210 (2126.0)	17891 (2255.2)	83360 (8706.3)
OCT 1974	4	8304 (1749.0)	49344 (8377.0)	38295 (6249.5)
NOV 1974	4	11724 (1857.9)	7734 (1220.9)	06670 (3750.2)
APR 1975	4	7683 (1132.7)	47 (41.8)	20417 (1790.7)
MAY 1975	4	9250 (671.7)	192 (69.6)	78399 (10584.5)
JUN 1975	4	5432 (879.4)	176 (35.1)	91183 (6786.8)
JUL 1975	4	71474 (6545.6)	77130 (10975.1)	571814 (49648.8)
AUG 1975	4	54239 (3834.1)	32691 (3934.6)	325089 (31904.9)
SEP 1975	4	44535 (5756.1)	27148 (4780.6)	29162 (8731.9)
OCT 1975	4	2552 (1012.3)	11463 (3381.9)	38044 (19858.0)
NOV 1975	4	1908 (281.8)	790 (111.4)	17015 (5279.6)

SUMMARY STATISTICS TABLE
FOR STATION 13
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
APR 1973	4	3809 (235.9)	254 (71.8)	2650 (234.5)
MAY 1973	4	4944 (195.8)	170 (43.8)	20317 (3908.9)
JUN 1973	4	16740 (2140.7)	1218 (224.7)	3065 (861.4)
JUL 1973	4	2947 (393.3)	65666 (11764.0)	10492 (3669.1)
AUG 1973	4	36835 (4200.7)	14357 (868.9)	2908 (509.0)
SEP 1973	4	29611 (4268.3)	16253 (2935.6)	1847 (1074.6)
OCT 1973	4	8147 (1197.9)	4043 (136.0)	183 (98.2)
NOV 1973	4	51422 (2260.3)	7663 (1166.5)	570 (359.5)
APR 1974	4	3223 (863.5)	20 (13.0)	61823 (6174.8)
MAY 1974	4	27300 (1171.4)	32 (12.1)	40437 (6008.2)
JUN 1974	4	5649 (231.2)	903 (197.6)	35328 (5767.8)
JUL 1974	4	7871 (5798.8)	198 (246.2)	122950 (14999.3)
AUG 1974	4	54912 (9169.4)	35525 (5636.9)	104312 (10298.4)
SEP 1974	4	16242 (2447.5)	33685 (6402.1)	107118 (13548.8)
OCT 1974	4	11268 (2029.4)	6479 (1563.7)	23385 (14614.4)
NOV 1974	4	12454 (1882.3)	2153 (234.8)	41468 (3569.7)
APR 1975	4	7242 (1283.3)	18 (21.8)	9695 (1056.7)
MAY 1975	4	14995 (1184.0)	139 (57.7)	72357 (8264.1)
JUN 1975	4	23701 (2180.8)	201 (142.5)	293010 (25102.1)
JUL 1975	4	89844 (6154.4)	23618 (3080.8)	247614 (26715.4)
AUG 1975	4	47981 (3910.4)	19259 (2486.5)	207019 (14038.7)
SEP 1975	4	47182 (3836.7)	53856 (4759.0)	25062 (2846.2)
OCT 1975	4	10401 (738.1)	8650 (2426.5)	14899 (3529.5)
NOV 1975	4	1723 (325.5)	592 (171.7)	11184 (1098.6)

SUMMARY STATISTICS TABLE
FOR STATION 15
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
APR 1973	4	7483 (1441.9)	335 (58.3)	1351 (156.2)
MAY 1973	4	4333 (523.3)	180 (91.1)	8132 (3214.9)
JUN 1973	4	4025 (425.2)	512 (134.7)	626 (26.1)
JUL 1973	4	1945 (365.7)	23225 (2178.0)	11809 (5351.1)
AUG 1973	4	11692 (2714.6)	11436 (5701.4)	3910 (599.8)
SEP 1973	4	34396 (3231.3)	14475 (3682.2)	1592 (796.9)
OCT 1973	4	3438 (1041.7)	8357 (2913.2)	301 (146.0)
NOV 1973	4	18967 (2050.5)	21119 (4552.8)	1754 (667.6)
APR 1974	4	5594 (1009.2)	84 (38.8)	65618 (12244.1)
MAY 1974	4	7771 (240.2)	104 (23.3)	123975 (16288.4)
JUN 1974	4	1585 (114.5)	566 (22.5)	77950 (9588.7)
JUL 1974	4	6724 (710.4)	3446 (380.2)	343639 (101438.5)
AUG 1974	4	39005 (6866.9)	53924 (11961.7)	438241 (87443.2)
SEP 1974	4	27356 (2156.5)	40533 (4231.1)	209495 (38752.1)
OCT 1974	4	7820 (1240.2)	23621 (8318.8)	36931 (8705.9)
NOV 1974	4	14507 (1243.0)	2627 (403.4)	48375 (1700.8)
APR 1975	4	6852 (701.8)	48 (18.5)	33157 (5391.8)
MAY 1975	4	9028 (1084.8)	33 (10.9)	76239 (17244.1)
JUN 1975	4	10349 (3610.5)	59 (55.0)	261485 (28301.1)
JUL 1975	4	94413 (5204.7)	45204 (14151.7)	308745 (26329.7)
AUG 1975	4	78037 (4864.1)	19635 (4056.8)	352027 (38078.7)
SEP 1975	4	23196 (3908.5)	9079 (2778.4)	15149 (2340.9)
OCT 1975	4	2686 (516.8)	51825 (12550.3)	37653 (5613.6)
NOV 1975	4	596 (182.2)	13117 (5823.0)	41953 (7298.5)

SUMMARY STATISTICS TABLE
FOR STATION 16
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/L**3)
APR 1973	4	4741 (587.5)	261 (70.4)	2648 (247.6)
MAY 1973	4	6853 (1200.8)	234 (80.1)	25089 (9616.3)
JUN 1973	4	11721 (2597.1)	814 (244.7)	2330 (843.3)
JUL 1973	4	1358 (778.6)	37431 (11063.6)	11052 (3194.5)
AUG 1973	4	29238 (1166.4)	21310 (2380.5)	4273 (475.2)
SEP 1973	4	26861 (3517.9)	13445 (1063.5)	2515 (169.9)
OCT 1973	4	8214 (5012.7)	10769 (4497.6)	640 (517.2)
NOV 1973	4	17523 (2701.9)	4643 (298.0)	428 (56.5)
APR 1974	4	3187 (624.9)	23 (14.2)	57378 (15039.4)
MAY 1974	4	12419 (1601.4)	45 (5.7)	44431 (8494.7)
JUN 1974	4	3273 (499.8)	728 (249.3)	79472 (8948.2)
JUL 1974	4	8603 (3070.7)	4109 (864.1)	386341 (97877.2)
AUG 1974	4	32283 (3260.2)	12 (13.9)	276433 (30976.1)
SEP 1974	4	22589 (1464.4)	23103 (2302.3)	139913 (22241.4)
OCT 1974	4	11338 (1599.5)	7770 (892.6)	18302 (4124.2)
NOV 1974	4	12597 (1389.2)	2754 (338.8)	42191 (5421.4)
APR 1975	4	9319 (1108.7)	30 (21.1)	20771 (2577.5)
MAY 1975	4	9960 (963.7)	54 (23.8)	68863 (9141.5)
JUN 1975	4	7730 (1257.7)	181 (60.8)	248818 (44806.4)
JUL 1975	4	94961 (11796.9)	5912 (3284.2)	249880 (30729.7)
AUG 1975	4	44943 (9596.2)	13853 (3796.6)	167997 (39282.7)
SEP 1975	4	26134 (2417.8)	10684 (2053.7)	20599 (1212.8)
OCT 1975	4	3897 (552.9)	8420 (914.0)	15913 (1607.0)
NOV 1975	4	1121 (352.5)	9477 (2501.5)	45994 (16566.6)

SUMMARY STATISTICS TABLE
FOR STATION 17
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
APR 1973	4	7511 (343.8)	246 (41.6)	2309 (343.5)
MAY 1973	4	13917 (2426.1)	268 (23.0)	11551 (2156.3)
JUN 1973	4	24836 (4842.7)	933 (339.7)	1297 (810.9)
JUL 1973	4	3969 (1273.0)	68731 (8076.8)	11593 (2882.3)
AUG 1973	4	44799 (3775.7)	14462 (1869.4)	2437 (557.2)
SEP 1973	4	29199 (3622.2)	21518 (3033.3)	1027 (259.0)
OCT 1973	4	4394 (1276.9)	2542 (651.0)	85 (25.3)
NOV 1973	4	26865 (2275.6)	2653 (196.8)	275 (150.8)
APR 1974	4	9632 (1521.5)	7 (7.5)	55645 (13211.8)
MAY 1974	4	56363 (16264.6)	16 (10.3)	23382 (3245.2)
JUN 1974	4	5983 (1626.7)	1570 (222.3)	46986 (13442.3)
JUL 1974	4	12773 (3977.2)	4 (2.5)	188049 (36541.9)
AUG 1974	4	54201 (4125.4)	27815 (6225.8)	112219 (15010.9)
SEP 1974	4	24402 (2925.5)	26273 (4619.5)	145032 (25524.4)
OCT 1974	4	11141 (828.5)	5138 (815.4)	15376 (2005.7)
NOV 1974	4	11872 (1120.4)	2529 (1010.4)	39455 (8784.1)
APR 1975	4	9607 (1163.5)	19 (8.8)	6574 (609.8)
MAY 1975	4	12222 (969.2)	29 (14.4)	60714 (5920.0)
JUN 1975	4	15646 (813.6)	114 (21.2)	338045 (47864.6)
JUL 1975	4	94517 (8168.6)	5805 (831.0)	123001 (8341.9)
AUG 1975	4	26336 (1315.8)	10389 (1340.7)	87714 (9018.0)
SEP 1975	4	29050 (4392.5)	4119 (888.1)	11327 (2597.1)
OCT 1975	4	10211 (1633.2)	13382 (3987.0)	19274 (3993.9)
NOV 1975	4	1580 (382.2)	268 (78.5)	12754 (1790.8)

SUMMARY STATISTICS TABLE
FOR STATION 20
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSV	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
MAY 1973	4	5129 (758.8)	209 (46.9)	7929 (1602.4)
JUN 1973	4	1079 (255.5)	226 (40.2)	971 (667.1)
JUL 1973	4	2299 (778.6)	25131 (3457.5)	30711 (7578.2)
AUG 1973	4	10670 (3156.7)	12615 (4854.4)	4578 (944.0)
SEP 1973	4	53670 (4261.0)	25848 (3089.9)	3448 (1317.6)
OCT 1973	4	26336 (5406.0)	58992 (19126.8)	1533 (142.9)
NOV 1973	4	18083 (6138.7)	38271 (6353.2)	634 (305.6)
APR 1974	4	5672 (1927.4)	121 (46.5)	57886 (14589.3)
MAY 1974	4	20636 (782.5)	34 (6.5)	92357 (15650.6)
JUN 1974	4	2433 (812.3)	734 (37.1)	68613 (6179.1)
JUL 1974	4	7530 (1995.5)	4272 (2198.0)	199861 (38515.7)
AUG 1974	4	13670 (1878.0)	13841 (3651.2)	162231 (28279.2)
SEP 1974	4	45753 (9997.3)	140274 (14390.4)	394782 (99923.6)
OCT 1974	4	13865 (3289.0)	28712 (5548.2)	34529 (7179.0)
NOV 1974	4	12587 (1248.6)	7831 (1450.9)	119149 (9053.6)
APR 1975	4	7936 (1425.4)	56 (38.6)	71332 (9560.5)
MAY 1975	4	11111 (1550.2)	51 (30.2)	81279 (4675.6)
JUN 1975	4	1863 (600.9)	43 (27.0)	119867 (12250.2)
JUL 1975	4	62189 (4518.1)	5174 (1631.8)	465749 (50270.3)
AUG 1975	4	46884 (9591.5)	11820 (3097.2)	614927 (114261.2)
SEP 1975	4	17396 (2321.4)	1575 (928.2)	29344 (4295.7)
OCT 1975	4	5637 (1408.5)	19795 (3924.4)	28443 (5179.7)
NOV 1975	4	2308 (1370.4)	19745 (6103.9)	60794 (23310.3)

SUMMARY STATISTICS TABLE
FOR STATION 21
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
MAY 1973	4	7745 (285.0)	280 (32.7)	19268 (4410.5)
JUN 1973	4	18204 (4029.4)	746 (149.8)	2913 (255.5)
JUL 1973	4	2418 (485.6)	31242 (5726.0)	15415 (2260.2)
AUG 1973	4	37667 (11725.3)	16299 (3255.3)	3183 (509.0)
SEP 1973	4	23363 (2190.7)	15709 (1389.3)	5280 (815.3)
OCT 1973	4	10579 (2728.8)	6006 (2539.0)	354 (329.0)
NOV 1973	4	53141 (10656.4)	19349 (2370.9)	884 (231.0)
APR 1974	4	6003 (1578.2)	12 (6.3)	42335 (11539.2)
MAY 1974	4	42980 (8556.8)	20 (15.5)	18494 (2534.3)
JUN 1974	4	3449 (543.0)	601 (173.0)	44363 (3168.7)
JUL 1974	4	4061 (485.1)	6595 (1788.0)	141033 (29989.6)
AUG 1974	4	28520 (4646.2)	17616 (1634.5)	190820 (36395.0)
SEP 1974	4	33063 (6309.4)	40880 (5349.8)	206794 (25110.7)
OCT 1974	4	8350 (1900.1)	13167 (3901.6)	27880 (5650.8)
NOV 1974	4	13865 (1748.9)	3756 (815.5)	64127 (4657.1)
APR 1975	4	9136 (1023.3)	18 (12.6)	16348 (1956.1)
MAY 1975	4	9393 (415.1)	74 (34.4)	67597 (12675.4)
JUN 1975	4	2828 (633.7)	156 (43.5)	151614 (26463.0)
JUL 1975	4	68182 (17212.3)	4001 (1029.4)	157887 (52395.5)
AUG 1975	4	33452 (6411.3)	8547 (2022.5)	192794 (49940.7)
SEP 1975	4	37299 (3193.2)	2005 (431.8)	6984 (1279.2)
OCT 1975	4	3805 (430.6)	6443 (1724.9)	13835 (2587.9)
NOV 1975	4	4098 (696.8)	1795 (348.5)	26781 (7989.7)

SUMMARY STATISTICS TABLE
FOR STATION 22
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	COPEPODA (#/M**3)	CLADOCERA (#/M**3)	ROTIFERA (#/M**3)
MAY 1973	4	12355 (1135.0)	203 (66.4)	11308 (1966.4)
JUN 1973	4	49377 (5988.6)	865 (659.2)	2731 (760.5)
JUL 1973	4	2987 (748.2)	48336 (5837.7)	9274 (2557.4)
AUG 1973	4	59864 (11801.4)	20860 (3503.4)	3589 (2251.3)
SEP 1973	4	32755 (3175.1)	20028 (1139.9)	1867 (336.0)
OCT 1973	4	9339 (1212.5)	2940 (313.2)	138 (65.8)
NOV 1973	4	40280 (5454.8)	9805 (1176.6)	374 (118.1)
APR 1974	4	13470 (11283.0)	33 (40.5)	42795 (2010.1)
MAY 1974	4	48797 (7915.0)	8 (6.5)	14698 (1605.1)
JUN 1974	4	9069 (623.6)	1314 (468.5)	59693 (13492.2)
JUL 1974	4	4969 (836.6)	3 (2.9)	104251 (53611.8)
AUG 1974	4	44929 (8169.5)	32796 (3519.8)	126554 (17812.0)
SEP 1974	4	27531 (1370.7)	14663 (3923.6)	134090 (23311.2)
OCT 1974	4	7697 (666.2)	26866 (3939.6)	35330 (7407.3)
NOV 1974	4	11588 (2956.8)	3158 (462.3)	46577 (7759.1)
APR 1975	4	8211 (1366.3)	19 (6.7)	10407 (2315.3)
MAY 1975	4	11366 (1803.8)	64 (13.2)	57252 (10572.6)
JUN 1975	4	12772 (3209.2)	43 (4.6)	140340 (26004.9)
JUL 1975	4	67683 (6014.4)	3305 (489.0)	124141 (10179.7)
AUG 1975	4	32222 (2619.5)	30167 (3390.0)	170384 (28277.7)
SEP 1975	4	29793 (6793.2)	1041 (230.5)	5305 (1166.4)
OCT 1975	4	10123 (2166.1)	9482 (4332.2)	15624 (3552.7)
NOV 1975	4	2013 (173.4)	964 (188.7)	18976 (5362.9)

SUMMARY STATISTICS TABLE
FOR STATION 3
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL BENTHOS (#/M**2)	CHIRONOMIDAE (#/M**2)	NAIDIDAE (#/M**2)
APR 1973	3	453 (367.6)	272 (220.9)	5 (4.0)
MAY 1973	3	635 (501.7)	325 (279.4)	17 (16.5)
JUL 1973	3	1516 (1183.2)	62 (41.2)	64 (63.4)
SEP 1973	3	1793 (836.7)	366 (49.4)	512 (185.9)
NOV 1973	3	1381 (259.5)	636 (137.2)	72 (48.8)
APR 1974	3	786 (337.7)	445 (152.2)	3 (2.6)
MAY 1974	3	595 (291.4)	357 (174.9)	10 (6.1)
JUL 1974	3	1121 (296.4)	199 (44.5)	273 (71.2)
SEP 1974	3	527 (133.6)	87 (43.0)	26 (9.9)
NOV 1974	3	699 (465.7)	307 (203.1)	1 (0.6)
APR 1975	3	760 (303.0)	374 (37.5)	0 (0.0)
MAY 1975	3	653 (102.9)	371 (55.2)	1 (1.0)
JUL 1975	3	434 (721.5)	866 (786.9)	189 (192.1)
SEP 1975	3	312 (19.4)	67 (5.1)	5 (4.9)
NOV 1975	3	1860 (393.6)	423 (168.1)	27 (15.5)

SUMMARY STATISTICS TABLE
FOR STATION 6
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL BENTHOS (#/M**2)	CHIRONOMIDAE (#/M**2)	NAIDIDAE (#/M**2)
APR 1973	3	82 (43.7)	47 (21.5)	1 (2.3)
MAY 1973	3	883 (567.6)	42 (9.5)	23 (13.1)
JUL 1973	3	385 (171.3)	86 (33.7)	58 (26.6)
SEP 1973	3	900 (393.4)	43 (8.3)	16 (10.0)
NOV 1973	3	2381 (3121.2)	402 (547.5)	812 (1323.8)
MAY 1974	3	113 (74.5)	50 (33.5)	8 (7.1)
JUL 1974	3	85 (18.2)	46 (6.7)	10 (3.1)
SEP 1974	3	133 (52.0)	91 (26.5)	31 (25.4)
NOV 1974	3	76 (43.3)	58 (34.1)	12 (2.5)
APR 1975	3	64 (13.7)	27 (2.5)	0 (0.6)
MAY 1975	3	9 (4.9)	4 (5.5)	0 (0.0)
JUL 1975	3	1019 (257.0)	262 (89.5)	437 (118.8)
SEP 1975	3	36 (13.3)	11 (6.0)	2 (1.5)
NOV 1975	3	36 (10.0)	20 (8.7)	1 (1.2)

SUMMARY STATISTICS TABLE
FOR STATION 7
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL BENTHOS (#/M**2)	CHIRONOMIDAE (#/M**2)	NAIDIDAE (#/M**2)
APR 1973	3	431 (196.5)	137 (43.2)	5 (1.5)
MAY 1973	3	258 (63.3)	53 (30.7)	5 (4.9)
JUL 1973	3	693 (427.2)	49 (28.7)	29 (33.7)
SEP 1973	3	3560 (2027.8)	281 (308.8)	1160 (603.6)
NOV 1973	3	2398 (1606.2)	307 (94.0)	528 (542.2)
APR 1974	3	65 (31.4)	38 (11.2)	0 (0.0)
MAY 1974	3	724 (39.8)	242 (85.0)	0 (0.0)
JUL 1974	3	1443 (614.1)	78 (19.6)	704 (334.4)
SEP 1974	3	251 (211.1)	51 (37.5)	53 (40.3)
NOV 1974	3	1189 (520.2)	411 (169.1)	34 (16.2)
APR 1975	3	696 (91.9)	222 (19.6)	2 (1.0)
MAY 1975	3	515 (369.8)	176 (187.5)	3 (2.9)
JUL 1975	3	883 (118.0)	282 (34.5)	60 (5.9)
SEP 1975	3	497 (157.7)	46 (4.0)	8 (3.6)
NOV 1975	3	2315 (588.4)	483 (37.0)	25 (9.1)

SUMMARY STATISTICS TABLE
FOR STATION 8
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL BENTHOS (#/M**2)	CHIRONOMIDAE (#/M**2)	NAIDIDAE (#/M**2)
APR 1973	3	285 (165.5)	285 (426.1)	4 (4.7)
MAY 1973	3	893 (525.8)	254 (132.6)	40 (13.7)
JUL 1973	3	2060 (3346.7)	156 (38.5)	513 (260.5)
SEP 1973	3	6541 (3889.4)	264 (138.4)	1188 (839.1)
NOV 1973	3	16224 (10878.8)	445 (211.3)	3131 (1561.0)
APR 1974	3	1029 (810.2)	171 (16.5)	1 (0.6)
MAY 1974	3	726 (718.4)	72 (47.8)	1 (1.7)
JUL 1974	3	1386 (1568.0)	225 (138.7)	497 (537.7)
SEP 1974	3	974 (286.8)	180 (117.5)	183 (71.5)
NOV 1974	3	728 (313.8)	355 (160.2)	11 (9.2)
APR 1975	3	505 (45.2)	184 (69.4)	2 (2.1)
MAY 1975	3	777 (245.8)	192 (72.1)	3 (1.5)
JUL 1975	3	1174 (344.2)	273 (19.7)	63 (73.9)
SEP 1975	3	423 (163.0)	44 (20.0)	30 (22.6)
NOV 1975	3	1131 (120.3)	219 (3.8)	21 (12.4)

SUMMARY STATISTICS TABLE
FOR STATION 11
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL BENTHOS (#/M**2)	CHIRONOMIDAE (#/M**2)	NAIDIDAE (#/M**2)
APR 1973	3	324 (36.5)	103 (49.0)	7 (4.0)
MAY 1973	3	154 (140.9)	78 (50.1)	2 (4.0)
JUL 1973	3	116 (14.0)	17 (16.7)	6 (4.7)
SEP 1973	3	409 (44.6)	82 (1.7)	44 (31.1)
NOV 1973	3	1279 (649.5)	367 (271.8)	383 (184.9)
APR 1974	3	40 (11.4)	33 (12.7)	10 (7.8)
MAY 1974	3	118 (83.6)	103 (82.7)	64 (34.6)
JUL 1974	3	168 (55.2)	78 (19.7)	295 (109.5)
SEP 1974	3	536 (159.0)	84 (23.0)	32 (8.2)
NOV 1974	3	573 (147.5)	255 (102.1)	6 (1.5)
APR 1975	3	67 (29.1)	47 (20.0)	2 (1.5)
MAY 1975	3	53 (5.5)	41 (11.0)	0 (0.0)
JUL 1975	3	40 (12.1)	18 (1.7)	3 (0.0)
SEP 1975	3	72 (15.4)	16 (4.7)	8 (5.1)
NOV 1975	3	301 (183.4)	117 (56.0)	10 (13.4)

SUMMARY STATISTICS TABLE
FOR STATION 12
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL BENTHOS (#/M**2)	CHIRONOMIDAE (#/M**2)	NAIDIDAE (#/M**2)
APR 1973	3	450 (154.6)	131 (53.8)	4 (2.5)
MAY 1973	3	475 (191.7)	225 (117.8)	21 (6.0)
JUL 1973	3	1298 (718.2)	64 (60.1)	107 (59.0)
SEP 1973	3	2893 (1172.0)	313 (143.3)	1318 (453.3)
NOV 1973	3	1661 (742.7)	684 (270.2)	244 (181.3)
APR 1974	3	773 (242.5)	273 (82.7)	0 (0.0)
MAY 1974	3	411 (124.6)	222 (31.5)	429 (185.0)
JUL 1974	3	1114 (181.8)	144 (52.4)	97 (36.9)
SEP 1974	3	816 (355.8)	131 (43.0)	109 (87.8)
NOV 1974	3	1437 (384.5)	659 (177.2)	0 (0.0)
APR 1975	3	548 (103.5)	134 (25.1)	0 (0.0)
MAY 1975	3	587 (114.7)	125 (51.4)	6 (2.9)
JUL 1975	3	1714 (249.5)	235 (75.7)	123 (23.2)
SEP 1975	3	654 (50.5)	75 (7.4)	66 (11.9)
NOV 1975	3	1159 (425.5)	392 (79.6)	14 (7.2)

SUMMARY STATISTICS TABLE
FOR STATION 13
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL BENTHOS (#/M**2)	CHIRONOMIDAE (#/M**2)	HAUTIDAE (#/M**2)
APR 1973	3	589 (453.8)	281 (289.0)	3 (3.5)
MAY 1973	3	676 (627.7)	299 (299.5)	40 (33.5)
JUL 1973	3	8614 (1134.1)	80 (16.6)	963 (207.6)
SEP 1973	3	8357 (3747.4)	626 (474.6)	3020 (839.9)
NOV 1973	3	3811 (2296.6)	866 (410.3)	363 (164.5)
APR 1974	3	155 (120.7)	60 (37.0)	6 (4.6)
MAY 1974	3	410 (149.4)	158 (86.7)	82 (37.8)
JUL 1974	3	478 (289.5)	135 (56.2)	516 (52.5)
SEP 1974	3	1305 (417.6)	245 (168.8)	25 (16.3)
NOV 1974	3	998 (406.8)	527 (253.1)	1 (1.0)
APR 1975	3	780 (109.8)	118 (53.3)	2 (1.5)
MAY 1975	3	422 (115.8)	106 (21.7)	1 (1.2)
JUL 1975	3	588 (158.5)	201 (10.8)	99 (58.0)
SEP 1975	3	294 (163.0)	33 (11.5)	9 (7.6)
NOV 1975	3	949 (283.2)	272 (54.2)	7 (8.1)

SUMMARY STATISTICS TABLE
FOR STATION 16
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL BENTHOS (#/M**2)	CHIRONOMIDAE (#/M**2)	NAIDIDAE (#/M**2)
APR 1973	3	364 (263.4)	127 (78.8)	6 (7.2)
MAY 1973	3	292 (187.2)	146 (80.0)	16 (21.1)
JUL 1973	3	2146 (419.0)	207 (49.7)	136 (39.1)
SEP 1973	3	5517 (4925.2)	613 (601.1)	3111 (3119.6)
NOV 1973	3	1712 (246.0)	331 (52.4)	465 (63.5)
MAY 1974	3	1341 (236.7)	241 (177.1)	65 (32.6)
JUL 1974	3	11340 (3451.5)	1327 (155.7)	1230 (811.8)
SEP 1974	3	2414 (2065.2)	177 (132.0)	1035 (950.9)
NOV 1974	3	400 (353.6)	215 (209.7)	25 (10.4)
APR 1975	3	211 (44.9)	52 (23.6)	0 (0.0)
MAY 1975	3	640 (126.5)	300 (64.1)	8 (6.0)
JUL 1975	3	2306 (523.8)	356 (138.3)	358 (150.9)
SEP 1975	3	2049 (330.6)	61 (28.7)	313 (151.0)
NOV 1975	3	1763 (106.0)	595 (44.6)	16 (13.7)

SUMMARY STATISTICS TABLE
FOR STATION 17
KEWAUNEE NUCLEAR POWER PLANT

DATE	# OBSN	TOTAL BENTHOS (#/M**2)	CHIRONOMIDAE (#/M**2)	NAIDIDAE (#/M**2)
APR 1973	3	270 (123.4)	149 (80.7)	2 (1.0)
MAY 1973	3	611 (240.4)	156 (47.3)	22 (13.9)
JUL 1973	3	3730 (2109.0)	140 (48.2)	363 (186.4)
SEP 1973	3	15583 (11069.0)	978 (786.5)	4119 (3119.4)
NOV 1973	3	1374 (1020.8)	225 (249.1)	105 (212.4)
APR 1974	3	470 (524.8)	137 (116.8)	0 (0.0)
MAY 1974	3	937 (258.1)	160 (25.9)	38 (24.4)
JUL 1974	3	1417 (527.5)	128 (35.6)	696 (255.4)
SEP 1974	3	408 (152.1)	83 (24.0)	149 (57.6)
NOV 1974	3	496 (372.8)	211 (117.6)	37 (46.1)
APR 1975	3	412 (92.1)	45 (20.6)	2 (0.6)
MAY 1975	3	406 (82.4)	121 (32.8)	3 (2.1)
JUL 1975	3	1328 (577.6)	315 (129.1)	65 (37.9)
SEP 1975	3	360 (122.5)	37 (16.2)	47 (9.5)
NOV 1975	3	1341 (294.2)	505 (19.3)	35 (30.1)