Evaluation of Nuclear Power Plant Environmental Impact Prediction, Based on Monitor- ing Programs

Summary and Recommendations

by
K. L. Gore
J. M. Thomas
L. D. Kannberg
D. G. Watson

February 1977

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PREFACE

The U.S. Nuclear Regulatory Commission, Office of Regulatory Research, has sponsored this research program on the evaluation of nuclear power plant environmental monitoring programs. Only nonradiological monitoring programs (hydrological and ecological) were evaluated from both a quantitative and disciplinary approach. Battelle, Pacific Northwest Laboratory (PNL) along with Argonne National Laboratory and Oak Ridge National Laboratory each screened ten nuclear power plants which have been operating for at least 1 year, and in which each laboratory had assisted the Nuclear Regulatory Commission in the preparation of the Environmental Statement. From these ten candidate sites, each laboratory chose three or more nuclear plants to evaluate in detail.

A listing of PNL reports follows:

<u>Title</u>	<u>Date Issued</u>	<u>Report Number</u>
Evaluation of Monticello Nuclear Power Plant Environmental Impact Prediction, Based on Monitoring Programs	November 1976	BNWL-2150
Evaluation of Haddam Neck (Connecticut Yankee) Nuclear Power Plant Environmental Impact Prediction, Based on Monitoring Programs	December 1976	BNWL-2151
Evaluation of Millstone Nuclear Power Station Environmental Impact Prediction, Based on Monitoring Programs	February 1977	BNWL-2152
Similarity Indices I: What Do They Measure?	February 1977	BNWL-2152 Addendum 1
Similarity Indices II: The Power of Goodall's Significance Test for the Simple Matching Coefficient	February 1977	BNWL-2152 Addendum 2
Evaluation of Nuclear Power Plant Environmental Impact Prediction, Based on Monitoring Programs: Summary and Recommendations	February 1977	BNWL-2153

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INTRODUCTION

This final report summarizes our findings and presents our conclusions and recommendations from the series of reports in which we quantitatively evaluated nonradiological environmental monitoring programs at three nuclear power plants. The monitoring programs were assessed as to their effectiveness in measuring environmental impacts. At the onset of this study ten candidate sites qualified for initial screening by meeting the following criteria: 1) at least 1 year of operating experience and 2) Battelle-Northwest had assisted the Nuclear Regulatory Commission in the preparation of the Environmental Impact Statement.

During the course of this study, efforts were directed toward:

1) assembling and reviewing the information available on the nonradiological environmental monitoring programs of the ten operating nuclear power plants, 2) selecting three of these plants for detailed analyses, and 3) quantitatively evaluating monitoring data from these three plants. The type of information reviewed included Environmental Statements, Environmental Reports, Nonradiological Monitoring Reports, Operating Reports, Unusual Incidence Reports, Nonradiological Environmental Technical Specifications and the open literature. The availability of monitoring information varied widely and played an important role in the plant selection process. In addition to report availability, selection was also based on other factors such as: time span covered by the monitoring reports (both preoperational and operational); general quality and quantity of data; consistency of preoperational to operational monitoring; continuity of sampling programs with respect to methodologies, sampling locations and sampling program design; habitat type i.e., riverine, lacustrine, estuarine and marine; and time and rate of plant operation. The possible environmental impacts from the operation of most of the plants examined were those associated with aquatic ecosystems. Therefore, little or no monitoring of the terrestrial ecosystem beyond that connected with plant construction was performed.

Out of the ten candidate sites (Cooper, Fort Calhoun, Haddam Neck, Maine Yankee, Millstone, Monticello, Oyster Creek, Pilgrim, Point Beach and Turkey Point), the following three were chosen for detailed analyses: 1) Monticello Nuclear Generating Plant, 2) Haddam Neck (Connecticut Yankee) Nuclear Power Plant, and 3) Millstone Nuclear Power Station. Monticello, located in Minnesota, uses the Mississippi River as its cooling water source, and thus represents a riverine ecosystem. The Connecticut River is the cooling water source for the Haddam Neck site, representative of a tidal-river ecosystem. Millstone, the third site, is also located in Connecticut and provides an example of a estuarine-marine ecosystem. This plant uses Niantic Bay (estuary) as its cooling water source, but discharges into Long Island Sound (marine). Most of the plants examined employed open cycle or once-through condenser cooling systems. Therefore, they may not be representative of the newer plants, that have gone largely to off-stream cooling (e.g. cooling towers and ponds) because of concerns over discharge of large amounts of heat to surface waters.

Preoperational as well as operational monitoring data were examined to test the usefulness of baseline information in evaluating impacts. This included an examination of the analytical methods used to measure ecological and hydrological parameters, and an assessment of sampling periodicity and sensitivity where the appropriate data sets were available. From these types of analyses, deficiencies in both preoperational and operational monitoring programs may be identified and provide a basis for suggested improvements.

A considerable amount of time was spent accumulating the original data and preparing it for analysis, and a large effort was expended on applying the proper statistical test to the appropriate data sets. Both current statistical methodologies and others developed at Battelle-Northwest were employed. It should be noted that some of the original data could not be obtained, while other data were found in unusable form (i.e., a determination could not be made of time or place of data collection).

The data sets examined included communities such as phytoplankton, periphyton, benthic macroinvertebrates and fish (including ichthyoplankton, juveniles, and adults). In addition to community effects, potential impacts resulting from entrainment, impingement and cold shock were also examined.

Statistical tests employed ranged from an overview of the entire data set via an analysis of variance to nonparametric tests for significant changes due to station position or time of year. We were able to obtain some replicate data sets, thus enabling us to check the distributional basis for some of the statistical analyses employed. In addition, we have investigated the usefulness of similarity indices in the statistical analysis of impact. Also, some effort was placed on investigating the statistical power of Goodall's Matching Coefficient for several of these measures.

Data recording and synthesis for statistical analyses were very important and, at times, cumbersome aspects of this study, but due to certain inconsistencies; e.g., additions and/or deletions of sampling stations, changing sampling gear or methodologies, and changing program design and reporting formats, much of this data could not be quantitatively evaluated.

We urge the reader to keep in mind when reviewing this document that the state-of-the-art of nuclear power plant monitoring has improved since the 1960's to a point where these environmental programs may not appear to be "up-to-date," however we believe these studies were among the best of their period. The hypothesis that a change (impact), whether beneficial, detrimental, or of no apparent consequence to the species, population or community was quantitatively tested and our results are summarized in the following section.

SUMMARY OF FINDINGS

MONTICELLO NUCLEAR GENERATING PLANT

THERMAL MONITORING PROGRAMS

Three programs provided temperature data in the region of the Monticello Nuclear Generating Plant surface thermal discharge. One program maintained continuous thermal monitoring at two points upstream from the discharge and at seven points covering the first 5.6 km distance downstream from the discharge. This was the only program providing preoperational temperature data for the site. The other two programs were the plume survey transect program and the periphyton monitoring program. Results of thirteen plume surveys each involving nineteen transects were available for analysis. The surveys spanned several operating, ambient flow and seasonal conditions. The periphyton program provided relatively little data because of infrequent sampling and variable plant operating loads.

The continuous monitoring program showed that the river was affected by plant discharges for more than 5 km downstream. During September 1972, downstream sampling stations experienced temperatures from 8°C to 12°C higher than upstream temperatures for at least 5.5 km from the point of discharge. During periods when the auxiliary cooling towers were operating, the temperatures in the river were significantly lower than when the cooling towers were not operating.

The thermal plume transect surveys, well performed and excellently documented, permitted comparison of most of the predicted thermal plume fields with survey results. The phenomenological model used for the hydrothermal predictions was incapable of matching field data. Models more appropriate to existing hydrological conditions possibly could have better replicated field data than the phenomenological model used. The survey results supported the data obtained from the continuous monitoring program where they were comparable. The thermal plume surveys showed that vertical

mixing of the thermal plume occurred rapidly downstream of the plant and significant vertical thermal stratification was absent 0.5 km below the discharge.

Temperature data collected during the periphyton monitoring program also illustrated general thermal plume characteristics, although they did not add to the results obtained from the hydrological programs.

ECOLOGICAL MONITORING PROGRAMS

Ecological monitoring programs were conducted for approximately 8 years at Monticello. Some populations have been extensively monitored (from 1968-1974), while other studies have been short-term (1 year or less).

Periphyton

During the first 2 years (1968 and 1969) of sampling very little data were reported due to collection gear design changes and testing. Productivity measurements (chlorophyll a) and individual cell counts were analyzed for the seven sampling stations that provided consistent data.

Two different statistical analyses were performed on 1 year of pre-operational (1970) data and 4 years of operational periphyton productivity measurements. The first approach utilized the ratio procedure (Eberhardt, 1976). Concurrent temperature and current velocity data for each periphyton sampling date were used in an attempt to construct a multiple regression model with productivity as the dependent variable.

Unlike the chlorophyll a data, very little preoperational count data were available, thus our comparisons were based on counts from heated and control stations only during periods of reactor operation. Wilcoxon's Signed-Ranks Test was used to statistically assess species (12) differences and regression analyses of total periphyton counts with distance downstream from the discharge canal (as the independent variable) were used to evaluate the operational data.

No statistically significant differences in periphyton productivity were attributed to the operation of the Monticello Nuclear Generating Plant. Qualitative examination of the data suggested some possible effects, but these were rejected because of inconsistencies in the data. Our efforts to devise a multiple regression model to explain the chlorophyll a data were not successful. No evidence for differences in periphyton counts could be associated with plant operation. However, since no preoperational data were available this observation should be considered qualitative. Both linear and quadratic models of log count and distance were significant but we found that if counts taken nearest the outfall were excluded that the models were no longer statistically significant. We concluded that most of the relationship between distance and total periphyton was associated with the area near the discharge canal.

Benthic Macroinvertebrates

Benthic macroinvertebrate data were evaluated using three different statistical approaches: 1) an overview of the entire data set via an analysis of variance, 2) a ratio approach, Eberhardt (1976) and 3) a non-parametric procedure to test for statistically significant changes due to position (station) or time.

Data were available from 1968 through 1974, but that collected between 1969 and 1972 (2 preoperational and 2 operational years) were evaluated. The 1968 and 1973-1974 data were not analyzed because in 1968 a different type of sampling gear was used; data collected in 1973 and 1974 were reported as percentages, whereas 1969-1972 data were reported as numbers per station. Numbers of stations and transects varied throughout the study; but four transects were consistent between 1969 and 1972. In addition, three short-term (1 year) studies were not examined because they merely supported the long-term monitoring program.

The results of an analysis of variance, Wilcoxon's Signed-Ranks Test and a ratio evaluation indicated no statistically significant changes in benthic fauna from operation of the Monticello Nuclear Generating Plant. If short-term changes were present, such as early aquatic insect emergence, our analysis did not detect these effects.

Fish

Fish studies utilized electrofishing, seining and creel census procedures to assess species composition and/or population densities. Special studies of impingement, entrainment and cold shock were also conducted. A portion of the 1968-1969 electrofishing study was devoted to a tag-recapture assessment to obtain population estimates for several species. These estimates were also used as an aid in the interpretation of a later cold-shock study conducted in 1974. We were unable to statistically evaluate most of the data from these studies for various reasons including lack of catch/effort information in the preoperational electrofishing study, and incomplete and biased monitoring for impingement and entrainment experiments. Additional specific problems are addressed for each study below, and some qualitative interpretations are offered where appropriate.

Electrofishing

Results of these studies were reported for 1968-1969, 1971-1972 and 1973-1974. Unfortunately, the numbers of fish actually caught in each of five sectors sampled were only reported in the first 2 year period, while percentage distribution of the catch was reported in the second 2-year interval. In the 1973-1974 period, data were reported in graphic form by thermal zones and on a catch/effort basis. Thus, a statistical comparison among the several two-year periods was not possible.

The data could not be quantitatively evaluated for the following reasons: 1) shocking times were not recorded for 1968, 2) no sector differentiation could be ascertained for 1969, 3) large and variable sampling time intervals existed between sectors (sometimes 2 week differences), and 4) inconsistent sector shocking pressure, i.e., some sectors had up to ten shocking runs, while others had as few as two runs.

The rough fish data for 1973 and 1974 showed no decreasing catch/effort for the control, immediate, intermediate and outer discharge areas, yet both yearly data sets indicate numerically diminished rough fish catches in the immediate area compared to other areas. Preoperational data might have clarified this point. Too few measurements (i.e., no catch or small

catch/effort values) were available for game fish to allow a similar qualitative appraisal. The population size estimates presented are of questionable reliability because the Schnabel method applied assumes a constant population with no recruitment or mortality; an unlikely situation in a flowing river. Further, statistical bias results when either the number of fish marked and examined or the number of recaptures is low [less than four is suggested as low by Ricker (1975)]. Finally even though the above limitations are ignored, no assessment of variability was presented for any of the population estimates. The intervals were quite large; i.e., for smallmouth bass we estimated the 95% confidence interval (using a Poisson approximation) as 238 to 2432 for the population value (609). More smallmouth bass would have to be marked and recaptured to obtain a more reliable population estimate.

Seining

Data were analyzed from two collection periods, a preoperational study conducted from 26 May 1970 to 20 November 1970 and a operational study done between 19 June 1972 and 25 July 1973. Noncontinuity of sampling stations was again a problem, only three stations were sampled during both surveys. Further the considerable time between studies, lack of catch/effort data and no indication of sampling frequency, made statistical analysis difficult.

It was reported that the percentage distribution of fish did not change during the preoperational and operational periods and the conclusion was made that the heated water had no effect on the fishing (supported by a rank correlation analysis of preoperational and operational percentage species distribution data). In the absence of catch/effort data or an indication of the dates actually fished, this conclusion may be unwarranted because it was based on a statistical procedure which ignored the numerical magnitude of species changes.

Since it was likely that some differences in species proportions at the same sampling stations occurred after 2 to 3 years, we calculated a chi-square (independence) for fish numbers observed at one downstream station for the

operational and preoperational periods. This statistic was found to be highly significant ($P < 0.01$), but we could not determine the causative factors. We also calculated the percentage of fish seined during preoperational and operational periods at upstream and downstream stations to assess possible changes due to operation of the plant. An analysis of variance of limited percentage distribution data showed the observed changes were associated with upstream and downstream site differences unrelated to operation of the plant.

Creeel Census

We did not quantitatively evaluate this study because only operational data were available. This program was designed to estimate plant effects on the sport fishery and provided estimates of fishing effort and an observation that 1973 fall smallmouth bass and walleye catch rates in the discharge canal were approximately ten-fold greater for than in river areas during the regular fishing season. Since no estimate was made for the "normally" fished areas in the fall of 1973 and because the source of the fall canal fish is unknown, a conclusion that a new sports fishery has been established may be premature.

Cold Shock

A series of experiments were performed in March 1974 to determine the effects of winter plant shutdown (cold shock) on fish in the discharge canal. Duplicate tests were made on six indigenous species. At the rate of 2.8°C every 12 min, the fish were subjected to an overall temperature decrease of 13.8°C , (from 15.5°C to 1.7°C), in 1 hour.

We believe the river fish population estimates based on 1969 electro-fishing data were inadequate (displaced too far in time) to use in estimating cold shock effects in 1974. In additon, estimates of mortality due to rapidly falling temperatures were based on only one to six test fish and observed for only 24 hours after cold shock. For these reasons we believe that calculation of estimates for cold shock losses may be subject to criticism. Sample size was inadequate for a statistical analysis.

Impingement and Entrainment

Fish entrainment studies were conducted for approximately 1 full year during 2 calendar years (1973-1974), while impingement studies were begun in July of 1973 and data were available through December of 1974. Both sets of data were evaluated even though sampling periodicities were very uneven over the intervals of data collection and unusual patterns of "day of the week" data collections were evident. Some days of the week were never sampled whereas others were sampled frequently. If power demand patterns and associated reactor operation levels were very different for weekends, week days, or periods of days, then the data may be biased if used to calculate results for the entire period. With the exception of three sample dates, impinged fish totaled less than 100/day while over 100/day (excluding suckers) were entrained on all sampling days with some values higher than 1000/day. Gamefish were a large part of the impingement "catch" as compared to the entrainment "catch."

When the data were presented as seasonal summaries, the shortcomings of attempting to estimate numbers of fish lost to entrainment were apparent. We obtained estimates ranging from 222 to 121,201 (with large errors) depending on the period chosen. Estimates of number of fish entrained per day are quite different, variable and sensitive to the occasional extreme observation.

HADDAM NECK NUCLEAR POWER PLANT

THERMAL MONITORING PROGRAMS

Two programs provided nonecological thermal information at the Haddam Neck Plant, the Hydrology Monitoring Program and the thermal plume surveys. Several ecological programs also produced temperature data.

The Hydrology Monitoring Program reported bottom and surface temperatures at five locations over approximately 26 km of the Connecticut River. An estimate of the thermal plume presence (degree and duration) at the monitoring sites was determined by comparing preoperational and operational data. This comparison showed that: 1) at a point across from the outfall, temperatures were sometimes as high as 10°C above the bottom mean temperatures, 2) that plume waters were confined to the upper 3 m of the river near the plant discharge, 3) that there was a slight observable temperature rise in the river 3.5 km downstream of the plant discharge, and 4) the river was virtually homothermal, vertically, at a short distance downstream of the plant. The information was useful in determining the plume presence at only three points. The study results would have been improved by more nearfield stations located at the ecological monitoring sites.

Thermal plume surveys were performed by two different groups with each using a different sampling methodology and reporting format. One group employed a single boat to survey the plume and reported the temperatures in the plume as horizontal isotherm plots at each 0.6 m depth. The second group used four boats and surveyed both upstream and downstream of the plant discharge on preassigned transects. They reported the horizontal water surface isotherms as well as selected cross-section isotherms. The first group did not report the locations of their transects or the times and durations of their surveys. The second group detailed their survey techniques reasonably well; however, they did not perform as many surveys as the first group and data were available for only about half of the surveys they conducted.

Surface areas enclosed within the 2°C and 4°C isotherms for surveys taken in 1968-69 by both groups vary considerably more than the surveys taken in 1970. The 1968-1969 isotherms varied by factors of 3-8, and the 1970 isotherms varied by factors of 2-3 and were more consistent. In 1970, the 2°C and 4°C isotherm areas showed reasonable tidal trends and were generally smaller for all tidal conditions than for the 1968-69 surveys.

Of the ecological temperature monitoring efforts, only the data from the benthic study were useful in our evaluation. The benthic data spanned both preoperational and operational periods with a number of temperatures taken near the discharge. Three sampling points near the discharge were selected as the ones most likely to detect plant induced thermal changes. Statistical analyses showed that there were no significant ($P = 0.05$) differences among the three stations. Thus, the temperatures reported for any one of the three stations would have been sufficient to thermally characterize the region of the discharge during the preoperational period. Comparison of operational temperatures in the area of the benthic study were significantly affected by the thermal discharge when referenced to each other and were thermally unique.

ECOLOGICAL MONITORING PROGRAMS

Ecological field collections were begun in June 1965 and produced nearly 2-1/2 years of preoperational and 5 years of operational data. Communities sampled included: microbiota and phytoplankton, benthic organisms, resident adult fish and their early life stages, ichthyoplankton, juvenile and adult American shad with special reference to their population dynamics and migrating behavior. In addition to the above studies, entrainment and impingement data were collected.

Microbiota and Phytoplankton

Both phytoplankton and microbiota data were collected between June 1965 and September 1969 at four stations. However, only data from two control and one heated station were evaluated because of change in location of the fourth station. Microbiota data were reported graphically and were not

usable for statistical analysis. Phytoplankton were collected at both the bottom and surface of the water column on a biweekly basis for the first year and triweekly thereafter. In order to investigate the hypothesis of no difference between counts obtained at the bottom and surface, we performed Wilcoxon's Signed-Ranks test on the matched data from all stations during preoperational, operational and the entire 4-year period. Statistically significant changes in phytoplankton numbers were found between surface and bottom samples at the two control stations and averages for surface and bottom samples at the control stations also were significantly different. Because of an unexplained increase in phytoplankton numbers with time at all stations we are reluctant to place high reliability on our results.

Benthic Macroinvertebrates

Benthic studies began in June 1965 and continued through December 1972 on a biweekly to quarterly sampling frequency depending on season and station location. Several areas and stations were sampled, but data from 6 of the 15 river stations were disregarded for the following reasons: no preoperational data, no operational data and different sampling methodologies.

A nested analysis of variance (ANOVA) was used for two reasons: 1) most of the available data would be utilized to the best advantage and 2) lack of an experimental design was more of a disadvantage in other methods of statistical analysis.

We calculated the intercorrelations between count, wet weight and dry weight for each species to determine the best variable for analysis. All three abundance measurements contained much of the same information and the count data were analyzed in detail; they were the most complete. Water temperature, sediment temperature and dissolved oxygen were not promising covariates in the ANOVA.

Different main effect terms (i.e., years, operation, etc.) were significant for different species. Yearly counts within the preoperational

and operational periods were significantly different. When counts from all stations (controls and exposed) were compared with each other over all years of data collections, no significant differences were found.

The interaction which reflected the differences between preoperational and operational status for control and exposed stations was statistically significant (an "impact") in the following instances:

- Mean numbers of the annelid (Limnodrilus hoffmeisteri) and the midge fly (Cryptochironomus fulvus) and the Phylum Arthropoda decreased in the month of April during the operational years as compared to the preoperational years.
- The fly (Procladius culiciformis) decreased in number for the months of July and August during the operational years.

Clam (Pisidium sp.) populations were reduced, but it is not clear whether this was due to direct thermal effects or to habitat change, i.e., elimination of eel grass (Vallisneria sp.) beds.

Numbers of several benthic canal species increased or decreased dramatically depending on the operating levels of the power plant and heat flow in the discharge canal.

Adult and Juvenile Resident Fish

Adult and juvenile resident fish were collected between 1965 and 1972 with bag seines and otter trawls. A statistically significant log-linear regression relationship over time was found for the otter trawl data at all stations, implying an exponential decrease in catch per effort. However, a similar analysis on the bag seine data showed a significant relationship at only one station. An analysis of covariance of the regression slopes for both data showed that all five seine slopes were similar, but that statistically significant differences existed among control and heated stations. The latter differences indicated nontrivial location differences which were unrelated to reactor operation. However, since fish can move freely in this stretch of the river, an influence of the plant on fish at

both heated and control stations cannot be discounted although preoperational data do not seem to support this latter hypothesis.

Juvenile American Shad

Juvenile shad (young-of-the-year) were sampled approximately every 2 weeks from June through November during 1965-1972 at 12 stations, but data useful for analysis were available from only 8 stations. The data were statistically evaluated using both linear regression analyses and Eberhardt's (1976) ratio approach. The linear regression analyses indicated no significant trends at either heated or control stations in preoperational-comparisons, but the variability was very large. The ratio test did not detect a statistically significant difference between heated and control stations, but the statistical power of this test was low due to limited and variable data. Our evaluations gave no indication of a plant effect on the abundance of juvenile American shad. Since only limited data were available for statistical comparisons, our conclusion is preliminary.

Impingement

During 1968 and 1969, screen washings were taken from each of the four intake screens for each of the three 8-hour work shifts; in 1970, two 12-hour daily collection from three screens were pooled because the fourth screen had been fitted with an electric device; only during 1971 were the results of all four screens reported separately for three 8-hour shifts. Wilcoxon's Signed-Ranks Test for differences among screens, time of day and the effect of intake screen electrification showed a changing pattern of catch size composition over years and that impingement of seasonal species can bias the expression of average number of fish impinged per day. Only in 1970 (summer data only) was nighttime impingement statistically greater than daytime for all size categories. The effect of electrification of one screen appeared dramatic, but other explanations for reduced impingement could not be ruled out, i.e., that less fish would have been impinged even in the absence of the intake screen change or that an equal number of fish were impinged but simply redistributed to the other screens.

Ichthyoplankton - Entrainment Studies

An extensive research and field sampling program to define the spawning and nursery grounds of the important fish species in the Connecticut River was conducted from 1965 to 1969. Stations were apparently not located to detect changes in ichthyoplankton due to any projected thermal effects in the river but rather to obtain the basic research information desired, i.e., distribution, abundance and development of Connecticut River ichthyoplankton. Our attempts to evaluate these data relative to plant heated effluents were unsuccessful.

An entrainment assessment was made for the fraction of the estimated concentration of both zooplankton and ichthyoplankton passing by the plant (by depth and for two time periods) at 11 transect stations and at each of the four intake bays. The values ranged from 1.68 to 5.79% and 1.2 to 14.9% for ichthyoplankton and zooplankton respectively. All entrained larval fish suffered 100% mortalities when temperatures exceeded 30°C in the discharge canal. This may justify discontinuing further monitoring if the small percentage loss is deemed acceptable.

MILLSTONE NUCLEAR POWER STATION

THERMAL MONITORING PROGRAMS

Temperature data were obtained from a variety of programs conducted in the vicinity of the plant. The bulk of the nonecological monitoring programs were designed for support of thermal modeling. There were only enough data for input and calibration of the models used and no data were available for verification of the model predictions.

The only survey providing calibration data for the thermal plume model (Stolzenbach and Harleman, 1971) required the introduction of dye in the effluent and the measurement of both dye concentrations and temperatures in the region around the plant discharge. Dye measurements were performed during two tidal conditions. The thermal model predictions compare reasonably well with calibration survey data. However, because of the variability in surface plume characteristics noted in our study of Haddam Neck thermal monitoring and by other researchers (Dunn et. al., 1975), it is unlikely that the model would provide good agreement with field surveys at other times.

The other model employed for simulations in the region of the plant effluent was the long wave model of Leendertse (1967). This model requires accurate boundary and water body conditions and simulates velocity and water level as a function of time. At Millstone, the model was found to be quite sensitive to the boundary conditions and their representation in time. The water current and water level studies were performed to gather data at various locations in the study area. In the first study the interval between measurements of the water level was too long (10 min) to delineate the phase lag across the model area with sufficient accuracy. The data gathered during the second study overcame these difficulties and were used as input, calibration (of the Manning Coefficients) and verification of the predictions. Because the data were used for calibration and model verification, the predictions may be biased. No use of the water current predictions of Leendertse's model were employed in the transport or diffusion of heat or chemicals. The only application of water current predictions was in the winter flounder study.

The ichthyoplankton monitoring was the only ecological study that produced temperature data suitable for analysis. One of the stations in the vicinity of the discharge had a small temperature increase due to plant operation.

There was a need for continuous monitoring in the vicinity of the discharge and the lack of any suitable preoperational data in the region of the Millstone discharge severely limited the value of any continuous monitoring after the plant became operational. Monitoring in support of thermal plume predictions at Millstone were incomplete (many additional surveys were needed to validate or assess the suitability of the computer model). The documentation of the surveys that were performed was also incomplete because important ancillary data were missing or unavailable (survey durations, transect locations for each survey, survey methodology, plant operating conditions and general meteorological data).

ECOLOGICAL MONITORING PROGRAMS

Our analysis of ecological monitoring programs at Millstone considered about 2-1/2 years of preoperational and 5 years of operational data. The sampling program began in 1968 and, for the most part, is still continuing.

Twenty-two separate monitoring programs have been conducted at Millstone but due to certain inconsistencies (e.g., adding and/or deleting sampling stations from year-to-year, changing sampling programs and changing sampling methodologies) only ten studies were evaluated.

Rocky Shore Community

Even though the rocky shore community study was qualitative (organism relative abundance was determined by visual inspection) we attempted to evaluate the study because it was one of the longest and the data were collected in a consistent manner. The percent coverage data were not assessed because of an ambiguous measurement error and limited data. A qualitative examination of the data indicated some changes in species "numbers" occurred, but these changes were difficult to relate to plant

operation. For the more abundant species, the data should be collected in a quantitative fashion, rather than estimated, if statistically reliable estimates of changes are desired. The usefulness of coverage estimates for the less abundant species is questionable.

Barnacles

The average of differences in barnacle diameters from four stations (one a control) were examined to compare preoperational to operational data. The data suggest there was a greater increase in barnacle diameters at the heated stations than at the control station; however, this observation could not be statistically supported.

Intertidal Sand Infauna

Total organisms counted and numbers of the most abundant species were compared at two ecologically similar stations (control-heated). No statistically significant changes could be attributed to the operation of the Millstone Plant.

Oyster Growth

Length and weight measurements of oysters at three heated and one control station were compared using control-heated station differences, and linear regression methods were used to investigate the relationship between these two measurements at each station. During the four "growing seasons," mean weights at the control station declined, while mean weights at the heated stations either did not decline or increased relative to their preoperational values. Without data from additional control sites, we could not be sure that the declining weights at the control site were normal for unheated areas. However, the data suggest that the heated effluent was not detrimental to oyster growth. The linear regression analysis showed that at two stations regression coefficients (weight as a function of length) were statistically significant and positive, but coefficients from the other two stations were not significantly different from zero, suggesting that both variables should be measured since they apparently do not reflect the same biological "end point" in all environments.

Trace Metals

Trace metal concentrations in seawater and tissues of oysters and mussels at one control and two heated stations were compared during the operational period. Both copper and iron concentrations in oysters were significantly higher at the discharge station than at the control station, but zinc concentration values lacked consistency and were not significantly different in oysters from the two stations. The effects of Millstone operation on tissue concentrations were difficult to evaluate because the oysters were subjected to trace metals in seawater where concentrations varied, (orders of magnitude between quarterly sampling dates) and metabolic factors related to season and life stages also were probably involved.

Shore-Zone Fish

Only one control station and three heated stations were assessed using graphical methods (showing temporal differences among stations) and by comparing average ratios of data from heated and control stations calculated for both preoperational and operational periods.

The variation was so great that a very large sampling effort would be necessary to detect a plant related change in shore-zone fish numbers. To detect a change in fish numbers an expanded seasonal sampling effort (July-September) is required. Even if changes on shore-zone fish populations were detected it is questionable that they could be related in a cost-effective or ecological way at the population level.

Exposure Panels

Boring and fouling organisms were collected (1968-1975) using exposure panels at the Millstone site. We did not attempt a statistical analysis of this data. We agree with the reasons outlined by Brown and Moore (1976) that a quantitative analysis of percent coverage data is extremely difficult and that the data are only useful for qualitative narrative descriptions of temporal changes at sampling stations. Moreover, the estimates would be difficult to relate to any changes due to plant operations because the

station sites were ecologically different and only one control site was sampled. No significant differences were found by Brown and Moore (op. cit.) for species presence/absence data using three different statistical procedures. However, Battelle (1975) found significant positive regressions of number of total species enumerated per year as a function of year observed. The same data were also used to compute species diversity indices. In a supplemental study, we have evaluated the usefulness of similarity measures as quantitative tools for detecting changes in species composition and found that they are very poor metrics for assessing such changes (Johnston, 1977a and 1977b).

Impingement

Economically important fish represented a large fraction of the greater than 15.2 cm size category but represented few fish per day (10, 6 and 5 fish/day for 1972-1974). Shellfish survive at a high rate after impingement, so the numbers of these species impinged may be of little ecological importance. Whether or not the extraordinary impingement of 50 million menhaden in 1971 was trivial will probably remain an open question.

Entrainment

Entrainment studies have been conducted at Millstone since 1971. Periodic estimates of daily entrainment were made and monthly and yearly estimates were constructed by summing each daily value until another daily measurement was available. We have previously noted, Gore et al. (1976a), that such a procedure can sometimes introduce a large bias when "catch" varies widely. Mortality estimates were also made for the entrained organisms (70%).

For the winter flounder, about 1.1% of the population was calculated to be entrained. Estimates of the surface zooplankton fraction killed (0.08-0.27%) were made by assuming 70% mortality through the plant, estimating the surface outflow from Long Island Sound and measuring zooplankton abundance. Once adequate estimates (in terms of precision) of entrainment (species with seasons) are obtained, then such studies should be terminated and their meaning at the population level should be studied.

Winter Flounder Model

An extensive effort has been made to devise a model to predict the effects of larval entrainment at Millstone on adult winter flounder populations.

When the calculated entrainment value (1%) for winter flounder larvae was used in conjunction with the model output, predicted losses (slightly over 5% of the local adult population would be lost over 35 years) were below levels which we consider to be detrimental. Since the assumptions used in the model assessment were conservative and since the larvae entrainment estimate is thought to be conservative, it does not appear that the flounder population was in jeopardy due to the operation of Millstone 1. However, it is nearly impossible (beyond the state-of-the-art) to construct a model for most ecological populations in which we can have complete confidence. In addition, in the case of the winter flounder model projections, we cannot separate Millstone effects from other insults such as oil pollution, changed fishing pressures, and carrying capacities. Another confounding factor is the inability to identify subpopulations.

RECOMMENDATIONS

THERMAL

1) We recommend that consideration be given to the development of a Thermal Monitoring Quality Guide.

- We found from our evaluation of nuclear power plant data that the thermal programs lacked consistency and were not coordinated with other monitoring programs. Most of the monitoring programs did not have adequate documentation of the sampling or analytical methodology. In addition, the monitoring design for input to, and calibration and verification of, hydrodynamic and hydrothermal computer codes rarely considered the assumptions, characteristics and requirements of the code used.
- The development of a Thermal Monitoring Quality Guide would provide direction for an applicant's development of a Thermal Monitoring Quality Assurance Plan (TMQAP) for each nuclear generating plant planned or under construction. We suggest that the responsibility of the applicant is to provide a satisfactory TMQAP to NRC. Each TMQAP could be examined either by NRC staff or designee using the Guide as the principal reference document. The Guide could provide a standard format for development of the TMQAP and would significantly ease the NRC staff review of proposed and ongoing monitoring programs.

Possible factors for inclusion in the guide should include:

- Measurements of site-specific and plant operating parameters such as temperature, flow rate (cooling system and water body), meteorology (as necessary), ambient water level, water current velocity, and power plant load.
- Procedures for regular and adequate calibration of all monitoring instruments.
- Documentation of all past, present, and future monitoring programs planned by the applicant or other agencies. This documentation

should include both ecological and nonecological monitoring programs. The documentation should also describe the location of monitoring stations and the frequency and duration of sampling.

- Careful design of the monitoring program to ensure data are compatible with any mathematical and computer models intended for application at the site.
- Provision for storage of monitoring data on devices directly accessible by computers (magnetic tape, paper tape, punch cards, etc.).
- Description of field equipment and of both field and data analysis methodologies.
- A standard format for power plant thermal monitoring annual reports to provide a brief description of the monitoring that occurred during the previous year, as well as any salient features of the monitoring data or subsequent analysis. The annual report should also include:
 - Details and supporting information on any thermally induced plant impact detected by monitoring (hydrological or ecological).
 - Results from the use of monitoring data for calibration and verification of mathematical and/or computer thermal plume models.
 - Results of any statistical analyses conducted on data from continuous monitoring.
 - Letters of noncompliance or deviation from the Thermal Monitoring Quality Assurance Plan.

2) We recommend that continuous thermal monitoring be conducted.

- We found in most cases that continuous monitoring programs employed too many stations outside the region affected by the thermal discharge. We also found that continuous monitoring could have provided support for thermal impact assessment on aquatic biota if the stations could have been coordinated with ecological stations. We recommend that continuous monitoring stations should be located

at ecological monitoring stations. We suggest that no fewer than five nor more than 15 continuous temperature monitoring stations be employed after the plant begins operation (three preoperational stations for plants on helper cooling systems, and one for plants using closed cycle cooling). At least one (and preferably more) continuous monitoring station should be in operation at least 2 years prior to plant startup. Relocation of preoperational continuous monitoring stations should not be permitted after plant operation, and the relocation of any operational temperature monitoring station should be discouraged. The continuous monitoring station instrumentation location, methodology, reporting format, results and analyses should be well documented in accordance with procedures described in the suggested Thermal Quality Assurance Plans and the NRC Guide describing its establishment.

- 3) We recommend that thermal plume surveys could be performed in support of hydrothermal and hydrodynamic predictions after the plant begins operation.
 - We found that thermal plume surveys could not be relied upon for support of assessment of thermal plume impact on aquatic biota; however, they did provide excellent verification of thermal plume models. We recommend that these surveys should be performed during periods of both typical power and maximum plant operation. The number of surveys necessary to support verification of model predictions depends on the anticipated severity of possible impact on aquatic organisms, the cooling mode and discharge system, the transient nature of the flow and thermal fields in the ambient water body, and the nature of the code used for simulation of the plume or ambient flow field. No fewer than four surveys should be performed. The survey instrumentation, equipment, methodology, reporting format, and results and analyses should be well documented in accordance with procedures set out in the suggested Thermal Monitoring Quality Assurance Plan and the NRC Guide describing its establishment. The plant cooling system, discharge operating conditions, meteorological

and site ambient water body conditions (water level, flow volume rate and velocity past the site, bathymetry at sampling stations, air temperature and humidity, and the cloud cover), should be reported throughout the duration of the plume survey. The exact location and time of each temperature measurement should be recorded and reported. The surveys performed for the Monticello Nuclear Generating Station are an example of a quality plume survey and reporting program for a surface discharge to a nontidal river.

ECOLOGICAL

- 1) We recommend that the emphasis be placed on the economically important species for impact assessment, unless there are extenuating circumstances, (e.g., a rare or endangered species present).
 - We found that at least one species within all trophic levels (i.e., phytoplankton, zooplankton, periphyton, etc.) was sampled in the monitoring programs we examined. Instead of this diversity of effort, we recommend reallocation of that effort to seasonal sampling of the economically important species.
- 2) We recommend that in most cases 2-3 years of preoperational data should be collected. However, where important species of long life cycles are present, then additional preoperational sampling is desirable.
 - We found that most of the preoperational monitoring programs were generally inadequate because of a lack of sampling design, inconsistent data collections and changing procedures. We recommend that at least 3 years of preoperational monitoring be conducted unless required preliminary data or information is available and can be obtained through a literature review; then only 2 years of preoperational field effort would be needed.
- 3) We recommend that once the seasonal occurrence of the economically important species has been determined (from field collections or literature review), the sampling intensity should be adjusted to apply greatest effort when the organisms are abundant or when critical life stages are present.
 - We found that most of the data were reported on a regular sampling basis for all species (i.e., monthly, quarterly, etc.). One year of preoperational data or an intensive literature review may provide the estimates of seasonal abundance for the organisms of interest, so that at least 2 years of a well designed sampling program can be implemented preoperationally. After each yearly period, appropriate statistical analyses and interpretations

should be made. Quantitative data analysis and interpretation should be relative to a hypothesis and be an integral part of monitoring reports. We found, in some cases, that information in these reports amounted to little more than tabular summaries of measurements, with no evaluations.

- 4) We recommend that the Environmental Technical Specifications be based on the potential impacts identified in the Environmental Statement (ES).
 - We found that the "Tech Specs" usually required more studies than were addressed in the ES. We believe that after a literature review, at least 2 years of quantitative preoperational data, (with the appropriate analysis) that the ES should provide better identification of the potential impacts.
- 5) We recommend that a statistical model be used in the program design and that the statistical analysis appropriate to the model be applied at least once each year.
 - We found that most of the monitoring programs were not designed with statistical analysis or addressing the question of detecting change in mind. The sampling design should be based on the objectives that define what is to be sampled and why. A justification should then be prepared for the design chosen accompanied by the anticipated analytical methodology to be employed for data analysis.
- 6) We recommend that once a sampling program is implemented that changes not be made, until an interrelationship between old and new methods and procedures has been established.
 - We found monitoring programs were frequently modified, e.g., changes in stations and/or transects, gear type, frequency of sampling, etc. We recommend that once a sampling program is designed and implemented that only changes that can reasonably be expected to improve the quality of data needed for impact evaluation be allowed.
- 7) We recommend the paired station concept be strongly considered for use in the sampling design, i.e., for each heated or treated station there be an equal number of control stations or at least enough control stations to allow for an estimate of sampling error for control regions.

- We found that most of the monitoring programs include a minimum number of control stations, thus, making statistical analyses difficult. Each pair of stations should be as closely matched ecologically as possible. Even if the statistical analysis is not based on ratio or differences analyses, pairing still will not preclude other statistical analyses.
- 8) We recommend that the original field data be attached as an appendix in a computer-compatible or key-punchable form to each annual or semiannual report.
- We found that summarized results were presented in annual reports in such a manner that they could not be used for statistical analysis, i.e., only tabular summaries of yearly averages or sometimes just percentage values were given. In addition, all zero counts and missing data should be specifically identified because the difference is critical in statistical analysis.
- 9) We recommend that once adequate estimates have been obtained for the fraction impinged and entrained for the economically important species during several periods and/or seasons, that such studies be terminated. Those resources should be reallocated towards field work to provide needed input for population dynamics models.
- We found that simple counts of impinged and entrained organisms cannot be used for impact assessment. The degree of insult can only be estimated when these losses are related to population size.
 - We also found that estimates of fraction entrained or impinged are of little use until some projection of effect to a population occurs. A model can aid in such a projection, suggest field studies and influence the decision-making process.
- 10) We recommend that similarity indices should not be used to quantitatively assess impacts.
- We found that similarity indices and, we suspect, diversity indices as well, provide little quantitative information about community similarity which can be used for impact assessment.

- 11) We recommend that attempts to quantitate changes in shore-zone fish population size be curtailed unless such an estimate is deemed crucial. If so, then a much larger sampling effort than currently expended would be necessary.
 - We found that if the detection of population changes in shore-zone fish are deemed important, then an expanded seasonal effort would be necessary because of the large heterogeneity in the population distribution of many species.
- 12) We recommend that the use of visually estimated abundance and/or percent coverage data be curtailed and replaced by quantitative measurements.
 - We found that these qualitative studies (e.g., some exposure panel and littoral zone transect studies) are of limited usefulness, because meaningful statistical analyses cannot be applied.
- 13) We recommend that measurements (e.g., D.O., current velocity, pH, temperature, salinity, etc.) should not be used for explanatory variables or covariates to model (explain) population changes.
 - Water quality measurements taken only coincident with ecological sampling do not provide the necessary basis for cause and effect relationships. They may be useful to assess immediate catastrophic events, but then measurements must be obtained on a more frequent or continuous basis.
- 14) We recommend a coordinated effort between ecologists and hydrologists in order to design a comprehensive sampling program so that the location of ecological and hydrological stations are as nearly similar as possible.
 - Sampling stations were changed during the course of monitoring in an attempt to better coordinate ecological monitoring locations with the thermal plume predictions. Hydrological and ecological monitoring were at times independent efforts, and not mutually supportive.

- 15) We recommend that the local and regional aspects of impacts should be considered when interpreting the monitoring results.
- We found that the monitoring programs were concerned with only the local or immediate environs. The potential impact from other sources of stress, e.g., other power plants, industries, sewage outfalls, should be considered in the evaluation. It is unrealistic to attempt to establish cause and effect relationships of a single source environmental stress in isolation of other environmental perturbations.
- 16) We recommend that the level of sampling effort should be commensurate with local conditions (environment).
- An economically productive ecosystem should receive a more intense sampling effort than one of lesser value (e.g., the Chesapeake Bay versus the Missouri River).

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