THE EFFECTS OF INTAKES AND ASSOCIATED COOLING WATER SYSTEMS ON PHYTOPLANKTON AND AQUATIC INVERTEBRATES OF THE HUDSON RIVER

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CHAPTER 1: <u>INTRODUCTION</u>

This report serves to document the combined impact of the entrainment of lower trophic level biota (phytoplankton and aquatic invertebrates) by the Roseton, Indian Point, and Bowline Point generating stations.

CHAPTER 2: PHYTOPLANKTON

2.1 INTRODUCTION

The evaluation of the impact of entrainment in areas of high involvement of the biota is dependent to a large degree on an estimation of the probability of surviving the entrainment exposure. Studies were performed at the Danskammer Point (Ecological Analysts 1976a), Roseton (Ecological Analysts 1976b, 1977a), Indian Point (NYU 1973, 1974, 1975, 1976), Lovett (Ecological Analysts 1977b), and Bowline Point (Ecological Analysts 1976c, 1977c) generating stations to address phytoplankton entrainment survival. Results of these studies were combined with results of laboratory studies, site-specific community studies, and plant operational data to evaluate the combined impact of the Roseton, Indian Point, and Bowline Point plants on Hudson River phytoplankton communities.

2.2 INTAKE-DISCHARGE STUDIES

Numerous parameters have been examined to address the effects of entrainment on phytoplankton biological function. Most of these relate to the role of phytoplankton as autotrophs or primary producers, which convert soluble inorganic molecules into cellular constituents through the photosynthetic process using sunlight as the energy source. Oxygen production as a by-product of photosynthesis supplies both autotrophic and heterotrophic organisms with a portion of the oxygen necessary for their continued existence. Parameters related to this photosynthetic role include primary productivity rate (as measured by oxygen production or carbon-14 uptake); levels of essential photosynthetic pigments, such as chlorophyll _a_; and levels of cellular adenosine triphosphate (ATP), the internal energy source of photosynthesis and other metabolic functions. These parameters, when considered in conjunction with parameters of species composition and abundance and the healthy condition of the algae as determined by fluorescence microscopy, provide a basis for the evaluation of entrainment effects.

At each of the power plants, many of the aforementioned parameters were examined (Table 2-1). Species composition and abundance, chlorophyll a, and primary productivity rate as determined by carbon-14 uptake were examined at all plants.

At the Indian Point plant, intake-discharge studies from 1971 to 1975 revealed no consistent trends in entrainment effects on primary productivity. No pattern of enhancement or suppression of productivity was observed over the entire range of discharge temperatures. The highest discharge temperature examined, 34.8 C, at station D-2 (July 1975) resulted in no significant reductions in carbon-14 uptake, assimilation number (metabolic efficiency), or chlorophyll a (NYU 1976:Tables 4-5, 4-6, and 4-4). Phytoplankton densities in intake and discharge samples were variable in all years studied, and no reduction trend in the discharge was noted. Also, no relationship between density and productivity was observed.

Studies at the Roseton plant revealed a trend of significant ($\alpha = 0.1$) reductions in discharge productivity rates at temperatures above 28 C, although exceptions occurred. Average reductions for all dates examined in 1975 and 1976 were 11 and 1 percent, respectively.

A reduction trend in discharge productivity and density was also observed at the Bowline Point plant. Reductions in productivity averaged 10 and 13 percent in 1975 and 1976, respectively; corresponding mean density reductions were 26 and 20 percent. Contrary to the Roseton plant, there appeared to be

TABLE 2-1 PHYTOPLANKTON PARAMETER STUDIED IN INTAKE-DISCHARGE SAMPLES AT THE MID-HUDSON RIVER POWER PLANTS, 1970-1976

Parameter	Danskammer Point	Roseton	Indian Point	Lovett	Bowline Point
Cell damage			1970-1971		
Species identification	1975	1975-1976	1970-1975	1975-1976	1975-1976
Percentage composition	1975	1975-1976	1970-1975	1975-1976	1975-1976
Diversity indices			1971		
Density	1975	1975-1976	1970-1975	1975-1976	1975-1976
Biomass	1975	1975-1976		1975-1976	1975-1976
Primary productivity					
by DO method	1975	1975-1976			
by C-14 method	1975	1975-1976	1971-1975	1973;1975-1976	1975-1976
Assimilation number	1975	1975-1976	1974-1975	1975-1976	1975-1976
Chlorophyll _a_	1975	1975-1976	1972-1975	1973;1975-1976	1975-1976
Chlorophyll _b_		1976		1976	1976
Chlorophyll _c_		1976		1976	1976
Phycoerythrin		1976		1976	1976
Adenosine triphosphate		1976		1976	1976
Fluorescence		1976		1976	1976

no relationship between discharge temperature and the occurrence or magnitude of productivity reductions. Again, no relationship of density to productivity was observed. Reductions in other parameters, including assimilation number, chlorophyll a and other pigments, and ATP level generally averaged 10-20 percent.

At the Danskammer Point and Lovett plants, no consistent trends in density or productivity were observed. Data at these sites were limited, however, and no discharge temperatures above 31.5 C were examined.

Much of the variability observed in all phytoplankton parameters might have been a function of the difficulty in obtaining representative intake samples. While discharge waters are usually well mixed, intake waters may be both horizontally and vertically heterogeneous or stratified. Intake sampling techniques, usually consisting of surface and bottom composited samples, poorly estimate the mean algal density in the intake, resulting in the variability observed in these studies. Thus, mean reductions in density, productivity, and other algal parameters on the order of 10-20 percent at some sites may simply reflect the inadequacy of the intake sampling methodology.

Chlorination, utilized at the Lovett, Indian Point, and Bowline Point plants for biofouling control mainly during the summer months, consistently suppressed primary productivity rates in discharge samples. Since chlorination is performed intermittently and for short time periods, only a small portion of the entrained phytoplankton community is affected.

2.3 THERMAL TOLERANCE STUDIES

Laboratory thermal tolerance studies on phytoplankton at the Indian Point plant were performed by NYU (1973, 1974). These studies, usually involving a 60-minute exposure to a relatively rapid temperature increase of 7 C or greater above summer ambient temperatures ranging from 24 to 26.5 C, noted consistent suppression of primary productivity rates at temperatures of 38 C or higher. Temperatures below this level led to inconsistent suppression and enhancement of primary productivity rates (NYU 1974:p.73).

Instantaneous temperature elevations from ambient temperatures of 0.9-9.5 C to test temperatures of 29.5-38.0 C for 60 minutes resulted in significant reductions in productivity. Exposures of 6, 33, and 60 minutes to temperature increases of 8 C above ambients of 5.0-24.4 C resulted in consistent productivity reductions only when the test temperature exceeded 30 C (NYU 1975:Table 4-17). Mean reductions for 6-, 33-, and 60-minute exposures to 31.7-32.4 C were 14, 9, and 12 percent, respectively. Based on these laboratory studies, reductions in discharge productivity might be expected at temperatures above 30 C, although 1973 results would indicate that the critical temperature is closer to 38 C. Since inconsistencies were observed at different plants at discharge temperatures of 28-35 C, temperatures of 38 C may be required before substantial reductions (greater than 10-20 percent) in productivity will occur.

2.4 MULTIPLANT IMPACT

Projected maximum midsummer discharge temperatures at the three mid-Hudson power plants are shown in Table 2-2. Discharge temperatures are based on predicted river ambient temperatures in the vicinities of the plants, and on projected plant temperature rises (delta-T) based on full-load, mean daytime load, and mean nighttime load operation and pump modes typical of those utilized during midsummer. Calculation of discharge temperatures was performed for ambient temperatures corresponding to both the 50th and 90th percentiles of a cumulative distribution of a 26-year record of daily Hudson

TABLE 2-2 PROJECTED MAXIMUM MIDSUMMER DISCHARGE TEMPERATURES AT HUDSON RIVER POWER PLANTS, BASED ON BOTH 50TH AND 90TH PERCENTILE AMBIENT TEMPERATURES, AS DETERMINED FROM THE CUMULATIVE DISTRIBUTION OF A 26-YEAR RECORD OF DAILY HUDSON RIVER WATER TEMPERATURES

Plant	River Mile	Maximum Ambient Temperature (C)	Full Load Operation: ΔT Range (C)[a]	Full Load Operation: Maximum Discharge Temperature (C)	Mean Daytime Operation: ΔT Range (C)	Mean Daytime Operation: Maximum Discharge Temperature (C)	Mean Nighttime Operation: ΔT Range (C)	Mean Nighttime Operation: Maximum Discharge Temperature (C)
50th Percentile								
Roseton	65	23	9.9-11.4	32.9-34.4	8.6-9.9	31.6-32.9	6.4-7.3	29.4-30.3
Indian Point	43	26.5[b]	8.3- 9.1	34.8-35.6	--[c]	--	--	--
Bowline Point	37	26.5	8.6-10.2	35.1-36.7	6.4-7.9	32.9-34.4	3.5-4.8	30.0-31.3
90th Percentile								
Roseton	65	24	9.9-11.4	33.9-35.4	8.6-9.9	32.6-33.9	6.4-7.3	30.4-31.3
Indian Point	43	27.5	8.3- 9.1	35.8-36.6	--	--	--	--
Bowline Point	37	27.5	8.6-10.2	36.1-37.7	6.4-7.9	33.9-35.4	3.5-4.8	31.0-32.3

(a) All ΔT values determined for pumps modes typically employed during midsummer operation.
(b) Ambient temperature based on that calculated for Bowline Point.
(c) Dashes indicate no data available.

River water temperatures in the vicinity of the Roseton and Bowline Point plants.

Laboratory thermal tolerance studies indicated that temperatures of 38 C or higher were necessary to consistently cause substantial reductions in phytoplankton productivity. Temperatures in that range would not be expected to occur at power plants on the Hudson River, although full-load operation at Bowline Point at 90th percentile ambient temperatures approaches that range.

Spatial and temporal distributions of phytoplankton have shown no trends within the vicinity of Roseton, Bowline Point, and Indian Point that suggest any effects of entrainment on the population or community level. The rapid regeneration rates of algal cells and the rapid mixing of discharge water with the receiving water body tend to compensate for and prevent the detection of any entrainment effects.

The effects of freshwater flow and density-induced circulation in diluting potential localized reductions in phytoplankton due to plant passage were discussed in Subsections 3.1.2.3.2 and 6.3.4 of the Roseton and Bowline Point near-field reports (CHGE 1977; Orange and Rockland Utilities, Inc. 1977). Ratios were provided to convert plant cropping to a conservative estimate of plant impact on river populations. This approach may also be applied on a multiplant basis.

The effects of the Indian Point and Bowline Point plants were considered to be additive because of the proximity of the two plants. However, effects of the Roseton plant were considered to be independent of the other two plants, since the transit time of water movement between the two regions of the river is greater than the generation times of most phytoplankton. Also, differences in species composition between the two regions (often reflecting salinity differences) indicate the uniqueness or independence of the algal communities of each region.

Utilizing the flow data of Subsection 3.1.2.3.2 of the near-field reports (CHGE 1977; Orange and Rockland Utilities, Inc. 1977), the multiplant dilution factors were calculated as follows:

Plant	Mean Plant Flow (cfs)	Incipient Salt Flow (cfs)	Long-term Mean Flow (cfs)	Dilution Factors(%)
Roseton	1,095	7,000	19,000	5.7 - 15.6
Indian Point (IP)	2,480	21,000	23,000	10.8 - 11.8
Bowline Point (BP)	1,163	26,000	30,000	3.9 - 4.5
IP + BP	3,643	23,500	26,500	13.7 - 15.5

Plant impact is determined by multiplying entrainment cropping factors by the appropriate dilution factor. The method assumes a uniform distribution of organisms in the water mass circulating past the plant, and uniform organism involvement with the plant intake both on a diel and seasonal basis. A plant cropping factor of 20 percent would lead to an impact of 1.14-3.12 percent at Roseton, and 2.74-3.10 percent at Bowline Point and Indian Point. Since the plants actually withdraw water from a relatively small zone in the immediate vicinity of the intakes (CHGE 1977:Subsection 3.1.3; Orange and Rockland Utilities, Inc. 1977:Subsection 3.1.3), local reductions in organism density might be greater than the average impact values determined above.

This approach is intended for illustration only, because of the assumptions and oversimplifications involved. However, the estimates derived therefrom are probably conservative. The rapid regeneration rates of algal cells would tend to compensate for localized reductions, since densities would then be at levels less than those limited by light, nutrients, and other algal growth-limiting factors. The lack of localized reductions in algal densities, as determined from site-specific investigations, is therefore not surprising.

2.5 CONCLUSIONS

No multiplant adverse effects of entrainment on Hudson River phytoplankton communities have been detected or are predicted. Peak discharge temperatures may result in slight reductions (10-20 percent) in algal productivity at some sites. However, no reductions should be detectable beyond the plant cooling systems.

CHAPTER 3: AQUATIC INVERTEBRATES

3.1 INTRODUCTION

The multiplant impact of entrainment on macroinvertebrate and microinvertebrate communities of the Hudson River has been evaluated much in the same manner as that employed with phytoplankton.

3.2 INTAKE-DISCHARGE STUDIES

Intake-discharge studies at Hudson River power plants have revealed low entrainment mortality of both microzooplankton and macrozooplankton, except in some cases at high discharge temperatures. Results of these studies were summarized in Subsections 7.3.4 and 8.4.4 of the Roseton and Bowline Point near-field reports (CHGE 1977; Orange and Rockland Utilities, Inc. 1977).

Initial entrainment mortality of microzooplankton at the Roseton and Bowline Point plants averaged less than 15 percent; that at Indian Point was generally less than 10 percent. Latent entrainment effects were usually negligible at all plants.

Microzooplankton entrainment mortality was usually not related to discharge temperature over the range examined (up to 37 C at the Bowline Point plant), except at the Indian Point plant where mortality of calanoid copepods increased at maximum discharge temperatures.

During August 1975 at the Indian Point plant, discharge temperatures of 34 C led to 83 percent initial entrainment mortalities of calanoids. During other months of 1975, no other significant entrainment mortalities of calanoids were observed. In 1974, the trend was not as consistent, with high mortalities reported in August, September, and December. Studies at the Roseton plant at discharge temperatures above 35 C yielded variable results. In 1975, at temperatures of 36 C, microzooplankton mortalities were less than 10 percent; while in 1976, at temperatures of 35.2 C, mortalities in excess of 50 percent were observed for both calanoid and cyclopoid copepods, but not for rotifers.

Initial entrainment mortality of macrozooplankton was also very low except at high discharge temperatures. During 1975 and 1976, mortalities of *Chaoborus punctipennis* at the Roseton and Bowline Point plants averaged 5.7 and 4.0 percent, respectively, showing no relationship with discharge temperature. *Gammarus daiberi* mortality averaged 6.8 and 0 percent at the Roseton and Bowline Point plants. Mortality of *G. daiberi* at the Roseton plant began to increase at 35 C, paralleling predicted curves from laboratory studies (Section 3.3). At the Bowline Point plant, temperatures up to 37 C led to no increases in *G. daiberi* mortality. Entrainment mortality of the estuarine *Monoculodes edwardsi* averaged 4.2 percent at Bowline Point, and, similar to *C. punctipennis*, remained low over the entire range of discharge temperatures examined. *Neomysis americana*, the most thermally sensitive of the species studied, sustained substantial entrainment mortality at discharge temperatures exceeding 32 C, as predicted from the laboratory data.

At the Indian Point plant, similar results were observed, with negligible entrainment mortalities of *Gammarus* sp. and *M. edwardsi* occurring at discharge temperatures up to 35 C, the highest measured. *Neomysis americana* sustained high mortalities at temperatures above 32 C, as was the case at Bowline Point.

No latent entrainment effects were observed at the Indian Point plant, although Gammarus sp. appeared to sustain latent mortalities averaging 7.1 and 19.2 percent at Bowline Point and Roseton, respectively. Latent mortalities were insignificant at discharge temperatures below 25 C, and increased with discharge temperatures from 25 to 35 C. Maximum latent mortalities approached 50 percent. Comparison of sample methodologies at the different sites revealed a correlation of latent mortality with the length of time the collected organisms were held at discharge temperatures during sampling. This period varied from 5 minutes at the Indian Point plant to over an hour at the Roseton and Bowline Point plants. Laboratory studies confirmed that the combination of high discharge temperatures and long exposures led to high latent mortalities. Thus, the mortalities observed at the Roseton and Bowline Point plants may be an artifact of the sampling design.

3.3 LABORATORY THERMAL TOLERANCE STUDIES

3.3.1 Microzooplankton

The upper thermal tolerance of several of the major microzooplankters was examined by Lauer et al. (1974). For Acartia tonsa, Halicyclops fosteri, Bosmina longirostris, and Eurytemora affinis acclimated to a summer ambient temperature of 24.6 C, upper lethal thermal thresholds observed for 15-minute exposures were 33.5, 36.0, 34.7, and 34.0 C, respectively. The thermal thresholds for 30-minute exposures were about 1 C lower. In both cases, temperatures leading to 50 percent mortality of the species tested were about 2-3 C higher than the threshold temperatures. Zubarik (1976) reported upper lethal temperatures of 34-36 C for E. affinis acclimated to 21-26 C, following 15-minute exposures. These studies indicate that discharge temperatures near 35 C approximate the upper lethal thermal thresholds for major microzooplankton species during midsummer. Thus, thermal entrainment mortality of these species is expected at temperatures of 35 C or above.

3.3.2 Macrozooplankton

The upper thermal tolerances of three key macrozooplankters, *Neomysis americana*, *Gammarus daiberi*, and *Chaoborus punctipennis*, were examined in laboratory studies (Ecological Analysts 1977). The results of multiple experiments with each species were combined to form multiple linear regression models designed to predict thermal mortality, given ambient or acclimation temperature, exposure duration, and test temperature. Thermal mortality was determined in order to detect latent effects. Based on 10-minute exposures, critical threshold temperatures for *G. daiberi*, *C. punctipennis*, and *N. americana* were 37, 40, and 32 C, respectively.

Laboratory thermal tolerance data collected at New York University (NYU) are also consistent with the laboratory results presented above. Upper thermal thresholds for 5-minute exposures for *Gammarus* sp., *Monoculodes edwardsi*, and *N. americana* acclimated to summer ambient temperatures were 38.0, 35.5, and 32.5 C, respectively. The temperatures leading to 50 percent mortality were generally 1-2 C higher (Lauer et al. 1974).

3.3.3 Thermal Entrainment Mortality Predictions

Intake-discharge studies at all five plants have indicated generally low entrainment mortalities of microzooplankton and macrozooplankton, except in some cases at peak discharge temperatures. The low mortalities were attributed to minimal mechanical and pressure stresses associated with plant passage.

Thermal mortality of some species was predicted at maximum discharge temperatures, based on the results of laboratory thermal tolerance studies. Actual intake-discharge entrainment mortality estimates closely resembled the predicted values.

Projected midsummer discharge temperatures at the three mid-Hudson power plants are shown in Table 2-2. As mentioned in Subsection 3.3.2, the calculated upper lethal threshold temperatures (above which thermal mortality increases rapidly) for 10-minute exposures for major macrozooplankton species C. punctipennis, G. daiberi, M. edwardsi, and N. americana acclimated to midsummer temperatures were 40, 37, 35.5, and 32 C, respectively. Based on the projected maximum discharge temperatures shown in Table 2-2, the potential for midsummer entrainment mortality at each site for each species was ascertained. The estuarine N. americana, for example, would be expected to sustain substantial or total entrainment mortality during one to three months in mid- to late summer at Bowline Point and Indian Point at full-load operation. Mean daytime loads would also result in substantial mortality. However, due to diel vertical migrations of N. americana, daytime involvement is considerably less than that at night. Mean nighttime reduced-load operation of the Bowline Point plant will result in negligible entrainment mortality of N. americana. However, since generating loads at the Indian Point plant should not fluctuate on a diel basis to the extent that they do at the Bowline Point plant, nighttime entrainment mortality of N. americana could remain high at that plant.

Monoculodes edwardsi may also sustain measurable entrainment mortalities during midsummer at the lower Hudson plants when they are operating near full load. However, mean daytime and nighttime operation of the Bowline Point plant should protect the species. Mortalities at the Indian Point plant even at full load would be negligible except during the warmest of summers.

Gammarus sp. should be protected under most conditions, although studies at the Roseton plant indicated thermal mortality at temperatures at or above 35 C. *Chaoborus punctipennis* appears capable of tolerating all projected discharge temperatures, even in the warmest years.

Calculated upper lethal thresholds for major microzooplankters *H. fosteri*, *B. longirostris*, *E. affinis*, and *A. tonsa* were 36.0, 34.7, 34,0, and 33.5 C, respectively. The calanoid copepods *E. affinis* and *A. tonsa*, the most sensitive to temperature, would be expected to sustain substantial entrainment mortality at maximum discharge temperatures at full load, especially in the warmer years. Mean daytime operation will minimize entrainment mortalities, while mean nighttime operation will eliminate them. Entrainment mortality of *B. longirostris* would be measurable at full load, but lower than the former two species. *Halicyclops fosteri* would be protected under most conditions. Intake-discharge studies at the Indian Point plant noted higher mortality of calanoid copepods than cyclopoid copepods at peak discharge temperatures, confirming the predicted results.

3.4 MULTIPLANT IMPACT

Spatial and temporal distributions of microzooplankton, macrozooplankton, and macrobenthos have shown no trends within the vicinity of the Roseton, Bowline Point, and Indian Point plants which suggest any effects of entrainment on the population or community level. The rapid generation times of most invertebrates and the rapid mixing of discharge water with the receiving water body tend to compensate for and prevent the detection of any entrainment effects. As in Section 2.4, dilution factors may be utilized to relate plant cropping to impact on the community level. Since under most conditions entrainment mortality of both microzooplankton and macrozooplankton average less than 10 percent, multiplant impact is nearly negligible. Despite the potential for high entrainment mortality during midsummer for some species, notably N. americana and A. tonsa, overall entrainment impact on these species is low. Neomysis americana and A. tonsa are found throughout the brackish-water portion of the estuary and are near the limit of their range at the Bowline Point and Indian Point plants. The periodic exposure of these populations to the plants during late summer and fall will not be critical to the survival of these species in the Hudson (NYU 1975:p.179-181).

Localized reductions of certain zooplankton populations, such as that of N. americana, would have little effect on population of consumers that rely on zooplankton as a food source. Young striped bass and white perch, for example, utilize a variety of zooplankters in their diet, including calanoid, cyclopoid, and harpacticoid copepods; cladocerans, amphipods, isopods, decapods, and N. americana, as well as a variety of benthic forms (TI 1976:pp. V-16, V-17). No one species is relied upon exclusively. Neomysis americana is not a major food source for striped bass and white perch, except for young striped bass in the brackish-water portion of the estuary during fall. Since young striped bass are widely distributed throughout this lower region of the river during fall, localized reductions in the size of the N. americana population will not adversely affect the striped bass population, particularly since other major food items are available (TI 1976:p. V-16). Although some N. americana may be cropped at plant sites, they are not lost from the food web and are still available for consumption.

The life history and behavior of many invertebrates tends to minimize the effects of entrainment on their populations. Many of the major macroinvertebrate fauna are benthic or epibenthic and are rarely involved with the plant cooling systems. Others, including the crustaceans G. daiberi and N. americana and the dipteran C. punctipennis, are benthic or epibenthic by day, and migrate into the water column at night. Since generating loads typically decline at night to levels as low as 20 percent of net capacity, discharge temperatures during periods of peak involvement are minimal. As seen in Subsection 3.3.3, this may result in dramatic reductions in entrainment mortality rates.

3.5 CONCLUSIONS

No multiplant adverse effects of entrainment on Hudson River invertebrate communities have been detected or are predicted. Peak discharge temperatures during summer will result in considerable entrainment cropping of certain species, notably N. americana and A. tonsa, depending on plant loads and ambient river temperatures. However, these species are at the limit of their range at the Indian Point and Bowline Point plants, and their river populations should not be affected.

It is concluded that the continued operation of the once-through cooling systems of the mid-Hudson power plants will have no adverse effects on the zooplankton communities of the Hudson River, nor on the organisms that feed on those communities.

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