A Selective Analysis of Power Plant Operation on the Hudson River with Emphasis on the Bowline Point Generating Station

Volume 1

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ENERGY DIVISION

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ON THE HUDSON RIVER WITH EMPHASIS
ON THE BOWLINE POINT GENERATING STATION

Volume 1

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ABSTRACT

A comprehensive study of the effects of power plant operation on the Hudson River was conducted for the U.S. Army. The study included thermal, biological, and air quality effects of existing and planned electrical generating stations.

The section addressing thermal impacts presents a comprehensive mathematical modeling and computer simulation study of the effects of heat rejection from the plants. The overall study consisted of three major parts: (1) near-field analysis, (2) far-field analysis, and (3) zone-matched near-field/far-field analysis. Near-field analyses were completed for Roseton, Danskammer, and Bowline Point Generating Stations, and near-field dilution ratios range from a low of about 2 for Bowline Point and 3 for Roseton to a maximum of 6 for both plants.

The far-field analysis included a critical review of existing studies and a parametric review of operating plants. The maximum thermal load case, based on hypothetical 1974 river conditions, gives the daily maximum cross-section-averaged and 2-mile-segment-averaged water temperatures as 83.80°F in the vicinity of the Indian Point Station and 83.25°F in the vicinity of the Bowline Station. This maximum case will be significantly modified if cooling towers are used at certain units. A full analysis and discussion of these cases is presented.

The Roseton and Danskammer plants give rise to maximum seasonal ground-level concentrations of about 40 $\mu\text{g}/\text{m}^3$, while the Bowline and Lovett plants are responsible for a maximum value which is about one-tenth of this concentration.

Section 5 focuses on the Hudson River striped bass population and is divided into the following eight subsections: (1) distribution of striped bass eggs, larvae, and juveniles in the Hudson River; (2) entrainment mortality factor (f_c); (3) intake factor (f_I); (4) impingement; (5) effects of discharges; (6) compensation; (7) model estimates of percent reduction; and (8) Hudson River striped bass stock.

ORNL estimates of f_c range from 0.50 to 0.73 for eggs, 0.57 to 0.86 for yolk-sac larvae, 0.00 to 0.82 for post-yolk-sac larvae, and 0.18 to 0.77 for entrainable juveniles. ORNL estimates of f_I range from 0.92 to 12.4 for eggs, 0.34 to 1.26 for yolk-sac larvae, 0.05 to 1.02 for post-yolk-sac larvae, and 1.9 to 16.1 for entrainable juveniles. Due to a number of sampling problems, ORNL has little confidence in either Consolidated Edison or ORNL estimates of f_I . Forecasts of the annual number of striped bass impinged for various power plant configurations indicate that the number impinged would be reduced to approximately 30% of the number impinged with the reference configuration (i.e., once-through cooling at Bowline, Indian Point, and Roseton) if closed-cycle cooling were installed at each of these three power plants. Installing closed-cycle cooling at Bowline, as compared to Indian Point, would be more effective in reducing the number of striped bass impinged annually.

Oak Ridge National Laboratory readily endorses the concept of compensation and the likelihood that some compensation is occurring and will continue to occur. The primary issue in controversy is the amount of compensatory capacity which a priori should be assumed to exist in the population and, therefore, the extent to which the effects of increased mortality due to power plants will be offset. The two lines of evidence for compensation in the Hudson River striped bass population presented by Texas Instruments (TI) are evaluated. A summary of ORNL's critique and sensitivity analysis of the compensation function used in the utilities, striped bass models is presented.

Estimates of percent reduction due to power plant operation are presented based on runs of the utilities' combined one-dimensional transport model and life-cycle model. Estimates of percent reduction are very sensitive to the strength and form of the compensation function. For the full range of values used for f factors and the preferred form of the compensation function, the ratio of maximum to minimum percent reduction is as much as a factor of 3.0. Percent reduction varies approximately 1:1 with power plant withdrawal rate, although there are variations in this relationship due to spatial effects. The risk of irreversible damage to the Hudson River striped bass population because of exploitation by the power plants and fishery combined is considered to be small.

Analyses by ORNL and TI support the position that the Hudson River stock contributes to the striped bass population found along the Atlantic coast at least as far north as Boston, Massachusetts, and as far south as somewhere along the coast of New Jersey. In the absence of a detailed report from TI documenting the additional statistical techniques to reduce bias, and in the absence of an independent analysis of the raw data, it seems reasonable to use the full range of TI's original and modified estimates of percent contribution of 15 to 32% to the NRC Inner Zone, 0 to 19% to the NRC Outer Zone, and 7 to 23% to the coastal fishery as "working ranges."

SUMMARY AND CONCLUSIONS

S.1 Thermal Effects

The conclusions related to the thermal effects can be stated in three parts based on the three analyses which were considered in the assessment of the potential thermal impact of power plant operations on the Hudson River.

S.1.1 Near-field analysis

The following conclusions are based on the results of the near-field analysis of the discharge conditions from Roseton Generating Station, Danskammer Point Generating Station, and Bowline Point Generating Station (Sect. 3.3):

1. The cooling of the thermal plumes in the near-field zones will depend on the mixing of the heated discharge water with the local ambient water according to the characteristics of the discharge diffusers. Dilution ratios within the general range of 2 to 6 can be expected.

2. The actual values of the dilution factors will depend on the spatially and temporally varying cross-flow conditions, which are dominated by the periodic tidal conditions. The lower limit of the dilution factor range for the submerged discharges will correspond to the high cross-flow conditions during maximum ebb and flood tidal stages due to the particular parallel orientations of the diffusers relative to the flow in the estuary.

3. The thermal behavior of the discharge plumes will be strongly dependent on the reentrainment and recirculation phenomena controlled by the tidal flow conditions in the far-field zone.

S.1.2 Far-field analysis

The analysis of the far-field thermal impact of multi-power-plant operation on the complete estuary (Sect. 3.4) was based on the reasonably typical natural river conditions during April 1 through September 30 in 1974. The following conclusions are based on the results of the far-field analysis:

1. The far-field thermal impact of power plant operations during the period April through September 1974 was extremely low. Although 1974 was a typical year for the natural conditions in the estuary and the region, the thermal load on the river was extremely low in comparison to the rated output capacity of the existing power plants. Hence, the field-measured data about the thermal conditions in the river during the period April through September 1974 are definitely not indicative of the potential thermal impact of power plant operations on the Hudson River.

2. Based on hypothetical 1974 river conditions, for case 3 (proposed maximum thermal load — Greene County power plant with closed-cycle plant cooling system, all other plants with once-through plant cooling systems) (see Table 3.4.13), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature conditions in the estuary will not exceed the limit of elevated temperature level 4°F above "the temperature that existed before the addition of the heat of artificial origin" (clean river conditions) as stated by the applicable State and Federal standards (see Sect. 3.1).

3. Based on hypothetical 1974 river conditions, for case 3 (proposed maximum thermal load), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature conditions will exceed the limit of "a maximum of 83°F" over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1).

4. Based on hypothetical 1974 river conditions, for case 3 (proposed maximum thermal load), the daily-maximum cross-section-averaged and 2-mile-segment-averaged water temperatures will be 83.80°F in the vicinity of the Indian Point power plant and 83.25°F in the vicinity of the Bowline power plant during late July and August. The daily-maximum cross-section-averaged and 2-mile-segment-averaged water temperatures will not exceed 83°F at any other location along the estuary. Hence, the limit of "a maximum of 83°F" over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1) will only be violated in the 6-mile section of the river where the Indian Point and Bowline plants are located.

5. Based on hypothetical 1974 river conditions, for case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system) (see Table 3.4.13), the daily-maximum cross-section-averaged and 2-mile-segment-averaged water temperatures will be 83.42°F in the vicinity of the Indian Point power plant and 82.63°F in the vicinity of the Bowline power plant. Hence, the thermal conditions in the river will again exceed the limit of "a maximum of 83°F" over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1). Hence, the operation of the Bowline power plant with closed-cycle plant cooling system will not be a feasible alternative for the reduction of the far-field thermal impact on the Hudson River.

6. Based on hypothetical 1974 river conditions, for case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system) (see Table 3.4.13), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperatures will be 80.70°F in the vicinity of the Indian Point power plant and 81.48°F in the vicinity of the Bowline power plant; and the daily-maximum cross-section-averaged and 2-mile-segment-averaged water temperatures will be 81.66°F in the vicinity of the Indian Point power plant and 82.00°F in the vicinity of the Bowline power plant. Therefore,

the temperature conditions will be approximately 2°F lower than the case with once-through plant cooling system and they will definitely comply with the limit of "a maximum of 83°F" over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1). Hence, the operation of the Indian Point power plant with closed-cycle plant cooling system will be a feasible alternative for the reduction of the thermal impact on the Hudson River.

7. Based on hypothetical 1974 river conditions, operation of Greene County power plant with once-through plant cooling system will increase the cross-section-averaged and 2-mile-segment-averaged water temperatures by less than 0.1°F in the vicinity of the Indian Point power plant and 0.05°F in the vicinity of the Bowline power plant. Hence, the operation of the Greene County power plant with once-through plant cooling system will not have any critical effect on the far-field thermal impact conditions on the Hudson River.

S.1.3 Zone-matched near-field and far-field (complete) analysis

The zone-matched near-field and far-field analysis (Sect. 3.5) was applied to the simulation of the detailed temperature distributions in the vicinities of the Bowline and Indian Point power plants based on hypothetical August 4, 1974, river conditions, when the far-field thermal impact on the estuary becomes critical for case 3 (proposed maximum thermal load plant operational conditions) (see Table 3.4.13). The following conclusions are based on the results of the zone-matched near-field and far-field analysis:

1. The critical thermal conditions in the vicinity of the Bowline power plant will generally occur during the afternoon and evening between 1300 and 2200 hr.

The operation of the Bowline power plant will violate the applicable New York State thermal standards (see Sect. 3.1) based on the occurrence of the following thermal conditions: (a) Surface temperature exceeding 91°F (90°F limit) will occur in the vicinity of the plant. Hence item i will be violated. (b) Water temperatures of 84°F (83°F limit) will occur over one-third of the surface as measured from water edge to water edge. Hence, item ii will be violated. (c) Water temperatures of 84°F (83°F limit) will occur over 50% of the cross-sectional area and/or volume of the flow of the estuary. Hence, item ii will be violated.

The operation of the Bowline power plant will violate the criterion recommended by the Environmental Protection Agency (see Sect. 3.1), which limits the extent of the 83°F temperature to 1000 ft from the discharge, based on the occurrence of the following thermal conditions: (d) Water temperatures of 87°F (83°F limit) will occur at distances more than 3000 ft from the discharge. (e) Water temperatures of 84°F (83°F limit) will occur at distances more than 6000 ft from the discharge.

2. The critical thermal conditions in the vicinity of the Indian Point power plant will generally occur during the afternoon and evening between 1300 and 2200 hr.

The operation of the Indian Point power plant will violate the applicable New York State thermal standards (see Sect. 3.1) based on the occurrence of the following thermal conditions: (a) Surface temperature exceeding 94°F (90°F limit) will occur in the vicinity of the plant. Hence item i will be violated. (b) Water temperatures of 84°F (83°F limit) will occur over the total surface area as measured from water edge to water edge. Hence, item ii will be violated. (c) Water temperatures of 84°F (83°F limit) will occur over 100% of the cross-sectional area and/or volume of the flow of the estuary. Hence, item ii will be violated.

The operation of the Indian Point power plant will violate the criterion recommended by the Environmental Protection Agency (see Sect. 3.1), which limits the extent of the 83°F temperature to 1000 ft from the discharge, based on the occurrence of the following thermal conditions: (d) Water temperatures of 87°F will occur at distances more than 2500 ft from the discharge. (e) Water temperatures of 84°F will occur at distances more than 8000 ft from the discharge.

S.1.4 Summary: conclusions and recommendations

The results of the overall thermal impact analysis can be summarized by the following conclusions:

1. The thermal conditions in the Hudson River for typical river flows and climatological conditions in the region and for the proposed maximum thermal load plant operational conditions (Greene County power plant with closed-cycle plant cooling system, all other plants with once-through plant cooling systems) with all power plants at full rated output power will violate the applicable New York State thermal standards and the thermal criterion recommended by the Environmental Protection Agency at certain days during late July and August.

2. The critical thermal conditions in the Hudson River which violate the applicable New York State thermal standards and the thermal criterion recommended by the Environmental Protection Agency will occur in the vicinities of the Indian Point and Bowline power plants during the afternoon and evening hours on various days in July and August.

3. The level of the violations of the applicable New York State thermal standards and the thermal criterion recommended by the Environmental Protection Agency will not be excessive for typical river flow conditions in the Hudson River.

4. The level of the violations of the applicable New York State thermal standards and the thermal criterion recommended by the

Environmental Protection Agency will increase with decreasing freshwater flow conditions in the Hudson River.

The results of the overall thermal impact analysis lead to the following recommendations (strictly based on thermal impact considerations):

1. Essential alternative: Indian Point power plant operating with closed-cycle plant cooling system.
2. Optional alternative: Greene County power plant operating with once-through plant cooling system.

The proposed two alternatives will reduce the thermal impact of power plant operations on the Hudson River by approximately 2°F at the locations of Indian Point and Bowline power plants for typical river flow and climatological conditions.

3. Reduced power output alternative: with essential alternative 1 and optional alternative 2 as applicable, the critical thermal conditions which could result from reduced freshwater flow conditions for short durations can be avoided by reducing power output at selected power plants along the estuary based on careful considerations of the overall thermal impact on the Hudson River.

S.1 Air Quality

It has been shown (Sect. 4.3.2) that the Roseton and Danskammer plants are responsible for much higher sulfur dioxide concentrations in their vicinity than the Bowline and Lovett plants are. The Roseton and Danskammer plants give rise to maximum seasonal ground-level concentrations of about 40 $\mu\text{g}/\text{m}^3$, while the Bowline and Lovett plants are responsible for a maximum value which is about one-tenth of this. When the combined effects of all four plants are considered (Sect. 4.3.3), the maximum seasonal ground-level concentration is still expected to be on the order of 40 $\mu\text{g}/\text{m}^3$.

Although cooling-tower-smokestack plume interactions will likely give rise to some acidic water droplet deposition, it is felt that this will not be a problem (Sect. 4.3.5). This conclusion is based on the fact that, over many years, the operation of wet cooling towers in proximity to fossil-fueled plant smokestacks has not proved to be a source of adverse effects. Furthermore, the lower sulfur content of the Bowline plant's fuel would further mitigate any adverse effects at that location.

The natural-draft cooling towers at Bowline and Roseton appear to pose no fogging problem at either site. As shown in Sect. 4.3.4, no incidence of ground fog due to tower operation was found, a result consistent with the observation that natural-draft cooling tower plumes rarely touch the ground.

Both the Bowline and Roseton sites showed a peak annual average aerosol concentration of about $0.2 \mu\text{g}/\text{m}^3$. This is substantially below the $10 \mu\text{g}/\text{m}^3$ found by Moser¹ to cause no detrimental effects in sensitive vegetation. Maximum salinity occurs in August, and the ratio of the peak salinity to the annual average is about 3. This would raise the aerosol level to about $0.6 \mu\text{g}/\text{m}^3$, still an order of magnitude smaller than the figure quoted by Moser.¹

Reference for Section S.2

1. B. C. Moser, "Airborne Sea Salt: Techniques for Experimentation and Effects on Vegetation," in *Cooling Tower Environment - 1974*, ERDA Symposium Series, CONF-740302, 1975, pp. 353-369.

S.3 Effects on the Hudson River Striped Bass Population

With respect to the assessment of the potential multiplant impact on the Hudson River striped bass population (Sect. 5), ORNL has reached the following conclusions.

S.3.1 Entrainment mortality factor (f_C) (Sect. 5.3)

Estimates of the entrainment mortality factor (f_C), defined as the probability that a live organism will be killed due to the entrainment process, depend on the life stage, the power plant, and the method of calculation. Consolidated Edison's estimates range from 0.49 to 0.78 for eggs, 0.57 to 1.00 for yolk-sac larvae, 0.00 to 0.73 for post-yolk-sac larvae, and 0.00 to 0.69 for entrainable juveniles (Table 5.3.11). ORNL estimates of short- and intermediate-term mortality range from 0.50 to 0.73 for eggs, 0.57 to 0.86 for yolk-sac larvae, 0.00 to 0.82 for post-yolk-sac larvae, and 0.18 to 0.77 for entrainable juveniles (Tables 5.3.12-5.3.15). Both Consolidated Edison and ORNL "best" estimates were used in model runs.

S.3.2 Intake f factor (f_I) (Sect. 5.4)

Estimates of the intake factor (f_I), which is the ratio of the concentration of entrainable ichthyoplankton in the intake water to the concentration in the river, also depend on the life stage, the power plant, and the method of calculation. Consolidated Edison's estimates, based on 1974 and 1975 data, range from 0.0 to 6.0 for eggs, 0.09 to 1.08 for yolk-sac larvae, 0.04 to 2.08 for post-yolk-sac larvae, and 0.0 to 1.0 for entrainable juveniles. ORNL estimates, based on data that became available after the IP3 FES, range from 0.92 to 12.4 for eggs, 0.34 to 1.26 for yolk-sac larvae, 0.05 to 1.02 for post-yolk-sac larvae, and

1.9 to 16.1 for entrainable juveniles (Tables 5.4.7, 5.4.11, 5.4.12, 5.4.14, and 5.4.15). Due to a number of sampling problems, ORNL has little confidence in the accuracy of either the Consolidated Edison or the ORNL estimates (whether those made in the IP3 FES or those indicated above). Consequently, in model simulations, ORNL has continued (as in the IP3 FES) to use the values of 0.5 and 1.0 for f_I for all four entrainable life stages at all power plants.

S.3.3 Striped bass impingement (Sect. 5.5)

1. Collection efficiency of impinged striped bass at Indian Point Unit 2 with the air curtain on was estimated by Texas Instruments to be 12% in 1974 and 17% in 1975. Estimates at Indian Point Unit 2 without the air curtain, Indian Point Unit 3, and the other power plants are not available. ORNL assumed a collection efficiency of 50% at all plants in calculating the annual number of striped bass expected to be impinged for various power plant configurations (Sect. 5.5.1.2).

2. Latent survival of impinged striped bass appears to be low. ORNL assumed a survival of 0% in calculating the annual number of striped bass expected to be impinged for various power plant configurations (Sect. 5.5.1.3).

3. For Bowline, Lovett, and Indian Point, collection rates tend to be high from December through April and low from May through October; primarily young of the year are impinged. For Roseton, Danskammer, and Albany, collection rates tend to be high from June through October or November and low from January through April; primarily yearling striped bass may be impinged (Sect. 5.5.1.4).

4. Forecasts of the annual number of striped bass impinged for various power plant configurations indicate that the number impinged would be reduced to approximately 30% of the reference configuration (i.e., once-through cooling at Bowline, Indian Point, and Roseton) if closed-cycle cooling were installed at each of these three power plants. Installing closed-cycle cooling at Bowline would be more effective in reducing the number of striped bass impinged annually than installing closed-cycle cooling at either Indian Point or Roseton (Sect. 5.5.2).

S.3.4 Effects of discharges (Sect. 5.6)

1. The temperature of the Hudson River in the immediate vicinity of the power plants may be increased under certain conditions to levels detrimental to young-of-the-year striped bass. Exposure temperature, duration of exposure, and size, mobility, and thermal history of each life stage will be important in determining the effects of thermal stress. Excess temperatures may attract striped bass to the intakes during the winter, which could cause additional impingement. Excess temperatures may alter the spawning distribution of striped bass to some extent (Sect. 5.6.1).

2. The dissolved oxygen concentration in the vicinity of Bowline, Roseton, and Indian Point may be reduced to levels detrimental to young-of-the-year striped bass during extreme conditions of low freshwater flow, high river temperatures, and full-power operation of these three plants (Sect. 5.6.2).

3. Chlorination of the once-through cooling systems at Bowline, Roseton, and Indian Point will result in high mortalities of young-of-the-year striped bass passing through the plant during chlorination (Sect. 5.6.3).

Overall, the direct and indirect effects of discharges on the various life stages of young-of-the-year striped bass are expected to be minor in comparison with those from entrainment and impingement.

S.3.5 Compensation (Sect. 5.7)

1. ORNL readily endorses the concept of compensation and the likelihood that some compensation (both natural and through the fishery) is occurring and will continue to occur to some degree. The primary issue in controversy for regulatory agencies, utilities, and society in general is the amount of compensatory capacity which a priori should be assumed to exist in the population and, therefore, the extent to which the effects of increased mortality due to power plants will be offset (Sect. 5.7.6).

2. Texas Instruments presents two lines of evidence for compensation in the Hudson River striped bass population. While there are uncertainties and problems associated with each analysis, the two analyses do suggest that some density-dependent population changes may have occurred during the period 1955-1973. ORNL's position is that the Hudson River striped bass population should be assumed to have the capacity to compensate to some extent for increased mortality such as that imposed by power plants. However, the TI analyses do not remove ORNL's concern for the long-term consequences of a protracted increase in density-independent mortality, such as the cropping imposed by power plants, because the range of cropping rates that could be offset by compensatory responses and the degree of offset are not known (Sect. 5.7.3).

3. ORNL's critique and sensitivity analysis of the compensation function used in the Lawler, Matusky, and Skelly Engineers Hudson River striped bass models indicates that (1) the mathematical formulation is not conceptually sound from a biological point of view, (2) none of the three parameters in the compensation function can be based directly or indirectly on observable data, (3) model estimates of percent reduction are sensitive to the values selected for each of the three parameters, and percent reductions can vary by a factor of 10 depending on that choice, and (4) disabling the left limb of the LMS compensation function results in a function that ORNL believes to be conceptually more sound but that leads to appreciably higher estimates of percent reduction. Model runs were done both with the original LMS function and with the left limb disabled (Sect. 5.7.4).

S.3.6 Model estimates of percent reduction (Sect. 5.8)

1. Estimates of percent reduction due to power plant operation were obtained using the LMS one-dimensional model linked to the LMS life-cycle model. The mean percent reduction for yearlings after one year of plant operation is 6.8% and the mean percent reduction for the adult population after 40 years of plant operation is 18.2% for the 12 runs with the left limb of the compensation function not disabled. ORNL considers the compensation function with the left limb disabled to be conceptually more sound. For the corresponding 12 runs with the left limb disabled, the corresponding two means are 7.9% and 32.9%. Thus disabling the left limb results in appreciably higher estimates of percent reduction (Sect. 5.8.3.1).

2. Estimates of percent reduction are very sensitive to the strength of the compensation function. Percent reduction values reflect a greater relative importance of impingement in the ORNL runs of the LMS 1-D model as compared to the LMS runs of this model (Sect. 5.8.3.2).

3. For the full range of values used for both compensation and the composite f factor, the ratio of maximum to minimum percent reduction of yearlings after one year or of adults after 40 years differs by a factor of 1.5 to 2.0. Considering these two sets of input parameters in combination, this ratio can differ by as much as a factor of 3.0. None of the compensation or f-factor levels used in this sensitivity analysis can be completely discredited; adequate data are simply not available. The effect of uncertainties in these two sets of input parameters is reflected in turn by estimates of percent reduction that can differ by as much as a factor of 2.0 to 3.0. Because of additional uncertainties that were not included in this sensitivity analysis (e.g., impingement rates, the reference population size, transport avoidance factors), the true range of uncertainty is somewhat greater than this (Sect. 5.8.3.3).

4. Percent reduction varies approximately 1:1 with power plant withdrawal rate. Percent reduction values with closed-cycle cooling at Bowline, Roseton, and Indian Point are lower than the values with once-through cooling at these three plants by factors of approximately 4 to 6. There are variations in the strict relationship between percent reduction and withdrawal rate due to spatial effects. It appears that installing cooling towers at Roseton would be less effective in decreasing percent reduction than installing cooling towers at either Bowline or Indian Point (Sect. 5.8.3.4).

5. The emphasis in discussing the results of the LMS 1-D model is on trends, inequalities, and qualitative and semiquantitative properties of the forecasts. ORNL emphasizes that the model is a single-species population model, which appears to simulate the behavior of the striped bass population in a reasonable manner. ORNL considers the model to be sufficiently realistic to a first approximation to serve as part of the basis for making a rational management decision concerning the acceptability or unacceptability of once-through cooling at Bowline, Roseton, and Indian Point and, if unacceptable, the timing of installation of closed-cycle cooling at the three plants (Sect. 5.8.4).

6. It is ORNL's judgment that the risk of irreversible damage to the Hudson River striped bass population due to exploitation by the power plants and fishery combined is considered to be small, even with once-through cooling at Bowline, Roseton, and Indian Point (Sect. 5.8.4).

S.3.7 Hudson River striped bass and Atlantic coastal populations
(Sect. 5.9)

1. ORNL and Texas Instruments analyses both support the position that the Hudson River stock does contribute to the striped bass population along the Atlantic coast, at least as far north as Boston, Massachusetts. The southern boundary of the zone of influence, based on location of recaptures, is still vague, although it is probably somewhere along the coast of New Jersey (Sect. 5.9.1).

2. The issue of the relative contribution of the Hudson River stock to the Atlantic coastal striped bass population figures prominently in reaching a reasoned decision on the need for closed-cycle cooling at Bowline, Roseton, and Indian Point. Thus, given the importance of this issue, the only recent availability of the TI report, and the obvious sensitivity of the estimates to the method of analysis, the following conclusion is appropriate at this time. The TI study does appear to have narrowed the range of uncertainty from the previous range which was approximately 10 to 80%. In addition, the new estimates are closer to 10% than to 80%. However, in the absence of a detailed report from TI documenting the "additional statistical techniques . . . to reduce the bias" and in the absence of an independent analysis of the raw data, it seems reasonable to use the estimates of percent contribution of 15 to 32% to the NRC inner zone, 0 to 19% to the NRC outer zone, and 7 to 23% to the coastal fishery as a "working range" (Sect. 5.9.2).

1. INTRODUCTION

This document presents the results of a study of power plant operation on the Hudson River conducted by the Oak Ridge National Laboratory staff for the Department of the Army, New York District, Corps of Engineers. The work was initiated by the Corps of Engineers in connection with litigation in the U.S. District Court, New York, Hudson River Fishermen's Association vs Orange and Rockland Utilities, Inc., et al., 72 Civ 5459 (CMM).

In our design of the study, we have attempted a reasonably complete appraisal of the effects of power plant operation on the Hudson River. We have examined the following plants, which include all those currently operating and those proposed in the immediate future.

Albany
Greene County Nuclear
Danskammer Units 1, 2, 3, 4
Roseton Units 1, 2
Cornwall Pumped Storage
Lovett Units 1, 2, 3, 4, 5
Bowline Point Units 1, 2
Indian Point Units 2, 3
59th Street

The degree to which each plant was considered varies, and explanation of these cases is made in the individual sections. In most instances, the size and location of each unit as it related to the parameter under study were the main considerations.

Primary efforts have been directed to far-field thermal effects from condenser cooling water and to impingement and entrainment of fish. The near-field thermal effects at Bowline and Roseton, as well as the air quality in the plant areas, have also been examined.

In undertaking this project, we have utilized the background, knowledge, and analytical tools we have developed over a five- to six-year involvement with power plants on the Hudson, particularly the Indian Point Nuclear Generating Plant. Additionally, the work of many utilities and consulting firms has been reviewed and is reflected in the analyses. The Hudson River has been under detailed scrutiny by many groups over the last ten years, and enormous amounts of data and numerous reports have resulted. We have made every effort possible to include this body of information in our review. As in any study of this type, we were forced to establish general guidelines and cutoff dates on the use of information. Therefore, the study represents as current an appraisal of the situation as we feel is possible.

The team participating in the study made a site visit to the Bowline 2 and Roseton plants, as well as a boat survey of the facilities between Bowline and Roseton, on November 3 and 4, 1976. We were accompanied by members of the Corps of Engineers and Mitre Corporation.

The report is divided into sections reflecting the environmental parameters being studied, namely, thermal effects, air quality, and fish population effects, and we present our final conclusions in the last section.

2. GENERAL CONSIDERATIONS OF THE HUDSON RIVER ESTUARY

The Hudson River represents one of the major ecologically significant estuaries in the United States. This section presents a summary of the important characteristics of the Hudson River and its surrounding region which controls the level of physical and biological impact of power plant operations on the estuary.

2.1 Physical Conditions in the Hudson River

The lower Hudson River extends from the Federal Dam at Troy to New York City (see Fig. 2.1.1). The length of the estuary between the upstream end at Troy Dam and the downstream end at the Battery is approximately 152 miles along the curvilinear axis of the river. The natural physical conditions in the estuary are controlled by three dominant phenomena consisting of the freshwater flow in the river, the tidal variations at the downstream ocean end, and the surface mass and heat transfer depending on the meteorological conditions in the geographical region. A summary of the available data describing the detailed physical conditions in the Hudson River is presented in ref. 1, with emphasis on the recently acquired data during the period from 1972 through 1975.

2.1.1 River geometry (general)

The necessary information about the channel geometry of the Hudson River can be obtained from the bathymetry data on the U.S. Coast and Geodetic Survey (U.S. C. & G.S.) navigational charts, Nos. 282, 283, 284, 745, and 746.² The important geometric dimensions of the channel do not exhibit uniform or uniformly varying characteristics along the river. A detailed discussion of the geometry data and the cross-section profiles of the river channel are presented in Appendix A.

The upstream 30-mile section of the Hudson River, between Troy and Catskill (see Fig. 2.1.1), is relatively shallow with an average depth less than 25 ft (see Figs. 2.1.2 and 2.1.3). This section is also relatively narrow, with the average width gradually increasing down the river from 1000 ft at Troy to approximately 5000 ft at Catskill (see Fig. 2.1.4).

The upper-middle 40-mile section, between Catskill and Poughkeepsie (see Fig. 2.1.1), has a gradual but nonuniformly increasing average channel depth, from less than 25 ft to approximately 60 ft (see Figs. 2.1.2 and 2.1.3). The channel width of the section is also very irregular, with variations from 1500 ft to more than 6000 ft occurring within distances of less than 1 mile along the river (see Fig. 2.1.4).

Fig. 2.1.1. Schematic representation of the Hudson River and the locations of the electric power generating stations along the estuary.

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Fig. 2.1.2. Variation of cross-section-averaged depth along the Hudson River. See Appendix A.

Fig. 2.1.3. Variation of maximum depth along the Hudson River. See Appendix A.

Fig. 2.1.4. Variation of surface width along the Hudson River.
See Appendix A.

The lower-middle 40-mile section, between Poughkeepsie and Jones Point, immediately upstream of Haverstraw Bay (see Fig. 2.1.1), has extremely irregular geometrical characteristics. The channel depth in this section varies from a relatively shallow average depth of 30 ft to maximum depths exceeding 120 ft in the deep holes (see Figs. 2.1.2 and 2.1.3). The surface width of the channel is also extremely irregular, varying between 1800 ft and 8000 ft at different locations along the river (see Fig. 2.1.4).

The downstream 40-mile section of the Hudson River, between Jones Point and the Battery at New York City (see Fig. 2.1.1), represents the overall largest section of the estuary. The average depth in the section varies from a minimum of 16 ft at Haverstraw Bay to approximately 35 ft at the Battery (see Figs. 2.1.2 and 2.1.3). The surface width also exhibits significant variations along this section. The distance between the banks at Haverstraw Bay reaches 17,000 ft, which represents the maximum width in the Hudson River. The width of the channel decreases sharply within a distance of 20 miles downstream of the bay area, and it increases to an approximately uniform width of 5000 ft (see Figs. 2.1.2 and 2.1.3) along the final 20-mile section of the river between Yonkers and the Battery (see Fig. 2.1.1).

The cross-sectional area of the Hudson River gradually increases within the 120-mile section of the estuary from the upstream end at Troy Dam to the Haverstraw Bay area, 38 miles upstream from the Battery (see Fig. 2.1.1). The minimum area of the channel is approximately 10,000 sq ft in the vicinity of the Troy Dam; the maximum area is more than 400,000 sq ft at Haverstraw Bay (see Fig. 2.1.5). The cross-sectional area sharply decreases downstream of Haverstraw Bay to less than 180,000 sq ft in the vicinity of the George Washington Bridge (see Fig. 2.1.1), and it again increases in the last 10-mile section of the river to more than 300,000 sq ft at the Battery (see Fig. 2.1.5). These relatively significant variations in the geometric characteristics of the river channel directly affect the local values of all the physical conditions of the river flow, and they also indirectly influence the distributions and the behavioral patterns of various aquatic biota in the estuary.

2.1.2 Flow conditions in the river (general)

The flow conditions in the Hudson River are dominated by the periodic tidal characteristics from the downstream end at the Battery to the upstream end at the Troy Dam, 152 miles away from the influence of the ocean. The net freshwater flow in the river does not contribute significantly to the hydrodynamic conditions; however, it controls the important water quality variables, including the temperature and the salinity distributions along the estuary.

Fig. 2.1.5. Variation of cross-sectional area of the channel along the Hudson River. See Appendix A.

2.1.2.1 Tidal flow conditions. The reversing tidal flow conditions in the estuary are controlled by the complex periodic tidal height variations at the ocean end of the estuary (approximately at the Battery). The maximum high-high water level at the Battery exceeds 4.0 ft and the minimum low-low water level drops below 3.8 ft relative to long-term mean water level at the Battery (see Fig. 3.4.6).

The periodic variations of the tide level at the downstream end of the estuary result in periodic tidal flow conditions which gradually decrease along the estuary toward the upstream end at the Troy Dam. The midmonth-day longitudinal distributions of the local maximum tidal flow rates in the Hudson River are presented in Fig. 2.1.6 for June, July, and August 1974 as typical representations of tidal flow conditions.

The local maximum tidal flow rates vary between approximately 300,000 cfs and 460,000 cfs at the Battery during June through August depending on the combined effects of the tidal elevations at the ocean end and the freshwater flow conditions in the river. Along the stretch of the river between 35 and 45 river miles upstream of the Battery (see Fig. 2.1.5), where Bowline, Lovett, and Indian Point power plants are located (see Fig. 2.1.1), the local maximum tidal flow rate varies between approximately 220,000 cfs and 290,000 cfs during the three months of the summer (June through August) (see Fig. 2.1.6). The tidal flow rates in the vicinity of the Danskammer and Roseton power plants, at approximately 66 river miles upstream of the Battery (see Fig. 2.1.1), also exhibit similar characteristics, with the local maximum tidal flow rates varying between 205,000 cfs and 250,000 cfs (see Fig. 2.1.6) during June through August (based on 1974 flow conditions in the river). The monthly variations in the tidal flow conditions decrease rapidly at distances more than 80 river miles upstream of the Battery, with the maximum tidal flow rates varying between approximately 202,000 cfs and 230,000 cfs at mile point 80 during June through August (see Fig. 2.1.6).

At distances more than 100 river miles upstream of the Battery, the tidal flow rates decrease uniformly (approximately linearly) toward the upstream end of the estuary at Troy dam (see Fig. 2.1.6) due to both the reduced influence of the tidal effects and also the rapid reduction in the cross-sectional area of the channel (see Fig. 2.1.5).

The midmonth-day longitudinal distributions of the local maximum cross-section-averaged tidal velocities in the Hudson River are presented in Fig. 2.1.7 for June, July, and August 1974 based on the computer simulations of the flow conditions in the estuary (see Sect. 3.4.4). The maximum cross-section-averaged velocities in the river occur at approximately 10 river miles upstream from the Battery, where the cross-sectional area of the channel is less than 200,000 sq ft (see Fig. 2.1.5). The local maximum cross-section-averaged tidal velocities vary between approximately 2.6 fps and 3.6 fps during June through August (see Fig. 2.1.7). The velocities at approximately 38 river miles upstream of the Battery drop to approximately minimum values due to the sudden increase of the cross-sectional area of the channel to more than 400,000 sq ft in the

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Fig. 2.1.6. Longitudinal distributions of local maximum tidal flow rates on midmonth days in June, July, and August 1974 in the Hudson River. Based on computer simulation results.

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Fig. 2.1.7. Longitudinal distributions of local maximum cross-section-averaged tidal flow velocities on midmonth days in June, July, and August 1974 in the Hudson River. Based on computer simulation results.

Haverstraw Bay area (see Fig. 2.1.5). The local maximum cross-section-averaged tidal velocities in Haverstraw Bay, in the vicinity of the Bowline power plant (see Fig. 2.1.1), vary between approximately 0.8 fps and 1.1 fps during June through August (see Fig. 2.1.7). In the vicinities of Lovett and Indian Point power plants at approximately 44-45 river miles upstream of the Battery (see Fig. 2.1.1), the local maximum cross-section-averaged tidal velocities vary between approximately 1.5 fps and 1.8 fps (see Fig. 2.1.7) during June through August. The tidal velocity conditions remain approximately uniform along a 50-mile stretch of the estuary between 55 and 105 river miles upstream of the Battery, where the local maximum cross-section-averaged tidal velocities in general vary between approximately 1.5 fps and 2.0 fps during the summer months (see Fig. 2.1.7). At 110 river miles upstream of the Battery, due to the reduction of the cross-sectional area of the channel (see Fig. 2.1.5), the local maximum tidal velocities increase, with variations between approximately 2.4 fps and 2.7 fps during June through August (see Fig. 2.1.7). The tidal velocity conditions decrease gradually between 110 river miles upstream of the Battery and Troy Dam from values of approximately 2.5 fps to values of approximately 0.7-0.8 fps for the local maximum cross-section-averaged tidal velocities. The effect of the freshwater flow becomes appreciable in this 30-mile stretch of the estuary, and the maximum tidal velocity conditions along the river become strongly dependent on the flow rates at the Troy locks.

The local tidal velocity conditions in the estuary control the turbulent mixing and the dispersion phenomena which influence the temperature and salinity distributions along the estuary.

2.1.2.2 Freshwater flow conditions. The major freshwater inflow to the Hudson River is from the river flow past the Troy Dam. The flow rates obtained from measurements at Green Island³ near the Troy Dam constitute 60 to 85% of the total fresh water entering the estuary during the summer months. The daily-averaged freshwater flow rates at Green Island are generally highest during April and May, reaching values of 60,000 to 80,000 cfs, and they generally drop to their minimum values during July through September of approximately 4000 to 10,000 cfs. The variation of the daily-averaged freshwater flow rate at Green Island for a typical water flow year (1974) is shown in Fig. 2.1.8 for the six-month period of April through September. The detailed discussions of the flow conditions at the dam are presented in Sect. 3.4.2.2 and also in Appendix B, which also includes the available data for the daily-averaged flow rates during the six-month periods April through September for 1973 and 1974.

The most of the remaining fresh water entering the estuary comes from tributaries in its northern section, between Troy and Poughkeepsie. Typically, the freshwater flow is greatest in the spring and decreases to a yearly minimum in the late summer or early fall. Although they follow seasonal patterns, the flow rates of the tributaries and of the river are not entirely determined by natural conditions. Over half of the major tributaries are sources of municipal water supplies. For

Fig. 2.1.8. Variation of daily-averaged freshwater flow at Troy Dam during the six-month period April through September 1974. Data from U.S. Geological Survey, "1974 Water Resources Data for New York. Part 1: Surface Water Records," Albany, N.Y., 1975, p. 73.

example, water from the Croton River, except for periods of spilling at the Croton Dam or release to augment the Croton-on-the-Hudson water supply, is entirely diverted for municipal supply of New York City. Some provide water for industrial use and for irrigation during the summer months. Flow in one of the larger tributaries, Rondout Creek, is occasionally regulated by a hydroelectric plant. The detailed discussions of the flow conditions in 14 tributaries which contribute to the freshwater flow in the Hudson River are presented in Sect. 3.4.2.4 and also in Appendix C, which also includes the available data for the estimation of daily-averaged flow rates from the tributaries during the six-month periods April through September for 1973 and 1974.

The 14 tributaries along with the Hudson River at Green Island accounted for about 10,000 sq miles of drainage area out of the approximate total of 13,400 square miles of drainage area of the Hudson River at the Battery. Since the entire drainage area is not gaged and since there are no gaging stations south of Green Island capable of measuring total river freshwater flow, figures for freshwater discharge south of Green Island are available as approximate flow rates. The estimates of monthly- and annually-averaged discharge rates of freshwater flow at the ocean end of the Hudson River (at New York City) are presented in Table 2.1.1 for the seven water years 1968-1974.

The tabulated values indicate that particularly during the summer months June, July, and August the net monthly-averaged freshwater flow rates in the estuary vary appreciably during different years. The minimum freshwater flow rates generally occur during August and could vary between approximately 4800 cfs (1970) and 13,400 cfs (1971) depending on the climatological conditions in the region.

The freshwater flow condition has a significant influence on the distribution of salinity, and it also affects the temperature conditions in the estuary.

2.1.3 Temperature conditions in the river (general)

The main channel water temperatures in the Hudson River approach the lower limit of 32°F during January and February, and they gradually increase after February to reach their maximum values of 77°F-79°F during August. The local cross-section-averaged water temperature values (see Fig. 2.1.9) depend on the location along the estuary.

During the summer months, June, July, and August, the temperature distributions (see Fig. 2.1.9) indicate that the combined effects of solar heating and the thermal impact of power plant operations tend to increase the temperatures of the water in regions away from the upstream and downstream ends, Troy Dam and the Battery, respectively. Particularly during June, the effect of solar heating becomes significant in the shallow areas between Troy Dam and 130 miles upstream of the Battery (see Fig. 2.1.9). Furthermore, the water in the large shallow regions in Haverstraw

Table 2.1.1. Estimates of net monthly and annual freshwater discharge of the Hudson River
at the Battery (New York City) for years 1968-1974

(In cubic feet per second)

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1968	8,880	15,500	25,900	13,200	17,300	39,600	26,800	28,800	30,300	15,000	5,180	5,140	19,200
1969	5,760	19,300	23,200	17,500	18,700	32,600	57,700	26,600	13,100	8,630	11,700	5,810	20,300
1970	6,260	23,500	20,400	11,400	31,600	26,100	59,800	18,900	8,550	6,990	4,820	6,870	18,600
1971	10,800	16,800	15,000	12,100	24,100	42,700	50,100	44,800	10,400	6,930	13,400	18,300	22,100
1972	13,400	12,900	31,000	21,400	17,300	48,900	55,600	54,300	53,800	27,600	9,600	7,200	29,300
1973	8,780	42,300	45,800	39,000	34,000	41,400	51,100	43,900	22,400	20,800	8,780	5,920	30,300
1974	6,670	10,400	46,300	34,600	29,100	33,200	48,500	30,600	12,000	14,500	7,830	14,600	23,900

Source: U.S. Geological Survey, "1974 Water Resources Data for New York. Part 1: Surface Water Records,"
Albany, N.Y., 1975, p. 73.

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Fig. 2.1.9. Distributions of cross-section-averaged water temperatures along the Hudson River on midmonth days for June, July, and August 1974. Computer simulations.

Bay also attains elevated temperatures due to the strong influence of solar heating (see Fig. 2.1.9). Hence, the maximum cross-section-averaged water temperatures in the estuary generally reach 80°F during August, although the main channel water temperatures rarely exceed 79°F.

The water temperatures drop gradually along the estuary toward the ocean end at the Battery. During the summer months, June, July, and August, the water temperatures at the Battery are generally 3°F-6°F lower than the maximum cross-section-averaged temperatures that occur along the estuary (see Fig. 2.1.9).

The water temperatures in the estuary also vary appreciably in the lateral and vertical directions during the summer months (June through August) due to the combined effects of solar heating and stratification. The water temperatures in the shallow bay areas are generally more than 2°F higher than the water temperatures in the main channel. Furthermore, the temperature gradients in the vertical direction could exceed 2°F depending on the flow conditions and salinity values in the estuary.

Detailed discussions of the temperature conditions in the Hudson River are presented in Sect. 3 based on the considerations of the cumulative effects of tidal and freshwater flows, salinity values, climatological conditions in the region, and the thermal impact of the power plant operations.

2.1.4 Salinity conditions in the river (general)

The salinity distributions along the river primarily depend on the freshwater flow conditions and secondarily on the tidal flow conditions in the estuary. The salinity conditions at the downstream ocean end at the Battery exceed 24 parts per thousand during July and August in the summer. The salinity decreases rapidly along the upstream direction from the Battery, particularly for high freshwater flow conditions in the spring months. At freshwater flow rates in excess of approximately 20,000 cfs, the salt intrusion length in the estuary is generally limited to less than 40 miles upstream of the Battery.

The maximum salt concentrations in the estuary occur during the summer months, July and August, when the net freshwater flow rates decrease to their minimum values. Representative longitudinal distributions of the daily-averaged and cross-section-averaged salinity conditions in the Hudson River are presented in Fig. 2.1.10 on the midmonth days in June, July, and August 1974.

The salinity intrusion in the estuary based on the location of the salt front (defined as 1.0 part per thousand) moves rapidly along the estuary with the changes in the freshwater flow conditions. The location of the salt front reaches approximately 60 miles upstream of the Battery for freshwater flow rates below 7500 cfs (see Fig. 2.1.10). However, for freshwater flow rates more than 12,000 cfs, the location of the salt front

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Fig. 2.1.10. Longitudinal distributions of daily-averaged and cross-section-averaged salinity in the Hudson River on midmonth days in June, July, and August 1974. Computer simulations.

drops below 30 miles upstream of the Battery (see Fig. 2.1.10). The salt intrusion in the estuary also depends on the tidal conditions in the estuary. Recently acquired salinity data at the Indian Point location¹ illustrate that the salinity conditions increase appreciably during the periods of maximum tidal effects.

The vertical variations in salt concentrations become appreciable in the salt intrusion range near the ocean end of the river, where the salinity conditions become typical of partially stratified (also partially mixed) estuaries in which the freshwater flow becomes primarily restricted to the upper layer. Under partially stratified conditions, the vertical gradients of salinity generally exceed 0.5 part per thousand during slack water conditions. However, due to the dominating effect of the tidal flows in the Hudson estuary, particularly near the ocean end at the Battery, severe stratification conditions do not remain continuously due to the existence of strong turbulent mixing conditions during flood and ebb tidal stages.

The distribution of salinity in the Hudson River could influence the behavior of the thermal discharge plumes from the power plants located in the region of the salinity intrusion in the estuary.

2.2 Climatological Conditions in the Region

The climatological conditions in the Hudson River valley are characterized by warm summers and relatively cold winters.

The mean ambient temperatures in the region exceed 75°F during July and August and drop down to 28°F in January and February. During hot summer days, the air temperatures could reach 90°F.

The precipitation in the area is fairly uniformly distributed throughout the year, with an average value of 46 in./year. Rainfall is continuous throughout the summer, including July and August, when the freshwater flow rates in the estuary are minimum.

Daily average relative humidity reaches 73% during June and remains reasonably uniform between 70% and 73% throughout the summer. The relative humidities exceed 90% during the days in the summer.

The wind conditions in the region are influenced by the local valley topography. Over the river and below the high ridges, there is a tendency for the wind direction to be upstream during the day and downstream during the night. The daily-averaged wind speed generally varies between 12 and 15 fps. The wind speeds in the valley are lower than the wind speeds that occur in the general region of the Hudson River.

The detailed discussions of the weather conditions in the Hudson River region, based on the climatological data employed in the assessment of the potential environmental impact of power plant operations, are presented in Sects. 3.4 and 4.1.

References for Section 2

1. Texas Instruments Incorporated Ecological Services, *A Synthesis of Available Data Pertaining to Major Physicochemical Variables Within the Hudson River Estuary*, prepared for Consolidated Edison Company of New York, Inc., November 1976.
2. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, C&GS charts 282, 283, 284, 745, 746.
3. U.S. Geological Survey, "1974 Water Resources Data for New York. Part 1: Surface Water Records," Albany, N.Y., 1975; p. 73.

3. ASSESSMENT OF THE POTENTIAL MULTIPLANT IMPACT LIMITS SET BY THERMAL STANDARDS

This section presents a comprehensive mathematical modeling and computer simulation study of the effects of heat rejection from the existing and proposed electric power generating stations on the thermal conditions in the Hudson River.

3.1 Discussion of the Thermal Impact

The applicable section of the New York State Compilation of Codes, Rules and Regulations related to thermal conditions in the Hudson River^{1,2} states:

- (i) The water temperature at the surface of an estuary shall not be raised to more than 90°F at any point.
- (ii) At least 50 percent of the cross sectional area and/or volume of the flow of the estuary including a minimum of one-third of the surface as measured from water edge to water edge at any stage of tide, shall not be raised to more than 4 Fahrenheit degrees over the temperature that existed before the addition of heat of artificial origin or a maximum of 83°F whichever is less.
- (iii) From July through September, if the water temperature at the surface of an estuary before the addition of heat of artificial origin is more than 83°F an increase in temperature not to exceed 1.5 Fahrenheit degrees at any point of the estuarine passageway as delineated above, may be permitted.
- (iv) At least 50 percent of the cross sectional area and/or volume of the flow of the estuary including a minimum of one-third of the surface as measured from water edge to water edge at any stage of tide, shall not be lowered more than 4 Fahrenheit degrees from the temperature that existed immediately prior to such lowering.

On November 10, 1971, the Environmental Protection Agency recommended thermal criteria^{3,4} which are similar, but with the difference that no more than a distance of 1000 ft on the surface in any direction shall be raised more than 4 F° over the temperature that existed before the addition of heat of artificial origin or a maximum of 83°F, whichever is less. Because of the studies that have been made on the estuarine portion of the Hudson River, the need for limiting the temperature rise during July through September to 1.5 F° was removed, and the conditions specified for October through June were permitted year-round.

According to the statements of the existing regulations, three important general criteria must be considered in the assessment of the thermal impact of power plant operations on the Hudson River. These criteria and the existing physical conditions in the Hudson River determine the requirements of models that must be included in the analyses of the thermal impact.

3.1.1 Limiting maximum local temperature criterion

According to item i the surface temperature shall not be raised to more than 90°F at any point of the estuary. Since the natural temperature conditions in the river reach 80°F on the surface during the summer months and the condenser cooling systems of the operational and proposed power plants can increase the temperature at the discharges to more than 10°F above the temperatures at the intakes, the discharge conditions from the power plants can and do exceed 90°F at the discharge cross sections. Hence, it is necessary to employ appropriate near-field models to determine the levels of dilution in the near-field zones which reduce the temperature of the discharge by mixing with the local, near-field ambient water before the discharge reaches the surface of the estuary. It must be realized that the near-field analyses cannot incorporate the effects of reentrainment, recirculation, and thermal interaction between the intakes and the discharges of the power plants.

3.1.2 Limiting maximum area and/or limiting maximum volume criterion for tolerable maximum temperature

According to item ii of the New York State criteria, 50% of the cross-sectional area and/or volume of the flow must be retained below the 4°F tolerable maximum temperature. Similarly, the thermal criteria recommended by the Environmental Protection Agency require that the 4°F tolerable maximum temperature shall not exceed distances of more than 1,000 ft from the discharge. Since the periodic reversing tidal conditions dominate the flows in the Hudson River, the thermal plumes from the discharges can travel appreciable distances due to tidal excursion (exceeding 6 miles) in both upstream and downstream directions from the location of the power plant along the estuary. Hence, it is necessary to employ appropriate tidal-transient two-dimensional zone-matched near-field-far-field models to determine the areas of the thermal plumes from the discharges.

3.1.3 Definition of natural ambient temperature

According to items ii and iii of the New York State thermal criteria and according to the thermal criteria recommended by the Environmental Protection Agency, the tolerable limits of thermal impact are based on temperature levels "over the temperature that existed before the addition of heat of artificial origin." Hence, the definition of the "ambient

temperature," according to the statements, cannot be determined by field measurements in the immediate vicinity of a power plant after the start of operation of the power plant. Furthermore, in the Hudson River, the "ambient temperature," according to the statements, cannot be determined by field measurements at "reasonable distances" away from a power plant, since, due to periodic reversing tidal flow conditions and due to the existence of other plants along the estuary, these "reasonable distances" fall into regions influenced by the thermal plumes from other power plants. Hence, it is essential to employ appropriate far-field models for the complete estuary which can incorporate realistically the thermal interaction between all major power plants.

3.1.4 Outline of the thermal impact analysis

The outline of the present study for the assessment of the thermal impact of power plant operations on the Hudson River is based on the careful considerations of the above-discussed three general criteria which are dictated by the statements of the thermal standards applicable to the Hudson River. The overall study consists of three major parts:

1. Near-field analysis. This part of the study is concerned with estimating the near-field dilution rates of the discharges from Bowline, Danskammer, and Roseton power plants based on (a) application of appropriate near-field mathematical models, (b) design charts based on experimental studies and mathematical model results, and (c) available field data measured during actual operational conditions.

2. Far-field analysis. This part of the study is concerned with the overall thermal impact of power plant operations on the Hudson River based on the application of a tidal-transient one-dimensional computer simulation model which realistically considers the thermal interactions between all major power plants along the river.

3. Zone-matched near-field-far-field analysis. This part of the study is concerned with determining the two-dimensional temperature distributions in the regions of the estuary where Bowline, Danskammer, and Roseton power plants are located. The tidal-transient two-dimensional computer simulation model employed in the analysis realistically considers the periodically reversing tidal flows, daily varying downstream flow of fresh water, and the plant-induced flows which could lead to reentrainment and recirculation of the heated discharge water.

3.1.5 Selection of the critical periods for the thermal impact analysis

The Hudson River estuary serves as one of the major spawning and nursery areas for the striped bass and other less economically important fish species which exist in the Atlantic Ocean. The spawning period of the striped bass usually starts in May and extends through the month. The different early life stages of the striped bass as eggs, yolk-sac

larvae, post-yolk-sac larvae, and juveniles move down the estuary through the summer months. During this period they are susceptible to destruction by the power plants on the Hudson River both due to direct entrainment and impingement and also due to possible elevated thermal conditions in the river. Furthermore, it is also suspected that the behavioral characteristics of the young-of-the-year life stages of various important fish species depend on the temperature and salinity conditions in the river. Hence, the thermal impact of power plant operations could conceivably affect their capabilities to avoid entrainment and impingement at the intakes.

Based on the statements of the applicable thermal standards and consideration of the biologically critical periods for the striped bass young-of-the-year life stages, it was decided to concentrate the thermal impact analysis on six-month periods from April 1 through September 30. The application of the thermal models, both for validation and also for the assessment of the individual and/or collective thermal impact of power plant operations, was predominantly based on the 1973 and 1974 data about the conditions in the river and also about operative conditions of the power plants. The decision to consider these particular two years was based on the availability of all the required data for a complete thermal analysis.

References for Section 3.1

1. New York State Department of Environmental Conservation, *Classification and Standards Governing the Quality and Purity of Waters of New York State*, Parts 700-703, Title 6, Official Compilation of Codes, Rules and Regulations; New York State Department of Environmental Conservation, Part 704 - *Criteria Governing Thermal Discharges*, approved by New York State Water Resources Commission, July 25, 1969.
2. New York State Department of Environmental Conservation, *Additional Rules and Regulations Applicable to Thermal Discharges*, Compilation of Codes, Rules and Regulations, Sections 73.9 through 73.18, August 12, 1969, in *Approval of Plans and Issuance of Permits under Public Health Law*, Article 12, Title V (10114 CRR, Part 73).
3. G. M. Hansler, Regional Administrator, Region II Office of Environmental Protection Agency, letter dated November 10, 1971 to H. L. Diamond, Commissioner, Department of Environmental Conservation.
4. G. M. Hansler, Regional Administrator, Environmental Protection Agency, letter dated January 17, 1973 to N. D. Rockefeller, Governor of the State of New York.

3.2 General Description of Heat Dissipation Systems

3.2.1 Bowline Point Generating Station

3.2.1.1 Intake system. At nominal station generating capacity (1200 MW), approximately 1712 cfs of condenser cooling water is withdrawn from the Hudson River through two adjacent shoreline intake structures located in the Bowline Pond. A site plan view and details of the intake structure are given in Figs. 3.2.1 and 3.2.2 respectively. The inlet channel of the pond has a trapezoidal cross section with a mean low-water depth of about 16.5 ft along its centerline. The flow of condenser cooling water through the mouth of this channel results in a maximum inlet velocity of about 0.61 fps. However, this velocity may increase by as much as 30% due to the additional inflow caused by the tide.

The intake structure for each 600-MW unit is constructed of reinforced concrete and is divided into three bays, each having a circulating-water pump rated to deliver 128,000 gpm at 35 ft total dead head (Fig. 3.2.2). The pump bays are interconnected and are located in the rear of the structure behind a common plenum, which extends the entire breadth of the two intake structures to allow water from any intake port to enter any pump bay. Water for each unit's service-water system is pumped at a rate of 8480 gpm from that unit's circulating-water supply header.

Cooling water enters the intake ports through bar trash racks and flows through conventional vertical traveling screens before entering the bays for transmission to the main condensers. The trash racks, which have 3-in.-wide openings, are designed to stop large objects such as logs from entering the intake structure. The traveling screens are constructed with a screen mesh, which provides 3/8-in. square openings to prevent the passage of small fish and debris. Near the top of the vertical screens, impinged fish and debris are backwashed into a water channel that flows to a fish recovery tank where an outlet channel is provided to allow fish to return to Bowline Pond.

Maximum intake velocities occur when the plant is operating at full power and the surface water elevation is lowest (about 4 ft below mean water level). For these conditions, assuming the flow to be uniformly distributed over the available flow area, approach velocities to the intake structure and to the traveling screens are 0.64 fps and 0.78 fps respectively. On passage through the bar trash racks and traveling screens, these velocities are accelerated to 0.81 fps and to 1.53 fps, respectively, because of the reduction in flow area.

3.2.1.2 Discharge system. The thermal effluents from the turbine-condenser system and the service-water system of each unit are pumped separately to the Hudson River through 10.5-ft-diam buried pipelines. The pipelines terminate at multiport diffuser structures located about

Fig. 3.2.1. Site plan view of Bowline Point Generating Station. Source: Orange and Rockland Utilities, Inc., Bowline Point Generating Station, Fig. II-2.

Fig. 3.2.2. Details of the Bowline Point intake structure. Source: Texas Instruments, Inc.; Lawler, Matusky, and Skelly Engineers, Inc.; and New York University Medical Center, *Influence of Indian Point Unit 2 and Other Steam Electric Generating Plants on the Hudson River Estuary, with Emphasis on Striped Bass and Other Fish Populations*, J. T. McFadden, ed., submitted to Consolidated Edison Company of New York, Inc., January 1977.

1300 ft off shore (Fig. 3.2.3). At the nominal generating capacity of 600 MW for each unit, waste heat is rejected at a total rate of 5.64×10^9 Btu/hr, and therefore approximately 1712 cfs of cooling water having an excess temperature of about 14.7°F is discharged through the ports of both structures.

Design details of the diffuser structure are given in Fig. 3.2.3. Each diffuser is 200 ft in length and consists of a 10.5-ft-diam pipe oriented at right angles to the transmission pipelines. Eight discharge nozzles having 3-ft-diam ports are spaced 25 ft on centers along the structure. The nozzles are angled upward 5° from the horizontal. Thus the average effluent discharge velocity is 15 fps in a direction normal to the longitudinal axis of the river. The centerline of the discharge ports is about 15 ft below the mean low water level.

3.2.2 Roseton Generating Station

3.2.2.1 Intake system. A site plan of the Roseton Power Generating Station is given in Fig. 3.2.4. Water for the once-through cooling system is drawn from the Hudson River through a shoreline intake structure. The basic operational design specifications of the circulating water system are presented in Table 3.2.1. As shown, pumping capacity varies with the number of units operating. Higher pumping rates are required during the critical periods of high ambient temperatures to reduce the condenser temperature rise to maintain a specific thermal regulatory criterion. However, for winter operation, the plant is designed to operate at half flow to minimize adverse intake effects.

Design details of the cooling water intake structure are given in Figs. 3.2.5 and 3.2.6. Prominent features of the design include four vertical circulating-water pumps (641,000 gpm at 44.2 ft total dead head) installed in separate bays of the reinforced concrete structure. Each bay consists of two intake cells, each of which is fitted with bar trash racks and conventional vertical traveling screens. A stop-log opening is provided between adjacent bays, which allows for the utilization of flow area of other intake cells when one or more of the pumps are not operating. The circulating-water pumps discharge into a 9-ft-square chamber and then to the condensers of both units via a 12-ft-diam pipe (Fig. 3.2.6).

Cooling water enters the intake cells through bar trash racks with 3-in.-wide openings, which are designed to stop large objects such as logs from entering the intake structure. The total projected flow area of the intake cells is approximately 2480 sq ft at the normal low water level. Thus, for this elevation and the maximum circulating-water flow, approach velocities to the intake are less than 0.58 fps. These velocities are accelerated to about 0.73 fps through the bar trash racks. Subsequent to passage through the trash racks, the cooling water enters a common plenum, which extends to each side of the intake structure. Here, the velocities decrease before being accelerated to 1.39 fps through the vertical traveling screens.

Fig. 3.2.3. Bowline Point plant submerged discharge details.

Fig. 3.2.4. General overview of the Roseton Generating Station.
 Source: Ecological Analysts, Inc., *Roseton Generating Station Impingement and Entrainment Survival Studies*, 1975 Annual Report, prepared for Central Hudson Gas and Electric Company, December 1976, Fig. 1.2-3.

Table 3.2.1. Operational design specifications for the pumping rate, system transit time, and condenser ΔT 's at the Roseton Generating Station

Number of units operating	Number of pumps operating	Total flow at mean water elevation (gpm)	Total transit time (min)	Transit time from condenser to river (min)	Full-load condenser ΔT ($^{\circ}\text{C}$)
1	1	217,982			13.2
1	2	375,970			7.6
1	3 ^a	560,955	7.1	3.9	5.2-10.3 ^b
2	2	417,967	9.5	5.2	12.8
2	3	560,955	7.1	3.9	10.3
2	4	640,949	6.3	3.4	9.0

^aNot normal operation.

^bThree-pump operation requires the condenser boxes of both units to be open. Thus, one unit will have a maximum ΔT (10.3 $^{\circ}\text{C}$), while the other unit will have none until it is mixed in the common discharge.

Adapted from: Ecological Analysts, Inc., *Roseton Generating Station Impingement and Entrainment Studies*, 1975 Annual Report, December 1976.

Fig. 3.2.5. Design details of the cooling water intake structure.

Source: Texas Instruments, Inc.; Lawler, Matusky, and Skelly Engineers, Inc.; and New York University Medical Center, *Influence of Indian Point Unit 2 and Other Steam Electric Generating Plants on the Hudson River Estuary, with Emphasis on Striped Bass and Other Fish Populations*, J. T. McFadden, ed., submitted to Consolidated Edison Company of New York, Inc., January 1977.

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Fig. 3.2.6. Design details of the cooling water intake structure.
 Source: Texas Instruments, Inc.; Lawler, Matusky, and Skelly Engineers, Inc.;
 and New York University Medical Center, *Influence of Indian Point Unit 2 and
 Other Steam Electric Generating Plants on the Hudson River Estuary with
 Emphasis on Striped Bass and Other Fish Populations*, J. T. McFadden, ed.,
 submitted to Consolidated Edison Company of New York, Inc., January 1977.

The traveling screens consist of a series of interconnected screen baskets, which are 2 ft wide and extend 9 ft across the intake cell. The baskets are constructed from a wire mesh that has 3/8-in. square openings. As shown in Fig. 3.2.6, the screens are backwashed near the top of the screen trajectory with high-pressure nozzles. A screen-wash sluiceway is provided for the return of impinged fish and debris to a downstream location in the river.

A deicing system is also included in the intake design. When ice forms on the river, a portion of the heated circulating water being returned to the river is diverted for discharge at the entrance of the intake structure. The heated effluent is jetted into each intake cell from 24-in. nozzles extending from a 42-in. header (Fig. 3.2.5). This recirculation prevents ice from forming on the trash racks by raising the temperature of the inlet water.

3.2.2.2 Discharge system. The thermal effluents from the main condensers of both units and from other plant systems are routed to a common discharge tunnel and then to a seal well, where provisions are made for the recirculation of heated water for the deicing system. Subsequent to passing through the seal well, the remaining effluent enters a 12-ft-diam pipe that leads to a multiport diffuser located approximately 800 ft downstream from the intake. The location and design of the diffuser are shown in Fig. 3.2.7.

At the nominal station generating capacity of 1200 MW for both units, the various cooling systems are designed to reject 5.92×10^9 Btu/hr of waste heat to the cooling water, which flows at a rate of 1462 cfs. This heat rejection rate results in a cooling water temperature increase of 18°F at design conditions. The transit time of entrained microorganisms through the circulating water system is given in Table 3.2.1.

The multiport diffuser is oriented parallel to the longitudinal axis of the river at about 300 ft off shore (Fig. 3.2.7). It consists of a 12-ft-diam pipe with 14 nozzles having 3-ft-diam ports spaced 25 ft on centers. The nozzles are directed off shore in a direction parallel to the riverbed and about 9 ft above it. Thus, at the design flow, the average effluent velocity is about 14.8 fps and in an offshore direction normal to the longitudinal river axis.

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Fig. 3.2.7. Roseton Generating Station discharge structure.

3.3 Near-Field Analysis of Thermal Discharges from the Major Power Plants on the Hudson River

3.3.1 Bowline Point Generating Station

The dilution characteristics of multiport diffusers are influenced by many physical processes. The near-field transport processes are governed by the geometric and dynamic characteristics of the diffuser and of the ambient water in the immediate diffuser vicinity. The initial jet mixing is the dominant transport mechanism; however, subsequent effluent dilution over longer time scales by far-field dispersion may influence the near-field processes. Hydraulic model studies¹ of unidirectional diffusers have shown that, in the presence of ambient currents, the diffuser orientation with respect to the current direction is the single most crucial parameter that affects diffuser behavior. In particular, increases in dilution as compared to zero-cross-flow conditions have been observed only in the case of diffusers discharging in the direction of the cross flow. For all other diffuser orientations relative to the cross flow, lower downstream dilutions were observed than for similar discharges in a stagnant ambient. This phenomenon is partly due to repeated reentrainment, which is caused by the current sweeping down the axis of the diffuser.

The arrangement of the Bowline Point diffuser with respect to the ambient flow changes with the tidal cycle because of the influence of the local topographic features. In Fig. 3.3.1, the diffuser is shown to be oriented nearly parallel to currents produced by the flood tide, but the topography forces littoral currents nearly perpendicular to the diffuser for the ebb tide. Considering the observations mentioned previously, this factor alone will significantly affect the near-field dilution characteristics of the Bowline Point diffuser (which will be shown later).

Other factors influencing dilution of the thermal effluent from the Bowline Point Generating Station are also associated with the tidal cycle. These include (1) stratification effects, which may suppress jet mixing between the various fluid strata, and (2) reversing currents, which may cause reentrainment of already mixed water from the far-field zone. Formulation of these complex phenomena in an analytical model to predict near-field dilution ratios for multiport diffusers is beyond present knowledge. However, analysis of the effluent behavior from a single port of the diffuser for the various flow conditions may provide some insight into the diluent capacity of the diffuser.

Therefore, the staff selected the turbulent buoyant jet model of Hirst² to investigate the discharge characteristics of a single jet from the diffuser, which is subject to the flow conditions associated with the tidal cycle. The interference of the remaining jets of the diffuser was neglected; however, the calculations were terminated at a point corresponding roughly to the depth at which the jet was expected to merge with adjacent jets. Because the diffuser orientation is parallel to the

Fig. 3.3.1. Surface isotherms (43°F) due to effluents discharged from the Bowline Point diffuser. Source: Lawler, Matusky, and Skelly Engineers, *Thermal Surveys at the Bowline and Lovett Generating Stations*, April 1975.

longitudinal axis of the river, shielding effects of adjacent jets make precise determination of jet merging difficult. Thus, for the sake of convenience, the plumes were assumed to merge at jet half widths of about 12.5 ft, which is one-half of the port spacing.

The results of the calculations are presented in Table 3.3.1. Dilution ratios are given for a range of tidal velocities and stratifications characteristic of the Hudson River estuary at Bowline Point. The salinities used in this analysis are possibly high; however, the plume rise characteristics for the Hirst model are only influenced by the magnitude of the vertical salinity gradient. For the given flow conditions (Table 3.3.1), the dilution ratios range from 6 to about 9. The plume dilution characteristics were shown to remain essentially unchanged for the various salinity gradients. As expected, the dilution ratio increased with increasing cross flows. These results indicate that, before the various plumes merge, dilution ratios ranging from 6 to 9 are obtainable. Thus, for all flow conditions and plant operating conditions, increases in surface temperature will be less than 2°F. To check the validity of these results, rough estimates of the surface dilution ratios were obtained from the Shirazi-Davis submerged discharge workbook.³ A dilution ratio of 5 was estimated for the diffuser discharging in a stagnant ambient of uniform density. Therefore, the Hirst model with the simplifying assumptions is consistent with the model of Shirazi and Davis.

It is very difficult to assess the applicability of these results (even neglecting the assumptions made), because of instabilities that are associated with diffuser flows, which can cause reentrainment,¹ and, most significant, because of the effects of the far field zone on tidal flows. The tidal action of the estuary has the characteristics of transporting effluents that are already diluted back to the near-field zone for reentrainment, momentarily causing an increase in the local temperature of the water surrounding the diffuser. The question then arises as to what value of the ambient temperature should be used for the near-field analysis. The temperature of the returning flow is a function of the tidal cycle because of the differences between the far-field dispersion characteristics of the ebb and flood tides. Variations in the dispersion characteristics of the estuary relative to the location of the diffuser are due to contrasting upstream and downstream topography and bathymetry and to the net seaward flow of riverine waters.

Further consideration of the dilution characteristics of the diffuser included analysis of the field data obtained from thermal surveys⁴⁻⁷ at Bowline Point. The thermal surveys were conducted during periods for which the monthly averaged seaward flow of fresh water and the plant operating conditions varied considerably. Therefore, the diluent capacity of the diffuser was measured for a wide range of conditions. The results of the surveys are presented in Table 3.3.2.

The dilution ratio is defined here as the ratio of the initial discharge excess temperature to the maximum observed excess temperature

Table 3.3.1. Jet behavior for a single port of the Bowline Point diffuser as estimated from the Hirst model
(Jet velocity, 15.0 fps. Influence of remaining jet from the multiport diffuser is neglected)

Case number	Ambient temperature ^a (°F)	Jet temperature (°F)	Salinity at outfall (ppt)	Vertical salinity gradient (ppt/ft)	Cross-flow velocity (fps)	Jet centerline depth at outfall ^b (ft)	Dilution ratio ^b ($\Delta T/\Delta T$ outfall)	Distance above discharge port ^b (ft)	Length of plume centerline ^b (ft)
1	80.0	94.8	11.0	-0.2	0.0	15	6.0	10.6	98.5
2	42	56.8	11.0	-0.2	0.0	15	6.0	8.5	98.5
3	80.0	94.8	5.0	-0.1	0.0	15	6.0	13.5	98.5
4	42.0	56.8	5.0	-0.1	0.0	15	6.0	10.9	98.5
5	80.0	94.8	8.0	0.0	1.0	17	9.1	6.2	54.4
6	80.0	94.8	8.0	0.0	0.5	17	7.6	9.1	68.2
7	80.0	94.8	8.0	0.0	1.0	14	9.1	6.8	58.4
8	80.0	94.8	8.0	0.0	0.5	14	7.6	9.1	68.1

^aUniform ambient temperature.

^bThese values were obtained at jet half widths of (1) 11.2 ft for case numbers 1-4 and (2) 13.4 ft for case numbers 5-8, roughly corresponding to points along the centerline at which the jets merge.

Source: E. A. Hirst, *Analysis of Round, Turbulent, Buoyant Jets Discharged to Flowing Stratified Ambients*, ORNL-4685, June 1971.

Table 3 3.2. Diluent capacity of the Bowline Point diffuser as
calculated from the 1976 thermal surveys
(ME, maximum ebt; LWS, low water slack; MF, maximum flow; HWS, high-water slack)

	April 1 ^e				June 18				August 19				October 20			
	ME	LWS	MF ^c	HWS	ME	LWS	MF	HWS	ME	LWS	MF	HWS	ME	LWS	MF	HWS
Net generation, MW	481	486	678	488	558	1028	1125	1040	1115	1120	1139	1121	487	440	568	410
Discharge excess temperature, °F	14	15	15	15	15	14	16	14	15	14.8	14.8	15	14	17	17	14
Ambient temperature, ^b °F	41.7	41.7	41.7	41.7	73	73	73	73	79	78.5	78.5	79	57	57	57	57
Maximum observed surface temperature, °F	44.8	47.8	48.2	45.3	75.6	78.6	78.6	75.4	82.4	84.6	84.4	82	59.5	62.4	61.9	59.4
Surface dilution ratio ^c	4.5	2.5	2.3	4.2	5.8	2.5	2.8	5.8	4.4	2.4	2.4	5	5.6	3.1	3.5	5.6

^a Both units were operating at significantly different power levels. Thus the excess temperature of effluent at diffuser was estimated.

^b Taken as given in surveys. However, these values may be in error because of the ambiguities associated in defining ambient temperatures in the vicinity of discharge structures for tidal flows.

^c Defined as the ratio of the discharge excess temperature to the maximum observed excess temperature at surface.

Sources: Lawler, Matusky, and Skelly Engineers, Thermal Surveys at the Bowline Point and Lovett Generating Stations, April 1975; Lawler, Matusky, and Skelly Engineers, Thermal Surveys at the Bowline Point and Lovett Generating Stations, June 1975; Lawler, Matusky, and Skelly Engineers, Thermal Surveys at the Bowline Point and Lovett Generating Stations, August 1975; Lawler, Matusky, and Skelly Engineers, Thermal Surveys at the Bowline Point and Lovett Generating Stations, October 1975.

at the surface. Dilution ratios ranging from 2.3 to 5.8 were obtained; however, for each survey period, significantly larger dilution ratios always occurred for maximum ebb and high-water-slack conditions than for the other tidal phases. These findings can be attributed to the diffuser orientation relative to the current direction and the differences in vertical salinity distributions for high-water slack and low-water slack.

Consider the relative positions of the surface isotherms for each tidal phase in Figs. 3.3.1 and 3.3.2, which were taken from the April and August thermal surveys respectively. The relative positions of the excess temperature isotherms for each tidal phase did not vary significantly with the survey period. Careful inspection of the spatial extent of the isotherms relative to the west riverbank reveals that currents associated with the flood tide sweep down the diffuser line and slightly against the diffuser flow. In contrast, currents associated with the ebb tide exhibit tendencies to flow with the discharged effluent. Therefore, topographic features in the immediate vicinity of the diffuser force the ambient currents in the direction for which higher near-field dilutions are achieved for ebb tide than for flood tide. These results are in accord with the model studies by Jirka and Harleman.¹

The excess temperature isotherms for low-water slack and high-water slack conditions cover areas relatively close to the diffuser when compared to those of the ebb and flood tides (Figs. 3.3.1 and 3.3.2). For these conditions, the diffuser is not subjected to strong cross flows, and the influence of vertical salinity distributions on the coupling between the near-field and far-field zones becomes more apparent. The vertical salinity distribution for both high-water slack and low-water slack resembles a stably stratified two-layered flow system; however, the salinity variations between the layers are much greater for high-water slack than for low-water slack.⁸ Thus, effluent that is already mixed has a much greater chance for being transported from the near-field zone into the upper layer for high-water slack, and the likelihood of reentrainment into the jet is decreased. However, for low-water slack conditions, where vertical salinity variations are not as pronounced, model studies have shown that, for similar discharges in shallow water, full vertical mixing due to strong boundary interactions may occur.¹ The stratified layers do not exist; therefore, the potential for reentrainment is enhanced if the far-field dispersion characteristics are unable to advect the effluent away from the diffuser. Moreover, the channel depth is much lower for low-water slack, which implies that less water is available for dilution. These phenomena could possibly justify the observed larger dilution ratios for high-water slack conditions than for low-water slack conditions. Evidence of full vertical mixing during low-water slack was found in all of the thermal surveys.

In most instances, dilution ratios calculated from the field measurements are considerably smaller than those estimated from the Hirst model (Tables 3.3.1 and 3.3.2). Because the Hirst analysis can only be used to approximate the behavior of a single jet of the diffuser, this trend may be expected. Other available analytical models would produce similar

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Fig. 3.3.2. Surface isotherms (2°F excess temperature) due to effluents discharged from the Bowline Point diffuser. Source: Lawler, Matusky, and Skelly Engineers, *Thermal Surveys at the Bowline and Lovett Generating Stations*, August 1975.

results (overestimates) because the near-field mixing characteristics, in this case, are governed by the current direction, which is, in turn, forced by the local topography. Moreover, the vertical salinity gradients are equally important. State-of-the-art diffuser models for shallow-water discharges are not equipped to handle these phenomena.

Conversely, physical models can effectively simulate near-field diffuser behavior under conditions characteristic of the Bowline Point diffuser. Table 3.3.3 summarizes the Bowline undistorted hydraulic model studies,⁸ which, in part, were aimed at determining the steady-state near-field surface temperatures rises under various flow conditions. The ambient currents were directed parallel to the diffuser axis and varied from 0.0 to 1.0 fps. Note that, in general, these results (Table 3.3.3) show that the dilution ratio decreases as the river current decreases, which is consistent with the results of other hydraulic model studies¹ in the case of ambient currents flowing normal to the diffuser flow. Moreover, values of the dilution ratios for the Bowline hydraulic model study, which ranged from 2.2 to 4.8, are in remarkably close agreement with the measured values (Table 3.3.2).

Conclusions. Near-field dilution ratios for the Bowline Point diffuser vary from about 2 to 6. These variations are associated with the tidal phase because of the changing current direction (relative to the diffuser arrangement), which is forced by the local topography. These flow phenomena are consistent with the determination of dilution ratios from existing plume models when considering the assumptions used in these models.

3.3.2 Roseton Generating Station

Inspection of the surface isotherms of the thermal effluents from the Roseton and Danskammer Point power stations in Figs. 3.3.3-3.3.6 reveals that the near-field diluent behavior of the Roseton diffuser is influenced by the magnitude and direction of the ambient currents and the discharge characteristics of the Danskammer plume. Field studies by Lawler, Matusky, and Skelly Engineers (LMS)⁹ have shown that, for freshwater flows exceeding 9000 cfs, vertical salinity gradients are undetectable at the Roseton site, and therefore salinity has little effect on effluents discharged in this area. This observation is also true for the long-term average (low) flows of July through August (5000 to 6500 cfs).¹⁰

The Danskammer Point Generating Station has a total net capacity of 472 MW (494 gross)⁹ from four generating units. At the design point, cooling water is discharged from three tunnels at a flow rate of 504 cfs and with an excess temperature of 17°F. The discharge tunnels are located just beneath the extreme low water level in approximately 15 ft of water; however, the bay area inshore of this point is very shallow, ranging from 2 to 10 ft in depth (Fig. 3.3.3). To illustrate the

Table 3.3.3. Summary of Bowline undistorted hydraulic model studies
(Alden Research Laboratories) of near-field diffuser behavior

River current (fps)	Plant temperature rise (°F)	Cooling water flow (cfs)	Maximum surface temperature rise (°F)	Dilution ratio ^a
<u>One-unit operation</u>				
1.0	15.2	855	5.5	2.76
0.5	14.2	855	5.2	2.73
0.5	15.2	855	4.9	3.10
0.0	17.5	855	4.1	4.27
0.0	13.0	855	2.7	4.82
Average	15.0	855	4.48	3.54
<u>Two-unit operation</u>				
1.0	14.8	1710	5.5	2.70
0.75	14.7	1710	6.0	2.46
0.50	15.7	1710	4.6	3.42
0.45	15.0	1710	6.7	2.24
0.25	15.0	1710	5.9	2.54
Average	15.0	1710	5.74	2.67

^aPlant temperature rise divided by maximum surface temperature rise.

Source: Quirk, Lawler, and Matusky, *Environmental Effects of the Bowline Generating Station on Hudson River*, vol. I, QL&M Project No. 169-1, March 1971, Table VII-1.

Fig. 3.3.3. Surface isotherms of thermal effluents from Roseton and Danskammer Point power stations. Source: Lawler, Matusky, and Skelly Engineers, *Thermal Surveys at Roseton/Danskammer Point Generating Stations*, April 1975.

Fig. 3.3.5. Surface isotherms of thermal effluents from Roseton and Danskammer Point power stations. Source: Lawler, Matusky, and Skelly Engineers, *Thermal Surveys at Roseton/Danskammer Point Generating Stations*, April 1975.

Fig. 3.3.6. Surface isotherms of thermal effluents from Roseton and Danskammer Point power stations. Source: Lawler, Matusky, and Skelly Engineers, *Thermal Surveys at Roseton/Danskammer Point Generating Stations, July 1975*.

effluent behavior from Danskammer Point, the equivalent jet velocity for the combined discharges (based on the total flow area of the tunnels) is about 4.8 fps. Thus the jet densimetric Froude number ranges from about 5.8 to 13, with the higher values occurring for winter operation. The equivalent aspect ratio is about 3.3 for a discharge depth of 8 ft. For these discharge conditions coupled with the bathymetric features of the cove area, the Danskammer surface discharge should exhibit poor near-field dilution characteristics (especially for ebb tide and slack conditions) and, therefore, should have an adverse effect on the Roseton plume dilution characteristics. However, penetration of the Danskammer surface plume into the immediate vicinity of the Roseton diffuser is primarily dependent on the plant load conditions.

Typical effluent behavior from the Danskammer station relative to the Roseton diffuser is displayed in Figs. 3.3.3-3.3.6 for the respective tidal phases (ebb, low-water slack, flood, and high-water slack). Although the plant operating conditions for the various tidal phases were different (see Tables 3.3.4-3.3.7), these data are judged to be characteristic for the Danskammer Point Generating Station operating from 31 to 58% of its total generating capacity. In Fig. 3.3.3, for the ebb tide, the Danskammer Point plume is confined to the cove area with very little dispersion into the main channel of the river. Vertical temperature surveys¹¹ indicate that water temperature in the cove area is uniform in the vertical direction. The surface isotherms show that the discharge plume attaches to the shore in the cove area and does not extend into the Roseton discharge area. However, these measurements were recorded when the plant was operating at 40% of its total generating capacity. Thus, for loads approaching peak capacity outputs, the Danskammer Point plume will undoubtedly penetrate into the Roseton discharge area. The surface isotherms in Fig. 3.3.4 are shown to be characteristic of early flood conditions rather than of low-water slack conditions. The influence of opposing tidal currents forces the plume outward from the cove area and, thus, out of the jet mixing area of the Roseton diffuser. (The full effect of maximum flood tides is shown in Fig. 3.3.5.) For both slack conditions (see Fig. 3.3.6 for high-water slack), the Danskammer Point plume is expected to have the same general behavior as for the ebb conditions.

Based on these observations, it can be concluded that, during ebb and slack conditions, the Danskammer Point plume will penetrate into the Roseton discharge area for sufficiently high-load conditions; however, the plume will be confined to the surface due to the effects of buoyancy in the deeper water near the diffuser.

The effects of the tidal current direction and magnitude on the Roseton diffuser are ascertainable from the near-field analysis of the Bowline Point diffuser (see Sect. 3.3.1). Higher dilution ratios are obtainable for diffusers in stagnant ambients than for diffusers discharging perpendicular to a cross flow. Whenever the cross flow sweeps down the axis of an unidirectional diffuser, reentrainment of effluent that is already diluted is likely to occur. Inspection of the local topography surrounding the Roseton diffuser and the diffuser orientation

Table 3.3.4. Plant conditions, September 4, 1974

Hour	Generation (MW _e)						Circulating water flow (10 ³ gpm)						Temperature rise (°F)					
	Danskammer Point					Roseton Unit 2	Danskammer Point					Roseton Unit 2	Danskammer Point					Roseton Unit 2
	Unit 1	Unit 2	Unit 3	Unit 4	Total		Unit 1	Unit 2	Unit 3	Unit 4	Total		Unit 1	Unit 2	Unit 3	Unit 4	Average	
4	0	51	51	161	303	578	21	42	82	150	295	378	0	15	12	12	11.6	15
5	0	52	52	158	302	525	21	42	82	150	295	378	0	13	13	13	12.1	14
6	0	43	52	135	260	562	21	42	82	150	295	378	0	11	12	11	10.5	14
7	0	42	51	150	273	585	21	42	82	150	295	378	0	14	13	12	11.7	14
8	0	41	108	156	305	591	21	42	82	150	295	378	0	14	16	13	13.1	15
9	0	44	122	173	339	597	21	42	82	150	295	378	0	12	15	13	12.4	15
10	0	44	123	162	329	599	21	42	82	150	295	378	0	13	16	12	12.4	14
11 ^a	0	43	123	153	319	601	21	42	82	150	295	378	0	13	16	11	11.9	14
12 noon ^a	0	44	123	150	317	601	21	42	82	150	295	378	0	13	16	12	12.4	15
1 ^a	0	43	114	151	308	601	21	42	82	150	295	378	0	12	14	12	11.7	15
2 ^a	0	44	109	167	320	601	21	42	82	150	295	378	0	12	14	12	11.7	15
3	0	43	109	160	312	592	21	42	82	150	295	378	0	12	14	12	11.2	16
4 ^a	0	44	110	150	304	552	21	42	82	150	295	378	0	12	13	11	10.9	15
Average					307	534					295	378					11.8	14.7

^aPlume-mapping period.Source: Lawler, Matusky, and Skelly Engineers, *Thermal Surveys at Roseton/Danskammer Point Generating Stations*, April 1975.

Table 3.3.5. Plant conditions, April 9, 1975

Hour	Gross generation (MWe)						Circulating water flow (10 ³ gpm)						Temperature rise (°F)					
	Danskammer Point					Roseton	Danskammer Point					Roseton	Danskammer Point					Roseton
	1	2	3	4	Total		1	2	3	4	Total		1	2	3	4	Average	
1	34	39	116	0	189	1067	21	21	41	0	83	378	20	21	23	0	21.7	22
2	38	38	109	0	185	1065	21	21	41	0	83	378	20	21	23	0	21.7	22
3	39	38	98	0	175	1065	21	21	41	0	83	378	21	21	20	0	20.5	22
4	38	38	93	0	169	1065	21	21	41	0	83	378	20	21	20	0	20.3	-
5	39	39	96	0	174	1067	21	21	41	0	83	378	21	22	22	0	21.8	-
6	34	38	99	0	171	1067	21	21	41	0	83	378	20	21	24	0	22.2	22
7	36	38	109	0	183	1066	21	21	41	0	83	378	23	21	25	0	23.5	22
8 ^a	37	39	106	0	182	1068	21	21	41	0	83	378	23	21	24	0	23.0	-
9 ^a	42	38	91	0	171	1068	21	21	41	0	83	378	22	21	18	0	19.8	22
10	40	38	110	0	188	1065	21	21	41	0	83	378	22	21	26	0	23.7	22
11 ^a				0		1067	21	21	41	0	83	378				0		22
12 ^a	39	40	106	0	185	1068	21	21	41	0	83	378	20	22	19	0	20.0	22
13 ^a	38	38	79	0	155	1069	21	21	41	0	83	378	20	21	18	0	19.3	22
14 ^a				0		1067	21	21	41	0	83	378				0		-
15				0		1068	21	21	41	0	83	378				0		22
16 ^a				0		1069	21	21	41	0	83	378				0		22
17 ^a	46	42	109	0	197	1063	21	21	41	0	83	378	26	24	26	0	25.5	22
18 ^a	47	43	118	0	208	1062	21	21	41	0	83	378	25	24	23	0	23.8	22
19	48	43	114	0	205	1068	21	21	41	0	83	378	25	24	24	0	24.3	22
Average					182.5	1066.5					83	378					22.0	22

^aPlume-mapping period.Source: Lawler, Matusky, and Skelly Engineering, *Thermal Surveys at Roseton/Danskammer Point Generating Stations, April 1975.*

Table 3.3.6. Plant conditions, July 17, 1975

Hour	Gross generation (MWe)						Circulating water flow (10 ³ gpm)						Temperature rise (°F)					
	Danskammer Point					Roseton	Danskammer Point					Roseton	Danskammer Point					Roseton
	1	2	3	4	Total		1	2	3	4	Total		1	2	3	4	Average	
3	28	0		129	157	853	42	21	41	150	254	561	10	1	0	11	8.3	12
4	29	0		153	182	812	42	21	41	150	254	561	10	1	0	13	9.5	11
5	28	0		150	178	833	42	42	41	150	275	561	10	1	0	12	8.7	11
6	31	0		192	223	853	42	42	41	150	275	561	11	1	0	14	9.5	11
7	33	0		117	150	870	42	42	41	150	275	561	12	3	0	11	8.3	12
8	33	04		116	153	948	42	42	41	150	275	464	11	6	0	12	9.1	13
9 ^a	38	28		205	271	1148	42	42	41	150	275	418	15	13	0	17	13.6	19
10 ^a	46	38		201	285	1151	42	42	41	150	275	444	15	14	0	15	12.6	22
11	46	36		215	297	1151	42	42	41	150	275	561	15	13	0	17	13.6	22
12	46	36		211	293	1152	42	42	41	150	275	522	15	14	0	18	14.3	22
13 ^a	46	36		220	302	1151	42	42	41	150	275	418	15	13	0	17	13.6	22
14 ^a	41	32		227	300	1143	42	42	41	150	275	418	14	12	0	18	13.8	23
15	34	30		223	287	1143	42	42	41	150	275	418	10	12	0	17	12.6	23
16 ^a	28	31		216	275	1180	42	42	41	150	275	418	10	12	0	17	12.6	24
17 ^a	38	35		214	287	1173	42	42	41	150	275	418	15	13	0	16	13.0	24
18 ^a	46	37		210	293	1153	42	42	41	150	275	418	15	13	0	17	13.6	24
19 ^a	47	37		215	299	1157	42	42	41	150	275	418	15	14	0	17	13.7	24
20	46	38		194	278	1157	42	42	41	150	275	544	15	14	0	15	12.6	24
Average					250.6	1057.9					272.7	482.4					11.8	19.1

^aPlume-mapping period.Source: Lawler, Matysky, and Skelly Engineers, *Thermal Surveys at Roseton/Danskammer Point Generating Stations, April 1975.*

Table 3.3.7. Plant operating conditions, August 4, 1976

Hour	Gross generation (MW)								Circulating water flow (MGH)									Temperature rise (°F)								
	Danskammer Point ^a					Roseton			Danskammer Point					Roseton				Danskammer Point					Roseton			
	1	2	3	4	Total	1	2	Total	1	2	3	4	Total	1	2	Total	1	2	3	4	Mean	1	2	Mean		
6	b	b	b	b	182	163	169	332	b	b	b	b	12.78	16.83	16.83	33.6	b	b	b	b	11.7	4.5	6.5	5.5		
7	b	b	b	b	183	166	171	337	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	11.8	4.5	6.7	5.6		
8	b	b	b	b	199	228	254	482	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	12.8	5.6	8.4	7.0		
9	b	b	b	b	247	312	511	823	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	15.9	7.9	15.0	11.4		
10 ^c	b	b	b	b	209	319	599	918	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	13.4	8.2	18.6	13.4		
11 ^c	b	b	b	b	209	319	601	920	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	13.4	8.2	19.0	13.6		
12 ^c	b	b	b	b	217	319	603	922	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	14.0	8.2	19.6	13.9		
13 ^c	b	b	b	b	217	319	601	920	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	14.0	8.0	20.5	14.2		
14	b	b	b	b	237	319	601	920	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	15.2	8.0	14.6	11.3		
15 ^c	b	b	b	b	230	320	601	921	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	14.8	8.1	14.8	11.4		
16 ^c	b	b	b	b	229	321	601	922	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	14.7	8.1	14.5	11.3		
17 ^c	b	b	b	b	263	320	601	921	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	16.9	8.1	14.5	11.3		
18 ^c	b	b	b	b	279	320	600	920	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	17.9	7.9	14.6	11.2		
19 ^c	b	b	b	b	272	321	600	921	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	17.5	7.8	14.6	11.2		
20 ^c	b	b	b	b	244	320	598	918	b	b	b	b	12.78	16.83	16.83	33.66	b	b	b	b	15.6	7.7	14.6	11.1		
Mean					228			806					12.78			33.66					14.6			10.7		

^aGross load = net load x 1.033; approximation.^bNot available, due to computer downtime.^cPlume-mapping period.

relative to the longitudinal axis of the river reveals that tidal currents for both ebb and flood conditions flow parallel to the diffuser axis. This implies that dilution ratios for the ebb and flood tides should be nearly equal and always less than those for the slack conditions, provided that the Danskammer Point plume does not enter the Roseton discharge area.

Data obtained from the thermal surveys at the Roseton and Danskammer Point stations^{9,11-13} are presented in Table 3.3.8. These data have been tabulated to show the near-field mixing characteristics of the Roseton diffuser for the various tidal phases. Plant operating conditions during these survey periods are recorded in Tables 3.3.4-3.3.7. The plume mapping periods for each of the surveys are included. The maximum output of the Danskammer Point station was about 58% of the total generating capacity, and the effluent did not affect the near-field behavior of the Roseton plume. Table 3.3.8 shows that the dilution ratios ranged from a low of 2.9 to a high of 6.3, with the lower values occurring for the ebb and flood tides. This result is consistent with the Bowline Point analysis, where correspondingly higher surface temperatures were found for tidal currents flowing down the axis of the diffuser as compared to slack conditions.

The mixing characteristics of the Roseton diffuser were also examined by approximating the effluent behavior from a single port of the diffuser with the Hirst jet model.² Dilution ratios were calculated at a point along the jet centerline corresponding to a jet half width of about 12.5 ft. The various jets of the diffuser were assumed to merge for this value of the half width. The results of the analysis are presented in Table 3.3.9, where dilution ratios are given for a range of flow conditions applicable to the various seasonal discharges and tidal conditions. As expected, mixing rates increased with increasing cross-flow velocities. In the presence of the various cross flows, these values of the dilution ratios are probably typical of the effluent behavior for the upstream diffuser port. However, shielding effects of the upstream jets and other flow phenomena increase the likelihood for downstream jets of the diffuser to reentrain already mixed effluents. For the case of a stagnant ambient, dilution ratios for the various discharge conditions were about 6.7, which is comparable to those calculated from the field data (Table 3.3.8) during slack conditions.

Conclusions. Plumes from the Danskammer Point Generating Station at plant loads up to 60% of maximum power do not penetrate into the Roseton discharge area. Thus, under these circumstances, near-field dilution ratios for the Roseton diffuser can be expected to vary from about 3 to 6, with the higher values associated with slack tide conditions.

3.3.3 Summary of near-field results

Analyses of the available field data for the Bowline Point and Roseton Generating Stations reveal that surface dilution ratios vary from a low of

Table 3.3.8. Diluent capacity of the Roseton diffuser as calculated from the Roseton and Danskammer Point thermal surveys

	September 4, 1974			April 9, 1975				July 17, 1975				August 4, 1976			
	Early flood	ME	HWS	ME	LWS	MF	HWS	ME	LWS	MF	HWS	ME	LWS	MF	HWS
Net generation, MW	601	601	562	1066	1066	1068	1066	1152	1180	1157	1148	920	918	920	921
Excess effluent temperature, °F	14	15	15	22	24	22	22	22	24	24	22	11.1	13.4	14.2	11.3
Ambient temperature, ^a °F	72	75	75.5	38	38	38	38	77.2	77.2	77.5	77.5	76.2	76.2	76.2	76.2
Maximum surface temperature reported, °F	76	77	78	45	44.8	45	43	84	83	84	83	80	79	80	78
Surface dilution ratio ^b	3.5	5	6	3.1	3.5	3.1	4.4	3.2	4.1	3.5	4.0	2.9	4.8	3.7	6.3

^a Taken as given in thermal surveys. However, it should be noted that these values may be in error because of the ambiguities associated in defining ambient temperatures in the vicinity of discharge structures for tidal flows.

^b Defined as the ratio of the discharge excess temperature to the maximum observed excess temperature at surface.

Sources: Lawler, Matusky, and Skelly Engineers, *Thermal Surveys at Roseton/Danskammer Point Generating Stations, September 1974*.

Lawler, Matusky, and Skelly Engineers, *Thermal Surveys at Roseton/Danskammer Point Generating Stations, April 1975*.

Lawler, Matusky, and Skelly Engineers, *Thermal Surveys at Roseton/Danskammer Point Generating Stations, July 1975*.

Lawler, Matusky, and Skelly Engineers, *Thermal Surveys at Roseton/Danskammer Point Generating Stations - August 1976*, STRN No. 76/0241 and 176-113.

Table 3.3.9. Jet behavior for a single port of the Roseton diffuser as estimated from the Hirst model
(Influence of remaining jets from the multiport diffuser is neglected. Jet velocity, 15.0 fps)

Case number	Ambient temperature ^a (°F)	Jet temperature (°F)	Cross-flow velocity (fps)	Jet centerline depth at outfall (ft)	Dilution ratio ^b ($\Delta T/\Delta T$)	Distance above discharge port ^b (ft)	Length of plume centerline ^c (ft)
1	80	98	0	19	6.7	12.0	107
2	80	98	0.5	22	6.8	3.5	64
3	80	98	1.0	24	8.0	2.2	54
4	40	58	0	19	6.8	7.4	111
5	40	58	0.5	22	6.7	1.9	64
6	40	58	1.0	24	8.0	1.2	53
7	40	65	0	19	6.9	10.9	111
8	40	65	0.5	22	6.8	2.8	64

^aUniform ambient temperature and salinity (100 ppm).

^bThese values were obtained at jet half widths of 12.5 ft, roughly corresponding to points along the centerline at which the jets merge.

Source: E. A. Hirst, *Analysis of Round, Turbulent, Buoyant Jets Discharged to Flowing Stratified Ambients*, Report No. ORNL-4685, June 1971.

about 2 for Bowline Point and 3 for Roseton to a maximum of 6 for both plants. Since the dilution characteristics of effluents from the Roseton station are influenced by the thermal plume from the Danskammer station, which propagates into the Roseton discharge area at maximum operating loads and increase the local ambient temperature, smaller dilution ratios are expected to occur whenever this condition prevails. The range of dilution ratios calculated for each station can be associated with the direction, relative to the diffuser structures, of the ambient currents, which are forced by the local topography to flow in different directions for the various tidal cycles. Significantly lower dilution ratios occur whenever ambient currents flow parallel to the diffuser axis.

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3.4 Far-Field Analysis of the Thermal Impact on the Hudson River

The analysis of the overall thermal impact of power plant operations on the Hudson River is based on a tidal-transient one-dimensional discrete-element transport model for predicting hydrodynamic, thermal, and salinity conditions in controlled rivers and estuaries.^{1,2} The mathematical model and its associated computer code ESTONE consider all the important natural and power-plant-induced effects which can influence the thermal conditions in the estuary. The model is one of the general one-dimensional class of "Unified Transport Approach" (UTA)³ models which are being developed specifically for the realistic assessment of the thermal, chemical, radiological, and biological impact of power plant operations on the aquatic ecology of large receiving water bodies.

3.4.1 Review of existing studies of the far-field thermal impact of power-plant operations

The early studies of the far-field thermal impact of power-plant operations on the Hudson River considered simplistic models^{4,5} based on pseudoempirical exponential decay formulations to simulate the temperature distributions along the estuary. Considering the complexity of the hydrodynamics and the importance of the transient effects of thermal and salinity conditions, these simplistic models are definitely inadequate for realistic assessment of the thermal impact of power plant operations on the Hudson River.

A steady-state, one-dimensional, multisegment thermal model was also developed by Lawler⁶ to incorporate the axial variations of the cross-section area of the channel and the dispersion coefficient along the estuary. Although the model utilized a direct computational solution scheme to simulate the variation of "excess temperature" in the 28 segments of the model, since it did not include the critically important effects of tidal flow conditions and temporal variations, the results of the model cannot be accepted as sufficiently reliable for the assessment of the thermal impact of power plant operations on the Hudson River.

The aforementioned simple mathematical models⁴⁻⁶ were developed for the Consolidated Edison Company of New York, Inc., to justify the requests of the company to operate their power plants with once-through cooling water systems. The results of the model predictions have consistently concluded that the thermal impact of open-cycle operations would not exceed the stated thermal standards in the estuary. These models are referenced and discussed in numerous other reports by the electric utility companies (e.g., refs. 7-9) as reliable and realistic models for the assessment of the overall thermal impact of power plant operations on the Hudson River. Three critical deficiencies of these models which render them unreliable are:

1. Unrealistic steady-state assumption. The steady-state conditions in the river do not exist due to continuous variations of the freshwater flow conditions in the river and the climatological conditions in the region.

2. Error in the development of the tidal-averaged "dispersion coefficient." The values assumed for the tidal-averaged "dispersion coefficient" associated with the thermal phenomenon are based on the "dispersion coefficient" determined from the salinity intrusion studies in the estuary. The particular formulation of the "dispersion coefficient" greatly overestimates the thermal dispersion in the vicinities of the power plants and it tends to underestimate the overall thermal impact on the estuary.

3. Unrealistic excess-temperature formulation. The general development of the models is based on an excess-temperature formulation which inherently assumes all important thermal phenomena to be linear. The critically important thermal effects of recirculation and thermal interaction between the power plants due to reversing tidal flow conditions cannot be considered as linear phenomena. Hence, the results of the steady-state excess-temperature models do not represent the actual conditions in the estuary.

Considering the present state of the art in the mathematical modeling of the thermal conditions in rivers and estuaries, these simple models⁴⁻⁶ could not be considered as reliable for the assessment of the thermal impact of power plant operations in the Hudson River.

A relatively simple, but physically more realistic, tidal-transient one-dimensional model was developed by Siman-Tov¹⁰ for the far-field thermal impact analysis of the power plants on the Hudson River as a part of the environmental statement related to operation of Indian Point Nuclear Generating Plant Unit No. 3 for the U.S. Nuclear Regulatory Commission. This model considered actual temperature distributions along the river for the natural "clean river" conditions and also for the power plant operational conditions to realistically determine the actual excess-temperature distributions representative of the thermal impact on the river. The results of this study¹⁰ indicated that the overall thermal impact resulting from the thermal interaction between the power plants could reach 4°F - 6°F excess temperatures in the river for low freshwater flow conditions (4000 cfs), depending on the assumed values for the surface heat transfer coefficients. The study¹⁰ concluded that the overall thermal impact of the proposed power plant operations with once-through cooling water systems will indeed exceed the thermal standards applicable to the water quality conditions in the Hudson River. Although this model is physically more realistic than the previously employed simple models,⁴⁻⁶ it also includes the following simplifying assumptions which could result in uncertainties in the prediction of the thermal impact:

1. Uniform channel geometry assumption. The model assumes that the cross-section geometry characteristics of the entire river are uniform and identical to the geometry characteristics of the channel at Indian Point.

2. Simplistic tidal flow assumption. The model assumes a simple harmonic form for the tidal flow conditions in the river without tidal lag variations along the river. This assumption results in input flow conditions to the model which are not accurate representations of the actual tidal flows in the estuary.

3. Uncertainty in the values of the "dispersion coefficient." The problems associated with the determination of the longitudinal thermal turbulent transport in the estuary were not resolved. Since the study considered simulations within the tidal cycle, the tidal-averaged values of the longitudinal dispersion coefficient were not applicable in the formulation of the model.

The above-stated weaknesses of the model¹⁰ could lead to uncertainties in the prediction of the overall thermal impact of power plant operations on the Hudson River. However, since the model includes the unsteady thermal conditions in the river, the approximate representations of the reversing tidal flow conditions, and the correct determination of the plant-induced excess-temperature distributions based on "clean river" conditions, it is clearly a more advanced state-of-the-art model than the previously employed simplistic models.⁴⁻⁶ The criticisms of the model¹⁰ in refs. 11 and 12 are not warranted in view of the uncertainties and indeed errors which are inherent in the formulations of the other simple models.⁴⁻⁶

Preliminary discussions of new tidal-transient one-dimensional multi-layer hydrodynamic, thermal, and salinity models were recently presented by Consolidated Edison Company^{13,14} with reference to the reports by Goericke et al.^{15,16} The applications of the models were limited to only a 56-mile section of the Hudson River which included the Indian Point, Lovett, and Bowline power plants. Based on the available limited descriptions of their mathematical formulations,^{13,14} it can be concluded that the models approximately incorporate most of the important hydrodynamic and thermal phenomena which control the far-field thermal impact of power plant operations on the Hudson River.

The critical problem of the longitudinal turbulent transport phenomenon was not resolved in these models. In the very limited applications of the models to the simulations of the salinity conditions in the estuary, the necessary values for the coefficients for the dispersion model were determined by trial and error. Furthermore, the variations based on salinity distributions were presented only for two constant freshwater flow rates (7000 cfs and 12,500 cfs) for periods of "four or more tidal cycles to determine the trends in the redistribution of salinity."¹⁴ The presently available results from these applications¹⁴ do not indicate that the new models are more accurate and reliable than the previously employed mathematical model developed by Thatcher and Harleman¹⁷ for the simulations of the salinity conditions in the Hudson River.

In conclusion, the most important and critical problem which is common to all previously employed far-field models for the Hudson River is that none of the mathematical models was ever validated based on field-measured temperature data for any reasonable period of simulation in the estuary. Hence, from pragmatic considerations, none of the aforementioned mathematical models can be classified as a reliable far-field model for the assessment of the overall thermal impact of power plant operations on the Hudson River.

3.4.2 Summary of the computational features of the ESTONE far-field model

The fast-transient (tidal-transient) one-dimensional mathematical model^{1,2} for the simulation of hydrodynamic, thermal, and salinity conditions in tidal estuaries and controlled rivers consists of the following discrete-element formulations of the governing physical principles:

Surface elevation equation (conservation of mass)

$$\begin{aligned}
 \frac{\partial \bar{H}_i}{\partial t} = & \frac{1}{\Delta x_i \bar{B}_{srf;i}} (\bar{G}_{x;i-1/2} - \bar{G}_{x;i+1/2}) + \frac{\delta_{int,m;i}}{\Delta x_i \bar{B}_{srf;i}} \bar{G}_{int,m} \\
 & + \frac{\delta_{dis,m;i}}{\Delta x_i \bar{B}_{srf;i}} \bar{G}_{dis,m} + \left(1 + \frac{\bar{A}_{drn;i}}{\Delta x_i \bar{B}_{srf;i}} \right) \bar{G}_{rnf} \\
 & + \frac{\delta_{srm,n;i}}{\Delta x_i \bar{B}_{srf;i}} \bar{G}_{srm,n;i} + \frac{1}{\Delta x_i \bar{B}_{srf;i}} \bar{G}_{grd;i} , \quad (3.1)
 \end{aligned}$$

where

$\bar{H}_i$ = surface elevation in the discrete element relative to an arbitrarily specified mean water surface level,

Δx_i = length of the discrete element along the curvilinear direction of the estuary,

$\bar{G}_{x;i\pm 1/2}$ = flow rates at the upstream and downstream enclosure surfaces of the discrete element,

$\bar{B}_{srf;i}$ = lateral surface width of the discrete element,

- $\bar{G}_{\text{int},m}$ = intake flow rate of the power plant m,
 $\bar{G}_{\text{dis},m}$ = discharge flow rate of the power plant m,
 $\bar{A}_{\text{drn},i}$ = drainage area for the discrete element,
 $\bar{g}_{\text{rnf}}$ = rainfall rate per unit area,
 $\bar{G}_{\text{srm},n,i}$ = flow rate from stream (tributary) n into the discrete element,
 $\bar{G}_{\text{grd},i}$ = groundwater flow rate into the discrete element,

and $\delta_{\text{int},m,i}$, $\delta_{\text{dis},m,i}$, $\delta_{\text{srm},m,i}$ represent the Kronecker deltas (flags) indicating the location of the flow rates relative to the discrete element.

Flow rate equations (second law of motion along axial direction)

$$\begin{aligned}
 \frac{\partial \bar{G}_{x,i\pm 1/4}}{\partial t} = & \pm \frac{2}{\Delta x_i} (\bar{G}_{x,i} \tilde{V}_{x,i} - \bar{G}_{x,i\pm 1/2} \tilde{V}_{x,i\pm 1/2}) \\
 & \pm \frac{2g_c}{\Delta x_i} \left[\bar{A}_i (\bar{H}_i - \bar{H}_{i\pm 1/4}) - \bar{A}_{i\pm 1/2} (\bar{H}_{i\pm 1/2} - \bar{H}_{i\pm 1/4}) \right] \\
 & \pm \frac{2}{\Delta x_i} \left[(\bar{G}_{x,i}^* - \bar{G}_{x,i\pm 1/2}^*) + \bar{F}_{\text{bot},x,i\pm 1/4} \right] \\
 & + \frac{\delta_{\text{int},m,i}}{\Delta x_i} \bar{G}_{\text{int},m} \tilde{V}_{\text{int},x,m,i} + \frac{\delta_{\text{dis},m,i}}{\Delta x_i} \bar{G}_{\text{dis},m} \tilde{V}_{\text{dis},x,m} \\
 & + \bar{B}_{\text{srf},i\pm 1/4} \bar{g}_{\text{rnf}} \left(\bar{V}_{\text{rnf},x} + \frac{\bar{A}_{\text{drn},i}}{\bar{B}_{\text{srf},i\pm 1/4} \Delta x_i} \bar{V}_{\text{drn},x,i} \right) \\
 & + \bar{f}_{\text{srf},x,i\pm 1/4} + \frac{\delta_{\text{srm},n,i}}{\Delta x_i} \bar{G}_{\text{srm},n,i} \tilde{V}_{\text{srm},x,n,i} \\
 & + \frac{1}{\Delta x_i} \bar{G}_{\text{grd},i} \tilde{V}_{\text{grd},x,i} ,
 \end{aligned} \tag{3.2}$$

where

$\bar{G}_{x;i\pm 1/4}$ = flow rates at two intermediate points upstream and downstream of the center of the discrete element,

$\tilde{V}_{x;i}$ = upwind differenced value of the axial velocity at the center of the discrete element,

$\tilde{V}_{x;i\pm 1/2}$ = upwind differenced values of the axial velocity at the upstream and downstream enclosure surfaces of the discrete element,

$\bar{A}_i$ = cross-section area at the center of the discrete element,

$\bar{A}_{i\pm 1/2}$ = cross-section areas at the upstream and downstream enclosure surfaces of the discrete element,

$\bar{H}_{i\pm 1/4}$ = surface elevations at two intermediate points upstream and downstream of the center of the discrete element,

$\bar{G}_{x;i}^*$ = momentum convection-defect transport rate across the cross section at the center of the discrete element,

$\bar{G}_{x;i\pm 1/2}^*$ = momentum convection-defect transport rate across the upstream and downstream enclosure surfaces of the discrete element,

$\bar{F}_{bot,x;i\pm 1/4}'$ = bottom friction force values at two intermediate points upstream and downstream of the center of the discrete element,

$\tilde{V}_{int,x,m;l}$ = upwind differenced value of the axial velocity at the intake of power plant m in the discrete element,

$\tilde{V}_{dis,x,m}$ = axial velocity at the discharge of the power plant m ,

$\bar{V}_{mf;x}$ = axial velocity of rainfall,

$\bar{V}_{dm;x;i}$ = axial velocity of drainage flow in the discrete element,

$\bar{f}_{srf;x\pm 1/4}'$ = surface shear stress at two intermediate points upstream and downstream of the center of the discrete element,

$\tilde{V}_{srm,x,n;i}$ = upwind differenced value of the axial velocity of the stream (tributary) flow into the discrete element,

$\tilde{V}_{grd,x;i}$ = upwind differenced value of the axial velocity of groundwater flow into the discrete element.

- $\bar{T}_{\text{rnf}}$ = temperature of the rainfall,
 $\bar{T}_{\text{drn}}$ = temperature of the drainage flow,
 $\bar{q}_{\text{srf};i}$ = net surface heat transfer flux,
 $\tilde{T}_{\text{srm},n;i}$ = upwind differenced value of temperature of the stream (tributary) flow into the discrete element,
 $\tilde{T}_{\text{grd};i}$ = upwind differenced value of the groundwater flow into the discrete element.

The particular discrete-element equation (3.3) of the conservation of thermal energy can be considered as the "intrinsic form," which is distinctly different from the classical finite-difference and finite-element formulations in "conservative" or "nonconservative" forms of the energy equation (see ref. 1).

Salinity concentration equation (conservation of salt mass)

$$\begin{aligned}
 \frac{\partial \bar{C}_{s;i}}{\partial t} = & \frac{1}{\Delta x_i \bar{A}_i} \left[\bar{G}_{x,i-1/2} (\tilde{C}_{s,i-1/2} - \bar{C}_{s;i}) - \bar{G}_{x,i+1/2} (\tilde{C}_{s,i+1/2} - \bar{C}_{s;i}) \right] \\
 & + \frac{1}{\Delta x_i \bar{A}_i} (\bar{G}'_{s,x;i-1/2} - \bar{G}'_{s,x;i+1/2}) \\
 & + \frac{\delta_{\text{int},m;i}}{\Delta x_i \bar{A}_i} \bar{G}_{\text{int},m} (\tilde{C}_{s,\text{int},m;i} - \bar{C}_{s;i}) \\
 & + \frac{\delta_{\text{dis},m;i}}{\Delta x_i \bar{A}_i} \bar{G}_{\text{dis},m} (\bar{C}_{s,\text{dis},m;i} - \bar{C}_{s;i}) \\
 & + \frac{\bar{B}_{\text{srf};i}}{\bar{A}_i} \bar{g}_{\text{rnf}} \left[(\bar{C}_{s,\text{rnf}} - \bar{C}_{s;i}) + \frac{\bar{A}_{\text{drn};i}}{\Delta x_i \bar{B}_{\text{srf};i}} (\bar{C}_{s,\text{drn}} - \bar{C}_{s,i}) \right] \\
 & + \frac{\delta_{\text{srm},n;i}}{\Delta x_i \bar{A}_i} \bar{G}_{\text{srm},n;i} (\tilde{C}_{s,\text{srm},n;i} - \bar{C}_{s;i}) \\
 & + \frac{1}{\Delta x_i \bar{A}_i} \bar{G}_{\text{grd};i} (\tilde{C}_{s,\text{grd};i} - \bar{C}_{s;i}) , \tag{3.4}
 \end{aligned}$$

The particular formulation of the momentum equation (3.2) considers two locations for the evaluation of the flow rates $\bar{G}_{x;i\pm 1/4}$ in the discrete element. The mathematical advantages of this new formulation, which is distinctly different from the classical staggered mesh formulations,^{18,19} are discussed in ref. 1 with particular emphasis on the consequences of the physical stability properties in relation to the mathematical stability of the numerical solutions.

Temperature equation (conservation of thermal energy)

$$\begin{aligned}
 \frac{\partial \bar{T}_i}{\partial t} = & \frac{1}{\Delta x_i \bar{A}_i} \left[\bar{G}_{x;i-1/2} (\tilde{T}_{i-1/2} - \bar{T}_i) - \bar{G}_{x;i+1/2} (\tilde{T}_{i+1/2} - \bar{T}_i) \right] \\
 & + \frac{1}{\Delta x_i \bar{A}_i} (\overline{Q'_{x;i-1/2}}^* - \overline{Q'_{x;i+1/2}}^*) \\
 & + \frac{\delta_{int,m;i}}{\Delta x_i \bar{A}_i} \bar{G}_{int,m} (\tilde{T}_{int,m;i} - \bar{T}_i) + \frac{\delta_{dis,m;i}}{\Delta x_i \bar{A}_i} \bar{G}_{dis,m} (\bar{T}_{dis,m;i} - \bar{T}_i) \\
 & + \frac{\bar{B}_{orf,i}}{\bar{A}_i} \bar{g}_{rnf} \left[(\bar{T}_{rnf} - \bar{T}_i) + \frac{\bar{A}_{drn,i}}{\Delta x_i \bar{B}_{srf,i}} (\bar{T}_{drn} - \bar{T}_i) \right] + \frac{\bar{B}_{orf,i}}{\rho_w \bar{c}_w \bar{A}_i} \bar{q}_{srf,i} \\
 & + \frac{\delta_{srm,n;i}}{\Delta x_i \bar{A}_i} \bar{G}_{srm,n,i} (\tilde{T}_{srm,n,i} - \bar{T}_i) + \frac{1}{\bar{A}_i} \bar{g}_{grd,i} (\tilde{T}_{grd,i} - \bar{T}_i), \quad (3.3)
 \end{aligned}$$

where

$\bar{T}_i$ = temperature in the discrete element,

$\tilde{T}_{i\pm 1/2}$ = upwind differenced values of temperature on the upstream and downstream enclosure surfaces of the discrete element,

$\overline{Q'_{x;i\pm 1/2}}^*$ = net nonconvective thermal transport rates across the upstream and downstream enclosure surfaces of the discrete element,

$\tilde{T}_{int,m;i}$ = upwind differenced value of the temperature at the intake of the power plant m in the discrete element,

$\bar{T}_{dis,m;i}$ = temperature at the discharge of the power plant m in the discrete element,

where

- $\bar{C}_{s,i}$ = salinity (salt concentration) in the discrete element,
- $\tilde{C}_{s,i\pm 1/2}$ = upwind differenced values of salinity on the upstream and downstream enclosure surfaces of the discrete element,
- $\overline{G}_{s,x,i\pm 1/2}^*$ = net nonconvective salt transport rates across the upstream and downstream enclosure surfaces of the discrete element,
- $\tilde{C}_{int,m;i}$ = upwind differenced value of the salinity at the intake of the power plant m in the discrete element,
- $\bar{C}_{dis,m;i}$ = salinity at the discharge of the power plant m in the discrete element,
- $\bar{C}_{s,rnf}$ = salinity of the rainfall,
- $\bar{C}_{s,drn}$ = salinity of the drainage flow,
- $\tilde{C}_{s,srm,n;i}$ = upwind differenced value of salinity of the stream (tributary) flow into the discrete element,
- $\tilde{C}_{s,grd;i}$ = upwind differenced value of the groundwater flow into the discrete element.

Again, the particular discrete-element equation (3.4) of the principle of the conservation of salt mass can be considered as the "intrinsic form," which is distinctly different from the classical formulations (see ref. 1). The present tidal-transient one-dimensional discrete-element model approximately considers the lateral and vertical variations of the flow variables according to rigorous formulations of the transport fluxes from the basic three-dimensional forms as:

$$\begin{aligned} v_x(t, t', x, y, z) &= \bar{V}_x(t, x) + \overline{v_x^*}(t, x, y, z) + v_x'(t', x, y, z) , \\ C_s(t, t', x, y, z) &= \bar{C}_s(t, x) + \overline{C_s^*}(t, x, y, z) + C_s'(t', x, y, z) , \\ T(t, t', x, y, z) &= \bar{T}(t, x) + \overline{T^*}(t, x, y, z) + T'(t', x, y, z) , \end{aligned} \quad (3.5)$$

where $\bar{V}_x(t,x)$, $\bar{T}(t,x)$, and $\bar{C}_s(t,x)$ are mean time-averaged and cross-section-averaged principal variables of formulation; $\bar{V}^*(t,x,y,z)$, $\bar{T}^*(t,x,y,z)$, and $\bar{C}_s^*(t,x,y,z)$ are differences between mean time-averaged distributions and cross-section-averaged principal variables; and $V'_x(t',x,y,z)$, $T'(t',x,y,z)$, and $C'_s(t',x,y,z)$ are high-frequency random turbulent fluctuations.

The general expressions in Eq. (3.5) are approximated as self-similar three-dimensional distributions according to linear dependence on depth (see ref. 1) along the lateral direction for all flow variables. The vertical distribution for the velocity is approximated by the power law turbulent profile (e.g., Blasius form with $n = 8$), and the vertical distributions of temperature and salinity are assumed as cubic variations, i.e.,

Axial velocity (Blasius $n = 8$ power law)

$$v_x(t,x,y,z) = \bar{V}_x(t,x) + \bar{V}_x(t,x) \left[\left(\frac{n+1}{n} \right) \frac{\bar{A}}{\bar{B}_{\text{srf}} \langle D^2 \rangle} D(y) (1 - \eta)^{1/n} - 1 \right] + u'(t',x,y,z) \quad (3.6)$$

Temperature distribution (cubic vertical profile)

$$T(t,x,y,z) = \bar{T}(t,x) + \frac{\Delta T_{\text{max}}^* \bar{B}_{\text{srf}} \langle D^2 \rangle}{\bar{A} D_{\text{max}}^*} \left[1 - \frac{2\bar{A}}{\bar{B}_{\text{srf}} \langle D^2 \rangle} D(y) (3\eta^2 - 2\eta^3) \right] + T'(t',x,y,z) \quad (3.7)$$

Salinity concentration distribution

$$C_s(t,x,y,z) = \bar{C}_s(t,x) - \frac{\Delta C_{s,\text{max}}^* \bar{B}_{\text{srf}} \langle D^2 \rangle}{2\bar{A} D_{\text{max}}^*} \left[1 - \frac{2\bar{A}}{\bar{B}_{\text{srf}}} D(y) (3\eta^2 - 2\eta^3) \right] + C'(t',x,y,z) \quad (3.8)$$

It is interesting to note that the present formulations of the approximate three-dimensional effects for flow variables include the second-order moment of depth $\langle D^2 \rangle$ over the cross-section area, indicating the importance of the detailed geometrical characteristics of the estuary channel.

The nonconvective transport model of the present formulation is based on rigorous mathematical considerations of the transport integrals over the cross-sectional areas of the discrete elements according to the general representations of the surface-integral terms of the physical principles. The mathematical formulation of the nonconvective transport model possesses certain novel features which are different from other existing one-dimensional models (e.g., ref. 17), namely:

1. Model does not require different friction coefficient values (e.g., Manning's parameter) for different sections of different estuaries and/or rivers. A universal value for the friction coefficient $\beta \approx 0.2$ can be used for all estuaries and rivers with reasonably similar morphological conditions which control the frictional drag effects. Convection-defect transport and the detailed geometrical characteristics of the cross sections are explicitly incorporated in the formulation.

2. Model does not employ any other coefficient associated with the turbulent transport phenomena. Questionable longitudinal dispersion coefficients which require different values for different sections of different estuaries and/or rivers are completely avoided in the formulation.

The final terms of the various transport terms of the one-dimensional computer simulation model, Eqs. (3.1) - (3.3), are:

Bottom friction force

$$\overline{F}_{\text{bot}} = \left(\frac{n+1}{n} \right) \left[\frac{\langle D^{2(n-1)/(n+1)} \rangle}{\overline{B}_{\text{srf}} \langle D^2 \rangle} \right] \overline{G}_x^{2n/(n+1)} \quad (3.9)$$

Momentum convection defect transport rate

$$\overline{G_x^*} = \iint_A \overline{v_x^*} \overline{v_x^*} dA = - \left[1 - \left(\frac{n+1}{n} \right)^2 \left(\frac{n}{n+2} \right) \frac{\langle D^3 \rangle \overline{A}}{\overline{B}_{\text{srf}} \langle D^2 \rangle^2} \right] \frac{\overline{G}^2}{\overline{A}} \quad (3.10)$$

Thermal nonconvective transport rate

$$\overline{Q_x'^*} = \overline{Q_x^*} + \overline{Q_x'} \quad (3.11)$$

Thermal convection defect transport rate

$$\begin{aligned} \overline{Q_x^*} &= \iint_A \overline{v_x^*} \overline{T^*} dA \\ &= \Delta T_{\text{max}}^* \frac{\overline{B}_{\text{srf}} \langle D^2 \rangle}{2 \overline{A} \overline{D}_{\text{max}}^*} \left[1 - \frac{12n^2}{(4n+1)(3n+1)} \left(\frac{\overline{A} \langle D^3 \rangle}{\overline{B}_{\text{srf}} \langle D^2 \rangle^2} \right) \right] \overline{G} \end{aligned} \quad (3.12)$$

Thermal turbulent transport rate

$$\overline{Q_x'} = \overline{E_1'^*} \frac{\partial \overline{T}}{\partial x} + \overline{E_2'^*} \frac{\partial \overline{F}_{1,T}}{\partial x} - \overline{E_2'^*} \frac{\partial \overline{F}_{2,T}}{\partial x}, \quad (3.13)$$

$$\begin{aligned} \overline{E_1'^*} &= \overline{\epsilon}_{\text{res}} + \frac{n^3}{(3n-1)(2n-1)} \left(\frac{n+1}{n} \right)^{(n-1)/(n+1)} \frac{2n/(n+1)}{\beta} \frac{2/(n+1)}{\nu} \\ &\quad \left[\frac{\overline{B}_{\text{srf}}^{2/(n+1)} \langle D^{(3n-1)/(n+1)} \rangle}{\langle D^2 \rangle^{(n-1)/(n+1)}} \right] \overline{G}^{(n-1)/(n+1)}, \end{aligned} \quad (3.14)$$

$$\begin{aligned} \overline{E_2'^*} &= \overline{\epsilon}_{\text{res}} + \frac{6n^5(10n-3)}{(6n-1)(5n-1)(4n-1)(3n-1)(2n-1)} \left(\frac{n+1}{n} \right)^{(n-1)/(n+1)} \frac{2n/(n+1)}{\beta} \frac{2/(n+1)}{\nu} \\ &\quad \left[\frac{\overline{B}_{\text{srf}}^{2/(n+1)} \langle D^{4n/(n+1)} \rangle}{\langle D^2 \rangle^{(n-1)/(n+1)}} \right] \overline{G}^{(n-1)/(n+1)}, \end{aligned} \quad (3.15)$$

where

$$\bar{F}_{1,T} = \frac{\bar{B}_{\text{srf}} \langle D^2 \rangle}{2 \bar{D}_{\text{max}}^* \bar{A}} \Delta T_{\text{max}}^* , \quad \bar{F}_{2,T} = \frac{\Delta T_{\text{max}}^*}{D_{\text{max}}^*} . \quad (3.16)$$

Salinity convection defect transport rate

$$\begin{aligned} \bar{C}_{\text{sx}}^* &= \iint_A \bar{v}_x^* \bar{C}_s^* dA \\ &= - \Delta C_{s,\text{max}}^* \frac{\bar{B}_{\text{srf}} \langle D^2 \rangle}{2 \bar{A} D_{\text{max}}^*} \left[1 - \frac{12n^2}{(4n+1)(3n+1)} \left(\frac{\bar{A} \langle D^3 \rangle}{\bar{B}_{\text{srf}} \langle D^2 \rangle^2} \right) \bar{G} \right] \end{aligned} \quad (3.17)$$

Salinity turbulent transport rate

$$\bar{G}_{s,x}' = \bar{E}_1'^* \frac{\partial \bar{C}_s}{\partial x} - \bar{E}_2'^* \frac{\partial \bar{F}_{1,s}}{\partial x} + \bar{E}_2'^* \frac{\partial \bar{F}_{2,s}}{\partial x} , \quad (3.18)$$

$$T_{\text{max}}^* = \frac{(\bar{T} - T_{\text{ref}}^*) \bar{D}}{(1 + a F_r^b) D_{\text{ref}}^*} , \quad C_{s,\text{max}}^* = \frac{(\bar{C}_s - C_{s;\text{ref}}^*) \bar{D}}{(1 + a F_r^b) D_{\text{ref}}^*} , \quad (3.19)$$

where

F_r = local densimetric Froude number based on local temperature and salinity conditions.

The detailed derivations of these nonconvective transport terms, Eqs. (3.9) - (3.19), are presented in ref. 1.

It is interesting to note that the present mathematical model explicitly considers the effects of three-dimensional distributions of flow variables on the overall transport along the estuary as "convection-defect transport rates" in the one-dimensional formulation of the model. These terms represent another novel feature of the present model which completely avoids the specification of dispersion coefficients.

The present fast-transient (tidal-transient) one-dimensional model and its associated computer code ESTONE represent the most advanced one-dimensional models for simulating hydrodynamic, thermal, and water quality conditions (with proper modifications) in estuaries and controlled rivers.

The special formulation of the one-dimensional model approximately considers both vertical and lateral variations for velocity, temperature, and salinity; hence, the computer simulations also generate three selected local values for both temperature and salinity conditions as (1) cross-section area average value, (2) surface value, and (3) bottom value (at maximum depth).

The numerical results can be obtained accurately for any specified temporal and/or spatial resolution for any period of time, depending only on the cost limitations of the computer run times.

In the application of the far-field model ESTONE to the simulation of the tidal-transient one-dimensional physical conditions in the Hudson River, 76 discrete elements were considered along the estuary. The total length of the river between the Troy Dam and the Battery was assumed as approximately 152 miles, and the curvilinear length of the discrete element was selected as approximately 2 miles along the river. Hence, the distributions of the physical conditions from the computer simulations were accurate to 2-mile spatial resolution.

The numerical solutions employed a time step of 0.0625 hr (225 sec) according to the stability criterion of the ESTONE model based on the maximum depth in the Hudson River. The computed results were stored at every 16-time-step interval. Hence, the 1-hr temporal resolution was obtained for the complete six-month simulation periods in 1973 and 1974. The daily-averaged conditions were obtained from the high temporal resolution of stored hourly values for the presentation of the results of the analysis.

3.4.3 Input data for the far-field model ESTONE

The mathematical formulation and the structure of the computer code ESTONE are specifically designed to simulate realistically the conditions in estuaries and rivers based on accurate, detailed input data. In the applications of the model, the necessary data can be supplied to the model at any desired temporal and spatial accuracy, without requiring assumptions to restrict the input variables to uniform values.

The simulation of the physical conditions in the Hudson River requires input data for the geometrical characteristics of the channel, the freshwater flow conditions at the Troy Dam, the tidal conditions at the Battery, the freshwater flow through the major tributaries and drainage areas along the estuary, atmospheric conditions, and intake and discharge flow conditions at the power plants. In the applications of the model ESTONE, the necessary data for 1973 and 1974 were obtained from numerous different sources in different formats. The different sets of information were analyzed, reduced, and reformulated into the special formats required by the model for the input data.

3.4.3.1 Geometrical characteristics of the river channel. The geometry input data to the thermal models were determined from the bathymetry information on the U.S. Coast and Geodetic Survey (USCGS) Navigational Charts Nos. 282, 283, 284, 745, and 746 for the Hudson River.²⁰ The cross-section profiles were obtained from the charts by taking transects at 2-mile intervals starting at Troy Dam with cross section No. 1 and ending at the Battery with cross section No. 77. The longitudinal axis of the river was assumed to be at the middle of the deepest part of each cross section, with the negative lateral locations corresponding to the left bank of the river, looking downstream from Troy toward the Battery.

The detailed actual profiles of the cross sections were approximated by straight line segments to minimize the computational effort in the applications of the models. Two comparisons of the detailed channel profiles and the approximated input data to the ESTONE model are presented in Fig. 3.4.1 for a typical relatively symmetric wide and deep cross section and also for a typical cross section at a transect with relatively large shoal area along one bank with the deep main channel near the other bank.

The approximated profiles for all 77 transect cross sections of the Hudson River at 2-mile intervals are presented in Appendix A, according to the format of the input data to the far-field model ESTONE.

3.4.3.2 Upstream end conditions at the Troy Dam. The Hudson River estuary is bounded on the northern end by the dam at Troy. During the six months of simulations for 1973 and 1974, the flow entering the estuary at the dam constituted 60 to 85% of the total fresh water entering the estuary.

The flow rates used as input to the model were obtained from measurements taken at Green Island by the United States Geological Survey (USGS).^{21,22} The Green Island gaging station is just upstream from the Troy lock and dam, and the flows given for Green Island represent flow over the spillway, through the lock, and through the power plant at the dam, i.e., the total fresh-water flow of the Hudson River entering the upper end of the estuary. All flow rates are given as daily, monthly, and yearly averages. Table 3.4.1 lists monthly average flow rates of the Hudson River at Green Island for the 1973 and 1974 simulation periods. The accuracy of the flow rates are described in terms of "excellent," "fair," and "poor" defined as follows (ref. 21, p. 12):

The station description under "REMARKS" states the degree of accuracy of the records. "Excellent" means that about 95 percent of the daily discharges are within 5 percent; "good" within 10 percent, and "fair" within 15 percent. "Poor" means that daily discharges have less than "fair" accuracy.

In the application of the model ESTONE daily averaged flow rates were employed directly as input data for freshwater flow at the Troy Dam.

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Fig. 3.4.1. Comparisons of detailed actual profiles and approximated input data to ESTONE model for two typical cross sections along the Hudson River. Actual profiles from U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, C&GS Charts Nos. 282, 283, 284, 745, 746.

Table 3.4.1. Monthly-averaged freshwater flow rates
at the Green Island station

Month	Flow rate (cfs)	
	1973	1974
April	30,960	30,170
May	27,600	22,260
June	13,050	8,791
July	10,390	11,780
August	5,591	6,359
September	4,791	10,390

Sources: U.S. Geological Survey, "1973 Water Resources Data for New York. Part 1: Surface Water Records," Albany, N.Y., 1974, p. 79; "1974 Water Resources Data for New York. Part 1: Surface Water Records," Albany, N.Y., 1975, p. 73.

The water temperature of the flow at the Troy Dam was considered on a daily-averaged basis for the six-month simulation periods for 1973 and 1974. The necessary information for two different years was obtained from two different sources.^{23,24} Furthermore, in the preparation of the complete input data for the model ESTONE, the missing records for various periods were approximated by extrapolation and/or interpolation from the available records.

April 1-September 30, 1973, period. The flow rates at the Troy Dam were obtained from the records for Green Island Station,²¹ which were described as "fair" except for August 27 through September 30, 1973, which were "poor."

Daily water temperatures taken above the Troy Dam April 17 through September 30, 1973, were obtained from the U.S. Army Corps of Engineers, Albany Field Office.²³ The temperatures for April 1 through April 16, 1973, which were not available, were estimated by extrapolation of the temperatures which were given for April 17 through April 30.

The input data for the ESTONE model were prepared on a daily-average basis for both the flow rate and the temperature conditions at the Troy Dam for the six months of the 1973 simulation period. A typical set of monthly input data is presented in Fig. 3.4.2 for April 1973.

April 1-September 30, 1974, period. The flow rates at the Troy Dam were obtained from the records for Green Island Station,²² which were described as "fair" for all the days of the six-month simulation period.

Fig. 3.4.2 Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: April 1973.

Daily water temperatures at Troy for April 15 through September 30, 1974, were obtained from USGS data reproduced in "Indian Point Nuclear Generating Station Intensive Thermal Survey Program August and October 1974" (ref. 24, Fig. 4.5.3). The temperatures for April 1 through April 14, 1974, which were not available, were estimated by extrapolation of the temperatures which were given for April 15 through April 30.

A typical set of input data for the daily flow rates and temperature conditions at the Troy Dam is presented in Fig. 3.4.3 for April 1974.

Two complete sets of six-month input data for flow rates and temperature conditions at the Troy Dam for the two simulation periods during 1973 and 1974 are presented in Appendix B.

3.4.3.3 Downstream end conditions at the Battery. The downstream end input data for the ESTONE model require the tidal elevation, temperature, and salinity conditions at the ocean end at the Battery.

The necessary data for the tidal elevation were obtained from the tidal function information in U.S. Department of Commerce Special Publication 98.²⁵ The standard data for tidal prediction functions were converted into the special six-cosine harmonic form used in the ESTONE model in terms of periods, time lags, and amplitudes. The values used in the model for the mean height of water level above the reference datum were based upon measurements of tidal heights at the Battery obtained from the U.S. Department of Commerce, National Oceanic and Atmospheric Association (NOAA).²⁶ The input data for the geometrical characteristics of the cross sections were determined based on a reference low mean water level of 200 ft above the datum used in the simulations. The measurements of tidal heights taken at the Battery by the NOAA were recorded on a scale where 3.15 ft represented the long-term average for mean low water (1941-1959 epoch). The long-term average for mean sea level at the Battery was 2.33 ft above mean low water; hence the tidal heights recorded by NOAA were centered approximately at 5.48 ft on the scale. Therefore, at the Battery, the tidal heights used in the model were centered approximately at 202.33 ft. The reference level of 202.33 ft represented the long-term mean sea level during the six-month simulation periods. The active tidal heights recorded during these periods required corrections to the tidal end condition data as input to the model. Two terms, one covering each of the six-month simulation periods, were used in the model. The terms were calculated to minimize the differences between the individual maxima of the predicting function and the corresponding recorded heights of high tides. Maximum height was used as the determining criterion, since in the model, errors in tidal height are more critical on the high side than on the low side.

The information about the water temperatures at the Battery was also obtained from the NOAA.²⁶ The original data were on a single measurement per day basis. The times of the measurements were arbitrary, with most of the data recorded between 11:00 AM and 1:00 PM. Continuous daily records were not available for the complete durations of the months considered in the simulations. The recorded data were typically limited to 15 to 20

Fig. 3.4.3. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code for April 1974.

days per month. In the preparation of the input data, as daily temperatures at the Battery, for the ESTONE code, the missing records for the temperatures were approximated by interpolating from the existing data.

The salinity conditions at the downstream end could not be obtained directly. The water density data at the Battery were obtained from the NOAA²⁶ both as measured values and also as reduced (15°C) values. The reduced density data were converted into salinity form by employing the simple linear equation of state.²⁷ The available density records at the Battery were measured at the same time and with the same frequency as the temperature records. Hence, it was again necessary to approximate the values for the days with missing data by interpolating and/or extrapolating the available water density data.

April 1-September 30, 1973, period. The six-harmonic form of the input data to the ESTONE model was used to approximate the tidal conditions at the Battery for the 183-day simulation period. The comparisons of the results of the six-harmonic functional predictions and the field-measured data for the minimum tide and the maximum tide conditions during the six-month period are presented in Fig. 3.4.4.

The computed results from the six-harmonic functional form and the field-measured data generally agreed reasonably well for the tidal elevations at the Battery during the 183-day period. The comparisons of the results of the six-harmonic functional predictions and the field-measured data for the best and poorest agreement cases are presented in Fig. 3.4.5.

The agreement between the six-harmonic functional representations and the 1973 field-measured data for the tidal heights at the Battery were generally acceptable (see Figs. 3.4.4 and 3.4.5) as input data to the far-field model ESTONE. A more representative comparison of the six-harmonic functional predictions and the field-measured data are presented in Fig. 3.4.6 for high-high and low-low water levels at the Battery.

The input data for daily water temperatures and salinity conditions at the Battery for the six-month simulation period in 1973 are presented in Fig. 3.4.7. The maximum water temperature at the Battery was approximately 74°F on July 14, and the maximum salinity was approximately 25 parts per thousand on September 30 during the six-month period of 1973 simulations.

April 1-September 30, 1974, simulation periods. The hourly variations of the minimum tide and the maximum tide conditions at the Battery during the six-month period of the 1974 simulations are presented in Fig. 3.4.8 both for six-harmonic functional values and for field-measured data.

The comparisons of the results of the six-harmonic functional predictions and the field-measured data for the best agreement and the poorest agreement cases during the six-month period of 1974 simulations are presented in Fig. 3.4.9 for the tidal conditions at the Battery.

Fig. 3.4.4. Comparisons of six-harmonic functional predictions and field-measured data for minimum tide and maximum tide conditions at the Battery during the period of simulations April 1-September 30, 1973.

Fig. 3.4.5. Comparisons of six-harmonic functional predictions and field-measured data for best agreement and poorest agreement cases for the tidal height at the Battery during the period of simulations April 1-September 30, 1973.

Fig. 3.4.6. Comparisons of six-harmonic functional predictions and field-measured data for high-high water level and low-low water level at the Battery during April 1-September 30, 1973, simulation period.

Fig. 3.4.7. Daily water temperature and salinity conditions at the Battery during April 1–September 30, 1973, simulation period.

The maximum and minimum surface elevations that occurred at the Battery during the six-month period of 1974 simulations are represented as high-high water level and low-low water level values for both six-harmonic functional predictions and field-measured data in Fig. 3.4.10.

The input data for daily water temperatures and salinity conditions at the Battery for the six-month simulation period in 1974 are presented in Fig. 3.4.11.

The maximum temperature at the Battery was approximately 77°F on August 27. Considering that in 1973 the maximum water temperature (74°F) occurred on July 14, there was more than a month difference between the days when the water temperature at the Battery reached its maximum values in 1973 and 1974. The maximum salinity at the Battery during the six-month simulation period was approximately 29 parts per thousand, and this value remained approximately uniform for more than a month during July 15–August 15 in 1974.

The significant differences between 1973 and 1974 values for the variations of temperature and salinity conditions at the Battery were mainly due to the differences in freshwater flow rates in the Hudson River

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Fig. 3.4.8. Comparison of six-harmonic functional predictions and field-measured data for minimum tide and maximum tide conditions at the Battery during the period of simulations April 1-September 30, 1974.

Fig. 3.4.9. Comparison of six-harmonic functional predictions and field-measured data for best agreement and poorest agreement cases for the tidal height at the Battery during the period of simulations April 1-September 30, 1974.

Fig. 3.4.10. Comparisons of six-harmonic functional predictions and field-measured data for high-high water level and low-low water level at the Battery during April 1-September 30, 1974, simulation period.

Fig. 3.4.11. Daily water temperature and salinity conditions at the Battery during April 1-September 30, 1973, simulation period.

during the six months of the two years. The average freshwater flow in the Hudson River during 1973 was a record high. However, the freshwater flow during 1974 was more representative of the normal yearly rates that actually occur in the estuary.

3.4.3.4 Tributary flows along the river. The available information about the freshwater flow rates for 14 major tributaries entering the Hudson River between Troy and the Battery were obtained from the U.S. Geological Survey (USGS) "Water Resources Data for New York."^{21,22} The recorded data about the tributary flow rates were available as daily, monthly, and yearly averages. Estimates of the accuracy of the records for the 14 tributaries were about equally divided between "good" and "fair," according to the definitions as stated in Sect. 3.4.3.2. The locations of the entrance of the 14 tributaries along the Hudson River are shown in Fig. 3.4.12. These tributaries for which data were available contributed about half the total estimated freshwater inflow to the estuary south of Troy.

The input data to the far-field model ESTONE for the tributary flow rates were prepared by considering all the available information about

Fig. 3.4.12. Locations of the entrance of 14 major tributaries along the Hudson River for which flow data were available.

the recorded tributary flows, municipal water supplies, and drainage estimations. The detailed discussions of the analysis and reduction of the tributary flow data are presented in Appendix C. Considering the freshwater inflow contributions from other sources in addition to the flow rates from the major tributaries for which data were available, the cumulative effect of all the freshwater inflow rates were combined into five groups as indicated in Table 3.4.2.

Table 3.4.2. Tributary groups and their selected location of entry into the estuary as input data to ESTONE model

Group number	Tributaries	Estuary entry location in the model	
		Element number	Distance from the Battery (miles)
1	Normans Kill, Moordener Kill, Coeymans Creek Hannacrois Creek	7	139
2	Catskill Creek, Tenmile Creek, Esopus Creek	24	105
3	Rondout Creek, Wallkill River	31	91
4	Casper Creek, Wappinger Creek, Fishkill Creek	44	65
5	Croton River, Sawmill River	50	33

In the simulations of the conditions in the Hudson River for the two six-month periods during 1973 and 1974, daily flow rate values were assigned to each of the five tributary groups based on the information available for the freshwater inflow rates to the estuary.

The input data to the far-field model ESTONE for the water temperature and salinity conditions of the tributary flows could not be determined from the available information. Hence, it was assumed that the temperature of the freshwater inflow from a tributary was equal to the local temperature in the main channel at the entrance of the tributary to the estuary. It was further assumed that the total of all the tributary flows (excluding the Green Island flow at the Troy Dam) was less than approximately 40% of the total freshwater flow in the river. The effects of these simplifying assumptions on the values of the input data for the temperature and salinity conditions of the tributary flows were not expected to be substantial in the simulation of the conditions in the estuary.

April 1-September 30, 1973, period. The sum of all the gaged monthly-averaged freshwater flow rates entering the estuary and the estimated total monthly-averaged freshwater discharge at the Battery for the six-month period of simulation in 1973 is presented in Table 3.4.3.

Table 3.4.3. Estimated monthly-averaged freshwater discharge at the Battery and the sum of all gaged monthly-averaged tributary flow rates during April 1-September 30, 1973

Month	Estimated freshwater discharge at the Battery (cfs)	Sum of Green Island and gaged tributary flows (cfs)
April	51,100	40,589
May	43,900	35,391
June	22,400	17,188
July	20,800	14,774
August	8,780	7,130
September	5,920	5,277

Source: U.S. Department of the Interior, Water Resources Division, New York District.

The flow at Green Island was considered separately as the flow rate end condition at the Troy Dam (see Sect. 3.4.2.2). The monthly-averaged flow rates of the 14 major tributaries for which data were available are presented in Table 3.4.4 for the six-month period of simulations in 1973.

The available daily freshwater flow information for the 14 tributaries was combined into tributary groups (see Appendix C) for the six-month simulation period in 1973. Two typical cases of the input data to the ESTONE model for the freshwater inflow from the combined tributary groups are presented in Fig. 3.4.13 for April and May 1973.

April 1-September 30, 1974, period. The sum of all the gaged monthly-averaged freshwater flow rates entering the estuary and the estimated total monthly-average freshwater discharge at the Battery for the six-month period of simulation in 1974 is presented in Table 3.4.5.

Table 3.4.4. Monthly-averaged flow rates of the 14 major tributaries during the simulation period April 1-September 30, 1973

Tributary	Confluence model element	Location (miles from the Battery)	Monthly-average discharge (cfs)					
			April	May	June	July	August	September
Normans Kill	5	142	456	350	159	126	36	24
Moordener Kill	8	137	84	84	38	23	16	8
Coeymans Creek	10	133	152	107	73	68	21	3
Hannacrois Creek	11	131	211	158	57	107	10	1
Catskill Creek	20	113	353	298	145	76	17	3
Tenmile Creek	20	113	132	101	75	37	15	2
Esopus Creek	26	126	1602	1399	544	747	226	54
Rondout Creek	31	91	1541	1293	935	500	464	109
Wallkill River	31	91	2942	2539	1405	1347	484	200
Casper Creek	42	69	43	28	19	20	6	3
Wappinger Creek	43	67	674	517	416	620	161	50
Fishkill Creek	47	59	236	150	87	168	33	14
Croton Creek	59	35	1103	700	145	506	26	2
Sawmill River	67	19	100	67	40	39	24	14
Total			9629	7791	4138	4384	1539	487

Table 3.4.5. Estimated monthly-averaged freshwater discharge at the Battery and the sum of all gaged monthly-averaged tributary flow rates during April 1-September 30, 1974

Month	Estimated freshwater discharge at the Battery (cfs)	Sum of Green Island and gaged tributary flows (cfs)
April	48,500	39,805
May	30,600	25,939
June	12,000	10,295
July	14,500	12,965
August	7,830	7,027
September	14,600	12,263

Source: U.S. Department of the Interior, Water Resources Division, New York District

The monthly-averaged flow rates for the 14 major tributaries for which data were available are presented in Table 3.4.6 for the six-month simulation period in 1974.

Two typical cases of the input data to the ESTONE model for the daily-averaged inflow from the combined tributary groups are presented in Fig. 3.4.14 for April and May 1974.

The reduced data for the monthly variations of the daily-averaged inflow from all combined tributary groups are presented in Appendix C for both six-month simulation periods during 1973 and 1974 in the format of the input data to the far-field model ESTONE.

3.4.3.5 Estuary surface conditions. The tidal-transient one-dimensional far-field model ESTONE considers fast-transient mass and heat transfer conditions at the estuary surface. Since the simulations by the ESTONE code are accurate to better than hourly temporal resolutions, the surface heat transfer model does not consider the classical thermal equilibrium concepts.

The general formulation of the surface conditions in the far-field model ESTONE considers mass transport due to rainfall, momentum transport due to rainfall and wind effects, and the fast-transient variations of surface heat transfer based on normal solar radiation, back radiation, evaporation, and convection modes. The input data to the model can be directly obtained from the climatological information about the geographical region.

Table 3.4.6. Monthly-averaged flow rates of the 14 major tributaries during the simulation period April 1-September 30, 1974

Tributary	Confluence model element	Location (miles from the Battery)	Monthly-average discharge (cfs)					
			April	May	June	July	August	September
Normans Kill	5	142	284	141	72	156	48	140
Moordener Kill	8	137	87	57	20	19	8	27
Coeymans Creek	10	133	120	68	17	40	3	12
Hannacrois Creek	11	131	154	71	11	28	1	5
Catskill Creek	20	113	355	126	23	99	19	69
Tenmile Creek	20	113	134	58	23	72	6	21
Esopus Creek	26	126	1745	651	203	162	52	152
Rondout Creek	31	91	1165	650	330	211	209	523
Wallkill River	31	91	2683	1011	552	269	237	692
Casper Creek	42	69	31	14	10	8	6	7
Wappinger Creek	43	67	668	281	114	88	52	157
Fishkill Creek	47	59	215	108	42	24	12	27
Croton River	59	35	1024	410	71	1	1	1
Sawmill River	67	19	70	33	17	8	14	40
Total			8735	3679	1505	1185	668	1873

Fig. 3.4.13. Freshwater flow rate of tributary group 3 (Rondout Creek, Wallkill River) as input data to the ESTONE code: April and May 1973.

Fig. 3.4.14. Freshwater flow rate for tributary group 3 (Rondout Creek, Wallkill River) as input data to the ESTONE code: April and May 1974.

In the applications of the far-field model ESTONE to the Hudson River estuary, it was necessary to consider atmospheric conditions along the 152-mile length of the river. Since the meteorological conditions could vary between the upstream end at the Troy Dam and the downstream end at the Battery, two sets of information from two different weather stations at Albany, New York, and at LaGuardia, New York, were used in the preparation of the reduced data to the ESTONE code. The local climatological data were obtained from the standard NOAA publications.²⁸⁻³¹ In determining the normal solar radiation on the water surface of the estuary, the information in the local climatological documents was supplemented by additional literature about the availability of solar radiation according to latitude and cloudiness³² in the geographical region. The reduced input data to the ESTONE code were determined by weighted averaging of the climatological data from the weather stations at Albany, New York, and at LaGuardia, New York²⁸⁻³¹ and generating daily-averaged conditions according to linear variations between each month.

The hourly results from the fast-transient surface heat transfer model were integrated over the 24-hr daily periods to obtain the total heat transfer across the surface of the estuary for different surface temperature conditions. The averaged results predicted daily surface heat transfer coefficients within the approximate range of 100 to 150 Btu/(ft² day °F) corresponding to the observed range of wind speeds (5 to 15 fps) along the Hudson River. These results compared very favorably with the theoretical and experimental values of surface heat transfer coefficients discussed in ref. 33.

The input data to the fast-transient surface model included daily-average values and also up to three harmonics to simulate the variations of the climatological conditions during each day. Hence, the temporal resolution of the climatological data was better than on hourly basis for normal solar radiation, cloud cover factor, air temperature, wind speed, wind direction, and relative humidity. The normal solar radiation was assumed as a sine function between sunup and sundown with specified maximum normal radiation flux value occurring around noon each day.

April 1-September 30, 1973, period. The input data to the ESTONE code for the maximum normal solar radiation flux and the daily cloud cover factor and daily maximum cloud cover factor variation are presented in Fig. 3.4.15 for the six-month simulation period in 1973. The maximum normal radiation flux was approximately constant around 300 Btu/(hr ft²) during the month of July; however, the normal radiation falling on the water surface varied according to the duration of the day and the cloud cover factor which reduced the amount of the radiation.

The daily-average air temperature, daily-maximum air temperature variation, daily-average wind speed, and daily-maximum wind speed variation for the six-month simulation period in 1973 are presented in Fig. 3.4.16. The maximum daily-average air temperature was approximately 78°F around

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Fig. 3.4.15. Maximum normal solar radiation flux, daily-average cloud cover factor, and daily maximum cloud cover factor variation during the simulation period April 1-September 30, 1973.

Fig. 3.4.16. Daily-average air temperature, daily-maximum air temperature variation, daily-average wind speed, and daily-maximum wind speed variation during the simulation period April 1-September 30, 1973.

August 1 with maximum daily-maximum air temperature variation of approximately 10°F. Hence, around August 1, air temperature in the region of the Hudson River estuary reached a maximum of 88°F during the day. Furthermore, the daily-average wind speed during August was relatively low at approximately 12 fps, with maximum daily variations not exceeding 5 fps. Hence, during the six-month simulation period in 1973, surface cooling effects were lowest in August.

The daily-average rainfall rate, daily-average relative humidity, and daily-maximum relative humidity variation are presented in Fig. 3.4.17 for the 1973 simulation period. Although 1973 was the year of record high for annual freshwater flow in the Hudson River, during the six-month simulation period, the rainfall was not excessive after the end of April. The daily-average relative humidity remained approximately uniform at 70% with daily-maximum relative humidity variation approximately uniform at 15%. Hence, the maximum relative humidity values (around 85%) occurred continuously during June through September, causing low values for back radiation and evaporation modes of surface cooling.

April 1-September 30, 1974, period. The maximum normal solar radiation flux, the daily-averaged cloud cover factor, and the daily-maximum cloud cover factor variation are presented in Fig. 3.4.18 for the six-month simulation period in 1974. The maximum normal solar radiation values and the duration of the days during the 1974 simulation period were assumed as identical to ones in 1973, since they are approximately fixed by the latitude of the geographical region. The decrease in cloud cover factor in 1974 between May 15 and July 15 was less pronounced, but during July, when the solar heating was maximum, the values for cloud cover factor remained approximately the same for both years.

The daily-average air temperature, daily-maximum air temperature variation, daily-average wind speed, and daily-average wind speed variation for the 1974 simulation period are presented in Fig. 3.4.19. The variations of the air temperature and the wind speed in the region during the period of 1974 simulations were very similar to the variations during the 1973 period. Again, the maximum daily-average temperature of approximately 78°F occurred around August 1, and the wind speed was minimum (below 15 fps) from July 1 through August.

The daily-average rainfall rate, daily-average relative humidity, and daily-maximum relative humidity variation are presented in Fig. 3.4.20 for the 1974 simulation period. The amount of rainfall during July 1 through September in 1974 was higher than the rainfall during the same period in 1973. The daily-average relative humidity during September was also slightly higher at approximately 72% during 1974 than for the same period in 1973, with lower daily-maximum relative humidity variation of less than 10% compared to over 15% during 1973.

Hence, the climatological conditions in the region which influence water surface conditions on the estuary were similar during both six-month simulation periods in 1973 and 1974.

Fig. 3.4.17. Daily-average rainfall rate, daily-average relative humidity, and daily-maximum relative humidity variation during the simulation period April 1-September 30, 1973.

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Fig. 3.4.18. Maximum normal solar radiation flux, daily-average cloud cover factor, and daily-maximum cloud cover factor variation during the simulation period April 1-September 30, 1974.

Fig. 3.4.19. Daily-average air temperature, daily-maximum air temperature variation, daily-average wind speed, and daily-maximum wind speed variation during the simulation period April 1-September 30, 1974.

Fig. 3.4.20. Daily-average rainfall rate, daily-average relative humidity, and daily-maximum relative humidity variation during the simulation period April 1-September 30, 1974.

3.4.3.6 Power plant operating conditions. The input data to the tidal-transient one-dimensional far-field model ESTONE for power plant operating conditions require the following: (1) locations of the cooling water intakes and discharges, (2) specified temperatures of the cooling water at the intake and discharge or, as a second option, a specified temperature change occurring between intake and discharge, (3) specified salinity of the cooling water at the intake and discharge or, as a second option, a specified salinity change between intake and discharge.

In the applications of the model to the simulations of the physical conditions in the Hudson River, the second options in items 2 and 3 were employed for the power plant input data. The plant operating characteristics of all existing and proposed electric power generating stations at full capacity are presented in Table 3.4.7.

In the applications of the far-field model ESTONE to the simulations of the thermal conditions in the Hudson River, the rated capacity characteristics for the operating conditions could not be used since none of the major power plants operated near full power during the six-month simulation periods (April 1-September 30) in 1973 and in 1974. Hence, to validate the model based on the field-measured data in the river during 1973 and 1974, it was necessary to generate detailed plant operating data for the cooling water flow rates and the temperature rise values for all the plants on the river. The necessary information for the plant operational conditions was obtained from various different sources in various different formats.^{34,35} The different forms and different quality of the plant operational data and the methods employed in the analysis and reduction of these data into a suitable format which can be used as input data to the ESTONE model are discussed in detail in Appendix D.

Based on the analysis of the complete plant operating data for the two six-month simulation periods, it was decided to consider at most daily-averaged accuracy for the flow rate and cooling system temperature rise values for all the power plants. The daily-averaged data which remained uniform within 10% bounds were combined into longer than daily-averaged forms to save data input and computational time (see Appendix D). The detailed plant operating data were only considered for the generating stations with high output ratings. Two power plants, Albany and 59th Street, were assumed to be operating at full power during the periods of the 1973 and 1974 simulations. The intake and discharge flow rates and the separate temperature rise conditions of the different units of the power plants were combined into single values for the flow rates and condenser temperature rise values representative of the overall operational characteristics of the power plants in the preparation of the input data to the ESTONE code (see Appendix D).

April 1-September 30, 1973, period. The operating conditions of all five major power plants on the Hudson River varied appreciably during the six-month simulation period in 1973. Hence, it was necessary to consider detailed daily-averaged plant operating data in the applications of the ESTONE model.

Table 3.4.7. Plant operating characteristics of existing and proposed electric generating stations at full capacity along the Hudson River

Power plant	Location (mile point above Battery)	Unit No.	In-service date	Capacity (MWe)	Plant flow rate (cfs)	Plant thermal discharge (billion Btu/hr)	Intake element	Intake flow rate (cfs)	Discharge element	Discharge flow rate (cfs)	Condenser temperature rise (°F)
Albany	140			400	784	1.917	6	784	6	784	11.0
Greene County	104.5			1191	43 ^a	8.57	24	43 ^a	24	12 ^a	28.0 ^b
Dans- kammer	66	1	1951	64	89	2.250	44	686	44	686	14.5
		2	1954	64	89						
		3	1959	127	231						
		4	1967	253	277						
Roseton	65.4	1	1974	600	724	5.000	44	1,448	44	1,448	15.4
		2	1974	600	724						
Cornwall (pumped storage)	57		1980-1983	2000	20,000 ^c		48	20,000 ^c	48	15,000 ^d	N/S
Indian Point	43	1	1962	265	709	15.755	55	2,647	55	2,647	14.3
		2	1973	873	1,938 ^e						
		3	1975	1033	1,938 ^f						
Lovett	42	1	1948	19	58	3.184	55	721	55	721	20.9
		2	1951	20	58						
		3	1955	68	96						
		4	1966	195	237						
		5	1969	202	272						
Bowline	37.5	1	1972	600	855.5	5.16	58	1,711	58	1,711	15.0
		2	1974	600	855.5						
59th Street	5			221	374	0.500	74	374	74	374	6.0

^aWith once-through cooling, the plant flow rate (intake and discharge) is 2234 cfs.

^bWith once-through cooling, the condenser temperature rise is 17.5°F.

^cIntake flow rate during 9 hr of a typical day.

^dDischarge flow rate during 12 hr of a typical day.

^eWith closed-cycle cooling, the intake flow rate is 125 cfs.

^fWith closed-cycle cooling, the intake flow rate is 135 cfs.

Danskammer plant. During the six-month period of simulations in 1973, the Danskammer power plant consistently operated at 300 to 450 MWe (at 60 to 90% of its rated capacity of 508 MWe). The plant cooling water flow rates were around 400 to 700 cfs, and the plant temperature rise values were usually within a 15 to 20°F range. A typical case for the daily variations of the plant operational conditions of the Danskammer power plant as input data to the ESTONE model is presented in Fig. 3.4.21 for April 1973. The complete set of operating data for the six-month period in 1973 for the Danskammer plant is presented in Appendix D.

Roseton plant. During the six-month period of simulations in 1973, electric power was not generated by the Roseton plant. The flow conditions through the power plant were intermittent with daily-averaged rates reaching 500 to 800 cfs during the pumping periods. The plant temperature rise was negligible during the pumping with values below 0.5°F. A typical case for the daily variations of the plant operational conditions of the Roseton generating plant as input data to the ESTONE model is presented in Fig. 3.4.22 for July 1973. The complete set of operating data for the Roseton plant is presented in Appendix D.

Indian Point plant. During the six-month period of simulation in 1973, Indian Point Unit 1 did not generate electric power. However, service and cooling water pumps were operated, and plant temperature rises over 14°F were recorded, although most were under 4°F. Indian Point Unit 2 did not produce electrical power until the end of June, after which electrical generation was intermittent, between 0 and 400 MWe (0 to 46% of the unit capacity of 873 MWe). After the beginning of power generation, plant temperature rises were in the 10 to 15°F range while electrical power was being generated. Plant cooling water flow rates were in the 500 to 1500 cfs range during most of the six-month period.

A typical case for the daily variations of the plant operational conditions of the Indian Point plant as input data to the ESTONE model is presented in Fig. 3.4.23 for August 1973. One complete set of operating data for the Indian Point plant is presented in Appendix D.

Lovett plant. During the six-month period of simulation in 1973, the Lovett plant operated consistently around 300 MWe (60% of its rated capacity of 504 MWe). The plant cooling water flow rates were 500 to 700 cfs, and the plant temperature rise was usually 10 to 15°F. A typical case for the daily variations of the plant operational conditions of the Lovett plant as input data to the ESTONE model is presented in Fig. 3.4.24 for July 1973. The complete set of operating data for the Lovett plant for the six-month period in 1973 is presented in Appendix D.

Bowline plant. Bowline Unit 1 was under construction during the entire six-month period of simulation in 1973. Bowline Unit 1 operated with moderate consistency, usually around 400 MWe (67% of its 600-MWe rated capacity). The plant cooling water flow rates were 500 to 900 cfs, and the plant temperature rise values were usually 10 to 15°F. A typical case for the daily variation of the plant operational conditions of the

Fig. 3.4.21. Danskammer plant operating conditions used as input to the ESTONE model. Plant cooling water flow rate and plant cooling water temperature rise, April 1973.

Fig. 3.4.22. Roseton plant operating conditions used as input to the ESTONE model. Plant cooling water flow rate and plant cooling water temperature rise, July 1973.

Fig. 3.4.23. Indian Point plant operating conditions used as input to the ESTONE model. Plant cooling water flow rate and plant cooling water temperature rise, August 1973.

Fig. 3.4.24. Lovett plant operating conditions used as input to the ESTONE model. Plant cooling water flow rate and plant cooling water temperature rise, July 1973.

Bowline power plant as input data to the ESTONE model is presented in Fig. 3.4.25 for July 1973. The complete set of operating data for the six-month period in 1973 for the Bowline plant is presented in Appendix D.

April 1-September 30, 1974, period. The operating conditions of all five major power plants on the Hudson River varied appreciably during the six-month simulation period in 1974. Hence, it was necessary to consider detailed daily-averaged plant operating data in the applications of the ESTONE model.

Danskammer plant. During the six-month period of simulation in 1974, Danskammer power plant consistently operated around 300 MWe (at 60% of its rated capacity of 508 MWe). The plant cooling water flow rates were around 500 to 700 cfs, and the plant temperature rise values were usually within the range of 10 to 25°F. A typical case for the daily variations of the plant operational conditions of the Danskammer power plant as input data to the ESTONE model is presented in Fig. 3.4.26 for June 1974. The complete set of operating data for the six-month period in 1974 for the Danskammer plant is presented in Appendix D.

Roseton plant. No power was generated until August and September during the six-month simulation period of 1974, and then intermittently at 0 to 115 MWe (less than 10% of the 1200-MWe rated capacity of the plant). The flow conditions through the power plant were intermittent throughout the entire six-month period, with daily-averaged values of 500 to 1000 cfs during pumping. Plant temperature rise values were less than 6°F throughout the entire period. A typical case for the daily variations of the plant operational conditions of the Roseton power plant as input data to the ESTONE model is presented in Fig. 3.4.27 for May 1974. The complete set of operating data for the six-month period in 1974 for the Roseton plant is presented in Appendix D.

Indian Point plant. During the six-month period of simulation in 1974, Indian Point Unit 1 operated at 200 to 250 MWe and Unit 2 operated at 400 to 500 MWe. The operation of the total plant, consisting of the two units, was intermittent at an average value around 350 MWe (31% of the 1138-MWe rated capacity of the two units). The plant cooling water flow rates were 1000 to 2500 cfs, and the plant temperature rise values were usually 10 to 15°F. A typical case for the daily variations of the plant operational conditions of the Indian Point power plant as input data to the ESTONE model is presented in Fig. 3.4.28 for July 1974. The complete set of operating data for the six-month period in 1974 for the Indian Point plant is presented in Appendix D.

Lovett plant. During the six-month period of simulation in 1974, the Lovett plant operated consistently around 220 MWe (44% of its rated capacity of 504 MWe). The plant cooling water flow rates were around 500 cfs, and the plant temperature rise values were usually 10 to 15°F. A typical case for the daily variations of the plant operational conditions of the Lovett power plant as input data to the ESTONE model is presented in Fig. 3.4.29 for July 1974. The complete set of operating data for the six-month period in 1974 for the Lovett plant is presented in Appendix D.

Fig. 3.4.25. Bowline plant operating conditions used as input to the ESTONE model. Plant cooling water flow rate and plant cooling water temperature rise, July 1973.

Fig. 3.4.26. Danskammer plant operating conditions used as input to the ESTONE model. Plant cooling water flow rate and plant cooling water temperature rise, June 1974.

Fig. 3.4.27. Roseton plant operating conditions used as input to the ESTONE model. Plant cooling water flow rate and plant cooling water temperature rise, May 1974.

Fig. 3.4.28. Indian Point plant operating conditions used as input to the ESTONE model. Plant cooling water flow rate and plant cooling water temperature rise, July 1974.

Fig. 3.4.29. Lovett plant operating conditions used as input to the ESTONE model. Plant cooling water flow rate and plant cooling water temperature rise, July 1974.

Bowline plant. Bowline Unit 1 did not produce electrical power until June during the six-month period of simulation in 1974, and Bowline Unit 2 did not produce power until its initial start of operations in May. Afterwards, electrical power generation increased uniformly, reaching about 675 MWe by the end of September (56% of the 122-MWe rated capacity of the plant). Cooling water flow rates were 500 to 1700 cfs, and plant temperature rise values were usually 5 to 10°F. A typical case for the daily variations of the plant operational conditions of the Bowline power plant as input data to the ESTONE model is presented in Fig. 3.4.30 for June 1974. The complete set of operating data for the six-month period in 1974 for the Bowline plant is presented in Appendix D.

3.4.4 Validation of the far-field ESTONE model based on 1973 and 1974 field-measured data

The tidal-transient one-dimensional ESTONE model does not consider the artificial concept of "excess temperature" (see refs. 4-7) in the simulations of the thermal impact of power plant operations.

In the Hudson River, the thermal interaction between the power plants, which results from the periodically reversing tidal flow conditions, makes it impossible to determine "ambient temperature" conditions in the estuary. Hence, the computational results obtained from simple mathematical models which consider excess-temperature formulations cannot be verified realistically based on field-measured data. Consequently, the results for different scenarios to be considered in the assessment of the thermal impact of proposed power plant operations become questionable.

In order to validate the present far-field model ESTONE, two six-month periods of simulations (April 1-September 30) for 1973 and 1974 were selected. The particular period corresponds to the period of spawning and nursery of the young of the year of striped bass and certain other fish species in the estuary (see Sect. 5); hence, it is biologically significant from environmental impact considerations. Furthermore, the highest water temperatures occur in the river during the period of July through August; hence, the period is also critical from strictly thermal impact considerations to check the compliance of power plant operations with the existing State and Federal thermal standards applicable to the estuary (see Sect. 3.1).

The computer simulations were started on April 1 for both 1973 and 1974 with the required input data as discussed in Sect. 3.2. The computations were continued through September 30 with hourly results stored on tape for the complete 183-day duration of simulations for (1) surface elevations, (2) flow rate, (3) velocity, (4) temperature, and (5) salinity at 76 locations along the Hudson River. Since the available field-measured data for hourly variations of the physical variables are limited, the detailed hourly results from the computer simulations were averaged over the 24-hr periods to obtain the daily-averaged results which can be compared directly with the existing data.

Fig. 3.4.30. Bowline plant operating conditions used as input to the ESTONE model. Plant cooling water flow rate and plant cooling water temperature rise, June 1974.

It is important to note that in the simulations of the physical conditions in the Hudson River, none of the values of the coefficients and/or parameters of the transport model were ever adjusted (tuned). Hence, the tidal-transient one-dimensional far-field model ESTONE was employed strictly as a predictive mathematical model in the simulations of the conditions during the April 1-September 30 periods in both 1973 and in 1974.

In general, the agreement of the computer simulations by the ESTONE code and the field-measured data for the hydrodynamic conditions was excellent. An example of the comparisons of the simulated results by ESTONE and the measured data for surface elevations at Staatsburg³⁶ approximately 84 miles upstream of the Battery is shown in Fig. 3.4.31. The agreement between the data and the predicted computer simulation results was as good as the agreement between the six-harmonic functional values and the field-measured data at the Battery which were used as input to the ESTONE model.

Fig. 3.4.31. Comparison of computer simulations by ESTONE and field-measured data for tidal height at Staatsburg, 84 miles upstream of the Battery. Field data from U.S. Department of the Interior, Geological Survey, Water Resources Division, *Summary of Tidal Estuary Stage Observations*, 1974.

Further discussions of the predictive capabilities of the far-field model ESTONE for simulating the hydrodynamic conditions in the Hudson River will not be included here. The comparisons of the results from the model and the field-measured data for various rivers and estuaries are presented in ref. 1.

Since the present study is concerned with the thermal impact, the discussions concerned with the validation of the ESTONE model will be primarily based on the comparisons of the simulations and field-measured data for temperature. The comparisons for the salinity concentrations will also be included in the discussions, since all previous far-field analyses⁴⁻⁹ of the thermal problem in the Hudson estuary have relied on the concept of salinity-induced densimetric effects to enhance the turbulent transport phenomena, which could lead to the under-prediction of the thermal impact of power plant operations on the river.

3.4.4.1 Comparisons of computer simulations by the ESTONE model and field-measured data for temperature and salinity conditions in the vicinity of Bowline power plant during April 1-September 30, 1973. The variations of the local water temperature in the vicinity of the Bowline area during April 1-September 30, 1973, are documented in ref. 37, Fig. VIII-10, as intermittent daily measurements. Similarly, the local values of the salinity of water in the vicinity of the Bowline area are presented in the same document in Fig. VIII-6 also as intermittent daily measurements during April 1-September 30, 1973. In the process of validation of the ESTONE model, it was decided to employ these readily available data for the preliminary comparisons with computer simulations.

The detailed computer simulation results for the hourly variations of temperature and salinity at 76 element locations along the estuary for the 183-day period were reduced by considering only the values at element 58, corresponding to the location of the Bowline plant, and by temporal averaging over the 24-hr periods to obtain the daily-averaged local temperature and salinity conditions for comparison with the existing data.³⁷ In order to approximately indicate the variations of the temperature and salinity conditions during the day, three computer-simulated values were presented as (1) daily maximum, (2) daily average, and (3) daily minimum for the comparisons of the predicted cross-section-averaged values of temperature and salinity with the intermittent daily measurements of local temperature and salinity in the area. The results of the computer simulations by the far-field model ESTONE for the cross-section-averaged water temperature and salinity conditions in the vicinity of the Bowline plant are presented as variations during each month for the period April 1-September 30, 1973, in Figs. 3.4.32-3.4.37 together with the intermittent daily field-measured data.³⁷

The agreement between the computer simulation results by the far-field model ESTONE and the intermittent daily data for the cross-section-averaged temperatures was remarkable (see Figs. 3.4.32-3.4.37). It is important to note that at the end of the simulation period on September 30, after 183 days of continuous computation by the ESTONE model, the agreement between

ES-3499

Fig. 3.4.32. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and intermittent daily measurements of temperature and salinity in the vicinity of Bowline area during April 1973. Measurements from Lawler, Matusky and Skelly Engineers, 1973 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, vol. V, prepared for Orange and Rockland Utilities, Inc., December 1974.

ES-3500

Fig. 3.4.33. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and intermittent daily measurements of temperature and salinity in the vicinity of Bowline area during May 1973. Measurements from Lawler, Matusky and Skelly Engineers, 1973 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, vol. V, prepared for Orange and Rockland Utilities, Inc., December 1974.

ES-3501

Fig. 3.4.34. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and intermittent daily measurements of temperature and salinity in the vicinity of Bowline area during June 1973. Measurements from Lawler, Matusky and Skelly Engineers, 1973 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, vol. V, prepared for Orange and Rockland Utilities, Inc., December 1974.

ES-3502

Fig. 3.4.35. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and intermittent daily measurements of temperature and salinity in the vicinity of Bowline area during July 1973. Measurements from Lawler, Matusky and Skelly Engineers, 1973 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, vol. V, prepared for Orange and Rockland Utilities, Inc., December 1974.

ES-3503

Fig. 3.4.36. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and intermittent daily measurements of temperature and salinity in the vicinity of Bowline area during August 1973. Measurements from Lawler, Matusky and Skelly Engineers, 1973 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, vol. V, prepared for Orange and Rockland Utilities, Inc., December 1974.

ES-3504

Fig. 3.4.37. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and intermittent daily measurements of temperature and salinity in the vicinity of Bowline area during September 1973. Measurements from Lawler, Matusky and Skelly Engineers, 1973 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, vol. V, prepared for Orange and Rockland Utilities, Inc., December 1974.

the predicted temperature values and the intermittent field-measured data was better than 1°F, which is less than the variation of the local temperature during the day in the Bowline area. Hence, considering the uncertainties involved about the actual times of measurements, it can be concluded that the agreement between the predicted values of cross-section-averaged temperatures and the field-measured data in the vicinity of Bowline area was excellent throughout the six-month period of simulation in 1973.

The agreement between the computer simulation results by the ESTONE model for the cross-section-averaged values of salinity and the intermittent field-measured data of local salinity in the vicinity of the Bowline area should also be classified as excellent in view of the uncertainties involved about the actual times and depths of the measurements. In particular, the excellent agreement between the computer predictions and the field data during the low-freshwater-flow period from June through August is extremely important. The results clearly conclude that the mathematical formulation of the overall turbulent transport phenomenon in the far-field model ESTONE can accurately predict the salinity intrusion upriver from the Battery without relying on unrealistic and unreliable "dispersion coefficient" concepts (see refs. 17 and 4-9 for the formulation of tidal-dominated transport in the estuary). Indeed, the computer simulation results during September 1973 predict local salinity values in the vicinity of the Bowline area higher than the values obtained by field measurements (see Fig. 3.4.37). The important consequences of these results will be discussed in the subsequent sections.

3.4.4.2 Comparisons of computer simulation results by ESTONE model and field-measured data for temperature and salinity conditions in the vicinity of Indian Point power plant during April 1-September 30, 1973. The best quality of field-measured data about the water temperature and salinity conditions in the Hudson River during April 1-September 30, 1973, was collected in the vicinity of the Indian Point power plant (see ref. 38). The available information includes continuous daily measurements of water temperature and salinity at the location of the power plant in addition to the intermittent data collected in the vicinity of the plant.

The detailed computer simulation results of the far-field model ESTONE for the hourly variations of temperature and salinity along the river were reduced by considering the values in element 55, corresponding to the location of the Indian Point power plant, by temporal averaging over 24-hr periods to obtain the daily-averaged local temperature and salinity conditions for comparisons with the existing data.³⁸ Again, three values representing daily minimum, daily average, and daily maximum of the cross-section-averaged temperature and salinity conditions were considered in the comparisons with the field-measured data. The results of the computer predictions by the far-field model ESTONE for the cross-section-averaged water temperature and salinity conditions in the vicinity of the Indian Point power plant are presented as variations during each month for the period April 1-September 30, 1973, in Figs. 3.4.38-3.4.43, together with data from continuous measurements at the location of the plant and intermittent field-measured data in the vicinity of the power plant.

ES-3505

Fig. 3.4.38. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during April 1973. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

ES-3506

Fig. 3.4.39. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during May 1973. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

ES-3507

Fig. 3.4.40. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during June 1973. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

ES-3508

Fig. 3.4.41. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during July 1973. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

ES-3533

Fig. 3.4.42. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during August 1973. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

ES-3534

Fig. 3.4.43. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during September 1973. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Again, the agreement between the computer simulation results and the intermittent daily data for the cross-section-averaged temperatures was remarkable (see Figs. 3.4.38-3.4.43). The data from the continuous temperature measurements at the location of the Indian Point power plant were consistently lower than the results of the computer predictions by the ESTONE model. In particular, during July, the temperature data from the continuous measurements at the location of the Indian Point power plant were more than 4°F lower than the computer simulation results (see Fig. 3.4.41). However, the intermittent field-measured data in the vicinity of the Indian Point plant agreed extremely well with far-field model predictions, and they were also consistently higher by approximately 4°F than the data from continuous temperature measurements at the location of the Indian Point plant. Hence, it can be concluded that the results of the computer simulations by the far-field model ESTONE predicted cross-section-averaged water temperature conditions in the vicinity of the Indian Point plant better than the continuous measurements at the location of the plant as representations of the cross-section-averaged temperature conditions in the estuary.

The agreement between the computer simulation results from the far-field ESTONE model for the cross-section-averaged salinity conditions in the estuary and the data both from continuous measurements at the location of the plant and also from intermittent field measurements in the vicinity of the Indian Point plant could again be classified as excellent in view of the uncertainties involved in the actual times and depth of the measurements. The predictions from the far-field model had excellent agreement with the field-measured data during the months of low fresh-water flow in the estuary, from June through August (see Figs. 3.4.40-3.4.42). Again, the computer simulations by the ESTONE model for the salinity conditions in the river accurately predicted the salinity intrusion phenomena in the river without requiring unrealistic formulations of the turbulent transport phenomena based on "dispersion coefficients" (see refs. 4-9).

3.4.4.3 Comparisons of computer simulation results by ESTONE model and field-measured data for temperature and salinity conditions in the vicinity of Indian Point power plant during April 1-September 30, 1974. The available water temperature and salinity data obtained at the location and in the vicinity of the Indian Point power plant during April 1-September 30, 1974, were used as the final case for the validation of the far-field model ESTONE for predicting the thermal conditions in the Hudson estuary.

The comparisons of the predicted results by the far-field model ESTONE for the cross-section-averaged water temperature and salinity conditions and the field data from both continuous measurements at the location of the Indian Point plant and intermittent measurements in the vicinity of the Indian Point plant³⁸ are presented in Figs. 3.4.44-3.4.49 for the six-month period of simulation in 1974.

ES-3535

Fig. 3.4.44. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during April 1974. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Fig. 3.4.45. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during May 1974. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

ES-3537

Fig. 3.4.46. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during June 1974. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

ES-3538

Fig. 3.4.47. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during July 1974. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

ES-3539

Fig. 3.4.48. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during August 1974. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

ES-3540

Fig. 3.4.49. Comparisons of computer simulation results by ESTONE for cross-section-averaged temperature and salinity variations and continuous daily measurements and field-measured data for temperature and salinity conditions in the vicinity of Indian Point area during September 1974. Measurements from Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

The agreement between the computer simulations of the cross-section-averaged water temperatures and the intermittent field-measured data in the vicinity of the Indian Point power plant was extremely good. The predictions continuously stayed within the upper and lower bounds of the scattered field-measured data throughout the simulation period, April 1-September 30. The comparisons of the predicted temperatures with the continuously measured data at the location of the Indian Point plant indicated approximately equal numbers of days of overprediction (see Figs. 3.4.44, 3.4.47, and 3.4.48) and underprediction (see Figs. 3.4.45, 3.4.46, and 3.4.49). However, throughout the six months of the simulations, on the average, the differences between the predicted results from the far-field model ESTONE for the cross-section-averaged water temperature conditions in the estuary and either the continuously measured data at the location of the Indian point power plant or the intermittent field-measured data in the vicinity of the Indian Point plant were consistently lower than the differences between the two sets of the available data. Hence, it was evident that the tidal-transient one-dimensional far-field model ESTONE could clearly predict the cross-section-averaged values for water temperature conditions in the estuary as accurately as two different sets of daily-measured field data for the temperature conditions in the Hudson River.

The computer simulation results for the cross-section-averaged salinity conditions in the river again agreed very well both with the continuously measured data at the location of the Indian Point power plant and also with the intermittent field-measured data in the vicinity of Indian Point in the view of the limits of accuracy of the times and depths of the measurements. The agreement between the far-field model predictions and the field-measured data was extremely good, particularly during the critical month of August 1974, when the salinity conditions reached maximum values in the vicinity of Indian Point.

3.4.4.4 Summary of validation results of the ESTONE far-field model and conclusion. The results of the previous sections have important consequences in relation to the assessment of the far-field thermal impact of power plant operations on the Hudson River according to the statements of the applicable State and Federal standards (see Sect. 3.1). The present procedure employed in the validation of the ESTONE far-field model is significantly different than the previous attempts in simulating the hydrodynamic, thermal, and salinity conditions in the estuary (e.g., see refs. 14 and 17). The important characteristics of the present validation study which are distinctly different than the previous simulation studies^{14,17} are summarized as follows:

1. The tidal-transient one-dimensional model was applied to the simulation of the conditions in the river as a completely predictive model. All the coefficients and the parameters of the model were specified at fixed values prior to the application of the model.

2. The formulation of the turbulent transport phenomenon in the far-field model was completely independent of the site-specific conditions in the Hudson River. None of the coefficients and/or parameters of the turbulent transport model were determined based on the conditions associated with special characteristics of the estuary.

3. The simulations were started on April 1 and continued through September 30, without any changes or adjustments in any of the coefficients and/or parameters of the model throughout the six-month periods of the simulations.

4. The necessary data for the model were prepared according to all the available information by considering all the realistic variations of the important physical conditions during the simulation periods. No major simplifying assumption was made to consider uniform conditions for the important input data which actually varied during the six-month periods of the simulations.

5. The predicted results from the computer simulations were obtained with hourly temporal resolution for 76 element locations along the 152-mile estuary with a spatial resolution accurate to within 2 miles. The high-resolution results were reduced to daily-averaged values strictly for comparison purposes with the existing field-measured data.

6. The predicted results from the far-field model were compared with the existing field-measured data for every data point which was available during the six-month periods of simulations, for two different years and at two different locations along the estuary.

7. The agreement between the predictions by the model and the field-measured data was generally excellent throughout the six-month periods of the simulations. The validation of the model was not limited to short simulation periods of a few days. Indeed, the general agreement between the simulations by the model and any set of the independently obtained data was better than the agreement between the two different sets of independently obtained data for temperature conditions in the estuary.

In view of the above-listed important consequences of the validation results, it can be concluded that the tidal-transient one-dimensional far-field model ESTONE is the only presently available mathematical model which can predict the physical conditions in the estuary with sufficient levels of accuracy and reliability to be employed in the assessment of the far-field thermal impact of power plant operations on the Hudson River.

3.4.5 Assessment of the far-field thermal impact of power-plant operations on the Hudson River estuary

According to the applicable State thermal standards (see Sect. 3.1), it is clear that the assessment of the thermal impact of power plant operations must be based on an "ambient temperature" value according to the statement, *"over the temperature that existed before the addition of heat of artificial origin."* Hence, for the two six-month periods of simulation (April 1 - September 30) which were considered in the present analysis, it is still impossible at this point to give an estimate of the level of the thermal impact of power plant operations on the Hudson River in accordance with the exact statements of the thermal standards.

3.4.5.1 Determination of "clean river" case for the 1974 conditions. According to the statements of the thermal standards, the actual thermal impact during the six-month periods can only be determined based on the predictions of the nonexistent cases of the "clean river" conditions without any power plants operating on the river during 1973 and 1974. Hence, it is necessary to determine the clean river cases corresponding to the natural conditions which may have existed in the river during 1973 and 1974 before considering the assessment of the thermal impact of power plant operations.

The 1973 simulation period was not considered in the determination of "typical" "clean river" conditions since the particular year was a record high year for the freshwater flow in the estuary. The "ambient temperature" conditions in accordance with the statements of the thermal standards were obtained by repeating the computer simulations for the 1974 conditions in the estuary without any power plant operating. The hypothetical "clean river" conditions for 1974 were used as the basis for all the subsequent comparisons of the thermal impact of different scenarios of power plant operational conditions.

The natural flow conditions in the river and the climatological conditions in the region continuously vary during the summer months, which are critical both from thermal and also biological considerations. Hence, it is more realistic to consider the actual natural conditions rather than the approximate limiting cases of specified uniform freshwater conditions (e.g., see refs. 4-16) in the simulations of the thermal impact of power plant operations on the estuary. During 1974, both the freshwater flow rates and the climatological conditions were close to being typical for the Hudson River. Hence, it was decided to consider the 1974 "clean river" conditions as the representative "ambient temperature" conditions for determining the thermal impact of power plant operations according to the statements of the thermal standards (see Sect. 3.1).

3.4.5.2 Selection of cases for the simulation of power plant operational conditions. The assessment of the overall far-field thermal impact of power plant operations on the Hudson River estuary, with emphasis on the Roseton and Danskammer power plants, Indian Point power plant, and Bowline power plant, was based on the results of the computer simulations with the tidal-transient one-dimensional far-field model ESTONE for the following cases:

- Case 1. "Clean river" (base case). This case was used as the "ambient temperature" conditions for 1974 to determine the thermal impact of different scenarios of power plant operations. The thermal conditions for the case were determined by repeating the simulations for the 1974 six-month period without any operating power plant on the river.
- Case 2. 1974 conditions (base case). The results of the validation of the ESTONE model (see Sect. 3.4.4) were used as the second base case for the comparisons of the far-field thermal impact of power plant operations on the river for the different scenarios.
- Case 3. Proposed maximum thermal load conditions (comparison case). This case was used as the proposed maximum thermal load condition on the river with all existing and proposed power plants operating at full rated capacity with once-through plant cooling systems except for the Greene County power plant with closed-cycle cooling (see Table 3.4.7). This case was also used as the proposed upper-limit conditions of thermal impact on the estuary for the comparisons of the results of other cases.
- Case 4. Full once-through thermal load conditions. This case was considered for the maximum thermal impact conditions on the river according to the scenario of all existing and proposed power plants, including the Greene County power plant, operating at full rated capacity with once-through plant cooling systems (see Table 3.4.7).
- Case 5. Clean river with only Roseton and Danskammer power plants case. This case was considered to estimate the hypothetical far-field thermal impact of the combined operation of the Roseton and Danskammer power plants at full rated capacity conditions with once-through plant cooling systems (see Table 3.4.7).
- Case 6. Clean river with only Bowline power plant. This case was considered to estimate the hypothetical far-field thermal impact of the operation of the Bowline power plant at full rated capacity with a once-through plant cooling system (see Table 3.4.7).
- Case 7. Proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system. This case was considered to determine the possible reduction in the far-field thermal impact by installing a closed-cycle plant cooling system at the Bowline power plant (see Table 3.4.7).
- Case 8. Proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system. This case was considered to determine the possible reduction in the far-field thermal impact by installing a closed-cycle plant cooling system at the Indian Point power plant (see Table 3.4.7).

In the comparisons of the levels of thermal impact on the Hudson River estuary for the above cases of power plant operating conditions, the "clean river" case and the 1974 river conditions were used as the basis of comparison. All simulations were started on April 1, 1974, by assuming that the actual conditions on April 1, 1974, existed along the estuary. The simulations were continued for six-month periods (April 1 - September 30) according to the plant operational conditions as specified in the above-listed cases (see Table 3.4.7). Considering the fact that the hydrodynamic conditions in the river are approximately independent of the plant operational conditions (except for the negligible changes in momentum due to the intake and discharge flows in the common discrete elements), the results of the surface elevations and flow rates, which were already evaluated for the validation of the model, were used as input data in the simulations of the different cases. Based on the stability criteria of the numerical solution technique used in the model, this modification reduced the computer run times to one-fifth of the run times of the complete simulation with the hydrodynamic solutions.

3.4.5.3 Computer simulation results for case 3 (proposed maximum thermal load conditions). The proposed maximum thermal load case from far-field thermal impact considerations was simulated first by the application of the far-field model ESTONE. The hourly results from computer simulations were averaged over 24-hr periods to determine the daily-averaged and cross-section-averaged temperature conditions on all 76 elements along the Hudson River. Since the simulations were started on April 1, 1974, the month of April was discarded in the considerations of the thermal impact since quasi-steady thermal conditions could not be completely reached during the period of one month.

The computer simulation results for the three base cases of case 1 ("clean river" case), case 2 (1974 conditions), and case 3 (proposed maximum thermal load) (see Table 3.4.7) are presented as longitudinal distributions of daily-averaged and cross-section-averaged water temperature at the locations of the 76 elements along the Hudson River on the midmonth days of the simulation period (May 15, June 15, July 15, August 15, and September 15) in Figs. 3.4.50-3.4.54.

The results of the simulation clearly illustrate the thermal interaction between the power plants along the river, particularly for Indian Point and Bowline, which are located at elements 55 and 58, respectively (see Figs. 3.4.51 - 3.4.53) for June 15, July 15, and August 15 days. The longitudinal distributions for different cases of the daily-averaged and cross-section-averaged temperatures indicate that the differences in temperature between case 3 (proposed maximum thermal load) and case 1 (clean river) are close to 4°F from June through September (the exact values for these critical temperatures will be discussed in the subsequent sections), particularly within the 10-mile section of the estuary between the Indian Point and Bowline power plants. Considering that the clean river case represents the true ambient conditions in the river, the results of the daily-averaged and cross-section-averaged temperature distributions for case 3 (proposed maximum thermal load) will result in elevated temperature levels approximately 4°F above "the temperature that existed before

Fig. 3.4.50. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 3 at midmonth on May 15, 1974.

Fig. 3.4.51. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 3 at midmonth on June 15, 1974.

Fig. 3.4.52. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 3 at midmonth on July 15, 1974.

Fig. 3.4.53. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 3 at midmonth on August 15, 1974.

Fig. 3.4.54. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 3 at midmonth on September 15, 1974.

the addition of the heat of artificial origin." Since the temperature results in Fig. 3.4.50 represent daily-averaged and cross-section-averaged temperatures in 2-mile-long segments of the estuary, it is evident that the maximum temperature that would occur at various cross sections within the 10-mile segment between the Indian Point and Bowline power plants will cover more than "50 percent of the cross-sectional area" of the estuary. Hence, case 3 (proposed maximum thermal load) conditions will exceed the thermal standard based on the 4°F excess temperature conditions in the Hudson River.

The computer simulation results by the far-field ESTONE model also indicate that at midmonth on August 15, 1974, the daily-averaged and cross-section-averaged temperature conditions for case 3 (proposed maximum thermal load) will exceed 83°F at the location of the Indian Point plant. Again, considering that the simulated results represent daily-averaged and cross-section-averaged temperature conditions in the 2-mile-long segments of the estuary, the maximum temperatures that exist at a cross section within the 2-mile segment at the location of the Indian Point power plant will definitely exceed the allowable limit of "a maximum of 83°F" over areas exceeding "50 percent of the cross-sectional area of the estuary."

Hence, from the point of view of the longitudinal distributions of the daily-averaged and cross-section-averaged temperatures along the estuary, the computer simulation results of the far-field model ESTONE clearly indicate that two conditions of the State thermal standard will be violated for case 3 (proposed maximum thermal load) with all existing and proposed power plants operating at full rated power with once-through plant cooling water systems (except for the Greene County power plant on closed-cycle cooling system).

An alternative way of presenting the computer simulation results is to consider the temporal variations of the daily-averaged and cross-section-averaged water temperature conditions at various specified locations along the estuary. Three elements corresponding to the locations of the three major power plants along the estuary were considered, namely, element 44 for the Danskammer and Roseton power plants, element 55 for the Indian Point power plant, and element 58 for the Bowline power plant.

The variations of the daily-averaged and cross-section-averaged water temperature conditions in the vicinity of the Danskammer and Roseton power plants are presented in Figs. 3.4.55-3.4.57 for the six months of the simulation period April through September 1974. The results clearly indicate that for case 3 (proposed maximum thermal load) of plant operating conditions, the temperatures in element 44, corresponding to the location of the Danskammer and Roseton power plants, will not exceed the State thermal standards.

The variations of the daily-averaged and cross-section-averaged water temperature conditions in the vicinity of the Indian Point power plant are presented in Figs. 3.4.58-3.4.60 for the six months of the computer simulation period. The results indicate that starting in June and through September, the difference between case 3 (proposed maximum thermal load) and

Fig. 3.4.55. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 3 during April and May 1974.

Fig. 3.4.56. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 3 during June and July 1974.

Fig. 3.4.57. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 3 during August and September 1974.

Fig. 3.4.58. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Indian Point power plant for cases 1, 2, and 3 during April and May 1974.

Fig. 3.4.59. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Indian Point power plant for cases 1, 2, and 3 during June and July 1974.

Fig. 3.4.60. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Indian Point power plant for cases 1, 2, and 3 during August and September 1974.

the clean river case for the daily-averaged and cross-section-averaged water temperature conditions in the vicinity of the Indian Point power plant will exceed but will also be very close to the 4°F excess temperature limit of the applicable State thermal standards (see Figs. 3.4.59 and 3.4.60). Again, considering that the maximum temperature at any cross section within the 2-mile segment of the element will be higher than the cross-section-averaged value of the temperature over partial areas larger than 50% of the cross-sectional area of the river, it is evident that the proposed maximum thermal load case will violate the 4°F excess temperature limitation of the State thermal standards.

Furthermore, at the end of July and at the beginning of August, the local daily-averaged and cross-section-averaged water temperature in the vicinity of Indian Point will exceed 83°F (accurate values will be presented in the subsequent sections according to the computer simulations by ESTONE) (see Figs. 3.4.59 and 3.4.60). Again, considering that the maximum temperature at any cross section within the 2-mile segment of the element would cover areas larger than 50% of the cross-sectional area of the estuary, the temperature conditions in the vicinity of the Indian Point plant will definitely violate the 83°F maximum limit restrictions of the State thermal standards for case 3 (proposed maximum thermal load) power plant operating conditions in the Hudson River.

The variations of the daily-averaged and cross-section-averaged water temperature conditions in the vicinity of the Bowline power plant are presented in Figs. 3.4.61-3.4.63 for the six months of the computer simulation period. The results again indicate that starting in June through September, the differences in local daily-averaged and cross-section-averaged temperature conditions between case 3 (proposed maximum thermal load) and the clean river case will exceed the 4°F excess temperature limit of the State thermal standards in the vicinity of the Bowline power plant (see Figs. 3.4.62 and 3.4.63).

Furthermore, again at the end of July and at the beginning of August, the local daily-averaged and cross-section-averaged water temperature in the vicinity of the Bowline power plant will exceed the 83°F maximum limit according to the results of computer simulations by the far-field model ESTONE (see Figs. 3.4.62 and 3.4.63). Hence, again considering the fact that the local maximum temperature at any cross section within the 2-mile segment of the Bowline element (58) could exceed the cross-section-averaged temperature over areas of more than 50% of the cross-sectional area of the estuary, the results of the computer simulations indicate that the 83°F limit condition of the State thermal standards will also be violated for case 3 (proposed maximum thermal load) power plant operating conditions on the Hudson River.

Based on the computer-simulated predictions by the far-field model ESTONE, the comparisons of the daily-averaged and cross-section-averaged values of water temperature conditions in the Hudson River, it can be stated that the thermal interactions between all existing and proposed

Fig. 3.4.61. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline power plant for cases 1, 2, and 3 during April and May 1974.

Fig. 3.4.62. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline power plant for cases 1, 2, and 3 during June and July 1974.

Fig. 3.4.63. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline power plant for cases 1, 2, and 3 during August and September 1974.

power plants operating at full rated power and with once-through plant cooling systems (except for the Greene County power plant on closed-cycle cooling system) will result in both elevated temperatures exceeding the 4°F limit and also maximum temperatures exceeding the 83°F limit of the State thermal standards.

3.4.5.4 Computer simulation results for case 4, full once-through thermal load conditions. This case represents the maximum thermal load on the Hudson River with all existing and planned power plants operating with once-through plant cooling systems. The plant operational scenario assumes that Greene County power plant is also operating with a once-through plant cooling system although it is actually planned for operation with a closed-cycle system (cooling towers). The importance of the results of this case will be evident later when compared with the results of the other cases.

The thermal impact of case 4, full once-through thermal load for power plant operational conditions was simulated by the application of the far-field model ESTONE. The hourly results from computer simulations were averaged over 24-hr periods to determine the daily-averaged and cross-section-averaged temperature conditions on all 76 elements along the Hudson River. Since the simulations were started on April 1, 1974, the month of April was discarded in the considerations of the thermal impact since quasi-steady thermal conditions could not be completely reached during the period of one month.

The computer simulation results for the two base cases as case 1 clean river and case 2 1974 conditions, and case 4, full once-through thermal load (see Table 3.4.7) are presented as longitudinal distributions of daily-averaged and cross-section-averaged water temperature at the locations of the 76 elements along the Hudson River on midmonth days of the simulation period (May 15, June 15, July 15, August 15, and September 15) in Figs. 3.4.64 through 3.4.68.

As expected, the results of the simulation of case 4, full once-through thermal load (including Greene County power plant with once-through plant cooling system) are similar to the results of the simulations of case 3, proposed maximum thermal load (Greene County power plant with closed-cycle plant cooling system) along the regions of the river downstream of the location of the Greene County power plant; that is, along the stretch of the river approximately 100 miles long, from 55 miles downstream of Troy to the Battery. The longitudinal distributions for different cases of the daily-averaged and cross-section-averaged temperatures (see Figs. 3.4.65 through 3.4.67) for June 15, July 15, and August 15 midmonth days again illustrate the strong thermal interaction between the Indian Point and Bowline power plants which are located at elements 55 and 58 respectively. The differences in temperature between case 4, full once-through thermal load and case 1, clean river are again approximately 4°F from June through September (the exact values for these critical temperatures will be discussed in the subsequent sections), within the 10-mile section of the estuary between Indian Point and Bowline power plants. Hence, as

Fig. 3.4.64. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for Cases 1, 2, and 4 at midmonth on May 15 (hypothetical 1974 river conditions).

ES-3601

Fig. 3.4.65. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 4 at midmonth on June 15 (hypothetical 1974 river conditions).

ES-3602

Fig. 3.4.66. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 4 at midmonth on July 15 (hypothetical 1974 river conditions).

ES-3603

Fig. 3.4.67. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 4 at midmonth on August 15 (hypothetical 1974 river conditions).

ES-3604

Fig. 3.4.68. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 4 at midmonth on September 15 (hypothetical 1974 river conditions).

expected, the simulation results for the temperatures in Figs. 3.4.65 through 3.4.67 conclude that the maximum temperature that would occur at various cross-sections within the ten-mile segment between Indian Point and Bowline power plants will cover areas more than "50 percent of the cross-sectional area" at elevated temperature that existed before the addition of the "heat of artificial origin." That is, case 4, full once-through thermal load operating conditions for the power plants will definitely exceed the thermal standard based on the 4°F excess temperature limitation in the Hudson River.

Similar to the results of case 3 (Greene County with closed-cycle plant cooling system), the results of case 4, full once-through thermal load also indicate that the far-field thermal impact of power plant operations will cause the daily-averaged and cross-section-averaged temperature at Indian Point to exceed 83°F on August 15 according to the 1974 conditions.

Hence, from the point of view of the longitudinal distributions of the daily-averaged and cross-section-averaged temperatures along the estuary, the computer simulation results of the far-field model ESTONE clearly indicate that two conditions of the State thermal standard will definitely be violated for case 4, full once-through thermal load with all existing and proposed power plants operating at full rated power with once-through plant cooling water systems (including Greene County power plant on once-through cooling system).

The alternate way of presenting the computer simulation results as the temporal variations of the daily-averaged and cross-section-averaged water temperature conditions at various specified locations along the estuary were considered at the locations of the three major power plants along the estuary as element 44 for Danskammer and Roseton power plants, element 55 for Indian Point power plant, and element 58 for Bowline power plant.

The variations of the daily-averaged and cross-section-averaged water temperature conditions in the vicinity of the Danskammer and Roseton power plants are presented in Figs. 3.4.69 through 3.4.71 for the six months of the simulation period April through September 1974. The results clearly indicate that the thermal interaction between Greene County power plant (operating with once-through plant cooling system) and Danskammer and Roseton power plants is not important. The far-field thermal impact of Greene County power plant (operating with once-through plant cooling system) is less than 1.5°F (the exact values for the temperature difference will be discussed in the subsequent sections) at the location of Danskammer and Roseton power plants (see Figs. 3.4.70 and 3.4.71). Hence, for case 4, full once-through thermal load of plant operating conditions, the temperatures in element 44, corresponding to the location of the Danskammer and Roseton power plants, will not exceed the State thermal standards.

The variations of the daily-averaged and cross-section-averaged water temperature conditions in the vicinity of the Indian Point power plant in element 55 are presented in Figs. 3.4.72 through 3.4.74 for the six months

Fig. 3.4.69. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 4 during April and May (hypothetical 1974 river conditions).

Fig. 3.4.70. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 4 during June and July (hypothetical 1974 river conditions).

Fig. 3.4.71. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 4 during August and September (hypothetical 1974 river conditions).

Fig. 3.4.72. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Indian Point power plant for cases 1, 2, and 4 during April and May (hypothetical 1974 river conditions).

Fig. 3.4.73. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Indian Point Power Plant for cases 1, 2, and 4 during June and July (hypothetical 1974 river conditions).

Fig. 3.4.74. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Indian Point Power Plant for cases 1, 2, and 4 during August and September (hypothetical 1974 river conditions).

of the computer simulation period. As expected, the results indicate that starting in June and through September, the difference between case 4, full once-through thermal load plant operational conditions and the clean river case for the daily-averaged, cross-section-averaged water temperature conditions in the vicinity of the Indian Point power plant will exceed but will again be very close to the 4°F excess temperature limit of the applicable State thermal standards (see Figs. 3.4.73 and 3.4.74).

Similar to case 3, as expected, the local daily-averaged and cross-section-averaged water temperature in the vicinity of Indian Point for case 4, full once-through thermal load plant operational conditions will exceed 83°F (accurate values will be presented in the subsequent sections for case comparisons) at the end of July and during August (see Figs. 3.4.73 and 3.4.74).

Comparing the results of the simulations for case 3, proposed maximum thermal load (Greene County with closed-cycle plant cooling system) and for case 4, full once-through thermal load (Greene County with once-through plant cooling system) it is evident that the differences in the local daily-averaged and cross-section-averaged water temperatures for the two cases (See Figs. 3.4.51 through 3.4.53, Figs. 3.4.65 through 3.4.67 and Figs. 3.4.59, 3.4.60, 3.4.73, and 3.4.74) are definitely not appreciable. Hence, the results indicate that the far-field thermal effect of Greene County operating with once-through plant cooling system is not important in influencing the temperature conditions in the vicinity of the Indian Point power plant. (The accurate values of the water temperature conditions will be presented in the subsequent sections for detailed case comparisons.)

The variations of the daily-averaged and cross-section-averaged water temperature conditions in the vicinity of the Bowline power plant are presented in Figs. 3.4.75 through 3.4.77 for the six months of the computer simulation period for case 4, full once-through thermal load plant operational conditions. As expected, the results again indicate that starting in June through September, the differences in local daily-averaged and cross-section-averaged temperature conditions between case 4, full once-through thermal load plant operational conditions and the clean river case will exceed the 4°F excess temperature limit of the State thermal standards in the vicinity of the Bowline power plant (see Figs. 3.4.76 and 3.4.77).

Similar to the results for case 3 (Greene County with closed-cycle plant cooling system), as expected, the results for case 4 (Greene County with once-through plant cooling system) also indicate that the end of July and during August, the local daily-averaged and cross-section-averaged water temperature in the vicinity of the Bowline power plant will exceed the 83°F maximum temperature limitations over areas more than 50% of the cross-sectional area of the estuary.

Based on the computer-simulated predictions by the far-field ESTONE model, the results indicate that the differences in the daily-averaged

Fig. 3.4.75. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline Power Plant for cases 1, 2, and 4 during April and May (hypothetical 1974 river conditions).

Fig. 3.4.76. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline Power Plant for cases 1, 2, and 4 during June and July (hypothetical 1974 river conditions).

Fig. 3.4.77. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline Power Plant for cases 1, 2, and 4 during August and September (hypothetical 1974 river conditions).

and cross-section-averaged values of water temperature for the two cases representing the high thermal conditions in the river are very small, particularly in the vicinities of Indian Point and Bowline power plants. Both the longitudinal distributions at midmonth days (see Figs. 3.4.50 through 3.4.54 and Figs. 3.4.64 through 3.4.68) and monthly variations in the vicinities of Danskammer and Roseton, Indian Point and Bowline power plants (see Figs. 3.4.55 through 3.4.63 and Figs. 3.4.69 through 3.4.77) clearly show that the far-field thermal interaction between the proposed Greene County power plant and Indian Point and Bowline power plants is extremely small (accurate values of the water temperatures will be presented in the subsequent sections for case comparisons) for case 4, full once-through thermal load (all existing and proposed power plants including Greene County with once-through plant cooling water systems) and for case 3, proposed maximum thermal load (Greene County with closed-cycle plant cooling system). The results of the computer simulations clearly establish that the critical conditions of far-field thermal interaction occur between Indian Point and Bowline power plants (see Figs. 3.4.50 through 3.4.77) with Lovett power plant also contributing to the elevated water temperature conditions in the ten-mile region between mile points 35 and 45 upstream of the Battery in the Hudson River.

3.4.5.5 Computer simulation results for case 5, clean river with only Roseton and Danskammer power plants. The far-field thermal impact of the combined operation of Danskammer and Roseton power plants on the Hudson River was considered as a hypothetical case with both plants operating at full rated power (see Table 3.4.7) and with once-through plant cooling water systems. The hourly results from computer simulations were averaged over 24-hr periods to determine the daily-averaged and cross-section-averaged temperature conditions on all 76 elements along the Hudson River. Since the simulations were started on April 1, 1974, the month of April was discarded in the considerations of the thermal impact since quasi-steady thermal conditions could not be completely reached during the period of one month.

The computer simulation results for the two base cases as case 1 clean river and case 2, 1974 conditions, and case 5, clean river with only Roseton and Danskammer power plants operating are presented as longitudinal distributions of daily-averaged and cross-section-averaged water temperature at the locations of the 76 elements along the Hudson River on midmonth days of the simulation period (May 15, June 15, July 15, August 15, and September 15) in Figs. 3.4.78 through 3.4.82. The results of the computer simulations indicate that the far-field thermal impact of the combined operation of Roseton and Danskammer power plants will be limited to the immediate vicinity of their locations and at full rated power output the elevated water temperature condition in the element of the power plants is lower than 1.5°F throughout the summer months from May through September.

An important consequence of the computer simulations for case 5, clean river with only Danskammer and Roseton operating at full rated power is that the results clearly illustrate the relative far-field thermal impact of 1974 power plant operational conditions on the estuary. The longitudinal

Fig. 3.4.78. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases, 1, 2, and 5 at mid-month on May 15 (hypothetical 1974 river conditions).

Fig. 3.4.79. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 5 at mid-month on June 15 (hypothetical 1974 river conditions).

Fig. 3.4.80. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 5 at mid-month on July 15 (hypothetical 1974 river conditions).

Fig. 3.4.81. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 5 at mid-month on August 15 (hypothetical 1974 river conditions).

Fig. 3.4.82. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 5 at mid-month on September 15 (hypothetical 1974 river conditions).

distributions of temperatures along the river (see Figs. 3.4.78 through 3.4.82) show that with the exception of the thermal impact of Albany power plant, the overall far-field thermal impact of 1974 power plant operations was actually less than the hypothetical thermal impact of the combined operation of Danskammer and Roseton power plants on the Hudson River.

The alternate representation of the computer results of the daily-averaged and cross-section-averaged water temperature conditions in the estuary are presented as monthly variations in the vicinity of the Danskammer and Roseton power plants for the six months of the simulation period April through September in Figs. 3.4.83 through 3.4.85. The results again show that the far-field thermal impact of the combined operation of Danskammer and Roseton power plants will cause elevated water temperature conditions less than 1.5°F (accurate values of temperatures will be presented in the subsequent sections for case comparisons) and that the maximum temperatures in the vicinity of the power plants will not exceed 81°F for the hypothetical 1974 river conditions. Since the far-field thermal effects of the combined operation of Danskammer and Roseton power plants are strictly limited to the vicinity of the plants, the results of the computer simulations of the temperature conditions at the locations of the other plants on the estuary need not be considered.

3.4.5.6 Computer simulation results for case 6, clean river with only Bowline power plant. The far-field thermal impact of Bowline power plant on the Hudson River was also considered as a hypothetical case with the plant operating at full rated power (see Table 3.4.7) and with once-through plant cooling system on the clean river. The hourly results from the high temporal resolution computer simulations were averaged over 24-hr periods to determine the daily-averaged and cross-section-averaged temperature conditions in all 76 elements along the Hudson River.

The computer simulation results for the two base cases as case 1, clean river, and case 2, 1974 conditions, and case 6, clean river with only Bowline power plant operating are presented as longitudinal distributions of daily-averaged and cross-section averaged water temperature at the 76 specified element locations along the estuary on midmonth days of the simulation period (May 15, June 15, July 15, August 15, and September 15) in Figs. 3.4.86 through 3.4.90. The results of the computer simulations indicate that the far-field thermal impact of the Bowline power plant will be limited to the immediate vicinity of the power plant, and at full rated power output the elevated water temperature conditions in the element of the discharge will be lower than 1°F throughout the six-month period from May through September under hypothetical 1974 river conditions.

The results of the simulations for case 6, clean river with only Bowline power plant operating at full rated output again indicate the low level of far-field thermal impact of the actual 1974 plant operational conditions in the Hudson River. The comparison of the longitudinal distributions of temperatures for case 6 (Figs. 3.4.86 through

Fig. 3.4.83. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 5 during April and May (hypothetical 1974 river conditions).

Fig. 3.4.84. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 5 during June and July (hypothetical 1974 river conditions).

Fig. 3.4.85. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 5 during August and September (hypothetical 1974 river conditions).

Fig. 3.4.86. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 6 at mid-month on May 15 (hypothetical 1974 river conditions).

Fig. 3.4.87. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 6 at mid-month on June 15 (hypothetical 1974 river conditions).

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Fig. 3.4.88. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 6 at mid-month on July 15 (hypothetical 1974 river conditions).

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Fig. 3.4.89. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 6 at mid-month on August 15 (hypothetical 1974 river conditions).

Fig. 3.4.90. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 6 at mid-month on September 15 (hypothetical 1974 river conditions).

3.4.90) and the 1974 operational conditions clearly show that the combined far-field thermal interaction of all the plants operating on the Hudson River during the six-month period in 1974 contributed less than 0.5°F to the excess temperature conditions in the vicinity of Bowline Point.

The alternative representations of the results of the daily-averaged and cross-section-averaged water temperature conditions in the estuary for case 6 (clean river with only Bowline power plant operating with once-through plant cooling system) are presented as monthly variations in the vicinity of the Bowline Point in Figs. 3.4.91-3.4.93 for the hypothetical 1974 river conditions. The results clearly show that the individual thermal impact of Bowline power plant on the river is small with elevated water temperature conditions in the discharge element remaining below 1°F throughout the six-month period of simulation (see Figs. 3.4.91-3.4.93). Furthermore, the maximum temperature conditions in the vicinity of the Bowline plant do not exceed 81°F, which occurs during the first week of August for the assumed 1974 river flow conditions.

The results of the computer simulations for the four cases of plant operational conditions on the Hudson River, case 3 (proposed maximum load conditions), case 4 (full once-through thermal load conditions), case 5 (clean river with only Roseton and Danskammer power plants), and case 6 (clean river with only Bowline power plant) conclude that the individual operations of the Roseton and Danskammer power plants and Bowline power plant would not cause critical thermal impact conditions on the estuary. On the other hand, the results of simulations for the two high-thermal-impact cases on the river, case 3 (proposed maximum thermal load conditions) and case 4 (full once-through thermal load conditions), indicate that the far-field thermal interactions between the power plants would cause critical thermal impact conditions on the river which would exceed the allowable limits of the State and Federal standards.

The results of the previous computer simulations generally indicated that the thermal interaction due to the tidal-flow-dominated far-field effects is maximum between Indian Point and Bowline power plants for high-thermal-load plant operational conditions on the estuary. Furthermore, since the maximum temperature conditions in the river always occurred in the 10-mile-long region of the river between Indian Point and Bowline, it was evident that the two plants were the major contributors to the overall thermal impact of power plant operations on the Hudson River. Hence, to study the feasibility of reduction of the thermal impact on the estuary by changing the heat rejection systems of the power plants from once-through operation to closed-cycle operation, two additional cases were considered.

3.4.5.7 Computer simulation results for case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system). The case represents an alternative approach in the assessment of the thermal impact of the Bowline power plant on the Hudson River. The computer simulation results were obtained by employing the far-field

Fig. 3.4.91. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline Power Plant for cases 1, 2, and 6 during April and May (hypothetical 1974 river conditions).

Fig. 3.4.92. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline Power Plant for cases 1, 2, and 6 during June and July (hypothetical 1974 river conditions).

Fig. 3.4.93. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline Power plant for cases 1, 2, and 6 during August and September (hypothetical 1974 river conditions).

model ESTONE to predict the conditions in the river for case 3 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system) (see Table 3.4.7). The hourly predictions for the temperature conditions in the river at 76 element locations were averaged over 24-hr periods to obtain the reduced results for daily-averaged and cross-section-averaged water temperature conditions along the Hudson River. Since the simulations were started on April 1, again the results for the month of April were discarded since quasi-steady thermal equilibrium conditions could not be completely reached during the period of one month.

The computer simulation results for the two base cases, case 1 (clean river) and case 2 (1974 conditions), and case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system) are presented as longitudinal distributions of daily-averaged and cross-section-averaged water temperature at the locations of the 76 elements along the Hudson River on midmonth days of the simulation period (May 15, June 15, July 15, August 15, and September 15) in Figs. 3.4.94-3.4.98.

The results of the simulations of case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system) are similar to the results of case 3 (proposed maximum thermal load, Greene County power plant with closed-cycle plant cooling system) (see Figs. 3.4.50-3.4.54) with slightly noticeable reduction in the differences in excess temperature in comparison to case 1 (clean river) (see Figs. 3.4.95-3.4.98), particularly in the vicinity of Bowline Point. The reduction in temperature is approximately 0.5°F (the exact values for the critical temperatures will be discussed in the subsequent sections) at the location of Bowline power plant. The results also indicate that a noticeable reduction in temperature conditions of approximately 0.4°F can be achieved in the vicinity of the Indian Point power plant for the closed-cycle operational conditions of Bowline power plant. However, the longitudinal distributions of temperature along the river in August (see Fig. 3.4.97) show that the differences in temperature between case 7 (proposed maximum thermal load except Bowline power plant with closed cycle plant cooling system) and case 1 (clean river) are again approximately 4°F (the exact values for these critical temperatures will be discussed in the subsequent sections) within the 10-mile section of the estuary between Indian Point and Bowline power plants. Hence, the simulation results for the temperatures in Fig. 3.4.97 conclude that the maximum temperature that would occur at various cross sections within the 10-mile segment between Indian Point and Bowline power plants will cover areas more than "50 percent of the cross-sectional area" at elevated temperature that existed before the addition of the "heat of artificial origin." That is, case 7 (proposed maximum thermal load except Bowline power plant with closed cycle plant cooling system) operating conditions for the power plants will again exceed the thermal standard based on the 4°F excess temperature limitations in the Hudson River.

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Fig. 3.4.94. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 7 at midmonth on May 15. Hypothetical 1974 river conditions.

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Fig. 3.4.95. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 7 at midmonth on June 15. Hypothetical 1974 river conditions.

Fig. 3.4.96. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 7 at midmonth on July 15. Hypothetical 1974 river conditions.

Fig. 3.4.97. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 7 at midmonth on August 15. Hypothetical 1974 river conditions.

ES-3780

Fig. 3.4.98. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 7 at midmonth on September 15. Hypothetical 1974 river conditions.

The results of case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system) also indicate that although approximately 0.5°F reduction in temperatures can be achieved due to the closed-cycle operation of Bowline power plant, the far-field thermal impact of power plant operations will cause the daily-averaged and cross-section-averaged temperature at Indian Point to exceed 83°F on August 15 according to the 1974 conditions (see Fig. 3.4.97).

Hence, from the point of view of the longitudinal distributions of the daily-averaged and cross-section-averaged temperatures along the estuary, the computer simulation results of the far-field model ESTONE clearly indicate that the two conditions of the State thermal standard will again be violated for case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system, also Greene County power plant on once-through cooling system) for the hypothetical 1974 conditions in the Hudson River.

The alternative way of presenting the computer simulation results as the temporal variations of the daily-averaged and cross-section-averaged water temperature conditions at various specified locations along the estuary were considered at the location of the Bowline power plant in element 58. The variations of the daily-averaged and cross-section-averaged water temperature conditions in the vicinity of the Bowline power plant are presented in Figs. 3.4.99-3.4.101 for the six months of the computer simulation period for case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle cooling system) plant operational conditions. The results again indicate that the differences in local daily-averaged and cross-section-averaged temperature conditions between the present case 7 and the clean river case may not exceed the 4°F excess temperature limit of the State thermal standards in the vicinity of the Bowline power plant (see Figs. 3.4.99-3.4.101). The results also indicate that in contrast to the results of case 3 (proposed maximum thermal load), during August, the local daily-averaged and cross-section-averaged water temperature in the vicinity of Bowline Point may not exceed the maximum temperature limitations over areas more than 50% of the cross-sectional area of the estuary due to the reduction of approximately 0.5°F in temperatures due to the closed-cycle operation of the Bowline power plant.

3.4.5.8 Computer simulation results for case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system). This case represents the most critical scenario in the simulation of the far-field thermal impact of power plant operations on the Hudson River. Since the proposed operation of the Indian Point power plant will have rated output power more than any other power plant on the estuary (1900 MW_e for the combined operation of Unit 1 and Unit 2 and 2170 MW_e for the combined operation of Unit 1, Unit 2, and Unit 3; see Table 3.4.7), it is reasonable to expect that the closed-cycle operation of the plant would decrease the overall thermal impact on the river. However, accurate estimation of the magnitude of the possible

Fig. 3.4.99. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline power plant for cases 1, 2, and 7 during April and May. Hypothetical 1974 river conditions.

Fig. 3.4.100. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline power plant for cases 1, 2, and 7 during June and July. Hypothetical 1974 river conditions.

Fig. 3.4.101. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline power plant for cases 1, 2, and 7 during August and September. Hypothetical 1974 river conditions.

reduction of the thermal impact requires careful consideration of the far-field thermal interaction between Indian Point power plant and Danskammer, Roseton, Lovett, and Bowline power plants, which are within the range of influence of the thermal discharge of the Indian Point power plant in view of the tidal flow conditions in the estuary.

The thermal impact of case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle cooling system) (see Table 3.4.7) power plant operational conditions was simulated by the application of the far-field model ESTONE. The hourly results from computer simulations were averaged over 24-hr periods to determine the daily-averaged and cross-section-averaged temperature conditions on all 76 elements along the Hudson River. Since the simulations were started on April 1, 1974, the month of April was discarded in the considerations of the thermal impact since quasi-steady thermal conditions could not be completely reached during the period of one month.

The computer simulation results for the two base cases, case 1 (clean river) and case 2 (1974 conditions), and case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle cooling system) (see Table 3.4.7) are presented as longitudinal distributions of daily-averaged and cross-section-averaged water temperature at the locations of the 76 elements along the Hudson River on midmonth days of the simulation period (May 15, June 15, July 15, August 15, and September 15) in Figs. 3.4.102-3.4.106 for the hypothetical 1974 river conditions.

The results clearly indicate that the overall thermal impact of power plant operations according to case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system, also Greene County with closed-cycle plant cooling system) (see Figs. 3.4.102-3.4.106) is substantially lower than the overall thermal impact of the conditions of case 3 (proposed maximum thermal load conditions, only Greene County with closed-cycle plant cooling system) (see Figs. 3.4.50-3.4.54). With Indian Point operating on closed cycle, simulation results clearly show that the excess temperature conditions along the Hudson River (in comparison to clean river conditions) are reduced by more than approximately 2°F in the vicinity of Indian Point and more than 1°F in the vicinity of Bowline Point. The reduced thermal impact conditions occur throughout the estuary and for the six months considered in the simulations starting with April through September. The longitudinal distributions of temperature for case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle cooling system) indicate that the temperatures in the river will not be higher than 2°F above the natural temperatures of the clean river for the hypothetical 1974 conditions (see Figs. 3.4.102-3.4.106).

One of the important results of the simulations for case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle cooling system) is that the predicted temperatures for the case would be extremely close to the actual conditions that existed in the estuary during the six-month period April through September in 1974. Indeed, the

Fig. 3.4.102. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 8 at midmonth on May 15. Hypothetical 1974 river conditions.

Fig. 3.4.103. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 8 at mid-month on June 15. Hypothetical 1974 river conditions.

Fig. 3.4.104. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 8 at midmonth on July 15. Hypothetical 1974 river conditions.

Fig. 3.4.105. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 8 at midmonth on August 15. Hypothetical 1974 river conditions.

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Fig. 3.4.106. Computer simulation results by ESTONE for the longitudinal distributions of daily-averaged and cross-section-averaged water temperatures along the Hudson River for cases 1, 2, and 8 at midmonth on September 15. Hypothetical 1974 river conditions.

only appreciable difference in temperatures between case 8 results and the 1974 conditions would be in the vicinity of Danskammer and Roseton power plants (see Figs. 3.4.103-3.4.106), and the difference in temperature values would be less than 1°F (the accurate values of the critical temperatures will be presented in the subsequent sections as case comparisons).

Hence from the point of view of the longitudinal distributions of the daily-averaged and cross-section-averaged temperatures along the estuary, the computer simulation results of the far-field model ESTONE indicate that the average temperature within any 10-mile segment of the estuary will not exceed values 4°F above the natural temperature conditions that existed before the addition of the "heat of artificial origin." It must be realized that this result definitely does not conclude that the maximum temperature conditions at a cross section would not cover areas more than "50 percent of the cross-sectional area" at elevated temperatures 4°F above that which existed before the addition of the "heat of artificial origin" as stated by the State thermal standards. The present results based strictly on far-field analyses only apply to a spatial resolution of 2-mile segments. The simulation of the temperature conditions in the estuary in the finer spatial scale of resolution as dictated by the thermal standards requires the zone-matched near-field and far-field analysis, which will be considered separately in the subsequent sections.

The results of the computer simulations for case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system) indicate that the daily-averaged and cross-section-averaged temperature values within the 2-mile segments of the estuary will not exceed 83°F at any location during the summer for the hypothetical 1974 river conditions. In contrast to the simulation results of case 3 (proposed maximum thermal load, only Greene County power plant with closed-cycle plant cooling system), which indicate that the water temperature in the vicinity of Indian Point will exceed 83°F (see Fig. 3.4.53), the simulation results for case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system, also Greene County power plant with closed-cycle plant cooling system) clearly show that the water temperature in August will not exceed 83°F at the same location (see Fig. 3.4.105) for the hypothetical 1974 river conditions. Again, the results of the far-field analyses do not guarantee that the 83°F limit of the State thermal standard would not be violated by the plant operations. The statement of the applicable standards requires more accurate spatial resolution than the 2-mile segments for determining the values of the cross-sectional temperatures covering more than "50 percent of the cross-sectional area" of the estuary.

The alternative way of presenting the computer simulation results as the temporal variations of the daily-averaged and cross-section-averaged water temperature conditions at various specified locations along the estuary were considered at the locations of the three major power plants

along the estuary as element 44 for Danskammer and Roseton power plants, element 55 for the Indian Point power plant, and element 58 for Bowline power plant for the hypothetical 1974 flow conditions.

The variations of the daily-averaged and cross-section-averaged water temperature conditions in the vicinity of the Danskammer and Roseton power plants are presented in Figs. 3.4.107-3.4.109 for the six months of the simulation period April through September 1974 for the power plant operational conditions case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system) (see Table 3.4.7). The computer simulation results clearly indicate that the far-field thermal impact of case 8 (Indian Point with closed-cycle plant cooling system) in element 44, corresponding to the location of the Danskammer and Roseton power plants, will not cause any appreciable elevated temperature conditions. The maximum difference in water temperature between case 8 and the base case 1 (clean river) will be less than 1.5°F during the six-month period April through September (see Figs. 3.4.107 and 3.4.108) for the 1974 river conditions.

The variations of the daily-averaged and cross-section-averaged water temperature conditions in the vicinity of the Indian Point power plant in element 55 are presented in Figs. 3.4.110-3.4.112 for the six months of the computer simulation period April through September for the power plant operational conditions case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system) (see Table 3.4.7). The computer simulation results for monthly variations of the water temperature clearly illustrate that there will be a substantial reduction in thermal impact in the vicinity of Indian Point (see Figs. 3.4.110-3.4.112) with the power plant operating on closed-cycle plant cooling system in comparison to the results for case 3 (proposed maximum thermal load with Indian Point on once-through plant cooling system) (see Figs. 3.4.58-3.4.60). The local values of daily-averaged and cross-section-averaged water temperature within the 2-mile segment at Indian Point will be approximately 2°F lower (the exact values of critical temperature conditions will be presented in the subsequent sections for case comparisons) for the closed-cycle plant cooling system than for the open-cycle case for the operational conditions of the Indian Point power plant according to 1974 hypothetical river conditions.

The variations of the daily-averaged and cross-section-averaged water temperature conditions in the vicinity of the Bowline power plant in element 58 are presented in Figs. 3.4.113-3.4.115 for the six months of the computer simulation period April through September for the power plant operational conditions case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system) (Table 3.4.7). The computer simulation results for the monthly variations of the water temperature again indicate that the far-field thermal impact in the vicinity of Bowline Point (see Figs. 3.4.113-3.4.115) will be substantially reduced for the closed-cycle operational conditions of the Indian Point power plant in comparison to the results for case 3 (proposed

Fig. 3.4.107. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 8 during April and May. Hypothetical 1974 river conditions.

Fig. 3.4.108. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 8 during June and July. Hypothetical 1974 river conditions.

Fig. 3.4.109. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Danskammer and Roseton power plants for cases 1, 2, and 8 during August and September. Hypothetical 1974 river conditions.

Fig. 3.4.110. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Indian Point power plant for cases 1, 2, and 8 during April and May. Hypothetical 1974 river conditions.

Fig. 3.4.111. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Indian Point power plant for cases 1, 2, and 8 during June and July. Hypothetical 1974 river conditions.

Fig. 3.4.112. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Indian Point power plant for cases 1, 2, and 8 during August and September. Hypothetical 1974 river conditions.

Fig. 3.4.113. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline power plant for cases 1, 2, and 8 during April and May. Hypothetical 1974 river conditions.

Fig. 3.4.114. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline power plant for cases 1, 2, and 8 during June and July. Hypothetical 1974 river conditions.

Fig. 3.4.115. Computer simulation results by ESTONE for the variations of daily-averaged and cross-section-averaged water temperature conditions in the vicinity of Bowline power plant for cases 1, 2, and 8 during August and September. Hypothetical 1974 river conditions.

maximum thermal load with Indian Point power plant on once-through plant cooling system) (see Figs. 3.4.61-3.4.63). The values of daily-averaged and cross-section-averaged water temperature within the 2-mile segment at Bowline Point will be more than 1°F lower (the exact values of critical temperature conditions will be presented in the subsequent sections for case comparisons) for the closed-cycle operation of the Indian Point power plant than for the open-cycle case 3 according to 1974 hypothetical river conditions.

The results of the computer simulations by the far-field ESTONE model for the power plant operational conditions of case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system) conclude that there will be a substantial reduction in the thermal impact on the Hudson River for the closed-cycle operational conditions of the Indian Point power plant.

3.4.6 Summary of results of the far-field thermal impact analysis and conclusions

In the assessment of the far-field thermal impact of power plant operations on the Hudson River, the computer simulation results by the ESTONE far-field model were obtained for the hourly variations of water temperature in 76 2-mile segments in the estuary. Hourly results from the computer simulations were averaged over 24-hr periods to determine the daily-averaged and cross-section-averaged water temperature conditions which were presented graphically in Sect. 3.4.5 both as longitudinal distributions along the estuary on mid-month days and as monthly variations at the locations of the major power plants (Figs. 3.4.50-3.4.115) during the six months of the simulation period (April through September) according to 1974 hypothetical river conditions.

Comparisons of the different levels of thermal impact conditions on the Hudson River caused by the eight different cases of power plant operational scenarios considered in the far-field analysis are summarized in tabulated form in Tables 3.4.8-3.4.12 for the mid-month days during the simulation period and at the critical locations of the three major power plants on the estuary. These condensed results of the computer simulations can readily indicate the far-field thermal impact of the different cases of power plant operational conditions based on comparisons to the three base cases - 1, 2, and 3 (Sect. 3.4.5.2). The tabulated values in Tables 3.4.8-3.4.12 contain information according to the following format:

- (1) Each table as a total represents the summary of the reduction of the simulation results of the case under consideration.
- (2) Column 1 represents the three cases, 1, 2, and 3, used as the base cases for the reduction of the results of the case under consideration.

Table 3.4.8. Summary comparison of results for case 4 (full once-through thermal load conditions) with the base cases, 1, 2, and 3 (hypothetical 1974 river conditions)

Case	Location	Condition	Temperature (°F)											
			April 15		May 15		June 15		July 15		August 15		September 15	
			Base case temp	Case 4 diff	Base case temp	Case 4 diff	Base case temp	Case 4 diff	Base case temp	Case 4 diff	Base case temp	Case 4 diff	Base case temp	Case 4 diff
Clean River Conditions (1974)	Roseton/Danskammer	Average	67.24	1.13	57.61	1.27	66.83	1.94	77.09	1.48	79.26	1.76	71.80	1.81
		Maximum	67.58	1.22	57.91	1.37	67.13	1.94	77.45	1.61	79.59	1.68	72.01	1.81
	Indian Point	Average	67.34	2.19	57.25	2.36	67.17	3.94	76.91	3.40	79.28	3.33	71.44	3.36
		Maximum	67.65	2.33	57.81	2.64	68.30	3.84	77.93	3.26	80.06	3.24	72.00	3.44
	Bowline	Average	67.95	2.02	57.75	2.46	68.39	2.83	77.84	2.42	79.86	2.34	71.36	2.67
		Maximum	68.46	1.17	58.35	2.38	69.06	2.76	78.33	2.43	80.17	2.60	71.68	2.84
1974 River Conditions	Roseton/Danskammer	Average	67.40	0.97	57.77	1.11	67.20	1.57	77.53	1.07	79.65	1.37	72.04	1.57
		Maximum	67.76	1.04	58.08	1.20	67.51	2.56	77.82	1.22	79.95	1.32	72.22	1.60
	Indian Point	Average	67.92	1.51	57.52	2.07	68.35	2.76	77.93	2.33	80.48	2.13	72.36	2.44
		Maximum	68.31	1.57	58.13	2.32	69.40	2.74	79.05	2.18	81.25	2.05	72.97	2.47
	Bowline	Average	68.41	1.56	58.14	2.07	69.25	1.97	78.65	1.61	80.70	1.50	72.07	1.97
		Maximum	68.93	1.70	58.74	1.99	69.83	1.99	79.17	1.64	81.12	1.65	72.42	2.10
Proposed ^a Maximum Thermal Load Conditions (1974)	Roseton/Danskammer	Average	67.88	0.49	58.22	0.66	68.44	0.33	78.42	0.17	80.81	0.21	73.21	0.41
		Maximum	68.30	0.50	58.64	0.64	68.77	0.30	78.62	0.44	81.06	0.21	73.44	0.38
	Indian Point	Average	69.21	0.32	59.26	0.33	70.99	0.12	80.14	0.17	82.56	0.05	74.64	0.14
		Maximum	69.66	0.32	60.13	0.32	72.04	0.10	81.12	0.14	83.26	0.04	75.34	0.10
	Bowline	Average	69.83	0.24	59.98	0.23	70.89	0.33	80.15	0.10	82.17	0.03	73.96	0.07
		Maximum	70.39	0.14	60.51	0.22	71.54	0.28	80.72	0.11	82.73	0.04	74.44	0.08

^aGreene County closed cycle, all other power plants once-through cooling.

Table 3.4.9. Summary comparison of results for case 5 (clean river with only Roseton and Danskammer power plants) with the base cases, 1, 2, and 3 (hypothetical 1974 river conditions)

Case	Location	Condition	Temperature (°F)											
			April 15		May 15		June 15		July 15		August 15		September 15	
			Base case temp	Case 5 diff	Base case temp	Case 5 diff	Base case temp	Case 5 diff	Base case temp	Case 5 diff	Base case temp	Case 5 diff	Base case temp	Case 5 diff
Clean River Conditions (1974)	Roseton/Danskammer	Average	47.24	0.56	57.61	0.53	66.83	1.36	77.09	1.14	79.26	1.21	71.80	1.14
		Maximum	47.58	0.65	57.91	0.65	67.13	1.38	77.43	1.10	79.59	1.17	72.01	1.15
	Indian Point	Average	47.34	0.40	57.23	0.61	67.17	0.39	76.91	0.36	79.28	0.31	71.44	0.45
		Maximum	47.65	0.40	57.81	0.59	68.30	0.32	77.98	0.31	80.06	0.25	72.00	0.39
	Bowline	Average	47.95	0.30	57.75	0.48	68.39	0.22	77.84	0.25	79.86	0.16	71.36	0.28
		Maximum	48.46	0.30	58.35	0.46	69.06	0.19	78.38	0.30	80.17	0.20	71.68	0.31
1974 River Conditions	Roseton/Danskammer	Average	47.40	0.40	57.77	0.37	67.20	0.99	77.50	0.73	79.65	0.82	72.04	0.90
		Maximum	47.76	0.47	58.08	0.48	67.51	1.00	77.82	0.71	79.95	0.81	72.22	0.94
	Indian Point	Average	47.92	-0.18	57.52	0.32	68.35	-0.79	77.98	-0.71	80.48	-0.89	72.36	-0.47
		Maximum	48.31	-0.26	58.13	0.27	69.40	-0.78	79.06	-0.77	81.25	-0.94	72.97	-0.58
	Bowline	Average	48.41	-0.16	58.14	0.09	69.25	-0.64	78.65	-0.56	80.70	-0.68	72.07	-0.43
		Maximum	48.93	-0.17	58.74	-0.07	69.83	-0.58	79.17	-0.56	81.12	-0.75	72.42	-0.43
Proposed ^a Maximum Thermal Load Conditions (1974)	Roseton/Danskammer	Average	47.88	-0.08	58.22	-0.06	68.44	-0.25	78.40	-0.17	80.81	-0.34	73.21	-0.27
		Maximum	48.30	-0.07	58.64	-0.08	68.77	-0.26	78.60	-0.07	81.06	-0.30	73.44	-0.28
	Indian Point	Average	49.21	-1.47	59.26	-1.42	70.99	-3.43	80.14	-2.87	82.56	-2.97	74.68	-2.79
		Maximum	49.66	-1.61	60.13	-1.73	72.04	-3.42	81.10	-2.81	83.26	-2.95	75.34	-2.95
	Bowline	Average	49.83	-1.58	59.98	-1.75	70.89	-2.28	80.16	-2.07	82.17	-2.15	73.96	-2.32
		Maximum	50.39	-1.63	60.51	-1.80	71.54	-2.29	80.70	-2.09	82.73	-2.36	74.44	-2.45

^a Greene County closed cycle, all other power plants once-through cooling.

Table 3.4.10. Summary comparison of results for case 5 (clean river with only Bowline power plant) with the base cases, 1, 2, and 3 (hypothetical 1974 river conditions)

Case	Location	Condition	Temperature (°F)											
			April 15		May 15		June 15		July 15		August 15		September 15	
			Base case temp	Case 6 diff	Base case temp	Case 6 diff	Base case temp	Case 6 diff	Base case temp	Case 6 diff	Base case temp	Case 6 diff	Base case temp	Case 6 diff
Clean River Conditions (1974)	Roseton/Danskammer	Average	47.24	0.00	57.61	0.00	66.83	0.02	77.09	0.01	79.26	0.03	71.80	0.03
		Maximum	47.58	0.00	57.91	0.00	67.13	0.02	77.45	0.01	79.59	0.02	72.01	0.02
	Indian Point	Average	47.34	0.02	57.23	0.03	67.17	0.34	76.91	0.29	79.28	0.35	71.44	0.32
		Maximum	47.65	0.01	57.81	0.04	68.30	0.46	77.93	0.40	80.06	0.44	72.00	0.40
	Bowline	Average	47.95	0.38	57.75	0.38	68.39	0.73	77.84	0.64	79.86	0.60	71.36	0.60
		Maximum	48.46	0.40	58.35	0.42	69.06	0.69	78.33	0.61	80.17	0.62	71.68	0.60
1974 River Conditions	Roseton/Danskammer	Average	47.40	-0.16	57.77	-0.16	67.20	-0.35	77.50	-0.40	79.65	-0.36	72.04	-0.21
		Maximum	47.76	-0.18	58.08	-0.17	67.51	-0.36	77.82	-0.38	79.95	-0.34	72.22	-0.19
	Indian Point	Average	47.92	-0.56	57.52	-0.26	68.35	-0.84	77.93	-0.78	80.48	-0.85	72.36	-0.60
		Maximum	48.31	-0.65	58.13	-0.28	69.40	-0.64	79.05	-0.68	81.25	-0.75	72.97	-0.57
	Bowline	Average	48.41	-0.08	58.14	-0.01	69.25	-0.13	78.65	-0.17	80.70	-0.24	72.07	-0.11
		Maximum	48.93	-0.07	58.74	0.03	69.83	-0.18	79.17	-0.18	81.12	-0.33	72.42	-0.14
Proposed ^a Maximum Thermal Load Conditions (1974)	Roseton/Danskammer	Average	47.88	-0.64	58.22	-0.61	68.44	-1.59	78.40	-1.30	80.81	-1.52	73.21	-1.38
		Maximum	48.30	-0.72	58.64	-0.73	68.77	-1.62	78.60	-1.16	81.06	-1.45	73.44	-1.41
	Indian Point	Average	49.21	-1.35	59.26	-2.00	70.99	-3.48	80.14	-2.94	82.56	-2.93	74.68	-2.92
		Maximum	49.66	-2.00	60.13	-2.28	72.04	-3.28	81.10	-2.72	83.26	-2.76	75.34	-2.94
	Bowline	Average	49.83	-1.50	59.98	-1.85	70.89	-1.77	80.16	-1.68	82.17	-1.71	73.96	-2.00
		Maximum	50.39	-1.55	60.51	-1.74	71.54	-1.79	80.70	-1.71	82.73	-1.94	74.44	-2.16

^a Greene County closed cycle, all other power plants once-through cooling.

Table 3.4.11. Summary comparison of results for case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system) with the base cases, 1, 2, and 3 (hypothetical 1974 river conditions)

Case	Location	Condition	Temperature (°F)											
			April 15		May 15		June 15		July 15		August 15		September 15	
			Base case temp	Case 7 diff	Base case temp	Case 7 diff	Base case temp	Case 7 diff	Base case temp	Case 7 diff	Base case temp	Case 7 diff	Base case temp	Case 7 diff
Clean River Conditions (1974)	Roseton/Danskammer	Average	47.24	0.64	57.61	0.61	66.83	1.59	77.09	1.30	79.26	1.52	71.80	1.39
		Maximum	47.58	0.72	57.91	0.73	67.13	1.62	77.43	1.24	79.59	1.43	72.01	1.40
	Indian Point	Average	47.34	1.85	57.23	2.01	67.17	3.47	76.91	2.96	79.28	2.93	71.44	2.93
		Maximum	47.65	2.00	57.81	2.28	68.30	3.27	77.98	2.75	80.06	2.76	72.00	2.95
	Bowline	Average	47.95	1.51	57.75	1.85	68.39	2.02	77.84	1.72	79.86	1.70	71.36	2.00
		Maximum	48.46	1.53	58.35	1.76	69.06	1.94	78.38	1.72	80.17	1.96	71.68	2.20
1974 River Conditions	Roseton/Danskammer	Average	47.40	0.48	57.77	0.45	67.20	1.22	77.50	0.89	79.65	1.13	72.04	1.15
		Maximum	47.76	0.54	58.08	0.56	67.51	1.24	77.82	0.85	79.95	1.07	72.22	1.19
	Indian Point	Average	47.92	1.27	57.52	1.72	68.35	2.29	77.98	1.89	80.48	1.73	72.36	2.01
		Maximum	48.31	1.34	58.13	1.96	69.40	2.17	79.06	1.67	81.25	1.57	72.97	1.98
	Bowline	Average	48.41	1.05	58.14	1.46	69.25	1.16	78.65	0.91	80.70	0.86	72.07	1.29
		Maximum	48.93	1.06	58.74	1.37	69.83	1.17	79.17	0.93	81.12	1.01	72.42	1.46
Proposed ^a Maximum Thermal Load Conditions (1974)	Roseton/Danskammer	Average	47.88	0.00	58.22	0.00	68.44	-0.02	78.40	-0.01	80.81	-0.03	73.21	-0.03
		Maximum	48.30	0.00	58.64	0.00	68.77	-0.02	78.60	-0.07	81.06	-0.04	73.44	-0.03
	Indian Point	Average	49.21	-0.02	59.26	-0.02	70.99	-0.35	80.14	-0.27	82.56	-0.35	74.64	-0.31
		Maximum	49.66	-0.01	60.13	-0.04	72.04	-0.47	81.10	-0.37	83.26	-0.44	75.34	-0.39
	Bowline	Average	49.83	-0.37	59.98	-0.38	70.89	-0.48	80.16	-0.60	82.17	-0.61	73.96	-0.60
		Maximum	50.39	-0.40	60.51	-0.40	71.54	-0.54	80.70	-0.60	82.73	-0.60	74.44	-0.56

^aGreene County closed cycle, all other power plants once-through cooling.

Table 3.4.12. Summary comparison of results for case 3 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system) with the base cases, 1, 2, and 3 (hypothetical 1974 river conditions)

Case	Location	Condition	Temperature (°F)											
			April 15		May 15		June 15		July 15		August 15		September 15	
			Base case temp	Case 8 diff	Base case temp	Case 8 diff	Base case temp	Case 8 diff	Base case temp	Case 8 diff	Base case temp	Case 8 diff	Base case temp	Case 8 diff
Clean River Conditions (1974)	Roseton/Danskammer	Average	47.24	0.64	57.61	0.61	66.83	1.45	77.09	1.22	79.26	1.31	71.80	1.24
		Maximum	47.58	0.72	57.91	0.73	67.13	1.46	77.43	1.18	79.59	1.25	72.01	1.25
	Indian Point	Average	47.34	0.73	57.23	0.02	67.17	1.30	76.91	1.13	79.23	1.14	71.44	1.23
		Maximum	47.65	0.95	57.81	0.96	68.30	1.33	77.58	1.15	80.06	1.13	72.00	1.27
	Bowline	Average	47.95	1.47	57.75	1.13	68.39	1.29	77.84	1.15	79.86	1.06	71.36	1.21
		Maximum	48.46	0.96	58.35	1.13	69.06	1.19	78.38	1.10	80.17	1.13	71.68	1.23
1974 River Conditions	Roseton/Danskammer	Average	47.40	0.48	57.77	0.45	67.20	1.08	77.50	0.31	79.65	0.92	72.04	1.00
		Maximum	47.76	0.54	58.08	0.56	67.51	1.08	77.82	0.79	79.95	0.89	72.22	1.04
	Indian Point	Average	47.92	0.05	57.52	0.63	68.35	0.12	77.98	0.05	80.48	-0.06	72.36	0.31
		Maximum	48.31	0.09	58.13	0.64	69.40	0.23	79.06	0.07	81.25	-0.06	72.97	0.30
	Bowline	Average	48.41	0.46	58.14	0.74	69.25	0.43	78.65	0.54	80.70	0.22	72.07	0.50
		Maximum	48.93	0.49	58.74	0.74	69.83	0.42	79.17	0.51	81.12	0.18	72.42	0.49
Proposed ^a Maximum Thermal Load Conditions (1974)	Roseton/Danskammer	Average	47.88	0.00	58.22	0.00	68.44	-0.16	78.40	-0.09	80.81	-0.24	73.21	-0.17
		Maximum	48.30	0.00	58.64	0.00	68.77	-0.18	78.63	0.01	81.06	-0.22	73.44	-0.18
	Indian Point	Average	49.21	-1.14	59.26	-1.11	70.99	-2.52	80.14	-2.10	82.56	-2.14	74.64	-1.97
		Maximum	49.66	-1.26	60.13	-1.37	72.04	-2.42	81.17	-1.97	83.26	-2.07	75.34	-2.07
	Bowline	Average	49.83	-0.77	59.98	-1.10	70.98	-1.21	80.15	-1.17	82.17	-1.25	73.96	-1.39
		Maximum	50.39	-0.97	60.51	-1.03	71.54	-1.29	80.77	-1.22	82.73	-1.43	74.44	-1.53

^aGreene County closed cycle, all other power plants once-through cooling.

- (3) Column 2 represents three stations along the estuary corresponding to the locations of the three major power plants. The water temperature values at these three locations for each base case are used in the analysis and reduction of the simulation results of the particular case under consideration.
- (4) Column 3 identifies the daily-averaged or daily-maximum water temperature conditions at the three locations for the three base cases, 1, 2, and 3.
- (5) Columns 4-9 contain two subcolumns for the comparison of the temperature values on mid-month days for the six months of the simulations.
 - a. The first subcolumn represents the daily-averaged and daily-maximum water temperatures at the three stations along the estuary for the three base cases, 1, 2, and 3, on the mid-month day of each month. These six columns for each month are identical in Tables 3.4.8-3.4.12, since they are associated with the base cases, 1, 2, and 3.
 - b. The second subcolumn for each month contains the important comparison summary of the simulation results of the case under consideration. The values in this column represent the differences in water temperature in degrees Fahrenheit for the case under consideration and the base case.

Hence, the sum of the first subcolumn and the second subcolumn temperature values corresponds to the actual water temperature for the simulated case at one of the three plant locations along the estuary. The positive values in the second subcolumn indicate that the water temperature conditions resulting from the particular case of plant operational scenario under consideration would be higher than the water temperature conditions for the base case at the common specified base station along the estuary. Conversely, the negative values in the second subcolumn indicate that the water temperature conditions resulting from the particular case of plant operational scenario under consideration would be lower than the water temperature conditions for the base case which is listed in the first subcolumn.

This particular summary form of the reduced results of the computer simulations as temperature difference values rather than actual temperature values directly indicates the relative comparisons of the far-field thermal impact of the different cases.

3.4.6.1 Summary comparison of results for case 4 (full once-through thermal load) conditions. The summary of the reduced computer simulation results for case 4 (full once-through thermal load) conditions on the Hudson River is presented in Table 3.4.8. The plant operational scenario

assumes that all existing and proposed power plants, including Greene County power plant, are operating with once-through plant cooling systems at their full rated power output capacities.

Considering the comparisons first with the base case 1 (clean river) conditions, the maximum differences between the values for the cross-section-averaged and daily-averaged water temperatures at mid-month days will be: (1) Roseton/Danskammer - 1.94°F (June), (2) Indian Point - 3.94°F (June), (3) Bowline - 2.83°F (June).

Hence, the results in Table 3.4.8 indicate that the cumulative far-field thermal impact of the power plant operations according to case 4 (full once-through thermal load conditions, Greene County with once-through plant cooling system) will increase the cross-section-averaged, daily-averaged, and 2-mile-segment-averaged water temperature maximum of 3.94°F above the natural ambient conditions at the location of the Indian Point power plant. This summary comparison for case 4, which represents the worst possible thermal load on the estuary based on already planned plant operation conditions, concludes that the maximum temperature elevation in any 2-mile segment of the river will not exceed 4°F .

The second important comparison, with base case 3 (proposed maximum thermal load, Greene County with closed-cycle plant cooling system), illustrates the additional thermal impact on the estuary which will be caused by the once-through operation of the proposed Greene County power plant. The maximum differences in cross-section-averaged and daily-averaged water temperatures at mid-month days will be: (1) at Roseton/Danskammer: 0.66°F (May), (2) at Indian Point: 0.33°F (May), (3) at Bowline: 0.23°F (May).

Hence, the reduced summary of the computer simulation results in Table 3.4.8 indicates that the additional thermal impact of the Greene County power plant operating with once-through plant cooling system will not cause appreciable increases in the water temperatures above the thermal conditions that would exist at the three stations for case 3 (proposed maximum thermal load Greene County with closed-cycle plant cooling system) plant operational conditions on the estuary. Indeed, the additional far-field thermal impact will be less than 0.5°F at the locations of Indian Point and Bowline power plants.

It is interesting to note that according to the temperature difference values in Table 3.4.8, the differences in the daily-averaged water temperature conditions could be higher than the differences in the daily-maximum water temperature conditions for two different cases of power plant operational conditions. For example, at Bowline Point, for case 4 (full once-through thermal load) and the base case 1 (clean river) conditions, the summary results indicate that the difference in daily-averaged water temperature is 2.83°F , whereas the difference in daily-maximum water temperatures is 2.76°F . Although the difference between the two temperature difference summary results is indeed small, the particular effect illustrates the nonlinear characteristics of the far-field thermal interaction of the power plant discharges on the tidal-flow-dominated estuary.

3.4.6.2 Summary comparison of results for case 5 (clean river with only Roseton and Danskammer power plants). The summary of the reduced computer simulation results for case 5 (clean river with only Roseton and Danskammer power plants operating at full rated output power on the Hudson River) is presented in Table 3.4.9 for the hypothetical 1974 conditions.

Considering the comparisons first with the base case 1 (clean river conditions), the maximum differences between the values for the cross-section-averaged and daily-averaged water temperatures at midmonth days will be: (1) at Roseton/Danskammer: 1.36°F (June), (2) at Indian Point: 0.61°F (May), (3) at Bowline: 0.48°F (May).

Hence, the results indicate that the far-field thermal impact of the operation of Roseton and Danskammer power plants on the river with the hypothetical 1974 conditions will be limited to the vicinity of the location of the plants and the increase in the daily-averaged water temperature will not exceed 1.36°F above the local natural ambient temperature conditions.

The comparison of the summary results of case 5 (clean river with only Roseton and Danskammer power plants) and the base case 2 (1974 river conditions) illustrates the special feature of the particular form of the tabulated values in Tables 3.4.8 – 3.4.12. The temperature difference value for the cross-section-averaged and daily-averaged water temperatures at the location of Roseton and Danskammer plants is indicated as 0.90°F in Table 3.4.9 on the midmonth day in September. This result states that the operation of only Roseton and Danskammer power plants at full rated output capacity on the clean river would have caused temperature conditions in the vicinity of Roseton and Danskammer 0.90°F higher than the temperature conditions that existed at midmonth day in September 1974. However, the temperature difference value for the cross-section-averaged and daily-averaged water temperatures at the location of Indian Point is indicated as -0.89°F on the midmonth day in August. Considering the previous discussion of the format of Tables 3.4.8 – 3.4.12, this result states that the operation of only Roseton and Danskammer power plants at full rated output capacity on the clean river would have caused temperature conditions in the vicinity of Indian Point 0.89°F lower than temperature conditions that existed on the midmonth day in August 1974. Conversely, the result states that the thermal conditions that existed in the vicinity of Indian Point on the midmonth day in August 1974 were 0.89°F higher than the conditions that would have existed at the same location for the hypothetical case 5 (clean river with only Roseton and Danskammer power plants operating at full rated output capacity on the estuary).

The important consequence of comparisons of the results for cases 5 and 2 is that the thermal impact conditions on the Hudson River during the summer months in 1974 were not appreciable. Indeed, the results conclude that the far-field thermal impact of power plant operations during the six months of the 1974 simulation period resulted in elevated water temperature conditions not more than 1°F above the thermal conditions that would have

existed in the river with only Roseton and Danskammer power plants operating at full rated output capacity.

The comparison of the results with base case 3 (proposed maximum thermal load, Greene County with closed-cycle plant cooling system) indicates as expected that the contribution of the Roseton and Danskammer power plants to the cumulative far-field thermal impact on the Hudson River estuary is limited to the immediate vicinity of the power plants. Furthermore, the results also show that the contribution of the thermal impact of the other power plants on the Hudson River is significantly higher (3.43°F at Indian Point) than the maximum thermal impact of 1.36°F caused by the operation of the two power plants on the clean river (see Table 3.4.9).

3.4.6.3 Summary comparison of results for case 6 (clean river with only Bowline power plant). The summary of the reduced computer simulation results for case 6 (clean river with only Bowline power plant operating at full rated output power on the Hudson River) is presented in Table 3.4.10 for the hypothetical 1974 conditions.

Considering the comparisons with the base case 1 (clean river conditions), the maximum differences between the values for the cross-section-averaged and daily-averaged water temperatures at midmonth days will be: (1) at Roseton/Danskammer: 0.03°F (negligible), (2) at Indian Point: 0.35°F (August), (3) at Bowline: 0.73°F (June).

Hence, the results indicate that the far-field thermal impact of the operation of Bowline power plant on the river with the hypothetical 1974 conditions will be limited to the immediate vicinity of the location of the Bowline plant and the increase in the daily-averaged water temperature will not exceed 0.73°F above the natural ambient temperature conditions of the estuary.

The comparisons of the results of case 6 (clean river with only Bowline power plant operating) with all the base cases, 1, 2, and 3 (see Table 3.4.10) conclude that the thermal discharge conditions of the Bowline power plant at full rated output capacity do not have a major contribution to the overall far-field thermal impact of power plant operations on the Hudson River.

3.4.6.4 Summary comparison of results for case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system). The summary of the reduced computer simulation results for case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system) is presented in Table 3.4.11 for the hypothetical 1974 river conditions. This particular plant operational scenario is important in considering alternatives for reducing the overall thermal impact of power plant operations on the Hudson River.

The comparisons of the results for case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system) with the results for the base case 3 (proposed maximum thermal load, only Greene County with closed-cycle plant cooling system) indicate that the reduction in local values of water temperature will not be appreciable for the closed-cycle operation of the Bowline power plant. The computer simulation results (see Table 3.4.11) show that the daily-averaged and cross-section-averaged water temperature in the vicinity of the Bowline Plant will be reduced by a maximum of 0.61°F for the closed-cycle operation of the power plant. Similarly, the daily-averaged and cross-section-averaged water temperature in the vicinity of Indian Point will be reduced by a maximum of 0.35°F on the midmonth day in August. Furthermore, considering the daily maximum water temperature of 83.26°F at the location of the Indian Point plant, the computer simulation results also suggest that the maximum water temperature averaged over the 2-mile segment may be reduced by 0.44°F (see Table 3.4.11) on the midmonth day in August to 82.82°F by the closed-cycle operation of the Bowline power plant.

In view of the fact that the applicable thermal standards limit the maximum water temperature in the estuary to 83°F over areas more than 50% of the cross-sectional area of the estuary, the reduction of the daily-maximum, cross-section-averaged, and 2-mile-segment-averaged water temperature to 82.82°F cannot be considered as an acceptable means of reducing the far-field thermal impact of power plant operations on the Hudson River. Hence, the computer simulation results conclude that the overall far-field thermal impact on the Hudson River cannot be reduced sufficiently to guarantee compliance with the applicable thermal standards by operating the Bowline power plant with a closed-cycle plant cooling system.

3.4.6.5 Summary comparison of results for case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system). The summary of the reduced computer simulation results for case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system) is presented in Table 3.4.12 for the hypothetical 1974 conditions. This particular case represents the most important scenario in the assessment of the far-field thermal impact of power plant operations on the Hudson River.

The important cases for comparison to illustrate the effect of once-through operation of the Indian Point power plant on the far-field thermal impact on the estuary are case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system) and base case 3 (proposed maximum thermal load conditions) (Greene County power plant with closed-cycle plant cooling system for both cases). The summary comparisons of the computer simulation results in Table 3.4.12 indicate that the daily-averaged and cross-section-averaged water temperature conditions in the 2-mile segment of the estuary in the vicinity of Indian Point will be reduced by 2.14°F for the case of operation of the Indian Point power plant with closed-cycle plant cooling system. Furthermore, the results also indicate that the daily-maximum, cross-section-averaged,

and 2-mile-segment-averaged water temperature in the vicinity of Indian Point will be reduced by 2.07°F (see Table 3.4.12) on midmonth day in August when the water temperature in the estuary reaches maximum values. Hence, the far-field thermal conditions in the vicinity of Indian Point will be 80.42°F for the daily-averaged and cross-section-averaged water temperature and 81.19°F for the daily-maximum, cross-section-averaged water temperature within the 2-mile segment of the estuary. These results clearly indicate that the operation of the Indian Point plant with closed-cycle plant cooling system will substantially reduce the thermal impact of power plant operations on the estuary.

The far-field thermal impact of case 8 (proposed maximum thermal load except Indian Point with closed-cycle plant cooling system) can be directly considered by comparing the results with the results of the base case 1 (clean river conditions). The maximum differences between the values for the cross-section-averaged and daily-averaged water temperatures at mid-month days will be: (1) at Roseton/Danskammer: 1.45°F (June), (2) at Indian Point: 1.30°F (June), (3) at Bowline: 1.29°F (June).

Hence, the reduced summary of the computer simulation results also indicates that the far-field thermal impact of case 8 (proposed maximum thermal load except Indian Point with closed-cycle plant cooling system) will raise the values of daily-averaged and cross-section-averaged water temperature not more than 1.5°F along the estuary.

These results are significantly important in view of the statements of the applicable State and Federal standards (see Sect. 3.1). Considering only the 2-mile-segment-averaged values of the cross-section-averaged water temperature, the reduced summary of the computer simulation results (see Table 3.4.12) concludes that the thermal conditions along the estuary will definitely comply with the standards. That is, the elevated temperature levels will not exceed 4°F above "the temperature that existed before the addition of heat of artificial origin," and furthermore, the maximum temperature will not exceed 83°F over areas exceeding "50 percent of the cross-sectional area of the estuary." Hence, considering the thermal conditions in the river based only on 2-mile-segment-averaged and cross-section-averaged values of either daily-averaged or daily-maximum water temperatures, the far-field thermal impact of power plant operation conditions according to case 8 (proposed maximum thermal load except Indian Point power plant with closed-cycle plant cooling system) will definitely comply with the limitations of the applicable State and Federal thermal standards (see Sect. 3.1). The variation of the water temperature conditions within the 2-mile segments of the estuary cannot be estimated based on the computer simulation results from the far-field ESTONE model. The detailed two-dimensional distributions of the water temperature conditions in the vicinities of the power plants will be studied in the subsequent sections in order to accurately determine the thermal impact of power plant operations on the Hudson River.

3.4.6.6 Maximum water temperature conditions for the plant operational cases. The computer simulation results from the far-field model ESTONE for the 183 days of the computer simulation period were analyzed to determine

the maximum values of the daily-averaged and daily-maximum water temperature conditions at three stations along the estuary corresponding to the locations of the three major power plants considered in the study. The maximum values of the water temperatures were determined for all eight cases considered in the assessment of the far-field thermal impact (see Table 3.4.13). The day when the maximum daily-averaged temperature occurred was not necessarily the same day when the daily-maximum temperature occurred at a location. Furthermore, the days of occurrence of maximum temperature values for different locations were different for the different cases of the plant operational conditions. However, for all plant operational cases and at all locations, both the maximum daily-averaged and the daily-maximum values of water temperatures occurred during the period approximately from July 15 through August 21 for the hypothetical 1974 river conditions.

The computer simulation results in Table 3.4.13 indicate that the critical maximum temperature conditions which exceed the 83°F limit of the State and Federal thermal standards occurred only for the three cases corresponding to high thermal load conditions on the estuary. For case 3 (proposed maximum thermal load), the daily-maximum, cross-section-averaged, and 2-mile-segment-averaged water temperatures are 83.80°F and 83.25°F at the locations of Indian Point and Bowline power plants, respectively. For case 4 (full once-through thermal load, Greene County power plant with once-through plant cooling system), the daily-maximum, cross-section-averaged, and 2-mile-segment-averaged water temperatures are 83.87°F and 83.28°F at the locations of Indian Point and Bowline power plants, respectively. Hence, the computer simulation results clearly establish that the far-field thermal interaction between Greene County power plant and Indian Point and Bowline power plants is completely negligible based on maximum water temperature considerations in the Hudson River.

The computer simulation results in Table 3.4.13 also indicate that for case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system), the daily-maximum, cross-section-averaged, and 2-mile-segment-averaged values of water temperature will be 83.42°F at the location of the Indian Point power plant.

The most important consequence of the computer simulation results of the far-field thermal analysis is that the maximum water temperature values that could occur in the Hudson River for the hypothetical 1974 conditions will exceed the 83°F maximum temperature limitation of the applicable thermal standards with very small temperature differences (less than 1°F). Hence, the critically important issue about compliance with the statements of the State and Federal standards about 83°F maximum conditions cannot be determined for the different cases based only on the assessment of the far-field thermal impact of power plant operations on the Hudson River.

3.4.6.7 Conclusions based on the results of the far-field analysis.
The computer simulation results by the far-field ESTONE model for the cross-section-averaged and 2-mile-segment-averaged water temperature conditions lead to the following conclusions about the far-field thermal impact of power plant operations on the Hudson River:

Table 3.4.13. Maximum water temperature conditions at the locations of three major power plants for all plant operational cases (hypothetical 1974 river conditions)

	Roseton/Danskammer (Element 44)		Indian Point (Element 55)		Bowline (Element 58)	
	<u>Temperature</u> Average Maximum		<u>Temperature</u> Average Maximum		<u>Temperature</u> Average Maximum	
Case 1 - Clean River (1974)	79.63	79.82	79.57	80.49	80.41	80.92
Case 2 - 1974 River Conditions	80.07	80.35	80.52	80.99	80.80	81.56
Case 3 - Proposed Maximum Thermal Load (1974)	81.12	81.42	82.91	83.80	82.73	83.25
Case 4 - Full Once-Through Thermal Load (1974)	81.35	81.57	82.97	83.87	82.76	83.28
Case 5 - Clean River with Roseton/Danskammer (1974)	80.85	81.14	79.51	80.78	80.59	81.09
Case 6 - Clean River with Bowline (1974)	79.66	79.93	79.88	80.89	81.02	81.56
Case 7 - Proposed Maximum Thermal Load Except Bowline Closed-Cycle	81.09	81.39	82.59	83.42	82.12	82.63
Case 8 - Proposed Maximum Thermal Load Except Indian Point Closed-Cycle	80.93	81.22	80.70	81.66	81.48	82.00

1. The far-field thermal impact of power plant operations during the period April through September 1974 was extremely low. Although 1974 was a typical year for the natural conditions in the estuary and the region, the thermal load on the river was extremely low in comparison to the rated output capacity of the existing power plants.

2. Based on hypothetical 1974 river conditions, for case 3 (proposed maximum thermal load, Greene County power plant with closed-cycle plant cooling system) (see Table 3.4.13), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature conditions in the estuary will not exceed the limit of elevated temperature level 4°F above "the temperature that existed before the addition of the heat of artificial origin" (clean river conditions) as stated by the applicable State and Federal standards (see Sect. 3.1).

3. Based on hypothetical 1974 river conditions, for case 4 (full once-through thermal load, Greene County power plant with once-through plant cooling system) (see Table 3.4.13), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature conditions in the estuary will not exceed the limit of the elevated temperature level 4°F above "the temperature that existed before the addition of the heat of artificial origin" (clean river conditions) as stated by the applicable State and Federal standards (see Sect. 3.1).

4. Based on hypothetical 1974 river conditions, for case 3 (proposed maximum thermal load), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature conditions will exceed the limit of "a maximum of 83°F" over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1).

5. Based on hypothetical 1974 river conditions, for case 4 (full once-through thermal load, Greene County power plant with once-through plant cooling system), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature conditions will exceed the limit of "a maximum of 83°F" over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1).

6. Based on hypothetical 1974 river conditions, for case 7 (proposed maximum thermal load except Bowline power plant with closed-cycle plant cooling system) (see Table 3.4.13), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature conditions will exceed the limit of "a maximum of 83°F" over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1). Hence, the operation of the Bowline power plant with closed-cycle plant cooling system will not be a feasible alternative for the reduction of the far-field thermal impact on the Hudson River.

7. Based on hypothetical 1974 river conditions, for case 8 (proposed maximum thermal load except Indian Point power plant with closed-

cycle plant cooling system) (see Table 3.4.13), the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature conditions will be approximately 2°F lower than the case with once-through plant cooling system, and they will definitely comply with the limit of "a maximum of 83°F" over areas exceeding "50 percent of the cross-sectional area of the estuary" as stated by the applicable State and Federal standards (see Sect. 3.1). Hence, the operation of the Indian Point power plant with closed-cycle plant cooling system will be a feasible alternative for the reduction of the thermal impact on the Hudson River.

8. Based on hypothetical 1974 river conditions, operation of Greene County with once-through plant cooling system will not result in appreciable elevation of temperature conditions in the river; hence, it will not have any critical effect on the far-field thermal impact conditions on the Hudson River.

9. The results of the far-field thermal analysis conclude that the predicted thermal conditions in the estuary are extremely close to the limiting conditions of the applicable State and Federal standards. Hence, more accurate thermal analysis is needed to determine the actual thermal impact of power plant operations on the Hudson River.

The results of the far-field thermal impact analysis will be supplemented by zone-matched near-field and far-field analysis in the subsequent sections.

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3.5 Zone-Matched Near-Field and Far-Field Analysis of the Thermal Impact on the Hudson River

The complete analysis of the thermal impact of power plant operations on the Hudson River requires the near-field and the far-field analyses to be supplemented by a zone-matched near-field and far-field analysis in order to take into account the critically important effects of reentrainment and recirculation, which control the behavior of the thermal discharges under the influence of the reversing flow conditions in the tidal-dominated estuary. The systematic methodology employed in the application of the zone-matched near-field and far-field analysis was developed as a part of the "Unified Transport Approach" (UTA) research project for the development of transport models for the realistic assessment of the thermal, chemical, radiological, and biological impact of power plant operations on the aquatic ecology of large receiving water bodies¹ (funded by the Health and Environmental Research Branch, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission). The simulation of the flow fields in different regions of the estuary was based on the model developed as a part of the "Development of Mathematical Models and General Usage Computer Codes for Predicting Entrainment and Impingement Losses at Power Plants" project (funded by the National Power Plant Team, Office of Biological Services, Fish and Wildlife Service, U.S. Department of the Interior).

3.5.1 Discussion of the thermal problems for the large regions of receiving water body in the estuary

The assessment of the thermal impact of power plant discharges into regions with severe reversing flow conditions in the Hudson River requires the consideration of certain unique problems which are different from the ones encountered in the analysis of discharges into uniformly flowing regions. The overall method of assessment of the thermal impact requires the identification and careful consideration of these problems before the selection of mathematical models.

Reentrainment (physical problem). The near-field dilution of the thermal discharge requires careful consideration of the reversing flow conditions in the Hudson River. Uniform values for the dilution ratios cannot be estimated under reversing cross-flow conditions. Furthermore, during different times within the periods of flow reversals, previously heated discharge water usually mixes with the locally "ambient" water entrained by the discharge. Hence, the reentrainment phenomena could appreciably reduce the overall effect of near-field dilution under reversing flow conditions in the estuary.

Recirculation (physical problem). The temperature of the intake water of a power plant on the Hudson River cannot be estimated at a specified value based on ambient conditions. Previously heated discharge water usually mixes with the natural ambient water to raise the temperature of the intake water during certain times within the periods of

flow reversals. The recirculation effects still exist even under conditions when the discharge and the intake are separated more than the excursion distance associated with the reversing flow periods due to the turbulent diffusion effects.

Thermal interaction (physical problem). The existence of more than one power plant on the body of receiving water in the Hudson River results in appreciable thermal interaction between the power plants due to periodically reversing flow conditions. Previously heated discharge water from different power plants enters the intakes of other plants and causes increases in the intake temperatures. Furthermore, the thermal interaction also reduces the near-field dilution of different discharges caused by the mixing of the locally "ambient" entrained water with the previously heated water from the discharges of other plants.

Delay in the attainment of thermal equilibrium conditions (physical problem). The locations of the thermal plumes continuously change under reversing flow conditions, causing continuously changing temperature distributions in large regions of the Hudson River during the periods of flow reversals. Therefore, attainment of quasi-steady-state thermal equilibrium conditions in the large regions requires long periods of time, over numerous flow reversal periods. Hence, the far-field thermal effects of power plant discharges into the large regions of the estuary with reversing tidal flow conditions cause gradually increasing background temperatures which cannot be easily detected in the near-field zones and within the individual periods of flow reversals.

Uncertainty in specifying open boundaries and open boundary conditions (mathematical problem). The selection of the sizes of the regions for the assessment of the thermal impact of power plant discharges inherently depends on the reversing flow conditions in the vicinity of the power plant on the Hudson River. The excursion distances during the reversal periods dictate the minimum dimensions of the regions. Unrealistically small region boundaries at relatively high temperatures could cause significant errors in thermal impact analyses. Furthermore, under reversing flow conditions, open boundaries cannot be classified as "inflow" or "outflow" boundaries since the directions of the flow across the boundaries reverse during the period of flow reversals. Hence, accurate timewise variations of temperature conditions cannot be assigned to the boundaries, since the flow conditions in the regions influence the conditions on the boundaries depending on whether the boundaries are at "inflow" or "outflow" conditions at different times within the periods.

3.5.2 Review of existing studies concerned with the modeling of transient two-dimensional distributions of temperature conditions in the Hudson River

The early studies of the behavior of the thermal plumes from the power plant discharges on the Hudson River are limited strictly to near-field analyses which determine the cooling of the heated discharge water

due to the dilution with the local ambient water. The discussions of these studies were presented in Sect. 3.3 as a part of the nearfield analysis of the discharges of the major power plants on the estuary.

A study of the mathematical modeling of the tidal-transient two-dimensional distributions of the temperature conditions in the region of the Indian Point, Lovett, and Bowline power plants in the Hudson River was recently presented in ref. 2 based on the application of the model developed by Boericke et al.^{3,4} The results of this limited study and the discussions of the features of the model were presented in Sect. 3.4.1. The necessary verification study of the model has now been completed to justify its applicability to the assessment of the thermal impact of the power plant operations on the Hudson River.

The physical modeling studies of the hydrodynamic conditions in the vicinities of the major power plants can only approximately determine the intake and discharge flow fields in the limited regions of the estuary (e.g., see ref. 5). The application of the physical models directly to the estimation of the temperature conditions in the Hudson River cannot be accepted as an accurate method of analysis of the thermal impact conditions, since the unavoidable scaling problems associated with the turbulent transport phenomenon and the surface heat transfer conditions usually render the laboratory models unreliable in simulating the actual thermal conditions in the estuary.

3.5.3 Summary of the near-field and far-field zone-matching methodology for the application of multidimensional models in the assessment of thermal impact

The accurate assessment of the thermal impact of power plant operations on the Hudson River requires at least two-dimensional distributions of the water temperature conditions in the vicinities of the major power plants. This requirement is dictated by the results of the far-field thermal analysis (see Sect. 3.4), which necessitates the accurate representation of the temperature conditions within the 2-mile segments of the estuary to check the compliance of the plant operational conditions with the elevated-temperature limitations of the applicable State and Federal thermal standards (see Sect. 3.1), which also limit the areas to "50 percent of the cross-sectional area of the estuary." Hence, the complete study of the thermal impact of the power plant operations on the Hudson River requires the application of tidal-transient multidimensional hydrodynamic and thermal models based on a systematic methodology (see ref. 6).

The far-field thermal impact analysis of the power plant operations according to the tidal-transient one-dimensional farfield ESTONE model (see Sect. 3.4) supplies the following necessary information for the subsequent application of the multidimensional models:

Estimation of size of region. Distance of the tidal excursion (or maximum distance traveled during flow reversals) determines the minimum length of the region for multidimensional models.

Approximate specification of boundary conditions. Temporal variations within the tidal cycle (or within the period of reversal) for surface elevation, flow rate (velocity), and temperature approximately specify the necessary open boundary conditions.

Approximate specification of initial conditions. The results for temporal variations within the tidal cycle specify approximate initial conditions in the region.

The zone-matching methodology is based on the following propositions for specifying the necessary flow conditions in the region:

A. Determination of far-field flow conditions. By excluding the effects of plant-induced flow conditions, (1) determine the reversing flow field in the region in terms of tidal harmonics (or according to known periods of reversals) as a part of the far-field flow conditions and (2) determine the mean flow field (e.g., freshwater flow) as a part of the far-field flow conditions. This step completes the approximate specification of the far-field effects.

B. Determination of near-field flow conditions. By excluding the effects of far-field flow conditions, (3) determine the discharge flow fields based on near-field models and (4) determine the residual flow conditions imposed on the enclosure boundaries of the region in the far-field zone according to the solutions of the near-field models. This step completes the approximate specification of the near-field discharge effects.

C. Determination of the near-field-induced far-field flow conditions. (5) Determine the necessary far-field flow conditions which will eliminate the residual flow conditions imposed on the boundaries of the region by the near-field flow conditions of the discharges (corrective far-field solution) and (6) determine the far-field flow field induced by the intakes. This step completes the approximate formulation of all the necessary parts for the specification of the complete flow field in the region.

D. Superposition postulate. (7) Determine the complete flow field in the region based on the superposition of all the far-field and near-flow conditions in the region.

The subsequent discussion of this study will not elaborate on the mathematical details of the propositions; rather it will summarize the important computational features of the various discrete-element models which will be employed in determining the different flow fields in the near-field and the far-field zones in the application of the zone-matching methodology.

3.5.3.1 Determination of the far-field flow conditions. The simulation of the reversing flow conditions in the far-field zone employs a fast-transient (tidal-transient) two-dimensional, multilayer discrete-element model based on the extension of the one-dimensional ESTONE model. The model considers four equations for the horizontal component of the flow rates, with a typical one as:

Equation for flow rate along x direction

$$\begin{aligned}
 \frac{\partial \bar{G}_{x;i\pm 1/4,j}^{(\ell)}}{\partial t} = & \frac{1}{\Delta x_{i,j}} \left\{ \pm 2 [\bar{G}_{x;i,j}^{(\ell)} \bar{V}_{x;i,j}^{(\ell)} - \bar{G}_{x;i\pm 1/2,j}^{(\ell)} \bar{V}_{x;i\pm 1/2,j}^{(\ell)}] \right. \\
 & + [\bar{G}_{y;i,j-1/2}^{(\ell)} \bar{V}_{x;i\pm 1/4,j-1/2}^{(\ell)} - \bar{G}_{y;i,j+1/2}^{(\ell)} \bar{V}_{x;i\pm 1/4,j+1/2}^{(\ell)}] \\
 & + [\bar{G}_{srf;i,j}^{(\ell)} \bar{V}_{srf,x;i\pm 1/4,j}^{(\ell)} - \bar{G}_{bot;i,j}^{(\ell)} \bar{V}_{bot,x;i\pm 1/4,j}^{(\ell)}] \Big\} \\
 & + \frac{g_c}{\rho \Delta x_{i,j}} \left(\pm 2 \left\{ \Delta y_{i,j} \bar{D}_{i,j}^{(\ell)} [\bar{P}_{i,j}^{(\ell)} - \bar{P}_{i\pm 1/4,j}^{(\ell)}] \right. \right. \\
 & - \Delta y_{i-1/2,j} \bar{D}_{i-1/2,j}^{(\ell)} [\bar{P}_{i-1/2,j}^{(\ell)} - \bar{P}_{i\pm 1/4,j}^{(\ell)}] \Big\} \\
 & + \Delta x_{i,j-1/2} \bar{V}_{x;i,j-1/2} [\bar{P}_{i,j+1/2}^{(\ell)} - \bar{P}_{i\pm 1/4,j}^{(\ell)}] \\
 & \left. \left. - \Delta x_{i,j+1/2} \bar{V}_{x;i,j+1/2} [\bar{P}_{i,j+1/2}^{(\ell)} - \bar{P}_{i\pm 1/4,j}^{(\ell)}] \right) \right. \\
 & + \frac{1}{\Delta x_{i,j}} \left\{ \pm 2 [\bar{F}_{xx;i,j}^{(\ell)} - \bar{F}_{xx;i\pm 1/2,j}^{(\ell)} + \bar{G}_{xx;i,j}^{(\ell)} - \bar{G}_{xx;i\pm 1/2,j}^{(\ell)}] \right. \\
 & + [\bar{F}_{yx;i,j-1/2}^{(\ell)} - \bar{F}_{yx;i,j+1/2}^{(\ell)} + \bar{G}_{yx;i,j-1/2}^{(\ell)} - \bar{G}_{yx;i,j+1/2}^{(\ell)}] \\
 & + [\bar{F}_{srf,x;i,j}^{(\ell)} + \bar{F}_{bot,x;i,j}^{(\ell)} + \bar{G}_{srf;i,j}^{(\ell)} + \bar{G}_{bot;i,j}^{(\ell)}] \Big\} \\
 & + \frac{\delta_{int,m;i,j}^{(\ell)}}{\Delta x_{i,j}} \bar{G}_{int,m} \bar{V}_{int,x,m;i,j}^{(\ell)} + \frac{\delta_{dis,m;i,j}^{(\ell)}}{\Delta x_{i,j}} \bar{G}_{dis,m} \bar{V}_{dis,x,m}^{(\ell)} \quad (3.20)
 \end{aligned}$$

with a similar expression for the flow rates along the y direction. The variables in Eq. (3.20) are similar to the ones in the one-dimensional model, Eq. (3.2), except for

$D_{i,j}^{(\ell)}$: depth of the discrete element,

$P_{i,j}^{(\ell)}$: pressure in the discrete element,

$\overline{F}_{xx;i,j}^{(\ell)}$: turbulent normal stress along x direction,

$\overline{F}_{yx;i,j}^{(\ell)}$: turbulent shear stress along y direction.

The mass conservation conditions on the surface are considered similar to the one-dimensional model for the solution of the surface elevation in two dimensions; i.e.,

Surface elevation equation

$$\begin{aligned} \frac{\partial \bar{H}_{i,j}}{\partial t} = & \frac{1}{\Delta x_{i,j} \Delta y_{i,j}} (\bar{G}_{x;i-1/2,j} - \bar{G}_{x;i+1/2,j} + \bar{G}_{y;i,j-1/2} - \bar{G}_{y;i,j+1/2}) \\ & + \frac{\delta_{int,m;i,j}}{\Delta x_{i,j} \Delta y_{i,j}} \bar{G}_{int,m} + \frac{\delta_{dis,m;i,j}}{\Delta x_{i,j} \Delta y_{i,j}} \bar{G}_{dis,m} + \bar{g}_{rnf} + \bar{g}_{bot;i,j} . \end{aligned} \quad (3.21)$$

The vertical flow rates in different layers are determined by considering the mass conservation equations by starting with the bottom layer, where the bottom flow rate corresponds to the seepage flow. Similarly, the vertical components of the nonconvective transport rates $\overline{Q}_{2;i,j}^{*}$ are considered in terms of bottom and surface nonconvective transport models. Hence, the formulation of the terms associated with the transport in the vertical direction in different layers can be summarized as;

For bottom layer ($\ell = 1$):

$$\overline{G}_{bot;i,j}^{(1)} = \Delta x_{i,j} \Delta y_{i,j} \bar{g}_{bot} , \quad (3.22)$$

$$\overline{G}_{bot;i,j}^{*(1)} = 0 , \quad (3.23)$$

$$\begin{aligned}\bar{G}_{\text{srf};i,j}^{(1)} = & -\bar{G}_{\text{bot};i,j}^{(1)} + \bar{G}_{i-1/2,j}^{(1)} - \bar{G}_{i+1/2,j}^{(1)} + \bar{G}_{i,j-1/2}^{(1)} - \bar{G}_{i,j+1/2}^{(1)} \\ & + \delta_{\text{int};m;i,j}^{(1)} \bar{G}_{\text{int},m}^{(1)} + \delta_{\text{dis},m;i,j}^{(1)} \bar{G}_{\text{dis},m}^{(1)},\end{aligned}\quad (3.24)$$

$$\bar{Q}_{\text{srf};i,j}^{(1)} = \bar{Q}_{z;i,j}^{(1+1/2)} \quad (\text{determined according to turbulent transport formulation}). \quad (3.25)$$

For internal layers ($1 < \ell < L$):

$$\bar{G}_{\text{bot};i,j}^{(\ell)} = \bar{G}_{\text{srf};i,j}^{(\ell-1)}, \quad (3.26)$$

$$\bar{Q}_{\text{bot};i,j}^{(\ell)} = \bar{Q}_{\text{srf};i,j}^{(\ell-1)}, \quad (3.27)$$

$$\begin{aligned}\bar{G}_{\text{srf};i,j}^{(\ell)} = & -\bar{G}_{\text{bot};i,j}^{(\ell)} + \bar{G}_{i-1/2,j}^{(\ell)} - \bar{G}_{i+1/2,j}^{(\ell)} + \bar{G}_{i,j-1/2}^{(\ell)} - \bar{G}_{i,j+1/2}^{(\ell)} \\ & + \delta_{\text{int};m;i,j}^{(\ell)} \bar{G}_{\text{int},m}^{(\ell)} + \delta_{\text{dis},m;i,j}^{(\ell)} \bar{G}_{\text{dis},m}^{(\ell)},\end{aligned}\quad (3.28)$$

$$\bar{Q}_{\text{srf};i,j}^{(\ell)} = \bar{Q}_{z;i,j}^{(\ell+1/2)} \quad (\text{determined according to turbulent transport formulation}). \quad (3.29)$$

For surface layer ($\ell = L$):

$$\bar{G}_{\text{bot};i,j}^{(L)} = \bar{G}_{\text{srf};i,j}^{(L-1)}, \quad (3.30)$$

$$\bar{Q}_{\text{bot};i,j}^{(L)} = \bar{Q}_{\text{srf};i,j}^{(L-1)}, \quad (3.31)$$

$$\bar{G}_{\text{srf};i,j} = \Delta x_{i,j} \Delta y_{i,j} \bar{g}_{\text{rnf}}, \quad (3.32)$$

$$\bar{Q}_{\text{srf};i,j}^{(L)} = \Delta x_{i,j} \Delta y_{i,j} \bar{q}_{\text{srf};i,j}, \quad (3.33)$$

It must be emphasized that the present model for the simulation of the hydrodynamic conditions is not a real three-dimensional model since the vertical component of the momentum equation is discarded in comparison to the horizontal components of the momentum. Hence, the model

cannot accurately predict flow conditions in regions when the vertical velocity is of the same order of magnitude as the horizontal components. However, in general the model can be employed with reasonable accuracy to simulate the far-field reversing flow conditions in the Hudson River. Furthermore, it is usually sufficient to consider the model as a single-layer, two-dimensional model with appropriate assumptions of self-similar distributions of velocity in the vertical direction for generating the necessary data for the flow conditions as input to the thermal models. Particularly, in regions with severe reversing flow conditions, the multilayer flows in different directions can exist only for short durations during slack water conditions. Hence, the two-dimensional simulations of the flow conditions can be considered as reasonable approximations of the actual three-dimensional flow fields.

To determine the far-field reversing flow conditions, the fast-transient (tidal-transient) two-dimensional, multilayer hydrodynamic model needs to be applied only for short durations (preferably within one period of the flow reversals) to obtain the maximum flood and ebb conditions in the estuary. Based on the results of the short-term application of the hydrodynamic model, the amplitudes of the velocity components in the discrete elements can be specified as input data to the thermal model. Furthermore, considering the results of the one-dimensional model and the two-dimensional short-time simulations, appropriate lag times for the velocity components in the discrete element can also be determined. The above-outlined procedure can be repeated more than once to obtain the components of the velocity and lag times for more than one harmonic. Therefore, for the long-time simulations of the periodically reversing flow conditions, the input data to the thermal models can be formulated as;

$$\begin{aligned} \bar{v}_{x;i,j}^{(\ell)} &= \sum_{r=1}^{Nr} \bar{v}_{x,max;i,j}^{(\ell)} \cos \frac{2\pi}{T_{rev}} (t - \tau_{r,x;i,j}) , \\ \bar{v}_{y;i,j}^{(\ell)} &= \sum_{r=1}^{Nr} \bar{v}_{y,max;i,j}^{(\ell)} \cos \frac{2\pi}{T_{rev}} (t - \tau_{r,y;i,j}) . \end{aligned} \quad (3.34)$$

In the application of the model, the magnitudes of the velocity components in Eq. (3.34) could also vary during long-term simulations. For the Hudson River, this variation usually occurs over the complete region, and it is usually directly proportional to the amplitude of the reversing flow in the region. To include this usually secondary effect, the magnitudes of the velocity components are formulated in terms of a reference flow rate and intermittently specified flow rates as;

$$\bar{V}_{x,max;i,j}^{(\ell)} = \left[\bar{V}_{x,max;i,j}^{(\ell)} \right]_{ref} \frac{\bar{G}_{max}(t)}{\bar{G}_{max,ref}}, \quad (3.35)$$

$$\bar{V}_{y,max;i,j}^{(\ell)} = \left[\bar{V}_{y,max;i,j}^{(\ell)} \right]_{ref} \frac{\bar{G}_{max}(t)}{\bar{G}_{max,ref}}.$$

Therefore, the reversing far-field tidal flow conditions in the estuary can be approximated by various harmonic terms based on the short-time application of the hydrodynamic model.

The detailed flow field for the freshwater flow in the Hudson River can also be determined by the application of the fast-transient two-dimensional, multilayer hydrodynamic model for short durations. Similar to the procedure for the reversing flow field, the mean flow field can also be approximated based on intermittently specified flow rates in the region as;

$$\bar{V}_{x,mf1;i,j}^{(\ell)} = \left[\bar{V}_{x,mf1;i,j}^{(\ell)} \right]_{ref} \frac{\bar{G}_{mf1}(t)}{\bar{G}_{mf1,ref}}, \quad (3.36)$$

$$\bar{V}_{y,mf1;i,j}^{(\ell)} = \left[\bar{V}_{y,mf1;i,j}^{(\ell)} \right]_{ref} \frac{\bar{G}_{mf1}(t)}{\bar{G}_{mf1,ref}}.$$

In the assessment of the thermal impact of power plant operations on the Hudson River, the approximate formulation [Eqs. (3.34)-(3.36)] of the flow fields according to the above-outlined procedure saves substantial computer time and cost in the long-time simulations of the thermal discharge conditions from different power plants at different locations on the estuary.

3.5.3.2 Determination of near-field flow conditions. The mathematical models for the simulation of the near-field flow of the discharges⁷ can be employed directly in the zone-matching methodology provided that the consequences of the limitations of the models are carefully considered in the construction of the complete flow fields in the regions.

3.5.3.3 Determination of the near-field-induced far-field flow conditions. The far-field flow conditions induced by the near-field discharge flows are based on the application of the uniformly valid singular perturbation theory.⁸ In general, the far-field effects of the

discharge flows cause reasonably slow velocity conditions in the large regions, with small inertia effects; therefore, the solution of these flow fields does not necessarily require complex hydrodynamic models.

A time-dependent two-dimensional model for simulating the far-field effects of plant-induced flow conditions was developed for the zone-matching methodology for application to large regions with geometrically complex boundary conditions. The model considers the reduced forms of the momentum equations with the inertia terms neglected.⁶

$$\frac{\partial \bar{H}_{i,j}}{\partial t} = \frac{1}{\Delta x_{i,j} \Delta y_{i,j}} (\bar{G}_{x;i-1/2,j} - \bar{G}_{x;i+1/2,j} + \bar{G}_{y;i,j-1/2} - \bar{G}_{y;i,j+1/2}) + \frac{\delta_{int,m;i,j}}{\Delta x_{i,j} \Delta y_{i,j}} \bar{G}_{int,m} + \frac{\delta_{dis,m;i,j}}{\Delta x_{i,j} \Delta y_{i,j}} \bar{G}_{dis,m} + \bar{g}_{rnf} + \bar{g}_{bot;i,j}, \quad (3.37)$$

$$\frac{\partial \bar{G}_{x;i\pm 1/2,j}}{\partial t} = \pm \frac{g_c}{\Delta x_{i\pm 1/2,j}} [\Delta y_{i,j} \bar{D}_{i,j} (\bar{H}_{i,j} - \bar{H}_{i\pm 1/2,j}) - \Delta y_{i\pm 1,j} \bar{D}_{i\pm 1,j} (\bar{H}_{i\pm 1,j} - \bar{H}_{i\pm 1/2,j})] + \Delta y_{i\pm 1/2,j} \bar{f}_{bot;i\pm 1/2,j}, \quad (3.38)$$

$$\frac{\partial \bar{G}_{y;i,j\pm 1/2}}{\partial t} = \pm \frac{g_c}{\Delta y_{i,j\pm 1/2}} [\Delta x_{i,j} \bar{D}_{i,j} (\bar{H}_{i,j} - \bar{H}_{i,j\pm 1/2}) - \Delta x_{i,j\pm 1} \bar{D}_{i,j\pm 1} (\bar{H}_{i,j\pm 1} - \bar{H}_{i,j\pm 1/2})] + \Delta x_{i,j\pm 1/2} \bar{f}_{bot;i,j\pm 1/2}. \quad (3.39)$$

The limiting time ($t \rightarrow \infty$) behavior of the solutions from the model [Eqs. (3.37)-(3.39)] represents the solutions of the generalized Poisson's equation; therefore, the model can also be used to simulate the potential flow conditions in large regions.

The simulation of the thermal conditions in the large regions of the Hudson River requires long periods of the application of the thermal models, during which time the operational conditions of the plants vary considerably (see Sect. 3.4). Hence, in the application of the zone-matching methodology the changes of the plant-induced flow conditions in the region due to the changes of the operational conditions of the plants are approximated by scaling the flow field based on the flow rates; i.e.:

$$\bar{v}_{x,int;i,j} = \left[\bar{v}_{x,int;i,j} \right]_{ref} \frac{\bar{G}_{int}(t)}{\bar{G}_{int,ref}}, \quad (3.40)$$

$$\bar{v}_{y,int;i,j} = \left[\bar{v}_{y,int;i,j} \right]_{ref} \frac{\bar{G}_{int}(t)}{\bar{G}_{int,ref}}.$$

with similar expressions for the discharge-induced velocity components.

3.5.3.4 Superposition of the flow fields. The complete flow field in the large regions of the estuary is determined according to the superposition postulate of the zone-matching methodology. The justification of the superposition of the near-field and far-field flow conditions is based on the fundamental assumptions of the uniformly valid singular perturbation theory; therefore, it can be rigorously established. The superposition of the induced flow fields of the different power plants is a more formal proposition which cannot be established based on rigorous mathematical derivation. However, considering that for slow flow conditions, when the inertia terms can be neglected, the momentum equations become approximately linear, it can be formally accepted that the superposition of the different flow fields could approximate the actual complete flow field in the large region.

According to the outlined procedure of the zone-matching methodology, the detailed fast-transient two-dimensional flow conditions in the Hudson River can be described for reasonably long periods of time without requiring continuous application of complex hydrodynamic models to generate the flow conditions in the region.

3.5.3.5 Tidal-transient two-dimensional, multilayer discrete-element transport model. The mathematical model employed in the simulation of temperature distributions in the large regions of the Hudson River is a fast-transient (tidal-transient) two-dimensional, multilayer discrete-element model consistent with all other mathematical models employed in the unified transport approach.¹ The formulation of the multidimensional model⁶ is completely consistent with the thermal transport part of the one-dimensional ESTONE far-field model (see Sect. 3.4).

Temperature equation

$$\begin{aligned}
\frac{\partial \bar{T}_{i,j}^{(\ell)}}{\partial t} = & \frac{1}{\Delta x_{i,j} \Delta y_{i,j} \bar{D}_{i,j}^{(\ell)}} \left\{ \bar{G}_{x;i-1/2,j}^{(\ell)} [\hat{T}_{i-1/2,j}^{(\ell)} - \bar{T}_{i,j}^{(\ell)}] \right. \\
& - \bar{G}_{x;i+1/2,j}^{(\ell)} [\hat{T}_{i+1/2,j}^{(\ell)} - \bar{T}_{i,j}^{(\ell)}] + \bar{G}_{y;i,j-1/2}^{(\ell)} [\hat{T}_{i,j-1/2}^{(\ell)} - \bar{T}_{i,j}^{(\ell)}] \\
& - \bar{G}_{y;i,j+1/2}^{(\ell)} [\hat{T}_{i,j+1/2}^{(\ell)} - \bar{T}_{i,j}^{(\ell)}] + \bar{G}_{srf;i,j}^{(\ell)} [\hat{T}_{srf;i,j}^{(\ell)} - \bar{T}_{i,j}^{(\ell)}] \\
& + \bar{G}_{bot;i,j}^{(\ell)} [\hat{T}_{bot;i,j}^{(\ell)} - \bar{T}_{i,j}^{(\ell)}] \left. \right\} + \frac{1}{\Delta x_{i,j} \Delta y_{i,j} \bar{D}_{i,j}^{(\ell)}} [\bar{Q}_{x;i-1/2,j}^{*\ell} - \bar{Q}_{x;i+1/2,j}^{*\ell} \\
& + \bar{Q}_{y;i,j-1/2}^{*\ell} - \bar{Q}_{y;i,j+1/2}^{*\ell} + \bar{Q}_{srf;i,j}^{*\ell} + \bar{Q}_{bot;i,j}^{*\ell}] \\
& + \frac{\delta_{int,m;i,j}^{(\ell)}}{\Delta x_{i,j} \Delta y_{i,j} \bar{D}_{i,j}^{(\ell)}} \bar{G}_{int,m} [\hat{T}_{int,m;i,j}^{(\ell)} - \bar{T}_{i,j}^{(\ell)}] \\
& + \frac{\delta_{dis,m;i,j}^{(\ell)}}{\Delta x_{i,j} \Delta y_{i,j} \bar{D}_{i,j}^{(\ell)}} \bar{G}_{dis,m} [\bar{T}_{dis,m;i,j} - \bar{T}_{i,j}^{(\ell)}] . \quad (3.41)
\end{aligned}$$

The multidimensional forms of the variables in Eq. (3.41) are similar to the ones defined for the ESTONE model (see Sect. 3.4).

The thermal model, Eq. (3.41), was specifically formulated to incorporate the detailed flow fields generated by the zone-matching methodology. The associated computer code TMPTWO of the model has the capability to use input data in terms of harmonic functions for the specification of the local flow conditions in the region and in terms of specified daily (or hourly) periods for the variations of the flow rates through the region and at the intakes and discharges of the power plants.

3.5.3.6 Determination of the boundary conditions. In the application of the model to the Hudson River estuary, the open boundary conditions are specified from the results of the one-dimensional computer

simulations by the far-field ESTONE model. Since the values for the temperatures from the one-dimensional model are only accurate over the cross sections of the region, they are only used as the limiting values of the boundary temperature conditions based on the following considerations:

1. From the transient results of the one-dimensional model, minimum $\bar{T}_{\text{bnd,min}}$, average $\bar{T}_{\text{bnd,avg}}$, and maximum $\bar{T}_{\text{bnd,max}}$ boundary values of the temperatures are determined.
2. The conditions on the temperature values at the "inflow" boundaries are determined by extrapolating within the minimum $\bar{T}_{\text{bnd,min}}$ and maximum $\bar{T}_{\text{bnd,max}}$ limits of the boundary conditions; e.g.,

$$\bar{T}_{I+1/2,j} = \text{extrapolation on } \bar{T}_{I-1,j} \text{ and } \bar{T}_{I,j}$$

$$\text{for } \bar{T}_{I+1/2,j} \geq \bar{T}_{\text{bnd,min}}: \bar{T}_{I+1/2,j} = \bar{T}_{I+1/2,j}$$

$$\text{for } \bar{T}_{I+1/2,j} < \bar{T}_{\text{bnd,min}}: \bar{T}_{I+1/2,j} = \bar{T}_{\text{bnd,min}}$$

(3.5.23)

$$\text{for } \bar{T}_{I+1/2,j} \leq \bar{T}_{\text{bnd,max}}: \bar{T}_{I+1/2,j} = \bar{T}_{I+1/2,j}$$

$$\text{for } \bar{T}_{I+1/2,j} > \bar{T}_{\text{bnd,max}}: \bar{T}_{I+1/2,j} = \bar{T}_{\text{bnd,max}}$$

with similar expressions for all boundary discrete elements.

The above specification of the open boundary conditions represents the most flexible and realistic form of conditions that can be assigned to the temperature values at the inflow boundaries of large regions of the Hudson River.

The systematic methodology and the different tidal-transient multi-dimensional mathematical models described in Sects. 3.5.3.1-3.5.3.6 were applied to the critical regions in the Hudson River to simulate two-dimensional temperature distributions in the vicinities of the major power plants to determine the thermal impact of the discharges accurately.

3.5.4 Selection of the power plants for the zone-matched near-field and far-field analysis

The computer simulation results by the one-dimensional far-field ESTONE model (see Sect. 3.4) indicated that the thermal interaction between the Indian Point and Bowline power plants (with secondary contribution from the Lovett power plant) caused the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperatures to reach elevated conditions close to and exceeding the maximum temperature limit of 83°F as stated by the applicable State and Federal standards within the 10-mile section of the Hudson River which contains the plants. Hence, two adjacent regions in the estuary were selected to study the thermal impact of the Indian Point and Bowline power plants in order to accurately determine the necessary high-spatial-resolution temperature distributions in the vicinities of the power plants. Since the results of the far-field thermal impact analysis indicated that the maximum temperature limit of 83°F will be exceeded within the 2-mile segments which contain the Indian Point and Bowline power plants (see Sect. 3.4), it becomes necessary to estimate the fractions of the river areas where the water temperature conditions will exceed the 83°F limit in order to be able to check the compliance of the plant operational conditions with the area limitations of "50 percent of the cross-sectional area of the estuary."

3.5.5 Discussion of the zone-matched near-field and far-field analysis of the thermal impact of the Bowline power plant

The systematic zone-matching methodology described in Sect. 3.5 was first applied to the analysis of the thermal impact of the Bowline power plant on the Hudson River. A region of approximately 5 miles of the estuary in Haverstraw Bay was considered in the near-field and far-field analysis of the discharge conditions of the Bowline power plant.

The discrete-element grid system for the application of the mathematical models was generated by the computer program PREPR2^{1,9} as shown in Fig. 3.5.1. The computational region was divided into variable-size discrete elements on a 30 x 27 grid system to guarantee the accuracy of the solutions in the vicinity of the power plant without requiring excessive computer run times in the application of the fast-transient two-dimensional models of the zone-matching methodology.

The necessary depth conditions in the discrete elements were input to the models based on the analysis of the bathymetry information (see Appendix A). A computer-generated representation of the depth conditions in the Haverstraw Bay area is presented in Fig. 3.5.2 for the region employed in the zone-matched near-field and far-field thermal analysis for the assessment of the thermal impact of the operation of the Bowline power plant on the estuary.

Fig. 3.5.1. Computer-generated discrete-element grid system for the section of the Hudson River in the vicinity of Bowline power plant.

Fig. 3.5.2. Computer-generated constant-depth contours and depth values for the section of the Hudson River in the vicinity of Bowline power plant.

3.5.5.1 Simulation of the flow conditions in the region of the Bowline power plant. Based on the outline of the zone-matching methodology (see Sect. 3.5.3), the two-dimensional velocity distributions in the region were simulated by application of the hydrodynamic models for short durations to determine the important characteristics of the different flow conditions.

A typical case for the computer simulations of the far-field velocity distributions in the Haverstraw Bay area is shown in Fig. 3.5.3 for the maximum flood conditions in the region of the Bowline power plant. It must be emphasized that the simulations of the far-field flow conditions in the region are based on various simplifying assumptions inherent to the formulation of the hydrodynamic models (see ref. 6). Hence, the flow conditions as shown in Fig. 3.5.3 are only acceptable approximations of the actual flow conditions in the Hudson River. The presently available hydrodynamic models cannot simulate the formation of vortices in the horizontal planes of the estuary; hence, they tend to simulate velocity fields similar to pseudoinviscid flow conditions.

The plant-induced flow conditions in the vicinity of the Bowline power plant were also determined by the application of the hydrodynamic models of the zone-matching methodology (see Sect. 3.5.3) to approximately incorporate the important recirculation flow conditions between the submerged diffuser discharge and the entrance to the Bowline pond. The computer simulation results of the general zone-matching methodology for the plant-induced flow conditions in the vicinity of the Bowline power plant are shown in Fig. 3.5.4. The exaggerated representation of the flow conditions illustrates the existence of recirculation in the region, particularly during slack water conditions in the estuary.

The complete flow field in the region of the Bowline power plant was determined by the superposition postulate of the zone-matching methodology (see Sect. 3.5.3). The amplitudes and the lag times for the harmonic functions for simulating the far-field tidal conditions in Eq. (3.34) were determined from the one-dimensional computer simulation results of the ESTONE far-field model (see Sect. 3.4) based on the maximum values and the temporal variations of the flow conditions in the 2-mile segment of element 55 at the location of the Bowline power plant. Similarly, the net daily-averaged freshwater flow in the Haverstraw Bay area was determined from the computer simulation results of the far-field ESTONE model based on the daily-averaged values of the flow conditions in element 58 at Bowline Point along the estuary.

In the application of the two-dimensional models, the operational conditions of the Bowline power plant and the climatological conditions in the region were considered according to the accurate and detailed information which was generated for the application of the one-dimensional far-field ESTONE model (see Sect. 3.4).

Fig. 3.5.3. Computer simulation of the far-field flow conditions in the Haverstraw Bay area during maximum flood conditions in the region.

Fig. 3.5.4. Computer simulation of the plant-induced recirculation flow conditions in the vicinity of the Bowline power plant during slack water conditions in the region.

3.5.5.2 Comparison of the computer simulation results of the zone-matched near-field and far-field thermal analysis and the field-measured data from the operation of the Bowline power plant. The zone-matching methodology was first applied to simulate the two-dimensional temperature distributions in the vicinity of the Bowline power plant for comparison with the available field-measured data for September 13, 1973.¹⁰ In the application of the tidal-transient two-dimensional, multilayer models, depth-averaged assumptions were used for both the hydrodynamic and temperature conditions in the region. This simplification was necessary from computer cost considerations, and it was justified based on the limits of accuracy of the available temperature data for the verification of the models.

In the application of the tidal-transient two-dimensional discrete-element thermal transport model TMPTWO (consistent with the application of the ESTONE far-field model), none of the values of the coefficients and/or parameters of the transport model were ever adjusted (tuned).

The field-measured data for the temperature distributions in the vicinity of the Bowline power plant on September 13, 1973, were obtained by boat surveys¹⁰ which required 1 to 3 hr of measurements. Therefore, the field-measured data could not be used as accurate representations of the temperature conditions in the estuary for different tidal stages in the region. Hence, in the comparisons of the model predictions and the field-measured data,¹⁰ multiple-time simulations were considered to span the durations of the boat surveys.

The computer simulations by the tidal-transient two-dimensional thermal transport model TMPTWO were started three days before the date of simulations on September 10, 1973, at 2400 hr (midnight). The initial and the boundary conditions to the model were input from the one-dimensional results of the far-field ESTONE model (see Sect. 3.4) according to the outline of the zone-matching methodology (see Sect. 3.5.3). The computer simulations were continued for three days until the day of the available field-measured data. The results of the computer simulations by the thermal transport model TMPTWO were presented in computer-generated graphical form for direct comparison with the field-measured data by employing the modified version of the computer graphics code GRAFAR.¹¹

The field-measured data for the two-dimensional temperature distributions in the vicinity of the Bowline power plant during the time period 1059-1203 hr on September 13, 1973 (corresponding approximately to the maximum flood tidal stage) for the region of Haverstraw Bay is shown in Fig. 3.5.5.

The computer simulation results by the general zone matching methodology for the flow field and thermal conditions in the region are presented as two-dimensional streak-line plots for the velocity (Figs. 3.5.6, 3.5.8, and 3.5.10) and as two-dimensional temperature values and constant-temperature contours (isotherms) (Figs. 3.5.7, 3.5.9, and 3.5.11) in the Haverstraw Bay area for three multiple-time simulations at 1030 hr, 1100 hr, and 1130 hr, which approximately span the period of the survey during 1059-1203 hr on September 13, 1973.

Fig. 3.5.5. Representation of field-measured data for constant-temperature contours (isotherms) for the two-dimensional thermal conditions in the vicinity of the Bowline power plant during 1059-1203 on September 13, 1973. See Lawler, Matusky and Skelly Engineers, 1973 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, vol. V, prepared for Orange and Rockland Utilities, Inc., December 1974.

Fig. 3.5.6. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay area at 1030 on September 13, 1973.

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Fig. 3.5.7. Computer simulation results for two-dimensional temperature conditions in the Haverstraw Bay area at 1030 on September 13, 1973.

Fig. 3.5.8. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay area at 1100 on September 13, 1973.

Fig. 3.5.10. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay area at 1130 on September 13, 1973.

Fig. 3.5.11. Computer simulation results for two-dimensional temperature conditions in the Haverstraw Bay area at 1130 on September 13, 1973.

The field-measured data (Fig. 3.5.5) and the computer-simulated temperature results are generally in very good agreement throughout the large region of Haverstraw Bay, except in the shallow areas along the shore and in the vicinity of the power plant discharge. The results of the computer simulations indicate that the heated discharge water will stay in these shallow areas between Grassy Point and the discharge of the Bowline power plant and will be at elevated temperatures of approximately 78°F, which is 2°F higher than the results based on the field-measured data (see Fig. 3.5.5). Furthermore, the computer simulation results indicate that in the shallow areas in the vicinity of the entrance to the Bowline pond, the water temperature conditions will reach 77°F (see Figs. 3.5.7, 3.5.9, and 3.5.11). This thermal recirculation effect is not indicated in the results of the field-measured data (see Fig. 3.5.5).

The field-measured data for the temperature distributions in the vicinity of the Bowline power plant during the time period 1215-1540 hr (corresponding approximately to the high-water-slack tidal stage) on September 13, 1973, are shown in Fig. 3.5.12 for the region in Haverstraw Bay.

The computer simulation results by the general zone-matching methodology for the flow field and the thermal conditions in the region are presented as two-dimensional streak-line plots for velocity (Figs. 3.5.13, 3.5.15, and 3.5.17) and as two-dimensional temperature values and constant-temperature contours (isotherms) (Figs. 3.5.14, 3.5.16, and 3.5.18) in the Haverstraw Bay area for three multiple-time simulations at 1330, 1400, and 1430 hr, which approximately span the period of the survey during 1215-1530 hr on September 13, 1973.

The field-measured data (Fig. 3.5.12) and the computer-simulated temperature results (Figs. 3.5.14, 3.5.16, and 3.5.18) are again in good agreement throughout the large region of the Bay area except in the shallow regions near the shore. The model predictions indicate higher water temperatures (79°F) in the shallow areas between Grassy Point and the location of the discharge of the Bowline power plant. The simulated temperatures are approximately 3°F higher than the temperatures indicated by the field-measured data (Fig. 3.5.12). The computer simulations again predict slightly higher temperature conditions (77°F) at the entrance of the Bowline pond (see Figs. 3.5.14, 3.5.16, and 3.5.18) than the conditions indicated by the field-measured data (Fig. 3.5.12).

The simulation results by the thermal transport model TMP TWO also predict higher temperature values (81° to 83°F) in the vicinity of the discharge and in the shallow areas near the shore, between the intake and the plant. Considering the fact that during the high-water-slack tidal stage, the flow conditions in the estuary are minimum, the recirculation between the intake and discharge could become appreciable. Hence, the higher temperature values as predicted by the model are indeed reasonable for short durations during high-water-slack conditions. Since the field-measured data were obtained during an approximately 3.5-hr period, these elevated temperature conditions which last for relatively

Fig. 3.5.12. Representation of field-measured data for constant-temperature contours (isotherms) for the two-dimensional thermal conditions in the vicinity of the Bowline power plant during 1215-1540 on September 13, 1973. See Lawler, Matusky and Skelly Engineers, 1973 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, vol. V, prepared for Orange and Rockland Utilities, Inc., December 1974.

Fig. 3.5.13. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay area at 1330 on September 13, 1973.

Fig. 3.5.14. Computer simulation results for two-dimensional temperature conditions in the Haverstraw Bay area at 1330 on September 13, 1973.

Fig. 3.5.15. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay area at 1400 on September 13, 1973.

Fig. 3.5.16. Computer simulation results for two-dimensional temperature conditions in the Haverstraw Bay area at 1400 on September 13, 1973.

Fig. 3.5.17. Computer simulation results for two-dimensional flow conditions in the Haversraw Bay area at 1430 on September 13, 1973.

Fig. 3.5.18. Computer simulation results for two-dimensional temperature conditions in the Haverstraw Bay area at 1430 on September 13, 1973.

short durations could not have been observed by the boat surveying techniques of data collection.

It is important to note that the temperature predictions by the thermal transport model TMPTWO, according to the zone-matching methodology for the near-field and far-field analyses, indicate temperature conditions of approximately 83°F in the immediate vicinity of the submerged discharge structure and 77°F at the entrance to the Bowline pond. Since the condenser temperature rise is approximately 14°F, the results of the model predictions agree very well with the estimated dilution ratios obtained by the near-field analysis of the Bowline power plant (see Sect. 3.3).

The field-measured data for the temperature distributions in the vicinity of the Bowline power plant during the time period 1616-1824 hr (corresponding approximately to the maximum ebb flow conditions of the tidal state) on September 13, 1973, are shown in Fig. 3.5.19 for the region of Haverstraw Bay.

The computer simulation results by the general zone-matching methodology for the flow field and the thermal conditions in the region are presented as two-dimensional streak-line plots for velocity (Figs. 3.5.20, 3.5.22, 3.5.24, and 3.5.26) and as two-dimensional temperature values and constant-temperature contours (isotherms) (Figs. 3.5.21, 3.5.23, 3.5.25, and 3.5.27) in the Haverstraw Bay area for four multiple-time simulations at 1630, 1700, 1730, and 1800 hr, which approximately span the period of the survey during 1616-1824 hr on September 13, 1973.

The agreement between the field-measured data (Fig. 3.5.19) and the computer-simulated temperature results (Figs. 3.5.21, 3.5.23, 3.5.25, and 3.5.27) is acceptable throughout the large region of Haverstraw Bay. The results of the model predictions again indicate higher temperature values (79°F) in the shallow regions near the shore, including the areas downstream of the entrance to the Bowline pond.

The computer-simulated temperature distributions also illustrate the important effect of solar heating on the temperature conditions in the shallow areas of Haverstraw Bay. At 1030 hr (see Fig. 3.5.7), the major part of the shallow areas (see Fig. 3.5.2) is at approximately 76°F. However, later in the evening at 1730 and 1800 hr, the water temperature conditions in the shallow areas reach 77°F throughout Haverstraw Bay (see Figs. 3.5.25 and 3.5.27) except in the deep channel region of the estuary, due to the continuous solar heating effect during the afternoon.

In the graphical representation of the computer simulation results for the thermal conditions in Haverstraw Bay, the values of the water temperature were rounded off to the nearest integer value (e.g., see Fig. 3.5.1) in degrees F. This simplification was introduced both for convenience in plotting and also for illustrating the margin of possible inaccuracy in the simulations.

Fig. 3.5.19. Representation of field-measured data for constant-temperature contours (isotherms) for the two-dimensional thermal conditions in the vicinity of the Bowline power plant during 1616-1824 on September 13, 1973. See Lawler, Matusky and Skelly Engineers, 1973 *Hudson River Aquatic Ecology Studies - Bowline Point and Lovett Generating Stations*, vol. V, prepared for Orange and Rockland Utilities, Inc., December 1974.

Fig. 3.5.20. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay area at 1630 on September 13, 1973.

Fig. 3.5.21. Computer simulation results for two-dimensional temperature conditions in the Haverstraw Bay area at 1630 on September 13, 1973.

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Fig. 3.5.22. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay area at 1700 on September 13, 1973.

Fig. 3.5.23. Computer simulation results for two-dimensional temperature conditions in the Haverstraw Bay area at 1700 on September 13, 1973.

Fig. 3.5.24. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay area at 1730 on September 13, 1973.

Fig. 3.5.25. Computer simulation results for two-dimensional temperature conditions in the Haverstraw Bay area at 1730 on September 13, 1973.

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Fig. 3.5.26. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay area at 1800 on September 13, 1973.

Fig. 3.5.27. Computer simulation results for two-dimensional temperature conditions in the Haverstraw Bay area at 1800 on September 13, 1973.

In summary, considering the fact that in the simulations of both the hydrodynamic and thermal conditions in the region, none of the parameters of the models were ever adjusted, it can be concluded that the general zone-matching methodology can be employed with confidence in predicting the two-dimensional temperature distributions in the vicinity of the Bowline power plant on the Hudson River.

3.5.6 Discussion of the zone-matched near-field and far-field analysis of the thermal impact of the Indian Point power plant

The systematic zone-matching methodology (see Sect. 3.5.3) was next applied to the analysis of the thermal impact of the Indian Point power plant on the Hudson River. A region of approximately 6 miles of the estuary which includes the Indian Point and Lovett power plants was considered in the near-field and far-field analysis of the thermal discharges of the two plants. The discrete-element grid system for the application of the mathematical models was computer-generated by the PREPAR code^{1,9} as shown in Fig. 3.5.28.

The computational region was divided into variable-size discrete elements on a 51 x 30 grid system to guarantee the accuracy of the solutions in the vicinity of the power plant without requiring excessive computer run times in the application of the fast-transient two-dimensional models of the zone-matching methodology.

The necessary depth conditions in the discrete elements were input to the models based on the analysis of the bathymetry information (see Appendix A). A computer-generated representation of the depth conditions in the region of the Indian Point power plant is presented in Fig. 3.5.29.

3.5.6.1 Simulation of the flow conditions in the region of the Indian Point and Lovett power plants.

Based on the outline of the zone-matching methodology (see Sect. 3.5.3), the two-dimensional velocity distributions in the region were simulated by application of the hydrodynamic models for short durations to determine the important characteristics of the different flow conditions.

A typical case for the computer simulations of the far-field velocity distributions in the vicinity of the Indian Point area is shown in Fig. 3.5.30 for the maximum ebb conditions in the region. Again, it must be emphasized that the simulations of the far-field flow conditions in the region are based on various simplifying assumptions inherent to the formulation of the hydrodynamic models (see ref. 6). Hence, the flow conditions as shown in Fig. 3.5.30 are only acceptable approximations of the actual flow conditions in the Hudson River.

The plant-induced flow conditions in the vicinity of Indian Point are very important since the discharge behaves like a pseudo surface jet along the lateral direction between the two banks of the estuary. The results of computer simulations of the discharge jet according to the zone-matching methodology based on singular perturbation theory are

Fig. 3.5.28. Computer-generated discrete-element grid system for the section of the Hudson River in the vicinity of Indian Point and Lovett power plants.

Fig. 3.5.29. Computer-generated constant-depth contours and depth values for the section of the Hudson River in the vicinity of Indian Point and Lovett power plants.

Fig. 3.5.30. Computer simulation of the far-field flow conditions in the vicinity of the Indian Point and Lovett power plants in the Hudson River during maximum ebb conditions in the region.

shown in Fig. 3.5.31. The extremely important reentrainment phenomenon, which was predicted for the first time by a mathematical model (see Fig. 3.5.31), was also observed in the physical modeling studies of the Indian Point plant flow conditions¹² (see Fig. 3.5.32). The flow field induced by the Indian Point intake conditions was also determined by employing the pseudo potential flow model (see Sect. 3.5.3) of the general zone-matching methodology. The plant-induced flow field of the Lovett power plant was not included in the formulation of overall flow conditions in the region since the plant cooling water flow rate is significantly lower than the natural flow conditions in the estuary.

The complete flow field in the region of the Indian Point and Lovett power plants was determined by the superposition postulate of the zone-matching methodology (see Sect. 3.5.3). The amplitudes and the lag times for the harmonic functions for simulating the far-field tidal conditions in Eq. (3.34) were determined from the one-dimensional computer simulation results of the ESTONE far-field model (see Sect. 3.4) based on the maximum values and temporal variation of the flow conditions in the 2-mile segment of element 55 at the locations of the Indian Point and Lovett power plants. Similarly, the net daily-averaged freshwater flow in the vicinity of Indian Point was determined from the computer simulation results of the far-field ESTONE model based on the daily-averaged values of the flow conditions in element 55 at Indian Point along the estuary. In the application of the two-dimensional models, the operational conditions of the Indian Point and Lovett power plants and the climatological conditions in the region were considered according to the accurate and detailed information which was generated for the application of the one-dimensional far-field ESTONE model (see Sect. 3.4).

3.5.6.2 Comparison of the computer simulation results of the zone-matched near-field and far-field thermal analysis and the field-measured data from the operational conditions of Indian Point and Lovett power plants. The zone-matching methodology was also applied to simulate the two-dimensional temperature distributions in the vicinity of the Indian Point and Lovett power plants for comparison with the available field-measured data for August 23, 1974. In the application of the tidal-transient two-dimensional, multilayer models, again depth-averaged assumptions were used for both the hydrodynamic and temperature conditions in the region. Similar to the conditions of the first application, none of the values of the coefficients and/or parameters of the transport model were ever adjusted (tuned) during the simulations.

The field-measured data for the temperature distributions in the vicinity of the Indian Point power plant were obtained on August 23, 1974, by boat surveys which required relatively short durations (approximately 45 min) for the completion of the measurements for a tidal stage. Hence, the field-measured data from Indian Point surveys can be considered as more accurate than the data available from Bowline surveys for comparison with the results of the mathematical model predictions. However, since the tidal flow conditions in the estuary may still vary

Fig. 3.5.31. Computer simulation results as streak lines for the flow induced by the horizontal jet discharge from Indian Point power plant during slack water conditions. Zone-matching methodology based on singular perturbation theory.

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Fig. 3.5.32. Comparison of the results and the observed flow conditions in the physical model for the flow induced by the horizontal jet discharge from Indian Point power plant. Source: F. E. Parkinson and F. Goulet, *Indian Point Generating Plants: Hydraulic Model Study of Hudson River Flows Around Cooling Water Intakes*, LHL-682, November, 1976.

appreciably during 45 min, in the comparisons of the model predictions and the field-measured data,¹² again multiple-time simulations were considered to approximately span the durations of the surveys.

The computer simulations by the tidal-transient two-dimensional thermal transport model TMPTWO were started two days before the date of simulations on August 23, 1974, at 2400 hr (midnight). The initial and the boundary conditions to the model were input from the one-dimensional results of the far-field ESTONE model (see Sect. 3.5.3). The computer simulations were continued for two days until the day of the available field-measured data. The results of the computer simulations were presented in computer-generated graphical form for direct comparison with the field-measured data.

The survey data for the two-dimensional distributions of water temperature in the vicinity of the Indian Point power plant during the time period 0852-0932 (corresponding to approximate ebb tidal stage) on August 23, 1974, are presented in Figs. 3.5.33-3.5.35 at three depths (0 ft, 3 ft, and 6 ft).

The computer simulation results by the general zone-matching methodology for the flow field and thermal conditions in the region are presented as two-dimensional streak-line plots for the velocity (Figs. 3.5.36 and 3.5.38) and as two-dimensional water temperature values and as constant-temperature contours (isotherms) in the region of Indian Point (Figs. 3.5.37 and 3.5.39) for two multiple-time simulations at 0900 and 0930 hr, which approximately span the period of the survey during 0852-0932 on August 23, 1974. The field-measured data (Figs. 3.5.33-3.5.35) and the computer-simulated temperature results (Figs. 3.5.37 and 3.5.39) are generally in very good agreement throughout the region based on depth-averaged considerations of the field-measured data. Both the qualitative and the quantitative behavior of the thermal plume from the Indian Point power plant are similar in both field-measured data (Figs. 3.5.33-3.5.35) and the computer simulation results from the TMPTWO thermal transport model (Figs. 3.5.37 and 3.5.39). The results of the computer simulations (Figs. 3.5.37 and 3.5.39) indicate water temperatures of 82°F near the shore of Indian Point, which agree very well with the field-measured data (Figs. 3.5.33-3.5.35) for the approximate maximum-ebb flow conditions in the region of Indian Point.

The field-measured data for the temperature distributions in the vicinity of the Indian Point power plant during the time period 1223-1315 (corresponding approximately to the low-water-slack tidal stage) on August 23, 1974, are presented in Figs. 3.5.40-3.5.42 at three depths (0 ft, 3 ft, and 6 ft).

The computer simulation results by the general zone-matching methodology for the flow field and the thermal conditions in the region are presented as two-dimensional streak-line plots for velocity (Figs. 3.5.43 and 3.5.45) and as two-dimensional distributions of temperature values and constant-temperature contours (isotherms) in the Indian Point region (Figs. 3.5.44 and 3.5.46) for two multiple-time simulations at 1230 and 1300 hr, which approximately span the survey period 1223-1315 on August 23, 1974.

Fig. 3.5.33. Representation of field-measured data for constant-temperature contours (isotherms) at 0 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 0852-0932 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Fig. 3.5.34. Representation of field-measured data for constant-temperature contours (isotherms) at 3 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 0855-0928 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September, 1976.

Fig. 3.5.35. Representation of field-measured data for constant-temperature contours (isotherms) at 6 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 0852-0932 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Fig. 3.5.37. Computer simulation results for two-dimensional temperature conditions in the region of Indian Point and Lovett power plants at 0900 on August 23, 1974.

Fig. 3.5.38. Computer simulation results for two-dimensional flow conditions in the region of Indian Point and Lovett power plants at 0930 on August 23, 1974.

Fig. 3.5.39. Computer simulation results for two-dimensional temperature conditions in the region of Indian Point and Lovett power plants at 0930 on August 23, 1974.

Fig. 3.5.40. Representation of field-measured data for constant-temperature contours (isotherms) at 0 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 1223-1315 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Fig. 3.5.41. Representation of field-measured data for constant-temperature contours (isotherms) at 3 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 1223-1315 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Fig. 3.5.42. Representation of field-measured data for constant-temperature contours (isotherms) at 6 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 1223-1315 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Fig. 3.5.43. Computer simulation results for two-dimensional flow conditions in the region of Indian Point and Lovett power plants at 1230 on August 23, 1974.

Fig. 3.5.44. Computer simulation results for two-dimensional temperature conditions in the region of Indian Point and Lovett power plants at 1230 on August 23, 1974.

Fig. 3.5.45. Computer simulation results for two-dimensional flow conditions in the region of Indian Point and Lovett power plants at 1300 on August 23, 1974.

Fig. 3.5.46. Computer simulation results for two-dimensional temperature conditions in the region of Indian Point and Lovett power plants at 1300 on August 23, 1974.

The field-measured data (Figs. 3.3.40-3.5.42) and the computer-simulated temperature results are again in good agreement throughout the region of the estuary influenced by the discharges from the Indian Point and Lovett power plants. Considering the field-measured data on a depth-averaged basis (Figs. 3.5.40-3.5.42), the behavior of the thermal plumes from the two plants is again both qualitatively and quantitatively similar in both field-measured data (Figs. 3.5.40-3.5.42) and the computer simulations (Figs. 3.5.44 and 3.5.46) during approximately low-water-slack tidal conditions. The results of the computer simulations predict a maximum temperature of 89°F at the location of the discharge, which is 2°F higher than the value of 87°F indicated by the field data (Fig. 3.5.40). However, in the general vicinity of the Indian Point discharge, the model predictions (Figs. 3.5.44 and 3.5.46) and the field-measured data (Figs. 3.5.40-3.5.42) agree very well for depth-averaged considerations of the data.

It is interesting to note that the computer simulation results by the TMPTWO model (Fig. 3.5.46) clearly indicate the rise of the temperature conditions in the vicinity of the Lovett power plant during the slack-water conditions, and in a sense the slight merging of the thermal plumes from the discharges of the two plants as also indicated by the field-measured data (Figs. 3.5.40-3.5.41).

The field-measured data for the temperature distributions in the vicinity of the Indian Point power plant during the time period 1536-1650 (corresponding approximately to the maximum-flood flow conditions of the tidal stage) on August 23, 1974, are presented in Figs. 3.5.47-3.5.49 at three depths (0 ft, 3 ft, and 6 ft).

The computer simulation results by the general zone-matching methodology for the flow field and the thermal conditions in the region are presented as two-dimensional streak-line plots for velocity (Figs. 3.5.50 and 3.5.52) and as two-dimensional temperature values and constant-temperature contours (isotherms) (Figs. 3.5.51 and 3.5.53) in the Indian Point region for two multiple-time simulations at 1600 and 1630 hr, which approximately span the survey period 1536-1650 hr on August 23, 1974.

The agreement between the field-measured data (Figs. 3.5.47-3.5.49) and the computer simulation results (Figs. 3.5.51 and 3.5.53) for the temperature distributions in the region is again very good for the depth-averaged considerations of the field data. The simulated results correctly predict the turning of the Indian Point thermal plume toward the upstream direction with the incoming tide and the widening of the plume as it bends away from the shore. The computer simulation results also correctly predict the high temperature conditions upstream of the discharge (see Figs. 3.5.51 and 3.5.53), which are also indicated by the field-measured data (Figs. 3.5.47-3.5.49).

The field-measured data for the temperature distributions in the vicinity of the Indian Point power plant during the time period 1838-1920 (corresponding approximately to high-water-slack conditions of the tidal stage) on August 23, 1974, are presented in Figs. 3.5.54-3.5.56 at three depths (0 ft, 3 ft, and 6 ft).

Fig. 3.5.47. Representation of field-measured data for constant-temperature contours (isotherms) at 0 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 1536-1650 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Fig. 3.5.48. Representation of field-measured data for constant-temperature contours (isotherms) at 3 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 1536-1650 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Fig. 3.5.49. Representation of field-measured data for constant-temperature contours (isotherms) at 6 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 1536-1650 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Fig. 3.5.50. Computer simulation results for two-dimensional flow conditions in the region of Indian Point and Lovett power plants at 1600 on August 23, 1974.

Fig. 3.5.51. Computer simulation results for two-dimensional temperature conditions in the region of Indian Point and Lovett power plants at 1600 on August 23, 1974.

Fig. 3.5.52. Computer simulation results for two-dimensional flow conditions in the region of Indian Point and Lovett power plants at 1630 on August 23, 1974.

Fig. 3.5.53. Computer simulation results for two-dimensional temperature conditions in the region of Indian Point and Lovett power plants at 1630 on August 23, 1974.

Fig. 3.5.54. Representation of field-measured data for constant-temperature contours (isotherms) at 0 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 1838-1920 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Fig. 3.5.55. Representation of field-measured data for constant-temperature contours (isotherms) at 3 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 1838-1920 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

Fig. 3.5.56. Representation of field-measured data for constant-temperature contours (isotherms) at 6 ft depth for the two-dimensional thermal conditions in the region of Indian Point and Lovett power plants during 1838-1920 on August 23, 1974. See Texas Instruments Incorporated Ecological Services, *Hudson River Ecological Study in the Area of Indian Point. Thermal Effects Report*, prepared for Consolidated Edison Company of New York, Inc., September 1976.

The computer simulation results by the general zone-matching methodology for the flow field and the thermal conditions in the region are presented as two-dimensional streak-line plots for velocity (Figs. 3.5.57 and 3.5.59) and as two-dimensional temperature values and constant-temperature contours (isotherms) (Figs. 3.5.58 and 3.5.60) in the Indian Point region for two multiple-time simulations at 1830 and 1900 hr, which approximately span the survey period 1838-1920 hr on August 23, 1974.

The agreement between the computer simulation results (Figs. 3.5.58 and 3.5.60) and the field-measured data (Figs. 3.5.54-3.5.56) for temperatures was very good for the Indian Point discharge conditions. The model predictions also indicated elevated temperature conditions in the vicinity of Lovett plant (see Figs. 3.5.58 and 3.5.60), reaching 83°F at the discharge locations. Since during slack water conditions the velocities in the estuary drop to minimum values, it is indeed reasonable to expect higher temperatures also in the vicinity of the discharges. Since the thermal plume from the Lovett power plant was not included in the survey of the field-measured data for the period 1838-1920 hr, the model predictions could not be compared with the data.

The computer-simulated temperature distributions also illustrate the important effect of solar heating on the temperature conditions in the shallow areas in the Indian Point region. At 0900 hr (see Fig. 3.5.37), the major part of the shallow area (see Fig. 3.5.29) is at approximately 79°F. However, later in the afternoon at 1830 and 1900 hr, the water temperature conditions in the shallow areas (see Figs. 3.5.58 and 3.5.60) reach 81°F in most of the bay areas of the Indian Point region as the result of the continuous solar heating effect during the afternoon hours.

In the graphical representation of the computer simulation results for the thermal conditions in the Indian Point region, the values of the water temperature were again rounded off to the nearest integer value (e.g., see Fig. 3.5.58) in degrees F. This simplification was introduced both for convenience in plotting and also for illustrating the margin of possible inaccuracy in the predictions.

In summary, considering the fact that in the simulations of both the hydrodynamic and thermal conditions in the region, none of the parameters of the models were ever adjusted, it can be concluded that the general zone-matching methodology can be employed with confidence in predicting the two-dimensional temperature distributions in the vicinity of the Indian Point power plant on the Hudson River.

Fig. 3.5.57. Computer simulation results for two-dimensional flow conditions in the region of Indian Point and Lovett power plants at 1830 on August 23, 1974.

Fig. 3.5.58. Computer simulation results for two-dimensional temperature conditions in the region of Indian Point and Lovett power plants at 1830 on August 23, 1974.

Fig. 3.5.59. Computer simulation results for two-dimensional flow conditions in the region of Indian Point and Lovett power plants at 1900 on August 23, 1974.

Fig. 3.5.60. Computer simulation results for two-dimensional temperature conditions in the region of Indian Point and Lovett power plants at 1900 on August 23, 1974.

3.5.7 Assessment of the complete thermal impact of Bowline and Indian Point power plants for case 3 (proposed maximum thermal load plant operational conditions on the Hudson River)

The results of the far-field thermal impact analysis (see Sect. 3.4) indicated that for the hypothetical 1974 river conditions, the simulations by the tidal-transient one-dimensional ESTONE far-field model could not state conclusively whether the thermal conditions in the estuary would violate the State and Federal standards (see Sect. 3.1) for the critically important plant operational cases. Hence, the zone-matched near-field and far-field thermal analysis was applied to the simulations of the temperature distributions in the regions where Bowline and Indian Point power plant discharges cause the major thermal impact on the estuary.

3.5.7.1 Zone-matched near-field and far-field (complete) thermal analysis of the operation of the Bowline power plant. The tidal-transient two-dimensional, multilayer thermal transport model TMPTWO was applied to the simulation of the depth-averaged temperature distributions in the vicinity of the Bowline power plant for case 3 (proposed maximum thermal load plant operational conditions on the river) (see Sect. 3.4). Based on the results of the far-field thermal impact analysis for the complete river (see Sect. 3.4), the highest daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature in the element (58) of the Bowline power plant was determined as approximately 83°F on August 4, 1974, for the case under consideration.

The computer simulations by the TMPTWO model were started at 0000 hr (midnight) on August 4, 1974, by assuming 83°F initial temperature conditions in the region. All the necessary data for the natural river flow and climatological conditions were input to the model for the day August 4, 1974. The temperature boundary conditions at the upstream and downstream open boundaries (see Fig. 3.5.1) were determined from the results of the one-dimensional far-field ESTONE model for the temperature conditions in elements 57 and 59 based on the approximate daily-minimum and daily-maximum values of 82.2°F and 83.8°F, respectively. These limiting temperature values were employed in the general formulation of the temperature boundary conditions (see Sect. 3.5.3.6). The computer simulations were continued through the day August 4, 1974, to determine the critical thermal conditions in the Haverstraw Bay area during the four stages of the tidal flow (high-water slack, maximum ebb flow, low-water slack, and maximum flood flow) in the river. The operational conditions of the Bowline power plant were assumed as uniform at the full rated output power (see Table 3.5.7) throughout the period of the simulations.

The results of the computer simulations by the general zone-matching methodology and the applications of the two-dimensional thermal transport code TMPTWO for the flow field and the thermal conditions in the Haverstraw Bay area are presented as two-dimensional streak-line plots for velocity (Figs. 3.5.61, 3.5.63, 3.5.65, and 3.5.67) and as two-dimensional distributions of temperature values and constant-temperature contours (isotherms) (Figs. 3.5.62, 3.5.64, 3.5.66, and 3.5.68) for the approximate

Fig. 3.5.61. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay region at 1300 (approximate high-water slack) on August 4, 1974.

Fig. 3.5.62. Computer simulation results of the two-dimensional temperature conditions in the Haverstraw Bay region at 1300 (approximate high-water slack) on August 4, 1974, for the assessment of the near-field and far-field thermal impact of the Bowline power plant for case 3 (proposed maximum thermal load plant operational conditions on the Hudson River).

Fig. 3.5.63. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay region at 1600 (approximate maximum ebb) on August 4, 1974.

Fig. 3.5.54. Computer simulation results of the two-dimensional temperature conditions in the Haverstraw Bay region at 1600 (approximate maximum ebt flow) on August 4, 1974, for the assessment of the near-field and far-field thermal impact of the Bowline power plant for case 3 (proposed maximum thermal load plant operational conditions on the Hudson River).

Fig. 3.5.65. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay region at 1900 (approximate low-water slack) on August 4, 1974.

Fig. 3.5.66. Computer simulation results of the two-dimensional temperature conditions in the Haverstraw Bay region at 1900 (approximate low-water slack) on August 4, 1974, for the assessment of the near-field and far-field thermal impact of the Bowline power plant for case 3 (proposed maximum thermal load plant operational conditions on the Hudson River).

Fig. 3.5.67. Computer simulation results for two-dimensional flow conditions in the Haverstraw Bay region at 2200 (approximate maximum flood) on August 4, 1974.

times of the occurrence of the four critical tidal stages in the estuary. The simulations were considered for the afternoon hours of August 4, 1974, when the maximum thermal conditions occur due to the combined effects of solar heating and the thermal discharge of the Bowline power plant.

The results of the computer simulations by the TMPTWO model for the approximate high-water slack conditions at 1300 hr (see Fig. 3.5.61) indicate that depth-averaged water temperature values exceeding 91°F will exist in the vicinity of the discharge of the Bowline power plant (see Fig. 3.5.62). Considering the fact that according to the formulation of the two-dimensional model the values of temperature represent the average temperature conditions in elements of approximately 200 ft by 200 ft size which contain the discharge structure, the water temperature at the surface of the estuary will definitely exceed 90°F at the location of the discharge. Hence, the operational conditions of the Bowline power plant will not comply with the applicable State standards since the temperature conditions will violate item i (see Sect. 3.1), which limits the allowable surface temperature to 90°F at any point along the estuary.

The results also indicate that the depth-averaged water temperatures will reach 87°F in the shallow regions near the shoreline in the vicinity of the discharge of the Bowline power plant (see Fig. 3.5.62) during approximate high-water slack conditions at 1300 hr in the afternoon. The area of the heated water (87°F) will extend approximately 4000 ft upstream of the location of the discharge and approximately 1500 ft from the discharge to the shore. It is interesting to note that the boundary of this area that contains the heated water (87°F) will not extend to distances more than 200 ft from the discharge location laterally toward the central axis (based on the location of the main channel) of the estuary. Based on the results of the computer simulations by the TMPTWO model, the thermal conditions in the vicinity of the Bowline power plant will also exceed the standard that was recommended by the Environmental Protection Agency (see Sect. 3.1), since the temperatures will exceed 83°F at distances more than 1000 ft from the discharge. However, it should be emphasized that the region of the heated water (87°F) will be strictly limited to the shallow regions near the shore and that the boundary line of this region will be located parallel to the shore and at distances less than 200 ft from the discharge along the lateral direction. Hence, although the temperatures in the region will exceed 83°F at distances more than 1000 ft from the discharge, the region of the elevated temperatures (87°F) will be strictly limited to a narrow band near the shoreline of the Bowline power plant (see Fig. 3.5.62) along the estuary.

The computer simulation results for the two-dimensional distributions of depth-averaged water temperature in Haverstraw Bay show that the major portions of the area and volume of the estuary will be at 83°F (see Fig. 3.5.62). Hence, during approximate high-water-slack tidal stage in the river at 1300 hr, the thermal conditions in the region will comply with

the limitation which states that "50 percent of the cross-sectional area and/or volume of the flow of the estuary including a minimum of one-third of the surface as measured from water edge to water edge" (see Sect. 3.1) shall not exceed 83°F.

The computer simulation results by the TMPTWO thermal transport model for the thermal conditions during approximate maximum-ebb-flow tidal stage at 1600 hr (see Fig. 3.5.63) indicate that depth-averaged water temperature values exceeding 91°F will exist in the shallow regions near the shore between the location of the discharge structure and the location of the entrance to the Bowline pond (see Fig. 3.5.64). Again, considering the fact that according to the formulation of the two-dimensional model the values of temperature represent the average temperature conditions in elements of approximately 200 ft by 200 ft size, the water temperature at the surface of the estuary will definitely exceed 90°F in the shallow regions. Hence, again, the operational conditions of the Bowline power plant will not comply with the applicable State standards since the temperature conditions will violate item i (see Sect. 3.1), which limits the allowable surface temperature to 90°F at any point along the estuary.

The results also indicate that depth-averaged temperatures exceeding 88°F will exist in shallow regions near the shoreline in the general vicinity of the Bowline power plant (see Fig. 3.5.64) during approximate maximum ebb flow conditions at 1600 hr in the afternoon. The area of the heated water (88°F) will extend approximately 2500 ft upstream and 3000 ft downstream of the location of the discharge. The boundary of this area that contains the heated water (88°F) will extend approximately 500 ft from the discharge location laterally toward the central axis of the estuary. Furthermore, a significantly larger area in the shallow regions will reach depth-averaged water temperatures exceeding 84°F near the shoreline of the Bowline power plant (see Fig. 3.5.64). This area will extend over 2 miles (approximately 12,000 ft) upstream and over 1 mile (approximately 7000 ft) downstream from the discharge location, and it will be limited by a boundary line parallel to the shore and extending more than 1500 ft from the discharge along the lateral direction across the river. Hence, the results of the computer simulations by the TMPTWO model indicate that the thermal conditions in the vicinity of the Bowline power plant will also exceed the limiting criterion that was recommended by the Environmental Protection Agency (see Sect. 3.1), since the temperatures will definitely exceed 83°F at distances more than 1000 ft from the discharge.

The computer simulation results for the two-dimensional distributions of depth-averaged water temperature show that the major portion of the Haverstraw Bay area will be at 84°F (see Fig. 3.5.64). Hence, during approximate maximum-ebb-flow tidal stage in the river at 1600 hr, the thermal conditions in the region will clearly exceed the limitation which states that "a minimum of one-third of the surface as measured from water edge to water edge" (see Sect. 3.1) shall not exceed 83°F. However, the part of the thermal standard about "50 percent of the

cross-sectional area and/or volume of the flow of the estuary" not to exceed 83°F will not be violated, since the parts of Haverstraw Bay that will have water temperatures at approximately 83°F will be the relatively deep main channel sections (see Fig. 3.5.2) with large cross-sectional areas and flow volumes.

It is also important to emphasize that solar heating contributes appreciably to the elevated thermal conditions in the region. The computer simulations clearly illustrate the effect of solar heating in the shallow regions less than 10 ft deep (see Fig. 3.5.2) in Haverstraw Bay, near the bank across the river from the location of the Bowline power plant.

The computer simulation results by the TMPTWO thermal transport model for the thermal conditions during approximate low-water-slack tidal stage (see Fig. 3.5.65) indicate that the two-dimensional distribution of the depth-averaged water temperature (see Fig. 3.5.66) in Haverstraw Bay at 1900 hr is generally similar to the distribution that existed during approximate maximum-ebb-flow tidal stage at 1600 hr (see Fig. 3.5.64). Hence, all of the conditions of the applicable State and Federal thermal standards which were exceeded during the approximate maximum-ebb-flow tidal stage at 1600 hr will also be exceeded during the approximate low-water-slack tidal stage at 1900 hr (see Fig. 3.5.66).

Furthermore, considering the areas where the depth-averaged water temperature will reach 84°F during approximate low-water slack conditions at 1900 hr (see Fig. 3.5.66), the computer simulation results indicate that a major portion of the main channel of the estuary in Haverstraw Bay (see Fig. 3.5.2) will contain water at elevated temperatures exceeding 83°F. Hence, the thermal conditions in the region of the Bowline power plant will violate all the conditions of the applicable State and Federal thermal standards based on the 83°F limit, including the part about "50 percent of the cross-sectional area and/or volume of the flow of the estuary" (see Sect. 3.1).

The computer simulation results again indicate the important contribution of solar heating in Haverstraw Bay (see Fig. 3.5.66), particularly in the shallow regions near the bank across the river from the location of the Bowline power plant.

The computer simulation results by the TMPTWO thermal transport model for the two-dimensional temperature distributions during approximate maximum-flood-flow tidal stage at 2200 hr (see Fig. 3.5.67) indicate that depth-averaged water-temperature values exceeding 91°F will exist in the shallow regions near the shore in the upstream vicinity of the discharge structure (see Fig. 3.5.68). Since, according to the formulation of the two-dimensional model, the values of temperature represent the average temperature conditions in elements of approximately 200 ft by 200 ft size, the water temperature on the surface of the estuary will definitely exceed 90°F in the shallow regions. Hence, again, the operational conditions of the Bowline power plant will not comply with the

applicable State standards, since the temperature conditions will violate item i (see Sect. 3.1), which limits the allowable surface temperature to 90°F at any point along the estuary.

The results also indicate that depth-averaged temperatures exceeding 87°F will exist in shallow regions near the shoreline in the general vicinity of the Bowline power plant (see Fig. 3.5.68) during approximate maximum flood flow conditions at 2200 hr in the late evening. The area of the heated water (87°F) will extend approximately 3000 ft upstream and 6000 ft downstream of the location of the discharge. The boundary of this area that contains the heated water (87°F) will only extend approximately 200 ft from the discharge location laterally toward the central axis of the estuary. Furthermore, a significantly larger area in the shallow regions will reach depth-averaged water temperatures exceeding 84°F near the shoreline of the Bowline power plant (see Fig. 3.5.68). This area will extend over 2 miles (approximately 12,000 ft) upstream and over 2 miles (approximately 13,000 ft) downstream from the discharge location, and it will be limited by a boundary line parallel to the shore and extending more than 2000 ft from the discharge along the lateral direction across the river. Hence, the results of the computer simulations by the TMPTWO model again indicate that the thermal conditions in the vicinity of the Bowline power plant will also violate the limiting criterion that was recommended by the Environmental Protection Agency (see Sect. 3.1), since the temperatures will definitely exceed 83°F at distances more than 1000 ft from the discharge.

The computer simulation results for the two-dimensional distributions of depth-averaged water temperature in Haverstraw Bay show that the major portions of the surface area and volume of the estuary will be at 83°F (see Fig. 3.5.68). Hence, during the approximate maximum-flood-flow tidal stage in the river at 2200 hr, the thermal conditions in the region will comply with the limitation which states that "50 percent of the cross-sectional area and/or volume of the flow of the estuary including a minimum of one-third of the surface as measured from water edge to water edge" (see Sect. 3.1) shall not exceed 83°F.

The results of the simulations correctly indicate the start of the effect of night cooling in the shallow regions of Haverstraw Bay. The depth-averaged water temperature in the shallow regions at 2200 hr is generally 83°F, which is 1°F lower than the temperature conditions (84°F) that existed in the same locations at 1900 hr. Hence, the simulations again, in a sense indirectly, illustrate the importance of solar heating and more generally the importance of surface heat transfer in the shallow regions in the Haverstraw Bay area.

The local values for the depth-averaged water temperature, as shown in the graphical representations of the thermal conditions in Haverstraw Bay (see Figs. 3.5.62, 3.5.64, 3.5.66, and 3.5.68), were intentionally rounded off to the nearest degree F in order to indicate the limits of accuracy of the computer simulations. Hence, it must be emphasized that the comparisons of the results of the simulations with the limiting criteria of the applicable State and Federal thermal standards were based

on realistic temperature values which described the thermal conditions in the region within the proper limit of accuracy of the thermal impact analysis.

3.5.7.2. Zone-matched near-field and far-field (complete) thermal analysis of the operation of the Indian Point power plant. The tidal-transient two-dimensional, multilayer thermal transport model TMPTWO was also applied to the simulation of the depth-averaged temperature distributions in the vicinity of the Indian Point power plant for case 3 (proposed maximum thermal load plant operational conditions on the river) (see Sect. 3.4). Based on the results of the far-field thermal impact analysis for the complete river (see Sect. 3.4), it was determined that the particular day August 4, 1974, which was considered in the thermal impact analysis of the Bowline power plant, also corresponded to one of the days when the daily-averaged, cross-section-averaged, and 2-mile-segment-averaged water temperature values in the element (55) of the Indian Point power plant were extremely close to 83°F and the daily-maximum, cross-section-averaged, and 2-mile-segment-averaged water temperature values were higher than 83°F. Hence, it was decided to simulate the thermal conditions in the vicinity of the Indian Point power plant also on August 4, 1974, in order to be consistent with the dates that were considered in the analysis of the thermal impact conditions of both Bowline and Indian Point power plants.

The computer simulations by the TMPTWO model were again started at 0000 hr (midnight) on August 4, 1974, by assuming 83°F initial temperature conditions in the region. All the necessary data for the natural river flow and climatological conditions were input to the model for the day August 4, 1974. The temperature boundary conditions at the upstream and downstream open boundaries (see Fig. 3.5.1) were determined from the results of the one-dimensional far-field ESTONE model for the temperature conditions in elements 54 and 56 based on the approximate daily-minimum and daily-maximum values of 82.4°F and 83.8°F, respectively. These limiting temperature values were employed in the general formulation of the temperature boundary conditions (see Sect. 3.5.3.6). The computer simulations were continued through the day August 4, 1974, to determine the critical thermal conditions in the region of the Indian Point power plant during the four stages of the tidal flow (high-water slack, maximum ebb flow, low-water slack, and maximum flood flow) in the river. The operational conditions of both Indian Point power plant and also Lovett power plant were assumed as uniform at their full rated output power capacities (see Table 3.4.7) throughout the period of the simulations.

The results of the computer simulations by the general zone-matching methodology and the applications of the two-dimensional thermal transport code TMPTWO for the flow field and the thermal conditions in the region of the Indian Point power plant are presented as two-dimensional streak-line plots for velocity (Figs. 3.5.69, 3.5.71, 3.5.73, and 3.5.75) and as two-dimensional distributions of temperature values and constant-temperature contours (isotherms) (see Figs. 3.5.70, 3.5.72, 3.5.74, and 3.5.76) for the approximate times of the occurrence of the four critical

Fig. 3.5.69. Computer simulation results of two-dimensional flow conditions in the Indian Point region at 1300 (approximate high-water slack) on August 4, 1974.

Fig. 3.5.70. Computer simulation results of the two-dimensional temperature conditions in the Indian Point region at 1300 (approximate high-water slack) on August 4, 1974, for the assessment of the near-field and far-field thermal impact of the Indian Point and Lovett power plants for case 3 (proposed maximum thermal load plant operational conditions on the Hudson River).

Fig. 3.5.71. Computer simulation results of two-dimensional flow conditions in the Indian Point region at 1600 (approximate maximum ebb flow) on August 4, 1974.

Fig. 3.5.72. Computer simulation results of the two-dimensional temperature conditions in the Indian Point region at 1600 (approximate maximum ebb flow) on August 4, 1974, for the assessment of the near-field and far-field thermal impact of the Indian Point and Lovett power plants for case 3 (proposed maximum thermal load plant operational conditions on the Hudson River).

Fig. 3.5.73. Computer simulation results of two-dimensional flow conditions in the Indian Point region at 2000 (approximate low-water slack) on August 4, 1974.

Fig. 3.5.74. Computer simulation results of the two-dimensional temperature conditions in the Indian Point region at 2000 (approximate low-water slack) on August 4, 1974, for the assessment of the near-field and far-field thermal impact of the Indian Point and Lovett power plants for case 3 (proposed maximum thermal load plant operational conditions on the Hudson River).

Fig. 3.5.75. Computer simulation results of two-dimensional flow conditions in the Indian Point region at 2200 (approximate maximum flood) on August 4, 1974.

Fig. 3.5.76. Computer simulation results of the two-dimensional temperature conditions in the Indian Point region at 2200 (approximate maximum flood) on August 4, 1974, for the assessment of the near-field and far-field thermal impact of the Indian Point and Lovett power plants for case 3 (proposed maximum thermal load plant operational conditions on the Hudson River).

tidal stages in the estuary. The simulations were considered for the afternoon hours of August 4, 1974, when the maximum thermal conditions occur due to the combined effects of solar heating and the thermal discharges of the Indian Point and Lovett power plants in the region of the estuary.

The results of the computer simulations by the TMPTWO model for the approximate high-water slack conditions at 1300 hr (see Fig. 3.5.69) indicate that depth-averaged water temperature values exceeding 93°F will exist in the vicinity of the discharge of the Indian Point power plant (see Fig. 3.5.70). Since the formulation of the two-dimensional model considers depth-averaged temperature conditions in elements of approximately 200 ft by 200 ft size which contain the discharge structure, the water temperature at the surface of the estuary will definitely exceed 95°F at the location of the discharge. Hence, the operational conditions of the Indian Point power plant will violate item 1 (see Sect. 3.1), which limits the allowable surface temperature to 90°F at any point along the estuary.

The results also indicate that the depth-averaged water temperatures will reach 85°F in the shallow regions near the shoreline upriver from the discharge of the Indian Point power plant (see Fig. 3.5.70) during approximate high-water slack conditions at 1300 hr in the afternoon. The area of the heated water (85°F) will extend approximately 10,000 ft upriver and cause elevated temperatures in the shallow bay areas. Again, it is interesting to note that the boundary of this area that contains the heated water (85°F) will not extend to distances more than 200 ft from the discharge location laterally toward the central axis (based on the location of the main channel) of the estuary. Based on the results of the computer simulations by the TMPTWO model, the thermal conditions in the vicinity of the Indian Point power plant will exceed the standard which was recommended by the Environmental Protection Agency (see Sect. 3.1), since the temperatures will exceed 83°F at distances more than 1000 ft from the discharge. However, it is important to note that the area of the estuary that contains heated water at 84°F (exceeding the limit of 83°F) (see Fig. 3.5.70) is limited to the shallow regions where the solar heating effect can contribute significantly to the elevated temperature conditions. Hence, the results do not necessarily conclude that the thermal plume from the Indian Point power plant is the only cause of the high-temperature (84°F) conditions in the shallow regions upriver of the location of the plant.

The computer simulation results for the two-dimensional distributions of depth-averaged water temperature in the Indian Point region show that the major portions of the area and volume of the estuary will be at 83°F (see Fig. 3.5.70). Hence, during approximate high-water-slack tidal stage in the river at 1300 hr, the thermal conditions in the region will comply with the limitation that states that "50 percent of the cross-sectional area and/or volume of the flow of the estuary including a minimum of one-third of the surface as measured from water edge to water edge" (see Sect. 3.1) shall not exceed 83°F.

The computer simulation results by the TMPTWO thermal transport model for the thermal conditions during approximate maximum-ebb-flow tidal stage at 1600 hr (see Fig. 3.5.71) indicate that depth-averaged water temperature values exceeding 91°F will exist in the shallow regions near the shore downstream from the location of the discharge of the Indian Point power plant (see Fig. 3.5.72). Again, considering the fact that according to the formulation of the two-dimensional model the values of temperature represent the average temperature conditions in elements of approximately 200 ft by 200 ft size, the water temperature on the surface of the estuary will definitely exceed 90°F in the shallow regions. Hence, again, the operational conditions of the Indian Point power plant will not comply with the applicable State standards since the temperature conditions will violate item i (see Sect. 3.1), which limits the allowable surface temperature to 90°F at any point along the estuary.

The results also indicate that depth-averaged temperatures exceeding 87°F will exist in shallow regions near the shoreline in the general vicinity downstream of the Indian Point power plant (see Fig. 3.5.72) during approximate maximum ebb flow conditions at 1600 hr in the afternoon. The area of the heated water (87°F) will extend approximately 3000 ft downstream of the location of the discharge. The boundary of this area that contains the heated water (87°F) will extend approximately 800 ft from the discharge location laterally toward the central axis of the estuary. Furthermore, significantly larger areas in the shallow regions will reach depth-averaged water temperatures exceeding 84°F near the shorelines of both the Indian Point and Lovett power plants (see Fig. 3.5.72) on both banks of the estuary. The area containing the heated water (84°F) on the Indian Point shoreline will extend over 2 miles (approximately 14,000 ft) upstream and over 1 mile (approximately 6500 ft) downstream from the discharge location, and it will be limited by a boundary line parallel to the shore and extending more than 1000 ft from the discharge along the lateral direction across the river. The area on the shoreline of the Lovett power plant containing the heated water (84°F) will extend over 1 mile (approximately 8000 ft) upstream and over 1 mile (approximately 7000 ft) downstream from the location of the plant, and it will be limited by a boundary line parallel to the shore and generally extending less than 1000 ft from the discharge along the lateral direction. Hence, the results of the computer simulations again indicate that the thermal conditions in the vicinities of both the Indian Point power plant and the Lovett power plant will violate the standard that was recommended by the Environmental Protection Agency (see Sect. 3.1), since the temperatures will definitely exceed 83°F at distances more than 1000 ft from the discharge.

The computer simulation results for the two-dimensional distributions of depth-averaged water temperature show that although the major portion of the surface area of the Indian Point region will be at 83°F (see Fig. 3.5.72), the areas along both shorelines of the estuary that contain the water at elevated temperatures (84°F) will approach each other sufficiently between the Indian Point and Lovett power plants to cover more than 50% of the surface area of the estuary. Hence, during approximate maximum-ebb-flow tidal stage in the river at 1600 hr, the thermal conditions in the

region will clearly exceed the limitation which states that "a minimum of one-third of the surface as measured from water edge to water edge" (see Sect. 3.1) shall not exceed 83°F. However, the part of the thermal standard about "50 percent of the cross-sectional area and/or volume of the flow of the estuary" not to exceed 83°F will not be violated, since the parts of the Indian Point region that will have water temperatures at approximately 83°F will be the relatively deep main channel (see Fig. 3.5.29) sections with large cross-sectional areas and flow volumes.

It is necessary to emphasize the important contribution of solar heating to the elevated thermal conditions in the shallow bay areas of the Indian Point region. The simulation results clearly illustrate the strong effect of solar heating in shallow areas less than 10 ft deep (see Fig. 3.5.29), located more than 3 miles (approximately 16,000 ft) upriver of the Indian Point power plant. The temperatures in these areas reach 85°F at 1600 hr in the afternoon as the result of the solar heating. Considering that the water temperature 1 mile downstream of the Indian Point discharge is only 84°F and that the ebb flow conditions in the estuary generally bend the thermal plume in the downstream direction from the discharge, the existence of water temperatures of 85°F upstream of the location of the plant clearly illustrates the significant influence of solar heating on the thermal conditions in the shallow areas in the Indian Point region.

The computer simulation results by the TMPTWO thermal transport model for the thermal conditions during approximate low-water-slack tidal stage (see Fig. 3.5.73) indicate that the two-dimensional distribution of the depth-averaged water temperature (see Fig. 3.5.74) in the region of the Indian Point power plant at 2000 hr is generally similar to the distribution that existed during approximate maximum-ebb-flow tidal stage at 1600 hr (see Fig. 3.5.72) with lower elevated temperature values. The maximum depth-averaged water temperature of 88°F will occur in the immediate vicinity of the discharge. Again, considering the fact that according to the formulation of the two-dimensional model the values of temperature represent the average temperature conditions in elements of approximately 200 ft by 200 ft size, the water temperature on the surface of the estuary will be higher than 88°F, but it will probably not exceed 90°F. Hence, the operational conditions of the Indian Point power plant during approximate low-water-slack tidal stage at 2000 hr will probably comply with item i (see Sect. 3.1) of the applicable State standards, which limits the allowable surface temperature to 90°F at any point along the estuary.

The results again indicate that depth-averaged temperatures exceeding 87°F will exist in shallow regions near the shoreline in the general vicinity downstream of the Indian Point power plant (see Fig. 3.5.74) during approximate low-water slack conditions at 2000 hr in the evening. The area of the heated water (87°F) will extend approximately 2500 ft downstream of the location of the discharge. The boundary of this area that contains the heated water (87°F) will extend approximately 400 ft from the discharge location laterally toward the central axis of the

estuary. Furthermore, a larger area in the shallow regions will reach depth-averaged water temperatures exceeding 84°F near the shoreline of the Indian Point plant (see Fig. 3.5.74). The area containing the heated water (84°F) will extend over 2 miles (approximately 14,000 ft) from the location of the discharge, and it will be limited by a boundary line parallel to the shore and extending to a distance of approximately 1500 ft from the location of the discharge along the lateral direction across the river. The area along the shoreline of the Lovett power plant containing the heated water (84°F) will extend less than 1 mile (approximately 4000 ft) downstream from the location of the plant, and it will be limited by a boundary line parallel to the shore and generally extending less than 600 ft from the discharge along the lateral direction. Hence, the results of the computer simulations again indicate that the thermal conditions in the vicinities of both the Indian Point power plant and the Lovett power plant will violate the standard that was recommended by the Environmental Protection Agency (see Sect. 3.1), since the temperatures will definitely exceed 83°F at distances more than 1000 ft from the discharge.

The computer simulation results for the two-dimensional distributions of depth-averaged water temperature again show that although the major portion of the surface area of the Indian Point region will be at 83°F (see Fig. 3.5.74), the areas along both shorelines of the estuary that contain the water at elevated temperatures (84°F) will again approach each other sufficiently between the Indian Point and Lovett power plants to cover more than 30% of the surface area of the estuary. Hence, during approximate low-water-slack tidal stage in the river at 2000 hr, the thermal conditions in the region will again exceed the limitation which states that "a minimum of one-third of the surface as measured from water edge to water edge" (see Sect. 3.1) shall not exceed 83°F . However, the part of the thermal standard about "50 percent of the cross-sectional area and/or volume of the flow of the estuary" not to exceed 83°F definitely will not be violated, since the parts of the Indian Point region that will have water temperatures at approximately 83°F will be the relatively deep main channel (see Fig. 3.5.29) sections with large cross-sectional areas and flow volumes.

The results of the computer simulations also indicate that the flow conditions in the estuary will cause possible accumulation of heated water in the shallow regions near the shoreline approximately 2.0 miles (approximately 10,000 ft) from the location of Indian Point power plant. The water in these shallow areas of depth less than 10 ft (see Fig. 3.5.29) moves considerably slower than the water in the main channel during the tidal periods. Hence, the combined effects of mixing with the thermal plume from the Indian Point power plant during ebb flow conditions and the continuous solar heating during the day cause the water temperatures to rise appreciably (85°F) during the early evening hours. The surface cooling effect usually requires more than 8 hr (until early morning at 0800 hr) to cool the shallow area to temperatures below 82°F .

The computer simulation results by the TMPTWO thermal transport model for the two-dimensional temperature distributions during approximate maximum-flood-flow tidal stage at 2200 hr (see Fig. 3.5.75) indicate that depth-averaged water temperature values exceeding 96°F will exist in the shallow regions near the shore in the upstream vicinity of the discharge structure (see Fig. 3.5.76) of the Indian Point power plant. Since according to the formulation of the two-dimensional model the values of temperature represent the average temperature conditions in elements of approximately 200 ft by 200 ft size, the water temperature on the surface of the estuary will definitely exceed 96°F in the shallow regions. This extremely high temperature condition will be caused by the strong recirculation of the heated water from the discharge to the intakes of the Indian Point power plant. Hence, the operational conditions of the Indian Point power plant will not comply with the applicable State standards, since the temperature conditions will definitely violate item i (see Sect. 3.1), which limits the allowable surface temperature to 90°F at any point along the estuary.

The results also indicate that depth-averaged temperatures reaching 84°F will exist in relatively large areas along the shorelines of both Indian Point and Lovett power plants (see Fig. 3.5.76) during approximate maximum flood conditions at 2200 hr. The area of the heated water (84°F) will extend approximately 3000 ft upstream of the location of the Indian Point power plant. Similarly, the area of the heated water (84°F) will extend over 2500 ft upstream of the location of the Lovett power plant. An important consequence of the computer simulation results is that during maximum flood flow conditions at 2200 hr the two areas of heated water (84°F) from the Indian Point and Lovett power plants actually merge across the estuary. Hence, the results clearly indicate that again the thermal conditions in the region of Indian Point will definitely violate the limiting criterion that was recommended by the Environmental Protection Agency (see Sect. 3.1), since the temperatures will definitely exceed 83°F at distances more than 1000 ft from the discharge.

The computer simulation results from the TMPTWO thermal transport model for the two-dimensional temperature distributions in the Indian Point region during the maximum-flood-flow tidal stage at 2200 hr also indicate that the depth-averaged water temperature across the river will reach approximately 84°F (will definitely exceed 83°F) between the Indian Point and Lovett power plants. Hence, the operational conditions of the Indian Point and Lovett power plants will cause water temperature conditions exceeding 83°F from water edge to water edge across the estuary. Furthermore, over the total area of any cross section of the estuary between the locations of Indian Point and Lovett power plants, the water temperature will exceed 83°F according to the results of the simulations. Hence, during approximate maximum-ebb-flow tidal stage at 2200 hr, the thermal conditions in the region of the Indian Point power plant will completely violate item ii of the applicable State standards (see Sect. 3.1), which states that "50 percent of the cross-sectional area and/or volume of the flow of the estuary including a minimum of one-third of the surface as measured from water edge to water edge" shall not exceed 83°F.

The local values for the depth-averaged water temperature, as shown in the graphical representations of the thermal conditions in the Indian Point region (Figs. 3.5.70, 3.5.72, 3.5.74, and 3.5.76) were again intentionally rounded off to the nearest degree F in order to indicate the limits of accuracy of the computer simulations. Hence, it must be emphasized that the comparisons of the results of the simulations with the limiting criteria of the applicable State and Federal thermal standards were based on realistic temperature values which described the thermal conditions in the region within the proper limit of accuracy of the thermal impact analysis.

It is important to emphasize that the worst thermal conditions (from the point of view of compliance with the applicable State and Federal thermal standards) will occur in the Indian Point region during maximum-flood-flow tidal stage at 2200 hr based on the computer simulations on August 4, 1974, conditions in the Hudson River. Although the operational conditions of the Indian Point and Lovett power plants will violate various different limiting criteria of the applicable State and Federal thermal standards during the afternoon and early evening hours, the complete violation of all the items of the thermal standards will only occur late in the evening and only during maximum-flood-flow tidal stage in the Indian Point region. Furthermore, this critical thermal condition which totally violates all the limiting criteria of the applicable State and Federal thermal standards will occur for the case of operation of both Indian Point and Lovett power plants (also all other existing and proposed power plants) at full rated output power continuously through the days of the simulation period.

3.5.7.3 Conclusions based on the results of the zone-matched near-field and far-field (complete) thermal analysis of the operations of Bowline power plant and Indian Point power plant. The computer simulation results by the thermal transport model TMPTWO, based on the application of the near-field and far-field zone-matching methodology for the two-dimensional distributions of depth-averaged water temperature conditions in the Haverstraw Bay and Indian Point regions of the estuary, lead to the following conclusions about the local thermal impact of the operational conditions of Bowline and Indian Point power plants (and according to case 3, proposed maximum thermal load plant operational conditions for all other plants) on the Hudson River:

1. Based on hypothetical August 4, 1974, river conditions, the critical thermal conditions in the Haverstraw Bay area in the vicinity of the Bowline power plant will generally occur during the afternoon and evening between 1300 and 2200 hr (see Sect. 3.5.7.1).

2. Based on hypothetical August 4, 1974, river conditions, the operation of Bowline power plant will violate the applicable New York State thermal standards (see Sect. 3.1) item i due to the occurrence of surface temperature of 91°F in the vicinity of the plant between 1300 and 2200 hr during all four tidal stages.

3. Based on hypothetical August 4, 1974, river conditions, the operation of Bowline power plant will violate the applicable New York State thermal standards (see Sect. 3.1) item ii due to the occurrence of surface temperatures of 84°F over one-third of the surface as measured from water edge to water edge between 1600 and 1900 hr during maximum-ebb-flow and low-water-slack tidal stages.

4. Based on hypothetical August 4, 1974, river conditions, the operation of Bowline power plant will violate the applicable New York State thermal standards (see Sect. 3.1) item ii due to the occurrence of water temperatures of 84°F over 50% of the cross-sectional area and/or volume of the flow of the estuary about 1900 hr during low-water-slack tidal stage.

5. Based on hypothetical August 4, 1974, river conditions, the operation of Bowline power plant will violate the 83°F limit criterion recommended by the Environmental Protection Agency (see Sect. 3.1) due to the existence of water temperatures of 87°F at distances more than 3000 ft and 84°F at distances more than 6000 ft from the location of the discharge between 1300 and 2200 hr, during all four tidal stages. The area of the heated water will be limited to shallow regions near the shoreline and will not extend more than 500 ft laterally across the river.

6. Based on hypothetical August 4, 1974, river conditions, the critical thermal conditions in the region of Indian Point in the vicinity of the Indian Point and Lovett power plants will generally occur during the afternoon and evening between 1300 and 2200 hr (see Sect. 3.5.7.2).

7. Based on hypothetical August 4, 1974, river conditions, the operation of Indian Point power plant will violate the applicable New York State thermal standards (see Sect. 3.1) item i due to the occurrence of surface temperatures exceeding 91°F in the vicinity of the plant between 1300 and 1600 hr during high-water-slack and maximum-ebb-flow tidal stages and about 2200 hr during maximum-flood-flow tidal stage.

8. Based on hypothetical August 4, 1974, river conditions, the operation of Indian Point power plant will violate the applicable New York State thermal standards (see Sect. 3.1) item ii due to the occurrence of surface temperatures of 84°F over one-half of the surface as measured from water edge to water edge between 1600 and 2000 hr during maximum-ebb-flood, low-water-slack, and maximum-flood-flow tidal stages.

9. Based on hypothetical August 4, 1974, river conditions, the operation of Indian Point power plant will violate the applicable New York State thermal standards (see Sect. 3.1) item ii due to the occurrence of water temperature of 84°F over 80% of the cross-sectional area and/or volume of the flow of the estuary about 2200 hr during maximum-flood-flow tidal stage.

10. Based on hypothetical August 4, 1974, river conditions, the operation of Indian Point power plant will violate the 83°F limit criterion recommended by the Environmental Protection Agency (see Sect. 3.1) due to the existence of water temperatures of 87°F at distances more than 2500 ft from the location of the discharge between 1600 and 2000 hr during maximum ebb flow and low-water slack and temperatures of 84°F at distances more than 8000 ft (on the average) from the location of the discharge between 1300 and 2200 hr during all four tidal stages. The areas of the heated water will generally be limited to regions near the shorelines and will not extend more than 800 ft laterally across the river between 1300 and 2000 hr during high-water-slack, maximum-ebb-flow, and low-water-slack tidal stages. However, about 2200 hr during maximum-flood-flow tidal stage the areas of heated water (84°F) will merge laterally across the river.

The results of the zone-matched near-field and far-field (complete) thermal analysis of the operations of Bowline power plant and Indian Point power plant conclude that, based on hypothetical August 4, 1974, conditions, applicable New York State thermal standards and the thermal criteria recommended by the Environmental Protection Agency (see Sect. 3.1) will be violated in the vicinities of the two power plants according to case 3 (proposed maximum thermal load plant operational conditions on the Hudson River).

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3.6 General Discussion of the Results of the Overall Analysis for the Assessment of the Thermal Impact of Power Plant Operations on the Hudson River

The overall analysis for the assessment of the thermal impact of power plant operations on the Hudson River was divided into three major parts which supplemented (and complemented) each other. Each individual part of the overall analysis was required in order to accurately determine (within the limits of the state of the art in mathematical modeling) the critical thermal conditions in the estuary, particularly in the vicinities of the major power plants.

The results of the near-field analysis concluded that the temperatures of the heated water from the discharges of the major power plants will be reduced by mixing with the entrained locally ambient water according to dilution ratios which generally varied between 2 and 6, depending on bathymetry and tidal flow conditions in the vicinities of the power plants. However, in view of the reversing tidal flow conditions in the estuary, it was evident that the local ambient temperature values in the vicinities of the power plant discharges could not be estimated without considering the important effects of reentrainment. Furthermore, again in view of the reversing tidal flow conditions, it was evident that the temperature values of the intake water could not be estimated without considering the important effects of recirculation, both between the discharges and the intakes of the individual power plants and also between different plants along the estuary. Hence, although the operational conditions for each power plant could be considered in terms of specified condenser flow rates and temperature rise conditions, since the water temperature values at the intakes could not be estimated, it was not possible to estimate the temperatures of the discharge water. Furthermore, although the dilution ratios for the discharges were estimated, since the temperature values of the local ambient water in the vicinities of the discharges could not be estimated, the final temperature conditions of the diluted discharge plume could not be estimated in the near-field zone. Hence, the values of the surface temperature and the distances from the intakes for the critical temperature conditions could not be accurately determined in order to be able to consider the compliance of the operational conditions of the power plants with the applicable State and Federal thermal standards. Therefore, a detailed far-field analysis was necessitated to determine the water temperature conditions in the vicinities of the major power plants by considering the overall thermal impact of multiplant operations on the common receiving water body of the estuary.

The far-field thermal impact analysis was based on hypothetical 1974 river flow and climatological conditions in the Hudson River region. The important freshwater flow conditions during the six-month period of the simulations, April-September 1974, were typical of the freshwater conditions which usually occur in the Hudson River. In selecting the particular period in 1974, the freshwater flow conditions during the previous seven years (1968-1974) were carefully considered. The summary of the available data for monthly-averaged freshwater flow rates in the lower Hudson River (see Sect. 2.1.2.2) are presented in Table 3.6.1 for the six months of the simulations.

The comparisons of the monthly-averaged freshwater flow rates for the six months (April-September) in 1974 with the seven-year-average (1968-1974) monthly-averaged freshwater flow rates clearly show that 1974 was a typical year. The six-month-averaged (April-September), monthly-averaged freshwater flow rate in 1974 was 21,300 cfs, which was in very good agreement with the six-month-averaged (April-September), seven-year-averaged, monthly-averaged freshwater flow rate of 23,100 cfs with a percentage error less than 8% (see Table 3.6.1).

In order to also consider a case of possible minimum tidal-averaged flow rates in the estuary, the seven-year-minimum (1968-1974) monthly-averaged freshwater flow rates in the lower Hudson River were also compared (see Table 3.6.1) for the period of six months (April-September) of the computer simulations. The comparisons of the monthly-averaged freshwater flow rates for the six months (April-September) in 1974 with the seven-year-minimum (1968-1974) monthly-averaged freshwater flow rates indicated that, on the average, the freshwater flow conditions in the Hudson River during April-September 1974 were about twice the freshwater flow conditions of the seven-year possible minimum case. The six-month-averaged (April-September), monthly-averaged freshwater flow rate of 21,300 cfs was approximately 94% more than the six-month-averaged, seven-year-minimum, monthly-averaged freshwater flow rate of 11,900 cfs (see Table 3.6.1).

The assessment of the overall far-field thermal impact of power plant operations on the Hudson River was based on the typical seven-year-average freshwater flow conditions during April-September 1974; hence the results of the particular analysis would represent the important dividing line conditions. If the freshwater flow conditions in the estuary drop below the freshwater flow rates considered in the simulations during April-September 1974, then it is realistic to expect that the thermal impact of power plant operations on the overall receiving water body of the estuary would be higher than the thermal impact based on the 1974 river conditions. Conversely, if the freshwater flow conditions in the estuary become higher than the freshwater flow rates considered in the simulations during April-September 1974, then the thermal impact of power plant operations would be lower than the thermal impact based on 1974 river conditions. The case of the possible seven-year-minimum (1968-1974) freshwater flow conditions (see Table 3.6.1) represents the minimum possible tidal-averaged flow conditions that can occur in the Hudson River with realistic frequencies. This case warrants consideration only if the thermal impact analysis based on the seven-year-average freshwater flow case, as represented by April-September 1974 river conditions, would conclude that the overall far-field thermal impact of power plant operations on the Hudson River would comply with the applicable State and Federal thermal standards. Hence, the case of seven-year-minimum freshwater flow conditions (see Table 3.6.1) was classified as the backup case, and the 1974 river conditions, which approximately represent the seven-year-average freshwater flow case, were considered in the assessment of the overall far-field thermal impact of power plant operations on the Hudson River.

The results of the computer simulations by the tidal-transient one-dimensional far-field ESTONE model indicated that cross-section-averaged and 2-mile-segment-averaged water temperature conditions would be 82.91°F for daily-averaged and 83.80°F for daily-maximum temperatures (see Table 3.4.13) in the vicinity of the Indian Point power plant for case 3 (proposed maximum thermal load plant operational conditions in the river) (see Sect. 3.4). The results concluded that the 83°F limiting criterion (see Sect. 3.1) of the thermal standards will be violated for the particular case. However, since the results of the one-dimensional simulations indicated water temperature values very close to the limiting 83°F criterion, exceeding only for daily-maximum conditions, it was required to consider the zone-matched near-field and far-field (complete) thermal impact analysis to accurately determine the detailed temperature conditions in the vicinities of the Bowline and Indian Point power plants.

The zone-matched near-field and far-field (complete) thermal impact analyses of the operations of Indian Point and Bowline power plants were based on the hypothetical conditions on August 4, 1974, in the Hudson River. The selection of the particular date was based on the results of the one-dimensional far-field thermal analysis, which indicated that August 4, 1974, was one of the days when the critical thermal conditions in the vicinities of Indian Point and Bowline power plants could exceed the limits of the applicable State and Federal thermal standards (see Sect. 3.1) for case 3 (proposed maximum thermal load plant operational conditions on the estuary) (see Sect. 3.4). The results of the zone-matched near-field and far-field (complete) thermal analyses established (see Sect. 3.5.7.3) (a) the locations along the estuary and (b) the times and durations during the tidal stages when the thermal conditions resulting from the full rated output power operational conditions of the Bowline and Indian Point power plants would violate the specific limiting criteria of the applicable State and Federal thermal standards (see Sect. 3.1) for the August 4, 1974, conditions in the Hudson River.

Hence, the results of the overall thermal impact analysis (see Sects. 3.4.6.7 and 3.5.7.3) conclude that on a typical day in August when the thermal conditions in the estuary are locally critical, during a six-month period in the summer when the freshwater flow rates in the Hudson River are typical, the operation of the Bowline and Indian Point power plants will violate the applicable State and Federal thermal standards during the afternoon and evening hours for case 3 (proposed maximum thermal load plant operational conditions on the Hudson River).

Table 3.6.1. Comparison of 1974 monthly-averaged freshwater flow rates with seven-year (1968-1974) monthly-averaged freshwater flow rates in the lower Hudson River (New York)

Month	1974 flow (cfs)	7-year-average flow (cfs)	1974 difference (%)	7-year-minimum flow (cfs)	1974 difference (%)
April	48,500	49,900	-3%	26,800 (1968)	+80%
May	30,600	35,400	-14%	18,900 (1970)	+62%
June	12,000	21,500	-44%	8,550 (1970)	+40%
July	14,500	14,000	+4%	6,980 (1971)	+108%
August	7,830	3,760	-11%	4,820 (1970)	+62%
September	14,600	9,120	+60%	5,140 (1968)	+184%
6-month average	21,300	23,100	-8%	11,900	+94%

Source: U.S. Department of the Interior, Geological Survey, Water Resources Division.

4. ASSESSMENT OF THE IMPACT ON REGIONAL AIR QUALITY

4.1 Characteristics of Atmosphere Environment

4.1.1 Meteorology of the area

The Hudson River valley is located in an area characterized by warm summers and relatively cold winters. Cold polar air masses influence the climate of the winter months, while warmer maritime air masses are experienced during summer.

The river valley topography influences the local wind patterns. Over the river and below the highest ridges (i.e., up to about 200 ft), there is a tendency for the winds to be upstream by day and downstream by night. Further, the valley wind speeds are lower than in the more open terrain. This situation prevails for more than one-third of the time. Wind roses are shown in Figs. 4.1.1 and 4.1.2; they are annual wind roses obtained from data taken at the Bowline and Roseton plant locations respectively.

Precipitation in the area is fairly uniformly distributed throughout the year. It averages 46 in./year. Mean ambient air temperatures for the area are 75°F in July and 28°F in January.

4.1.2 Fossil-fueled plants: their characteristics and their effluents

The two major fossil-fueled plants in the area of interest are the 1200-MW Bowline Point plant near Haverstraw and the 1200-MW Roseton plant near Newburgh. The former plant is operated by Orange and Rockland Utilities and the latter by Central Hudson Gas and Electric. Orange and Rockland Utilities also operates the older Lovett plant about 3.5 km north of the Bowline plant; Central Hudson Gas and Electric operates the older Danskammer plant adjacent to the Roseton plant.

The Bowline plant consists of two 600-MW units each having a stack 87 m in height.

The Roseton plant consists of two 600-MW units each having a stack about 79 m in height.

The Lovett plant has five units with a combined capacity of 504 MW. Only Units 3, 4, and 5 will concern us in this study because the other units are operated in a standby capacity. Units 3, 4, and 5 have capacities of about 79, 188, and 198 MW, respectively, and have stack heights of 51.8 m, 62.8 m, and 72.8 m respectively.

Fig. 4.1.1. Annual Bowline wind rose.

The Danskammer plant has a capacity of 532 MW. It consists of four units having capacities of about 77, 77, 143, and 235 MW respectively.

The Bowline and Lovett plants are within the New York City airshed and are restricted to the burning of 0.37% sulfur fuel. The Roseton and Danskammer plants are outside the airshed, and the sulfur content of their fuel is higher, being on the order of 2%. All of these plants burn oil. Tables 4.1.1 and 4.1.2 show some plant characteristics that are relevant to the analysis of the atmospheric effluents.

Fig. 4.1.2. Annual Roseton wind rose.

4.1.3 Characteristics of an alternative closed-cycle cooling system

Natural-draft wet cooling towers have been proposed as a closed-cycle cooling system alternative to once-through cooling for both the Bowline and Roseton power plants.

4.1.3.1 Bowline Point. The general characteristics of natural-draft cooling towers for possible use as an alternative closed-cycle cooling system at Bowline were obtained primarily from a preliminary study made by Bechtel¹ for Orange and Rockland Utilities and are presented in Table 4.1.3. Bechtel quotes a drift rate of 0.05% for circulating water

Table 4.1.1. Plant characteristics relevant to analysis of atmospheric effluents

	Bowline (each unit)	Lovett Unit 3	Lovett Unit 4	Lovett Unit 5
Stack height, m	87	51.8	62.8	72.8
Stack diameter, m	5.72	3.81	3.96	4.88
Stack emission velocity, m/sec	26.8	10.1	23.8	17.1
Stack gas temperature, °C	132	227	152	143
SO ₂ emission rate, g/sec	263	32	76	80

Table 4.1.2. Plant characteristics relevant to analysis of atmospheric effluents

	Roseton (each unit)	Danskammer Units 1 and 2	Danskammer Unit 3	Danskammer Unit 4
Stack height, m	79.2	67.1	73.2	73.2
Stack diameter, m	7.01	3.66	3.78	4.88
Stack emission velocity, m/sec	18.3	9.0	15.7	15.5
Stack gas tem- perature, °C	138	154	127	149
SO ₂ emission rate, g/sec	1544	96	179	294

Table 4.1.3. General characteristics of possible natural-draft cooling towers at Bowline Point

Height	149.40 m
Range	8.3 C° (15.00 F°)
Water:air ratio	1.45
Inner radius	35.10 m
Efflux speed	3.50 m/sec
Total heat out	395.00 megacal/sec
Drift fraction	0.00005
Latitude	41.21° north
Longitude	73.97° west
Tower base elevation	3.05 m (10.00 ft) above mean sea level

Source: Bechtel Associates Professional Corporation, *Natural Draft Cooling System Mitigating Measure Study for Orange and Rockland Utilities, Inc., Bowline Point Station, West Haverstraw, N.Y., Gaithersburg, Md., December 1974 (revised January 1975 and March 1975).*

flow. This figure is quite high in the light of current practice, and we used 0.005% as a more representative figure. The total heat out is for two towers spaced approximately 161 m on centers.

The drift drop size and mass distributions were selected from Table 5-4 of ref. 2 and are given in Table 4.1.4.

Monthly salinity variations in the cooling water were obtained by interpolating at mile point 37.5 among the Hudson River salt intrusion curves presented in Fig. B-5, Appendix I, of ref. 3 and are shown in Table 4.1.5. The mile point for Bowline Point Station was obtained from Table V-3, ref. 4. Dissolved solids in the cooling tower drift were based on a concentration factor of 2.88, obtained from a makeup flow of 0.505 m³/sec (8000 gpm) and a blowdown flow of 0.175 m³/sec (2780 gpm) per unit.

4.1.3.2 Roseton. With the exception of location and tower-base elevation, tower characteristics for Roseton were taken to be the same as those for Bowline Point. For Roseton, the latitude and longitude become 41.57° north and 73.98° west respectively. Tower base elevation is 6.10 m (20 ft) above mean sea level.

Cooling water salinity variations were obtained as described for Bowline Point except that the mile point was taken as 65.4, as given in Table V-3 of ref. 4.

Table 4.1.4. Drift characteristics of possible natural-draft cooling towers at Bowline Point

Mean drop size (μ)	Percent of total drift mass
25	19
75	34
125	18
175	11.8
225	7.7
275	4.6
325	2.6
375	2.3

Source: U.S. Nuclear Regulatory Commission, *Final Environmental Statement Related to Selection of the Preferred Closed Cycle Cooling System at Indian Point Unit No. 2*, NUREG-0042, Docket No. 50-247, August 1976, Table 5-4.

4.2 Atmospheric Transport Modeling

4.2.1 Transport calculations for stack pollutants

Calculation of atmospheric pollutant transport and dispersion was accomplished by using the atmospheric transport model of Culkowski and Patterson.⁵ This is a Gaussian-plume-type model. Source locations are specified by longitude and latitude, and average ground-level concentrations are calculated for points whose coordinates are specified. By specifying a suitable grid, one can visually display the calculated ground-level pollutant concentrations for a region.

The data that the model requires for the estimations of ground-level concentrations of aerial-borne pollutants are primarily source-related data and meteorological data. Source data include emission rates for pollutants and emission characteristics of the stacks. These stack characteristics serve to estimate the initial atmospheric rise of the plume due to momentum and/or buoyancy.

Meteorological data needed to estimate atmospheric dispersal are wind speed and wind direction, which give information on pollutant advection, and atmospheric stability data, which allow one to calculate the rate of atmospheric diffusion. Wind speed, wind direction, and atmospheric stability (from temperature gradient data) were available for a number of years at the Bowline and Roseton sites. Seasonal averaged dispersion climatologies were constructed using these data.

Table 4.1.5. Monthly variation in salinity and dissolved solids in cooling tower drift at Bowline Point and Roseton stations

(Bowline Point, mile point 37.5; Roseton, mile point 65.4)

Month	Monthly average river flow ^a (cfs)	Salinity ^b (ppm)		Dissolved solids ^c (ppm)	
		Bowline Point	Roseton	Bowline Point	Roseton
January	14,900	450	100	1,296	288
February	11,300	1,692	100	4,873	288
March	27,500	100	100	288	288
April	37,500	100	100	288	288
May	21,000	100	100	288	288
June	11,000	1,889	100	5,440	288
July	8,000	5,700	100	16,416	288
August	6,500	6,621	800	19,068	2,304
September	7,200	6,174	283	17,781	815
October	9,200	3,665	100	10,555	288
November	14,500	521	100	1,500	288
December	15,600	348	100	1,002	288

^aConsolidated Edison Company, *Environmental Report, Indian Point Unit No. 3, Appendices*, vol. 1, Appendix I, Fig. 2.

^bIbid., Fig. B-5.

^cBased on a concentration factor of 2.88.

4.2.2 Modeling of cooling tower fog and drift

ORFAD,^{6,7} a computer program developed at the Oak Ridge National Laboratory, has been used to estimate the amounts of fog, ice, and drift to be expected from operation of wet cooling towers at the Bowline and Roseton sites. Principal inputs to the program are the tower dimensions, operating parameters, and hourly meteorological data. The meteorological data may be obtained either on site or from weather tapes available from the National Climatic Center, Asheville, North Carolina.

The ORFAD model assumes that the effluent from a wet cooling tower may be treated as a plume containing both pure water vapor and saline droplets having an initial salt concentration equal to that in the cooling tower basin water. The horizontal transport rate of the tower effluent is equated to wind speed, which is assumed independent of height.

The distribution of water vapor density is assumed to be Gaussian with respect to the plume centerline, ground effects being accounted for by the method of images. Plume rise is obtained from the relationships of Briggs⁸ as modified by Hanna⁹ to account for moisture in the plume. Increased buoyancy from the merger of multiple plumes is accommodated by an empirical rise enhancement factor.¹⁰

Computations are performed for 16 compass directions and for various user-specified distances down wind. Fogging is assumed to occur if, at any point, the moisture added by the plume equals or exceeds the saturation deficit of the entrained air. If, under fogging conditions, the ambient temperature is below freezing, icing is assumed to occur. The fog calculation is bypassed if the data indicate that natural fog is present.

The saline water droplets are assumed to travel in ballistic trajectories set by the rise velocity of the plume and the fall velocity of a droplet relative to the plume. The relative fall velocity is found from the relations of Hosler et al.¹¹ as a function of droplet size and relative humidity range. Relative humidity determines whether the drop falls without evaporation, evaporates to a saturated solution, or evaporates to a dry particle.

A distribution of fractional mass with respect to particle diameter is used to assign drops to classes. Each class has a nominal diameter and represents a certain fraction of the total drift emitted from the tower. Separate calculations are made for each class, and the results are summed to get the total drift.

4.3 Atmospheric Impacts in the Hudson River Basin

4.3.1 Effects due to the Bowline and Lovett plants

Data on wind speed, wind direction, and atmospheric stability were obtained from an observation tower located at the Bowline plant. This instrumented tower was operated and maintained by Environmental Research and Technology, Inc. (ERT), Concord, Massachusetts, and we have used observations from September 1972 to May 1976 in constructing average yearly and seasonal probabilities. Wind directions were classified from 16 directions. Wind speed was described by six classes: 1.8, 3.3, 4.5, 8.0, 11.0, and greater than 11.0 m/sec. Atmospheric stability was given in terms of six stability classes, namely, Pasquill-Gifford classes A, B, C, D, E, and F.

The terrain surrounding the Bowline area is hilly and mountainous in places. Because some of these hills are quite near to the pollutant sources, one must account for them by using a value of ground-level elevation that is representative of the terrain adjacent to the power plants. By examining topographic maps of the areas, a value of 88 ft (27 m) was chosen.

Ground-level values for sulfur dioxide concentration were calculated on a seasonal and an annual basis. The results of these calculations are shown in Figs. 4.3.1-4.3.5. All of the values are relatively low, on the order of $4 \mu\text{g}/\text{m}^3$ at a maximum. This is to be expected because the power plants are located within the New York City airshed. The calculations indicate that the sulfur dioxide levels due to Bowline and Lovett are well within Federal and State standards.

4.3.2 Effects due to the Roseton and Danskammer plants

Data on wind speed, wind direction, and atmospheric stability were available for the period September 1972 through August 1976. These data were obtained at the Roseton site, where a meteorological tower is operated and maintained by ERT. The data from this tower were treated in a similar manner to the data from the Bowline tower, and joint frequency distributions were constructed for wind speed, stability, and wind direction.

Using data on the elevation of the terrain near the plant, we estimated an average terrain height of 200 ft (61 m), which was used for ground level in the calculations.

Figures 4.3.6-4.3.10 show the annual and seasonal ground-level concentrations for sulfur dioxide in an area surrounding the Roseton and Danskammer plants.

The combined effects of the Roseton and Danskammer plants on the surrounding area are about a factor of 10 times the effects of the Bowline and Lovett plants on their surrounding area. This is to be expected due to the low sulfur content of the fuel burned by plants within the New York City airshed.

The maximum seasonal ground-level concentration occurs in the vicinity of the Roseton and Danskammer plants. This occurs during June, July, and August and reaches a value of about $40 \mu\text{g}/\text{m}^3$. Thus we conclude that the effects of the plants alone keep sulfur dioxide levels within Federal and State standards.

Some recent work by Lange et al.¹² is relevant to these calculations. They have done a detailed study of an area on the Hudson River using a particle-in-cell (PIC) model and have compared their results with a Gaussian plume model in order to investigate the effects of topography. The area chosen was in the vicinity of Indian Point. Because of the detailed nature of the PIC model, only a 24-hr period was studied. However, the Gaussian plume results agreed quite well with the PIC results during unstable and neutral conditions, and they gave higher ground-level concentration than the PIC model did for stable conditions.

Therefore, it is likely that the Gaussian plume approach is conservative; that is, it overestimates ground-level concentrations under some conditions. However, the PIC approach is still being studied. It

Fig. 4.3.1. Calculated average ground-level sulfur dioxide concentration due to Bowline and Lovett plants during the season December-January-February. The Bowline plant is at the center of the circular area.

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Fig. 4.3.2. Calculated average ground-level sulfur dioxide concentration due to Bowline and Lovett plants during the season March-April-May. The Bowline plant is at the center of the circular area.

Fig. 4.3.3. Calculated average ground-level sulfur dioxide concentration due to Bowline and Lovett plants during the season June-July-August. The Bowline plant is at the center of the circular area.

Fig. 4.3.4. Calculated average ground-level sulfur dioxide concentration due to Bowline and Lovett plants during the season September-October-November. The Bowline plant is at the center of the circular area.

Fig. 4.3.5. Calculated average ground-level sulfur dioxide concentration due to Bowline and Lovett plants, annual average. The Bowline plant is at the center of the circular area.

Fig. 4.3.6. Calculated average ground-level sulfur dioxide concentration due to Roseton and Danskammer plants during the season December-January-February. The Roseton plant is at the center of the circular area.

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Fig. 4.3.7. Calculated average ground-level sulfur dioxide concentration due to Roseton and Danskammer plants during the season March-April-May. The Roseton plant is at the center of the circular area.

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Fig. 4.3.8. Calculated average ground-level sulfur dioxide concentration due to Roseton and Danskammer plants during the season June-July-August. The Roseton plant is at the center of the circular area.

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Fig. 4.3.9. Calculated average ground-level sulfur dioxide concentration due to Roseton and Danskammer plants during the season September-October-November. The Roseton plant is at the center of the circular area.

Fig. 4.3.10. Calculated average ground-level sulfur dioxide concentration due to Roseton and Danskammer plants, annual average. The Roseton plant is at the center of the circular area.

attempts to treat the difficult problem of terrain-height variability. The Gaussian plume, on the other hand, assumes streamlining of trajectories over the terrain features (beyond the immediate vicinity of the source); in view of the PIC results, there is every reason to believe that Gaussian plume estimates are reasonable.

4.3.3 Long-range effects

The effects of the Roseton and Danskammer plants on the area in the vicinity of Bowline have been investigated. Annual ground-level sulfur dioxide concentrations in an area surrounding the Bowline plant resulting from the Roseton and Danskammer plants are shown in Fig. 4.3.11. Likewise, annual ground-level concentrations of sulfur dioxide in the vicinity of Roseton resulting from the Bowline and Lovett plants are shown in Fig. 4.3.12. Figure 4.3.13 is a map of the general area. In all cases, a circular area of 40 km radius has been studied. Figure 4.3.13 indicates how these areas are located relative to all of the plants involved. Again, it can be seen that the overall effects of Roseton and Danskammer are about an order of magnitude higher than the effects of the Bowline and Lovett plants. However, there is no evidence that the combined effects of these various plants produce concentrations that approach Federal standards.

4.3.4 Cooling tower effects

4.3.4.1 Bowline Point. Two cases were run with ORFAD using onsite meteorological data. These data cover a one-year period from September 1974 through August 1975.

Results of these two case runs are shown in Figs. 4.3.14-4.3.17. Because the first case showed a pronounced clustering of contours at less than 1 mile from the tower, the second case was run with an expanded scale in order to resolve the close-in details. All other parameters for the two cases were kept the same.

No occurrence of fog attributable to tower operation was found. For the same period, 120 hr of natural fog were calculated (natural fog is defined here as occurring in those periods having an ambient relative humidity of 100%).

The peak deposition of approximately $7 \text{ g year}^{-1} \text{ m}^{-2}$ occurs at about 0.4 mile south of the tower, as seen in Fig. 4.3.16.

Predictions of aerosol salt concentrations are presented in Figs. 4.3.15 and 4.3.17. A rather broad peak of about $0.3 \text{ } \mu\text{g}/\text{m}^3$ occurs south of the tower from roughly 0.3 to 0.9 mile. A second similarly broad peak of the same magnitude occurs to the southeast but slightly closer in.

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Fig. 4.3.11. Calculated average annual ground-level concentrations of sulfur dioxide in an area surrounding the Bowline plant and due to emissions from the Roseton and Danskammer plants.

Fig. 4.3.12. Calculated average annual ground-level concentrations of sulfur dioxide in an area surrounding the Roseton plant and due to emissions from the Bowline and Lovett plants.

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Fig. 4.3.13. Location of four power plants (indicated by X's on the map) on the Hudson River. Arcs of circles of 40 km radius are centered on Roseton and Bowline.

Fig. 4.3.14. Amount of drift measured May 10, 1977, Haverstraw meteorological data, Bowline Point case 1. Contour 1, $7.100 \text{ g year}^{-1} \text{ m}^{-2}$; 2, 3.550; 3, 1.775; 4, 0.887; 5, 0.444.

Fig. 4.3.15. Amount of salt in the air measured May 10, 1977, Haverstraw meteorological data, Bowline Point case 1. Contour 1, $0.300 \mu\text{g}/\text{m}^3$; 2, 0.150 ; 3, 0.075 ; 4, 0.037 ; 5, 0.019 .

Fig. 4.3.16. Amount of drift measured May 10, 1977, Haverstraw meteorological data, Bowline Point case 2. Contour 1, 7.000 $\text{g year}^{-1} \text{m}^{-2}$; 2, 3.500; 3, 1.750; 4, 0.875; 5, 0.437.

Fig. 4.3.17. Amount of salt in the air measured May 10, 1977, Haverstraw meteorological data, Bowline Point case 2. Contour 1, $0.300 \mu\text{g}/\text{m}^3$; 2, 0.150 ; 3, 0.075 ; 4, 0.037 ; 5, 0.019 .

4.3.4.2 Roseton. Two cases were run with ORFAD using onsite meteorological tower data. Because relative humidities were not measured at the Roseton site, humidity values from Bowline Point were used to complete the required data base for ORFAD. The data cover a one-year period from September 1974 through August 1975.

Results are presented in Figs. 4.3.18-4.3.21. As before, a second case was run with an expanded scale in order to resolve close-in details, with all other parameters being kept the same.

No occurrence of fog attributable to tower operation was found. For the same period, 115 hr of natural fog were calculated.

A peak deposition of less than $0.5 \text{ g year}^{-1} \text{ m}^{-2}$ occurs at approximately 0.8 mile north-northeast of the tower, as shown in Fig. 4.3.20.

Predictions of aerosol salt concentrations are shown in Figs. 4.3.19 and 4.3.21. A broad peak of about $0.02 \text{ } \mu\text{g}/\text{m}^3$ occurs north-northeast of the tower from roughly 0.6 to 1.5 miles.

4.3.5 Stacks and cooling tower plume interaction

The proximity of the smokestacks to any natural-draft cooling towers that could be built at the Bowline Point and Roseton generating stations would result in their plumes frequently being merged. Observations and photographs of power plants show that this is the case, particularly for meteorological conditions resulting in long visible plumes.¹³ Investigations of the mist in the merged cooling-tower-stack plumes at the Keystone station in Pennsylvania indicate that water droplets in the merged plume are acidic, having pH values as low as 1 to 3.^{14,15} The merged plumes at the Bowline Point and Roseton generating stations probably would have acidic water droplets. However, the acidity of these droplets could be lower than those observed at the coal-burning Keystone station because the Bowline Point station is required to use 0.37% sulfur fuel and the Roseton station uses about 2% sulfur fuel.

Knowledge of the fate of this acid mist and how it is returned to the ground is limited.¹³ Ambient air that is entrained in the merged plume contains water and ammonia, which will dilute and neutralize the acid in the water droplets.¹⁶ Furthermore, natural weather processes (such as fog, clouds, rain, and snow) will react with sulfur dioxide present in the air from sources other than the power station. This makes it difficult to determine the impacts of merged cooling-tower-stack plumes experimentally. Some limited observations in England indicate that fossil-fueled power station cooling tower plumes do not noticeably increase the acidity of the natural rainfall in the vicinity of the power station.¹⁷

Fig. 4.3.18. Amount of drift measured April 30, 1977, Roseton meteorological tower data, Roseton case 1. Contour 1, $0.400 \text{ g year}^{-1} \text{ m}^{-2}$; 2, 0.200 ; 3, 0.100 ; 4, 0.050 ; 5, 0.025 .

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Fig. 4.3.19. Amount of salt measured in the air, April 30, 1977, Roseton meteorological tower data, Roseton case 1. Contour 1, 0.010 $\mu\text{g}/\text{m}^3$; 2, 0.005; 3, 0.002; 4, 0.001; 5, 0.001.

ES-3583

Fig. 4.3.20. Amount of drift measured April 30, 1977, Roseton meteorological tower data, Roseton case 2. Contour 1, $0.400 \text{ g year}^{-1} \text{ m}^{-2}$; 2, 0.200 ; 3, 0.100 ; 4, 0.050 ; 5, 0.025 .

Fig. 4.3.21. Amount of salt measured in the air, April 30, 1977, Roseton meteorological tower data, Roseton case 2. Contour 1, $0.020 \mu\text{g}/\text{m}^3$; 2, 0.010 ; 3, 0.005 ; 4, 0.002 ; 5, 0.001 .

Therefore, it cannot be said with certainty what the impacts of the merged cooling-tower-stack plume will be. However, hundreds of wet cooling towers have operated for many years at fossil-fueled power stations in the United States and Europe. There does not appear to be a significant body of data which shows that adverse impacts result from the acid mist produced in the cooling-tower-stack plumes.^{13,18}

Because of the above reasons, we do not feel that any significant adverse impact will result from the interaction of the smokestack and cooling tower plumes at the Bowline Point and Roseton generating stations.

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Appendix A

CROSS-SECTION PROFILES OF THE HUDSON RIVER AS INPUT DATA TO THE THERMAL MODELS

The geometry input data to the thermal models were determined from the Bathymetry information on the U.S. Coastal and Geodetic Survey navigational charts Nos. 282, 283, 284, 745, and 746 for the Hudson River.¹ The cross-section profiles were obtained from the charts by taking transects at 2-mile intervals starting at Troy Dam with cross section 1 and ending at the Battery with cross section 77. The longitudinal axis of the river was assumed to be at the middle of the deepest part of each cross section, with the negative lateral locations corresponding to the left bank of the river looking downstream from Troy toward the Battery.

The detailed actual profiles of the cross sections were approximated by straight line segments to minimize the computational effort in the applications of the models. A comparison of the detailed channel profile and the approximated input data for a typical relatively symmetric, wide, and deep cross section is presented in Fig. A-1.

The comparison of the detailed channel profile and the approximated data for a typical cross section at a transect with relatively large shoal areas along one bank and with the deep main channel near the other bank is shown in Fig. A-2.

The cross sections in regions with large embayment areas or with islands in the middle of the river constitute multiply connected profiles for the transects. To simplify the geometry input data and to reduce the computational effort, these cross sections were reduced to simply connected transect profiles for the input data by keeping approximately equivalent values for width, depth, and cross-sectional area. A comparison of the detailed actual multiply connected channel profile and the approximated simply connected input data for a typical cross section with large embayment area is shown in Fig. A-3.

The approximated profiles of all the transect cross sections of the Hudson River are presented in Figs. A-4-A-42, according to the input data to the thermal models.

REFERENCE FOR APPENDIX A

1. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, C&GS charts 282, 283, 284, 745, 746.

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Fig. A-1. Comparison of the detailed actual profile and the approximated input data for a typical relatively nonsymmetric transect along the Hudson River.

ES-3478

Fig. A-2. Comparison of the detailed actual profile and the approximated input data for a typical relatively nonsymmetric transect along the Hudson River.

ES-3479

Fig. A-3. Comparison of the detailed actual profile and the approximated input data for a typical multiply connected cross section with relatively large embayment area along the Hudson River.

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Fig. A-4. Schematized geometry for cross sections 1 and 2 as input data to ESTONE. Profiles from C&GS chart 284.

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Fig. A-5. Schematized geometry for cross sections 3 and 4 as input data to ESTONE. Profiles from C&GS chart 284.

ES-3595

Fig. A-6. Schematized geometry for cross sections 5 and 6 as input data to ESTONE. Profiles from C&GS chart 284.

Fig. A-7. Schematized geometry for cross sections 7 and 8 as input data to ESTONE. Profiles from C&GS chart 284.

Fig. A-8. Schematized geometry for cross sections 9 and 10 as input data to ESTONE. Profiles from C&GS chart 284.

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Fig. A-9. Schematized geometry for cross sections 11 and 12 as input data to ESTONE. Profiles from C&GS chart 284.

ES-3424

Fig. A-10. Schematized geometry for cross sections 13 and 14 as input data to ESTONE. Profiles from C&GS chart 284.

ES-3425

Fig. A-11. Schematized geometry for cross sections 15 and 16 as input data to ESTONE. Profiles from C&GS chart 284.

ES-3426

Fig. A-12. Schematized geometry for cross sections 17 and 18 as input data to ESTONE. Profiles from C&GS charts 283 and 284.

ES-3427

Fig. A-13. Schematized geometry for cross sections 19 and 20 as input data to ESTONE. Profiles from C&GS chart 283.

Fig. A-14. Schematized geometry for cross sections 21 and 22 as input data to ESTONE. Profiles from C&GS chart 283.

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Fig. A-15. Schematized geometry for cross sections 23 and 24 as input data to ESTONE. Profiles from C&GS chart 283.

ES-3430

Fig. A-16. Schematized geometry for cross sections 25 and 26 as input data to ESTONE. Profiles from C&GS chart 283.

Fig. A-17. Schematized geometry for cross sections 27 and 28 as input data to ESTONE. Profiles from C&GS chart 283.

Fig. A-18. Schematized geometry for cross sections 29 and 30 as input data to ESTONE. Profiles from C&GS chart 283.

Fig. A-19. Schematized geometry for cross sections 31 and 32 as input data to ESTONE. Profiles from C&GS chart 283.

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Fig. A-20. Schematized geometry for cross sections 33 and 34 as input data to ESTONE. Profiles from C&GS chart 283.

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Fig. A-21. Schematized geometry for cross sections 35 and 36 as input data to ESTONE. Profiles from C&GS chart 283.

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Fig. A-22. Schematized geometry for cross sections 37 and 38 as input data to ESTONE. Profiles from C&GS chart 283.

ES-3437

Fig. A-23. Schematized geometry for cross sections 39 and 40 as input data to ESTONE. Profiles from C&GS chart 283.

ES-3438

Fig. A-24. Schematized geometry for cross sections 41 and 42 as input data to ESTONE. Profiles from C&GS chart 283.

ES-3439

Fig. A-25. Schematized geometry for cross sections 43 and 44 as input data to ESTONE. Profiles from C&GS charts 282 and 283.

ES-3440

Fig. A-26. Schematized geometry for cross sections 45 and 46 as input data to ESTONE. Profiles from C&GS chart 282.

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Fig. A-27. Schematized geometry for cross sections 47 and 48 as input data to ESTONE. Profiles from C&GS chart 282.

Fig. A-28. Schematized geometry for cross sections 49 and 50 as input data to ESTONE. Profiles from C&GS chart 282.

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Fig. A-29. Schematized geometry for cross sections 51 and 52 as input data to ESTONE. Profiles from C&GS chart 282.

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Fig. A-30. Schematized geometry for cross sections 53 and 54 as input data to ESTONE. Profiles from C&GS chart 282.

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Fig. A-31. Schematized geometry for cross sections 55 and 56 as input data to ESTONE. Profiles from C&GS chart 282.

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Fig. A-32. Schematized geometry for cross sections 57 and 58 as input data to ESTONE. Profiles from C&GS chart 282.

Fig. A-33. Schematized geometry for cross sections 59 and 60 as input data to ESTONE. Profiles from C&GS chart 282.

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Fig. A-34. Schematized geometry for cross sections 61 and 62 as input data to ESTONE. Profiles from C&GS chart 282.

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Fig. A-35. Schematized geometry for cross sections 63 and 64 as input data to ESTONE. Profiles from C&GS chart 282.

Fig. A-36. Schematized geometry for cross sections 65 and 66 as input data to ESTONE. Profiles from C&GS chart 282.

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Fig. A-37. Schematized geometry for cross sections 67 and 68 as input data to ESTONE. Profiles from C&GS chart 282.

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Fig. A-38. Schematized geometry for cross sections 69 and 70 as input data to ESTONE. Profiles from C&GS chart 282.

ES-3473

Fig. A-39. Schematized geometry for cross sections 71 and 72 as input data to ESTONE. Profiles from C&GS charts 282 and 746.

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Fig. A-40. Schematized geometry for cross sections 73 and 74 as input data to ESTONE. Profiles from C&GS chart 746.

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Fig. A-41. Schematized geometry for cross sections 75 and 76 as input data to ESTONE. Profiles from C&GS chart 745.

ES-3476

Fig. A-42. Schematized geometry for cross section 77 as input data to ESTONE. Profile from C&GS chart 745.

Appendix B

DAILY FRESHWATER FLOW RATES AND TEMPERATURES AT TROY DAM FOR APRIL 1-SEPTEMBER 30, 1973, AND APRIL 1- SEPTEMBER 30, 1974, SIMULATION PERIODS

Freshwater flow rates were obtained from measurements taken at Green Island by the U.S. Geological Survey, available as daily averages.^{1,2} the accuracy of the flow rates is described as "excellent," "fair," or "poor," defined as follows (ref. 1, p. 12):

The station description under "Remarks" states the degree of accuracy of the records. "Excellent" means that about 95 percent of the daily discharges are within 5 percent; "good" within 10 percent, and "fair" within 15 percent. "Poor" means that daily discharges have less than "fair" accuracy.

Except for August 27 through September 30, 1973, when records were described as "poor," the records covering all days during the simulation periods were described as "fair."

Water temperatures for April 1 through September 30, 1973, were obtained from the U.S. Army Corps of Engineers,³ and water temperatures for April 1 through September 30, 1974, were obtained from USGS data reproduced in ref. 4, Fig. 4.5.3. The missing records for various periods were approximated by extrapolation and/or interpolation from the available records.

Both the flow rate and temperature conditions at the Troy Dam were prepared on a daily average basis as input data for the ESTONE model. The complete set of freshwater flow rates and temperatures in the form used for input data is presented in Figs. B-1-B-12.

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Fig. B-1. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: April 1973.

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Fig. B-2. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: May 1973.

Fig. B-3. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: June 1973.

Fig. B-4. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: July 1973.

Fig. B-5. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: August 1973.

Fig. B-6. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: September 1973.

Fig. B-7. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: April 1974.

Fig. B-8. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: May 1974.

Fig. B-9. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: June 1974.

Fig. B-10. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: July 1974.

Fig. B-11. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: August 1974.

Fig. B-12. Freshwater flow rate and temperature conditions at the Troy Dam as input data to the ESTONE code: September 1974.

Appendix C

FRESHWATER FLOW RATES FOR TRIBUTARIES

Freshwater flow rates for 14 tributaries entering the Hudson River between Troy and the Battery were obtained from the U.S. Geological Survey.^{1,2} All flow rates were given as daily averages, as well as monthly and yearly averages. Estimates of the accuracy of the records for the 14 tributaries were about equally divided between "good" and "fair," according to the definitions given in Appendix B. The flow rates recorded were those observed at the individual gaging stations and did not necessarily represent actual discharge into the estuary. Many of the gaging stations were several miles from the estuary, and the most distant, the Wallkill River station, was almost 20 miles away. Also, the 14 tributaries for which flow data were available did not represent all sources of fresh water entering the estuary between the Troy Dam and the Battery. The 14 tributaries along with the Hudson River at Green Island accounted for about 10,600 square miles of drainage area out of the approximate total of 13,400 square miles of drainage area of the Hudson River at the Battery. Since the entire drainage area was not gaged and since there were no gaging stations south of Green Island capable of measuring total river freshwater flow, figures for freshwater discharge of the river south of Green Island were available as estimates only. The estimates of freshwater discharge at the Battery indicated that the fresh water entering the estuary from the Hudson River at Green Island plus the gaged flow of the 14 tributaries accounted for 80 to 90% of the total.

Daily flow rates of the 14 tributaries were used as the basis for the input to the model. However, some method was needed to introduce the fresh water not accounted for by the gaged flows, so that the total freshwater input to the ESTONE computer code would equal the total estimated freshwater discharge at the Battery. In order to ensure that the input data were consistent with the estimates of freshwater flow and at the same time preserve a realistic approximation of daily variations in flow, the daily tributary flows were scaled so that the sum of the scaled tributary flows and the unscaled Green Island flows gave monthly totals equal to the estimated monthly freshwater discharge at the Battery. Green Island flows were not included in the scaling because they represented direct measurements of total river flow at a location outside the range of tidal influence and provided the most accurate available data for total river flow at that point. Also, the flow at Green Island was regulated according to flood or drought conditions and hydroelectric power generation requirements, and its daily variation therefore had no necessary relation to the variation of other freshwater flows into the estuary.

The assumption inherent in the scaling process was that the unmeasured sources of fresh water, such as the smaller tributaries and

riverbed seepage, were similar to the gaged tributaries, both in their daily variation in flow rates and their locations along the river. Since such sources would not be expected to reflect the extent of human regulation of diversion that affects the flow of the larger tributaries, some bias may have been introduced by the assumption. However, since a relatively small percentage of the estimated total flow was involved, no further refinement was attempted in the assignment of daily flow values. In addition, no practical alternative was available.

While it was desired to maintain daily flow rates as an input option, it was decided to reduce the number of separate data sets used for the tributaries in order to conserve computer storage and execution time. The reduction was accomplished by dividing the tributaries into five groups and treating the combined flows of the tributaries in each group as a single tributary flow for input purposes. The points at which the group flows entered the estuary in the model were determined according to the magnitudes of the flows of the individual tributaries within the group. For example, a group of two tributaries, with one having an average flow twice as large as the other, would have an entry point one-third of the distance from the larger to the smaller tributary, as measured along the river axis. The determination was made once, using flows averaged over both the 1973 and 1974 simulation periods, so that the points at which the tributary groups entered the estuary remained fixed during all simulation runs.

The tributaries used in forming each group were selected according to their proximity to each other, so that their combined scaled flows would enter the estuary within a reasonable distance from their individual locations. Except for group 5, the group entry points are less than 10 miles from the entry points of any of the tributaries in the group. In group 5, the group entry point is 14 miles from Sawmill River but only 2 miles from Croton River, as would be expected from the relative magnitudes of the averaged flows. Although the group 5 entry location becomes unrealistic in the later months, when the Croton River flow is drastically reduced, presumably by diversion to New York City, Sawmill River is at that time a relatively small part of total freshwater flow. Group 3, the major freshwater contributor, enters the estuary at the same location as its two constituents, Rondout Creek and Wallkill River.

As a check, the flows generated by the model input data were compared to the freshwater flows at Poughkeepsie estimated by the USGS. The sums of the flows for Green Island and the scaled flows for the first three tributary groups (those north of Poughkeepsie) were 102 to 108% of the monthly freshwater discharge estimates at Poughkeepsie during the 12 months covered by the two simulation periods. The USGS estimates and the flow rates used in the ESTONE model are shown in Table C-1. Since the flows in the model were representative of a 26-mile segment of the estuary extending approximately 10 miles south of Poughkeepsie, it was proper that they were somewhat greater than the estimated flow at

Table C-1. Comparison of USGS estimates of freshwater discharge at Poughkeepsie with freshwater discharge used in the ESTONE model for the 26-mile segment of the estuary including Poughkeepsie

Month	Freshwater flow rate (cfs)			
	1973		1974	
	Estimated ^a	ESTONE model	Estimated ^a	ESTONE model
April	45,200	46,596	42,800	44,289
May	39,600	40,837	28,200	28,841
June	19,600	20,799	11,100	11,459
July	16,200	17,542	13,900	14,201
August	7,750	8,256	7,460	7,643
September	5,540	5,733	13,600	14,080

^aU.S. Geological Survey, Water Resources Division, New York District.

Poughkeepsie. Thus a reasonable approximation of both the total freshwater flow and the distribution of inflow along the estuary was provided by the model input data.

In addition to the scaled daily flow rates for each of the five tributary groups, data sets with averaged flow rates were generated for each of the tributary groups as an option for reduced data input to the model. The reduced data consisted of time-averaged flow rates based upon daily rates in which there was no more than 10% difference between an initial flow rate and any other flow rate in a series of successive days.

Figures C-1-C-30 present both daily and averaged flow rates of the tributary groups. Throughout, the scale used for the flow rates remains the same for all tributary groups and all time periods and is the same scale used in Appendix B to present freshwater flow rates at the Troy Dam. Thus it is possible to see the relative magnitudes of freshwater inflows from all different sources and to follow seasonal variations in the flow from each source.

REFERENCES FOR APPENDIX C

1. U.S. Department of the Interior Geological Survey, "1973 Water Resources Data for New York Part 1: Surface Water Records," Albany, N.Y., 1974, p. 79.
2. U.S. Department of the Interior Geological Survey, "1974 Water Resources Data for New York Part 1: Surface Water Records," Albany, N.Y., 1975, p. 73.

Fig. C-1. Freshwater flow rate for tributary group 1 (Normans and Moordener Kills, Coeymans and Hannacrois Creeks) as input data to the ESTONE code: April and May 1973.

Fig. C-2. Freshwater flow rate for tributary group 1 (Normans and Moordener Kills, Coeymans and Hannacrois Creeks) as input data to the ESTONE code; June and July 1973.

Fig. C-3. Freshwater flow rate for tributary group 1 (Normans and Moordener Kills, Coeymans and Hannacrois Creeks) as input data to the ESTONE code: August and September 1973.

Fig. C-4. Freshwater flow rate for tributary group 1 (Normans and Moordener Kills, Coeymans and Hannacrois Creeks) as input data to the ESTONE code: April and May 1974.

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Fig. C-5. Freshwater flow rate for tributary group 1 (Normans and Moordener Kills, Coeymans and Hannacrois Creeks) as input data to the ESTONE code: June and July 1974.

Fig. C-6. Freshwater flow rate for tributary group 1 (Normans and Moordener Kills, Coeymans and Hannacrois Creeks) as input data to the ESTONE code: August and September 1974.

Fig. C-7. Freshwater flow rate for tributary group 2 (Catskill, Tenmile, and Esopus Creeks) as input data to the ESTONE code: April and May 1973.

Fig. C-8. Freshwater flow rate for tributary group 2 (Catskill, Tenmile, and Esopus Creeks) as input data to the ESTONE code: June and July 1973.

Fig. C-9. Freshwater flow rate for tributary group 2 (Catskill, Tenmile, and Esopus Creeks) as input data to the ESTONE code: August and September 1973.

ES-3509

Fig. C-10. Freshwater flow rate for tributary group 2 (Catskill, Tenmile, and Esopus Creeks) as input data to the ESTONE code: April and May 1974.

Fig. C-11. Freshwater flow rate for tributary group 2 (Catskill, Tenmile, and Esopus Creeks) as input data to the ESTONE code: June and July 1974.

ES-3511

Fig. C-12. Freshwater flow rate for tributary group 2 (Catskill, Tenmile, and Esopus Creeks) as input data to the ESTONE code: August and September 1974.

Fig. C-13. Freshwater flow rate for tributary group 3 (Rondout Creek and Wallkill River) as input data to the ESTONE code: April and May 1973.

Fig. C-14. Freshwater flow rate for tributary group 3 (Rondout Creek and Wallkill River) as input data to the ESTONE code: June and July 1973.

Fig. C-15. Freshwater flow rate for tributary group 3 (Rondout Creek and Wallkill River) as input data to the ESTONE code: August and September 1973.

Fig. C-16. Freshwater flow rate for tributary group 3 (Rondout Creek and Wallkill River) as input data to the ESTONE code: April and May 1974.

Fig. C-17. Freshwater flow rate for tributary group 3 (Rondout Creek and Wallkill River) as input data to the ESTONE code: June and July 1974.

Fig. C-18. Freshwater flow rate for tributary group 3 (Rondout Creek and Wallkill River) as input data to the ESTONE code: August and September 1974.

Fig. C-19. Freshwater flow rate for tributary group 4 (Casper, Wappinger, and Fishkill Creeks) as input data to the ESTONE code: April and May 1973.

Fig. C-20. Freshwater flow rate for tributary group 4 (Casper, Wappinger, and Fishkill Creeks) as input data to the ESTONE code: June and July 1973.

ES-3521

Fig. C-21. Freshwater flow rate for tributary group 4 (Casper, Wappinger, and Fishkill Creeks) as input data to the ESTONE code; August and September 1973.

ES-3522

Fig. C-22. Freshwater flow rate for tributary group 4 (Casper, Wappinger, and Fishkill Creeks) as input data to the ESTONE code: April and May 1974.

Fig. C-23. Freshwater flow rate for tributary group 4 (Casper, Wappinger, and Fishkill Creeks) as input data to the ESTONE code: June and July 1974.

Fig. C-24. Freshwater flow rate for tributary group 4 (Casper, Wappinger, and Fishkill Creeks) as input data to the ESTONE code: August and September 1974.

Fig. C-25. Freshwater flow rate for tributary group 5 (Croton and Sawmill Rivers) as input data to the ESTONE code: April and May 1973.

Fig. C-26. Freshwater flow rate for tributary group 5. (Croton and Sawmill Rivers) as input data to the ESTONE code: June and July 1973.

Fig. C-27. Freshwater flow rate for tributary group 5 (Croton and Sawmill Rivers) as input data to the ESTONE code: August and September 1973.

Fig. C-28. Freshwater flow rate for tributary group 5 (Croton and Sawmill Rivers) as input data to the ESTONE code: April and May 1974.

ES-3529

Fig. C-29. Freshwater flow rate for tributary group 5 (Croton and Sawmill Rivers) as input data to the ESTONE code: June and July 1974.

ES-3530

Fig. C-30. Freshwater flow rate for tributary group 5 (Croton and Sawmill Rivers) as input data to the ESTONE code: August and September 1974.

Appendix D

PLANT OPERATING CONDITIONS

The plant operating data available from the utility companies and from various reports were not all available in the form required by the ESTONE model, namely, daily plant cooling water flow rate and cooling water temperature rise. Except for a limited number of cases in which data were missing, the cooling water flow rates were always explicitly stated. However, for several of the plants it was necessary to estimate ΔT 's from records of electrical power generation. In the following discussion, the forms in which the data were available and the particular procedures followed to reduce the data for input to the model are described.

D-1 Danskammer Plant

Plant ΔT 's were computed from plant electrical generation records, "Danskammer Point Steam Generating Station - Net MWHR Output - 1973" and "Danskammer Point Generating Station, Monthly Flow Data," which were transmitted by the Central Hudson Gas and Electric Corporation.¹ Both electrical generation and cooling water flow were given as daily totals.

Since the ΔT 's required for input to the model were not available in explicit form, it was necessary to define a functional relationship which would generate ΔT 's from the available data. Assistance was requested from Mr. Floyd Dooris of Central Hudson, and the following information was obtained by telephone.²

1. The Danskammer plant ΔT at maximum electrical power generation and maximum cooling water flow is approximately 19°F.

2. Plant ΔT 's are dependent upon total plant gross electrical generation, which is approximately 22.0 MW greater than the total plant net electrical generation.

3. Plant ΔT 's for cooling water flows or electrical generation at other than maximum capacity are expected to be related linearly to the 19°F maximum ΔT .

Based upon the above, the daily ΔT 's were computed as the product of the 19°F maximum temperature, the ratio of actual to maximum gross megawatt generation, and the ratio of maximum to actual flow rate. The plant maximum gross generation was set at 530.0 MW, the total plant rated capacity of 508.0 net megawatts plus the 22.0 MW required to convert from net to gross generation. The plant maximum flow rate was set at 455,040,000 gal/day, the maximum reported flow rate during the 1973 and 1974 simulation periods.

D-2 Roseton Plant

Plant operating data were obtained from plant electrical generation records, "Roseton Electric Generating Station - Net MWHR Output - 1974," plant cooling water flow records, "Total Circulating Water Flow, Roseton Generation Station, 1974," and a chart relating electrical power generation to heat rejection to cooling water, "Roseton Generating Plant Circulating Cooling Water System Heat Rejection, Discharge-Intake Temperature Difference," which were transmitted by Central Hudson Gas and Electric Company.¹ Both electrical generation and cooling water flow were given as daily totals.

Since plant ΔT 's were not given explicitly, they were determined using the chart mentioned above, which is reproduced in part as Fig. D-1. Before using the chart it was necessary (1) to convert the plant operating data, available only as net electrical generation, and (2) to decide whether to consider one or two units as having been in operation, since the electrical generation and cooling water flow rates were available only as plant totals.

Mr. Floyd Dooris of Central Hudson was asked for assistance in converting the data from net to gross generation. In a telephone conversation he stated that the addition of 22.0 MW per unit (no relation to the 22.0 MW conversion figure for Danskammer) to the unit net megawatt generation would yield the approximate unit gross electrical generation.² There is no way to make a definite determination as to the number of units in operation, and it was assumed that no more than one unit was operating unless the power output for the plant was greater than the 600 net megawatt rated capacity of a single unit. Since the maximum generation for the total plant was only slightly over 110 MW during the entirety of the two simulation periods, this was equivalent to the assumption that both units were never in operation at the same time.

D.3 Indian Point Plant

Daily average flow rates and ΔT 's were obtained from "Indian Point Impingement Study Report for the Period June 15, 1972, through December 21, 1973" (draft) for the 1973 formulation period.³ Plant generating data for the 1974 simulation period were obtained from "Indian Point Semi-Annual Operations Reports."^{4,5}

The 1974 data included average plant ΔT , total Btu release to the river, and individual unit cooling water discharge. All were reported as daily figures. Since both ΔT and Btu release were available as total plant data, it was convenient to use them to arrive at a calculated cooling water flow rate. However, it was discovered after generation of the data sets that cooling water flow rates were obtained which were in excess of the total rated capacity of Indian Point Units 1 and 2. New data sets were then created based upon the reported plant average ΔT and cooling water flow rates which were the sum of the reported individual flow rates for Units 1 and 2.

Fig. D-1. Roseton generating plant circulating water system heat rejection as related to gross electrical power generation.

During 15 days in the 1973 simulation period and 7 days in the 1974 simulation period, ΔT 's were not recorded when power was being generated. Those ΔT 's were estimated according to ΔT 's for similar power generation and cooling water flow levels recorded on days nearest the times during which the ΔT 's were missing. Where no power was being generated but water was being circulated, a nominal ΔT of 1.0°F was assumed.

D-4 Lovett Plant

Plant operating data were obtained from "Lovett Plant Industrial Waste Sampling Program — Circulating Water Plan" and were transmitted by Orange and Rockland Utilities, Inc.⁶ Daily total cooling water flows and daily average intake and discharge temperatures were provided for each of the five operating units.

D-5 Bowline Plant

Plant operating data were obtained from "Bowline Point Circulating Water Data" and "Bowline Point Electrical Log — Generation and Station Serv.," which were transmitted by Orange and Rockland Utilities, Inc.⁷

Daily cooling water flows and daily average ΔT 's were obtained from the circulating water data, except for 3 days in 1973 and 48 days during 1974 during which data were not recorded. The flow rates and ΔT 's for these days were estimated according to power generation levels reported in the electrical log. They were assumed the same as the ΔT 's and flow rates recorded for an equivalent electrical generation rate occurring on a day nearest the time the data were missing.

D-6 Input to the ESTONE Computer Code

Operating data for all plants except Roseton and Danskammer were provided separately for each unit of the plant. In those cases the individual unit cooling water flow rates were added to provide a total plant flow rate for input to the model. The ΔT used for input to the model in association with the combined flow rate was weighted according to the magnitudes of the flow rates of the individual units.

While the basic form of the input data was a daily average cooling water flow rate and ΔT , alternative data sets were also generated, using averaged temperatures and flow rates specified by time periods of varying length. Averaging was only done in cases in which neither the temperature nor flow rate in a series of days was more than 10% greater than the temperature or flow rate on the first day of the series. Where averaging was done, the average flow rate was a simple average of the daily values, while the average ΔT was weighted according to flow rates so that total heat discharge to the river was not changed by the averaging process.

The detailed plant operating conditions in the form used as input to the ESTONE computer code are presented in Figs. D-2-D-61.

Fig. D-2. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, April 1973.

Fig. D-3. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, May 1973.

Fig. D-4. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, June 1973.

Fig. D-5. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, July 1973.

Fig. D-6. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, August 1973.

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Fig. D-7. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, September 1973.

Fig. D-8. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, April 1973.

Fig. D-9. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, May 1973.

Fig. D-10. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, June 1973.

ES-3677

Fig. D-11. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, July 1973.

Fig. D-12. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, August 1973.

ES-3679

Fig. D-13. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, September 1973.

Fig. D-14. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, April 1973.

ES-3681

Fig. D-15. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, May 1973.

ES-3682

Fig. D-16. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, June 1973.

Fig. D-17. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, July 1973.

Fig. D-18. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, August 1973.

Fig. D-19. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, September 1973.

Fig. D-20. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, April 1973.

Fig. D-21. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, May 1973.

Fig. D-22. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, June 1973.

Fig. D-23. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, July 1973.

Fig. D-24. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, August 1973.

Fig. D-25. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, September 1973.

Fig. D-26. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, April 1973.

Fig. D-27. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, May 1973.

Fig. D-28. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, June 1973.

Fig. D-29. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, July 1973.

Fig. D-30. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, August 1973.

Fig. D-31. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, September 1973.

Fig. D-32. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, April 1974.

Fig. D-33. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, May 1974.

Fig. D-34. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, June 1974.

Fig. D-35. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, July 1974.

Fig. D-36. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, August 1974.

ES-3704

Fig. D-37. Danskammer plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, September 1974.

Fig. D-38. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, April 1974.

Fig. D-39. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, May 1974.

Fig. D-40. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, June 1974.

Fig. D-41. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, July 1974.

Fig. D-42. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, August 1974.

Fig. D-43. Roseton plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, September 1974.

Fig. D-44. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, April 1974.

ES-3712

Fig. D-45. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, May 1974.

Fig. D-46. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, June 1974.

Fig. D-47. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, July 1974.

Fig. D-48. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, August 1974.

ES-3717

Fig. D-49. Indian Point plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, September 1974.

Fig. D-50. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, April 1974.

Fig. D-51. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, May 1974.

Fig. D-52. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, June 1974.

Fig. D-53. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, July 1974.

Fig. D-54. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, August 1974.

Fig. D-55. Lovett plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, September 1974.

Fig. D-56. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, April 1974.

Fig. D-57. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, May 1974.

Fig. D-58. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, June 1974.

Fig. D-59. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, July 1974.

ES-3727

Fig. D-60. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, August 1974.

Fig. D-61. Bowline plant operating conditions used as input to the ESTONE model: plant cooling water flow rate and plant cooling water temperature rise, September 1974.

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4. Consolidated Edison Company of New York, Inc., "Indian Point Units Nos. 1 and 2 Semi-Annual Operations Report No. 23, January 1, 1974 - June 30, 1974," 1974.
5. Consolidated Edison Company of New York, Inc., "Indian Point Units Nos. 1 and 2 Semi-Annual Operations Report No. 24, July 1, 1974 - December 31, 1974," 1975.
6. R. H. Metzger, Orange and Rockland Utilities, Inc., letter dated January 13, 1977, to J. L. Harris, University of Tennessee.
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