CHAPTER 143

HYDROTHERMAL MONITORING: SURRY NUCLEAR POWER PLANT

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ABSTRACT

A hydrothermal monitoring program has been designed and deployed to gather data on the temperature distribution in the tidal James River near the outfall of the Surry Nuclear Power Plant at Surry, Virginia, U.S.A.

Monitoring to date has included two years of background data (1971 and 1972) taken prior to plant operation, and one year (1973) of data with the plant in operation.

The results of the first year post operational monitoring effort has been compared with the pre-operation background data and with the thermal effects that were predicted from studies by Carpenter and Pritchard on the James River Hydraulic Model at Vicksburg, Mississippi.

INTRODUCTION

The primary objective of this study is to thoroughly document waste heat distribution and related phenomena for the James River estuary due to the thermal discharge from the Surry Nuclear Power Plant. Results obtained to date will be compared to those predicted by the Hydraulic Model (Pritchard and Carpenter, 1967).

Circulating water for the Surry Nuclear Power Plant is taken from the James River on the downstream side of the site, transported through the condensers, and discharged into the river on the upstream side. The shoreline distance between intake and discharge points is about 5.7 miles; the overland distance across the peninsula, about 1.9 miles.

The plant discharges water by open channel flow to the

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James River. This discharge, due to its free surface nature, is a source of both momentum and buoyancy, spreading vertically, laterally, and longitudinally due to turbulent diffusion and density driven motions.

The first unit (822 Mw) of the Surry Nuclear Power Plant began operation December 27, 1972; the second unit (also 822 Mw) began operation in March 1973. Prior to these times, two years of background data were obtained. Both pre-operational and post-operational data collection were accomplished using a moving boat sampling system.

INSTRUMENTATION, DATA COLLECTION, AND REDUCTION

To adequately define a thermal plume in three dimensions, procedures and instrumentation have been designed to allow a large area to be covered rapidly while sampling temperature as a function of depth. Bolus et.al. (1971) have given a detailed description of the design and operation of the data acquisition system, calibration procedures, regression equations, and derived calibration curves. Photographs of the equipment utilized in the study are contained in a report by Chia et.al. (1972). Calculated instrument accuracy and an analysis of boat position error are discussed by Shearls et.al. (1973).

A schematic diagram of the basic information gathering and recording system used on the boat is shown in Figure 1.

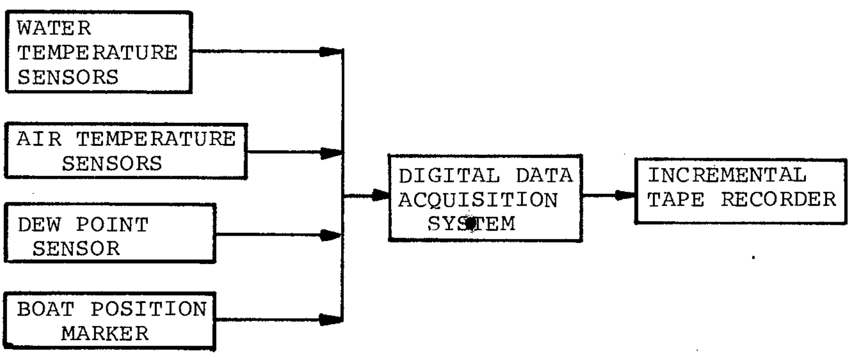

Figure 1. Data Acquisition System for Survey Boat.

Thermistors were used as water and air temperature sensors. Water temperatures were obtained at 0.5, 3, and 6 feet below the surface by mounting thermistors on a submerged boom attached to the boat. Thermistors were mounted in fan ventilated housings on the boat at 3 feet and 6 feet above the water surface to measure air temperatures. Dew point temperatures were measured using a hygrometer mounted in a special housing attached to the boat.

These data, along with a zero reference voltage, a high voltage reference, and a boat position marker, were sampled sequentially every 6 seconds and multiplexed by a digital data acquisition system, then recorded on IBM compatible tape by a high speed incremental tape recorder, as the research vessel moved at constant speed along the sampling transects. A computer program was developed to reduce the field data to final form.

During each sampling run surface and bottom water samples were taken at several fixed stations and brought back to the lab for DO and salinity analysis.

This data acquisition system allows approximately 1000 samplings of all sensors to be taken during the one hour and forty minutes required to traverse the designated transects.

After the data has been reduced, isothermal maps are made by equally spacing the data for each transect between the end points of that transect. Isothermal lines are then drawn by hand.

Instrument and system accuracy are presented in Table 1.

Table 1. Instrument and System Accuracy

Measurement	Instrument Accuracy	System Accuracy
Water Temperature	0.2°F	0.5°F
Air Temperature	0.2°F	0.5°F
Dew Point Hygrometer	1.0°F	1.5°F

The survey transects are shown in Figure 2.

RESULTS OF 1973 FIELD SURVEYS

Water Temperatures

Monthly average surface water temperatures for 1973 showed a steady rise from 56.8°F in March to 81.8°F in June, continued to rise through July (83.3°F) and peaked in August at 84.4°F. Temperatures then declined slowly to 82.6 in September, and dropped rapidly to 72.4°F in October. In 1971 and 1972 average temperatures (see Shearls, et.al., 1973) were above 80°F only in July and August, July

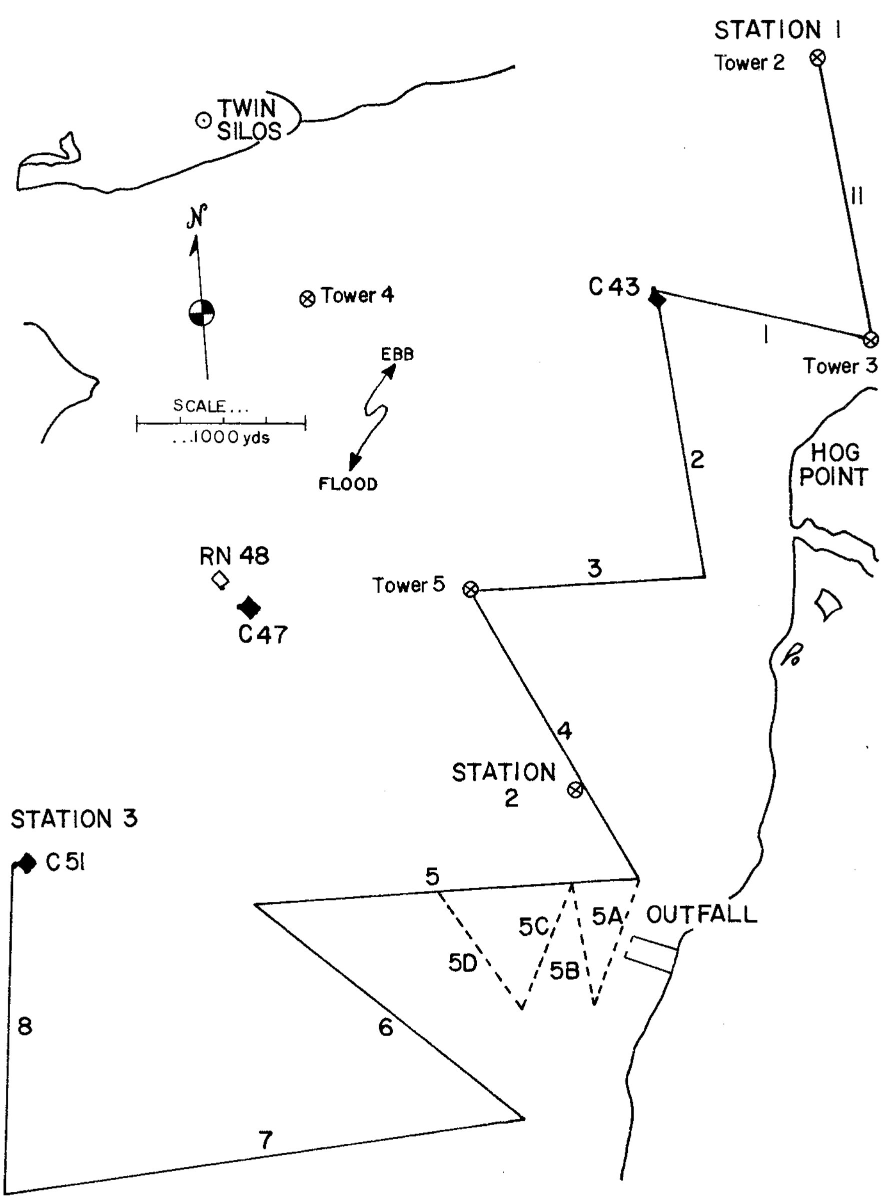

Figure 2. Survey area showing transects monitored and D.O. and salinity stations. Dashed lines are the near field transects added in July 1973.

being the peak month; while in 1973, temperatures exceeded 80°F from June - September inclusive, with the peak in August. Furthermore, October temperatures were approximately 5°F and 12°F hotter in 1973 than in 1971 and 1972 respectively, and May 1973 temperatures were 2-3°F hotter than in 1971 and 1972.

The rate of excess water surface temperature decrease with distance from the plant outfall is presented in figure 3. In this Figure, T represents the surface water temperature at distance x from the outfall. T_a represents ambient surface water temperature, and T_o represents initial outfall temperature. Data plotted in Figure 3 was obtained from isothermal maps from 5 different dates during July-September 1973. The position of the plume centerline was estimated.

This figure shows that temperatures decrease to ambient conditions generally within 1200 yards of the outfall. The line drawn in Figure 3 represents a rough linear approximation to the temperature decrease.

Table 2 lists average monthly values of surface water temperature (°F) for each transect during the three year sampling period. Beginning with July 1973, transects 5A, B, C, D are included in addition to transect #5. Values for transect #11, initiated in 1973, are also included in Table 2. No temperature averages for March 1971 are presented because sampling did not begin until April of that year. During 1972 transect #8 was not sampled during the March runs, and therefore is not shown.

Water Stratification

Background data from 1971 and 1972 indicate a slight thermal stratification (approximately 1°F cooler three to six feet below the water surface) during May through September. The water column during the rest of the year showed little temperature stratification within the top 6 feet.

Figure 4A, B, and C show the isothermal lines for July 24, 1973 at the surface, 3 feet, and 6 feet, respectively. These isothermal plots indicate that in the vicinity of the outfall the area covered by the 84° - 89° isotherms was larger at a depth of three feet than at the surface, and was greatest for the 6 feet depth. In the region of Hog Point, temperature isotherms show that water temperatures at 3 feet were the same as at the surface, and that 6 feet water temperatures were lower.

Figure 5 shows the water temperature profiles for October 18 at several selected stations. The station locations are shown in Figure 6. On October 18, only one unit was operating at 93%, the discharge rate was approxmately 1900 cfs, air temperature was 67.0°F, dew point

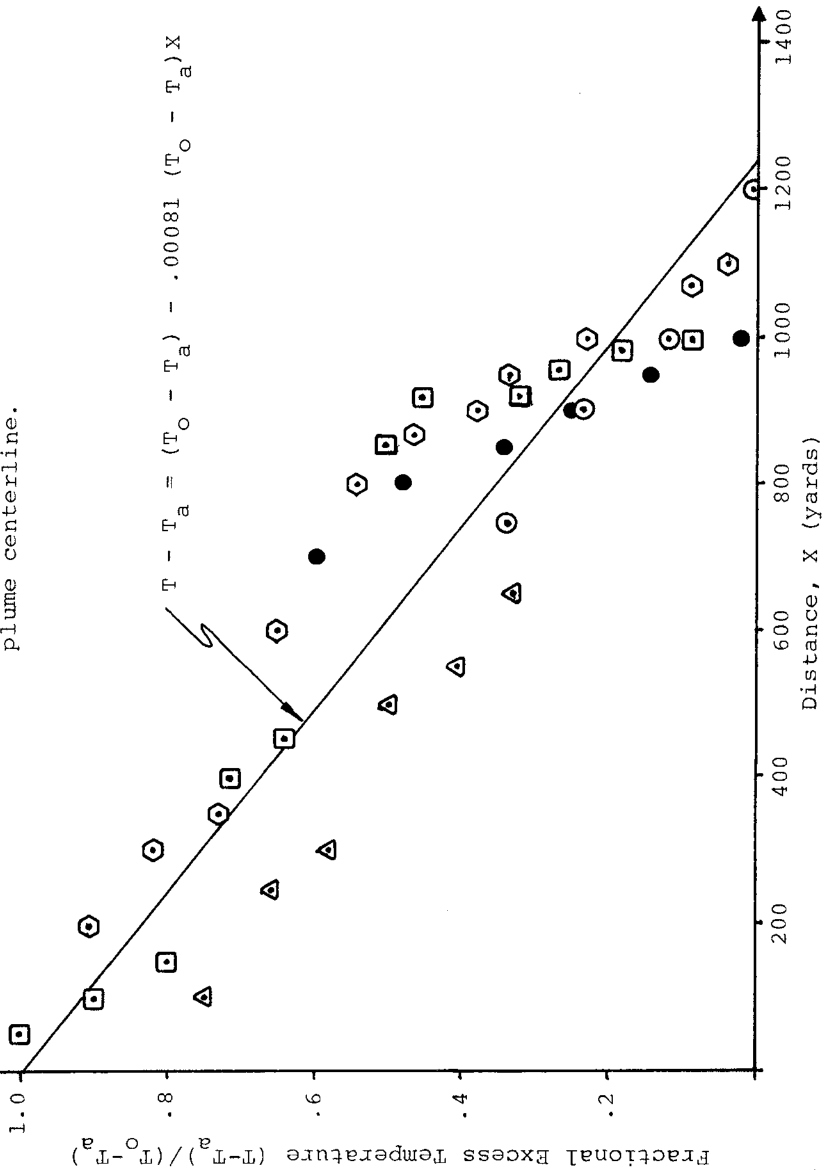

Figure 3. Water temperature decrease along plume centerline.

Table 2. Monthly Averages of Surface Temperature/Transect, °F

Transect		March	April	May	June	July	Aug.	Sept.	Oct.	Nov.
1	(1971)	-	57.8	66.4	76.0	81.0	80.9	77.1	67.2	58.5
	(1972)	50.4	58.2	68.2	73.1	80.6	80.2	76.0	60.1	54.7
	(1973)	51.7	56.7	71.0	82.2	83.7	84.1	82.7	71.8	-
2	(1971)	-	57.8	66.6	74.8	81.6	80.7	77.5	67.6	58.4
	(1972)	50.6	58.7	68.0	73.0	80.8	80.4	76.2	60.2	54.6
	(1973)	52.6	56.8	71.6	82.6	83.5	84.7	82.6	71.8	-
3	(1971)	-	57.9	67.2	75.5	82.1	80.7	77.8	67.5	58.9
	(1972)	50.6	58.3	68.2	73.2	80.9	80.5	76.3	60.3	54.3
	(1973)	53.0	56.5	71.4	81.8	82.9	84.3	81.8	71.8	-
4	(1971)	-	58.3	67.6	75.9	82.3	81.0	77.9	67.7	58.6
	(1972)	50.5	58.6	68.4	73.6	81.2	80.7	76.4	60.3	54.4
	(1973)	52.4	56.6	70.3	81.9	83.1	83.7	82.4	71.9	-
5A	(1973)	-	-	-	-	83.8	85.3	84.4	75.2	-
5B	(1973)	-	-	-	-	83.9	85.3	83.7	72.5	-
5C	(1973)	-	-	-	-	85.0	85.3	83.7	73.0	-
5D	(1973)	-	-	-	-	83.2	85.1	83.3	72.7	-
5	(1971)	-	58.5	68.2	76.1	82.6	81.2	77.9	67.8	58.6
	(1972)	50.7	59.1	68.5	73.8	81.2	80.6	76.3	60.4	54.4
	(1973)	52.8	56.4	70.1	82.1	83.0	83.6	81.6	72.0	-
6	(1971)	-	59.0	68.2	76.4	83.0	81.1	78.0	68.0	58.3
	(1972)	50.8	59.5	68.4	73.8	81.2	80.7	76.4	60.4	54.5
	(1973)	53.2	56.6	70.4	81.8	83.2	84.5	82.0	72.4	-
7	(1971)	-	59.0	68.2	76.8	83.3	81.3	78.2	68.2	58.2
	(1972)	50.7	59.4	68.6	73.8	81.4	80.6	76.4	60.2	54.5
	(1973)	52.2	57.0	-	81.4	82.8	84.6	82.4	72.1	-
8	(1972)	-	59.0	68.5	73.7	81.5	80.5	76.2	60.3	54.4
	(1973)	51.4	57.0		80.5	82.8	83.6	82.2	72.1	-
11	(1973)	-	-	-	81.9	83.2	83.4	82.1	71.7	-

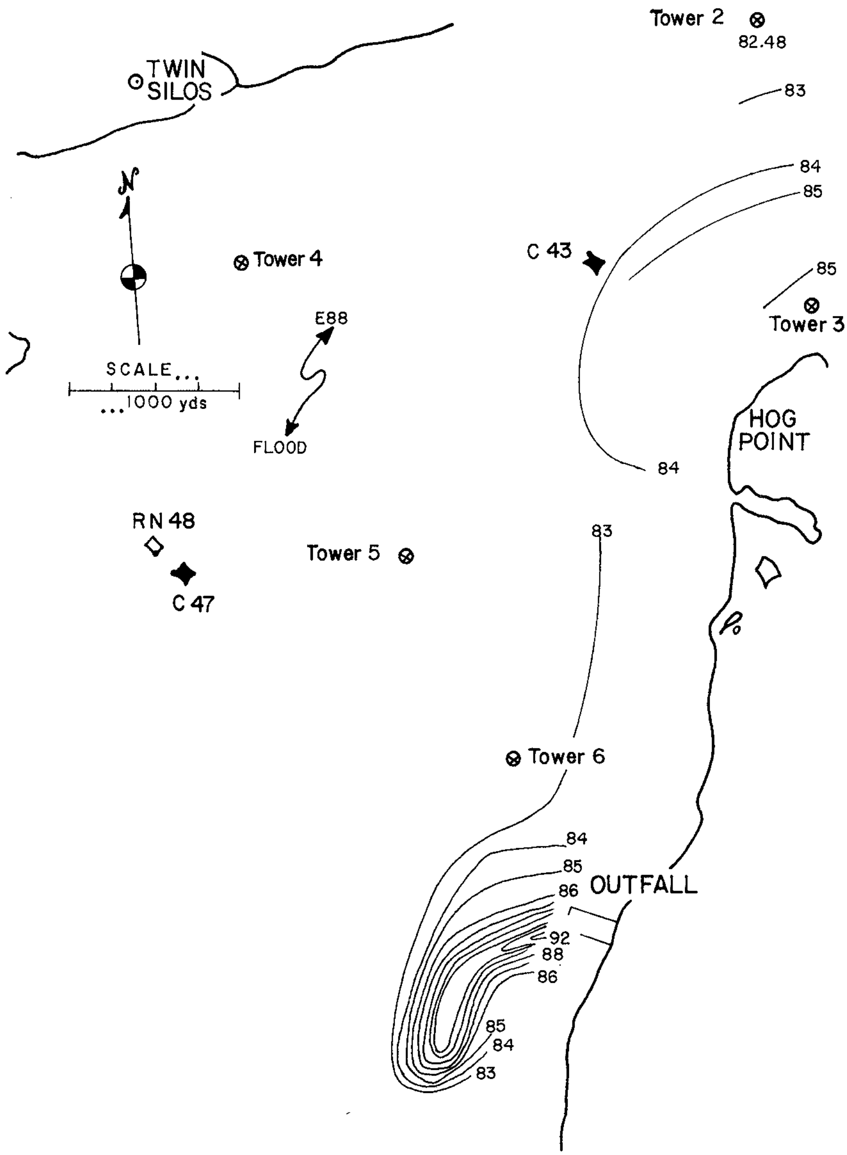

Figure 4A. Isothermal plot for July 24, 1973, flood, at a depth of 1/2 foot.

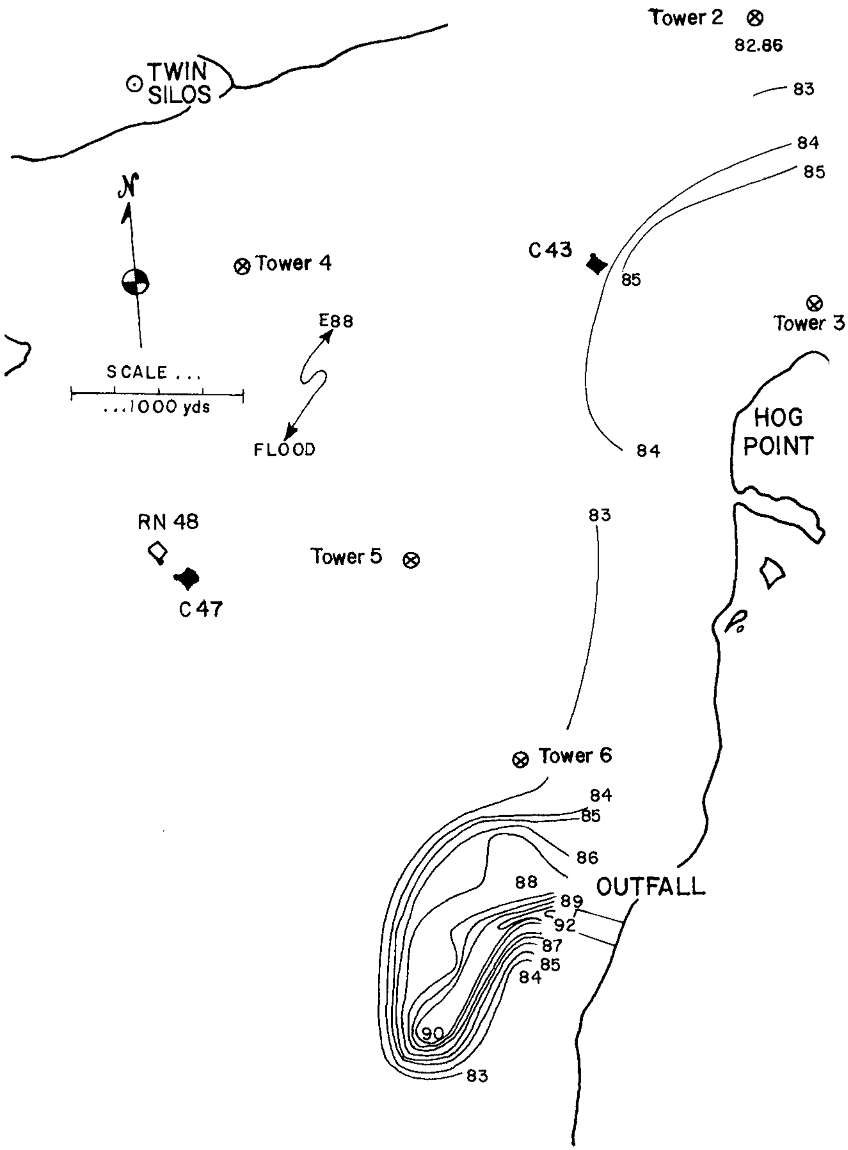

Figure 4B. Isothermal plot for July 24, 1973, flood, at a depth of 3 feet.

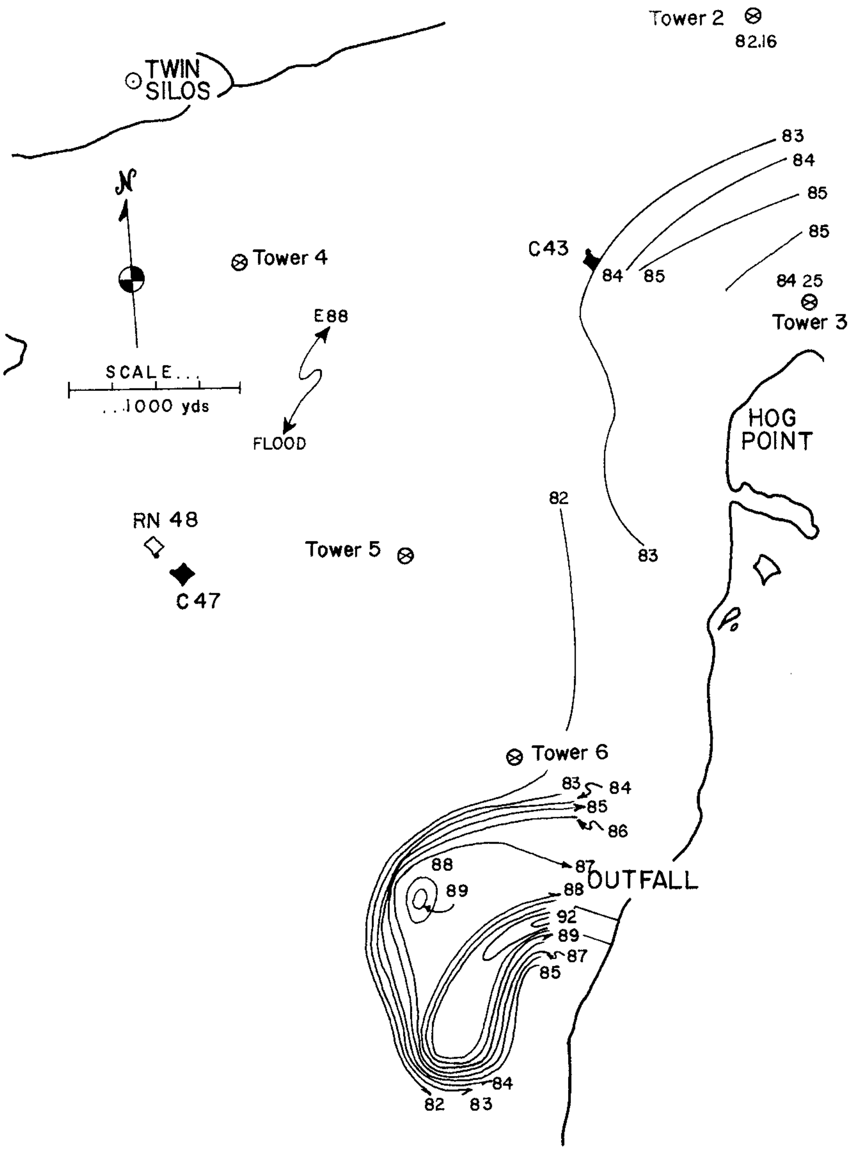

Figure 4C. Isothermal plot for July 24, 1973, flood, at a depth of 6 feet.

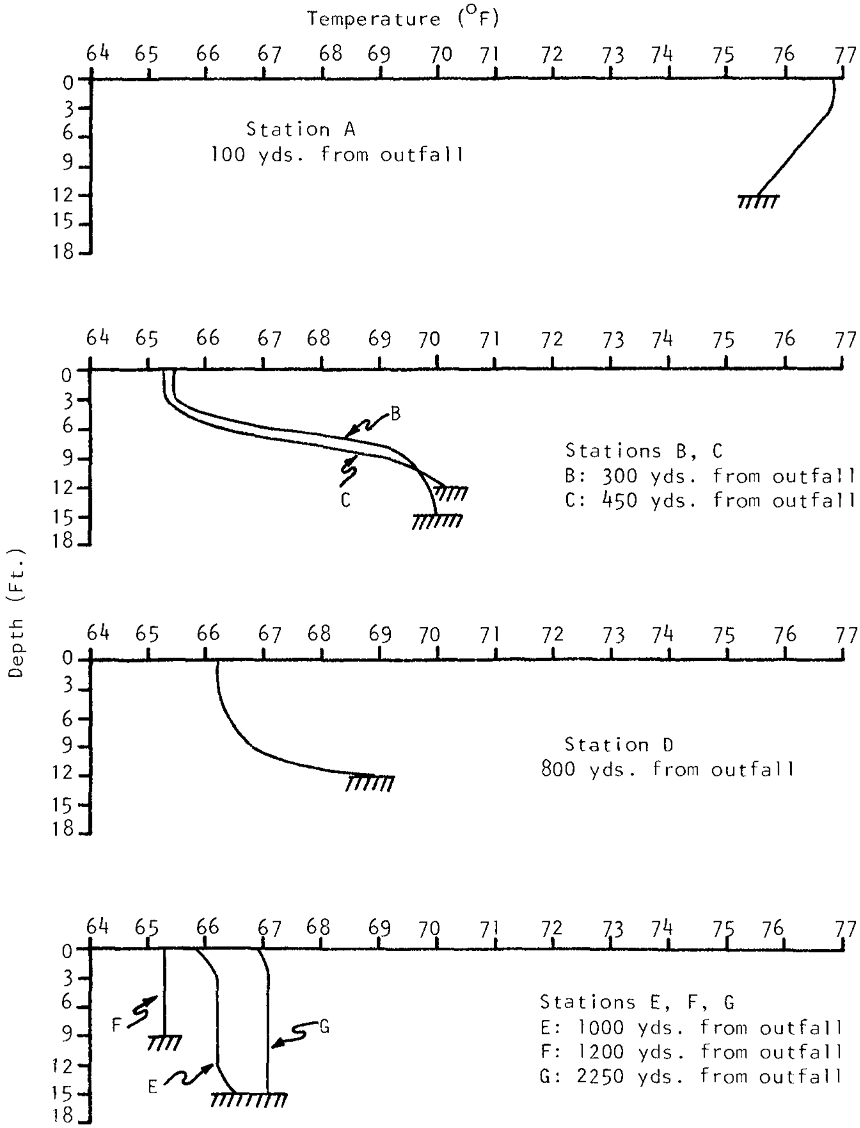

Figure 5. Water temperature profiles for October 18 at selected stations (see Figure 6).

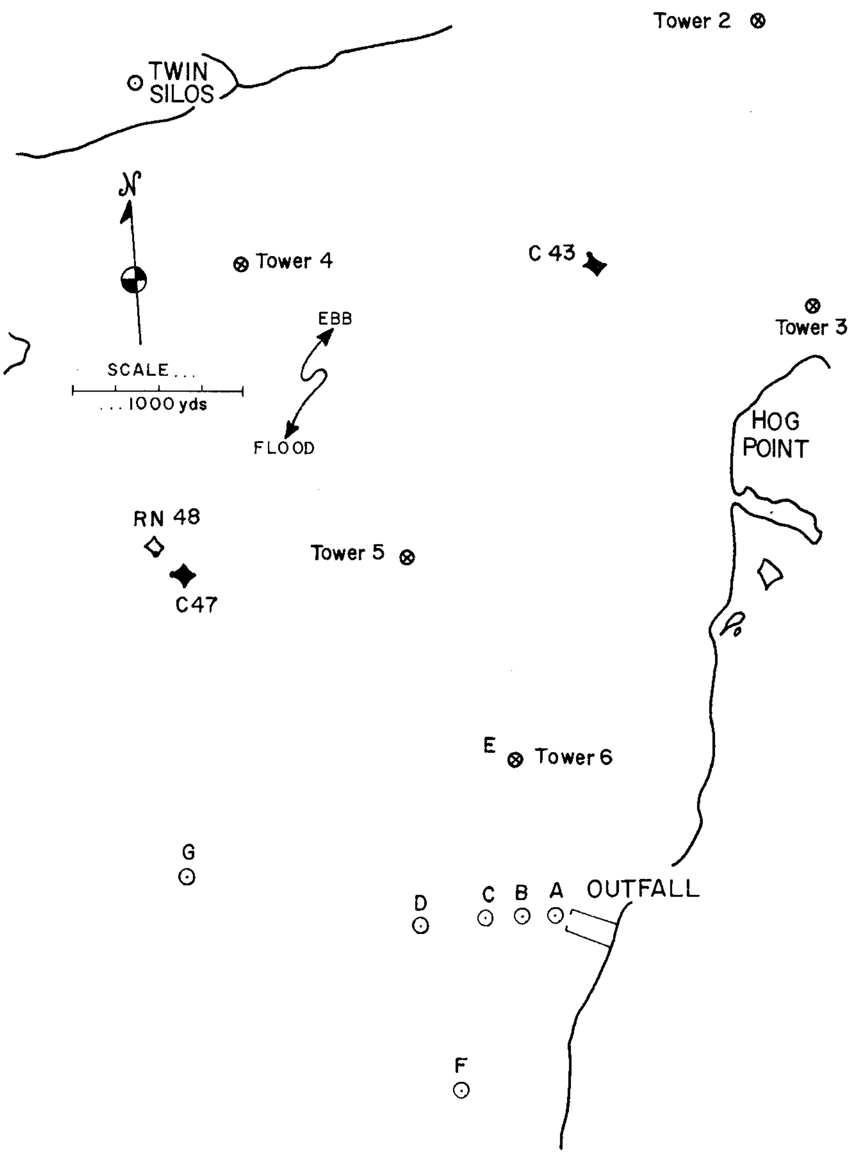

Figure 6. Station locations for temperature profiles (Figure 5) on October 18.

temperature was 36.0°F, and the winds were 5-10 MPH from the southwest.

The water temperature profile for station A, approximately 100 yards from the mouth along the axis of the discharge, shows that the water surface temperatures are 76.8°F while the water temperature at the bottom (12 feet depth) are 75.5°F. At station B and C, 300 and 450 yards from the discharge respectively, the surface water temperatures are considerably lower, at approximately 65.4°F. Water temperatures at the 3 feet depth are the same as at the surface. From the 3 feet depth water temperatures steadily increase to approximately 70°F at the bottom. At these stations, water temperatures at the 6 feet depth, the deepest depth normally sampled by the boat system, were only 1° - 1.5°F above surface temperatures. Station D, 800 yards from the discharge, shows the same pattern as stations B and C, but in this case, bottom temperatures reach a maximum of 68.8°F.

Of the last three stations, E, F, and G, only station E, 1000 yards from the mouth of the discharge and 850 yards downstream, shows warmer waters at the bottom. In this case, water temperatures from 3 feet to 12 feet are constant at 66.2°F and are a maximum of 66.5°F at the 15 feet depth of the bottom.

These water temperature profiles indicate that in the near field region of the outfall water temperatures in the top 3 feet decrease rapidly, but that below this depth the temperature decrease is less rapid. This would indicate that the plume was sinking in the near field region. This "sinking" plume phenomena was apparently a result of salinity differences between the discharge waters and surrounding waters. On the occasions when outfall salinity samples have been taken, the salinity of the discharge waters has been 1ppt - 2ppt higher than salinity samples taken at Tower 6. Within the ranges of salinities and temperatures found in this area, an increase in temperature of 6.3°F has the same effect on the density of the water as a decrease in 1 ppt in the salinity. This means that water which had a salinity which was 1 ppt greater than ambient water would have to be 6.3°F warmer than the ambient water to have the same density. A simplified temperature-salinity-σ_T (density) diagram, Figure 7 shows this clearly.

Starting at point C, a decrease in salinity of 1 ppt at constant temperature results in point A, where σ_T (density) is σ_{t_1}. Starting at C and increasing temperature 6.3°F at constant salinity results in point B, where σ_t is also σ_{t_1}. Therefore, if A represents ambient conditions, an increase in 1 ppt salinity must be accompanied by an increase in temperature of 6.3°F in order for the densities to remain the same.

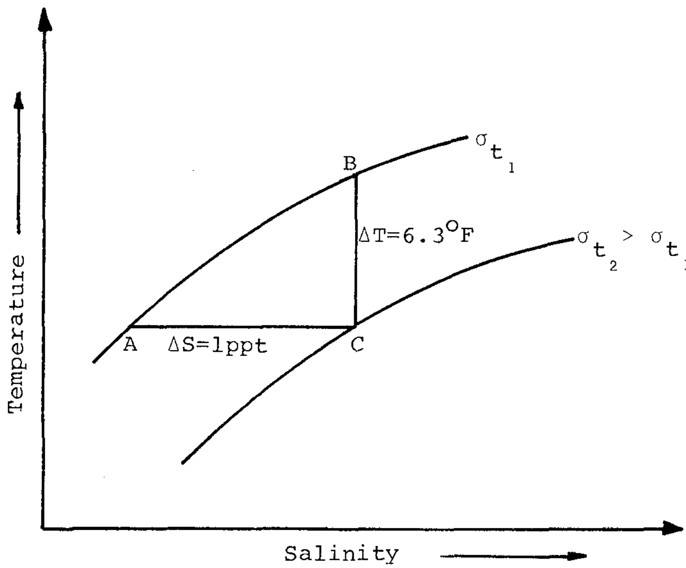

Figure 7. Temperature-Salinity-Density (σ_T) Diagram.

The plume reaches a point at which the temperature decrease more than compensates for the decrease in salinity due to mixing, and the denser plume waters sink with respect to the surrounding waters. This is generally a near field effect and occurs within a maximum radius of approximately 1000 yards from the outfall.

Dissolved Oxygen (DO) Concentrations

During 1972 DO concentrations in the area ranged from a low of 5.0 - 7.5 mg/ℓ during the hottest months (July and August) to a high of 11 mg/ℓ and over during the cooler months.

Of 366 total D.O. samples taken at all stations during 1972, only two bottom samples had D.O. concentration less than 5 mg/ℓ.

D.O. concentrations during 1973 showed the same trend as for 1972, with concentrations of 6.0 - 8.0 mg/ℓ during the summer and concentrations over 11 mg/ℓ during the cooler months.

In 1973 five of 98 surface samples and four of 97 bottom samples had D.O. concentrations below 5 mg/ℓ.

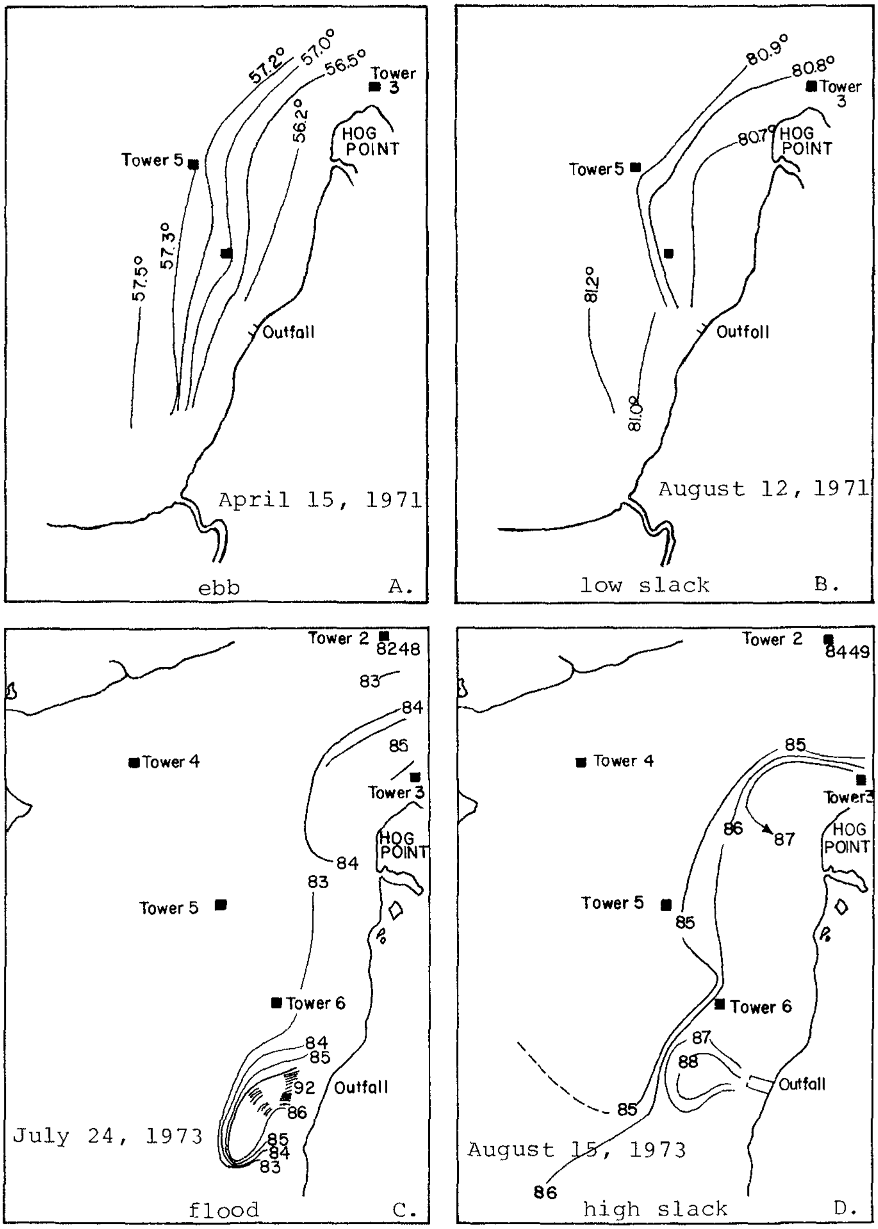

Figure 8. Typical isotherms for the Hog Point region under natural conditions (A,B) and after plant operation (C,D).

Salinity

Data from 1971 and 1972 indicates that average salinities varied from 0.10 to 4.42 ppt in the downstream part of the study area and from 0.10 to 2.63 ppt in the upstream part. The minimum values were attained between December and March and peak salinities usually occurred in September. During 1973 salinities averaged 0.2 - 4.0 ppt higher than in 1971 or 1972 from June through October due to lower fresh water discharge in 1973.

COMPARISON OF PRE- AND POST-OPERATIONAL TEMPERATURE DISTRIBUTION

Typical isothermal plots for the Hog Point region under natural conditions, i.e. prior to plant operation, are shown in Figure 8. These plots indicate that surface water temperature gradients were small in the survey area and the water can be considered horizontally homogeneous. Temperatures generally varied less than 1°F throughout the area.

Typical isothermal plots for the area during 1973, with the power plant in operation also are shown in Figure 8. The temperature gradients in the area have been greatly enhanced due to the thermal effluent.

The greatest temperature gradients occur in the near field region of the outfall and between towers 2 and 3 at Hog Point. Temperatures increase towards shore, and temperature variations in the far field region are generally within the range 2° - 4°F. Near field temperature variations are higher, usually within the range 5° - 9°F.

The isothermal plots for 1973 indicate that the 1°F, 2°F, and to a lesser extent, the 3°F excess temperature isotherms generally remained fairly constant in their position throughout the tidal cycle. At low slack they extended around Hog Point. During flood stage they were pushed upstream slightly until at high slack they reached their maximum upstream position. Ebb tidal stages showed them again extending farther toward Hog Point. The 1°, 2°, and 3°F excess temperature isotherms, then, describe an area affected by the heated effluent at all stages of the tide and can be regarded as a secondary or permanent plume. The region occupied by excess temperature isotherms of 4° or higher showed greater movement with the tidal flow. These isotherms were more closely spaced than those for the permanent plume and showed a definite downstream trend during ebb and low slack water, and a definite upstream direction during flood and high slack water. These isotherms represent the area of greatest heat dissipation of the heated effluent and can be considered the primary plume.

COMPARISON OF FIELD RESULTS WITH PREDICTIONS MADE FROM THE HYDRAULIC MODEL

Studies conducted by Carpenter and Pritchard on the hydraulic model of the James River estuary resulted in predictions of excess temperature distribution which would result from the discharge of waste heat by the Surry Nuclear Power Station. One of the purposes of this study was to compare these predictions to actual temperature distributions observed in the field in order to determine the reliability of hydraulic modeling as a method of predicting the effects of man made systems on the natural environment.

Carpenter and Pritchard did their experiments under various conditions of river flow and heat rejection. The conditions which are most applicable for comparison with field data are for river discharges of 2000 and 6000 cfs and a heat rejection of 12 x 10^9 Btu/hr. Their results were presented as a series of isothermal maps of temperature distribution throughout a tidal cycle. In order to compare prototype and model data, a planimeter was used to determine the areas within each excess temperature isotherm for a run during 1973 and a comparable hydraulic model run.

On five of the days sampled during 1973 the power plant was operating at 90% capacity or above, with a heat rejection of 11 x 10^9 Btu/hr or above. These days obcurred during the end of August and the first half of September. During this period the river discharge averaged 1900 cfs.

These five days represent the closest agreement between actual fresh water discharge and heat rejection and modeled fresh water discharge and heat rejection and are the most directly comparable.

Table 3 shows comparison between the areas within equivalent excess temperature isotherms for the hydraulic model and the prototype for a river flow of 1900 cfs.

Table 4 shows a comparison between the areas within equivalent excess temperature isotherms for the hydraulic model and the prototype for a river flow of 7200 cfs.

Comparing results between prototype temperature distribution and model temperature distribution for two river flow conditions indicate that the model predictions were more accurate for the higher river flow conditions.

Lower values for heat rejection in the prototype were partially responsible for the smaller areas within each excess temperature isotherm. Heat rejection values on the days compared with hydraulic model predictions were from 8-14% lower than the modeled heat rejection. If it is assumed that at full plant capacity the areas in

Table 3. Comparison between predicted areas from the hydraulic model and areas found in the prototype for river flow of 1900 cfs.

Prototype Date	Area ($x10^7 ft^2$) within Equivalent Isotherms Hyd. Mod. 2^oC	Proto. 2^oC	Hyd. Mod. 3^oC	Proto. 3^oC	Hyd. Mod. 5^oC	Proto. 5^oC
8-29-73	6.85	4.12	2.88	0.48	0.72	.076
9-10-73	5.94	2.67	5.04	0.17	0.36	.049
9-18-73	4.68	0.80	2.34	0.24	0.72	.028
8-29-73	3.32	0.24	1.80	0.70	0.54	.024
9-5-73		1.00		0.062		.035
9-7-73		1.83		0.26		.056
Average	5.17	1.78	3.02	0.21	0.59	.045

Table 4. Comparison between predicted areas from the hydraulic model and areas found in the prototype for river flow of 7200 cfs.

Prototype Date	Area ($x10^7 ft^2$) within Equivalent Isotherms Hyd. Mod. 2^oC	Proto. 2^oC	Hyd. Mod. 3^oC	Proto. 3^oC	Hyd. Mod. 5^oC	Proto. 5^oC
6-25-73	6.12	1.04	4.14	0.15	0.36	-
6-28-73		2.47		0.92		-
6-20-73	4.32	2.29	3.24	0.27	0.36	-
6-22-73	7.75	4.36	1.80	0.73	0.18	-
6-25-73	4.18	1.33	2.32	0.92	0.36	-
Average	5.59	2.30	2.88	0.60	0.32	-

the prototype would have been 10-20% larger, which is probably an over-estimation, the differences between the model predictions and the prototype would still have been significant.

Qualitatively, the temperature distributions in the field are similar to those predicted by the model in that the heated waters are carried downstream during the ebb tidal cycle and are carried upstream on the flood tide.

CONCLUSIONS

1) Ambient water temperatures for 1973 ranged from 1.2°-5.1°F higher than for 1971 and 1972. The pre-operational data indicates that ambient temperatures varied by as much as 8°F. The higher ambient temperatures for 1973 could be due to natural heating, since air temperatures were higher for 1973 than either 1971 or 1972 except for the month of July.

2) Salinities were from .2 - 4 ppt higher than in 1971 or 1972 from June through October due to the lower fresh water discharge. The pumping of more saline downstream waters through the plant increased the salinities at tower 6.

3) Dissolved oxygen concentration has not been adversely affected in the survey region. Only on two of the days sampled were bottom salinities below 5 mg/ℓ at any station.

4) Water temperatures decrease very rapidly within 1000-1500 yards from the outfall. In several instances the water on the bottom had higher temperatures than the surface waters, due to the higher salinity of the discharge water.

5) Data that has been collected to date does not indicate that there are any extreme temperatures, outside the near field region of the outfall, that could cause biological damage. Outside the outfall region, heated water is generally confined to the upper 6' of the water column. Heated waters generally do not cover more than half of the width of the estuary at it's narrowest point.

6) The James River Hydraulic Model, due to it's distorted scale, is best suited for far field analysis of the thermal effluent. The attempt to model all three regions with this model leads to quantitative values for temperature distributions which were higher than those values found in the field. Qualitatively the model predictions of plume movement with the tides are in close agreement with the prototype plume movement. Higher plant production will increase the agreement between prototype and model temperature distributions, but model values will probably still be higher than the temperature distributions found in the field.

7) Plant operation during 1973 averaged only 67% of capacity on the days monitored. In order to draw definitive conclusions concerning the maximum extent of the thermal effects or the agreement between hydraulic model and prototype temperature distributions, plant operation should be at a continuously high percentage of capacity. Indications as to the effects of the thermal discharge can be drawn from the 1973 data, but no definitive conclusions can be made without further monitoring.

ACKNOWLEDGEMENTS

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