CONSOLIDATED EDISON COMPANY
OF NEW YORK, INC.

EFFECT OF
INDIAN POINT COOLING WATER DISCHARGE
ON
HUDSON RIVER TEMPERATURE DISTRIBUTION

February, 1969

Revision of Report of January, 1968

QUIRK, LAWLER & MATUSKY ENGINEERS
Environmental Science & Engineering Consultants
505 Fifth Avenue
New York, New York 10017

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encl # 12

CONSOLIDATED EDISON COMPANY OF NEW YORK, INCORPORATED
NEW YORK, NEW YORK

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FEBRUARY, 1969

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505 FIFTH AVENUE
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212 867-0080

WATER RESOURCES DEVELOPMENT
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THOMAS P. QUIRK
JOHN P. LAWLER
FELIX E. MATUSKY

WILLIAM A. PARSONS
LEONARD J. EDER
ROBERT A. NORRIS
VINCENT J. BOCCHINO

February 17, 1969

Mr. George T. Cowherd
Environmental Engineer
Consolidated Edison Company
 of New York
4 Irving Place
New York, New York 10003

Dear Mr. Cowherd:

We are submitting our report on the expected effect of simultaneous operation of three nuclear units at Indian Point on Hudson River temperatures.

This report is a revision of, and should be considered as superceding, our original report on this subject of January, 1968.

The several changes in the proposed thermal discharge criteria of the New York State Health Department since early 1968 have necessitated this revision. In particular, criteria on water surface temperatures have required replacement of the planned surface discharge by a submerged outfall.

Data made available since our earlier report have been utilized. These include infra-red surveys of surface temperature by Texas Instruments and operation of Indian Point Model II by the Alden Research Laboratory. Our earlier mathematical model has been adjusted to yield better agreement with field data.

A summary of findings, conclusions, and recommendations precedes the report on pages S-1 to S-4 inclusive.

Very truly yours,

John P. Lawler

John P. Lawler

JPL/mmn
Enclosure

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SUMMARY OF FINDINGS, CONCLUSIONS & RECOMMENDATIONS

1. In January, 1968, Quirk, Lawler and Matusky Engineers submitted a report entitled "Effect of Indian Point Cooling Water Discharge on Hudson River Temperature Distribution." This report presented a mathematical analysis of the effect of three unit discharge on temperature rises in the River. Results were evaluated against a set of thermal discharge criteria, which were, at the time, proposed by the New York State Department of Health (NYSDH).

   The analysis was conservative; computation of temperature rises for one unit operation were significantly higher than field observations for this condition. The analytical results, however, did not contravene the proposed criteria, so the model was submitted as evidence that the three unit discharge would meet the thermal standard.

2. The proposed NYSDH criteria have undergone significant changes since the submission of the January, 1968 report. In particular, surface temperature criteria have been added. These include a maximum surface water temperature of 90°F at any point in the surface, and a requirement that no more than two thirds, or 67%, of the surface width be subject to temperatures greater than 83°F, or artificial temperature rises of 4°F.

   These surface temperature criteria have necessitated a revision of the prior work. The 90°F criterion will require a subsurface discharge; the early work was predicated on a surface discharge.

   Furthermore, the conservative mathematical model shows only marginal agreement with the 4°F, 67% surface width criterion. The model, therefore, has been adjusted to agree with field measurements, and, as a result, shows clear ability of the three unit discharge to meet these new criteria.

3. The first adjustment in the mathematical model consisted of reducing the heat load to 79% of the value used in prior calculations.

   Previously, the heat load used was 6% higher than that associated with the maximum possible three unit electrical output (stretch rating) of 2351 MW. Planned operation, however, is 90% of this value, or 2114 MW. This latter value is slightly less than the manufacturer's guaranteed rating of 2123 MW, the maximum value at which the station may operate under initial Atomic Energy Commission operating licenses.

These facts, in addition to crediting 5% of the heat generated against in-plant heat losses, lead to a design heat load of 340×10^9 BTU/day, which is 79% of the previous employed loading of 430×10^9 BTU/day.

Circulating water flow is 2,040,000 gpm, rounded previously to 2,100,000 gpm. The three unit effluent channel temperature rise is now 14°F, rather than the 17°F used previously.

4. The maximum River ambient surface water temperature is 78° to 79°F and usually occurs in August. Hydraulic model studies show that the 14°F effluent channel temperature rise can be reduced markedly, before reaching the River's surface, by discharging these waters to the River through a submerged outfall.

   Model studies showed that six rectangular ports, each 30 ft. wide by 4 ft. high, and separated by 10 ft. wide partitions, located along the bottom of the west wall of the discharge canal, would yield maximum surface temperatures substantially lower than the 90°F criterion. Results for various submergences are given as follows:

Submergence to Top of Port (ft. below MSL)	Depth to Channel Bottom (ft. below MSL)	Maximum Surface Temperature Rise, °F	
		For $\Delta T_p = 17^{\circ}F$	For $\Delta T_p = 14^{\circ}F$
16	20	88	86.5
21	25	87	85.5
26	30	85	84

5. Comparison of the values predicted by the unadjusted mathematical model for Unit No. 1 behavior with the field measurements is given in Table 4 in the text. The mathematical model was ad-

justed to yield these observed values when operating at the Unit No. 1 heat load.

This adjusted model showed that the area-average temperature rises across the plane of discharge is some 50 to 75% of the values previously predicted. Furthermore, the decay of temperature above and below the plane of discharge becomes much more rapid, resulting in a substantial reduction of the extent of temperature rises greater than 1°F.

This improved dilution and dispersion is believed to be the result of salinity-induced circulation in the estuary. Detailed explanation of this mechanism, and the unique role it appears to have in dispersing thermal discharges is discussed in Chapter IV under "Rationale for Model Revision."

Results obtained from operation of the Indian Point Hydraulic Model II were also employed to confirm the rapid dispersion of heat given by the adjusted mathematical model.

6. Two critical conditions were studied. The condition of maximum severity was defined as that set of hydrology and meteorology which occurred in November, 1964. A sustained six month drought flow of 4000 cfs and a low heat transfer coefficient of 90 BTU/SF/day/°F, which occurred at that time, were shown, in the January 1968 report, to cause maximum temperature rises.

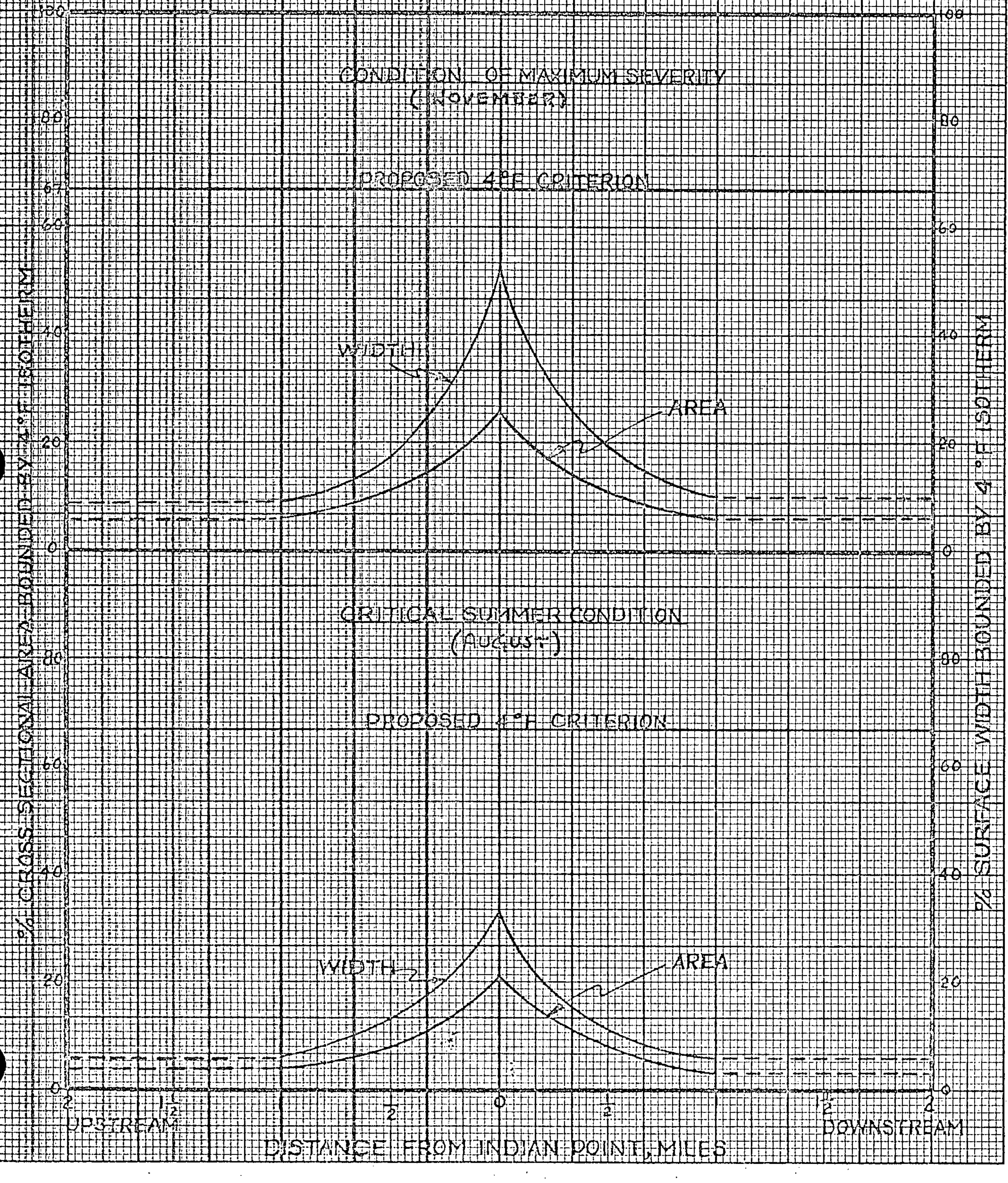
The critical summer condition consisted of the same flow, but used the August heat transfer coefficient of 135 BTU/SF/day/°F. Although this condition yields lower River temperature rises, it was studied because summer conditions are reported by many to constitute the critical biological condition.

Figure S-1 shows the predictions for the percentage of surface width and cross-sectional area bounded by the 4°F isotherm. These were obtained using the adjusted model.

The maximum percentage of either parameter occurs at the plane of discharge and, in the case of both width and area, is clearly less than the proposed cirterion. These plane of discharge results are summarized as follows:

FIGURE S-1

BOUNDARIES OF THE 4°F ISOTHERM FOR THREE UNIT DISCHARGE AT INDIAN POINT



Condition	% Area Bounded by the 4°F Isotherm		% Surface Width Bounded by the 4°F Isotherm	
	Criterion	Prediction	Criterion	Prediction
Maximum Severity	50	26	67	52
Critical Summer	50	21	67	33

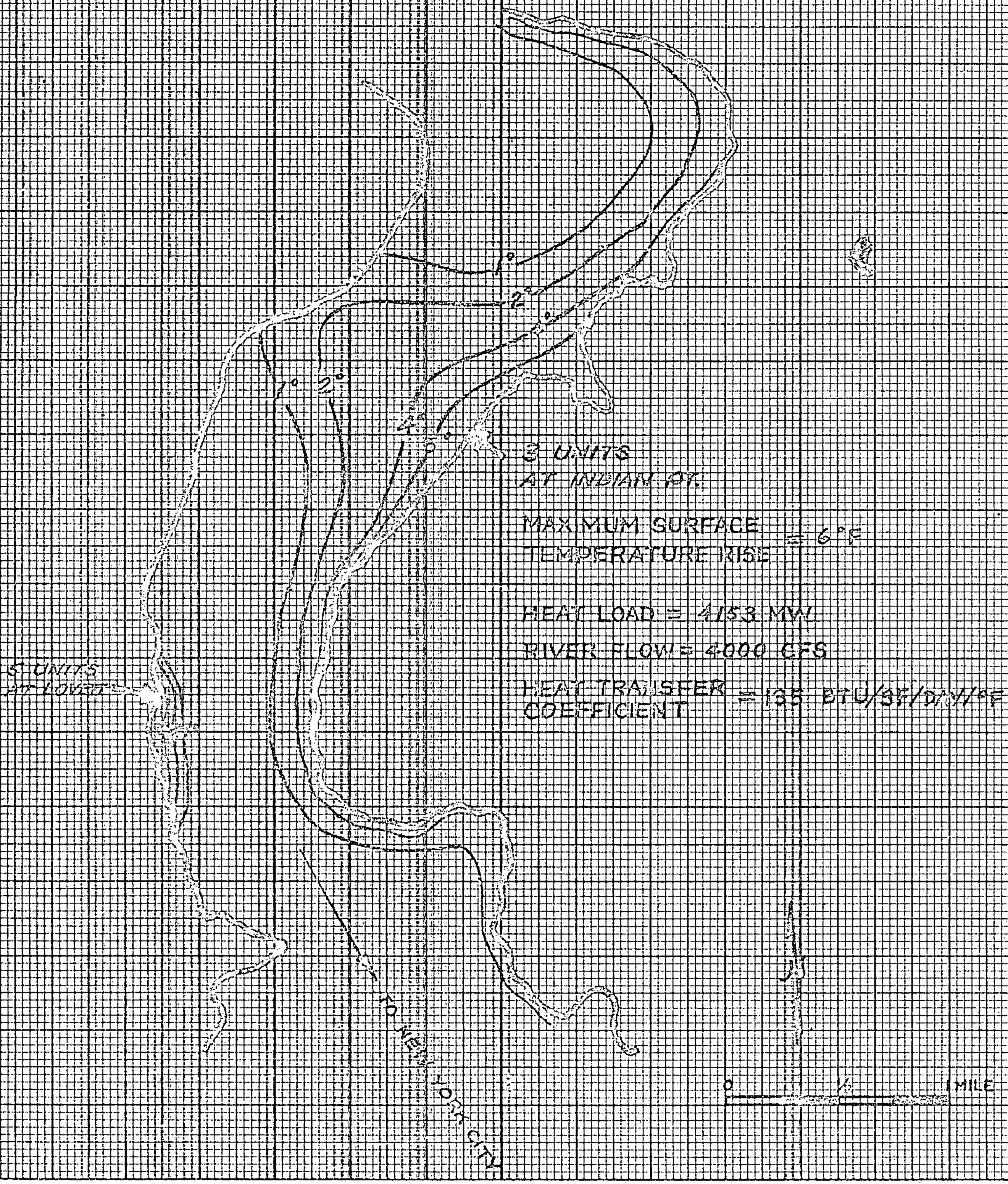
7. The percentages of the surface width bounded by other isotherms at various distances above and below Indian Point were also computed using the adjusted model. These results are shown in Figure S-2.

Figure S-2 shows clearly that temperature rises greater than 1°F are limited to the vicinity of Indian Point. The Indian Point heat load is not expected, for instance, to influence the temperature pattern at Orange and Rockland Utilities' Lovett Plant.

In conjunction with Figure S-2, it should be remembered that, for effluent channel temperature rises between 14°F and 17°F, the maximum temperature rise at any point in the surface can be held between 5°F and 9°F, depending on the submergence depth.

BOUNDARIES OF STATED SURFACE ISOTHERMS
FOR
THREE UNIT DISCHARGE AT INDIAN POINT

SUMMER CRITICAL CONDITION
(AUGUST)



3 UNITS
AT INDIAN PT.

MAXIMUM SURFACE TEMPERATURE RISE = 6°F

HEAT LOAD = 4153 MW

RIVER FLOW = 4000 CFS

HEAT TRANSFER COEFFICIENT = 135 BTU/SF/DAY/°F

I. EVENTS LEADING TO THE REPORT

On January 15, 1968, Quirk, Lawler & Matusky Engineers submitted a report entitled Effect of Indian Point Cooling Water Discharge on Hudson River Temperature Distribution, to the Consolidated Edison Company of New York, Incorporated.

The purpose of this report was to evaluate River temperatures expected from three unit operations at Indian Point against the thermal discharge criteria of the New York State Department of Health (NYSDH).

These criteria had been developed by NYSDH to provide numerical means of applying the thermal discharge (heated liquids) standard which, for the Class I waters of the Hudson River near Indian Point, reads:[1]

> "None alone or in combination with other substances or wastes in sufficient amounts to be injurious to edible fish and shellfish, or the culture or propagation thereof, or which shall in any manner affect the flavor, color, odor, or sanitary condition of such fish or shellfish so as to injuriously affect the sale thereof, or which shall cause any injury to the public and private shellfisheries of this State; and otherwise none in sufficient amounts to impair the waters for any other best usage as determined for the specific waters which are assigned to this class."

Since the time of preparation and submission of the January '68 report, the development of means of applying this thermal discharge standard was made the responsibility of the New York State Water Resources Commission (NYSWRC). The original NYSDH criteria have undergone some revision and the NYSWRC is now considering these revisions for adoption, subject to public hearings. This supplementary report presents an evaluation of the three unit discharge in the light of these recently proposed criteria.

The predicted temperature distributions which appear in the January '68 report are the results of a conservative analysis.

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[1] "Classification and Standards of Quality and Purity for Waters of New York State." (Parts 700-703, Title 6, Official Compilation of Codes, Rules and Regulations.) Prepared and Published for Water Resources Commission by NYSDH (Nov, 1967)

Waste heat loads used exceed the design waste heat load. River Temperature was not permitted to decay as rapidly as it actually does; i.e., as indicated by field measurements made during Unit No. 1 operation.

Using this conservative approach, the January '68 report showed the three unit operation would not contravene the early NYSDH criteria. Further refinement was therefore considered unnecessary.

Evaluation of three unit operation against the new, more restrictive criteria, using the conservative approaches given in the January '68 report, shows only marginal conformity to these criteria.

Therefore the conservative approach has been relaxed in the present report, and the predictions are made recognizing the actual expected heat load and the observed rapid decay behavior.

II. PURPOSE AND SCOPE

The purpose of this report is to redefine the surface and lateral Hudson River temperature distributions which can be expected as a result of three unit operation at Indian Point.

These temperatures will be compared to the allowable degree and extent of elevated temperatures as delineated in the present proposed criteria. These criteria require that temperature rises of $4^{o}F$, or absolute temperatures of $83^{o}F$, not be exceeded over more than 50% of the River's cross-section nor over more than two thirds of the River's surface width. Furthermore, surface water temperatures should not exceed $90^{o}F$ at any point.

The work required to achieve this objective includes:

1. Determination of heat loads that can be expected for three unit operation. These heat loads are those which result from planned operation of the three nuclear units.
2. Revision of the predictive model to conform more closely to field experience. This will be done by adjusting the mathematical model to yield results for Unit No. 1 operation similar to the field temperature measurements obtained during operation of Unit No. 1.
3. Prediction of three unit temperature profiles using the revised River model. These results will be correlated with results obtained from a second hydraulic model simulation of Indian Point three unit behavior.
4. Analysis of a planned submerged discharge design.

III. INDIAN POINT HEAT LOADS

The nuclear-fueled electric generating units at Indian Point will operate at an efficiency slightly in excess of 32%. That is, of the total thermal energy produced within the reactor, 32% will be converted to electrical output. The remaining 68% represents the waste heat which is lost within the plant or which is discharged to the river in the cooling water.

Typical in-plant losses are about 5% of the thermal input.[2] Consequently, approximately 63% (100-32-5) of the total thermal energy is discharged to the river as waste heat in the cooling water.

Table 1 lists the thermal input and its breakdown into electrical output, loss within plant and loss to river for the average summer week, for three unit operation, during 1973. After 1973, Consolidated Edison will have additional power sources and electrical output required from the three units operating at Indian Point will be reduced.

The electrical outputs presented in Table 1 were determined by Consolidated Edison system engineering personnel. These 1973 estimates represent the power that will be needed from the three units at Indian Point in accordance with the projected 1973 power needs and with the most efficient operation of all power sources within the Consolidated Edison system.

Table 1 shows that, during the average summer week in 1973, the weekly average of daily average electrical outputs would be 2114 MW. This agrees with the manufacturer's guaranteed output of 2123 MW and operation of Indian Point as a base load plant.

The maximum possible output stretch rating that the three units are believed to be capable of producing is 2351 MW. Operation at this level is not planned, however, and furthermore, will not be permitted by the Atomic Energy Commission in issuing the original operating permits.

The mode of operating the three unit Indian Point complex given

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[2] "Industrial Waste Guide on Thermal Pollution." U.S. Department of Interior, Federal Water Pollution Control Administration, Pacific Northwest Water Laboratory, Corvallis, Oregon (Sept, 1968)

TABLE 1

ESTIMATE OF THE BREAKDOWN OF HEAT PRODUCED AT INDIAN POINT

Three Unit Operation
Average Summer Week - 1973

Day (MW)	Electrical Output (MW)	Heat Loss within Plant (MW)	Heat Loss to River (MW)	Thermal Input (Heat Produced by Reactor) (MW)
Monday	2195	342	4313	6850
Tuesday	2147	335	4218	6700
Wednesday	2147	335	4218	6700
Thursday	2147	335	4218	6700
Friday	2147	335	4218	6700
Saturday	2080	325	4095	6500
Sunday	1935	320	3795	6050
Weekly Average	2114	333	4153	6600

in Table 1 is the result of efficient operation of the entire Edison system, considering sources of power. If the nuclear units are operated at their maximum output during night hours when the demand is small, less efficient fossil-fueled units might have to be shut down completely. These fossil-fueled units are required to meet the heavy demand during peak hours. They should be kept operational to insure a smooth transition from periods of low demand to periods of high demand.

Furthermore, Consolidated Edison supplies steam to the New York City steam system. This steam is produced in fossil-fueled plants within N.Y.C. Although the steam can be piped directly to the steam system, bypassing the turbines, it becomes economically justifiable to direct the steam through the turbines and obtain electrical output as a by-product.

In Table 1, the weekly average of the daily average heat loads to the river is shown to be 4153 MW. In the January 1968 report, all temperature predictions for three unit operation were based upon operation with a cooling water flow of 2,100,000 GPM and a temperature rise in these cooling waters of 17°F.

This is equivalent to a heat load of 430 X 10^9 BTU/DAY or 5250 MW. Consequently, all estimates in the January 1968 report are based upon a three unit heat load that is 26% ((5250-4153)X100/4153) greater than the load that can be expected when three units are actually operating at Indian Point.

All subsequent analyses presented in this report, are based on a three unit Indian Point heat load to the River of 4153 MW or 340 X 10^9 BTU/day. Cooling water flow will remain equal to the design total of 2,040,000 gpm. The temperature rise across the condensers will be 13.9 °F, rather than 17 °F. This value has been rounded to 14°F in calculating areal and surface behavior in this report.

IV. RIVER DATA FOR PRESENT CONDITIONS

The purpose of this section is to present River temperature data measured by Northeastern Biologists, Incorporated (NBI), in July, 1966 and April, 1967, and by Texas Instruments, Incorporated (TXI), in October, 1967 and April, 1968.

These data, which define the temperature effect for one unit operation, will be used as the basis for extrapolations of temperature effects for three unit operation. The accuracy of the measurements is supported by comparisons of the NBI and TXI survey results.

Furthermore, a comparison is included of the measured extent of the surface and lateral temperature effect to the degree allowable as stated in the proposed criteria.

NBI Indian Point Surveys, July, 1966 and April, 1967

The Indian Point plant site is located on the east shore of the Hudson, about 43 river miles above New York Harbor. Consolidated Edison operates one nuclear unit at Indian Point, with a maximum expected electrical output of 285 MW.

Temperature surveys were performed in the vicinity of Indian Point by Northeastern Biologists, Incorporated, in July, 1966 and in April, 1967. There were fourteen and seventeen actual survey days for the July, 1966 and April, 1967 surveys, respectively.

A grid system was established for consistent location of sampling points. The grid system covered an area of two million square feet extending in the north-south direction from a point 1,000 feet downstream of the outfall to a point 1,000 feet upstream of the outfall and extending in the east-west direction from the east shore to a point 1,000 feet west of the shore.

Temperature measurements during the July survey were made at the surface, middle and bottom only, rather than at every integral degree Fahrenheit, as was the case with the April survey. Therefore, for purposes of constructing subsurface temperature distributions, the July data is less reliable.

The temperature data reflects different stages of both the ebb and flood tidal phases. The temperature effect on the surface and across the cross-section was plotted for seven different tidal phases. The seven tidal phases spanned a full tidal cycle and an average tidal condition was constructed by averaging the temperature distributions that existed for the seven tidal phases.

Figures 1 and 2 depict the surface temperature distribution for the average tidal condition for the July and April surveys, respectively. The temperature distributions result from heat loads of 482 MW and 422 MW, respectively, average heat loads for Indian Point Unit No. 1 during each survey period. These heat loads conform to operation at about 85% of the maximum electrical output (285MW), the output during that period approximating 245 MW.

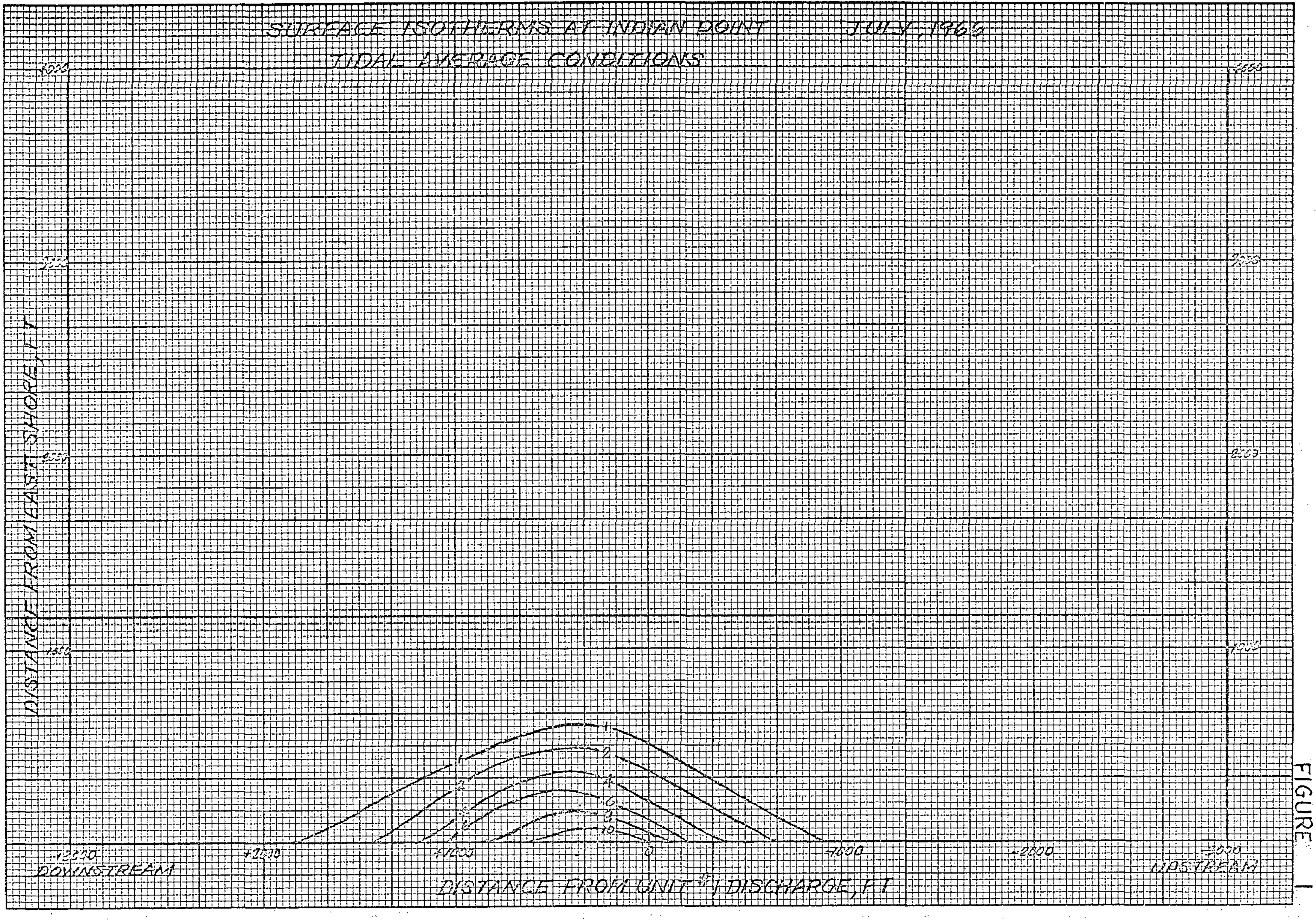
Temperatures are presented in terms of the rise above the ambient temperature, i.e., naturally occurring river temperature prior to discharge of waste heat.

For the April survey, Figure 2 shows that the 4°F temperature rise extends approximately 330 feet off shore. Correspondingly, for the July survey, the 4°F rise extends 360 feet off shore. The width of the river at this point is 4,000 feet.

Figures 3 and 4 depict the temperature distribution across the cross-section for the section at the discharge point for two tidal phases during the April survey, early flood and maximum ebb, respectively. Both Figures 3 and 4 represent only the first 700 feet of width out of a total of 4,000 feet. Temperature rises beyond 700 feet were not measurable and therefore, the remainder of the river cross-section was not plotted. Five figures similar to Figures 3 and 4 were plotted for five other tidal phases and an average tidal condition was determined by averaging the seven temperature distributions.

Figure 5 represents the cross-sectional area enclosed by temperature rises for the April average tidal condition. The 4°F temperature rise encloses approximately 1,700 square feet. As the total cross-sectional area at this point is 160,000 square feet, the 4°F rise encloses 1% of the total cross-sectional area.

The average temperature rise over the entire cross-section was 0.093°F. This value was obtained by computing the area under the curve in Figure 5 and dividing the result by the total River cross-sectional area.



SURFACE ISOTHERMS AT INDIAN POINT JULY, 1969

TIDAL AVERAGE CONDITIONS

FIGURE 1

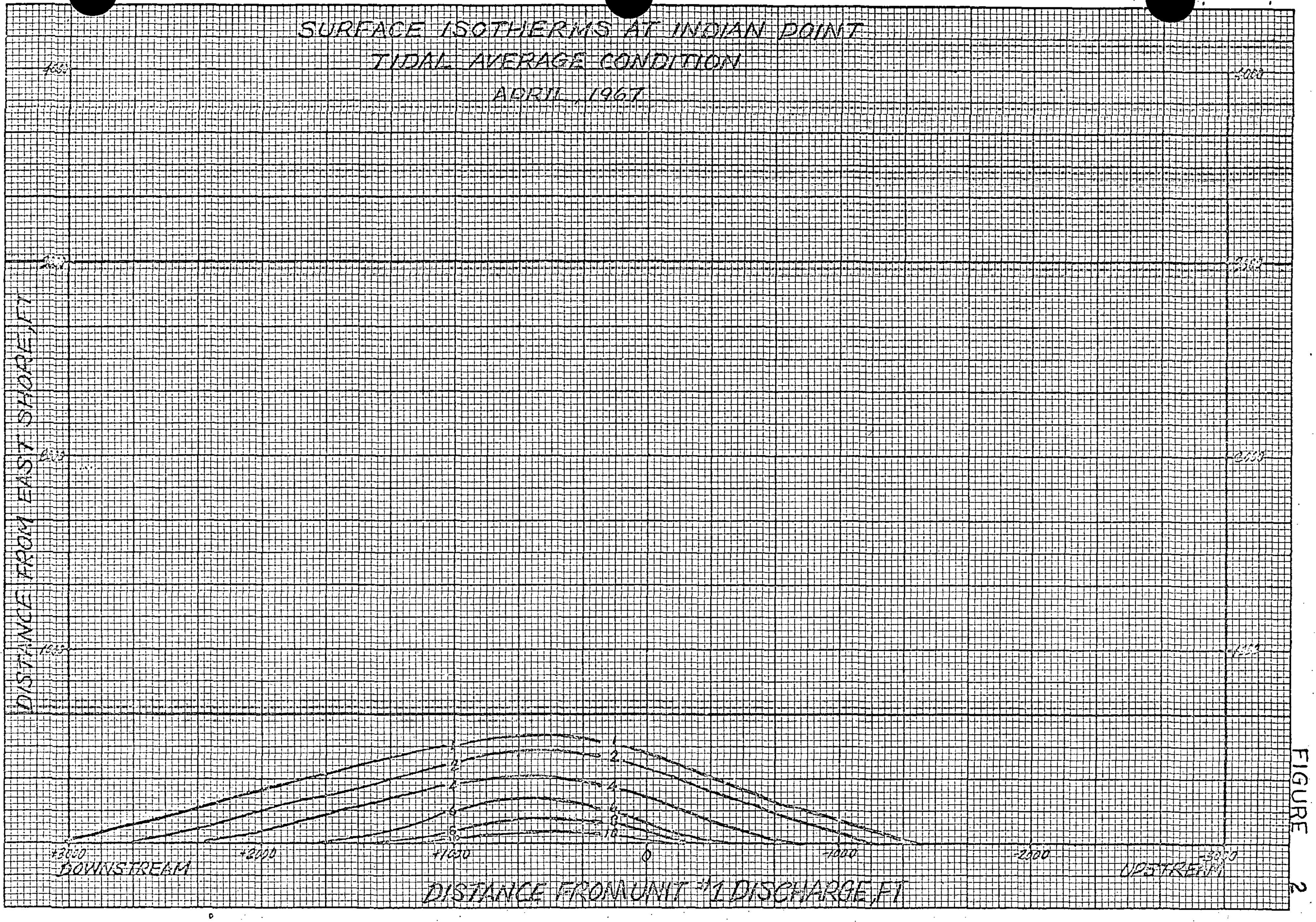
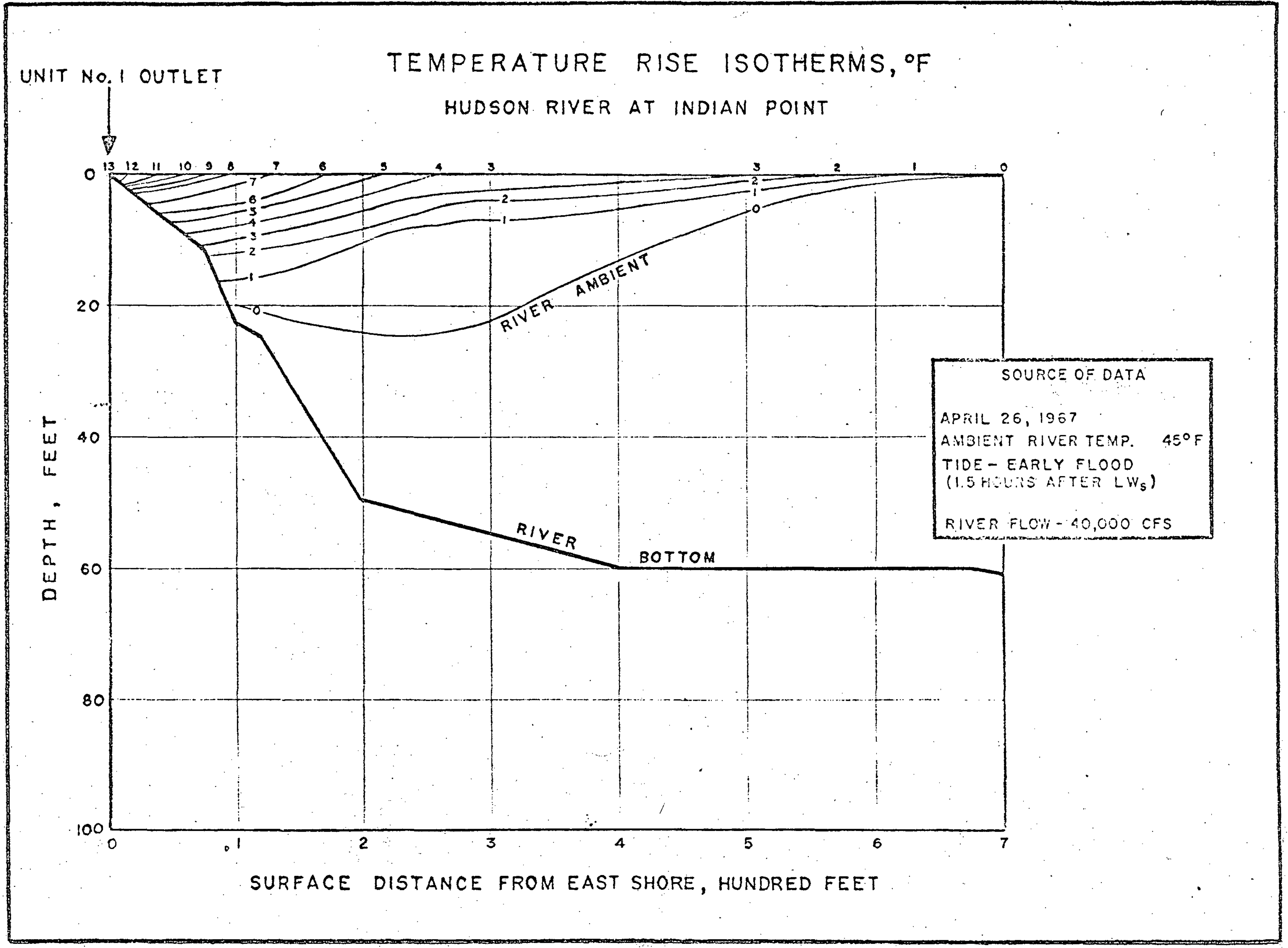

SURFACE ISOTHERMS AT INDIAN POINT
TIDAL AVERAGE CONDITION
APRIL, 1967

FIGURE 2



TEMPERATURE RISE ISOTHERMS, °F

HUDSON RIVER AT INDIAN POINT

SOURCE OF DATA

APRIL 26, 1967

AMBIENT RIVER TEMP. 45°F

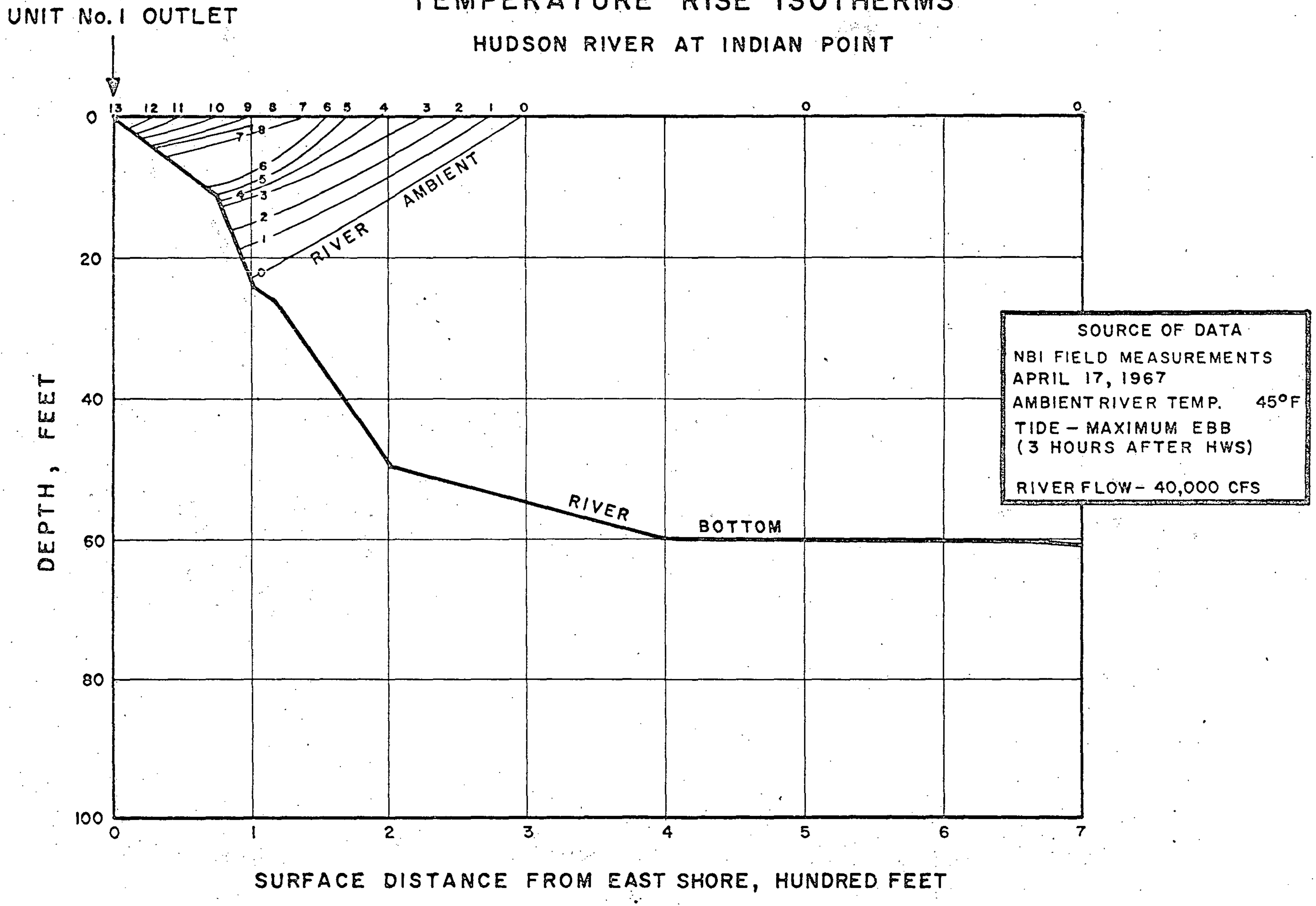
TIDE – EARLY FLOOD (1.5 HOURS AFTER LW_S)

RIVER FLOW – 40,000 CFS

FIGURE 3

TEMPERATURE RISE ISOTHERMS

HUDSON RIVER AT INDIAN POINT

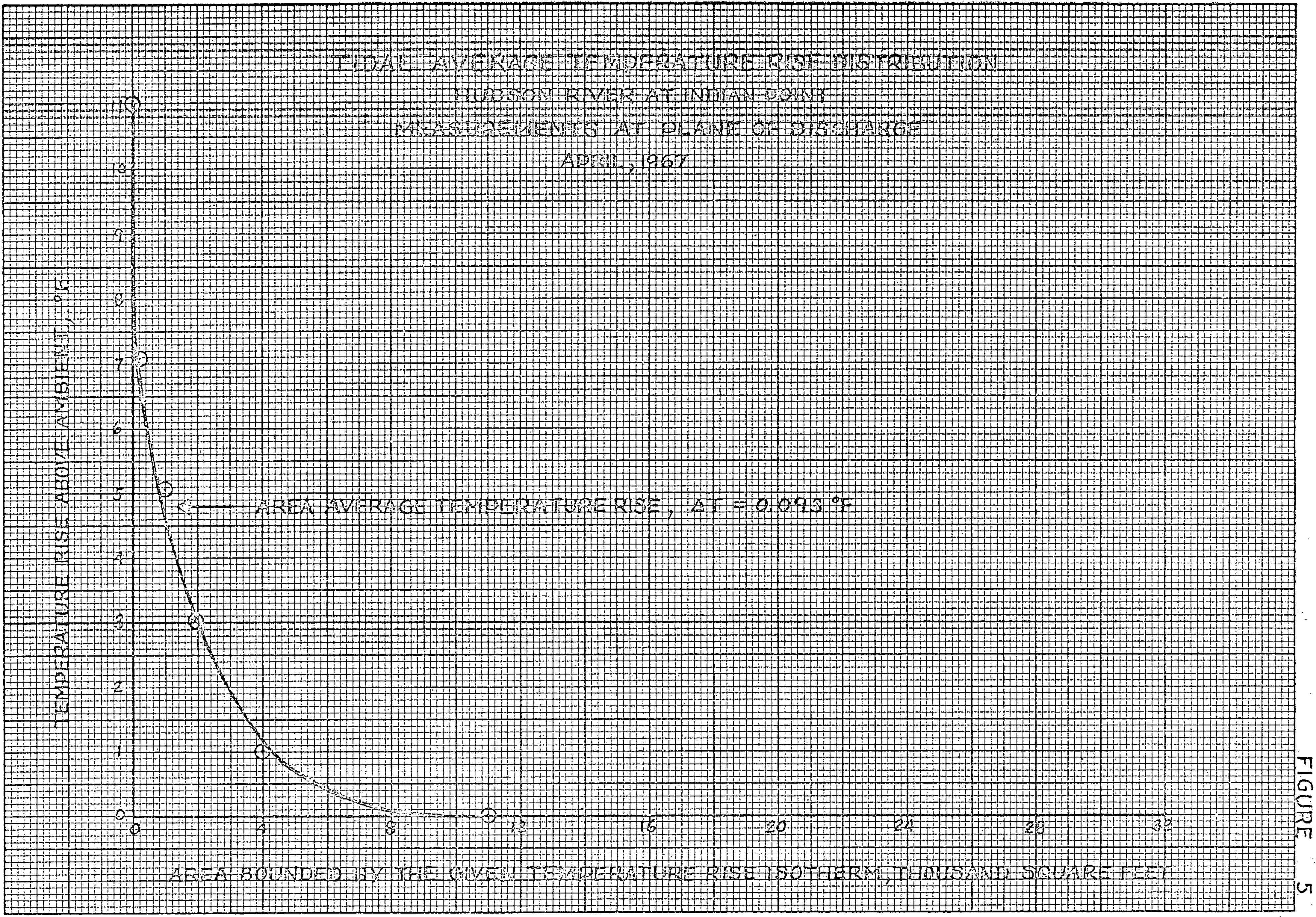


SOURCE OF DATA

NBI FIELD MEASUREMENTS
APRIL 17, 1967
AMBIENT RIVER TEMP. 45°F
TIDE – MAXIMUM EBB
(3 HOURS AFTER HWS)

RIVER FLOW – 40,000 CFS

FIGURE 4



TIDAL AVERAGE TEMPERATURE RISE DISTRIBUTION
HUDSON RIVER AT INDIAN POINT
MEASUREMENTS AT PLANE OF DISCHARGE
APRIL, 1967

FIGURE 5

Figure 6 represents the cross-sectional area enclosed by temperature rises for an average condition for the July survey.

The average temperature rise over the entire cross-section was 0.2°F and the 4°F temperature rise enclosed approximately 2,000 square feet. This corresponds to 1% of the total cross-sectional area.

Although the average temperature rise in July is twice that of April, the local and surface temperature effects are not proportionately increased. The July average temperature rise is higher because of the retention of a greater amount of heat below the surface of the river.

The higher temperature rises below the surface are the result of the low flow conditions and related high mixing characteristics which occurred during July. The freshwater flow during July was 7,300 cfs as compared to 40,000 cfs during April.

Table 2 summarizes the portion of the river at Indian Point effected by temperature rises in excess of 4°F. The proposed standard requires that a minimum of 1/3 of the surface and 1/2 of the cross-sectional area have temperature rises of less than 4°F. The NBI data shows that more than 90% of the surface and approximately 99% of the cross-sectional area will have temperature rises less than 4°F.

<u>Texas Instruments, Incorporated, Airborne Infrared Surveys, October 28, 1967 and April 6, 1968</u>

Two airborne infrared data surveys of the Hudson River in the Indian Point vicinity were performed for Consolidated Edison by TXI. The surveys were undertaken to collect data for compilation of isothermal maps of the river surface.

The following excerpt from the TXI report, Airborne Infrared Survey, Indian Point Area, Hudson River, New York, December 1968, presents the theory behind infrared imagery and describes the procedure employed for the Hudson River survey.

> "Infrared imagery, similar in appearance to strip photography, is produced by a series of scan lines perpendicular to the flight direction. Relative radiometric temperature differences are represented by different gray tones. Light

TIDAL AVERAGE TEMPERATURE RISE DISTRIBUTION

ACROSS PLANE OF DISCHARGE

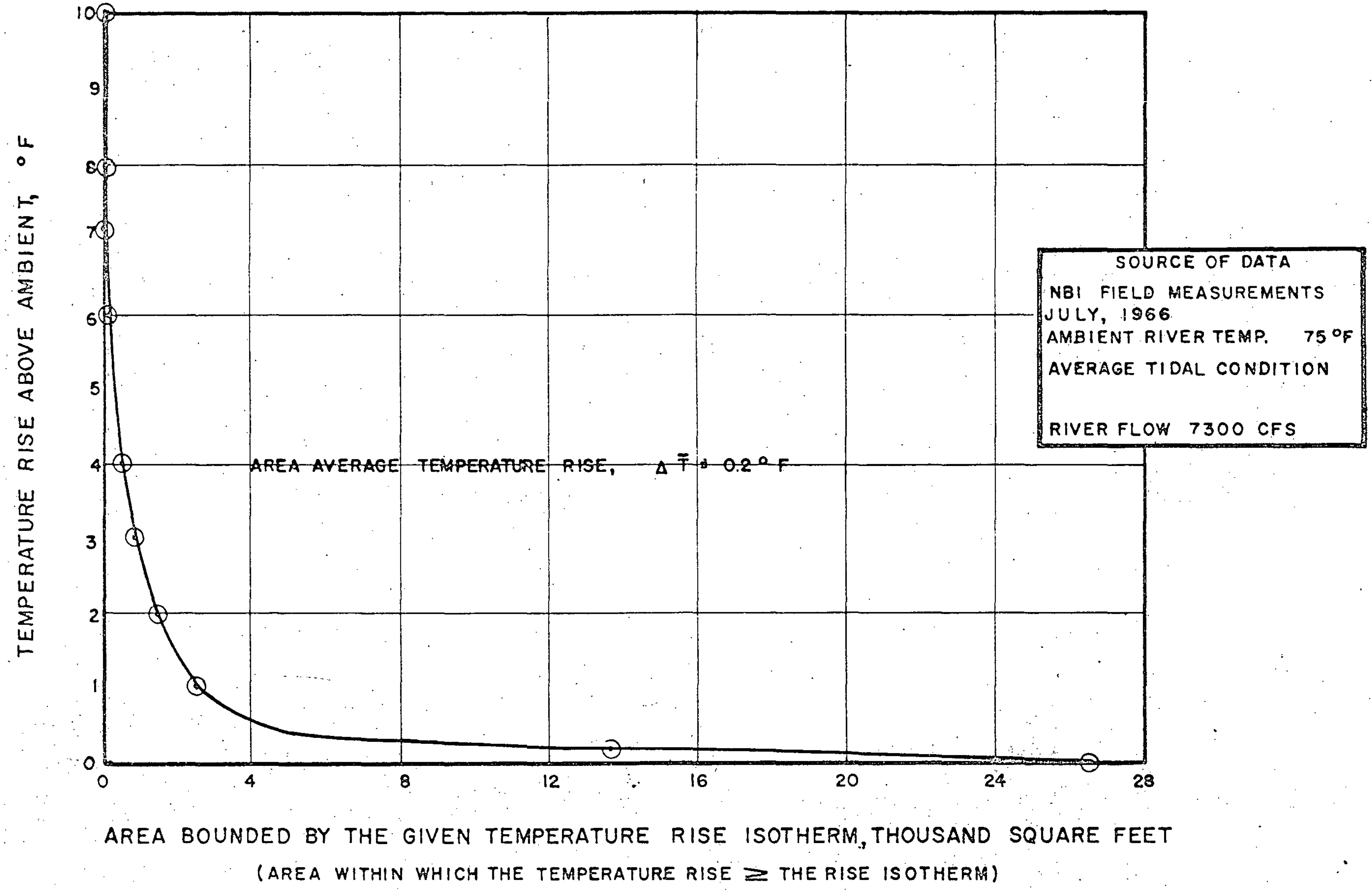


FIGURE 6

TABLE 2

PORTION OF RIVER AT INDIAN POINT EFFECTED BY TEMPERATURE RISES IN EXCESS OF 4°F

Survey	Lateral Distance		Area	
	FT	% of full width	FT^2	% of total cross-sectional area
July	360	9	2000	1
April	330	8	1700	1

tones on a positive print of infrared imagery represent relatively high radiometric temperatures. Dark tones are related to relatively low radiometric temperatures.

The TXI system produces imagery in the 8 to 14 micron wavelength band which is not rectified; i.e., the scale along the flight direction is relatively constant, but the scale perpendicular to the flight direction becomes smaller with increased distance away from the centerline.

Infrared mapping systems are designed so that electronic signal displacement between hot and cold objects is controlled within the dynamic range of the recording film. The system's thermal baseline continually adjusts itself to the average between hot and cold temperatures of the scanned area. This compensation occurs in the circuitry prior to the glow-modulator which exposes the recording film. Thus, the imagery contains the effects of thermal baseline adjustment.

The Texas Instruments system also monitors the video signal from the detector at the preamplification stage by a type-A oscilloscope. The oscilloscope presentation of individual sweeps (single scan lines) of the detectors are recorded by a 35-mm camera. These A-Scope profile data, used to compile isothermal maps, are not affected by system compensation and can be considered quantitative.

Radiometric temperature references are provided by temperature-controlled blackbody baffles mounted within the scanning system's field of view. The temperature of each reference baffle is closely monitored during flight. The amplitude difference between the two reference baffles can be converted to a temperature scale from which temperature values can be assigned to individual points along the A-Scope trace. Correlation between A-Scope data and the scanner imagery is supplied by a difucial system which also provides a means of tying airborne data to ground position.

Overflights were made between Croton Point and Bear Mountain Bridge at altitudes of 5000 and 10,000 ft above the river surface. Three straight segments were flown for each tidal coverage because of the meandering configuration of the

> river in the survey area. The first segment was flown northwestward from Croton Point to the vicinity of Tomkins Lake. Segment 2 covered the area from the town of Tomkins Cove to Annsville Creek. The third flightline extended from Peekskill Bay to Bear Mountain Bridge."

Survey results are presented as a set of eight isothermal maps. Figures 7 through 10 were compiled from the October, 1967 data while Figures 11 through 14 show the results of the flights in April, 1968.

During the October survey, the unit at Indian Point was shut down.

Orange and Rockland Utilities, Incorporated, which operates four fossil-fueled units at its Lovett plant site, located two miles downstream of Indian Point on the west shore of the Hudson, was operational. The heat load discharged from the four units at Lovett is shown on an hourly basis for October 28, 1967 in Figure 15. The average heat load for the day was approximately 200 MW.

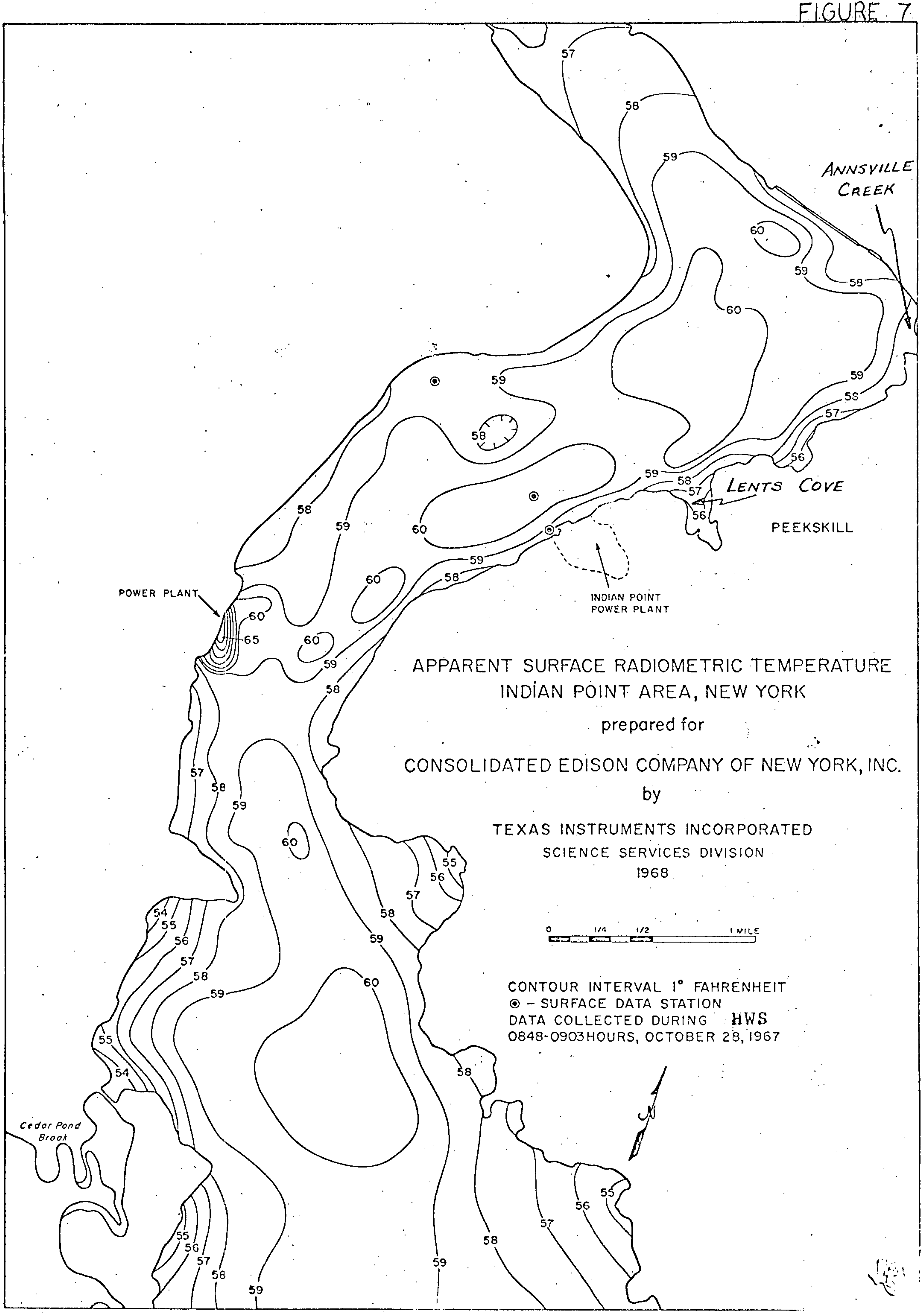
Designated on Figure 15, are the times and tidal phase for the four isothermal maps given in Figures 7 through 10. Although, the hourly heat loads prior to any one particular survey may differ, this does not result in an corresponding change in the temperature distribution of the river. The river does not react instantaneously to changes in heat load, but more accurately reflects the average heat load for several hours prior to an actual measurement. Thus, in analyzing these isothermal maps, each map should be associated with an average loading condition prior to the survey.

The heat loads discharged from the four units at Lovett and for the one unit at Indian Point are shown on an hourly basis for April 6, 1968 in Figures 16 and 17 respectively. The average heat loads for the day were 395 MW and 195 MW for Indian Point and Lovett, respectively.

Figure 17 shows that the surveys at early ebb and late ebb would more accurately reflect a load of 285 MW while the surveys at mid flood and high water slack reflect a load of 487 MW. As the four surveys will be averaged and associated with an average tidal condition, the average daily load of 395 MW will be used as responsible for the average tidal effect.

The following discussion of Figures 7 through 14 is taken from the the TXI, December 1968 report.

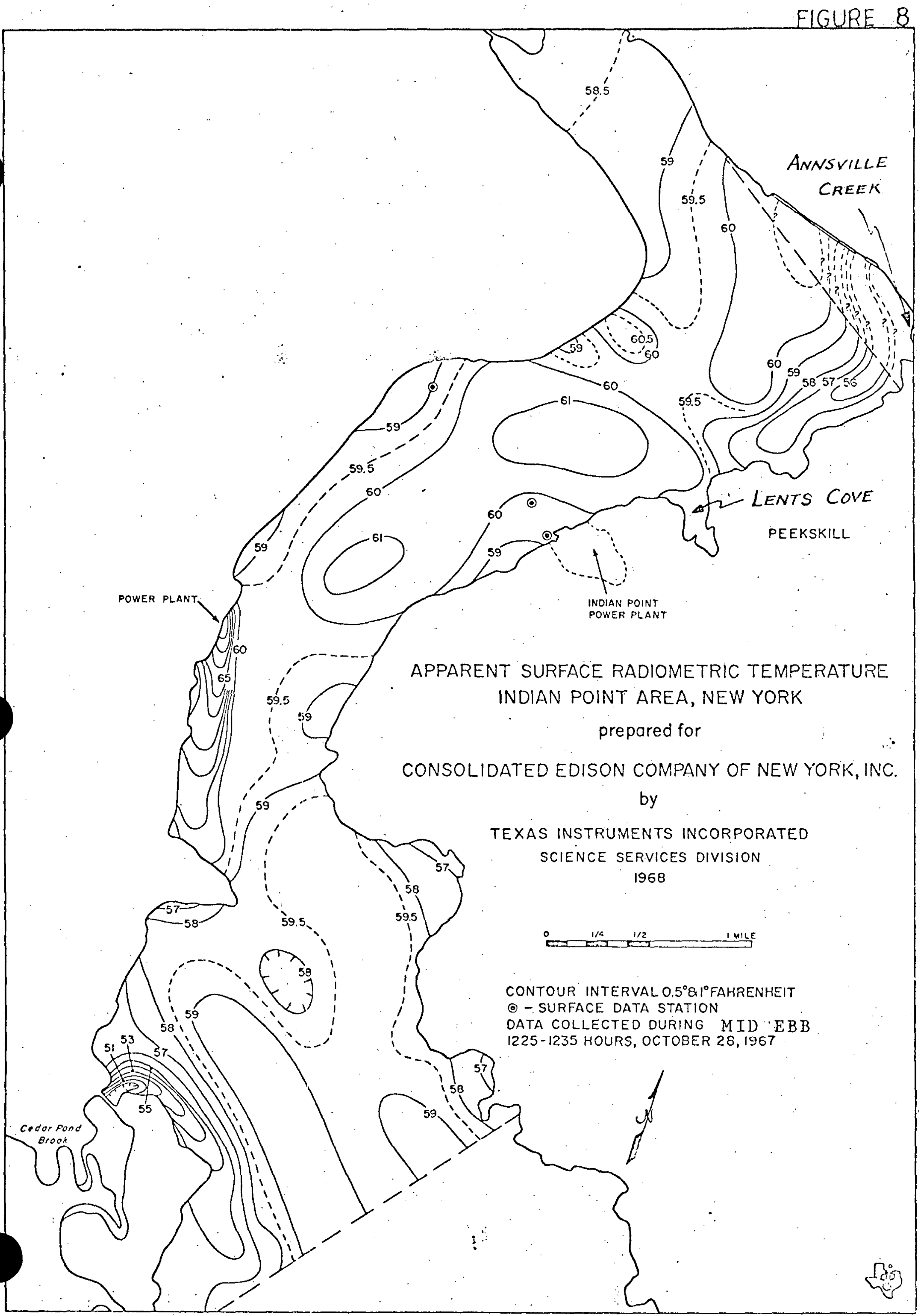
FIGURE 7



APPARENT SURFACE RADIOMETRIC TEMPERATURE
INDIAN POINT AREA, NEW YORK
prepared for
CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.
by
TEXAS INSTRUMENTS INCORPORATED
SCIENCE SERVICES DIVISION
1968

CONTOUR INTERVAL 1° FAHRENHEIT
◉ – SURFACE DATA STATION
DATA COLLECTED DURING HWS
0848-0903 HOURS, OCTOBER 28, 1967

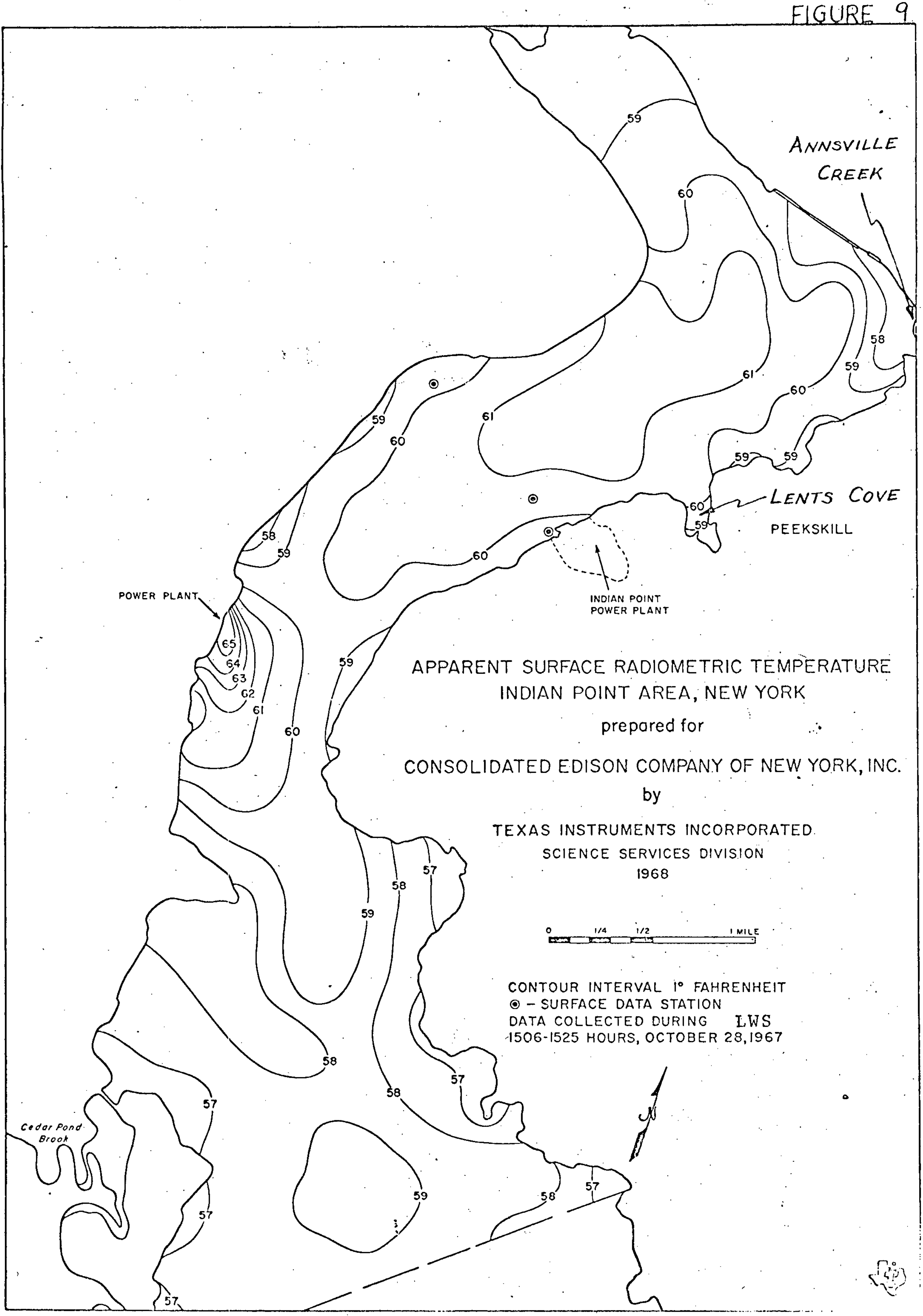
FIGURE 8



APPARENT SURFACE RADIOMETRIC TEMPERATURE
INDIAN POINT AREA, NEW YORK
prepared for
CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.
by
TEXAS INSTRUMENTS INCORPORATED
SCIENCE SERVICES DIVISION
1968

CONTOUR INTERVAL 0.5°& 1° FAHRENHEIT
⊙ – SURFACE DATA STATION
DATA COLLECTED DURING MID EBB
1225-1235 HOURS, OCTOBER 28, 1967

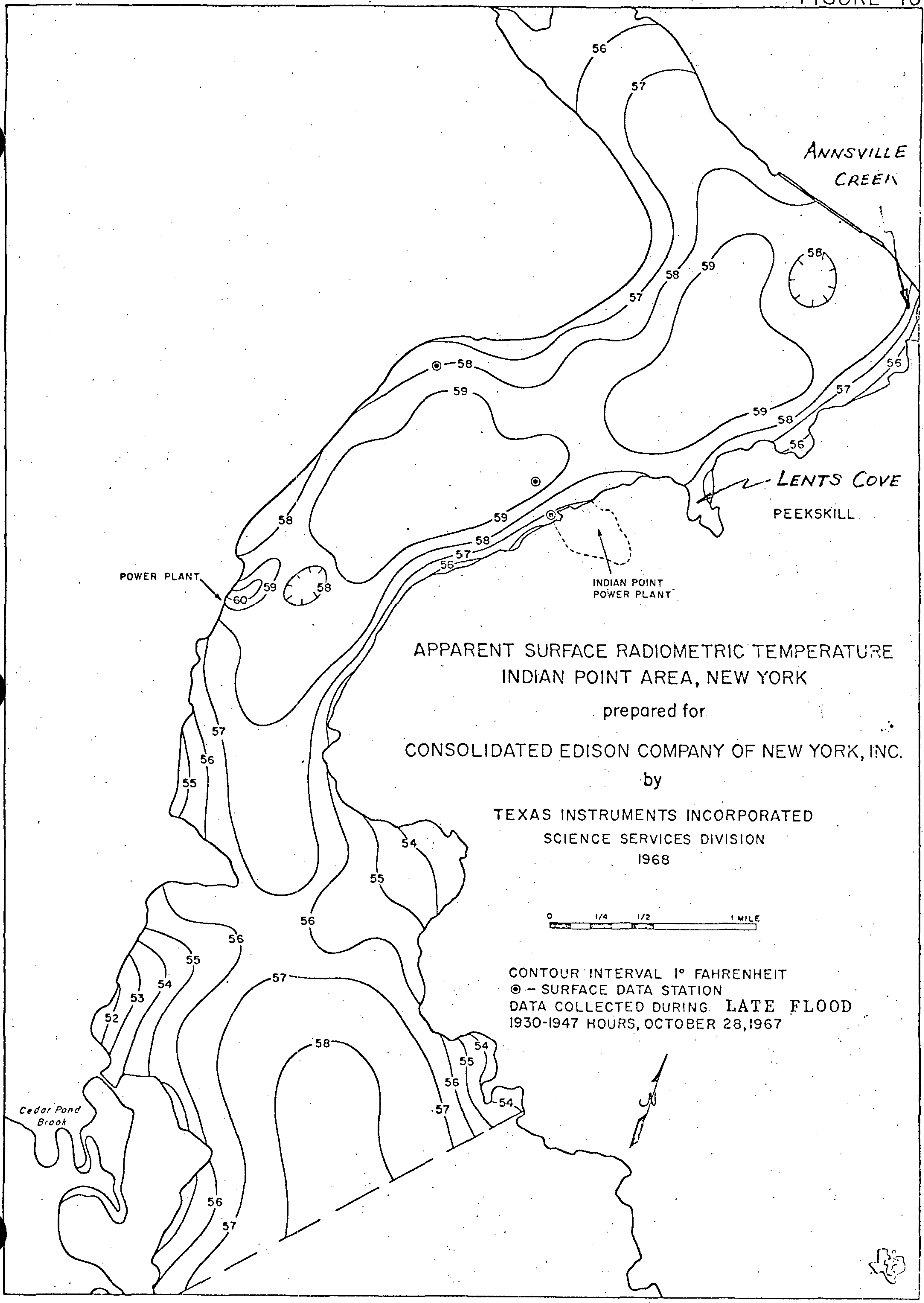
FIGURE 9



APPARENT SURFACE RADIOMETRIC TEMPERATURE
INDIAN POINT AREA, NEW YORK
prepared for
CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.
by
TEXAS INSTRUMENTS INCORPORATED
SCIENCE SERVICES DIVISION
1968

CONTOUR INTERVAL 1° FAHRENHEIT
◉ – SURFACE DATA STATION
DATA COLLECTED DURING LWS
1506-1525 HOURS, OCTOBER 28, 1967

FIGURE 10



APPARENT SURFACE RADIOMETRIC TEMPERATURE
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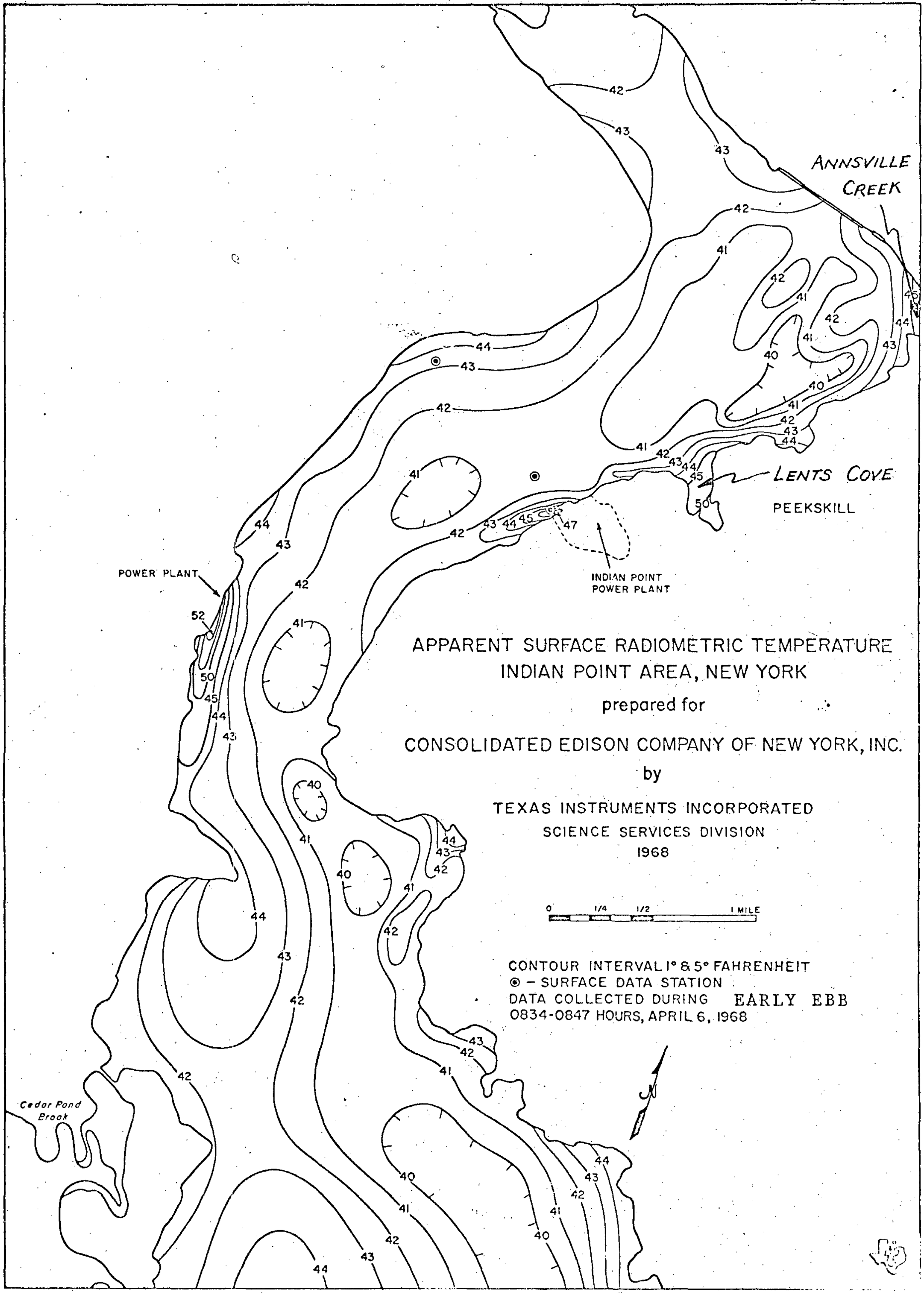
CONTOUR INTERVAL 1° FAHRENHEIT
◉ – SURFACE DATA STATION
DATA COLLECTED DURING LATE FLOOD
1930-1947 HOURS, OCTOBER 28, 1967

FIGURE 11



APPARENT SURFACE RADIOMETRIC TEMPERATURE
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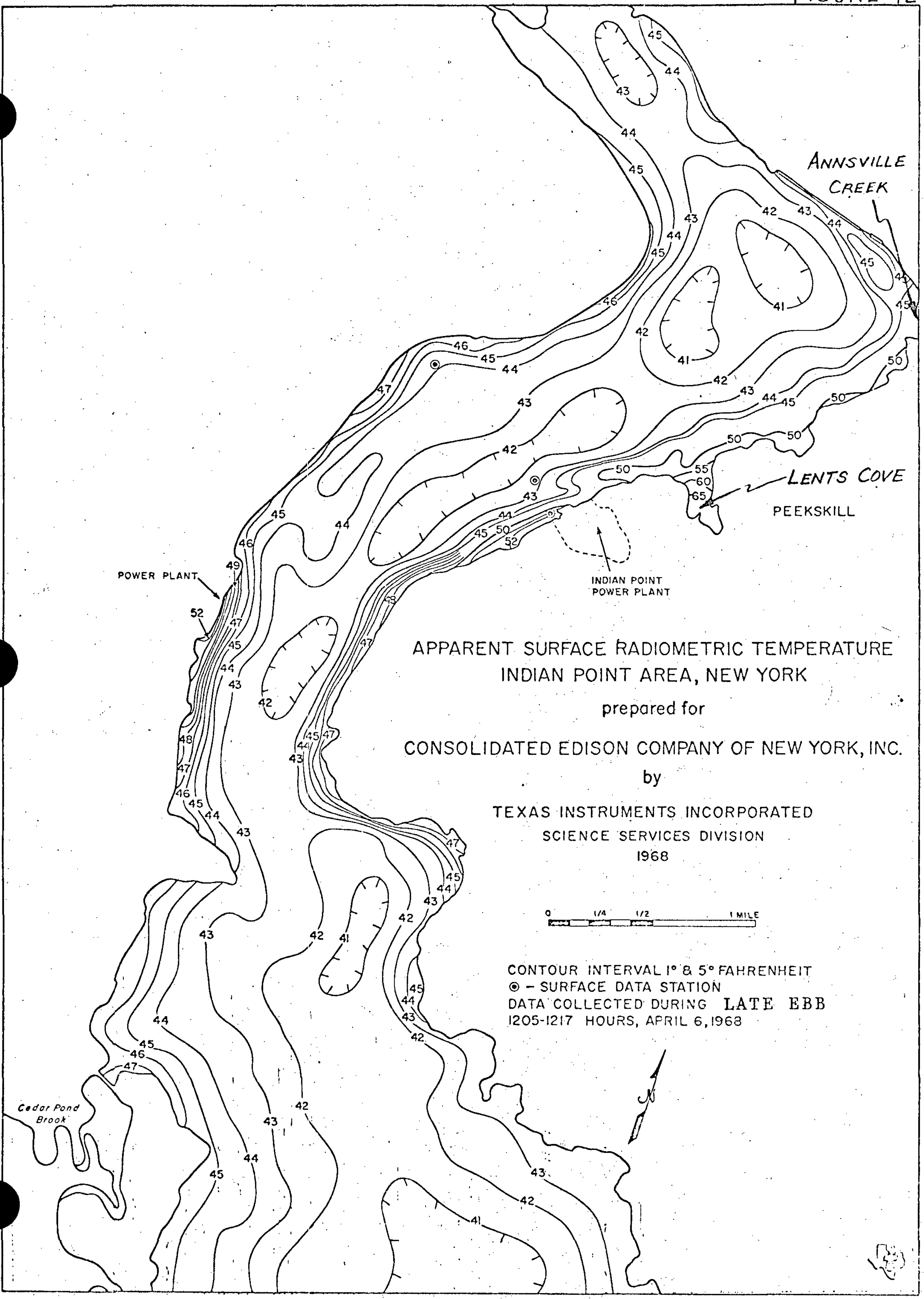
1968

CONTOUR INTERVAL 1° & 5° FAHRENHEIT
◉ – SURFACE DATA STATION
DATA COLLECTED DURING EARLY EBB
0834-0847 HOURS, APRIL 6, 1968

FIGURE 12



APPARENT SURFACE RADIOMETRIC TEMPERATURE
INDIAN POINT AREA, NEW YORK
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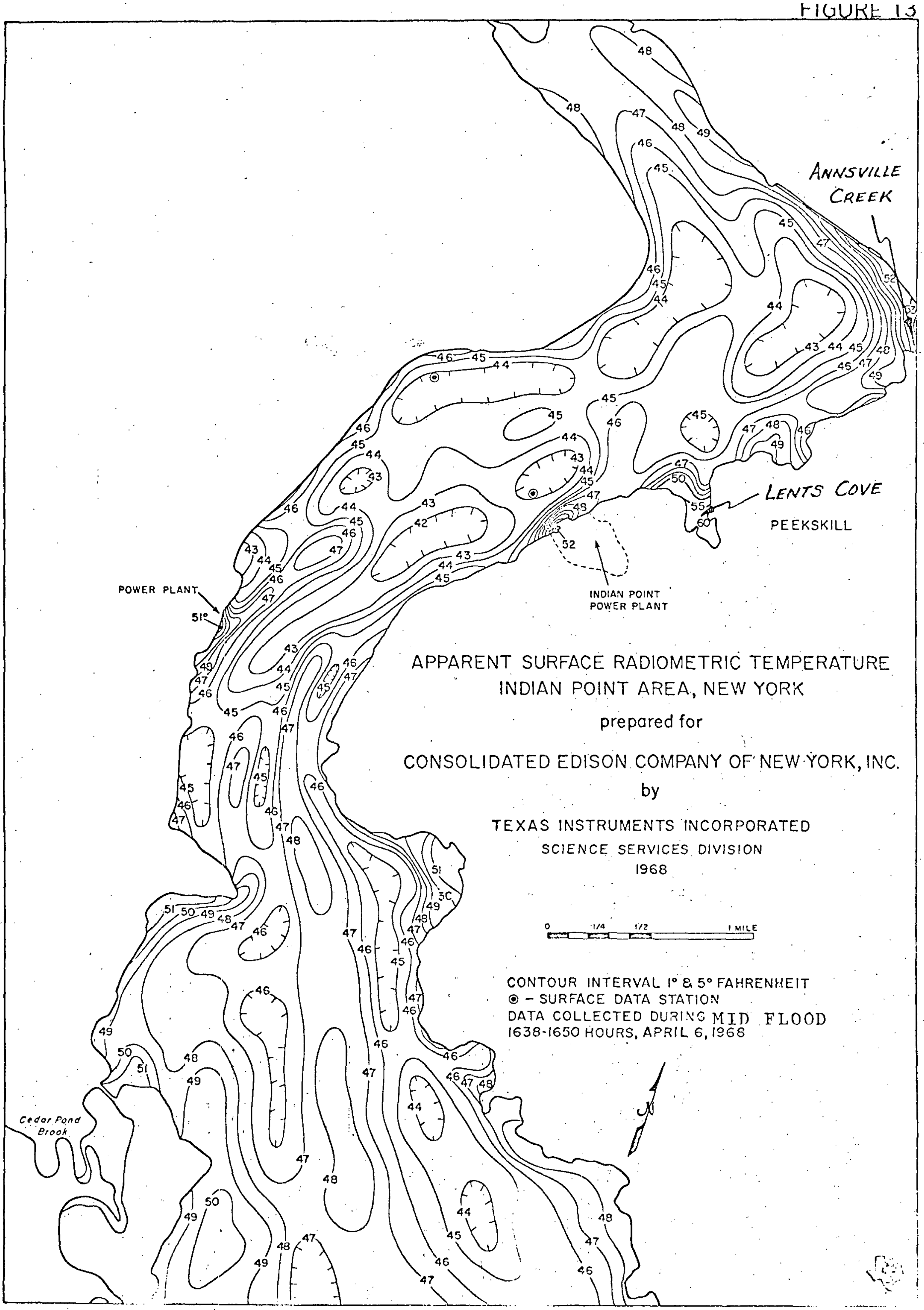
SCIENCE SERVICES DIVISION
1968

CONTOUR INTERVAL 1° & 5° FAHRENHEIT
⊙ – SURFACE DATA STATION
DATA COLLECTED DURING LATE EBB
1205-1217 HOURS, APRIL 6, 1968

FIGURE 13



APPARENT SURFACE RADIOMETRIC TEMPERATURE
INDIAN POINT AREA, NEW YORK
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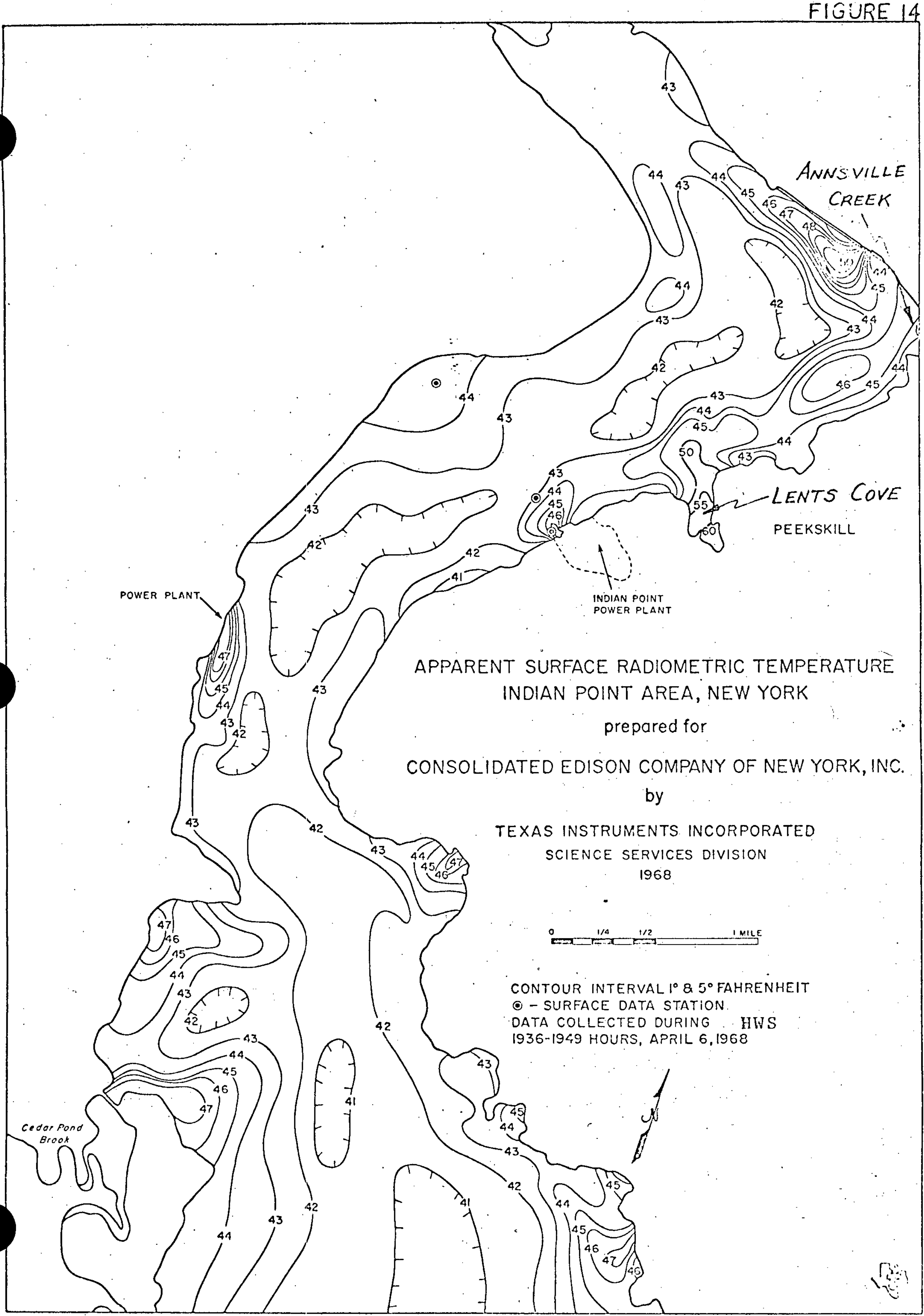
1968

CONTOUR INTERVAL 1° & 5° FAHRENHEIT
◉ – SURFACE DATA STATION
DATA COLLECTED DURING MID FLOOD
1638-1650 HOURS, APRIL 6, 1968

FIGURE 14



APPARENT SURFACE RADIOMETRIC TEMPERATURE
INDIAN POINT AREA, NEW YORK
prepared for
CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.
by
TEXAS INSTRUMENTS INCORPORATED
SCIENCE SERVICES DIVISION
1968

CONTOUR INTERVAL 1° & 5° FAHRENHEIT
⊙ – SURFACE DATA STATION
DATA COLLECTED DURING HWS
1936-1949 HOURS, APRIL 6, 1968


VARIATION IN HOURLY HEAT LOAD AT LOVETT
Oct. 22, 1967
HEAT LOAD, MW
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
22
24
12 MIDNIGHT
6:00 AM
12 NOON
6:00 PM
12 MIDNIGHT
TIME, HOURS
HWS CONTOUR
MID EBB CONTOUR
LWS CONTOUR
LATE FLOOD CONTOUR

FIGURE 15

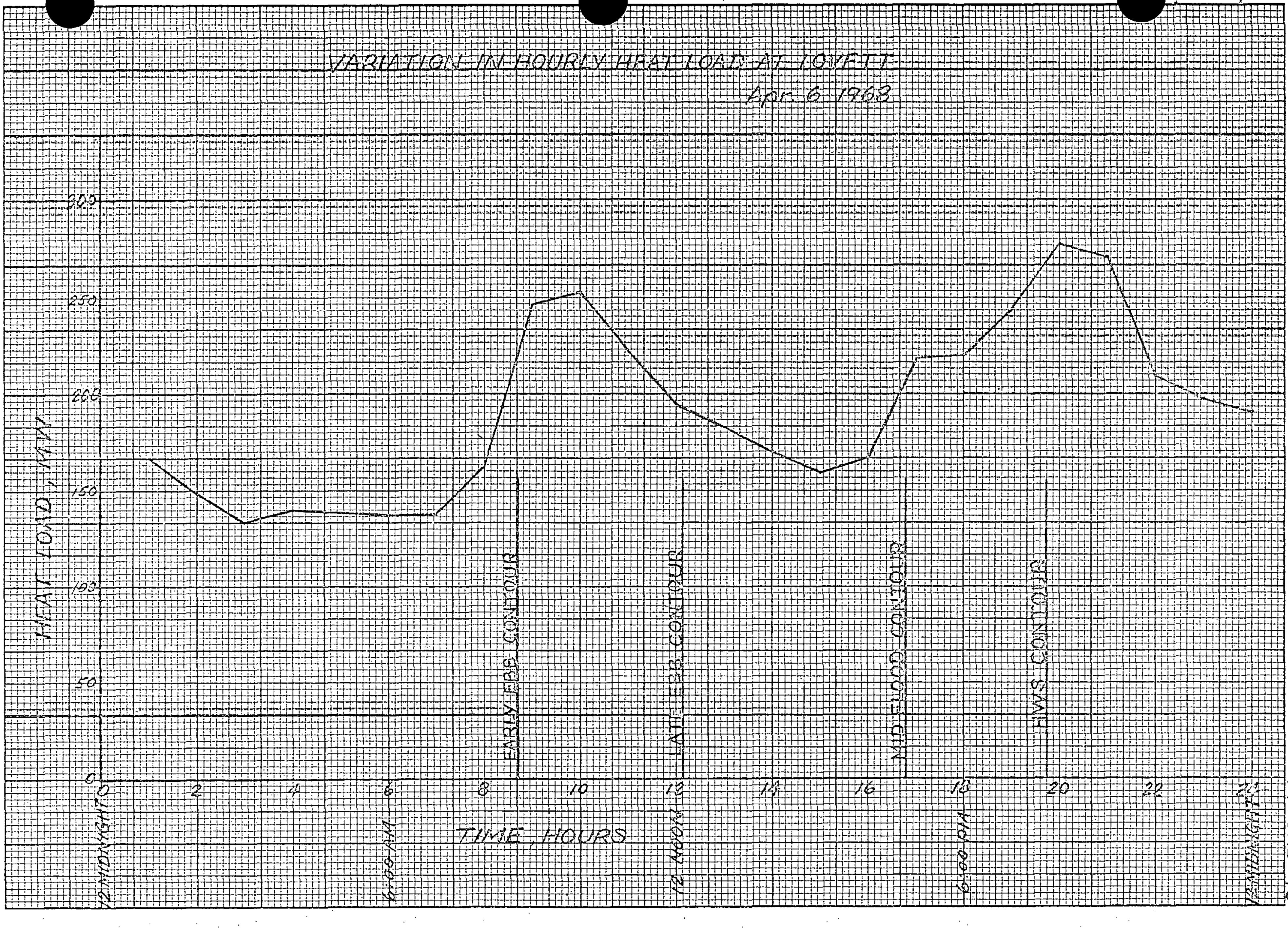
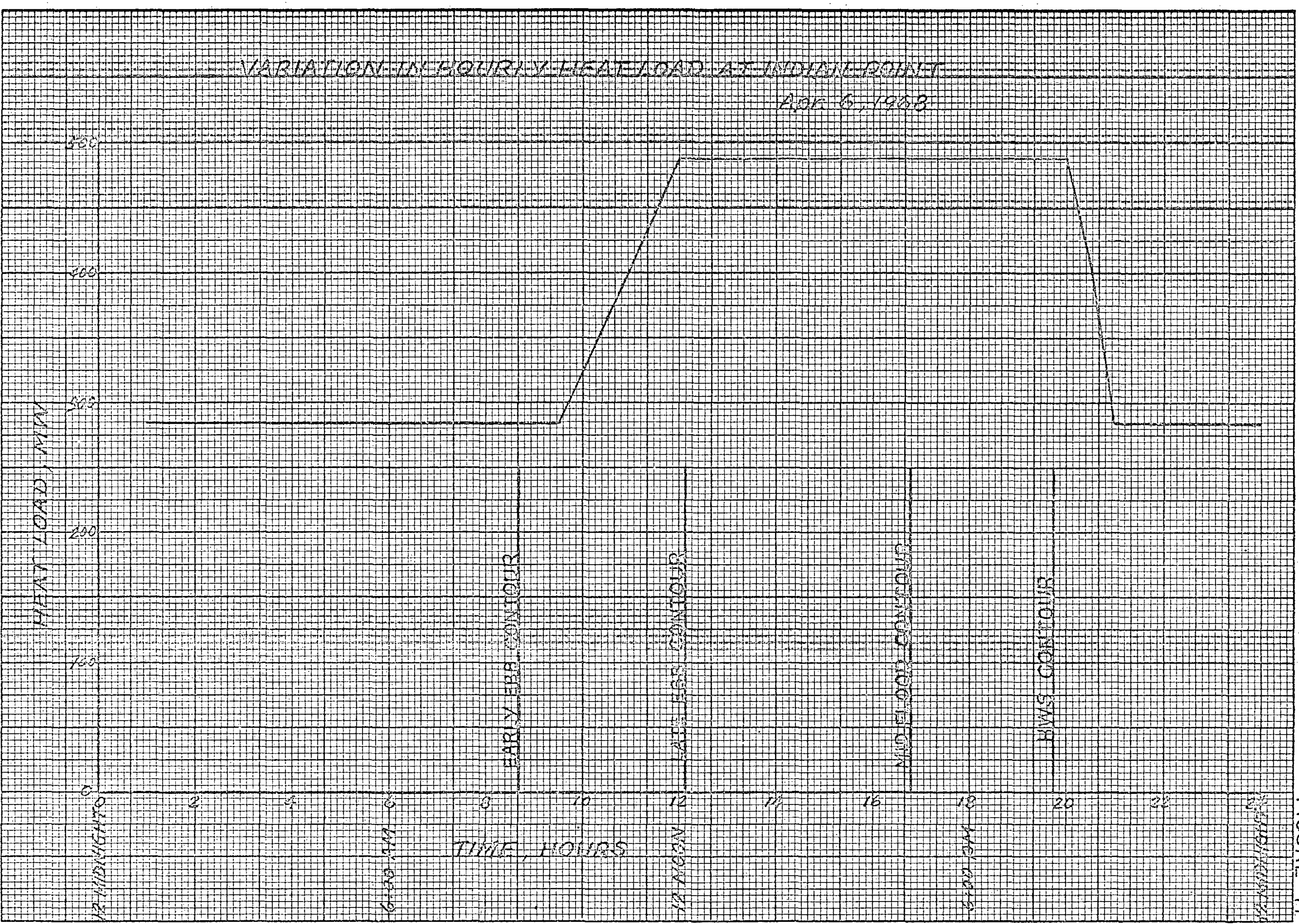

VARIATION IN HOURLY HEAT LOAD AT LOVETT
Apr. 6 1968
HEAT LOAD, MW
0
50
100
150
200
250
300
TIME, HOURS
0
2
4
6
8
10
12
14
16
18
20
22
24
12 MIDNIGHT
6:00 AM
12 NOON
6:00 PM
12 MIDNIGHT
EARLY EBB CONTOUR
LATE EBB CONTOUR
MID FLOOD CONTOUR
HWS CONTOUR

FIGURE 16


VARIATION IN HOURLY HEAT LOAD AT INDIAN POINT

Apr. 6, 1968

FIGURE 17

The isothermal maps indicate that during October survey the Hudson River was warm relative to the temperature of the small lakes, ponds, and tributary streams. This is particularly well illustrated on Figure 8. The discharge from Annsville Creek and Cedar Pond Brook is several degrees cooler than the main part of the Hudson River. The relatively cool surface runoff appears to keep the river surface cool along the shoreline, compared to the relatively warm midstream area.

The change in the surface thermal pattern during each tidal condition is indicated by the contours. The thermal discharge from the Lovett power plant on the west side of the river varies considerable in shape and direction from one map to the next. The highest temperature (about 8°F above river temperature) is indicated on Figure 8. The mapped amplitude variations of this thermal discharge are related to the interval at which quantitative data were collected, approximately 1.5 sec or about 300 ft on the ground at normal flight speeds. This interval is suitable for mapping general surface thermal variations but is not adequate to observe on each overflight a small target such as a discharge channel. On Figure 10, for example, the effluent from the Lovett power plant is not only restricted in area because of the current/tide situation but is mapped as only a 2°F thermal anomaly. During this overflight the discharge channel falls between two A-Scope profiles; thus, the true temperature of the thermal discharge was not measured.

During the April survey the surface runoff from the tributary streams was warm relative to the Hudson River. All of the maps of the second set show that the central portion of the river is cool relative to the warm marginal zones.

The mapped thermal effluent from the Lovett power plant also varies in amplitude on the second set due to the data collection interval. However, a maximum temperature of 52°F was recorded on two of the maps, indicating that the water temperature at the discharge channel was about 9°F above the river temperature.

The Indian Point power plant thermal discharge varies in temperature, but the maximum value of 52°F on Figures 12 and

13 agrees well with the observed surface data.

> "It is significant that the highest temperatures recorded in the second set of data are related to the discharge from Annsville Creek and from Dickey Brook, which enters the Hudson River at Lents Cove. Industrial or sewage disposal plants may contribute to the relatively high temperature of these creeks. However, the imagery and A-Scope data during some of the overflights indicate that the small lakes and ponds in the area have a high surface temperature, probably due to solar heating. Thus, the airborne data suggest that at certain parts of the year a considerable volume of warm water entering the Hudson River may be due to solar heating of shallow surface water."

Table 3 shows the surface at Indian Point with temperature rises in excess of 4°F for the April survey. The 4°F rises were computed for three different ambient conditions, 42°F, 43°F and 44°F. Three different ambient conditions were assumed because a single ambient temperature applied over the full surface would not be appropriate.

The isothermal maps demonstrate the marked temperature variation on the surface. To evaluate the added temperature caused by the power plant heat load at any time, the naturally occurring temperature at that point, prior to power plant heat load, would have to be known. However, this can not be done because addition of heat artificially has changed the surface temperature contours and it would only be possible to approximate what the surface temperature might have been, had there been no artificial heating.

In any event, temperature rises computed for several different ambient temperatures provides a method of establishing a range from which the true effect of the power plant heat load may be selected.

Table 3 shows that for the average of the four tidal phases, the surface width at Indian Point effected by temperature rises in excess of 4°F ranged from 200 feet to 360 feet, corresponding to a range of from 5% to 9% of the total width.

TABLE 3

WIDTH AT INDIAN POINT SUBJECTED TO TEMPERATURE RISES IN EXCESS OF 4°F

APRIL 6, 1968

Time	Tidal Phase	WIDTH					
		T_A=42		T_A=43		T_A=44	
		FT	%	FT	%	FT	%
0834-0847	Early Ebb	240	6	150	4	-	-
1205-1217	Late Ebb	550	14	500	12.5	450	11
1638-1650	Mid Flood	300	7.5	270	7	240	6
1936-1949	High Water Slack	360	9	150	4	-	-
Average		360	9	270	7	200	4.5

Comparison of NBI and TXI Data

The TXI data represents surface temperatures only. Consequently, all comparisons will be for surface effects.

Also, comparison will only be made for the April surveys. This is reasonable because surveys, taking place during the same month of the year, would be subject to similar meteorological and freshwater runoff conditions.

The TXI results for the 42°F and 43°F ambient temperatures demonstrated good agreement with the results reported by NBI for their April, 1967 survey. The NBI April, 1967 survey showed that on a tidal average basis temperature rises in excess of 4°F consumed 330 feet or 8% of the total width at Indian Point. The TXI April, 1968 survey showed for the 42°F ambient temperature that 360 feet or 9% of the width was consumed. Correspondingly, for the 43°F ambient temperature, 270 feet or 7% of the width was consumed.

The average heat load discharged at Indian Point during the April, 1967 survey was 472 MW, almost 20% higher than the 395 MW that was discharged on April 6, 1968. Therefore, it might be more appropriate to associate the April 6, 1968 temperature rise result with the 43°F ambient temperature; the temperature effect for April, 1968, associated with a smaller heat load, should be less than the temperature effect for April, 1967.

In any event, the NBI and TXI survey results are in agreement. This gives support for their use as a basis for extrapolating to temperature effects resulting from future heat loads. Also, from the results of these surveys, it can be concluded that at the present time the surface width at Indian Point effected by temperatures in excess of 4°F is less than 10% of the total width. Correspondingly, the area consumed by a 4°F rise is in the order of 1%.

V. REVISION OF PREDICTIVE MODEL

This chapter first compares the predictions of River temperature profiles for Unit No. 1 operation using the January '68 report model, to field observations of River temperature in the vicinity of Indian Point during several periods of Unit No. 1 operation in 1966 and 1967.

Reasons for differences are suggested, and the model is then adjusted empirically to yield results compatable with field measurements.

Use of this adjusted model to predict temperature profiles for three unit operation is given in Chapter VI.

Comparison of Predicted and Measured Profiles - January '68 Report.

To determine the temperature effect caused by operation at Indian Point, QL&M Engineers developed an unsteady-state mathematical model, which generated the longitudinal profile of area-average temperature rises. Model results for one unit operation were compared to river temperature measurements made in the vicinity of the Indian Point Unit No. 1 discharge by Northeastern Biologists, Incorporated (NBI), in July, 1966 and April, 1967.

Table 4 presents this comparison. For July 1966, the predicted temperature rise was 25% higher than the actual temperature rise at the plane of discharge and 69% higher than the actual temperature rise at the cross-section 800 feet downstream of the plane of discharge. Correspondingly, for April 1967, the predicted temperature rises were 85% and 100% higher than the measured temperature rises.

These area-average values are extremely small and the validity of the comparison could be questioned; i.e., should a reviewer consider temperature rises of 0.1 to 0.2°F negligible, he might conclude comparison of such results is unacceptable.

This potential objection is answered by pointing out that these area-averages represent the weighted effect of significant temperature rises near the east shore of each cross-section considered, and zero temperature rises over most of the remainder of the cross-section. The very small area-averages are merely the result of measurable temperature rises over less than 10% of the cross-section, reduced by the ratio of the affected area to the total area of some 160,000 sq. ft.

TABLE 4

COMPARISON OF PREDICTED AND MEASURED AREA-AVERAGE TEMPERATURE RISES

HUDSON RIVER NEAR INDIAN POINT

	Area-Average Temperature Rise[1]					
	July 1966			April 1967		
Location	Measured °F	Predicted °F	Predicted / Measured	Measured °F	Predicted °F	Predicted / Measured
Across Plane of Discharge	0.2[1]	0.25[1]	1.25	0.093[1]	0.172[1]	1.85
Across Plane 800 Ft. Below Discharge	0.145[2]	0.245[3]	1.69	0.0825[1]	0.17[3]	2.06

1- Data taken from January, 1968 Report, Table 1 and pages 9,11 and 21.

2- Obtained from field data by same procedures outlined in January 1968 report, to obtain plane of discharge averages.

3- Computed using unrevised one-dimensional mathematical models.

The methods used to compute the measured area-average temperature rise are given in detail in the January '68 report. These are summarized below to clarify the answer to the potential objections stated above.

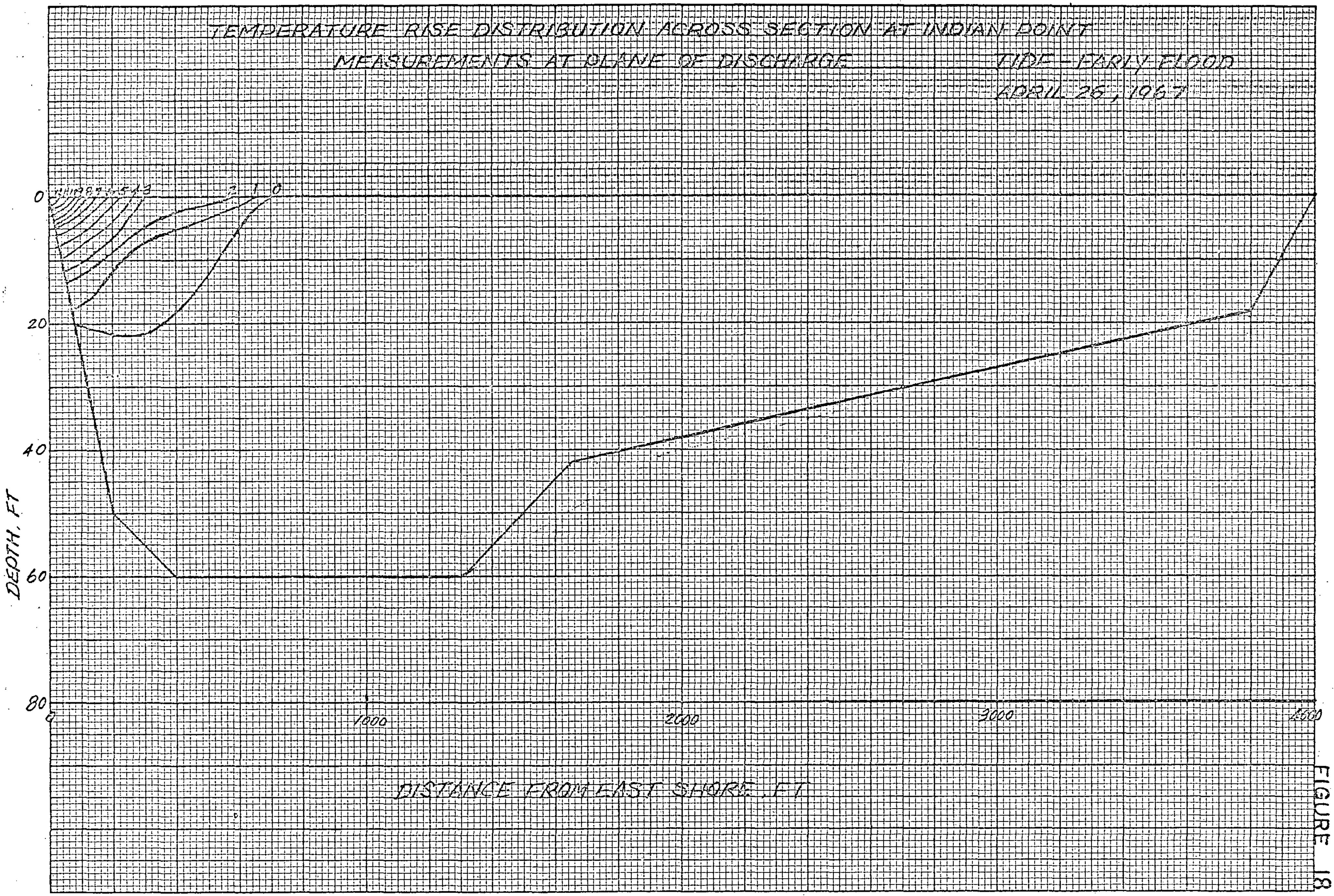
Figure 18 depicts the temperature rise distribution at the plane of discharge for an early flood tidal condition during the April 1967 survey. Seven figures similar to Figure 18 were constructed for different tidal phases and the areas enveloped by each isotherm were averaged. For a given isotherm, the average of the eight different areas, corresponding to the eight tidal phases, equally spaced in time, was considered representative of the average tidal condition.

Figure 5 (following page 7) shows the cross-sectional areas enveloped by different temperature rises for the average tidal condition. Figure 5 shows that, while the temperature effect averaged over the full 160,000 square feet may be negligible ($<0.1^{o}F$), temperature rises in the immediate vicinity of the discharge are significant. Temperature rises of greater than $1^{o}F$ existed for 4,000 square feet.

Spreading the effect that exists within the first 11,000 square feet (boundary of the $0^{o}F$ isotherm) over the full 160,000 square feet area results in the apparent negligible average effect. Averaging the temperature rise over the local area effected (the first 11,000 square feet) would have resulted in higher temperatures that might be considered more meaningful. However, as the area-average model predicts area-averages only, field measurements had to be converted to area averages for purposes of comparison.

A more valid objection would be to question the point at which the measured temperature versus area curves are extrapolated to zero. This objection is considered and answered in the January '68 report (pages 9 and 10). This question can be answered further by plotting the temperature rise isotherm versus area of influence of the isotherm for both the measured and predicted area-average temperature rises. Such a comparison is made in Figure 19.

Figure 19 is a comparison of exponential model predicted areas enveloping different temperature rises to actual measurements made during the April 1967 survey (see Figure 5). Figure 19



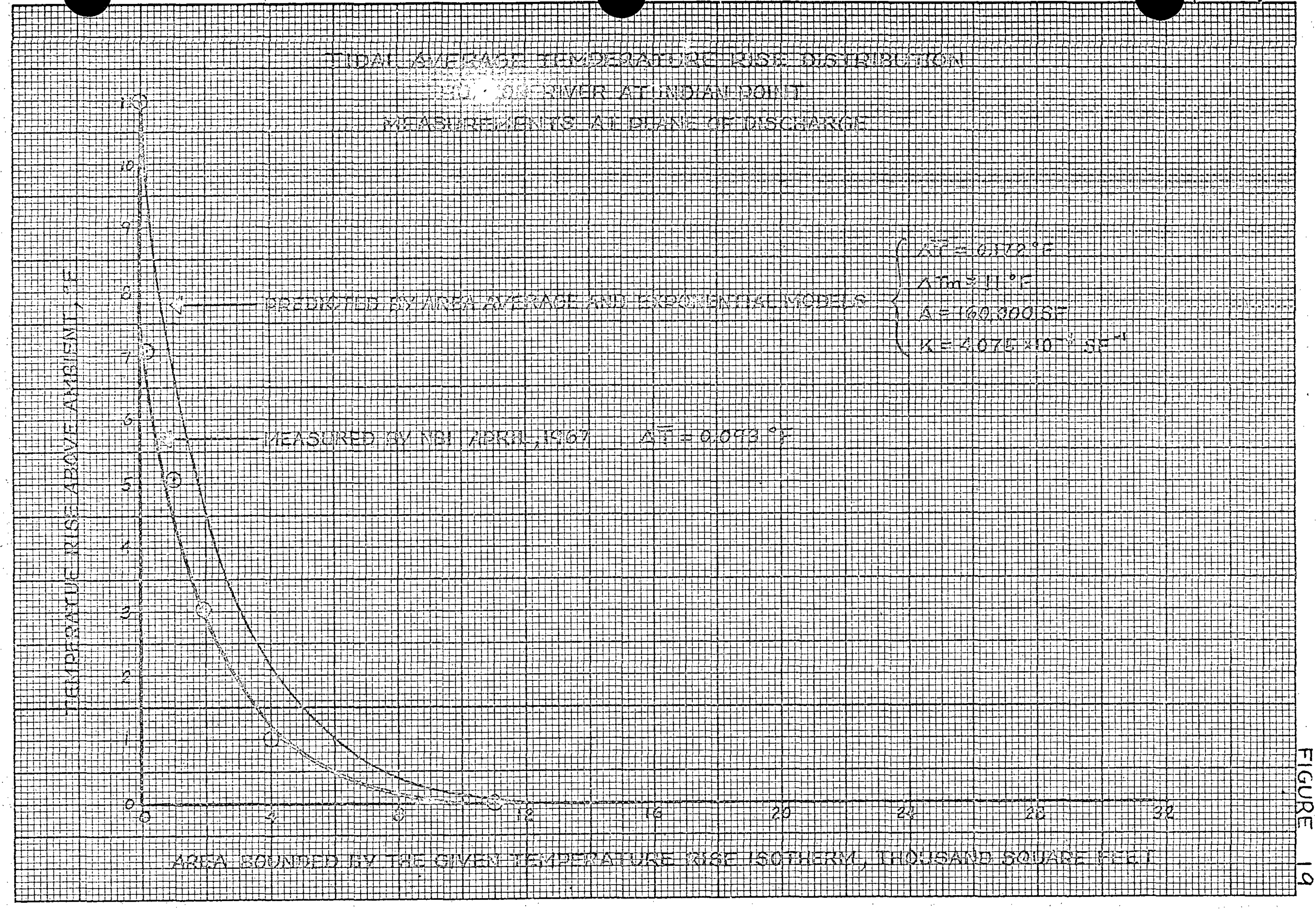
TEMPERATURE RISE DISTRIBUTION ACROSS SECTION AT INDIAN POINT

MEASUREMENTS AT PLANE OF DISCHARGE

TIDE - EARLY FLOOD

APRIL 26, 1967

FIGURE 18



TIDAL AVERAGE TEMPERATURE RISE DISTRIBUTION

HUDSON RIVER AT INDIAN POINT

MEASUREMENTS AT PLANE OF DISCHARGE

FIGURE 19

demonstrates more clearly the extent to which model computed temperature rises exceed the measured temperature rises.

Rationale for Model Revision

Table 4 shows clearly that the observed area-average temperature, a good parameter of the effect of the thermal discharge on the River, is substantially lower than its predicted counterpart at the plane of discharge, and here more so at a plane a short (800 ft) distance away from the discharge plane. Before adjusting the model to conform to these observations, reasons for these differences are discussed.

Net non-tidal Flow and Thermal Stratification

Partially stratified estuaries, such as the Hudson, are subject to a net upstream movement of sea water in their lower layers and a downstream movement in their upper layers. This movement is induced by density differences which exist on account of the vertical and longitudinal distribution of salinity. This effect is often called the net non-tidal flow, but must be distinguished from the freshwater runoff, which is the actual difference between total upstream and downstream tidal movement.

The net non-tidal flow has never been measured in the Hudson but has been shown to exist.[3] Extensive field current measurements, at various depths throughout cross-sections within the salt intruded reach, and over a full tidal cycle, are necessary to obtain this quantity. Measurements meeting these requirements are not available for the Hudson.

Measurements of net non-tidal flow in other estuaries, such as the James River in Virginia, have been made. Values of ten to forty times the freshwater runoff have been observed. The actual value increases in the seaward direction of the estuary due to entrainment of the lower layer water by the flow in the upper layer.

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[3] Quirk, Lawler & Matusky Engineers - Hudson River Report files

[4] Pritchard, D.W., "Observations of Circulation in Coastal Plain Estuaries." Chapter in "Estuaries", G.H. Lauff, Editor, Publication No. 83, American Association for the Advancement of Science, Washington, D.C. 1967

In any event, this phenomenon provides substantially more capacity for diluting waste discharges than the fresh water runoff. The net effect is, of course, less than straight dilution by the magnitude of the net non-tidal movement, because this effect is partially offset by vertical mixing due to tidal turbulence. Vertical mixing causes contaminants, originally diluted and washed downstream in the upper layer's flow, to return in the lower layer's upstream movement.

This net dilution effect is generally considered to be accounted for by the longitudinal dispersion coefficient. The longitudinal dispersion coefficient, however, is measured by analysis of longitudinal profiles of the area-averaged salinity. In the case of dilution of non stratifying discharges such as sewage or most industrial wastes, the vertical distribution of these contaminants in the estuary is roughly the same as that of the ocean generated salt, and the net dilution effect is estimated fairly well by using longitudinal dispersion coefficients obtained from salinity profiles. There is reason to believe that the combined net non-tidal flow, vertical mixing dilution effect is greater for an inherently stratifying discharge, such as is a thermal discharge, than that which is obtained using dispersion coefficients generated from salinity profiles.

The reason for this belief lies in the balance of energy which exists between the tendency of tidal turbulence to force complete vertical mixing, and the tendency of the landward directed flow of highly saline ocean water to ride underneath the seaward directed flow of non-saline fresh water. This balance and which mechanism is stronger can be observed by the relative steepness of the vertical salinity profile at any cross section of the estuary.

For rivers like the Mississippi, the fresh water flow is large, the Gulf tides relatively weak, and the net result is a very stratified estuary. In a river like the Delaware, particularly in the summer, just the reverse is true, the vertical salinity profiles are quite flat, and the estuary is classified as completely mixed.

The Hudson more closely approximates the conditions in the Delaware, but due to the attenuating influence of New York Harbor on tidal power, and larger fresh water flows, the vertical salinity gradients are not quite as flat as those of the Delaware. The Hudson estuary is usually classified as partially mixed.

Now the introduction of a discharge, which will tend to stratify of itself, effectively superimposes a condition on the estuary's existing energy balance, which it is not equipped to alter. In other words, the heated liquid, being lighter, will rise to the surface, and tend to stay there; since there is little excess turbulent energy available to cause vertical mixing. Vertical mixing is present, of course, but is counteracted by the tendency of the estuary itself to stratify. Before introduction of the heated effluent these opposing mechanisms are already in a state of balance. An effluent, whose stable state is to locate near the surface, will not be subject to the same extent of vertical mixing as are the natural waters of the estuary.

If the heated effluent is not as strongly subject to vertical mixing as a non-stratifying discharge, then the net dilution effect of the estuary on this discharge should be greater than the usual dilution effect as measured by the magnitude of the longitudinal dispersion coefficient. In other words, the salinity induced circulatory flow is still present, the heated effluent finds its way into the upper seaward directed portion of the circulatory flow, and is diluted by it. The net dilution is greater than it would be for the non-stratifying discharge, because there is insufficient excess tidal turbulence to break up the lighter and therefore stable upper layer. Little of the heated water, therefore, is transferred to the lower, upstream moving layer, and the diluting effect of net non-tidal flow is offset to a lesser degree by vertical mixing than in the case of a non-stratifying discharge.

Vertical mixing, of course, will eventually occur, but the point is that such an effect may take a lot longer than usual. Since the temperature decay is primarily at the surface, the heat has every opportunity to dissipate to the atmosphere, and by the time the water in the upper layer is exchanged with lower layer's water, much of the heat may be gone. Thus the return of this water in the lower layer past the original plane of discharge will be at a time when this water possesses relatively little heat.

The improved dilution will therefore tend not to be seriously offset. Were the material conservative, it would not be lost from the estuary until it was exchanged with the ocean, and the net dilution would not be as great.

The January '68 report shows clearly that the heat from Indian Point is concentrated in the upper layers of the estuary. The profiles for the section some 800 ft. below the discharge show that the elevated temperatures remain in the surface layer longer than in the layers below. This is to be expected since the thickness of the heated layer would tend to decrease as heat is transferred to the atmosphere, the upper most layer being the last to retain elevated temperature.

Thus it appears that one reason for the marked differences between predicted and measured values is in the improved dilution by net non-tidal flow, available to the thermal discharge since it stabilizes in the surface layers of the estuary, where it can decay to the atmosphere.

This mechanism should not have as strong an influence in April, when fresh water flow is high and Indian Point salinity correspondingly very low, as during the summer, when the reverse is true, since the net non-tidal flow decreases as salinity decreases. The differences in the April data may be due in part to this effect and in part to a significant longitudinal dispersion accompanying the high fresh water flows. (Model calculations in the January '68 report for the high spring flows considered longitudinal dispersion to be very small.)

Surface Heat Transfer

Area-average model calculations were made using heat transfer coefficients that related the difference between the actual surface water temperature and the ambient surface water temperature to the rate at which heat was dissipated to the atmosphere.

Since the area-average model does not differentiate between average temperature and surface temperature , a correction factor was employed to account for differences between these two. This factor was termed the thermal stratification factor (TSF) and is equal to the ratio of the average surface temperature to the area average temperature.

This factor computed at Indian Point plane of discharge was equal to 3.0 for the July 1966 data and 6.0 for the April 1967 data. Results presented in the January '68 report include the above corrections.

Observation of the temperature distribution in planes some distance from the plane of discharge shows that the elevated temperatures tend to concentrate at the surface as the heated water moves away from the plane of discharge. Determination of the correction factor at sections both upstream and downstream of Indian Point showed higher factors existed at these planes by comparison to that at the plane of discharge.

For example, at the section 800 feet downstream of Indian Point, this factor was twice the Indian Point value in July 1, 1966.

Had increased TSF values been used in computing temperature behavior above and below the plane of discharge, in accordance with what measured data showed, the total heat given off to the atmosphere would be greater and resulting predicted river temperature lower.

Model Adjustment

In this section the area-averaged model is adjusted to yield agreement with the measured area-averages of 1966 and 1967. The exponential model is then used to show that the model generated rise isotherm versus bounded area and surface width curves agree reasonably well with the corresponding measured curves.

The area-averaged model used in the January '68 report consisted of equilibrium behavior of a transient, variable space parameter, one dimensional energy transport equation. For the sake of relation simplicity in illustration, this model is replaced by an equivalent, infinite receiver model as shown in Table 5.

The factors f_1 and f_2 were computed by determining the ratios of the exponential decay rates exhibited by the variable parameter model to those of the infinite receiver model. The low flow conditions summarized in Table 5 of the January '68 report were used to obtain the following numerical values.

upstream $f_1 = 0.90$

downstream: $f_2 = 1.44$

In other words, the more precise variable parameter model decays quite a bit more rapidly in the downstream direction (due primarily to the rapidly expanding area) and slightly less rapidly in the upstream direction, than does the infinite receiver model. For high flow conditions, the predicted area averages in Table 4 were obtained using the infinite receiver model, so the f_1, f_2 values for high flows are unity. For this condition, the segmented, variable parameter model gave even higher area average temperatures and is less precise than the infinite receiver.

Table 4 shows a far more rapid decay in the observed data occurs than is predicted by the area-average model. The observed decay data is rather limited, but can safely be presumed to decay expo-

TABLE 5

EQUIVALENT AREA AVERAGE MODEL

The form of the infinite receiver model, modified to yield the variable parameter model results is:

$$\left.\begin{matrix}\Delta\bar{T}_{I}\\ \Delta\bar{T}_{II}\end{matrix}\right\} = \frac{H\, e^{\begin{pmatrix}f_1\\ f_2\end{pmatrix}\frac{U}{2E}\left(1\pm\sqrt{1+\frac{4K'E}{U^2}}\right)X}}{\rho C_p Q\sqrt{1+\frac{4K'E}{U^2}}}$$

in which: $\overline{\Delta T}$ = area-average temperature rises, °F
I - designates behavior above Indian Point
II - designates behavior below Indian Point

H = thermal discharge, BTU/day

ρ = water density, #/ft.^{3}

C_ρ = heat capacity, BTU/#/°F

Q = River freshwater flow, ft.^{3}/day

K' = temperature decay coefficient, day^{-1}

U = freshwater velocity, Q/A, miles/day

E = longitudinal dispersion coefficient, sq. miles/day

f_1, f_2 = upstream & downstream model conversion factors

X = distance from plane of discharge (positive direction downstream), miles nentially in the longitudinal direction. This presumption is based on theory and observed lateral decay behavior. The adjusted area-average model is then written:

$$\left.\begin{matrix} \Delta\bar{T}_{I} \\ \Delta\bar{T}_{II} \end{matrix}\right\} = \frac{f_5 H e^{\begin{pmatrix} f_1 \\ f_2 \end{pmatrix}\begin{pmatrix} f_3 \\ f_4 \end{pmatrix} \frac{U}{2E}\left(1 \pm \sqrt{1 + \frac{4K'E}{U^2}}\right) x}}{\rho C_p Q \sqrt{1 + \frac{4K'E}{U^2}}} \qquad \ldots\ldots\ldots\ldots (1)$$

The coefficient f_5 adjusts the model to agree with observed area-averages at Indian Point. The coefficients f_3 and f_4, in conjunction with f_5, adjust the model to agree with observed area-averages upstream and downstream of Indian Point, respectively.

Table 4 shows the actual differences between field data and model predictions of Unit No. 1 behavior, as given in the January '68 report. Before computing the f_3, f_4 and f_5 values, the estimates of H for Unit No. 1 operation were corrected to account for the actual electrical energy output during the survey periods.

The estimate used in the January '68 report for July, 1966 was based on effluent channel flow and River temperature measurements taken in the near vicinity of the discharge and for this reason can be expected to be slightly lower than the true effluent channel heat load. Table 6 shows that it was 91% of the correct value.

Table 6 shows excellent agreement between the April heat load, as estimated using April electrical energy output, 32% thermal efficiency, and, 5% in-plant heat loss, and the effluent channel flow and temperature rise values. Temperature measurements in April were made in the channel; hence the better agreement.

Table 7 summarizes the correction factors to be employed in using Equation 1. The upstream factor f_3 has been assumed to be equal to the downstream factor f_4. Temperature rises in the upstream direction in April were virtually zero due to the high freshwater flow, and correspondingly negligible back mixing. July upstream data were very sparse and were not analyzed for this purpose.

TABLE 6

ESTIMATES OF HEAT LOSS TO RIVER DURING OPERATION OF INDIAN POINT UNIT NO. 1

Item	July, 1966	April, 1967
On Basis of Average Monthly Plant Output		
Average Output, MWE	245	240
Heat Generated, MW	765	750
In-plant Loss, MW	38	38
Waste Heat Load	482	472
On Basis of Effluent Channel Characteristics		
Channel Flow, gpm	300,000	300,000
Outlet Temperature, °F	10	11
Waste Heat Load, MW	440	480
Waste Heat Load Comparison		
$\frac{\text{On Basis of Channel Values}}{\text{On Basis of Average Output}}$	0.91	1.02

TABLE 7

SUMMARY OF MODEL ADJUSTMENT FACTORS

Factor	Location	Adjustment	Flow Regime	
			12000 CFS	12000 CFS
f_1	Upstream	Convert upstream and downstream decay rates of infinite receiver to agree with segmented model	1.0	0.90
f_2	Downstream		1.0	1.44
f_3	Upstream	Convert upstream and downstream decay rates of segmented model to agree with observed data	12.9	15
f_4	Downstream		12.9	15
f_5	Plane of Discharge	Convert maximum area average value of either model to agree with observed data	0.54	0.73

This adjusted area-average model is used in conjunction with the exponential decay model (pages 15 and 16, January '68 Report) to obtain the areas and surface widths bounded by a given temperature rise isotherm. The exponential model for area is:

$$\Delta T = \Delta T_m \ e^{-KA} \qquad \text{.......................} \quad (2)$$

in which:

ΔT = temperature rise isotherm, ^oF

ΔT_m = maximum temperature at any point in the cross-section, ^oF

A = that portion of the cross-section within which the temperature rises equal or exceed ΔT,SF.

K = exponential decay coefficient for area, SF^{-1}

The exponential model for surface width is:

$$\Delta T_s = \Delta T_{sm} \ e^{-kb} \qquad \text{.......................} \quad (3)$$

in which:

ΔT_s = surface temperature rise isotherm, ^oF

ΔT_{sm} = maximum surface temperature

b = that portion of the surface width within which the surface temperature rises equal or exceed ΔT_s,FT.

k = exponential decay coefficient for surface width, FT^{-1}

The exponential decay coefficients, K and k, are found by recognizing that the curves given by equations 2 and 3 can be uniquely defined if the maximum and average temperatures and the total cross-sectional area, ΔT, and surface width,B, are known. The area-average and surface average temperatures are respectively:

$$\overline{\Delta T} = \Delta T_m \left(\frac{1}{K A_T}\right)\left(1 - e^{-K A_T}\right) \qquad \ldots\ldots\ldots \quad (4)$$

$$\overline{\Delta T_s} = \Delta T_{sm} \left(\frac{1}{kB}\right)\left(1 - e^{-kB}\right) \qquad \ldots\ldots \quad (5)$$

The adjusted one dimensional area-averaged model is used to compute ΔT. The surface average temperature, $\overline{\Delta T_S}$, is equal to $\overline{\Delta T}$ multiplied by the thermal stratification factor (TSF). Equation 4 and 5 are solved to obtain K and k. Equations 2 and 3 are then used to obtain the percentages of cross-sectional area ($100\,A/A_T$) and surface width ($100\,b/B$) corresponding to selected temperature rises, ΔT and ΔT_S.

This procedure is illustrated using the July, 1966 and April, 1967 NBI data to show the reasonably good behavior which is obtained using the adjusted model.

Figure 20 shows the areas bounded by a given rise isotherm as observed in April, 1967 and as obtained using both the unadjusted and adjusted models. The shape of the curve obtained using the adjusted model does not agree perfectly with the observed data, although it can be seen that the area-average value, $\overline{\Delta T}$, for the two curves will be the same. The unadjusted curve is seen to heat significantly more area, as described above in discussing Figure 19.

Figure 21 shows a comparison of the measured surface width behavior to that computed using equations 3 and 5 for the April, 1967 data. The agreement is quite good, particularly between 1 and 4°F, the contours of interest in considering zones of passage. Better agreement between the higher values would have been obtained had 12°F maximum been used. This would not be justified by the discharge channel temperatures. Furthermore, to preserve the average, the computed exponential would have tailed off more rapidly then did the observed data.

Table 8 summarizes the calculation procedure employed to obtain the computed curves shown in Figures 20 and 21.

Figure 22 shows the computed and measured curves for decay of surface temperature with surface width for the April, 1967 conditions at the surface of a plane 800 ft below the discharge plane. The exponential model does not yield precise agreement with the measured data (the actual decay being more linear in nature,) but the

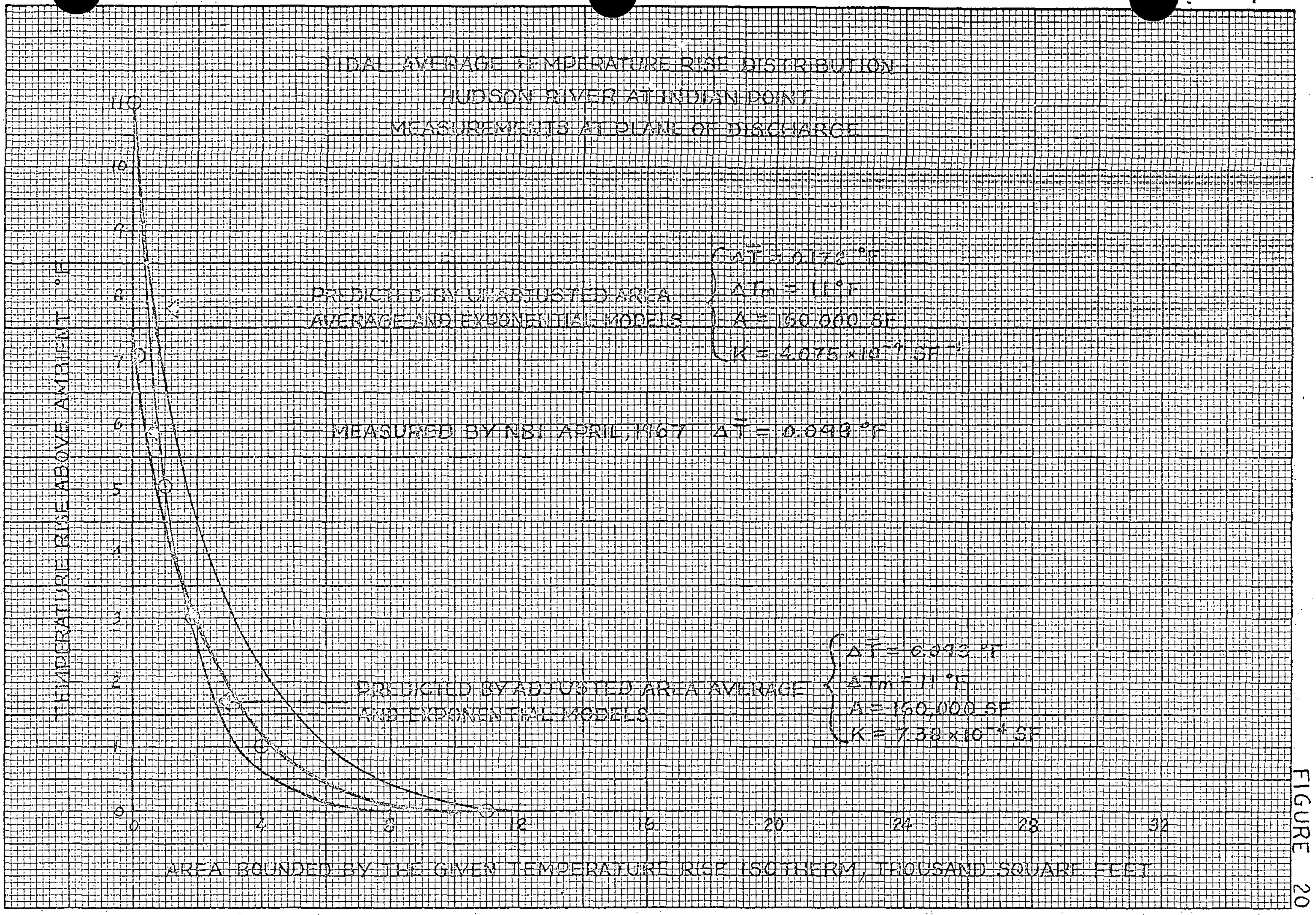

TIDAL AVERAGE TEMPERATURE RISE DISTRIBUTION
HUDSON RIVER AT INDIAN POINT
MEASUREMENTS AT PLANE OF DISCHARGE
PREDICTED BY UNADJUSTED AREA AVERAGE AND EXPONENTIAL MODELS
ΔT̄ = 0.172 °F
ΔTm = 11 °F
A = 160,000 SF
K = 4.075 × 10⁻⁴ SF⁻¹
MEASURED BY NBI APRIL, 1967 ΔT̄ = 0.093 °F
PREDICTED BY ADJUSTED AREA AVERAGE AND EXPONENTIAL MODELS
ΔT̄ = 0.093 °F
ΔTm = 11 °F
A = 160,000 SF
K = 7.38 × 10⁻⁴ SF
TEMPERATURE RISE ABOVE AMBIENT °F
11
10
9
8
7
6
5
4
3
2
1
0
0
4
8
12
16
20
24
28
32
AREA BOUNDED BY THE GIVEN TEMPERATURE RISE ISOTHERM, THOUSAND SQUARE FEET

FIGURE 20

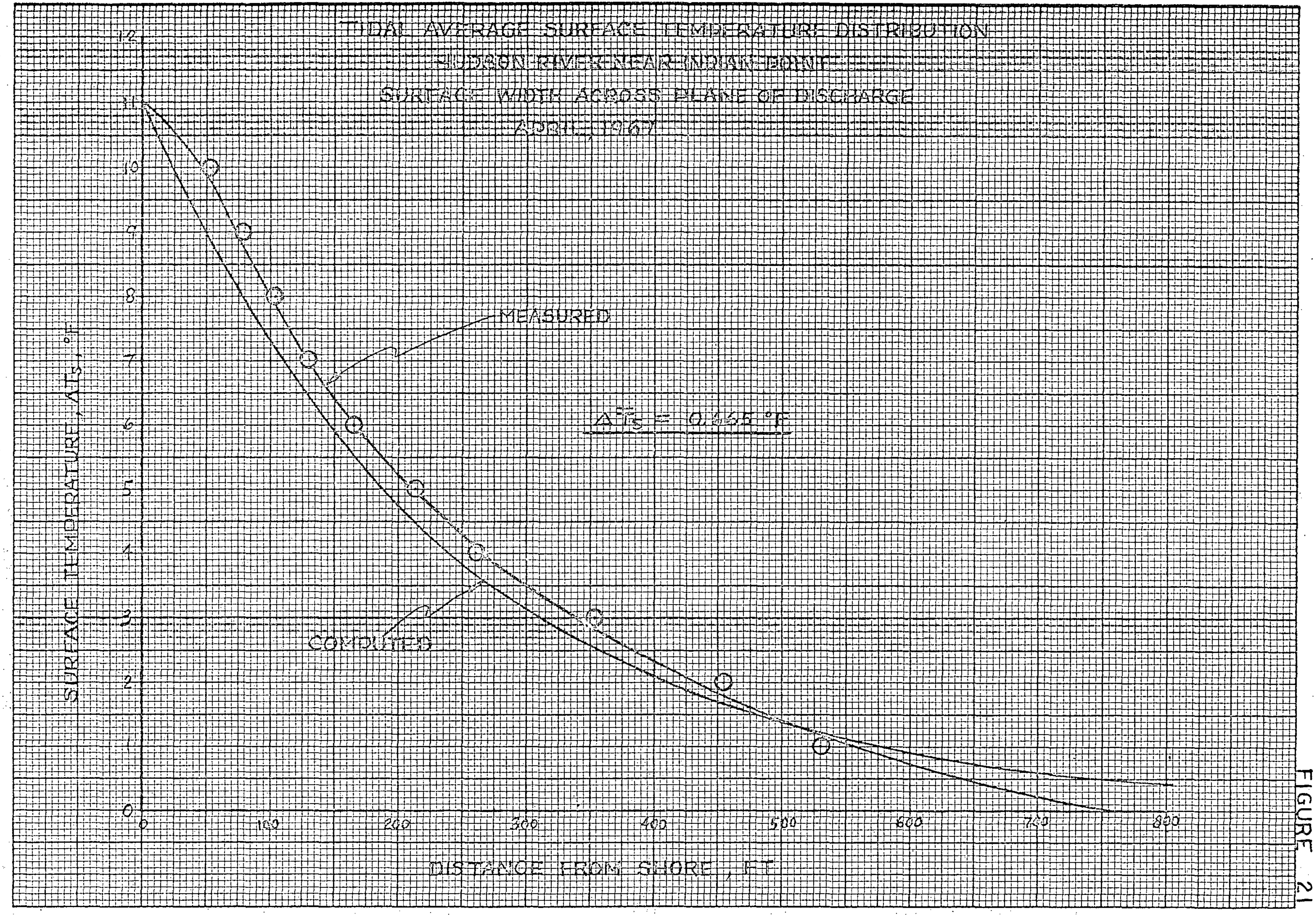

TIDAL AVERAGE SURFACE TEMPERATURE DISTRIBUTION
HUDSON RIVER NEAR INDIAN POINT
SURFACE WIDTH ACROSS PLANE OF DISCHARGE
APRIL, 1967
MEASURED
COMPUTED
$\Delta \bar{T}_s$ = 0.465 °F
SURFACE TEMPERATURE, ΔT_s, °F
DISTANCE FROM SHORE, FT
0
1
2
3
4
5
6
7
8
9
10
11
12
0
100
200
300
400
500
600
700
800

FIGURE 21

TABLE 8

CALCULATIONS REQUIRED TO OBTAIN COMPUTED CURVES OR FIGURES 20 AND 21

Conditions for April, 1967

$H = 39.3 \times 10^{9}$ BTU/day

$Q = 40{,}000$ CFS

$E = 2$ sq. miles/day

$K' = 0.264\ \text{Day}^{-1}$ ($K = 110$ BTU/SF/day/°F, TSF = 6, D = 6)

$U = 4.1$ miles/day ($A = 160{,}000$ SF)

Calculation of Area--Average Temperature Rise

From Table 5, $\Delta\bar{T} = 0.172\ ^{\circ}F$ (unadjusted)

From Equation 1 and Table 7, $\Delta\bar{T} = 0.54 \times 0.172$

$= 0.093$ (adjusted)

Calculation of Exponential Decay Behavior for Area (Figure 20)

$\Delta Tm = 11^{\circ}F$, $\Delta T = 0.093$, $A_T = 160{,}000$ SF

From Equation 4, $K = 7.38 \times 10^{-4}\ SF^{-1}$

From Equation 2, $\Delta T = 11\ \text{Exp}\ (-7.38 \times 10^{-4}\ A)$

Calculation of Exponential Decay Behavior for Surface Width (Figure 20)

$\Delta T_{sm} = 11^{\circ}F$, $\Delta\bar{T} == 0.665\ ^{\circ}F$, $B = 4000$ ft

From Equation 5, $k = 4.13 \times 10^{-3}\ ft^{-1}$

From Equation 3, $\Delta T_{s} = 11\ \text{Exp}\ (-4.13 \times 10^{-3}\ b)$

TIDAL AVERAGE SURFACE TEMPERATURE DISTRIBUTION
HUDSON RIVER NEAR INDIAN POINT
SECTION 800 FT BELOW PLANE OF DISCHARGE
APRIL, 1967

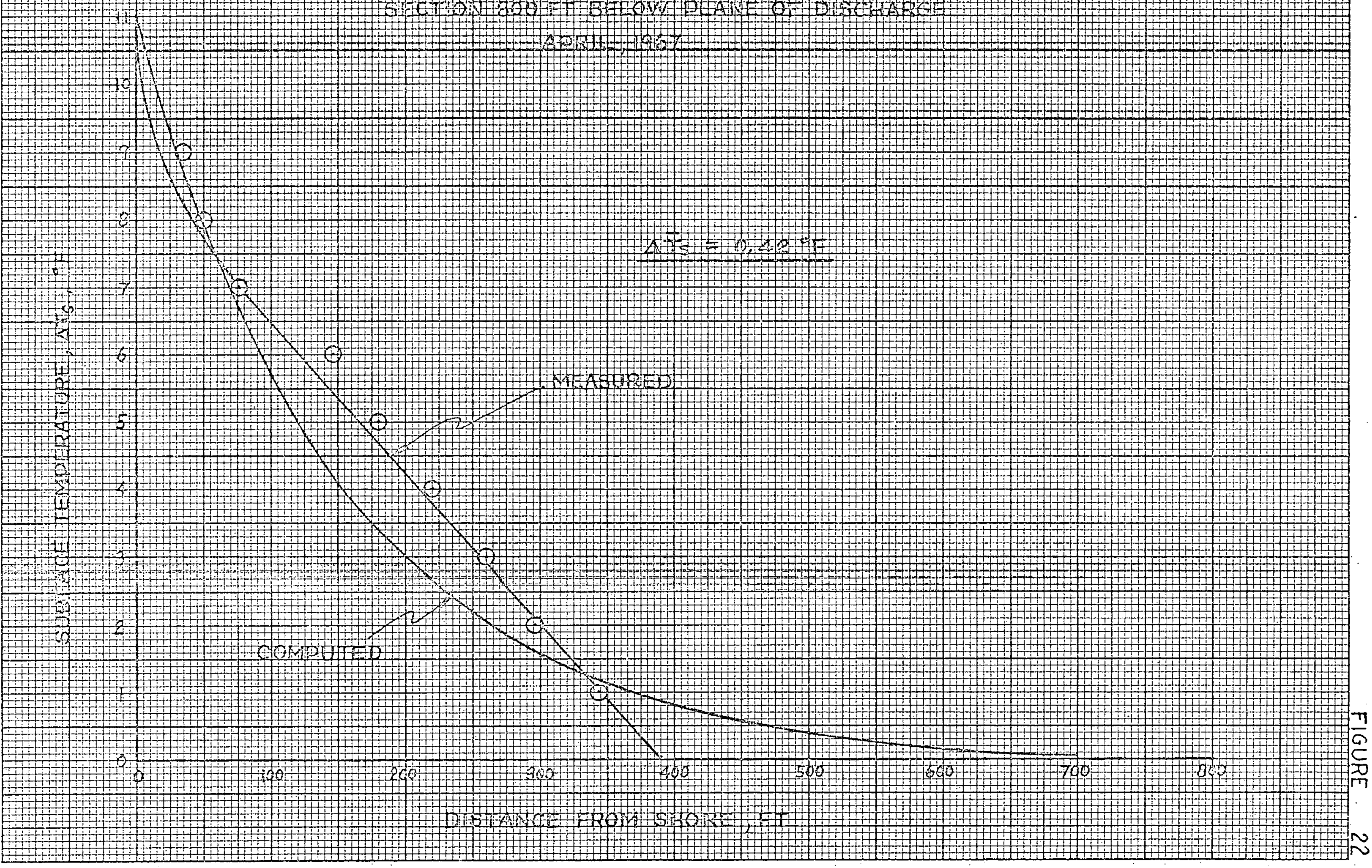


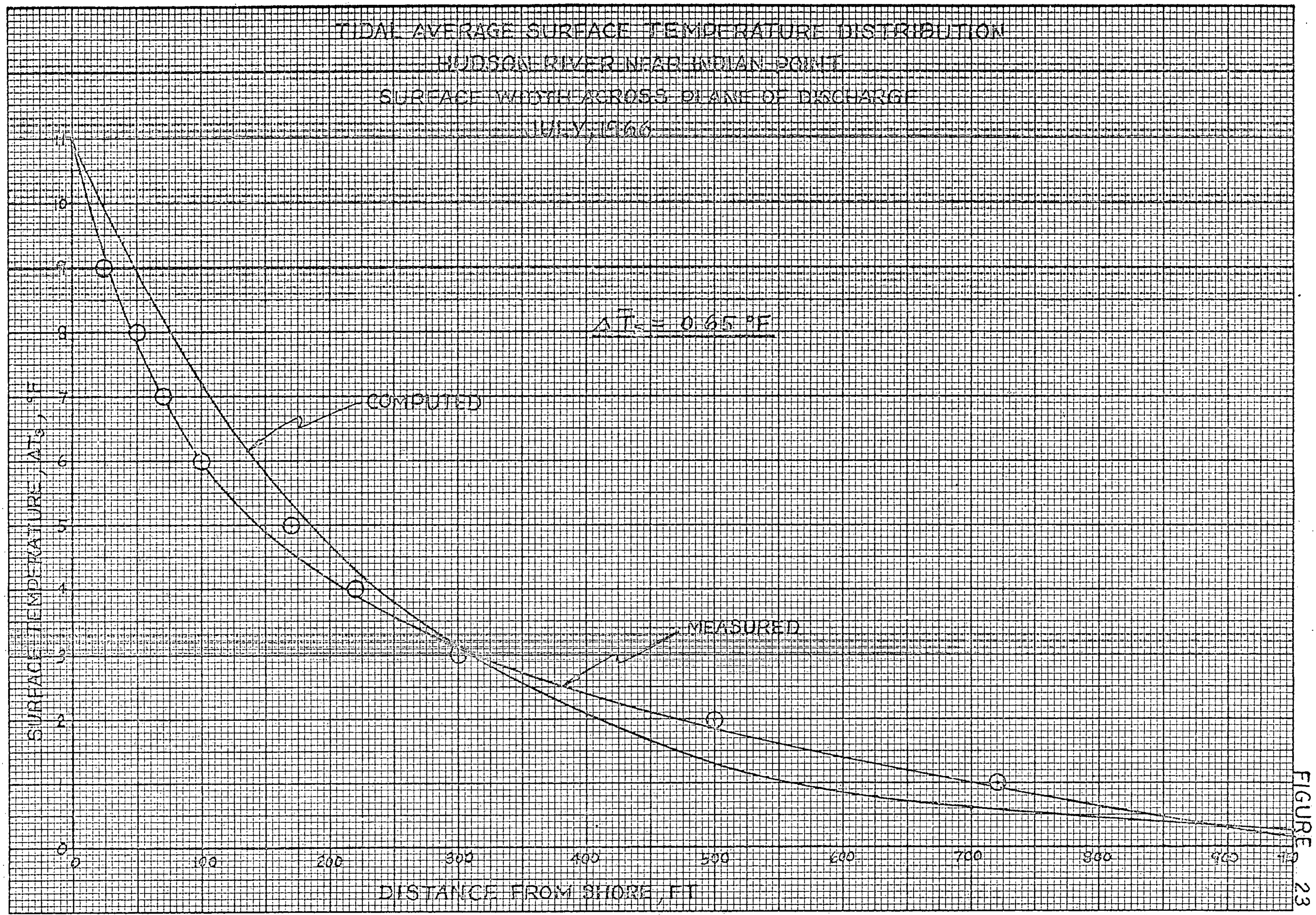
FIGURE 22

surface average temperature, $\overline{\Delta T_S}$, is the same for both curves.

Figure 23 shows the computed and measured surface behavior at the discharge plane for the July, 1966 conditions. The exponential curve, with a maximum temperature of 11°F, diverges somewhat from the measured curve, but opposite to the departure seen in Figure 21. Again, control is maintained by the fact that the surface average temperature rise, $\overline{\Delta T_S}$, is the same for both curves.

These results show that exponential decay behavior of both the area and surface temperature rises, across planes perpendicular to the longitudinal areas of the River, gives a reasonably accurate description of the actual behavior of these parameters, provided the area-average model is adjusted to yield the measured area-average values.

These models and the procedures for using them are employed in the next chapter to predict the effect of three unit operation at Indian Point on the temperature rise pattern in the Hudson River.



TIDAL AVERAGE SURFACE TEMPERATURE DISTRIBUTION
HUDSON RIVER NEAR INDIAN POINT
SURFACE WIDTH ACROSS PLANE OF DISCHARGE
JULY, 1966

FIGURE 23

VI. TEMPERATURE DISTRIBUTION FOR THREE UNIT OPERATION

This chapter utilizes the adjusted mathematical model to predict the Hudson River temperature rise distribution which can be expected in the presence of a 4153 MW waste heat load from Indian Point. Results obtained by the Alden Hydraulic Laboratory for three unit operation of Indian Point Hydraulic Model II are presented to support these predictions.

Generalized Solution - Exponential Decay Model

Figure 24 is a generalized solution of the exponential decay models given by Equations 2 through 5 in the previous chapter. The curves are valid for both area and surface width calculations because the upper abscissa is presented as a fraction of the total cross-sectional area or surface width. Use of Figure 24 is described in Table 9.

Conditions of Maximum Severity

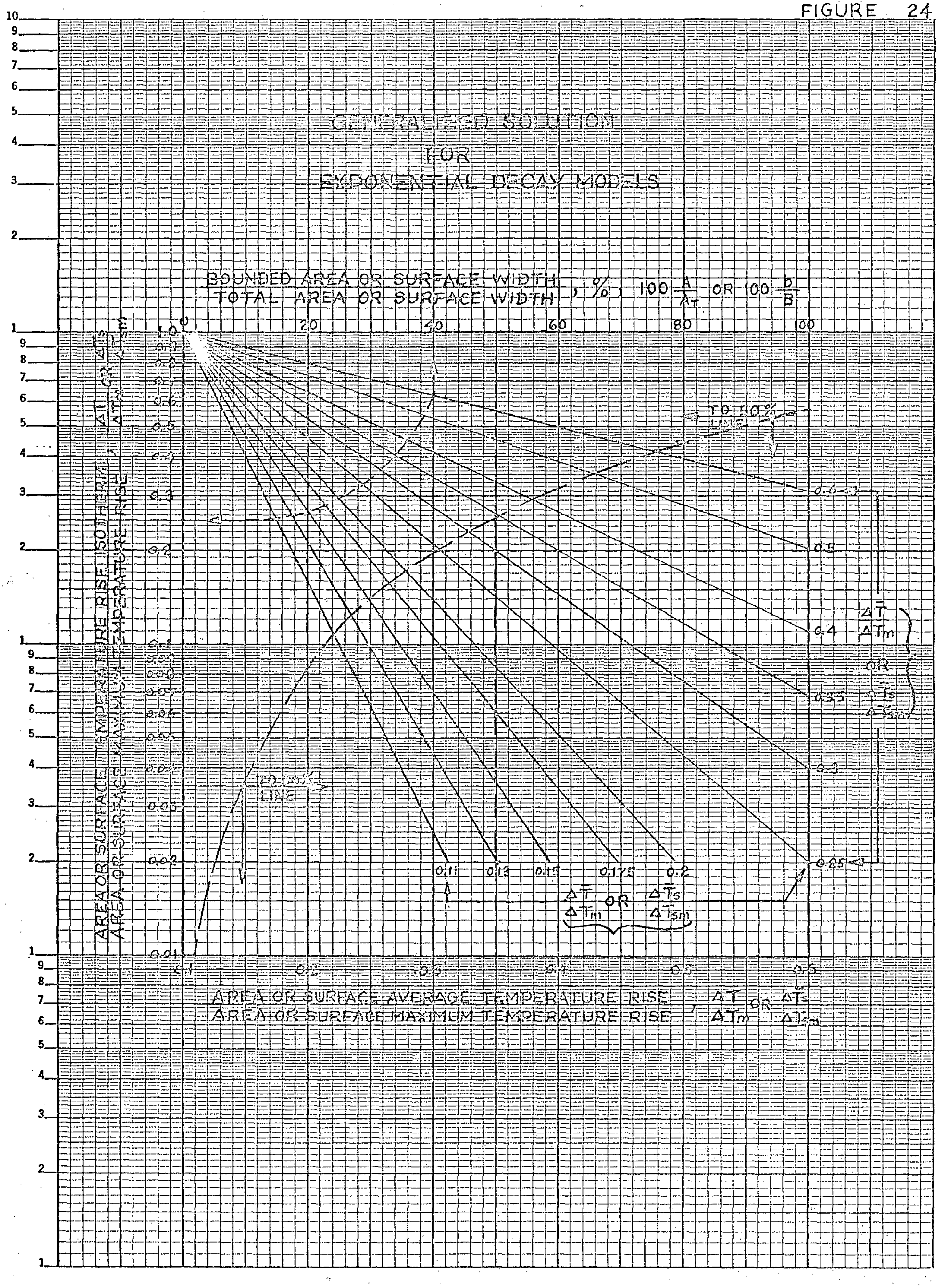
The January '68 report shows that conditions of maximum severity were reached in November, 1964. A sustained six month low flow of 4000 CFS, and a relatively low heat transfer coefficient of 90 BTU/SF/day/^{O}F combined to create the maximum computed area-average temperature rises. These conditions are employed below to compute a probable extreme condition.

Thermal Stratification Factors

Since a submerged discharge is planned, the thermal stratification factor for the low flow condition has been reduced from 3.0 to values between 1.5 and 2.5. The value of 1.0 represents a minimum which can only be approached. In addition to the influence of submerged discharge, the increased heat load is expected to drive the stratification factor down, because, by comparison to Unit No. 1 behavior, the increased flow of heated water into the River will have a greater effect on the subsurface temperatures.

A thermal stratification factor of 1.0 would be obtained if the heated discharge were completely mixed across the plane of discharge. For this case, Table 10 (following page 27) shows that the area-average temperature rise would be 3.4^{O}F. Since complete mixing is assumed, the temperature at every point would be 3.4^{O}F and nowhere would the 4^{O}F criterion be exceeded.

FIGURE 24



GENERALIZED SOLUTION FOR EXPONENTIAL DECAY MODELS

TABLE 9

APPLICATION OF GENERALIZED SOLUTION FOR EXPONENTIAL DECAY MODELS (FIGURE 24)

GIVEN: Area or Surface Average Behavior

OBJECT: Find Percentage of Area or Width Enveloped by a Given Temperature Use.

1. Select maximum temperature value

2. Compute ratio of average to maximum temperature

3. Enter bottom abscissa at value computed in 2.

4. Move vertically upward to dashed curve

5. Value on left ordinate is the temperature ratio at 50% of the cross-section or surface width

6. Move horizontally left or right and intersect dashed vertical line (the 50% vertical)

7. Dimensionless temperature profile is obtained by drawing straight line between intersection in 6 and upper right corner.

8. Select desired temperature. Divide by maximum temperature in 1 to obtain dimensionless counterpart. Enter line drawn in 7 at this ordinate and obtain desired percentage of area or width.

For the reverse case of finding the average behavior, given the profile, compute and plot the dimensionless profile, interest the 50% vertical with this profile, move horizontally from this point to the dashed curve, and then vertically down to the bottom abscissa to find the dimensionless average.

A thermal stratification factor of 3.0 was obtained for the surface discharge conditions of July, 1966. Were a surface discharge planned for the three unit operation, the maximum surface temperature, for the planned waste heat load of 4153 MW, would be 14°F. Assume that under these conditions, the thermal stratification factor would reach 3.0.

These concepts suggest that the thermal stratification factor increases with an increase in the maximum surface water temperature. In this analysis of low flow, River temperature behavior, the thermal stratification factor has been assumed to vary linearly with the maximum surface water temperature, from a minimum value of 1.0 at the completely mixed temperature of 3.4°F, to a maximum of 3.0 at the effluent channel temperature of 14°F.

Assuming a maximum ambient temperature of 78°F, the maximum surface temperature rise must not be more than 12°F to avoid contravening the 90°F surface water temperature standard. Submerged discharge studies[5] show that maximum surface water temperatures between 6 and 9°F can be expected if the heated effluent is discharged through ports along the bottom of the west wall of the discharge channel. The actual value which will occur depends on the effluent channel temperature and the depth of submergence. More details on the submerged discharge are given in a later section in this chapter.

For purposes of establishing the areal and surface bounds of the 4°F contour, maximum surface water temperatures of 6,9 and 12°F were considered. The thermal stratification factor to be used with each of these temperatures was determined using the linear assumption described above and yielded:

	Thermal Stratification Factor	
Maximum Surface Temperature, °F	Linear Model	Rounded Value
3.4	1.0	1.0
6	1.5	1.5
9	2.05	2.0
12	2.6	2.5
14	3.0	3.0

---

[5] Progress Report on Indian Point II Studies for Consolidated Edison Company of New York. Alden Research Laboratory (1968) This report is appended to the present QL&M report.

Thus the TSF values of 1.5, 2.0 and 2.5 correspond to ΔT_{sm} values of 6,9 and 12°F, respectively.

Bounding Area-Plane of Discharge

Table 10 summarizes the computation of the area-average temperature rises across the plane of discharge for the low flow condition and several TSF, and of the corresponding percentages of the total cross-section, within which the temperature rise equals or exceeds the 4°F criterion. Table 10 indicates the area bounded by the 4°F isotherm can be expected to range between 20 and 26% of the total Indian Point cross-section. Notice that the temperature bounding 50% of the cross-section, the maximum percentage permitted by the proposed criteria as a bound on the 4°F isotherm, ranges between 0.6 and 1.3°F, considerably lower than the 4°F upper limit.

Bounding Surface Width-Plane of Discharge

Table 11 summarizes the computation of the percentage of surface width bounded by the 4°F surface water temperature rise at the plane of discharge. Table 11 shows that some 50 to 60% of the surface width will have temperatures equal to or greater than 4°F. The proposed standard permits up to 67% of the surface width to have surface temperatures greater than 4°F. This criterion, therefore, will not be contravened.

Table 11 shows clearly the value of the submerged discharge. The 6°F maximum surface water temperature rise condition can be obtained by submerging the discharge. Not only does this case yield the lowest surface width percentage (52%), but the temperatures within that 52% will have to range between 4 and 6°F.

By comparison, the condition of a ΔT_{sm} of 12°F, which is more representative of a surface discharge, has the highest surface width percentage (60%), and the temperatures with that 60% will range between 4 and 12°F.

Areal and Surface Boundaries - Summer Conditions

The foregoing represent what are considered to be extreme conditions from the standpoint of low flows and low heat transfer coefficients. From a biological standpoint, conditions which occur in August, when low flows and high ambient water temperatures prevail, probably represent the critical condition.

TABLE 10

COMPUTATION OF AREA-AVERAGE TEMPERATURE RISE AND AREA BOUNDED BY THE 4°F ISOTHERM FOR THE DISCHARGE PLANE AT INDIAN POINT FOR CONDITIONS OF MAXIMUM SEVERITY

Conditions

$H = 340 \times 10^9$ BTU/day, $\Delta T_m = 14°F$
$Q = 4000$ CFS, $U = 0.41$ mile/day, $E = 12$ sq miles/day
$\bar{K} = 90$ BTU/SF/day/°F, $K' = [0.0361 \times \text{TSF}]\,\text{day}^{-1}$
$f_5 = 0.73$

Area Average Temperature Calculation

$$f_5 H/\rho C_p Q = \frac{0.73 \times 340 \times 10^9}{54 \times 10^5 \times 4 \times 10^3} = 11.5°F$$

$$4K'E/U^2 = \frac{4 \times 0.036 \times 12}{0.41 \times 0.41}\,(\text{TSF}) = 10.3\ \text{TSF}$$

TSF	10.3TSF	$\sqrt{1 + 10.3\text{TSF}}$	$\Delta\bar{T}$ (By Equation 1)
1.0	10.3	3.36	3.42
1.5	15.4	4.05	2.84
2.0	20.6	4.64	2.47
2.5	25.7	5.16	2.23
3.0	30.9	5.64	2.04

Percentage of Cross-Section Bounded by 4°F Isotherm

$\overline{\Delta T}$	$\frac{\overline{\Delta T}}{\Delta T_M}$ (For 14°F Condenser rise)	$\frac{\Delta T}{\Delta T_M}$ @ $100\frac{A}{A_T} = 50$	$100\frac{A}{A_T}$ @ $\frac{\Delta T}{\Delta T_M} = 0.286$ (% Area @ 4°F)	Isotherm Bounding 50% of Area (For 14°F Condenser rise)
2.84	0.203	0.090	26	1.26
2.47	0.176	0.060	22	0.84
2.23	0.159	0.044	20	0.62

TABLE 11

COMPUTATION OF AREA AVERAGE TEMPERATURE RISE AND AREA BOUNDED BY THE $4^{\circ}F$ ISOTHERM FOR THE DISCHARGE PLANE AT INDIAN POINT FOR CONDITIONS OF MAXIMUM SEVERITY

CONDITIONS: SAME AS TABLE 10

SURFACE WIDTH CALCULATIONS

Item	Source	Value Corresponding to a ΔT_{sm} of:		
		$6^{\circ}F$	$9^{\circ}F$	$12^{\circ}F$
TSF	Page 26	1.5	2.0	2.5
$\Delta\bar{T}$, $^{\circ}F$	Table 10	2.84	2.47	2.23
$\Delta\bar{T}_s$, $^{\circ}F$	$\Delta\bar{T}$ x TSF	4.26	4.94	5.57
$\Delta\bar{T}_s / \Delta T_{sm}$	Calculate	0.71	0.550	0.463
$\frac{\Delta T_s}{\Delta T_{sm}}$ @ $\frac{100b}{B} = 50$	Figure 24	0.68	0.51	0.40
$\frac{\Delta T_s}{\Delta T_{sm}}$ @ $\Delta T_s = 4^{\circ}F$	Calculate	0.667	0.444	0.333
$\frac{100b}{B}$ @ $\Delta T_s = 4^{\circ}F$	Figure 24	52	60	60

Table 12 summarizes calculations for this condition. Parameters include a $6^{O}F$ maximum surface water temperature rise, a sustained low flow of 4000 CFS and an August heat transfer coefficient of 135 BTU/SF/day/^{O}F (Figure 3, January '68 Report).

Table 12 shows that 21% of the cross-section and 33% of the surface width are bounded by the $4^{O}F$ isotherm. These are significantly lower than the 26 and 52% values obtained for similar discharge conditions in Tables 10 and 11, respectively, in which the 90 BTU/SF/day/^{O}F November heat transfer coefficient was used.

Behavior Beyond the Plane of Discharge

Table 13 shows the decay of the area-average temperature rise with distance above and below the plane of discharge at Indian Point. Both August and November conditions are presented; ΔT_{sm} is assumed to be held to $6^{O}F$ in both cases and the TSF is held constant at 1.5. Adjustment coefficients are those developed in Table 7 for low flow conditions.

Table 13 shows a very rapid decay of the area-average temperature with distance away from Indian Point. This rapid decay is caused by the large values obtained for the adjustment factors, f_3 and f_4.

The adjusted model is presumed to apply within the first mile above and below the plane of discharge. The model cannot be applied over an infinite distance because the adjusted decay rates, by comparison to the area-averaged rise at the plane of discharge, will not permit all the heat to be rejected.

The adjusted model is considered to represent the rapid dispersal and dilution of the heated effluent by the net non-tidal flow mechanism. Average temperature will be reduced to about $1^{O}F$ within the first mile above and below the plant.

Most of the heat (BTU) introduced to the River still remains at this point. This residual heat dissipates slowly to the atmosphere as the water particles move up and down the estuary. Whatever residual heat still remains is eventually exchanged with incoming ocean waters.

This loss of residual heat is similar to the way in which other residual pollutants are lost from the estuary. The difference is that the intensity of the heat, i.e., the temperature rise, is

TABLE 12

COMPUTATION OF $4^{\circ}F$ AREA/AND SURFACE BOUNDARIES AT THE PLANE OF DISCHARGE FOR SUMMER CONDITIONS

Conditions

$H = 340 \times 10^9$ BTU/day, $\Delta T_m = 14^{\circ}F$, $\Delta T_{sm} = 6^{\circ}F$

$Q = 4{,}000$ CFS, $U = 0.41$ mile/day, $E = 12$ sq. miles/day

$\bar{K} = 135$ BTU/SF/Day/$^{\circ}F$, TSF = 1.5, $K' = 0.08/\text{day}^{-1}$

$f_5 = 0.73$

Area Average Temperature Rise

$$\Delta\bar{T} = f_5 \, H \, [pCpQ]^{-1} \, [1 + 4K'E/U^2]^{-1/2}$$

$$= 11.5 \times [1 + 23.1]^{-1/2} = \underline{\underline{2.34}}^{\circ F}$$

Percentage of Cross-Sectional Area Bounded by $4^{\circ}F$ Isotherm

$\Delta\bar{T}/\Delta T_m = 2.34/14 = 0.167$

$\Delta T/\Delta T_m$ at $\Delta T = 4^{\circ}F$ is 0.286

$100\ A/_{AT}$ (at $^{\Delta T}/_{\Delta T_m} = 0.286$) $= \underline{\underline{21\%}}$ Figure 24

Percentage of Surface Width Bounded by $4^{\circ}F$ Isotherm

$\Delta\bar{T}_s = \text{TSF} \times \Delta\bar{T} = 3.5^{\circ}F$

$\Delta\bar{T}_s/\Delta T_{sm} = 3.5/6.0 = 0.583$

$\Delta T_s/\Delta T_{sm}$ at $\Delta T = 4^{\circ}F$ is 0.67

$100b/B$ (at $\Delta T_s/\Delta T_{sm} = 0.67$) $= 33\%$ Figure 24

TABLE 13

CALCULATION OF AREA-AVERAGE TEMPERATURE RISES ABOVE AND BELOW INDIAN POINT FOR THE CRITICAL SUMMER AND MAXIMUM SEVERE CONDITIONS

Calculation of Longitudinal Exponential Decay Rate

$$J_1 = f_1 f_3 \frac{U}{2E} \left[1 + \sqrt{1 + \frac{4K'E}{U^2}}\right] \qquad \text{upstream}$$

$$J_2 = f_2 f_4 \frac{U}{2E} \left[1 - \sqrt{1 - \frac{4K'E}{U^2}}\right] \qquad \text{downstream}$$

Critical Summer Condition (August) (See Tables 7 & 12 for Parameters)

$$J_1 = 0.90 \times 15 \times \frac{0.41}{2 \times 12} \left[1 + \sqrt{24.1}\right] = 1.36 \text{ Miles}^{-1}$$

$$J_2 = 1.44 \times 15 \times \frac{0.41}{2 \times 12} \left[1 - \sqrt{24.1}\right] = 1.44 \text{ Miles}^{-1}$$

Condition of Maximum Severity (November) (See Tables 7 & 10 for Parameters)

$$J_1 = 0.9 \times 15 \times 0.0171 \left[1 + 4.05\right] = 1.17 \text{ Miles}^{-1}$$

$$J_2 = 1.44 \times 15 \times 0.0171 \left[1 - 4.05\right] = - 1.125 \text{ Miles}^{-1}$$

Calculation of Area-Average Temperatures

Distance (Miles)	Area Average Temperature, $\Delta\bar{T}$, $^{\circ}F$	
	August	November
-1.0	0.60	0.88
-0.5	1.19	1.58
0	2.34	2.84
0.5	1.14	1.62
1.0	0.55	0.92

reduced much more quickly than is the intensity of particulate pollutants, i.e., the concentration, since the inherent stratification enhances dilution by net non-tidal slow. Correspondingly, this improved dilution effect will result in a greater portion of the residual heat being flushed from the estuary, as opposed to dissipation from the estuary's surface, by comparison to the relative proportions of the soluble organic pollutant, which are flushed out of or decay within the estuarine waters.

Figures 25 and 26 show the boundaries of the 4°F and 2°F surface and area isotherm. Additional decay will occur beyond the one mile limit. The exact behavior of this decay is not know, but is presumed to be slow, in accordance with the loss of residual heat mechanism described above. A horizontal dash line is shown in Figure 25 and represents the upper limit of the isotherms' boundaries beyond this point.

The surface curves in these Figures were developed using a ΔT_{sm} value of 6°F. This value was also used for ΔT_m, in constructing the area curves, beyond the plane of discharge, since this will be the maximum expected temperature at any point beyond the zone of initial dilution of the 14°F effluent. Figure 27 shows the expected surface isotherm pattern.

Hydraulic Model Results

During the period of the foregoing analysis, a hydraulic model of the Indian Point three unit operation was built and operated by the Alden Hydraulic Laboratory of the Westchester Polytechnic Institute, Worchester, Massachusetts. This model is designated Indian Point Model II and extends two miles above and below the plane of discharge at Indian Point and over the Rivers' full width and depth.

Model scale is 1 to 250 in the horizontal plane and 1 to 60 in the vertical. Tidal action is simulated by varying the flow introduced or withdrawn at each end of the model. Heated effluent is discharged through a series of submerged ports and directed toward the River's channel.

Figures A-1 through A-7 are reproductions of results received from the Alden Hydraulic Laboratory and represent surface temperature rises during different phases of the tidal cycle for three units discharging 2,100,000 gpm at a 17°F temperature rise. Figure A-8 is a map showing the highest instantaneous temperature measured at any point in the surface for these operating conditions.

FIGURE 25

BOUNDARIES OF THE 4°F ISOTHERM FOR THREE UNIT DISCHARGE AT INDIAN POINT

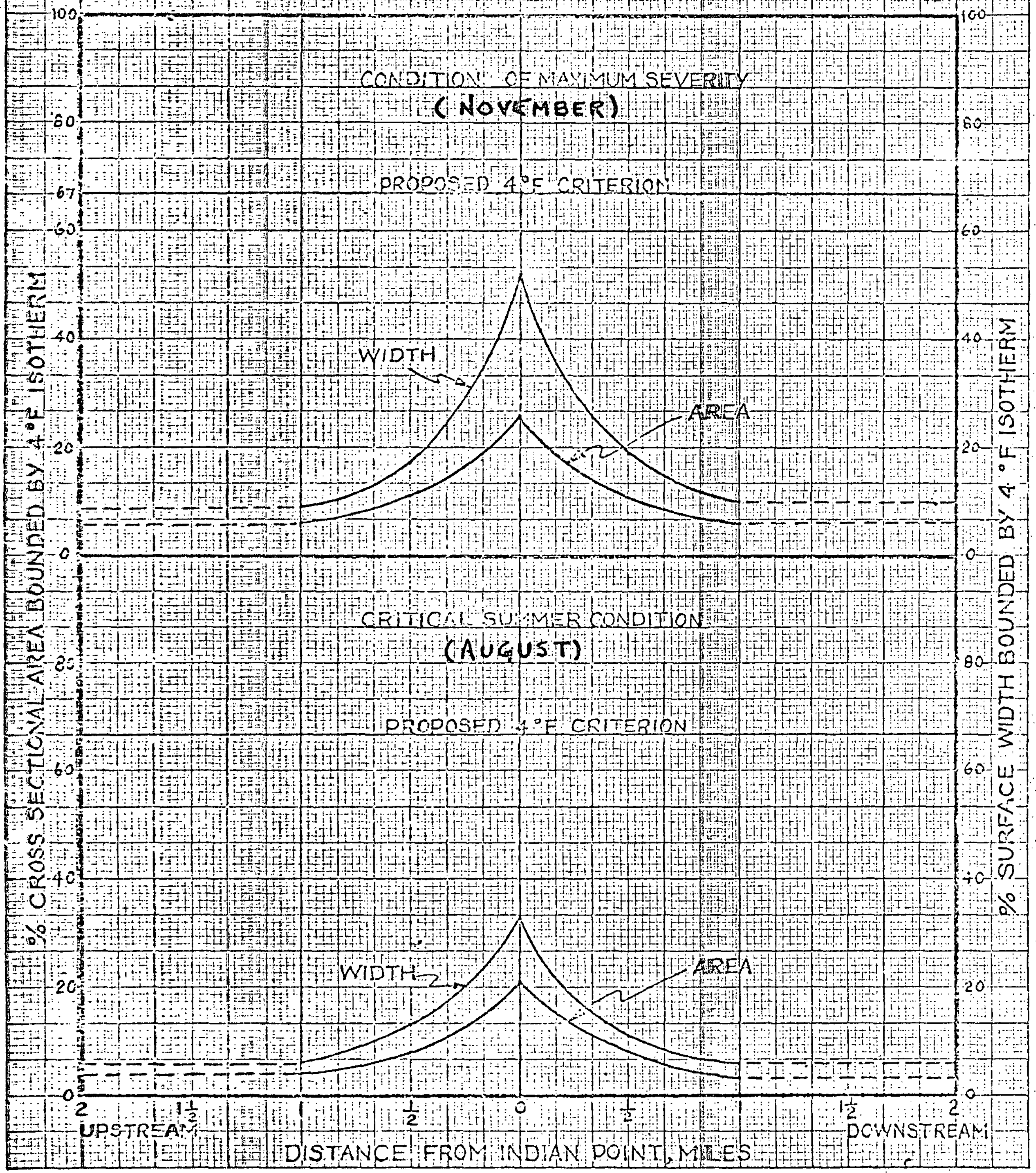


FIGURE 26

BOUNDARIES OF THE 2°F ISOTHERM
FOR
THREE UNIT DISCHARGE AT INDIAN POINT

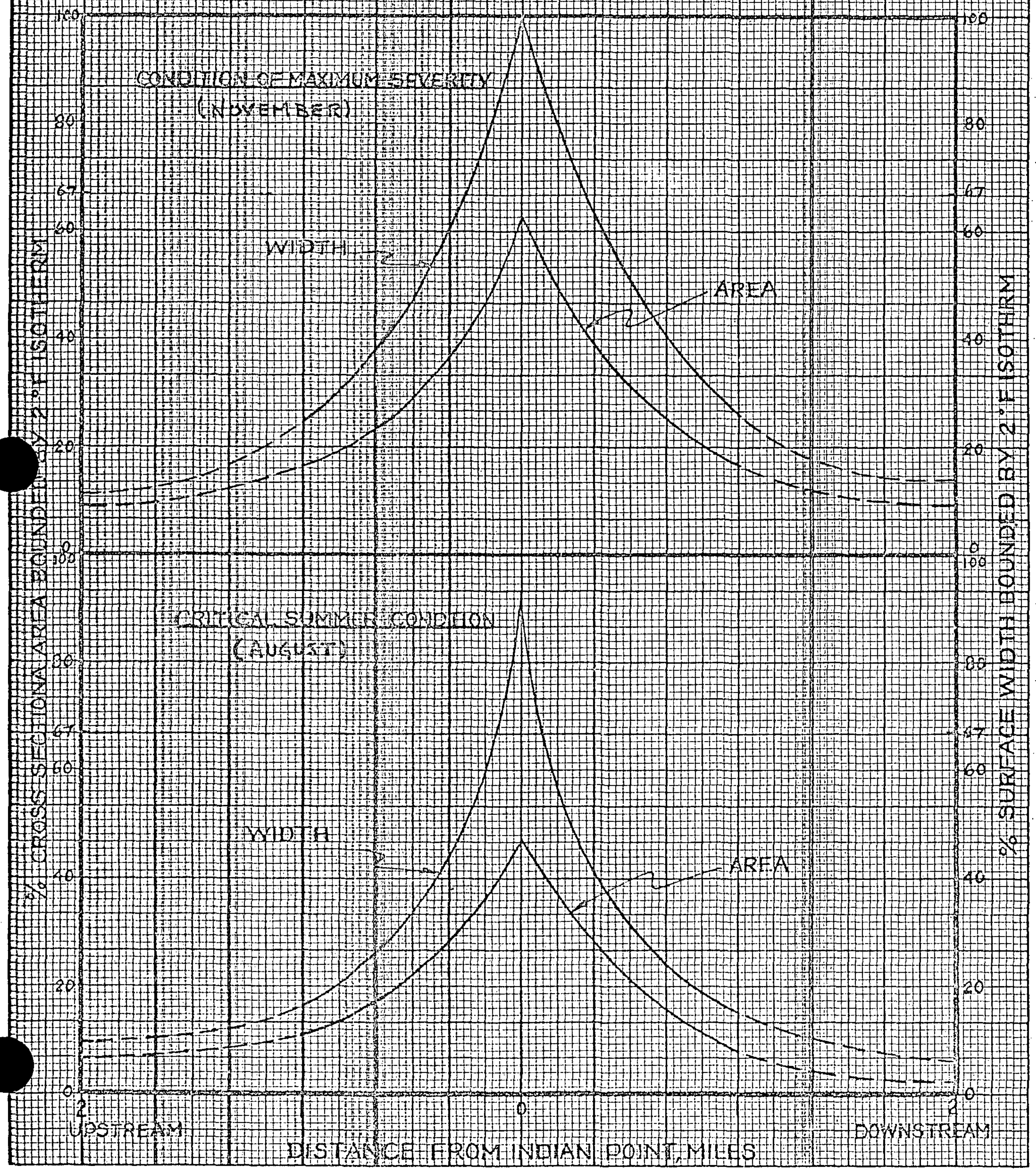
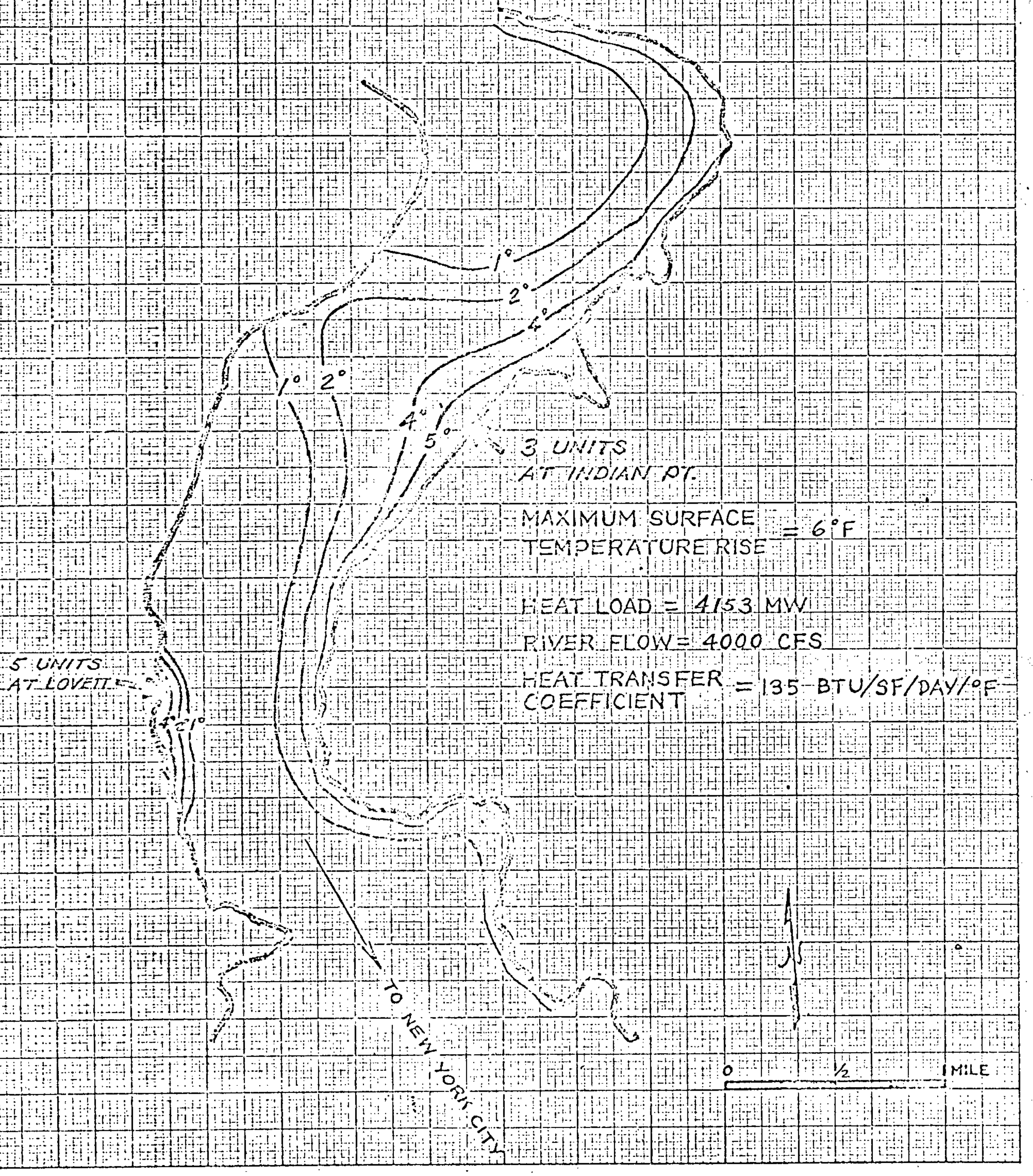


FIGURE 27

BOUNDARIES OF STATED SURFACE ISOTHERMS
FOR
THREE UNIT DISCHARGE AT INDIAN POINT

SUMMER CRITICAL CONDITION
(AUGUST)



3 UNITS
AT INDIAN PT.

MAXIMUM SURFACE TEMPERATURE RISE = 6°F

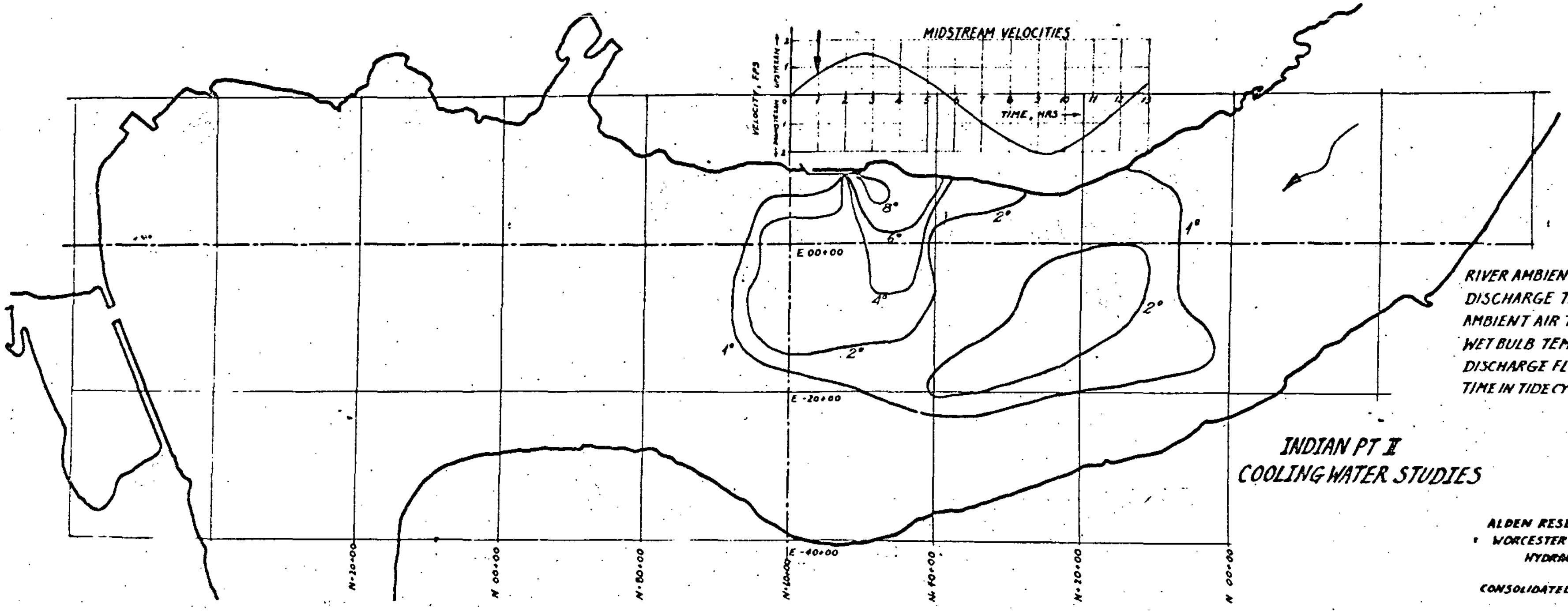
HEAT LOAD = 4153 MW

RIVER FLOW = 4000 CFS

HEAT TRANSFER COEFFICIENT = 135 BTU/SF/DAY/°F

FIG A-1

~~Fig 1~~



RIVER AMBIENT TEMPERATURE 50 °F
DISCHARGE TEMPERATURE 67 °F
AMBIENT AIR TEMPERATURE 52 °F
WET BULB TEMPERATURE 49 °F
DISCHARGE FLOW RATE 4670 cfs (3 units)
TIME IN TIDE CYCLE, SEE DIAGRAM

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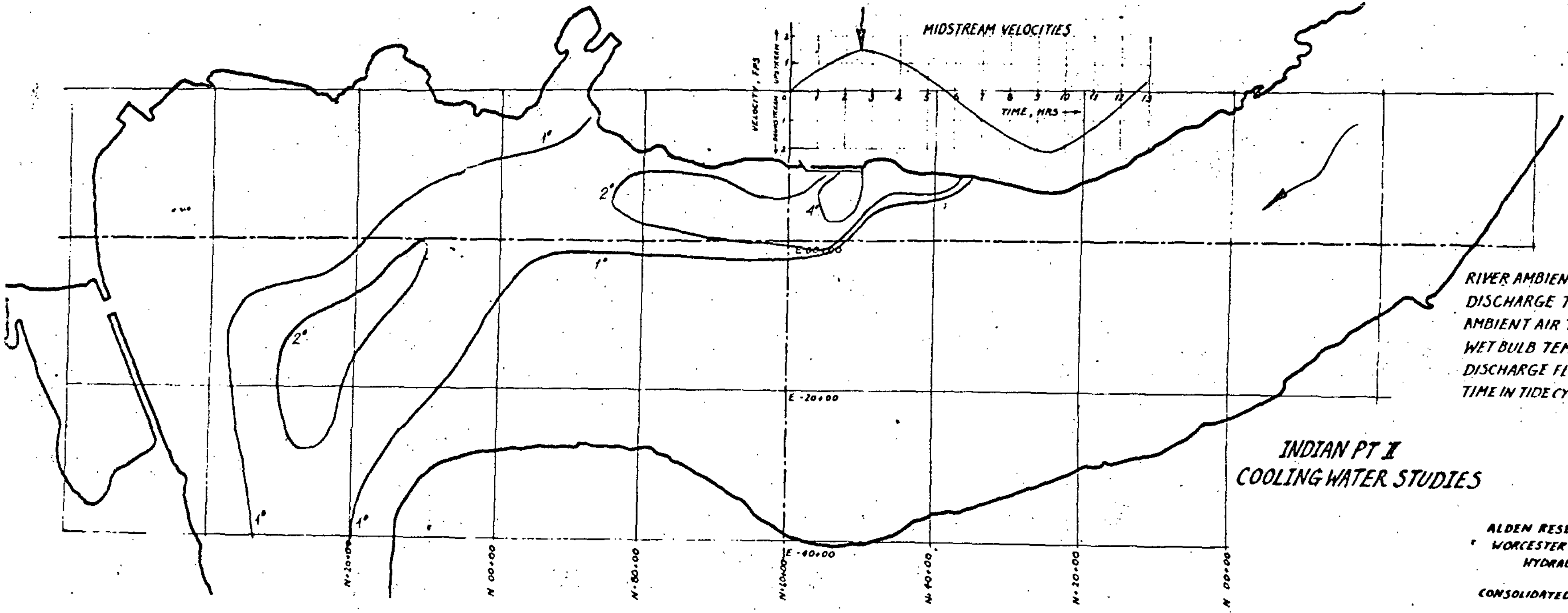
FIG A-2

~~Fig 2~~



RIVER AMBIENT TEMPERATURE 50° F
DISCHARGE TEMPERATURE 67°
AMBIENT AIR TEMPERATURE 52°
WET BULB TEMPERATURE 49°
DISCHARGE FLOW RATE 4670 CFS (3 UNITS)
TIME IN TIDE CYCLE, SEE DIAGRAM

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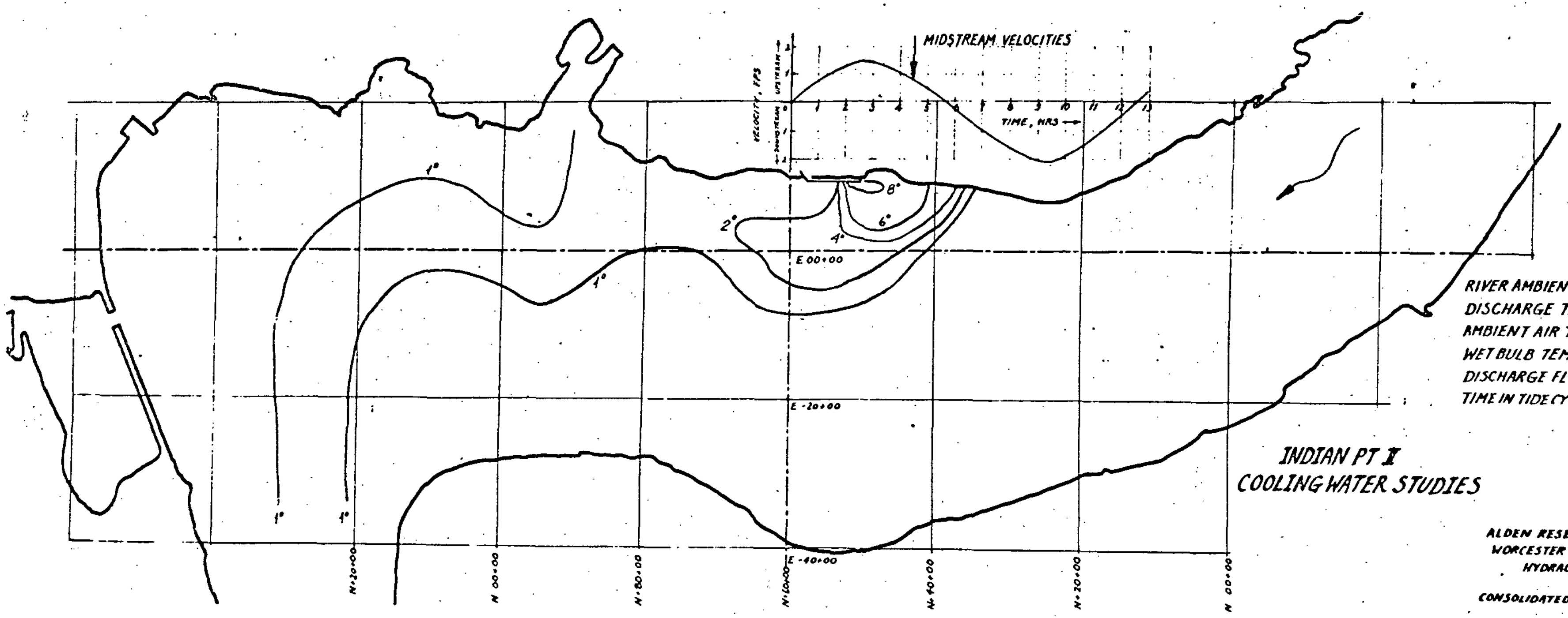
FIG A-3

~~Fig 3.~~



RIVER AMBIENT TEMPERATURE 50 °F
DISCHARGE TEMPERATURE 67 "
AMBIENT AIR TEMPERATURE 52 "
WET BULB TEMPERATURE 49 "
DISCHARGE FLOW RATE 4670 CFS (3 UNITS)
TIME IN TIDE CYCLE, SEE DIAGRAM

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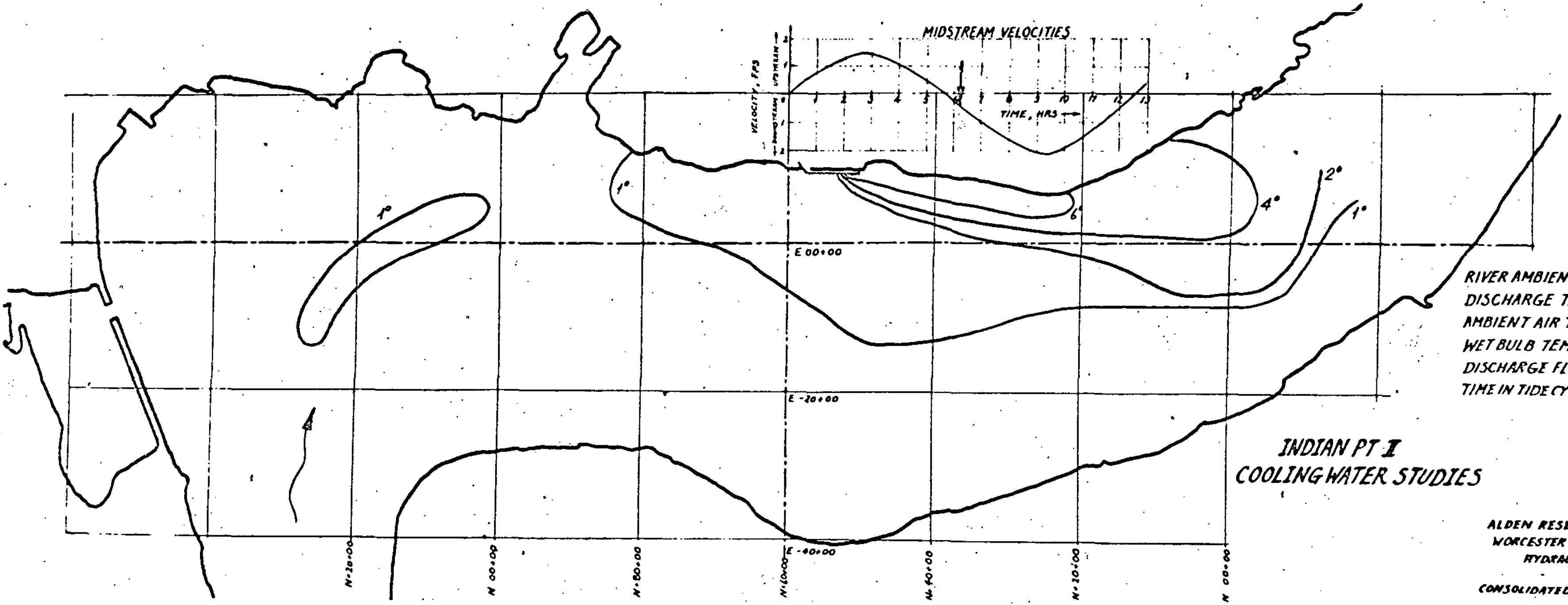
FIG A-4

~~Fig 4~~



RIVER AMBIENT TEMPERATURE 50 °F
DISCHARGE TEMPERATURE 67°
AMBIENT AIR TEMPERATURE 52°
WET BULB TEMPERATURE 49°
DISCHARGE FLOW RATE 4670 CFS (3 UNITS)
TIME IN TIDE CYCLE, SEE DIAGRAM

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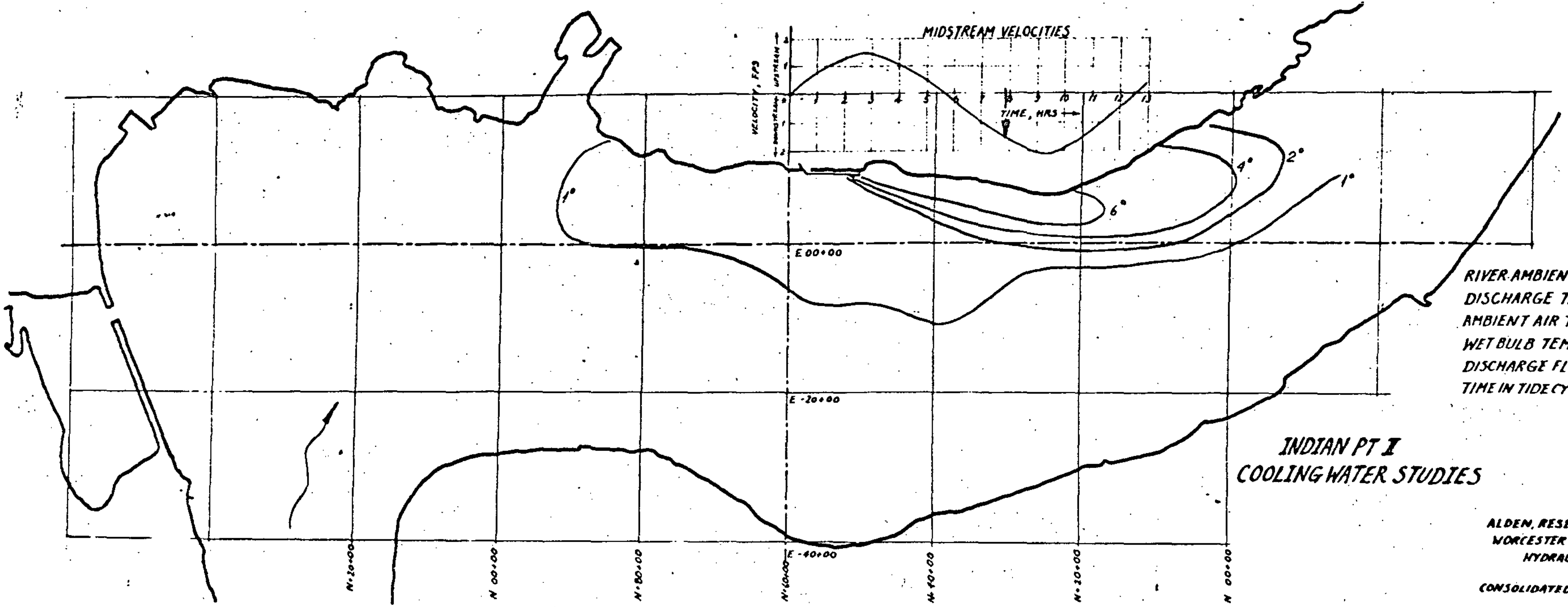
FIG A-5

~~Fig 5~~



RIVER AMBIENT TEMPERATURE 50°F
DISCHARGE TEMPERATURE 67°
AMBIENT AIR TEMPERATURE 52°
WET BULB TEMPERATURE 49°
DISCHARGE FLOW RATE 4670 CFS (3 UNITS)
TIME IN TIDE CYCLE, SEE DIAGRAM

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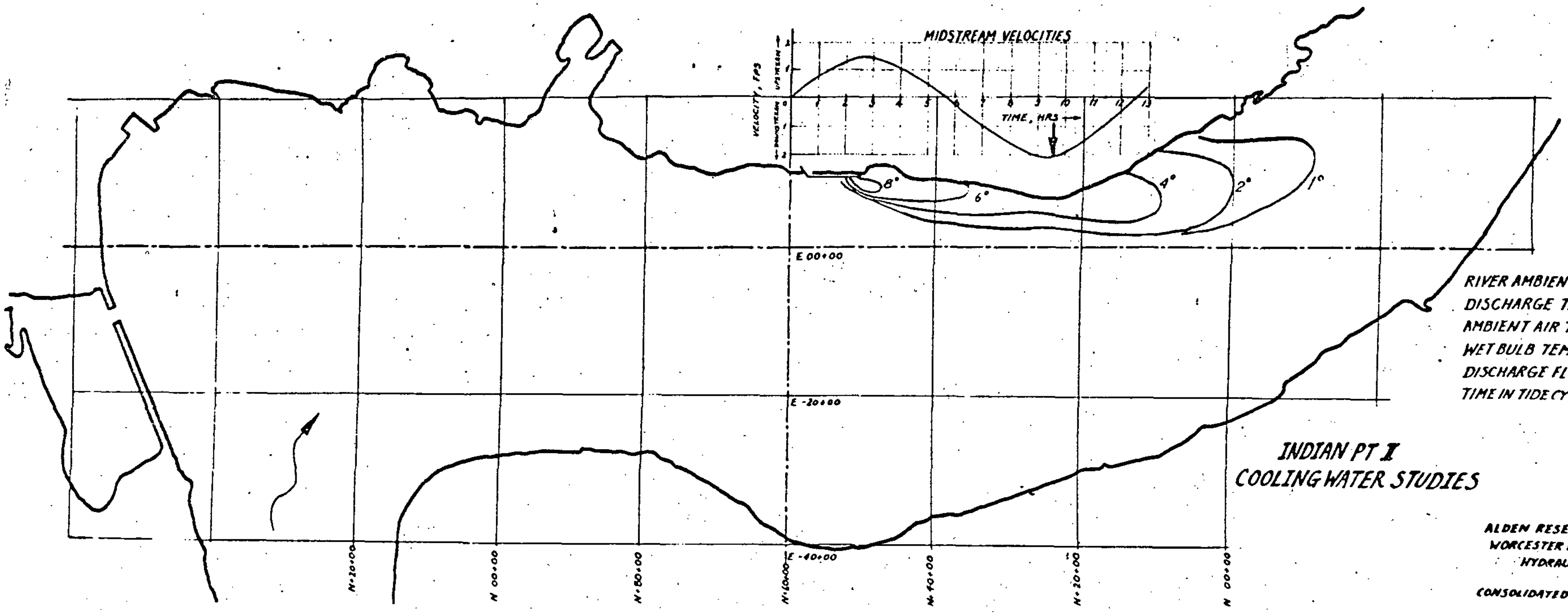
FIG A-6

~~Fig 6.~~



RIVER AMBIENT TEMPERATURE	50° F
DISCHARGE TEMPERATURE	67°
AMBIENT AIR TEMPERATURE	52°
WET BULB TEMPERATURE	49°
DISCHARGE FLOW RATE	4670 CFS (3 UNITS)
TIME IN TIDE CYCLE, SEE DIAGRAM	

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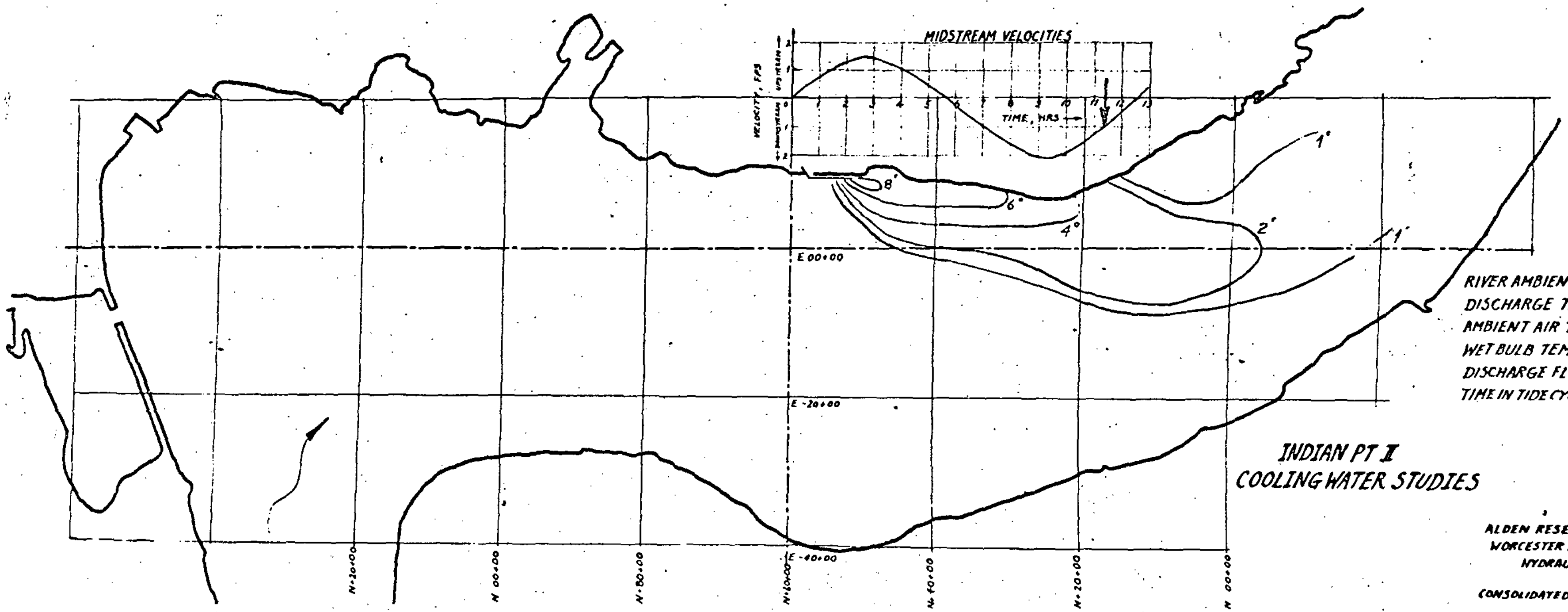
FIG A-7

~~Fig 7.~~



RIVER AMBIENT TEMPERATURE 50° F
DISCHARGE TEMPERATURE 67°
AMBIENT AIR TEMPERATURE 52°
WET BULB TEMPERATURE 49°
DISCHARGE FLOW RATE 4673 cfs (3 units)
TIME IN TIDE CYCLE, SEE DIAGRAM

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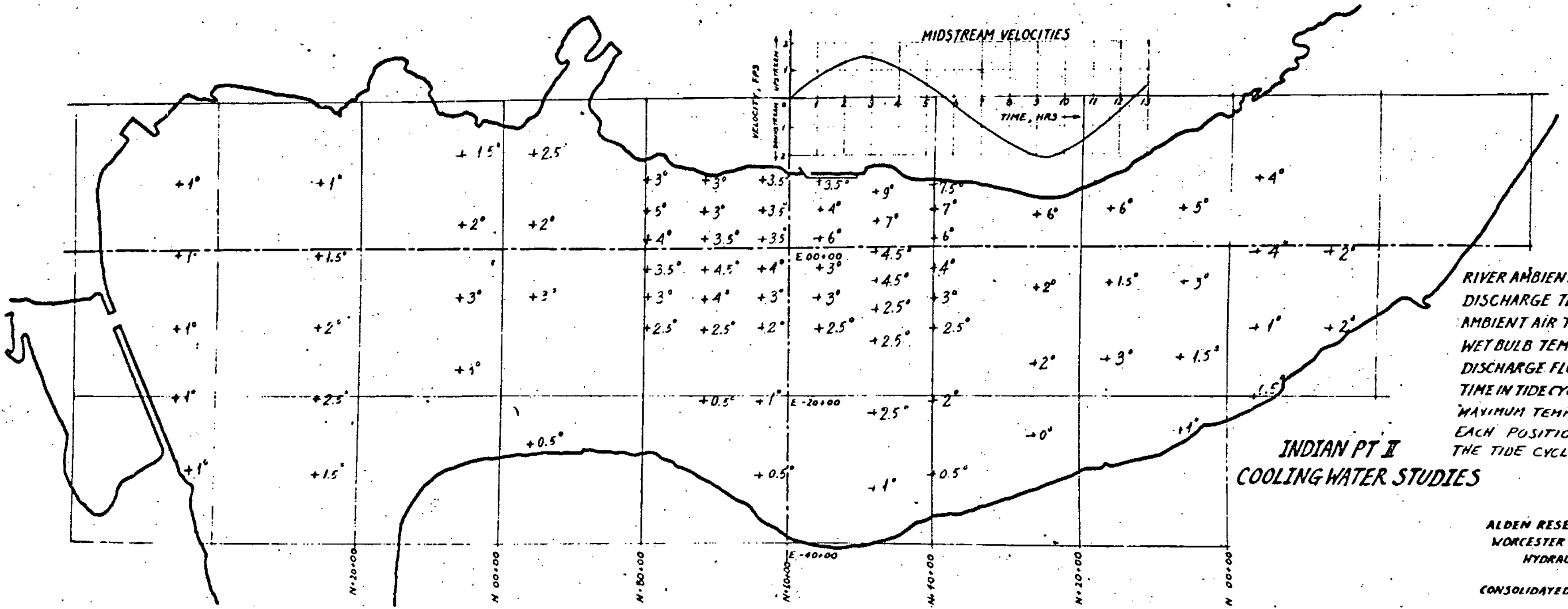
FIG A-8

~~FIG 8.~~



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COOLING WATER STUDIES

RIVER AMBIENT TEMPERATURE 55 °F
DISCHARGE TEMPERATURE 67 °
AMBIENT AIR TEMPERATURE 52 °
WET BULB TEMPERATURE 49 °
DISCHARGE FLOW RATE 4670 cfs (3 units)
TIME IN TIDE CYCLE, SEE DIAGRAM
MAXIMUM TEMPERATURE RISE AT EACH POSITION INDICATED THROUGHOUT THE TIDE CYCLE.

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Note that Figure A-8 does not represent a pattern that can occur at any one time in the River. Each maximum value occurs at a different time during the tidal cycle. This figure merely reflects the fact that all the water particles, including the warmest, oscillate back and forth. At any given point in time these warmest particles will locate in a certain limited area. Figure A-8 shows the locus of this area throughout the tidal cycle.

The behavior of the heated discharge, as it mixes with River water, is described by the Alden Laboratory in correspondence accompanying the submission of Figures A-1 through A-8 to Consolidated Edison. These remarks are as follows:

> "1. The maps are produced to show the distribution at the surface with time of the heated cooling water. The conditions of the test represented an ambient river temperature of 50°F and a discharge temperature of 67°F from Units #1, 2 and 3 (4670 cfs). T = 0 is arbitrarily taken as the time when flow starts being fed into the model at its downstream end (Verplanck Point.) The isotherms are based on the recording of 78 thermocouples in different positions in the model from which has been subtracted the ambient river temperature. The ambient temperature was evaluated from two thermocouples placed in the incoming flow to the model.
>
> Figure A-1 shows the conditions at T = 1 hour. During the slack preceeding flood a build-up of warm water takes place and in this period of time the width of the river being affected by warm water assumes a maximum for this section of the river.
>
> Figure A-2 indicates the conditions 1-1/2 hours later (t = 2.6 hrs). The cooling water is now forced with the river flow in an upstream direction. The build-up shown on Figure 1 has produced an "island" of warmer water, 2°, which is on its way to leave the model. It is also noted that the maximum temperature rise in the vicinity of the plant is reduced due to the higher flow velocities and following more efficient mixing.

Letter from Alden Research Laboratories (C.C. Neale), dated December 30, 1968 to Mr. Edward G. Watkins, Structural Engineer - Consolidated Edison Company of New York, Inc. 4 Irving Place, New York, N.Y. 10003.

Figure A-3 at 4.5 hours is towards the end of the flood tide. As a result of the reducing flood current the isotherms indicate a trend towards swelling. Also due to less efficient mixing the isotherms in the plant vicinity assume higher values.

Figure A-4 shows the conditions shortly after slack before ebb. An "island" of 1° warm water is left behind upstream of the plant and there is seen to be an accumulation of cooling water in the river section adjacent to the plant. However, the build-up of cooling water is not so extensive at slack preceeding ebb as with slack preceeding flood since the change from flood to ebb takes place more swiftly than the change from ebb to flood.

Figure A-5 shows the conditions towards maximum ebb strength. The cooling water is now swept downstream along the east shore. Some cooling water is still left behind upstream of the plant.

Figure A-6 indicates the situation at maximum ebb. The cooling water is swept downstream in a relatively narrow position of the river along the east shore. Due to the efficient mixing at the rather high current velocities the isotherms are closed curves -i.e., even the 1° isotherm terminates within the model.

Figure A-7 shows the conditions towards the end of the e ebb tide. Compared to Figure 6 the current velocities are reduced and the isotherms tend to spread out and also to extend further downstream. This isotherm pattern eventually transforms itself into the pattern shown on Figure 1, thereby completing a cycle.

2. Figure A-8 shows the maximum temperatures at each of the 78 probe locations as recorded at any time within the tide cycle. It should be noted that the picture presented in this way tends to give a pessimistic impression of the temperature effect on the river."

The following section considers these results in the context of the mathematical analyses presented previously, and relates the model behavior to the prototype.

Correlation of Hydraulic Model With Predictive Model

The net flow in the hydraulic model for the conditions shown in Figures A-1 through A-8 was 33,000 cfs. This represents a high runoff condition, similar to that which existed during the April, 1967 field survey.

This high flow is necessary for correlation with the prototype. The model contains no salt, and, therefore, the normal estuarine net non-tidal flow pattern is not reproduced in the model. However, this effect is weakest where salt is not present, which is the case at Indian Point when the freshwater runoff exceeds 20,000 cfs.

On Page 19, in discussing the net non-tidal flow mechanism, it is noted that it is unlikely that this effect explains the rapid temperature decay observed in the River during the April, 1967 high flow condition. The observed high dilution and rapid decay is presumed to be caused by relatively high longitudinal dispersion coefficients accompanying the high runoffs.

During low flow conditions in the Hudson River, longitudinal dispersion has been shown, in previous studies, to be primarly a function of salinity induced circulation and tidal turbulence. Since the runoff is small, the contribution of fresh water velocity gradients to the overall dispersion effect is small, and beyond the salt front, dispersion becomes negligible. A discussion of why this is not the case in the presence of high freshwater flows follows.

In the presence of these salt and tide mechanisms, back-mixing or dispersion of salt or a pollutant upstream of its source occurs, and is explained in terms of a longitudinal dispersion coefficient which permits upstream as well as downstream movement. Hence the location of the salt front is generally considered to be the point where the contribution of salt to the dispersion is small.

During low flows, the salt intrudes relatively far up into the estuary and, since tidal power also decreases with distance upstream, the tidal contribution to the dispersion is also small at this point. Thus, beyond the salt front in the presence of low runoff, the longitudinal dispersion coefficient is small and is often neglected.

In the presence of high flows, however, the runoff is the predominant mechanism, and forces the salt well downstream. The longitudinal dispersion effect accompanying these high flows may be quite high, but may only be utilized to describe downstream pollutant movement.

Some back-mixing will occur since tidal power is still relatively high but this will generally be limited to a tidal excursion. Upstream pollutant movement, therefore, can be considered to be negligible beyond a tidal excursion.

Thus, for high flow conditions, the model simulates the prototype and the adjusted mathematical model may be employed to show correlation between model and prototype behavior.

Table 14 summarizes calculations, for model conditions, for the area-average and surface width temperature rises at the plane of discharge in the model, using the adjusted mathematical model. Note that the usual low dispersion coefficient of the unadjusted model is employed. The improved effect, described above, must be considered as being contained in the adjusted coefficient.

With respect to this adjusted mathematical model, it should be noted that it is now primarily an empirical formulation. It is not likely that the parameters which appear in Equation 1 will appear in the same order in the correct theoretical description of these thermal phenomena. For this reason, there seems to be little value in converting the adjustment factors in Table 7 into improved flows, dispersion coefficients, etc.

The value of the adjusted model is that it represents correctly the observed exponential behavior. The functional form, which the physical parameters in the unadjusted model take, has been maintained because it provides a convenient means of considering seasonal changes in the hydrological and meteorological mechanisms that control the temperature distributions. The major extrapolation from observed data is in the heat load itself. The temperature response is believed to remain linearly dependent on this parameter, so that use of Equation 1 is presumed to be valid.

The model heat transfer coefficients are not well defined. The value of $\bar{K}$ used in Table 14 is roughly equal to the average of available data on this parameter. Observation of Equation 1, however, shows this value plays a relatively small role in the rapid decay of temperature in the vicinity of Indian Point. As described previously, mixing, dispersion and dilution are the primary reasons for the observed temperature behavior, and, for high flow conditions, the model effects these.

TABLE 14

CALCULATIONS FOR AREA-AVERAGE TEMPERATURE RISE AND SURFACE WIDTH ISOTHERMS AT PLANE OF DISCHARGE HYDRAULIC MODEL CONDITIONS

Conditions

$H = 430 \times 10^9$ BTU/day, $\Delta T_{sm} = 8.4^\circ F$

$Q = 33{,}000$ CFS, $U = 3.38$ miles/day, $E = 2$ sq. miles/day

$\bar{K} = 110$ BTU/SF/Day/$^\circ$F, TSF = 1.2, $K' = 0.053 \text{ day}^{-1}$

$f_5 = 0.54$

Area Average and Surface Average Temperature Calculations

$$\frac{f_5 H}{\rho C_p Q} = \frac{0.54 \times 430 \times 10^9}{54 \times 10^5 \times 3.3 \times 10^4} = 1.31^\circ F$$

$$\frac{4K'E}{U^2} = \frac{4 \times 0.053 \times 2}{3.38 \times 3.38} = 0.037$$

$$\Delta\bar{T} = 1.31 \times {}^{-1}\sqrt{1 + 0.037} = 1.28^\circ F$$

$$\Delta\bar{T}_s = 1.2 \times 1.28 = 1.53^\circ F$$

Percentage of Surface Width Bounded by Given Isotherm

$\Delta\bar{T}_s/\Delta T_{sm} = 1.53/8.4 = 0.18$

% Surface Width	$\Delta T_s/\Delta T_{sm}$ (Fig. 24)	ΔT_s, $^\circ$F
10	0.58	4.9
20	0.33	2.8
30	0.19	1.6
40	0.11	0.9

The maximum tidal average surface temperature across the plane of discharge is 8.4°F, as will be shown shortly in Figure 28. This is higher than the 6°F which the submerged discharge will be able to effect, due to a smaller submergence in the distorted model.

The thermal stratification factor employed in this model analysis is 1.2, considerably smaller than the values used previously in projecting actual River performance under critical conditions. This value was chosen because the distorted vertical scale is believed to create conditions closer to complete mixing than will occur in the prototype.

Table 14 shows exponential decay of surface temperature with surface width across the discharge plane. These results agree very well with the plane of discharge tidal average surface temperature rise isotherms shown in Figure 28.

The curves in Figure 28 were constructed by first constructing similar curves at each station for each of the seven tidal phases represented in Figures A-1 through A-7. For each station, the seven sets of data, which consist of surface rise isotherms versus percentage of surface width bounded by a given isotherm, were then averaged to yield average surface width bounded by a given isotherm, and the curves of Figure 28 drawn.

Figure 28 shows that the exponential decay model is followed closely at the plane of discharge (Station 0 + 0 in Figure 28) and immediately above and below the plane of discharge.

The agreement between the results obtained in Table 14, analyzing the hydraulic model conditions with the adjusted mathematical model, and those in Figure 28, obtained directly from hydraulic model surface isotherms, is shown below:

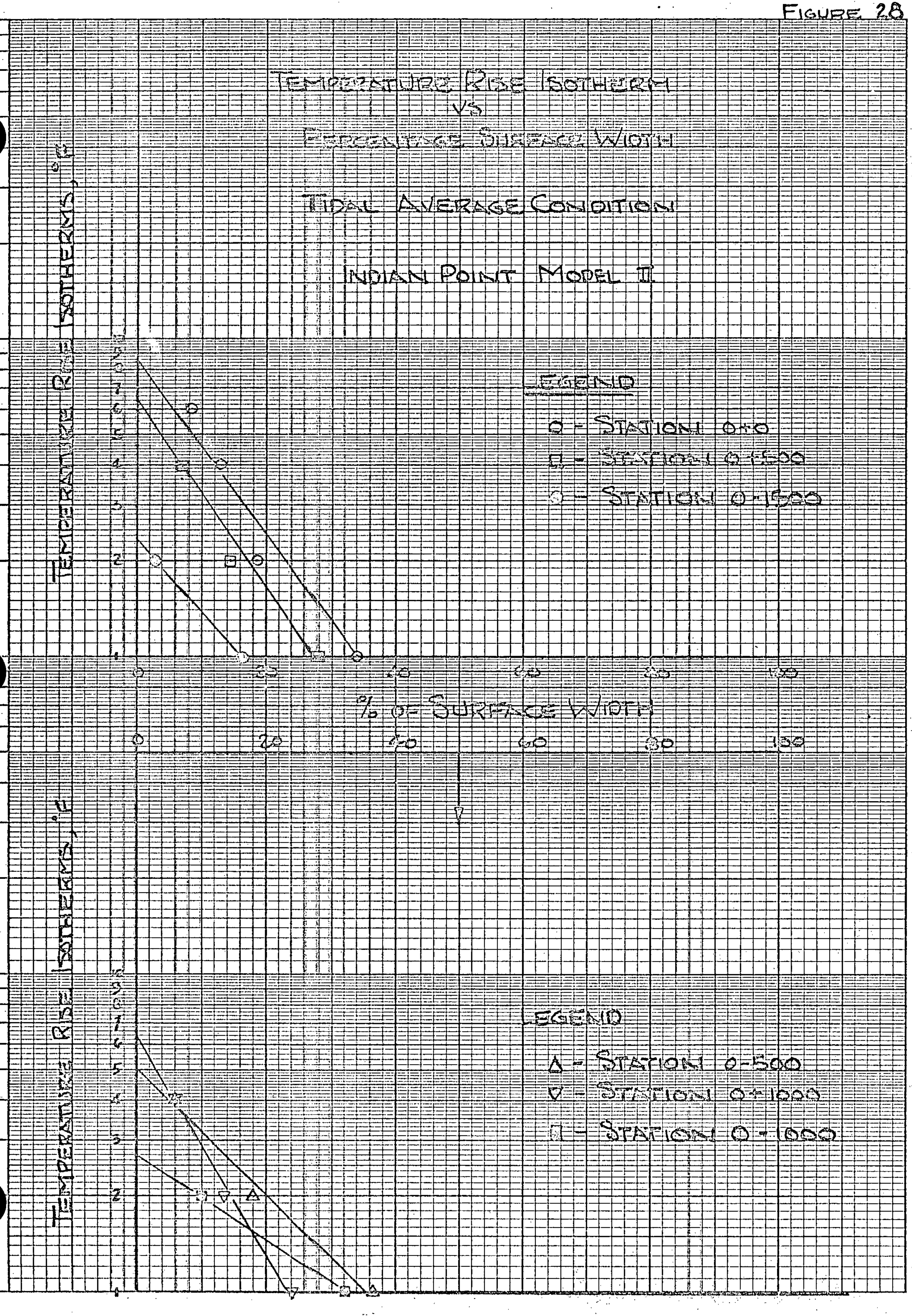
% of Surface Width	Hydraulic Model Surface Temperature Rise, $\Delta\bar{T}_s$, °F	
	Using Math. Model (Table 14)	Averaging Measured Surface Isotherms (Figure 27)
10	4.9	4.5
20	2.8	2.4
30	1.6	1.3
40	0.9	0.7

FIGURE 28

TEMPERATURE RISE ISOTHERM
VS
PERCENTAGE SURFACE WIDTH

TIDAL AVERAGE CONDITION

INDIAN POINT MODEL II



This agreement is quite good and further confirms the validity of using the adjusted model to predict three unit behavior. The average surface temperature rise, ΔT_s, for the plane of discharge curve in Figure 28 was 1.35°F by comparision to the 1.53°F obtained in Table 14. Of course, latitude in the selection of the thermal stratification factor affords some control over these results; the value chosen however, is believed to be approximately correct for the reason given.

The surface average temperature rise, $\Delta \bar{T}_s$, of each curve in Figure 28 was also computed. These results are given below:

Station	Location	ΔT_s, $^{\circ}$F
0-1,500	1,500 ft. upstream	0.44
0-1,000	1,000 ft. upstream	0.81
0- 500	500 ft. upstream	1.00
0+0	Plane of discharge	1.35
0- 500	500 ft. downstream	0.94
0+1,000	1,000 ft. downstream	0.77

Area average temperature rises should be slightly less than these values. The TSF values for the station above and below the plane of discharge are probably closer to unity then is the value for the plane of discharge, as evidenced by the rapid decay of the maximum surface temperature shown in Figure 28.

The rapid decay shown above was compared to decay according to Equation 1 for the hydraulic model conditions given in Table 14. The procedures shown in Table 13 were used with the parameters in Table 14 to compute the decay coefficients j_1 and j_2.

The decay coefficients j_1 and j_2, using the model adjustment factor given in Table 7, were 22 and 0.22 miles^{-1}, respectively. The upstream value of 22 mile^{-1} is for more rapid than that observed in the Alden model and is probably due to the fact that the f_4 factor for April, 1967 of 12.9, representing observations below Indian Point at that time, was arbitrarily applied to the upstream region as well.

In light of the discussion above of the longitudinal dispersion effect in the presence of high flows, this procedure effectively does not credit the upstream region with back-mixing. The f_3 factor is probably actually substantially lower than f_4, rather than equal to it. This would yield surface average values substantially in agreement with those given above.

The downstream decay coefficient of 0.22 mile^{-1} yields $\Delta \bar{T}$, and therefore $\Delta \bar{T}_s$, values which are larger then those given above. This is probably due to the fact that the term $(1- \sqrt{1+N})$ is very sensitive for small values of N. The value obtained, (-0.02), may not be extremely accurate.

Submerged Discharge

A submerged outlet in the effluent channel is planned for discharging the heated effluent to the River. This type outfall was selected to insure that the proposed criterion of a 90°F maximum surface water temperature at any point in the River's surface be met at all times. The submerged outfall, by comparison to a surface discharge, will also reduce the percentage of the surface width subject to temperature rises greater than 4°F.

The effect of various submerged outfall designs and depths of submergence was studied in detail in an undistorted model of the River in the near vicinity of Indian Point by the Alden Hydraulic Laboratory. A copy of Alden's report on this study is appended to this present report. A summary of the major findings is given in Table 15.

Reduction in temperature occurs by entrainment of the surrounding ambient water as the jet of heated liquid works it way toward the surface. This phenomenon is called initial jet dilution and has been the subject of numerous theoretical analyses.

A simplified analyses of this mechanism was attempted to permit evaluation of submerged discharge under conditions of submergence and effluent channel temperature rise other than those studied in the Alden model.

This approach first obtained the path of the jet by assuming it follows the kinematics of projectile motion, employing the acceleration due to the buoyancy of the lighter warmer water, and the average horizontal velocity of the jet. The normal dilution formulae for jet entrainment were then employed to determine the extent of the dilution by the time the jetted fluid reached the River's surface.

TABLE 15

SUMMARY OF ALDEN HYDRAULIC LABORATORY FINDINGS FOR DISCHARGE OF THREE UNIT HEATED WATER THROUGH A SUBMERGED OUTFALL

Test Conditions

Model Scale: 1:50 undistorted

Three Unit Flow: 4,660 CFS (2,100,000 GPM)

Effluent Channel Temperature Rise: 17°F

Total Length of Discharge Canal from First Through Last Port: 230 Ft.

Port Design: 6 Rectangular Ports, each 30 Ft. Long, 4 Ft. High

Port Spacing: 10 Ft.

River Flow: Approximately 25% of Average Ebb Tide

Port Velocity: 10Ft/Sec

Summary of Maximum Surface Temperature Rises

Submergence to Top of Port (Ft. below MSL)	Depth to Channel Bottom (Ft. below MSL)	Maximum Surface Temperature Rise (°F)	Location of Maximum Rise (Ft. of Shore)
16	20	9	200
21	25	8	200
26	30	6	200

This approach yielded results which showed substantially greater dilution than was obtained in the model. The fact that buoyant acceleration, which appears in the calculations, is extremely sensitive to small density changes is the probable reason for the lack of good agreement.

Since the model results were more conservative, they were used, in conjunction with an extremely simple but very conservative view of jet dilution, to predict behavior at the planned discharge temperature of 14°F.

The second approach begins by assuming the jet rises to the surface in a straight vertical direction. The formula for dilution of a jet into a fluid of equal density is used. This is written:

$$S_o = 0.32\ X/D_o \qquad (6)$$

in which: S_o = ratio of River water entrained in the jet to the discharge channel flow

X = distance from the port at which the dilution, S_o, is measured

D_o = effective port diameter, or better, the effective diameter of the jet's vena contracta

The value of S_o is computed at X equal to the submergence of the port center line. A computed maximum surface temperature rise, ΔT_{sm}, is then obtained as follows:

$$\Delta T_{sm} = \frac{\Delta T_p}{1+S_o} \qquad (7)$$

in which: ΔT_p = effluent channel temperature rise

Table 16 shows values of ΔT_{sm}, obtained by using Equations 6 & 7, for the model conditions given in Table 15. The values of ΔT_{sm} observed in the model are smaller, as expected, since Equations 6 & 7 ignore the horizontal nature of the initial jet velocity and the resultant curvilinear path, as well as the additional entrainment due to the relative motion induced by the buoyancy effect.

The ratio of the observed to computed values of ΔT_{sm} is computed in Table 16 for each of the three model submergence conditions.

TABLE 16

COMPARISON OF COMPUTED AND OBSERVED MAXIMUM SURFACE TEMPERATURE RISES FOR $\Delta T_p = 17^oF$, AND PREDICTIONS FOR $\Delta T_p = 14^oF$

Computed Surface Temperature Rise for $\Delta T_p = 17^oF$

$$\Delta T_{sm} = \frac{\Delta T_p}{1 + \frac{0.32x}{D_o}}$$

$$D_o = \frac{120 \times 0.65}{0.785} = 10 \text{ FT.}$$

Centerline Submergence, FT (x)	ΔT_{sm} Computed From Equations 6 & 7	ΔT_{sm} Measured in Model (See Table 15)
18	10.8	9
23	9.8	8
28	8.9	6

Computed Surface Temperature Rise for $\Delta T_p = 14^oF$

Centerline Submergence	ΔT_{sm}, Computed	$\frac{\Delta T_{sm}\text{, observed}}{\Delta T_{sm}\text{, computed}}$	ΔT_{sm}, Adjusted
18	8.9	0.833	7.4
23	8.1	0.817	6.6
28	7.4	0.675	5.0

Equation 7 is then adjusted by these ratios, and used to compute expected temperatures for the planned effluent channel temperature rise of 14°F. Results are given in Table 16.

These results show that, in the presence of a 14°F effluent channel temperature rise, a maximum River surface temperature rise of 6°F can be expected at a center line submergence of about 26 ft., corresponding to a total depth of 28 ft. Model results, of course, show the 6°F surface rise can be obtained for the 17°F channel rise with a center line submergence of 28 ft., or total depth of 30 ft.

APPENDIX A

PROGRESS REPORT

on

INDIAN POINT II STUDIES

for

CONSOLIDATED EDISON COMPANY OF NEW YORK

at

ALDEN RESEARCH LABORATORIES
WORCESTER POLYTECHNIC INSTITUTE
WORCESTER, MASSACHUSETTS, 01609

INTRODUCTION

Different outfall configurations for the cooling water from the Indian Point Power Plant have been studied in the existing Indian Point II model. During the course of these studies it was found desirable to discharge the cooling water from submerged outfall openings facing toward the river. Preliminary studies in the Indian Point II model, which has a distortion of 4.16, indicated that the testing of submerged outlets would yield local results not corresponding to equivalent prototype outlets. The reason was that a jet formed by an outlet, is a specific hydraulic phenomenon, which develops without regard to the model distortion. A free jet, issuing into an infinite ambient recipient, has an angle of divergence of about 11.3°. Therefore in the distorted model the spread of the jet would appear to occur at too low a rate. The cooling water jet would entrain excessive ambient water at the point where the river surface was reached and would therefore indicate a resulting temperature on the low side. Since the results thus would be on the optimistic side, rather than on the conservative side, it was decided to carry out the detailed investigation of the outfall configuration in an undistorted model. The aim of these tests was two-fold: 1) To determine the geometry of the outfalls so as to meet specified requirements with respect to river surface temperatures. 2) To determine the boundary condition to be imposed on the distorted model so as to obtain correct results from this model outside the area directly affected by the outfalls.

THE MODEL

It was decided to construct the undistorted outfall model utilizing the heat capacity of the boiler supplying the distorted model. Part of the sump area for the distorted model was found to be a convenient site for the undistorted model, providing river ambient water for the model without any extra effort in terms of piping, installing of pump capacity, etc. Based on the above conditions a model scale ratio of 1:50 was chosen. Photos #1 and #2 show the model and Figure #1 shows the extent of the modeled area in comparison with the equivalent area of the distorted model. The river bottom topography was modeled on the basis of the data used for the distorted model. The lateral slope of the river bottom outside the outfall is relatively gentle and constitutes an almost plane sloping surface within the nearest 300 to 400 feet off shore. Therefore the increased submergence of the outfalls could be modeled by increasing the depth of water in the model rather than by actually excavating to greater depth of the outfall. This saved considerable time in testing and also gave the advantage of more direct comparison of different amounts of submergence.

Part of the discharge channel and the sheet piling along the river shore, containing the outfall openings, was modeled in sheet metal to an elevation such that a water depth in the discharge channel of up to 32 feet could be modeled. A regulating gate was installed at the downstream end of the model to regulate the depth of water. A 4" warm water pipeline containing an orifice meter and valves for adjusting the temperature as well as the flow rate was installed.

The model was equipped with 22 thermocouples already connected to one of the recorders of the distorted model. These were placed with reference to a grid system for which N60 and the grant of water line were base lines. For detailed measurements a thermistor set with 12 probes was used which provided more flexibility than the more stationary thermocouples.

TEST PERFORMED

The advantage of subsurface discharge is that the cooling water issuing from the discharge openings becomes mixed with ambient water which is entrained from essentially 4 directions. The forced mixing increases with increasing momentum of the discharge flow. However, the force required to produce the momentum must be supplied from the cooling water pumps. It was indicated by the Consolidated Edison Company that an increase of the discharge head of 1.5 feet could probably be tolerated. This was used as a guide for the testing.

An elevation difference of 1.5 feet between the water level in the channel and that of the river corresponds in terms of velocity head to a velocity of about 10 fps. This would theoretically be the velocity of the discharge at the vena contracta of the jet. It was found experimentally that an outfall opening area of about 720 feet^2 was the minimum area for discharging 4660 cfs from units 1, 2 and 3 and not exceeding 1.5 feet water surface elevation difference. (The corresponding coefficient of contraction was 0.65 which was compatible with the configuration of the discharge structure.) It was reasoned that the lower the height of the discharge openings the greater the submergence and thus the more efficient the mixing. Based on the above considerations six discharge openings 4 feet high and 30 feet wide were chosen, separated by 10 foot-wide partitions. The total length of the discharge structure thus was 235 feet including 5 feet of wall downstream from the last opening. The end of the channel was blanked off.

The degree of mixing and thus the drop in effluent temperature depends on the degree of submergence of the outfall openings. This is particularly the case for the temperature at the river surface in the area where the effluent reaches the surface. Therefore three different degrees of submergence of the above described outfall openings were tested.

A test series was performed using a continuous, low slot, again based on 1.5 feet back-up of the water in the discharge channel. Temperature measurements did not reveal any advantage of this design over that consisting of separate openings.

Vanes were tested to help deflect the water at a greater angle to the direction of the discharge channel. Although this visually seemed to indicate an improvement, temperature measurements did not bear this out.

For all tests the discharge temperature was elevated about 17°F above ambient river temperature. Evidently no tidal action was attempted in testing but a slight downstream flow through the model was maintained to prevent heat from building up due to the warm water discharge from the outfall.

TEST RESULTS

Figures 1, 2 and 3 show the test results in terms of surface isotherms. Figure 1 is for a submergence of the outfall openings of 16 feet, ie. the channel bottom was 20 feet below mean sea level. It is seen that the maximum surface temperature above ambient river temperature was 9°F. The highest temperatures occurred downstream from the outfall about 200 feet off shore.

Figure 2 shows the results with a submergence of 21-foot or 25-foot channel depth. The maximum surface temperature was reduced to 8°, again occurring about 200 feet off shore and downstream from the outfalls.

Figure 3 indicates the effect of 26-foot submergence. The maximum temperature rise was found to be 6°F approximately 200 feet off shore, slightly downstream from the end of the channel. Thus an assumed ambient river water temperature of 79° would be expected to yield a maximum surface temperature of 85°F. The channel bottom elevation with this design corresponded to 30 feet below mean sea water level.

Temperature distribution in vertical direction was measured at a couple of points in the area of maximum surface temperature. The temperatures were found to be essentially constant with depth as indicated in the temperature profile shown in Figure 4.

Since the highest temperatures were found at rather close proximity to the model back wall the temperature results did not convince that the model yielded the maximum surface temperature. Tests were therefore conducted to scale 1:75 by changing the outfall model structure and adjusting the flow rate. It was found that the 6°

isotherm was not exceeded. Temperatures, however, stayed constant to about 350' off shore, the maximum distance that could be measured for this model scale ratio without interference with the model back wall. This result was compatible with the finding that the vertical temperature distribution was constant.

Also with the 1:75 model good agreement was found with results from the 1:50 model when corresponding points were compared.

Finally, to verify that the trend towards temperature concentration downstream from the outfall structure would not be accentuated by a downstream river flow, tests were performed with an ambient river flow in the downstream direction. The flow velocities corresponded roughly to an average ebb condition. It was found that the cooling water was deflected so that the maximum temperature would occur close to the shoreline. However, the maximum temperatures were not higher than for the condition of no river flow.

CONCLUSIONS

Model tests in an undistorted scale model of ratio 1:50 indicated that an outfall structure consisting of a vertical wall along the grant of water line, containing six openings 4 feet high and 30 feet wide with partitions of 10 feet and submerged 26 feet to the top of the openings would yield river surface temperature increases not exceeding 6°F. The discharged water had a temperature of 17°F above ambient river temperature.

For constructional reasons it may be desirable to limit the width of the openings. It is felt that as long as the overall length of the outfall structure is maintained the results of this investigation will still be valid. (For example, 12 openings with 5 foot wide partitions.) [Each opening would be 15 FT. wide]

The model tests yielded information for reproducing the temperature conditions in a boundary in the vicinity of the distorted Indian Point II model outfall area.

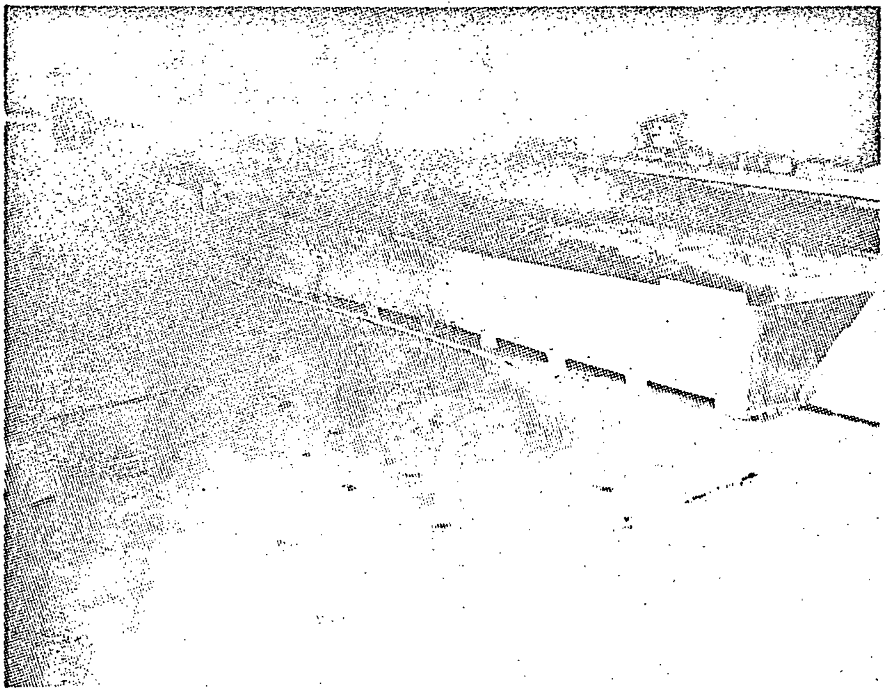


Figure 1

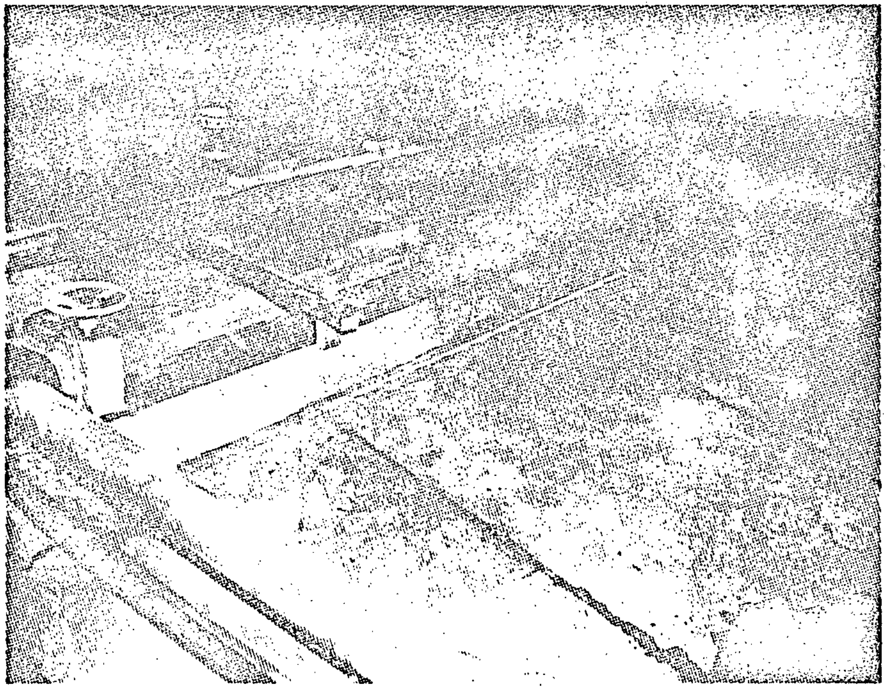
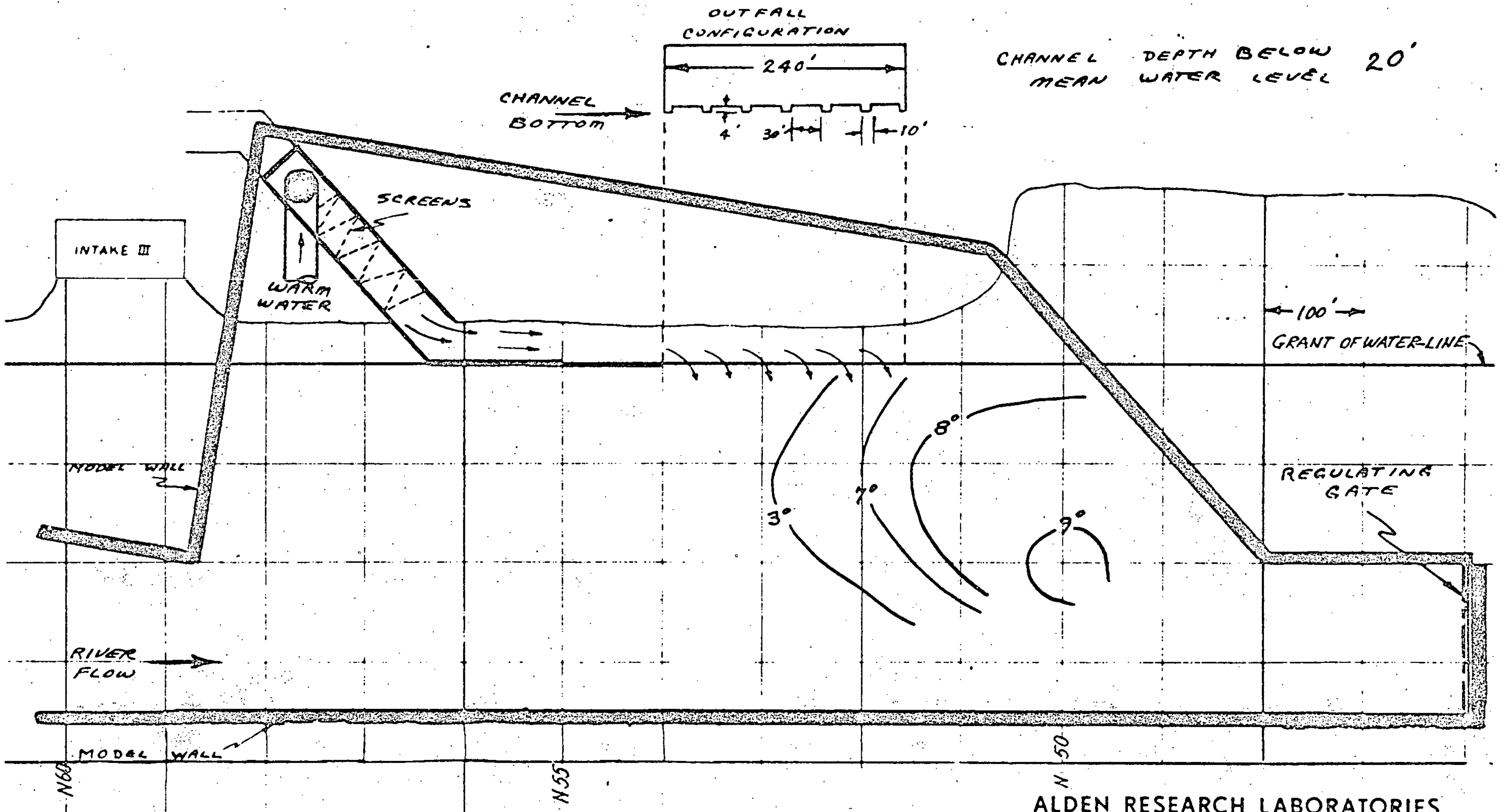


Figure 2

FIG 1



ISOTHERMS ARE SURFACE TEMPERATURES ABOVE AMBIENT RIVER TEMPERATURE.

WARM WATER IS 17°F ABOVE AMBIENT RIVER TEMPERATURE.

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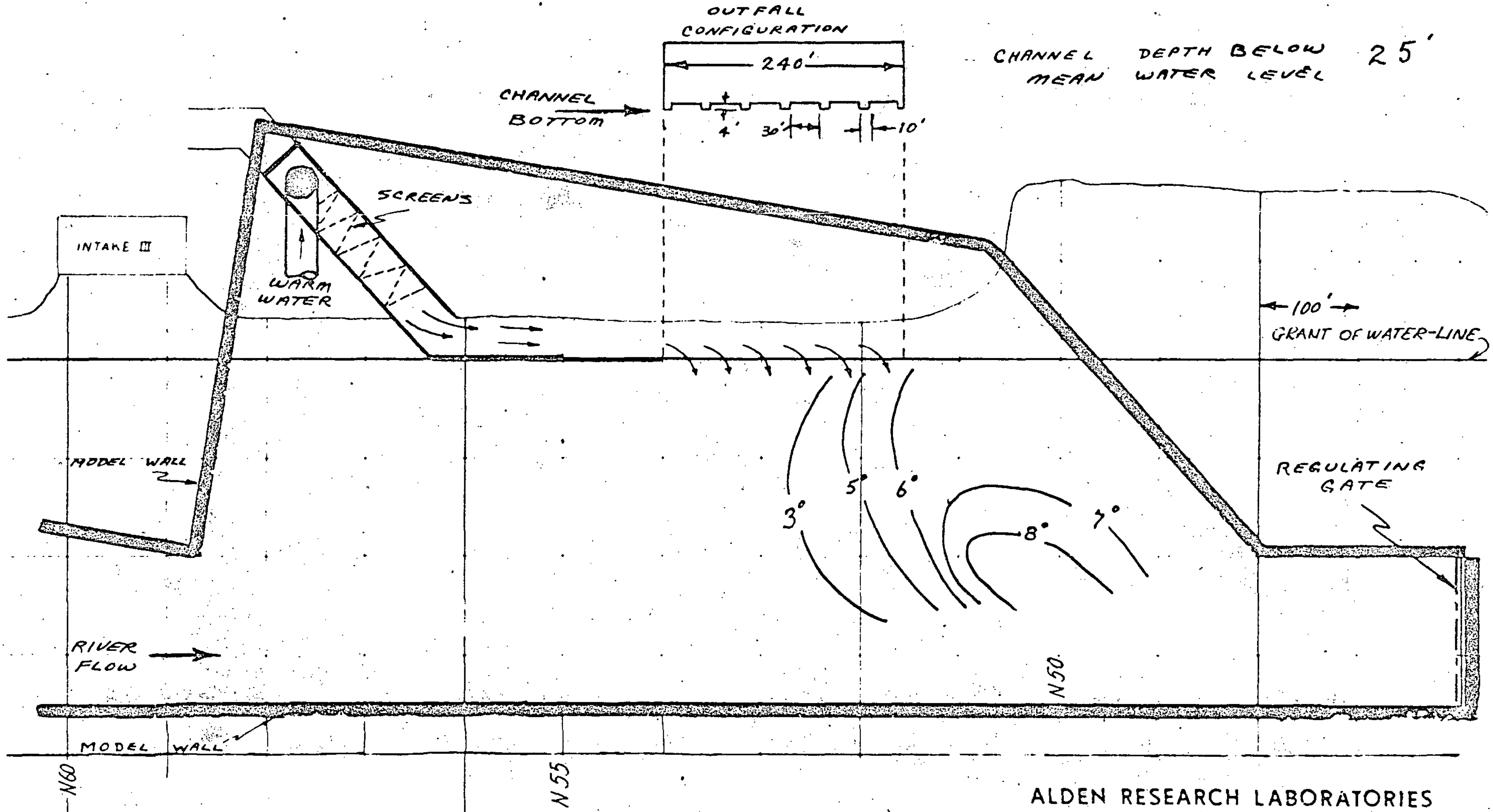
HYDRAULIC MODEL STUDIES FOR
CONSOLIDATED EDISON COMPANY NY
INDIAN POINT II MODEL*
MODEL SCALE: 1' = 50'
*(UNDISTORTED) SUB MODEL

FIG 2



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* (UNDISTORTED) SUB-MODEL

FIG 3

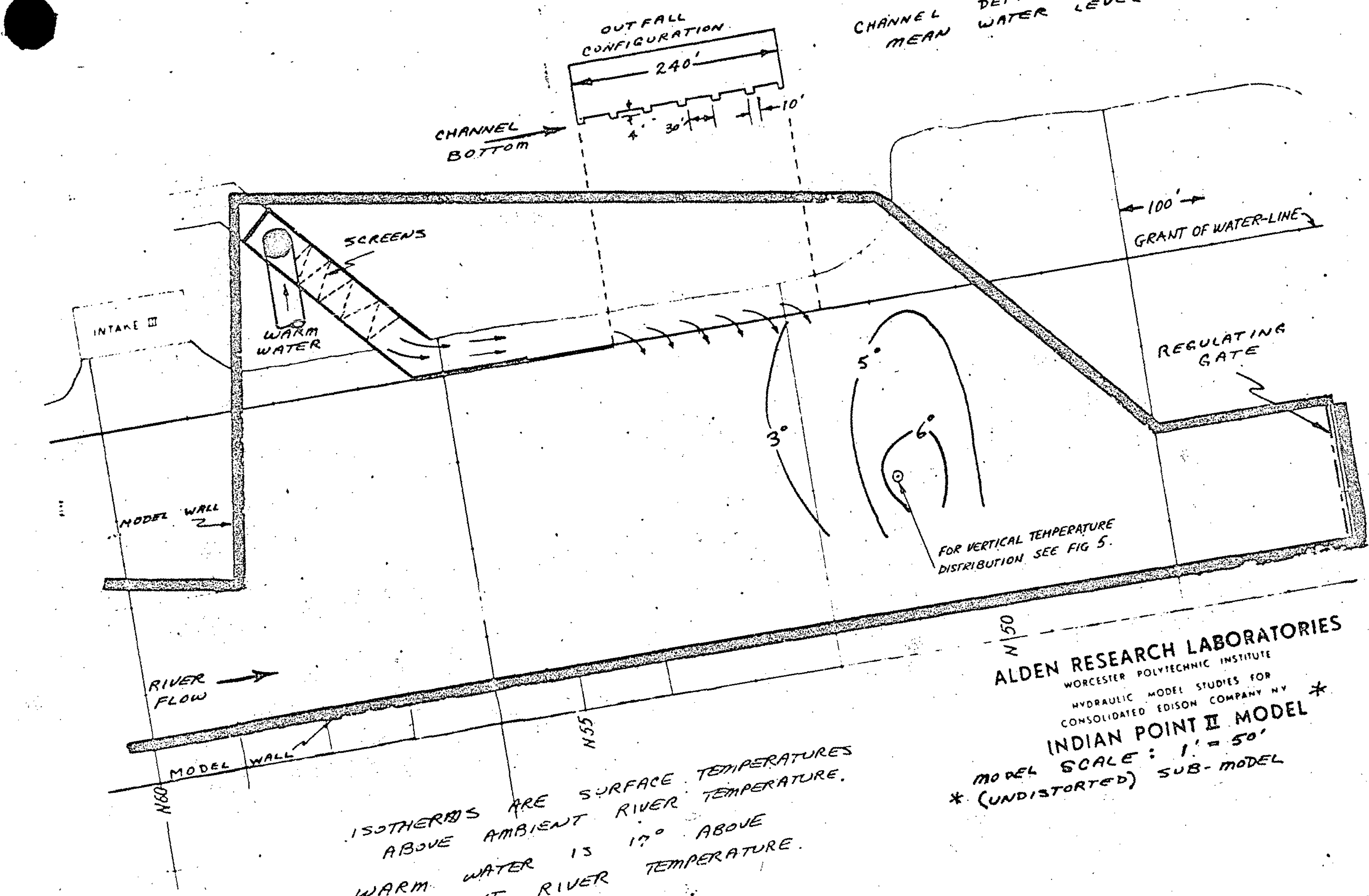

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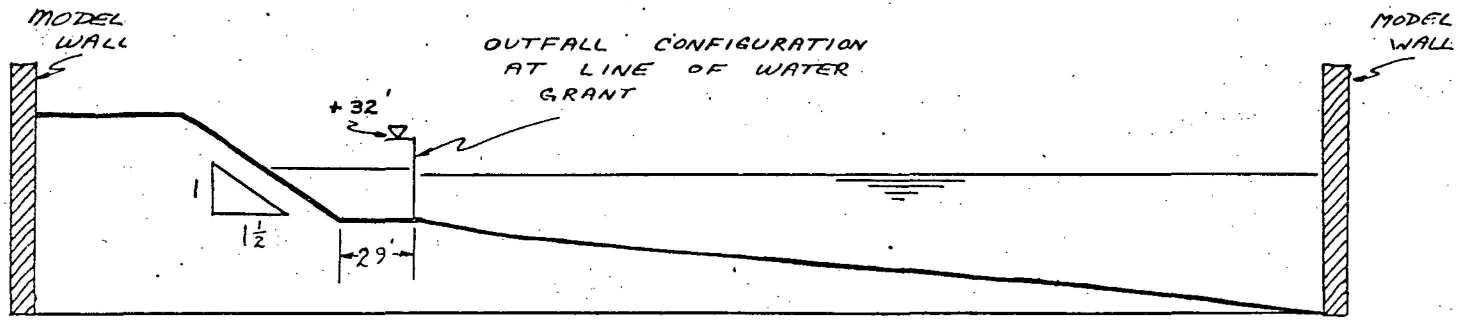
FIG4

TYPICAL CROSS-SECTION



SCALE : 1" = 50'

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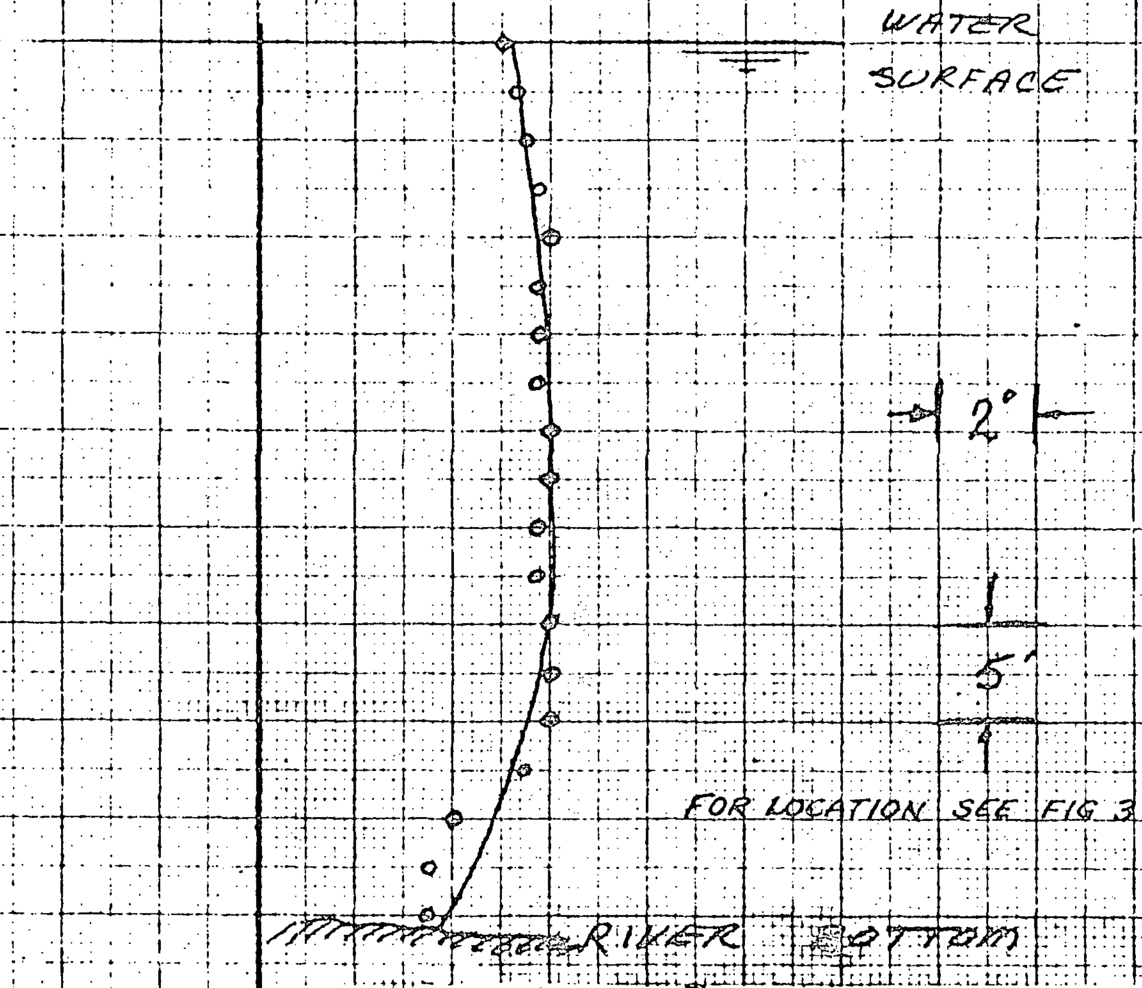
* UNDISTORTED SUB-MODEL
SCALE 1:50

FIG 5

TEMPERATURE VS DEPTH
AT
(N 51, 200' FROM LINE of
WATER GRANT)

DISCHARGE WATER 17° ABOVE AMBIENT



AMBIENT
RIVER
TEMPERATURE

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SCALE 1:50