

ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF ENFORCEMENT

REMOTE SENSING STUDY

OF

THERMAL DISCHARGES

TO

LAKE MICHIGAN

WISCONSIN - ILLINOIS - INDIANA - MICHIGAN

National Field Investigations Center
Denver, Colorado
and
Region V
Chicago, Illinois

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I. SUMMARY AND CONCLUSIONS

An aerial reconnaissance study was conducted along pre-designated segments of the shoreline of Lake Michigan on September 14, 1972. The purpose of this remote sensing study was to document the extent of thermal discharges from the major electric power plants over the area extending from Muskegon, Michigan, to Twin Creeks, Wisconsin. A total of ten power stations were in operation at the time of flight while three others were not in operation.

At the Third Session of the Lake Michigan Enforcement Conference, Recommendation No. 1 was adopted by the Conferees representing Indiana, Michigan, Wisconsin, and the U. S. Environmental Protection Agency which stated that:

"Applicable to all waste heat discharges except as noted above: (*) At any time, and at a maximum distance of 1,000 feet from a fixed point adjacent to the discharge, (agreed upon by the State and Federal regulatory agencies), the receiving water temperature shall not be more than 3°F above the existing natural temperature nor shall the maximum temperature exceed those listed below whichever is lower."

The maximum "surface to three-foot depth" temperature recommended for September is 80°F. Recommendation No. 1 was interpreted in this report to include all power plants discharging directly to Lake Michigan or within three miles of the shoreline.

Thermal data obtained at a distance of 1,000 feet from the outfall, for each of the ten power stations which were in operation on September 14,

*Municipal waste and water treatment plants, and vessels.

1972 are summarized in the following table:

<u>Power Plant</u>	<u>Surface Temperature Increase Over Lake Background at 1,000 Feet From Discharge</u>
Oak Creek	11.5°F (7.4°F at 2,000 feet)
Port Washington	Violation not ascertained
Edgewater	5.5°F (4°F at 2,000 feet)
Point Beach	5.5°F
J. H. Campbell	12°F (6°F at 2,000 feet)
Michigan City	7°F (7°F at 2,000 feet)
Bailly	10.5°F (5°F at 2,000 feet)
Mitchell	4°F
Stateline	3.5°F
Waukegan	6.5°F (4°F at 2,000 feet)

Nine of the above plants were violating the recommended 3°F maximum temperature increase at the distance of 1,000 feet. In addition, six of the power plants were also violating this permitted 3°F increase even at a distance of 2,000 feet from the plant discharge. None of the discharges caused the surface temperature of the receiving water, at the 1,000-foot point, to exceed the maximum allowable surface temperature limit for September of 80°F.

Furthermore, Recommendation No. 3, adopted at the Third Session of the Lake Michigan Enforcement Conference, stated that:

"Discharge shall be such that geographic areas affected by thermal plumes do not overlap or intersect. Plumes shall not affect fish spawning and nursery areas nor touch the lake bottom."

In the vicinity of the Indiana-Illinois state line, eight thermal discharges were recorded, one of which was the Commonwealth Edison Stateline Power Plant. The discharge temperature levels from each of the other unidentified waste sources were considerably higher than that of the Commonwealth Edison Stateline Plant. It was observed that the thermal plumes from these various waste sources were overlapping in most cases, which is in violation of Recommendation No. 3 as stated above.

From the above data, it must be concluded that the recommendations of the Lake Michigan Enforcement Conference are not being met by many sources of thermal and industrial discharges within the Conference area.

II. INTRODUCTION

An aerial remote sensing study of the thermal discharges to Lake Michigan was conducted on 14 September 1972 between the hours of 1300-1500 CDT. This effort was requested by the Enforcement Division, Region V, EPA. The study area included waters affected by discharges from the following electric power generating facilities/areas of interest:

- ..Wisconsin Electric Power Company - Oak Creek Power Station.
- ..WEPC - Lakeside Power Station.
- ..WEPC - Port Washington Power Station.
- ..WEPC - Edgewater Power Station.
- ..WEPC - Point Beach Power Station.
- ..Fox River, Wisconsin (Lake Winnebago to Green Bay).
- ..Michigan Consumers Power Company - B. C. Cobb Power Station.
- ..Muskegon Lake, Michigan (Western Area).
- ..Michigan Consumers Power Company - J. H. Campbell Power Station.
- ..Michigan Consumers Power Company - Palisades Power Station.
- ..Northern Indiana Public Service - Michigan City Power Station.
- ..Northern Indiana Public Service - Bailly Power Station.
- ..Northern Indiana Public Service - Mitchell Power Station.
- ..Commonwealth Edison - State Power Station.
- ..Commonwealth Edison - Waukegan Power Station.

The location of each power station is shown on the map which appears at the back of this report.

The thermal data were recorded by an infrared line scanner (IRLS) on board a USAF RF-4C (Phantom) aircraft. Two such aircraft were utilized

during this study. The temperature resolution of this scanner is 0.1° Centigrade.

The IRLS will record only surface temperatures in water. Water is opaque to this region of the intermediate infrared band. The maximum depth penetration in either fresh or salt water is 0.01 cm. Therefore, a submerged thermal discharge can be detected from an aircraft with an infrared line scanner only if all or part of the warm wastewater reaches the surface of the receiving body of water.

The thermal data were recorded on 5-inch film in the form of a thermal map. At the time of flight, ground truth, in the form of surface water temperatures, was obtained for each power station location. The cooling water inlet and discharge temperatures, and in most cases background water surface temperatures of Lake Michigan, were obtained and provided by EPA, Region V. If the background surface temperatures were not obtained by ground measurements, then the background temperature was extrapolated from the film by a process explained in Section III of this report. These temperature values served as an absolute reference for the calibration, and subsequent analysis of the airborne thermal data, especially for the surface waters 1,000 feet distant from the respective points of thermal discharges. The accuracy placed upon these temperature values, as given in this report, is $\pm 1^{\circ}$ Fahrenheit. Once the calibration described above has been affected, this accuracy becomes a relative number which is not dependent upon or a function of any particular temperature value within the established temperature limits. This accuracy does not include the respective accuracies of the terrestrial instrumentation used by the ground truth personnel to obtain the Lake Michigan surface water, inlet and

discharge temperatures. These values would, to a good approximation, add to the $\pm 1^{\circ}\text{F}$ given above to form a total accuracy for a given temperature value presented.

The wind velocity, at all locations within the flight regime was 5 to 15 knots from the north as determined by the ground truth personnel. The respective power station discharge flow rates at the time of flight, were also provided by ground truth personnel.

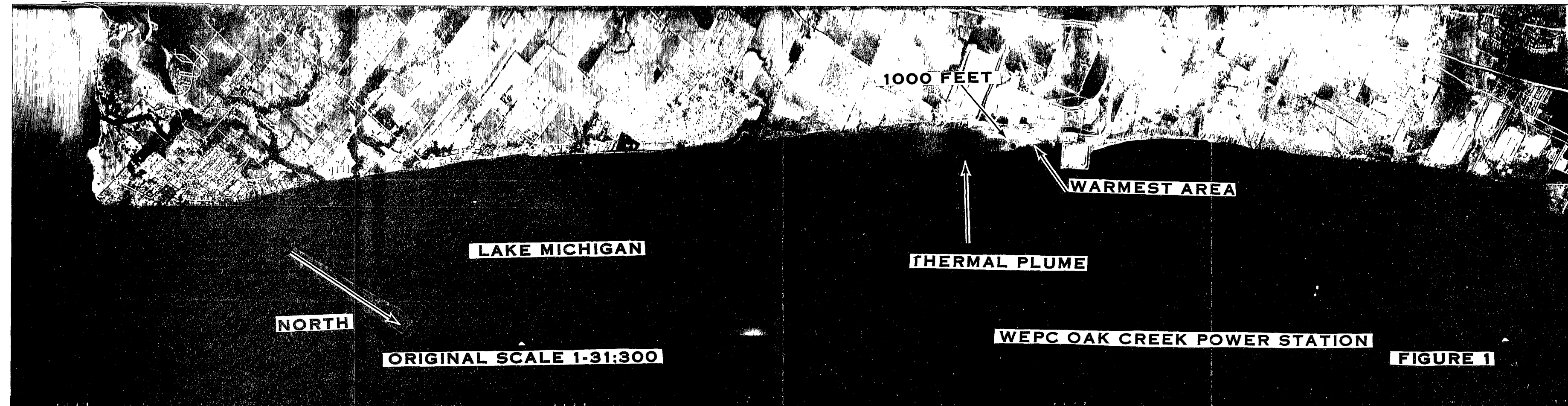
III. RESULTS OF THERMAL DATA ANALYSIS

All data interpretations and analyses were carried out on the original negative from the infrared line scanner. Results of the thermal analyses for each respective power station discharge are presented as follows:

A. Wisconsin Electric Power Company - Oak Creek Power Station

1. The inlet water temperature was 62°F as provided by ground truth.
2. The discharged water temperature at the exit was 76°F, also provided by ground truth.
3. The thermal plume is shown in Figure 1.
4. A thermal transect was optically made along a line approximately 500 feet from and parallel to the shore within the main body of the plume. The temperature vs distance from discharge along the transect is given in the table below:

<u>Distance</u>	<u>Temperature</u> °F
Discharge Exit	76
815 feet	76
1,000 feet	73.5
2,100 feet	69.4
3,225 feet	67
4,070 feet	69.5
5,415 feet	66.6
6,885 feet	65.5
8,515 feet	63.0
9,795 feet	62.5



NORTH

ORIGINAL SCALE 1-31:300

LAKE MICHIGAN

THERMAL PLUME

WEPC OAK CREEK POWER STATION

WARMEST AREA

1000 FEET

FIGURE 1

5. The overall length of the plume was 9,900 feet with respect to the discharge.
6. The maximum width of the plume was 1,220 feet at a point 4,540 feet from the discharge.
7. The discharge flow rate at the time of flight was 858,000 gallons per minute (gpm).

B. Wisconsin Electric Power Company - Lakeside Power Station

1. This plant was not discharging at the time of flight.

C. Wisconsin Electric Power Company - Port Washington Power Station

1. The temperature of the inlet water from Lake Michigan was 60°F.
2. No pronounced thermal plume was detected in this area. The shoreline in the vicinity of the power station, is shown in Figure 2. The power station is located adjacent to the rectangular projections (from the shoreline) on the southern side. Two-dimensional scan was made on the IR film within this area at the points shown in Figure 2. Ground truth reported that the plant's discharge water temperature was 67°F on 14 September 1972, 1300-1400 CDT local. The highest surface water temperature in this area was located approximately 0.5 statute miles south (left) of the rectangular area. Its value was 66°F. The thermal plume may have been dispersed significantly before reaching the water's surface, or otherwise, the station may have ceased discharging, prior to the time of flight. This would explain the temperature variation over the 2.5 square mile area.

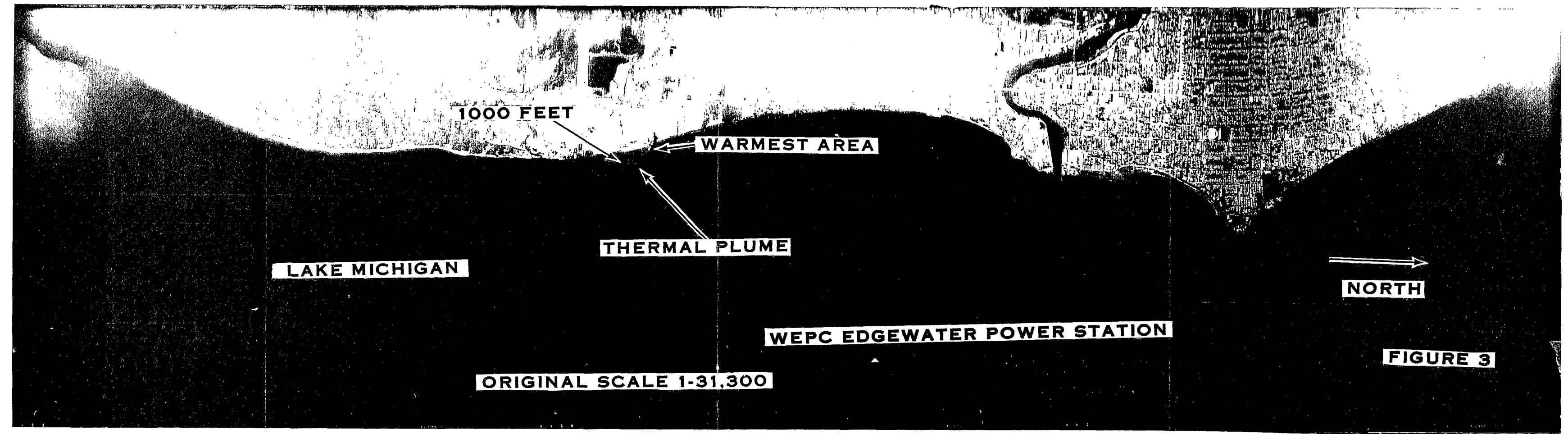
3. In the literature published by the Argonne National Laboratory, the power station discharge position is located at the point indicated in the figure.

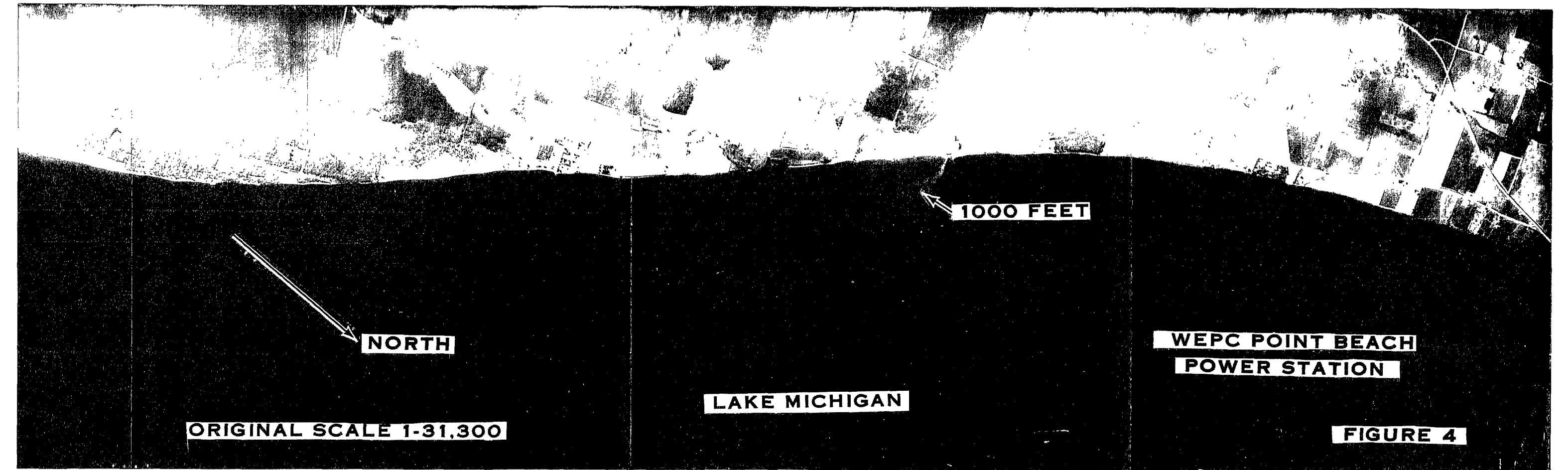
D. Wisconsin Electric Power Company - Edgewater Power Station

1. No ground truth was provided for this power station.
2. The thermal plume is shown in Figure 3.
3. The plume is 4,070 feet long and its maximum width from shore is 1,030 feet.
4. If the ambient background water temperature were 60°F, then the optical analysis shows that the temperature at the 1,000-foot mark, from the discharge point as shown in Figure 3, would have been 65.5°F. The warmest area, also shown in Figure 3, would be 68.5°F. The temperature at 2,000 feet from the outfall within the plume would be 64°F and that from 3,800 feet would be 61°F.

E. Wisconsin Electric Power Company - Point Beach Power Station

1. The inlet for this power station is 2,000 feet from shore in Lake Michigan and is submerged. The inlet water temperature was 52°F at the time of flight.
2. The thermal plume is shown in Figure 4.
3. Only the southernmost discharge location was being used at the time of flight.
4. The temperature of the heated water at the discharge was 68°F as provided by ground truth.
5. The background surface water temperature, in this area of Lake Michigan, was approximately 61°F. This value was achieved by





NORTH

1000 FEET

LAKE MICHIGAN

WEPC POINT BEACH
POWER STATION

FIGURE 4

ORIGINAL SCALE 1-31,300

temperature calibration curve extrapolation based upon the data (film densities vs ground truth temperatures) recorded in the vicinity of the other power station located along the Wisconsin shore of Lake Michigan.

6. The temperature, within the plume as shown in Figure 4, of the surface water 1,000 feet from the discharge point was 66.5°F and at 2,800 feet was 62.8°F.
7. The discharge flow rate was given as 391,000 gpm.

F. Fox River Wisconsin (Lake Winnebago to Green Bay)

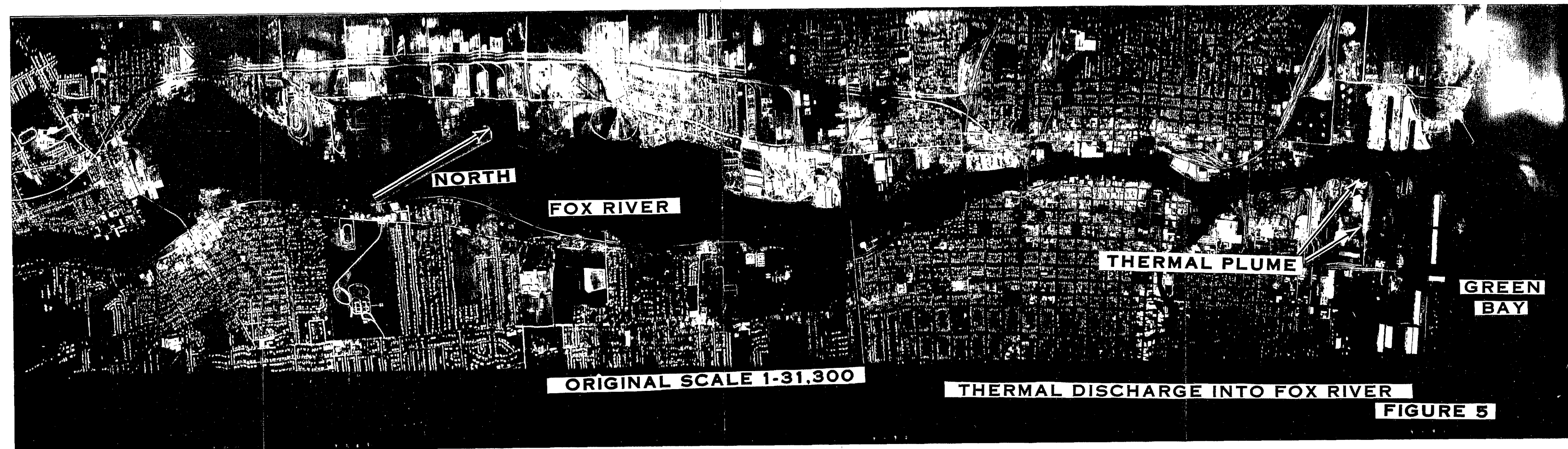
1. Only one thermal discharge was detected in the Fox River. Its location is shown in Figure 5. This thermal plume did not originate from the WPSC Pulliam Power Station which is located near the mouth of the river on the northern bank.
2. The temperature of the surface water in the canal, shown in Figure 5, is estimated to be 71°F and the river water to be 60°F. This is achieved from the data given in the vicinity of power station located on the western shore of Upper Lake Michigan.
3. No ground truth was provided in this area.

G. Michigan Consumers Power Company - B. C. Cobb Power Station

1. The B. C. Cobb power station was not covered during this mission.

H. Muskegon Lake, Michigan (western area)

1. The IRLS thermal maps of Muskegon Lake are presented in Figures 6 and 7. Figure 6 shows the southern half of the lake and Figure 7 gives the northern half.



NORTH

FOX RIVER

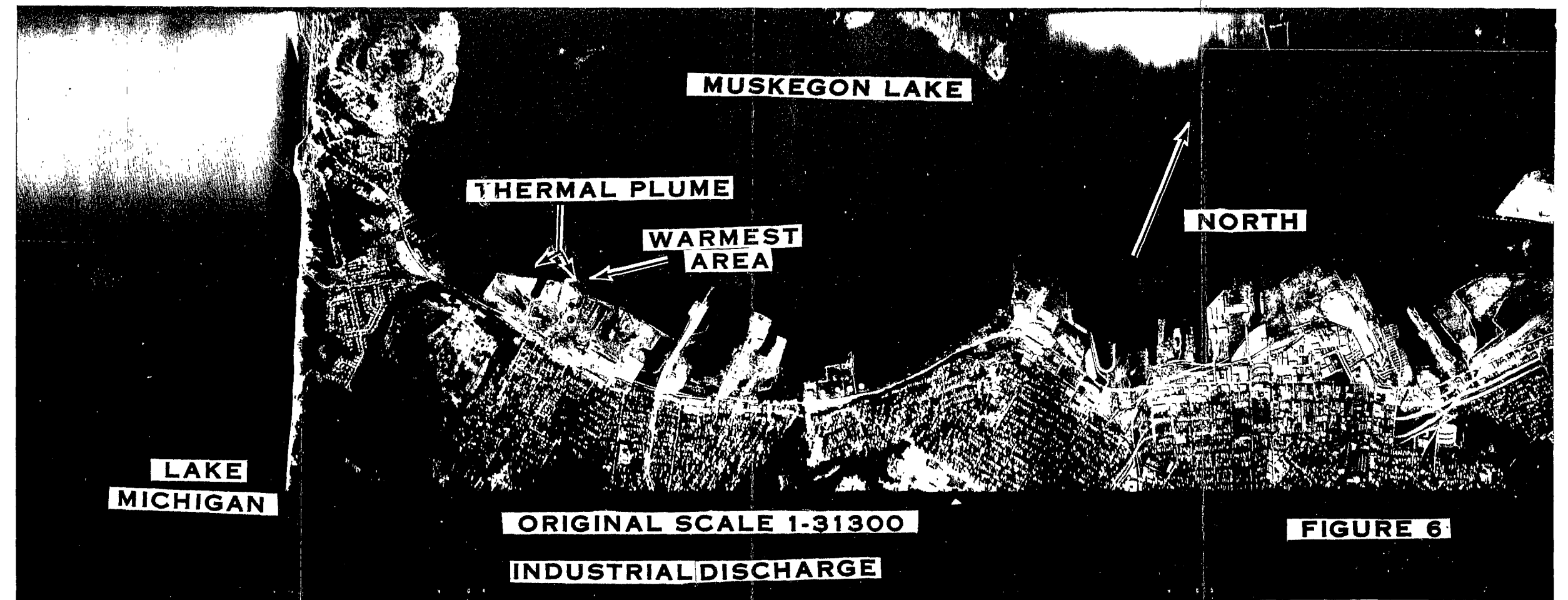
THERMAL PLUME

GREEN
BAY

ORIGINAL SCALE 1-31,300

THERMAL DISCHARGE INTO FOX RIVER

FIGURE 5

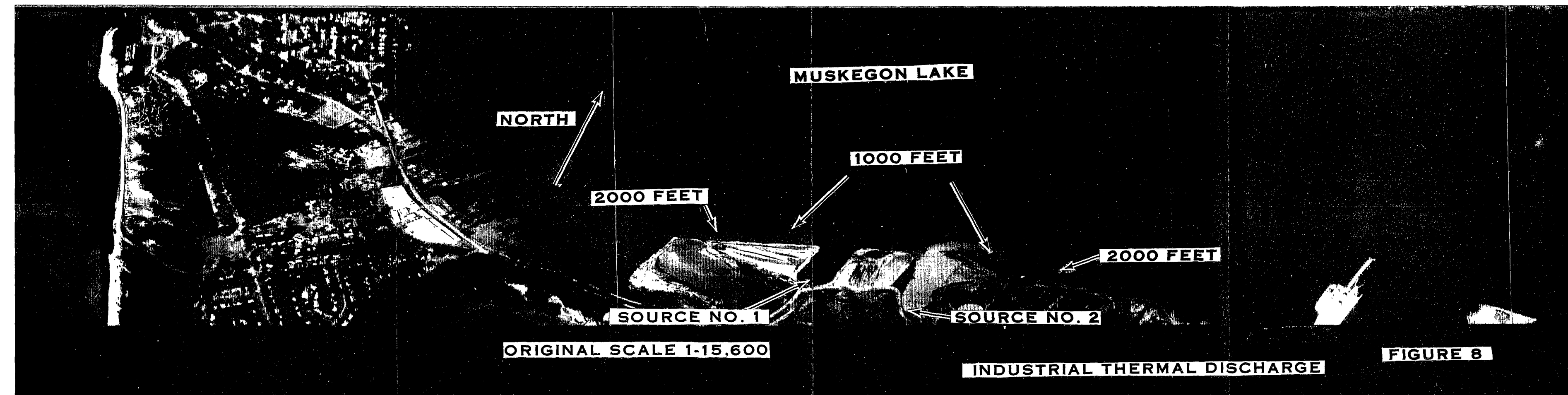




2. The presence of two thermal plumes was detected on the lake's southern shore as shown in Figure 6. A magnified scale of these plumes is presented in Figure 8. No ground truth was provided for this area.
3. The thermal map of the outflow of the Muskegon Lake waters into Lake Michigan is also shown in Figure 7. There was a definite thermal plume as shown in the far right side of this figure. This thermal plume extended southward for a considerable distance. By the temperature calibration curve extrapolation technique discussed in previous sections, the ambient (background) water surface temperature of Lake Michigan was determined to be approximately 61°F at the time of flight. This temperature value is based upon an optical correlation of the film densities in this location with known temperatures/film densities for other power station locations within the upper Lake Michigan vicinity. The surface temperatures are provided below:

<u>Point Number</u>	<u>Surface Temperature in °F</u>
1	73
2	70.5
3	72

Point 1 is 300 feet from the ends of the parallel breakwaters. Points 2 and 3, respectively, are 300 feet and 1,100 feet from the ends of the converging geometrical breakwater pilings. Points 1, 2, and 3 are shown in Figure 7.

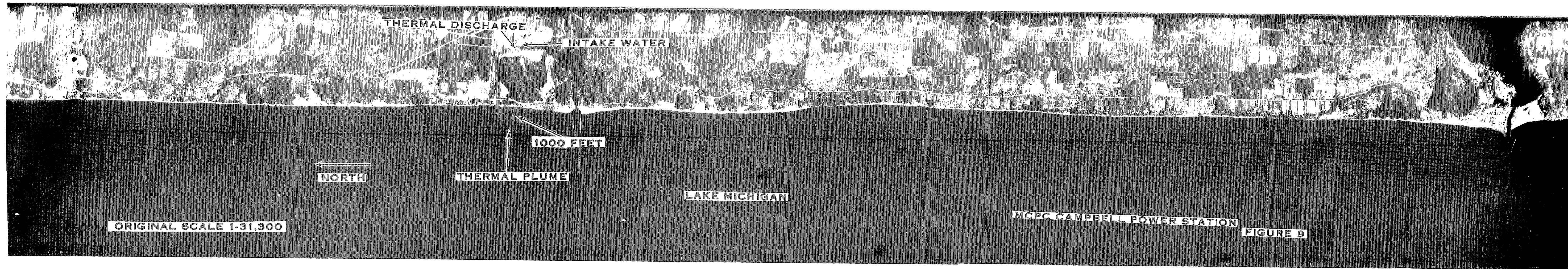


I. Michigan Consumers Power Company - J. H. Campbell Power Station

1. The temperature of the inlet water was 65°F. This temperature was obtained, as a part of the ground truth, from the canal labeled "intake water" in Figure 9 which is a thermal map of this area.
2. This plant was discharging at two locations in the small channel labeled "thermal discharge" in Figure 9. Ground truth information provided that the southernmost location was discharging water whose temperature was 70°F. The northern location discharge water temperature was 79°F. The airborne data show that the plumes were well-mixed in the channel within 265 feet from the northern discharge point.
3. The surface temperature in the channel, between the 90° bend and the above-mentioned mixing area, was 79°F.
4. The surface temperature of the channel water at its mouth was 73°F.
5. The surface temperatures of the plume waters in Lake Michigan, 1,000 feet and 2,000 feet respectively, from the mouth of the channel were 72°F and 66°F. The former point is shown in Figure 9.
6. The surface temperature of the background receiving waters in Lake Michigan was 60°F. This temperature value was obtained by temperature calibration curve extrapolation since no ground truth was provided in this area.

J. Michigan Consumers Power Company - Palisades Power Station

1. This power station was not in operation at the time of flight.



THERMAL DISCHARGE

INTAKE WATER

1000 FEET

NORTH

THERMAL PLUME

LAKE MICHIGAN

ORIGINAL SCALE 1-31,300

MCPC CAMPBELL POWER STATION

FIGURE 9

K. Northern Indiana Public Service - Michigan City Power Station

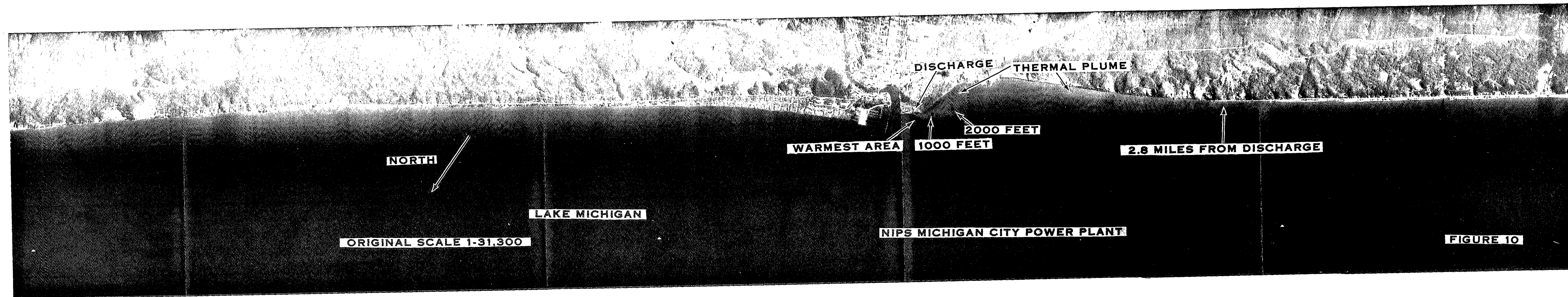
1. The inlet water temperature was 67°F which was provided by ground truth.
2. The discharge water temperature was 77°F as provided by ground truth.
3. The location of the power station and the thermal plumes are shown in Figure 10.
4. Within the thermal plume, the following temperatures are provided:

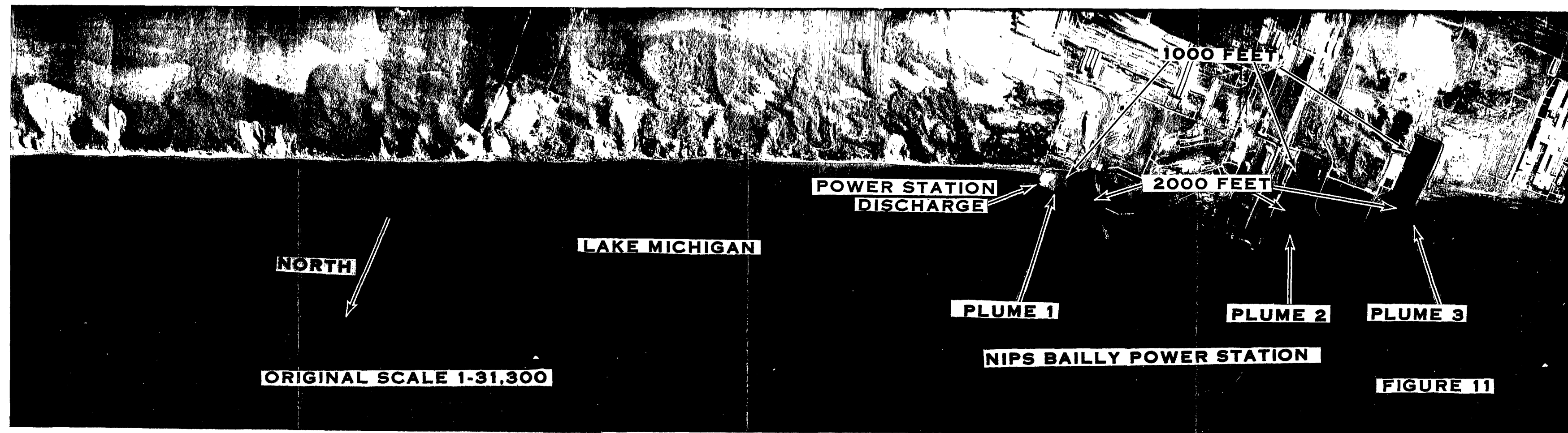
<u>Distance from Discharge (ft)</u>	<u>Surface Temperature (°F)</u>
500	75.5
1,000	74
2,000	74
2,500	73

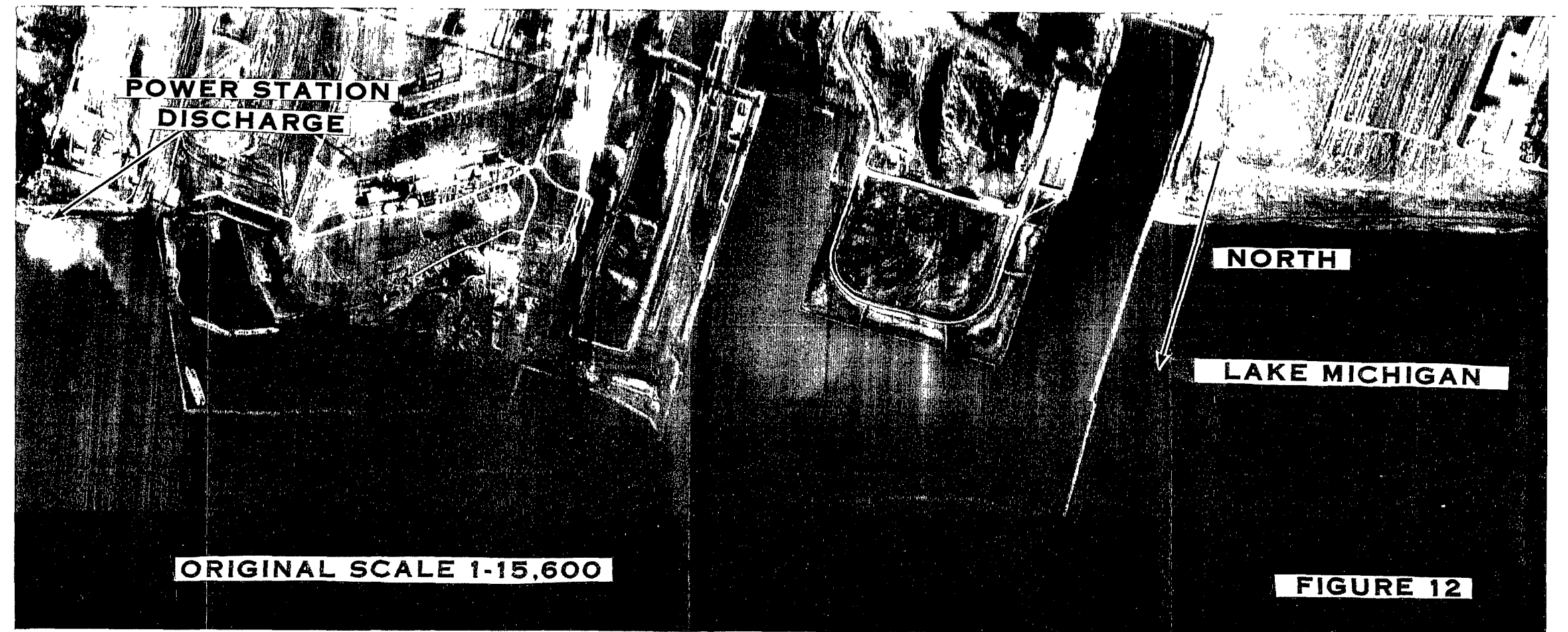
5. Traces of the thermal plume could be seen as far as 2.8 miles from the point of discharge.

L. Northern Indiana Public Service - Bailly Power Station

1. The inlet water temperature was 68.5°F at the time of flight which was provided by ground truth.
2. The temperature of the discharge water was 83°F also provided by ground truth.
3. The thermal plume is shown in Figure 11 to the left of the industrial area (labeled Plume No. 1). A lower altitude thermal map of this plume is shown in Figure 12.
4. The temperature of the surface water 1,000 feet, 2,000 feet from the discharge was 79°F and 73.5°F, respectively.







5. The discharge flow rate was 307,800 gpm.
6. Three other plumes are also seen in Figures 11 and 13 which are not related to the Bailly plant. Their surface temperature data are as follows:

	<u>Plume No. 2</u>	<u>Plume No. 3</u>
1,000 feet from slip apex	79.5°F	76°F
2,000 feet from slip apex	74°F	73°F

These slips are shown in a smaller scale in Figure 12.

7. The surface temperature at the mouth of the creek, marked Plume No. 4 in Figure 13, was 73.5°F.
8. Reportedly, two steel mills are located in these areas.

M. Northern Indiana Public Service - Mitchell Power Plant

1. The temperature of the inlet water from Lake Michigan was 65°F as provided by ground truth. The inlet was submerged below the Lake's surface.
2. The temperature of the discharge water was 77°F as provided by ground truth.
3. The surface temperature of the background water in Lake Michigan was 67°F as provided by ground truth.
4. The thermal plume from the power station is shown in center of Figure 14. The plume's surface temperature, at a point 1,000 feet from the discharge, was 71°F.
5. The discharge flow rate was 260,000 gpm at the time of flight.
6. The thermal plumes shown on the right or western side of Figure 14 are from industrial sources.

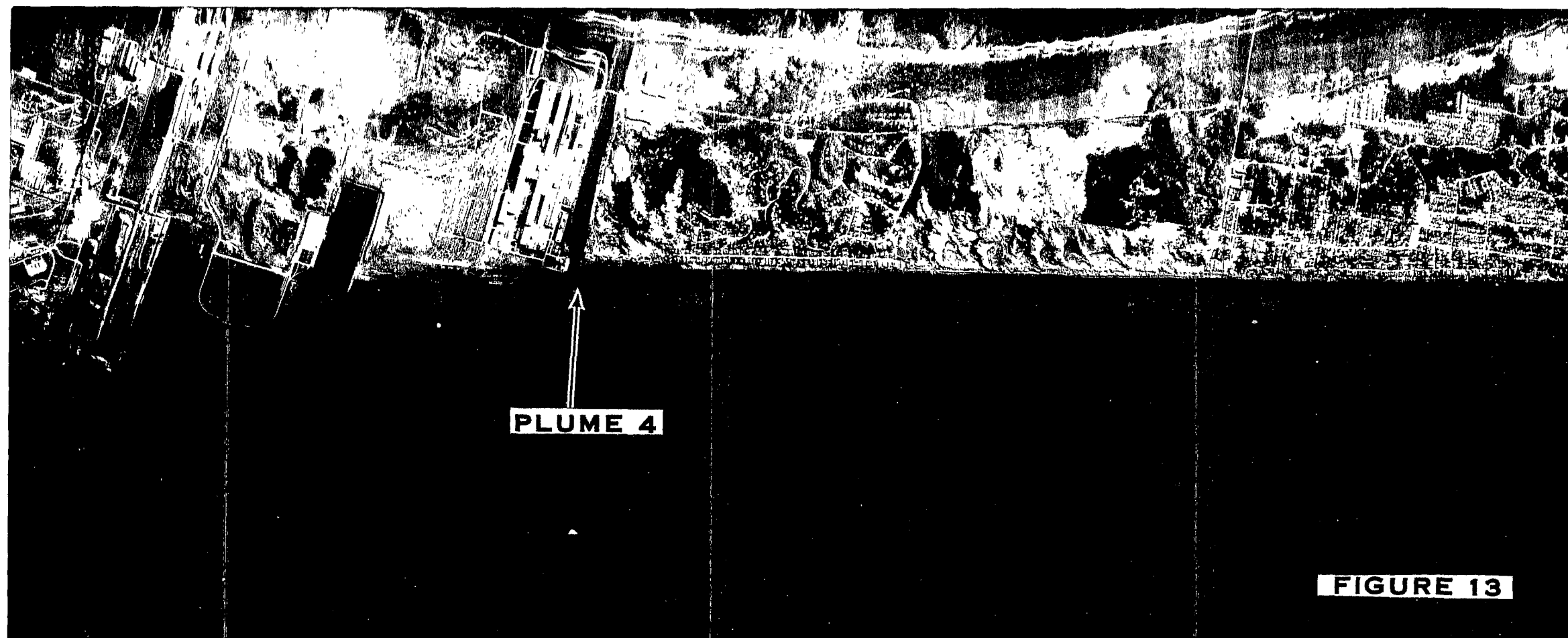


FIGURE 13

N. Industrial Discharges in the Vicinity of the Indiana-Illinois State Line

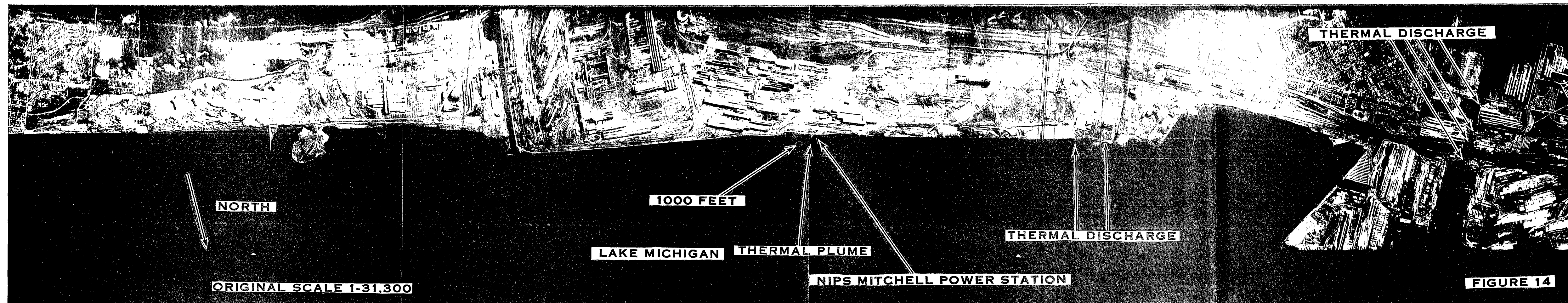
At this point in the report, a brief description is also given of the industrial thermal discharges in the vicinity of the Indiana-Illinois state line. This discussion is based upon Recommendation No. 3 adopted by the Third Session of the Lake Michigan Enforcement Conference, which states that:

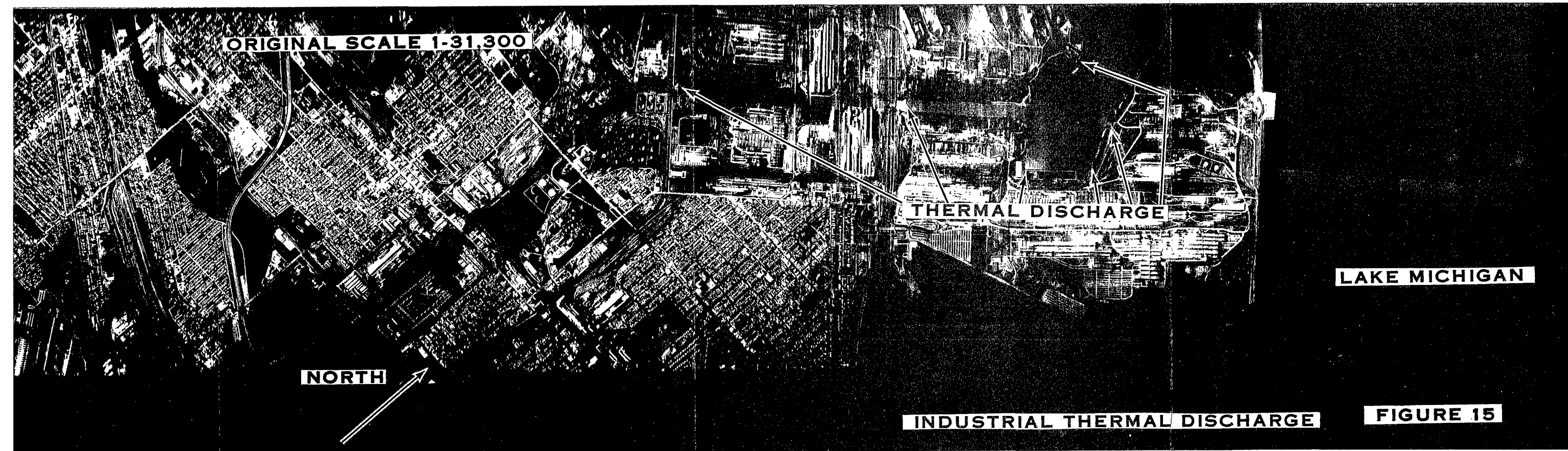
"Discharge shall be such that geographic areas affected by thermal plumes do not overlap or intersect. Plumes shall not affect fish spawning and nursery areas nor touch the lake bottom."

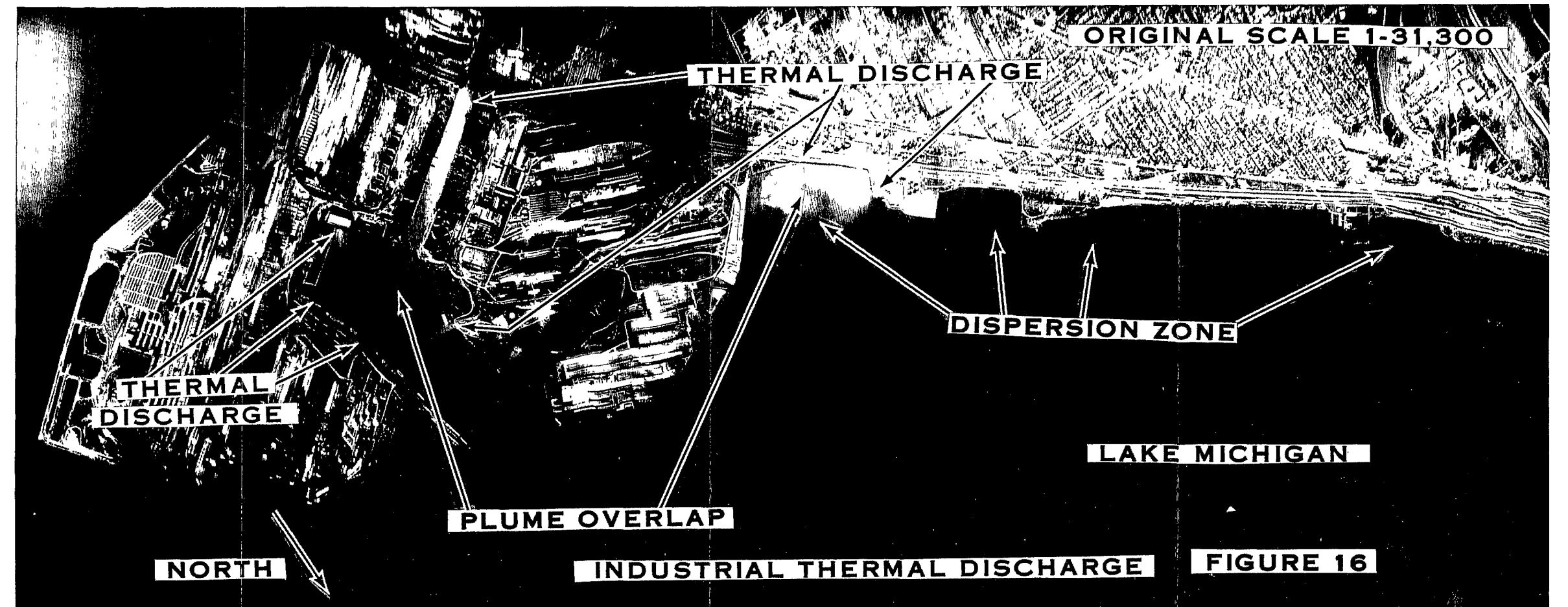
The aforementioned area contains thermal plumes which violate the intent of Recommendation No. 3. The respective industrial thermal plumes are shown in the right side of Figures 14, 15, and 16. These particular thermal maps represent the areas depicted in Figure 17 which is a portion of the Chicago 1:250,000 (Sectional) USGS map. The overlapping of thermal plumes is especially evident in the left and center of Figure 16. The plumes found in the center of this figure are significantly hot. The plumes are seen to be dispersing along the shore to the right as indicated by the label "dispersion zone."

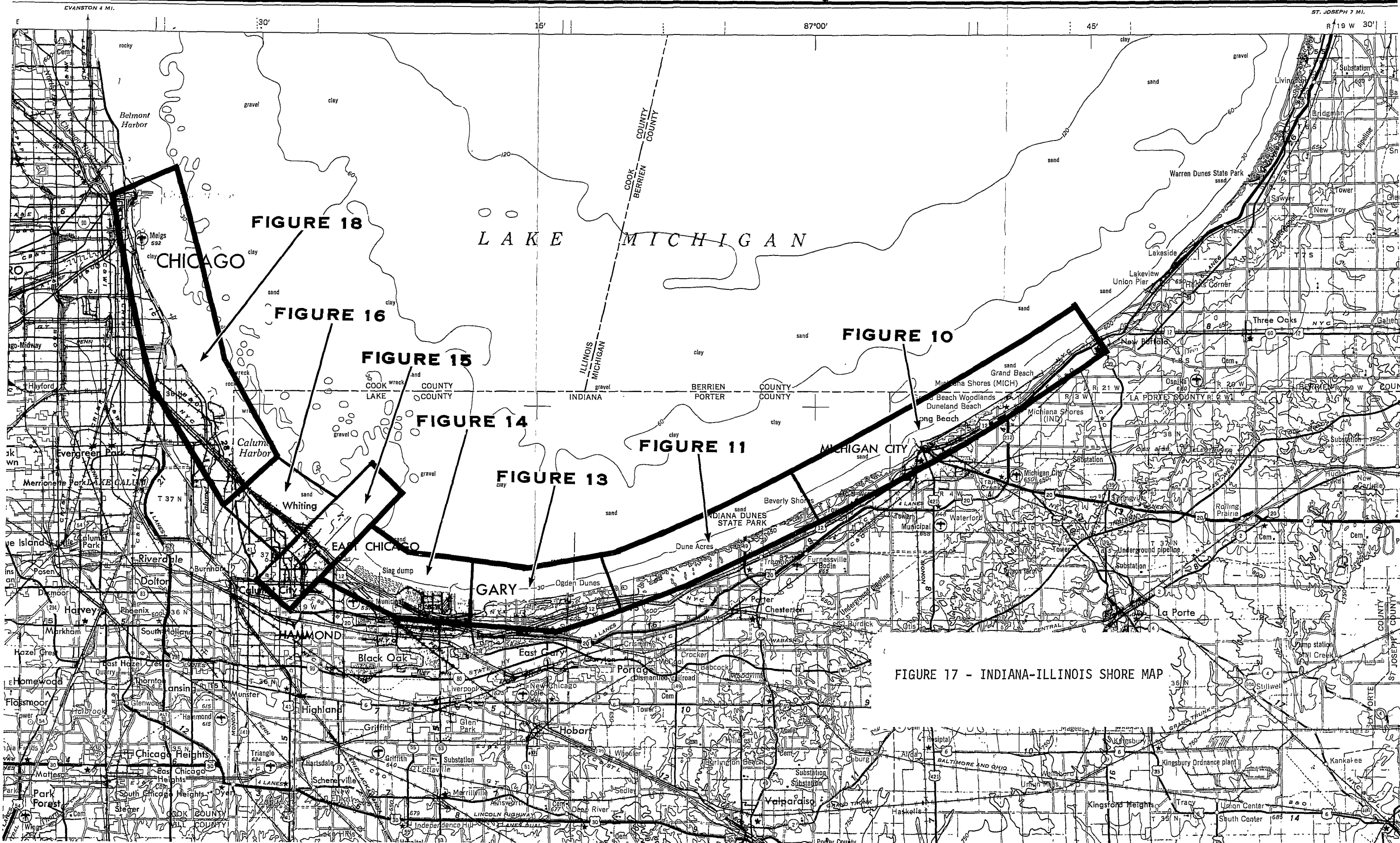
O. Commonwealth Edison Company - Stateline Power Station

1. The temperature of the inlet water from Lake Michigan was 70°F as provided by ground truth.
2. The temperature of the discharge water was 79°F also provided by ground truth.





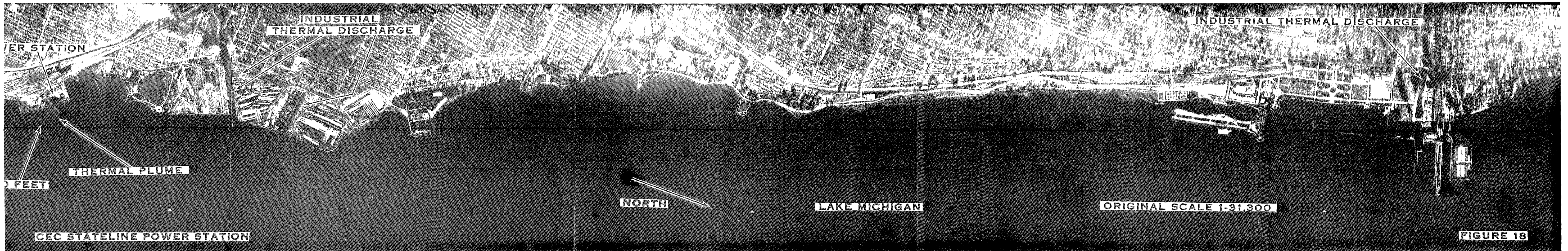


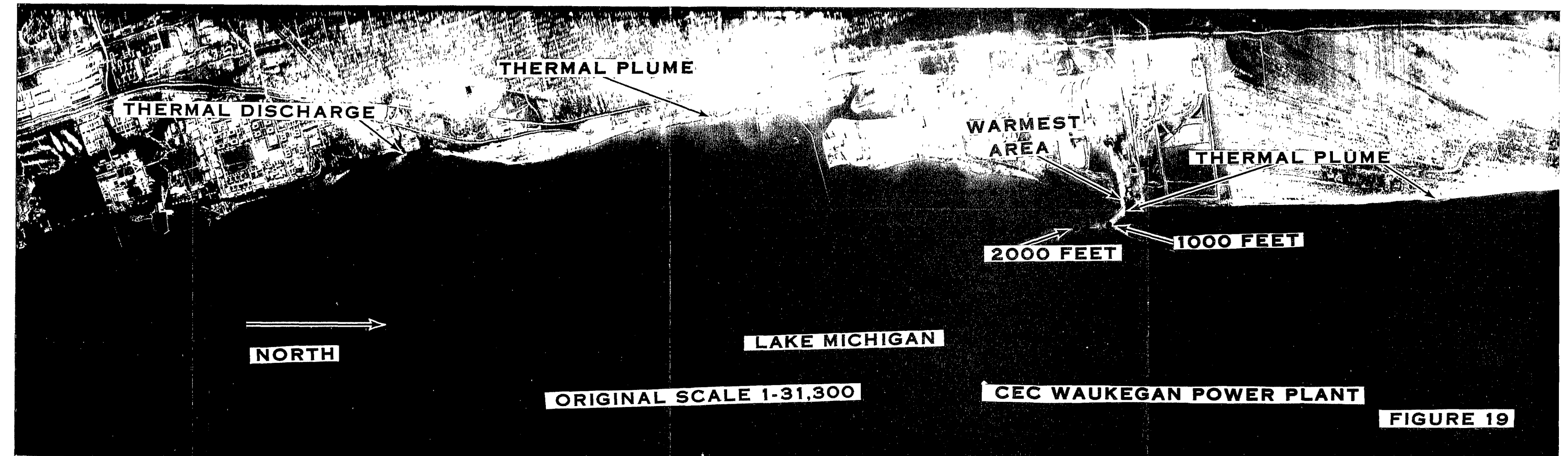


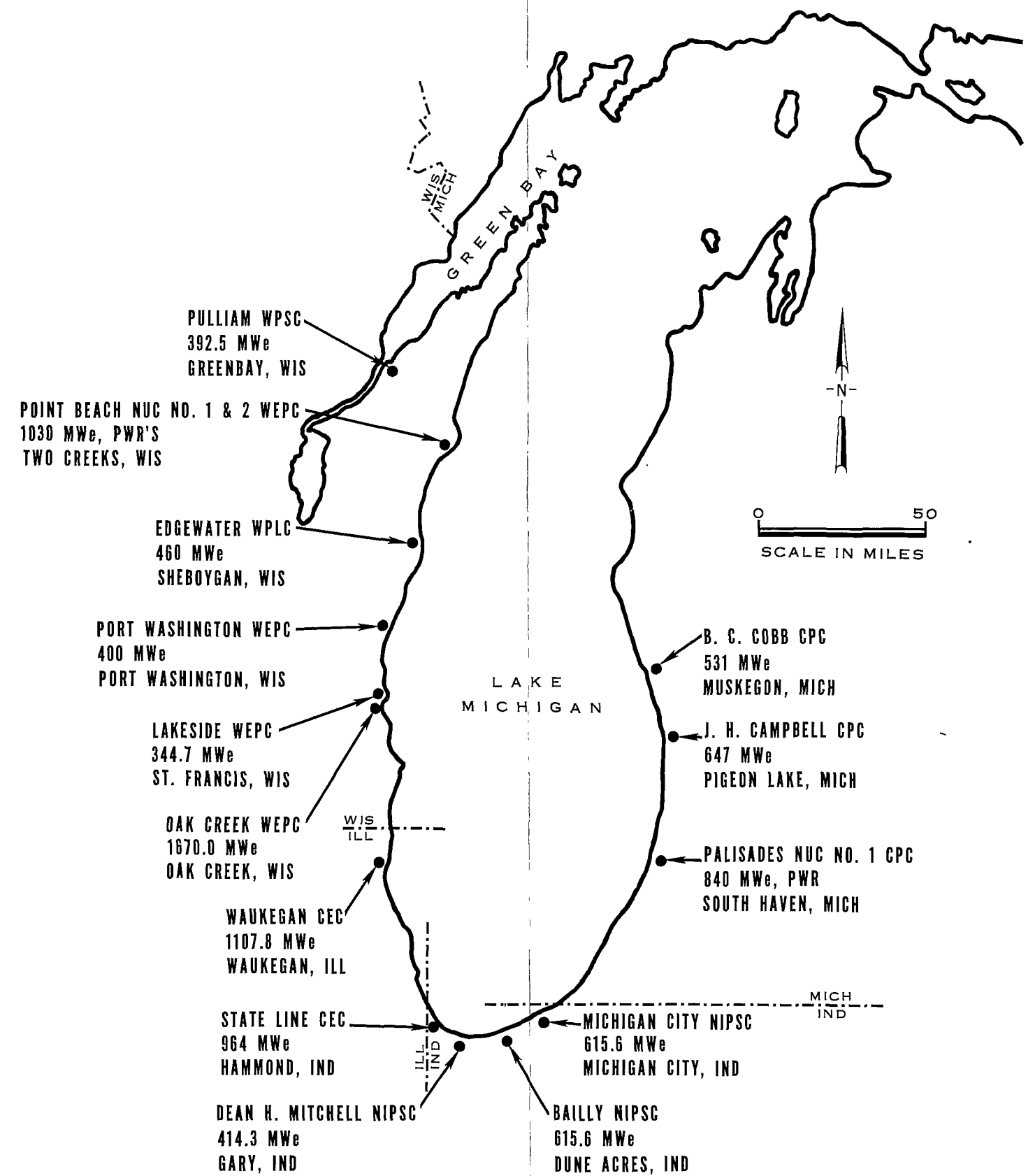
3. The thermal plume is shown in Figure 18 on the far left side. The other thermal plumes, as depicted, originate from industrial sources.
4. The thermal plume was travelling to the reader's left. The surface temperature of the water 1,000 feet from the discharge, within the plume, was 73.5°F.
5. The discharge flow rate was 516,000 gpm.

P. Commonwealth Edison Company - Waukegan Power Station

1. The temperature of the inlet water from Lake Michigan was 72°F as provided by ground truth.
2. The temperature of the discharge water was 81°F also provided by ground truth.
3. The thermal plume is shown in the right-center of Figure 19. The thermal plumes, indicated in the left center of the Figure are reported to be caused by industrial sources.
4. The surface temperature of the water, within the plume, was 78.5°F and 76°F at points 1,000 feet and 2,000 feet, respectively, from the discharge.
5. The overall length of the plume was 2.1 miles.
6. The discharge flow rate was 720,000 gpm.







LOCATION MAP LAKE MICHIGAN ELECTRIC POWER GENERATION STATIONS