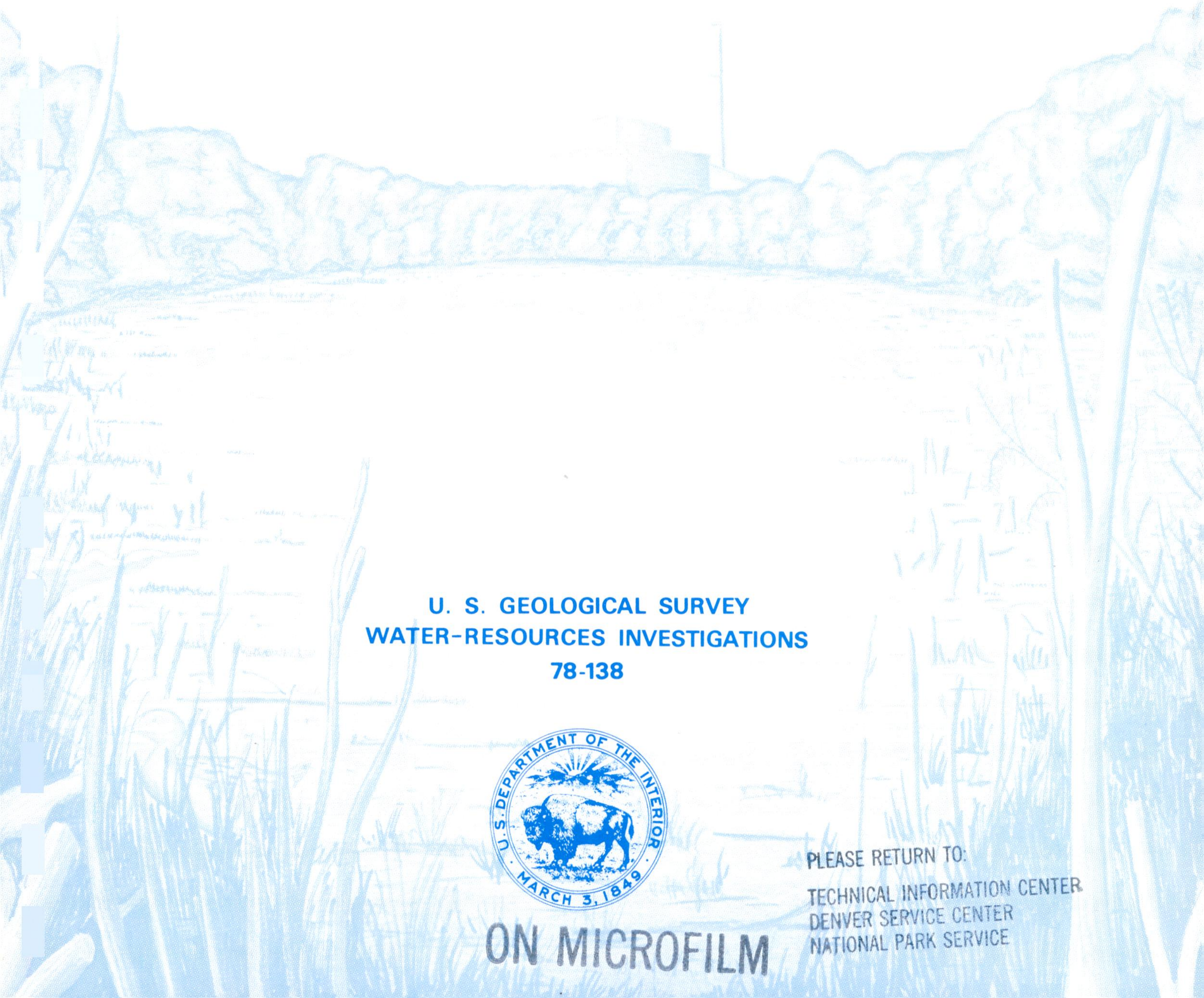
EFFECTS OF SEEPAGE FROM FLY-ASH SETTLING PONDS AND CONSTRUCTION DEWATERING ON GROUND-WATER LEVELS IN THE COWLES UNIT, INDIANA DUNES NATIONAL LAKESHORE, INDIANA

PREPARED IN COOPERATION WITH THE NATIONAL PARK SERVICE



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78-138

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16. Abstracts

Part of the Indiana Dunes National Lakeshore shares a common boundary with the Northern Indiana Public Service Company (NIPSCO). This area is underlain by unconsolidated deposits approximately 180 feet thick. NIPSCO accumulates fly ash from the burning of coal in electric-power generating units in settling ponds. Seepage from the ponds has raised ground-water levels above natural levels approximately 15 feet under the ponds and more than 10 feet within the Lakeshore. NIPSCO is presently (1977) constructing a nuclear powerplant, and construction activities include pumping ground water to dewater the construction site. The company has installed a slurry wall around the site to prevent lowering of ground-water levels within the Lakeshore. Plans call for continuous pumping through at least December 1979. A multilayered digital flow model was constructed to simulate the ground-water system. The model was used to demonstrate the effects of seepage from the fly-ash ponds on ground-water levels. Also, the model indicated a decline of 3 feet or less in the upper sand unit and 5 feet or less in the lower sand unit within the Lakeshore.

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UNITED STATES DEPARTMENT OF THE INTERIOR
CECIL D. ANDRUS, Secretary
GEOLOGICAL SURVEY
H. William Menard, Director

For additional information write to:

U.S. Geological Survey
1819 N. Meridian Street
Indianapolis, Indiana 46202

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CONVERSION FACTORS

Inch-pound units used in this report can be converted to metric units as follows:

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
inch (in.)	25.40	millimeter (mm)
inch per year (in./yr)	2.540	centimeter per year (cm/yr)
gallon per minute (gal/min)	0.0631	liter per second (L/s)
million gallon per day (Mgal/day)	0.0438	cubic meter per second (m^3/s)
foot per day (ft/day)	0.3048	meter per day (m/day)
degree Fahrenheit [(°F)-32]	0.556	degree Celsius (°C)

EFFECTS OF SEEPAGE FROM FLY-ASH SETTLING PONDS AND CONSTRUCTION DEWATERING ON GROUND-WATER LEVELS IN THE COWLES UNIT, INDIANA DUNES NATIONAL LAKESHORE, INDIANA

By William Meyer and Patrick Tucci

ABSTRACT

Part of the Indiana Dunes National Lakeshore shares a common boundary with the Northern Indiana Public Service Company (NIPSCO), an electric-power generating company. This area is immediately underlain by unconsolidated deposits whose average thickness is approximately 180 feet. The deposits consist of four major lithologic units, which, in descending order, are: a tan, fine, well-sorted sand, ranging in saturated thickness from 0 to 35 feet; a clay containing minor amounts of silt and sand, ranging in thickness from 0 to 80 feet; a gray, fine to medium sand, ranging in thickness from 0 to 80 feet; and a gray clay till, ranging in thickness from 60 to 140 feet.

As part of their present activities, NIPSCO accumulates fly ash from the coal burned in the electric-power generating units in a series of settling ponds. The ponds are in the upper sand layer. Seepage from the ponds has created a ground-water mound whose maximum height immediately under the ponds is approximately 15 feet above the natural water levels. Water levels within the park boundary have risen more than 10 feet, changing some former marshlands into interdunal ponds. The rate of seepage from the settling ponds into the sand, at least 2.0 million gallons per day, is based on the results obtained from a multilayered digital model designed to simulate the ground-water system in the study area.

NIPSCO is presently (1977) constructing a nuclear powerplant on their property. Because construction activities include pumping of ground water to dewater the construction site, the company has installed a slurry wall around the site to prevent lowering of ground-water levels in the Indiana Dunes National Lakeshore by the pumping. The slurry wall extends to the top of the upper clay unit. Pumping of ground water from the site, which began on March 17, 1977, has been nearly continuous. NIPSCO's plans call for continuing the pumping through at least December 1979. The amount of water removed from the construction site by December 15, 1977, represents from 7 to 14 times the original amount of water stored within the slurry wall boundaries and indicates that either the slurry wall is leaking or that enough water to sustain the pumpage is moving upward from the lower sand, or both. The digital model indicated a decline of 3 feet or less in the upper sand and a decline of 5 feet or less in the lower sand within the National Lakeshore.

INTRODUCTION

The Indiana Dunes National Lakeshore in northwestern Indiana extends discontinuously from Michigan City to Gary as a narrow band generally less than 2 miles wide along the southern shore of Lake Michigan (fig. 1). Several isolated areas of the park extend farther inland. At one location (fig. 2), the "National Lakeshore" shares a common boundary with Northern Indiana Public Service Co. (NIPSCO) Bailly Generating Station. At present (1977) two coal-fired, electric-power generating units are operated at the Bailly site, and a nuclear-powered unit is under construction at the site. A series of settling ponds is used to accumulate the fly ash from the coal burned in the two coal-fired units. The National Park Service believed that seepage from these ponds was keeping the ground-water levels artificially high.

Construction of the nuclear plant was begun in 1974 but was interrupted from shortly afterward until March 1977, pending court decisions on the possible effect of construction on the environment. Items of concern included the effect of dewatering the excavation site on water levels in ponds within National Lakeshore property. Before the resumption of construction and dewatering on March 17, 1977, a slurry wall was emplaced around the excavation site in an attempt to prevent water-level declines in the ponds.

As part of their management responsibilities, the National Park Service asked the U.S. Geological Survey to investigate the present and potential effect of seepage from NIPSCO's fly-ash settling ponds and nuclear power-plant construction dewatering on the ground-water system within the jurisdiction of the Indiana Dunes National Lakeshore. Accordingly, the Geological Survey in cooperation with the National Park Service began a 2-year study in 1976. A detailed map of the study area is shown in figure 2.

This report summarizes ground-water conditions within the study area from October 1976 through December 1977 and describes the construction of and results obtained from a digital model of the ground-water system designed to determine the effects of the fly-ash ponds and construction dewatering on ground-water levels within the National Lakeshore. The effects of fly-ash ponds on ground-water quality will be discussed in another Geological Survey report.

REGIONAL SETTING

The study area consists of 3.8 square miles in Porter County in the northwest corner of Indiana (fig. 1). It is bounded on the north by Lake Michigan; on the west by a highly industrialized complex of steel mills and associated industries; on the east by the town of Dune Acres and the dunes and wetlands in the National Lakeshore; and on the south by small farms, private houses, and National Lakeshore property. The area is part of the

Calumet Lacustrine Plain (Schneider, 1966, p. 41), a region of old beach ridges and associated dunes, and various wetland environments including cattail marshes, swamps, and boglike areas (Mark Reshkin, Indiana University Northwest, written commun., 1975).

The major streams in the region are the Little Calumet River to the south, Dunes Creek to the east, and Burns ditch to the west. In the immediate study area, however, the only surface drainages are man-made ditches that form the headwaters of Dunes Creek. The major part of the drainage for the study area flows directly to Lake Michigan as ground water.

The climate of the region is temperate continental. Average annual precipitation ranges from 37 in at Ogden Dunes to 45 in at Michigan City. Both localities are shown in figure 1. At Ogden Dunes, average precipitation in July, the wettest month, is 4.50 in, and in February, the driest month, it is 2.06 in. The mean annual temperature is 50.5°F, the mean daily high in July is 82.6°F, and the mean daily low in January is 18.4°F (Wayne Kiefer, Central Michigan University, written commun., 1975).

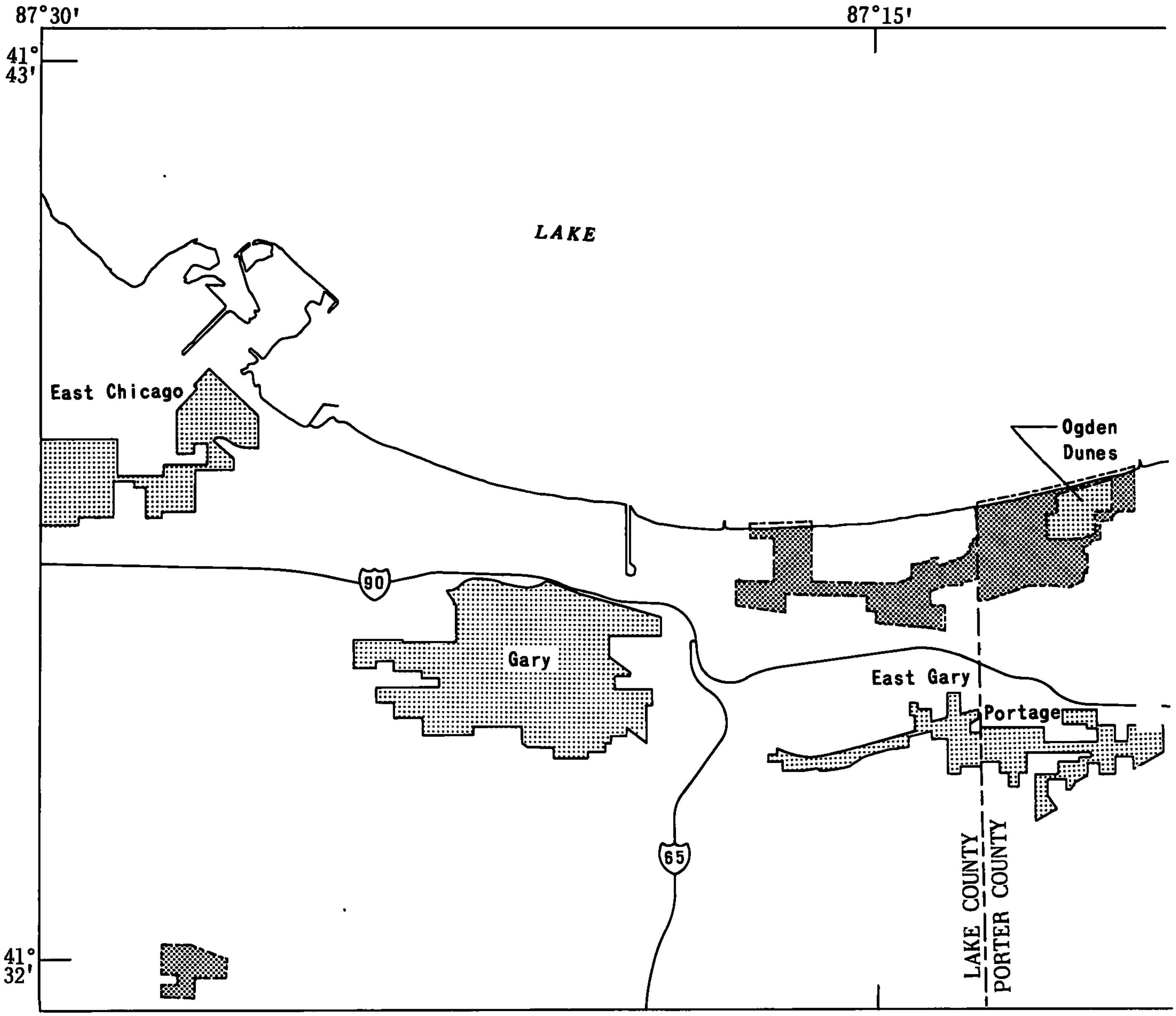
PREVIOUS WORK

The study area is underlain by both unconsolidated and consolidated rocks. The unconsolidated rocks immediately below land surface are Holocene or Pleistocene age. Underlying these rocks are consolidated, Paleozoic sedimentary rocks, which, in turn, overlie Precambrian granite.

During an investigation of the geohydrology and ground-water potential of Porter and LaPorte Counties, Ind., Rosenshein and Hunn (1968) mapped the distribution of the major lithologic units in the unconsolidated rocks underlying these two counties and divided the unconsolidated deposits into four major lithologic units 1, 2, 3, and 4, in descending order. According to these authors, unit 4, which directly overlies the bedrock, is a gray clay till that contains discontinuous zones of sand and gravel; unit 3 is sand and gravel that locally contains thick clay beds of small areal extent; unit 2 is chiefly silty till that contains discontinuous intertill sand and gravel zones; and unit 1 is chiefly sand that locally contains zones of sand and gravel.

In addition to describing the lithology and distribution of the unconsolidated deposits, Rosenshein and Hunn (1968) established an approximate range of lateral hydraulic conductivity for units 3 and 1 and approximate recharge rates and coefficients of storage for these two units. They also established the approximate porosity and vertical hydraulic conductivity of units 4 and 2.

Marie (1976) constructed a two-dimensional model of the area to provide preliminary information on the effects of construction dewatering. Mark Reshkin (Indiana University Northwest, written commun., 1975), prepared a detailed geologic history of the area.



Base from National Park Service, Indiana Dunes National Lakeshore, Lake, LaPorte, and Porter Counties, Indiana, October 1976

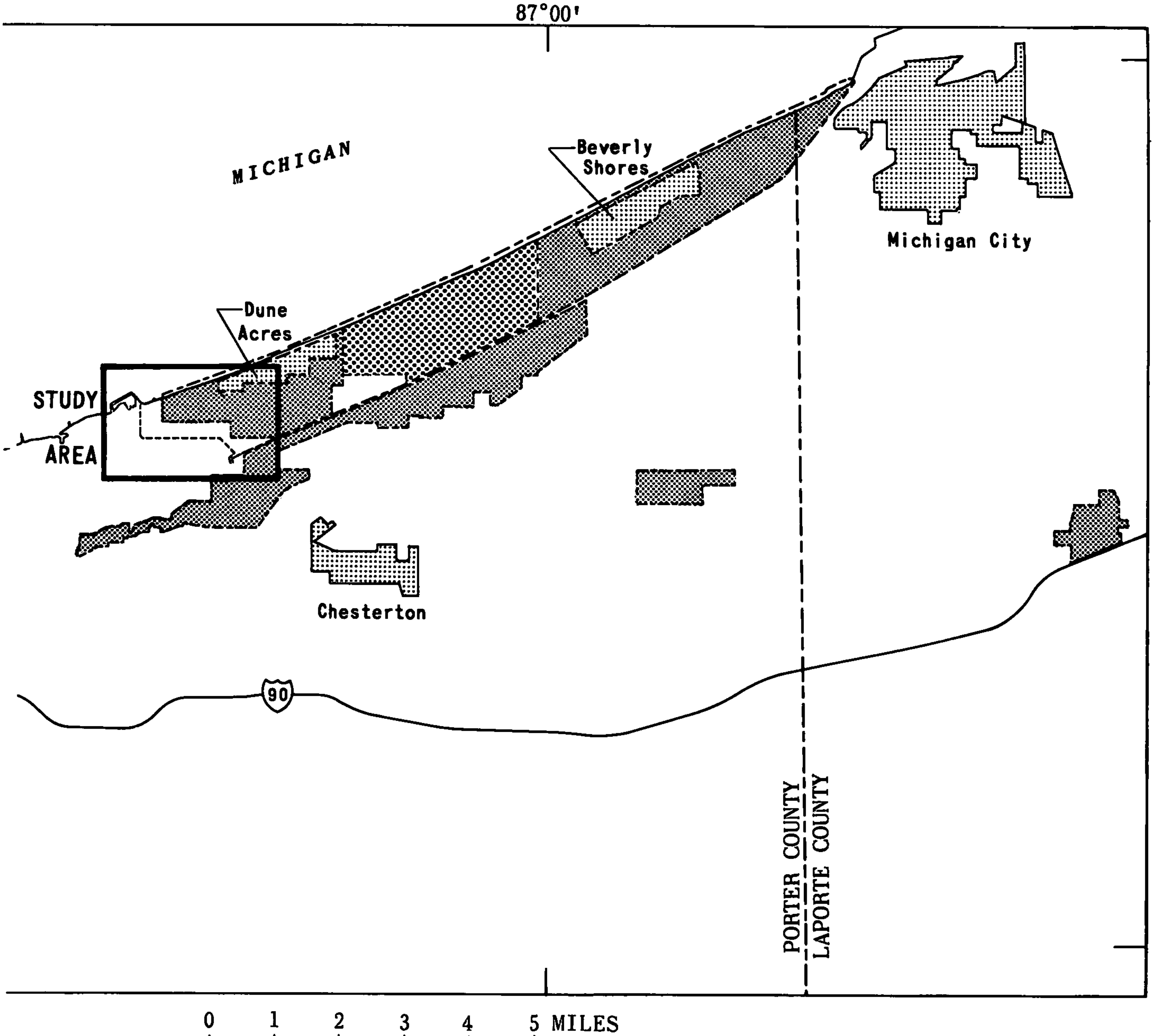
EXPLANATION

Indiana Dunes National Lakeshore (Present and proposed areas)

Indiana Dunes State Park

Areas of town and city development

Figure 1.-- Location of Indiana Dunes National Lakeshore, Indiana, and study area.


87°00'
MICHIGAN
Beverly Shores
Michigan City
Dune Acres
STUDY AREA
Chesterton
90
PORTER COUNTY
LAPORTE COUNTY
0 1 2 3 4 5 MILES


Study area
INDIANA

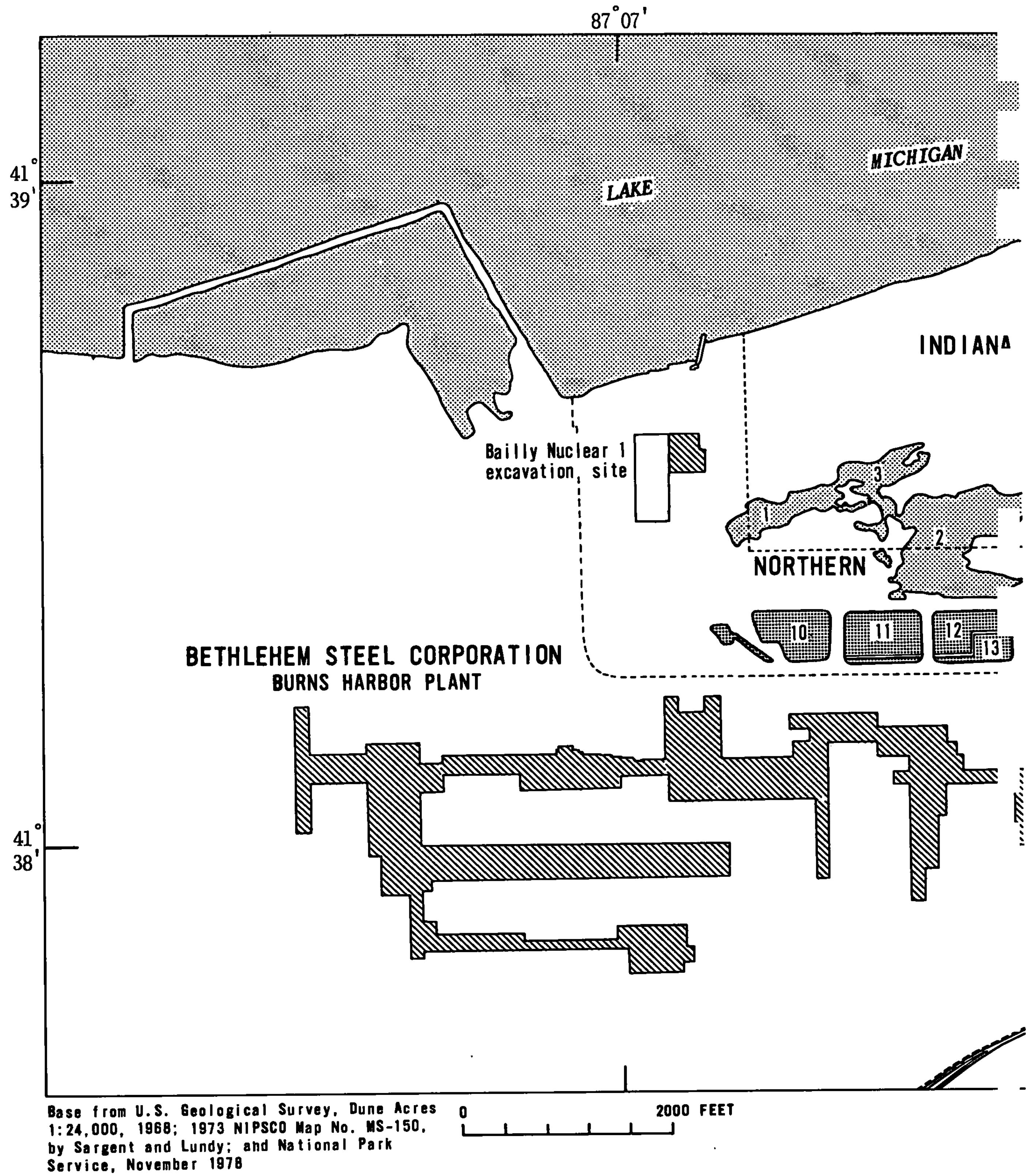
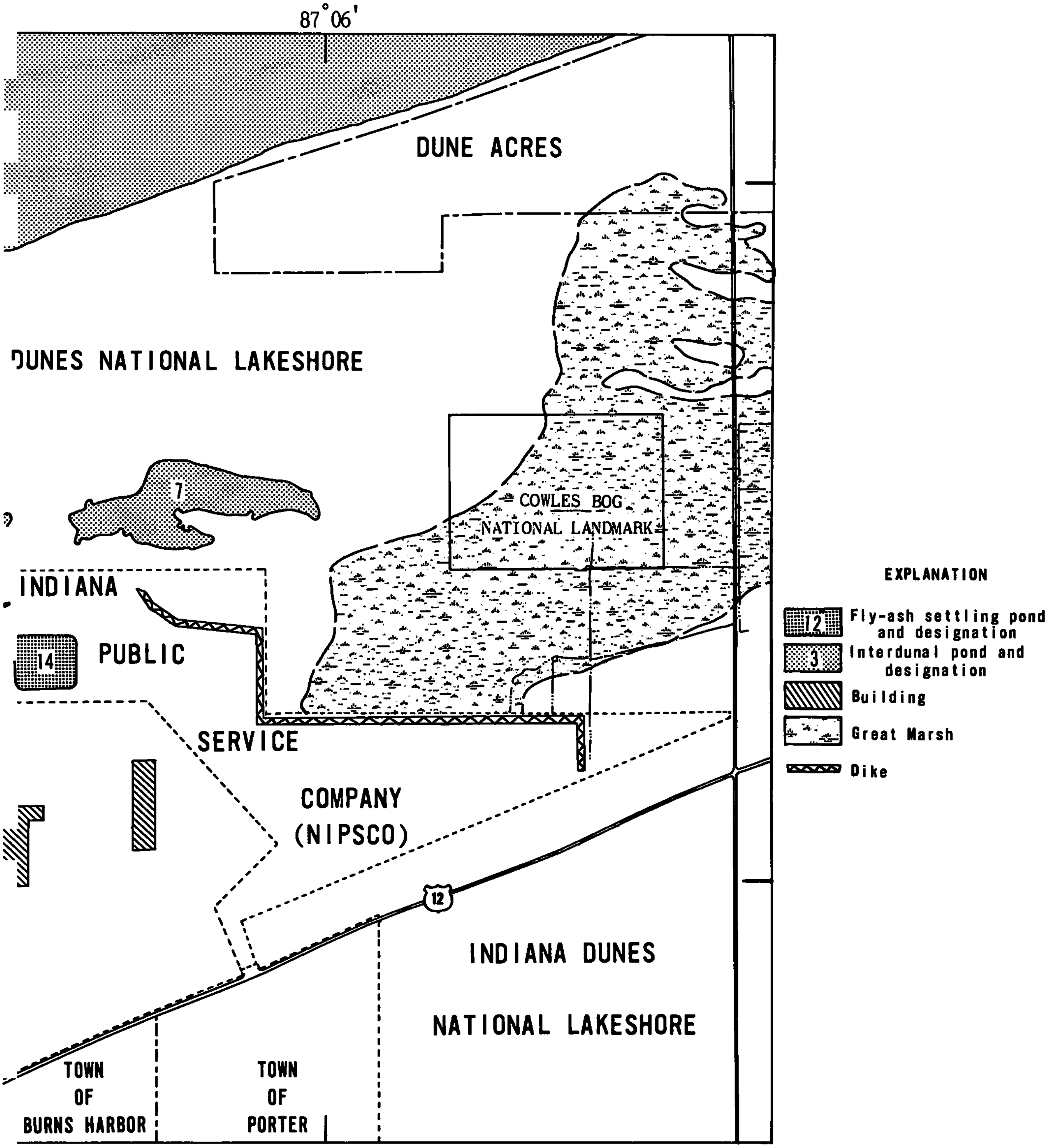


Figure 2.-- Study and model areas.



87°06'
DUNE ACRES
DUNES NATIONAL LAKESHORE
7
COWLES BOG
NATIONAL LANDMARK
INDIANA
14
PUBLIC
SERVICE
COMPANY
(NIPSCO)
12
INDIANA DUNES
NATIONAL LAKESHORE
TOWN
OF
BURNS HARBOR
TOWN
OF
PORTER
EXPLANATION
12 Fly-ash settling pond and designation
3 Interdunal pond and designation
Building
Great Marsh
Dike

PHYSICAL SETTING

As indicated by the property lines in figure 2, the study area is approximately 80 percent industrialized land, associated with the activities of Bethlehem Steel Corp. Burns Harbor Plant and NIPSCO, and 20 percent National Lakeshore.

Surficial physical features include the Great Marsh, the interdunal ponds, the fly-ash settling ponds, and the nuclear powerplant excavation site (fig.2). The Great Marsh occupies part of the northeastern quarter of the study area. The Great Marsh is wet during most of the year, when the water table is at or near the surface. Ditches that were dug years ago to help drain the marsh are still present. Two of these ditches cross the eastern boundary of the study area, but discharge through them is minimal. The marsh area also contains an area known as Cowles Bog, which was designated as a National Natural Landmark by Congress in 1965. There is some question as to the exact location of the bog and whether or not that particular part of the wetland is in fact a bog (William Hendrickson, National Park Service, oral commun., 1977).

A complex of sand dunes follows the Lake Michigan shoreline eastward from the NIPSCO property line through the town of Dune Acres and beyond the study area. The average height of the dunes is approximately 50 feet, but some dunes are more than 100 feet high. Most of the dunes are stabilized by vegetation, but a few dunes and blowouts are still active.

Ponds have formed between sand dunes in some areas where the elevation of the land surface is below that of the water table. These ponds are referred to as "interdunal ponds." For discussion, each pond has been designated by a number as shown in figure 2. The areal extent of these interdunal ponds varies with the elevation of the water table. A succession of aerial photographs and maps made before 1966 shows the interdunal-pond areas as marshes, containing water only during periods of high water table. Beginning with 1967 and continuing through 1977, aerial photographs of the interdunal ponds reveal standing water. Maximum depth of the ponds is approximately 6 ft. The marsh and dunal areas on the Geological Survey 1953 Dunes Acres, 1953 Ogden Dunes, and the 1960 Portage quadrangles, as well as location of the present interdunal ponds in relation to marsh areas, are shown in figure 3. Areal extent and bottom of each of the interdunal ponds, as mapped during this study, are shown in figure 4. Before the present study, ponds 1, 2, and 3 were not interconnected as shown in figure 4. Previous work (Marie, 1976) refers to those ponds by the numbering system shown in the figure.

NIPSCO's fly-ash settling ponds are in a line parallel to the company's east-west property lines between the National Lakeshore and Bethlehem Steel Corp. Numbering of the fly-ash ponds, as shown in figure 2, follows NIPSCO's numbering system, except for pond 14. This pond is a relief-surge pond that was used during the study but was not numbered by NIPSCO. Fly-ash and bottom-ash slurries are piped separately from the coal-fired, electric-power generating units to the settling ponds, where the heavier bottom ash settles out immediately at the west end of ash pond 10. Overflow from ash ponds 10 and 11 is directed into ash ponds 12 and 13, respectively. The ash ponds have a maximum depth of 6 ft. Periodic removal of fly ash from the ponds keeps the bottom elevations of the ponds at an average of 612 ft. The bottoms and sides of the unlined ponds consist of sand when the ash has been removed from them.

Fly ash removed from the ash ponds is dumped into a fill area in the southeastern part of NIPSCO's property. A dike composed of native sand (fig. 2) separates the fill areas from the National Lakeshore. Standing water is present behind the dike.

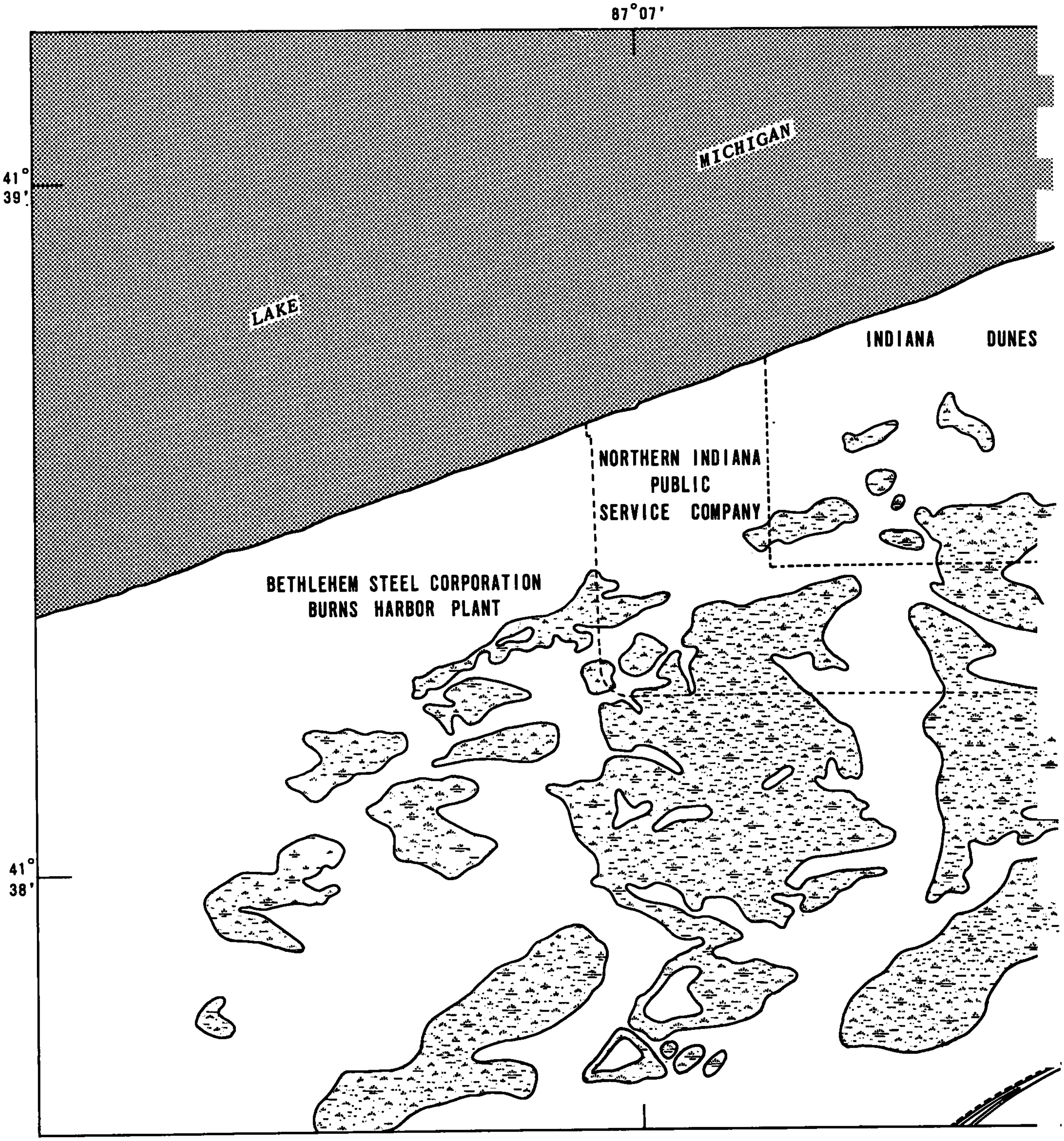
Adjacent to the west side of the coal-fired, electric-power generating units is the excavation site for the Bailly Nuclear 1 power generator. A map of the site is shown in figure 5. The approximately 900-ft long by 400-ft wide excavation grades down from an elevation of approximately 620 ft to a projected low of 580 ft. Ground-water level in the excavation just before dewatering was 596 ft above mean sea level, and the bottom elevation of the excavation was 591 ft. During the winter of 1976-77, a slurry wall consisting of a mixture of 5 percent bentonite clay, 11 percent cement, and 84 percent water by weight was built just inside the excavation. The average length of the wall is 820 ft, average width is 320 ft, and range in depth is from 34 to 46 ft. Average elevation of the wall's bottom is 569 ft, except along the southern wall, where the bottom elevation generally ranges from 569 ft at the west end to 557 ft at the east end. The planned thickness of the wall was 3 in, but the actual thickness is probably varied. In one place (fig. 5), the slurry wall is replaced by sheet piling. The wall extends down to the top of unit 2.

To the south and west of NIPSCO is the Bethlehem Steel Burns Harbor Plant. The original land surface has been uniformly graded in the plant by leveling dunes and filling in marsh and pond areas.

GEOLOGY

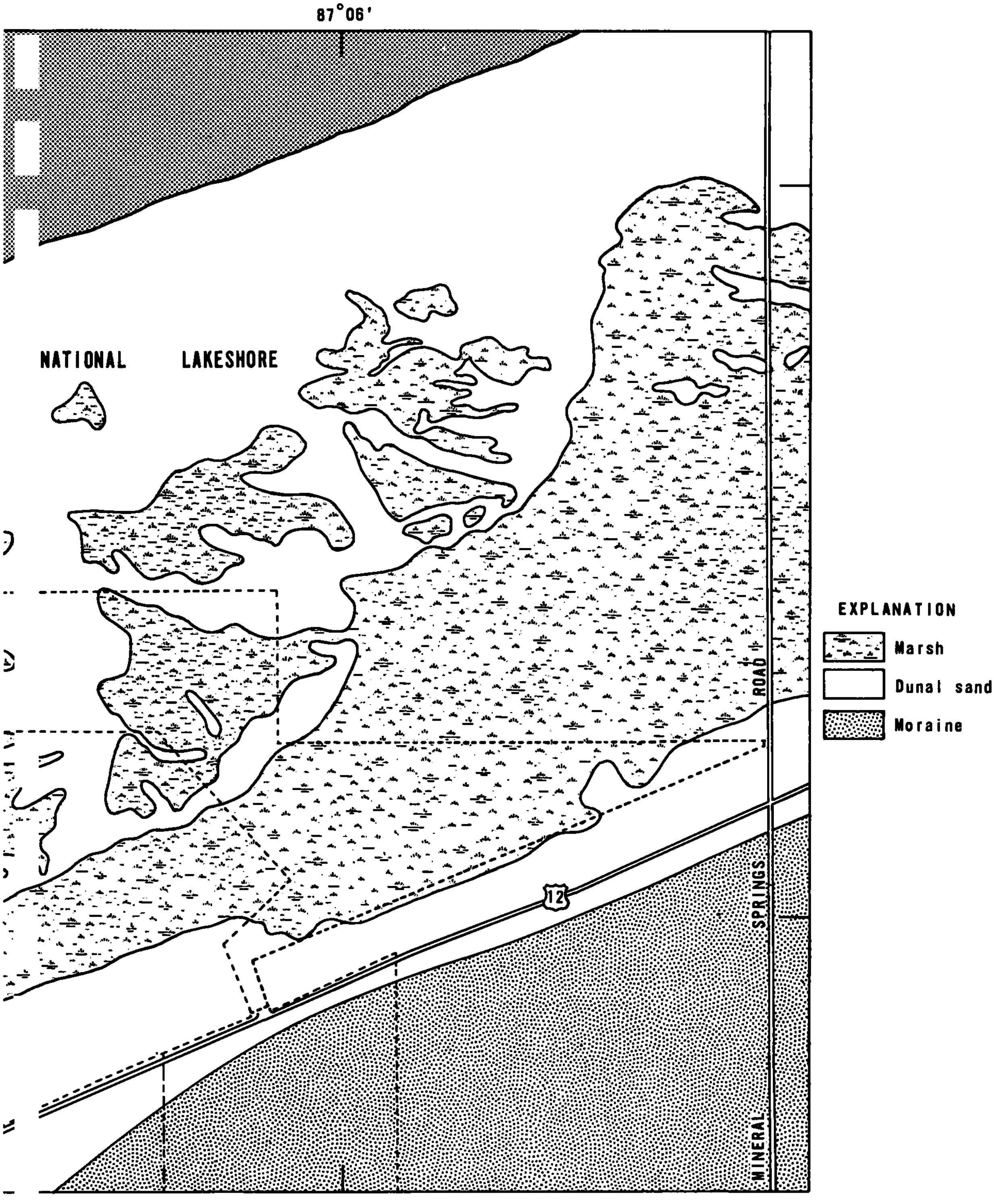
Thickness of the unconsolidated glacial deposits immediately underlying the study area averages 180 ft. These deposits are composed of till, silt and clay, sand and gravel, and dune sand, and all are related to the Wisconsin Glaciation and the degeneration of Lake Chicago to its present form, Lake Michigan (Mark Reshkin, Indiana University Northwest, written commun., 1975). The four units, identified from drillers' logs of wells and test drilling, for the Geological Survey, correspond closely with but are not exactly the same as the units of Rosenshein and Hunn (1968). Their mapping indicated that their unit 3 was absent in this area.

Descriptions of the four units in descending order follow: Unit 1 consists primarily of a tan, fine, well-sorted sand typical in dune areas. The lower part of this unit is a gray, fine to medium sand, containing some



Base from U.S. Geological Survey
Ogden Dunes 1:24,000, 1953;
Dune Acres 1:24,000, 1953; and
Portage 1:24,000, 1960

Figure 3.-- Preindustrial extent of marsh



and dunal-sand areas in study area.

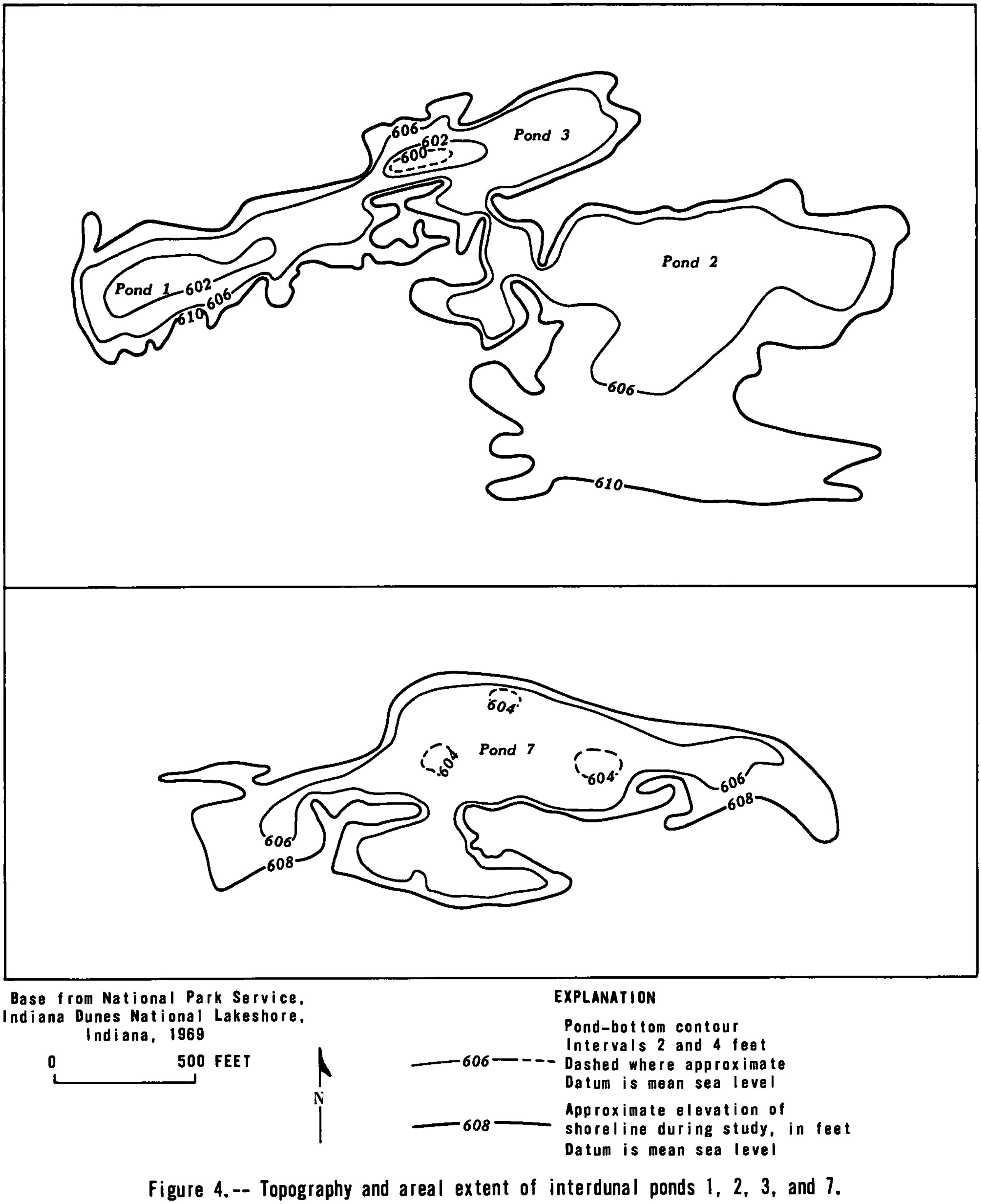


Figure 4.-- Topography and areal extent of interdunal ponds 1, 2, 3, and 7.

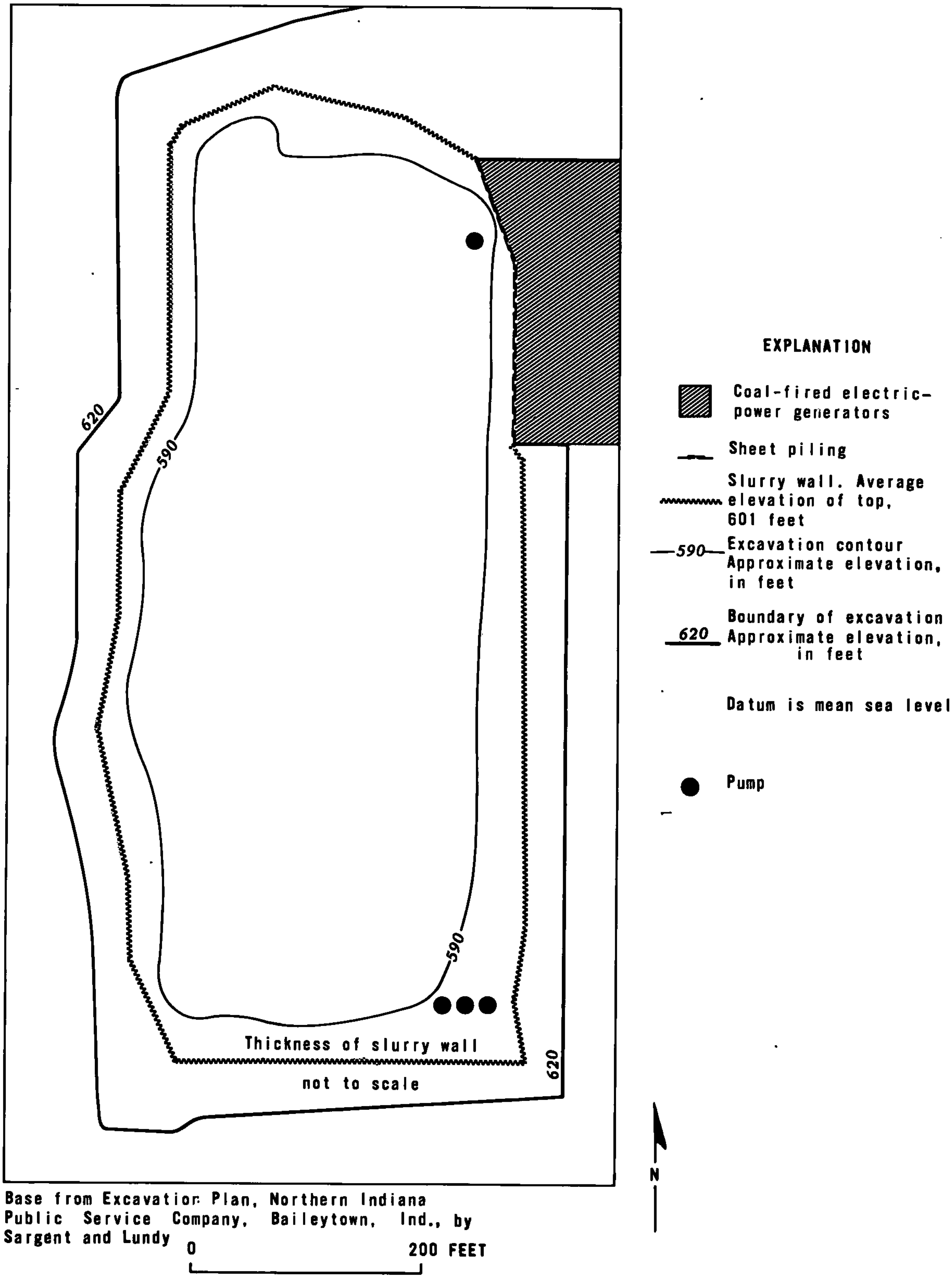


Figure 5.-- Elevations of slurry wall and excavation site.

gravel locally. For their study, Rosenshein and Hunn (1968) identified only the lower part of this layer as unit 1. As shown in figure 6, saturated thickness of this unit generally ranges from 0 to 35 ft. It thins and disappears in the southeast corner of the study area, where the moraine intersects the model area.

Unit 2 consists chiefly of clay but contains minor amounts of silt and sand. In the eastern part of the study area, unit 2 is a mixture of almost equal amounts of sand, silt, and clay. Thickness of the unit ranges from 0 to 80 ft. Lines of equal thickness of the unit are shown in figure 7. The unit is thickest just north of the Bailly Nuclear 1 excavation site and is thinnest in the southwestern and western parts of the study area, where it may be discontinuous. Elevation of the surface of unit 2 is shown in figure 8. The top of unit 2 dips northeast with an average slope of approximately 0.7 percent, except in the southeast part of the study area where the clay surface slopes appreciably more owing to a small moraine.

Unit 3 consists chiefly of a gray, fine to medium sand but contains thin lenses of sandy clay, clay, and sand and gravel. Thickness of unit 3 ranges from 0 to 80 ft (fig. 9). The unit is thickest beneath the central and south-central parts of the study area. Where unit 3 is absent, unit 4 merges with unit 2.

Unit 4, primarily silt and clay, contains minor amounts of sand and gravel as lenses of small areal extent in the till. In general, unit 4 is more compact and hardest at its base than elsewhere. Thickness of unit 4 generally ranges from 60 to 140 ft. Lines of equal thickness of the unit are shown in figure 10.

Although not a part of of the original environment, the foundations of Bethlehem Steel Corp. Burns Harbor Plant play an important part in the hydrogeologic setting. The foundations of the buildings extend to an average depth of 20 ft below the surface, causing unit 1 to be thinner below the buildings. Some of the foundations extend below the top of unit 2 and interrupt the continuity of unit 1. These areas are indicated on figure 10 as areas of zero thickness.

The bottoms of interdunal ponds 3 and 7 are almost entirely composed of sand. Thickness of the organic silt, clay, and sand deposit over most of the bottoms of interdunal ponds 1 and 2 ranges from 0 to 4 ft and averages 1.5 ft. The Great Marsh is underlain by unit 1, although, in places, generally thin deposits of organic silt, clay, and sand cover the bottom of the marsh.

Exploratory drilling in Porter County indicates that approximately 4,000 ft of Paleozoic sedimentary rocks overlie the Precambrian granite. In the study area the uppermost unit of this sequence and therefore the unit immediately beneath the unconsolidated deposits is the Antrim Shale of Late Devonian and Early Mississippian age.

HYDRAULIC CHARACTERISTICS OF THE UNCONSOLIDATED DEPOSITS

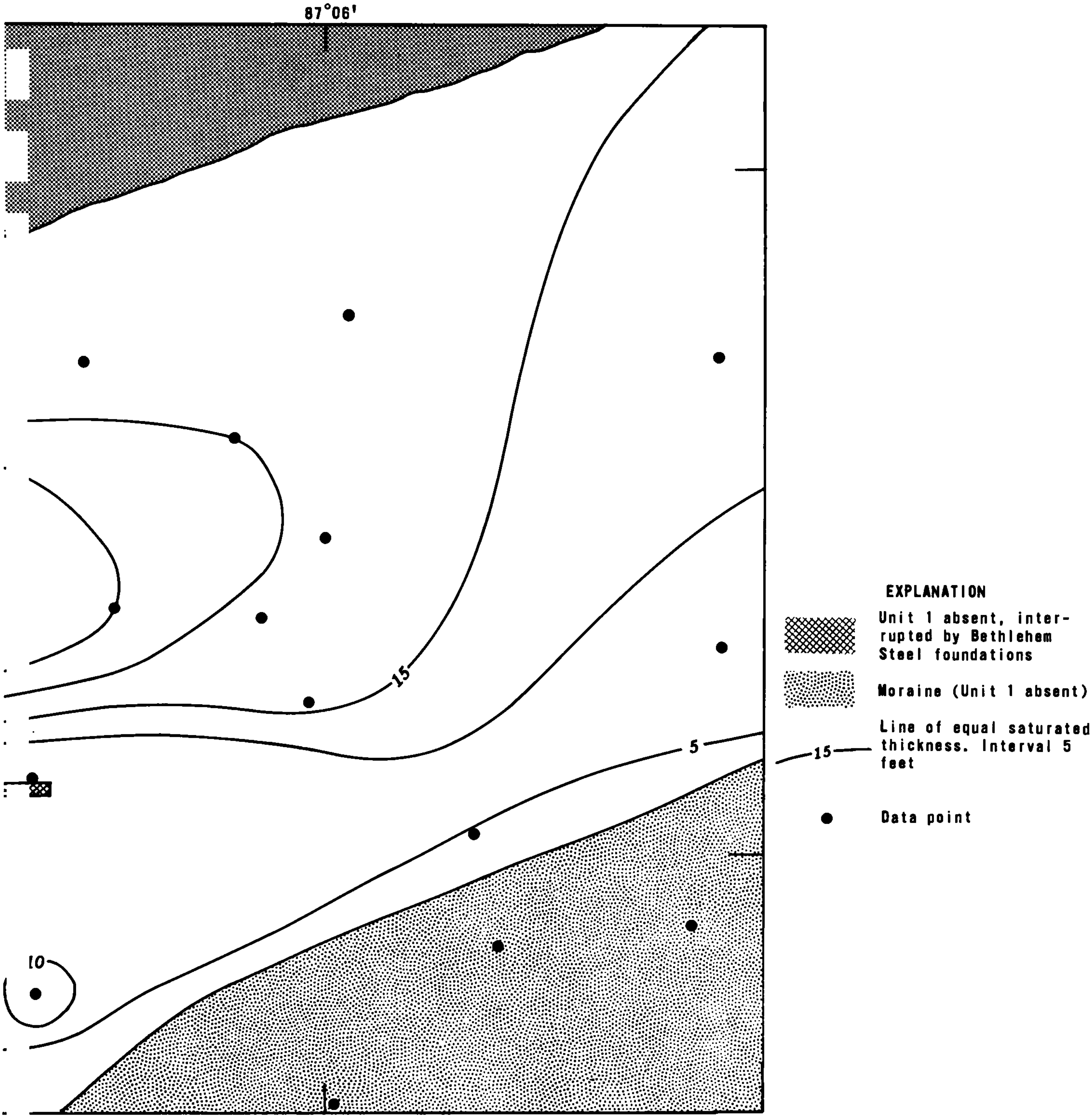
Lateral hydraulic-conductivity values for unit 1 were calculated from specific-capacity data for four large-diameter industrial wells in the study area. The specific capacities were first converted to transmissivities for the individual screened interval of each well by the nonsteady technique for unconfined aquifers (Theis, 1963). The value of the screened-interval transmissivity thus obtained was divided by the screen length of the well to obtain the hydraulic conductivity. Meyer and others (1975, p. 17-21) have explained this technique and the assumptions inherent in it. Hydraulic-conductivity values for each of the wells in unit 1 were averaged to obtain an average lateral hydraulic conductivity of 167 ft/day for unit 1. This value is at the upper end of the range of lateral hydraulic-conductivity values reported for this unit in Porter and LaPorte Counties by Rosenshein and Hunn (1968).

A determination of hydraulic conductivity by the procedure used for unit 1 was attempted for unit 3, by using specific-capacity data for large industrial wells constructed in unit 1 and the nonsteady techniques for confined aquifers by Brown (1963). Analysis of the data was complicated because breaching of the confining layer by the gravel pack around each well permitted vertical movement of water from unit 1 to unit 3 during pumping. This condition would tend to cause the hydraulic-conductivity values for unit 3 to be too large. Correction of the data for this violation of one of the necessary conditions for using the preceding techniques was not possible. Because the two units are similar lithologically, generally consisting of fine to medium sand, and because, as reported by Rosenshein and Hunn (1968), the lateral hydraulic conductivities of the two units are similar, a value of lateral hydraulic conductivity equal to that of unit 1 was assumed for unit 3.

Lines of equal transmissivity for units 1 and 3 were obtained by multiplying the average hydraulic-conductivity value by thickness, as determined from the thickness maps for each unit. The distributions of transmissivity for units 1 and 3 are shown in figures 11 and 12, respectively. Although the preceding technique can lead to a systematic estimate of transmissivity either too high or too low, these maps (figs. 11 and 12) did not require adjustment during model analysis.

No data were available for the direct calculation of the storage coefficient for either unit 1 or 3. On the basis of their work in an adjacent area, Rosenshein and Hunn (1968) suggested regional values of 0.12 and 0.003, respectively, for these units. As is discussed in the section "Model Simulation of Construction Dewatering," a range of values for the storage coefficient for unit 1 was used for the model analysis of the effect of the fly-ash ponds and construction dewatering on the ground-water system.

Figure 6.-- Saturated thickness of unit 1,



October 26, 1976.

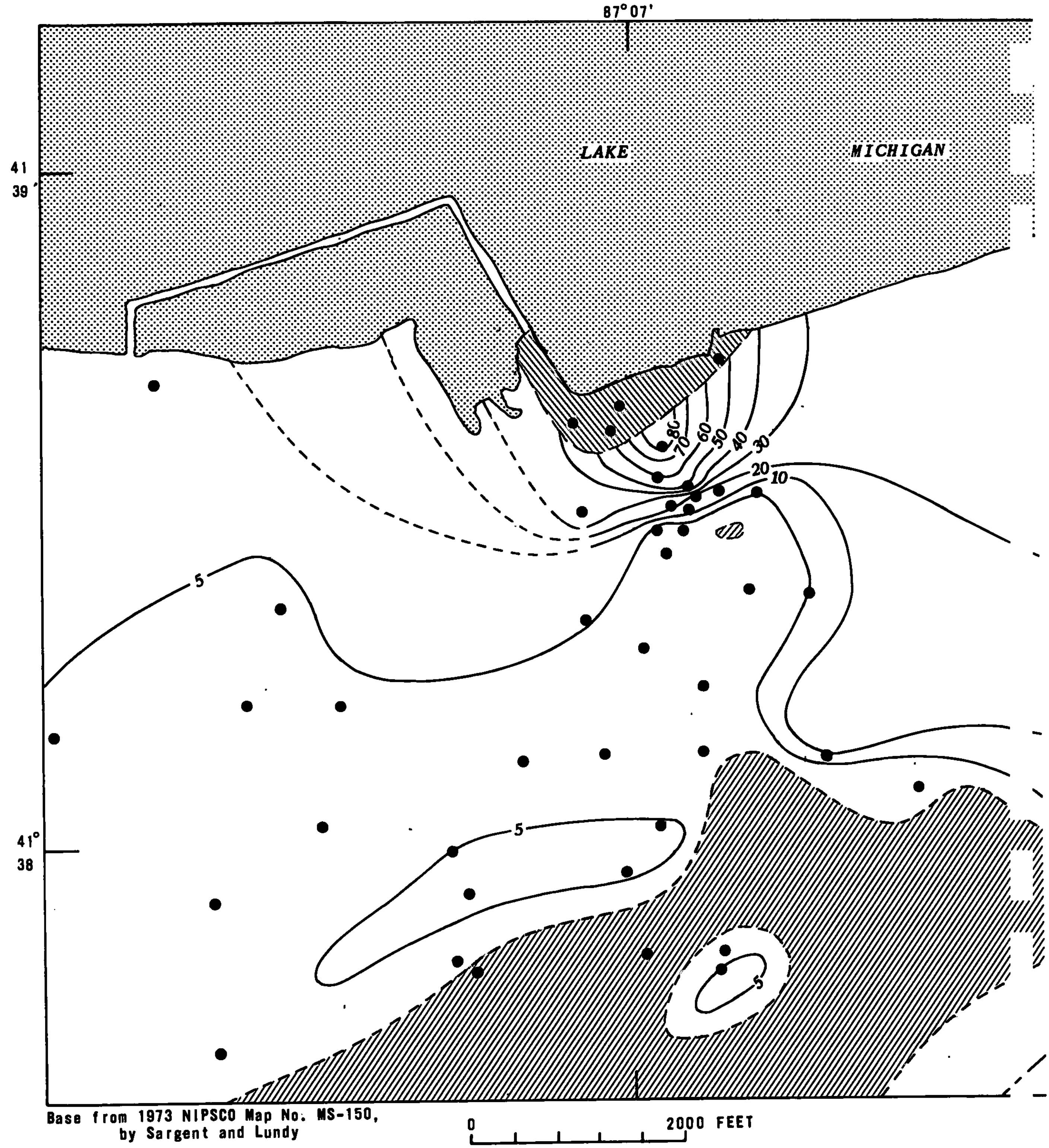
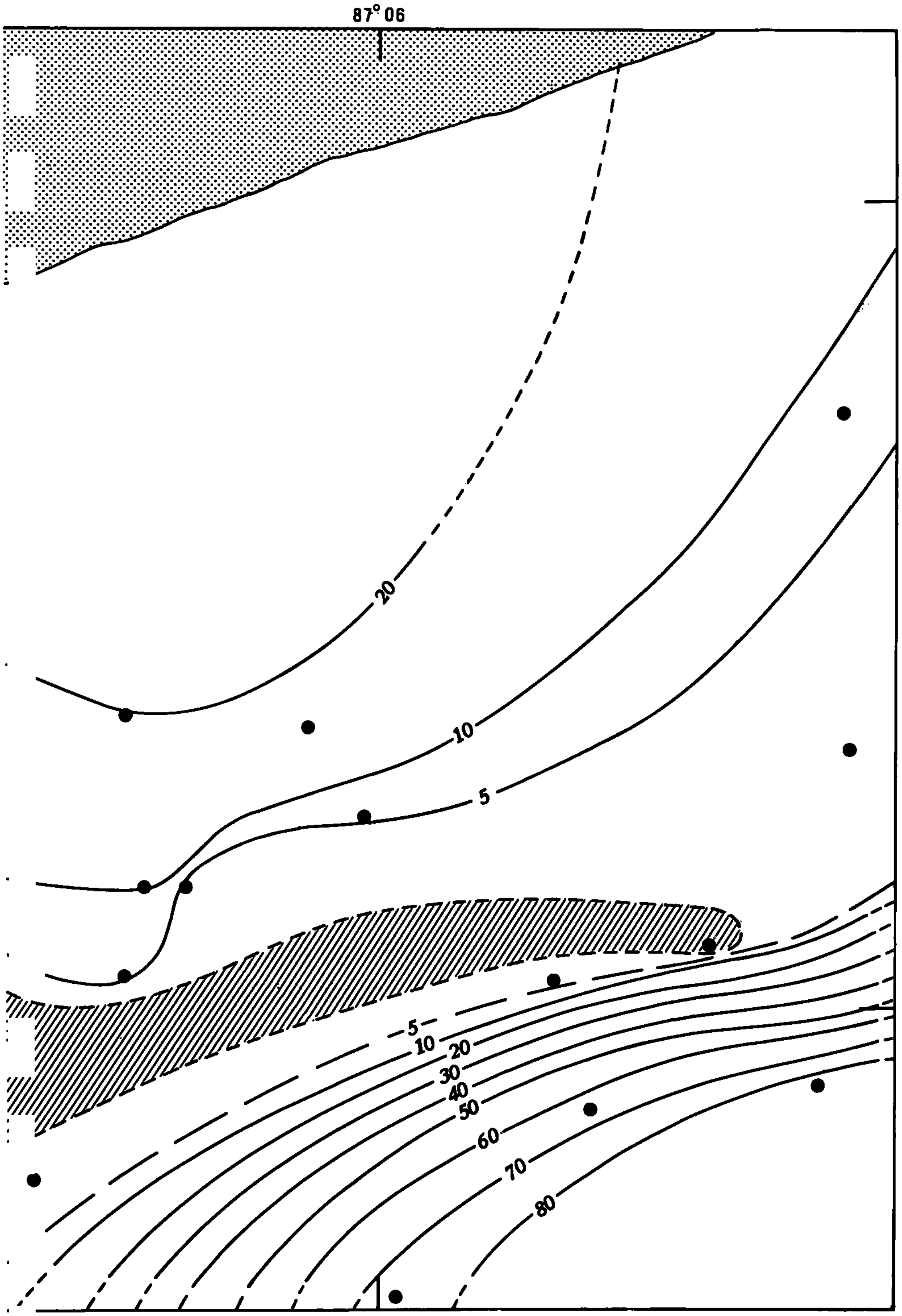


Figure 7.--Thickness of unit 2.



EXPLANATION

Unit 3 absent

Unit 2 absent
Areal extent unknown

—10— - - Line of equal thickness
Intervals 5 and 10 feet
Dashed where approximate

● Data point

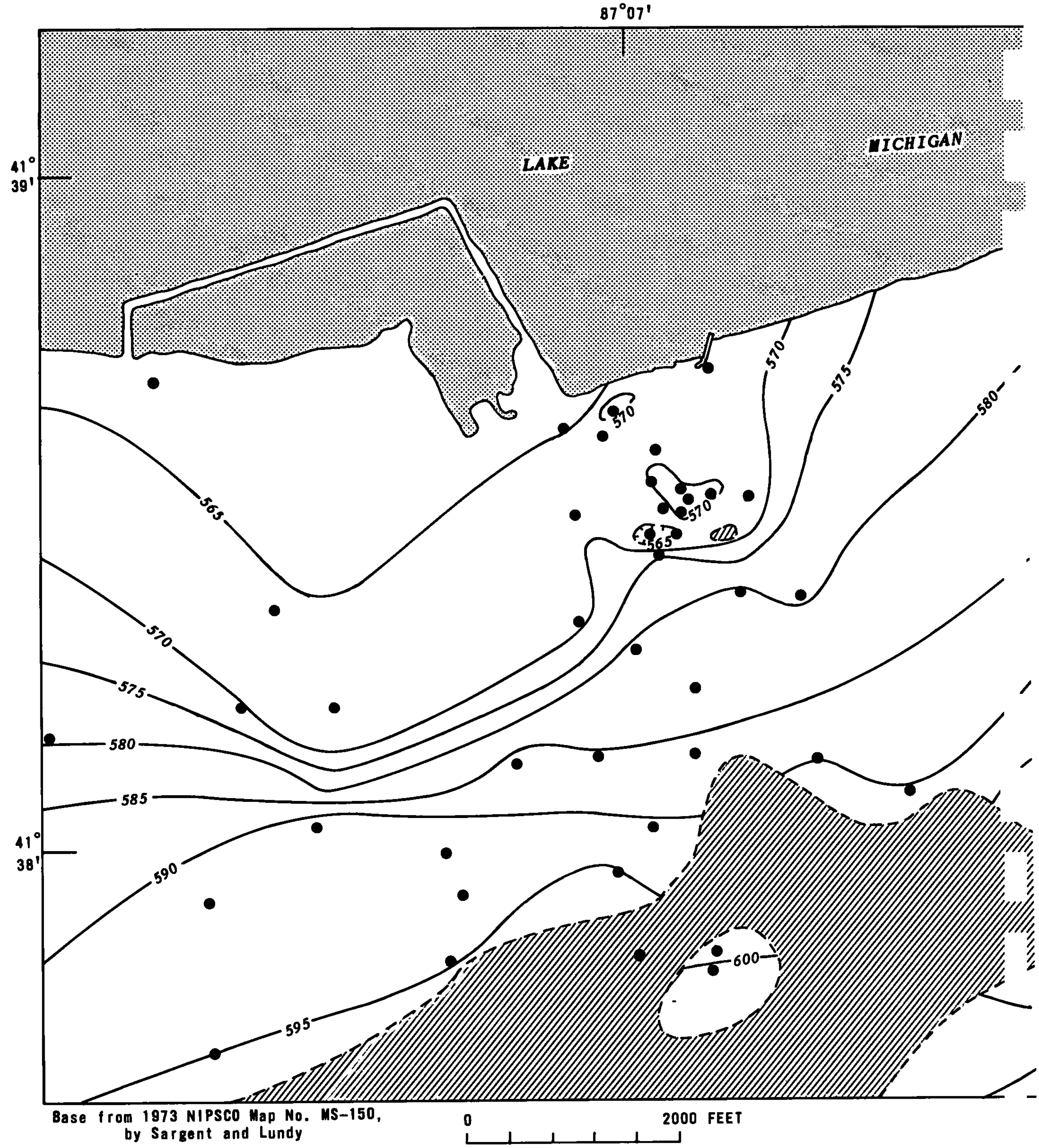
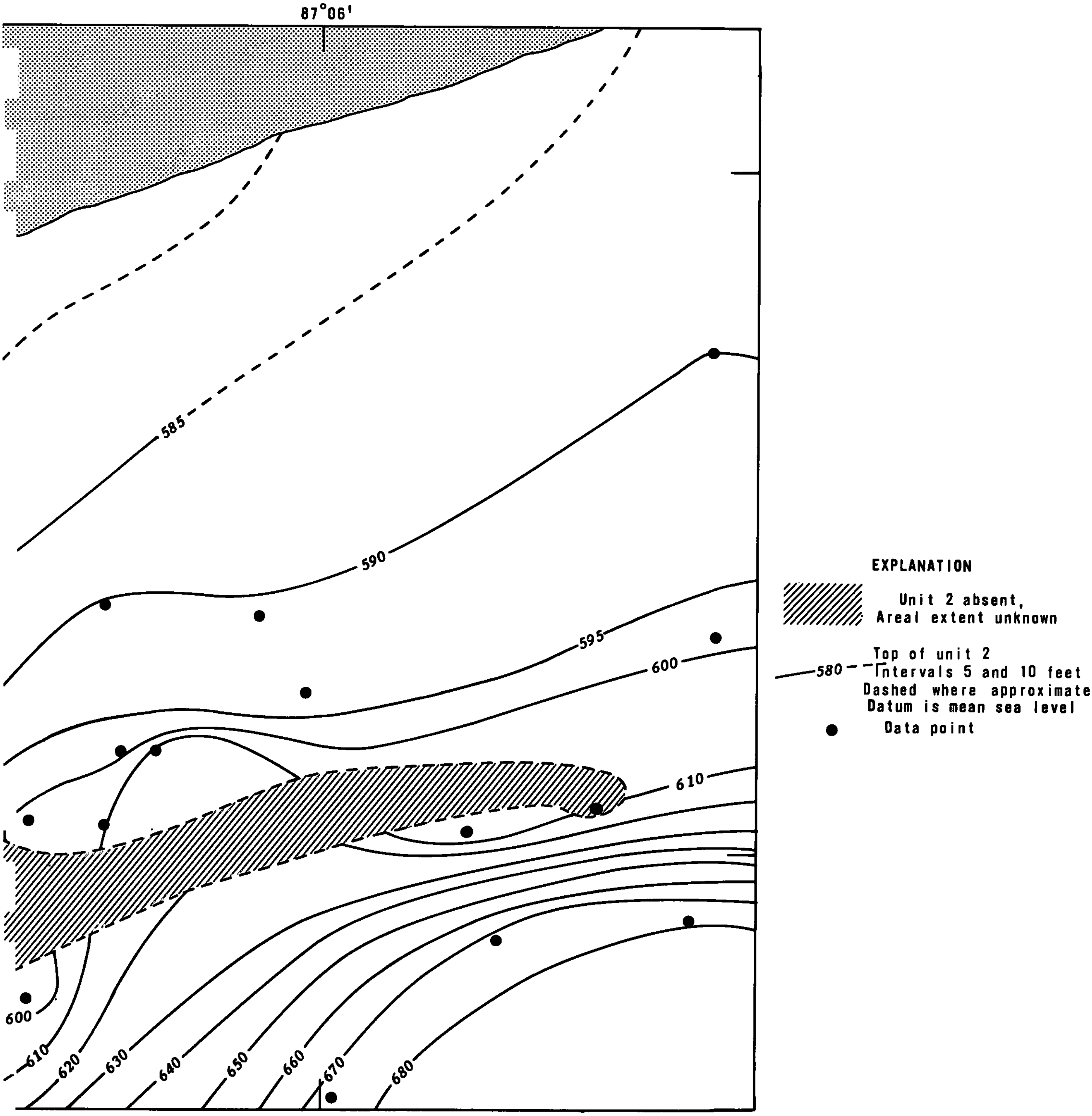


Figure 8.-- Elevation of the surface of unit 2.


87°06'
585
590
595
600
610
600
610
620
630
640
650
660
670
680
EXPLANATION
Unit 2 absent,
Areal extent unknown
Top of unit 2
580
Intervals 5 and 10 feet
Dashed where approximate
Datum is mean sea level
Data point

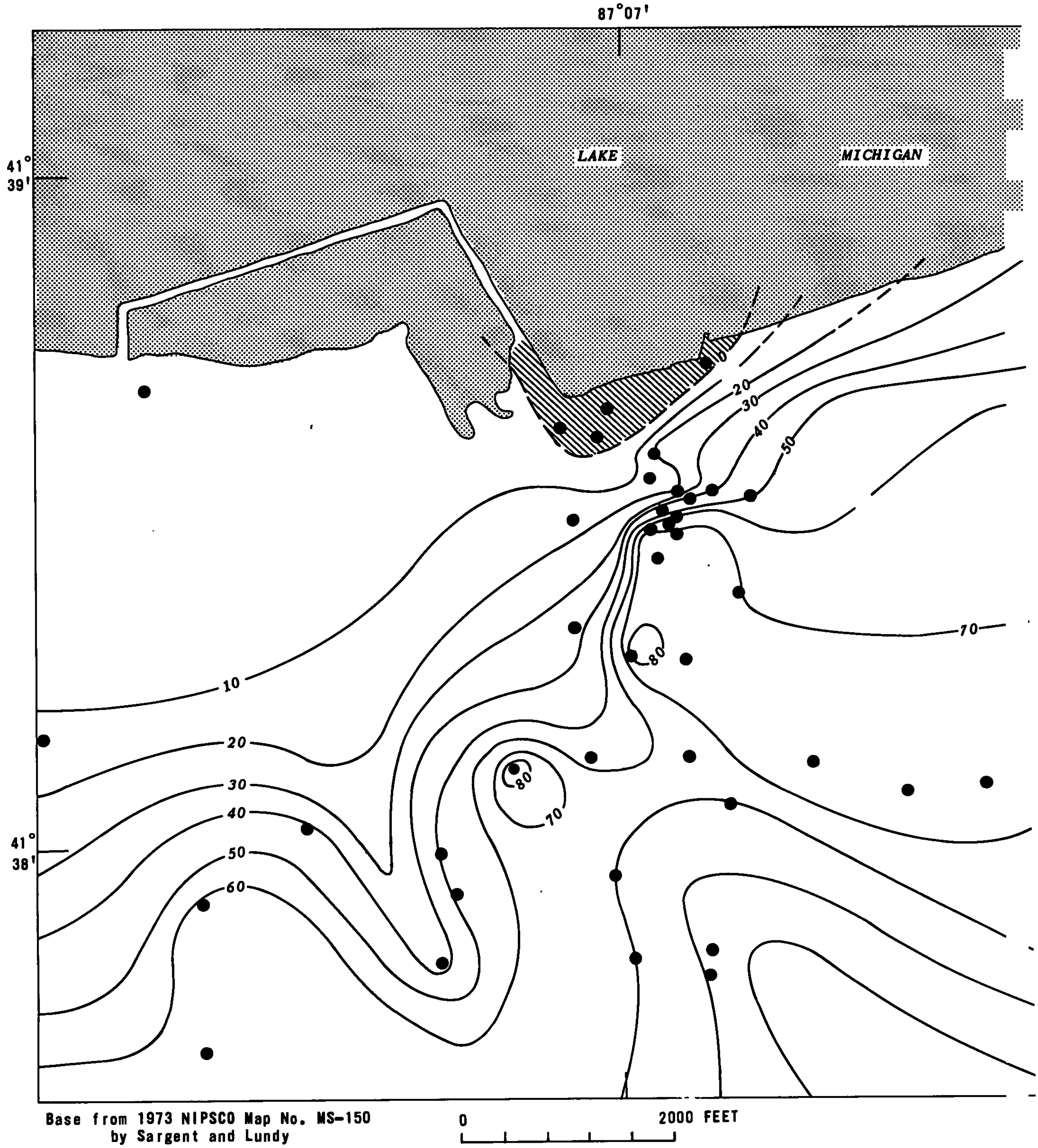
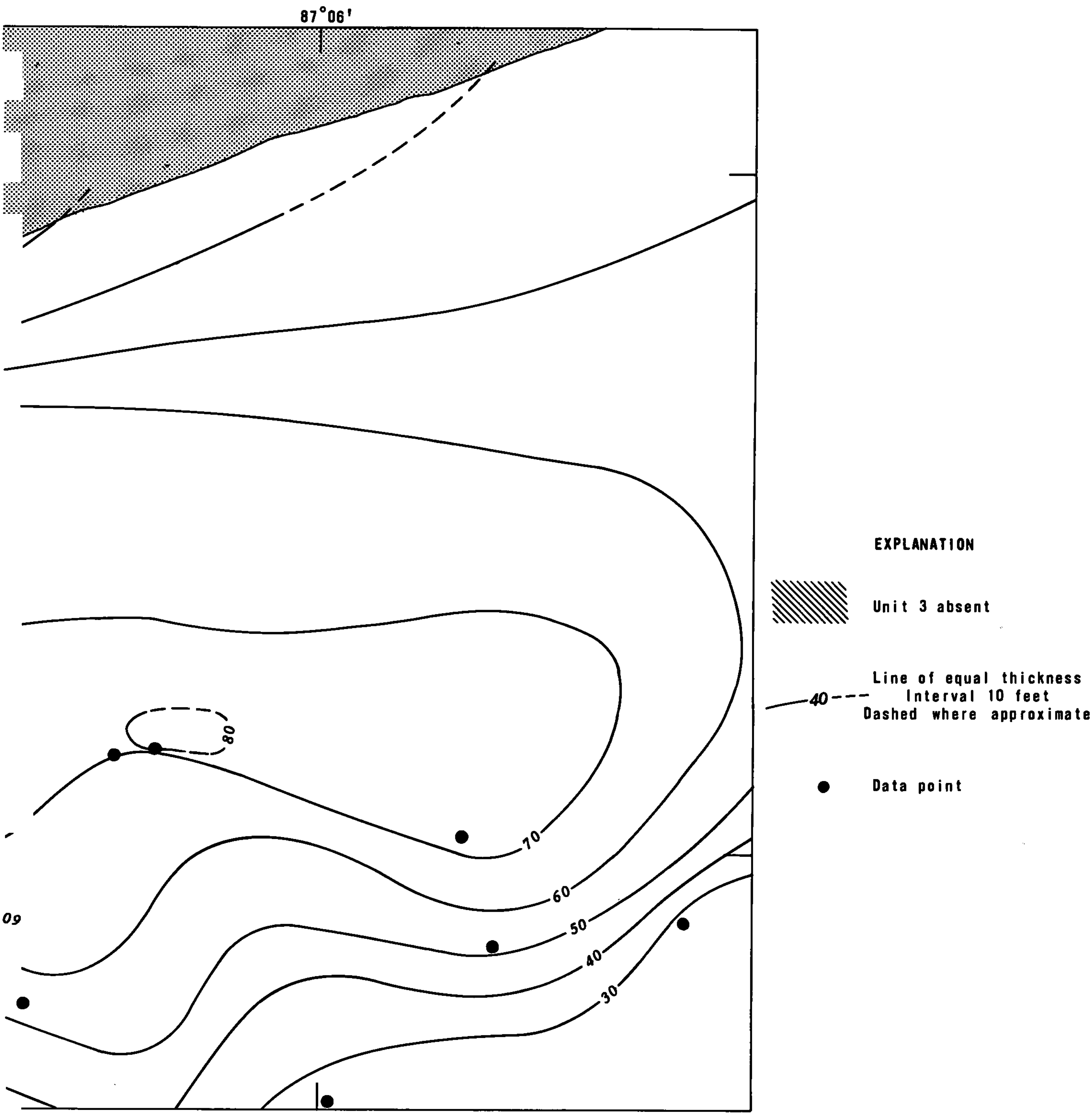


Figure 9.-- Thickness of unit 3.


87°06'
80
70
60
50
40
30
60
EXPLANATION
Unit 3 absent
40
Line of equal thickness
Interval 10 feet
Dashed where approximate
Data point

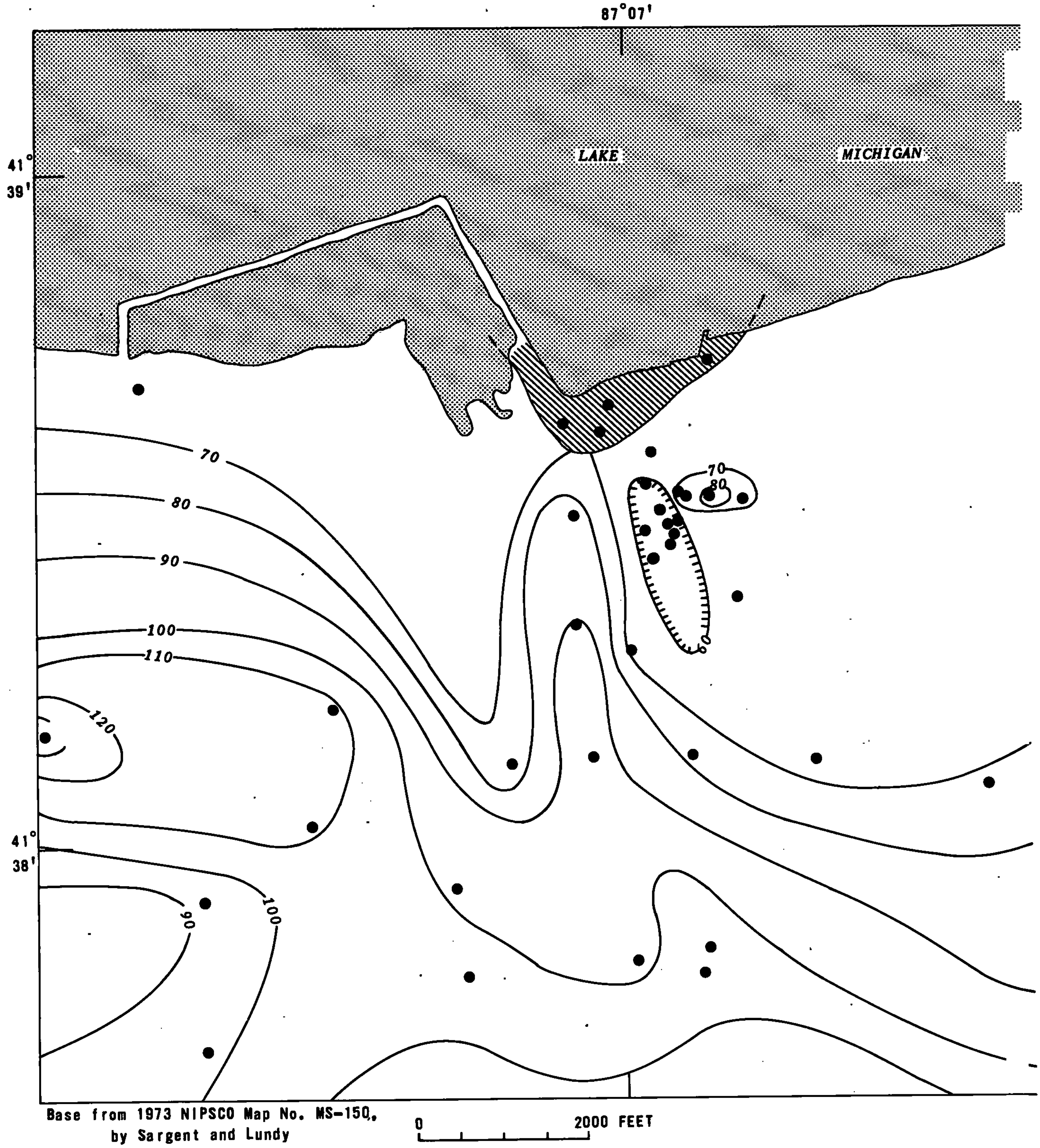
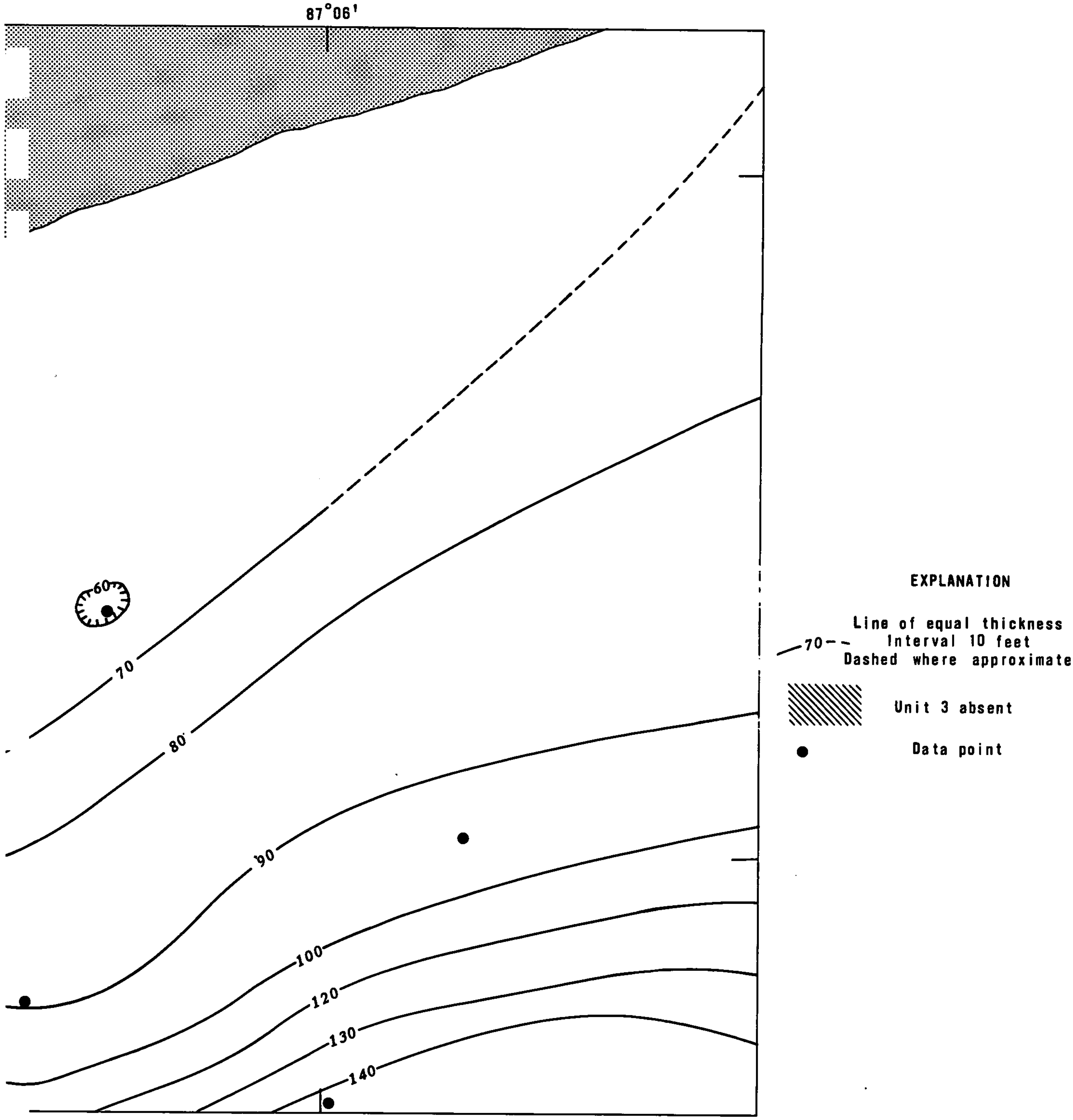


Figure 10.-- Thickness of unit 4


87°06'
60
70
80
90
100
120
130
140
EXPLANATION
Line of equal thickness
70
Interval 10 feet
Dashed where approximate
Unit 3 absent
Data point

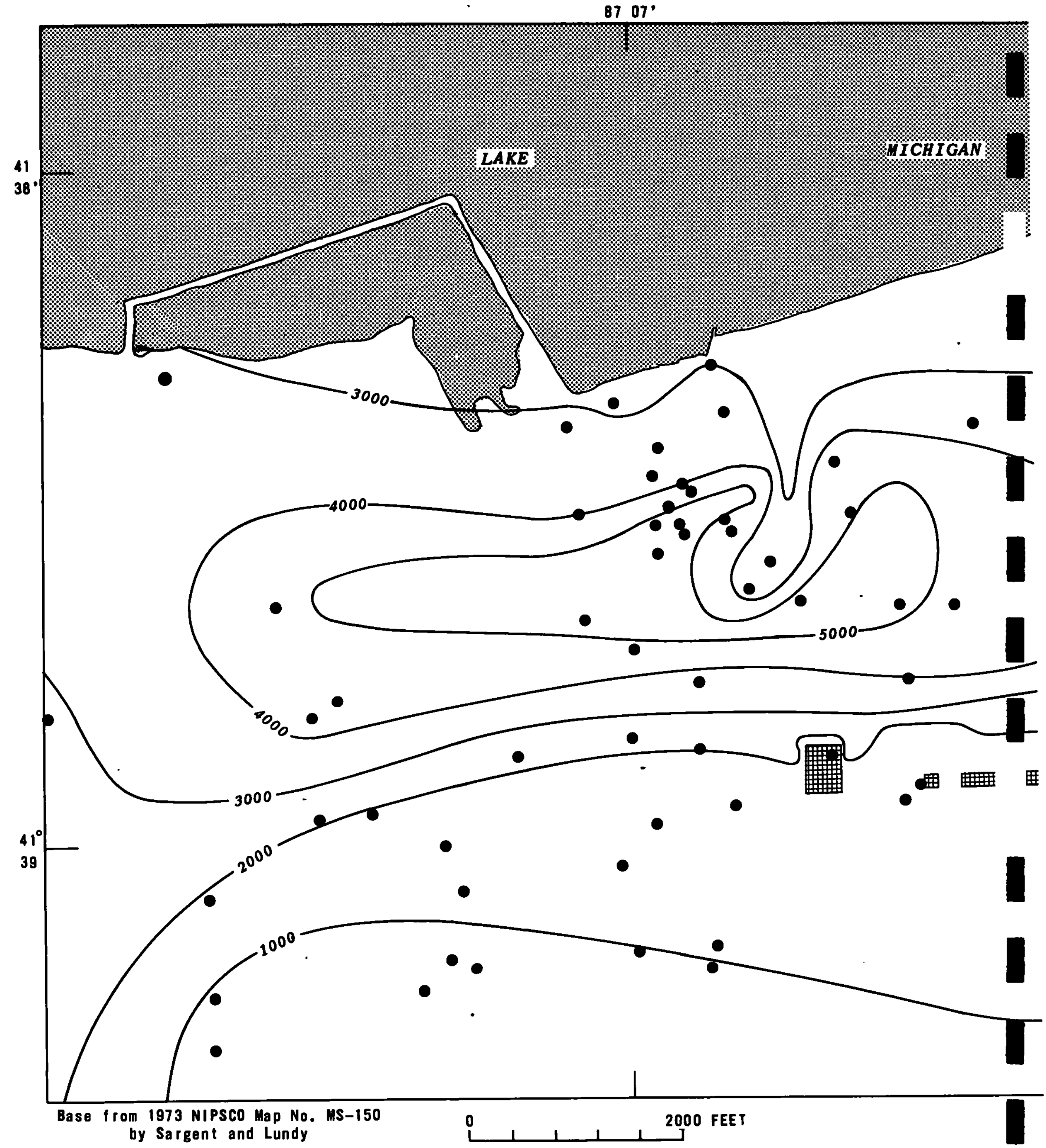
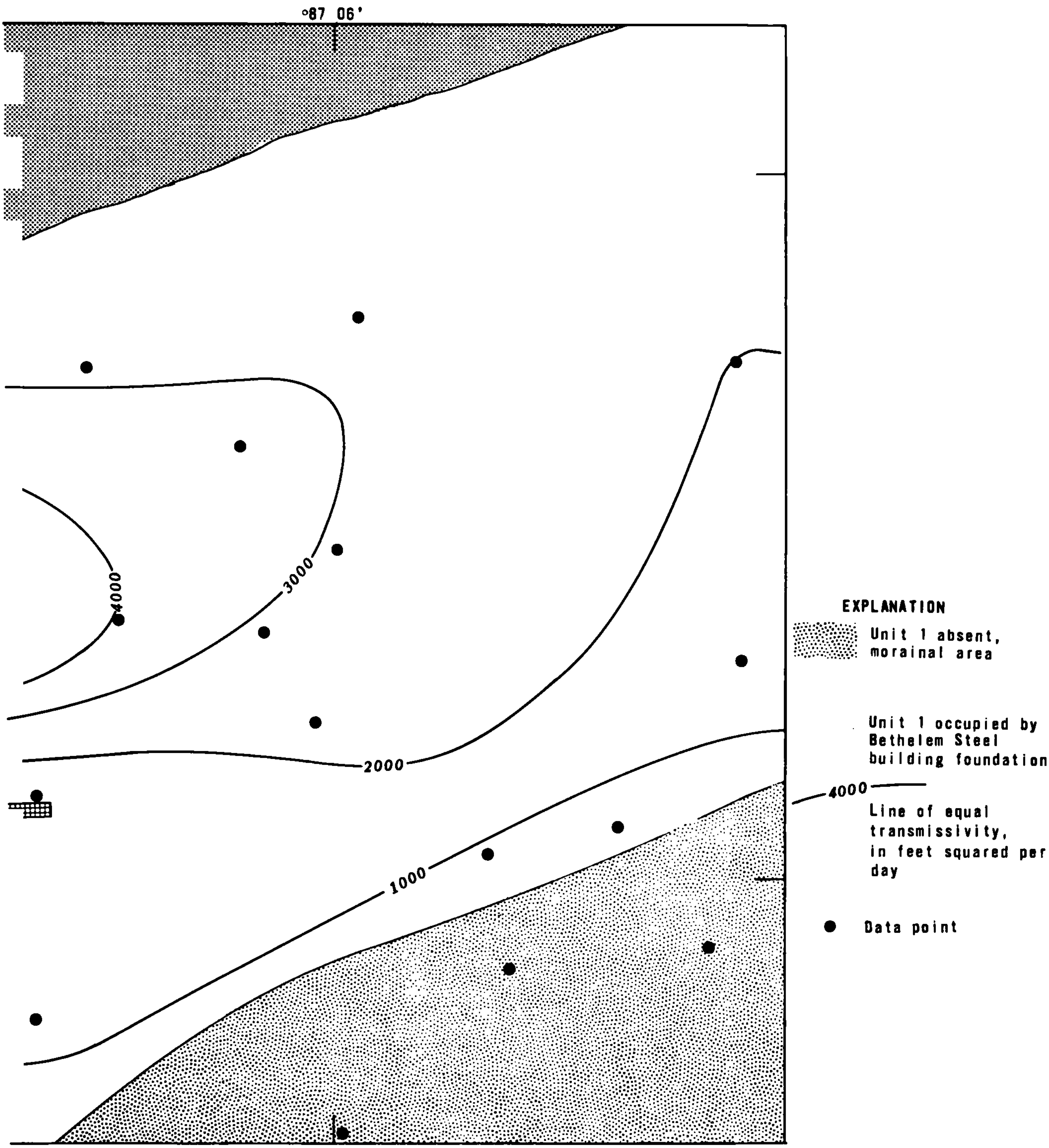


Figure 11.--Transmissivity of unit 1,



October 26, 1976.

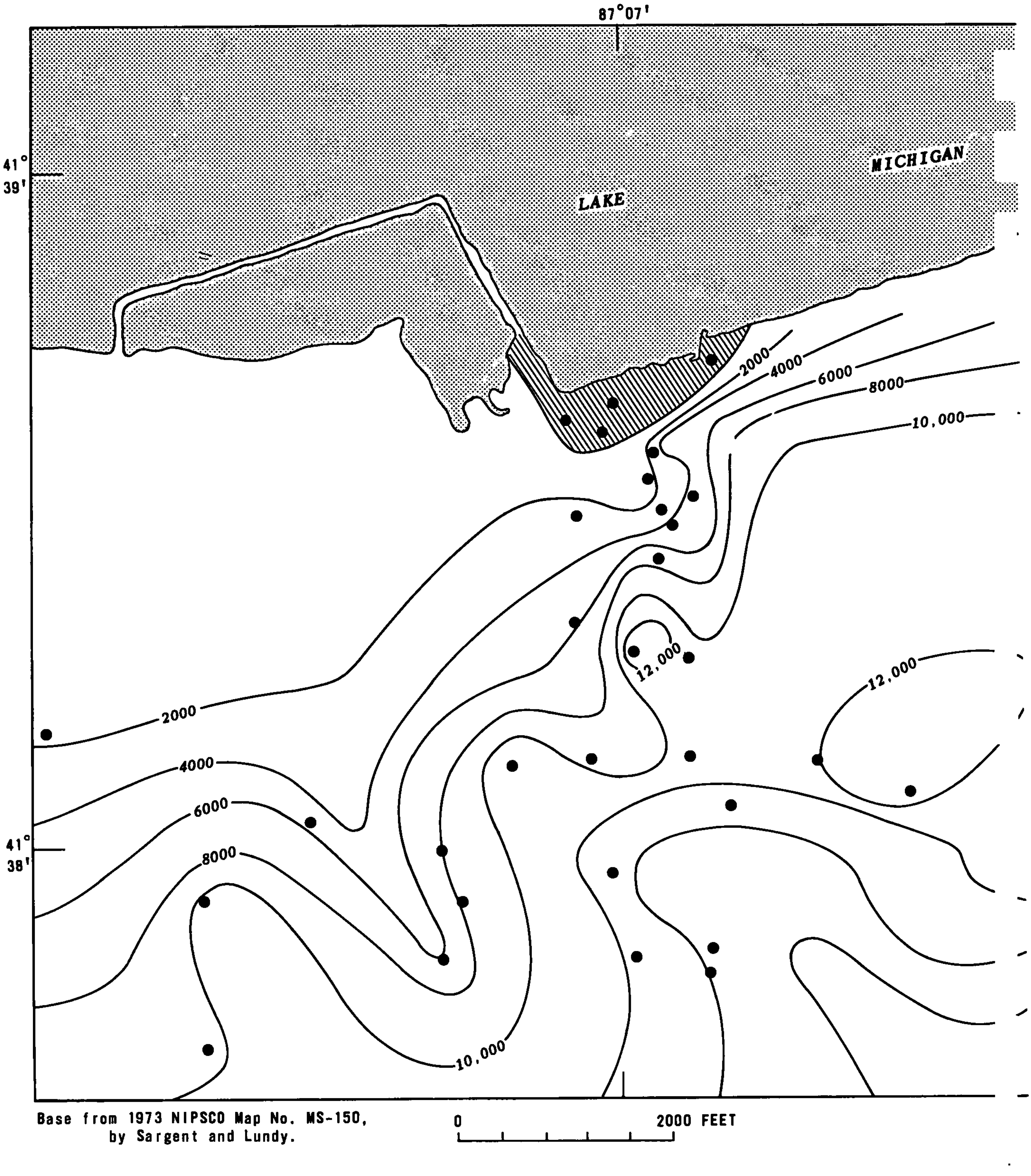
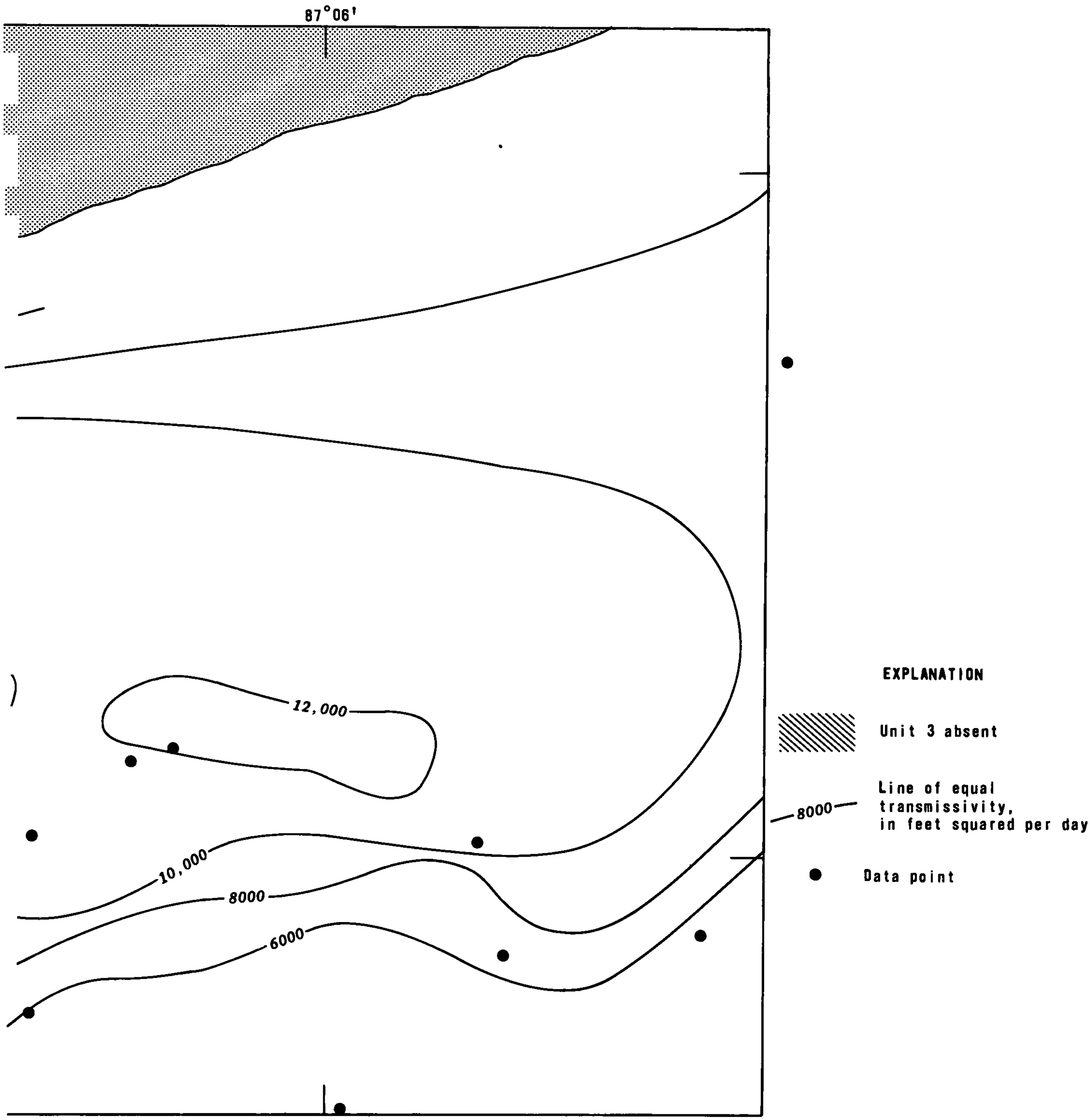


Figure 12.-- Transmissivity of Unit 3



October 26, 1976.

The storage coefficient of unit 3 was estimated from the equation by Jacob (1940):

$$S = S_s m = \theta \gamma m \left(\beta + \frac{\alpha}{\theta} \right)$$

where

γ is specific weight of water,

β the reciprocal of the bulk modulus of elasticity of water,

α the reciprocal of the bulk modulus of elasticity of the solid skeleton of the aquifer,

m the thickness of aquifer,

S_s the specific storage of the aquifer,

and

θ the aquifer porosity.

The confined sand-and-gravel aquifers were assumed to be twice as compressive as water, and θ was assumed to be 0.30. The specific storage calculated for unit 3 was 3.3×10^{-6}. Because of the uncertainties inherent in Jacob's technique, no attempt was made to contour the storage coefficient by multiplying this specific storage by individual values of aquifer thickness. Rather, use of an average thickness of 60 ft for the unit yielded an average storage coefficient of 2×10^{-4}.

Other hydraulic parameters necessary for completing the study objectives include the vertical hydraulic conductivity of the clay, the vertical hydraulic connection between unit 1 and the fly-ash ponds, and the vertical hydraulic connection between unit 1 and the interdunal ponds. Each of these is discussed in the section "Model Construction and Calibration." The lateral and vertical hydraulic conductivities of the Antrim Shale immediately underlying the unconsolidated rocks should be low enough for this unit to be considered as an impermeable base throughout the study area.

GROUND-WATER MOVEMENT

Observation-Well Data

In late 1973 NIPSCO began to monitor ground-water levels in four observation wells screened in unit 1 by a continuous recorder. By May 1975 three additional observation wells were added. NIPSCO plans to install additional observation wells in 1978.

During 1974 and 1975 seven additional observation wells screened in unit 1 were installed by the Geological Survey and the National Park Service.

Five of these wells were in the immediate vicinity of interdunal pond 1, and two were along Mineral Springs Road. During the summer of 1976, the Geological Survey and the National Park Service installed 18 additional wells screened in unit 1. These wells were distributed throughout the eastern part of the study area. Finally, in early 1977, eight more wells were installed in the eastern part of the study area. Five of these wells were screened in unit 3, and three were screened in unit 1. Only one of these wells was installed before the beginning of dewatering.

In June 1977, the Geological Survey obtained permission from Bethlehem Steel Corp. to measure water levels in 25 wells on their property, 12 screened in unit 1 and 13 in unit 3. Later, water levels measured in these wells on September 20, 1976, and February 24, 1977, were made available to the Geological Survey. Records of water levels in these wells for various times dating back to 1972 were also made available then.

Lateral Movement

Water levels in units 1 and 3 have been mapped for various times since the start of the study. The first date when sufficient water-level data for unit 1 were available for plotting on a map was October 26, 1976. Water levels recorded in Geological Survey and NIPSCO observation wells in unit 1 for this date are plotted in figure 13. Water levels recorded in Bethlehem Steel Corp. wells in unit 1 on September 20, 1976, were adjusted downward an average of 0.5 feet for use in the mapping process. Adjustments were based on straight-line interpretation of water-level changes measured in these wells from September 1976 to either January or February 1977. The decline of water levels in all the preceding wells during this period ranged from 0.2 to 1.5 ft. As indicated by the water levels in figure 13, ground water in unit 1 flows into the study area across the southwest boundary. The ground-water mound underlying the fly-ash ponds (fig. 13) indicates that water from these ponds seeps downward into unit 1. Locations of three cross sections of water levels in unit 1 on October 26, 1976, are shown in figure 14; the sections are shown in figure 15. The data indicate that seepage from the fly-ash ponds is saturated flow. Pumping from units 1 and 3 has caused localized cones of depression in both units. This pumping will be discussed more fully in the section, "Ground-water pumpage."

A map (fig. 16) showing the approximate configuration of the October 26, 1976, potentiometric surface of unit 3 provides a base map for the unit before dewatering at the nuclear excavation site or pumping at the coal-fired plant. Pumping at the plant began in January 1977, and dewatering at the nuclear excavation site began in March 1977.

Constructing the map of the potentiometric surface of unit 3 involved adjusting the water levels in Bethlehem Steel Corp. wells in unit 3 in a manner similar to that done for wells in unit 1. A decrease in water levels in Bethlehem Steel Corp. observation wells from September 1976 to January

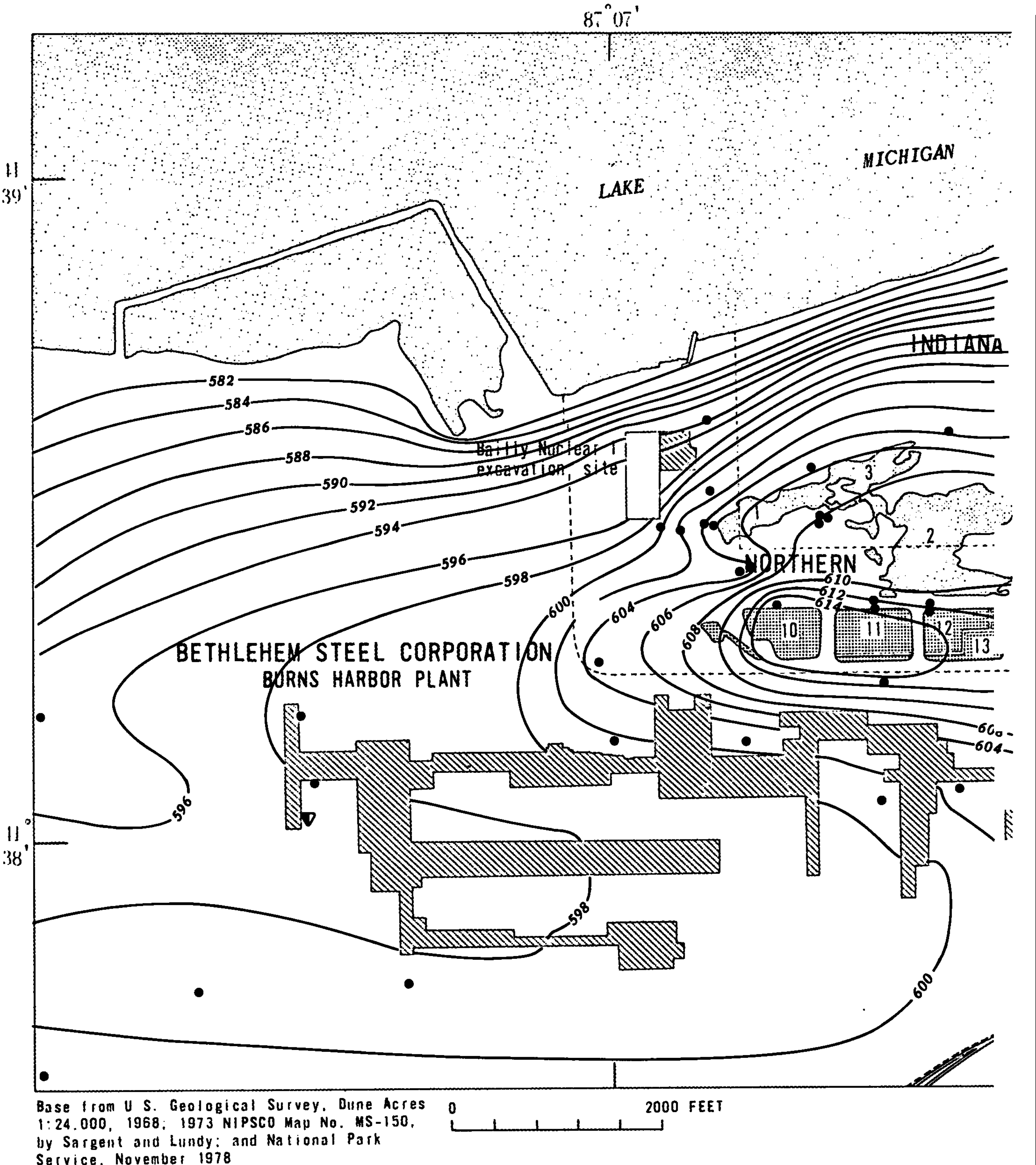
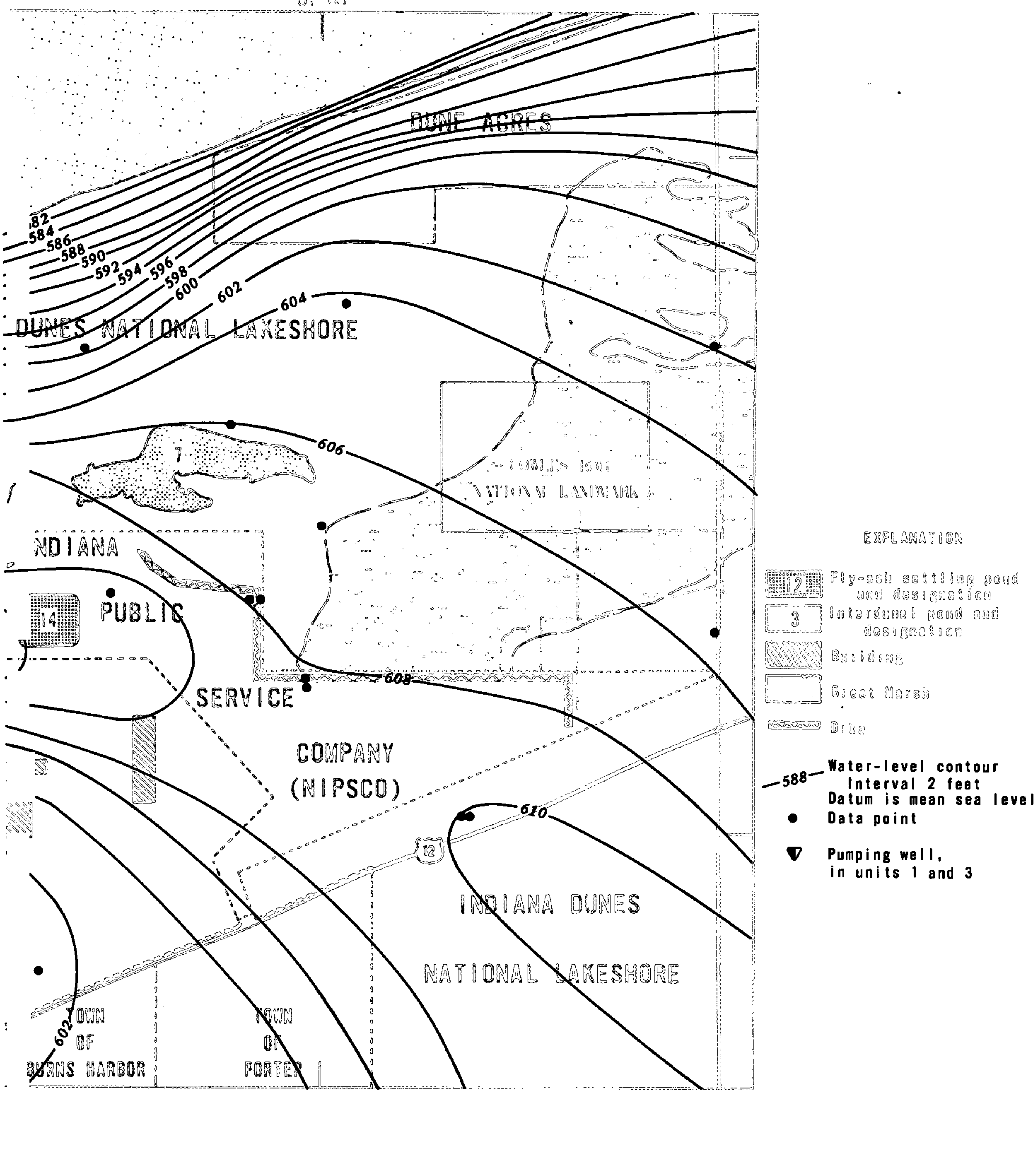


Figure 13.-- Unconfined water levels in unit 1, October 26, 1976, for Geological Survey and NIPSCO observation wells and estimated water levels October 26, 1976, for Bethlehem Steel Corporation observation wells.



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DUNES NATIONAL LAKESHORE
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COWLES BOG
NATIONAL LANDMARK
INDIANA
14
PUBLIC
SERVICE
608
COMPANY
(NIPSCO)
610
12
INDIANA DUNES
NATIONAL LAKESHORE
TOWN
OF
BURNS HARBOR
602
TOWN
OF
PORTER
EXPLANATION
12 Fly-ash settling pond and designation
3 Interdunal pond and designation
Building
Great Marsh
Dike
588 Water-level contour
Interval 2 feet
Datum is mean sea level
Data point
Pumping well, in units 1 and 3

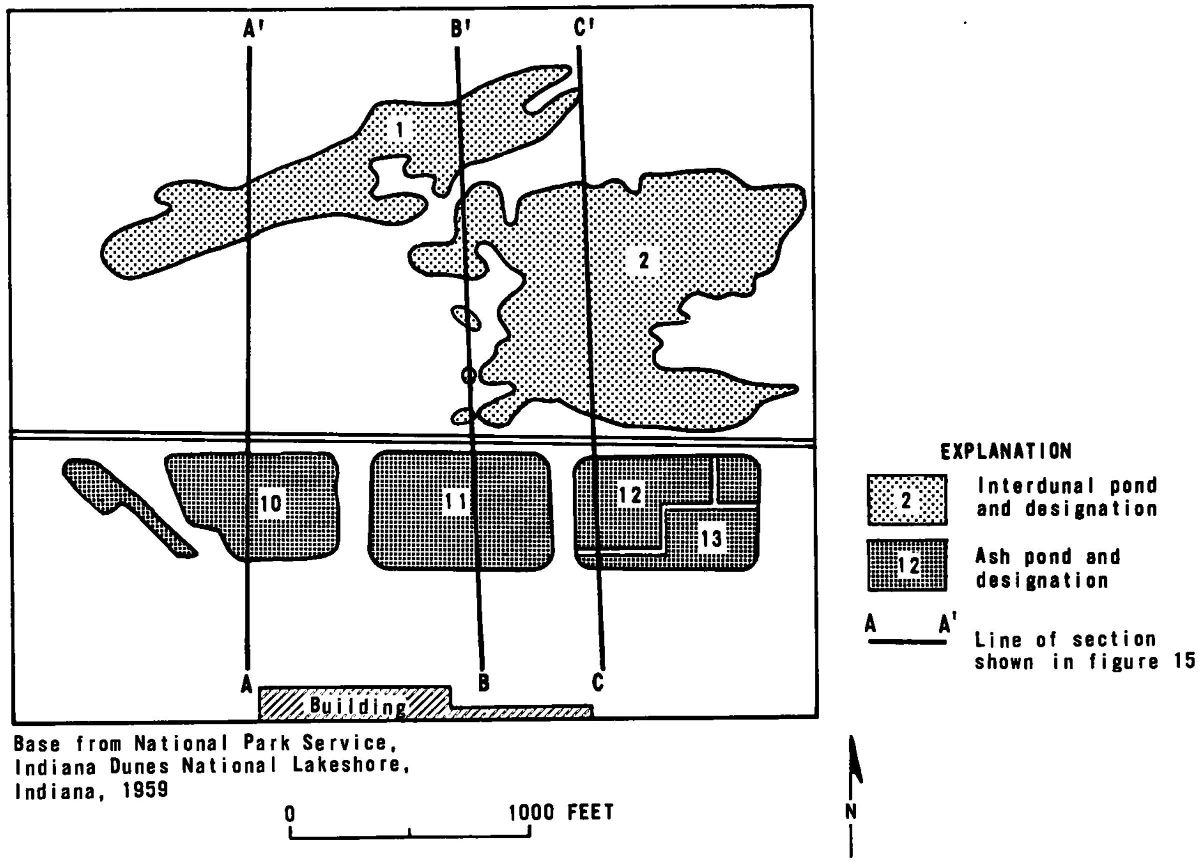


Figure 14.--Location of cross sections A-A', B-B', and C-C'.

1977 ranged from 0.60 to 4.4 ft. Water levels for the Geological Survey wells in unit 3 for October 26, 1976, were estimated by following the trends of the water level in the unit in Bethlehem Steel Corp. wells from September 1976 to April 1977, when water levels were available for all the Geological Survey wells. The adjustment required was an increase of 2.0 ft over April water levels. The potentiometric surface of unit 3 on October 26, 1976, constructed by the preceding method, is shown in figure 16. Although not based on data for this date, the map of this surface for October 26 represents an approximation that is probably accurate within the contour interval of the map and should allow a reasonable interpretation of the flow direction in unit 3 on this date.

The map indicates a general movement of ground water from southeast to northwest in unit 3 into the study area. Pumping has created several cones of depression in unit 3, and the water-level map (fig. 16) indicates a general east to west movement toward these cones. Ground water in the northeastern part of the study area is moving in a northerly direction and eventually discharges upward into unit 1.

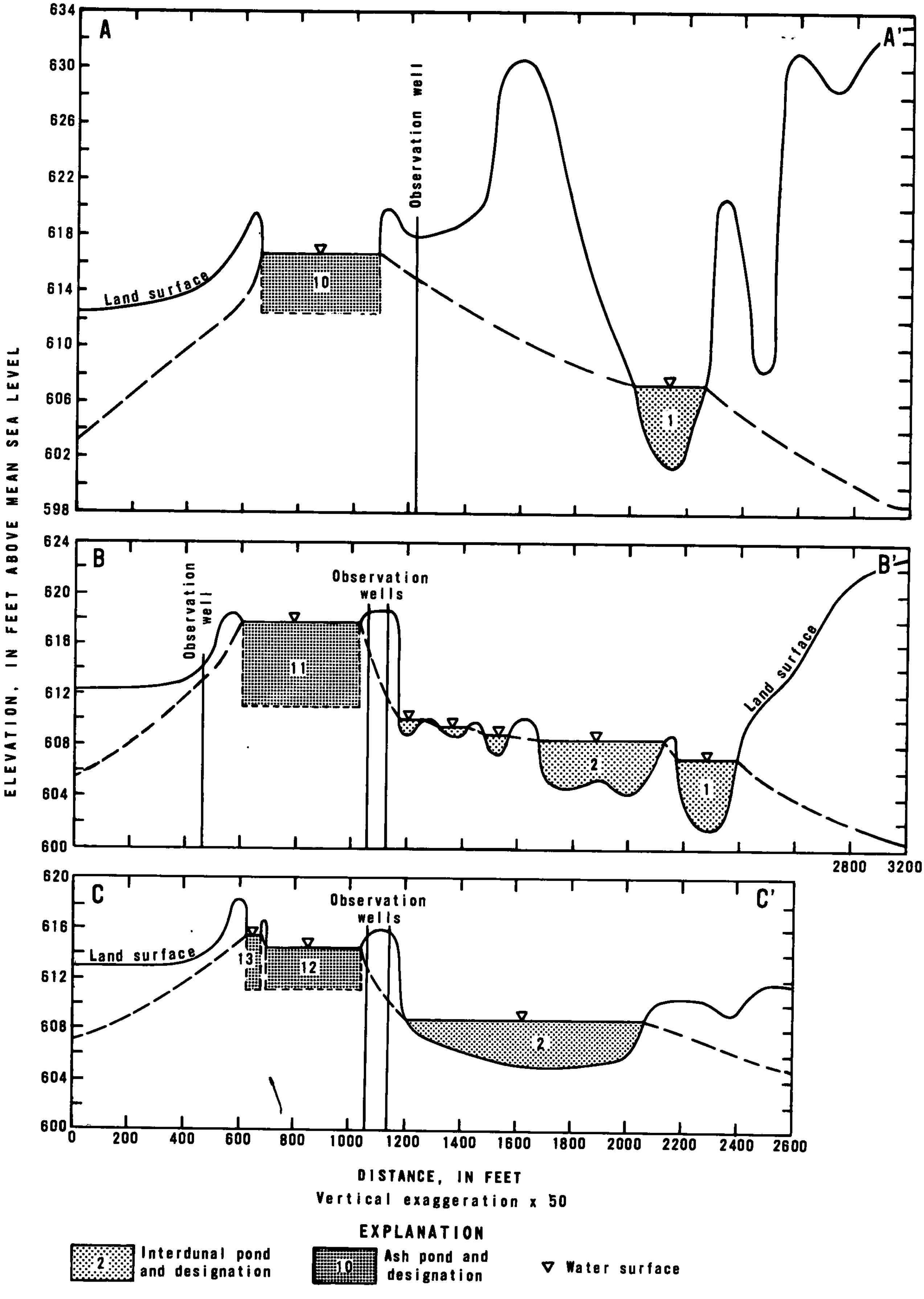


Figure 15.--Elevation of water surface along lines A-A', B-B', and C-C', October 26, 1976.

Vertical Movement Between Units 1 and 3

As indicated by the contour maps and by observation wells screened in both units 1 and 3, ground-water flow in October 1976 was generally upward from unit 3 to unit 1, except in areas influenced by man's activities. Ground-water flow was downward from unit 1 to unit 3 in the immediate vicinity of areas of pumping from unit 3 and in the immediate vicinity of the ash ponds. In the northern, northeastern, eastern, and southeastern parts of the study area, including the Great Marsh and the nuclear construction site, ground-water flow was upward.

Ground-Water Level Changes

Changes in ground-water levels and, consequently, in flow directions and rates are caused by (1) fluctuation in the stage of Lake Michigan, (2) fluctuation in the water level maintained in the fly-ash ponds, (3) a change in the distribution and (or) rates of pumping within and near the study area, and (4) changes resulting from natural variations in recharge to unit 1, including precipitation, discharge from unit 1, and evapotranspiration.

Since March 1972, NIPSCO has measured the stage of Lake Michigan monthly and precipitation daily. Water levels in interdunal ponds 1 and 2 and in ash pond 13 have also been measured since that time every 1 to 2 weeks. In October 1973, the remaining interdunal and fly-ash ponds were added to the measuring routine.

Water levels in NIPSCO's observation wells have been monitored on a continuous basis since late 1973. Selected hydrographs of these data, prepared by NIPSCO and shown in figure 17, indicate a close correlation in water-level fluctuations among the observation wells; that is, rising and falling trends in one well are observable in the other wells. The magnitude of these changes has varied from well to well, but the minimum and the maximum fluctuations have ranged from 1.6 to 6.6 ft, respectively. Although the cutoff date for the study of dewatering in the Cowles unit, Indiana Dunes National Lakeshore, was December 31, 1977, NIPSCO has constructed additional wells on its property since then and is monitoring the water levels in these wells.

To help determine the effect of construction dewatering at the nuclear powerplant site, the Geological Survey prepared maps showing the change in water levels in unit 1 for various times since the start of dewatering. Water-level changes in the unit from March 17 through December 15, 1977, are shown in figure 18. Water levels have risen in most of the area where data are available, except within the excavation site and in the immediate vicinity of the site. The maximum decline inside the excavation was 8.5 ft, and the maximum decline outside was 1.9 ft. The maximum rises recorded were 1.7 ft in the ground-water system, 2.8 ft in fly-ash pond 10, and 0.2 ft in the

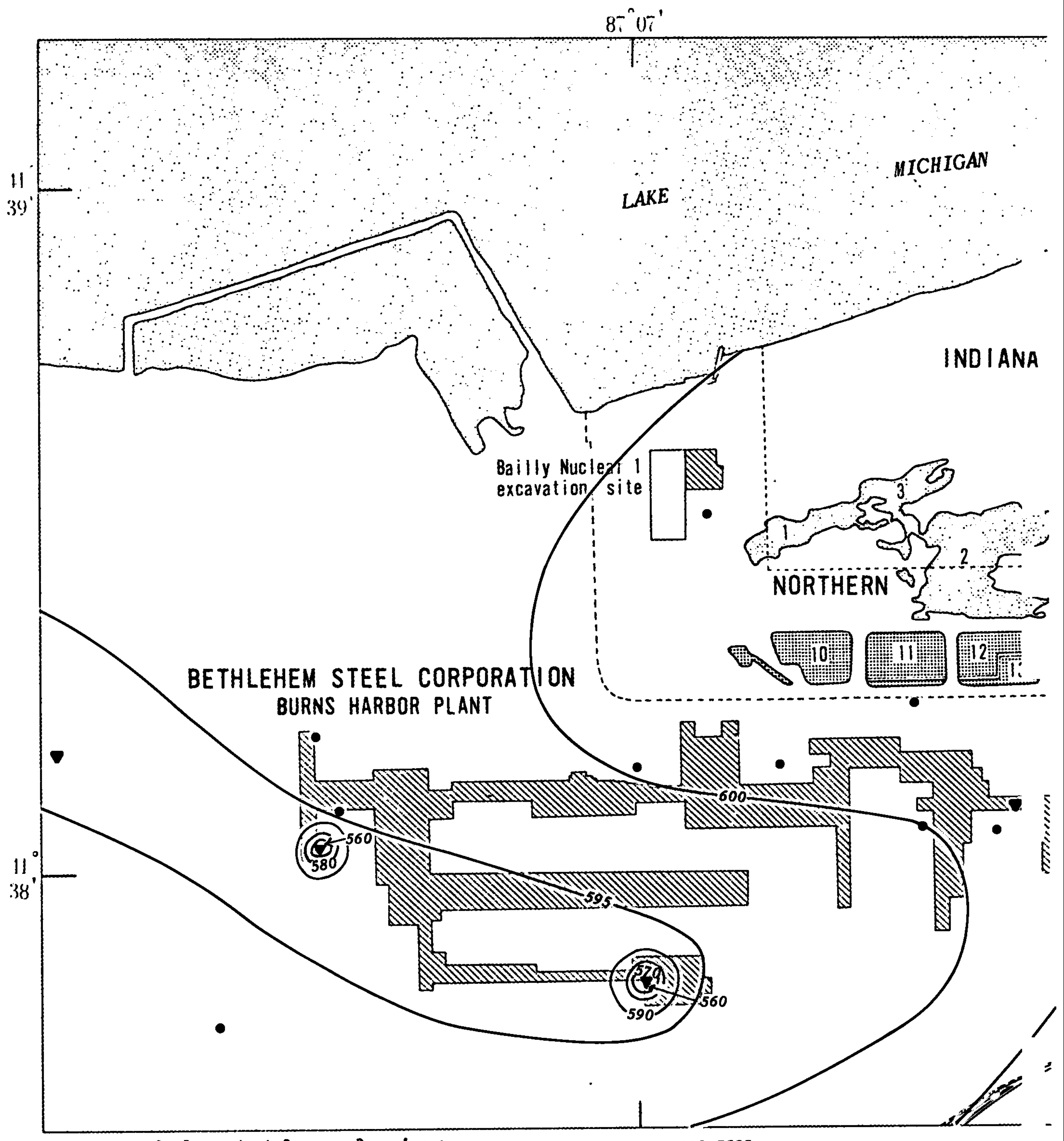
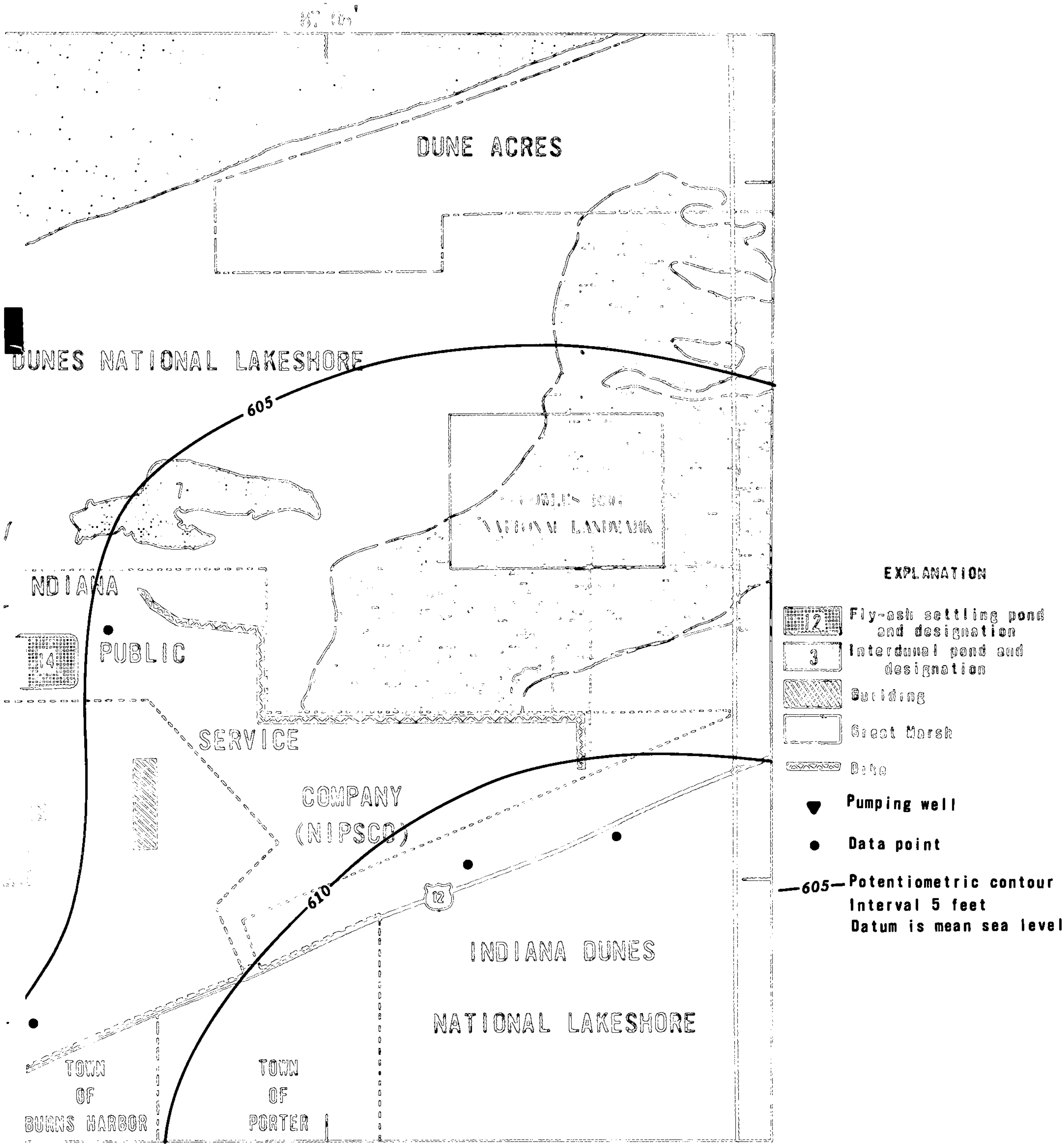


Figure 16.-- Potentiometric surface of unit 3, October 26, 1976.



DUNE ACRES
DUNES NATIONAL LAKESHORE
605
610
INDIANA
PUBLIC
SERVICE
COMPANY
(NIPSCO)
14
7
12
INDIANA DUNES
NATIONAL LAKESHORE
TOWN
OF
BURNS HARBOR
TOWN
OF
PORTER
EXPLANATION
Fly-ash settling pond and designation
Interdunal pond and designation
Building
Great Marsh
Dike
Pumping well
Data point
605 Potentiometric contour
Interval 5 feet
Datum is mean sea level

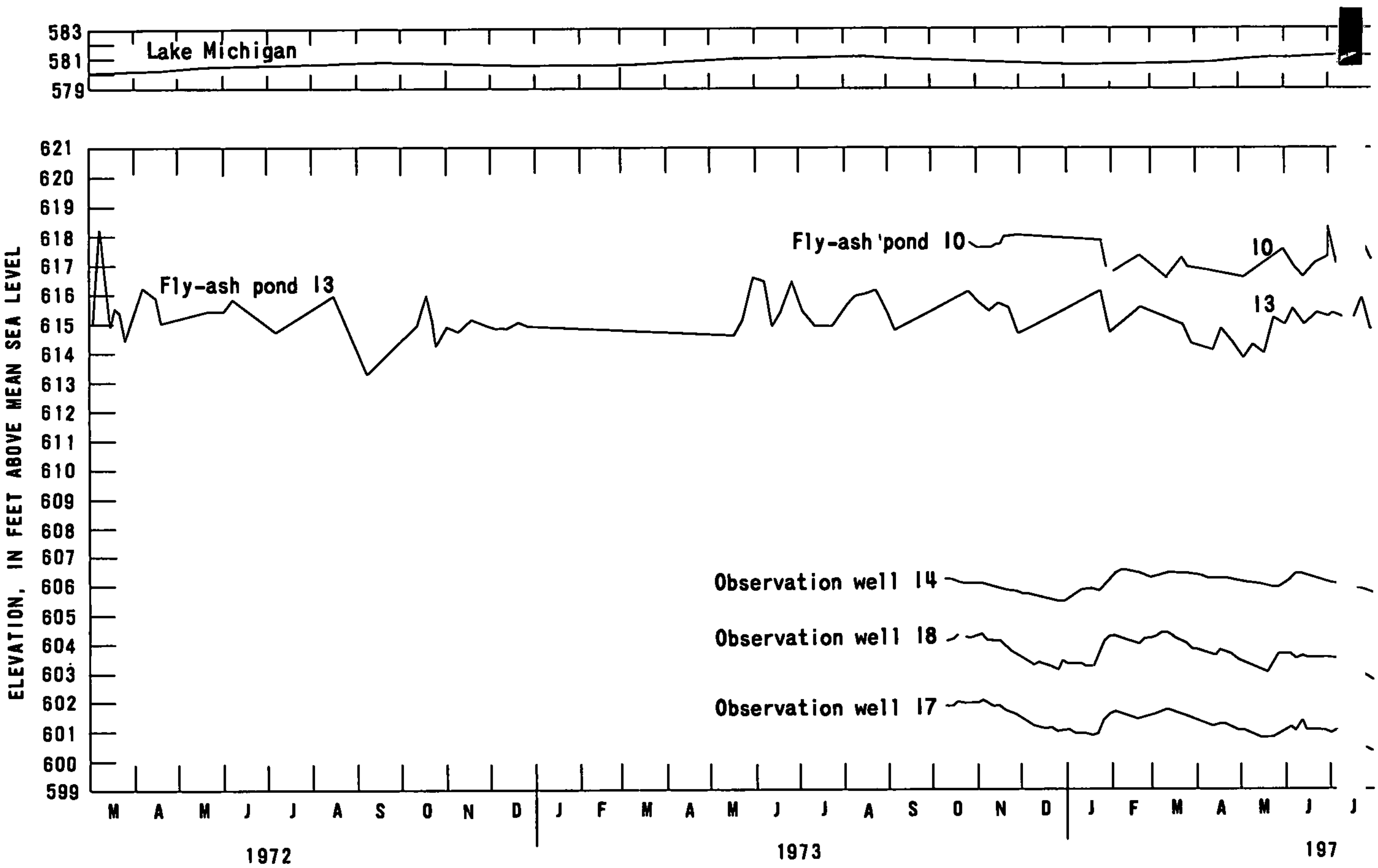
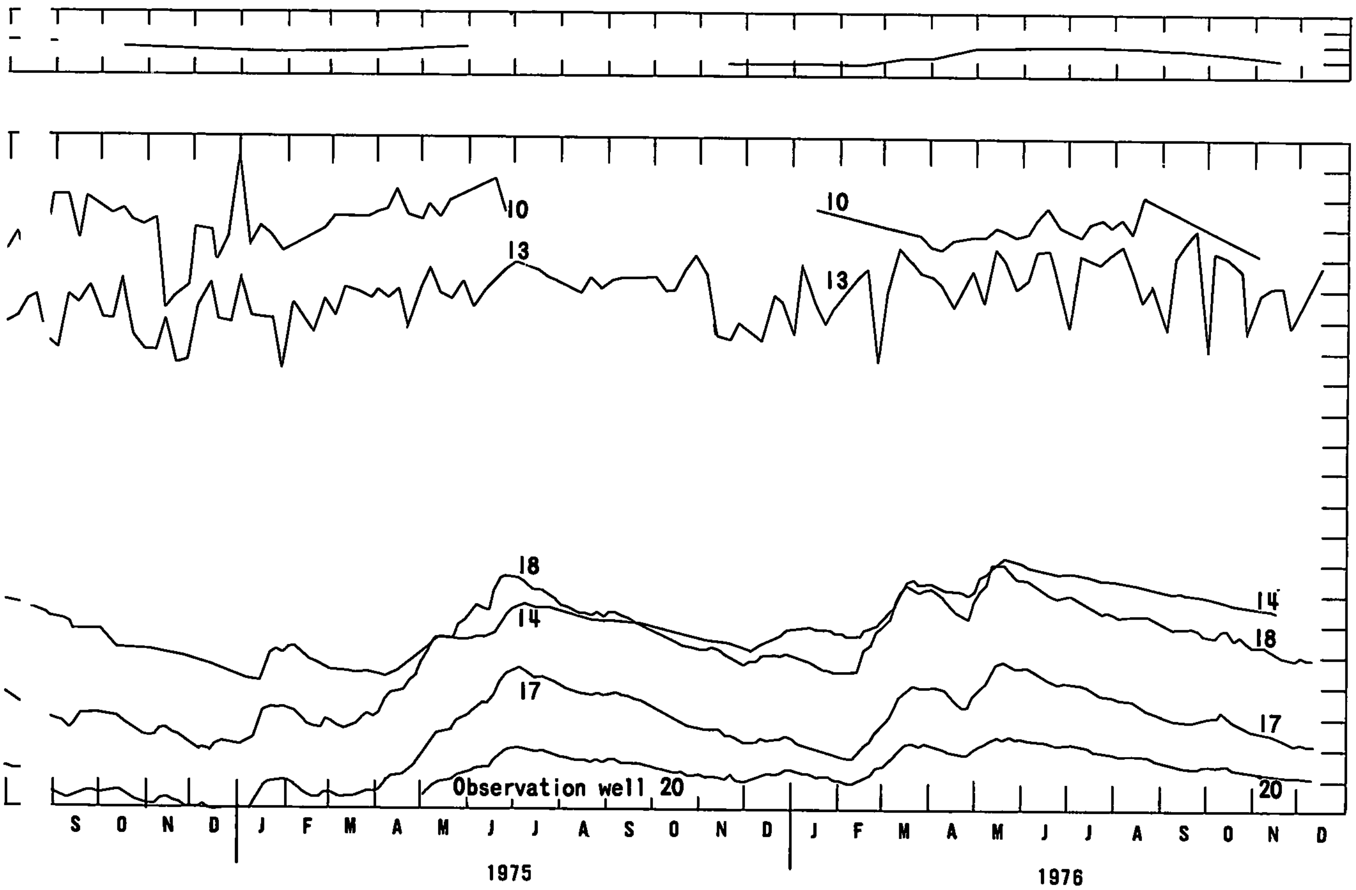
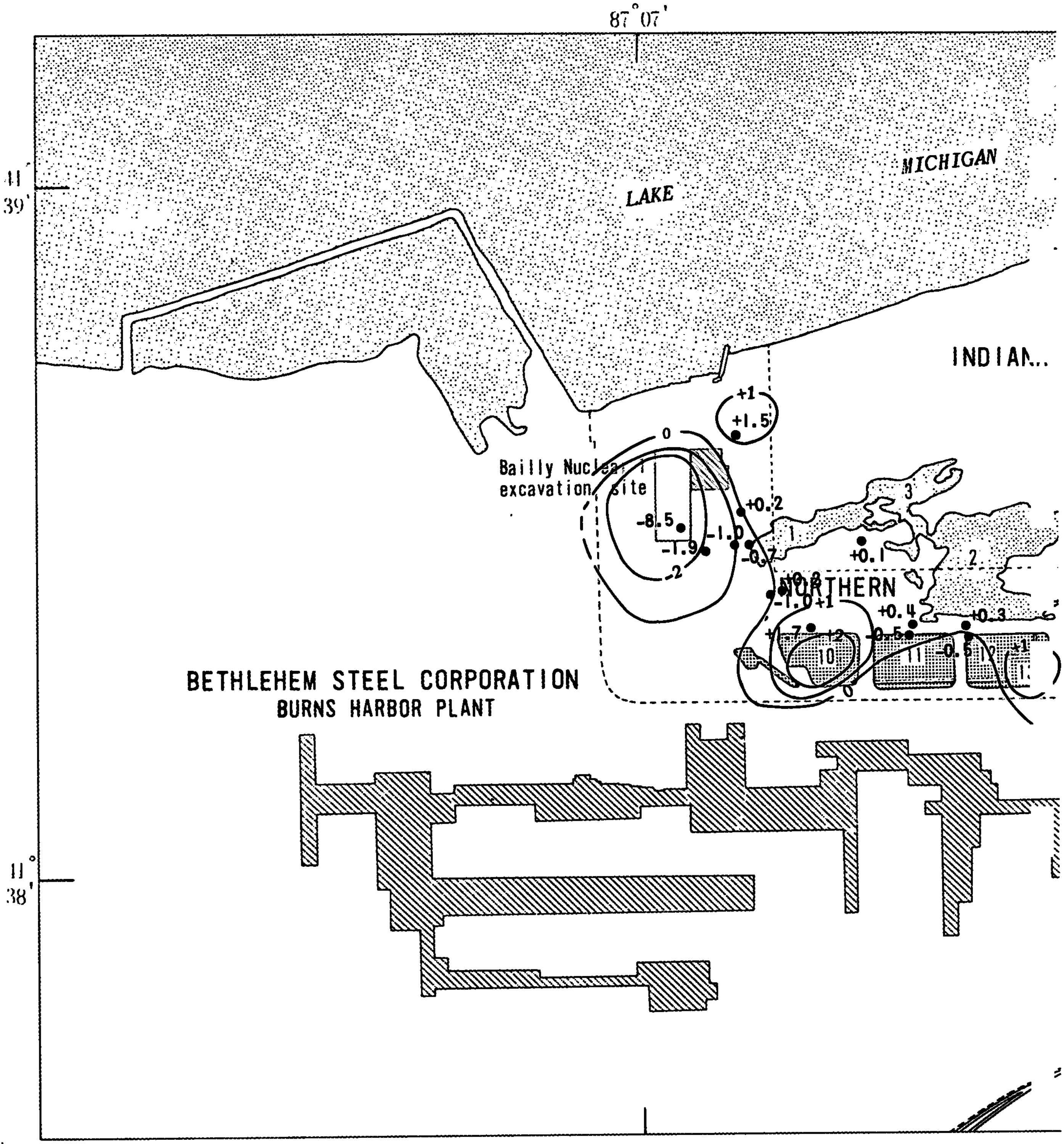


Figure 17.--Hydrograph of Lake Michigan and selected hydrographs of NIPSCO's fly-ash ponds and observation wells 1972-76.



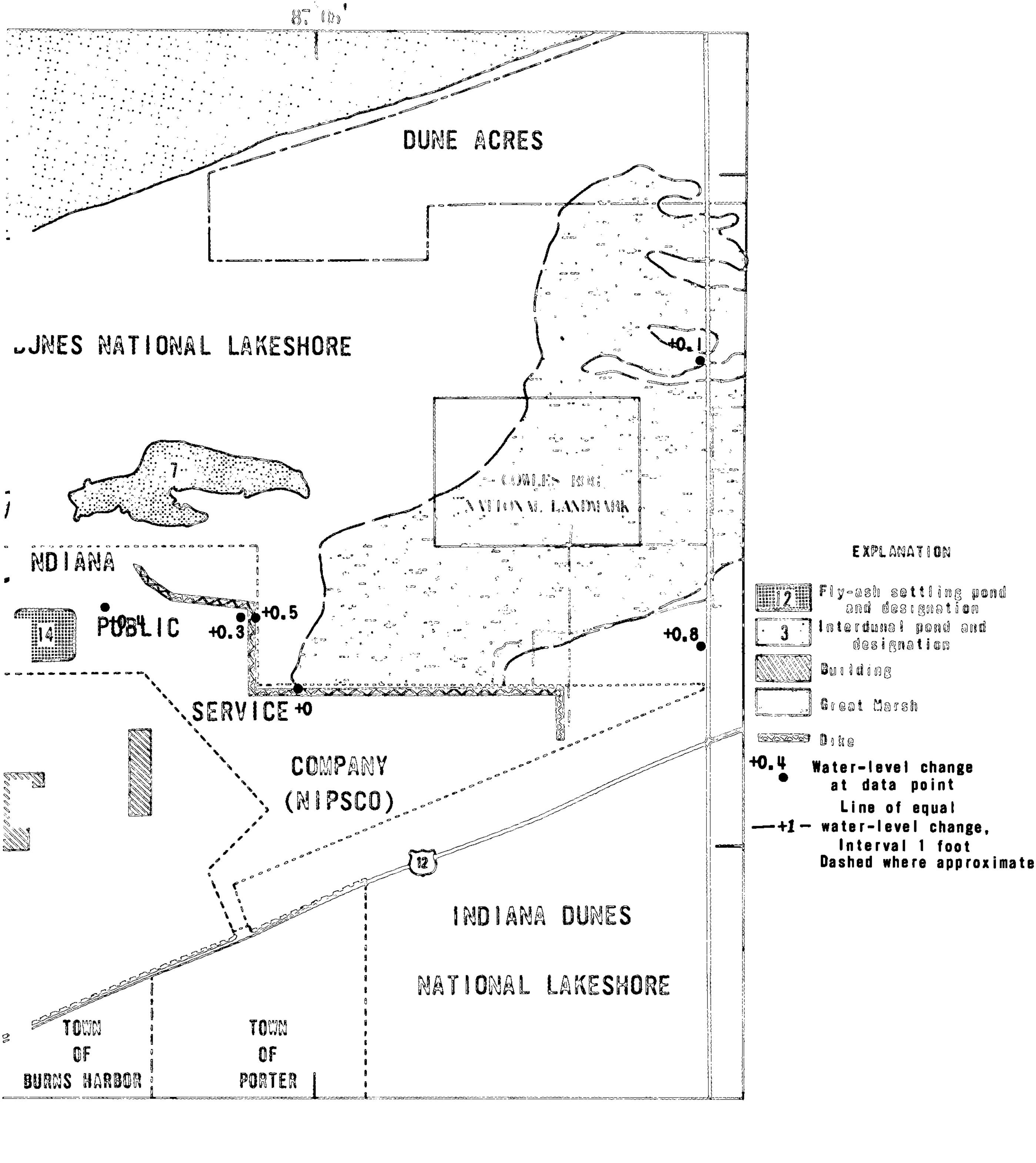
Hydrographs prepared by Northern Indiana Public Service Company



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968; 1973 NIPSCO Map No. MS-150, by Sargent and Lundy; and National Park Service, November 1978

0 2000 FEET

Figure 18.-- Water-level changes in unit 1,



March 17 to December 15, 1977.

interdunal ponds. Lake Michigan rose a net 0.2 ft above its March 17, 1977, stage. Owing to the complex interaction of all the factors that affect changes in water levels in the area, the data presented in figure 18 are probably not completely attributable to construction dewatering. Graphs of the changes in the stage of Lake Michigan and of the stages of most of the fly-ash ponds from March 17 to December 15, 1977, shown in figure 19, indicate that these changes should have generally raised water levels in unit 1 during this time period. Thus, any declines recorded should reflect declines caused by increased pumpage.

Installation of Geological Survey observation wells in unit 3 was not completed until April 8, 1977, 22 days after the start of dewatering. Bethlehem Steel Corp. measured water levels in their observation wells on February 24, 1977; however, water levels in these wells were not measured again until June 9, 1977, when Geological Survey personnel measured water levels in both Bethlehem Steel Corp. and Geological Survey wells.

Accurate water-level-change maps in unit 3 could not be constructed beginning on March 17, as was done for unit 1, because adjustment of the known data for the unit to synthesize March 17 water levels would have been inappropriate. The expected changes due to dewatering would have been of the same magnitude as the adjusted change. Rather, maps depicting water-level changes from April through December 15, 1977, in the five Geological Survey observation wells were prepared. The net changes in water levels recorded in these wells up to December 15, 1977, are shown in figure 20. The greatest water-level decline, 2.5 ft, was in the deep observation well in the immediate vicinity of the excavation site. Water levels in the eastern part of the study area rose by less than 0.5 ft.

To utilize the data from Bethlehem Steel Corp. wells in unit 3, the Geological Survey prepared hydrographs of the water levels in these wells and in the Geological Survey wells in unit 3. Four representative hydrographs are shown in figure 21. The water levels in these wells tend to follow each other in rising and falling trends, except from August 23 to October 6, 1977. During this time, water levels rose an average of 1 ft in all the wells except Geological Survey well 101, where it declined approximately 1 ft. This well is within 200 ft of the Bailly nuclear excavation site and is the closest well screened in unit 3 to the dewatering site. The decline between August 23 and October 6 is also significant because NIPSCO's pumpage at the site increased by 60 percent on August 21, as shown in figure 23.

Because ground-water levels fluctuate in response to the total interaction of the four items mentioned at the beginning of this section, the hydrographs and water-level changes in figures 19, 20, and 21 are not entirely attributable to dewatering.

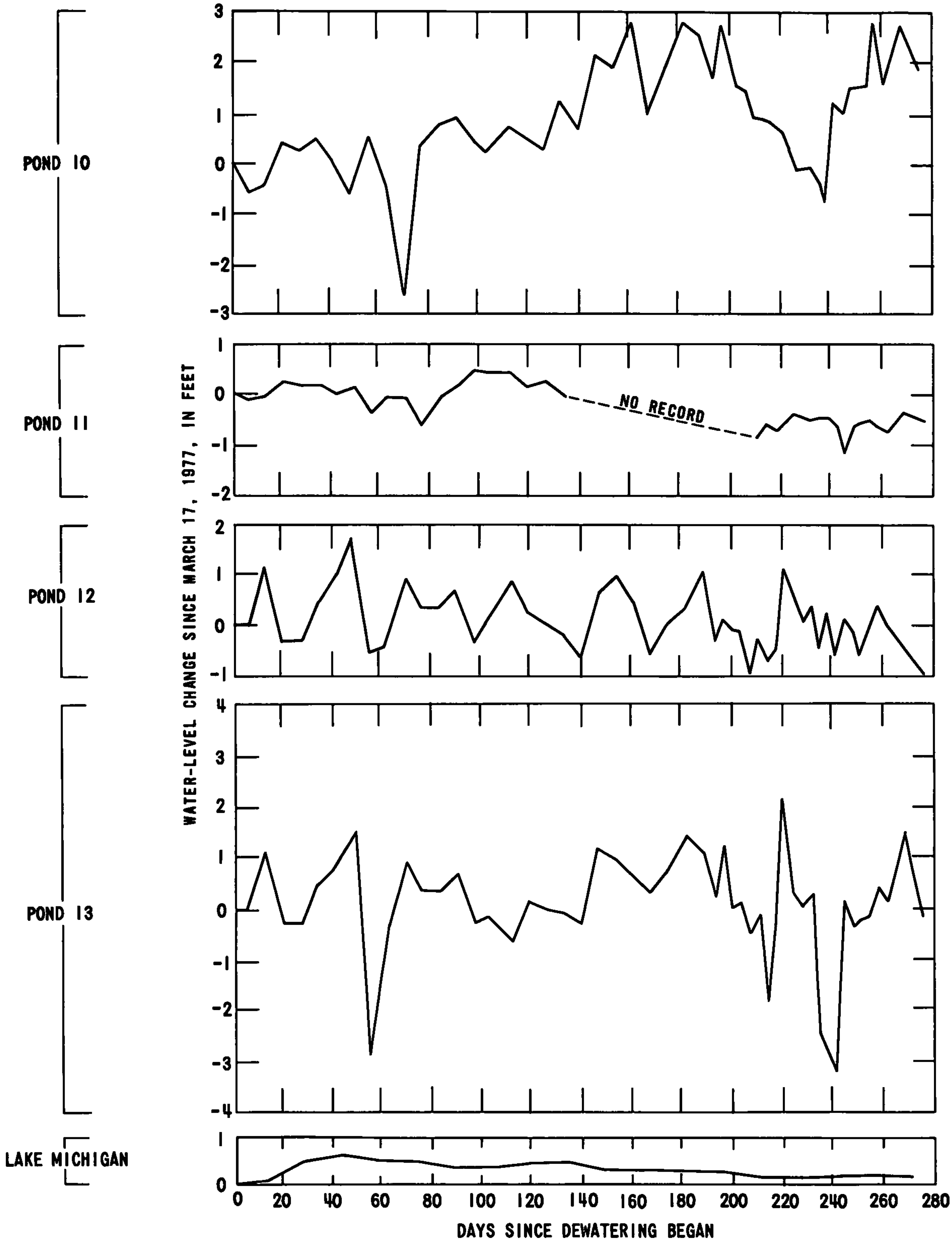
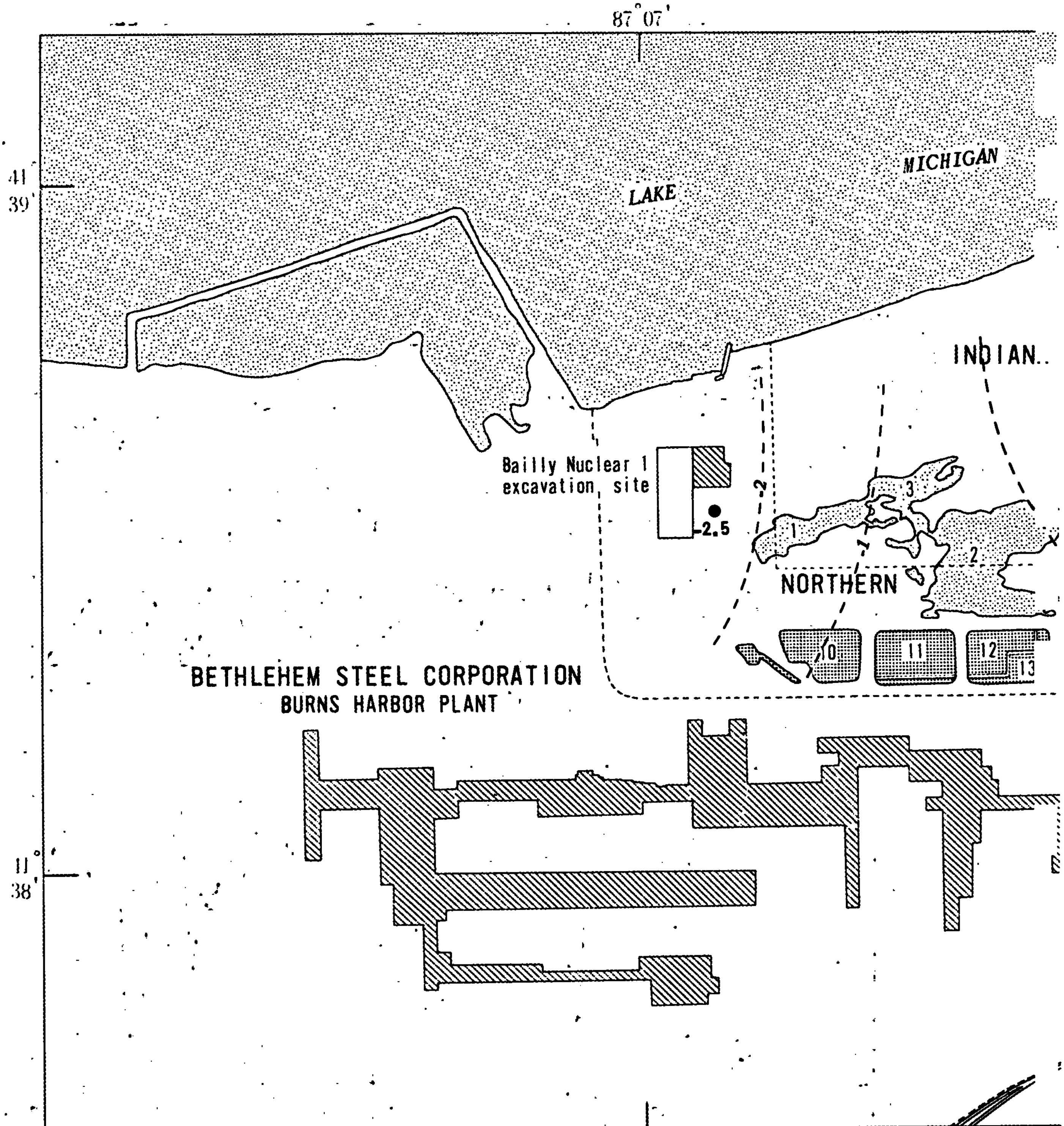
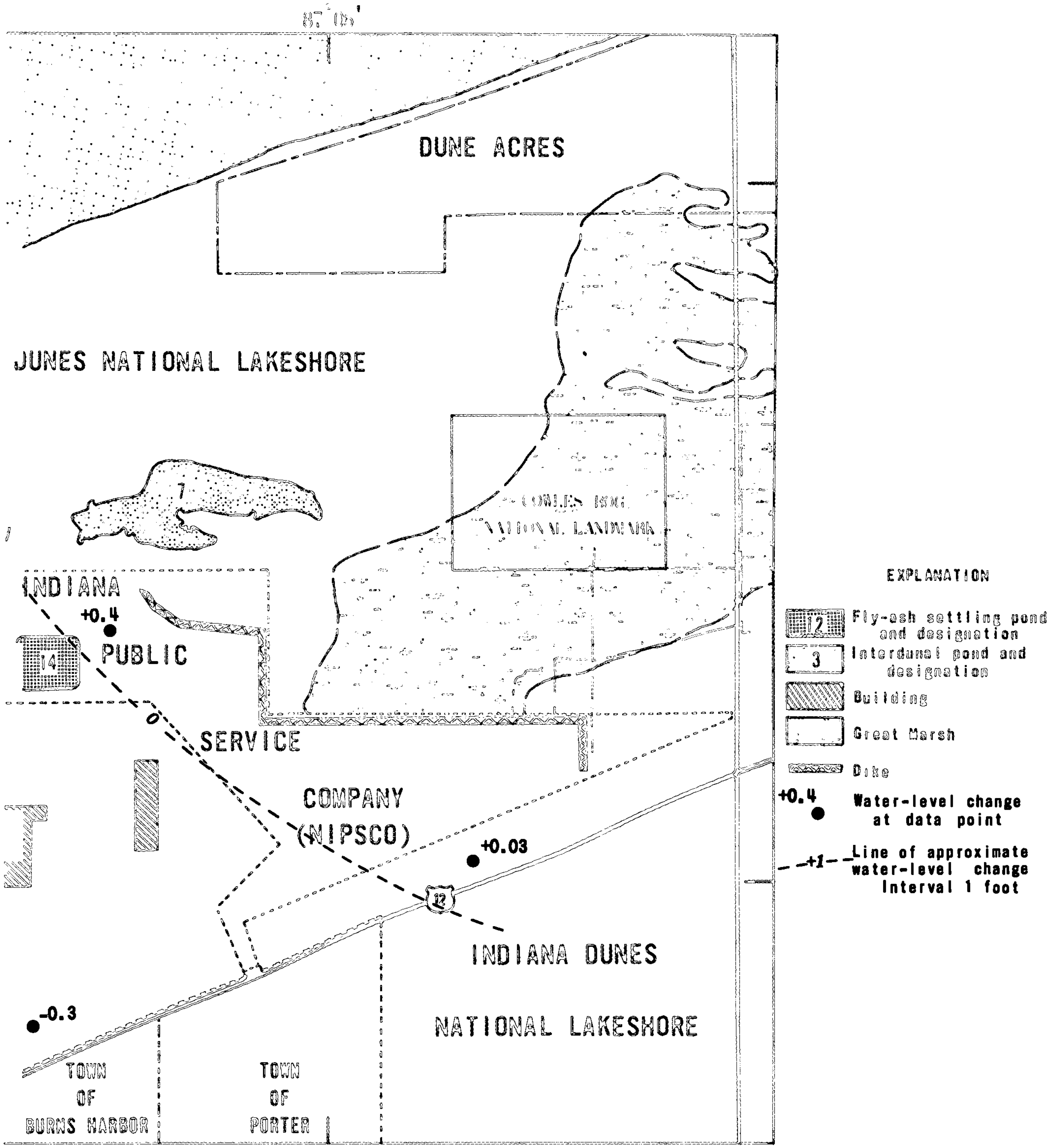


Figure 19.-- Hydrographs of the stages of fly-ash-ponds 10, 11, 12, and 13, and Lake Michigan, March 17 to December 15, 1977.



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968; 1973 NIPSCO Map No. MS-150, by Sargent and Lundy; and National Park Service, November 1978

Figure 20.-- Water-level changes in unit 3, April 8 to December 15, 1977, recorded in Geological Survey observation wells.



DUNE ACRES
JUNES NATIONAL LAKESHORE
7
COWLES BOG NATIONAL LANDMARK
INDIANA PUBLIC SERVICE COMPANY (NIPSCO)
14
+0.4
0
+0.03
12
INDIANA DUNES NATIONAL LAKESHORE
-0.3
TOWN OF BURNS HARBOR
TOWN OF PORTER
EXPLANATION
12 Fly-ash settling pond and designation
3 Interdunal pond and designation
Building
Great Marsh
Dike
+0.4 Water-level change at data point
+1 Line of approximate water-level change Interval 1 foot

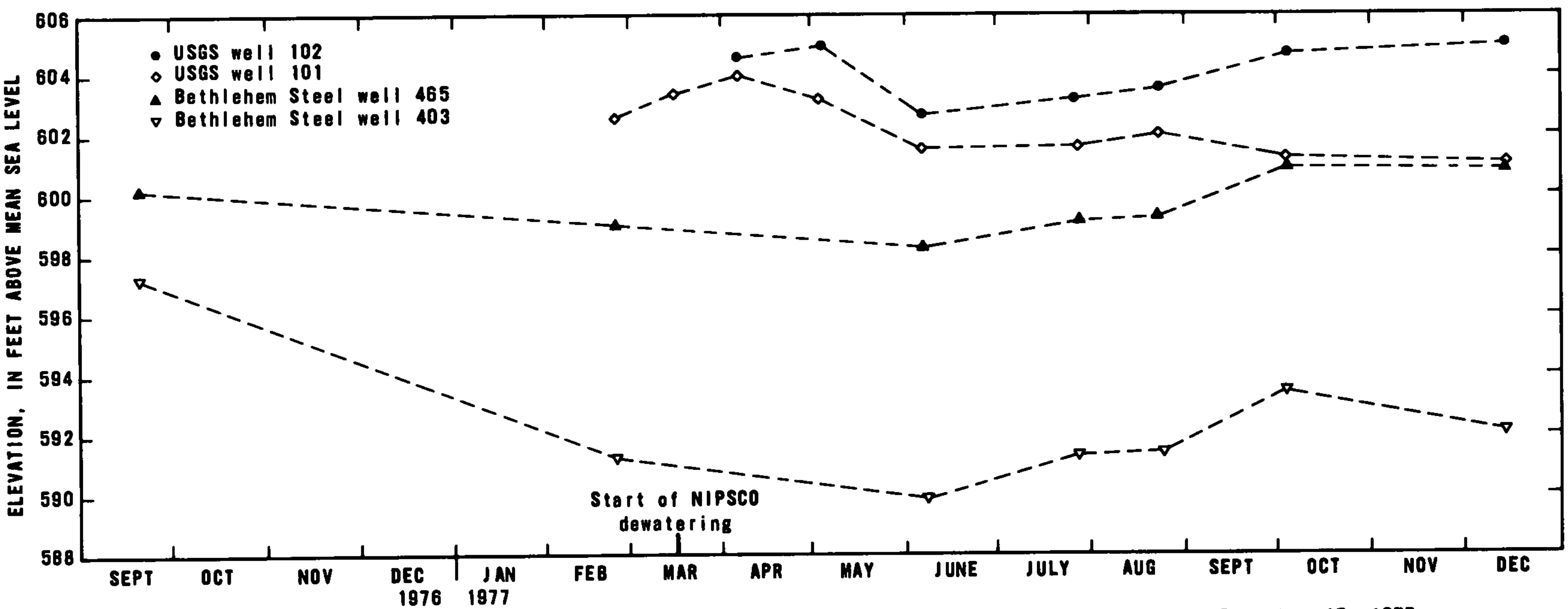


Figure 21.-- Hydrographs of selected observation wells in unit 3, September 20, 1976, to December 15, 1977.

GROUND-WATER PUMPAGE

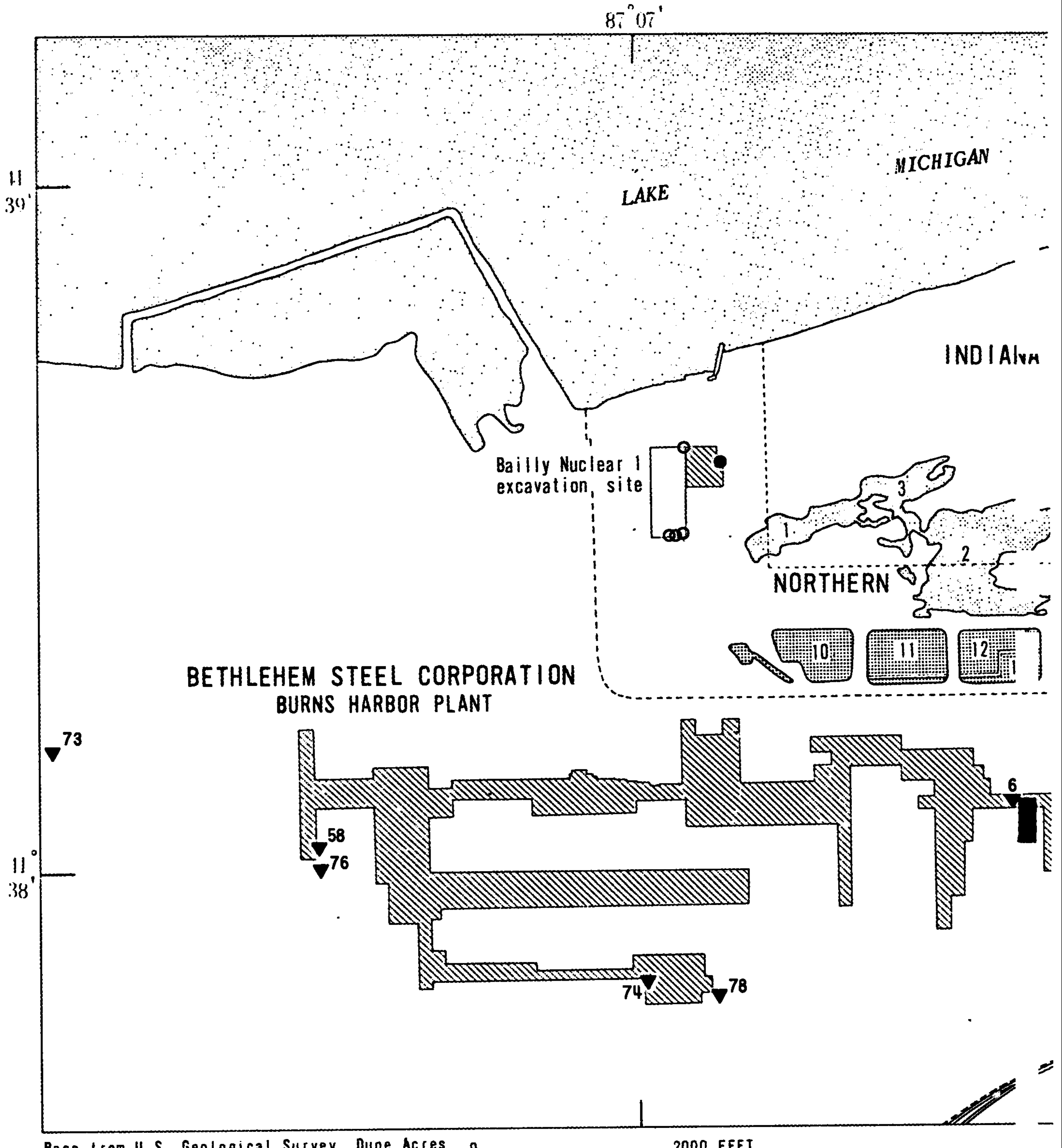
NIPSCO's and Bethlehem Steel Corp.'s long established regime of pumping in the study area continues. The corporation's pumping history, associated mainly with construction has been complex. At present (1977) it is pumping 5 wells, although it has pumped more than 70 wells at different times. Information on well locations, well construction, historic water levels, and specific-capacity tests for the major wells constructed during the last 5 years was made available to the Geological Survey by Bethlehem Steel Corp. during the study. Locations of the wells that would have significantly affected the ground-water system during the study are shown in figure 22. Information on these wells is summarized in table 1. The corporation keeps no record of the rate or volume of water pumped at a given well, but their pumping procedure consists simply of maintaining pumping levels within a few feet of the top of the well screen. Pumping at a given well is virtually continuous, although breakdowns have caused downtimes of unspecified length. After completion, each well was pumped for 24 to 48 hours to establish the pumping rate necessary for lowering the water level to within a few feet of the screen and keeping it at that level. The pumping rates in table 1 are based on these data. The rates should represent the maximum rate of withdrawal per well because steady-state conditions would not have been reached within 48 hours of pumping, and well efficiency would probably have tended to decrease with time. Short-term pumping of less than 1 year, as well as well-point systems, have been used at the steel plant primarily for construction dewatering.

Table 1.--Information summary of Bethlehem Steel Corp. wells significantly affecting ground-water levels during study

Well	Date activated	Active or date terminated	Unit in which well is screened	Elevation of top of screen (feet above m.s.l.)	Pumping rates (gal/min)[1]
6	8-76	Active	3	559	600
58	4-70	do	3 and 1	560	700
73	2-75	do	3	568	400
74	8-76	2-77	[2]3 and 1	551	615
76	2-77	Active	3 and 1	542	525
78	7-77	do	3	566	330

[1] Estimated by the U.S. Geological Survey.

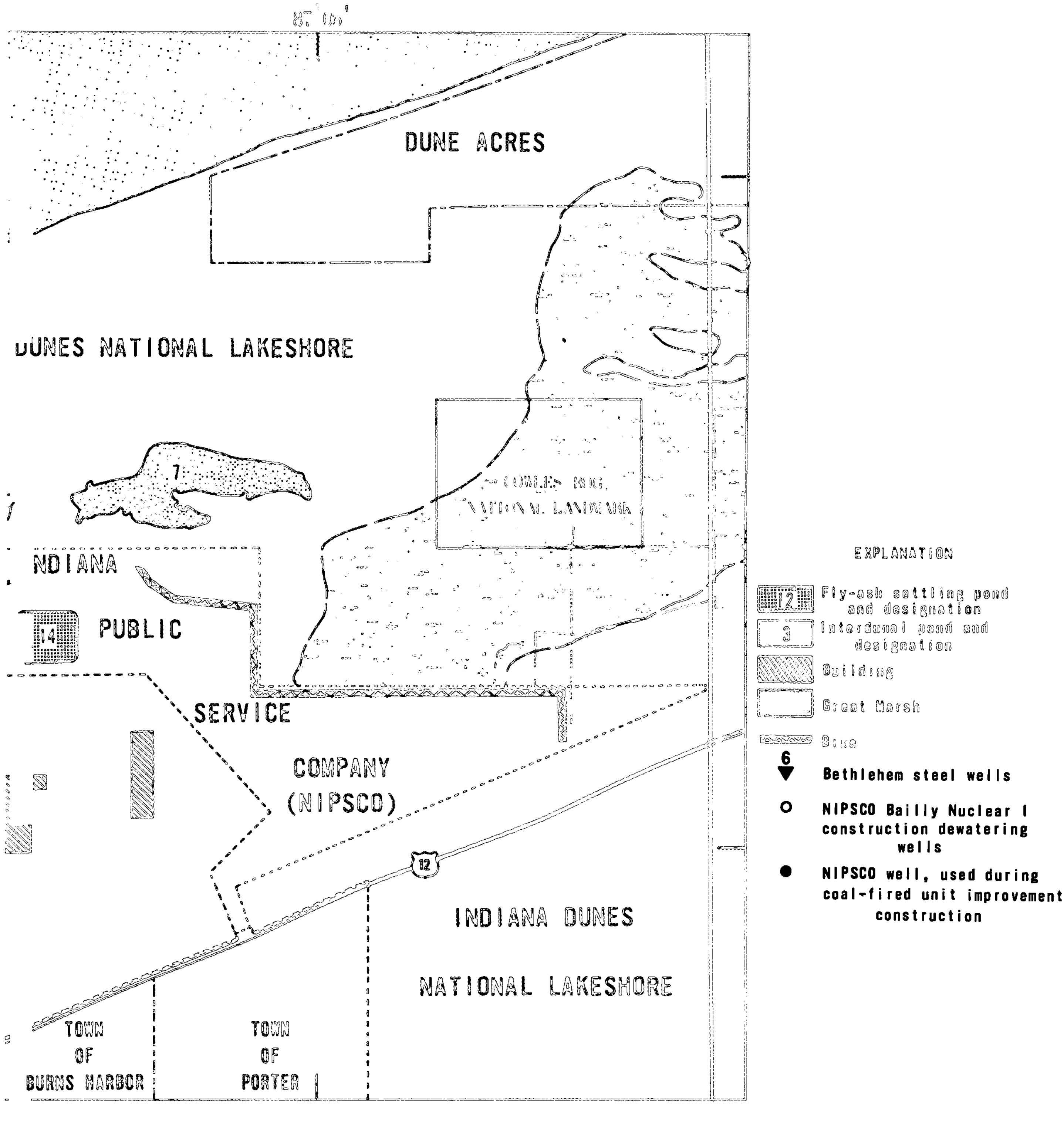
[2] Unit 3 is unconfined at this location.



Base from U S Geological Survey, Dune Acres 1:24,000, 1968, 1973 NIPSCO Map No. MS-150, by Sargent and Lundy; and National Park Service, November 1978

0 2000 FEET

Figure 22.--Location of industrial pumping, September 1976 to December 1977.


DUNE ACRES
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NATIONAL LAKESHORE
TOWN
OF
BURNS HARBOR
TOWN
OF
PORTER
EXPLANATION
Fly-ash settling pond and designation
Interdunal pond and designation
Building
Great Marsh
Dike
Bethlehem steel wells
NIPSCO Bailly Nuclear I construction dewatering wells
NIPSCO well, used during coal-fired unit improvement construction

Bethlehem Steel Corp. also operates three deep-injection wells for disposal of coke and pickling wastes. These wells are screened at an average depth of 2,500 ft in the Mount Simon Sandstone. Rates of injection from these wells into the sandstone are low, and the wells are not considered in this analysis.

Pumping by NIPSCO during the study has been significant in the two areas shown in figure 22. Construction associated with the coal-fired units required pumping from unit 1 for dewatering from January to August 1977. Average discharge was approximately 425 gal/min until June; pumpage gradually decreased to less than 50 gal/min in July.

Pumping associated with the construction of the nuclear powerplant began on March 17, 1977. A graph of the pumpage history is shown in figure 23. No records were kept of the discharge until mid-June, when a meter was installed in the discharge line. The total volume of water discharged up to the date of the installation of the meter was estimated from data provided by NIPSCO. Total discharge for the unmeasured period was estimated to be 16 million gallons. Pumpage from June to the end of August averaged 230 gal/min. The pumping system was revised then for more efficient use. Discharge was increased to a maximum of 430 gal/min and was gradually decreased to an average of 350 gal/min by the end of December 1977. As shown in figure 22, pumping from the excavation presently (1977) is from three wells in the south end and one in the northeastern corner of the excavation site. All are screened in unit 1.

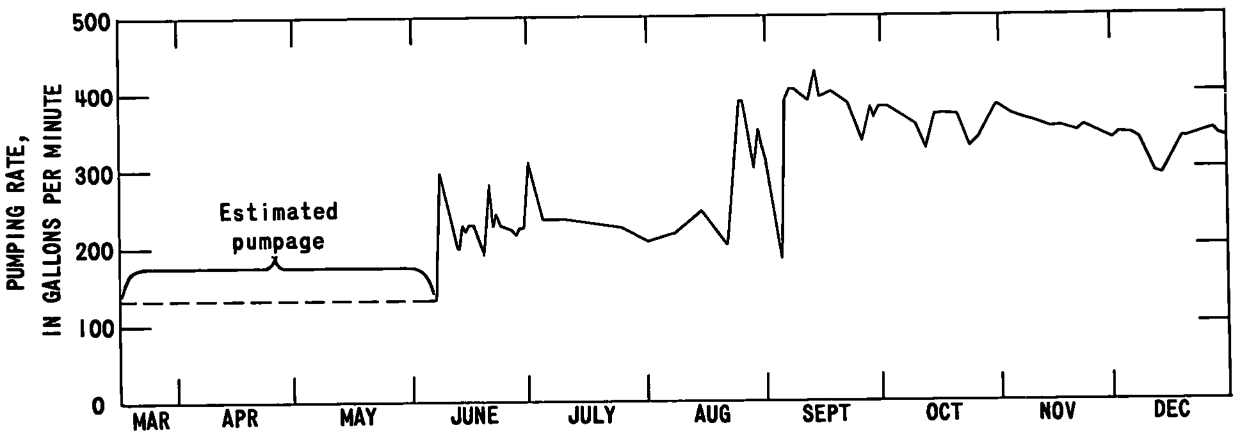


Figure 23.-- Pumpage from Bailly Nuclear 1 excavation site, March 17 to December 31, 1977.

NIPSCO also periodically operates a well-point system south of the ash ponds to reduce the effect of seepage from the ash ponds into Bethlehem Steel Corporation's Burns Harbor Plant. Discharge from the well points is returned to the overflow system in the ash ponds.

Water is pumped for domestic use in Dune Acres and in the southeast part of the study area, but this pumpage is minimal and has only a very localized effect on ground-water levels.

DIGITAL-MODEL SIMULATION OF THE GROUND-WATER SYSTEM

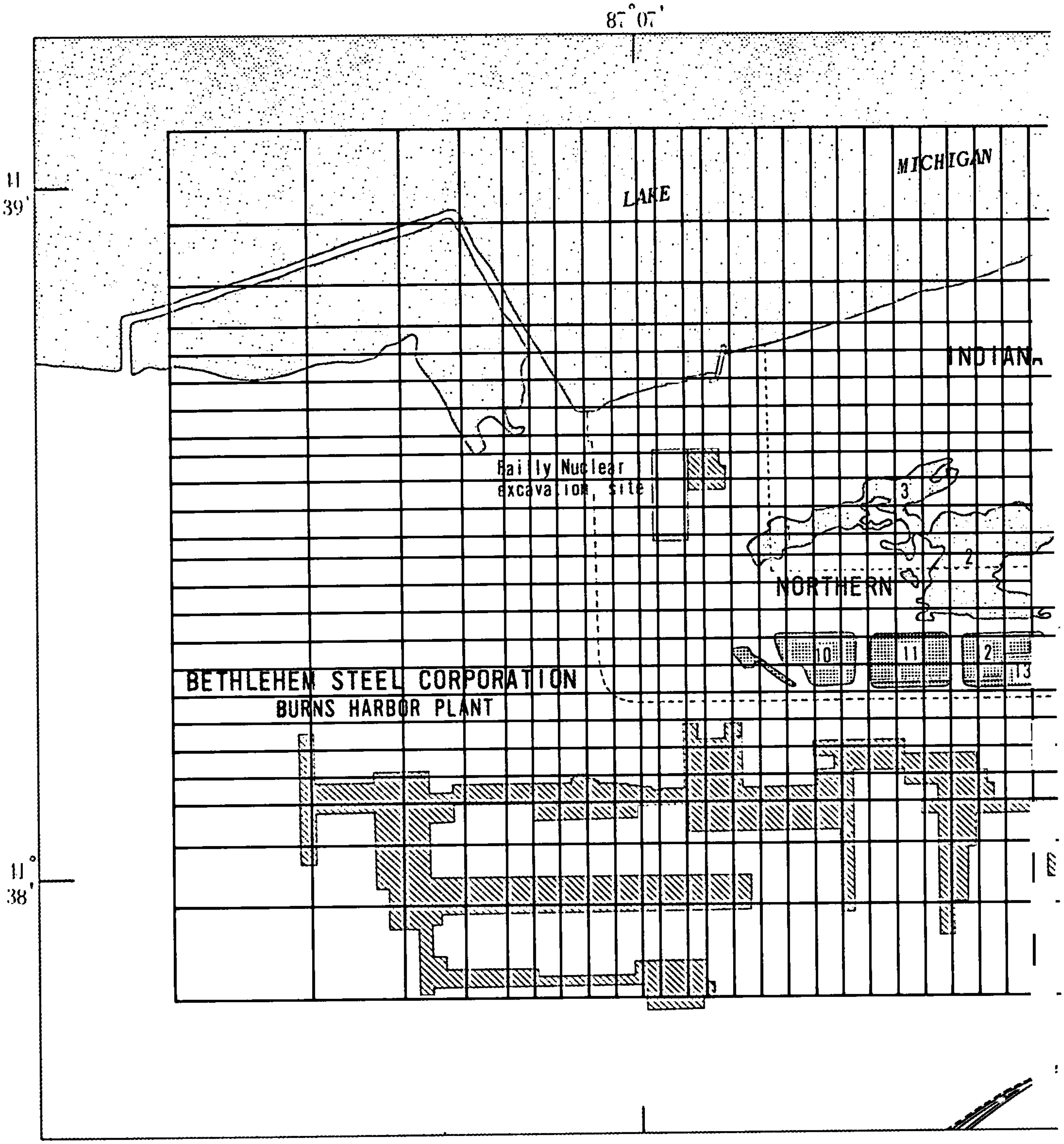
The finite-difference model of Trescott (1975) for simulation of unsteady or steady, confined or unconfined, ground-water flow in three dimensions was used to simulate the movement of ground water in the unconsolidated rocks underlying the study area. The boundaries of the model are simulated to be slightly inside the boundaries of the study area (fig. 2). The model consists of four layers. Units 4 and 3 are represented as individual layers, and unit 1 is divided into two separate model layers for reasons to be described subsequently. Unit 2 was not represented as a layer in the model for reasons explained in the following paragraph.

The model permits lateral flow within a given layer and vertical flow between layers. Because unit 2 was not modeled as a layer, lateral flow within it was not represented in the model. Owing to the low values of lateral hydraulic conductivity for this unit, lateral flow can be assumed to be negligible. Vertical flow from unit 1 to unit 3 through unit 2 was simulated in the model by incorporating the hydraulic connection in the model. The shale underlying unit 4 probably represents an impermeable base for the model. Although there may be some vertical flow through the shale, the rate of this flow should be negligible compared with other rates of water movement in the unconsolidated deposits. Therefore, terminating the model at base of unit 4 should permit a reasonable approximation of the total flow in the study area.

The finite-difference grid network used to approximate the ground-water system is shown in figure 24. A rectangular grid expanding outward from the excavation site was used in the model. The smallest and the largest spacings between nodes were 167 ft and 1,265 ft, respectively.

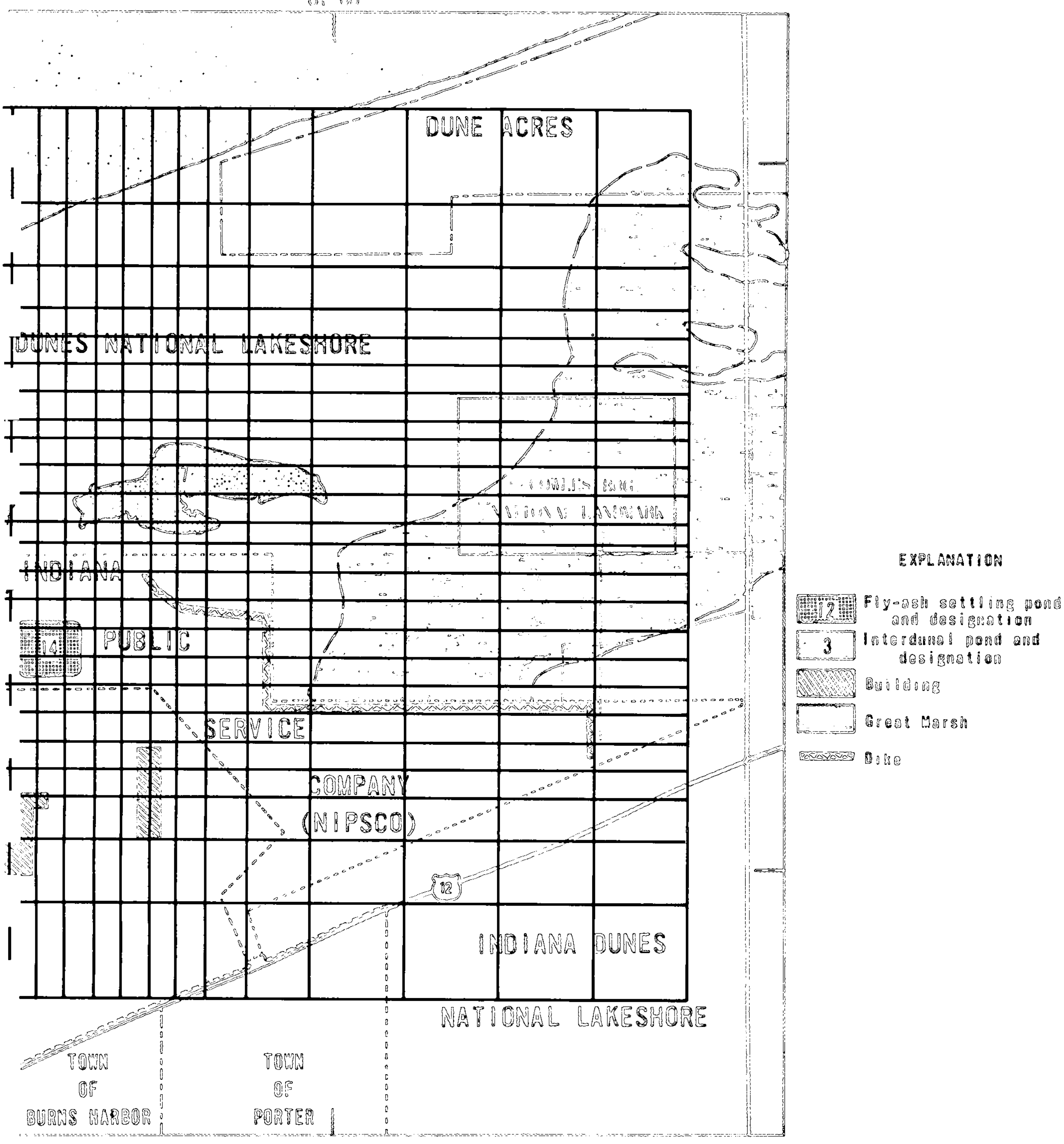
Model Construction and Calibration

The model was calibrated on the basis of water levels on October 26, 1976, and assumed steady-state conditions for that time, although steady-state conditions do not prevail within the study area. Data collected by NIPSCO show fluctuations of approximately 3.0 and 4.0 ft, respectively, in the stage of Lake Michigan and in water levels in the fly-ash ponds since March 1972. Water levels in NIPSCO wells 14-20 have changed as much as 6.6 ft since October 1973. Water levels on October 26, 1976, represent the combined interaction between the stage and fluctuations in the stage of Lake Michigan, water levels and changes in these levels in the fly-ash ponds, distribution and rates of pumping ground water, and natural changes in recharge to or discharge of ground water from the area. Average stage of Lake Michigan and water levels in the fly-ash ponds for 1976 were selected for use in the model during calibration. Although actual rates of ground-water discharge to Lake Michigan and seepage to unit 1 from the fly-ash ponds could have been higher or lower than those indicated by the calibrated model, the model still represents average stresses imposed on the ground-water system by these variables during the preceding year.



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968; 1973 NIPSCO Map No. MS-150, by Sargent and Lundy; and National Park Service, November 1978

Figure 24.-- Finite-difference grid used in model.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PORTER
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Fly-ash settling pond and designation
3
Interdunal pond and designation
Building
Great Marsh
Dike

The distribution and rates of pumping ground water imposed on the model during calibration represented Bethlehem Steel Corp. pumpage for October 1976. Calculations based on the methodology of Jenkins (1970) were made to determine if water levels in October were still depressed because of previous Bethlehem Steel Corp. pumpage. These calculations indicated that recovery of water levels should have been complete by October. Subsequent model analyses substantiated the calculations.

Ground-water flow either into or out of the study area was induced in the model by assigning constant heads to nodes representing the southern, western, and eastern boundaries. The water-level elevation assigned at a given model node as a constant head was obtained from the appropriate water-level contour map. A succession of model experiments after calibration indicated that water levels in unit 3 were very responsive to the flux rate introduced at the boundaries of this unit and that variations in pumpage in unit 3 caused corresponding variations in the rate of flux necessary to match water levels in unit 3. These responses and variations result from the closeness of pumping in unit 3 to the model boundaries and indicate that care must be exercised to use the model when pumping distribution and (or) rates change in unit 3.

Transmissivity at a given node for unit 4 was obtained by multiplying the average thickness of this layer (fig. 6) in the nodal area by a hydraulic conductivity of 0.13 ft/day. This value should represent a maximum for the layer except for isolated areas of sand and gravel within it. Values of transmissivity for unit 3, taken from figure 12, were used in the model layer for this unit. As mentioned, unit 1 was divided into two separate layers in the model. The bottom elevation of the uppermost layer was fluctuated purposely so that it corresponded to the bottom of the fly-ash ponds and the interdunal ponds and otherwise maintained an equal thickness between the layers. Transmissivity values at a given node for the layer representing the lower half of unit 1 were obtained by multiplying the thickness of unit 1 still remaining below the upper layer by the lateral hydraulic conductivity of unit 1, 167 ft/day. The upper layer of unit 1 represented the unconfined part of this unit, and, accordingly, the average hydraulic conductivity for the unit was used in the appropriate nodes representing this layer in the model. At those nodes where the layer represented standing water (the fly-ash ponds and the interdunal ponds), a lateral hydraulic conductivity of 8.64×10^8 ft/day was used in the model. This value was the highest possible, as dictated by model programming constraints, but nevertheless it should be adequate to simulate the ponds. A value of zero was used for the transmissivity or lateral hydraulic conductivity of unit 1 at those nodes where construction at the Burns Harbor Plant had removed the unit, or at least the upper layer of the unit.

Vertical hydraulic-conductivity values of units 3 and 1 were set at one-tenth the lateral value of those units. This value should represent a reasonable approximation of the vertical hydraulic conductivity of these units.

The rate of movement of water from unit 1, derived from fly-ash pond seepage into unit 3, and the potential increased rate of movement of water from unit 3 into unit 1, because of dewatering at the nuclear construction site, are directly dependent on the vertical hydraulic conductivity of unit 2. In addition, the rate of seepage of water from the fly-ash ponds into unit 1 is a function of the vertical hydraulic conductivity of the bottom of the ponds and the lateral hydraulic conductivity of the sides of the ponds. Because the fly ash is deposited only on the bottom, the lateral hydraulic conductivity of the pond sides should be identical with the lateral hydraulic conductivity of unit 1.

To identify the vertical hydraulic conductivity of unit 2 and the hydraulic connection between the bottom of the fly-ash ponds and unit 1, a series of model experiments were made. A value for the vertical hydraulic conductivity of unit 2 was selected, and the corresponding average annual rate of recharge to unit 1 derived from rainfall infiltration was identified. In the experiments, the vertical hydraulic connection between the fly-ash ponds and unit 1 was arbitrarily set at 0.01 day^{-1}. After identification of a range of values for the vertical hydraulic conductivity of unit 2 that allowed an acceptable match of water levels in units 1 and 3 and reasonable recharge rates to unit 1, the vertical hydraulic connection between the fly-ash ponds and unit 1 was varied in a series of experiments to identify the values of this parameter that permitted saturated flow under the fly-ash ponds. The hydraulic gradient between the fly-ash ponds and unit 1 was recorded in each of the experiments and was compared with gradients measured in the field. The comparison indicated a vertical hydraulic connection equal to or greater than 1.3×10^{-2} day^{-1} between the fly-ash pond and unit 1. Values for the vertical hydraulic conductivity of unit 2, 6.7×10^{-4} and 6.7×10^{-3} ft/day, combined with values 1.3×10^{-2} day^{-1} and 3.9×10^{-2} day^{-1}, respectively, for the hydraulic connection between the fly-ash pond bottom and unit 1, allowed an acceptable match in ground-water levels in units 1 and 3 and reasonable recharge rates to unit 1 from rainfall infiltration. The value 6.7×10^{-4} ft/day for the vertical hydraulic conductivity of unit 2 is consistent with the value for the parameter suggested by Rosenshein and Hunn (1968).

Because using the value 1.3×10^{-2} day^{-1} for the hydraulic connection between the fly-ash pond bottoms and unit 1 would tend to make subsequent model experiments for determining the effect of the fly-ash ponds on the ground-water system conservative, it was used for the remaining model experiments. The average annual recharge rates representing infiltration from rainfall was 20 in. per year for a vertical hydraulic conductivity of 6.7×10^{-4} ft/day in unit 2 and 23 in. per year for a vertical hydraulic conductivity of 6.7×10^{-3} ft/day in unit 2. Thus, the effective infiltration rate to unit 1 ranges from 54 to 62 percent of the total annual precipitation. Rosenshein and Hunn (1968) reported an average infiltration rate of 35 percent for unit 1 throughout LaPorte and Porter Counties. The higher rate of recharge in the study area is logical because unit 1 of Rosenshein and Hunn is not overlain by dunal sand; however, it is in the study area.

The rate of recharge from precipitation to the Great Marsh and the interdunal ponds simulated on the model was different from that used over the rest of the study area and was derived from the relationship

$$\text{effective recharge} = R - ET$$

where
R is average annual precipitation

and
ET the average annual evapotranspiration.

The average annual potential evaporation rate for the area, determined from a Class A Weather Bureau pan in Valparaiso, Ind., 15 miles south of the study area, is 40 in/yr. This rate was adjusted by a pan coefficient of 0.7 to give an approximate value for ET in the study area equal to 28 in/yr. Subtracting this value from the average annual precipitation rate of 37 in/yr, yielded a value of 9 in/yr for the effective recharge rate to both the Great Marsh and the interdunal ponds. No recharge to the fly-ash ponds or Lake Michigan was simulated because water-level elevations in the model nodes representing these bodies of water were held constant. In addition, recharge was not simulated on the model in areas of unit 1 where industrial buildings cover the surface.

The hydraulic connection between the bottom of the interdunal ponds and unit 1 was simulated with a value equal to 0.13 day^{-1} during model calibration. This connection was reduced to 6.7×10^{-3} day^{-1} and then was increased to 16 day^{-1} without appreciable change in flow in the model. These two values represent probable extremes for the degree of hydraulic connection between the bottom of the interdunal ponds and unit 1, and the results indicate that the movement of water between these ponds and unit 1 is nearly entirely lateral. To simulate a magnitude of connection less than that at a sand-water interface, the value 0.13 day^{-1} was used in the remaining model experiments.

Contour maps of model-derived water levels for units 1 and 3 are shown in figures 25 and 26, respectively. Water levels measured or estimated in observation wells in these units on October 26, 1976, are shown in the figures, also.

The water budget derived from the model based on the preceding hydrologic concepts and hydraulic data is presented in table 2.

MODEL SIMULATIONS

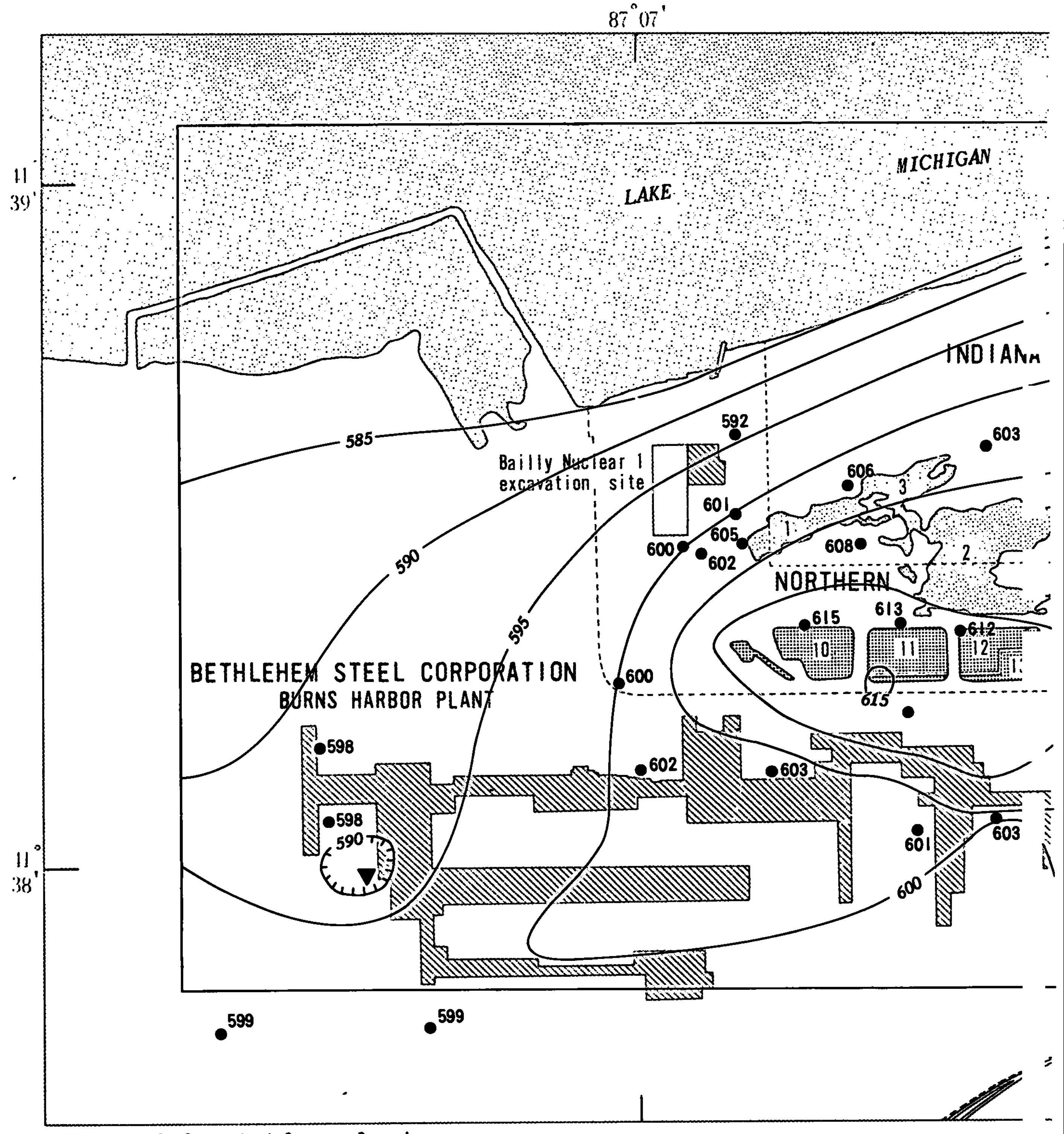
After calibration, the model was used to (1) investigate the effect of termination of fly-ash-pond seepage on ground-water levels, (2) establish the approximate magnitude of the hydraulic conductivity of the slurry wall, and (3) establish the effect of construction dewatering on ground-water levels.

Table 2.--Model-derived steady-state ground-water budget for conditions simulated in October 1976

Sources	Rate (Mgal/day)
Infiltration from precipitation	1.61
Underflow into model area	4.95
Fly-ash pond seepage	1.96
Total	8.52
Discharges	
Ground-water discharge into Lake Michigan	2.40
Underflow from model area	2.30
Industrial pumpage	3.78
Total	8.48
Percent difference: Discharge-recharge	0.47

Termination of Fly-Ash-Pond Seepage

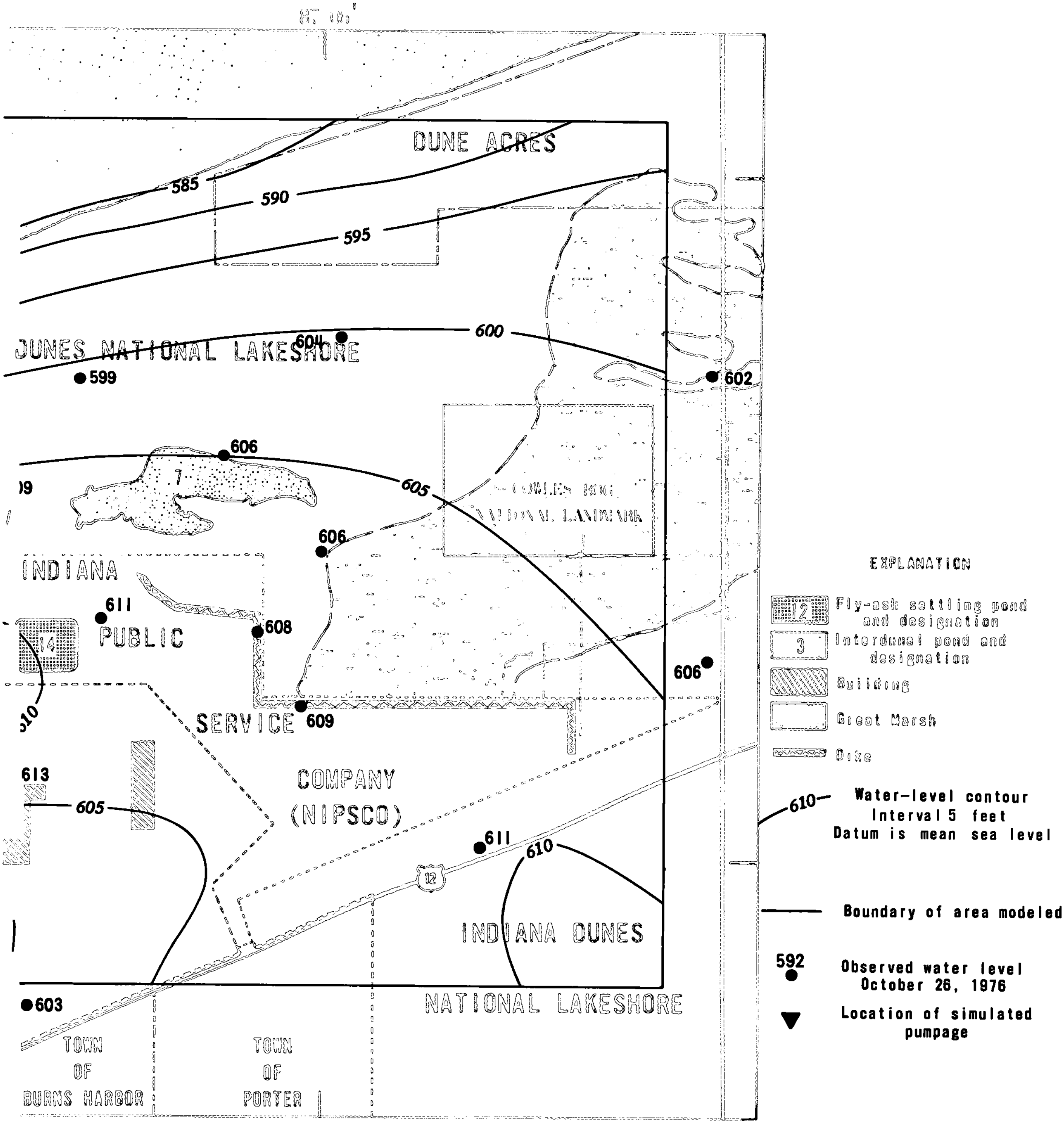
The effect of terminating fly-ash-pond seepage on ground-water levels was investigated in five model experiments (A-E). In all five experiments, fly-ash-pond seepage was terminated by removing the constant heads at those nodes representing the fly-ash ponds and was replaced by the recharge rate of the non-marsh areas. In experiment A, the vertical hydraulic conductivity of units 2 and 4 was 6.7×10^{-4} ft/day. A further condition imposed on the model for this experiment was a constant flux at the model boundaries. The direction and magnitude of the flux at a given node was identical with that established in the calibration process using constant-head boundaries. Model-derived water-level declines in units 1 and 3 resulting from these conditions are shown in figures 27 and 28. A maximum decline of approximately 15 ft was realized in unit 1 immediately under one of the fly-ash-pond nodes in the model. As indicated by figure 27, the water level declined more than 10 ft in unit 1 in the southwest corner of National Park Service property. Water levels in all the interdunal ponds fall several feet below the pond bottoms, except in the deep holes in pond 7 where some water would remain. This decline in water levels is within the range of naturally occurring fluctuations in ground-water levels. Although most of the interdunal ponds would become marshlike areas, standing water could



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968; 1973 NIPSCO Map No. MS-150, by Sargent and Lundy; and National Park Service, November 1978

0 2000 FEET

Figure 25.-- Model-derived steady-state water levels in unit 1.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INDIANA DUNES
NATIONAL LAKESHORE
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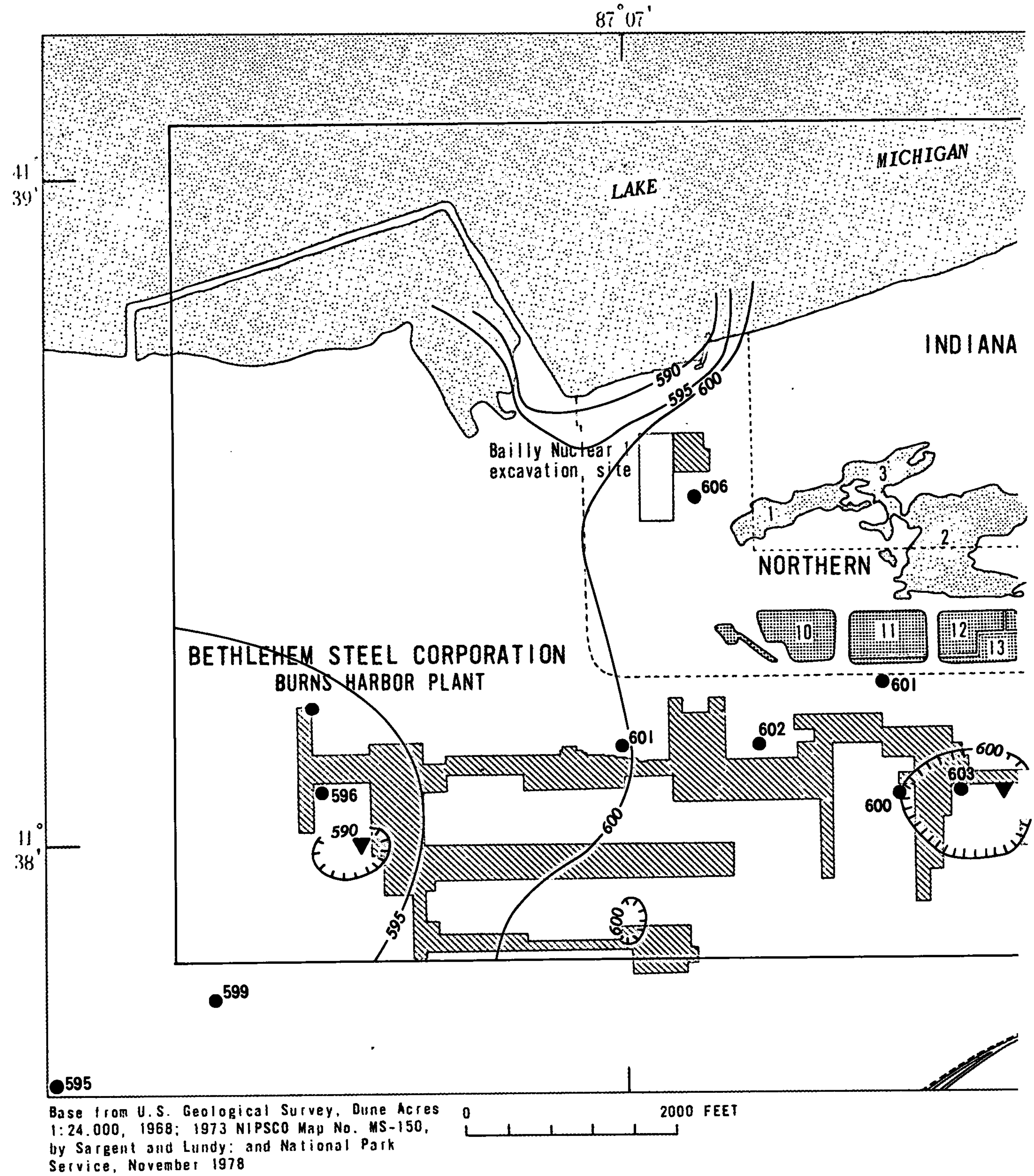
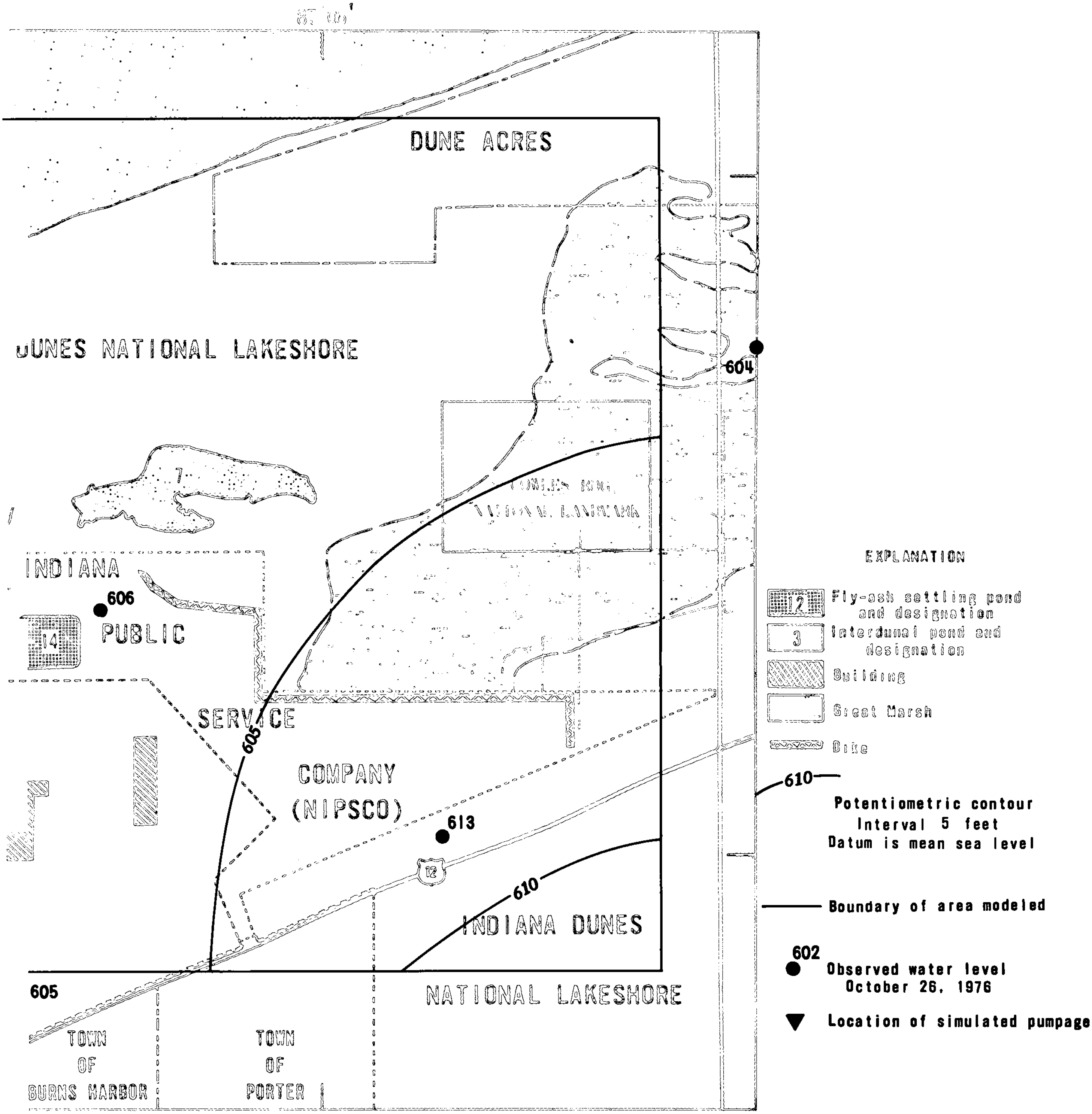
TOWN OF BURNS HARBOR
TOWN OF PORTER
EXPLANATION
Fly-ash settling pond and designation
Interdunal pond and designation
Building
Great Marsh
Dike
610 Water-level contour Interval 5 feet Datum is mean sea level
Boundary of area modeled
592 Observed water level October 26, 1976
Location of simulated pumpage



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968; 1973 NIPSCO Map No. MS-150, by Sargent and Lundy; and National Park Service, November 1978

Figure 26.-- Model-derived steady-state potentiometric surface of unit 3.



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EXPLANATION
Fly-ash settling pond and designation
Interdunal pond and designation
Building
Great Marsh
Dike
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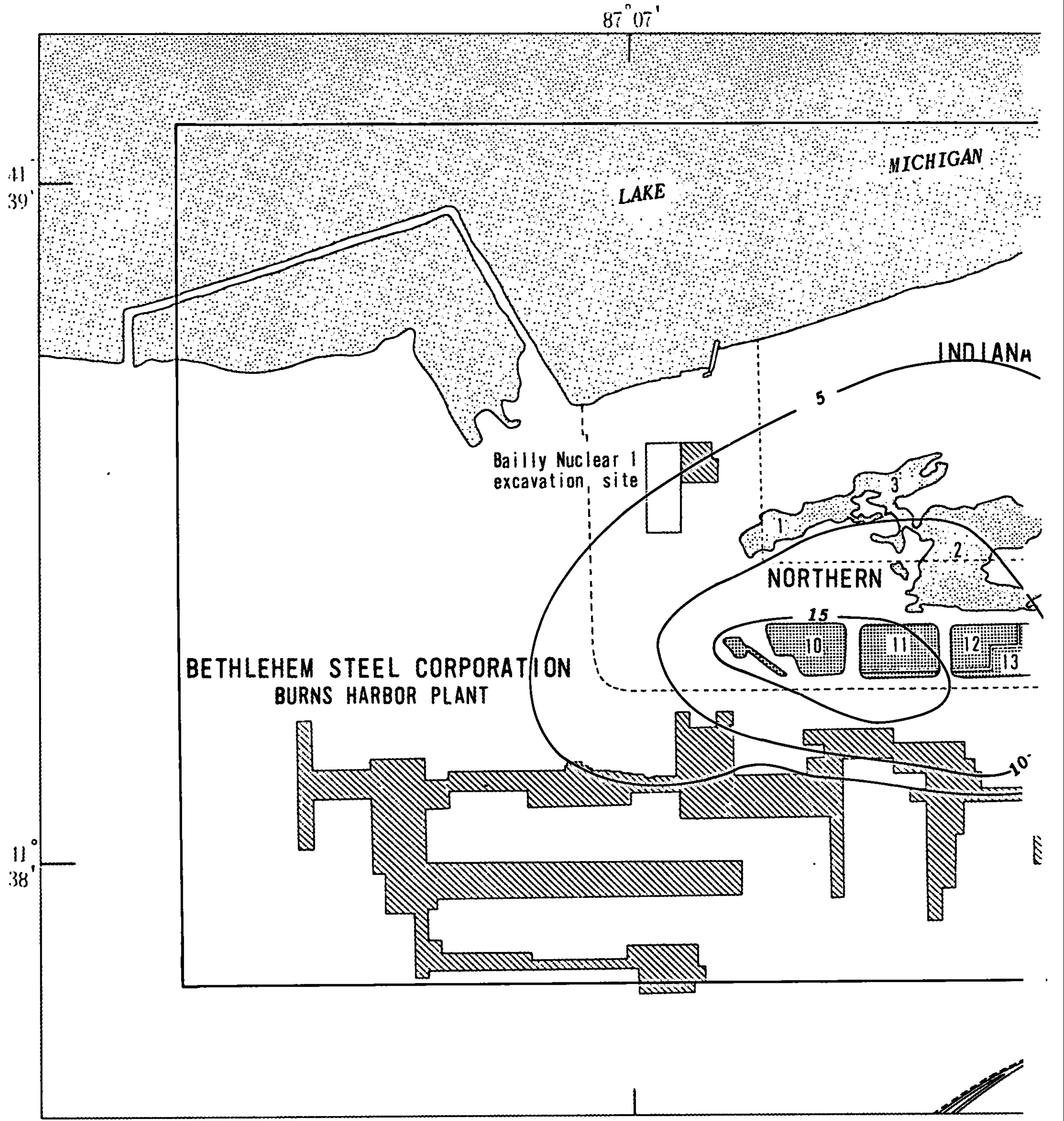
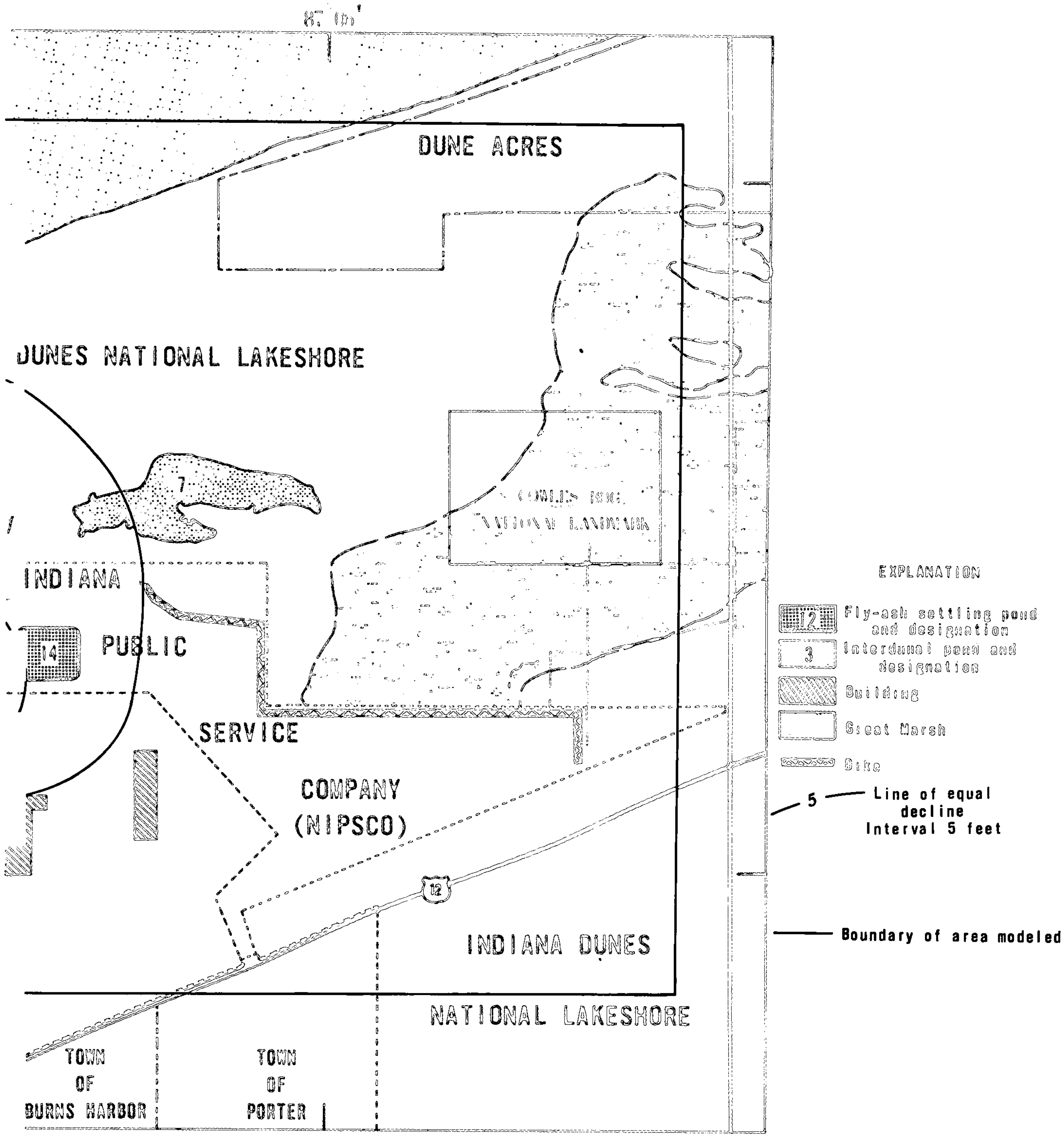
Potentiometric contour
Interval 5 feet
Datum is mean sea level
Boundary of area modeled
602
Observed water level
October 26, 1976
Location of simulated pumpage



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968; 1973 NIPSCO Map No. MS-150, by Sargent and Lundy; and National Park Service, November 1978

0 2000 FEET

Figure 27.-- Model-derived water-level declines in unit 1 for simulated termination of fly-ash-pond seepage.



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Fly-ash settling pond and designation
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Interdunal pond and designation
Building
Great Marsh
Dike
5 Line of equal decline
Interval 5 feet
Boundary of area modeled

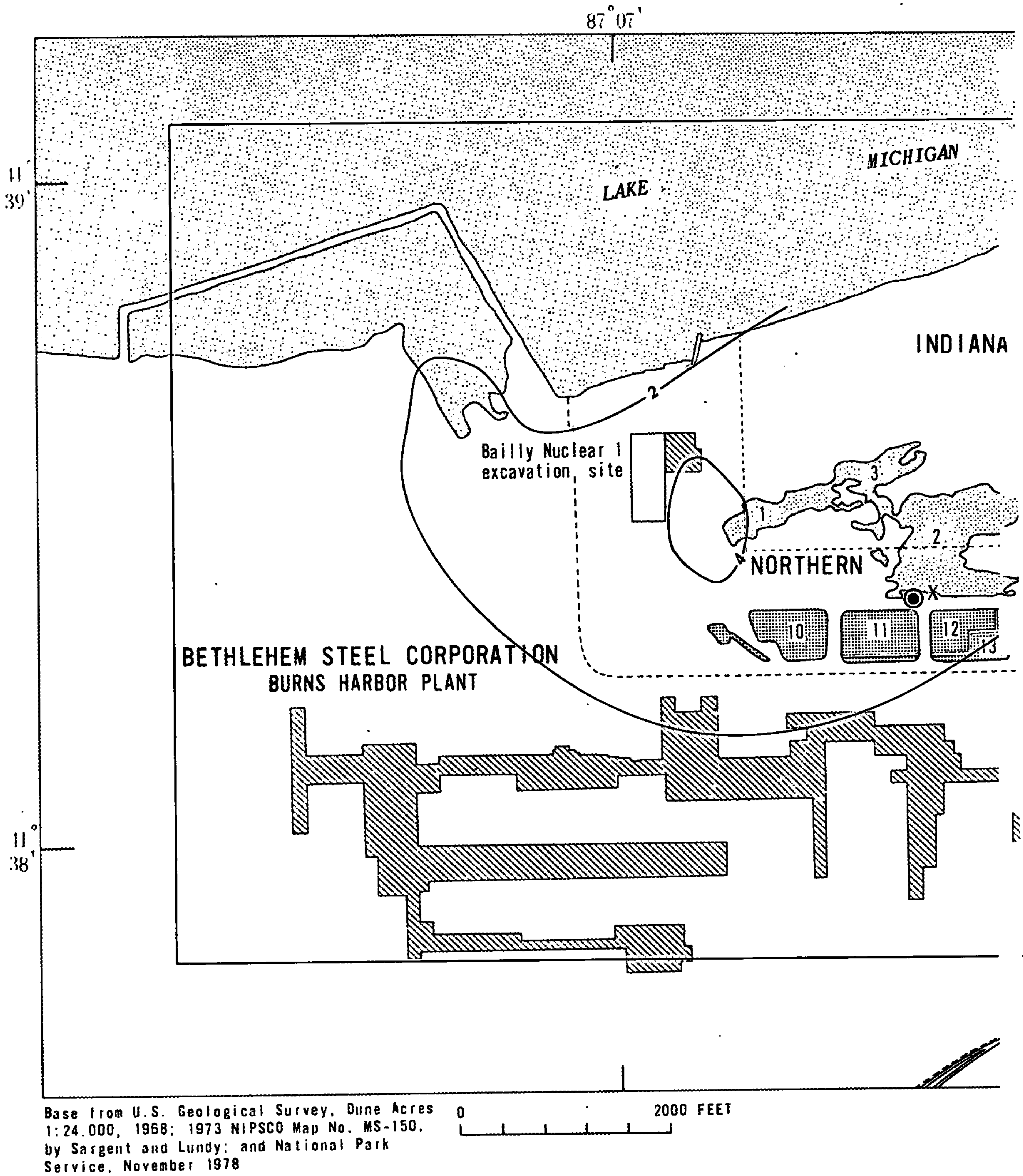
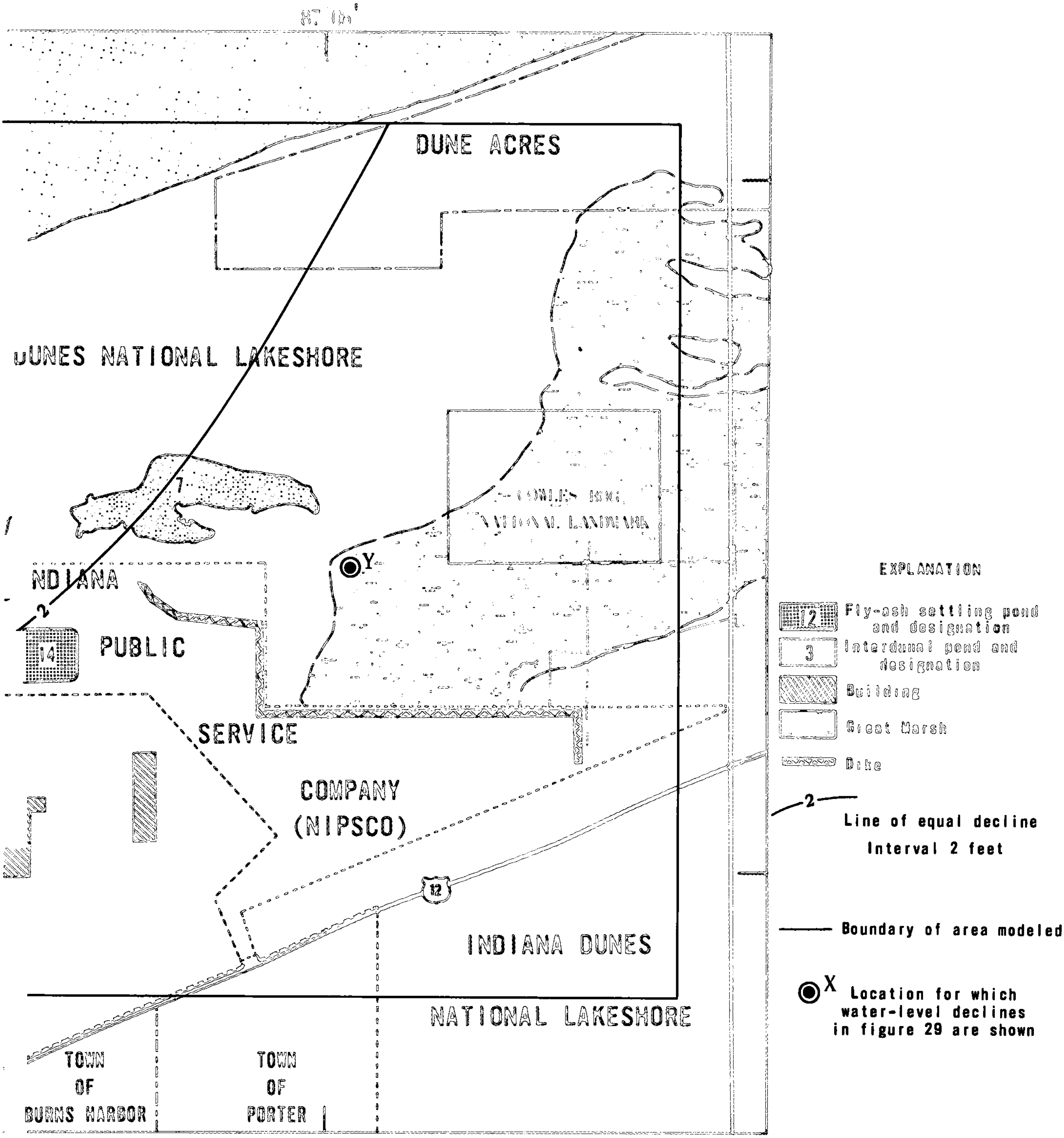


Figure 28.-- Model-derived decline of the potentiometric surface of unit 3 for simulated termination of fly-ash-pond seepage.



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EXPLANATION
12 Fly-ash settling pond and designation
3 Interdunal pond and designation
Building
Great Marsh
Dike
2 Line of equal decline
Interval 2 feet
Boundary of area modeled
X Location for which water-level declines in figure 29 are shown

still be present in those areas during periods of high ground-water levels. Therefore, the model-derived water levels resulting from these five experiments are consistent with pre-seepage conditions.

Although the results of experiment A indicated virtually no water-level declines at the boundaries, and thus indirectly indicated that the condition of constant flux at the model boundaries did not affect the model prediction, a second experiment, experiment B, examined the influence of the model boundaries on the results of experiment A more closely. Experiment B was identical in all aspects with experiment A, except that the model boundaries were changed to constant heads. The value of head assigned to a given boundary node was identical with that established during model calibration. Under this condition, flux into or out of the model boundaries could vary as ground-water levels in the interior of the model declined.

The constant-flux boundaries of experiment A might induce too much water-level decline by arbitrarily maintaining a constant flux out of the model. On the other hand, the constant-head boundaries might arbitrarily hold water levels higher than that which would occur by removing the fly-ash pond seepage. Water-level declines in the interior of the modeled area for units 1 and 3 simulated by the model for experiment B, however, were virtually identical with those obtained in experiment A, indicating that the boundary conditions imposed on the model did not substantially influence the model results.

In experiment C the value for the vertical hydraulic conductivity of units 2 and 4 was set at 6.7×10^{-3} ft/day, and the average annual recharge rate was increased accordingly (23 in/yr); otherwise, the conditions of experiment A were repeated. Water-level declines in unit 1 were within 1 ft of those in experiment A. Model-derived water-level declines in unit 3 for experiment C are much more extensive and as much as 3 ft greater than the model-derived declines in experiment A.

The purpose of experiments D and E was to examine the temporal change in water levels that would be associated with the termination of fly-ash-pond seepage. In experiment D, the coefficient of storage of unit 1 was set at 0.12, and in experiment E it was set at 0.30. These values should represent probable extremes for the coefficient of storage of this unit. Other than this change, all the conditions of experiment A were repeated. Figure 29 shows the model-derived temporal water-level declines at points X and Y shown in figure 28 for the two coefficients of storage. The graphs in figure 29 indicate that the water-level declines associated with termination of fly-ash-pond seepage are a maximum within about 2 yr after the termination and that the water levels would stabilize within approximately 9 yr after the termination.

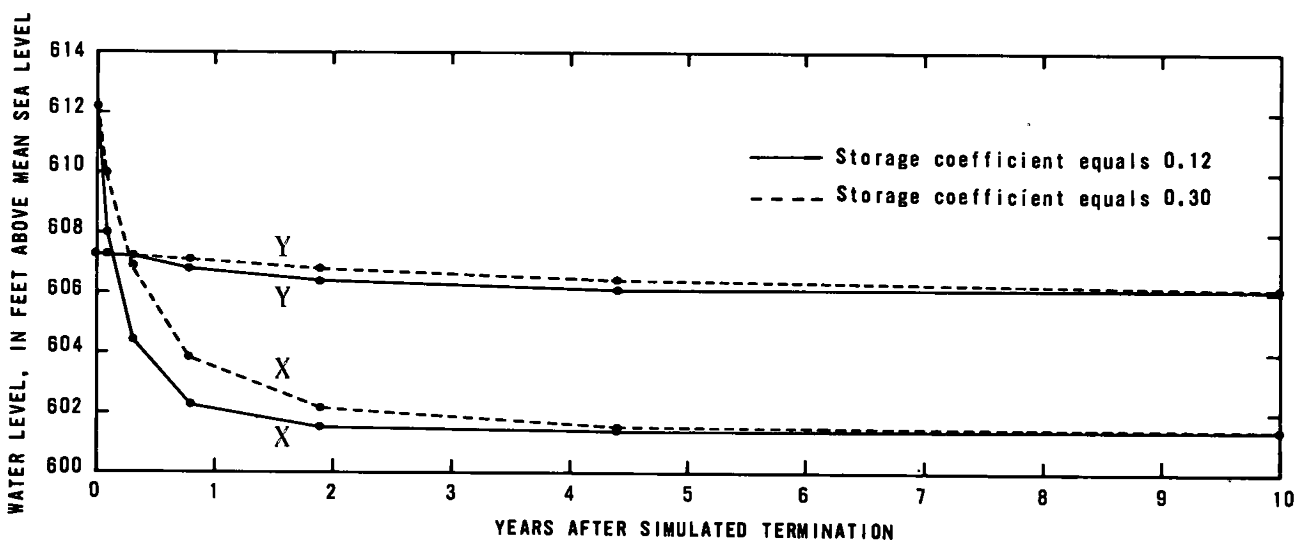


Figure 29.-- Model-derived water-level declines at points X and Y in unit 1 after termination of fly-ash-pond seepage for storage coefficients 0.12 and 0.30.

Model Simulation of Construction Dewatering

The second part of the modeling phase of the study was to predict the effect of construction dewatering at the Bailly Nuclear 1 excavation site on ground-water levels in the Indiana Dunes National Lakeshore. The design hydraulic conductivity of the slurry wall was reported to be 2.8×10^{-4} ft/day (John Dunn, Northern Indiana Public Service Co., oral commun., 1977), and NIPSCO assumed that this value would prevent nearly all lateral leakage into the site. NIPSCO also assumed that vertical leakage into the site would not be a factor owing to the existence of unit 2 beneath the construction site. Pumping at the site has been nearly continuous since March 17, 1977, and the volume of water removed from the site represents between 7 and 14 times the original amount of water stored within the limits of the slurry wall and the top of unit 2. The water-level decline inside the excavation site since dewatering began has only been 8.5 ft, compared with an expected 30-ft decline. The preceding data indicate that the slurry wall is leaking, the movement of water through unit 2 is sufficient to maintain the pumpage, or some combination of both. Although not indicated by geologic mapping, unit 2 may not be continuous beneath the extreme south end of the excavation site; and, further, construction inside the excavation site, including driving hundreds of steel I-beam piles into unit 3, has possibly increased the hydraulic connection between units 1 and 3.

Because the water being pumped from the excavation site could be leakage through the slurry wall and (or) movement of water from unit 3 into unit 1, model experiments were designed to consider these possibilities and to predict the future effect of pumping at the site on ground-water levels in the Indiana Dunes National Lakeshore.

Assuming that unit 2 is continuous and given the rate and distribution of pumping ground water, the water level inside the excavation site will be a function of (1) the coefficient of storage of unit 1, (2) the vertical hydraulic conductivity of unit 2, and (3) the lateral hydraulic conductivity of the slurry wall. Only these three parameters are mentioned because the remaining hydraulic and hydrologic parameters have been identified and incorporated in the model to an acceptable degree. The coefficient of storage of unit 1 is probably between 0.1 and 0.3, and, as established previously, the vertical hydraulic conductivity of unit 2 is between 6.7×10^{-4} and 6.7×10^{-3} ft/day.

Because of the possible range in value of the variables, a series of four groups of model experiments, F thru I, were made to approximate the lateral hydraulic conductivity of the slurry wall. After these experiments, another experiment, J, was made where the lateral hydraulic conductivity of the slurry wall was set at its design value and the vertical hydraulic connection between units 1 and 3 in the southern one-third of the excavation site was progressively increased above 6.7×10^{-3} ft/day. A series of model simulations was designed to determine if the observed pumpage from the excavation site could be sustained by vertical flow from unit 3. In all these experiments, the average pumpage from the excavation site and all other pumpage through December 15, 1977, within the model area was simulated, and the resultant model-derived water-level decline inside the excavation site was compared with the observed water level at this time. In addition, the average stage of the fly-ash ponds was simulated. The stage of Lake Michigan was not altered from that used in the steady-state calibration because the change in its stage from this value was minimal.

In experiments F and G, the simulated values of the coefficient of storage of unit 1 was 0.12. In experiment F, the vertical hydraulic conductivity of unit 2 was modeled as 6.7×10^{-4} ft/day, whereas in experiment G it was modeled as 6.7×10^{-3} ft/day. In experiments H and I, the coefficient of storage of unit 1 was set at 0.3. The vertical hydraulic conductivity of unit 2 was modeled as 6.7×10^{-4} ft/day in experiment H and as 6.7×10^{-3} ft/day in experiment I. Otherwise, all the conditions simulated in experiments F and G were repeated.

In experiments F through I, the lateral hydraulic conductivity of the model nodes containing the slurry wall, all of which are in unit 1, was initially set at 2.3×10^{-4} ft/day but was progressively increased in successive model simulations. The model-derived water level for the excavation site corresponding to these simulations under the conditions of experiment F are shown in figure 30. These data indicate that a lateral hydraulic conductivity for the model nodes containing the slurry wall equal to approximately 45 ft/day correlates with the observed water level in the excavation site. Because the length of the nodes containing the slurry wall is much

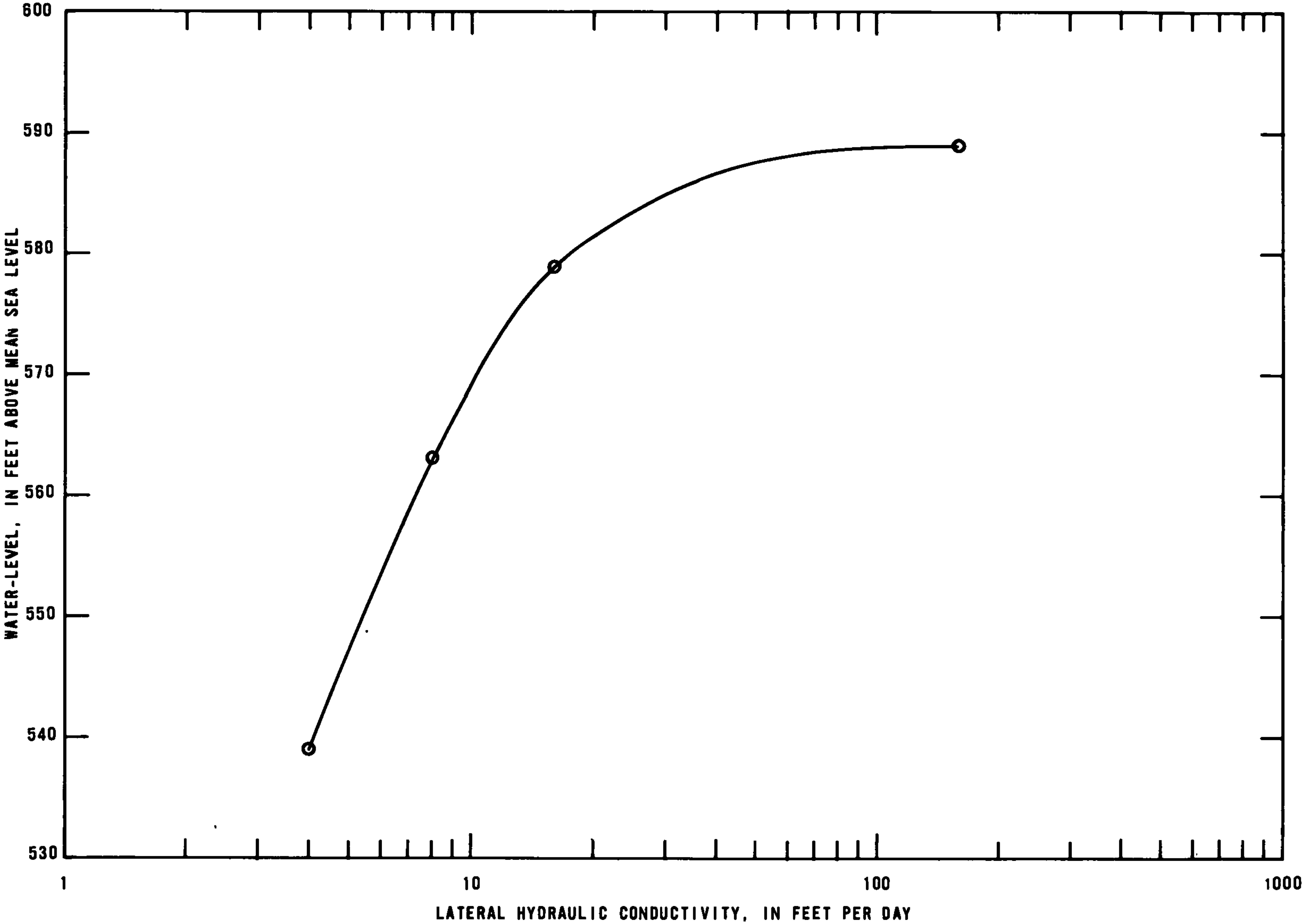


Figure 30.--Relation of model-derived water levels at the south end of the excavation site to lateral hydraulic conductivity at slurry-wall nodes.

wider than the slurry wall, the lateral hydraulic-conductivity values shown in figure 30 must be adjusted by the equation

$$K_{node} = \frac{2K_{sw} K_{unit\ 1}}{K_{sw}\ \Delta X_2 + K_{unit\ 1}\ \Delta X_1}$$

where

K_{node} is the lateral hydraulic conductivity of the model node,

K_{sw} the lateral hydraulic conductivity of the slurry wall,

$K_{unit\ 1}$ the lateral hydraulic conductivity of unit 1, 167 ft/day,

ΔX_1 the width of the slurry wall is 0.25 ft,

and ΔX_2 the width of the node minus X_1, or, 167-0.25 = 166.75 ft,

to obtain the actual hydraulic conductivity of the slurry wall that was represented. Substituting of the appropriate values in the preceding equation indicates only small differences between the nodal lateral hydraulic conductivities simulated and corresponding slurry-wall values. The series of model simulations did not allow for natural changes in water levels such as fluctuations resulting from changes in the stage of Lake Michigan and variation in precipitation. Historical data discussed previously indicate that the model-derived water level in the excavation site and the observed water level could differ by approximately 7 ft as a result of these natural changes. Allowing for the natural changes, figure 30 indicates that values for the lateral hydraulic conductivity of the model nodes containing the slurry wall lower than about 16 ft/day result in water levels in the excavation site that are significantly lower than the observed value. The water level inside the excavation site remains at approximately 589 ft for the lateral hydraulic conductivity of the slurry wall greater than approximately 90 ft/day.

The set of conditions modeled in the series of simulations under experiment F maximized the predicted drawdown in unit 1 and resulted in the maximum estimate of the lateral hydraulic conductivity of the slurry wall. All the model simulations in experiments G, H, and I involved either a larger value for the vertical hydraulic conductivity of unit 2 or a larger value for the coefficient of storage of unit 1, or both, than in experiment F. Model-derived water levels inside the excavation site for experiments G and I are all within several feet of those for experiment F, however.

Model experiments F through I indicate that, if unit 2 is continuous beneath the excavation site, the value of the lateral hydraulic conductivity of the slurry wall would be approximately 20 ft/day, or much greater than the design value 2.8×10^{-4} ft/day.

After completion of model experiments F-I, model experiment J was done to determine if pumping from the excavation site had been sustained primarily by the vertical movement of water from unit 3, assuming the lateral hydraulic conductivity of the slurry wall was at or near its design value. The ultimate goal of this experiment was to set limits on the range of vertical hydraulic conductivity of unit 2 under the southern one-third of the excavation site on the basis of the water level in the site on December 15, 1977, and pumpage from the site until then. In experiment J, the lateral hydraulic conductivity of the model nodes containing the slurry wall was set at 2.8×10^{-4} ft/day, the design value for the slurry wall. The coefficient of storage of unit 1 was set at 0.3 in all the model simulations under experiment J. Selection of this value as compared with 0.1 would minimize the water-level decline in the excavation site during the early stages of pumping, but for the length of time modeled, the model results should not be dependent on this value. As in experiments F through I, the average ground-water pumpage from the excavation site and all other ground-water pumpage through December 15, 1977, within the model area was simulated, the average stage of the fly-ash ponds was modeled, the stage of Lake Michigan was set at the same stage used for calibration, and the vertical hydraulic conductivity of unit 2, except at the southern one-third of the excavation site, was modeled as 6.7×10^{-3} ft/day.

The vertical hydraulic conductivity of unit 2 under the node representing the southern one-third of the excavation site was progressively increased in successive model simulations, and the corresponding water level inside the excavation site was recorded. The results obtained from these simulations are shown in figure 31. The data indicate that a vertical hydraulic conductivity equal to approximately 2.0 ft/day corresponds to the water level inside the excavation site on December 15. A range of values for this parameter is actually possible because the water-level declines may be due to natural changes as well as pumping. On the basis of this consideration, the range from 0.67 to 6.7 ft/day should adequately describe the range of the vertical hydraulic conductivity of unit 2 under the southern part of the excavation site that would be consistent with field observations if the hydraulic conductivity of the slurry wall were actually at its design value.

The hydraulic connection between units 1 and 3 obtained by use of the range of vertical hydraulic conductivity (0.67-6.7 ft/day) can be interpreted several ways. Literally interpreted, the range represents the vertical hydraulic conductivity of unit 2 in the nodal area. It may also represent the average value obtained by combining the flow for a subarea in the nodal area, whose vertical hydraulic conductivity is high, with the flow from the remaining nodal area, whose vertical hydraulic conductivity is within the range from 6.7×10^{-4} to 6.7×10^{-3} ft/day.

Plans for future construction dewatering include continuing the present (December 1977) pumping rate at the construction site until August 1978, when the water level inside the southern one-third of the excavation site will be lowered to and will be held at an elevation of 578 ft for 18 months by increasing the pumping rate (John Dunn, Northern Indiana Public Service

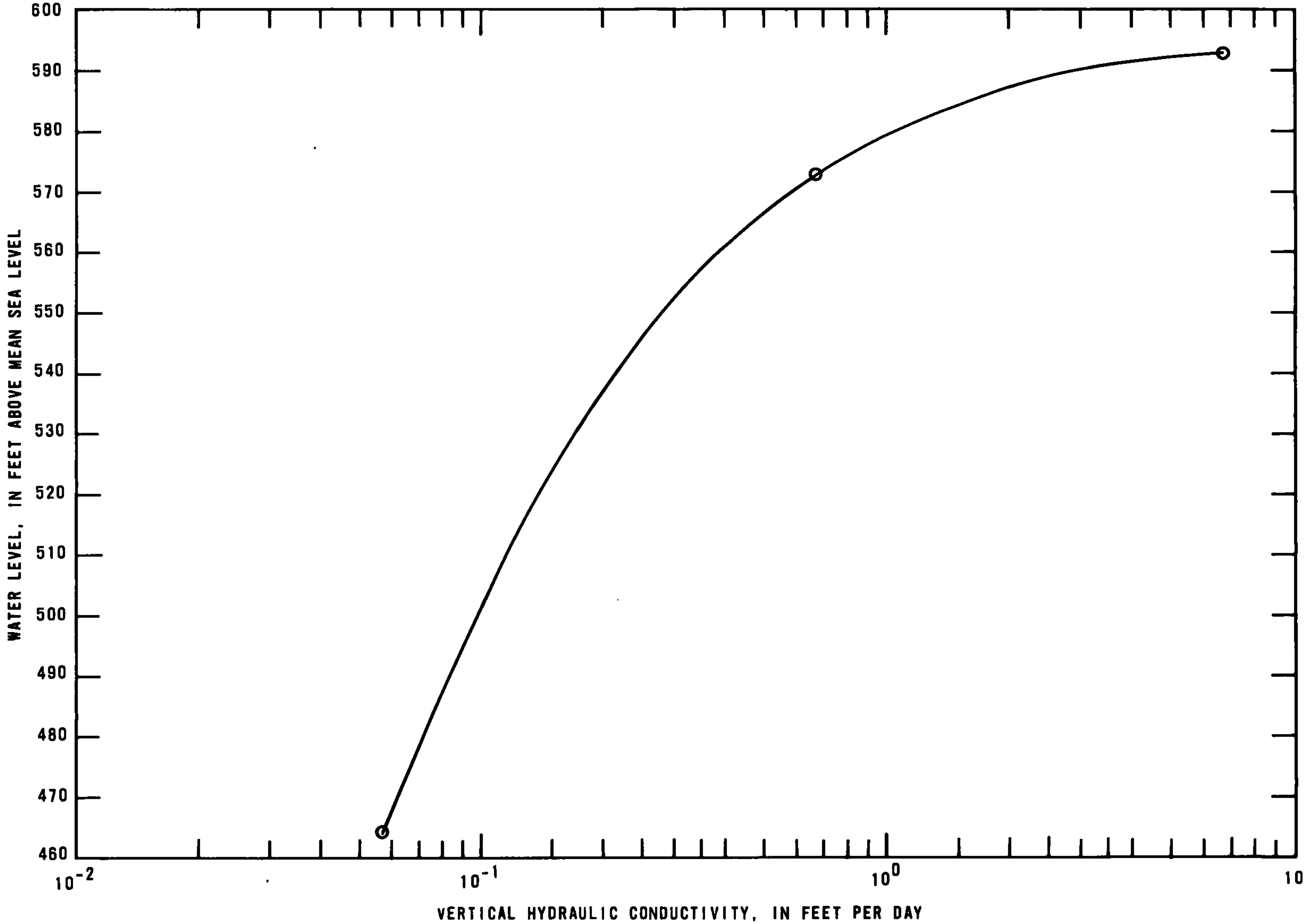


Figure 31.-- Relation of model-derived water levels at the south end of the excavation site to vertical hydraulic conductivity of unit 2 under the southern one-third of the excavation site.

Co., oral commun.,1977). For a given pumping rate, the water level inside the construction site and the effect of this pumping rate on water levels in the National Lakeshore is, in part, a function of (1) the coefficient of storage of unit 1, (2) the lateral hydraulic conductivity of the slurry wall, (3) the vertical hydraulic conductivity of unit 2, and (4) the continuity or lack thereof and vertical hydraulic conductivity of unit 2 within the southern one-third of the excavation site.

Model experiments F through I identified a range of lateral hydraulic conductivity of the slurry wall for a unit 2 that was assumed to be continuous beneath the excavation site. Model experiment J identified a range of vertical hydraulic conductivity of unit 2 in the southern one-third of the excavation site for a unit 2 that is either absent in some part of this area or at least has a higher vertical hydraulic conductivity at this location than in the remaining part of the study area. Using the range of hydraulic conductivities obtained from experiments F and J, the range established previously for the coefficient of storage of unit 1, and the vertical hydraulic conductivity of unit 2 in most of the study area, the authors made a final series of experiments to identify the maximum and minimum effects of construction dewatering at the Bailly site on ground-water levels in units 1 and 3 within the Indiana Dunes National Lakeshore.

Sixteen model experiments (K through Z) were needed to identify the preceding maximum and minimum effects. In these experiments, the only pumping simulated was that during the steady-state calibration and the proposed pumping for the dewatering at the Bailly site. By this procedure, the simulated water-level declines would be caused only by dewatering at the construction site.

Each of the 16 experiments consisted of two phases. In the first phase, the 280 gal/min average pumpage from the excavation site was simulated from March 17, 1977, to August 1, 1978. In the second phase of each experiment, pumpage was simulated in the model by holding the head in unit 1 at an elevation of 577.7 ft constant for 18 months. Maps showing the cumulative water-level decline at the end of the 18-month pumping period were made for each experiment.

Conditions assumed in model experiments K through R were a continuous unit 2 beneath the excavation site and a leaky slurry wall. Conditions assumed in experiments S through Z, were the design value for the lateral hydraulic conductivity of the slurry wall and a leaky unit 2 under the southern one-third of the excavation site.

Listed in table 3 are the values of the hydraulic properties simulated in experiments K through R, the model-derived water-level declines in the National Lakeshore for each experiment, and the model-derived pumping rate required in the southern one-third of the excavation site to maintain a water level of 578 ft during the last 18 months of dewatering.

The results of experiments K through R indicate that, for a given value of the lateral hydraulic conductivity of the slurry wall, the predicted

Table 3.--Summary of hydrologic data for second phase of dewatering, model experiments K through R, Indiana Dunes National Lakeshore

Experiment	Coefficient of storage, unit 1	Vertical hydraulic conductivity, unit 2 (ft/day)	Lateral hydraulic conductivity, slurry wall (ft/day)	Model-derived pumpage, second phase (gal/min)	Model-derived water-level declines, Indiana Dunes National Lakeshore (ft)	
					Unit 1	Unit 3
K	0.12	6.7×10^{-4}	160	645	≤ 3	≤ 1
L	.12	6.7×10^{-4}	16	250	< 1	< 1
M	.12	6.7×10^{-3}	160	700	≤ 3	≤ 1
N	.12	6.7×10^{-3}	16	250	< 1	< 1
O	.30	6.7×10^{-4}	160	645	≤ 3	≤ 1
P	.30	6.7×10^{-4}	16	250	< 1	< 1
Q	.30	6.7×10^{-3}	160	700	≤ 3	≤ 1
R	.30	6.7×10^{-3}	16	250	< 1	< 1

water-level declines in units 1 and 3 are virtually independent of the vertical hydraulic conductivity of unit 2 and the storage coefficient of unit 1. By the end of the dewatering, removal of water from storage is no longer a factor in water-level declines. The amount of water induced from unit 3 into unit 1 by drawdowns in unit 1 is not enough to cause drawdowns in unit 3 greater than 1 ft for the range of the vertical hydraulic conductivity of unit 2.

The maximum model-derived water-level declines in units 1 and 3 correlate with the high lateral hydraulic conductivity of the slurry wall. These maximum declines are shown in figures 32 and 33, respectively; minimum model-derived declines in unit 1 are shown in figure 34. All the minimum declines for unit 3 are less than 1 ft. Maximum declines were derived by experiments K, M, O, and Q, and minimum declines were derived by experiments L, N, P, and R. The experiments indicate that the pumping rate necessary to maintain water levels in the excavation site at 578 ft for the 18 months of the second phase of dewatering, under the different assumptions of vertical hydraulic conductivities of unit 2 and lateral hydraulic conductivities of the slurry wall, ranges from 240 to 675 gal/min.

Listed in table 4 are the values of the hydraulic properties simulated in experiments S through Z, model-derived water-level declines in the National Lakeshore for each experiment, and the model-derived pumping rate required in the southern one-third of the excavation site to maintain a water level of 578 ft during the last 18 months of dewatering.

The results of these experiments indicate a greater range of model-derived water-level declines in units 1 and 3 than in experiments K through R. The maximum water-level decline in unit 1 corresponds to that in experiment U, where the coefficient of storage of unit 1 was modeled as 0.12, the vertical hydraulic conductivity of unit 2 was simulated as 6.7×10^{-3} ft/day, and the vertical hydraulic conductivity of unit 2 in the southern one-third of the excavation site was set at 6.7 ft/day. A contour map of water-level declines in unit 1 (experiment U) is shown in figure 35. The minimum decline in unit 1 corresponded to that in experiment X. Contours of water-level declines for this experiment are shown in figure 36. The cone of depression outside the excavation site, shown in figures 35 and 36, results from the absence of unit 2 in that area, as shown in figure 8. Water-level declines in the park boundaries are all less than 1 ft in experiment X.

The maximum model-derived water-level declines in unit 3 were for the hydraulic conditions simulated in experiment S. Contours of these declines within the modeled area are shown in figure 37. Declines of 2 ft or more reach the edge of the area. These declines could be influenced by the boundary condition imposed on the model. In experiments K through Z, the boundaries were simulated as constant flux on the basis of steady-state conditions before dewatering, and, therefore, the figure should represent the maximum declines for unit 3. The minimum decline in unit 3 is for the hydraulic values incorporated in experiment Z. Water-level declines in the unit are shown in figure 38.

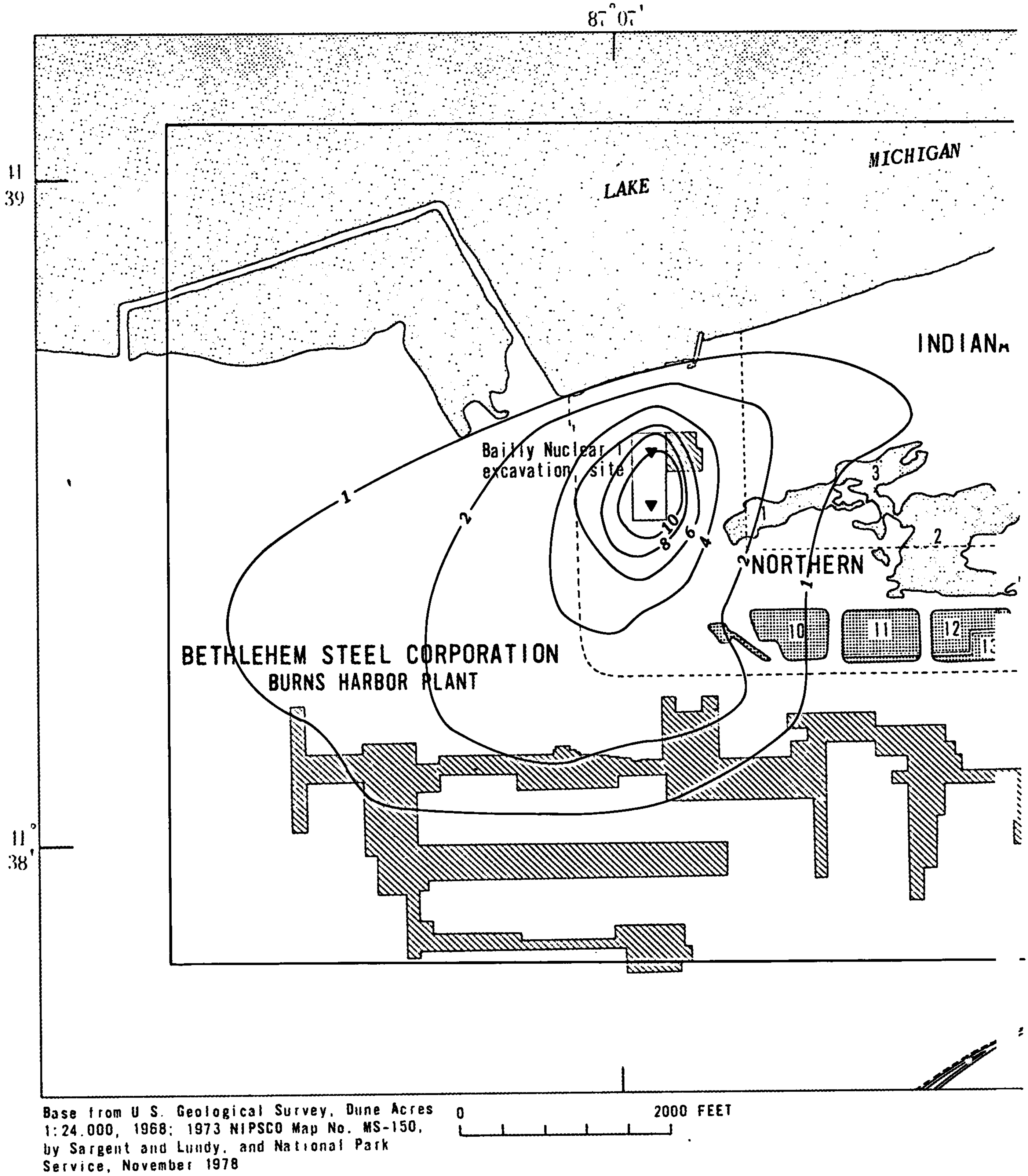
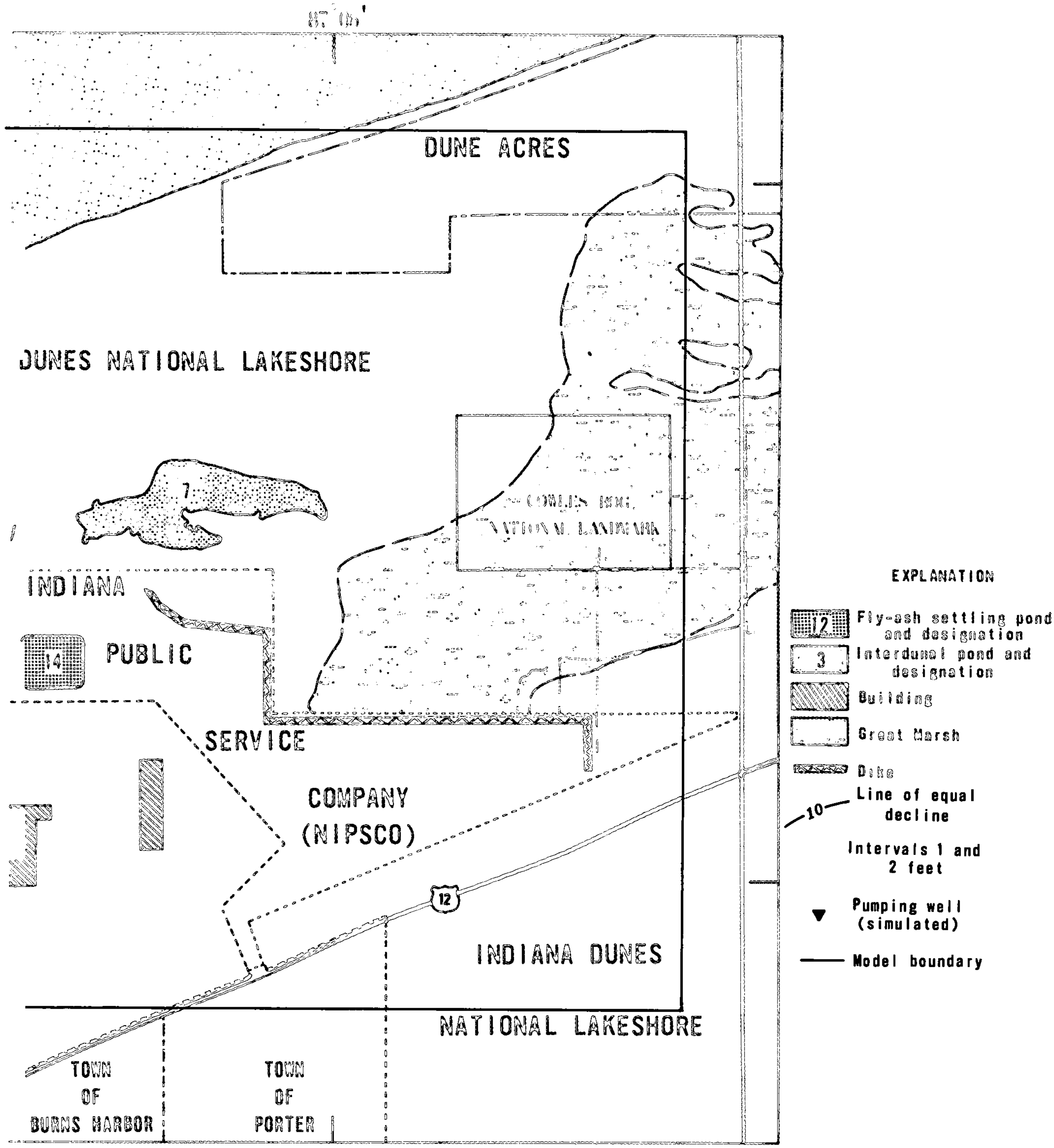


Figure 32.-- Model-derived maximum water-level declines in unit 1 due to construction dewatering for conditions simulated in experiment K.



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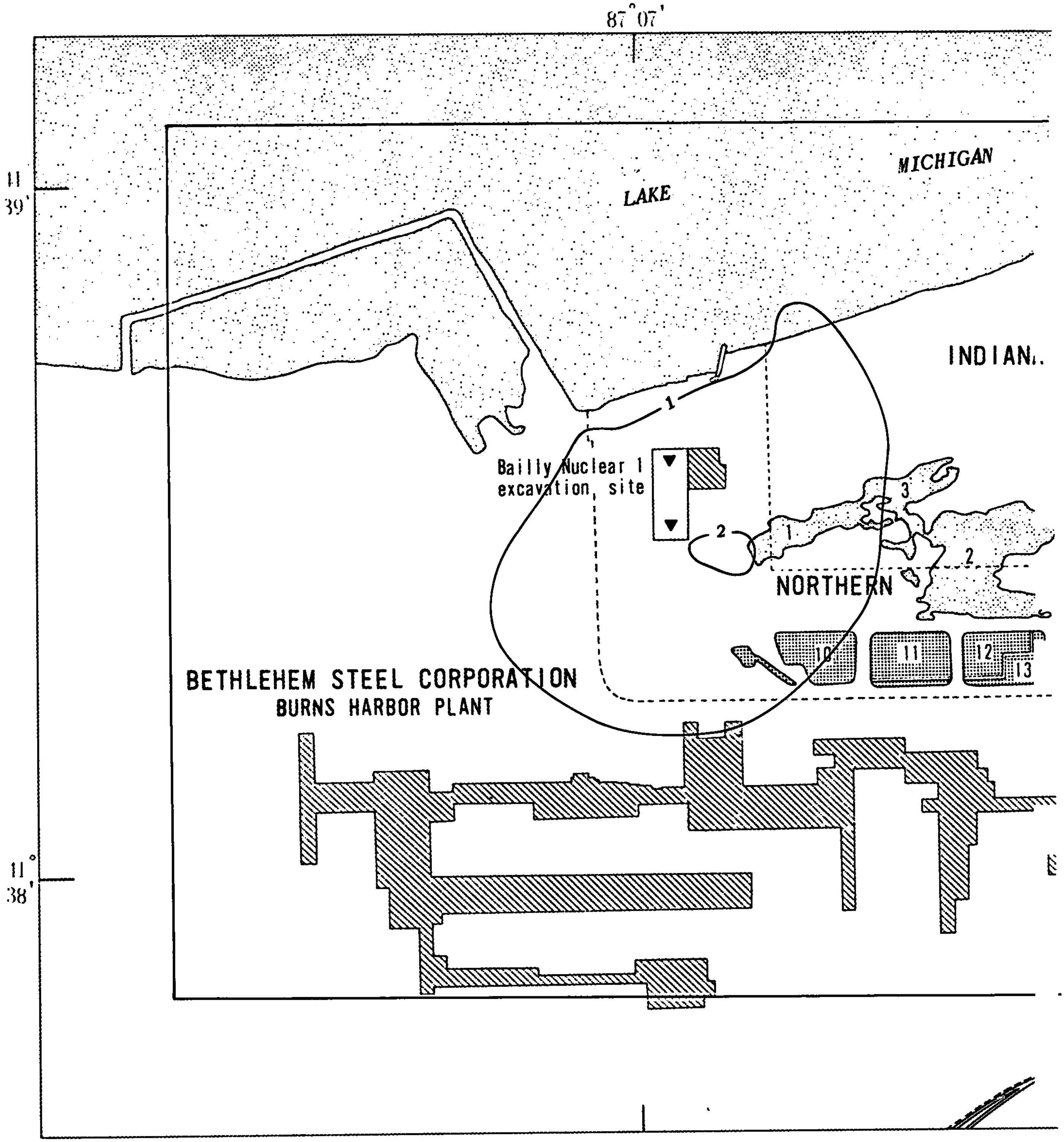
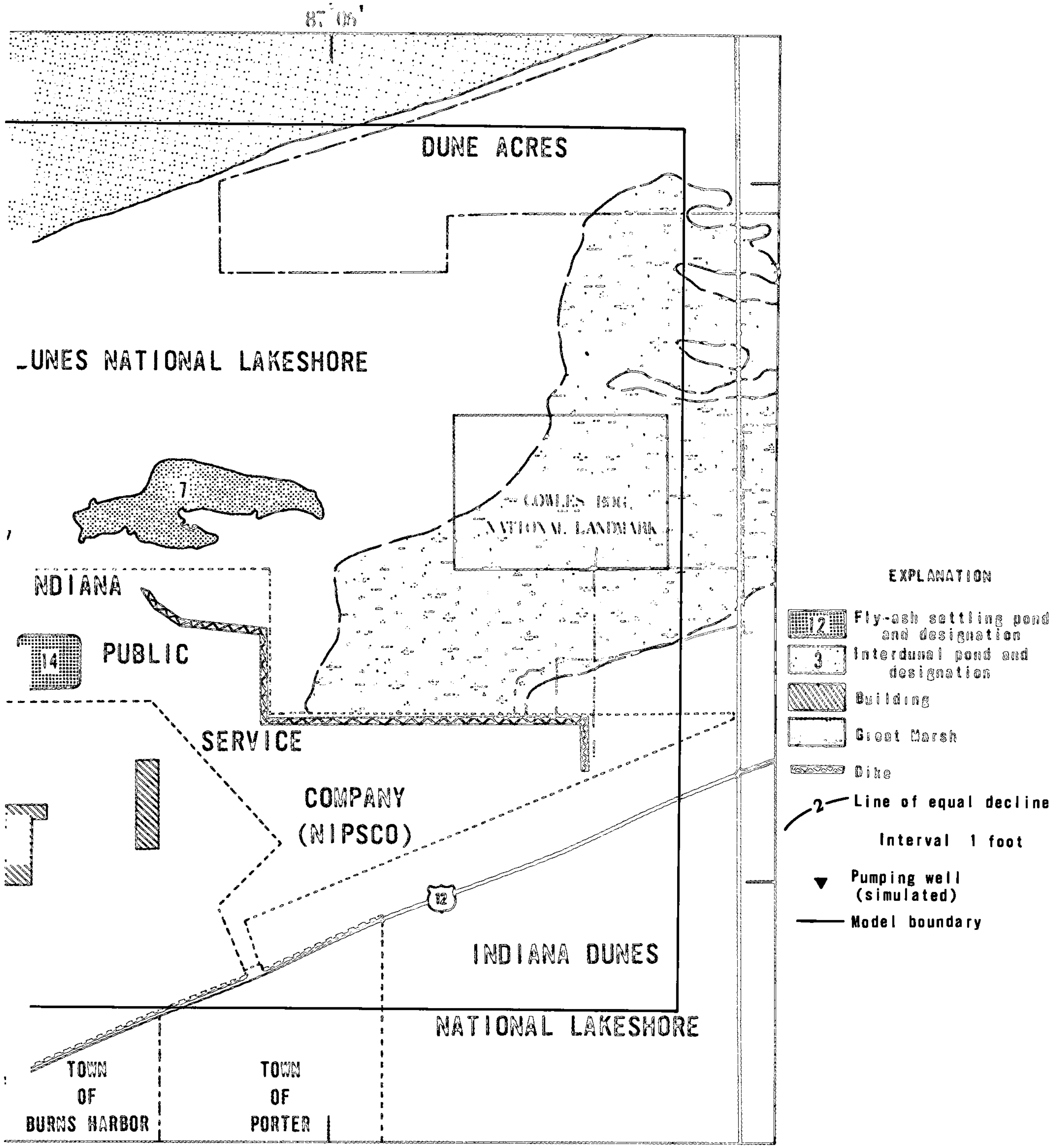
Intervals 1 and 2 feet
Pumping well (simulated)
Model boundary



Base from U S. Geological Survey, Dune Acres 1:24.000, 1968, 1973 NIPSCO Map No. MS-150, by Sargent and Lundy, and National Park Service, November 1978

Figure 33.-- Model-derived decline of the potentiometric surface in unit 3 due to construction dewatering for conditions simulated in experiment Q.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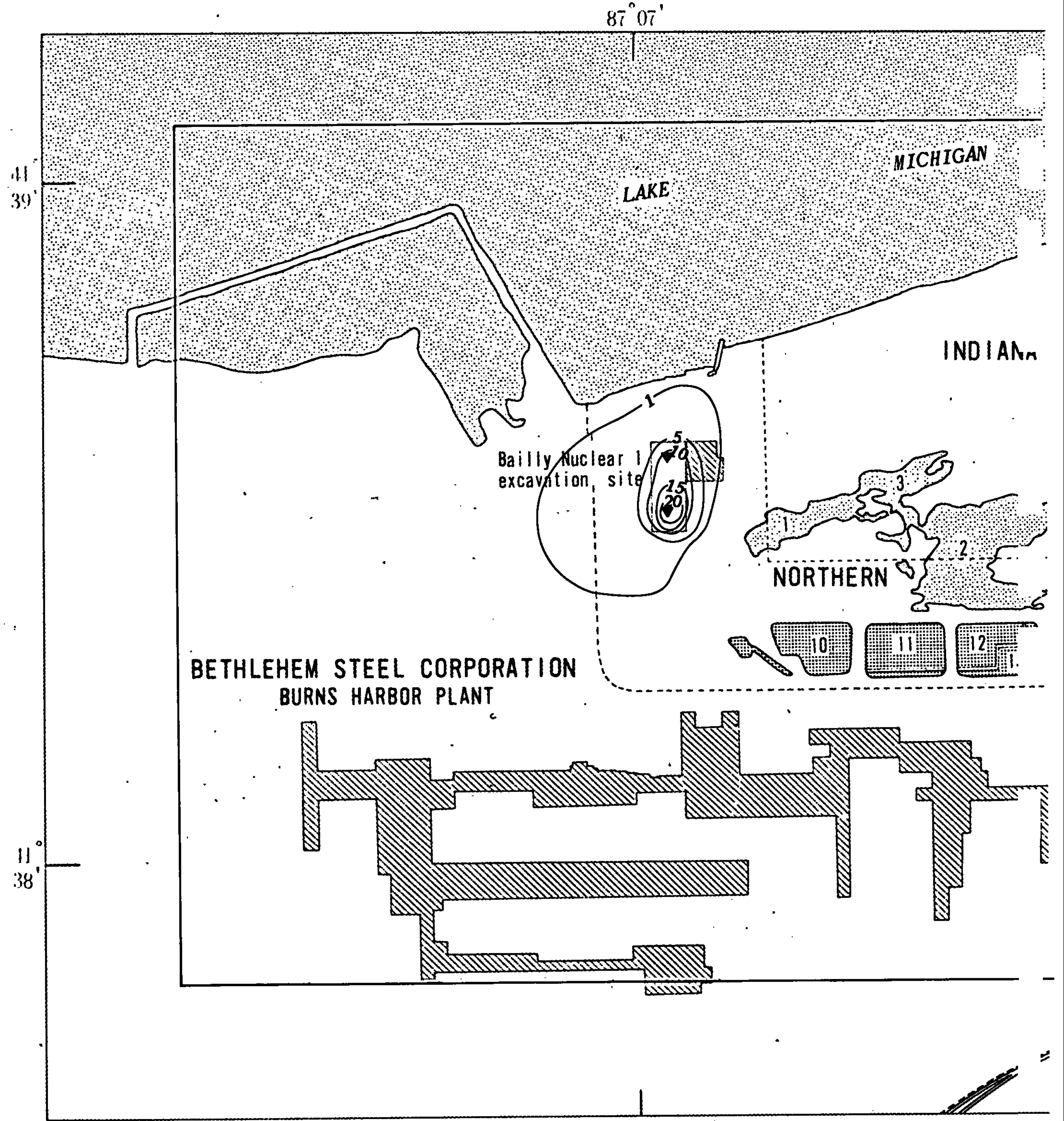
Pumping well (simulated)
Model boundary



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968; 1973 NIPSCO Map No. MS-150, by Sargent and Lundy; and National Park Service, November 1978

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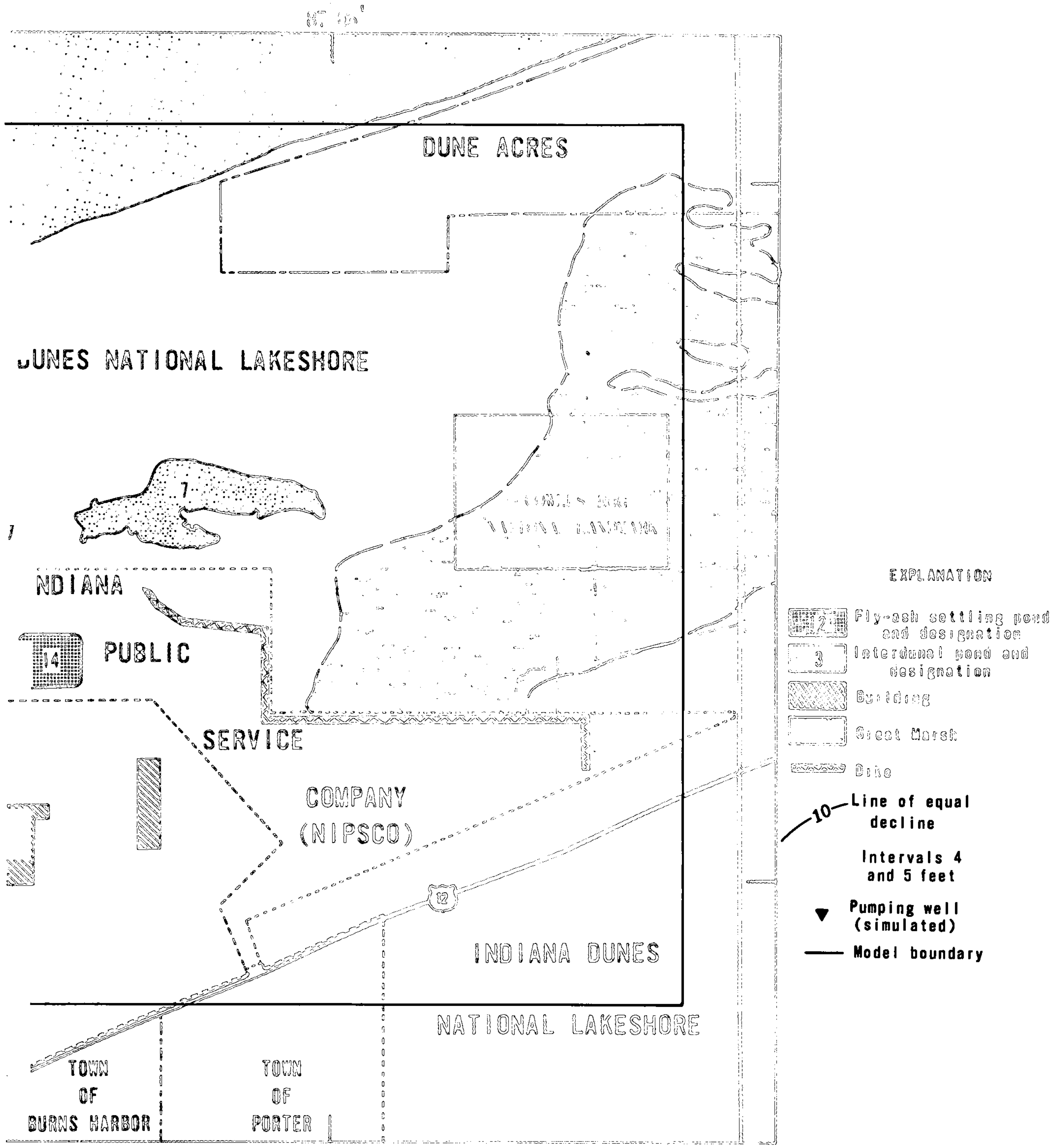
Figure 34.-- Model-derived water-level declines in unit 1 due to construction dewatering for conditions simulated in experiment R.



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Interdunal pond and designation
Building
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Dike
Line of equal decline
Intervals 4 and 5 feet
Pumping well (simulated)
Model boundary

Table 4.--Summary of hydrologic data for second phase of dewatering, model experiments S through Z, Indiana Dunes National Lakeshore

Experiment	Coefficient of storage, unit 1	Vertical hydraulic conductivity, unit 2 (ft/day)	Vertical hydraulic conductivity, unit 2, southern one-third excavation site (ft/day)	Lateral hydraulic conductivity, slurry wall (ft/day)	Model-derived pumpage, second phase (gal/min)	Model-derived water-level declines, Indiana Dunes National Lakeshore (ft)	
						Unit 1	Unit 3
S	0.12	6.7×10^{-4}	6.7	2.8×10^{-4}	650	≤ 2	1-5
T	.12	6.7×10^{-4}	.67	2.8×10^{-4}	155	< 1	≤ 1
U	.12	6.7×10^{-3}	6.7	2.8×10^{-4}	710	≤ 3	≤ 4
V	.12	6.7×10^{-3}	.67	2.8×10^{-4}	155	< 1	< 1
W	.3	6.7×10^{-4}	6.7	2.8×10^{-4}	680	< 1	2-5
X	.3	6.7×10^{-4}	.67	2.8×10^{-4}	140	< 1	≤ 1
Y	.3	6.7×10^{-3}	6.7	2.8×10^{-4}	720	≤ 1	≤ 4
Z	.3	6.7×10^{-3}	.67	2.8×10^{-4}	150	≤ 1	≤ 1

Model-derived water-level declines within the National Lakeshore for all the experiments (K-Z) in unit 1 ranged from less than 1 ft to 3 ft, whereas those in unit 3 generally ranged from 1 to 5 ft. If the physical setting at the excavation site is such that both the slurry wall and unit 2 in the southern one-third of the excavation site are leaking, the ranges in maximum and minimum water-level declines for units 1 and 3 would be less than those predicted in experiments K through Z.

Model-derived pumping rates for the second phase of dewatering ranged from 150 to 720 gal/min, depending on the hydraulic parameters simulated.

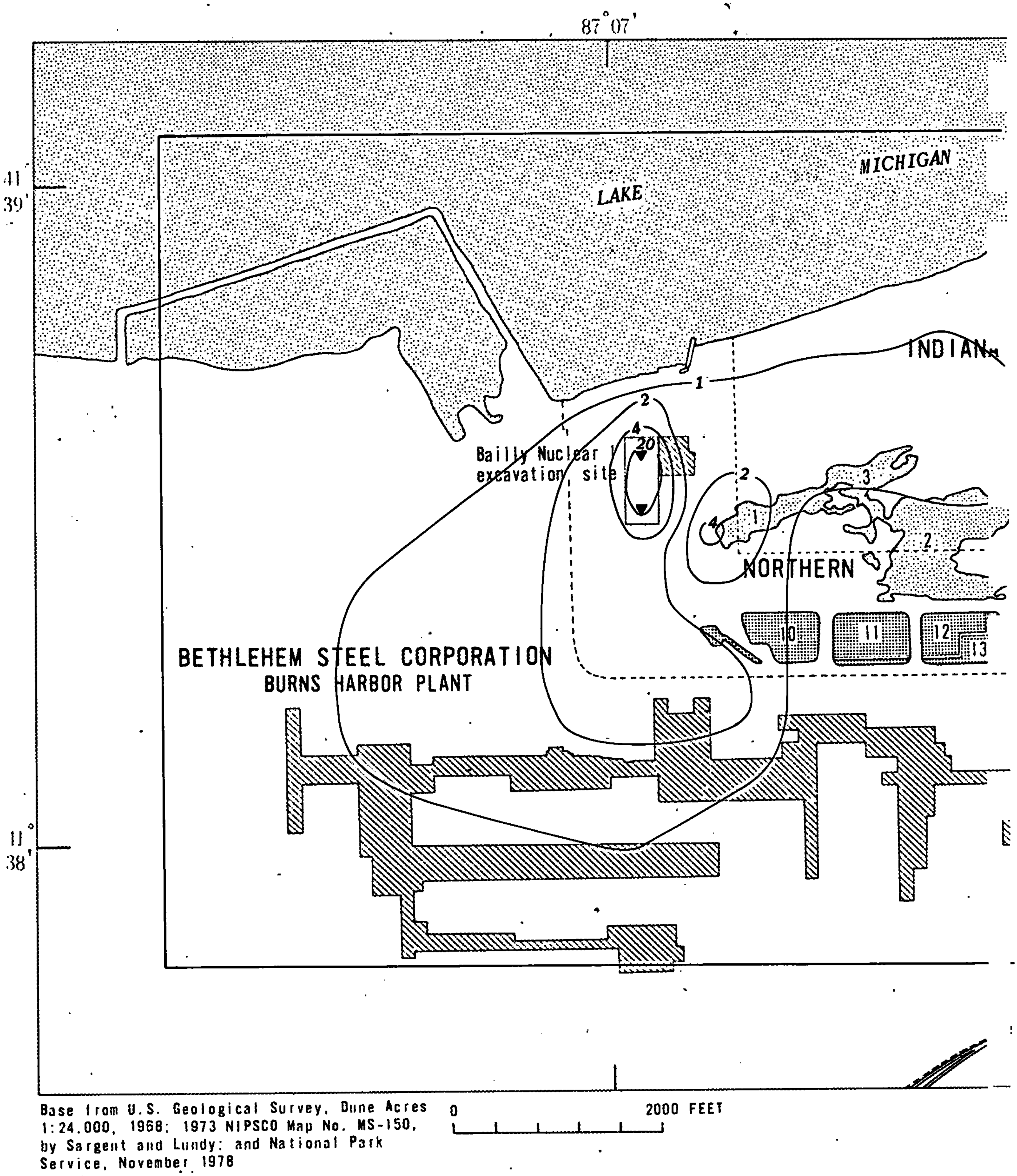
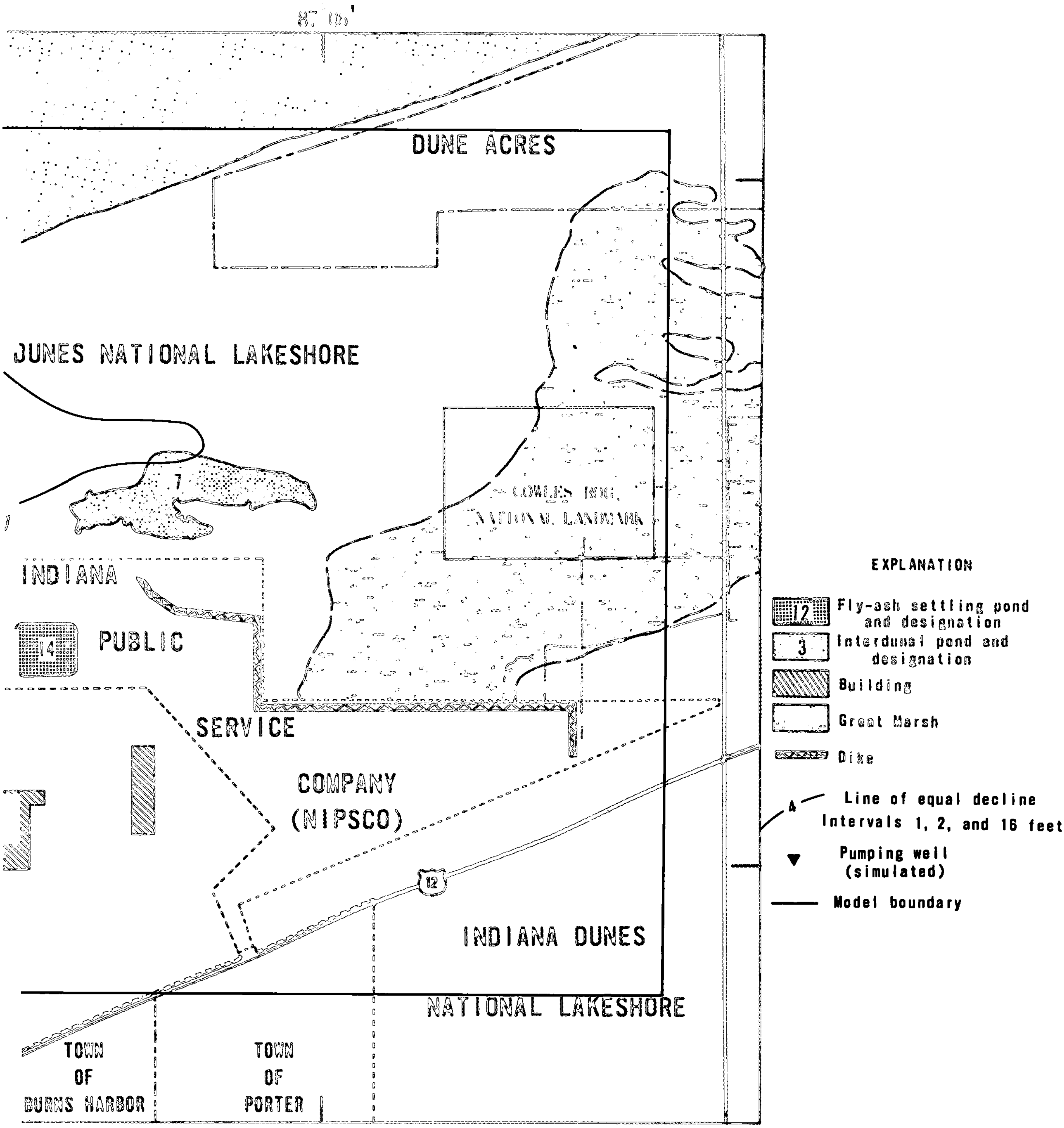


Figure 35.--Model-derived water-level declines in unit 1 due to construction dewatering for conditions simulated in experiment U.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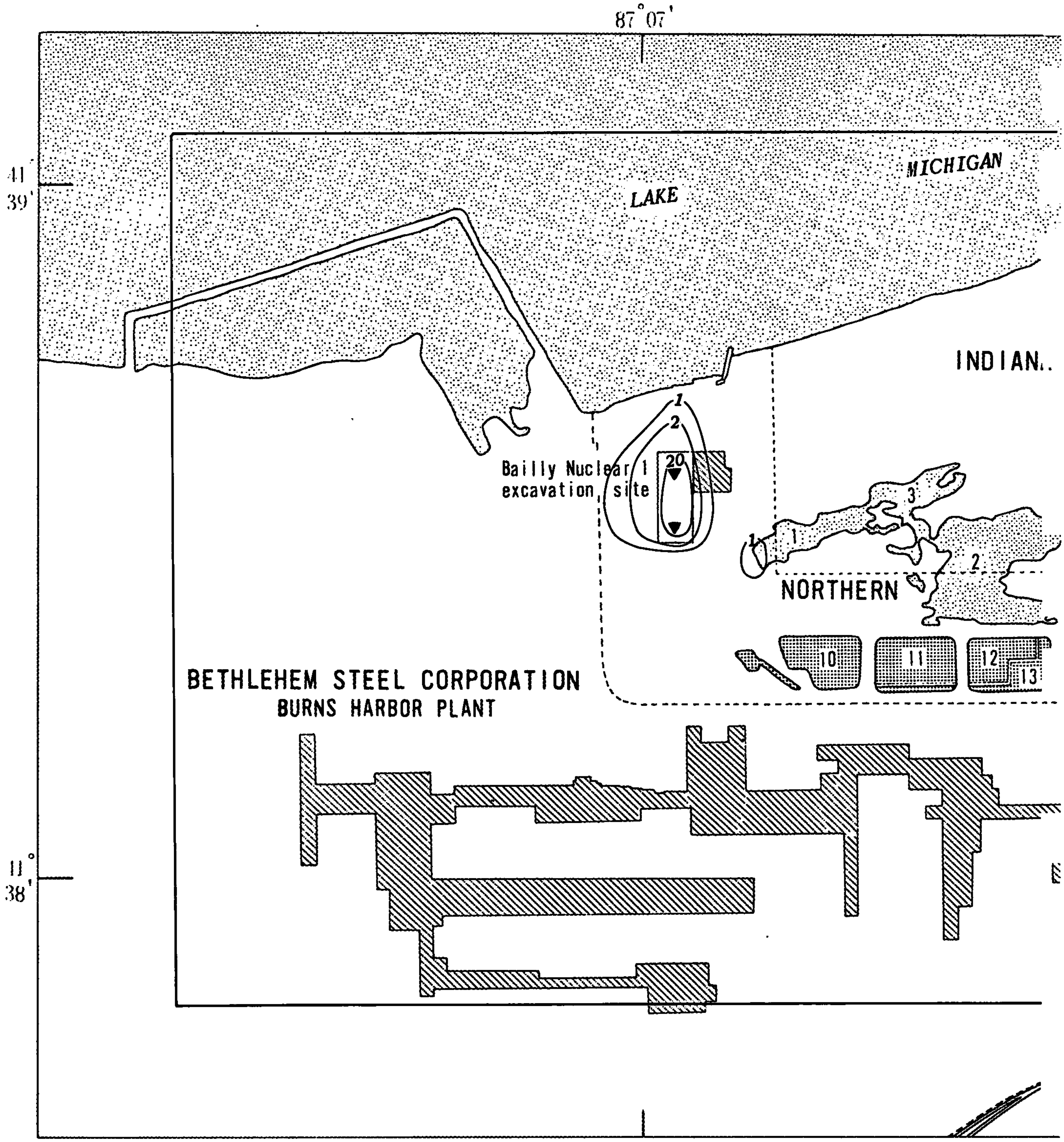
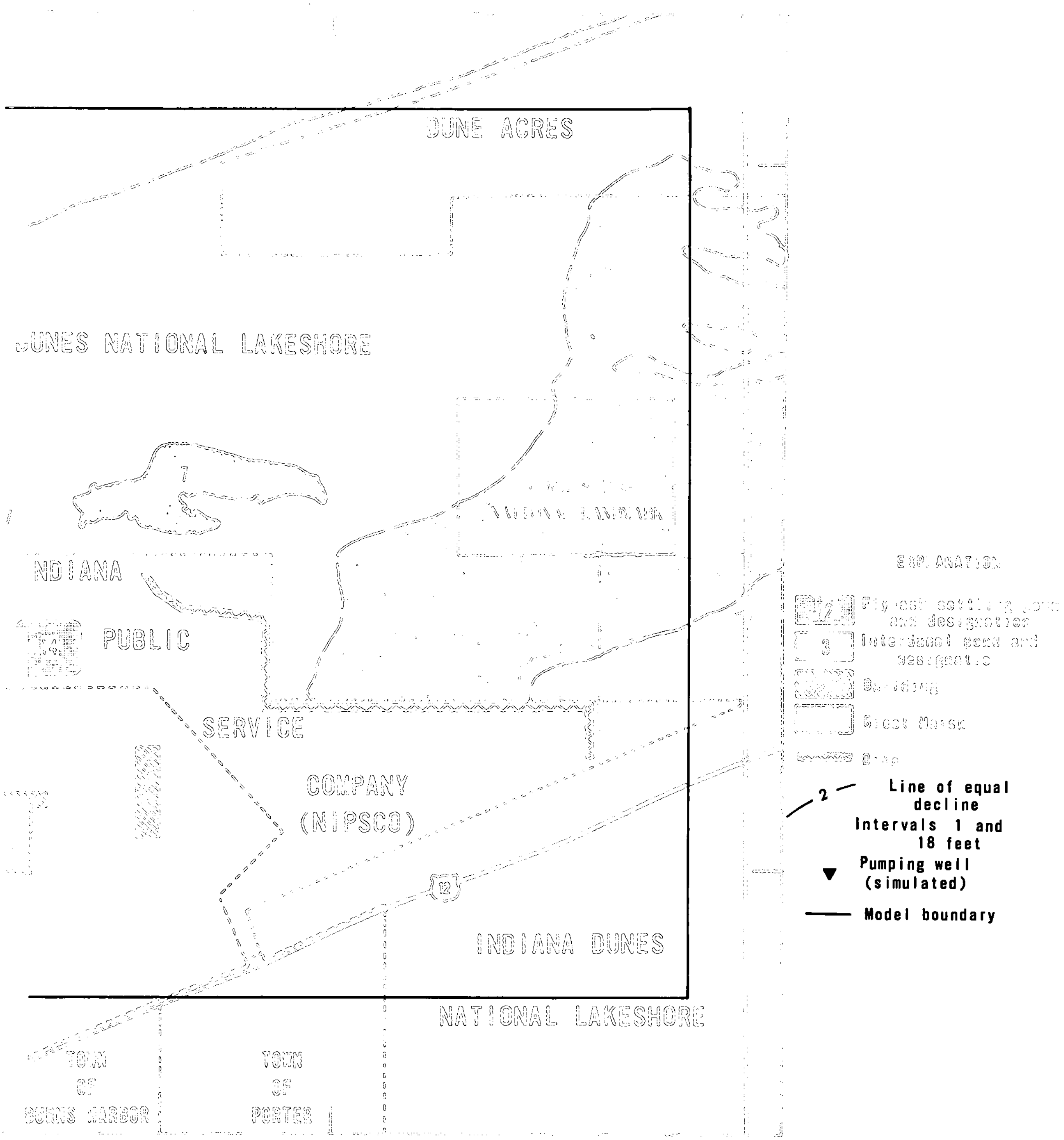
Intervals 1, 2, and 16 feet
Pumping well (simulated)
Model boundary



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968; 1973 NIPSCO Map No. MS-150, by Sargent and Lundy; and National Park Service, November 1978

Figure 36.-- Model-derived water-level declines in unit 1 due to construction dewatering for conditions simulated in experiment X.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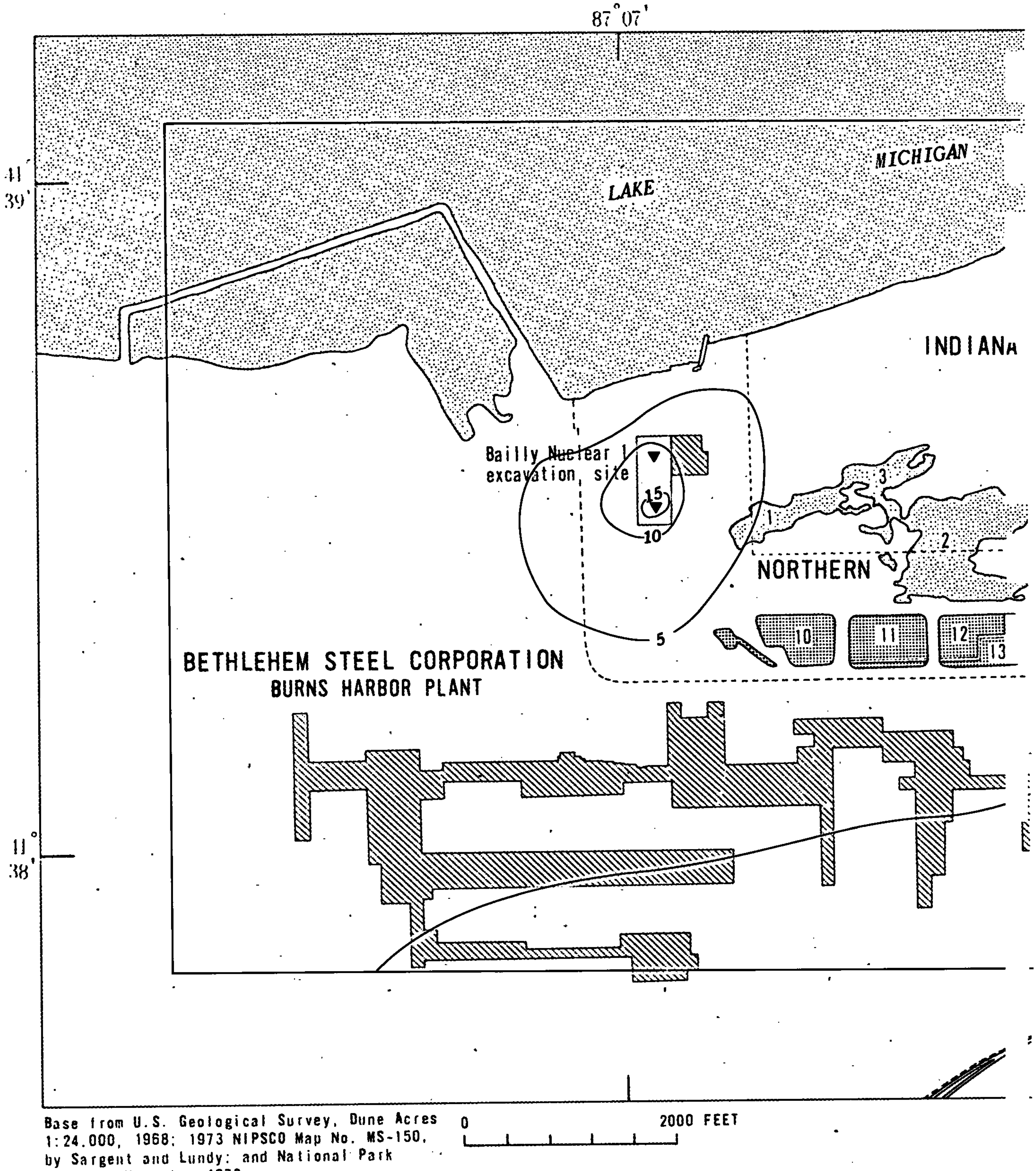
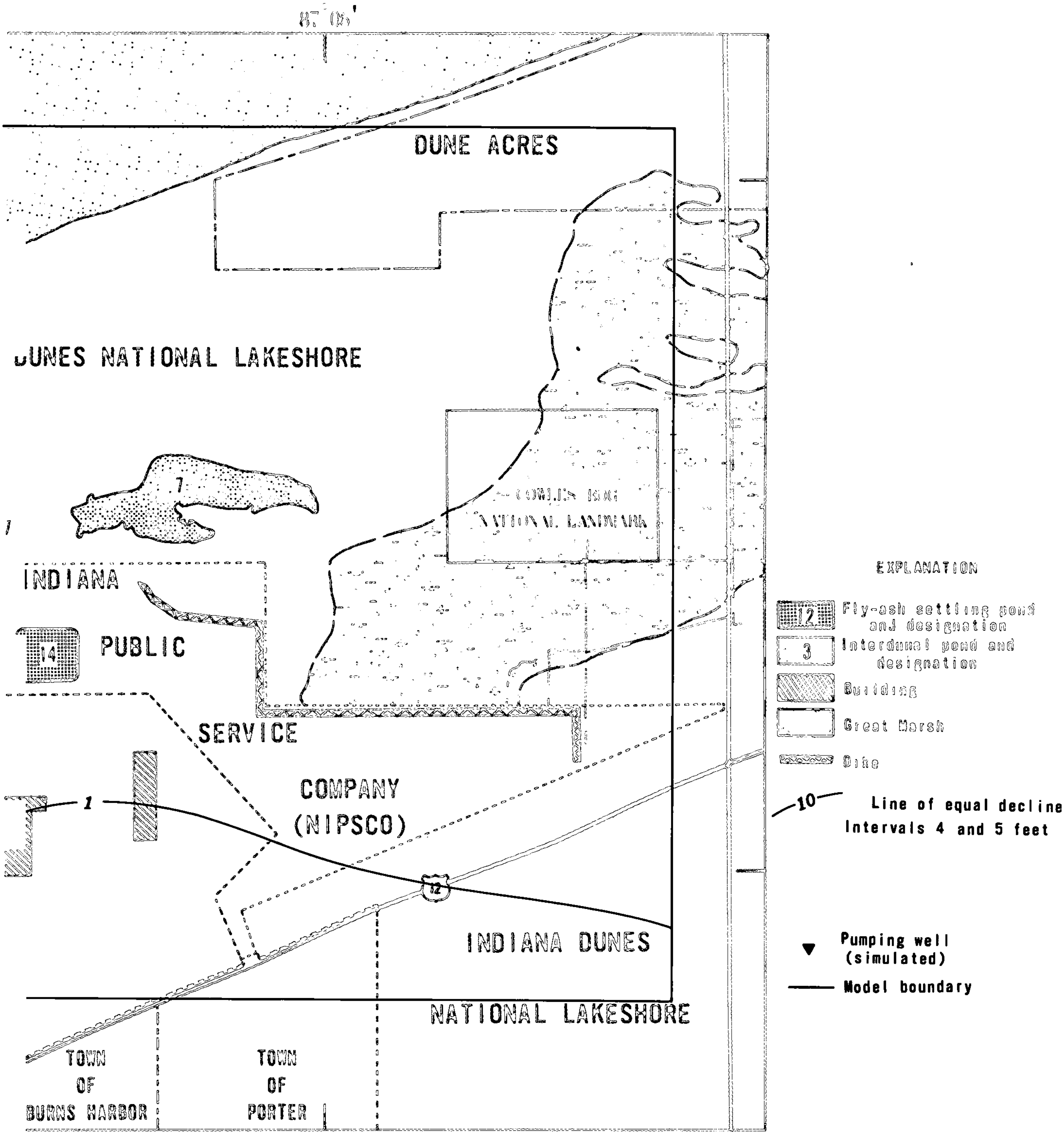


Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968; 1973 NIPSCO Map No. MS-150, by Sargent and Lundy; and National Park Service, November 1978

Figure 37.-- Model-derived decline of the potentiometric surface in unit 3 due to construction dewatering for conditions simulated in experiment S.



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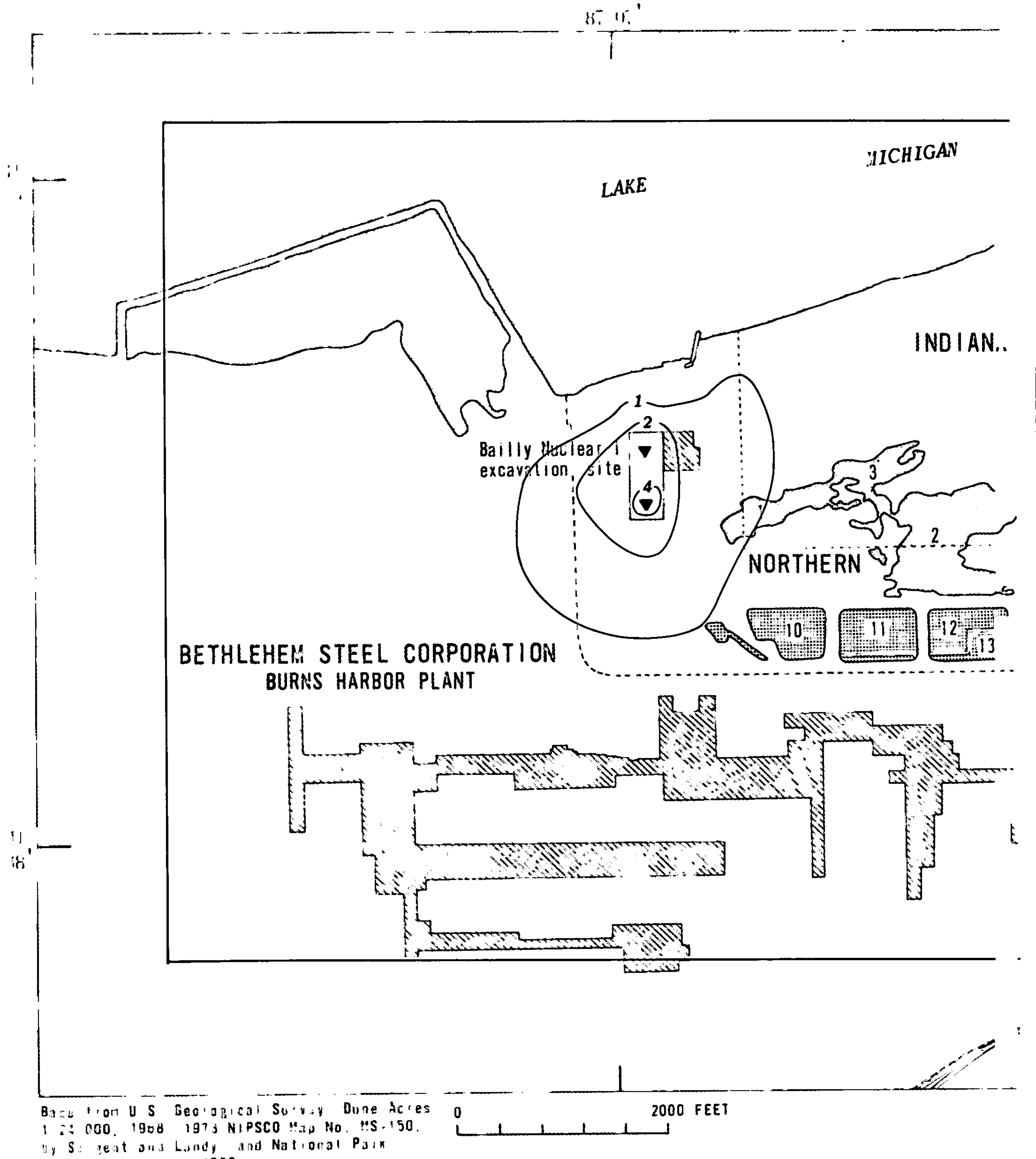
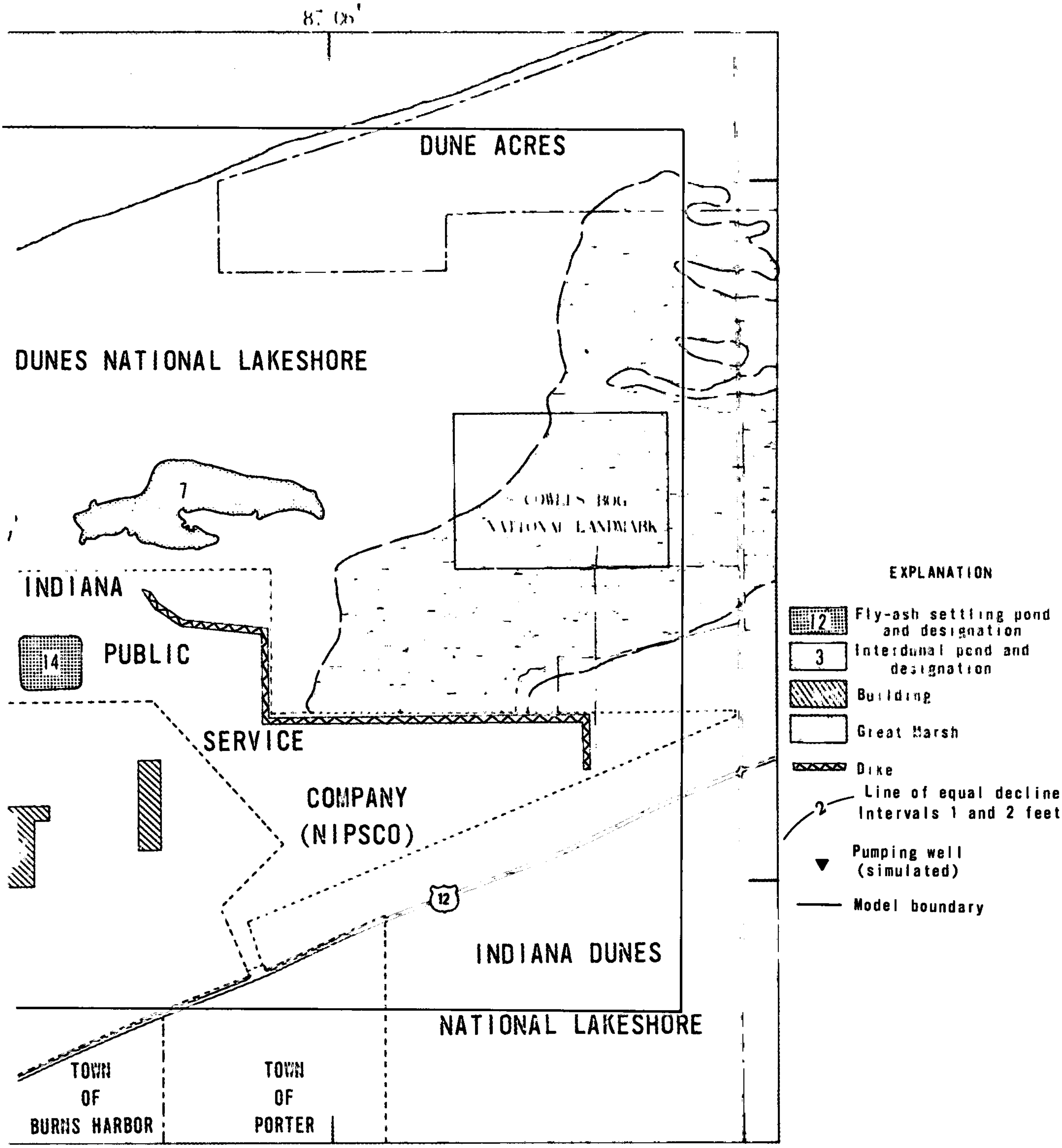
Pumping well (simulated)
Model boundary



Base from U S Geological Survey Dune Acres 1:24 000, 1968 1973 NIPSCO Map No. MS-150, by Sargent and Lundy and National Park Service November 1978

Figure 38.--Model-derived decline of the potentiometric surface in unit 3 due to construction dewatering for conditions simulated in experiment Z.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Intervals 1 and 2 feet
Pumping well (simulated)
Model boundary

SUMMARY AND CONCLUSIONS

The unconsolidated deposits underlying the study area consist of four distinct lithologic units, which, in descending order, are a tan, fine, well-sorted sand; a clay containing minor amounts of silt and sand; a gray, fine to medium sand; and a gray clay till. The total thickness of these deposits averages approximately 180 ft. Underlying the deposits are consolidated Paleozoic sedimentary rocks, which, in turn, overlie Precambrian granite.

Ground water in the unconsolidated deposits flows to Lake Michigan. Except in areas affected by man, the direction of movement is horizontally to the northwest and vertically upward. The uppermost consolidated formation is the Antrim shale, which should restrain any significant movement of water between the unconsolidated and consolidated rocks.

Seepage of water from the settling ponds used by NIPSCO for the removal of fly ash obtained from their coal-fired electric generating plants has created a mound on the ground-water system that, as determined from field data and a model analysis of the seepage, is approximately 15 ft above the natural water level immediately under the ponds. This mound has caused water in the immediate vicinity of the settling ponds to move downward into the lower sand unit (unit 3) and the water levels in this unit to rise 4 ft or less. The rate of seepage out of the settling ponds is at least 2.0 Mgal/day.

The rise in water levels caused by seepage in the upper sand unit (unit 1) within the National Lakeshore generally ranges from 10 ft to 1 ft in the study area. This rise has caused some areas that were formerly marshland to become interdunal ponds. Conversely, interdunal ponds in the study area would cease to exist if the seepage were stopped. The seepage has reversed the flow direction in the area immediately south of the ponds. Ground-water flow in the upper sand unit that was formerly northward is now generally southward.

To minimize the effect of dewatering associated with the construction of a nuclear powerplant on water levels in the National Lakeshore, NIPSCO installed a slurry wall around the excavation site. The slurry wall was installed to the top of the upper clay unit, except that in the southern area of the excavation site NIPSCO reports that the upper clay unit may be absent. The amount of water pumped from the excavation site by December 15, 1977, exceeded the original amount of water stored within the site by 7 to 14 times. In addition, NIPSCO reports that the corresponding water-level decline inside the site was only 8.5 ft, although they had expected a decline of 30 ft. These data indicate that either the slurry wall is leaking or that water is able to move upward from the lower sand unit through the clay unit into the upper sand unit, or both.

A multilayered digital ground-water flow model was constructed for the unconsolidated rocks to determine the effect of the seepage from the fly-ash settling ponds and the effect of the construction dewatering on ground-water levels in the National Lakeshore. Model results indicate that within the National Lakeshore the decline of water levels resulting from the construction dewatering would be 3 ft or less in the upper sand unit and 5 ft or less in the lower sand unit.

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