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A PRELIMINARY EVALUATION OF LAKE MICHIGAN "REEFS" IN ILLINOIS AS POTENTIAL BREEDING SITES FOR INDIGENOUS FISH SPECIES

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MAY 08 1978

Rodney D. Norby
Charles Collinson

U.S. DEPARTMENT OF COMMERCE NOAA
COASTAL SERVICES CENTER
2234 SOUTH HOBSON AVENUE
CHARLESTON, SC 29405-2413

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ILLINOIS STATE GEOLOGICAL SURVEY

for

THE ILLINOIS COASTAL ZONE MANAGEMENT PROGRAM

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A PRELIMINARY EVALUATION OF LAKE MICHIGAN "REEFS" IN ILLINOIS AS POTENTIAL BREEDING SITES FOR INDIGENOUS FISH SPECIES

Rodney D. Norby
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ABSTRACT

Bedrock "reefs", offshore gravelly areas and irregular till bottoms are suitable spawning grounds for lake trout in the Illinois portion of Lake Michigan. Fractured bedrock offers the best prospects whereas gravel and till are less attractive. Spawning grounds must be free from smothering suspended silt and clay as well as damaging wave surges. At the same time, bottom currents must be sufficient to oxygenate the wintering eggs. Oxygenating currents generally are more reliable on lake floor slopes.

The Green Lake strain of lake trout, presently used for stocking in Illinois, spawns at depths ranging between nearshore shallows and 150 feet. In Lake Michigan, depths must be greater than 30 feet to be relatively free from destructive wave surge. Suffocating sediment plumes, extending two to five miles lakeward, line the shore during storms.

Geophysical soundings, grab and core sediment samplings, remote sensing by satellite as well as field studies have identified broad areas in southwestern Lake Michigan that meet general requirements for breeding sites. The most attractive area extends from the Wisconsin border southward to Evanston at depths between 50 and 100 feet in a 3 to 7 mile-wide band centered 4 to 9 miles offshore. A less promising area, 10 to 13 miles wide, lies adjacent to and lakeward of the prime grounds. Rocky "reefs" with their broken blocks offer the best prospects for successful stocking and breeding of lake trout.

Spawning ground requirements for yellow perch are significantly less stringent than those for trout. Eggs of the yellow perch do not winter over on the lake floor. They are dropped in March or April and hatch in about three weeks. Relatively shallow areas which are protected from large waves and offer egg attachment surfaces on vegetation, rubble or debris are necessary. Such conditions exist all along the Illinois shore around wreckage, piers, riprap and rubble.

The present study continues in order to identify and describe specific breeding sites and to observe the performance of selected sites.

INTRODUCTION

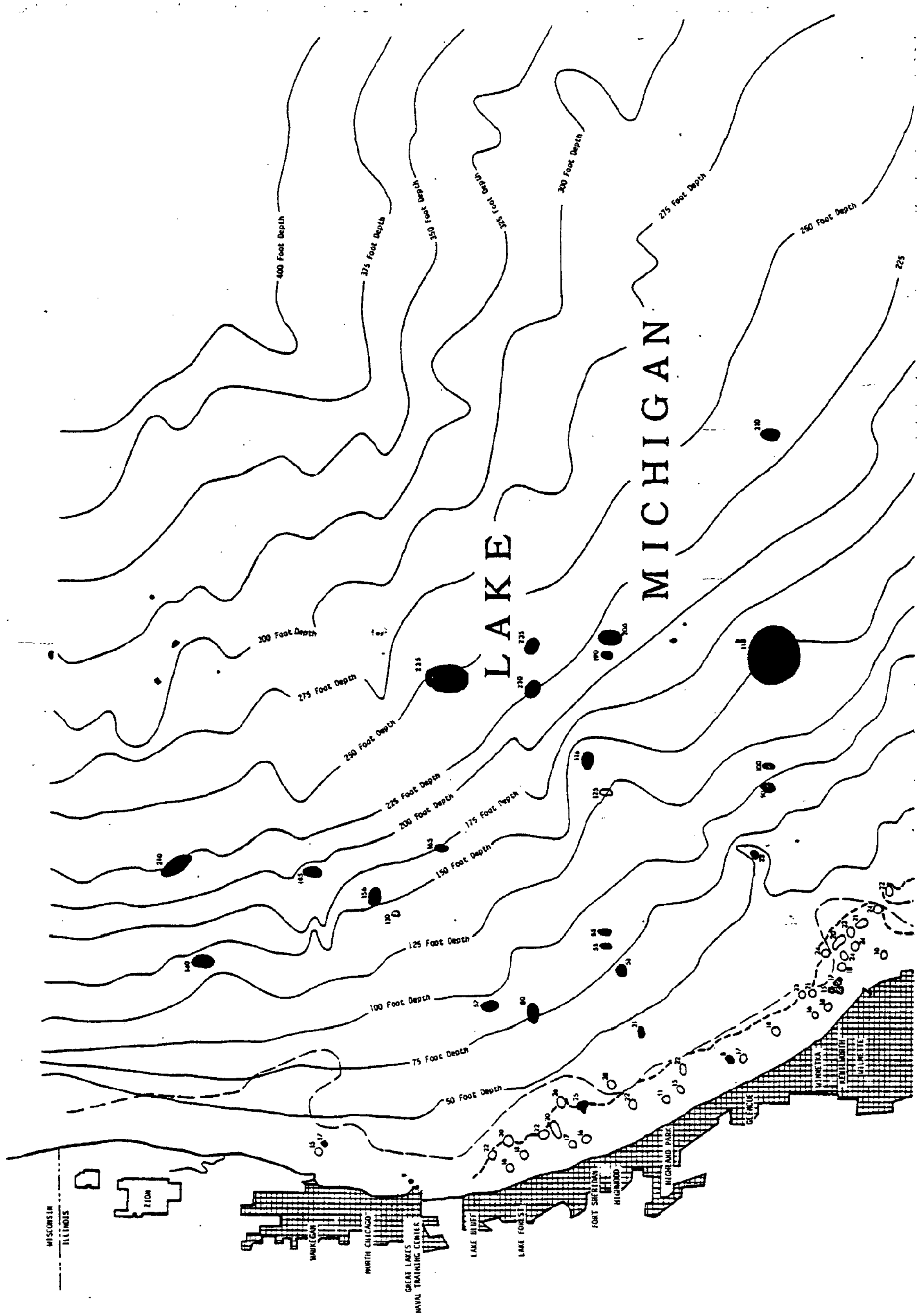
The need to reestablish and strengthen self-sustaining populations of sport and commercial fish species in Lake Michigan is widely recognized. Among the most desirable of species are the lake trout Salvelinus namaycush (Walbaum) and the yellow perch Perca flavescens (Mitchill), which once flourished in Great Lakes waters, but today are represented by non-reproducing and depressed populations. Prior to the decade of the fifties, lake trout were an important contribution to the stocks of commercial fish. By about 1955, however, lampreys decimated reproducing strains and removed the species from Lake Michigan. Perch, although not endangered, are a depressed population expected to recover normally in a few years but which may require stocking.

Only two strains of lake trout have been used for stocking in Lake Michigan. The Green Lake strain, a fat, deep-spawning, fast-maturing trout has been introduced to deep bare till bottoms in Lake Michigan. This restocking effort, conducted by the states of Michigan and Wisconsin, was begun in 1965 after the lamprey was brought under control. Wisconsin has planted yearling trout annually, but as of 1976 no natural reproduction had been noted (Becker, 1976). The Green Lake strain is not available at present, but a second available stock - the Lake Superior strain - is being introduced in Illinois waters by the Illinois Department of Conservation with the help of the International Great Lakes Fishery Commission and the U.S. Fish and Wildlife Service. The Lake Superior trout is a generalized stock that will spawn on bare rock bottoms almost up to shoal level. It spawns between mid-October and early November. The eggs winter over in rock fissures or clean gravel, and hatch in March. The stock requires seven years to reach maturity and spawning age. The fish live mainly on the bottom, feeding on smaller fish. Their optimum temperature is 7-8°C when they are immature; 10°C when they are mature.

The trout eggs require silt-free areas with sufficient water circulation for oxygenation. Because the trout are strew spawners, it is important that protective depressions such as cracks, crevices, and holes provide protection from predators and destructive water surges. In general the eggs should lie more than 30 feet deep in order to survive the effect of winter storm waves.

Perch are hardier than lake trout in being able to survive low oxygen levels. Perch prefer warm water (19°- 21°C) and commonly inhabit shoal waters. Eggs are laid in long gelatinous strings. The incubation period is relatively short - about three weeks - with hatching in April or early May. The eggs generally are attached to vegetation, submerged structures or rubble.

The purpose of the present study, which begins a major program, is to examine the lake floor and circulation of Lake Michigan in Illinois and identify areas that may best serve as spawning grounds and thereby provide favorable stocking locations. For this purpose, we have used extensive geophysical, hydrographic and sedimentologic records of the Illinois Geological Survey as well as LANDSAT remote imagery, low-level aerial photography, and field examinations. It is anticipated that this general introductory phase of the study will be followed by specific site identification and description.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350 Foot Depth
325 Foot Depth
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275 Foot Depth
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225
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125 Foot Depth
100 Foot Depth
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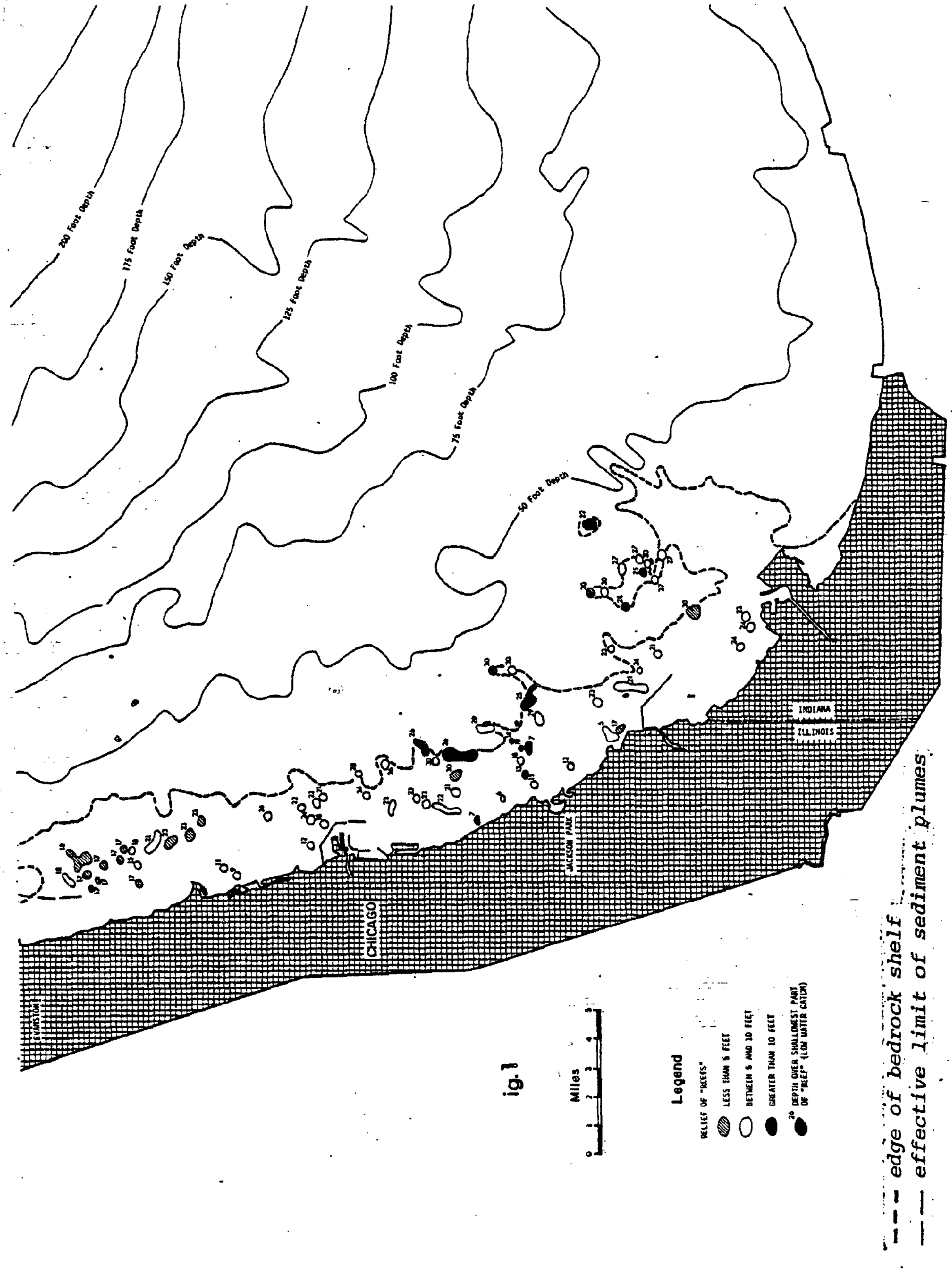
50 Foot Depth
WISCONSIN
ILLINOIS
ZION
WAUKEGAN
NORTH CHICAGO
GREAT LAKES NAVAL TRAINING CENTER
LAKE BLUFF
LAKE FOREST
FORT SHERIDAN
HIGHWOOD
HIGHLAND PARK
GLENCOE
WINNETKA
KENILWORTH
WILMETTE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0 1 2 3 4 5
Legend
RELIEF OF "REEFS"
LESS THAN 5 FEET
BETWEEN 5 AND 10 FEET
GREATER THAN 10 FEET
DEPTH OVER SHALLOWEST PART OF "REEF" (LOW WATER DATUM)
edge of bedrock shelf
effective limit of sediment plumes

ACKNOWLEDGEMENTS

A number of colleagues contributed to this report. Especially important information has been given by Dr. Ross Horrall of the University of Wisconsin (Madison) Marine Studies Center, who summarized the spawning requirements, history and present status of lake trout in the Great Lakes in a conference designed for that purpose. Jerry Wickham, a graduate research assistant at the Illinois State Geological Survey, made a preliminary survey of geophysical information for the authors and plotted reef and profile locations. Charlene Anchor, Sergio Estenssoro and Janet Marks prepared the illustrations.

Geophysical data were derived from ship logs and geophysical records from the June 1970 and July 1971 cruises of the University of Michigan Research Vessel INLAND SEAS on which Drs. D. L. Gross and J. A. Lineback were geological scientists in charge and Dr. R. P. Meyer was geophysical scientist in charge. The geophysical profiles were made by personnel from the University of Wisconsin (Madison) Geophysics and Polar Research Center.

Fig. 2 - Oblique aerial photography showing sediment plumes along the Lake Michigan shore. The plume in the center of the picture extends out 2500 feet from the Great Lakes Naval Training Center shore. Another plume in the upper right extends out from Waukegan Harbor.

DESCRIPTION OF POTENTIAL SPAWNING GROUNDS

The Illinois portion of Lake Michigan appears to contain numerous potential fish spawning grounds. Favorable areas include rocky "reefs" gravel and/or cobble bottoms, and bare till bottoms. The word "reef", as used in this report, is defined as a ridge or area elevated above the surrounding lake bottom, composed of sand, till or rock. Figure 1 shows the location of many known reefs. The reefs are classified according to their relief above the surrounding lake bottom. The number on the map beside the reef indicates water depth in feet above the shallowest part of the reef at low water datum, I.G.L.D.

In general, most of the reefs in the Illinois waters of Lake Michigan are bedrock exposures of the Racine Formation which is predominantly a pure dolomite rock. The bedrock reefs in most cases are fossil reefs that formed during the geological Silurian Period. The structures were formed by an accumulated build-up of debris and skeletal remains from a variety of marine animals. Not all of the nearshore reefs shown on figure 1 have been verified as bedrock, some may be till or sand and gravel mounds that may or may not be associated with bedrock structures. All offshore reefs illustrated on figure 1 are bedrock but in some cases a thin layer of till or other sediments may cover the bedrock.

The reefs in general are subcircular in shape with irregular margins. The size varies from about 100 feet to 2½ miles across. The size and configuration of many shown on figure 1, particularly those offshore, are only approximations. The configuration of the top of any of these reefs is not known precisely, but fathometer and geophysical profiles show many to have an irregular ridge-shaped cross-section, while others appear to be round or flat with 1- to 2-foot irregularities. Most reef tops are probably deeply fissured and fractured. The relief above the lake floor of the reefs ranges from a few feet to about 50. Fractured rock and other irregularities provide excellent protection for the fish during spawning as well as protection for the eggs during the incubation period.

The reach of lake bottom between the Wisconsin state line and Lake Bluff shows two small reefs (presumably till over bedrock) near the entrance of Waukegan Harbor and one near Great Lakes Naval Training Center Harbor. All are in depths between 20 and 25 feet. Five larger bedrock reefs occur farther offshore between Zion and Lake Bluff. Depths of 30 feet or less, are subject to severe storm wave surge and sediment movement in Lake Michigan. Surges commonly destroy eggs that are scattered unprotected by lake trout on bare bottoms in shallow water. In addition, sediment movement along the bottom as well as silt and clay settling out of sediment plumes may smother eggs during their long incubation period. Plumes may extend 10 miles or more lakeward during storm episodes. Generally, however, the highest turbidity lies within two or three miles of the shore. Figure 2 is an aerial photograph showing sediment plumes extending lakeward from the Great Lakes Naval Training Center and Waukegan Harbor. These plumes impinge upon nearby nearshore reefs. The thin dashed line shown on figure 1 indicates the outer limit of high to moderately high turbidity along the southwestern shore of Lake Michigan. The term, "high turbidity" is only qualitative as composition and quantity

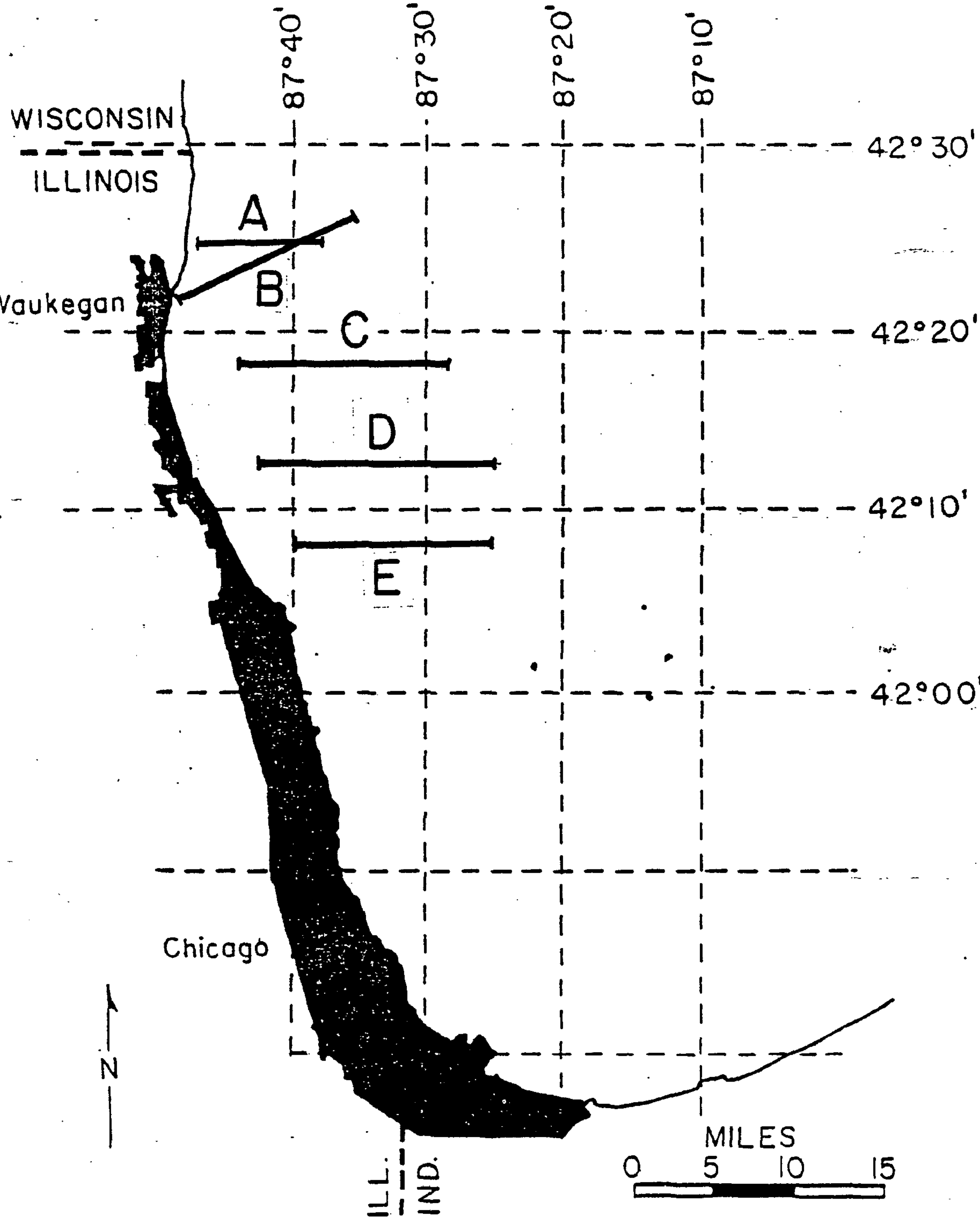

Figure 3 - Index to geologic cross-sections (figure 4) and seismic profiles (figures 6-10) of southern Lake Michigan.

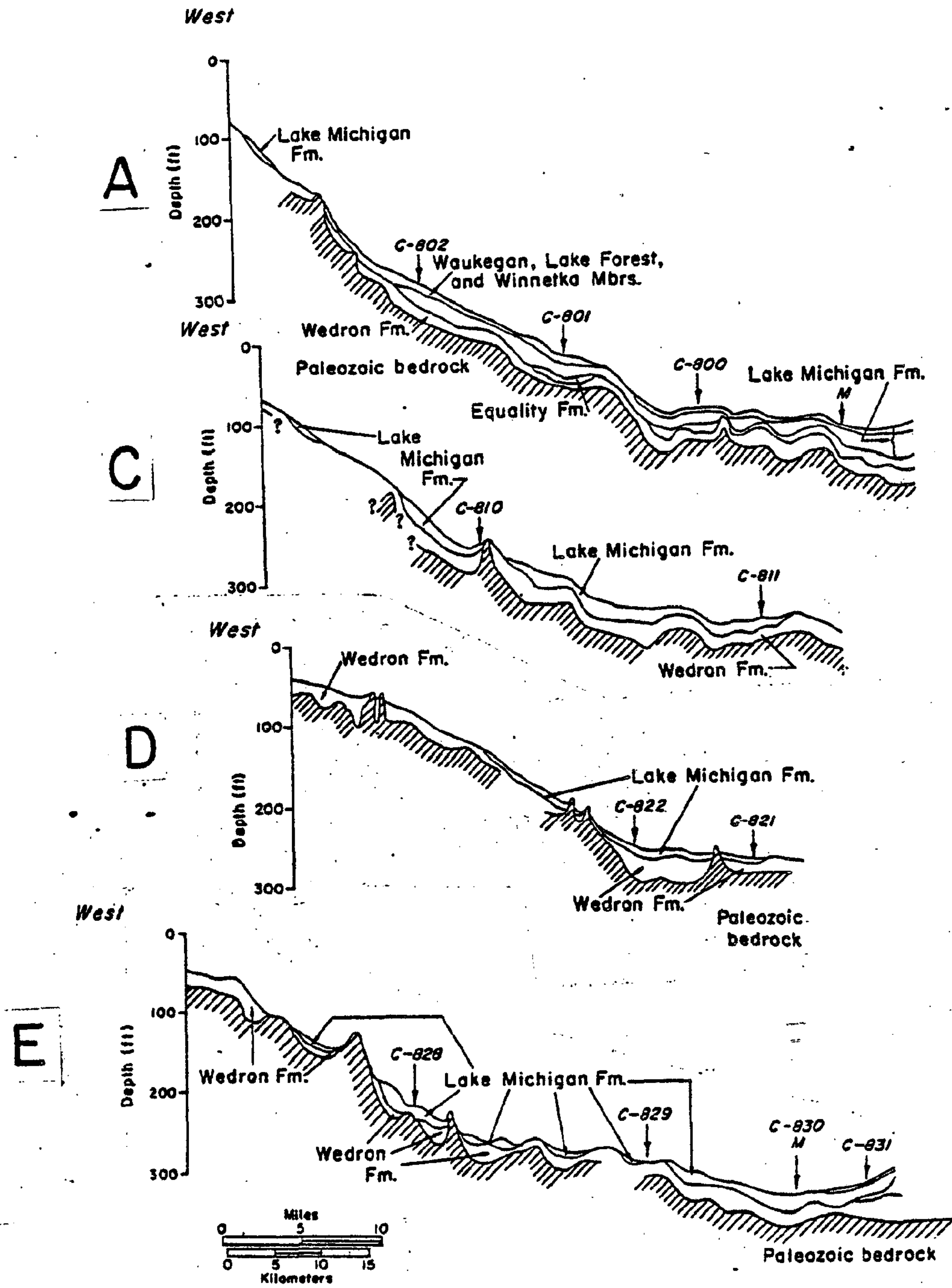

Figure 4 - Generalized geologic cross-sections showing sediments underlying the southwestern portion of Lake Michigan. Figures 6 to 10 show the seismic profiles for these cross-sections. All cross-sections were modified from figures 4 and 5 of Lineback and others (1972). Figure 5 illustrates the nomenclature of the geologic units involved.

Series	Stage	Substage	Fm	Member	Description
PLEISTOCENE SERIES	HOLOCENE STAGE		Lake Michigan	Ravinia Sand	Sand on beaches
				Waukegan	Dark gray silt and silty clay; silty sand
				Lake Forest	Gray clay, black beds and mottling
				Winnetka	Brownish gray clay, some black beds and mottling
	WISCONSINAN STAGE	VALDERAN SUBSTAGE		Sheboygan	Reddish brown clay
				Wilmette Bed	Dark gray clay
					Reddish brown clay
				South Haven	Reddish gray clay
			Equality	Carmi	Gray and reddish gray clay, silt, sand, clay-pebble conglomerate
			Unnamed	Two Rivers Till	Reddish brown silty clayey till
		TWOCREEKAN SUBSTAGE			No deposits found
		WOODFORDIAN SUBSTAGE	Wedron	Manitowoc Till	Brown to reddish brown silty clayey till
				Shorewood Till	Reddish gray to pinkish gray silty clayey till
				Wadsworth Till	Gray silty clayey till

Fig. 5 - Late Pleistocene sediments underlying southern Lake Michigan. The Shorewood and Wadsworth Tills underlie much of the offshore areas. The younger units represent lacustrine silt and clays.

of sediment in a plume has not been adequately studied. This line is a composite determined from LANDSAT satellite photographs for 32 days between August 1972 and October 1974 (Lineback and Collinson, 1975). Reefs shoreward from this line would make unsuitable spawning grounds for many fish species due to high turbidity and wave action.

The reefs east, northeast, and southeast from Waukegan (figure 1) lie in about 130 to 220 feet of water and may be potential spawning grounds for fish that prefer breeding at these depths. The nearshore area for this reach is covered by a thick accumulation of sand, particularly north of Waukegan where it may extend out to 50 to 60-foot depths. South of Waukegan the sand commonly ends near the 30-foot depth. The remainder of the bottom is floored by till with some patches of lag gravel.

Between Lake Bluff and Wilmette, many reefs have been identified in depths shallower than 30 feet. They are particularly numerous along the Wilmette shore. Most of these reefs have a relief of 10 feet or less. The heavy dashed line on figure 1 outlining the outer edge of this reef zone closely corresponds to the 30-foot depth contour. Reefs exist beyond 30 feet but in most cases are not as clearly defined. Some, particularly along the Highland Park and Glencoe shores, lie only a few feet below the water surface and a few hundred feet offshore. Many are small and are not shown on figure 1. In the same area, an extensive bedrock plain or slope with 1- to 2-foot irregularities extends along the shore for several miles at depths between 20 and 30 feet. Sand in this area is generally limited to depths of 20 feet or less, but in places it may extend out to 30 feet or more. Gravel bottoms are present in irregular patches in the nearshore zone, while till bottom, silts and clays cover much of the offshore zone, particularly in the Wilmette area.

Offshore from Lake Forest, Highland Park and Wilmette several reefs are known at various water depths. Two reefs due east of Lake Forest occur in depths of about 75 feet and have between 10 and 20 feet of relief. In depths of 175 and 250 feet, two additional reefs are present; the reef at 250 feet is over a mile wide off Highland Park, four reefs are present at moderate depths; one occurs in about 35 feet of water; the others in 60 to 70 feet. These reefs have between 10 and 20 feet of relief. Farther offshore from Highland Park, five additional reefs can be found in water depths of 120, 130, 210, 230 and 250 feet, respectively, with relief of more than 10 feet for most. Five reefs occur east and northeast from Wilmette. One of these is in about 50 feet of water and has a relief of about 30 feet. This particular reef was utilized as the stocking site for yearling lake trout in July 1977. Two other reefs are low-relief bedrock protrusions in about 100 feet of water. The fourth reef with a known dimension of two miles is in 150 feet of water with nearly 40 feet of relief. The fifth lies at a depth of 230 feet and has about 20 feet of relief.

From Evanston to the Indiana state line, numerous reefs are present in the nearshore zone in depths of thirty feet or less. Most have low relief but some off the southern part of Chicago have relief in excess of 10 feet. No offshore reefs in depths between 40 and 200 feet are definitely known in this area but geophysical information does not adequately cover this reach of the lake. It is believed, however, that offshore bedrock reefs are probably present but less numerous than in the area north of Wilmette.

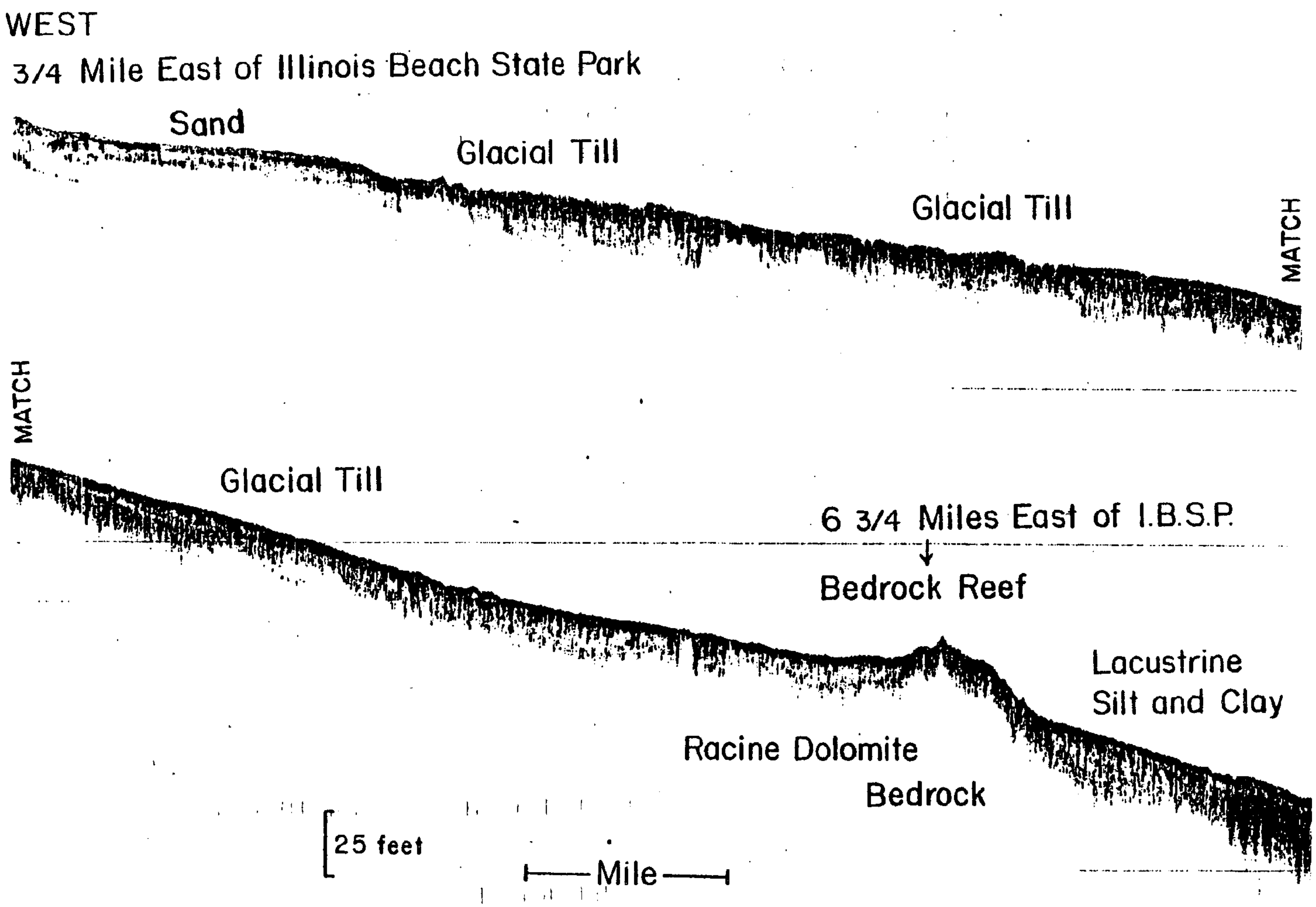

FIG. 6

Fig. 6 - Seismic geophysical profile extending due eastward from Illinois Beach State Park (just north of Dead River) for 8 1/2 miles. A sand apron extends 2 1/2 miles offshore beyond which hummocky glacial till floors the lake as far as a bedrock reef 6 3/4 miles offshore. The irregular glacial till and the irregular reef surface represent potential spawning surfaces.

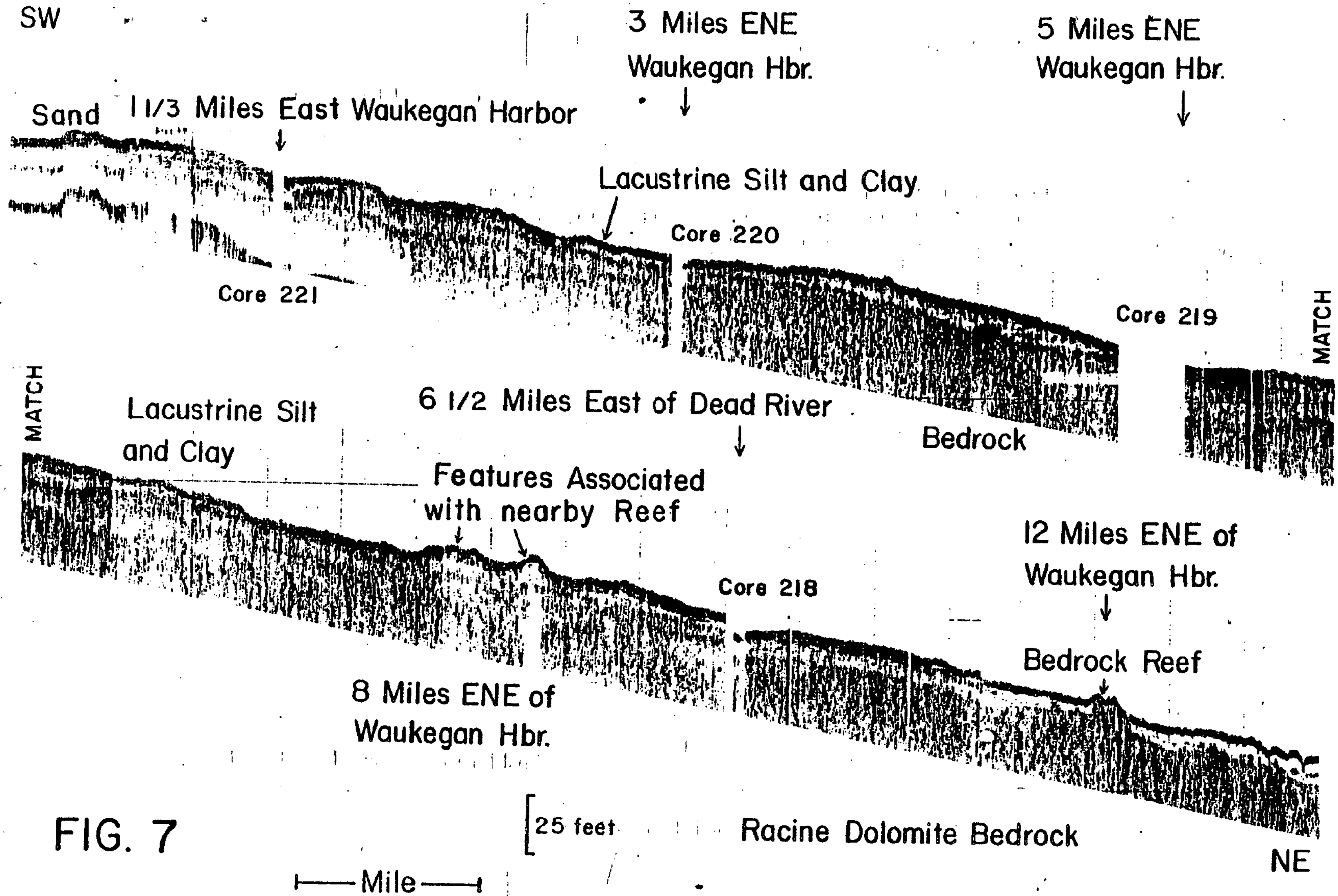

FIG. 7

Fig. 7 - Seismic geophysical profile extending east-northeast from a point 1 1/3 miles east of Waukegan Harbor. An apron of sand covers the floor lakeward a half-mile beyond the Core 221 location. Lacustrine silt and clay (light and dark layers) line the lake floor eastward to depths greater than 400 feet. The relatively smooth lake floor is broken by scattered low reef-related hummocks.

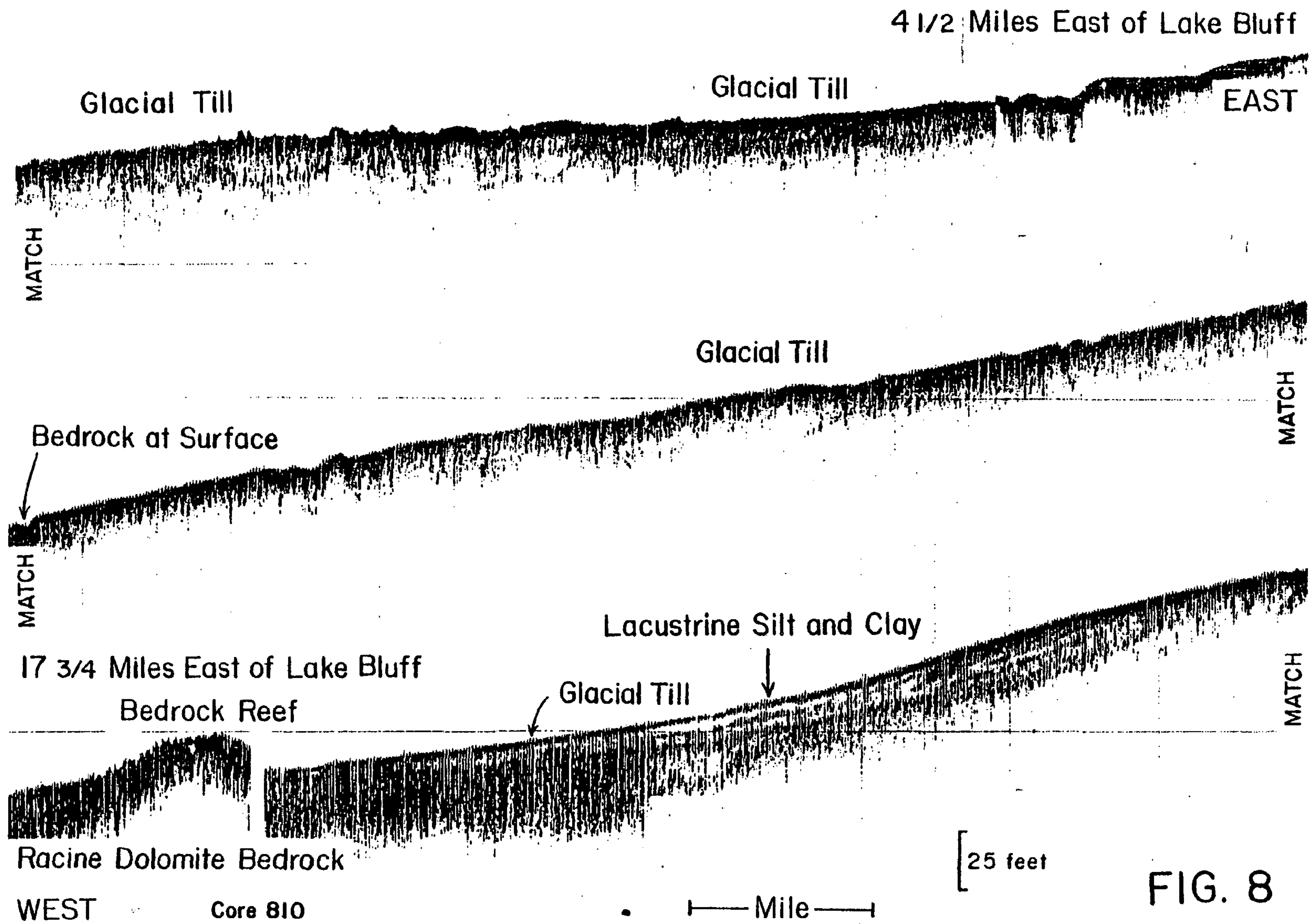

FIG. 8

Fig. 8 - Seismic geophysical profile extending eastward from Lake Bluff (just south of Shore Acres Country Club). The profile mainly represents a glacial till slope on the upper part of which bedrock projections cause low hills and mounds. The middle slope, which is on glacial till, is quite smooth whereas the smooth lower slope overlies lacustrine silt and clay. A bedrock dolomite reef about a mile across projects 20 feet above the lake floor on the lower slope.

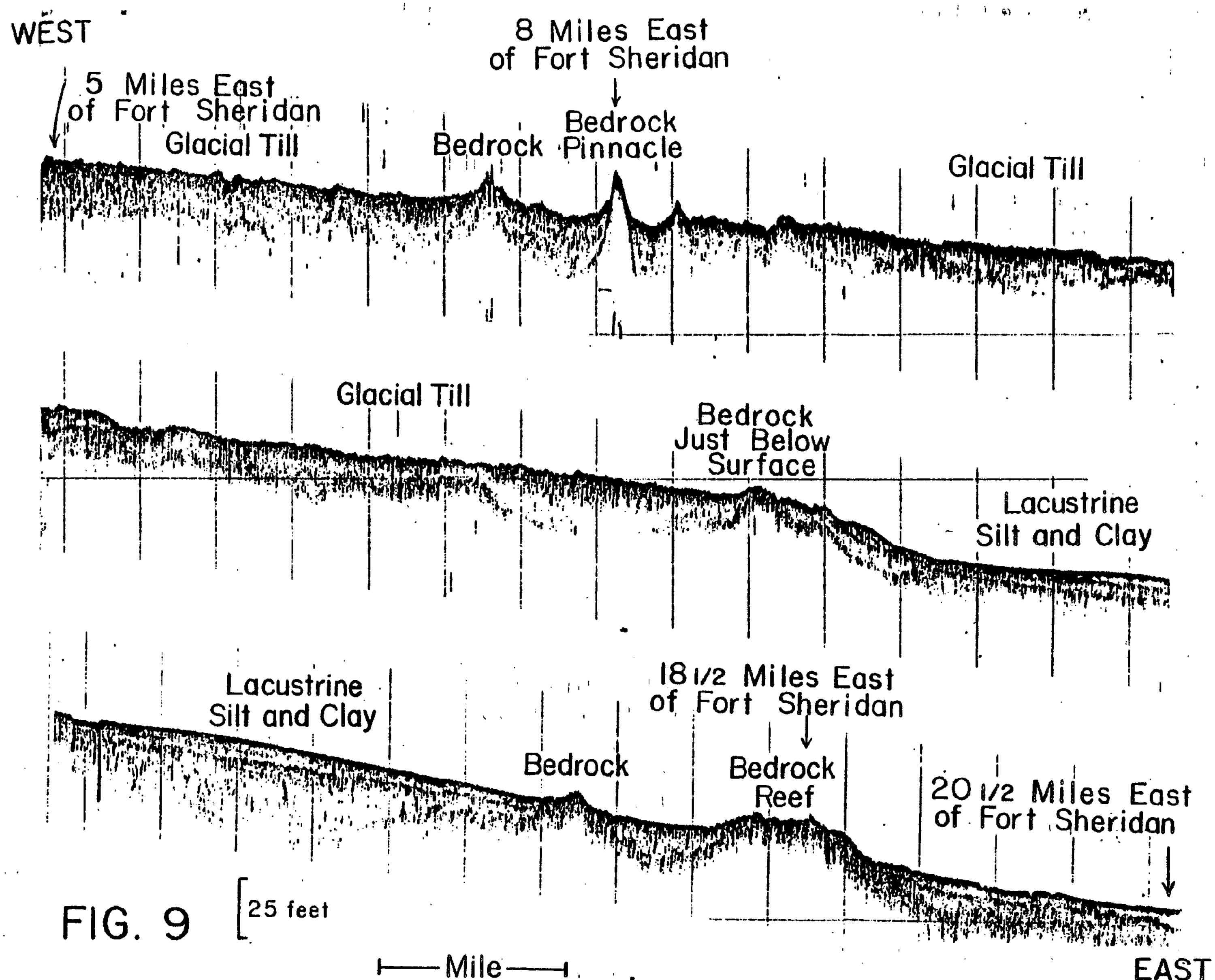

FIG. 9

Fig. 9 - Seismic geophysical profile extending due east from Fort Sheridan. An irregular till plain, broken by small distinct bedrock reefs, extends 5 to 10 miles from the shore. From there the lake is floored by smooth surfaced lacustrine silt and clay pierced by scattered low broad bedrock reefs.

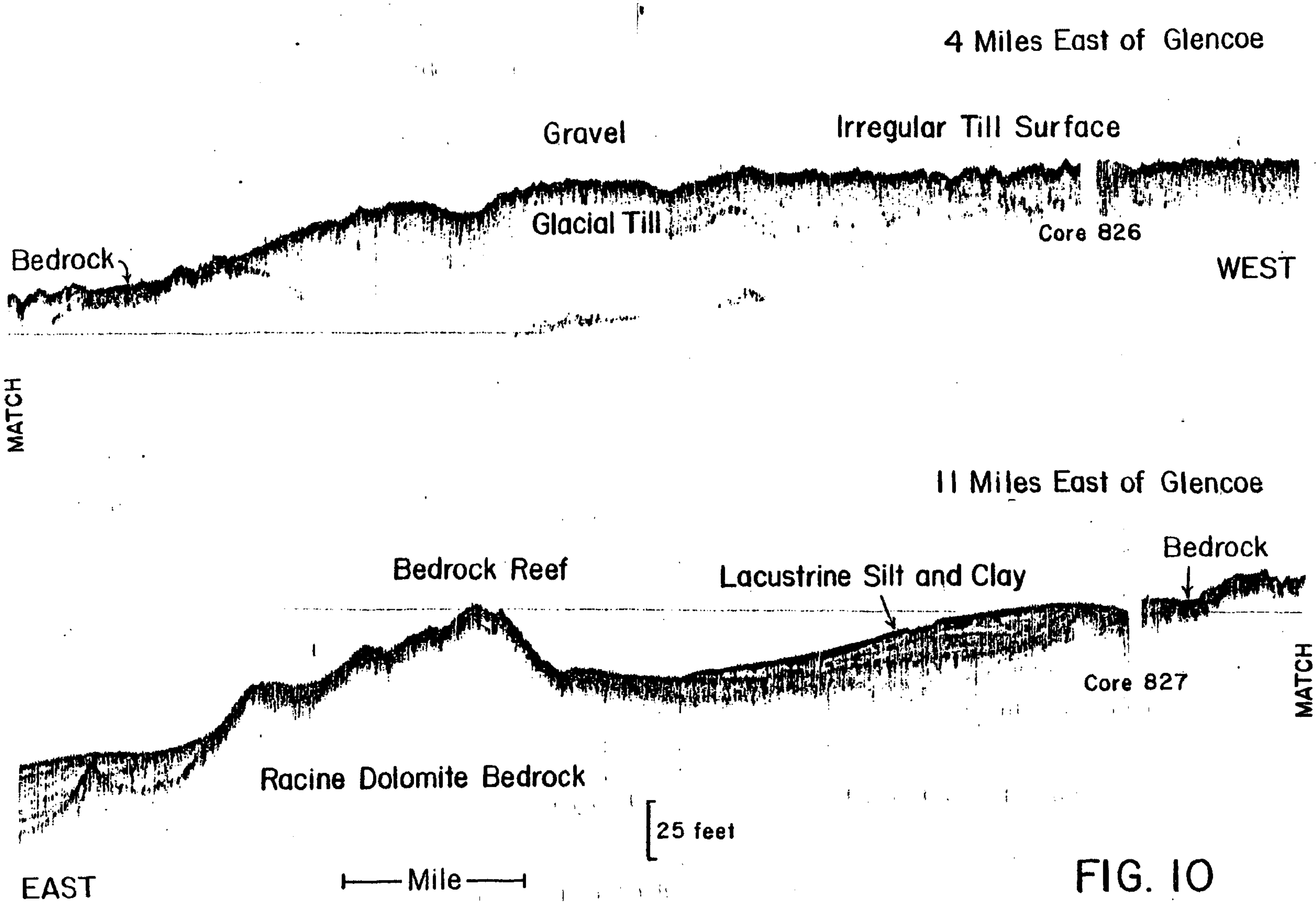

FIG. 10

Fig. 10 - Seismic geophysical profile extending due east from Glencoe (Dundee Road). The profile shows a bedrock reef as well as bedrock in the lake floor. The irregular upper surface of the Wadsworth Till covers the area nearest the shore whereas the smooth surfaced lacustrine silt and clay of the Lake Michigan Formation covers the areas near the reef. Fig. 3 shows the profile location. Fig. 4 shows an interpretive geologic cross-section.

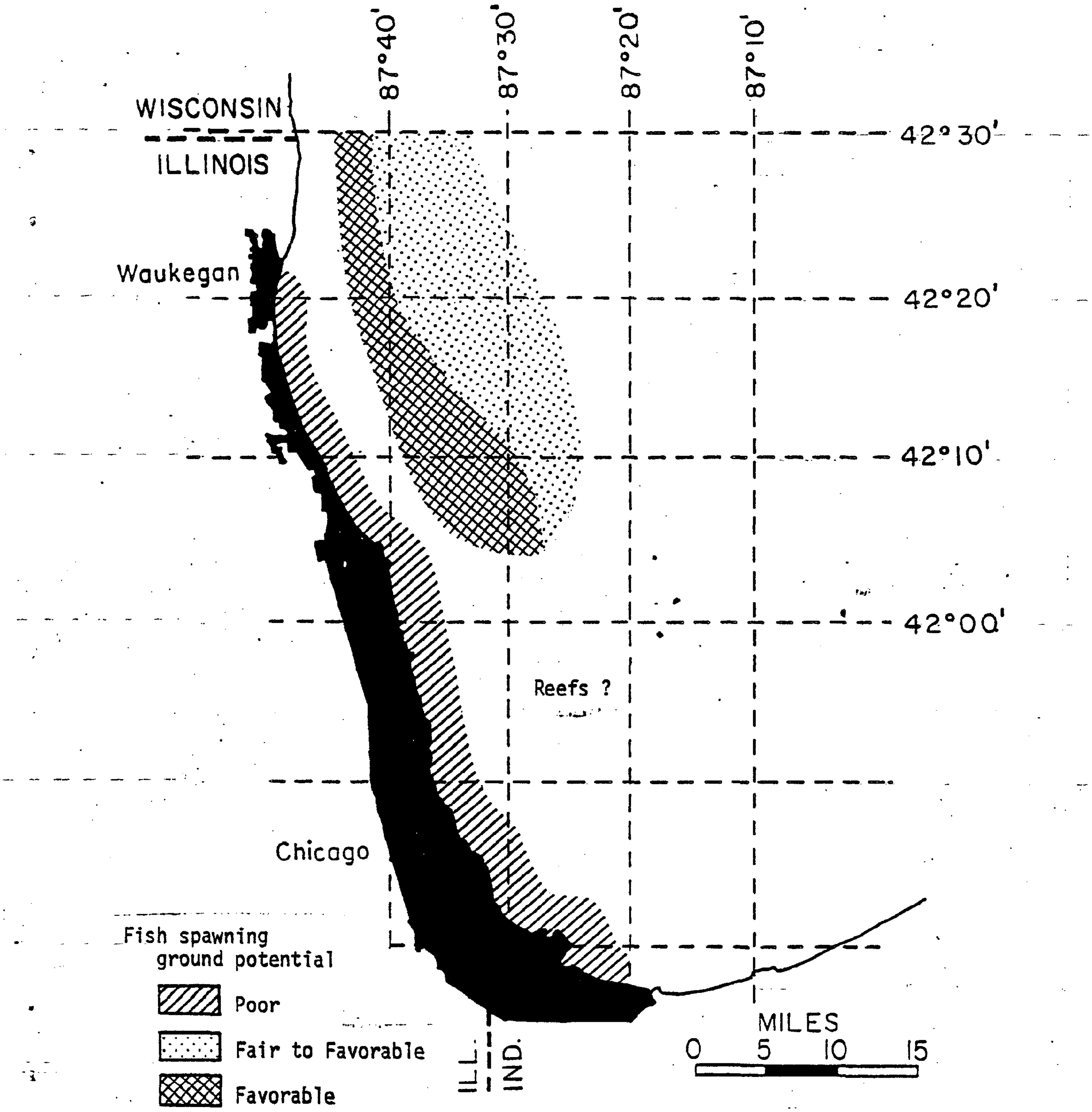

Figure 11. - Map showing approximate location of potential fish spawning grounds, primarily with respect to lake trout.

Patches of gravel are present at irregular intervals on the lake bottom along the entire Illinois shore of Lake Michigan. This bottom-type should provide excellent spawning grounds for lake trout as the pore space between the gravel particles would provide excellent protection of the trout eggs. Gravel bottoms are commonly present as lag concentrates formed by the winnowing action of waves. Most gravel bottoms occur in depths of 30 feet or less where they are subject to wave and current action. Because lake trout need seven years to reach spawning age, gravel bottoms could be covered by sand or silt between the time of stocking and spawning. More desirable bottoms occur in deeper water and can be most easily located by grab sampling. The Illinois Geological Survey has identified gravel deposits at about the 30-foot depth at several successive sampling stations east of Evanston.

Bare till probably represents the most common bottom sediment type in the Illinois waters of Lake Michigan. The till is very compact and provides surface irregularities that may be sufficient to give protection to eggs. Areas showing irregularities have been noted on geophysical profiles. Nevertheless, specific sites would require individual examination by underwater photography or by scuba observation.

GEOPHYSICAL AND SEDIMENTOLOGIC DATA

Seismic profiles have provided information useful in locating offshore bedrock reefs for use as potential fish spawning areas. Figure 3 shows the geographic locations of several profiles used to determine the reef locations and sizes shown in figure 1. Figure 4 shows an interpretive geologic cross section of four of the five seismic profiles (figures 6-10). Figure 5 is a geologic column of sediments identified from seismic profiles with the aid of sediment cores.

Utilizing the interpretive geologic cross sections and sediment core data the following picture of the lake floor can be made. Sediments of the lake floor consist of littoral and sublittoral sand nearshore with spotty patches of gravel and sand near the edge of the bedrock platform at depths of 25 to 30 feet. In areas where sand and gravel are absent, tills and soft silts are present. Beyond 30-foot depth, till is prevalent on the gentle lake bottom slope but is succeeded by the lacustrine silt and clay of the Lake Michigan Formation at depths of 200 feet where the gentle slope flattens into a smooth lake plain.

The lake slope between depths of 50 and 100 feet commonly is surfaced with gravel derived from the underlying tills or from prehistoric low lake level stands. In some places the floor consists of compact glacial till which may be ridged and irregular. The lower lake slopes at depths of about 200 feet are commonly veneered with layers of soft lake clays and silts which form an exceedingly smooth and featureless surface. Since nearly every available seismic profile for the reach north of Wilmette showed bedrock reefs, it is believed that additional reefs would be discovered if a geophysical survey were conducted with closely-spaced seismic profiles. Only a few seismic profiles are available for the reach of lake south of Wilmette to the Indiana state line. These profiles showed no bedrock reefs, although bedrock could be identified just a few feet below the lake bottom surface at several places. Therefore it is likely that bedrock reefs would be found offshore from Chicago if additional geophysical surveying were run.

POTENTIAL SPAWNING GROUND LOCATION

An analysis of lake floor geology, bathymetry and sediment movement indicates that several areas have varying degrees of potential for fish spawning (figure 11). The area most favorable for lake trout spawning is shown by crosshatching. This area contains numerous reefs in water depths of 50 to 100 feet, and is relatively free from suspended sediment. A second area, adjacent to the first (shown by the open stippled pattern of figure 11), has a fair to favorable potential for fish breeding. Several bedrock reefs are present and the water depths range between 100 and 200 feet. The near-shore reef area is indicated on figure 11 by the diagonal lines. This area is considered poor for lake trout spawning due to potentially high wave surges and turbidity. For other species, such as yellow perch, breakwaters, piers, rubble, etc., may provide sufficient protection for spawning. The usefulness of the remainder of the Illinois portion of Lake Michigan as potential fish breeding areas is questionable and cannot be adequately evaluated at the present time.

CONCLUSIONS

Where reefs on the lake floor exhibit fractured, rough textured, rubbly or gravelly surfaces they offer excellent protection and spaces for lodgement of trout eggs which must winter over on the lake floor between late October and the following March. Reefs lying in nearshore waters at depths of 30 feet or less do not provide favorable spawning grounds inasmuch as wave surges dislodge and scatter the eggs. Seismic profiles indicate that scattered bedrock projections and till-covered bedrock reefs are present on the lake slope between 50 and 200 feet. These reefs below the limit of wave action offer adequate protection for trout eggs.

Clean gravel, rubble, and rough till bottoms provide surfaces for potential egg attachment but do not offer as much protection as some reef areas.

Plumes of suspended sediment are generated by wave storms that send them several miles into the lake. The outer reaches of such plumes carry only the finest sediment, whereas amounts sufficient to affect fish eggs lying on the bottom occur in a belt two to four miles wide extending along the entire shore.

Optimum depths for lake trout breeding are between 50 and 100 feet. These depths lie 2 to 7 miles offshore at Winthrop Harbor on the north, 4 to 8 miles offshore at Wilmette, and 6 to 16 miles offshore at Jackson Park in Chicago.

The bottom slopes rather rapidly and uniformly from the Wisconsin state line south as far as the Great Lakes Naval Training Center. From there southward a shallow, less than 30 feet, bedrock-supported platform 1½ miles wide at Lake Forest, 2½ miles wide at Wilmette and 4 miles wide off Evanston and south Chicago, provides shallow water breeding places for yellow perch on bedrock, vegetated bottoms, piers, breakwaters, and rubble bottoms.

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Illinois State Geological Survey

Recreation Capacity of Beaches and Bluffs, Illinois Lake Michigan Shore

ILLINOIS COASTAL ZONE MANAGEMENT DEVELOPMENT PROJECT

RECREATION CAPACITY OF BEACHES AND BLUFFS, ILLINOIS LAKE MICHIGAN SHORE

Richard C. Berg
Cynthia A. Morgan
Charles Collinson

Prepared by the

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MANAGEMENT PROGRAM

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OCTOBER 1977

RECREATION CAPACITY OF BEACHES AND BLUFFS, ILLINOIS LAKE MICHIGAN SHORE

Richard C. Berg
Cynthia A. Morgan
Charles Collinson

ABSTRACT

The increased recreational use of the Illinois shore has created pressures on a delicate lake shore environment. Studies have shown that slight increases in lake level or minor climatic changes can lead to serious erosion of both beaches and bluffs. This report classifies the shoreline according to the recreational potential of specific sites, based on existing shore conditions. Beach and bluff conditions were observed in the field and on low-level oblique air photos.

Air photos dated 1964 and 1973, representing the years of the extreme low and high lake levels, respectively, were studied to observe the changes of the beach and bluff zone with fluctuating water levels. This provided insight as to potential recreational capabilities along the shore.

The 30 miles of beach from the Wisconsin line to Evanston (excluding federal lands) include 37 per cent not suitable for any recreational use, 18 per cent suitable for limited use, 9 per cent suitable for moderate use, while 35 per cent is suitable for heavy use.

The 16 miles of high bluff from North Chicago to Wilmette (also excluding federal lands) are 17 per cent publicly-owned stable bluffs suitable for moderate use, 39 per cent privately-owned stable bluffs suitable for limited use, 18 per cent showing evidence of incipient instability and not suitable for use, and 26 per cent characterized by severe erosion, not suitable for any use. Lake Bluff (with 70 per cent of its bluff severely eroding) has the largest combined total of shoreline not suitable for any use.

INTRODUCTION

The beaches, bluffs and nearshore shallows represent a resource that balances between natural stability or instability on one side and human uses on the other. In the course of detailed geologic studies of the shore it has been possible to assess the relative durabilities of the bluff and beach areas as they are affected by weather, climate, lake fluctuations and human impact. The present report represents a summary of suggested limits derived from these studies.

Slight changes in lake level or climate, or a single damaging wave storm can cause serious erosion of both beaches and bluffs (Berg, 1977; Berg and Collinson, 1976; Norby and Collinson, 1976). A one-foot rise in lake level significantly reduces beach widths, which in turn allows for a greater frequency of wave impact at the base of bluffs. A slight seasonal increase of rainfall or the number of freeze-thaw days increases bluff face erosion and the potential for slump block erosion. Lastly, frequent wave storm days increase the potential for erosion. A single storm in 1973, for example, caused over 130 feet of shoreline beach recession along a reach at Illinois Beach State Park.

This report, including a series of 33 maps extending from the Wisconsin-Illinois border to Northwestern University in Evanston (Fig. 1), evaluates the usefulness of shore reaches for both public and private recreational purposes. All federally-owned bluffs and beaches are excluded from the study. Through field work over the last three years and examination of low-level oblique photographs dated June and July 1977, it was possible to observe existing beach and bluff conditions. Based on known physical restraints on the shoreline and rates of bluff and beach erodibility, the shoreline was classified into site-specific recreation potential reaches, which indicate the maximum use that a shore reach should sustain at any given time.

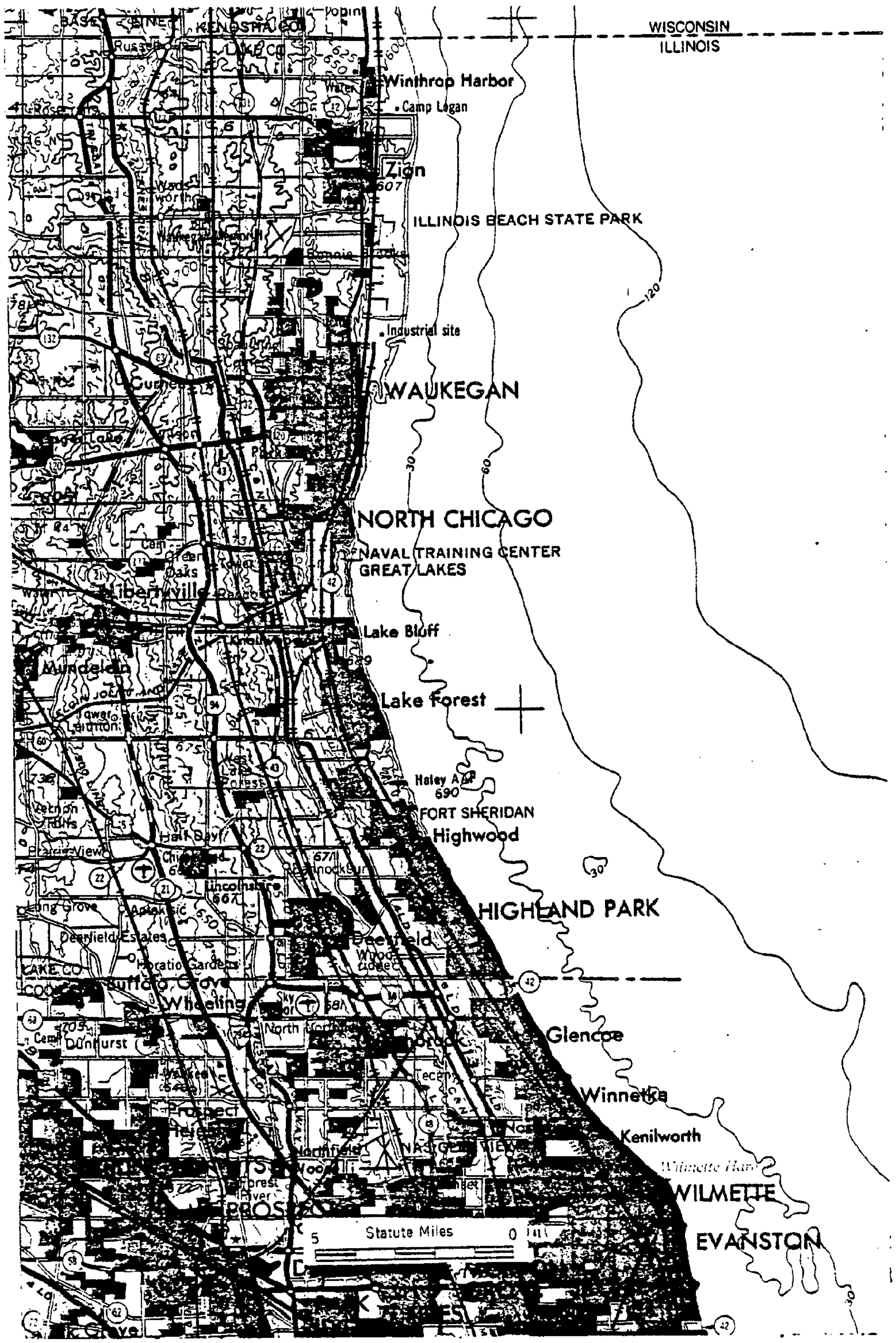


Fig. 1 - Location map showing the Illinois shore of Lake Michigan-
Wisconsin state line to Evanston.

CLASSIFICATION OF BEACH AND BLUFF

The following classification was used to zone beaches into types of potential recreation areas:

1. Beaches suitable for heavy general use include only facilities that have been designated by the state or a municipality as a public beach. This category includes much of the beach at Illinois Beach State Park and the Illinois Beach Nature Preserve as well as numerous facilities between Waukegan and Evanston (Fig. 2). Characteristically these beaches are wider than 20 feet, usually in excess of 100 feet, are sandy throughout from either natural or artificial replenishment, and are adequately accessible. The beaches may or may not be protected by shoreline structures, and a stable bluff back of the beaches is present.

2. Beaches suitable for moderate general use include those public beaches where the beach width is less than 20 feet, and hence are unable to accommodate numerous users, as well as all private beaches with average widths greater than 20 feet (Fig. 3). The private beaches must be sandy, with little rubble. In all cases, a stable bluff is present back of the private beaches, and the beaches are protected from wave attack by groins or a seawall. They may or may not be readily accessible from inland locations. The moderate restrictions placed on use of private beaches is to discourage overuse of the beach and the bluff back of the beach by land owners, and also to discourage use of private facilities by outside interests.

3. Beaches suitable for limited use include only private beaches less than 20 feet wide, commonly composed of coarse-textured materials (Fig. 3). Beach use should be restricted to facilities for docking boats and limited swimming. These beaches are commonly at the base of an unstable bluff, and in many cases are not protected by shoreline structures.

4. Beaches unsuitable for recreation may be either public or private and are generally those where a danger is imminent in the form of nearby offshore, nearshore or onshore hazards, all of which impair general use of the beach for swimming or boat moorings (Fig. 4). There is no width requirement, although most recreationally unsuitable beaches are narrow, particularly where a seawall or bluff abuts the lake, resulting in no usable beach (Fig. 5). Commonly these beaches are backed by an unstable bluff that is eroding.

Bluffs, unlike beaches, regardless of their degree of stability, can never support recreational use. If a bluff is stable, groundwater seepage, steep slopes and vegetative cover are in delicate balance. Overuse of a stable slope, even by foot pathways, may unbalance the slope enough to cause denudation and slumping of the bluff.

In this context, the following scheme was used to classify bluffs according to recreational capabilities:

1. Bluffs suitable for moderate use are only public-owned slopes that are completely stable and vegetated, with public routes (established roads, pathways, and stairs) from the bluff top to the beach. Suitable bluff

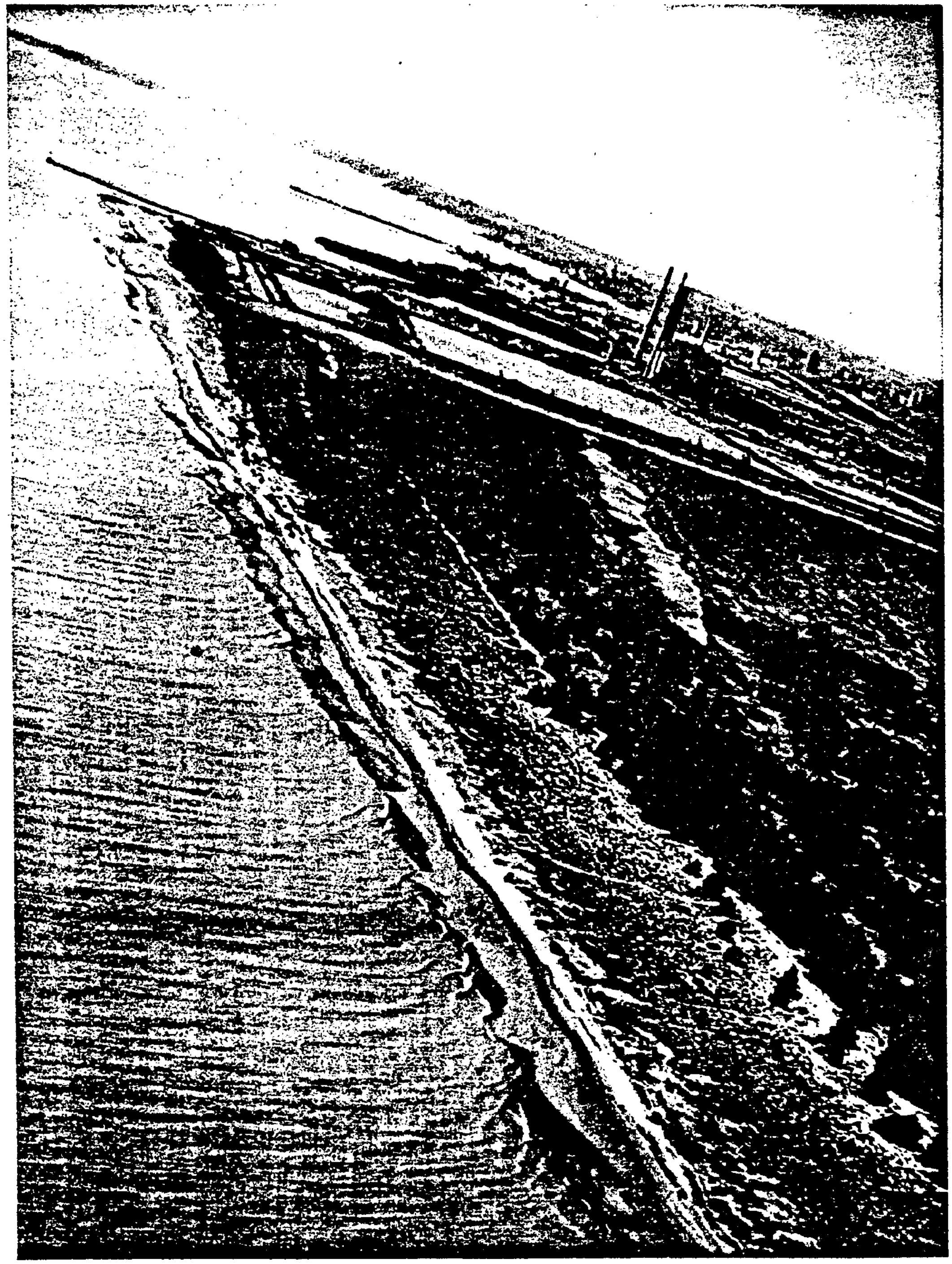


Fig. 2 - This photograph shows the wide stable beach from the Illinois Beach Nature Preserve to Waukegan Harbor. About 75 percent of the shoreline from the Wisconsin state line to the harbor is suitable for heavy recreational beach use. (see Maps 7-10)

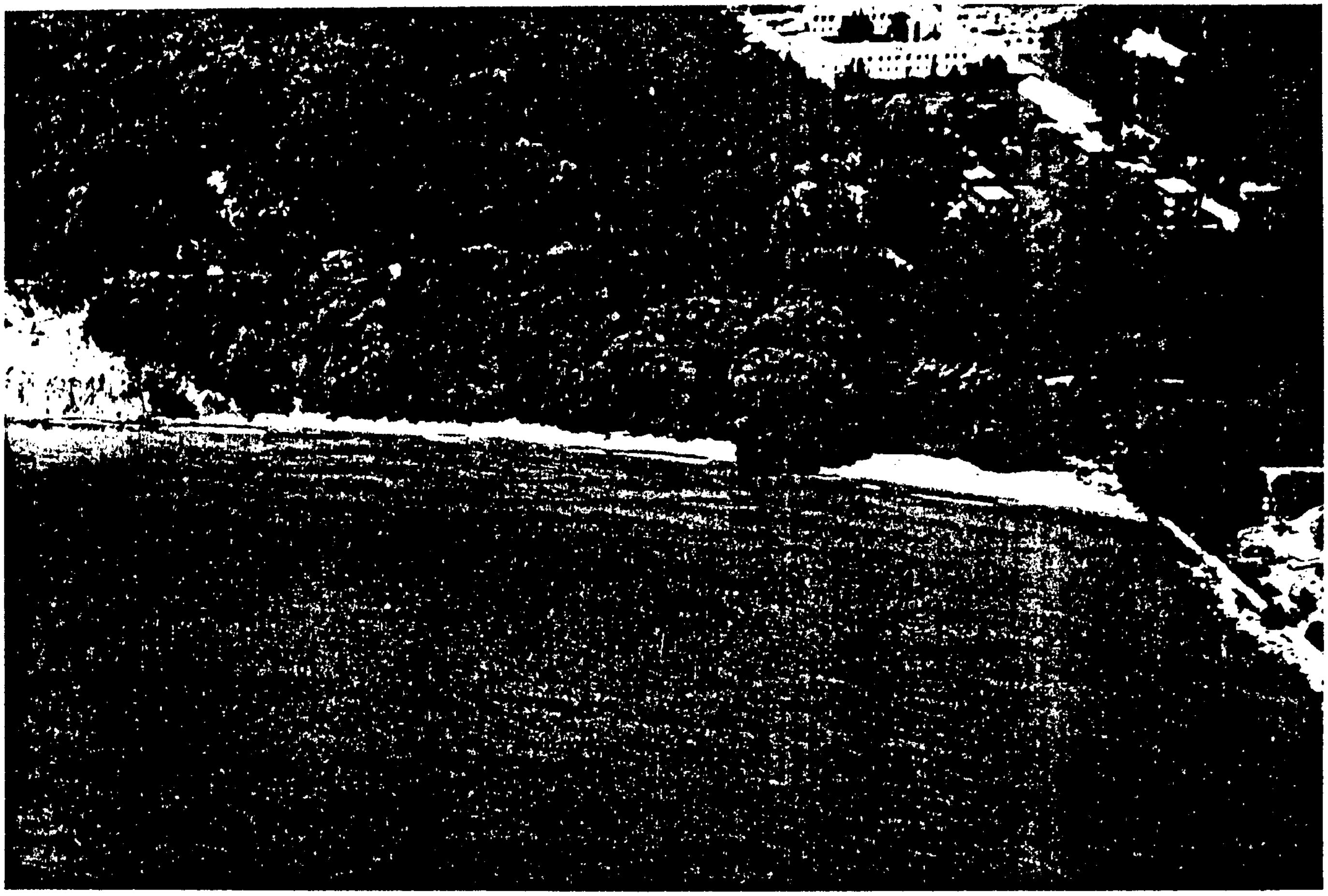


Fig. 3 - Aerial view of shore and bluffline in northernmost Lake Bluff. Two beach and bluff recreation suitability classes are evident. From right to left on the photograph, the shoreline character changes from a wide privately owned beach suitable for moderate use backed by a completely stable bluff, to a narrow beach suitable for limited use backed by a bluff exhibiting toe erosion. (see Map 14)

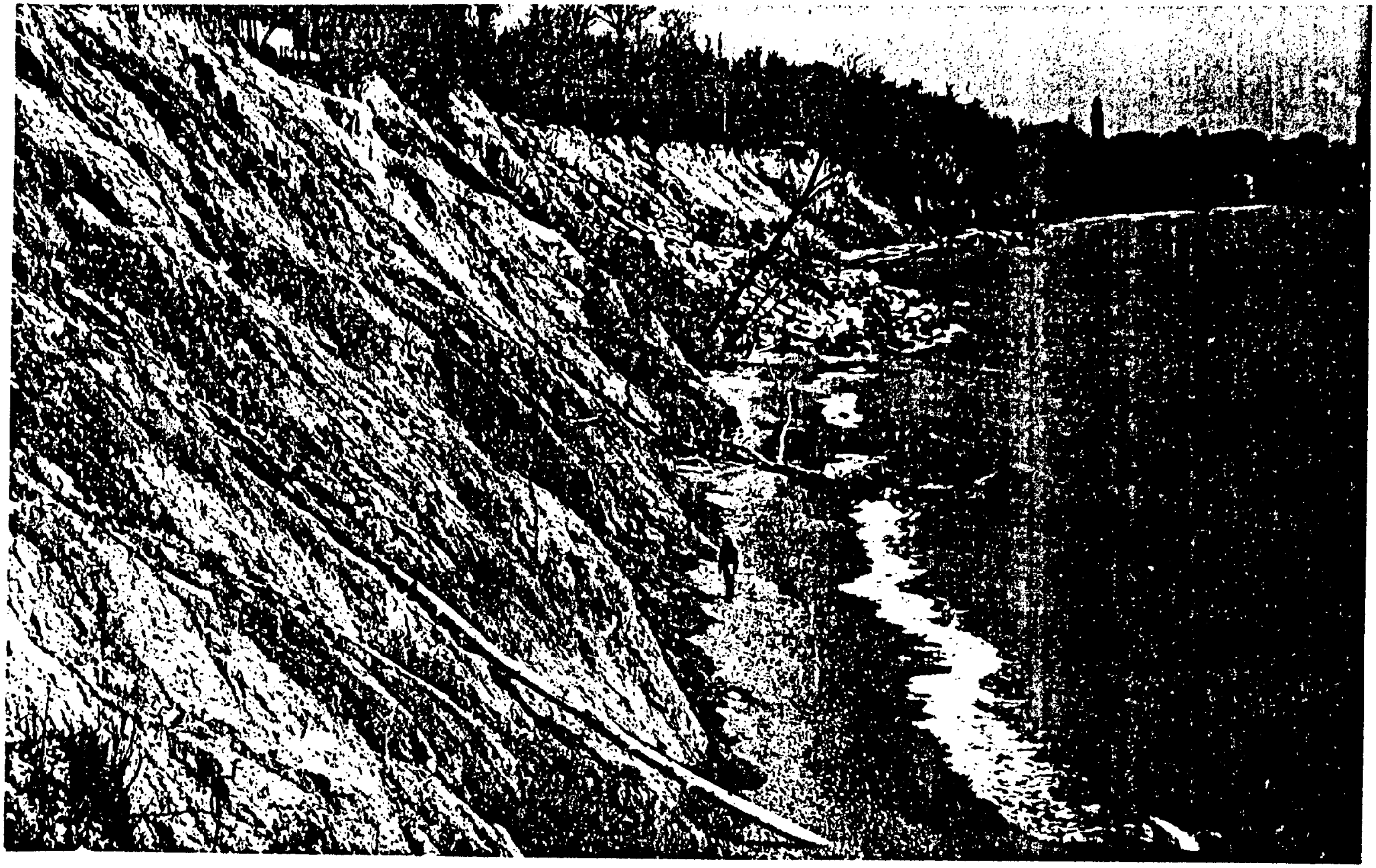


Fig. 4 - Much of the shoreline reach north of Shoreacres Country Club in Lake Bluff is not suitable for any use. Both the beach and the bluff are hazardous as evidenced by fallen trees, mudflows, and active slumping seen on the photograph. (see Map 15)

Fig. 5 - The most severely eroding area along the Illinois shore is in south Lake Forest, where over 17 feet of recession has been occurring each year since 1973. In this photo, a large slump block is moving down the bluff face. There is no useable beach. (see Map 20)

management practices were adopted when access routes were established as no signs of bluff deterioration resulted from the modification.

2. Bluffs suitable for limited use include only privately-owned slopes that are completely vegetated and stable (Fig. 3). Since in many cases there is no access to Lake Michigan from the bluff top, use of the bluff face is restricted. This category not only includes naturally vegetated slopes, but also artificial slopes that have been terraced or graded in the hope of avoiding erosion.

3. Bluffs that show the slightest evidence of erosion of the toe or slumping of the face are not suitable for any use except for bluff or shore maintenance practices (Fig. 3). These slopes may be either publicly or privately owned and in all cases present the first stage of a potentially severe erosion problem. Any recreational use of the bluff can only add to the problem.

4. Bluffs dangerous even for maintenance purposes, are not suitable for any use. The bluff reaches are characterized by oversteepened slopes with numerous seeps, and greater than 30 percent of the bluff face denuded and eroding. These slopes may be either publicly or privately owned, although most are privately owned. Shoreline structures at the base of these bluffs typically are absent or improperly maintained. Bluffline recession rates average about 3.5 feet per year along the Lake Bluff and Lake Forest shore, while along the Highland Park, Glencoe, Winnetka, Kenilworth, and Wilmette shore the erosion rate is 1 to 1.5 feet per year. This category includes the areas of most serious erosion along the Illinois shore of Lake Michigan (Figs. 4 and 5).

After each shoreline land parcel was classified according to the capability criteria, the length of shoreline and bluffline was measured on the map for each governmental unit or municipality to gain further insight into specific potential shoreline recreational capabilities. Tables 1 and 2 summarize recreational land use for the beach and bluff. Included in the tables are the four categories of usage, plus the length of reach in feet for each governmental unit or municipality.

CHANGING BEACH AND BLUFF ZONES WITH LAKE LEVEL FLUCTUATIONS AND ITS POSSIBLE IMPACT ON RECREATION CAPACITIES

The beach and bluff was classified during a period of intermediate water levels (578.7 feet). High and low water conditions could significantly alter the recreational capacity of present-day beaches and bluffs. Photos taken in 1964 and 1973, representing years of peak low and high water levels, were studied to evaluate changing beach and bluff conditions. The lake levels on the dates the photographs were taken were 575.5 feet on April 16, 1964 and 580.6 feet on April 24, 1973.

Beach width is closely related to lake level. Based on beach width - lake level correlations at Lake Bluff (Berg, 1977), a one-foot change in lake level creates a 12.5-foot change in beach width. Hence the 2.8-foot water level differential between 1964 and 1977, resulted in beaches about 35 feet wider in 1964. Along many reaches, the differential was greater than 35 feet due

TABLE 1 - RECREATIONAL LAND USE CAPABILITY OF LAKE MICHIGAN BEACHES
WISCONSIN-ILLINOIS STATE LINE TO NORTHWESTERN UNIVERSITY, EVANSTON

Shore Reach	Percent of beaches suitable for heavy use	Percent of beaches suitable for moderate use	Percent of beaches suitable for limited use	Percent of beaches not suitable for use	Length of Reach (feet)
Wisconsin-Illinois state line to Waukegan	76	2	0	21	37,680
Waukegan	60	0	2	38	19,720
North Chicago	0	14	0	86	7,160
Lake Bluff	7	6	14	73	13,920
Lake Forest	23	17	31	29	15,840
Highland Park	7	16	49	28	21,520
Glencoe	12	7	49	32	10,200
Winnetka	13	14	34	39	15,280
Kenilworth	19	17	22	42	3,080
Wilmette	47	20	6	27	9,480
Evanston to Northwestern	21	0	2	77	4,360
Totals - Wisconsin to Evanston	35	9	18	37	158,240

TABLE 2 - RECREATIONAL LAND USE CAPABILITY OF LAKE MICHIGAN HIGH BLUFFS--NORTH CHICAGO TO WILMETTE, ILLINOIS

Shore Reach	Percent of Bluff suitable for moderate use--stable vegetated, public land	Percent of Bluff suitable for limited use--stable vegetated private land	Percent of Bluff not suitable for use--toe erosion and/or minor slumping	Percent of Bluff not suitable for use--severely eroding	Length of Reach (feet)
North Chicago	32	4	11	53	3,120
Lake Bluff	8	12	10	70	13,840
Lake Forest	25	45	15	15	15,840
Highland Park	14	38	26	22	21,240
Glencoe	10	46	33	11	10,680
Winnetka	11	55	16	18	14,160
Kenilworth	22	68	7	3	2,920
Wilmette	50	50	0	0	3,680
Totals - North Chicago to Wilmette	17	39	18	26	85,480

to local beach and nearshore slopes.

In 1964, the entire beach from the Wisconsin state line to Evanston was sufficiently wide to be suitable for moderate or heavy recreational use. Only riprap promontories at the Illinois Beach Acquisition area, the riprapped shore at U.S. Steel in Waukegan, the bulkhead at Shoreacres Country Club in Lake Bluff, the bulkheads at Lake Forest, Highland Park and Winnetka Waterworks, and those few wide beaches, mostly at Lake Bluff, backed by hazardous eroding bluffs, were not suitable for use.

Beaches were about 24 feet narrower with water levels 1.9 feet higher in 1973 than in 1977. Consequently, many of those beaches classified suitable for limited or moderate use in 1977, were not suitable for any use, or just limited use in 1973. The only shoreline reaches that retained a consistent high use classification were at the public beach facilities.

High or low lake levels also correlate closely with the amount of bluff that is denuded and eroded (Berg and Collinson, 1976). But a lag commonly occurs, mainly because of the time required to revegetate denuded bluffs, whereby erosion is maintained or even accelerated following a peak year of high lake levels. Conversely, maximum bluff stabilization occurs several years after the peak year of low lake level. In Lake Bluff, since 1968 when the bluff showed maximum stability, an 80 per cent increase in exposed eroding bluff occurred as lake levels rose. From 1955, when the bluff was severly eroding following the 1952 peak low lake level year, to 1968, there was a 76 per cent decrease in the amount of eroding bluff, with decreasing lake levels. These data must be considered when assessing the recreational capability of the bluffs. Bluff reaches for the most part continued to stabilize from the low lake level year of 1964 to 1968-1969. With rising lake levels, serious bluff erosion did not become significant until the average annual lake level exceeded 579 feet I.G.L.D. (Berg and Collinson, 1976). Erosion progressed rapidly after this threshold was passed. Hence, bluffs with toe erosion or minor slumping evident in 1964, were often characterized by severe erosion in 1973. Other slopes which were completely stable and vegetated in 1964, and therefore suitable for moderate or limited recreational use, showed evidence of toe erosion, minor slumping, and in some instances severe erosion in 1973 (Fig. 5). Erosion progressed at accelerated rates until 1976. Since 1976, infrequent wave storm periods, reduced precipitation and lowered lake levels have reduced bluff erosion.

Cognizant of the changing character of the beach and bluff zones with fluctuating water levels, the 1977 classification, provides insight to possible future recreational capabilities along the Illinois shore. Those reaches classified for moderate or limited use in 1977, are most subject for placement into a limited or no use category, respectively, under a regime of high water. Conversely, during a period of low water levels, wider beaches and more stable bluffs will undoubtedly prevail, elevating many limited or no use beaches, into a moderate or limited use category, respectively.

RECREATIONAL LAND USE CAPACITY OF ILLINOIS LAKE MICHIGAN BEACHES

Table 1 indicates that from the Wisconsin-Illinois state line to Northwestern University in Evanston there are 158,240 linear feet or approximately 30 miles of beach. (This is exclusive of federal lands at Great Lakes and Fort Sheridan.) Of this 30 miles, 34 per cent is suitable for heavy use (Fig. 2). This figure is somewhat deceiving since about 40,500 linear feet or 7.7 miles of heavily-used beaches are located at Illinois Beach State Park, Illinois Beach Nature Preserve, Illinois Beach State Park Acquisition Area and along the entire Waukegan shoreline south to Waukegan Harbor (Maps 1-10). From the Wisconsin state line to Waukegan, there is only one small reach of moderately used shore, located lakeward of the Zion Nuclear Reactor (Map 4). The 21 per cent of reach considered not suitable for any use is all located north of the reactor along a riprapped shore with many offshore hazards (Maps 1-3).

The Waukegan shoreline extends for 19,720 feet or about 3.7 miles. The reach north of Waukegan Harbor, lakeward of the Johns-Manville Corporation, Commonwealth Edison fossil fuel plant, Northshore Sanitary District, Johnson Outboard Marine Corporation, and the Waukegan Waterworks, is suitable for general heavy usage (Maps 9-10). The beaches are all more than 100 feet wide. South of Waukegan Harbor (Maps 11-12) the beach is not suitable for any use as riprap lines about 95 per cent of the shore except for a shore 400-foot reach south of South Avenue, suitable for limited use as a beach (Map 11, property nos. 8-9).

The North Chicago shoreline (Maps 12-13) is 7,160 linear feet or about 1.4 miles. This reach has the greatest percentage (86%) of its beaches not suitable for any use, as much is protected by riprap, particularly lakeward of the United States Steel Plant. Only the small portion of the shoreline at Foss Park is suitable for moderate use (Map 13, property no. 4).

Beaches not suitable for use at Lake Bluff (Maps 14-17) constitute 73 per cent of the 13,920-foot (2.6 miles) shoreline. The maximum restriction is placed on these beaches primarily because of the severely eroding, over-steepened bluffs to their rear, which present a hazard from falling debris (Fig. 4). Many of these restricted areas are characterized by a narrow beach or no beach. Fourteen per cent of the Lake Bluff beach is suitable for limited use. The two most extensive reaches are immediately south of the southern outer harbor jetty at the Great Lakes Naval Training Center (Fig. 3 and Map 14, property nos. 3-5) and a portion of the beach in the McCormick-Blair property (Map 15, property nox. 16, 18, and Map 16, property no. 1). Only 13 per cent of the Lake Bluff shoreline, located at the publicly-owned Sunrise Park, is suitable for heavy beach use (Map 16, property no. 24), while a 600-foot beach north of Sunrise Park is suitable for moderate use (Map 16, property nos. 20-23).

In contrast to Lake Bluff, Lake Forest (Maps 17-20) has only 20 per cent of its 15,840-foot or 3-mile beach not suitable for any recreational use. The restricted shores occur at municipal facilities protected by riprap or seawalls (Map 17, property no. 8, and Map 18, property no. 13), and also along the base of severely eroding bluffs, where falling debris and narrow beaches create a hazard. The latter is observable along the shore of the Lake Forest Nature Preserve in south Lake Forest (Map 20, property nos. 8-15). Beaches restricted to limited use constitute 31 per cent of the shore. These beaches are narrow and generally found at the base of unstable bluffs (Fig. 5). The two most extensive such beaches are located just south of the Lake Forest Waterworks, and immediately north of the Forest Park Public Beach (Map 17, property nos. 11-12, and Map 18, property nos. 2-5). A well-maintained groin system, seawalls, and stable vegetated bluffs make possible more than one mile of beaches classified for heavy or moderate recreational use. Twenty-three per cent of the Lake Forest shore in public land is suitable for heavy use, while 17 per cent of the shore is suitable for moderate beach use.

The Highland Park shore reach (Maps 22-26) extends for 12,520 feet or about 4.1 miles. Only 7 per cent of this is in public land suitable for heavy use. Only the Park Avenue Beach (Map 23, property no. 2) and the Cary Avenue-Rosewood Beach (Map 24, property nos. 57, 59, and Map 25, property nos. 1-6) are sufficiently wide to support heavy use. Beaches suitable for moderate use constitute 16 per cent of the shoreline. The longest reaches suitable for moderate use include the beach at Moraine Park and those reaches extending about 700 feet north and south of the park (Map 22, property nos. 9-13, 16, 18, 29). The greatest percentage (49 per cent) of Highland Park beaches is suitable for only limited use. These reaches are characterized by beaches less than 20 feet wide and are often backed by an unstable bluff. Twenty-eight per cent of the shoreline is not suitable for any use. Along several reaches of the Highland Park shore seawalls abut the lake allowing for no beach (Map 23, property nos. 9, 30-32, etc.). Submerged structures are a hazard to beach use at many places (Map 23, property no. 32, Map 24, property nos. 21-22, 35-38, etc.).

The 10,200-foot (1.9-mile) shore at Glencoe (Maps 26-27) is very similar to the Highland Park shore. Thirty-two per cent is not suitable for any use while 49 per cent is suitable for only limited use. Oversteep slopes, submerged structures, and shoreline protection abutting the lake contribute to the limitations. The only reach suitable for moderate use is a 500-foot parcel north of Harbor Street (Map 27, property nos. 46-48), while the only beach suitable for heavy use is the Glencoe Park public beach (Map 27, property nos. 1, 4, 6).

The Winnetka shore (Maps 27-30) extends for 15,280 feet or about 2.9 miles. The 13 per cent of Winnetka beaches suitable for heavy recreational use is located at Tower Road Park (Map 28, unnumbered park) Lloyd Park, and Lakefront Park (Map 29, property nos. 1, 7). The wide beach at Tower Road Park is over 1,000 feet long. Fourteen per cent of the beaches are suitable for moderate use. Two reaches, at Elder Lane Park and Centennial Park, are public beaches with widths less than 20 feet (Map 30, property nos. 11-13, 15). The remaining 73 per cent of the shoreline is suitable for limited use (34 per cent) or no use (39 per cent). Unlike the reaches at Highland Park and Glencoe, the primary restriction on recreational use is because of narrow beaches with riprap or seawalls abutting the lake. An extensive reach of riprap is along the shore north of Willow Road (Map 30, property nos. 1-5).

Kenilworth (Maps 30-31) has the least extensive shoreline—3,080 feet or about .6 miles. The solitary public beach accounts for all of the 19 per cent of shoreline that is suitable for heavy use (Map 30, property nos. 40-42. Sixty-four per cent of the shoreline is suitable for limited or no use; the restrictions are solely due to retaining walls and bulkheads abutting the lake allowing for no beach or just narrow beaches. The 17 per cent of the shore suitable for moderate use includes just 5 privately-owned beaches—three in south Kenilworth (Map 31, property nos. 6-8) and two in north Kenilworth (Map 30, property nos. 32-33).

The 9,480-foot (1.8 mile) shoreline at Wilmette (Maps 31-32) has a large percentage of its beach suitable for heavy use (47 per cent) due to the extensive beach at Gillson Park and Wilmette Beach (Map 32, property no. 4). North of Wilmette Beach is a 1,500-foot privately-owned beach suitable for moderate use that accounts for 20 per cent of the Wilmette shore, (Map 31, property nos. 23-38). Beaches suitable for limited use include two small reaches north of Langdon Park (Map 31, property nos. 15, 18, 19), and one reach about 800 feet south of Wilmette Harbor (Map 32, property nos. 11-12). Reaches not suitable for any beach use include those parcels where retaining walls or bulkheads are in direct contact with the lake.

The shore from the Wilmette-Evanston municipal boundary to Northwestern University (Map 33) extends 4,360 feet or about .8 miles. Due to bulkheads and retaining walls lining the shore, 77 per cent of the reach is not suitable for recreational use. The only reach suitable for heavy use, which accounts for 21 per cent of this shoreline, is the public beach at Northeast Park (Map 33, property nos. 24-25). No beaches are suitable for moderate use, and just one small reach north of Ingleside Place is suitable for limited use (Map 33, property no. 15).

RECREATIONAL LAND USE CAPACITIES OF THE HIGH BLUFFS ALONG LAKE MICHIGAN IN ILLINOIS

The high bluffs along the Illinois shore extend for 16 miles between North Chicago and the northern portion of Wilmette. At North Chicago (Maps 12-13), 53 per cent of the bluff is severely eroding at a rate of 1 to 1.5 feet per year and is not suitable for any use. The absence of shore protective structures has left erosion essentially unchecked. Of the 3,120 feet or .6 miles of bluffline, 32 per cent is stable and vegetated, publicly-owned land with access to Lake Michigan from the bluff top, hence suitable for moderate use (Map 13, property no. 4). Just 4 per cent of the bluff reach is suitable for limited use (Map 12, property no. 7), while the remaining 11 per cent is characterized by toe erosion or minor slumping, and, hence is not suitable for any use (Map 13, property no. 4).

The bluffline reach at Lake Bluff (Maps 14-17) extends for 13,840 feet or 2.6 miles, of which 70 per cent is not suitable for any use due to severe erosion (Fig. 4). The Lake Bluff shore has been studied in great detail (Berg and Collinson, 1976, 1977), and the bluff here has been calculated to erode at an average rate of about 2.8 feet per year. As much as 400 feet has eroded along the reach north of Shore Acres Country Club since 1872 (Map 14, property nos. 6-7, and Map 15, property nos. 1-8). Only in the last few years has there been a serious attempt to protect the bluff from erosion. The absence of shoreline protective structures, the dilapidated state of many existing shoreline structures and the unstable geological consistency of the glacial bluff materials account for the high rate of bluff erosion. Ten per cent of the bluff at Lake Bluff is characterized by toe erosion or minor slumping, placing these reaches in the category of no use (Fig. 3). This includes a short reach north of Shore Acres Country Club and another one along a portion of the McCormick-Blair property (Map 15, property nos. 1-2, 18 and Map 16, property no. 1).

Only 12 per cent of the bluffline is suitable for limited use (Fig. 3). This category includes one reach immediately south of the south jetty of Great Lakes Naval Training Center (Map 14, property nos. 3-5) and another along the northern bluff of the McCormick-Blair property (Map 15, property nos. 16-17). The 8 per cent of the bluffline suitable for moderate usage is restricted to a 1,100-foot reach at Sunrise Park (Map 16, property nos. 21-24).

The number of well-maintained shore structures has kept erosion at Lake Forest (Maps 17-20) to a minimum. Only 30 percent of the bluffline is not suitable for any use. Fifteen per cent is characterized by minor toe erosion and/or slumping, while the other fifteen per cent is severely eroding. The severely eroding reaches are restricted to three primary areas: (1) immediately south of the Waterworks (Map 17, property nos. 10-12) and (2) north and south of Stonegate Road (Map 19, property nos. 8-9, 15-16), both having average annual recession rates of 1 to 1.5 feet per year, and (3) along the bluffline reach of the Lake Forest Nature Preserve, which has eroded at the rate of 17 feet per year since 1973 (Map 20, property nos. 8-15). The 3 miles of bluff along the Lake Forest shore include 2.1 miles of completely stable and vegetated slopes. Twenty-five per cent of the Lake Forest stable slopes is publicly-owned land, most of which is at the Waterworks (Map 17, property no. 8) and at Forest Park (Map 18, property no. 13), while 45 per cent is in privately-owned land.

The bluffs not suitable for any use at Highland Park (Maps 22-26) include 48 per cent of the 21,240-foot, 4-mile shore. Eleven separate reaches are characterized by severe erosion, while there are 12 reaches with toe erosion or minor slumping. Recession rates have not exceeded 1.5 feet per year in any area. Although the shore generally is well protected by shore structures, narrow beaches are common, resulting in a greater frequency of erosion by wave impact. Fifty-two per cent of the bluff reach is completely stable and vegetated and suitable for moderate or limited use. Stable and vegetated publicly-owned bluffs are located at the Park Avenue Beach-Central Park Waterworks (Map 23, property nos. 2-3), the Old Sewage Plant (Map 24, unnumbered property), and at the Cary Avenue-Rosewood Beach facility (Map 24, property nos. 57, 59, and Map 25, property nos. 1, 5).

The Glencoe bluffline (Maps 26-27) extends for 10,680 feet or about 2 miles. Severely eroding bluffs, not suitable for any use, account for 11 per cent of the reach. Two short reaches of severely eroding bluffs are located north of Maple Hill Road (Map 26, property nos. 33-34, 39) and a third is located on the Glencoe-Winnetka municipal boundary (Map 27, property nos. 50, 54). Bluffline recession has not exceeded 1.5 feet per year at any of these places. Twelve individual reaches with toe erosion or minor slumping account for 33 per cent of the Glencoe reach. Fifty-six per cent of the reach is completely stable and vegetated, with no signs of erosion. The publicly-owned bluff at Glencoe Park Beach and the Glencoe Waterworks account for 10 per cent of the reach (Map 27, property nos. 1. 4, 6).

The 14,160-foot (2.7-mile) bluff reach at Winnetka (Maps 27-30) has 9 areas of severe bluff erosion, not suitable for any use, but this only accounts for 18 per cent of the total reach. Bluffline recession has not exceeded 1.5 feet per year at any site. The primary cause of erosion appears to be narrow or nonexistent beaches. In addition, bluff toe or minor slumping is evident at 8 reaches. Much of the Winnetka bluff is completely vegetated and stable, privately-owned land. Fifty-five per cent of the bluff is therefore classified suitable for limited use. The remaining 11 per cent of publicly-owned bluff suitable for moderate use is located at Tower Road Park (Map 28, property nos. 47-50), Lloyd Park (Map 28, property no. 61), Lake Front Park (Map 29, property no. 7), and Centennial-Elder Lane Parks (Map 30, property nos. 11-13, 15).

The Kenilworth bluff (Map 30-31) extends for 2,920 feet or about .6 miles. Only 10 per cent is not suitable for any use. Severe erosion is evident only at Mahoney Park with an average annual recession rate of 1 foot per year (Map 31, property no. 11). The remaining 90 per cent is suitable for moderate or limited use.

The high bluff trends inland just north of Wilmette Harbor in Wilmette, thus extending for only 3,680 feet or about .7 miles along the Wilmette shore of Lake Michigan (Maps 31-32). The extensive sand buildup north of the harbor has positioned the bluff a substantial distance from the lake. Therefore completely stable vegetated slopes prevail that are suitable for moderate or limited use. One-half of the reach is privately-owned. Langdon Park (Map 31, property nos. 20-33) and Wilmette Beach (Map 32, property no. 4) are publicly-owned bluff reaches.

SUMMARY

Increased use of the beaches and bluffs along the Illinois shore of Lake Michigan has resulted in pressures on the lake-shore environment. A classification of beach and bluff reaches based on limiting physical characteristics has been developed to assign individual shoreline parcels into categories according to their potential for supporting recreational and other activities. The classification provides information that leads to the following conclusions:

1. Of the 30 miles of beach between the Wisconsin-Illinois state line and Northwestern University in Evanston, 37 per cent is not suitable for any use, 18 per cent is suitable for limited use, 9 per cent is suitable for moderate use, and 35 per cent is suitable for heavy use. Over one-half of the beach length suitable for heavy use is located north of Waukegan Harbor. Those municipalities with the smallest percentage of their beaches in public land suitable for heavy use are North Chicago, Lake Bluff, and Highland Park. Wilmette, Waukegan and Lake Forest have the greatest percentage of their beaches in public land suitable for heavy use.

2. The percentage of beach length suitable for moderate use is remarkably similar for those communities from North Chicago to Wilmette. The percentage varies from 6 per cent at Lake Bluff to 20 per cent at Wilmette.

3. The percentage of beach suitable for limited use is greatest at Highland Park and Glencoe, both with 49 per cent of these reaches good for only limited swimming and boat docking.

4. Those communities with the greatest percentage of their reaches not suitable for any use are North Chicago, Lake Bluff and Evanston. Although both limited or no use beach restrictions prevail throughout North Chicago, Lake Bluff, Highland Park, Glencoe and Winnetka, all with at least 73 per cent of their beaches in a limited or no use category, the factors restricting beach use vary from community to community. At North Chicago and Lake Bluff, narrow, nonexistent beaches result generally from the absence of shore protection and dilapidated shore protection in combination with severely eroding bluffs. Beaches are restricted for use in Highland Park and Glencoe due to dangerous offshore hazards and bulkheads or seawalls in contact with lake water, both of which often are associated with severely eroding bluffs. The beaches south of Glencoe, particularly in Winnetka, have narrow or nonexistent beaches due primarily to bulkheads or seawalls abutting the lake. There are few offshore hazards, and bluff erosion is minimal.

5. The data on capabilities of the high bluff from North Chicago to Wilmette for recreational land use indicate that 17 per cent of the bluff's reach is publicly-owned, completely stable and vegetated land suitable for moderate use. Thirty-nine per cent is stable privately-owned bluff suitable for limited use, while 18 per cent shows evidence of toe erosion or minor slumping and 26 per cent is characterized by severe erosion. The latter two classes are not suitable for any use. The communities with the greatest percentage of completely stable and vegetated publicly-owned bluff are Willmette, North Chicago, and Lake Forest. The communities with the lowest percentage of stable public bluff are Lake Bluff, Glencoe, and Winnetka.

6. The percentage of bluff suitable for limited use is greatest at Kenilworth, Winnetka and Wilmette. It is also quite high at Glencoe and Lake Forest. Only Highland Park, North Chicago and Lake Bluff have exceptionally low percentages.

7. The percentage of bluff characterized by toe erosion or minor slumping, and thus not suitable for any use, is fairly uniform throughout the communities. Only Highland Park and Glencoe have a slightly greater percentage of their bluffs in this category.

8. Bluffs characterized by severe erosion are concentrated in Lake Bluff and North Chicago. This percentage decreases fairly constantly from Lake Bluff to Wilmette.

9. Lake Forest is a community surrounded by municipalities with severe beach and bluff problems. However, an abnormally high percentage of reaches suitable for recreational use prevails. The wise use and maintenance of shore protection structures has successfully aided shore managment practices and increased the potential for recreational land use.

APPENDIX

MAPS OF THE ILLINOIS SHORE OF LAKE MICHIGAN FROM THE WISCONSIN STATE LINE TO NORTHWESTERN UNIVERSITY, EVANSTON, SHOWING THE RECREATION CAPABILITIES OF THE BEACH AND HIGH BLUFF

The following maps have been modified from the 1977 "Map Atlas, Lake Michigan Shore in Illinois." Included on the maps are beach and bluff shoreline reaches classified according to recreation capabilities. The bluffline is shown by a straight dashed line. Shore protective structures are labelled according to type. Submerged shore structures are indicated as offshore dashed lines. Depth contours are at 5-foot intervals. Individual properties are numbered consecutively from north to south on each map.

MAP LEGEND

BEACH

Suitable for heavy use--wide public beaches.

Suitable for moderate use--narrow public beaches and wide private beaches.

Suitable for limited use--narrow private beaches.

Not suitable for use--absence of beach or dangerous for use.

BLUFF

Suitable for moderate use--stable vegetated public land.

Suitable for limited use--stable vegetated private land.

Not suitable for use--toe erosion and/or minor slumping.

Not suitable for use--severe erosion.

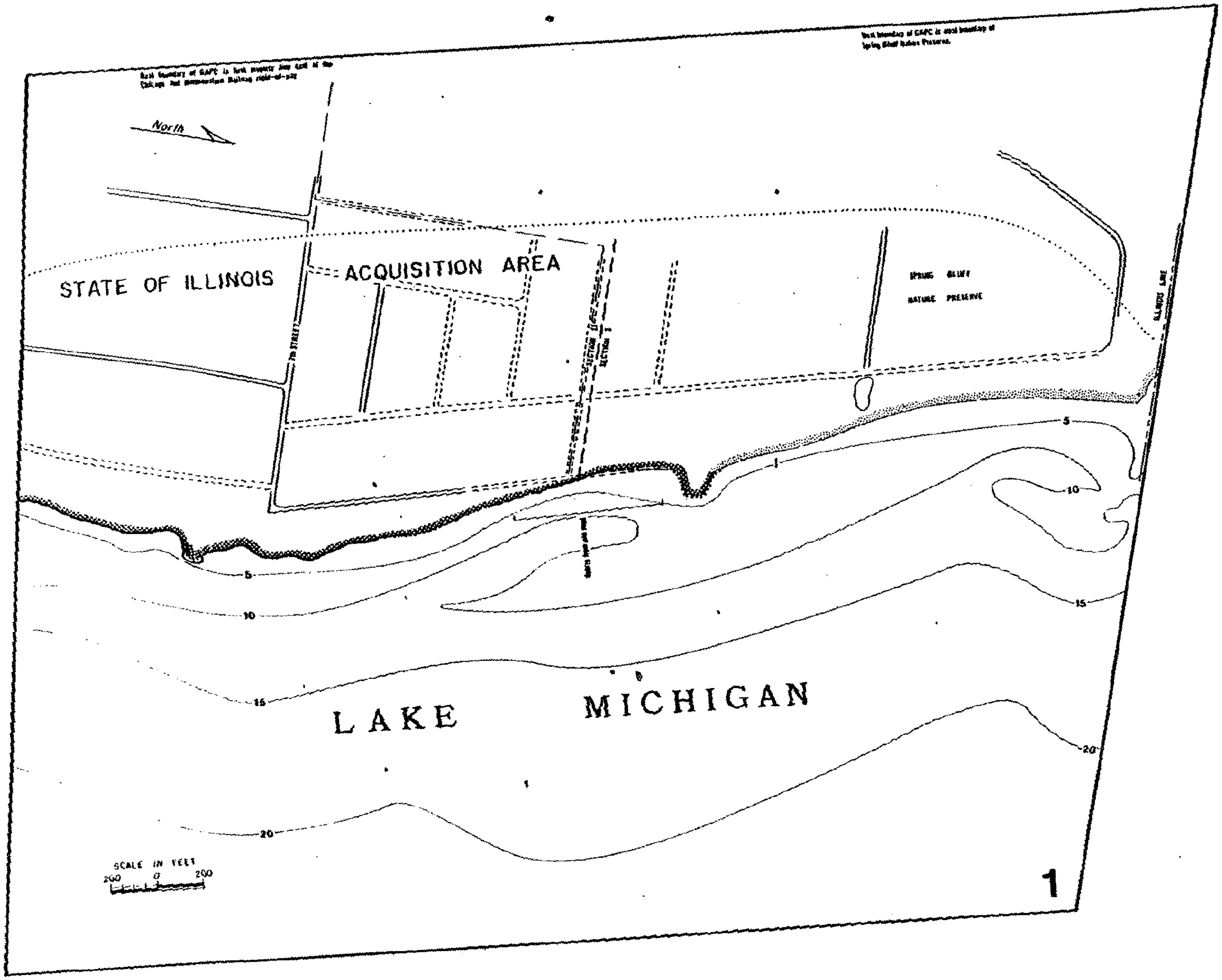
Submerged and hazardous structures, May 1976

Riprap or rubble

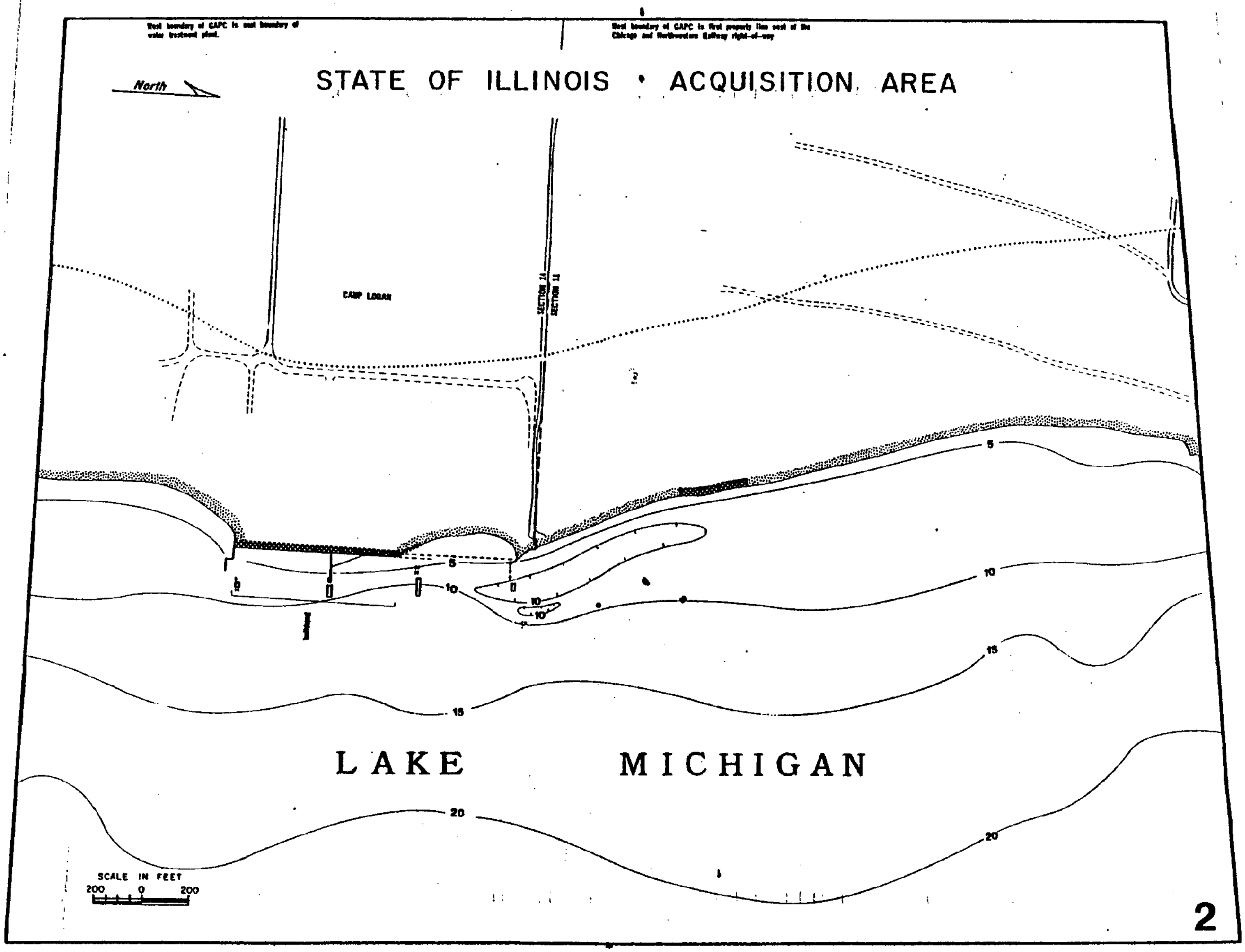
Bluffline, April 1976

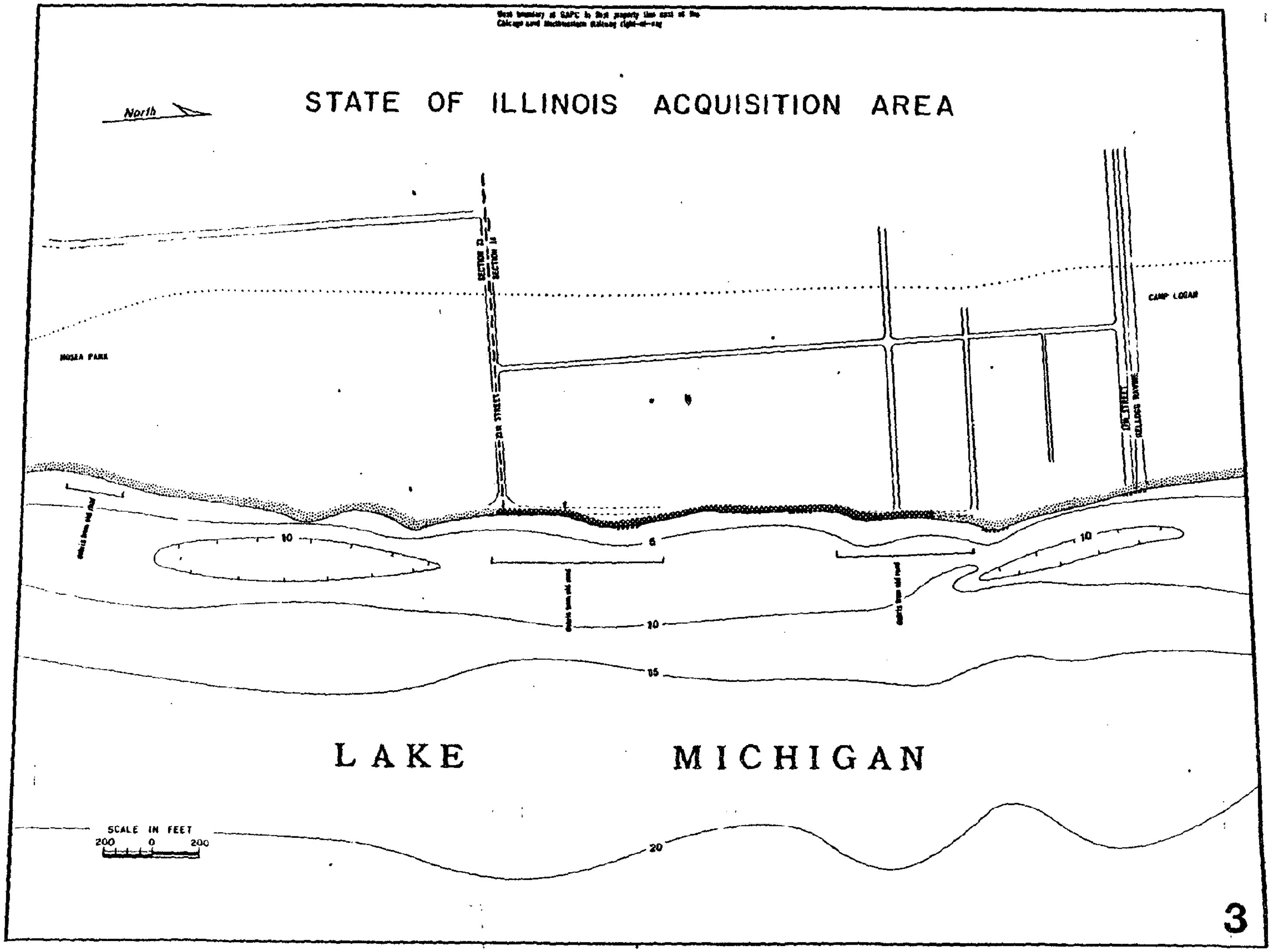
Anticipated 100-Year Bluffline, 2076 A.D.

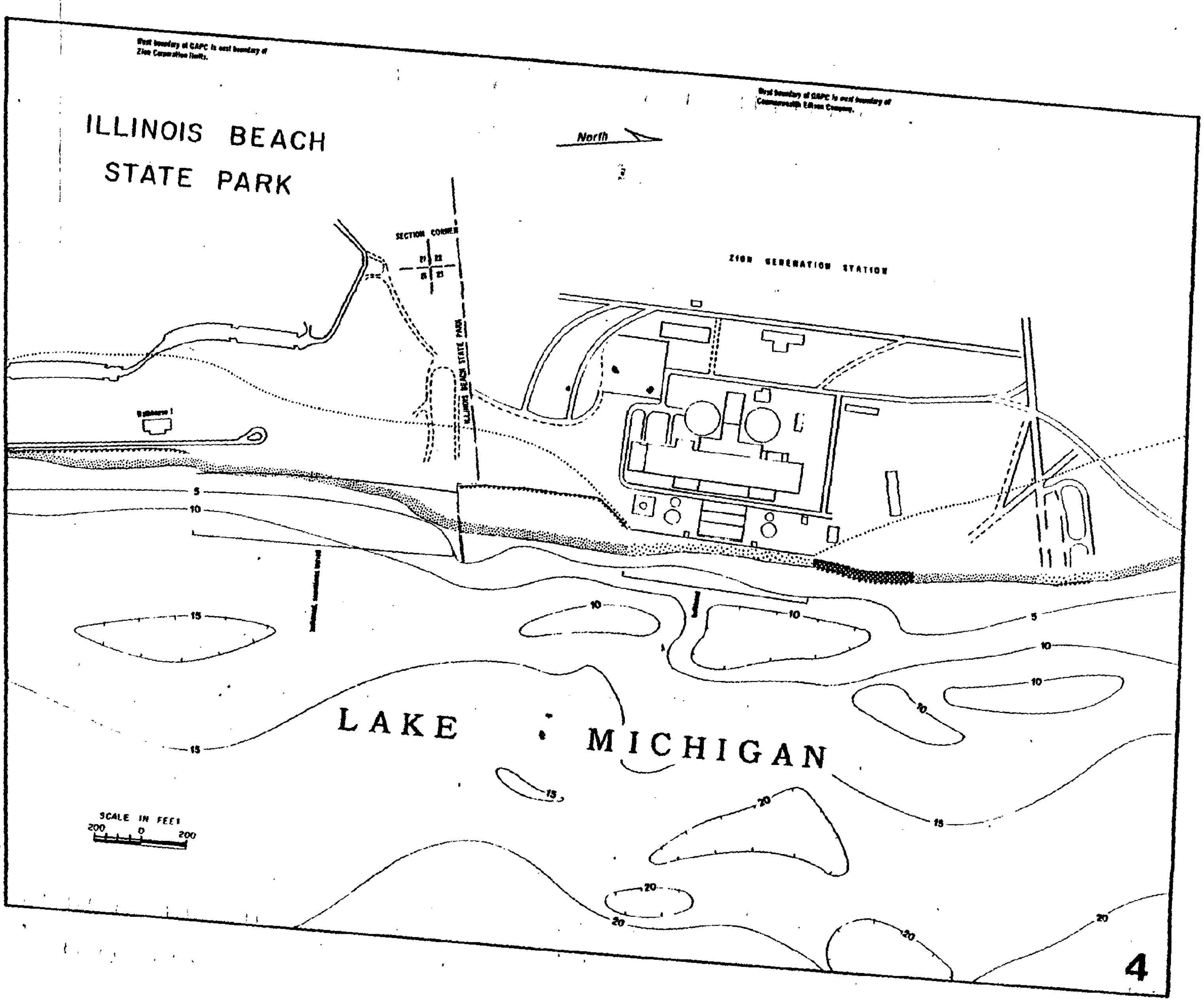
1, 2, 3, etc. Ravine and lakefront properties

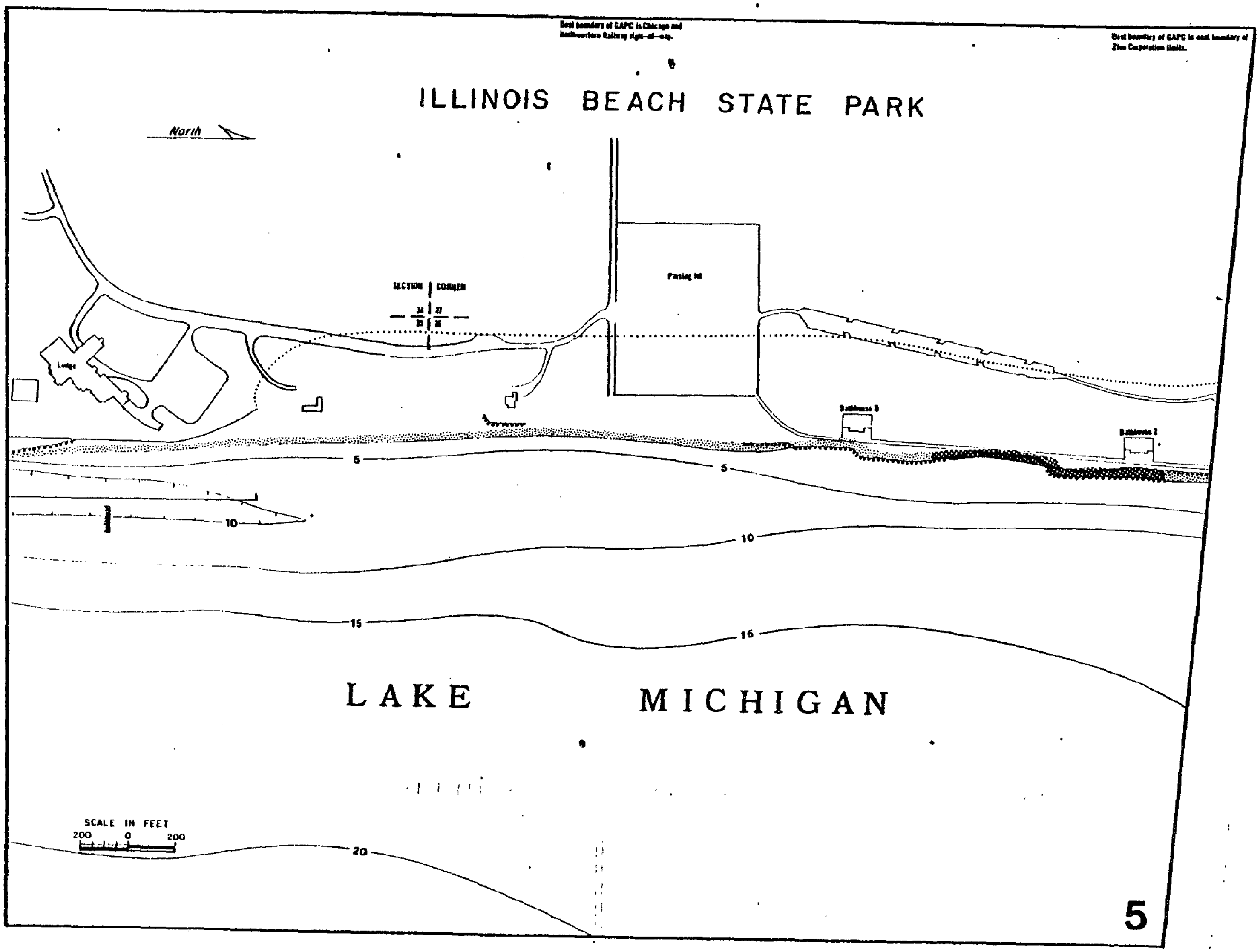

North
STATE OF ILLINOIS
ACQUISITION AREA
SPRING BLUFF
NATURE PRESERVE
LAKE MICHIGAN
5
10
15
20
SCALE IN FEET
200 0 200

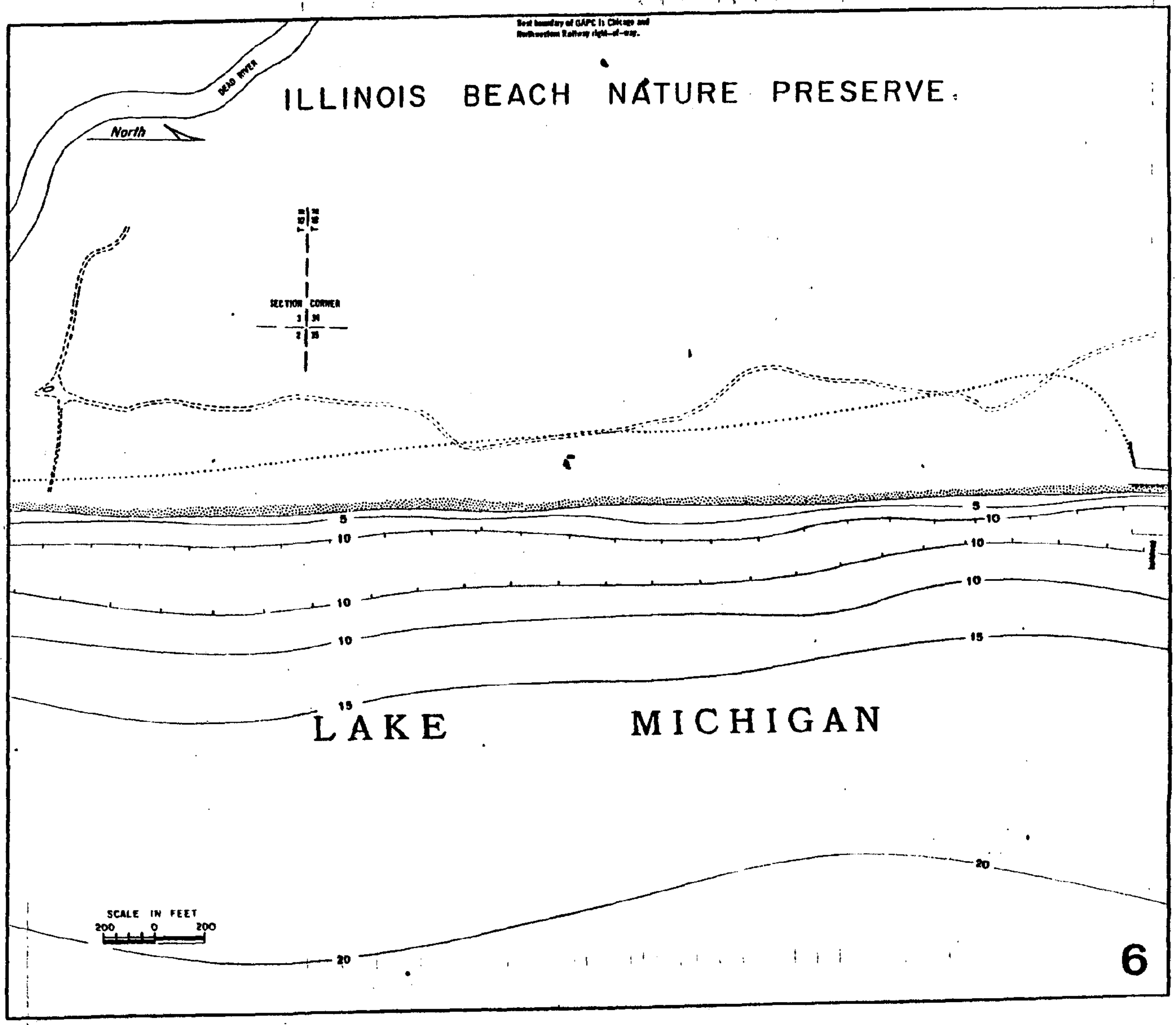
1

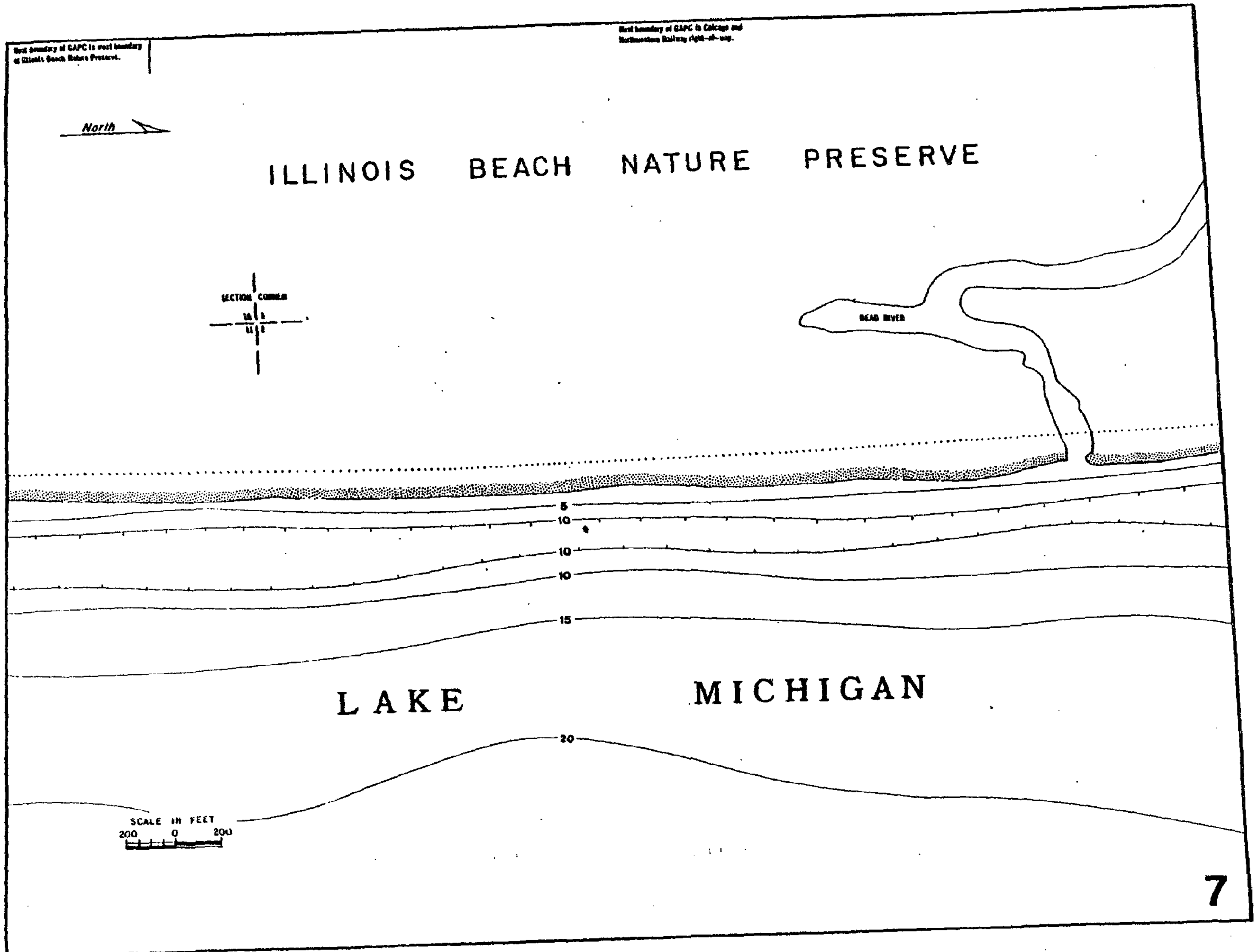

West boundary of CAPC is east boundary of water treatment plant.
West boundary of CAPC is first property line east of the Chicago and Northwestern Railway right-of-way
North
STATE OF ILLINOIS • ACQUISITION AREA
CAMP LOGAN
SECTION 14
SECTION 11
5
10
15
20
LAKE MICHIGAN
SCALE IN FEET
200 0 200
2

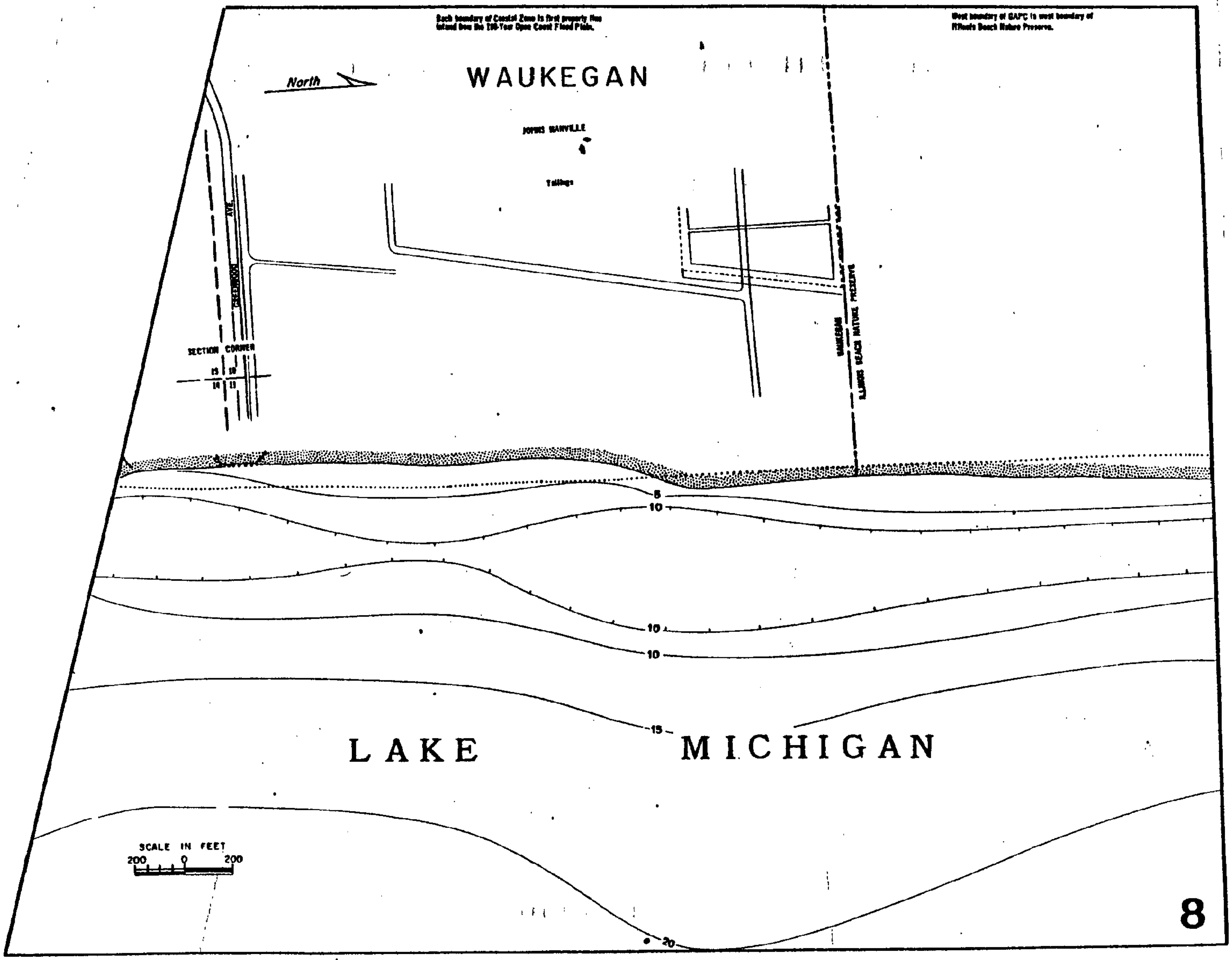

STATE OF ILLINOIS ACQUISITION AREA
North
CAMP LOGAN
10
5
10
10
15
LAKE MICHIGAN
SCALE IN FEET
200 0 200
20
3

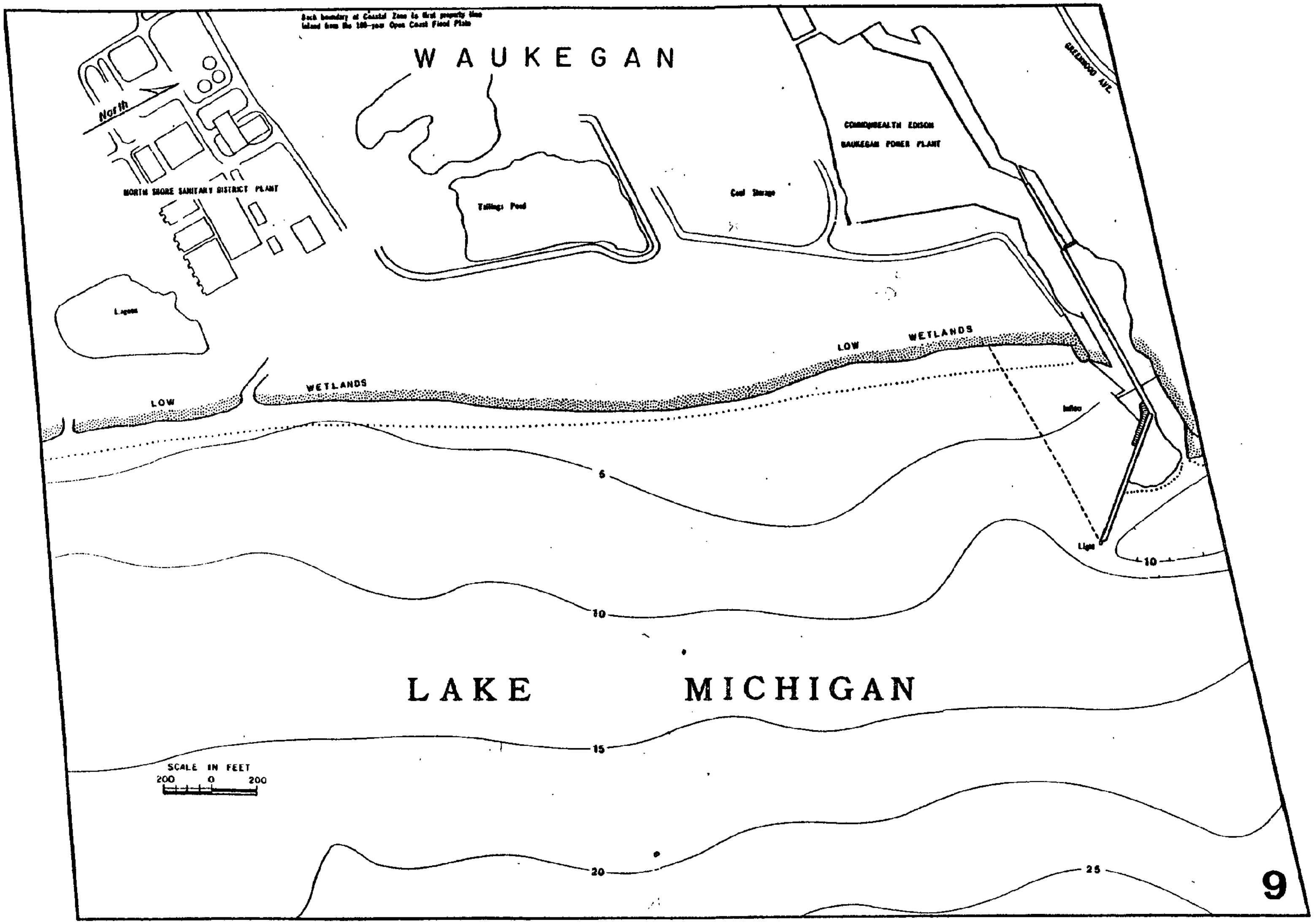

West boundary of GAPC is east boundary of Zion Corporation limits.
ILLINOIS BEACH
STATE PARK
North
West boundary of GAPC is west boundary of Commonwealth Edison Company.
SECTION CORNER
21 22
28 27
ILLINOIS BEACH STATE PARK
ZION GENERATION STATION
LAKE MICHIGAN
SCALE IN FEET
200 0 200
4

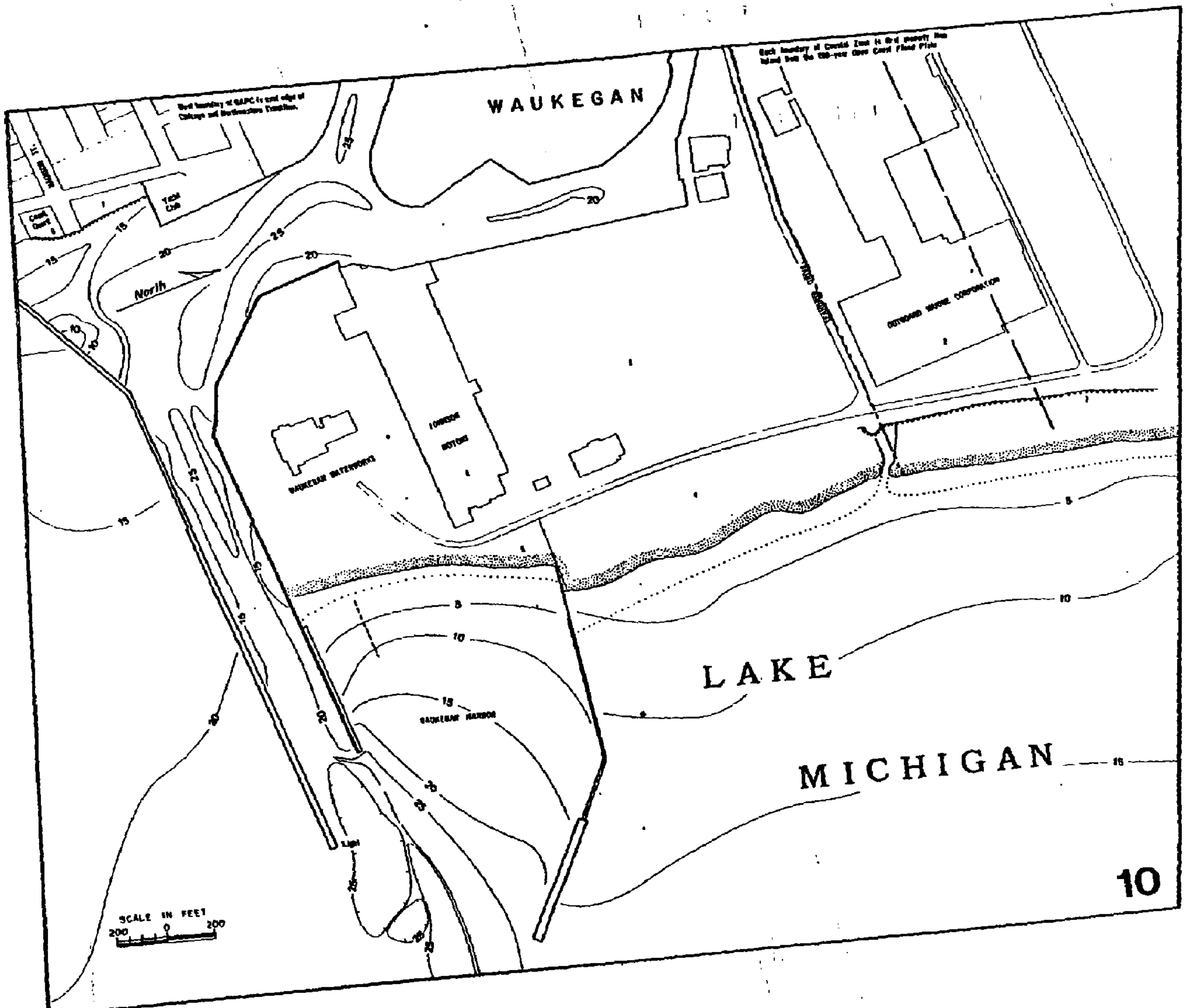

West boundary of GAPC is Chicago and Northwestern Railway right-of-way.
West boundary of GAPC is east boundary of Zion Corporation limits.
ILLINOIS BEACH STATE PARK
North
SECTION CORNER
34 27
35 26
Lodge
Parking lot
Bathhouse 3
Bathhouse 2
5
10
15
20
LAKE MICHIGAN
SCALE IN FEET
200 0 200
5

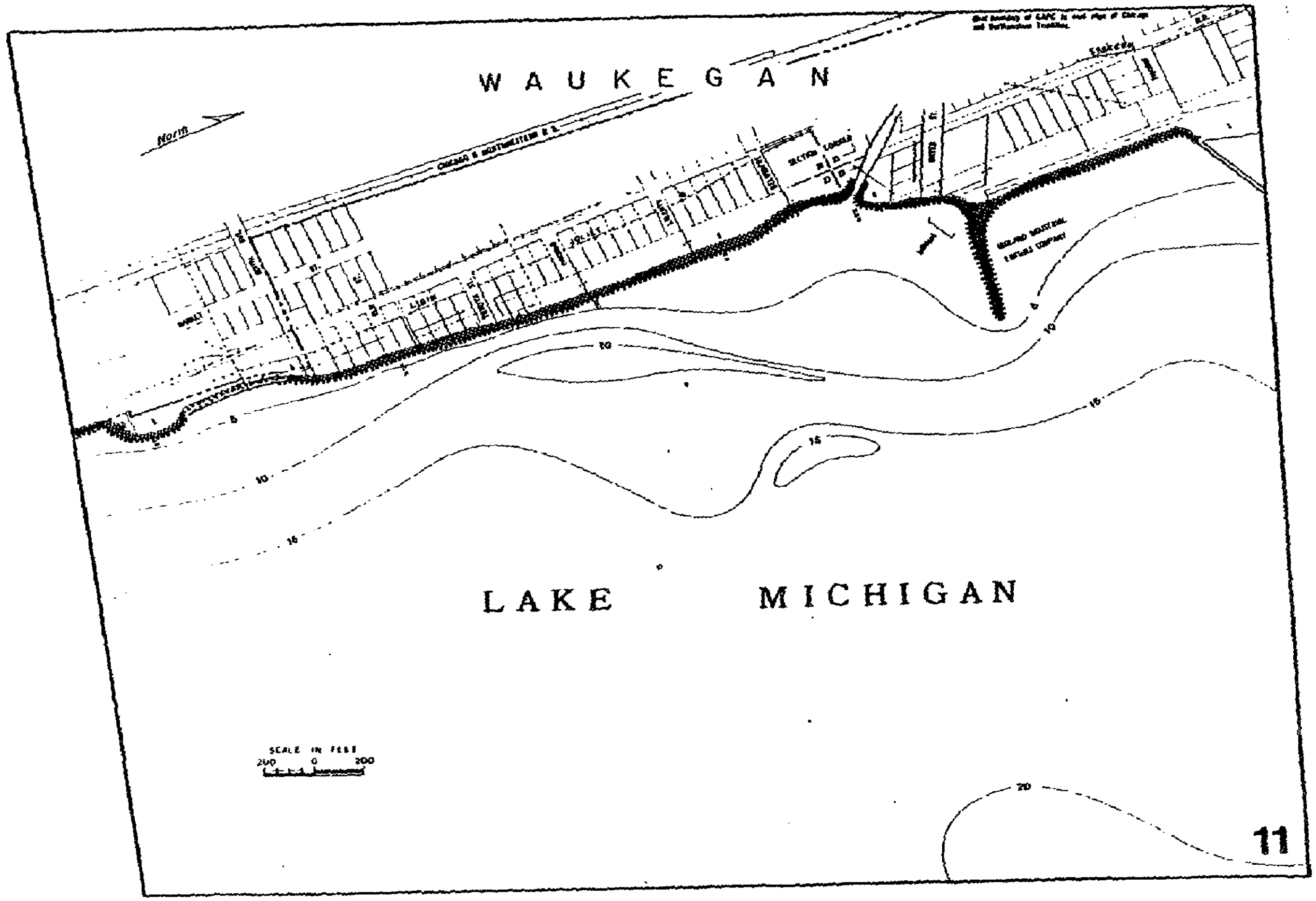

ILLINOIS BEACH NATURE PRESERVE
West boundary of GAPC is Chicago and Northwestern Railway right-of-way.
DEAD RIVER
North
SECTION CORNER
3 | 34
2 | 35
5
10
10
10
15
20
LAKE MICHIGAN
SCALE IN FEET
200 0 200
6

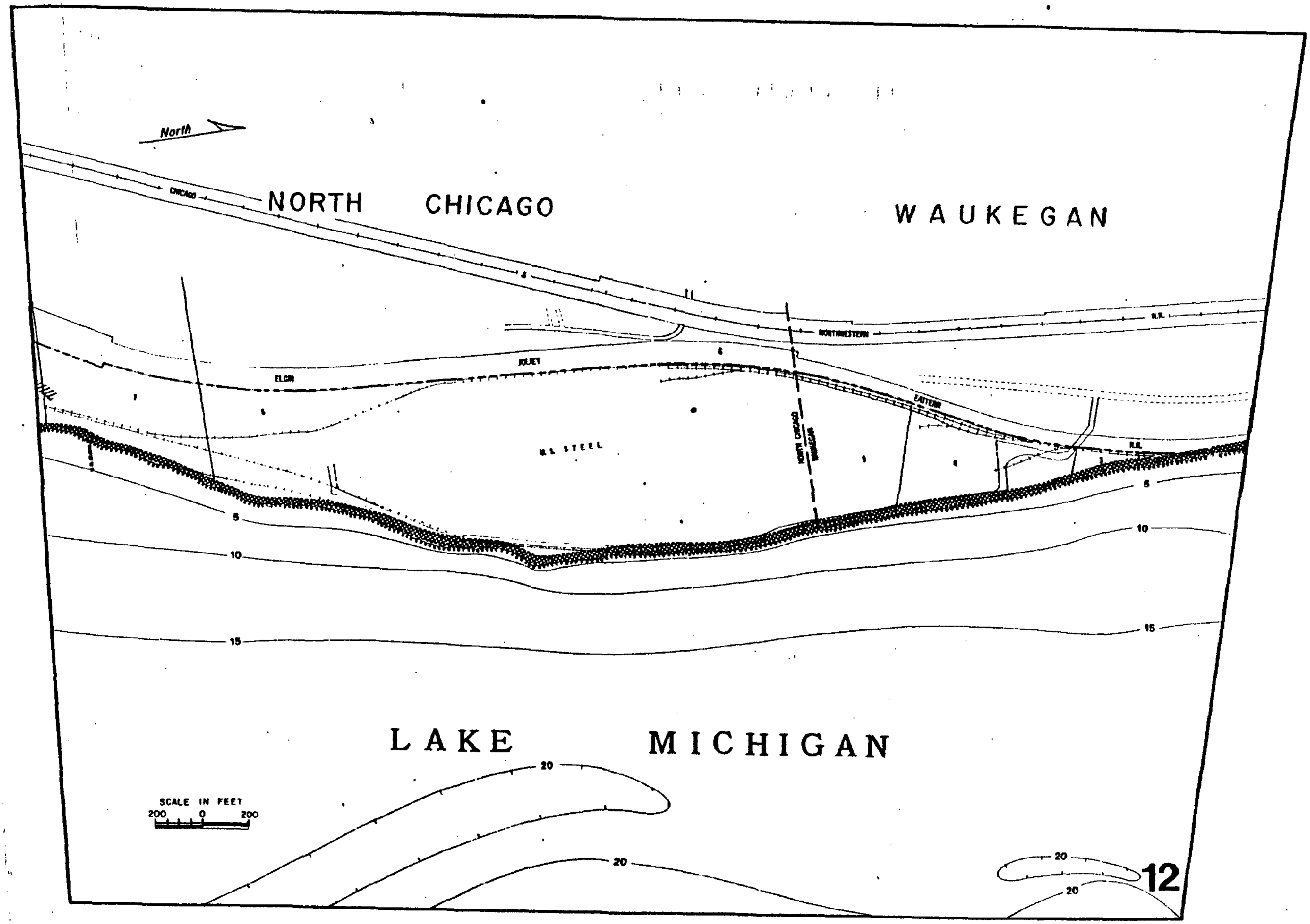

North
ILLINOIS BEACH NATURE PRESERVE
SECTION CORNER
DEAD RIVER
5
10
10
10
15
LAKE MICHIGAN
20
SCALE IN FEET
200 0 200
7

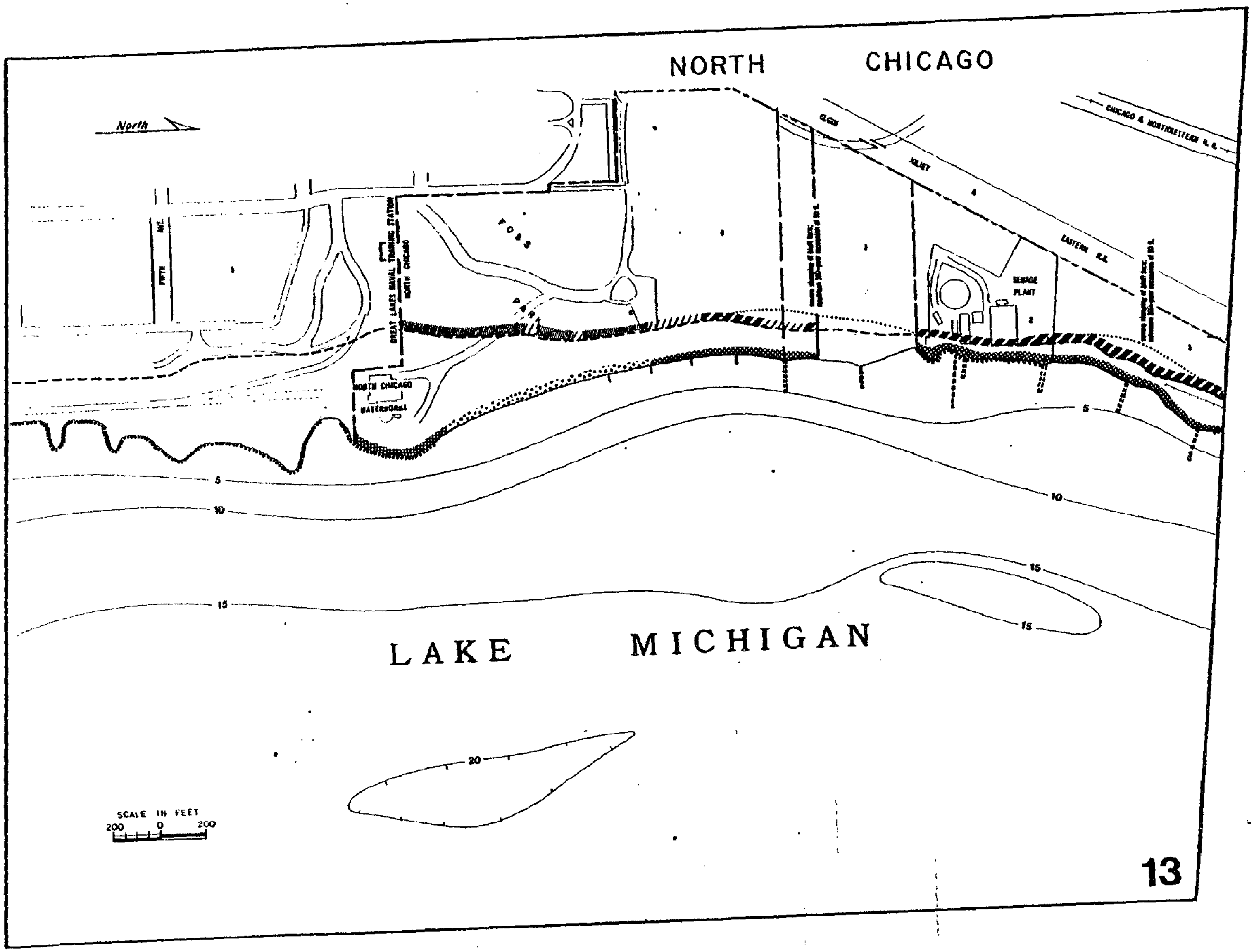

Each boundary of Coastal Zone is first property line inland from the 100-Year Open Coast Flood Plain.
West boundary of GAPC is west boundary of Illinois Beach Nature Preserve.
North
WAUKEGAN
JOHNS MANVILLE
Tailings
AVE
GREENWOOD
SECTION CORNER
15
10
14
11
WAUKEGAN
ILLINOIS BEACH NATURE PRESERVE
5
10
10
10
15
LAKE MICHIGAN
20
SCALE IN FEET
200
0
200
8

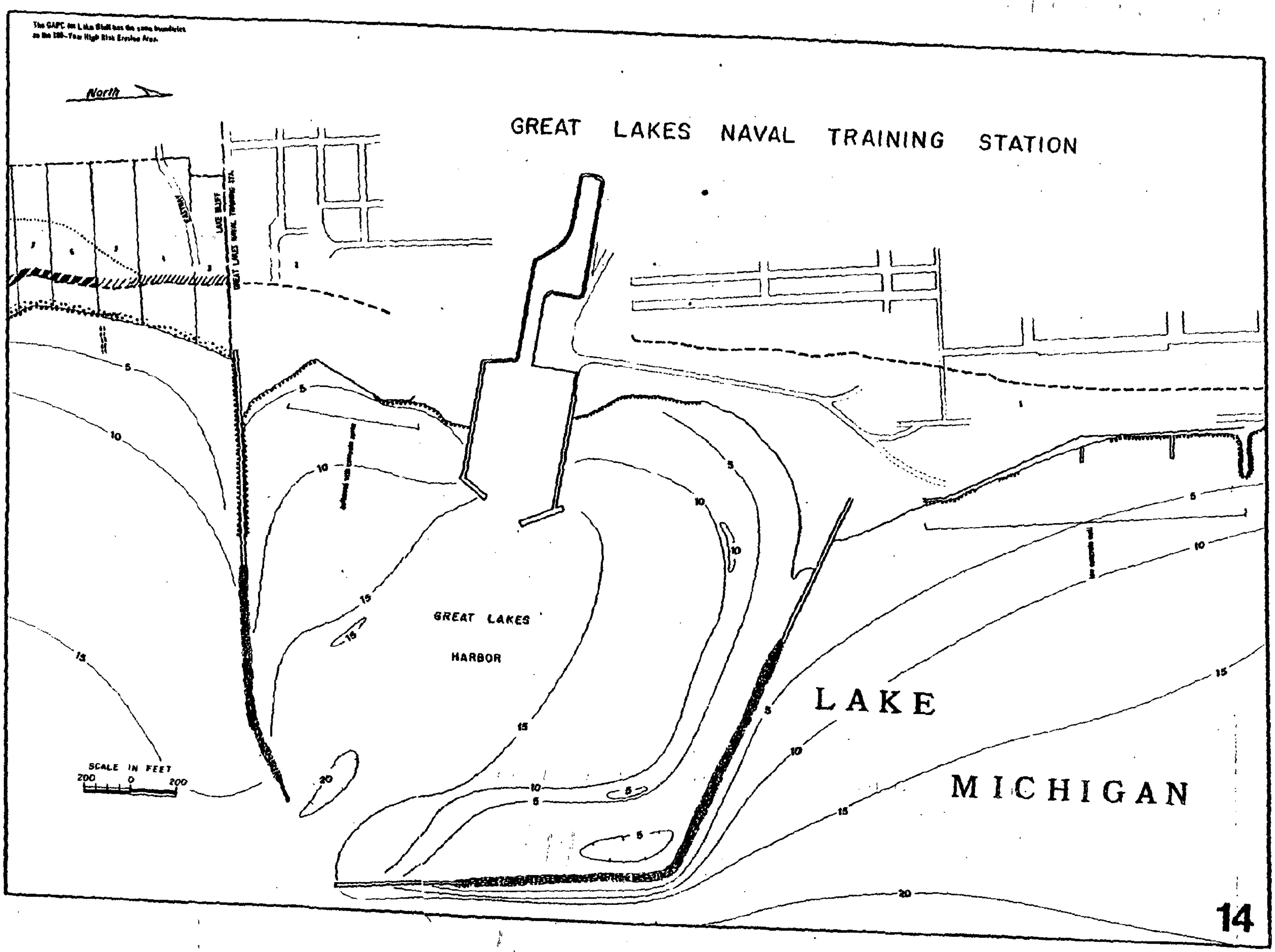

Back boundary of Coastal Zone is first property line inland from the 100-year Open Coast Flood Plain
W A U K E G A N
North
NORTH SHORE SANITARY DISTRICT PLANT
Lagoon
Tailings Pond
Coal Storage
COMMONWEALTH EDISON
WAUKEGAN POWER PLANT
GREENWOOD AVE.
LOW WETLANDS
LOW WETLANDS
Inflow
Light
5
10
10
15
20
25
LAKE MICHIGAN
SCALE IN FEET
200 0 200
9

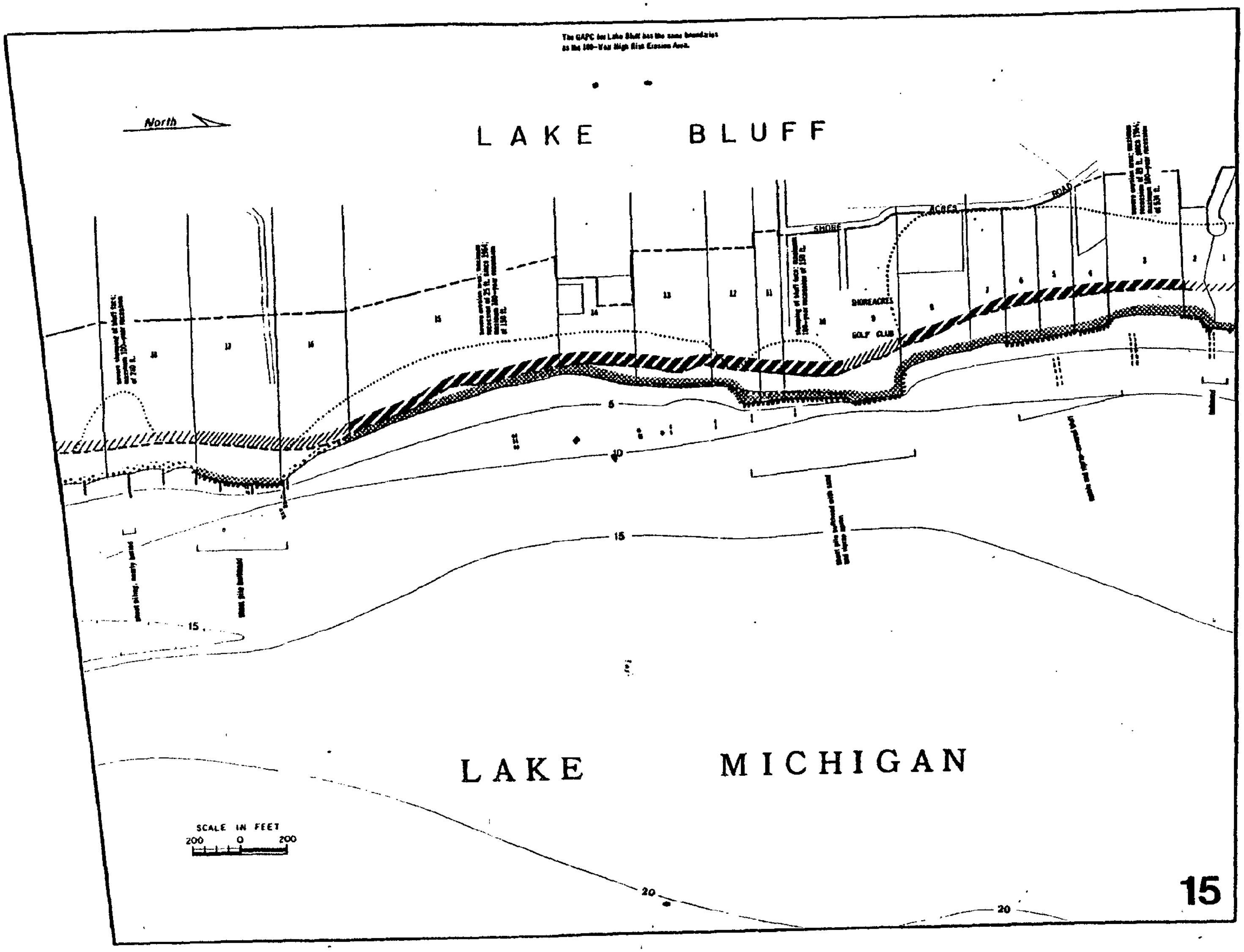

WAUKEGAN
LAKE MICHIGAN
North
SCALE IN FEET
10

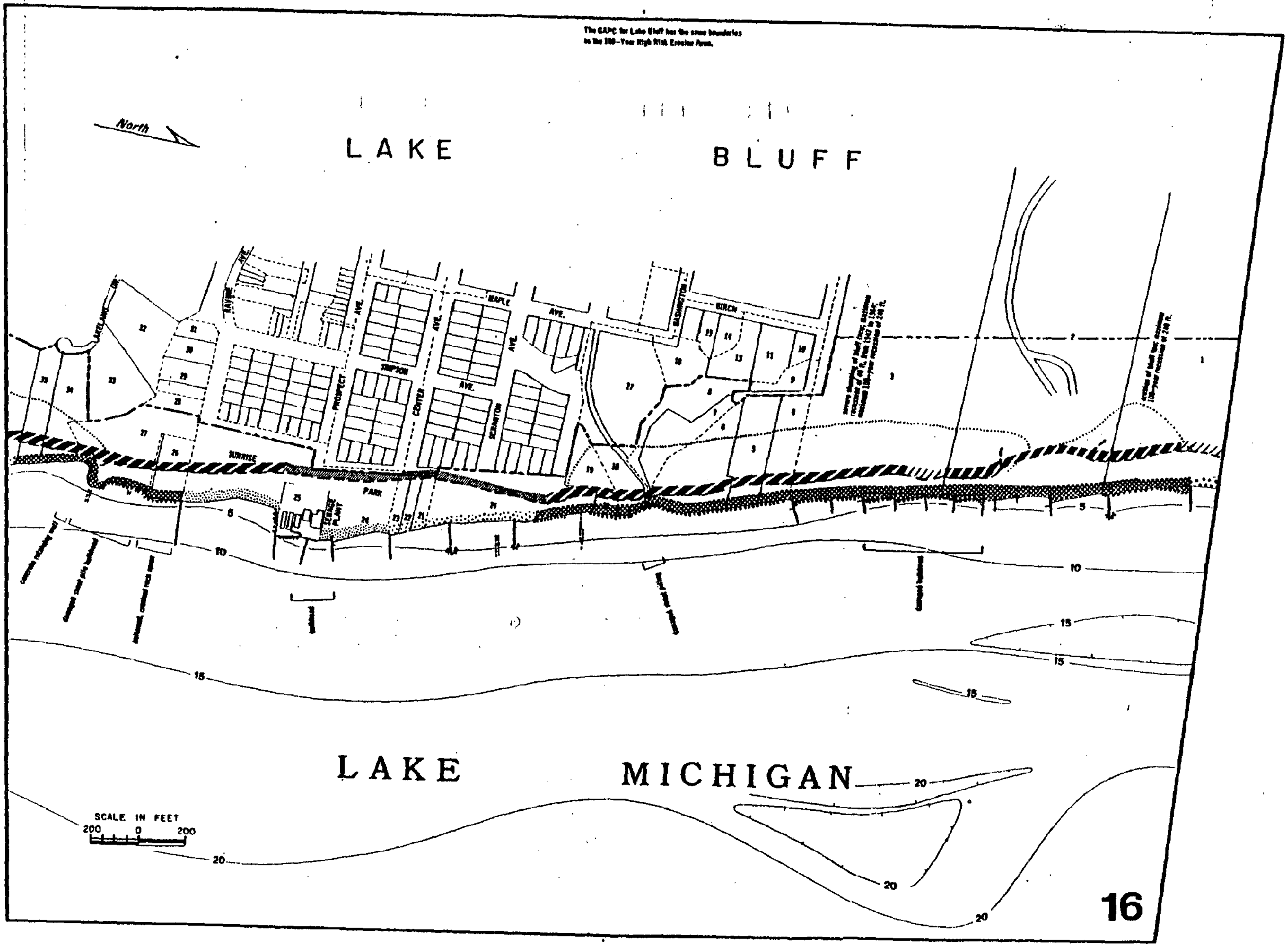

WAUKEGAN
North
CHICAGO & NORTHWESTERN R.R.
LAKE MICHIGAN
SCALE IN FEET
200 0 200
11

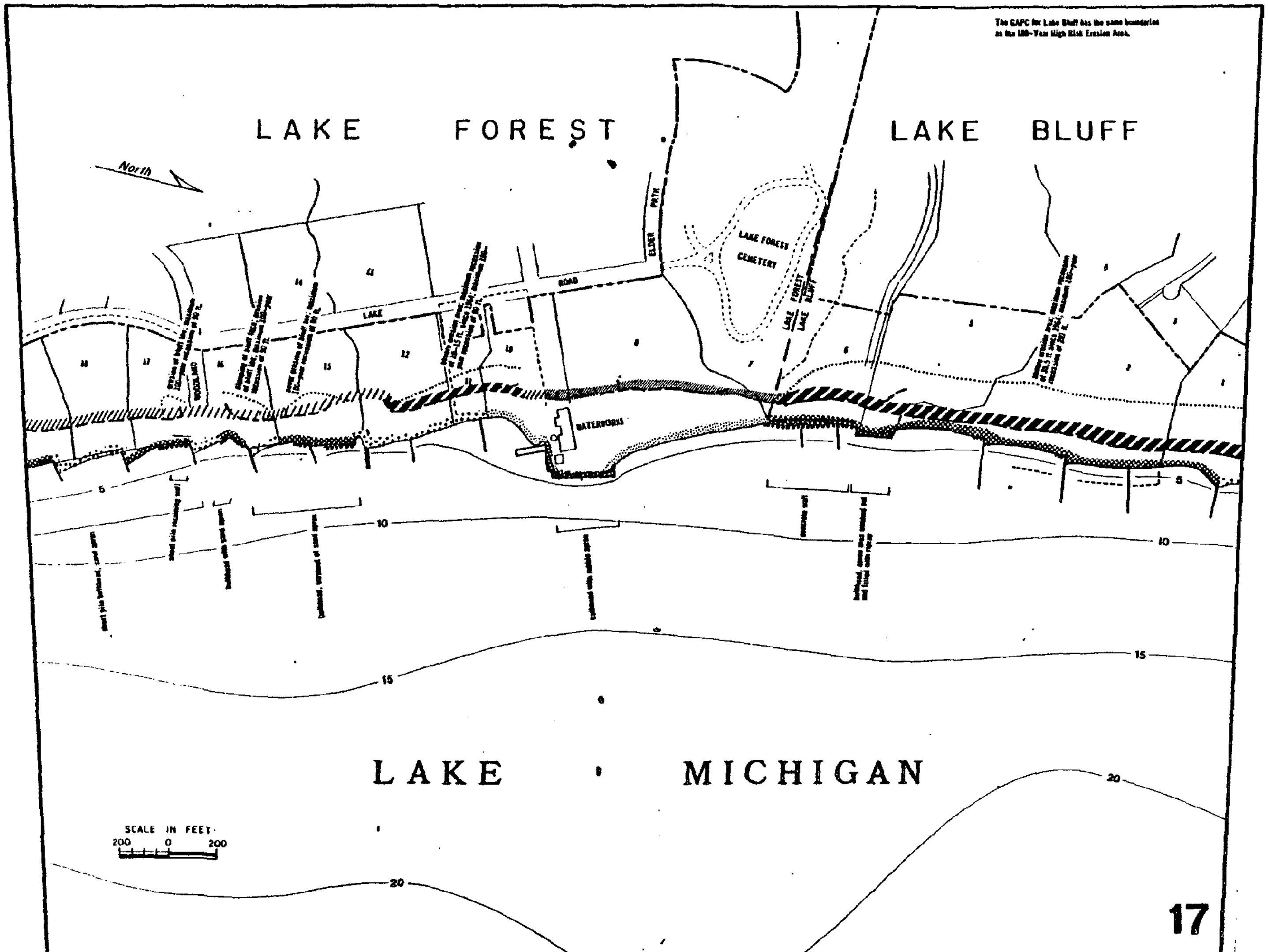

North
NORTH CHICAGO
WAUKEGAN
CHICAGO
NORTHWESTERN
R.R.
ELGIN
JOLIET
EASTERN
U.S. STEEL
NORTH CHICAGO
WAUKEGAN
5
10
15
20
LAKE MICHIGAN
SCALE IN FEET
200 0 200
12

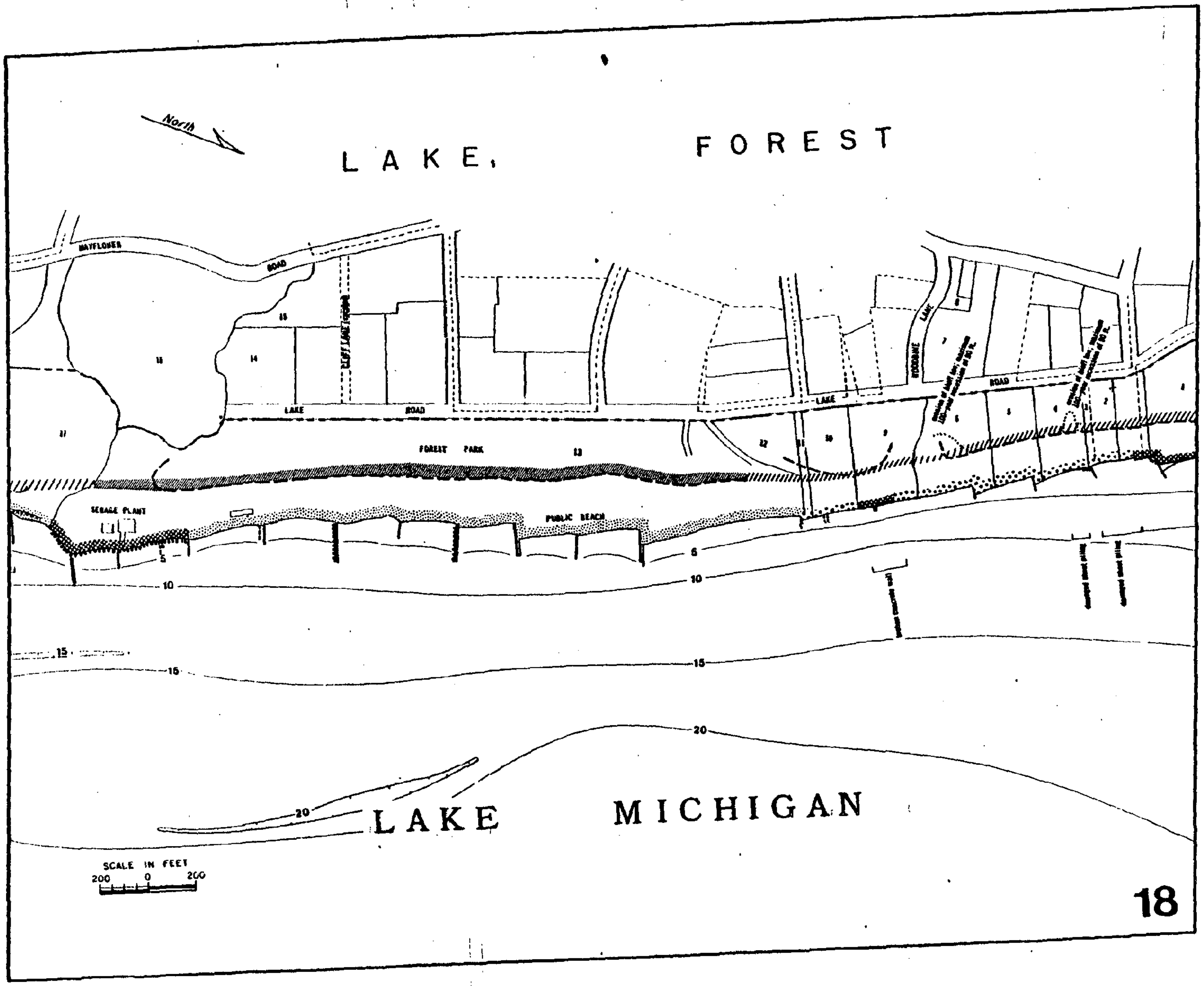

NORTH CHICAGO
North
CHICAGO & NORTHWESTERN R. R.
ELGIN JOLIET & EASTERN R.R.
SEWAGE PLANT
FOSS PARK
GREAT LAKES NAVAL TRAINING STATION
NORTH CHICAGO
NORTH CHICAGO WATERWORKS
FIFTH AVE.
LAKE MICHIGAN
5
10
15
20
SCALE IN FEET
200 0 200
13

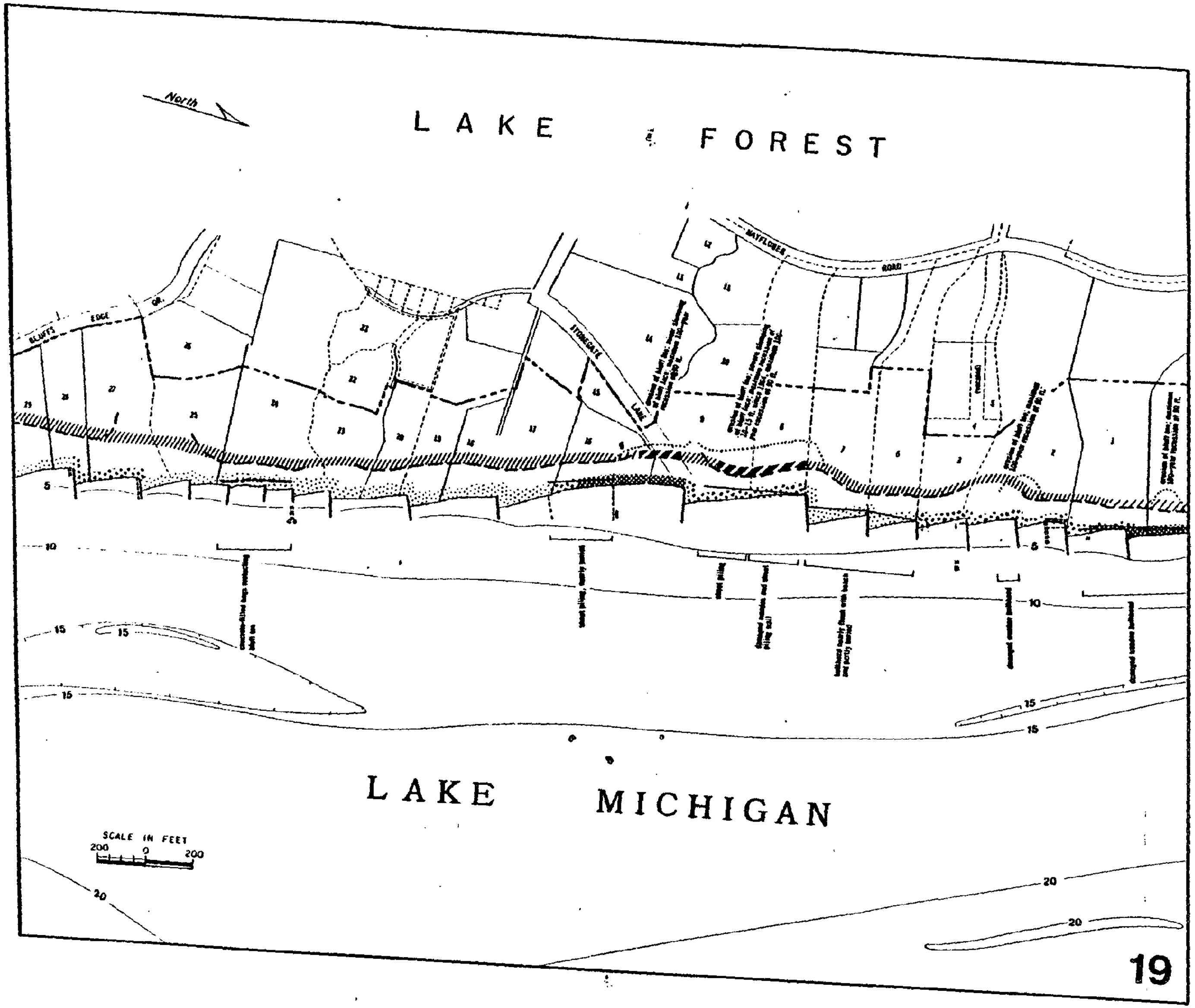

North
GREAT LAKES NAVAL TRAINING STATION
LAKE BLUFF
GREAT LAKES NAVAL TRAINING STA.
GREAT LAKES
HARBOR
LAKE
MICHIGAN
SCALE IN FEET
200 0 200

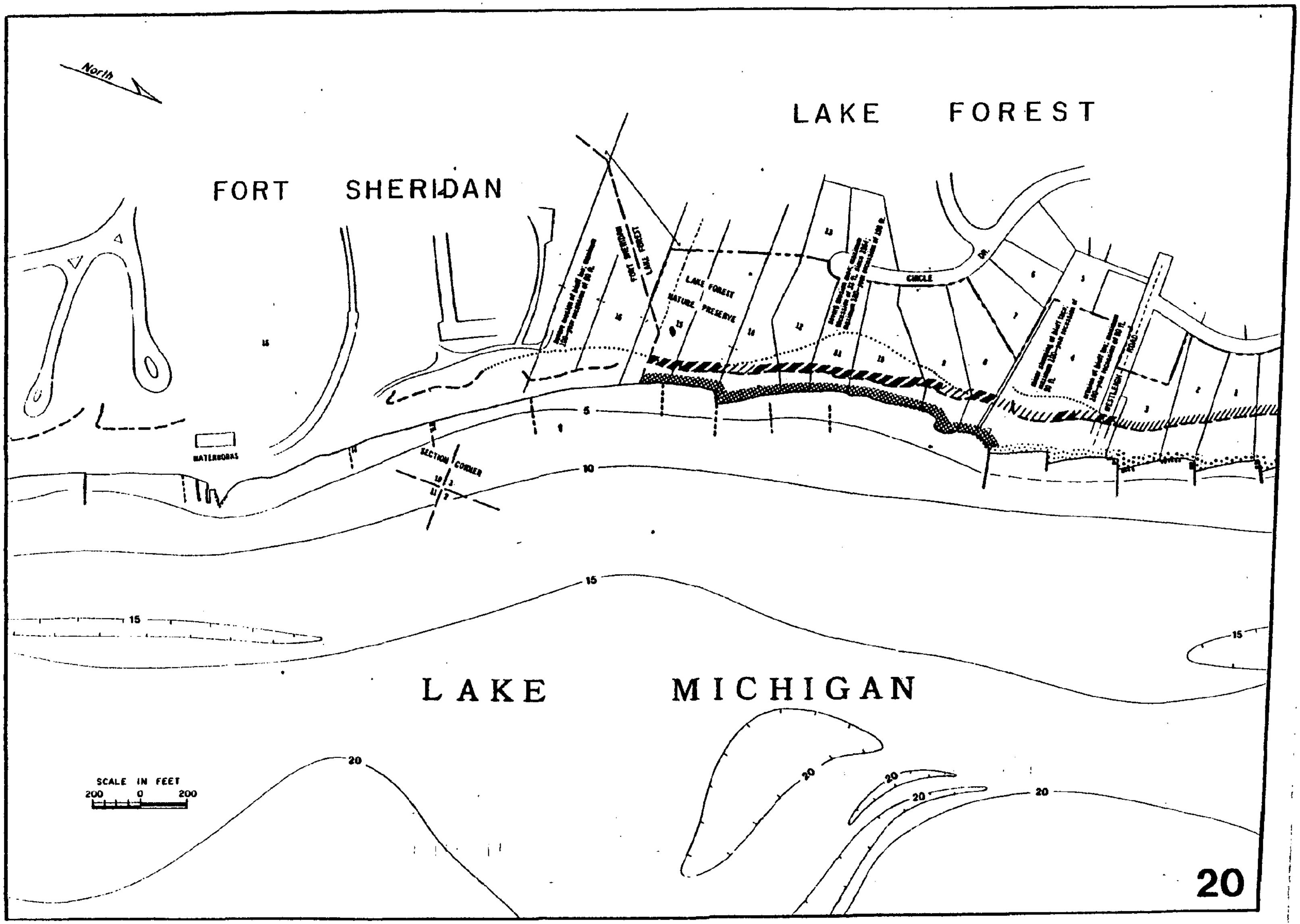

North
LAKE BLUFF
SHORE ACRES ROAD
SHOREACRES
GOLF CLUB
LAKE MICHIGAN
SCALE IN FEET
200 0 200
15

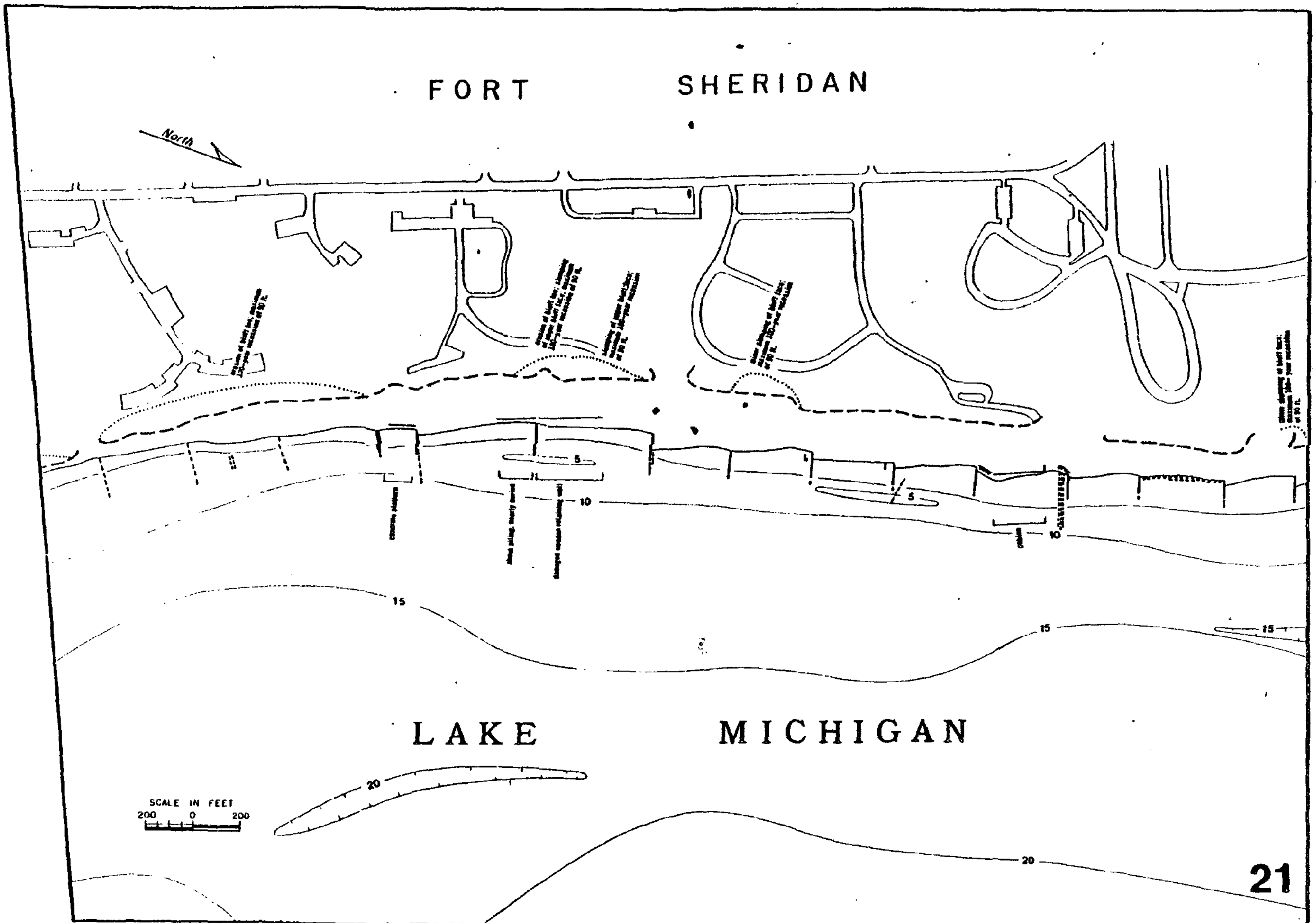

North
LAKE BLUFF
LAKE MICHIGAN
MAPLE AVE.
BIRCH
WASHINGTON
PROSPECT AVE.
SIMPSON
CENTER AVE.
SCRANTON AVE.
RAVINE AVE.
SUNRISE
PARK
SCALE IN FEET
200 0 200
16

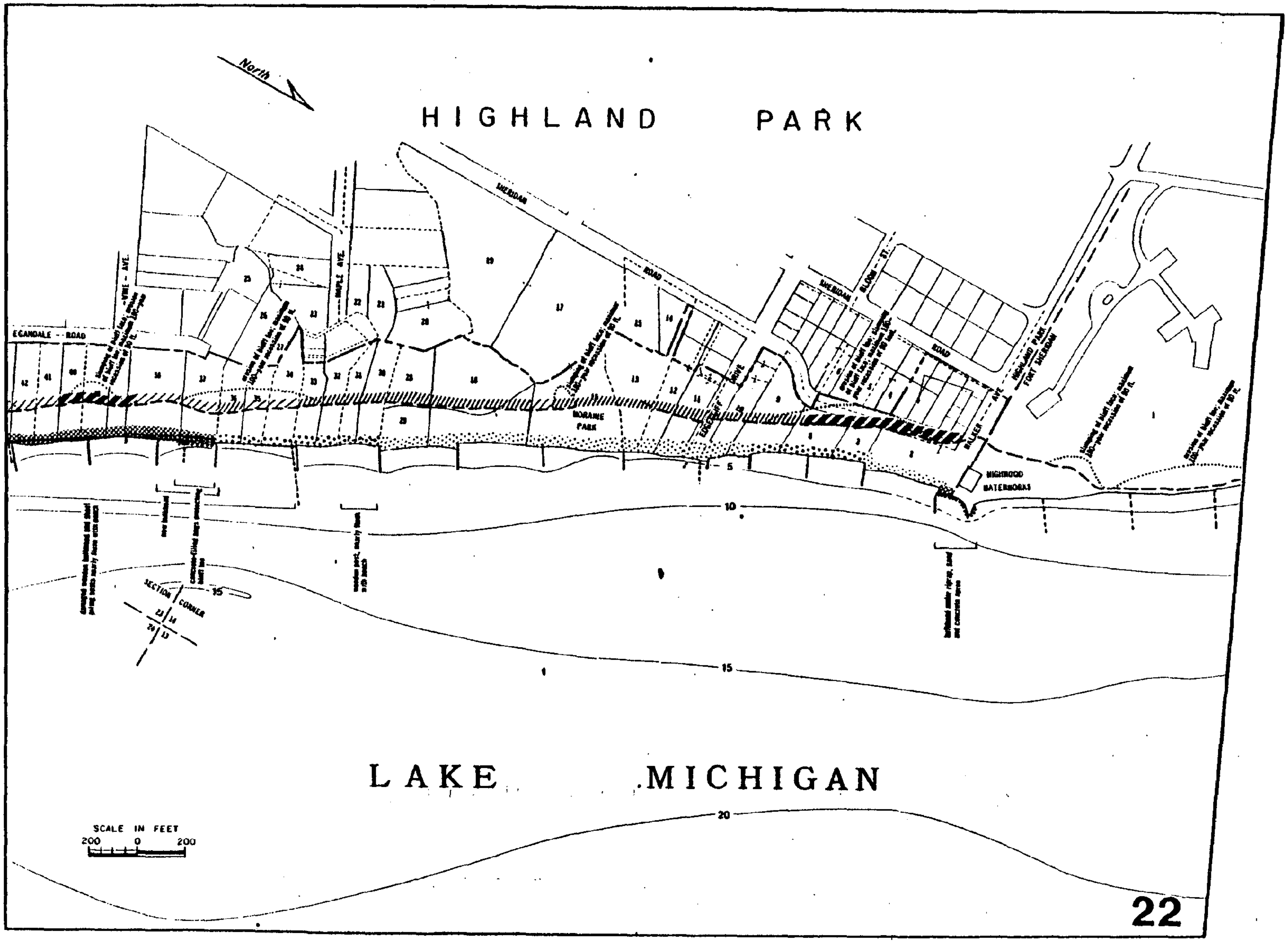

LAKE FOREST
LAKE BLUFF
North
LAKE FOREST CEMETERY
ELDER PATH
LAKE ROAD
WOODLAND
WATERWORKS
LAKE MICHIGAN
SCALE IN FEET
200 0 200
5
10
15
20
17


North
LAKE FOREST
MAYFLOWER ROAD
LAKE ROAD
FOREST PARK
SEWAGE PLANT
PUBLIC BEACH
LAKE MICHIGAN
SCALE IN FEET
200 0 200
18

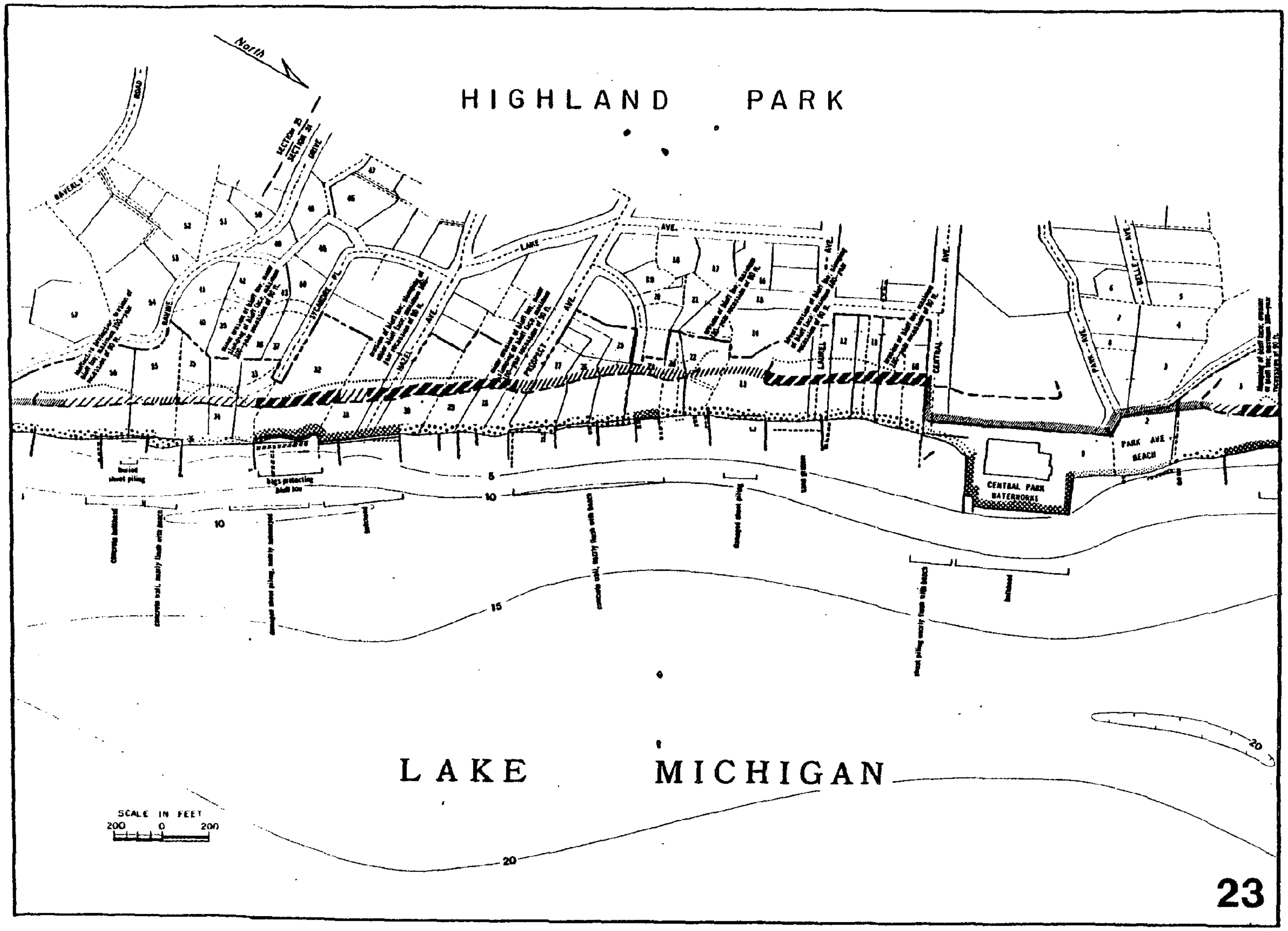

North
LAKE FOREST
MAYFLOWER ROAD
STONEGATE LANE
BLUFFS EDGE DR.
LAKE MICHIGAN
SCALE IN FEET
200 0 200
19

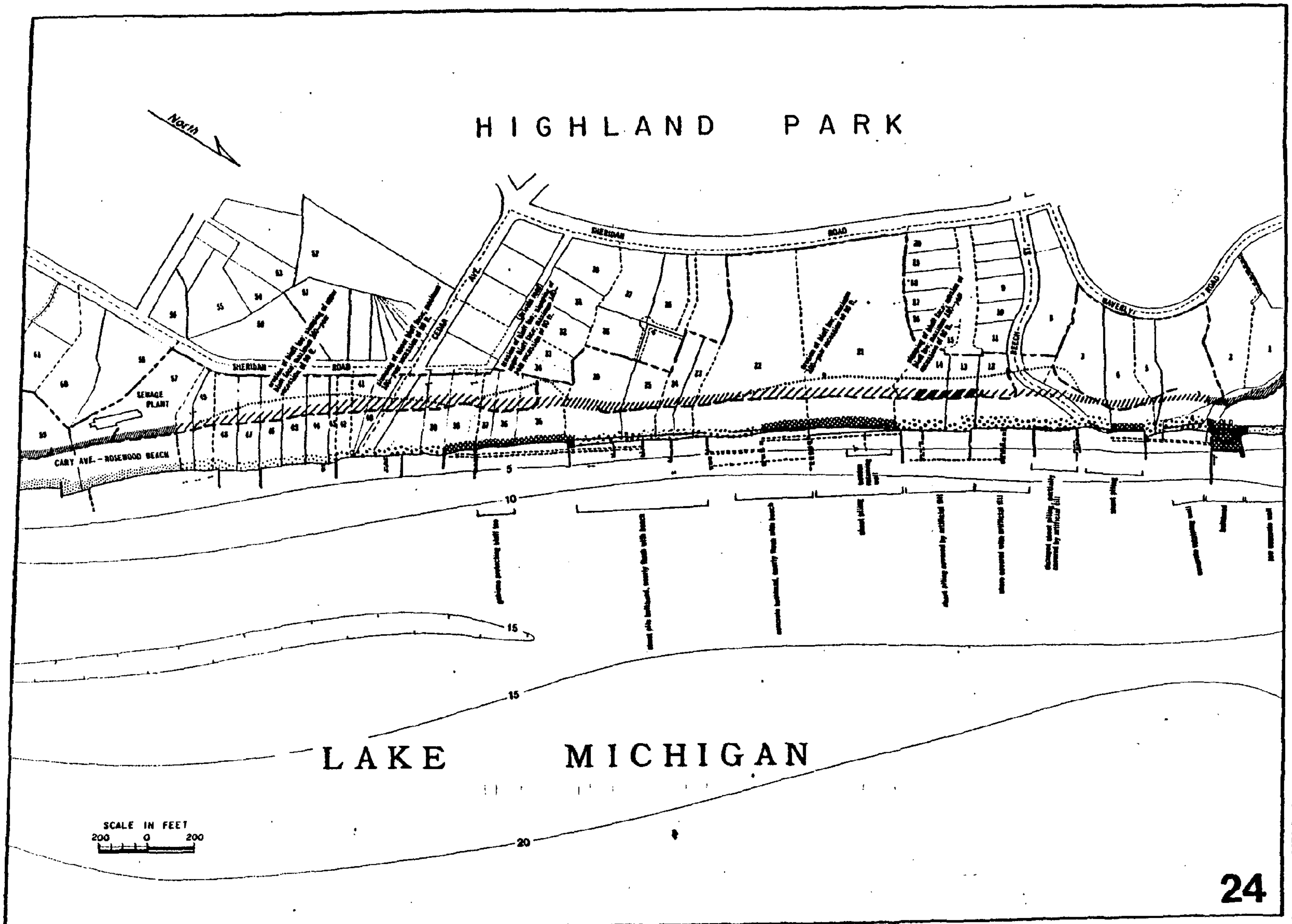

North
FORT SHERIDAN
LAKE FOREST
LAKE FOREST NATURE PRESERVE
FORT SHERIDAN
LAKE FOREST
CIRCLE
DR
WESTLEIGH
ROAD
WATERBOARS
SECTION CORNER
LAKE MICHIGAN
SCALE IN FEET
200 0 200
20

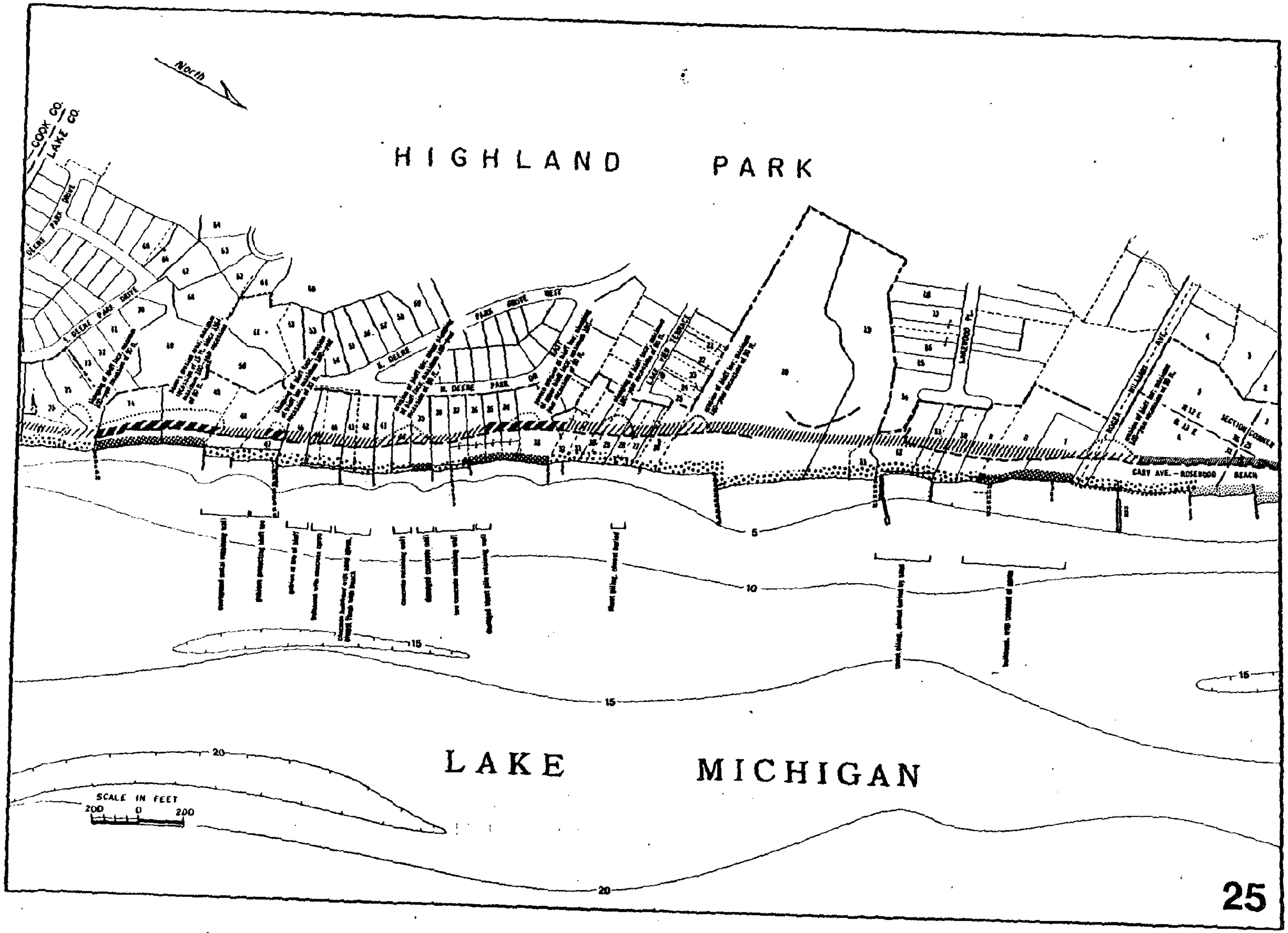

FORT SHERIDAN
North
LAKE MICHIGAN
SCALE IN FEET
200 0 200
5
10
15
20
21

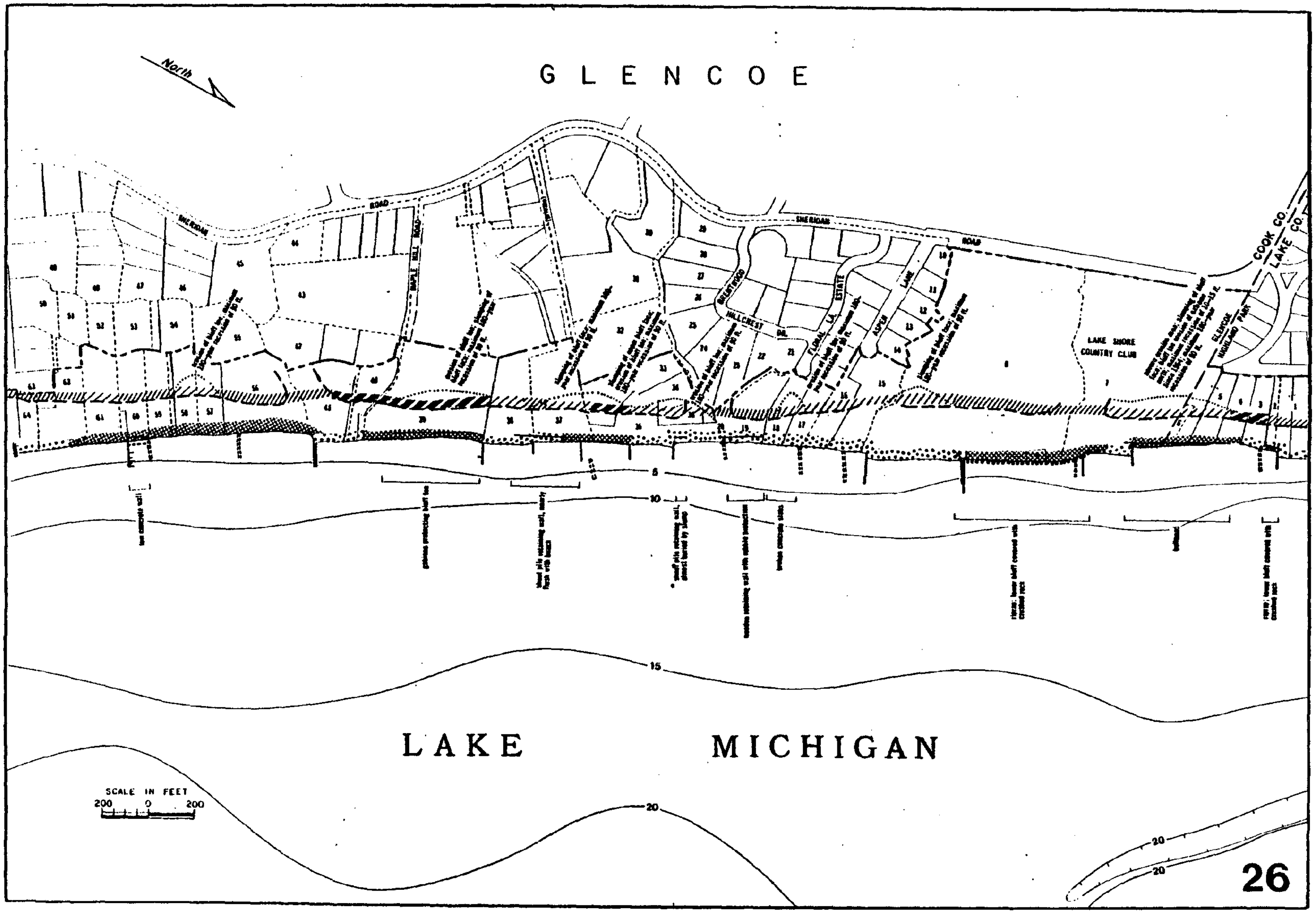


North
HIGHLAND PARK
LAKE MICHIGAN
SHERIDAN ROAD
EGANDALE ROAD
VINE AVE.
MAPLE AVE.
BLOOM ST.
WALKER AVE.
HIGHLAND PARK
FORT SHERIDAN
MORAINE PARK
HIGHWOOD WATERWORKS
SECTION CORNER
SCALE IN FEET
200
0
200
10
15
20
22

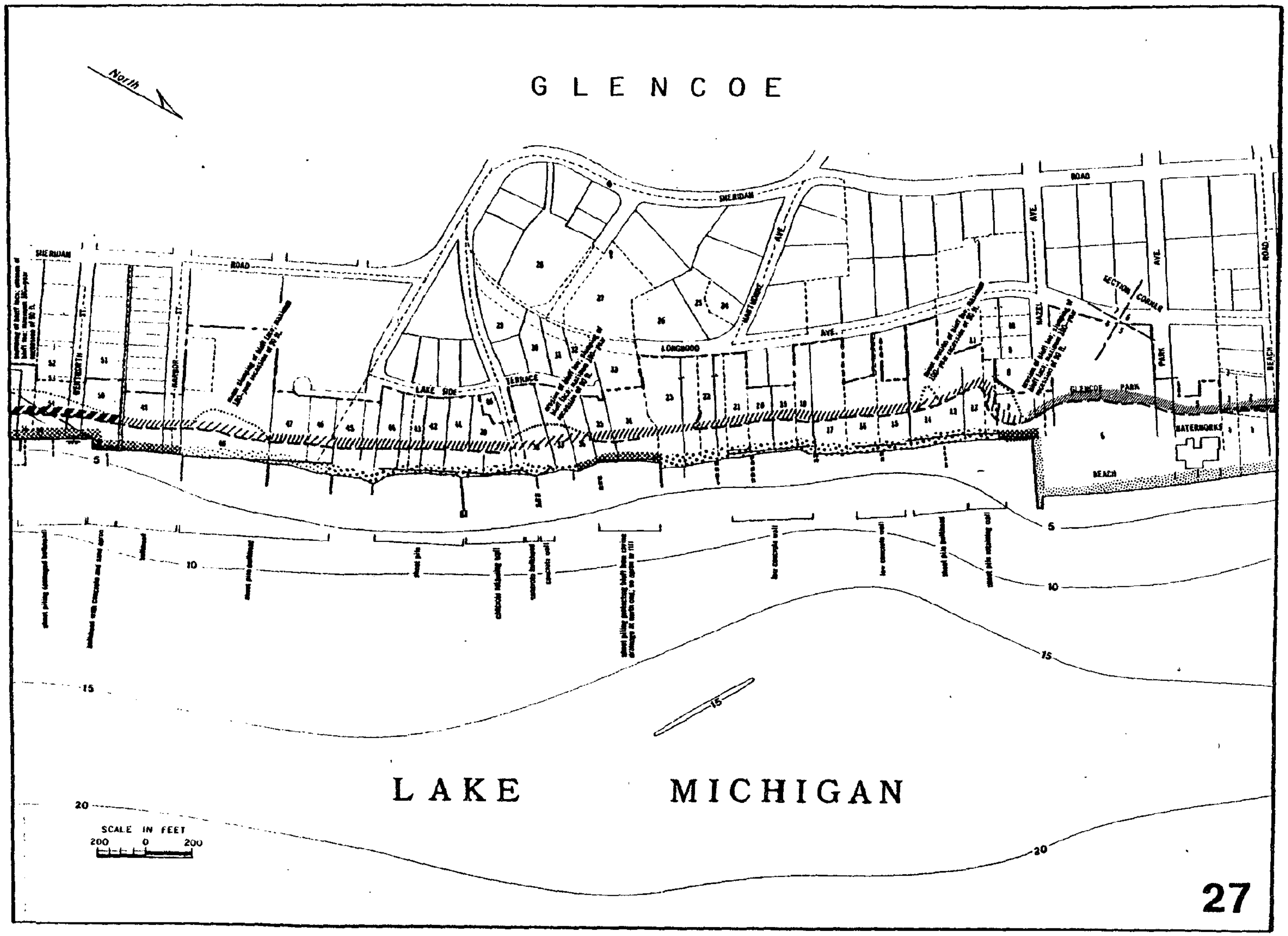

North
HIGHLAND PARK
LAKE MICHIGAN
CENTRAL PARK WATERWORKS
PARK AVE BEACH
SCALE IN FEET
200 0 200
23

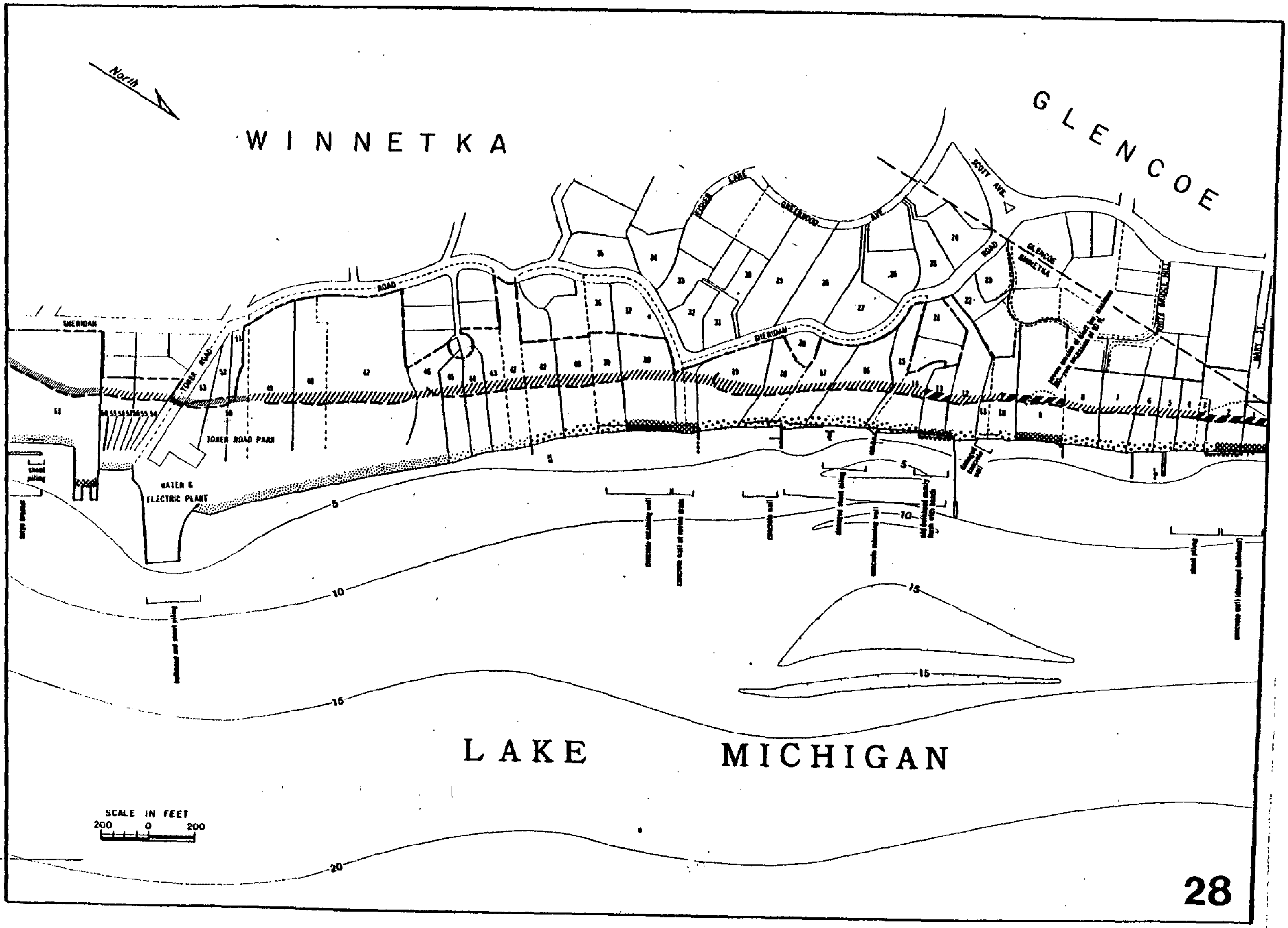

HIGHLAND PARK
North
SHERIDAN ROAD
CEDAR AVE.
BEECH ST.
WAVERLY ROAD
SEWAGE PLANT
CARY AVE. - ROSEWOOD BEACH
LAKE MICHIGAN
SCALE IN FEET
200 0 200
24


North
COOK CO.
LAKE CO.
HIGHLAND PARK
LAKE MICHIGAN
LAKEWOOD PL.
SECTION CORNER
SCALE IN FEET
200 0 200
5
10
15
20
25

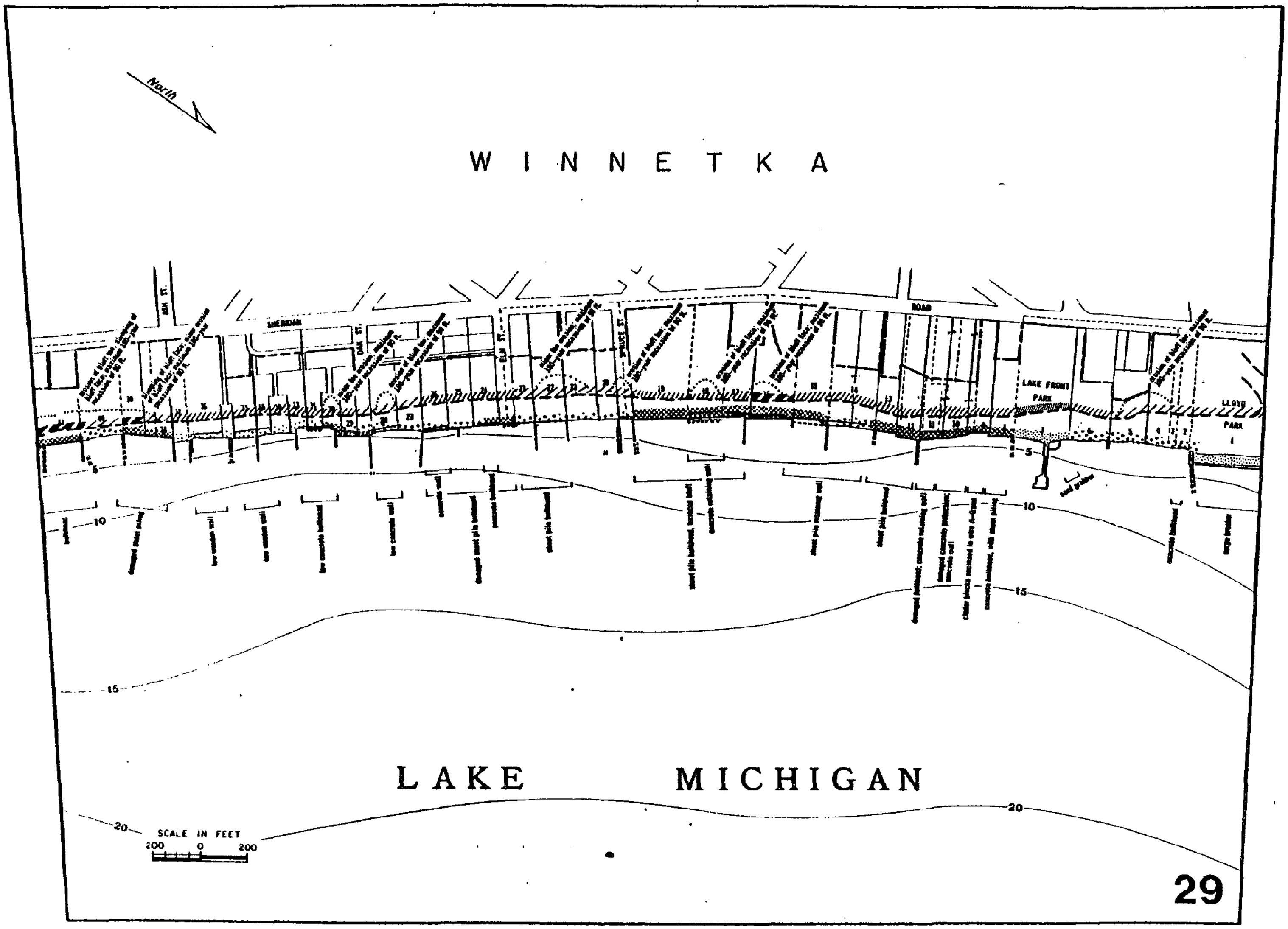

GLENCOE
North
SHERIDAN ROAD
MAPLE HILL ROAD
BRENTWOOD
HILLCREST DR.
FLORAL LA.
ASPEN LANE
ESTATE
LAKE SHORE COUNTRY CLUB
GLENCOE HUBBARD PARK
COOK CO.
LAKE CO.
LAKE MICHIGAN
SCALE IN FEET
200 0 200

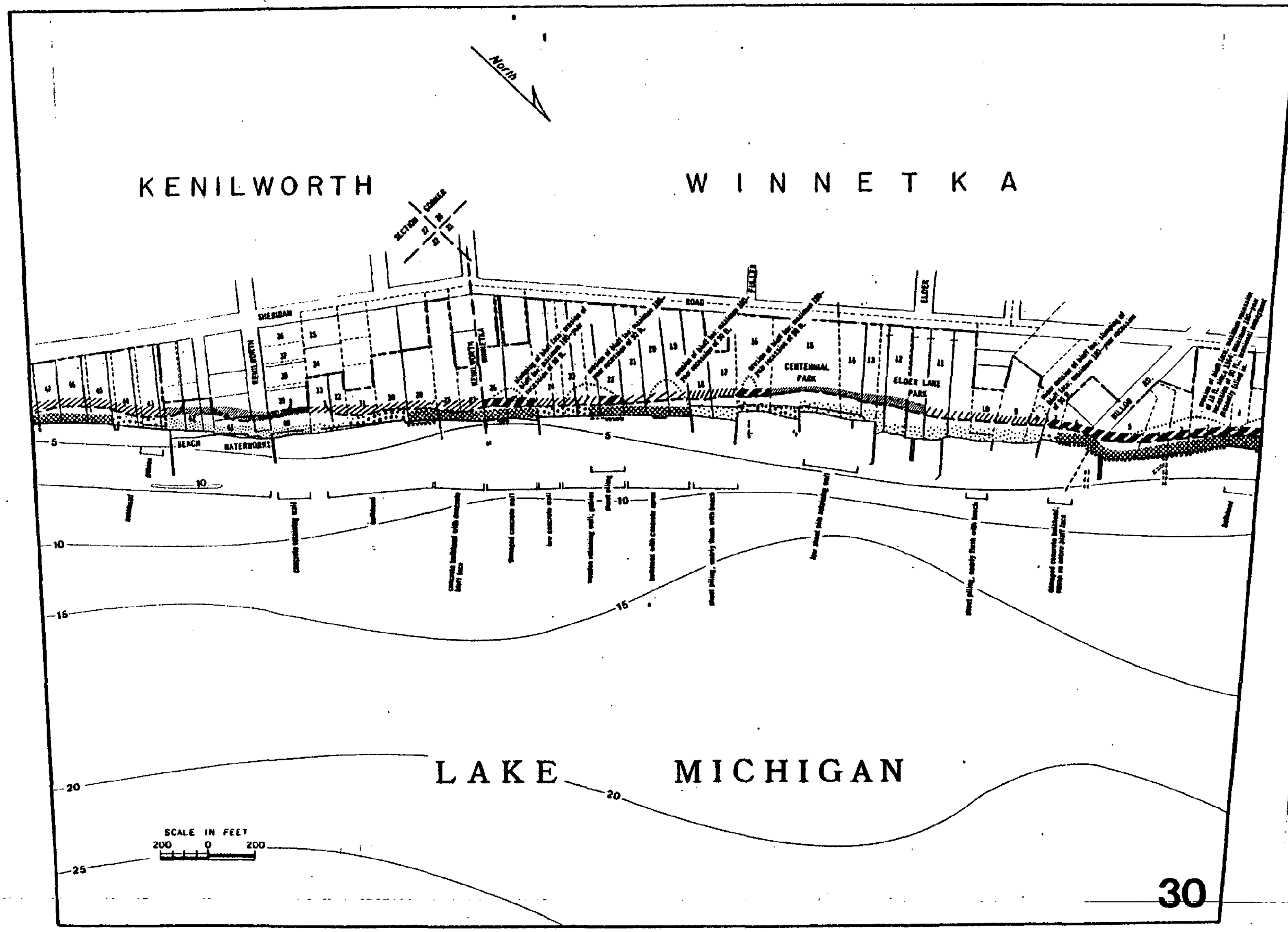
26

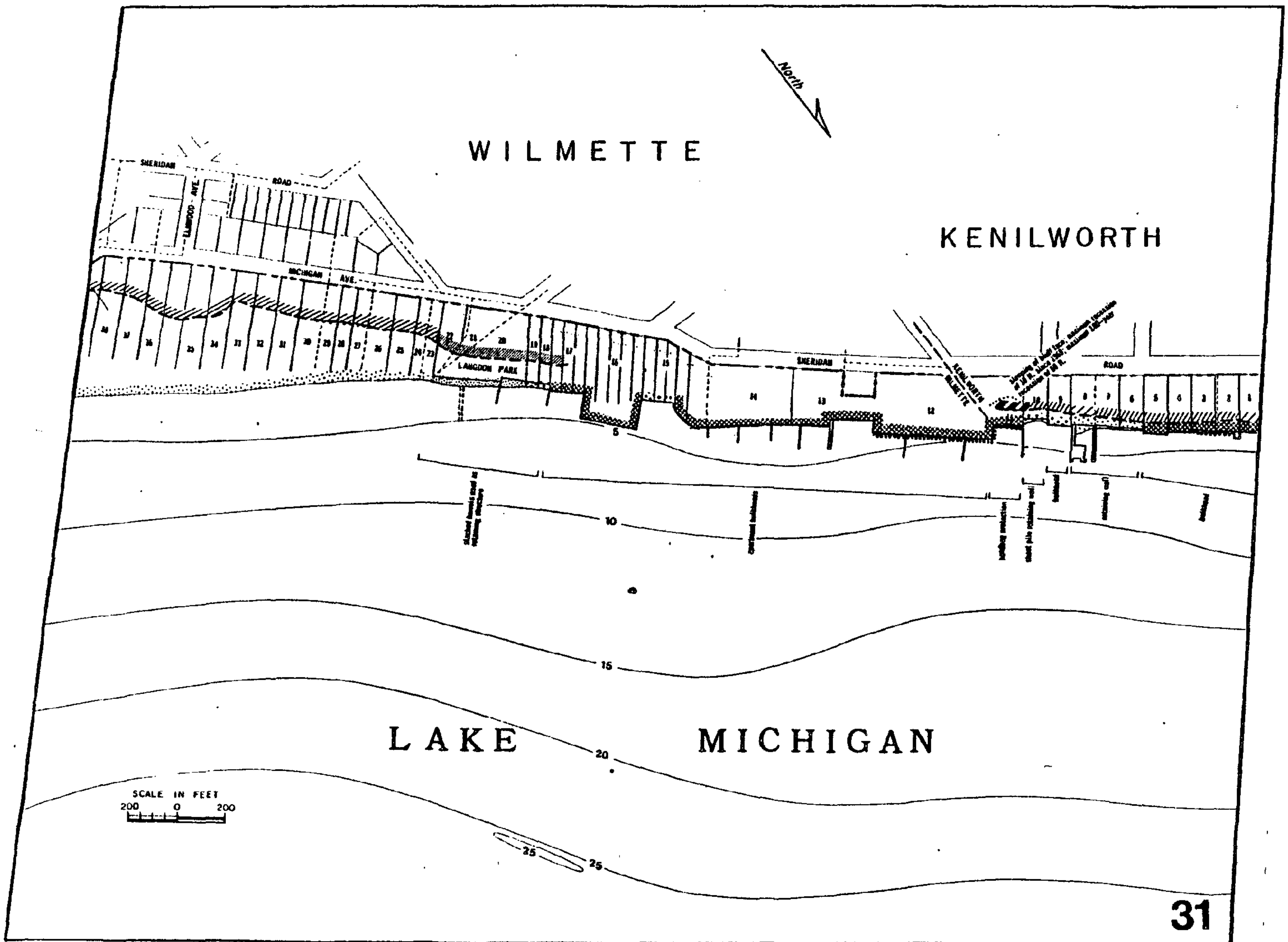

GLENCOE
North
SHERIDAN
ROAD
WENTWORTH ST.
HARBOR ST.
LAKE SIDE
TERRACE
LONGWOOD AVE.
HAWTHORNE AVE.
HAZEL AVE.
PARK AVE.
SECTION CORNER
GLENCOE PARK
BEACH ROAD
WATERWORKS
BEACH
LAKE MICHIGAN
SCALE IN FEET
200 0 200
5
10
15
20
27


North
WINNETKA
GLENCOE
SCOTT AVE.
GLENCOE
WINNETKA
GREENWOOD AVE.
SHERIDAN
TOWER ROAD
TOWER ROAD PARK
WATER & ELECTRIC PLANT
LAKE MICHIGAN
SCALE IN FEET
200 0 200

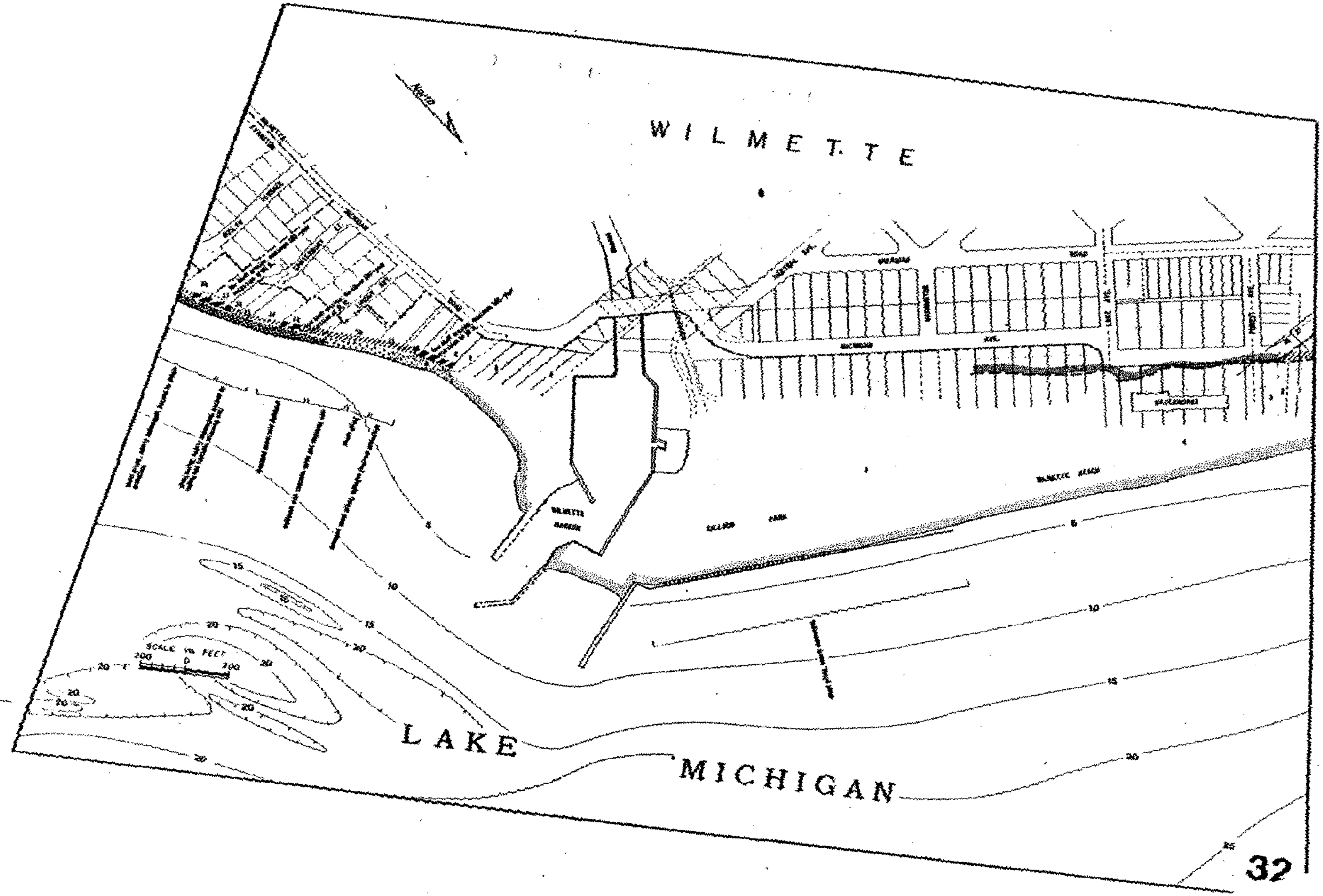
28

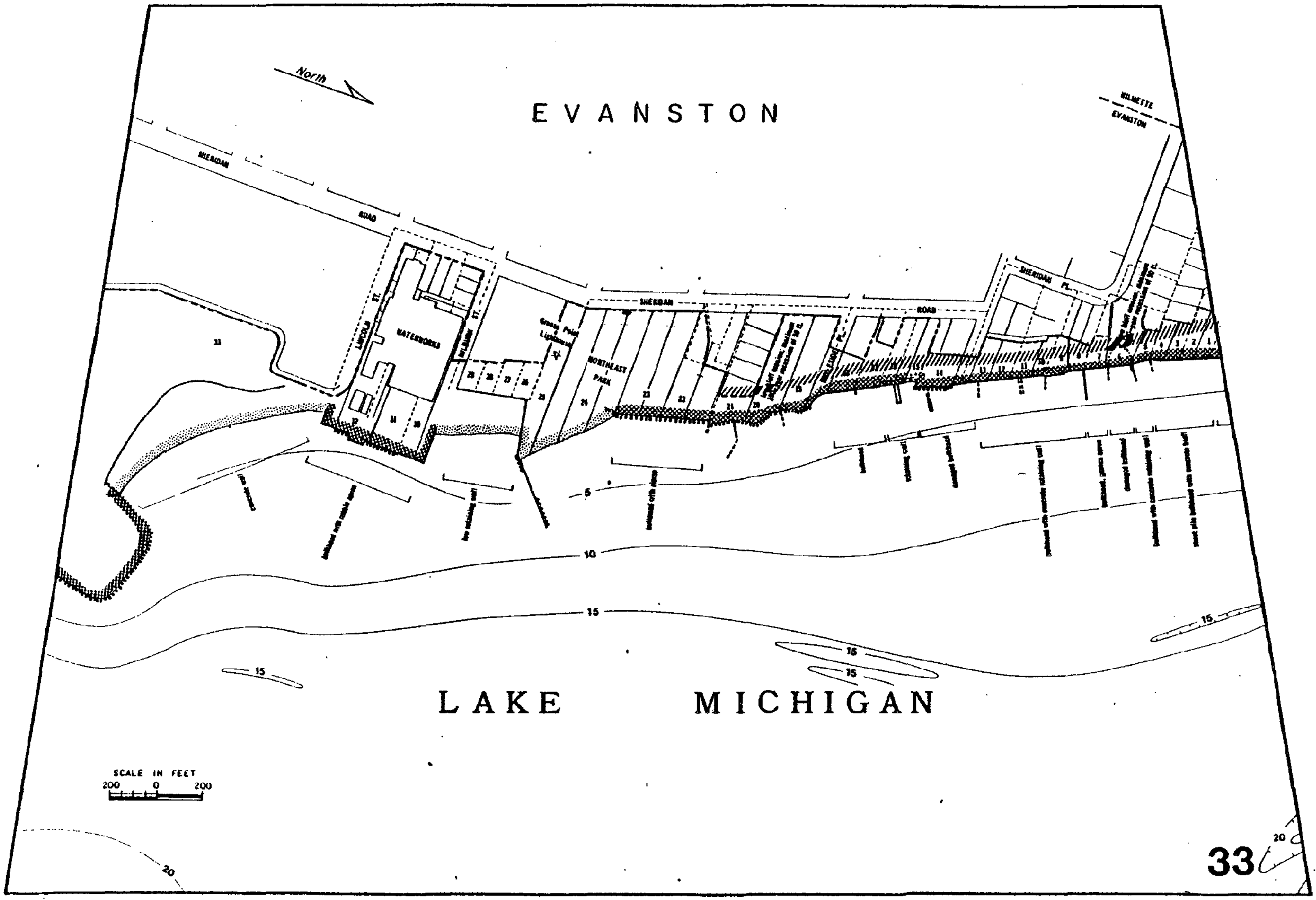

North
WINNETKA
ASH ST.
SHERIDAN
OAK ST.
ELM ST.
SPRUCE ST.
ROAD
LAKE FRONT PARK
LLOYD PARK
LAKE MICHIGAN
5
10
15
20
SCALE IN FEET
200 0 200
29


North
KENILWORTH
WINNETKA
SECTION CORNER
SHERIDAN
ROAD
KENILWORTH
WINNETKA
ELDER
CENTENNIAL PARK
ELDER LANE PARK
BEACH
WATERWORKS
LAKE MICHIGAN
SCALE IN FEET
200 0 200
5
10
15
20
25



WILMETTE
KENILWORTH
North
SHERIDAN
ROAD
MICHIGAN AVE.
LANGDON PARK
LAKE MICHIGAN
5
10
15
20
25
25
SCALE IN FEET
200 0 200
31


WILMETTE
North
WILMETTE HARBOR
LAKE MICHIGAN
SCALE IN FEET
200 0 200
32



North
EVANSTON
WILMETTE
EVANSTON
SHERIDAN
ROAD
SHERIDAN PL.
LINCOLN ST.
WATERWORKS
MILBURN ST.
NORTHEAST PARK
LAKE MICHIGAN
SCALE IN FEET
200 0 200
33

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Collinson, C., R. D. Norby, P. L. Drake, R. C. Berg, and C. Anchor, 1977, Map Atlas, Lake Michigan shore in Illinois, Illinois Coastal Zone Management Program, Second Year Work Product, 30 p.

Norby, R. D., and C. Collinson, 1976, Illinois coastal processes, resources and geology, Zion Beach Ridge and Dune Plain: Illinois State Geological Survey open file report, 50 p.

Illinois State Geological Survey

The Effect on Coastal Processes of Large Shore Structures at Waukegan and Great Lakes, Illinois

ILLINOIS COASTAL ZONE MANAGEMENT DEVELOPMENT PROJECT

THE EFFECT ON COASTAL PROCESSES OF LARGE SHORE STRUCTURES AT WAUKEGAN AND GREAT LAKES, ILLINOIS

Richard C. Berg

Prepared by the

ILLINOIS STATE GEOLOGICAL SURVEY

for

THE ILLINOIS COASTAL ZONE

MANAGEMENT PROGRAM

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OCTOBER 1977

THE EFFECT ON COASTAL PROCESSES OF LARGE SHORE STRUCTURES AT WAUKEGAN AND GREAT LAKES, ILLINOIS

Richard C. Berg

ABSTRACT

Analyses of shore and nearshore accretion and recession, associated with piers and jetties at Waukegan and at the Great Lakes Naval Training Center, were made for the period 1872 through 1976. Consideration of sand resources, littoral drift, wave reflection and refraction, nearshore slope and hydrography as well as the characteristics of shore protective structures were taken into account. Aerial photography, hydrographic maps and field studies were utilized.

Examination of nearshore and adjacent offshore slopes before and after construction of the Great Lakes Naval Training Center and Waukegan jetties clearly shows their effects on longshore sediment drift, beach widths, bluff erosion and wave phenomena.

It is concluded that the jetties of the Great Lakes Naval Training Center afford protection from damaging northeast wave storms for the nearby downdrift bluff shore in Lake Bluff but at the same time intercept a lean littoral drift that moves southward from Waukegan. Waukegan jetties impound most of the littoral sediment derived from shores to the north as demonstrated by the fact that littoral sand thickness exceeds 30 feet north of Waukegan but rarely exceeds 10 feet south of the harbor.

On balance, the effect of the Great Lakes jetties on the downdrift shore is moderately beneficial whereas the effect of the Waukegan jetties is strongly negative.

INTRODUCTION

Large shore structures -- jetties, piers, and long groins -- have been constructed along the Illinois shore of Lake Michigan for the purposes of increasing updrift beach accumulation, preventing active shoreline erosion, and reducing sedimentation at the mouths of harbors. Although such structures are successful shoreline protectors, they commonly have adverse effects on downdrift reaches of shore. Oftentimes sand is trapped on the updrift side causing a downdrift sediment deficit that results in steep nearshore slopes, narrow starved beaches and high rates of bluff recession. In addition, large structures can cause wave reflections that concentrate wave energies, modify currents and cause eddies all of which may result in sediment loss and increased shoreline erosion. The effect of large structures on shore processes is discussed by Bruun (1952), Hartley (1964), and Carter (1976).

In areas where beaches are narrow and nearshore slopes are steep, the toes of shoreline bluffs are subject to wave attack and undercutting that eventually lead to shoreline erosional losses. Along the Illinois shore of Lake Michigan, particularly at Lake Bluff, there are numerous reaches where unstable and oversteepened slopes (some as steep as 90°) exhibit high rates of recession. It has been the contention of some downdrift property owners and municipal officials that such erosion along the Lake Bluff shore is the result of sand-entrapment by the long jetties at the Great Lakes Naval Training Station (Fig. 1).

Because shoreline losses are excessively high at Lake Bluff and could be ameliorated by sediment bypass techniques at the Great Lakes Naval Training Station jetties,if indeed they were responsible for the losses, the present detailed study was undertaken. In addition, it was anticipated that results from this study might be widely applicable on Lake Michigan shores. The study was additionally attractive because of the existence of excellent maps and photographic records of shore history. With this in mind, detailed bluff erosion measurements were made along the shore between Shore Acres Country Club and the south jetty of the Great Lakes Naval Training Station Harbor. These were reported in a previous paper (Berg and Collinson, 1976). The measurements disclosed that the recession rate of bluffs in the northern part of Lake Bluff was considerably greater preceding construction of the jetties. The bluff eroded at a rate of 6.20 feet per year between 1872 and 1910, while from 1964 to 1975, the rate was 3.64. The overall recession rate for Lake Bluff from 1872 to 1910 was 4.13 feet per year while from 1964 to 1975 it was 2.77. Although the differences in erosion rates can in part be explained by the greater frequency of high lake level years between 1872 and 1910, the post-construction rate is nevertheless smaller than the rate preceding construction of the jetties. It was attributable to factors other than deprivation of littoral sediments by sand entrapment at the updrift side of the Great Lakes Naval Training Station jetties.

The purpose of this study was to investigate in detail the relative effect of the Great Lakes Naval Training Station jetties on lake and shore processes -- wave reflection and wave refraction, sediment deflection, changes in the nearshore slope and hydrography, and effects on offshore sand resources. This study of these phenomena, the distribution updrift and downdrift, and their relative magnitudes, has revealed that the jetties at Waukegan are the primary contributors to beach starvation, nearshore scour and high rates of bluff erosion along the Lake Bluff shore and that the Great Lakes jetties in fact have had a beneficial effect by providing a measure of protection.

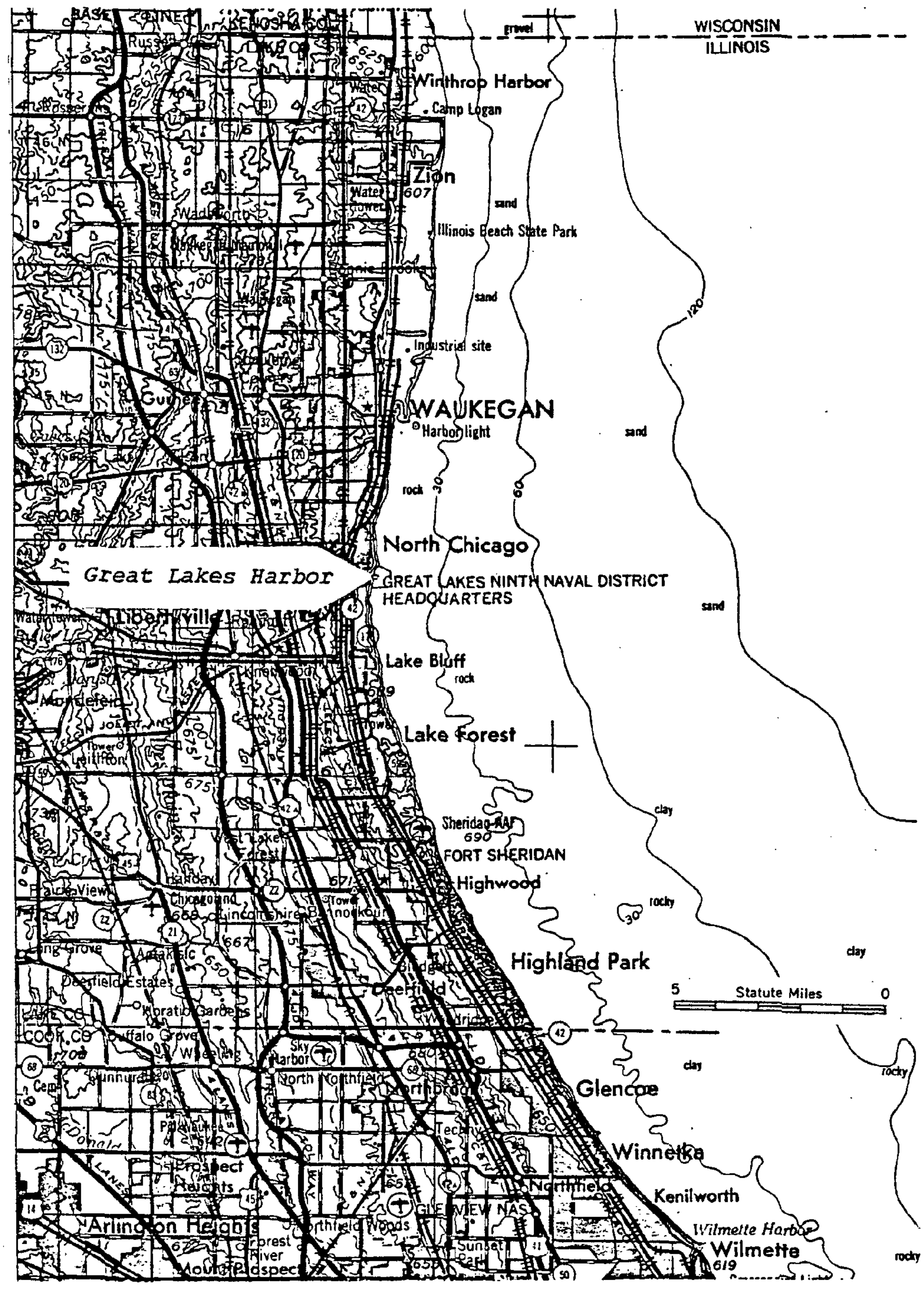


Fig. 1 - Map showing the location of the Great Lakes Harbor and the reach of shore studied.

Physical Setting and Characteristics of the Jetties

Two outer harbor jetties at Great Lakes Naval Training Station were constructed in 1923 to maintain a quiet water harbor and prevent shoreline erosion. The jetties are composed of a limestone core with riprap added to the surface. (The total length of the northern jetty is 3152 feet from shore. The east-west portion is 1660 feet long, while the north-south section, which acts as breakwater, is 1492 feet long. Fig. 2.) The northern jetty is void of riprap at the tip for 541 feet and also in a 500-foot portion nearest the shore. The southern jetty has just two small sections where riprap is not apparent—a 110-foot section at the tip and a 170-foot section in the midportion. About 700 feet of riprap was added to the western portion of the southern jetty in late 1965 or in early 1966. The total length of the southern jetty is 1999 feet. The east-west portion is 1560 feet long, while its short northeasterly-southeasterly tip is 439 feet long. The maximum protrusion of these jetties from shore is 2350 feet, thus having a large potential to offset the general longshore transport.

SEDIMENT BYPASS AND WAVE REFLECTION

Sediment diversion around and into Great Lakes Naval Training Station Harbor is clearly shown on several photos. Severe storm waves from a northeasterly direction resulted in the bypassing by a large volume of material in suspension visible on the 1937 photo (Fig. 3). Much of this sediment settled on the leeside of the jetties downdrift of the southerly moving current in an area protected from damaging northeasterly storm waves. Sediment bypassing is also visible, but to a lesser extent, on the 1955, 1966, and 1967 photos (Figs. 4, 5, and 6). Both photos show the settling of material south of the jetties resulting from wave trains from an easterly-northeasterly direction. The broad flat sand plain south of the jetties, visible on a hydrographic map of the area (see appendix), is attributed to the quiet water condition downdrift of the jetties and indicates the high degree of protection that these structures offer to the nearby north Lake Bluff shore.

Sediment diversion into Great Lakes Naval Training Station Harbor represents a permanent removal of sand from the general longshore transport. Sediment washover and removal from the littoral system are clearly shown along the inside of the north jetty on the 1955 (Fig. 4), 1958 (Fig. 7), and 1961 (Fig. 8) photos indicating a situation similar to that described by Hartley (1964) at Lorain Harbor on Lake Erie in Ohio.

Since the most damaging waves approach the shore from a northeasterly direction, sediment washover primarily occurs over the northern jetty. This is particularly noticeable on the 1964 photo, (Fig. 9) where lowered lake levels have exposed sand deposits which were previously submerged during a regime of higher water levels. Exposed sand deposits are not visible along the southern jetty.

The settling of sediment on the leeside of the jetties, the presence of sediment buildup along the inside of the northern jetty, and the absence of sediment along the inside of the southern jetty all indicate the importance of these structures in protecting the shoreline immediately to the south from damaging northeasterly waves.

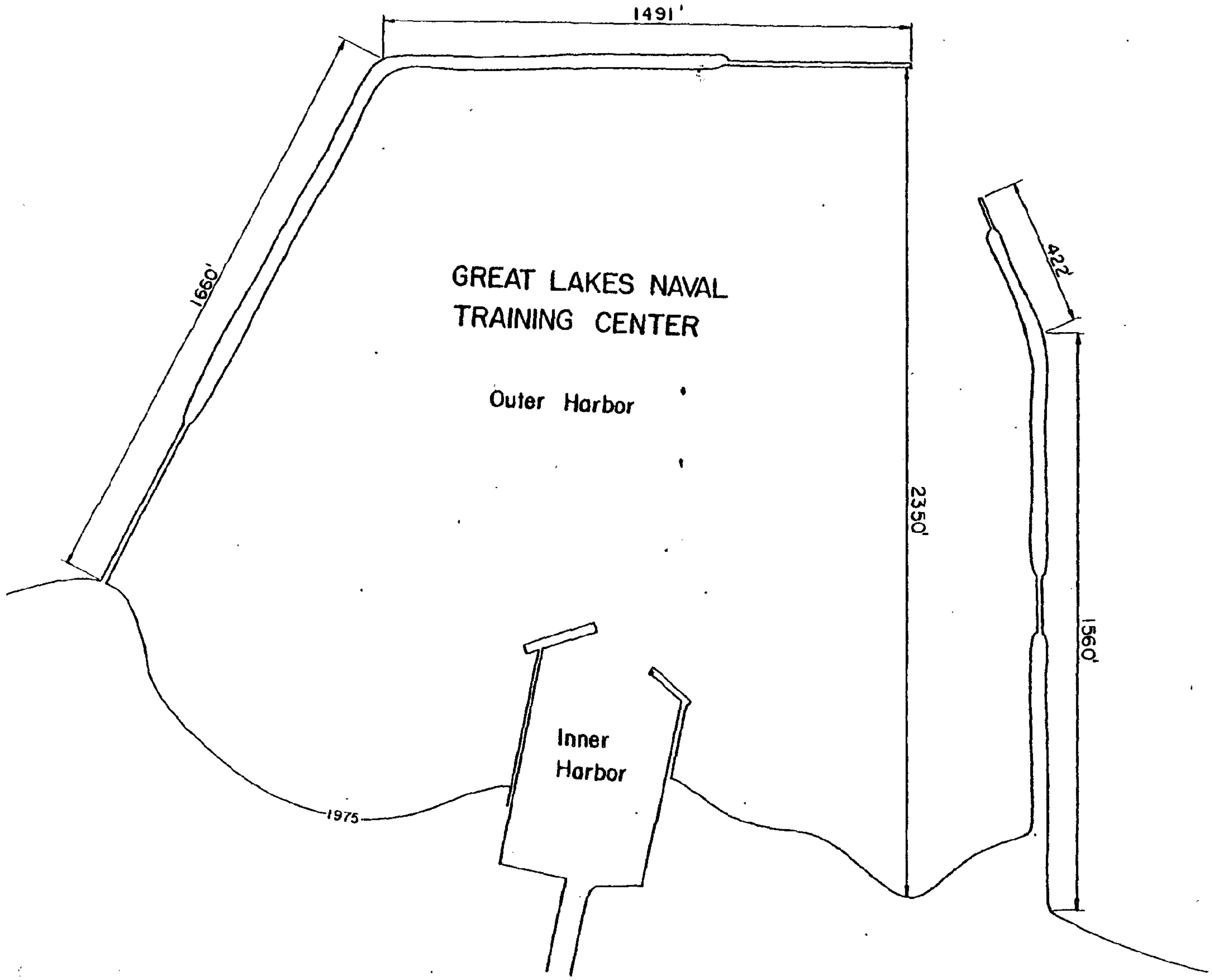


Fig. 2 - Dimensions of harbor jetties at Great Lakes Naval Training Station.

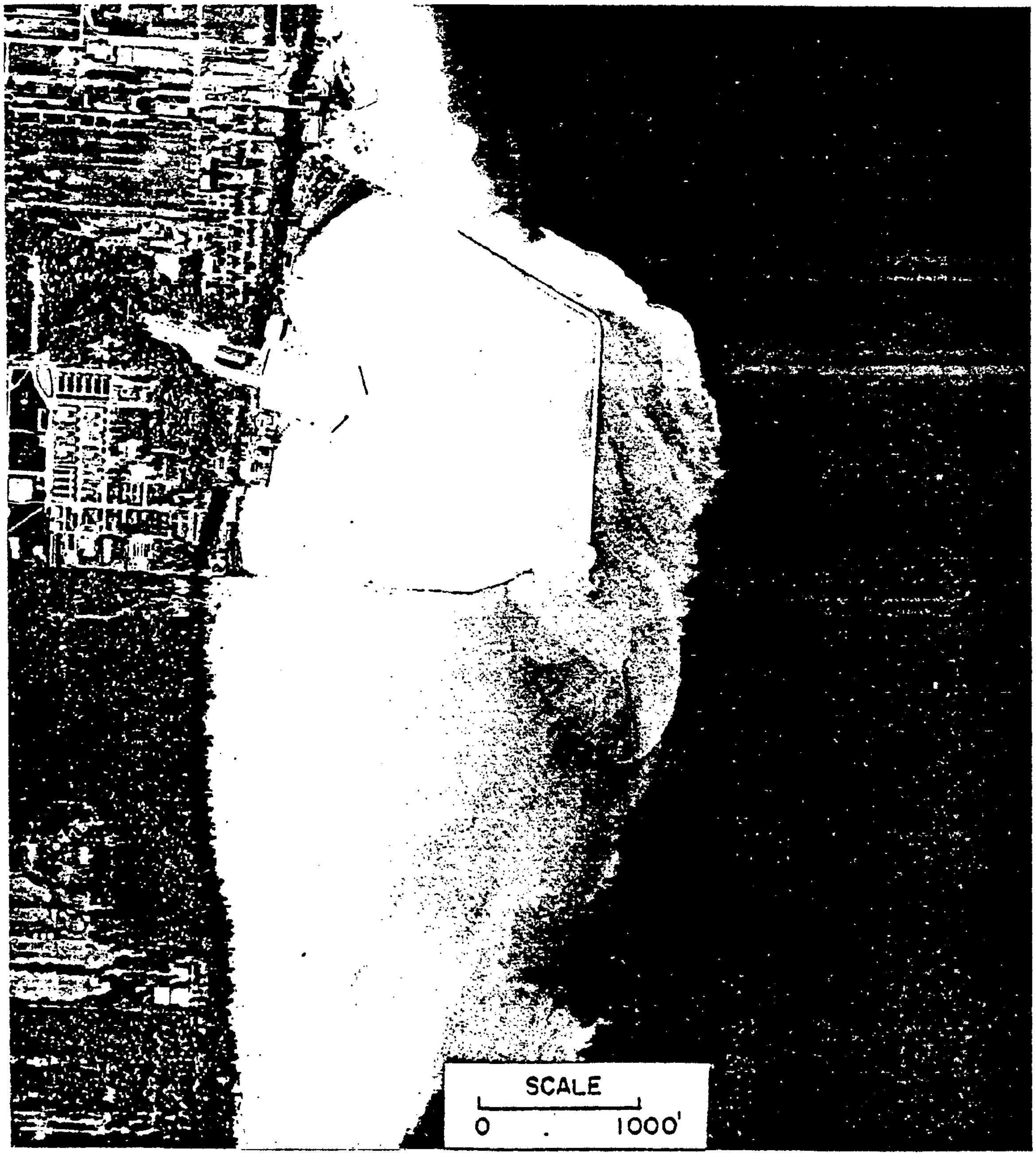


Fig. 3 - Photo Taken in 1937 Showing Jetties at Great Lakes Naval Training Station and Adjacent Lakeshore.

The suspended sediment load is bypassing the northern outer jetty. The net longshore transport direction from north to south is shown by sediment plumes moving around the jetties. The densities and shapes of the sediment plumes indicate the currents and current direction. Suspended sediment is clearly visible leaving the harbor and settling along a 1500-foot stretch of shore to the south. Concentrations are relatively great in this downdrift area. The bluff is in shadows so eroded bluffs in northern Lake Bluff are difficult to see. Groins on southern part of the shore seem to be effective in trapping sand and maintaining beaches.

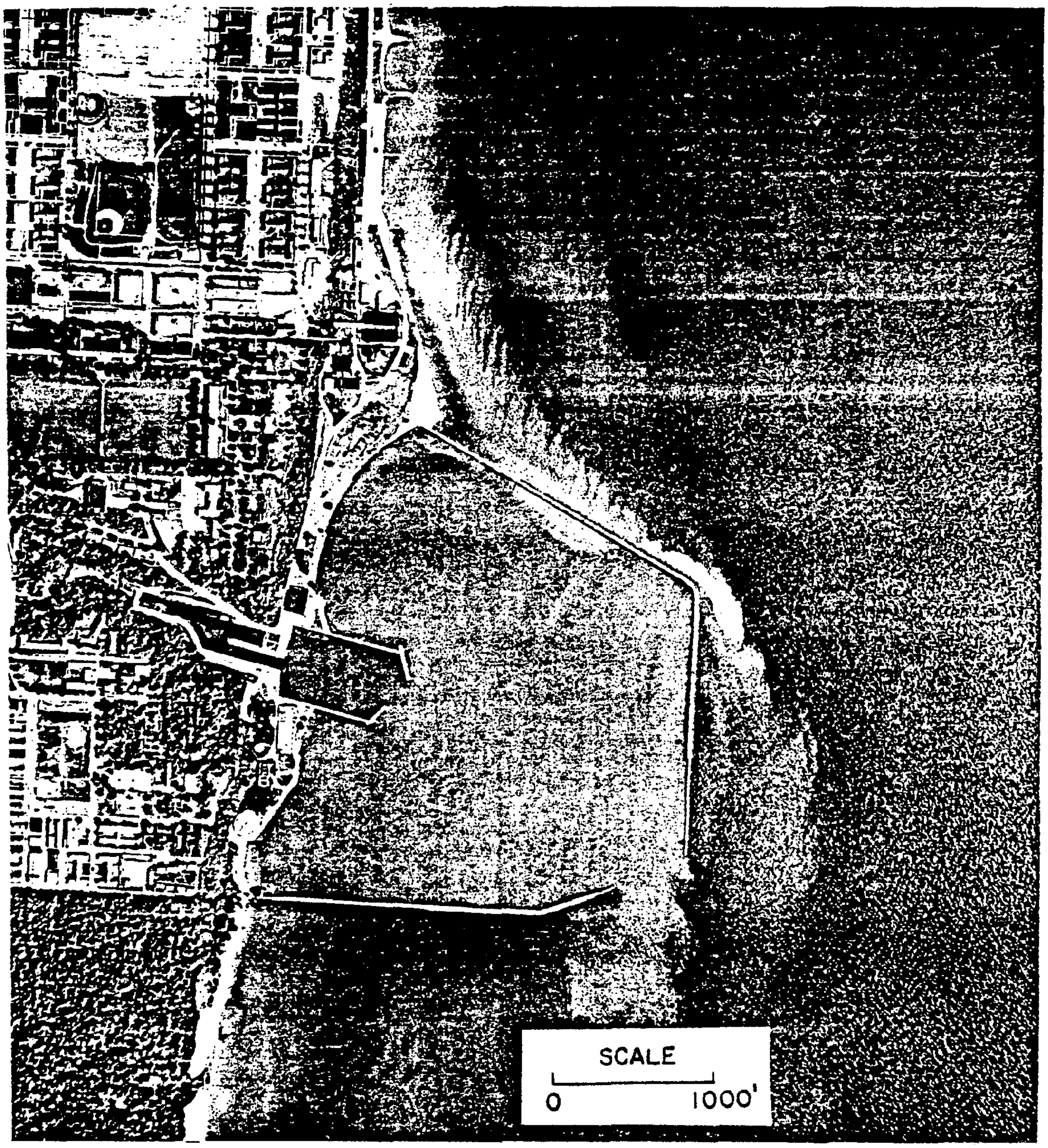


Fig. 4 - Photo Taken in 1955 Showing Jetties at the Great Lakes Naval Training Station and Adjacent Lakeshore.

This photo, similar to the 1937 photo (Fig. 3), shows suspended sediment load bypassing the outer harbor jetty. The sediment plume narrows near the bend of the northern jetty. The southward-bound littoral current is deflected along the jetty and its velocity appears to increase until it rounds the bend. Maximum scour occurs on the updrift side of the bend, and sediment is concentrated at this place. The sediment plume widens downdrift of the bend, indicating that the littoral current widens and slows. This and the following photos of this reach of the shore (Fig. 5 to 10) show the 600-foot stretch of shore with stable bluffs immediately downdrift of the southern jetty with rapidly eroding bluffs in northern Lake Bluff extending south from there.

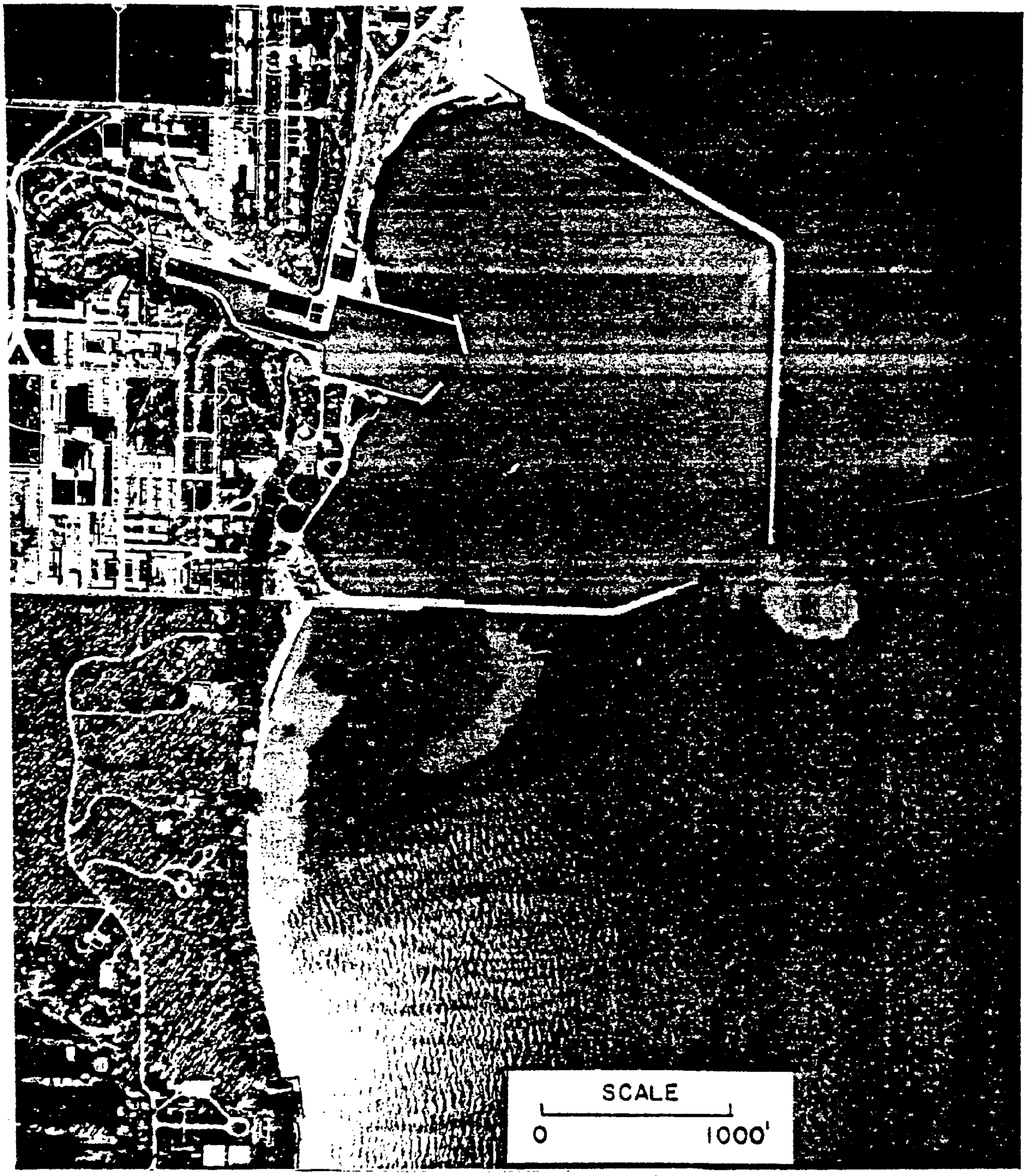


Fig. 5 - Photo Taken in 1966 Showing Jetties at the Great Lakes Naval Training Station and Adjacent Lakeshore.

This photo shows sediment plumes created by easterly waves. Suspended sediment in and near the harbor suggest that northeasterly waves may have preceded the easterly waves and washed sediment over the jetty. The low concentration of sediment off the north jetty suggests that the waves slowed or even stopped the littoral current along the jetty after the wind shifted to the east. Sediment plumes outside the south harbor jetty show that sediment carried around the jetties is moving toward shore and settling.

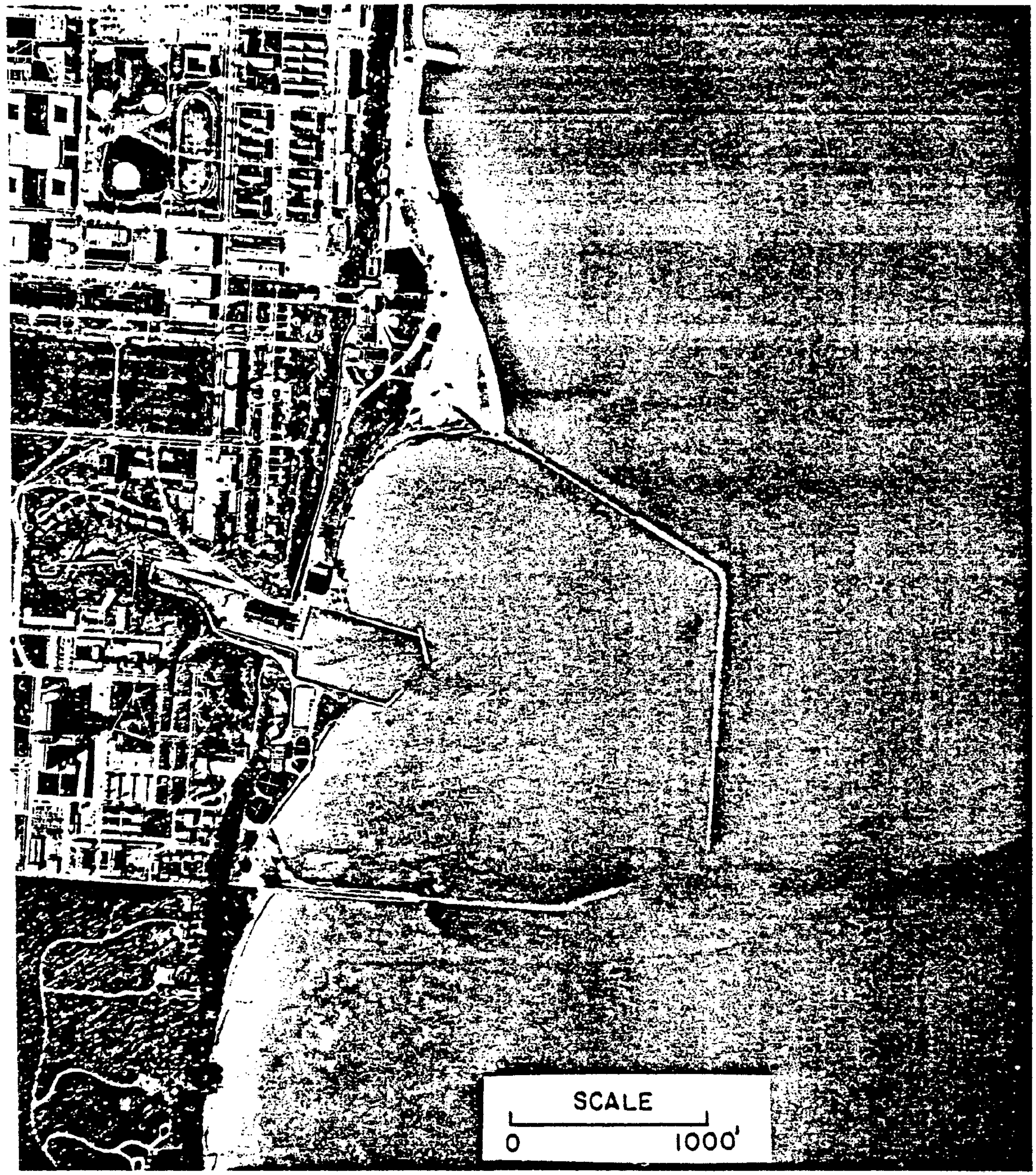


Fig. 6 - Photo Taken in 1967 Showing Jetties at the Great Lakes Naval Training Station and the Adjacent Lakeshore.

This photo shows a large sediment plume offshore from the jetties at the Great Lakes Naval Training Station. The plume has not moved far downdrift of the jetties because wind-generated waves are absent. The plume appears static. Suspended sediment is settling far from shore. Suspended sediment is absent along the shore of northern Lake Bluff.

Fig. 7 - Photo Taken in 1958 Showing Jetties at the Great Lakes Naval Training Station and the Adjacent Lakeshore.

This photo shows an excellent example of wave reflection under northeast winds. The unriprapped southern tip of the north jetty reflects waves in an arcuate pattern. The reflected waves then are incorporated into the wave trains moving southwest, adding to their strength and increasing potential for severe erosion. The riprapped portion of the jetty also reflects waves, but much of the energy is absorbed by the revetment. Sediment washed over the jetty appears in suspension along the inner side of the north jetty. The location corresponds with that of exposed sand deposits shown on the photo taken in 1964. The effectiveness of the northern jetty as a breakwater is indicated by the quiet water inside the harbor.

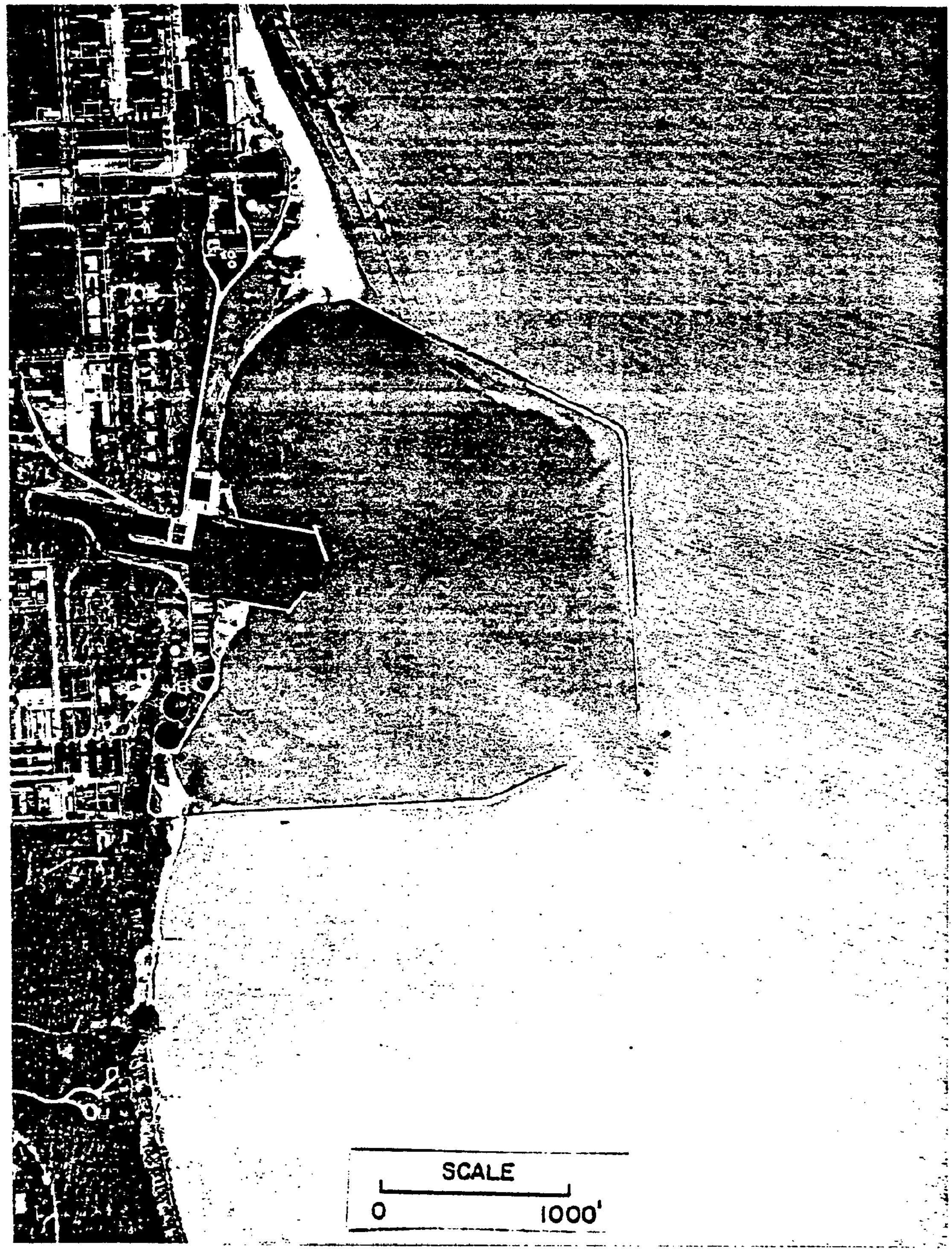


Fig. 8 - Photo Taken in 1961 Showing Jetties at the Great Lakes Naval Training Station and the Adjacent Lakeshore.

This photo shows evidence of sediment accumulation along the inner side of the northern jetty while attacked by northeasterly waves. Pollutant material is visible near the northern edge of the photo and also along the inner side of the northern jetty. Wave reflection is barely visible on this photo. Note the narrow beaches at the base of the bluff in north Lake Bluff.

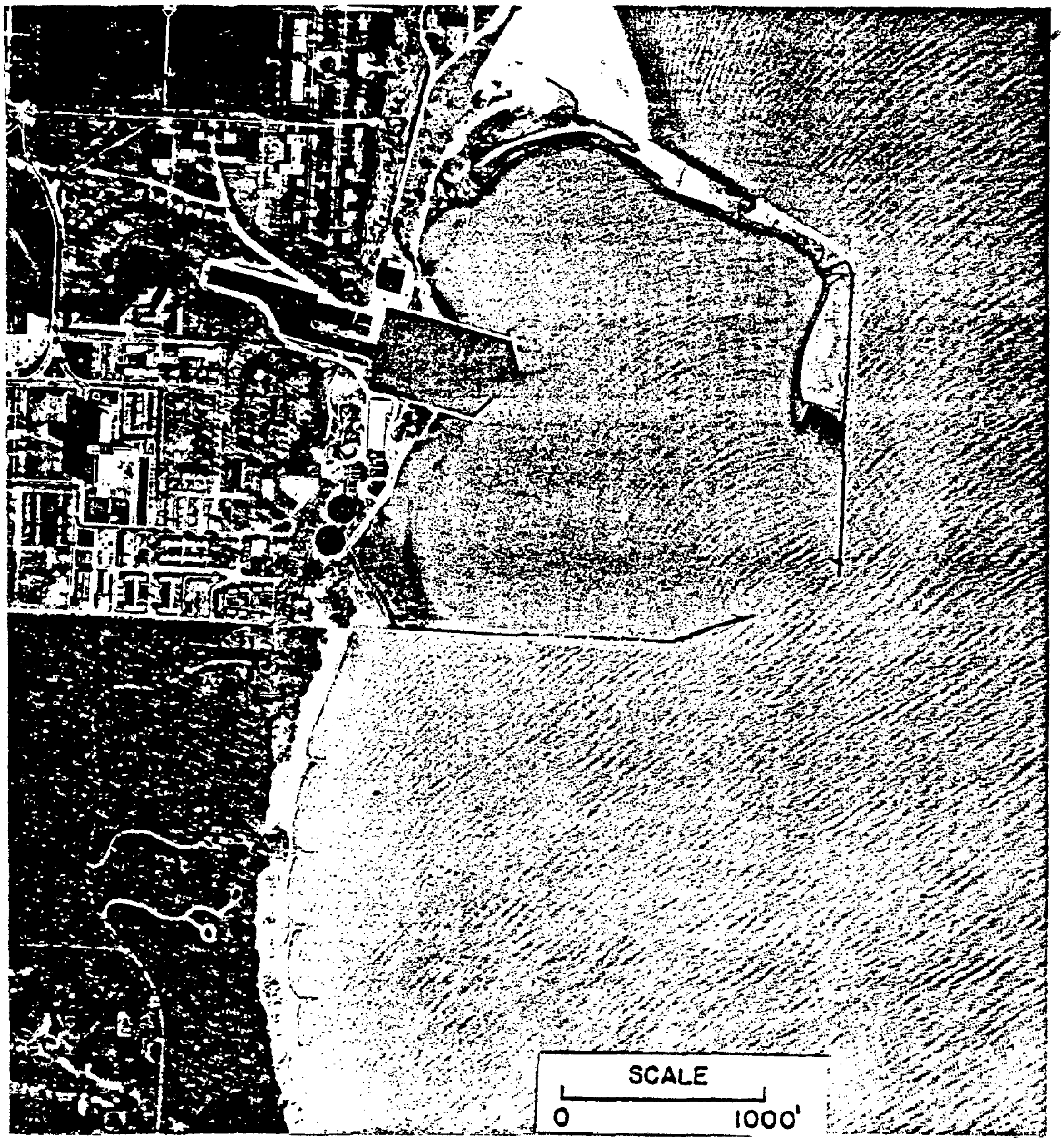


Fig. 9 - Photo Taken in 1964 Showing Jetties at the Great Lakes Naval Training Station and the Adjacent Lakeshore.

This photo, taken during the low-water level of 1964, shows sand deposits exposed along the inner side of the northern jetty. This sediment was washed over the jetty by prevalent northeasterly waves. The absence of sediment along the inner side of the southern jetty indicates that southeasterly waves are not strong enough to wash appreciable amounts of sand over the jetty.

The photo also shows reflected waves impinging from the southeast. Waves reflected from the unriprapped western portion of the southern jetty create some local shoaling together with sediment transport from south to north, adding to the area of stable bluffs just south of the jetty. The riprapped portion of the southern jetty absorbs most of the wave energy. Southeasterly waves, after passing through the harbor entrance, show an arcuate pattern.

Wave trains from a southeasterly direction, visible on the 1964 photo, show little or no adverse effect on the shore downdrift of the jetties. Waves reflected off the western portion of the unriprapped wall of the southern jetty toward the shore at an angle, appear to create local shoaling, as seen on the photo, which in part resulted in wider beaches and stable bluffs for about a 600-foot distance downdrift of the southern jetty, a situation uncommon to northern Lake Bluff. Updrift sediment accumulation may also be partially responsible for the wider beaches. Noticeable on the 1964 photo is the absence of waves reflected from the riprapped portion of the southern jetty, indicating that the rubble material was absorbing rather than reflecting wave energy. In late 1965 or early 1966, the southern jetty was completely riprapped, making the jetty an energy-absorbing structure. Since this revetment has been added, approximately 50 to 75 feet of previously stable bluffline was denuded and recession commenced. It does not appear that the increase of bluff instability was the result of the high lake levels of the 1970's since this portion of bluff remained stable from 1937 to 1965. There was no apparent increase in bluff erosion even during the 1952-1955 high level period, a time when bluff erosion closely resembled the present state (Berg and Collinson, 1976). Since the southern jetty does not provide protection from northeasterly wave attack, which usually is the most severe, and since southeasterly wave attack is usually nondamaging, it may be beneficial to remove the riprap along the southern jetty. This should increase reflection of southerly waves, resulting theoretically in wider beaches extending further southward and lending more protection to the rapidly eroding bluffs of north Lake Bluff.

Waves from a northeasterly direction cause the most damage on the Illinois shore, since northeasterly winds have the greatest fetch distance and thus can generate the largest waves. Northeasterly waves are visible on the 1937, 1955, 1958, 1961, and 1969 (Fig. 10) photos. The 1958, 1961, and 1969 photos clearly show the reflection and absorption of wave energy by the northern jetty. The riprapped portion of the jetty, as seen on the 1958 photo, absorbs most of the wave attack, thereby providing needed protection for the nearby shore. On the other hand, the unriprapped area at the tip of the jetty reflects the waves in an arcuate southeasterly direction, from which they appear to become incorporated into the northeasterly wave movement, adding to its strength, and capacity for erosion as the waves approach the shore. Note the crossing of the reflected waves and the normal wave train in the southeastern portion of the photograph.

Since the riprapped portion of the northern jetty reflects waves toward the shore to the south, it may be beneficial to add riprap to the tip of the northern jetty, thus absorbing incoming energy from a northeastern direction. This should aid in slowing bluff erosion in north Lake Bluff.

Waves incidences from an easterly direction also can result in severe erosion of the shore. Since the Great Lakes Naval Training Station jetties are oriented in a general east-west position, they have little or no mitigating effect on erosion of the shore by waves from the east. Fortunately, wind-driven waves from the east have the least fetch-distance, and therefore have the least energy. On the 1966 photos note that the sediment off the northern jetty appears static, even though under the influence of easterly waves. The sediment plumes indicate that the easterly waves probably were preceded by northeasterly waves.

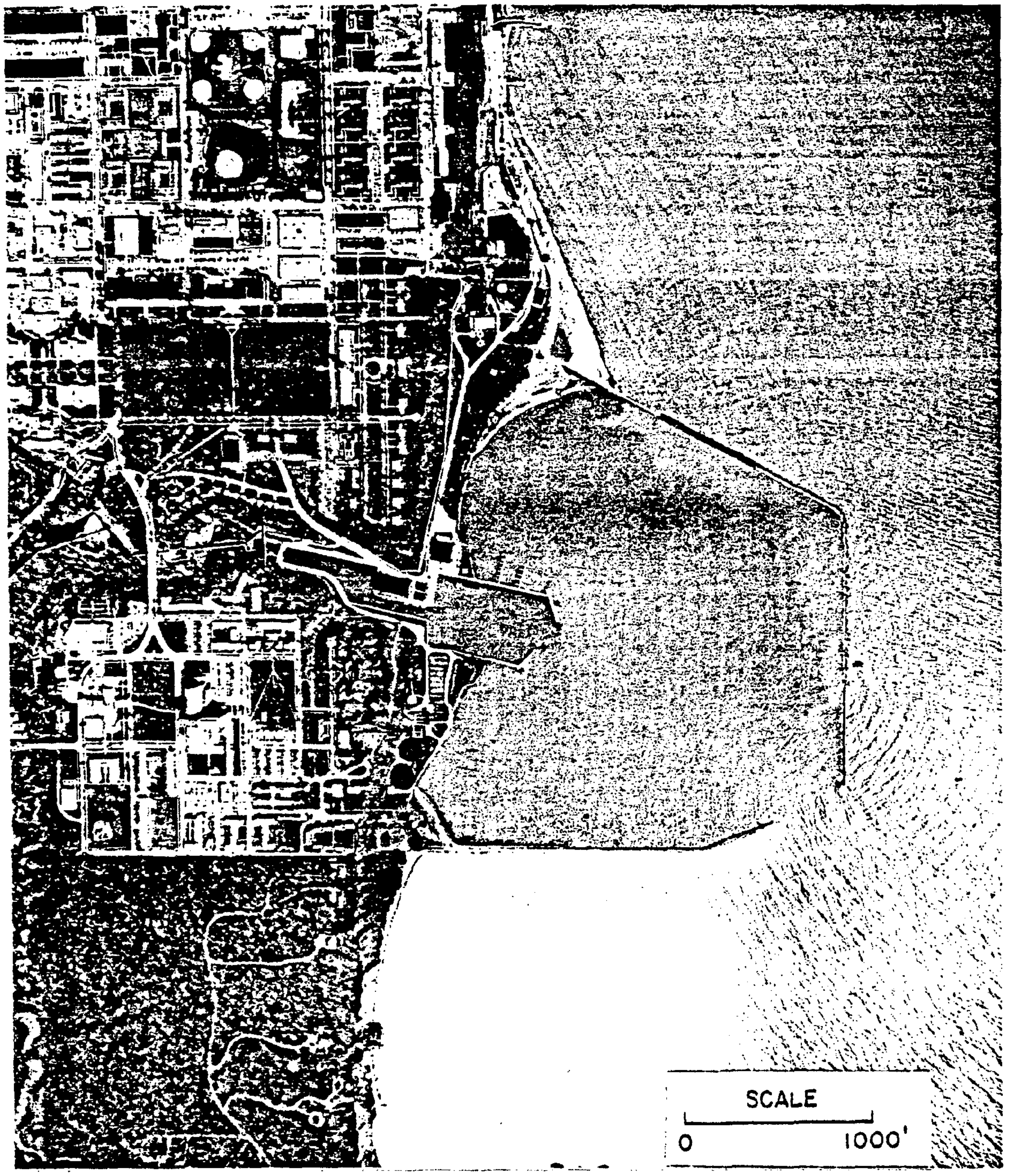


Fig. 10 - Photo Taken in 1969 Showing Jetties at the Great Lakes Naval Training Station and the Adjacent Lakeshore.

This photo shows the unriprapped portion of the southern tip of the northern jetty reflecting waves from the northeast. The riprapped portion of the jetty is poor reflector; it absorbs most of the wave energy. Sediment visible along the inner side of the northern jetty indicates that washover provides much of the sediment within the harbor.

EFFECT OF LARGE STRUCTURES AND BEACH STARVATION

Although the jetties at Great Lakes Naval Training Station provide a wave-storm protective barrier for the shore in extreme north Lake Bluff, they are also a contributing factor, together with other large shore structures updrift in Waukegan, in causing downdrift beach starvation and erosion. According to Bruun (1952), jetties terminate beach drift on their updrift side, resulting in erosion on the downdrift side. The composition of beach drift changes from a predominance of sand-size particles to suspended load and bed load as the littoral current passes around a projecting and obstructing shore structure. The result is a sand deficit on the leeward side of the jetty.

Hartley (1964) measured beach widths and lengths on 1956 air photos in studying the effects of large structures on shore processes along the Lake Erie shore in Ohio. It was concluded that most large structures result in beach accretion on their updrift side, accompanied by beach starvation and accelerated bluff erosion downdrift of the structure. The length of starved and eroding shore on the leeside of a large structure was about five times the length of shore containing trapped sand updrift of the structure. This ratio varied from 2:1 to about 7:1. The shore structures ranged in length from 400 feet to 7800 feet. Of particular interest was the fact that of the 13 shore structures studied, only 8 showed downdrift erosion. At Sandusky, a 6000-foot structure was completely beneficial to the adjoining shore.

Along the Illinois shore of Lake Michigan beach widths were measured to determine the length of starved shore downdrift of large shore structures. To compare these results with those of Hartley, photos from 1956 were used, so that beach width variations due to lake fluctuations of Lake Michigan levels were comparable to beach widths of Lake Erie. In north Lake Bluff, between the bulkhead at Shore Acres Country Club and the south Great Lakes jetty, beach widths did not exceed 30 feet. Beaches to the rear of groins in south Lake Bluff maintained a maximum width of only 35 feet.

Immediately south of the Lake Forest waterworks, and continuing southward through central Lake Forest, beach widths along this groined reach of shore were considerably wider than at Lake Bluff. Minimum beach widths behind groins were 40 feet, maximum beach widths were 110 feet, while midgroin widths were 50 to 90 feet. In south Lake Forest beach widths were slightly less, with midgroin beaches attaining a maximum width of about 70 feet while minimum and maximum beach widths were 40 and 90 feet respectively.

Beach widths visible on 1976 photos showed a pattern similar to widths measured in 1956. The ungroined beaches in north and central Lake Bluff were 0 to 50 feet wide, while along groined shore reaches, widths ranged from a minimum of 10 feet to a maximum of 60 feet with midgroin widths of 20 feet. In Lake Forest, groined beaches ranged in width from a minimum of 35 feet to a maximum of 100 feet. Midgroin beach widths were 50 to 60 feet.

The length of the starved shore south of the Great Lakes Naval Training Station jetties coincides with the most seriously eroding reach of bluff on the Illinois shore, this including the entire village of Lake Bluff, a total distance of 14,300 feet. Beach widths in Lake Bluff are approximately one-half the width of the beaches in north and central Lake Forest. The deprivation of sediment along the Lake Bluff shore is a primary factor in the accelerated recession rate of the bluff. Sediments supplied from the erosion at Lake Bluff are the main source of sand for the beaches of north and central Lake Forest.

Although a stable area exists at the McCormick-Blair property north of Blodgett Avenue, in Lake Bluff, the beach along this reach of shore is still considered sand-starved, since its width is narrower than comparable beaches at Lake Forest. A second major area of stable bluffs is at Sunrise Park in central Lake Bluff, where three groins were placed to trap sand and maintain a public beach. The Sunrise Park groins are effective in trapping what meager amounts of sand travel down the coast, but further contribute to sand starvation in south Lake Bluff. The primary contributing factor leading to beach starvation and erosion in south Lake Bluff does not appear to be the Sunrise Park groins, but rather the larger shore structures north of Lake Bluff.

The 14,300-foot length of the Lake Bluff shore was considered to be the extent of starved shore south of the jetties at Great Lakes Naval Training Station. This distance was then compared with the shoreline extent of trapped sand north or updrift of the jetties. In 1956, the beach was approximately 1000 feet long and 200 feet wide. Applying Hartley's starvation trapped sand ratio to these beaches a ratio of 14.3:1 was obtained, which is over two times greater than Hartley's largest ratio of 7.1:1. The length of sand-starved and eroding shore is exceedingly great for the amount of updrift sand trapped by the Great Lakes Naval Training Station jetties. Hence, the jetties are not the sole contributor to sand starvation along the Lake Bluff shore. Sand starvation actually extends northward to Waukegan Harbor. Beaches along an unprotected area north of the jetties at North Chicago in 1956 were 20 to 30 feet wide, comparable to the width of sand-starved beaches in Lake Bluff. Beach widths in 1976 were slightly less.

Although the jetties at Great Lakes Naval Training Station contribute to erosion in Lake Bluff by depriving the shore of sediments, the jetties provide protection to a portion of the shore extending from the southernmost structure to Shore Acres Country Club. Eighteen beach profiles were used to measure changes visible on air photos dated 1947, 1952, 1953, 1954, 1957, 1958, 1959, 1961, 1962, 1963, 1964, 1969, 1970, 1973, and 1975 (Fig. 11, Table 1). Photos of other years were also available, but not used since they were taken during wave-storm periods, thus making beach-width determinations highly questionable due to inconsistent widths of the beach zone. Beach widths along each profile were measured accurately within five feet, averaged for each year, and then correlated to the lake level on the day the annual photographs were taken. The lake levels used were the average of those recorded at Milwaukee and Calumet Harbor. A correlation coefficient of -.88 showed the close dependency of beach width to lake levels. As one would suspect, when lake levels drop, beaches accrete and when lake levels rise, beaches recede.

Beach widths along selected profiles were then correlated to lake levels. All 18 profiles could not be used since wave wash-up at particular locales along the shore was anomalously variable on certain photos or various attempts at shore protection prevailed, with both resulting in unnatural beach widths. Hence, only profiles 1, 4, 9, 11, 12, 16, 17, and 18 were correlated with lake levels. Table 2 shows that the correlation between beach widths and lake levels was very significant along profiles 17 and 18 with a coefficient of -.90. The correlation became less significant in a southerly direction: beach widths and lake levels had an average correlation of -.84 at profiles

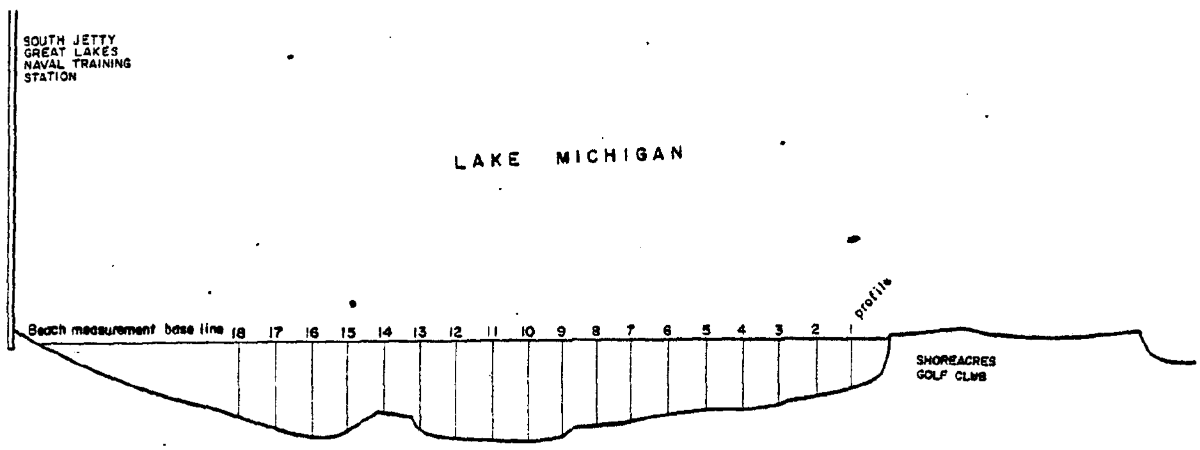


Fig. 11 - Location of beach profiles along the shore south of Great Lakes Naval Training Center. Beach widths shown in Table 1 were measured along these profiles, which are spaced 100 feet apart. The south jetty extends East-West.

TABLE 1 - BEACH WIDTHS (IN FEET) MEASURED FROM AERIAL PHOTOS OF THE SHORE SOUTH OF GREAT LAKES HARBOR. WIDTHS WERE MEASURED ALONG 18 PROFILES SHOWN IN FIGURE 11. DATES ARE THOSE OF THE PHOTOS.

PROFILE NUMBERS	4/26/75	4/24/73	6/11/70	2/29/69	4/16/64	4/11/63	4/20/62	4/2/61	4/6/59	4/7/58	4/21/57	5/15/54	5/9/53	4/25/52	4/3/47
1	21	0	40	23	28	41	29	26	19	51	21	20	10	15	15
2	14	0	21	19	40	38	27	21	21	51	20	--	8	15	20
3	10	28	20	12	34	42	40	26	32	69	30	28	7	--	15
4	4	33	21	5	53	37	32	25	51	51	26	17	15	15	0
5	--	--	18	0	54	43	40	28	48	51	32	35	20	12	15
6	--	--	6	0	75	30	25	29	59	45	41	15	10	5	10
7	--	--	24	0	70	27	25	27	65	32	43	8	10	0	27
8	--	--	35	0	70	36	39	29	56	36	29	10	17	3	9
9	53	10	35	0	78	31	29	29	56	38	29	14	12	3	12
10	38	0	--	--	--	--	--	--	--	--	--	--	--	--	--
11	33	0	25	15	63	53	41	38	48	35	30	15	16	0	10
12	33	0	19	10	65	46	32	30	51	37	35	15	20	0	15
13	28	11	10	15	71	42	21	22	39	30	30	--	11	0	20
14	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
15	--	--	--	--	65	52	31	29	58	51	23	10	20	27	17
16	19	0	25	8	59	40	26	22	52	39	28	18	18	15	10
17	14	0	11	8	74	42	25	29	70	39	30	8	10	9	20
18	24	0	10	12	99	55	26	32	61	46	65	25	15	10	50
number of measurements	12	12	15	15	16	16	16	16	16	16	16	14	16	15	16
average	24.3	6.8	21.3	8.5	62.4	40.9	30.5	27.6	49.1	43.8	32.0	17.0	13.7	8.6	16.6
average lake level	580.14	580.63	579.35	579.03	575.53	576.54	577.73	577.67	576.29	577.68	577.35	579.47	579.95	580.55	577.75

TABLE 2 - CORRELATION COEFFICIENTS REPRESENTING THE RELATIONSHIP BETWEEN LAKE LEVELS AND BEACH WIDTH MEASURED IN FEET ALONG SELECTED PROFILES (TABLE 1) IN LAKE BLUFF FROM 1947 to 1975.

Profile	Correlation coefficient
1	-.47
4	-.63
9	-.63
11	-.84
12	-.86
16	-.82
17	-.90
18	-.90

11, 12, and 16; at profiles 4 and 9 the coefficient decreased to -.63 and at profile 1 the correlation was -.47. All correlations were highly significant at the .05 probability level.

The trend of higher correlation coefficients between beach widths and lake levels closer to the Great Lakes Naval Training Station jetties suggests partial protection by the large structure. Wave-storm attack from a northeasterly direction is intercepted to some extent by the jetties. The protective influence of the jetties becomes progressively less important in a southerly direction as the full impact of northeasterly waves on sand-starved beaches results in severe bluff erosion. Thus along the reach of shore nearest the Shore Acres Country Club, the beach widths are less dependent on lake levels, and more dependent of local wave conditions and scour.

In an early report on shore erosion along the Illinois shore of Lake Michigan by Wood (1930), the importance of beaches as a protection against erosion by storm waves was stressed as follows.

> "It is nature's plan that these forces (lake forces) combine with their allies—streams, springs, frost, etc., toward the reduction of the land to a level near that of the lake. The long gradual slope of a beach, well supplied with sand and gravel helps to defeat this, as it is the ability to rob a storm of its destructive power. There is no better natural protection than a wide sloping sand beach."

NEARSHORE SLOPE AND HYDROGRAPHY (1872-1976)

Study shows that nearshore slope angles and changes of slope angles are useful indicators of the relative effects of shore structures on altering shoreline recession rates and other lake shore processes. These relationships were studied in detail by Carter (1976) along a portion of the Ohio shore of Lake Erie. It was revealed that downdrift of large shore structures, the nearshore area is sediment-starved and scouring leads to steeper nearshore slopes and narrower beaches. On the updrift side of structures sand is trapped, resulting in gentler nearshore slopes and wider beaches. Along shore reaches with a gentle nearshore slope, wave energy is reduced by friction as approaching waves "touch bottom" at considerable distances from shore. The steeper the nearshore slope angle, the greater is the amount of wave energy that strikes the shore; hence, when this is coupled with sand-starved narrow beaches downdrift of large structures, higher rates of recession are evident.

If the jetties at Great Lakes Naval Training Station are the prime contributors to shore erosion along Lake Bluff there should be a marked increase in the magnitude of the nearshore slope angles downdrift of the structures. In addition, historical hydrogrpahic data should reveal that downdrift nearshore slopes were gentler prior to construction of the jetties in 1923.

The present-day hydrographic mapping of this reach of shore was done in July, 1974 and June, 1976, using a Ross Straightline Depth Recorder, mounted on a small radio-equipped inflatable runabout. Maps were made at a scale of 1":200' with a 1-foot contour interval. Although hydrographic data are available from Wisconsin to Chicago, only 38 bottom profiles extending from Waukegan Harbor to central Lake Forest (see appendix) were studied in detail for this work. Depths were recorded along traverses spaced from 200 feet to about 1500 feet apart. In order to evaluate the relative effect of sediment starvation and trapping updrift and downdrift of the Great Lakes Naval Training Station jetties, 13 additional profiles were analyzed updrift of Waukegan Harbor. Following the procedure outlined by Carter (1976), water depths at designated distances from the shore were recorded to determine differences in nearshore slope angles. Unlike Carter's study, depths were recorded out to 3000 feet instead of 2000 to gain further insight about the possible effects of large structures on nearshore slopes further from shore. Depths were not recorded 50 and 100 feet from shore, since in some instances the water depths were exceedingly variable and not accurately recorded.

Tables 3 and 4 indicate the modern day water depths 200, 300, 400, 500, 1000, 1500, 2000, 2500, and 3000 feet from shore along 51 bottom profiles plus the average water depth at each distance from shore. Table 3 indicates the average water depths at the 15 bottom profiles between Waukegan Harbor and the Great Lakes Naval Training Station jetties and the 23 profiles from the Great Lakes jetties southward to central Lake Forest. Depths were not available along certain profiles lakeward of 2000 feet, but the data are still sufficient to draw valid conclusions. Lake level datum is corrected to that of July, 1974 (581.1 feet I.G.L.D.).

Historical hydrographic data, indicating water depths prior to construction of large shore structures, were obtained from a U. S. Army Corps Lake Sheet showing the results of a survey in August, 1872 and published in 1873 at a scale of 1:20,000. The locations of the bottom profiles made in 1974-76 were plotted (within 20 to 30 feet) onto the 1873 map. Fortunately there were sufficient cultural landmarks and surveyed lines on the 1873 maps that could be used as guides to place the position of the 38 bottom profiles which now extend along the reach of the shore from Waukegan Harbor to central Lake Forest. The 1872 hydrographic data were then contoured and depths were recorded from 200 to 3000 feet from shore along each profile in a manner similar to the procedure of recording depths on the 1974-76 hydrographic maps. Table 5 indicates the water depths at the designated intervals from shore along each profile, the average depths at each distance, and the average depths at each distance for profiles 1 to 15 and 16 to 38, these profiles including the shore reaches updrift and downdrift of the present-day locations of the jetties at Great Lakes Naval Training Station. Lake level datum during August, 1872 was 579.7 feet I.G.L.D., hence all water depths indicated in Table 5 are corrected to July, 1974 datum.

The depths shown in Tables 3 to 5 provide indications of the nearshore slope angle. For example, a 1° angle corresponds to a 36 foot depth, 2000 feet from shore. At 3000 feet from shore the depth would have to be 54 feet to have a 1° slope. All nearshore slopes from beyond 2000 feet are thus easily less than 1°. Landward of 1000 feet, slope angles are considerably steeper. At 1000 feet from shore an 18-foot depth corresponds to a 1° slope, and this is quite common. The sines of the slope angles are ratios; thus 20/2000 feet,

TABLE 3 - WATER DEPTHS ALONG 38 HYDROGRAPHIC PROFILES WAUKEGAN TO CENTRAL LAKE FOREST 1974-76 (SEE APPENDIX MAPS FOR PROFILE NUMBERS AND LOCATIONS)

DISTANCES FROM SHORE

Bottom Profiles	200	300	400	500	1000	1500	2000	2500	3000
1	4	7	9	10	14	16	18	20	
2	2	5	8	10	18	19	19	19	
3	5	5	6	7	15	17	16	18	20
4	10	9	11	13	15	16	16	17	18
5	11	12	14	15	17	16	16	17	18
6	9	10	11	13	16	16	17	18	18
7	8	11	12	14	16	18	21		
8	9	11	12	14	18	19	20		
9	11	13	14	17	20	20			
10	4	6	9	12	15	17	19	19	20
11	10	12	12	13	15	16	17	18	19.5
12	7	10	13	13	14	17	18	18	19.5
13	9	11	11	13	19	21	20	20	20.5
14	10	12	13	14	17	18	19.5	20.5	21.5
15	6	8	9	10	14	16	18	21.5	22.5
→ Location of Great Lakes Naval Training Station									
16	7	8	8	9	12	15	15	18	21.5
17	4	6	8	8	12	14	15	16	19.5
18	7	9	11	11	14	15	16	18	21.5
19	9	10	12	12	15	16	17	20.5	21.5
20	11	12	14	15	19.5	18	19.5	20.5	22.5
21	12	13	14	14	18	19	19	21	23
22	6	9	11	13	17	19	20	21	
23	12	12	13	13	18	21	21	21	22
24	7	8	11	13	18	21	21	22	22
25	8	10	12	14	16	19	21	21	22
26	9	11	11	13	17	21	20	21	23
27	10	12	12	13	18	23	24	25	
28	9	11	12	12	17	20	24	25	
29	7	8	10	11	16	21	22	23	25
30	9	11	13	14	18	19	21	25	
31	6	6	8	10	14	18	20	22	23
32	5	6	8	10	15	18	20	22	23
33	9	13	14	14	19	24	26		
34	7	11	14	14	21	23	25		
35	6	8	11	12	18	23	24	25	
36	10	13	13	15	18	21	21		
37	7	9	10	13	16	20	22	24	24
38	5	6	9	11	15	19	21	23	25
Overall water depth average	7.82	9.58	11.13	12.42	16.43	18.66	19.70	20.63	21.40
Average water depth updrift of jetties	7.67	9.47	10.93	12.53	16.20	17.47	18.18	18.83	19.75
Average water depth downdrift of jetties	7.91	9.65	11.26	12.35	16.59	19.43	20.63	21.70	22.57

TABLE 4 - WATER DEPTHS ALONG 13 HYDROGRAPHIC PROFILES, ILLINOIS BEACH NATURE PRESERVE TO WAUKEGAN HARBOR 1974-76 (SEE APPENDIX MAPS FOR PROFILE NUMBERS AND LOCATIONS)

	DISTANCES FROM SHORE								
Bottom Profiles	200	300	400	500	1000	1500	2000	2500	3000
North of Commonwealth Edison Pier									
1	12	14	9	10	17	21	23	24	
2	10	12	10	9	17	21	23	24	
3	8	12	12	11	15	18	21	24	
4	13	13	13	12	15	18	21	23	25
5	6	10	10	10	16	20	23	25	
6	12	14	12	12	16	20	24	26	
Overall water depth average profiles 1-6	10.17	12.50	11.00	10.67	16.00	19.67	22.50	24.33	25.00
Ranges between Commonwealth Edison pier and Waukegan Harbor									
7	3	5	5	5	6	11	14	19	
8	3	4	5	5	8	13	18	21	
9	3	4	6	9	9	12	14	19	
10	6	6	6	8	10	12	14	16	18
11	2	3	4	7	11	13	16	18	
12	1	2	2	3	6	11	14	17	18
13	1	2	3	4	8	16	18		
Overall water depth average profiles 7-13	2.71	3.71	4.43	5.86	8.29	12.57	15.43	18.33	18.00

TABLE 5 - WATER DEPTHS ALONG 38 HYDROGRAPHIC PROFILES - WAUKEGAN HARBOR TO CENTRAL LAKE FOREST, 1872

	DISTANCES FROM SHORE								
Bottom Profiles	200	300	400	500	1000	1500	2000	2500	3000
1	5.4	6.4	9.4	10.4	16.4	20.4	26.4	27.4	28.4
2	6.4	8.4	10.4	13.4	16.4	20.4	25.4	29.4	28.4
3	4.4	8.4	9.4	10.4	16.4	21.4	21.4	27.4	27.4
4	8.4	10.4	12.4	13.4	18.4	21.4	25.4	27.4	25.4
5	8.4	10.4	12.4	14.4	13.4	18.4	24.4	25.4	26.4
6	7.4	8.4	8.4	9.4	13.4	17.4	20.4	24.4	26.4
7	8.4	8.4	9.4	10.4	14.4	17.4	19.4	25.4	26.4
8	8.4	9.4	9.4	10.4	14.4	16.4	21.4	24.4	26.4
9	6.4	8.4	8.4	8.4	15.4	20.4	21.4	24.4	23.4
10	7.4	8.4	10.4	11.4	15.4	16.4	19.4	19.4	19.4
11	7.4	8.4	10.4	11.4	15.4	18.4	19.4	[illegible]	20.4
12	7.4	8.4	10.4	11.4	16.4	18.4	18.4	19.4	20.4
13	7.4	7.4	10.4	11.4	16.4	19.4	22.4	22.4	21.4
14	7.4	8.4	10.4	12.4	19.4	19.4	19.4	21.4	23.4
15	7.4	8.4	10.4	11.4	16.4	19.4	20.6	26.6	25.4
Location of Great Lakes Naval Training Station									
16	8.4	8.4	9.4	13.4	19.4	21.4	24.4	24.4	29.4
17	10.4	11.4	12.4	13.4	18.4	21.4	22.4	24.4	26.4
18	8.4	10.4	11.4	12.4	16.4	21.4	22.4	23.4	26.4
19	7.4	8.4	9.4	10.4	16.4	19.4	21.4	23.4	28.4
20	6.4	7.4	10.4	13.4	17.4	21.4	22.4	27.4	29.4
21	7.4	8.4	11.4	13.4	17.4	21.4	29.4	30.4	30.4
22	7.4	8.4	10.4	12.4	15.4	20.4	27.4	26.4	25.4
23	7.4	8.4	9.4	12.4	15.4	21.4	22.4	23.4	24.4
24	8.4	8.4	9.4	10.4	16.4	19.4	21.4	22.4	24.4
25	8.4	9.4	10.4	12.4	17.4	19.4	21.4	22.4	24.4
26	8.4	9.4	10.4	13.4	16.4	19.4	21.4	22.4	24.4
27	8.4	10.4	11.4	12.4	18.4	23.4	22.4	28.4	31.4
28	8.4	9.4	10.4	12.4	17.4	19.4	24.4	27.4	30.4
29	8.4	10.4	11.4	12.4	16.4	20.4	23.4	25.4	31.4
30	7.4	8.4	10.4	12.4	15.4	19.4	22.4	26.4	31.4
31	8.4	9.4	11.4	12.4	17.4	21.4	24.4	27.4	30.4
32	11.4	12.4	12.4	13.4	16.4	21.4	23.4	25.4	30.4
33	8.4	10.4	13.4	16.4	21.4	25.4	25.4	28.4	31.4
34	6.4	8.4	9.4	10.4	16.4	25.9	26.4	29.4	31.4
35	7.4	9.4	11.4	12.4	15.4	18.4	27.4	28.4	29.4
36	6.4	9.4	10.4	10.4	16.4	20.4	26.4	29.4	31.4
37	8.4	9.4	10.4	10.4	15.4	19.4	24.4	28.4	30.4
38	6.4	8.4	9.4	10.4	15.4	18.4	20.4	22.4	28.4
Overall water depth average	7.69	9.01	10.51	11.93	16.43	20.16	22.95	25.32	27.11
Average water depth updrift of jetties	7.20	8.53	10.13	11.33	15.87	19.13	21.67	24.17	24.60
Average water depth downdrift of jetties	8.01	9.31	10.75	12.31	16.88	20.83	23.79	26.01	28.75

28/3000 feet, etc. These are easier to use than converting depths to degrees and degree fractions.

Nearshore Hydrography (1974-1976)

If the jetties at Great Lakes Naval Training Station are effectively trapping updrift sand supplies, there should be a marked decrease in the nearshore slope angle along profiles from Waukegan Harbor to the northern outer harbor jetty. Water depths along bottom profiles 1 to 15 do not show this pattern to any great extent. Only along profile 15, located about 1500 feet updrift of the jetty, is the nearshore slope a gentler angle.

The bottom profiles (16-20) immediately downdrift of the jetties, located between Shore Acres Country Club and the southern outer harbor jetty in north Lake Bluff, indicate a protective influence by the jetties on this reach of shore. The nearshore slopes of profiles 16 and 17, respectively 20 and 950 deet downdrift of the southern jetty, have gentler angles than profile 15, updrift of the jetties. Slope angles increase progressively from profile 17 to 20, as the protective influence of the jetties decreases. At 2000 feet from shore, for example, the water depth increases from 15 feet at profile 17 to 19.5 feet at profile 20.

Slope angles along this reach of shore correlate closely with data on beach widths, wave reflection, and bluff erosion rates. The trend of higher correlation coefficients closer to the Great Lakes Naval Training Station jetties indicates the partial protective harboring effect of the structures. Along the shore adjacent to profiles 16 and 17, both having the gentlest nearshore slopes, beach widths are highly dependent on lake level fluctuations. The bluff landward of this beach is vegetated and stable. Wave reflection studies indicate that this short shore reach is protected from northeasterly wave attack while southeasterly waves promote shoaling leading to wider beaches. The progressively steeper nearshore slopes from profile 17 to profile 20 indicate that the protective influence of the jetties becomes less important in a downdrift direction as sand-starved beaches and northeasterly wave attack result in severe shore erosion. Downdrift toward Shore Acres Country Club, beach widths become less dependent on lake level changes as local wave conditions and scour become the dominant variables affecting beaches and erosion.

Although a close relationship exists between nearshore slope, beach width variations and erosion rates along the shore reach between the southern jetty at Great Lakes Naval Training Station and the Shore Acres Country Club property, little relationship appears to exist between these variables when considering the entire shore from the jetties to central Lake Forest. Table 6 compares the average depths at 200 to 3000 feet for profiles 16 to 29, which includes the entire sand-starved and eroding shoreline at Lake Bluff, with profiles 30 to 38 along the relatively stable, noneroding, sand-surplus shore of north and central Lake Forest. For 200 to 1500 feet from shore there is no significant average difference between nearshore slopes at Lake Bluff and Lake Forest. Although slopes are slightly steeper from 200 feet and 500 feet at Lake Bluff, slopes are gentler at 300, 400, 1000, and 1500 feet. Lake Bluff slopes are considerably gentler lakeward of 2000 feet. Average depths 3000 feet from shore at Lake Forest are almost 3 feet deeper than the average depth at

TABLE 6 - COMPARISON OF AVERAGE WATER DEPTHS 200-3000 FEET FROM SHORE BETWEEN LAKE BLUFF AND CENTRAL LAKE FOREST, ILLINOIS

	AVERAGE DEPTHS 200-3000 FEET FROM SHORE								
Ranges	200	300	400	500	1000	1500	2000	2500	3000
16-29	6.71	7.79	9.29	11.08	14.93	19.29	21.93	23.07	26.21
30-38	6.44	8.11	9.56	10.67	15.22	19.74	23.20	25.89	29.11

3000 feet at Lake Bluff. When considering this entire reach of shore, nearshore slope apparently has little affect on erosion and beach width. A well-maintained groin system in Lake Forest apparently has offset potentially severe erosion of the shoreline.

In determining whether the jetties at Great Lakes Naval Training Station solely produce an adverse downdrift effect on the nearshore zone by significantly increasing the slope as a result of sediment deprivation, the average depth at each distance from shore, 200 to 3000 feet, for profiles 1 to 15 located between Waukegan Harbor and the northern jetty, was compared with the downdrift profiles, 16 to 38, including the entire reach from Lake Bluff to central Lake Forest. Table 3 indicates no significant difference in water depths out to 1000 feet. From 1500 to 3000 feet nearshore slopes are considerably steeper as water depths are about 1.5 to 3.0 feet deeper south of Great Lakes Naval Training Station. This difference in part may be due to an interruption of the littoral drift by the jetties causing a deprivation of sediment and scour, but since a majority of the deeper depths occur a considerable distance from the jetties, the steeper slopes appear due to other factors.

In order to compare the relative effect of sand entrapment and scour updrift and downdrift of the jetties at Great Lakes Naval Training Station, nearshore slopes and hydrography were studied updrift of the piers at Waukegan Harbor and Commonwealth Edison (Table 4). The pier at Commonwealth Edison has little adverse downdrift affect on nearslope slope angles. Sand appears to bypass this structure with relative ease. Water depths from 200 to 2500 feet from shore are considerably shallower downdrift of the structure. The piers at Waukegan Harbor, on the other hand, appear to be the primary contributors to updrift sand accumulation and downdrift sand starvation and erosion. Nearshore slopes are gentler along the seven profiles between Commonwealth Edison and Waukegan Harbor than along any reach in the study area. Six and eight-foot depths 1000 feet from shore at profiles 6 and 7 attest to the large volume of sand trapped updrift of the structures. The shallow depths and sand accumulations immediately south of the piers at Commonwealth Edison result from an extension of the zone of updrift sand trapped by the Waukegan Harbor piers and in part explain the absence of downdrift scour.

Nearshore slopes downdrift of Waukegan Harbor are considerably steeper than slopes updrift of the harbor piers. Of importance is the relative consistency of nearshore slopes extending south of the harbor to central Lake Forest. The interruption of the shoreline by the Great Lakes Naval Training Station jetties produces little change in ths slopes, except along those few profiles immediately updrift and downdrift of the structures. The starvation of sediments by the harbor piers at Waukegan appears to be responsible for the downdrift narrower beaches, steeper nearshore slopes and severe shore erosion. Measurements of beach widths along the starved shore at North Chicago downdrift of Waukegan Harbor, but updrift of the jetties at Great Lakes Naval Training Station, were comparable to measurements along the entire Lake Bluff shore, further attesting to the fact that Waukegan Harbor traps most of the sediment before it reaches the jetties at Great Lakes Naval Training Station.

Nearshore Hydrography (1872)

If the jetties at Great Lakes had been seriously detrimental to downdrift lake and shore processes, there should have been an increase in the nearshore slope following construction of the jetties in 1923. The 38 bottom profiles located between Waukegan Harbor and central Lake Forest used to study the 1974-76 hydrography were compared to 1872 hydrography (Fig. 12 and Appendix) in order to determine water depth and nearshore slopes prior to constructon of the jetties at Great Lakes and Waukegan Harbor. A comparison of Tables 3 and 5 shows that although average nearshore slopes increased at 200, 300, 400, and 500 feet from shore, since construction of the large shore structures in 1923, thus indicating starvation and scour due to the structures, there appears to be no significant change of nearshore slope north and south of the location of the jetties at Great Lakes Naval Training Center.

Since the construction of large shore structures, water depths beyond 1500 feet from shore decreased significantly along the 38 profiles. At 1500, 2000, 2500, and 3000 feet from shore the average water depth decreased by 1.50, 3.25, 4.69, and 5.71 feet respectively. It appears that the construction of large shore structures, while creating starvation and scour landward of 500 feet, caused sediment diversion and deposition of material beyond 1500 feet. A transition area exists between 500 and 1500 feet. In 1872 and 1974-76 the average water depth at a distance of 1000 feet from shore was 16.43 feet.

Table 5 indicates that at each distance from shore in 1872, average water depths and slopes consistently were greater at the 23 profiles downdrift of the present-day location of the jetties at Great Lakes Naval Training Station than at the 15 profiles located updrift of the jetties' location. Water depths recorded in 1974-76 revealed a smaller difference between nearshore slopes updrift and downdrift of the jetties, and depths were not consistently greater along the downdrift reach. Since this same difference was found in the 1974-76 data to a lesser extent and existed prior to the construction of the jetties, it is unlikely that the jetties are responsible for the scour.

The 1872 hydrographic map (Fig. 12) shows that an offshore area of naturally occurring sediment extends from the present-day location of the United States Steel Works in Waukegan to about the location of the jetties at Great Lakes Naval Training Station. This may in part explain differences in the nearshore slope angles updrift and downdrift of the jetties. The area of sedimentation corresponds to the location of bottom profiles 9 to 15, where depths lakeward of 2000 feet are considerably less than depths along the 8 updrift profiles and the 23 downdrift profiles. This area appears due to the configuration of the shoreline. The shoreline north of the study area trends almost due north-south, and thus the littoral current, carrying the sand supply, parallels the coast. In the vicinity of the city of Waukegan and the Great Lakes Naval Training Station, the coast indents considerably. The southward-bound sediment-carrying littoral current does not necessarily closely parallel the coastal indentation, but rather continues in a general southerly direction further from shore. Since the current is less confined to a channel, its energy becomes depleted and much of the sand is deposited offshore from the coastal indentation. This process of deposition is analogous to the formation of offshore bars and spits at the mouths of harbors or natural embayments.

The sediment supply gradually becomes depleted as the current continues in a general southerly direction, resulting in sediment starvation and steeper nearshore slopes downdrift of the present-day location of the jetties at Great

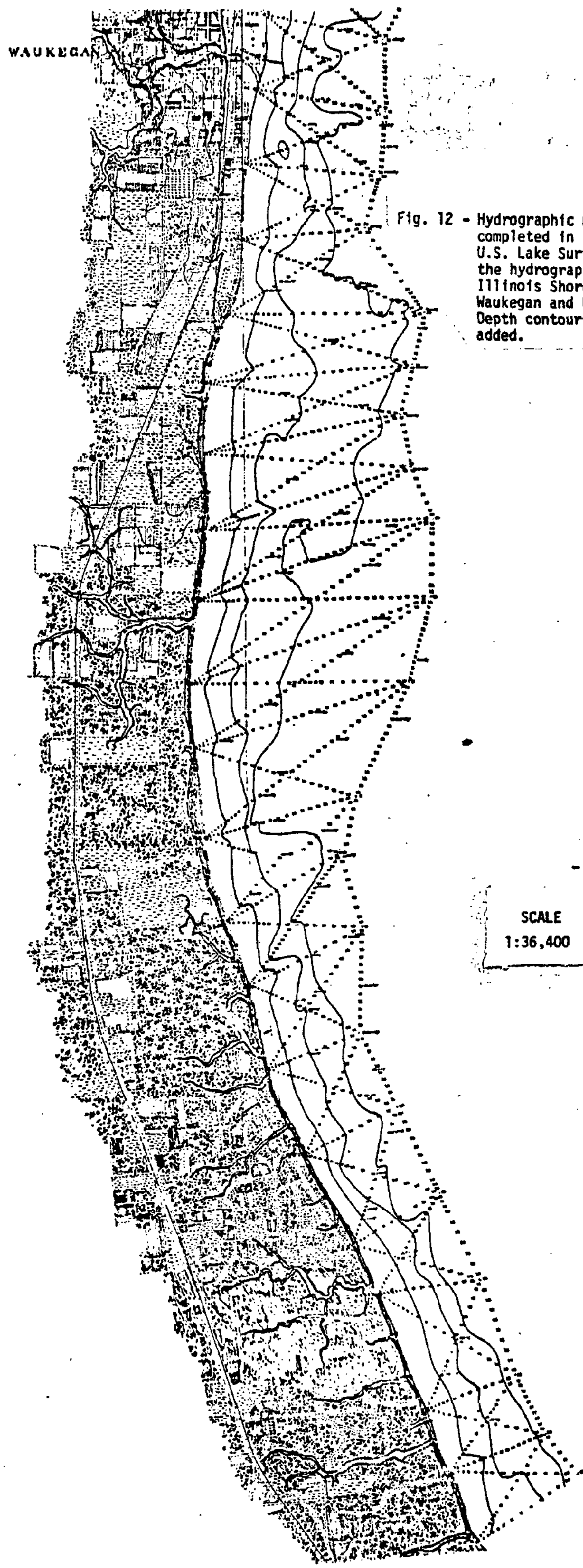


Fig. 12 - Hydrographic map completed in 1873 by U.S. Lake Survey showing the hydrography of the Illinois Shore between Waukegan and Lake Forest. Depth contours have been added.

SCALE
1:36,400

Lakes Naval Training Station. As the coast begins to trend more in a northwesterly-southeasterly direction, the south-bound sediment-depleted littoral current comes closer to the shore. The result is significant scour and steepening of the nearshore slope lakeward of 200 feet. This scour is particularly noticeable along bottom profiles 27 to 38. A similar pattern is evident for 1974-76

Large shore structures resulted in considerable updrift sediment accumulation accompanied by downdrift scour and increase in the nearshore slope landward of about 1000 feet. The 1872 hydrographic data suggest that the shore reach from Waukegan to Great Lakes Naval Training Station was an area of sediment accumulation resulting in downdrift starvation, before any large structures were built. Thus not all of the downdrift sediment-starvation, even that which originates at Waukegan Harbor, can be attributed to sand-trapping by large shore structures.

Sediment Thicknesses

Offshore sediment samples were taken in July, 1976 from cores to determine sand thicknesses along the Illinois shore of Lake Michigan. Seventeen sampling sites were located from just north of the Commonwealth Edison pier to central Lake Bluff. The locations of the samples are shown on the hydrographic maps with sand thicknesses shown in parentheses. These data confirm the consensus that most of the sand that travels down the coast is trapped by the piers at Waukegan Harbor, leaving lesser amounts to be trapped by the jetties at Great Lakes Naval Trianing Station. Sampling sites W6, W7, W8, W9, and W10, all located about 1000 feet updrift of the Waukegan Harbor piers, have thicknesses of 22.2, 15.2, 11.0, 15.75, and 17.7 feet, respectively, of fine to medium sand. Sites W6, W7, and W8, show a thinning of sand away from the shoreline. At sampling sites W3, W4, and W5 off the mouth of Waukegan Harbor, the sediment supply is depleted and scouring is evidentas sand depths thin from 8 feet at site W3 to 4.5 at site W5.

South of the piers at Waukegan Harbor sand starvation is quite noticeable as sediment thicknesses at sites W1, W1b, and W2 are 8, 6, and 8 feet respectively. Just north and east of the jetties at Great Lakes Naval Training Station, sediment thicknesses at sites GL 1and GL 2 reveal a continuation of sediment starvation from Waukegan Harbor as 7 and 8 feet of sand were found. South of the jetties at Great Lakes Naval Training Station, sand thicknesses at sites GL 3, GL 5, GL 6, and GL 7 were 4.5, 4.1, 3.0, and 0 feet respectively. The 13.2 feet of sand at the harbor entrance (site GL 4) appears to be the result of dredging.

The study of offshore sand thicknesses indicates that most of the longshore sediment is trapped by the piers at Waukegan Harbor, creating severe downdrift sand starvation. The jetties at Great Lakes Naval Training Station also trap sediment, but the downdrift effect of starvation is considerably less than at Waukegan Harbor. This agrees with other data on beach widths and nearshore slope angles showing that the Great Lakes Naval Training Station jetties are not the primary contributors to downdrift sediment starvation and shore erosion.

Conclusions

Large structures that extend from the shore commonly have an adverse affect on downdrift shore processes. The trapping of updrift sediment starves the downdrift shore reaches, resulting in a steepening of the nearshore slope, a decrease in the width of beaches, and an increase in rates and amounts of shoreline erosion. It has been the purpose of this study to evaluate the relative effect of the jetties at Great Lakes Naval Training Station in causing serious downdrift changes of lake shore processes. The following conclusions summarize the results:

1. Evaluation of air photos and hydrography indicates that the jetties provide some protection from northeasterly wave attack for the downdrift shore in northern Lake Bluff.

2. Reflection of southeasterly waves from the southern jetty appears to have caused shoaling and beach building for a distance of 600 feet downdrift of the structure, resulting in stable non-eroding bluffs. When riprap was added to a portion of the jetty it appears to have caused a reduction in reflected waves whereupon erosion commenced.

3. Reflection of northeasterly waves from a highly reflective portion of the northeastern jetty appears to add to northeasterly wave trains that carry southward from the jetties, possibly increasing erosion.

4. Comparison of sand trapped north of the Great Lakes harbor with the length of starved shore south of the harbor suggests that starvation greatly exceeds the amount of available littoral drift. Examination of littoral drift characteristics north of Great Lakes and the sand impoundment at Waukegan Harbor indicates that Waukegan Harbor jetties are the main cause of littoral drift starvation at North Chicago and at Lake Bluff.

5. A comparison of beach widths and lake levels along the shore between the Great Lakes Naval Training Station jetty and the Shore Acres Country Club reveals that beach widths close to the jetty are directly dependent on lake level changes, indicating a protective influence by the structure. Further from the jetty beach widths are subject to starvation and local scour.

6. Comparison of preconstruction maps with recent hydrography indicates that the Great Lakes and Waukegan shore structures have caused significant downdrift scour to a depth of 500 feet in the lake, whereas beyond 1500 feet, sediment diversion has resulted in a decrease of nearshore slopes. The major decrease in nearshore slope occurs updrift of the piers at Waukegan Harbor, verifying the fact that the jetties at Great Lakes Naval Training Station are not the primary cause of downdrift sediment starvation.

7. Study of nearshore slopes from 1974-76 hydrographic data suggests that no significant difference in slope angle presently exists updrift and downdrift of the jetties out to 1000 feet from shore. An increase of slope beyond 1500 feet on the downdrift side of the Great Lakes Naval Training Station jetties, may be attributed to sediment starvation, but appears more likely due to the presence of a bedrock elevation.

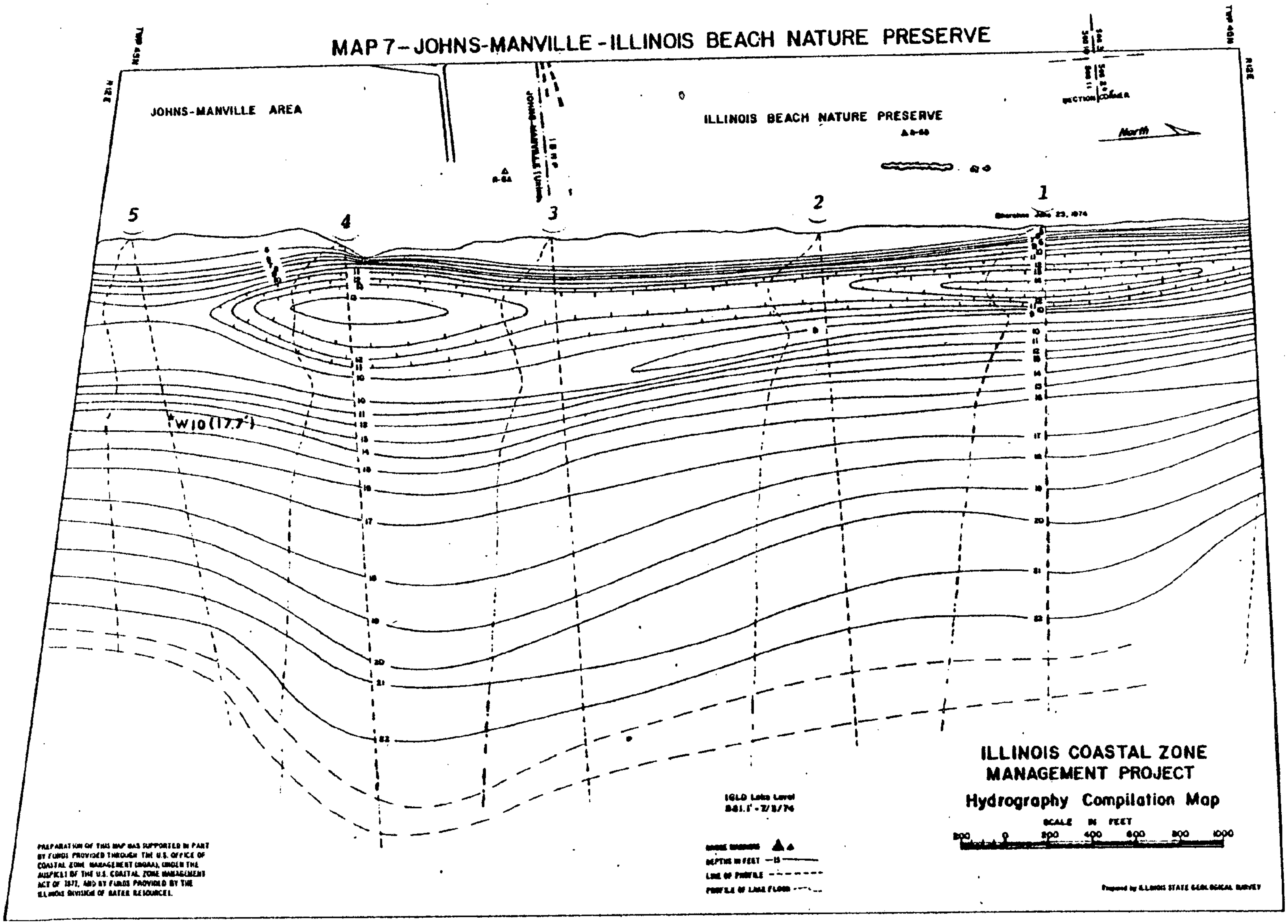
8. Finally, sediment depths reveal that the thickest sand accumulations are updrift of the Waukegan Harbor jetties accompanied by a significant decrease in sand thickness downdrift of the jetties. Sand deposits are also thinner downdrift of the jetties at Great Lakes Naval Training Station, but starvation is much less than that which occurs at Waukegan Harbor.

APPENDIX

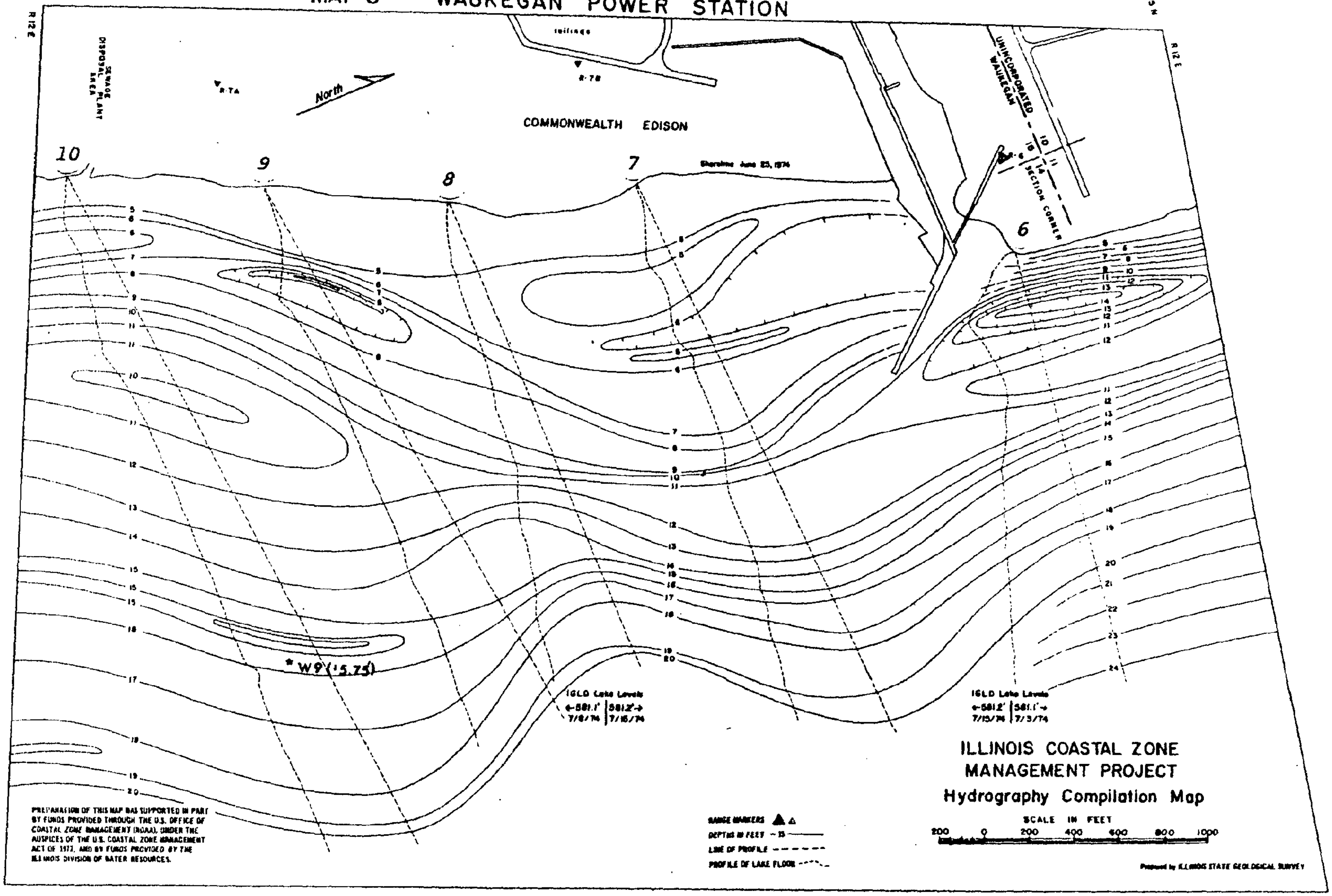
Hydrographic Maps of the Illinois Shore between Illinois Beach State Park and central Lake Forest

The following maps have been modified from the 1975 report "Hydrography of the Lake Michigan Nearshore between the Wisconsin State Line & Wilmette Harbor" (First Year Work Product, Volume II, Coastal Geological Studies, Illinois Coastal Zone Management Program, Illinois Division of Water Resources). They represent Maps 7 through 17, which show lake bottom profiles and boreholes upon which many conclusions in this report are based. Depths are given in feet below water level. The positions of the profiles are shown by straight dashed lines. Curved dashed lines adjacent to them represent the actual profile configuration.

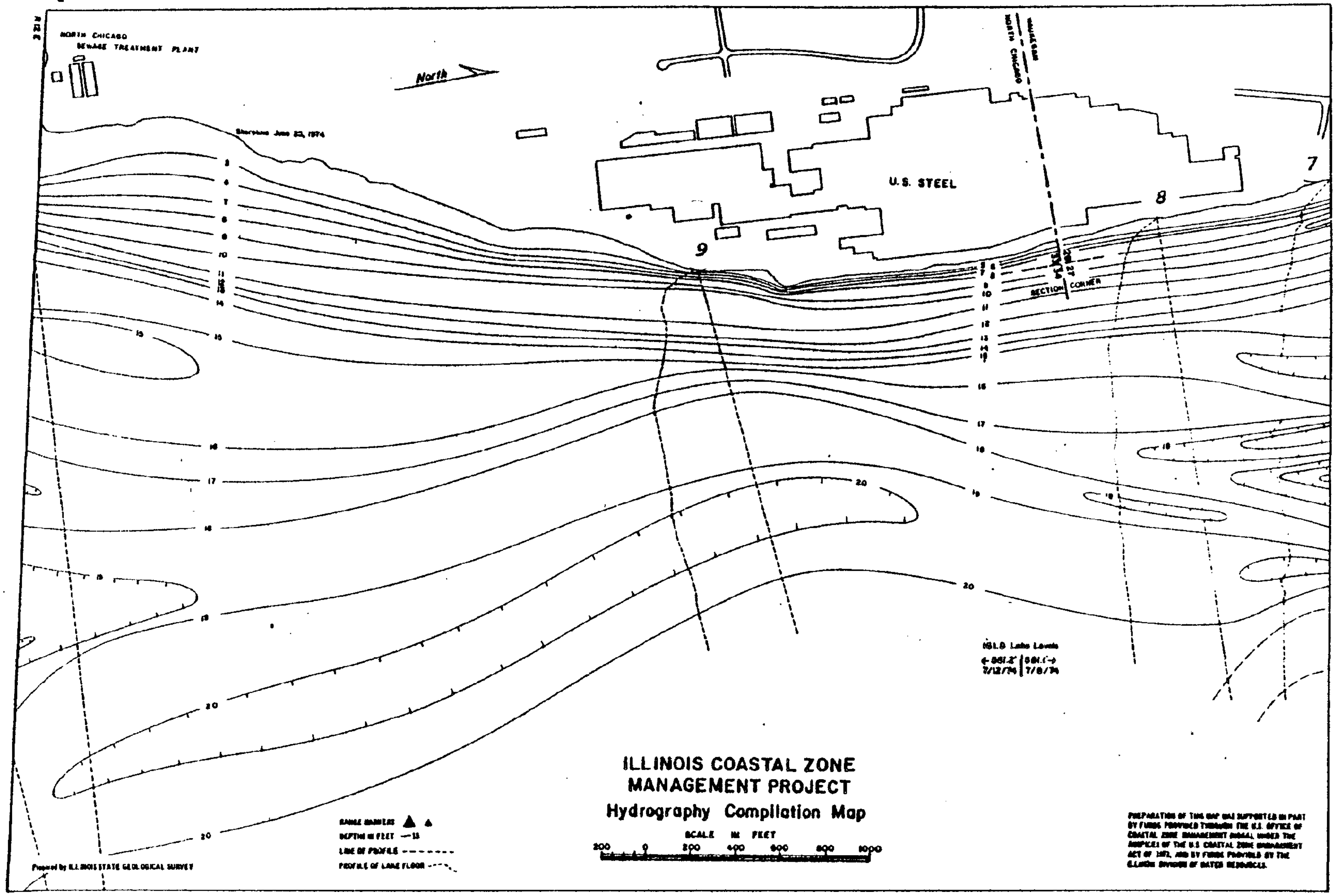
MAP 7–JOHNS-MANVILLE-ILLINOIS BEACH NATURE PRESERVE



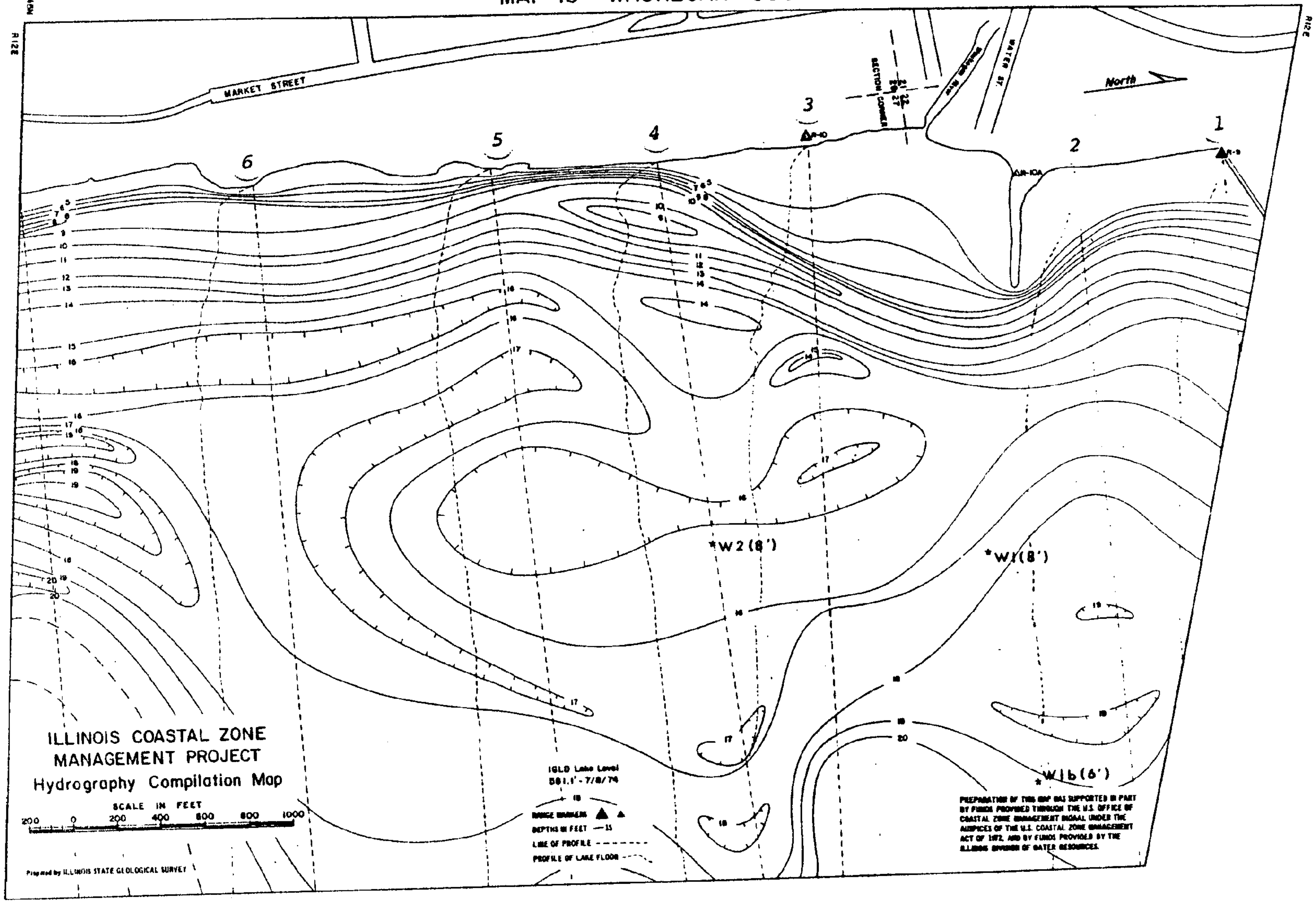
MAP 8 - WAUKEGAN POWER STATION



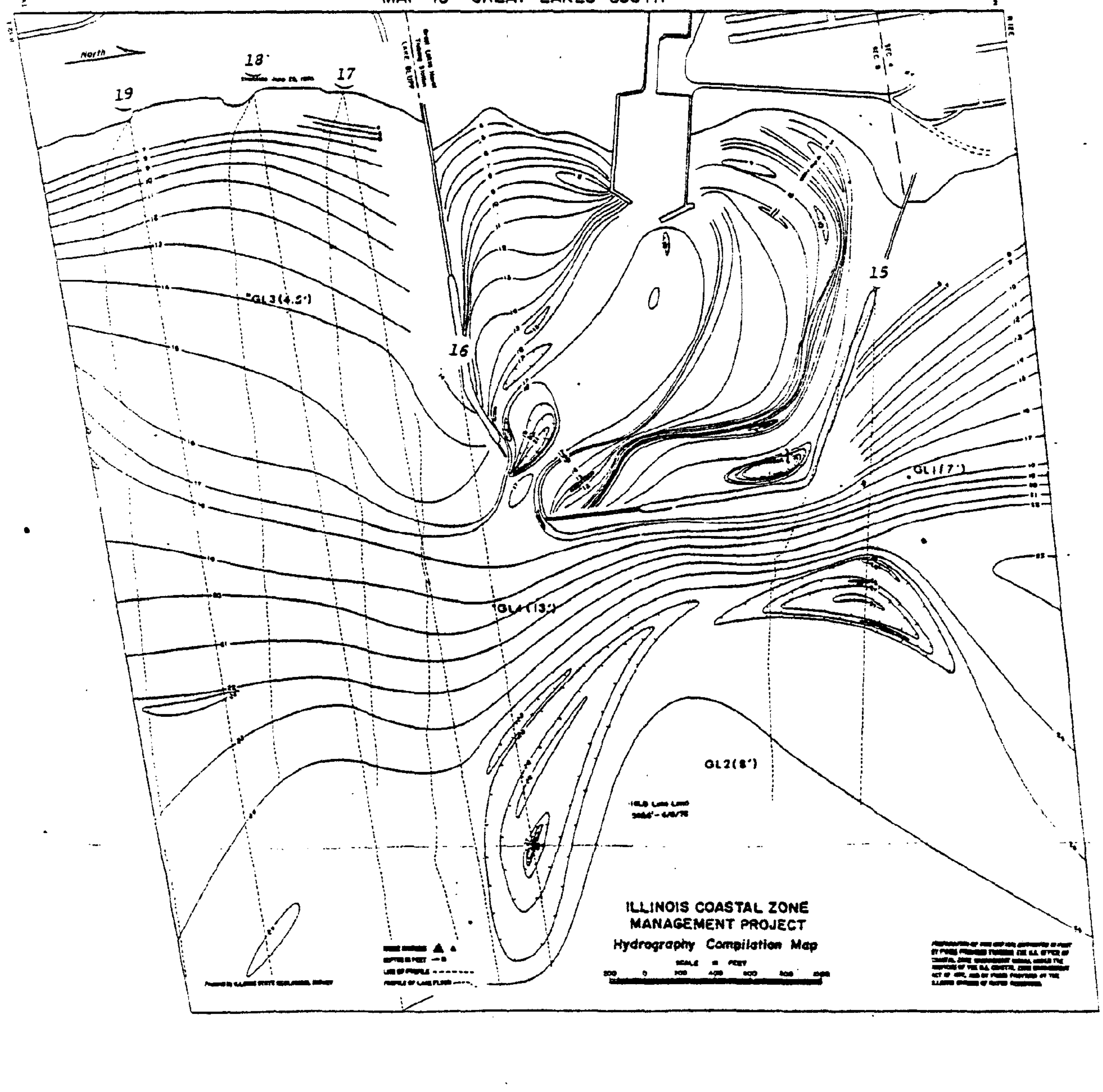
MAP II - NORTH CHICAGO



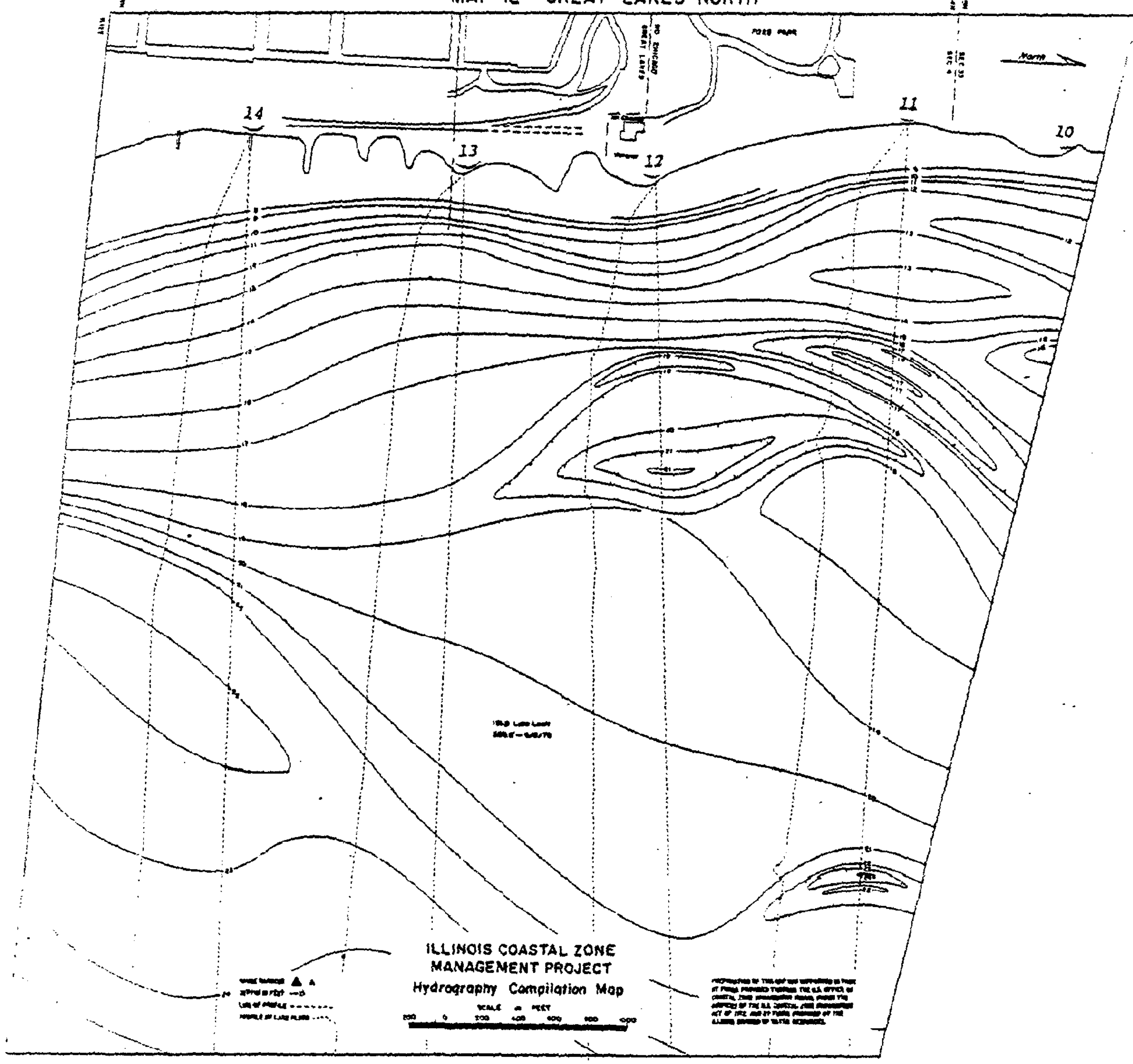
MAP 10 - WAUKEGAN SOUTH



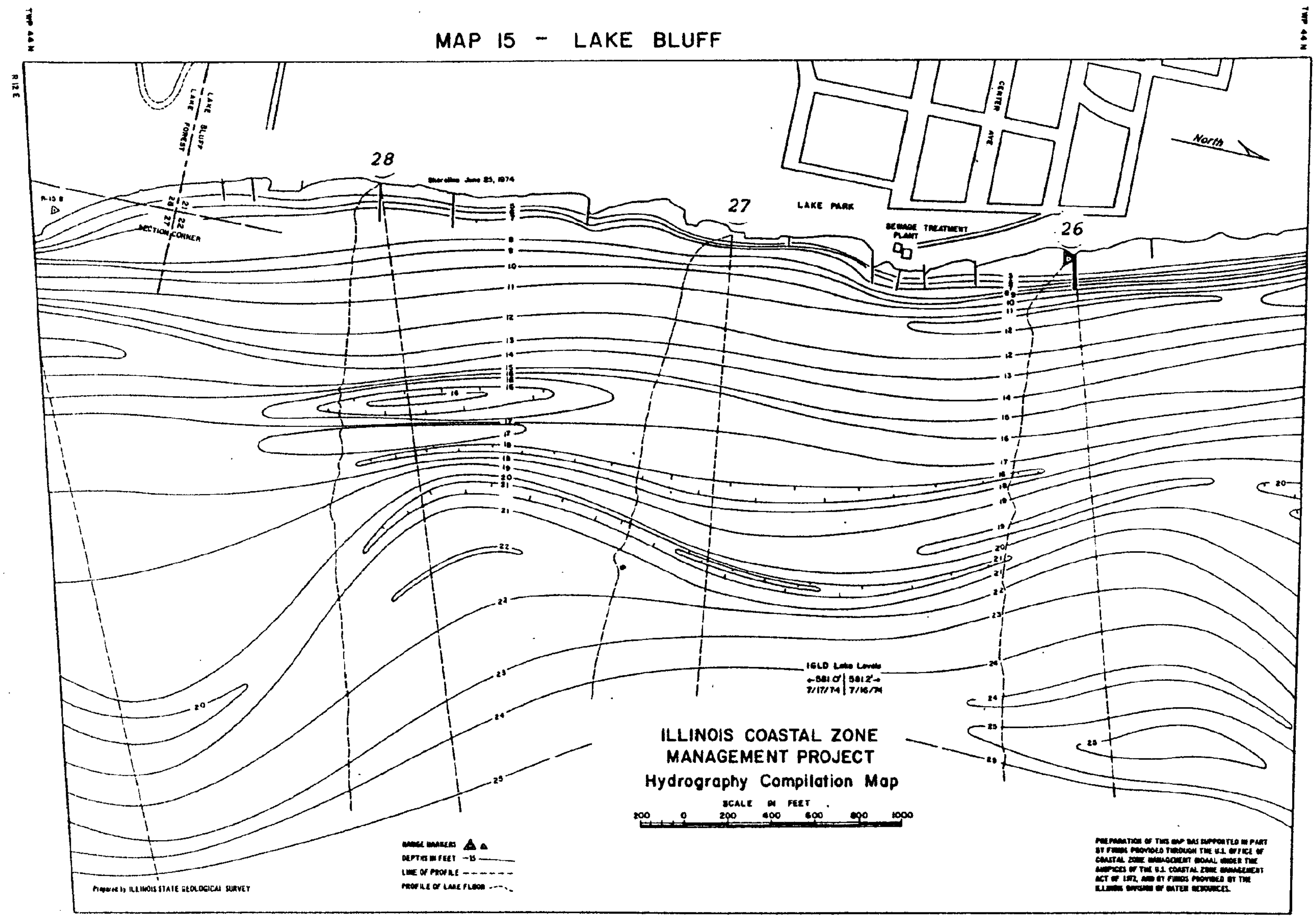
MAP-13 GREAT LAKES SOUTH



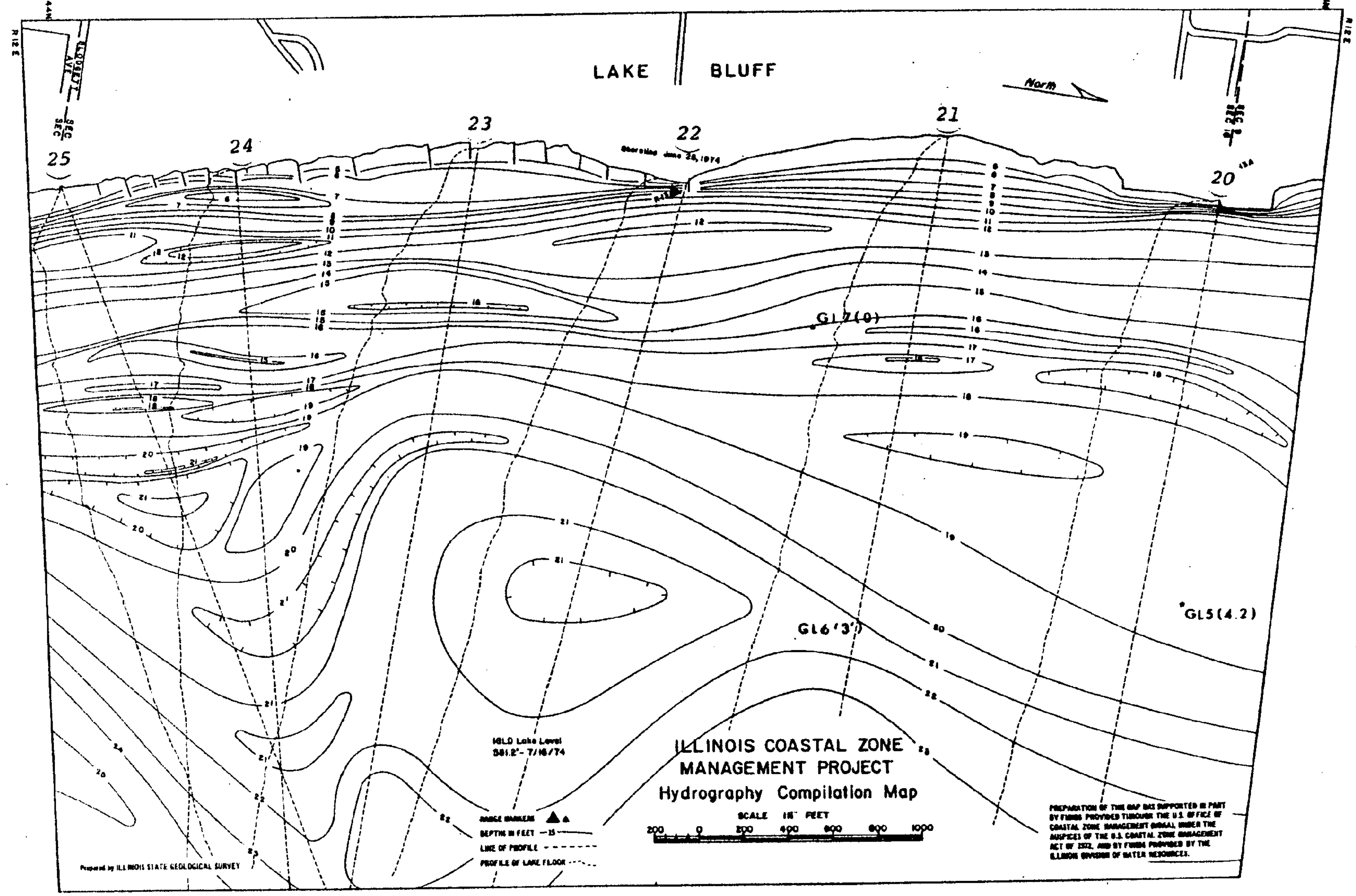
MAP 12 - GREAT LAKES NORTH



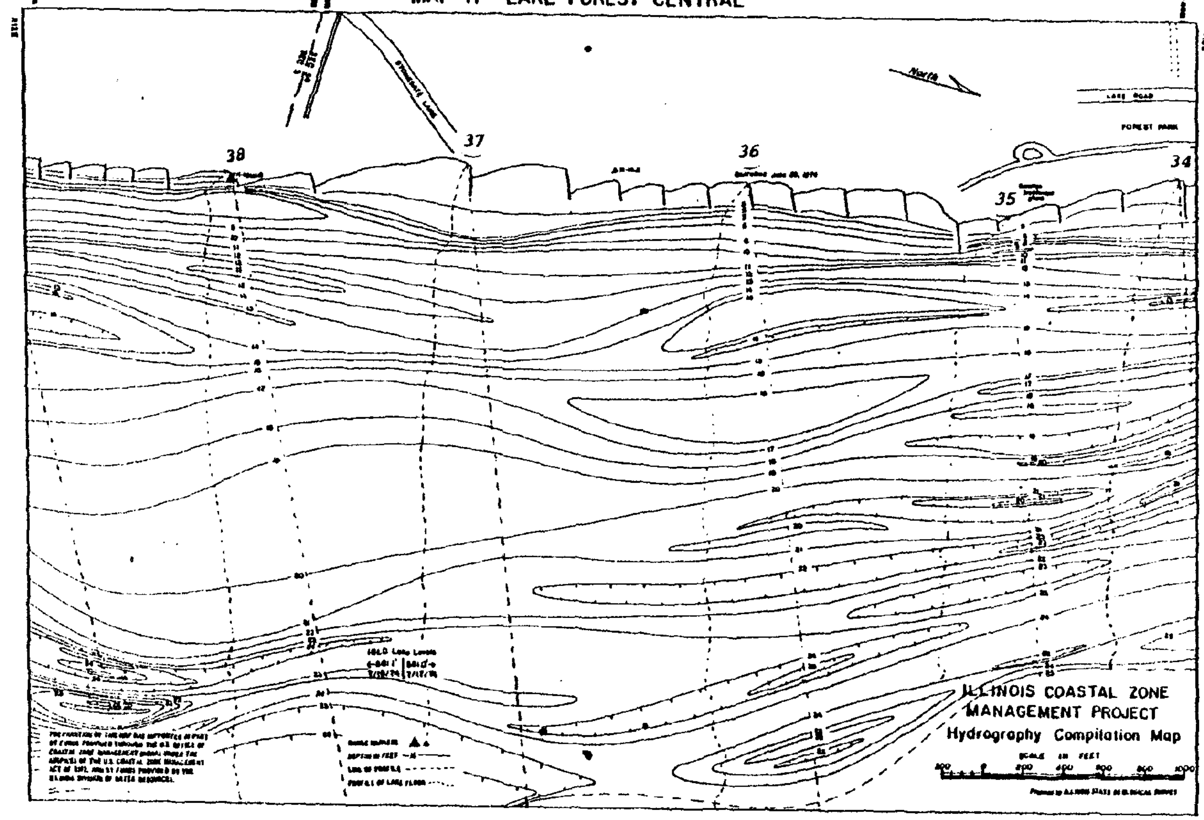
MAP 15 - LAKE BLUFF



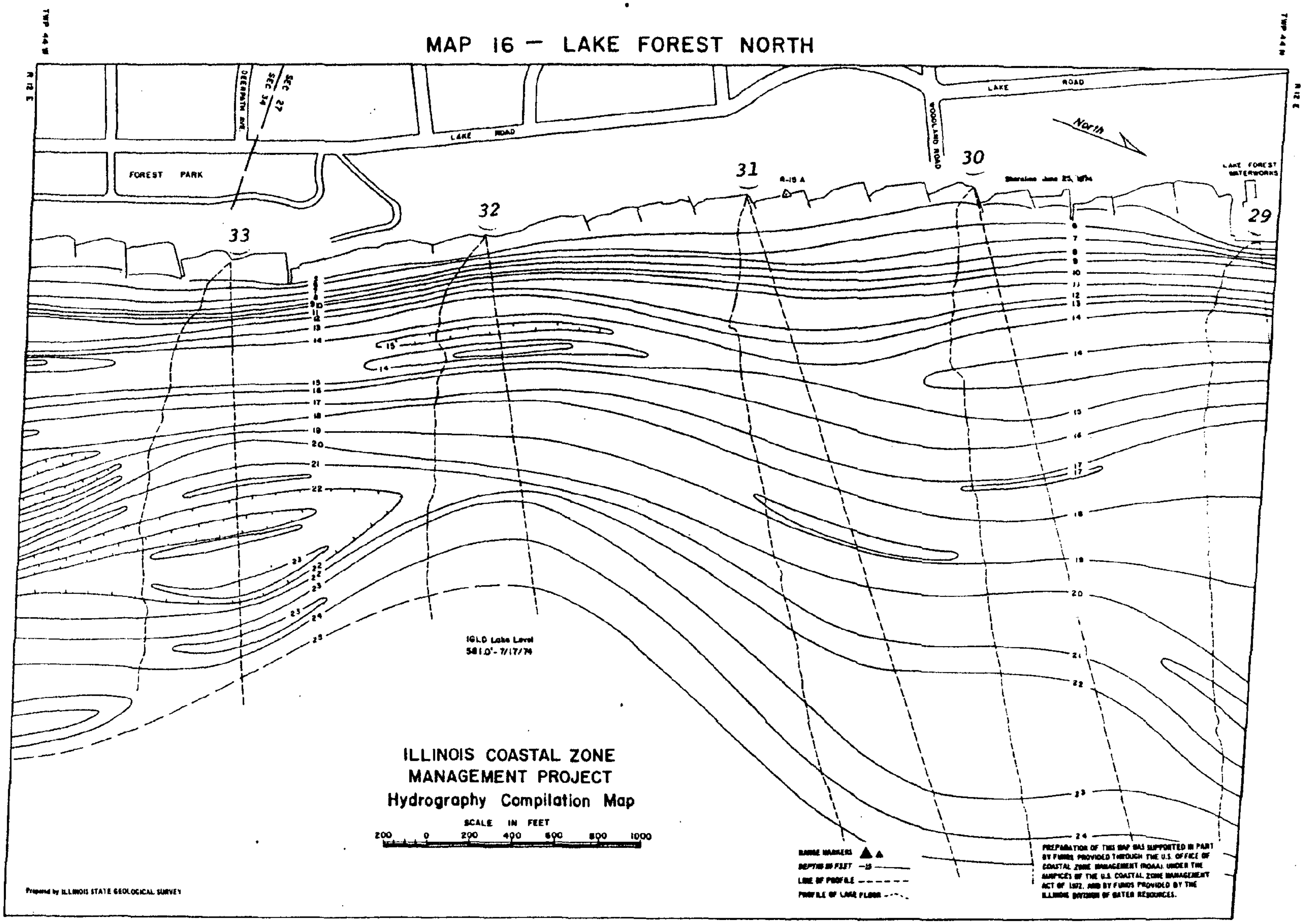
MAP 14 - SHOREACRES COUNTRY CLUB



MAP-17 LAKE FOREST CENTRAL



MAP 16 — LAKE FOREST NORTH



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Illinois State Geological Survey

CLIMATIC, WATER LEVEL & GEOLOGIC FACTORS:

Lake Michigan Bluff Recession and Denudation

ILLINOIS COASTAL ZONE MANAGEMENT DEVELOPMENT PROJECT

CLIMATIC, WATER LEVEL AND GEOLOGIC FACTORS: LAKE MICHIGAN BLUFF RECESSION AND DENUDATION

Richard C. Berg

Prepared by the

ILLINOIS STATE GEOLOGICAL SURVEY

for

THE ILLINOIS COASTAL ZONE

MANAGEMENT PROGRAM

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OCTOBER 1977

CLIMATIC, WATER LEVEL AND GEOLOGIC FACTORS:
LAKE MICHIGAN BLUFF RECESSION AND DENUDATION

Richard C. Berg

ABSTRACT

Analyses of seasonal and climatic regimes, local geology and lake fluctuations were studied to determine their effect on bluff denudation and erosion. Monthly field measurements of bluff recession from 1975 to 1977 were compared to monthly data on precipitation, wind variables and freeze-thaw phenomena to determine which have the greatest influence on recession. Patterns of erosion were then compared to the earth materials that comprise the bluffs, since inherent stability or instability depends on variations in these materials. Finally, the effect of fluctuating lake levels on rates of denudation and erosion was studied in Highland Park, Glencoe, Winnetka, and Kenilworth in order to more fully comprehend the lag effect wherein time is required for the bluff to adjust to fluctuating water conditions.

It is concluded that most bluffline recession occurs during high lake level years in late winter-early spring following the first major thaw of the year. Frequent wave-storm episodes and heavy precipitation are less important. During a low lake level year with infrequent wave-storm periods and low precipitation, bluff recession is almost negligible.

Recession rates are greatest where thick sand and silt deposits are associated with till layers. The porous sand unit is thickest in north Lake Bluff. Between central Lake Bluff and central Lake Forest the bed is considerably thinner, while south of Lake Forest, a continuous porous bed is virtually absent.

Along the Highland Park, Glencoe, Winnetka, and Kenilworth shore maximum bluff denudation occurred 3 to 6 years following the 1952 peak high lake level year while maximum revegetation occurred 4 to 6 years following the 1964 record low lake level year. These data single out the importance of vegetation in preventing or slowing erosion.

INTRODUCTION

Bluff erosion along the Illinois shore of Lake Michigan is dependent on a number of variables: earth materials, rainfall, storm frequencies, freeze-thaw phenomena, lake levels, public use and management. Consequently, erosion rates vary widely with time and geographic location (Berg and Collinson, 1976; Berg, 1977). The greatest recession losses in Illinois have occurred at Lake Bluff where the average loss for 1½ miles of shore is almost 270 feet for the last one-hundred years. At south Lake Forest, where losses are more recent, over 30 feet has been lost since 1973. Losses occur in lesser amounts along other reaches of the shore. Rates of bluff recession have been shown to be closely related to denudation and subsequent revegetation processes. Maximum denudation and recession occur during periods of high lake level and continue for a few years following, while maximum bluff stabilization occurs during and immediately following episodes of low lake level. Hence, a lag is evident wherein time is required for the bluff to adjust to new conditions arising from fluctuations in lake level.

The purpose of this study was to isolate the several factors controlling bluff erosion rates along the Illinois shore through use of oblique and vertical aerial photographs dating back to 1937 as well as systematic field measurement of bluffline recession. Measurements were made during the period between September, 1975 and July, 1977. Original plans called for measurements to be made over a one year cycle. However, significant changes in rainfall made it important to continue measurements a second year. Seasonal and climatic regimes, local geology, and lake levels were studied to determine their relative effects on rates of bluff denudation and erosion.

Monthly data on climate, precipitation, wind variables and freeze-thaw phenomena were compared to monthly field measurements of bluff recession for the purpose of determining which exert the greatest influence on recession.

Study of the effect on erosion of fluctuating lake levels begun by Berg and Collinson at Lake Bluff and Lake Forest was extended southward to Highland Park, Glencoe, Winnetka and Kenilworth, where areas of denudation and active erosion are relatively small (Fig. 1).

The factors isolated by the foregoing studies were then compared to variations in the earth materials that comprise the bluffs. The inherent stability or instability of the materials represent the baseline against which the other factors operate.

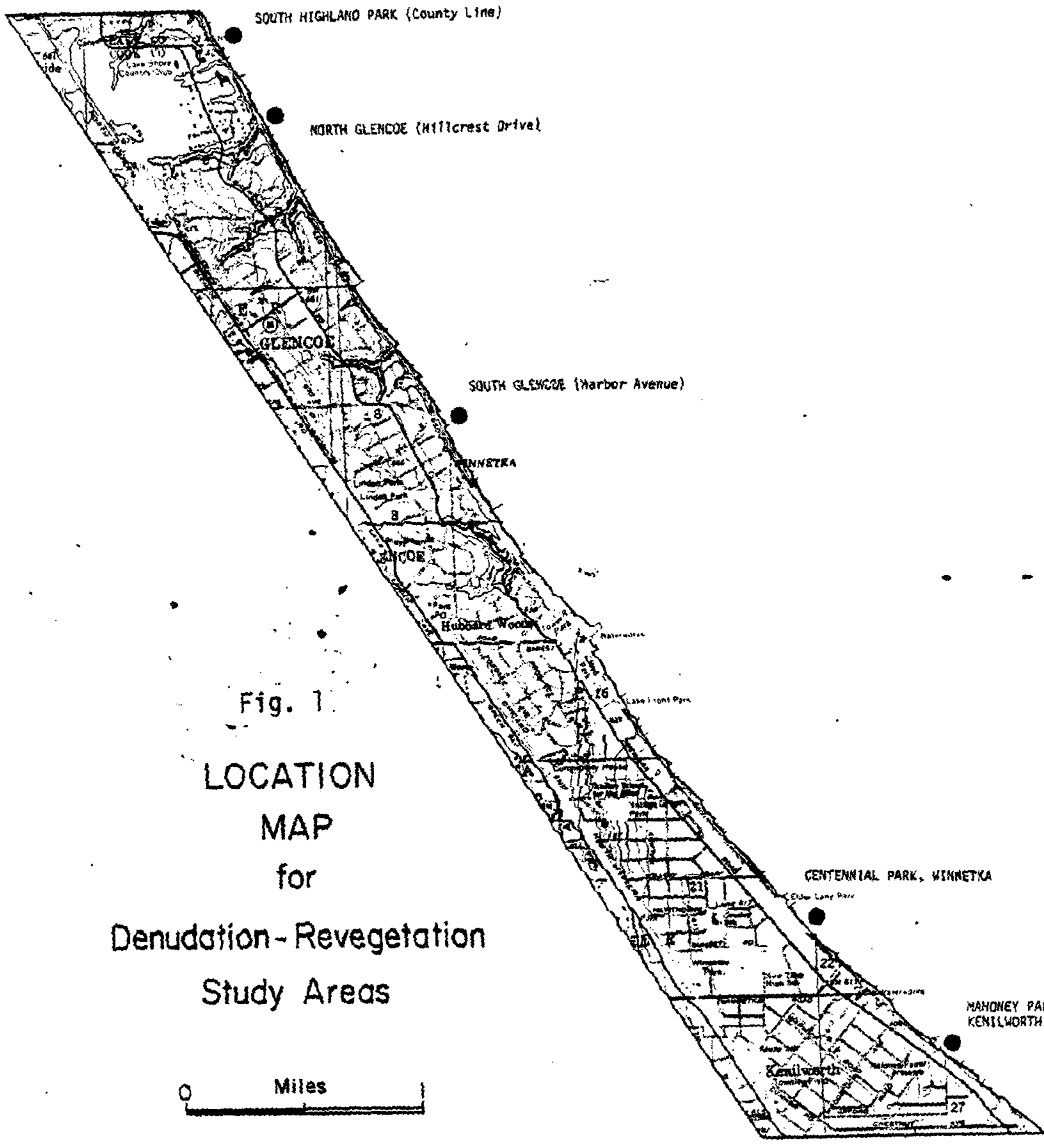

Fig. 1

LOCATION MAP for Denudation - Revegetation Study Areas

0 Miles 1

RELATION OF BLUFF RECESSION RATES TO WEATHER FACTORS

Bluffline erosional losses along a portion of the Illinois Lake Michigan shore (Fig. 2) were studied to determine their relation to seasonal weather cycles. Forty-three traverses were established between the bluffline and stakes set on the bluff top in Lake Bluff and the Lake Forest Nature Preserve area in south Lake Forest (Figs. 3-7). From September 24, 1975 to July 18, 1977 measurements were made monthly between the bluffline and 32 stakes set 100 feet apart and 11 stakes set 25 feet apart (Figs. 3-7). Measurements were not made during November, December, and January because the bluff was deeply frozen.

Measurements showed recessional losses related to wind direction and velocity, precipitation, diurnal and annual temperatures. According to Gelinas and Quigley (1973), erosion occurs when the internal resistance of the bluff material is less than the forces of abrasion and impact of water. Precipitation and freeze-thaw activity affect rates of bluff erosion by removing bluff face materials with sheet wash that have been loosened by freeze-thaw action and by influencing the hydrostatic pressure of ground water following a long freeze period. In addition, ground water discharging as seeps on the bluff face is a primary cause of erosion.

Seibel (1973), Davis (1974), and Dugas and Mecum (1975) concluded that a storm condition ensues when the average daily wind speed is greater than 15 mph. The theory of wind-wave generation in shallow water relates wind velocity, fetch and duration with wave period and height (Bretschneider, 1963). A strong onshore wind from the direction of greatest fetch promotes the most damaging wave erosion. Along Lake Bluff and Lake Forest, waves with maximum energy originate from the northeast. Waves which arrive from due north or due east are not as damaging. From the southeast waves approach the shore at an oblique angle, with potential for producing great damage but duration times are relatively short and the frequency of occurrence of such episodes is low. A strong onshore wind results in damaging waves and promotes bluff erosion by two mechanisms. Wave impact notches the bluff toe. Wave splash erodes the bluff face by sheet wash and further weakens it by wetting. Erosion of the bluff toe is the more serious. Actual bluffline recession commonly does not occur simultaneously with wave storm episodes due to lag time between oversteepening caused by toe erosion and subsequent slumping.

Table 1 summarizes wind, precipitation and freeze-thaw data for each bluff-measurement period. The data used are derived from U.S. Weather Service records from Chicago, Illinois and are considered representative of the Lake Bluff and Lake Forest area. Only storm days with a minimum average daily wind speed of 15 mph from the north, northeast or east are listed. Precipitation data include total rainfall and the number of days when more than a trace of precipitation was recorded. Freeze-thaw data used are: (1) the number of freeze-thaw days when the minimum daily temperature was below freezing and the maximum daily temperature above freezing, and (2) protracted freeze periods with average daily temperatures below freezing alternating with thaw days with average daily temperatures above freezing.

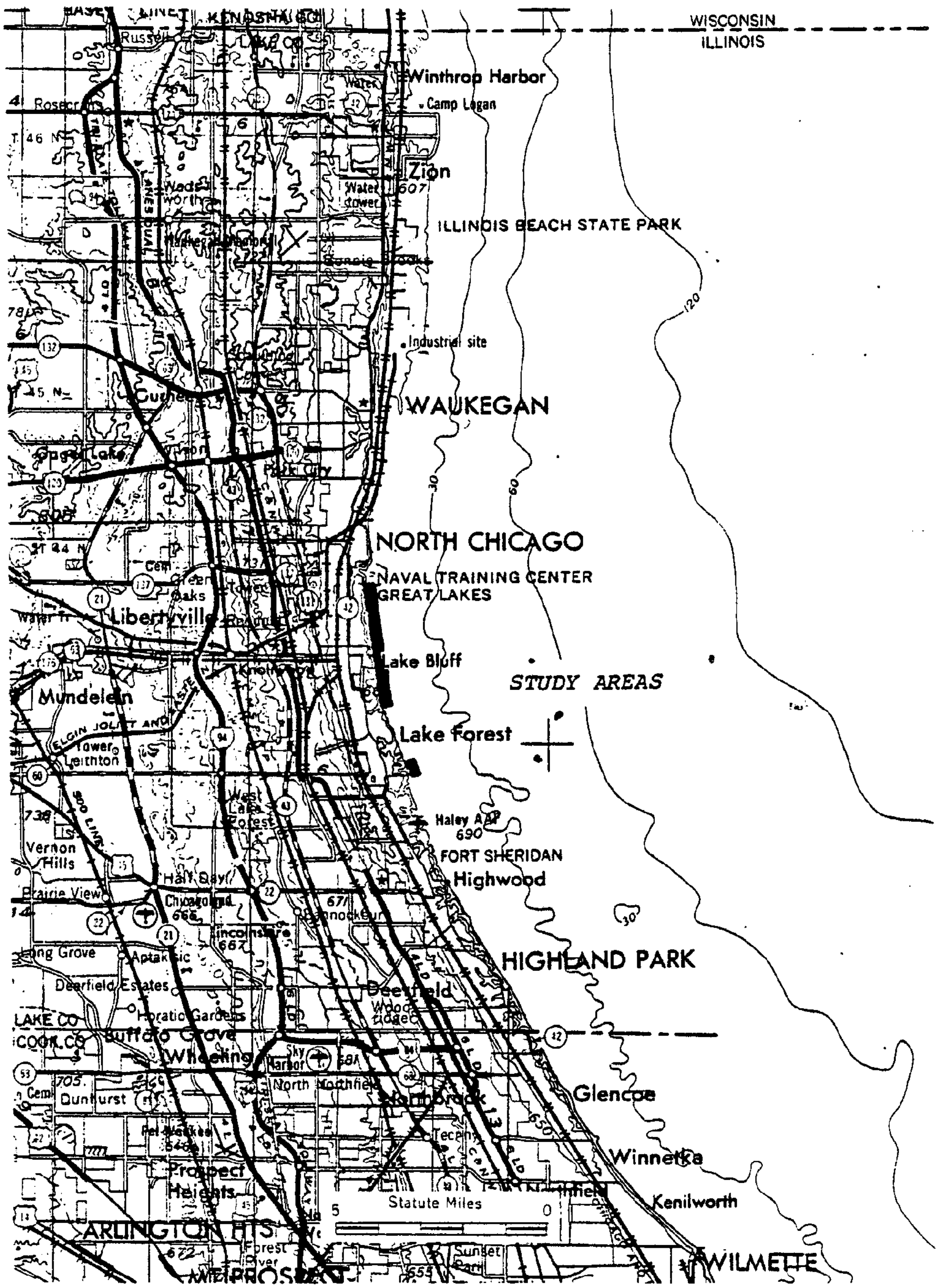

Fig. 2 - Index map showing the Lake Bluff and Lake Forest reaches of shore where recession measurement stakes were set.

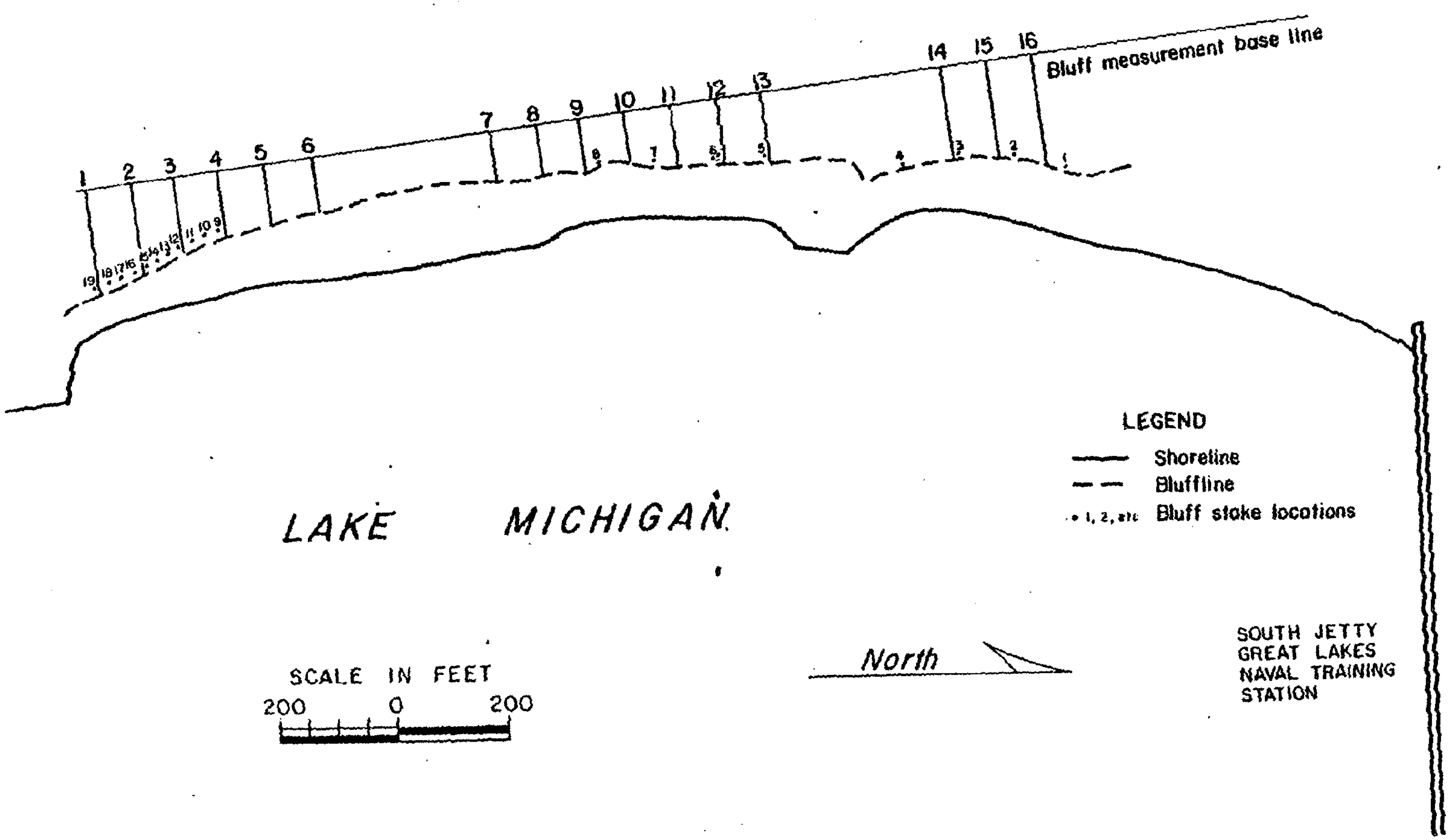

Fig. 3 - Locations of Traverses 1 through 19 (small figures) along the shore in northermost Lake Bluff. The large figures (1-16) are baseline references used to measure recession from aerial photographs.

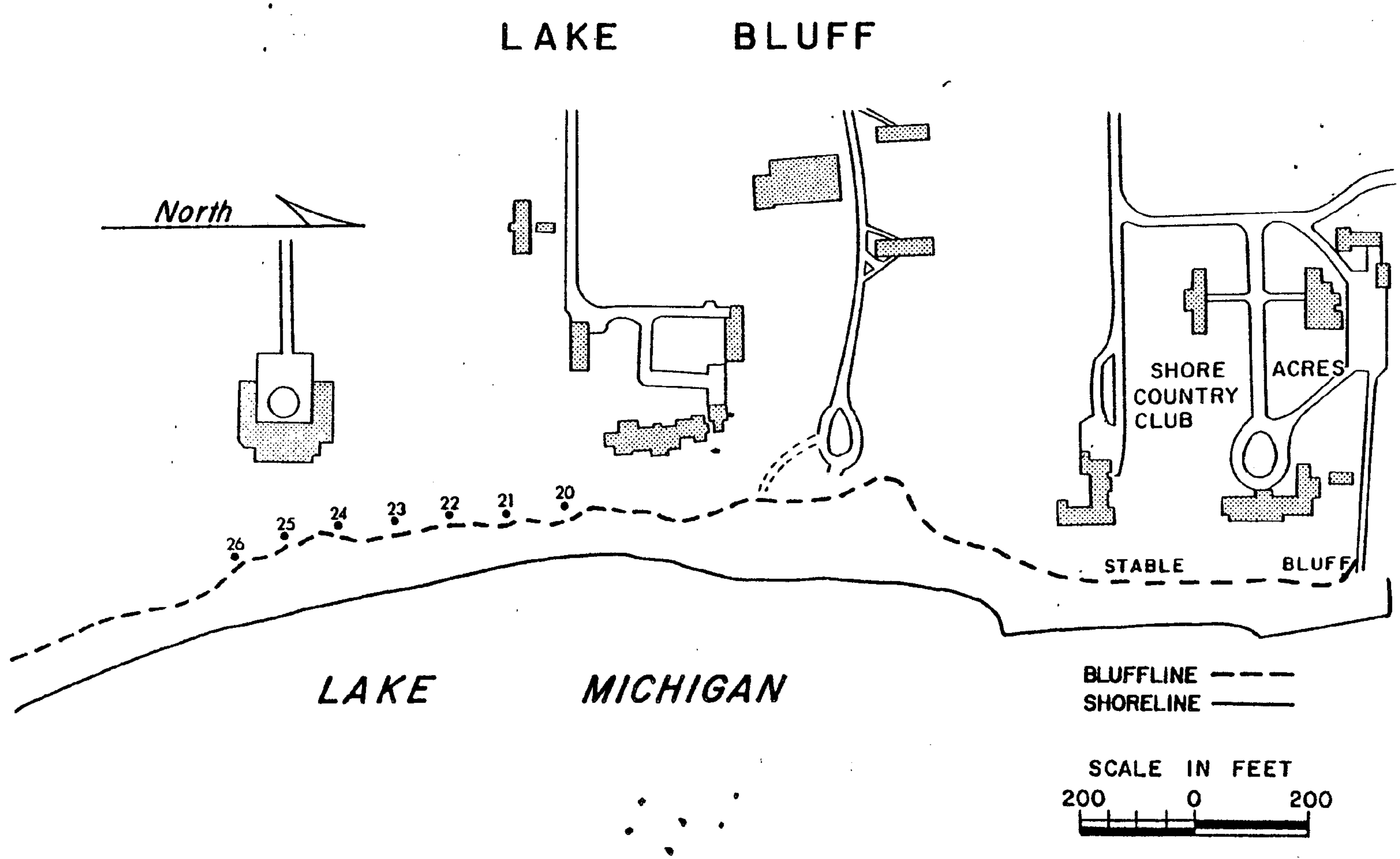

Fig. 4 - Locations of traverses 20-26 in north central Lake Bluff.

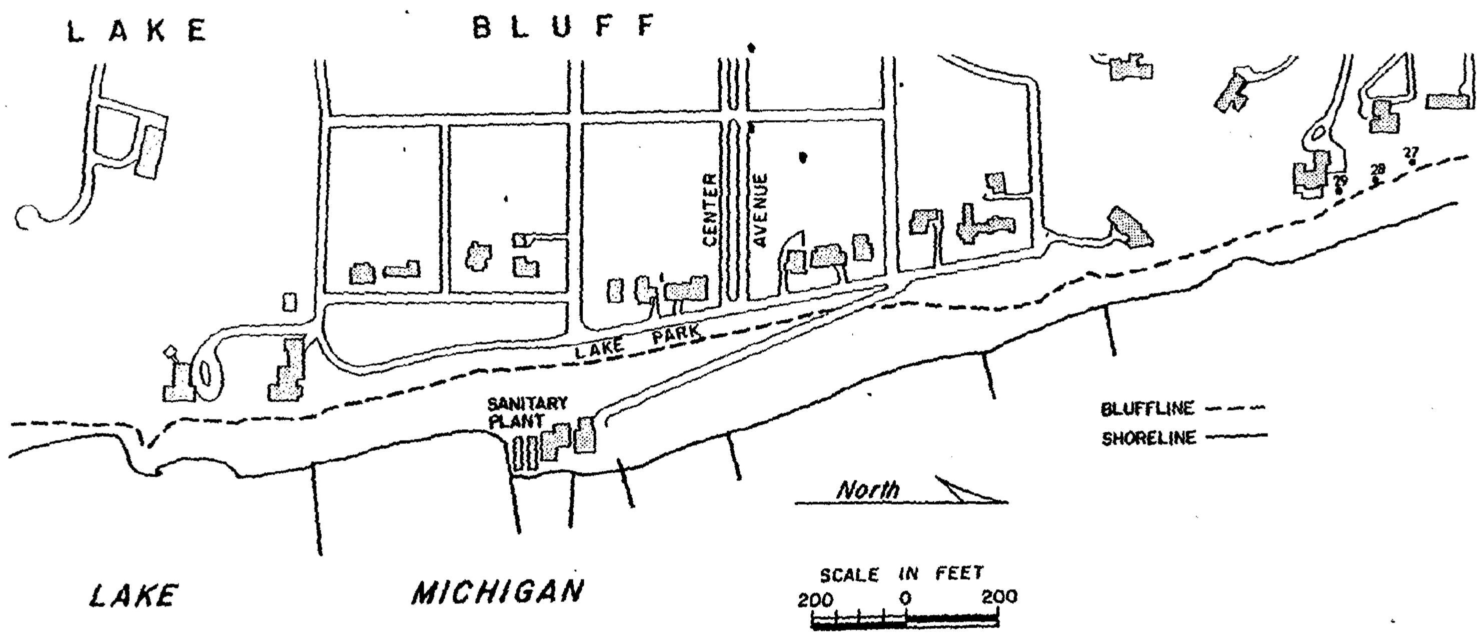

Fig. 5 - Location of traverses 27-29 in central Lake Bluff.

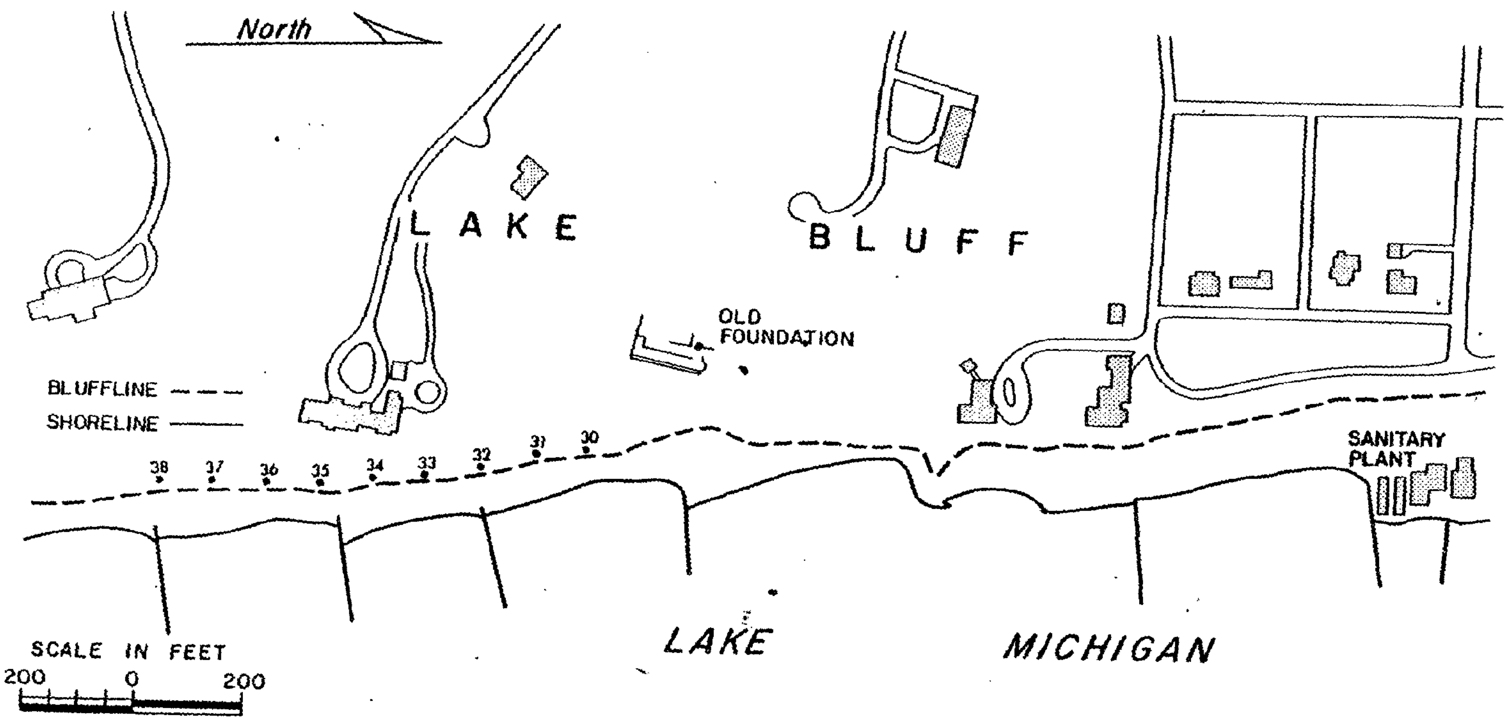

Fig. 6 - Location of traverses 30-38 in south Lake Bluff.

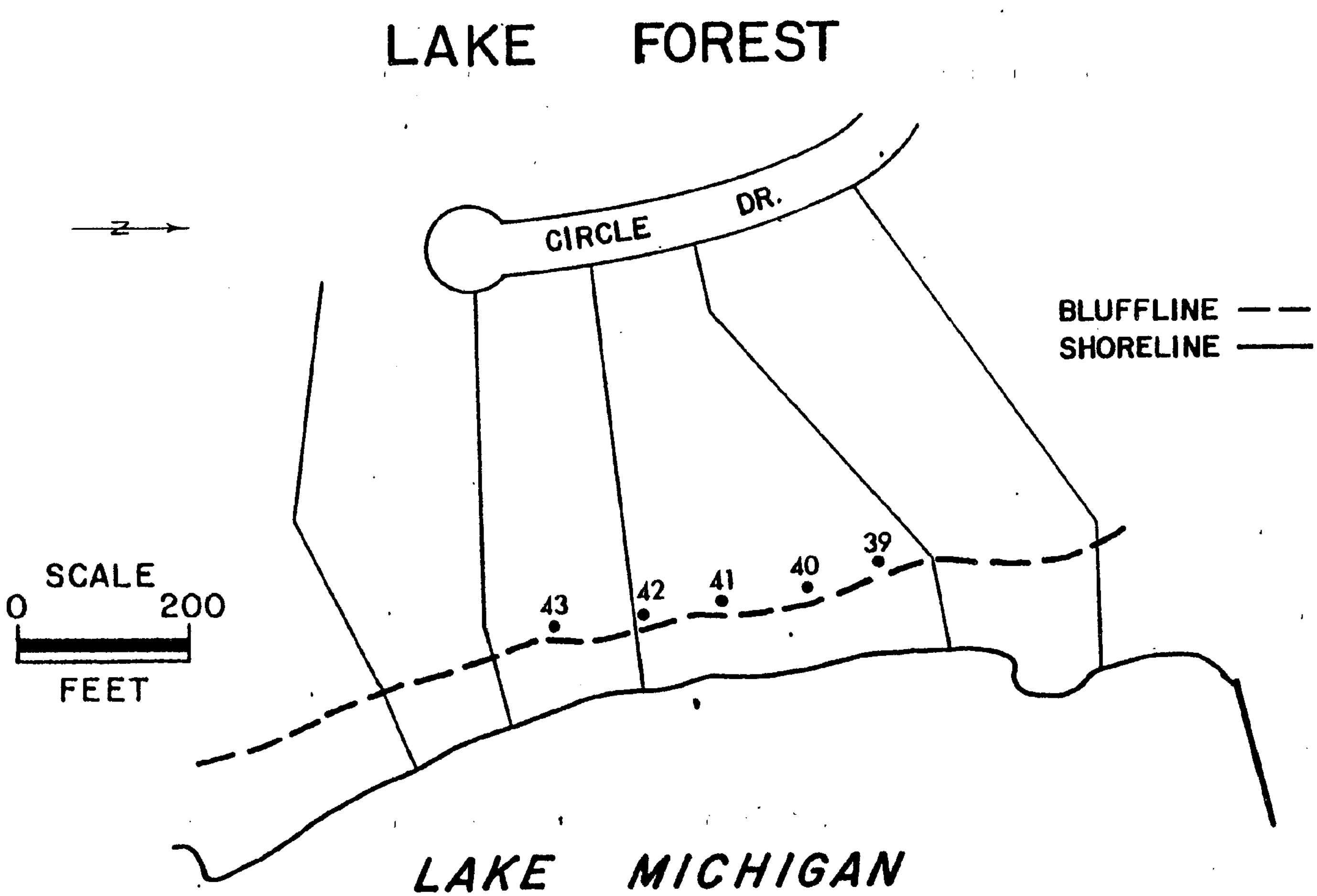

Fig. 7 - Location of traverses 39-43 in southernmost Lake Forest.

Measuring Period	Wave Storm Days Date	Wind Direction	Average Daily Wind Speed	Precipitation Total Inches	Daily Distribution	Freeze-Thaw Days	Protracted Freeze Periods
September 24 to October 28, 1975	Sept. 24	NE	20.4				
	Sept. 25	NE	15.0				
	Oct. 17	NE	17.0	2.55	6	0	0
	Oct. 18	NE	19.0				
October 28 to February 19, 1976	Dec. 6	NE	17.7				
	Dec. 12	E	16.3	7.36	51	48	7
	Dec. 26	NE	17.0				
February 19 to March 16, 1976	Feb. 21	NE	19.4	5.73	12	11	1
	March 1	E	15.1				
March 16 to April 20, 1976	Apr. 4	N	21.9	1.94	10	5	1
	Apr. 11	N	15.8				
April 20 to May 20, 1976	Apr. 25	NE	21.7				
	May 6	N	16.7	7.02	11	0	0
	May 17	N	18.0				
May 20 to June 17, 1976		0		5.07	4	0	0
June 17 to July 20, 1976	July 11	N	16.1	3.67	11	0	0
July 20 to August 18, 1976	July 31	N	15.1	1.95	11	0	0
	Aug. 6	N	16.5				
August 18 to September 27, 1976		0		2.32	6	0	0

TABLE 1 - STORM DAYS, RAINFALL, FREEZE-THAW DAYS AND PROTRACTED PERIODS OF FREEZE FOR THE STUDY PERIOD.

Measuring Period	Wave Storm Days: Date	Wind Direction	Average Daily Wind Speed	Preciptation: Total Inches	Daily Distribution	Freeze-Thaw Days	Protracted Freeze Periods
September 27 to October 25, 1976	0			1.97	6	0	0
October 25 to February 18, 1977	0			3.22	37	40	6
February 18 to March 21, 1977	0			2.16	12	11	2
March 21 to April 19, 1977	0			3.40	10	4	0
April 19 to May 19, 1977	Apr. 28	N	15.0	2.86	11	1	0
May 19 to June 20, 1977	June 6	N	18.3	2.78	9	0	0
June 20 to July 18, 1977	N.A.*						
July 18 to August 10, 1977	N.A.*						
August 10 to September	N.A.*						

*N.A. Data not available at time of publication.

TABLE 1 (continued) - STORM DAYS, RAINFALL, FREEZE-THAW DAYS AND PROTRACTED PERIODS OF FREEZE FOR THE STUDY PERIOD.

Tables 2 and 3 average recession data for each month between September, 1975 and September, 1976. Measurements at stakes 27-29 are excluded from recession totals because they were set up to measure erosion along a bluff where the toe is stabilized with riprap. All other traverses measure recession along unprotected bluffs. Traverse 34 was excluded because it was utilized to determine the rate of bluff denudation rather than recession. The total recession for the monthly period was then divided by the number of eroding sites, arriving at a recession average per eroding site. The overall bluffline recession rate was derived by dividing the total recession by 39. These average rates (43 sites minus the 4 sites excluded) are an index of the severity of erosion and represent the base data for comparison of relationships between bluff recession and weather variables.

Table 3 shows the calculated average recession data for each month from October, 1976 to July, 1977. As in Table 2, bluff stake locations 27, 28, 29, and 34 are excluded from the recession totals. In addition, beginning with the February, 1977 date, locations 1 through 4 were excluded because riprap was added to the bluff toe. Recessions nevertheless were recorded for traverses 1 to 3 and a brief analysis is presented in a following discussion. Traverse number 4 was eliminated altogether because of home construction. The overall bluffline recession rate was thus derived by dividing the total recession by 35.

WEATHER AND RECESSION DATA FOR THE FIRST YEAR OF STUDY, 1975-1976

September 24, 1975 through October 28, 1975

From September 24 through October 28, 1975, recession along 7 traverses (5, 19, 25, 26, 30, 31, and 41) averaged 1.41' over these 7 traverses, or .25' for all 39 traverses. The severity of recession during the period is considered low to moderate. Four major storm days, September 24 and 25 and October 17 and 18, had average daily wind velocities from the northeast of 20.4, 25.0, 17.0, and 19.0 mph, respectively. Recession was minimal, however, occurring at only 7 sites. Precipitation during the period occurred on 6 days with a total rainfall of 2.55 inches, which was approximately .50 inches below normal. The low rate of recession, despite frequent storm periods, is attributed mainly to the relatively low precipitation and the fact that bluffs were dry. Slope wash and bluff face seepage were minimal.

October 28, 1975 through February 19, 1976

The period October 28 to February 19 spanned the mid and late autumn and early and mid winter seasons when bluff measurements were not taken. Although the period spans nearly 4 months, only 8 out 39 traverses showed measurable bluff recession. The average recession for these 8 was only .90 feet per traverse. The recession average for all 39 traverses was .18 feet. This October through February period was characterized by 3 major storm periods, December 6, December 12, and December 26. The total rainfall of 7.36 inches was distributed over 51 days. A total of 48 freeze-thaw days

Bluff stakes	9/24/75	10/28/75	2/19/76	3/16/76	4/20/76	5/20/76	6/17/76	7/20/76	8/18/76	9/27/76	Recession totals/site
1	--	--	--	--	--	--	--	--	--	.3	.3
2	--	--	--	--	--	3.0	--	--	--	.6	3.6
3	--	--	--	--	--	3.0	1.5	--	--	--	4.5
4	--	--	--	--	--	.3	--	--	--	--	.3
5	--	1.5	--	--	--	--	--	--	--	--	1.5
6	--	--	.7	.4	.3	--	.5	--	--	--	1.9
7	--	--	--	--	.3	--	--	--	--	--	.3
8	--	--	.3	--	--	1.0	1.0	--	--	--	2.3
9	--	--	--	--	--	--	--	--	--	--	--
10	--	--	--	--	.5	.4	--	2.0	.5	--	3.4
11	--	--	--	3.3	--	--	.5	--	1.0	--	4.8
12	--	--	--	2.0	--	--	--	--	--	--	2.0
13	--	--	1.0	--	--	.3	--	--	--	--	1.3
14	--	--	--	--	--	--	--	--	--	--	--
15	--	--	--	--	--	--	--	--	--	--	--
16	--	--	--	--	--	--	--	--	--	--	--
17	--	--	--	.9	--	--	--	--	--	--	.9
18	--	--	--	--	--	--	--	--	--	--	--
19	--	3.3	--	--	--	--	--	--	--	--	3.3
20	--	--	.3	.2	.2	.2	--	--	--	--	.9
21	--	--	--	.5	--	--	--	--	--	--	.5
22	--	--	.3	1.3	--	--	--	--	1.0	--	2.6
23	--	--	--	--	--	1.5	--	--	--	--	1.5
24	--	--	--	.8	--	--	--	1.1	--	--	1.9

TABLE 2 - DISTANCES (FEET) BETWEEN REFERENCE STAKES AND THE BLUFF EDGE AT 43 LOCATIONS IN LAKE BLUFF AND LAKE FOREST (NOS. 39-43). DATES INDICATE THE DAY MEASUREMENTS WERE MADE.

Bluff stakes	9/24/75	10/28/75	2/19/76	3/16/76	4/20/76	5/20/76	6/17/76	7/20/76	8/18/76	9/27/76	Recession totals/site
25	--	.8	--	1.0	--	--	--	--	--	--	1.8
26	--	1.8	--	2.7	--	--	--	--	--	--	4.5
27	--	--	.3	--	.2	.3	--	--	--	.2	1.0
28	--	--	--	1.0	--	--	--	--	--	--	1.0
29	--	--	--	--	--	--	--	--	--	--	--
30	--	1.0	--	6.5	.6	--	--	--	--	--	8.1
31	--	.5	--	4.8	--	.3	--	--	--	--	5.6
32	--	--	--	1.3	--	.7	--	--	--	--	2.0
33	--	--	--	3.3	--	--	--	--	--	--	3.3
34	--	4.8	--	.7	--	--	28.7	--	--	--	34.2
35	--	--	1.0	5.5	--	--	--	--	--	--	6.5
36	--	--	.5	1.9	4.0	7.0	--	--	--	--	13.4
37	--	--	--	--	.5	--	--	--	--	--	.5
38	--	--	--	--	--	--	--	--	--	--	--
39	--	--	--	--	--	--	--	1.7	1.3	.7	3.7
40	--	--	3.1	--	--	--	--	--	1.0	--	4.1
41	--	1.0	--	--	16.5	--	--	.5	--	--	18.0
42	--	--	--	13.4	--	--	--	1.3	--	--	14.7
43	--	--	--	.9	--	1.0	1.0	--	--	--	2.9
Overall recession average		.25	.18	1.30	.55	.48	.12	.17	.13	.04	3.25

*Exclusive of stakes 27, 28, 29, and 34.

TABLE 2 (continued) - DISTANCES (FEET) BETWEEN REFERENCE STAKES AND THE BLUFF EDGE AT 43 LOCATIONS IN LAKE BLUFF AND LAKE FOREST (NOS. 39-43). DATES INDICATE THE DAY MEASUREMENTS WERE MADE.

Bluff stakes	10/25/76	2/18/77	3/21/77	4/19/77	5/19/77	6/20/77	7/18/77	8/10/77	9/16/77	Recession totals/site
1	--	--	--	.3	.5	--	--			.8
2	--	--	--	--	--	--	--			--
3	--	--	--	--	--	--	--			--
4	--	--	--	--	--	--	--			--
5	--	--	--	--	--	--	--			--
6	--	--	--	.1	--	--	--			.1
7	.5	--	--	--	--	--	--			.5
8	--	--	--	--	--	--	--			--
9	--	--	1.0	--	--	--	--			1.0
10	--	--	--	--	--	--	--			--
11	--	--	--	--	--	--	--			--
12	--	--	--	--	--	--	--			--
13	--	--	--	--	--	--	--			--
14	--	--	--	--	--	--	1.1			1.1
15	--	--	--	--	--	--	--			--
16	--	--	--	--	--	--	--			--
17	--	--	--	--	--	--	--			--
18	--	--	--	--	--	--	--			--
19	--	--	--	--	--	--	--			--
20	--	--	--	--	.5	--	--			.5
21	--	.7	--	--	--	--	--			.7
22	--	--	--	--	--	--	--			--
23	--	--	--	--	--	--	--			--
24	--	--	--	--	--	--	--			--

TABLE 3 - DISTANCES (FEET) BETWEEN REFERENCE STAKES AND THE BLUFF EDGE AT 43 LOCATIONS IN LAKE BLUFF AND LAKE FOREST (NOS. 39-43). DATES INDICATE THE DAY MEASUREMENTS WERE MADE.

Bluff stakes	10/25/76	2/18/77	3/21/77	4/19/77	5/19/77	6/20/77	7/18/77	8/10/77	9/16/77	Recession totals/site
25	--	--	--	.8	--	--	--			.8
26	--	--	--	--	--	--	--			--
27	--	--	--	--	--	--	--			--
28	--	--	--	--	--	--	--			--
29	--	--	--	--	--	--	--			--
30	--	--	--	--	--	--	--			--
31	--	--	--	--	--	--	.7			.7
32	--	--	--	--	--	.3	--			.3
33	--	--	--	--	--	--	--			--
34	--	--	--	--	--	--	--			--
35	--	--	--	--	--	--	--			--
36	--	--	--	--	--	--	--			--
37	--	--	--	--	--	--	--			--
38	--	--	--	--	--	--	--			--
39	--	--	--	--	--	--	--			--
40	--	--	.9	--	--	--	--			.9
41	--	--	--	--	--	--	--			--
42	--	--	--	--	--	--	--			--
43	.5	--	--	--	--	--	--			.5
Overall recession average	.03	.02	.05	.03	.01	.01	.05			.20

*Exclusive of stakes 27, 28, 29 and 34 and beginning with 2/18/77 data stakes 1, 2, 3 and 4.

TABLE 3 (continued) - DISTANCES (FEET) BETWEEN REFERENCE STAKES AND THE BLUFF EDGE AT 43 LOCATIONS IN LAKE BLUFF AND LAKE FOREST (NOS. 39-43). DATES INDICATE THE DAY MEASUREMENTS WERE MADE.

and 6 prolonged periods of freeze (with daily temperatures averaging less than 32°F) were interspersed with thaw periods.

Although this period contained numerous freeze-thaw days and prolonged periods of freeze, bluff erosion was minimal. The low rates of recession are attributed to four main factors: (1) minimal erosion by flowing seeps and slope wash due to low precipitation; (2) little mechanical breaking of the bluff material by freeze-thaw due to low water supply for freezing; (3) onshore ice protected the bluff toe from waves; and (4) few (3) storm periods from October 28 to February 19.

February 19, 1976 through March 16, 1976

The late winter period, February 19 to March 16, was the time of greatest bluff recession. Eighteen of the 39 sites experienced an average bluffline recession of 2.82 feet per measuring site. The recession average for the 39 sites was 1.30 feet. There were two storm days--February 21, with northeasterly winds averaging 19.4 mph, and March 1, with easterly winds averaging 15.5 mph. Storm conditions on February 29 were also quite severe, with northeasterly winds averaging 14.8 mph. Precipitation totaling 5.13 inches, 3.5 inches above normal, was distributed over 12 days. There were 11 freeze-thaw days and one 2-day freeze period. Above-normal precipitation and numerous freeze-thaw days increased the erosional power of ground water seeps and slope wash. Perhaps the most important factor contributing to the high rate of bluff recession during this period was the onset of the first major thaw of the season. From January 2 to February 9, the daily average temperature was well below freezing, averaging 19.1°F for the period. From February 10 to 29, except for two days of near normal temperatures, daily temperatures averaged 17°F above normal, with an average daily temperature of 45.4°F.

Daily freezing and thawing loosens the surface materials on the bluff face, increasing their erodibility. During the warming trend that began on February 10, thawing temperatures penetrated deeply into the bluff face, resulting in the disaggregation of slump blocks. The major thaw also released previously frozen ground water that gradually made its way to the bluff face, appearing as erosional seeps. The data for February through March suggest that the combination of high precipitation, onshore wave attack, and the release of large volumes of water by thawing is sufficient to cause severe bluff erosion.

March 16, 1976 through April 20, 1976

From March 16 to April 20 there was one major storm (April 11 with north winds averaging 21.9 mph), 1.94 inches of precipitation distributed over 10 days, 5 freeze-thaw days, and one freeze period lasting 2 days. Bluff erosion was measurable at 8 sites, averaging 2.86 feet per site. Average recession for the 39 sites was .59 feet.

Although 2 days of severe wave attack occurred, precipitation was below average, the effects of the seasonal thaw were over, and there was less than one-half the number of freeze-thaw days as the previous month. Hence, recession was considerably less than for the preceding measuring period. An average of 10.3 feet of recession occurred at two of the eight traverses (41 and 36) where the bluff was undoubtedly weakened by the severe weather of the preceding month. Recession measurements at the remaining 6 traverses were all below .6 feet and erosion appeared due to removal by slope wash.

April 20 through May 20, 1976

During the period April 20 to May 20, 12 sites showed bluffline recession, with an average of 1.56 feet per site. The average for all 39 sites was .48 feet. There were three major storm periods—April 25 with northeasterly winds of 21.7 mph, May 6 with northerly winds averaging 16.7 mph, and May 17 with northerly winds averaging 18.0 mph. The April 25 storm was the worst storm of the entire study period as north or northeasterly winds prevailed for the 7 days from April 23 to April 29. Precipitation was about 4 inches above normal with 7.02 inches distributed over 11 days. There were no freeze-thaw days. Although precipitation was plentiful and storm wave attack quite severe, bluff erosion was minimal. Slope wash seems to have caused most of the erosion.

May 20, 1976 through June 17, 1976

The bluff receded during this period at only 5 sites with an average recession of .90 feet per site. For all sites bluffline recession averaged .12 feet. The relatively low level of erosion was undoubtedly due to the absence of storm periods. Precipitation totaled 5.07 inches, but over 4.5 inches fell during one storm with the remainder spread over 3 other days.

June 17, 1976 through July 20, 1976

From June 16 to July 20, 5 sites experienced an average 1.32 feet of recession per site. Weather conditions were similar to the previous measuring month, as typical summer conditions prevailed. There were no storm days and precipitation totaled 3.67 inches distributed over 11 days.

July 20, 1976 through August 18, 1976

This period was similar to the two previous measuring periods; only five sites showed evidence of recession with an average of .96 feet per site. The recession average for all sites was .13 feet. Despite two wave storm days, low erosional activity can be attributed to the relatively small amount of precipitation (1.95 inches distributed over 11 days).

August 18, 1976 through September 27, 1976

This measuring period was characterized by the least recession recorded during the first year of study. Only 4 sites showed recession with an average per site of .48 feet while the average for all sites was .05 feet. The relatively dry, storm-free conditions that prevailed account for the extreme low erosional activity. Only 2.32 inches of precipitation fell, distributed over 6 days. This, combined with the absence of storm days, provided no impetus for erosion of the bluff by waves or slope wash.

1975-1976 Summary of monthly climate-erosion data

Low erosion rates prevailed during the summer months. Recession was recorded each month at 5 sites from May 20 through August 18, 1976 and at 4 sites from August 18 through September 27, 1976. Recession did not exceed two feet at any one site for any measuring period. Low precipitation and the infrequent occurrence of onshore wave attacks account for the low rates of recession during the summer. Seasonal lake level fluctuations resulted in levels about 1.5 feet higher in summer than in late winter and early spring. The higher levels resulted in little bluff erosion even though beaches at the toe of the bluffs were narrower. The most pronounced seasonal recession occurred during the late winter period, February 19 to March 16, a period with the first major thaw, higher precipitation, a high frequency of onshore wave attacks, and frequent freeze-thaw days. These four parameters are characteristic of that time of year. The importance of the first major thaw of the season and frequent freeze-thaw days as primary contributors leading to severe bluff erosion is evident when recession from September 24 to October 28, 1975 is compared with recession from March 16 to May 20, 1976. The September to October data suggest that frequent storm days and considerable rainfall (25 inches) do not cause severe erosion. From March 16 to April 20, 1976, freeze-thaw periods were numerous and two storm days occurred; but with less than two inches of precipitation, erosion was not severe. From April 20 to May 20, 1976, precipitation and frequency of wave storm days were comparable to those occurring during the February 19 to March 16, 1976 period. Bluff erosion, however, was considerably less than during the February to March period which contained the first thaw of the season and frequent freeze-thaw days.

WEATHER AND RECESSION DATA FOR THE SECOND YEAR OF STUDY, 1976-1977

September 27, 1976 through October 25, 1976

The recession measured in October, 1976 is characteristic of the losses that prevailed throughout the entire second year study period. Only 2 measuring sites showed recession yielding a total of 1.0 foot. The recession average per site was .5 feet while the overall average was .03 feet. The absence of wave storm days and a low 1.97 inches of precipitation accounted for the low erosional amounts.

October 25, 1976 through February 18, 1977

The October-February measuring period spanned the time when lake levels significantly lowered from the previous year. This factor combined with a total absence of wave storm days, only 3.22 inches of precipitation (less than one-half of what was recorded during the same period the previous year), and on-shore ice buildup resulted in only one site showing recession. The overall recession average was .02 feet. Forty freeze-thaw days and six prolonged freeze periods apparently caused very little recession.

February 18, 1977 through March 21, 1977

The first major thaw of the season had little effect on bluff erosion during this measuring period, unlike the thaw during the February-March period of 1976. Only 2 sites showed noticeable recession yielding a total of 1.0 foot of recession with an overall recession average of .05 feet. Despite the 11 freeze-thaw days and 2 periods of prolonged freeze, minimal recession of the bluffline resulted from the absence of wave-storm days, 2.16 inches of precipitation, well distributed over 12 days, and lake levels about 1.5 feet lower than during the same period the previous year.

March 21, 1977 through April 19, 1977

From March 21 to April 19, there were no major storms, 3.40 inches of precipitation fell, and there were 4 freeze-thaw days. Erosion was measured at 2 sites averaging .45 feet per site. Although precipitation was greater than that for any measuring period since June-July 1976, the overall recession for the 35 sites averaged only .03 feet.

April 19, 1977 through May 19, 1977

This period was similar to the previous four measuring periods. Just one site showed recession. The overall recession average was .01 feet. One wave storm day and 2.86 inches of precipitation characterized this period.

May 19, 1977 through June 20, 1977

Identical to the April-May period only one site showed recession with an overall average of .01 feet. There was one storm day and precipitation totaled 2.78 inches distributed over 9 days.

June 20, 1977 through July 18, 1977

Erosion during this period was slightly greater than that for the previous two periods. Two sites showed erosion with an average recession of .9 feet per site. The overall average was .05 feet. Climatological data were not available at the time of manuscript preparation.

1976-77 Summary of monthly climatic erosion data

Unlike erosional losses during the previous year of study, recession was considerably less from September, 1976 to July, 1977. Overall recession averaged between .01 and .05 feet and not more than 2 sites recorded recession during any one measuring period. The consistency of the data suggests the important role exerted by climate in controlling rates of erosion. Low precipitation not only lowered lake levels as much as 2 feet giving rise to wider protective beaches but also resulted in less water available for seeps and surface wash. In addition, from September, 1976 to July, 1977, only 2 wave-storm days were evident, which helped minimize bluffline recession.

SUMMARY OF ANNUAL RECESSION TOTALS 1975-77

Recession rates are commonly calculated as losses along specific reaches of shore averaged over a number of years. (Larsen, 1976; Valentin, 1971; Great Lakes Shore Damage Survey, 1976). Data covering a short time span are subject to a large random factor that could result in large calculated losses in areas which generally have experienced minimal recession or in small calculated losses in areas which characteristically experience severe recession. Although there is good agreement between the bluff erosion rates shown by this study and previously reported rates (Berg and Collinson, 1976) caution should be exercised in interpreting the results.

September, 1975 to September, 1976

Measurements taken at each site during the year show that the bluffline receded at 33 of the 39 bluff stake traverse locations, with an average of 3.85 feet per site. The recession average for all 39 locations is 3.26 feet. The amount of recession during this one year of study can be considered typical. The recession average agrees well with data on previous recession rates (Berg and Collinson, 1976). It is about .5 feet greater than the average rate for the 1964 to 1975 period and about .8 feet less than that for the 1872 to 1910 period. These data also indicate that approximately 85% of the denuded bluff along the Lake Bluff - Lake Forest shore receded during the year. At seven of the stake locations slope wash was the sole contributor to bluffline recession, since less than one foot of recession was recorded. At the remaining 26 bluff stake locations active slumping was quite evident. Hence, along reaches of denuded bluff at Lake Bluff and at Lake Forest approximately 69% was subject to active slumping.

Of particular interest is the absence of bluffline recession between stakes 14 and 18. This was the area which had recorded some of the highest recession rates along the Illinois shore during the past century. The absence of recession suggests either cyclical or shifting erosion, or possibly an anomalous year. Another explanation may be that the shore reach immediately updrift was protected with riprap to stabilize the bluff and prevent recession near a newly constructed residence. This may have caused local downdrift shoaling and beach building since the revetment extends about 30 feet from shore. Again, further measuring is necessary in order to better comprehend the nature of erosion along this reach of shore.

Except for the area between stakes 14 and 18, only 2 other localiities showed no recession, stake locations 9 and 38. Stake location 29 also showed no recession but this is discussed in a section devoted to special study areas.

September, 1976 to July, 1977

Recession totals for the second year of study show bluffline recession at only 11 of the bluff stake traverse locations. The average rate per active site was .65 feet while the recession average for all sites was .20 feet. This is considerably less than the erosional loss of 3.85 feet per active site during the previous year and the average loss of 3.26 feet for all sites. Slope wash was the primary cause of recession. No massive slumping was visible at any locale along the shore. The amount of recession during this second year, while not consistent with previous data, indicates the stability of slopes during years of low precipitation and infrequent storm days coupled with lake levels about 1 to 2 feet lower than the previous year.

AREAS OF SPECIAL INTEREST

Inasmuch as most of the data gathered was related to recession of natural unprotected bluffs, brief studies also were made of (1) a partially protected bluff site (2) a naturally vegetated bluff undergoing toe erosion and (3) a site previously undergoing erosion but recently protected by riprap.

At the partially protected site, three bluff stakes (numbers 27, 28, and 29) were set. They were set just east of Blodgett Avenue in Lake Bluff on top of a partially vegetated bluff protected by riprap (Fig. 8). From September, 1975 to July, 1977 most of the erosion resulted from slope wash during the spring season of high precipitation. Slumping of the bluff face was not evident. Bluffline recession measured from the three stakes was only .8, 1.0, and 0 feet during the first year of study, whereas no recession was measured during the second year of study. The stabilization of the bluff toe and subsequent revegetation has proven beneficial in preventing severe bluffline recession in this area.

The second special study site was located at bluff stake 34 (figs. 6, 9). The measuring traverse extended over the bluffline, down the vegetated bluff face to the line of active erosion. Recessional losses shown on Table 4 indicate the expansion of toe erosion upward on the bluff face. The area became increasingly unstable throughout the study period with 4.8 feet of recession recorded in October, 1975 and .7 feet measured in March, 1976. The oversteepening caused by active toe erosion culminated in late May or early June of 1976 when the entire upper bluff slumped, resulting in a recessional loss of 28.7 feet. Recession along the traverse does not appear due to any one or two severe storms, any one month of heavy precipitation or any one freeze-thaw period. Rather, the recession appears due to the combination of these climatic occurrences acting over a longer time span. Note that the major recessional losses since September, 1975 occurred when the shore elsewhere in Lake Bluff and Lake Forest was the most stable. Since the slumping of the vegetated bluff face, measurements have been taken to the bluff line.

Fig. 8 - View of the partially vegetated bluff, protected by riprap, just east of Blodgett Avenue in Lake Bluff at the location of bluff stakes 27, 28, and 29. Slumping of the bluff face is not evident. Bluffline recession since 1975 has been negligible.

Fig. 9 - Eroding bluff in south Lake Bluff during the winter at the location of stake traverse 34. In late May or early June of 1976 the entire upper bluff face slumped resulting in a recessional loss of almost 29 feet. Active toe erosion, as seen on this pre-slump photograph, oversteepened and notched the base of the bluff considerably, resulting in the slump. Traverse 34 is located on the promontory near the center of the photograph.

The third special study area materialized at the location of stakes 1, 2, and 3 (Fig. 3) where riprap was added to the toe of the bluffs in November, 1976, so that the reach was no longer a natural bluff erosion area. To date no measurable recession has occurred at stake locations 2 and 3, but at location 1 surface wash removed .3 feet from March 21 to April 19, 1977 and .5 feet from April 19, to May 19, 1977. Continued monitoring of erosion at this newly protected, completely denuded reach of bluff should further reveal the response of a severely eroding bluff to riprap toe protection.

RELATIONSHIP OF LOCAL GEOLOGY TO VARIATIONS IN BLUFF EROSION RATES

The ability of a bluff to withstand erosion is primarily a function of the composition of the local earth materials (Gelinas and Quigley, 1973). Cohesive resistance and shear strength are the basic factors in the materials that greatly effect erosion resistance (Quigley and Tutt, 1958). The relatively strong cohesive properties of clayey-silt till and silty-clay glacial till make them erosion resistant. Sand and silty materials are least resistant. Bluffs with high shear strengths, containing the least percentage of sand and gravel, are the most resistant to erosion. The bluffs at Highland Park and Glencoe have high shear strengths.

The glacial stratigraphy of the bluff from Lake Bluff to central Lake Forest is variable but it generally consists of an upper and lower silty-clay till layer (Wadsworth Till Member) with a sandy-silty proglacial water-laid deposit between the tills. A postglacial Lake Glenwood deposit of laminated silts (Equality Formation) overlies the upper till layer along certain reaches of the shore.

The material at the base of the bluff along Lake Bluff and Lake Forest is fine-textured; therefore the bluff toe is relatively resistant to erosion by waves. Erosion of the toe and subsequent slumping of the bluff face occurs as repeated wet-dry cycles weaken the fine-grained till. Contraction and cracking occur during dry cycles, weakening the structure of the bluff. Subsequent wetting by wave splash and rainfall results in expansion and slaking of the bluff materials away from the fissures. Contraction cracks that form during freeze-thaw periods, particularly in the spring when rainfall is plentiful, allow water to penetrate deeply into the bluff face. The water then freezes and expands increasing the width of fissures. When melting occurs, the bluff is charged with this added water, increasing the effectiveness of slaking.

Inasmuch as the basal glacial unit is relatively uniform in its resistance to erosion, variations in the percentage and distribution of sand and silt in the upper two layers are primarily responsible for differences in erosion rates. This is particularly notable along the bluff between Shore Acres Country Club and the south jetty of Great Lakes Naval Training Center where detailed bluff descriptions are available (Berg and Collinson, 1976). An exposure in the northern portion of this area, just south of the Great Lakes jetty (corresponding with the location of bluff stakes 1 to 4) consists of a water-laid deposit of 2.5 feet of silt at the top underlain by 4 feet of silty-clay till, 19.5 feet of coarse sandy water-laid proglacial materials, 14 feet of interbedded deformed sand with silt and clay lenses, and silty-clay till extending down to the water line. This exposure contains an average of 79 percent sand, which is more than in any other exposure along the Illinois shore of Lake Michigan. A total of 36 feet of sandy and silty material is exposed on the bluff face.

Additional exposures have been described by DuMontelle, Stoffel, and Brossman (1975) located several hundred feet south of the exposure described above. They are 82, 329 and 391 feet, respectively, north of the seawall protecting the clubhouse at Shore Acres Country Club. The sections coincide with the locations of bluff stakes 9 to 19. The stratigraphy of these additional exposures differs from that at stakes 1 through 4 in that the sandy-silty layer between the till layers is considerably thinner and the beds are contorted.

Two years of observation have not been long enough to completely reveal the general pattern of bluff erodibility between stakes 1-19. Berg and Collinson (1976) indicate that this reach represents the most severely receding area on the Illinois bluffs. Losses have been greatest along the southern 600 feet of the reach, least in the mid-portion, and intermediate along the northern 300 feet. At bluff stakes 2 and 3 in the northern portion a total of 3.6 and 4.5 feet, respectively, receded between September, 1975 and September, 1976. Measurements at stakes 9-19 do not reflect historical recession patterns; only 6 of the 11 traverses showed evidence of recession. Losses at those 6 ranged from .9 feet at stake 7 to 4.8 feet at stake 11. Losses since September, 1976 were even more atypical with only 2 of the 11 sites showing recession.

Because measurements of recession at stake locations 1-19 did not reflect the general expected pattern of recession, supplemental measurements were made from air photos dated 1964, 1969, 1974, and 1975 in an effort to identify the factors responsible for the anomaly. Recession was measured along 16 profiles (Table 4), each starting from a baseline near the bluff top (Fig. 3, large numbers). Measurements are accurate within 5 feet. Table 4 shows bluff recession from 1964-1969, 1964-1974, and 1964-1975. The pattern is similar to that shown by earlier studies but shows greater amounts of material removed from the southern part of the reach. Recession along the southern six profiles from 1964 to 1975 averaged 58 feet, whereas along the northern 10 profiles, recession averaged 28.4 feet. Of particular interest along the northern 10 profiles are relatively large recession losses recorded for traverses 14, 15, and 16, which correspond to the area east of bluff stakes 1 to 4 (Fig. 3, small numbers). Traverses 14-16 averaged 43.7 feet of recession, whereas traverses 7-13 averaged only 21.9 feet.

Although the potential for recession along traverses 14-16 is high due to the presence of an overthickened sand layer, recession has been lower than that for traverses 1-6. The anomaly can be explained by the presence of the south jetty of the Great Lakes Naval Training Center which protects the reach from northeasterly waves. The high recession rate along traverses 1-6 reflects the presence of sand deposits and contracted beds. The upper till unit is flat-lying, but truncates contorted sand and silt layers below, resembling an angular unconformity. The deformation is responsible for great inherent instability by locally increasing silt and

TABLE 4 - RECESSION ALONG 16 PROFILES, 1964-1975, EACH MEASURED FROM A BASELINE AT THE BLUFF TOP IN NORTH LAKE BLUFF (Fig. 3, large numbers)

Profile	1964-1969	1964-1974	1964-1975
1	11	51	58
2	4	41	45
3	0	42	56
4	3	69	69
5	17	57	57
6	13	63	63
7	18	20	20
8	19	31	34
9	4	15	15
10	3	14	23
11	1	12	29
12	4	11	19
13	3	3	13
14	0	32	45
15	2	45	46
16	0	25	40

sand deposits, and by localizing the seeps that occur at the contact between the porous sands and nonporous tills. This uncommon geological situation results in the most severe erosion along the Illinois shore of Lake Michigan.

The glacial stratigraphy extending from between central Lake Bluff southward to central Lake Forest is similar to that of north Lake Bluff, except that the layer of proglacial sand and silt sandwiched between silty-clay tills is thinner. As a result less water is transmitted through the bluff and recession rates are considerably lower. North of Shore Acres Country Club the recession rate averages 3.64 feet per year whereas in central and south Lake Bluff the recession rate averages 2.6 feet per year.

At bluff stakes 39-43 in south Lake Forest, the upper part of the bluff consists of irregularly bedded friable sand which produces numerous seeps and is very weak. Along stake traverses 41 and 42, total losses of 18.0 and 14.7 feet were measured from September, 1975 to September, 1976. These figures approximated the annual recession rate of 16.5 feet determined from measurements taken from air photos annually since 1973 (F.M.).

The bluff south of Lake Forest to north Wilmette is made up of relatively uniform silty-clay till. The porous beds and associated seeps are not as thick or as widespread as those in Lake Bluff and Lake Forest. Average bluffline recession rates of 1.0 to 1.5 feet per year reflect the resistant character of the bluff.

Water seeping from porous sand and silt beds which are present along much of the Illinois Lake Michigan bluff, is a primary agent of erosion, removing sediment directly from the bluff face. A seep commonly occurs at a textural discontinuity between porous coarse-grained beds and a relatively impervious till below. The till acts as an aquiclude, allowing ground water to pass along the top of the layer until it surfaces on the bluff face as a seep. The presence of interlayered till, sand and silt lenses produces large numbers of seeps on the bluff face, increasing the general instability of the bluff.

The erosional effect of seeps is heightened during freeze-thaw periods, particularly during the first major thaw. The water near the exposed bluff face upon freezing results in the mechanical breakup of materials. During winter months much water is stored in the bluffs, as only small amounts are taken up by plants and surface evaporation is at a minimum. The potential outlet for the ground water is the bluff face which is frozen during the coldest part of the year. The first major thaw of the season, such as the thaw which began on February 10, 1976, results in a deep penetration by warming temperatures that eventually releases the stored ground water under pressure to the bluff face. This process obviously occurred during 1976 when massive erosion was recorded at the time of the first thaw. As ground water levels subsided throughout the spring the rate of recession gradually decreased. Nearly all seeps occur in erosional reentrants into the bluff face. Bluffline recession immediately above an active seep often exceeds the recession between active seeps by as much as 30 feet. Much of the jaggedness of the bluffline results from seep erosion and subsequent slumping of the upper bluff face.

LAKE LEVEL FACTOR

Cycles of denudation and revegetation as well as bluffline recession in Lake Forest, and especially in Lake Bluff, have been investigated in detail by Berg and Collinson (1976) and found to be related to lake level fluctuations. During the period of high lake levels in the early 1950's, denudation commenced in Lake Bluff and then proceeded at accelerated rates for 3 to 5 years beyond the date of peak level, despite lowering lake levels. Revegetation of the bluff face likewise lagged following the record low level of 1964. Maximum stabilization did not occur until 1968. Once the bluff face became denuded at Lake Bluff, recession quickly followed. At present, over 50 percent of the bluff at Lake Bluff is denuded and receding at an average annual rate of .26 feet/year.

Severe recession is not a major problem along the bluffs south of Fort Sheridan in Highland Park, Glencoe, Winnetka, Kenilworth, and north Wilmette. Shore protection structures line the entire shore and only in restricted areas is the bluff denuded and receding (Collinson, Drake, and Anchor, 1975).

Investigation by means of low level oblique aerial photographs as well as field checks along the shore south of Fort Sheridan revealed many areas of incipient erosion in the form of toe erosion or slumping of the bluff face. Considering the rate of bluff recession that followed denudation at Lake Bluff, it is apparent that incipient erosion foretells serious recession problems, particularly whenever high lake levels persist.

Five areas that have a history of cyclical denudation and revegetation were selected for special study. By means of aerial photographs it was possible to estimate the relative stability of the bluff at each study area and thereby identify stages of denudation, revegetation and recession during the period 1937 through 1977. Low level oblique aerial photographs dated August, 1974, October, 1975 and July, 1977 were used along with vertical air photos (scales 1:2400 to 1:12000) for the years 1937, 1947, 1952, 1953, 1954, 1956, 1957, 1958, 1959, 1960, 1961, 1962, 1963, 1964, 1965, 1966, 1967, 1968, 1969, 1973, 1974, and 1975. Except for the late 1930's and early 1940's, 1948-1951 and 1970-1972, it was possible to monitor bluff changes on an almost annual basis.

The locations of the case study areas are as follows: (1) Mahoney Park in south Kenilworth; (2) Centennial Park in Winnetka; (3) 400 feet south of South Avenue in South Glencoe; (4) 2500 feet south of the Glencoe-Highland Park municipal boundary in north Glencoe; and (5) immediately north of the Glencoe-Highland Park municipal boundary in south Highland Park (Fig. 2). Table 5 indicates bluff conditions between the years 1937 and 1975 at each of these sites. Gaps between dates indicate either an absence of air photo coverage or that there was no visible change in the condition of the bluff from the previous year.

Erosional cycles at five localities and theri relation to lake levels.

At Mahoney Park, Kenilworth, the bluff quickly became unstable in 1969 with massive slumping (Fig. 10). The bluffline receded a maximum of 10 feet in the following five years. The bluff is presently completely denuded, with the toe now protected by gabion.

At Centennial Park, Winnetka, the entire bluff face became unstable in 1947 as lake levels rose, was completely denuded by 1952 as the highest levels were reached, and had receded 10 to 15 feet by 1954 as the lake level slowly fell. In 1959, the bluff was still denuded even though the lake reached a very low stage. At that time a groin immediately to the north was lengthened. By 1961 vegetation was reestablished; and by 1970 the bluff face was completely stabilized by trees. At present the area is artificially terraced (Fig. 11) and entirely stable.

TABLE 5 - SUMMARY OF EROSIONAL HISTORIES OF SITES IN HIGHLAND PARK, GLENCOE, WINNETKA AND KENILWORTH - 1937 TO 1975

BLUFF EROSION STUDY AREAS

1. Mahoney Park, Kenilworth

    1937 - stable
    1947 - stable; vegetated with trees
    1969 - entire bluff incipiently unstable; no visible recession; toppled trees common on bluff face
    1974 - maximum bluffline recession of 10 feet

2. Centennial Park, Winnetka

    1937 - stable with trees
    1947 - entire bluff incipiently unstable; no visible recession
    1952 - bluff totally denuded; bluff edge 10 feet from a path
    1953 - 5 feet of additional recession
    1954 - path is totally absent; 10-15' of recession since 1952
    1957 - still denuded; no further visible signs of recession
    1959 - in late 1959 or early 1960 a groin to the north was increased in length
    1961 - vegetation taking hold
    1964 - small trees on bluff
    1969 - bluff totally stabilized
    1970 - tall trees on bluff
    1975 - roads were constructed with access to the lake

3. S. Glencoe - 400 feet south of Harbor Avenue

    1937 - stable; completely vegetated with tall trees; groined shore
    1952 - no change in bluff; submerged groins are visible
    1953 - toe erosion begins, includes the lower 30% of the bluff face; top of bluff completely stable with tall trees
    1954 - 5-foot extension upslope of bluff toe erosion; a bulkhead was emplaced in late 1954 or early 1955
    1955 - bluff toe erosion includes the lower 50% of the bluff face
    1956 - bluff toe denudation includes the lower 70% of the bluff face
    1957 - no further denudation; some revegetation
    1958 - groins emerging with lowering lake levels; further bluff revegetation

Fig. 10 - Eroded bluff at Mahoney Park in Kenilworth where ten feet of recession has occurred since 1969. The bluff was stable until the recent high lake level cycle.

Fig. 11 - Bluff at Centennial Park in Winnetka where 10 to 15 feet of recession occurred between 1952 and 1954. With the construction of an updrift groin in 1959-1960 during a period of decreasing lake levels, the bluff began revegetating in 1961. The bluff is now artificially terraced.

TABLE 5 (continued)

3. S. Glencoe - 400 feet south of Harbor Avenue

1959 - bluff revegetation almost total; wide beaches evident
1962 - total revegetation
1969 - bluff artificially terraced

4. North Glencoe - near Hillcrest Drive

1937 - completely stable with tall trees
1947 - 250 feet of bluff toe erosion including the lower 50% of the bluff face; top of bluff is stable
1952 - bluff toe erosion includes the lower 75% of the bluff face; no bluffline recession
1953 - bluff top still stabilized to some extent but entire bluff is unstable
1954 - minor bluffline recession; 400-foot lateral expansion of bluff toe erosion to the north; patches of vegetation on the main erosion area
1955 - total denudation at 250-foot erosion area
1960 - minor recession
1965 - revegetation beginning particularly on the northern 400 feet; small shrubs and grasses on southern 250 feet
1967 - northern 400' almost totally vegetated; southern 250' shows further revegetation with shrubs
1970 - toe of 250-foot area stabilized by small trees
1975 - entire bluff incipiently unstable again

5. South Highland Park, at the Glencoe municipal boundary

1937 - completely stable with shrubs and grasses
1947 - bluff toe erosion includes the lower 25% of the bluff face; bluff top is stable
1952 - toe erosion includes lower 50% of the bluff face; some slumping at the top
1953 - slumping along entire bluff face; patches of slumped vegetation on the slope; total instability but not total denudation
1954 - minor bluffline recession in the southern part of the erosion area; some revegetation in the northern portion
1955 - almost total denudation; vegetated slump blocks still moving downslope in the north
1958 - total denudation
1959 - bluff revegetation commences
1962 - further revegetation
1968 - bluffs stabilized by shrubs and grasses; slumping at top
1970 - base of bluff stable with small trees and shrubs; bluff top still unstable
1975 - central portion of previously denuded area is still partially vegetated; to the north and south total denudation prevails; 10-15 feet of recession since 1970.

The bluff at south Glencoe near Harbor Avenue was stable through 1952. At that time high lake levels submerged the groin field in front of the bluff. By 1953, erosion of the toe extended 300 feet along the shore and included the lower 30 percent of the bluff face. By 1955, erosion extended halfway up the bluff face, and by 1956 it included about 70 percent of the face. In 1957, at a low lake stage, erosion ceased and revegetation commenced. The bluffs stabilized quickly after 1958 as shoreline groins reemerged with lower lake levels. By 1962, the bluff was completely stabilized. The study area has since been artificially terraced in anticipation of another erosional episode (Fig. 12).

In north Glencoe in 1947 erosion of the bluff extended along the shore about 250 feet, and exposed the lower 50 percent of the bluff face. By 1952 erosion expanded upslope to include 75 percent of the bluff face; by 1953, as the lake attained very high levels, the entire bluff face was denuded except for portions of the upper few feet. In 1954, erosion extended 400 feet farther to the north. Complete denudation of the 250-foot area was evident in 1955. Revegetation did not commence until 1965, the year following a record low lake level, and by 1967 the northern 400 feet were almost totally revegetated. It was not until 1970 that the southern 250 feet became totally stabilized. By 1975, the bluff face was again incipiently unstable (Fig. 13).

In south Highland Park in 1947, the lower 25 percent of the bluff face was eroded. By 1952, erosion extended to include the lower 50 percent of the bluff face, which was undercut by waves that caused massive slumping of the upper slope. Maximum denudation occurred by 1958. Vegetation returned quickly to the bluff face, with the first signs of revegetation visible in 1959. Maximum plant cover did not occur until 1968. In 1968 as lake levels rose again, the second denudation cycle commenced with slumping visible at the bluff top. In 1975, the central portion of the bluff was still partially vegetated, but to the immediate north and south complete denudation was evident, with a maximum bluffline recession since 1964 of 10 to 15 feet (Fig. 14). The bluff has seen little improvement since 1975.

The differences in rates of bluff face denudation, revegetation and bluffline recession from site to site are related to such factors as composition of bluff materials, ground water gradients, natural exposure to wave action, extent of shore protection, availability of sand for protective beaches, and the degree to which the bluff is stabilized by vegetation. Perhaps the most important factor affecting bluff stability is lake level. When levels are high, (1) beaches generally are starved, leading to greater frequency of wave impact at the base of the bluffs; (2) many groins are submerged, thereby decreasing their ability to trap sand and absorb and deflect waves; and (3) sea walls and bulkheads are topped by waves. For these reasons bluff erosion is most extensive during periods of high lake level.

Erosion of the toe of the bluff is the initial sign of a potential problem. Notching of the toe leads to general oversteepening of the bluff face. Denudation from this point may proceed upslope, while the top of the bluff shows little or no slumping, as seen at the Glencoe study areas, or oversteepening created by toe erosion may cause the entire face to become unstable and lead to massive slumping as seen at Mahoney and Centennial Parks.

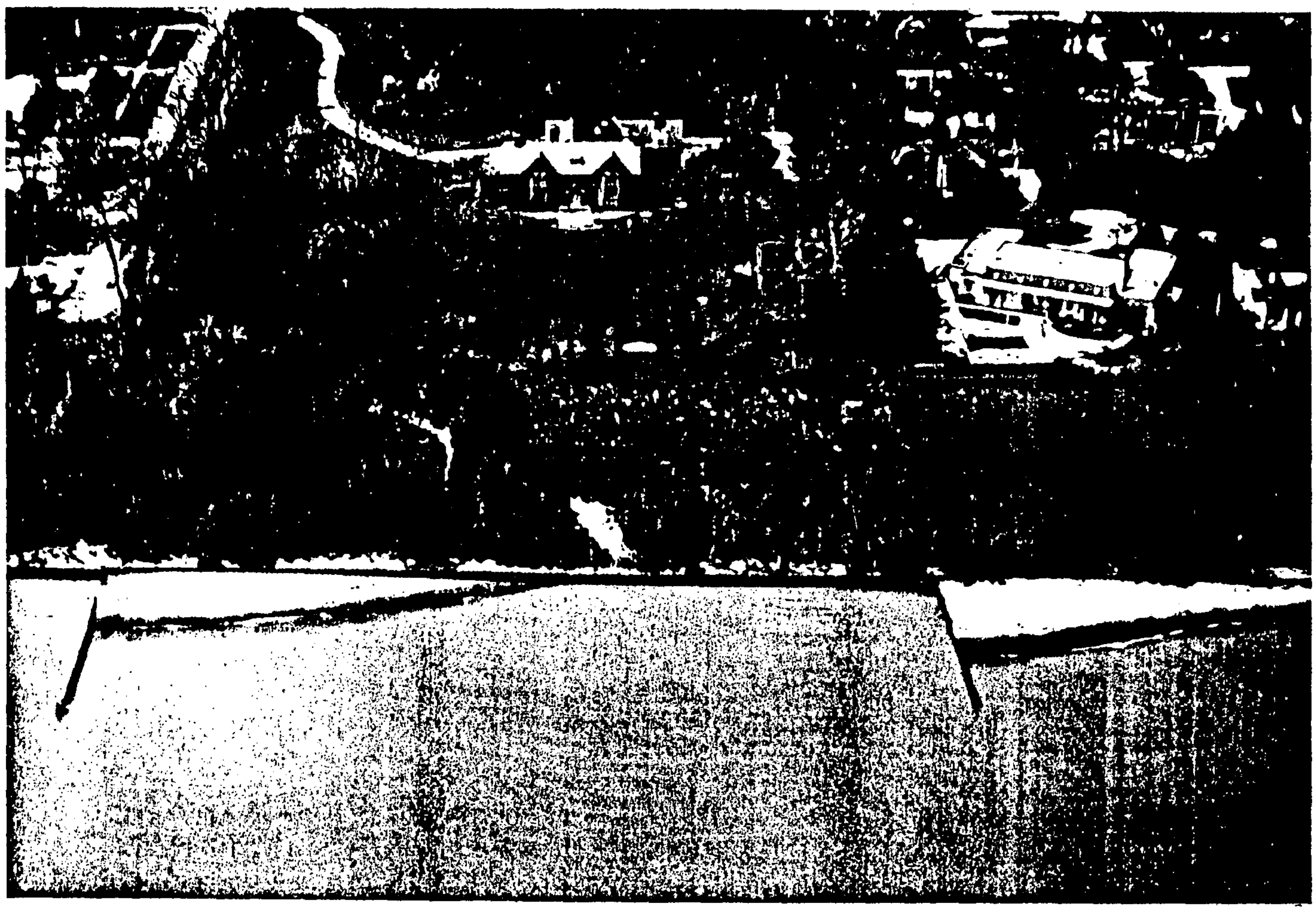

Fig. 12 - Bluff near Harbor Avenue in south Glencoe. From 1953 to 1957 bluff face denudation increased in severity, until lowering lake levels and the emergence of a protective groin field allowed the bluffs to stabilize and vegetate. By 1962, the bluff was totally vegetated and in 1969 was artificially terraced in anticipation of another denudation episode.

Fig. 13 - The bluff near Hillcrest Drive in north Glencoe suffered cyclic denudation episodes commensurate with the last two high lake level periods. From 1947 to 1965, denudation increased considerably, expanding both up the bluff face and linearly northward. Revegetation of the bluff proceeded from 1965 to 1975. Since 1975, toe erosion and denudation are again occurring.

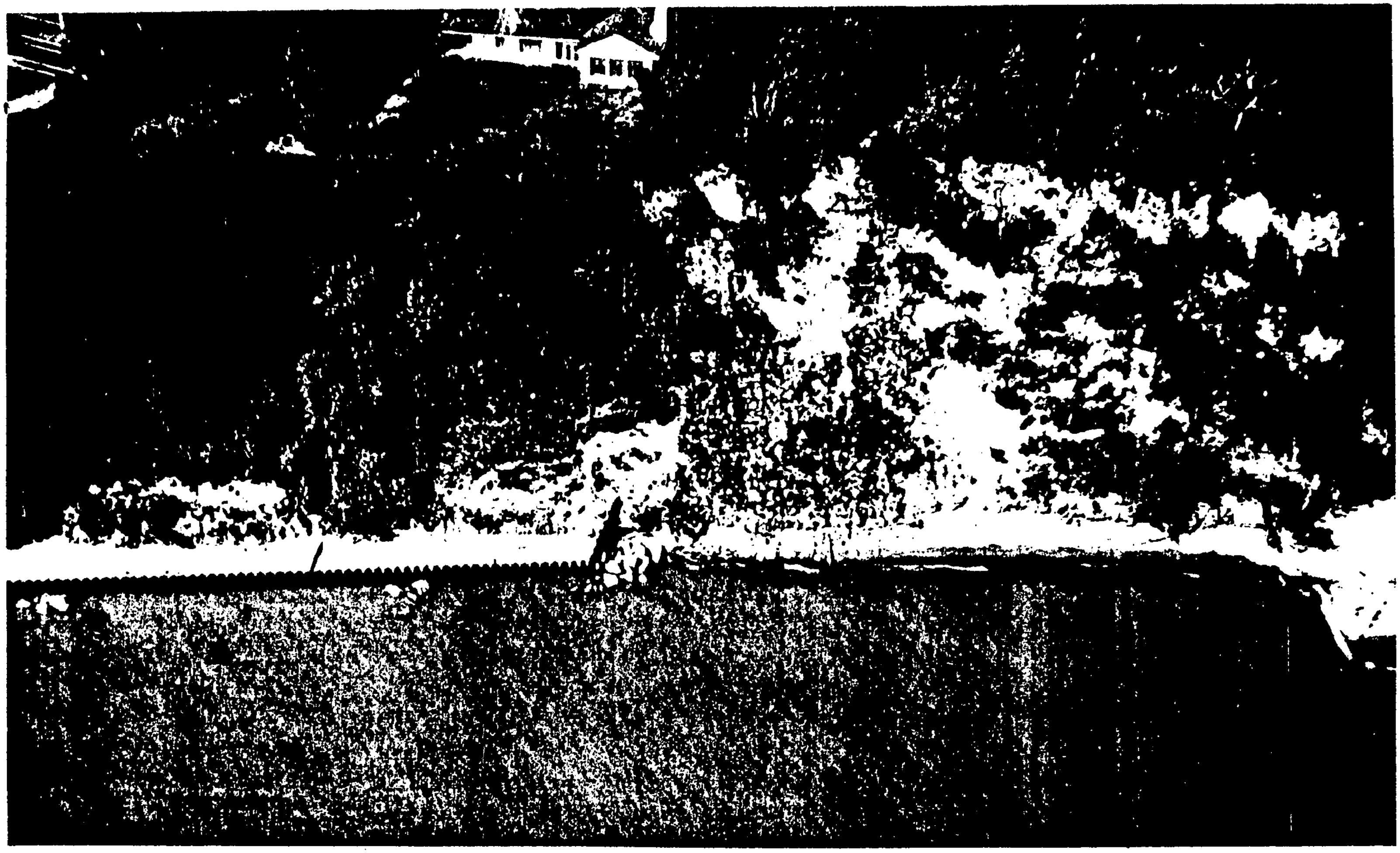

Fig. 14 - This bluff reach in south Highland Park was characterized by denudation from 1947 to 1958 with minor bluffline recession (less than 10 feet), occurring during and several years following the 1952 high lake level year. From 1958 to 1968 revegetation of the bluff occurred during the low lake level years surrounding 1964. Since 1970, with the onset of another high lake level cycle, 10 to 15 feet of recession was evident.

This relationship is observed at Mahoney Park at the north Glencoe area, and in south Highland Park. The other two study areas at Centennial Park in south Glencoe were modified by man. During the time of high lake levels in the 1950's, all study areas, except Mahoney Park, experienced some form of denudation. Although lake level reached a peak in 1952, maximum denudation did not occur until sometime between 1955 and 1958, even though lake levels were lower. Thus there was a 3 to 6 year time lag in bluff denudation following a time of peak lake level. This is similar to the results observed at Lake Bluff. The same sort of lag was observed after 1964, being associated with the low lake levels and bluff revegetation and stabilization of that time. At south Highland Park, Centennial Park, and the north Glencoe site, maximum stabilization occurred during the rising lake level years of 1968, 1969, and 1970 respectively; this 4 to 6 year time lag is consistent with bluff statilization rates at Lake Bluff.

The Glencoe study area near South Avenue showed a relationship between bluff denudation and the submergence of a groin field adjacent to the bluff during the high lake levels of the 1950's. Significant erosion of the bluff toe was evident in 1953, one year after the submergence of the groin field. Revegetation of the entire bluff did not occur until 1958, when the groins emerged. The relation of groin submergence and emergence to bluff denudation and stabilization is not known, since the erosion may have commenced regardless of the submergence of the groins. Nevertheless with the submergence of the groin field in 1952 less sand was trapped, resulting in narrow beaches and wave attack from all angles. All areas along the bluff shore of Illinois where groins are submerged, and particularly where toe erosion is occurring behind the groins, should be designated as immediate potential problem areas.

CONCLUSIONS

Severe erosion is a problem along many portions of the Illinois shore of Lake Michigan. Previous studies have shown that there is a significant variation in bluffline recession rates along the shore. The most actively eroding areas are located at Lake Bluff, where an average of 267 feet of recession has occurred since 1872, and in south Lake Forest where there has been 33 feet of recession since 1973. Along an isolated reach at Fort Sheridan and Highland Park, recession is less severe, not exceeding 15 feet since 1964. Finally, there are numerous areas in Highland Park, Glencoe and Winnetka where erosion is minor, resulting in denudation and active slumping, but no significant recession.

Through the study of vertical and oblique air photos and field monitoring of bluffline recession on a month-to-month basis, certain factors of bluff erosion can be isolated at specific sites along the Illinois shore of Lake Michigan. These factors, in part, control the location and timing of active recession.

WEATHER - Most bluffline recession occurs in late winter-early spring following the first major thaw and is characterized by numerous freeze-thaw days. Heavy precipitation and wave-storm episodes appear to be of lesser importance. Frequent heavy rains and wave-storms during the late spring and autumn are not very effective agents in the absence of a major thaw and frequent freeze-thaw days. The winter and summer months are characterized by minor recession. During the winter, the build-up of onshore ice protects the toe of the bluff from attack by waves. Water that otherwise might cause erosion is locked up in the form of ice. Bluff erosion in the summer months is negligible due to relatively infrequent wave-storm periods and precipitation.

During a year of low lake level with infrequent wave storm periods and low precipitation, bluff recession is almost negligible, regardless of the season. Wide beaches protect the bluff toe from wave attack and there is little water for erosion-producing seeps and surface wash.

EARTH MATERIALS - The geographic distribution of eroding areas and variations in recession rates is strongly influenced by the local glacial geology. Recession rates are highest along the north Lake Bluff shore where contorted and silt deposits are sandwiched between till layers. Ground water transmitted by porous sands and silts escapes through the bluff as erosional seeps. The sandwiched layer of coarse-grained materials is thinner along the shore from central Lake Bluff to central Lake Forest than it is in northern Lake Bluff, contributing to lower recession rates (2.60 ft/yr). South of Lake Forest, average recession rates of 1.0 to 1.5 ft/yr reflect the absence of a continuous bed of porous material. The bluff is comprised mostly of fine-grained tills, with porous sand in lenses constituting a relatively small proportion of the unit.

LAKE LEVELS - Along the shore south of Fort Sheridan maximum denudation occurred 3 to 6 years following the peak high lake level in 1952 and maximum revegetation occurred 4 to 6 years following the record low lake level in 1964. The lag effect, whereby bluff erosion does not immediately decrease with lowering lake levels or increase with rising lake levels, not only reflects the relationship between lake level fluctuations and bluff erosion but also singles out the important effect of vegetation in preventing or slowing erosion. These data corroborate previous information on denudation-revegetation episodes at Lake Bluff.

Erosion, most active during periods of high lake level, also coincides with periods of high precipitation and ground saturation. Where bluffs are oversteepened and severely eroding, recession is greatly accelerated - such is the case at Lake Bluff and in south Lake Forest. Where bluffs are less vulnerable, as in Highland Park, Glencoe, Winnetka and Kenilworth, cycles of denudation and revegetation are closely attuned to lake levels. Where bluffs are well vegetated, with broad beaches and ample littoral drift, some denudation of the lowermost bluff may occur but vegetation is quickly restored as levels fall.

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