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BLUFF EROSION, RECESSION RATES, AND VOLUMETRIC LOSSES ON THE LAKE MICHIGAN SHORE IN ILLINOIS

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ABSTRACT

The present high-water transgression of Lake Michigan has produced significant bluff erosion at more than 21 sites on the Illinois shore between Winnetka and Waukegan. South of Lake Bluff virtually all of the recession has occurred since 1969 and is relatively minor, even though approximately 215,000 cubic yards of material has been eroded. From reaches of shore at Fort Sheridan 50,000 cubic yards of material has been removed and from Lake Forest 45,000 cubic yards has eroded, placing those areas among the most severely damaged on the Illinois shore. Those are small areas compared to the Lake Bluff area, where 1.5 miles of eroding shore has been retreating since at least the mid-1800s. The eroding portions of Lake Bluff have receded an average of 30.5 feet since 1964 and have given up about 636,000 cubic yards of material. Since 1872, the areas eroding in Lake Bluff have receded an average of 267 feet and contributed more than 6 million cubic yards of sediment to the lake.

Because erosion is so severe, the Lake Bluff shore has been studied in some detail to determine what characteristics contribute to its instability and recession. The study suggests that the recession can be attributed to (1) high lake levels, (2) bluff denudation, (3) inadequate shore protection, (4) weakness of earth materials in the bluffs, (5) oversteep slopes, (6) excessive water pressures affecting groundwater quantity and gradient, (7) surface drainage and seepage, and (8) lack of littoral drift sediments and the resultant absence of protective beaches.

Study of the present erosional cycle and the cycles caused by previous high lake levels has suggested several generalizations. (1) Bluff erosion from wave attack becomes significant when lake levels rise above 579 feet IGLD (International Great Lakes Datum). (2) Bluff erosion does not always decrease as lake levels decrease. A lag commonly occurs wherein the rate of bluff recession is maintained or even accelerated, mainly because of the time required to revegetate denuded bluffs. (3) When

lake levels are rising, well developed beaches will delay the onset of maximum erosion, because it takes time to deplete the beaches. (4) A natural bluff shore without protective structures or littoral drift replenishment, even if it has well developed beaches, cannot long withstand the attack of waves at lake levels above 579 feet IGLD.

INTRODUCTION

Severe erosion and slumping of the glacial materials that form the till bluffs on the Illinois Lake Michigan shore are a major concern of the Illinois Coastal Zone Management Development Project. Two studies of problems were made by the Project in 1975. The first was designed to (1) identify engineering characteristics of the earth materials that affect bluff stability and erosion resistance, (2) measure the characteristics of the till bluffs, (3) map bluff stratigraphy, and (4) summarize and interpret the characteristics of the earth materials and their relation to instability and erosion problems. Preliminary results from the study were summarized by DuMontelle, Stoffel, and Brossman (1975) and are used in the present report.

The second study, reported here, identified and described the areas on the Illinois shore that had bluff erosion problems, determined recession rates and the history of shore recession, identified and correlated topography and characteristics of earth materials with areas of instability, and correlated wind, waves, currents, surface drainage, and ground water with critical erosion. It also made evident the need for data on specific sites that will make it possible to distinguish the erosional effects of rainfall, freeze-thaw phenomena, vegetation, and ground-water gradients. Such data would indicate the amounts of sediment and chemicals entering the lake. In addition, seasonal variations in recession and the detailed processes involved in bluff failure should be investigated.

Acknowledgments

Many people assisted and/or cooperated during the course of this study. Murray Pipkin of the Illinois Division of Water Resources provided a library of aerial photos and did much to encourage and support the project. Ralph Fisher of the same organization was ever available for guidance and help. Richard Olson, a graduate student at the University of Illincis, Urbana, piloted the light aircraft for low-level aerial photos. Patricia Drake and Michael Larimore of the Illinois Geological Survey made the ground-truth measurements.

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THE TILL BLUFFS

As the front of the Pleistocene glacier that occupied the Lake Michigan Basin some 14,000 radiocarbon years ago melted back to the north, glacial Lake Chicago, the ancestor of Lake Michigan, formed between the ice front and the moraines bordering the basin. Waves then washed away the unconsolidated glacial sediments along the shoreline, gradually cutting the surface back, probably as much as a mile, to form a high bluff. Wave-cut terraces were formed at various levels, and they record the lake-level stands that persisted long enough to leave their marks.

The southernmost part of the bluff is encountered on the campus of Northwestern University, where the 11,000-year-old shoreline of the Toleston stage of Lake Chicago (Willman, 1971, p. 57) runs obliquely out to the modern lake. North of there the bluff is lower (20 feet) and is capped by beach deposits from that final stage (605 feet MSL*) of Lake Chicago.

Just south of Wilmette Harbor on Grosse Point, the old shoreline of the Calumet stage (620 feet MSL) of Lake Chicago meets the present lake, and the bluff rises about 40 feet. The Calumet terrace caps the bluff northward as far as Lloyd Park in Winnetka, where the oldest and highest of the ancient shorelines, the Glenwood (640 feet MSL), meets the shore. There the bluff rises sharply to a height of 70 feet.

In the reach between Lloyd Park and North Chicago, the lake lies against the Highland Park Moraine, a terminal glacial moraine. South of Lloyd Park, the lake is in contact with the ground moraine that preceded the Highland Park Moraine. The materials of the ground moraine are gray silty till mantled by thin lacustrine sands, silts, and clays. North of Lloyd Park as much as the upper third of the Highland Park Moraine consists of sand, silt, and clay interbedded with glacial till. These materials are inherently weak and contribute to a basic instability that increases northward to a maximum at Lake Bluff. The upper surface of the bluff, which is the top of the Highland Park Moraine, continues to rise north of Winnetka, reaching an elevation of 655 feet (73 feet above high lake level) in Highland Park. The bluff reaches its highest elevation, more than 670 feet MSL (88 feet above high water level), south of the Central Avenue Waterworks in Highland Park. From there northward it descends to about 80 feet in North Chicago and to less than 70 feet in south Waukegan.

From Glencoe northward, the bluff is cut by more than 30 deep ravines that range from a tenth of a mile to more than a mile long. Many are incised more than 70 feet into the bluffs and provide the main drainage east of the watershed divide about a mile west of the bluff. The ravines represent a young drainage system, cut into weak materials on the surface of the moraine, that eventually became entrenched in the stronger gray till that constitutes the lower part of the high bluff and all of the lower bluff.

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* MSL refers to Mean Sea Level, which is 1.3 feet higher than the International Great Lakes Datum (IGLD). MSL is used for land elevations in the United States. IGLD is used for lake surface elevations in both the United States and Canada.

AREAS OF BLUFF EROSION

Areas of bluff erosion and instability along the Illinois shore can be placed in three categories.

1. Areas where erosion is minor and relatively temporary. These areas are related to stages of the present high-water cycle, in which levels have exceeded 579 feet IGLD and erosion has caused active slumping and denudation but no significant recession. One such area is in Winnetka, two are in Glencoe, ten in Highland Park, and two in North Chicago. All of these areas were described by Collinson, Drake, and Anchor (1975) in their physical inventory of the Illinois shore.

2. Large areas where erosion is of short duration, is related to the present high-water cycle, and has resulted in significant recession. Two areas fall into this category. One is at the southern end of Fort Sheridan where more than 50,000 cubic yards of material has been lost from the shore since 1964 and an average of 15 feet of recession has been measured. The second is in southernmost Lake Forest and northernmost Fort Sheridan where 45,000 cubic yards of material has been contributed to the lake and the shore has receded an average of 33 feet since 1964. Virtually all of the recession identified in both areas has occurred since 1969. The Lake Forest — Fort Sheridan area is later discussed in detail.

3. Large areas where recession has been severe and of long duration. This category includes only the 1.5 miles of eroding shore in Lake Bluff. The Lake Bluff shore has been actively receding for much of the time since accurate maps of the area have been available. The oldest map is a U.S. Army Corps of Engineers sheet at 1:20,000 scale that is dated 1872-1873.

Because the Lake Bluff shore is of immediate concern and the solutions to its erosional problems are applicable to the entire shore, we have devoted most of our study to its history and characteristics. Vertical and oblique aerial photographs, topographic maps, lake survey charts, and field measurements were used to determine temporal bluffline changes. Bluff recession was measured (accuracy within 10 percent) along profiles for which scalar corrections were made to compensate for photographic distortion and a variety of map scales.

A previous study of bluff recession of the Illinois shore was made by Larsen (1973), who used shoreline erosion as an indicator of bluff erosion. This technique approximates bluff positions, but shorelines commonly accrete

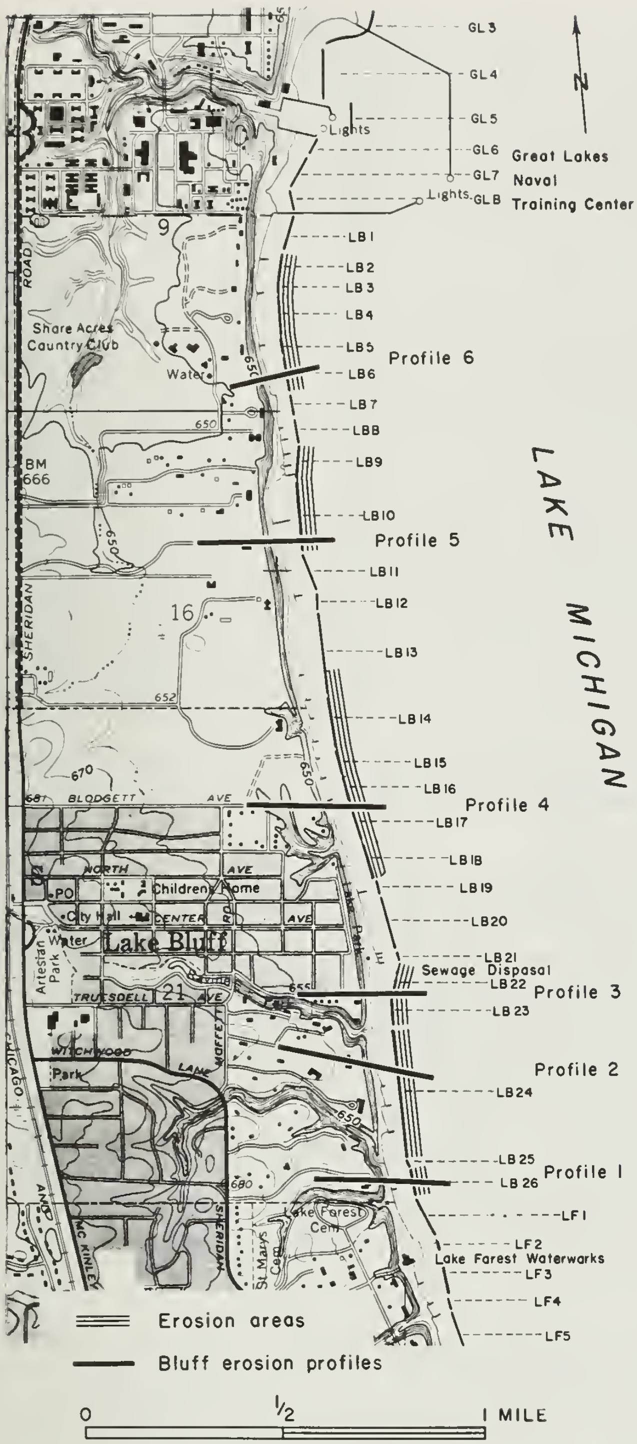


Fig. 1 - The lake shore from Great Lakes Naval Training Center to northern Lake Forest. Bluff recession was measured in detail along the numbered profiles. The profile number also designates the erosion area. Symbols LB1, LB2, and so on, designate segments of shore described by Collinson, Drake, and Anchor (1975).

as lake levels fall, while bluffs continue to recede. Larsen's profiles were plotted at scales of 1:30,000 and 1:36,000, with a resolution of 25 feet. For the present study, base maps at a scale of 1:2400 were used whereon bluffline positions were measured from cultural features on top of the bluff. Differences in bluff positions were resolvable within 5 feet. Areas that had never been protected or had lost their protection were given special attention in the determination of detailed recession rates.

Temporal variations in the size of erosion areas were determined by measuring the actual extent of eroding shoreline. A map-measuring device that differentiated small annual changes in area was used on air photos taken from 1947 through 1975.

LAKE LEVELS, AREAS OF EROSION, AND THE EROSION THRESHOLD AT LAKE BLUFF

The Lake Bluff study area (fig. 1) extends southward from the south jetty of the Great Lakes Naval Training Center to the Lake Forest Waterworks, a distance of about 14,300 feet. Except for two groin fields, one just north of Blodgett Avenue in Lake Bluff and the other north of the waterworks in Lake Forest, the shoreline has only minimal protection and is highly susceptible to wave attack.

The duration of high lake levels (figs. 2, 3) correlates closely with the amount of bluff that is denuded and eroded. Aerial photographs of the area were studied for evidence of high lake levels, and two significant bluff erosion periods were noted, one from 1951 to 1955 and another from 1969 to 1975. During these periods average annual lake levels exceeded 579 feet. The lower lake levels of the late 1940s and from the late 1950s to the mid-1960s accentuate the two higher stands.

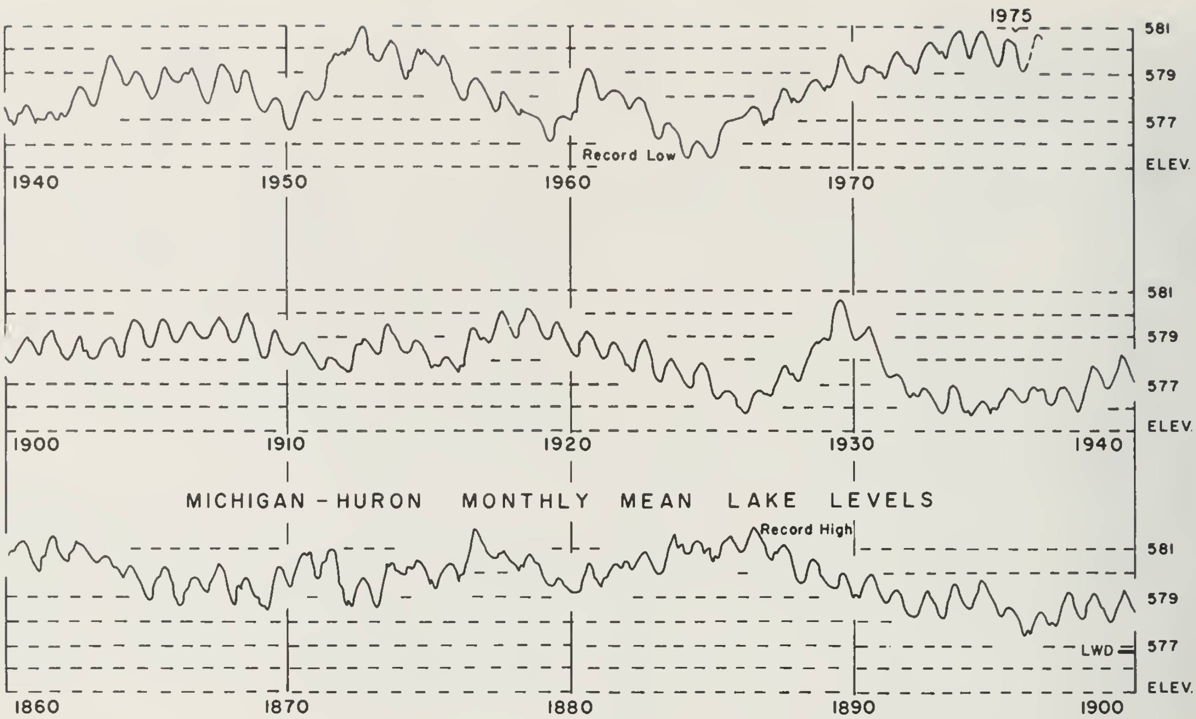


Fig. 2 - Monthly mean lake levels, in feet above mean sea level, measured at Harbor Beach, Michigan (from National Oceanic and Atmospheric Administration, Lake Survey Center, Detroit).

From 1951 to 1955, lake-level averages were consistently high (table 1 and fig. 3). From 1947, when the average lake level was 578.54 feet at Milwaukee, to 1952, when the level was 580.29 feet, there was no increase in bluff exposure; in fact, the linear distance of exposed bluff actually decreased. In 1947 approximately 38 percent, or 5500 linear feet, of the bluff was actively eroding; in 1952 about 32 percent, or 4600 linear feet, was exposed—a decrease of 16 percent, despite the high lake levels of that year.

From 1952 to 1955 average annual lake levels dropped 1.2 feet, but levels were still relatively high and the percentage of exposed bluff increased from 32 percent to 47 percent during the period. Levels dropped to an all-time low in 1964, and the percentage of exposed bluff decreased to about 37 percent, 5300 linear feet.

Lake levels from 1965 to 1968 increased to a level 2.85 feet above the 1964 low, but a progressively lower percentage of the bluff was eroded. Not until 1969 did higher lake levels directly affect bluff erosion. By 1973, 49 percent of the bluff was eroding, and by May 1975, 53 percent was eroding. The transgression of lake levels from the 1964 low to the high level of 1975 was accompanied by an increase of 2300 linear feet (43 percent) in exposed bluff. Since 1968, when the bluff was most stable, a 65 percent increase has occurred.

It is evident that high lake levels bring about increases in the extent of bluff that becomes exposed, but the highest or lowest water levels

TABLE 1—LAKE LEVELS AND PERCENTAGE OF SHORE DENUDED OF VEGETATION AT LAKE BLUFF

Year	Linear feet of exposed bluff (total bluff length 14,300 ft)	Bluff exposed and eroding (%)	Annual average lake levels at Milwaukee (IGLD)
			Below 579:
1947	5500	38	578.54
1948	—	—	578.43
1949	—	—	577.35
1950	—	—	577.53
			Above 579:
1951	—	—	579.13
1952	4600	32	580.29
1953	5200	36	579.79
1954	5500	38	579.49
1955	6800	47	579.09
			Below 579:
1956	6100	43	578.19
1957	5400	38	577.60
1958	5600	39	576.92
1959	5500	38	576.80
1960	5200	36	578.33
1961	5200	36	578.04
1962	4700	33	577.55
1963	5000	35	576.55
1964	5300	37	575.76
1965	4900	34	576.55
1966	4800	34	577.35
1967	4700	33	577.81
1968	4600	32	578.34
			Above 579:
1969	4700	33	579.19
1970	5200	36	579.05
1971	—	—	579.39
1972	—	—	579.75
1973	7000	49	580.55
1974	7500	52	580.50
1975	7600	53	580.04

do not correlate directly with the highest or lowest percentages of exposed bluff. Nor does bluff erosion always decrease with decreasing lake levels or increase with increasing lake levels. Rather, there is a time lag between attainment of high or low levels and bluff erosion or stabilization. During the period of relatively high lake level from 1951 to 1955, maximum erosion did not occur until 1955, even though water levels had already begun to decrease. Maximum bluff stabilization was not attained until 1968, 4 years after the record low lake level. An erosion threshold appears to have occurred during periods such as 1954-1955 and 1970-1973, when erosion rates increased rapidly within short periods.

Erosion thresholds and time lags are probably the result of two phenomena: (1) the process whereby beaches in general are destroyed as higher lake levels are reached and the bluffs are eventually subjected to greater frequency of wave attacks and under-

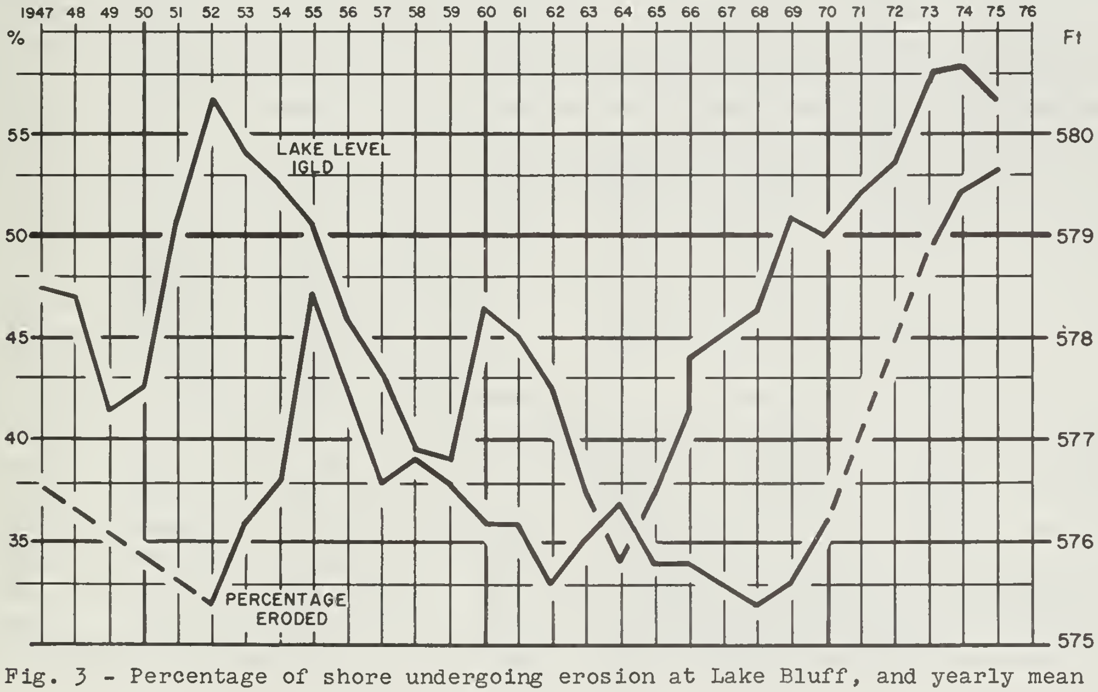


Fig. 3 - Percentage of shore undergoing erosion at Lake Bluff, and yearly mean lake levels of Lake Michigan.

cutting, and (2) the failure of vegetation, the primary natural agent in bluff stabilization, to colonize barren slopes immediately, because time is required for plants to root.

Table 1 and figure 3 show that significant bluff erosion occurs when the annual average lake level reaches 579 feet or higher. As levels drop below 579 feet, stabilization begins and continues if lake levels remain low. Between 1969 and 1975 lake levels were persistently above 579 feet and correlated with the greatly increased erosion of bluffs. The persistence of high levels, abetted by storm activity, further increases the amount of bluff that is exposed and denuded. A shorter period of high levels has a less drastic effect, as was shown by the 1951 to 1955 high (fig. 3).

If cultural conditions on the present shoreline and the present high lake level continue, the area of erosion will keep growing. A gradual lowering of the mid-1970s high to below the 579 level is probable. Even if a significant decline in lake levels (similar to the 1952 to 1953 drop) should occur in the near future and lake levels should continue to drop (as they did in the 1952 to 1955 period), bluff erosion will probably continue at accelerated or present rates for several years. While some aspects of the high lake level problem may appear to be solved, bluff erosion will continue to be a problem.

EROSION RATES AT LAKE BLUFF

Because the accelerated erosion associated with the present lake transgression is of concern to public officials and landowners alike, aerial photographs for the years 1975, 1974, 1973, 1970, 1969, 1964, and 1947 were studied in detail for the purpose of measuring annual and 10- and 25-year recession distances. Recession was determined by measuring profiles drawn from the edge of the bluff to a known cul-

TABLE 2—BLUFF RECESSION SINCE 1964 MEASURED ALONG SIX PROFILES IN LAKE BLUFF

Profile no. (fig. 1)	Year	Cumulative bluffline recession since 1964 (ft)
1	1964	0
1	1969	0
1	1970	0
1	1973	10
1	1974	15
1	1975	31
2	1964	0
2	1969	29
2	1970	39
2	1973	39
2	1974	39
2	1975	39
3	1964	0
3	1969	15
3	1970	15
3	1973	15
3	1974	15
3	1975	20
4	1964	0
4	1969	0
4	1970	3
4	1973	18
4	1974	28
4	1975	28
5	1964	0
5	1969	0
5	1970	5
5	1973	5
5	1974	22
5	1975	25
6	1964	0
6	1969	35
6	1970	75
6	1973	80
6	1974	80
6	1975	89

tural feature on the bluff. The position of the bluff on small-scale photographs was accurately located with a stereoscopic viewer and by direct measurement on 1:24,000-scale photographs. Accuracy of 3 to 5 feet was generally realized when measurements from the aerial photographs were checked against on-the-ground measurements.

The positions of the bluffs approximately 50 and 100 years ago were determined from U.S. Corps of Engineers maps for 1872-1873 and 1910-1911. The 65-year (1910-1975) and 103-year (1872-1975) bluff erosion rates are, respectively, used as representative of 50- and 100-year rates. Figures 4 and 5 show the locations at which detailed bluff recession rates were measured and also the positions of the bluff edge between 1872 and 1975.

Erosion Rates, 1964 to 1975

Six profile lines were measured between the bluff edge and known cultural features on the bluff (figs. 1, 4, 5). The profiles were located where distance to the edge of the bluff could be measured from a road intersection, driveway, or other feature. For each profile, segments of bluff with characteristics in common were grouped into "erosion areas," which were used as units in calculating bluff recession (fig. 1). Because of variations within the erosion areas, the bluff recession rates derived should be considered as careful approximations.

Table 2 shows how much bluff recession has occurred since 1964, the year in which lake level reached the record low of 575.76 IGLD. Erosion thresholds can be identified along profiles 1, 4, and 5. Little or no erosion occurred at those profiles between 1964 and 1973. As lake levels continued high, however, a threshold of bluff erosion was reached and recession accelerated. Profiles 2 and 3 display erosion patterns much like those of 1, 4, and 5, although different amounts of materials were removed. Erosion along profiles 2 and 3 was most severe between 1964 and 1969. Along profile 2, the bluff then remained stable from 1970 to 1975. Along profile 3, stability was evident from 1969 to 1974. Profile 6 was located in an area just north of Shore Acres Country Club, where massive slumping has produced a maximum of 89 feet of recession since 1964. Because this high rate was anomalous, additional profiles were measured between profile 6 and the south jetty of the Great Lakes Naval Training Center, to the north. The new profiles indicated the bluff in the area receded 40 feet between 1964 and 1975 (table 3).

TABLE 3—BLUFF RECESSION RATES ALONG SELECTED PROFILES AT LAKE BLUFF, 1964 TO 1975

Profile no. (fig. 1)	Recession since 1964 (ft)	Average rate (ft/yr)	10-year rate (ft)
1	31	2.82	28.2
2	39	3.55	35.5
3	20	1.82	18.2
4	28	2.54	25.4
5	25	2.27	22.7
6*	40	3.64	36.4
All profiles (av.)	31	2.77	27.8

* Profile 6 was established in an area of anomalously high recession, from which 89 feet of material has been lost since 1964. The 40 feet of recession for area 6 is the average footage from several profiles.

Fig. 4 - Profiles along which bluff recession rates were measured along the southern part o

If the 40-foot recession average is used instead of the 89-foot average for erosion area 6 (fig. 1), the bluff has receded an average of 27.8 feet along the six Lake Bluff profiles since 1965, and 30.5 feet if 1964 is included. Average annual rates were quite consistent, ranging from 1.82 feet per year for erosion area 3 (table 3) to 3.64 feet per year at erosion area 6.

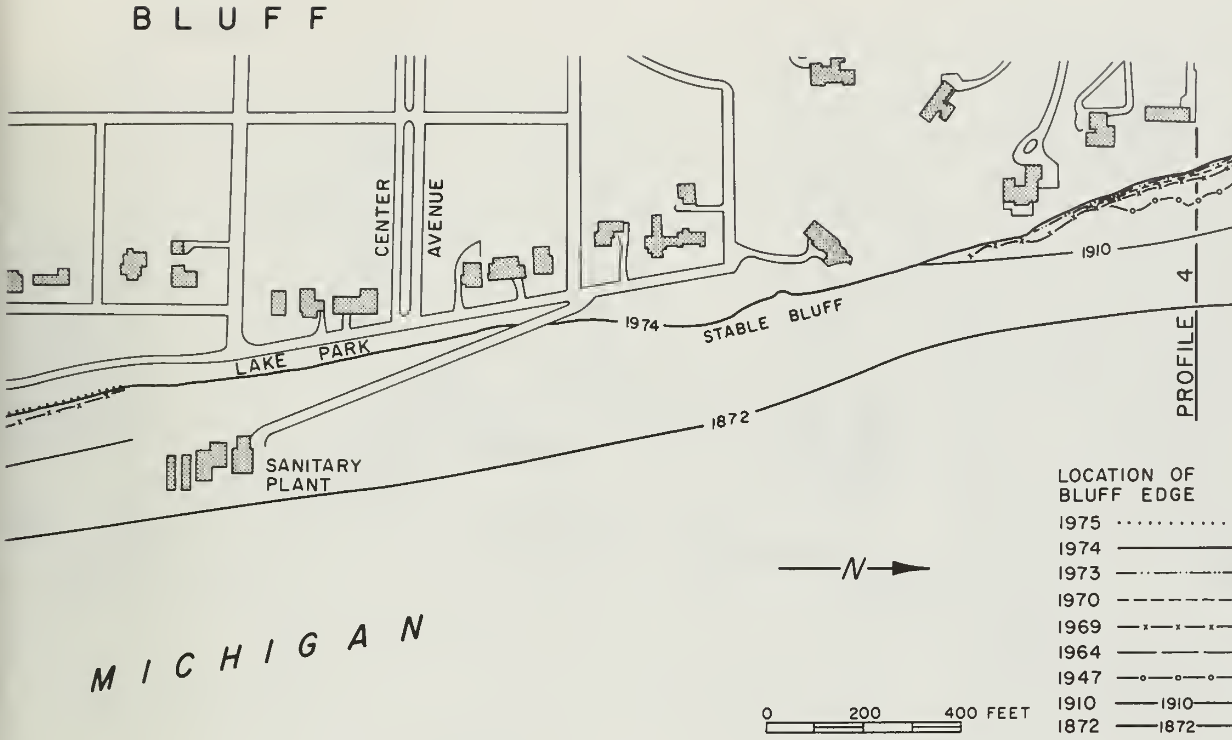
TABLE 4—CUMULATIVE BLUFF RECESSION AND RECESSION RATES ALONG SELECTED PROFILES IN LAKE BLUFF, 1947 TO 1975

Profile no. (fig. 1)	Recession since 1947 (ft)	Average rate (ft/yr)	25-year rate (ft)
1	31	1.11	27.5
2	59	2.11	52.7
3	20	0.71	17.8
4	68	2.42	60.5
5	25	0.89	22.3
6*	60	2.14	53.6
All profiles (av.)	44	1.56	39.1

* Profile 6 was established in an area of anomalous rates.

Erosion Rates, 1947 to 1975

The position of the bluff 25 years ago was measured along profiles 1 to 6 from aerial photographs. When the anomaly at profile 6 was compensated, the bluff proved to have receded an average of 39.1 feet during the past 25 years (table 4). Bluff erosion was greatest along profiles 2, 4, and 6, a pattern similar to that shown by the 1964 to 1975 erosion data (table 3). Low annual erosion rates along profiles 3 (0.71 ft/yr) and 5 (0.89 ft/yr) reflect stabilization by vegetation during the late 1940s and 1950s.



Lake Bluff. The various positions of the edge of the bluff between 1872 and 1975 are shown.

Erosion Rates 1872 to 1910, 1910 to 1975, and 1872 to 1975

Inasmuch as aerial photographs were not available for 50- and 100-year bluff positions, bluff contours on U.S. Corps of Engineers maps for 1910-1911 and 1872-1873 (scale 1:20,000) were compared to present bluff contours on the Waukegan 7.5-minute quadrangle topographic map (scale 1:24,000). An accuracy of ± 10 feet was attained. The location of the bluff edge was measured from Sheridan Road and the Chicago and Northwestern Railroad tracks, the only north-south features present during the 1870s that persist today. East-west profiles were established—perpendicular to Sheridan Road or the railroad tracks—along roads, property boundaries, or surveyed lines. In areas where no cultural features or surveyed lines existed, east-west profiles were constructed at equal intervals. This method was used extensively between the Shore Acres Country Club and the south jetty at Great Lakes (figs. 5, 6).

Table 5 presents average bluff recession on the Lake Bluff shore for the periods 1872-1910, 1910-1975, and 1872-1975. Average over-all recession rates for the three periods are 4.1, 1.7, and 2.6 feet per year, respectively. The high rate for the 1872-1910 interval was caused by the unusually high lake levels of that time (fig. 2), whereas the rate for 1910-1975 reflects relatively low lake levels. The 1872-1975 rate of 2.6 feet per year covers both periods and, until more detailed data are available, is used to calculate the 50-year and 100-year recession intervals of, respectively, 84.5 feet and 259 feet, as shown in table 6.

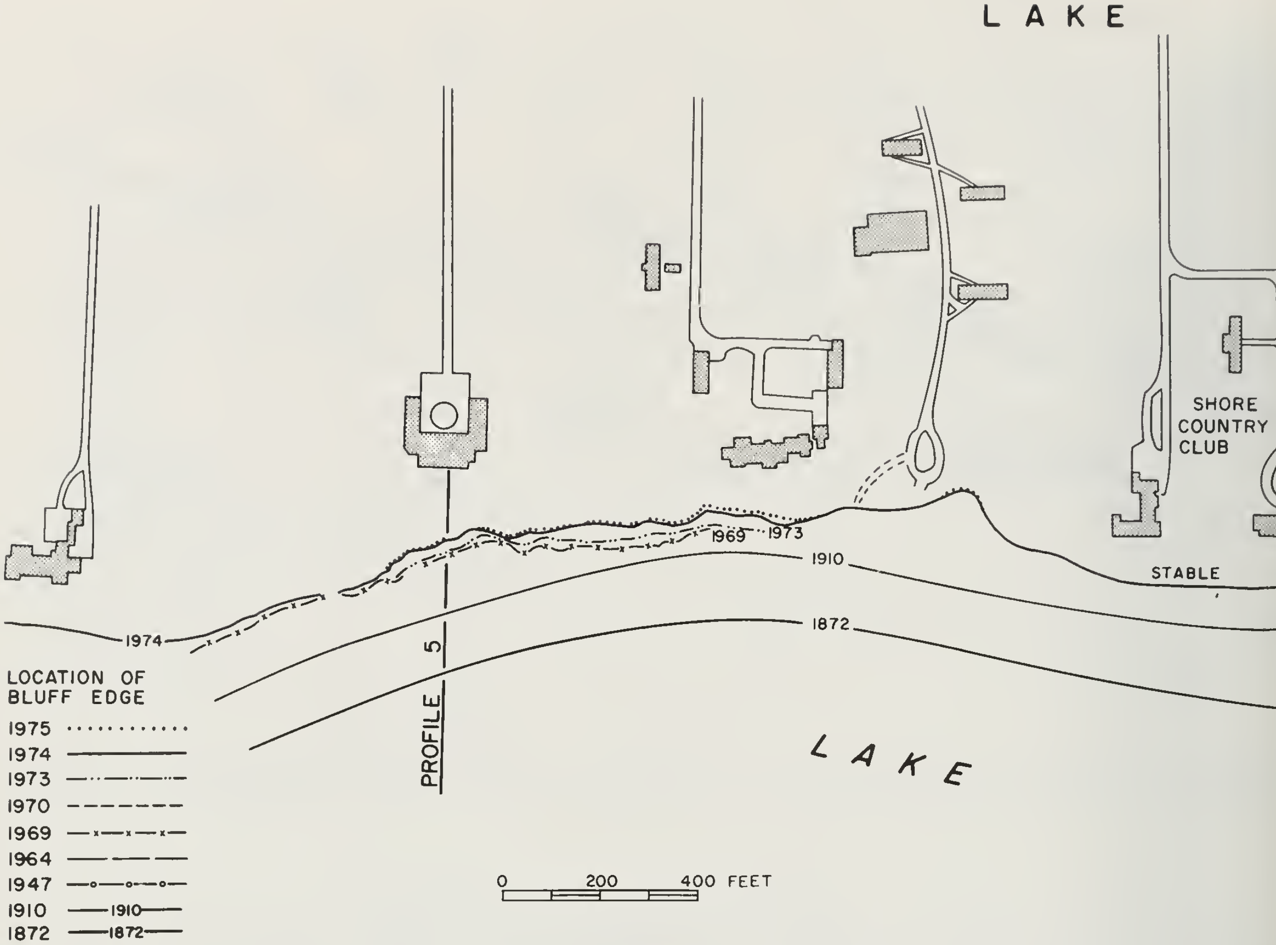
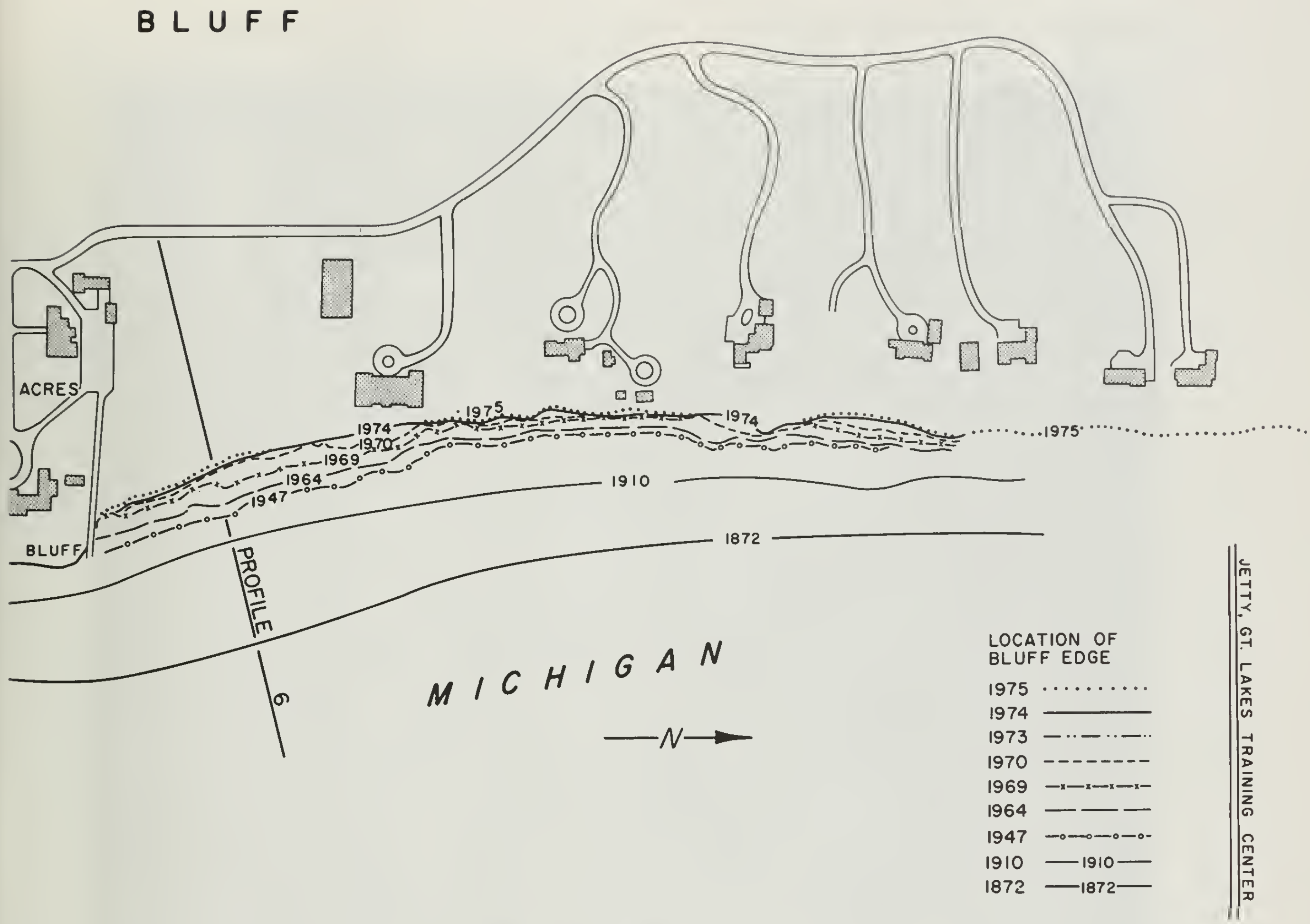


Fig. 5 - Positions of shorelines along northern Lake Bluff between 1872 and

TABLE 5—BLUFF RECESSION AT LAKE BLUFF, BY PERIODS

Recession area	1872 to 1910 (38 years) (ft)	1910 to 1975 (65 years) (ft)	1872 to 1975 (103 years) (ft)
Over-all recession	157	110	267
Area north of Shore Acres Country Club (northernmost 2400 ft of shore)	235	171	406
Area south of Shore Acres Country Club (11,900 ft of shore)	140	88	228



1975. Profiles along which bluff recession was measured are shown.

The period 1872-1910 (tables 5 and 7) is of special interest for interpretations of recessional history of the shore between Shore Acres Country Club and the jetties at Great Lakes Naval Training Center. The jetties deprive the southern shore of littoral sediment that might otherwise be transported along the nearshore from the north. However, the period from 1872 to 1910 preceded the building of the Great Lakes harbor, and recession during that period has been calculated as 6.2 feet per year.

In comparison, the 1910-1975 annual recession rate north of Shore Acres Country Club was about 2.6 feet per year, and the 1964-1975 rate was 3.64 feet per year. The 1872-1910 period included 32 years during which the annual mean lake level was 579 feet or more, whereas the 1910-1975 period included 27 such years.

TABLE 6—AVERAGE RECESSION FOR SIX PROFILES AT LAKE BLUFF

Period	Average amount of recession (ft)
1965-1975	27.8
1950-1975	39.1
1925-1975	84.5
1872-1975	259.0


N
1
2
3
4
5
6
0
950 Ft

The recession rate since 1964 is lower than that for the 1872-1910 period, which preceded construction of the jetty, although lake-level differences during these two periods may in large part account for the decline. It is also obvious that the Shore Acres—Great Lakes reach erodes rapidly for reasons other than a deficit in littoral drift. The 1872 and 1910 maps plainly show greater recession in the area north of Shore Acres Country Club than in the area south of it (figs. 6, 7). Comparative measurements (table 5) show that the difference in the two areas has apparently existed since records have been kept.

Geological investigations of the bluff area indicate that weak materials in the upper part of the bluff probably account for the Lake Bluff shore's susceptibility to erosion. Sands, gravels, and silts were found to be thickest and weakest in the area north of the country club (figs. 6, 8). In addition, springs and seeps are generally present all along the Lake Bluff shore. They arise mainly from weak, porous sands and silts in the upper part of the bluff, and the water not only carries away sediment directly, but, during cold seasons, subjects the sediments to the severe weathering effects of freezing and thawing. Parts of the bluff as far south as Winnetka suffer from seeps and

TABLE 7—EAST-WEST DISTANCES BETWEEN A BASELINE AND THE BLUFF EDGE, NORTHERNMOST 2400 FEET OF LAKE BLUFF

1875 (ft)	1910 (ft)	Change* (ft)
3350 North	3118	232
3366	3102	264
3350	3118	232
3333	3135	198
3350	3135	215
3350	3135	215
3316	3135	181
3333	3135	198
3316	3135	181
3316	3151	165
3350	3151	199
3366	3151	215
3400	3151	249
3450	3151	299
3466	3151	315
3500	3151	349
3500 South	3217	283

* Average for northernmost 1800 feet is 235 feet; average for southernmost 600 feet is 311 feet.

Fig. 6 - Shore at Lake Bluff extending northward from Blodgett Avenue to the Great Lakes Naval Training Center.

1—500 feet of shore adjacent to the south jetty at Great Lakes Training Center. Note the presence of a normal beach.

2—A beach house stabilized by concrete seawalls.

3—Area of most rapid bluff recession. The bluff's position south of the Great Lakes jetty and the presence of weak contorted glacial materials in the bluff contribute to instability.

4—Bulkhead of Shore Acres Country Club.

5—Area previously protected by groins but now exposed to wave and current effects.

6—The north end of an effective groin field. Note the light-colored currents bypassing the jetty and the clay-laden waters passing southward along the southern shore.


N
1
2
0
950 Ft

springs, but the porous beds that give rise to them are thinner and less widespread than those at Lake Bluff.

DuMontelle, Stoffel, and Brossman (1975) described the earth materials in the bluff (fig. 8) and differentiated the unstable areas. Studies during 1976 will determine the quantity and gradient of ground water in the bluff and its role in bluff stability. Methods for correcting ground-water problems will be suggested.

VOLUME OF MATERIALS ERODED AT LAKE BLUFF

The volume of eroded materials is a function of bluff height, slope angle, length of receding bluffline, and recession distance. Estimates of the volume of material eroded (table 8) were made for the six Lake Bluff areas shown on figure 1, taking into account the variation in size of the areas that occurs through time. Bluff recession was measured along the six profiles associated with the erosion areas (fig. 1). Slope angles varied from 45 to 50 degrees, except at one small location in area 3 where the angle was 75 degrees. The height of the bluff was 70 feet in areas 1 through 5 and 67 feet in area 6. A parallel retreat of slopes was assumed. In area 1, 450 feet of bluff was exposed, the slope angle was 45 degrees, and the bluff height was 70 feet. Recession during the present high water cycle commenced after 1970. About 31 feet of recession was measured by May 1975. The volume of eroded material for area 1 was therefore estimated at 988,400 cubic feet. In area 6, the bluff was 67 feet high, the slope was 48 degrees, the bluff length was 1850 feet, and recession was measured at 40 feet from 1964 to 1975. Approximately 5,104,000 cubic feet of material, therefore, was eroded from area 6.

TABLE 8—ESTIMATED VOLUME OF MATERIALS LOST TO EROSION AT LAKE BLUFF SINCE 1964

Erosion area (fig. 1)	Material lost (cu ft)
1	988,400
2	3,365,000
3	834,400
4	4,431,500
5	2,457,000
6	5,104,000
	17,180,300 (636,300 cu yd)

For all six erosion areas in Lake Bluff, about 17,200,000 cubic feet (636,000 cubic yards) of bluff material has been eroded since 1964. Inasmuch as 267 feet of recession has occurred there since 1872, approximately 172,000,000 cubic feet (6,360,000 cubic yards) has been yielded to the lake during the past 100 years.

BLUFF EROSION AT SOUTH LAKE FOREST

The Lake Forest erosion area is about 800 feet south of an east-west line extending from Westleigh Road to

Fig. 7 - Reach of shore covering central Lake Bluff from Arden Shore at the north to Lake Forest Cemetery at the south.

1—The well stabilized reach north of and adjacent to the Lake Bluff Sewage Disposal Plant. The area is protected by groins and bulkheads. See also figure 4.

2—The site at which a bulkhead failure caused severe erosion of the bluff for approximately four years (fig. 14). The areas immediately north and south, protected by bulkheads, have remained relatively stable.

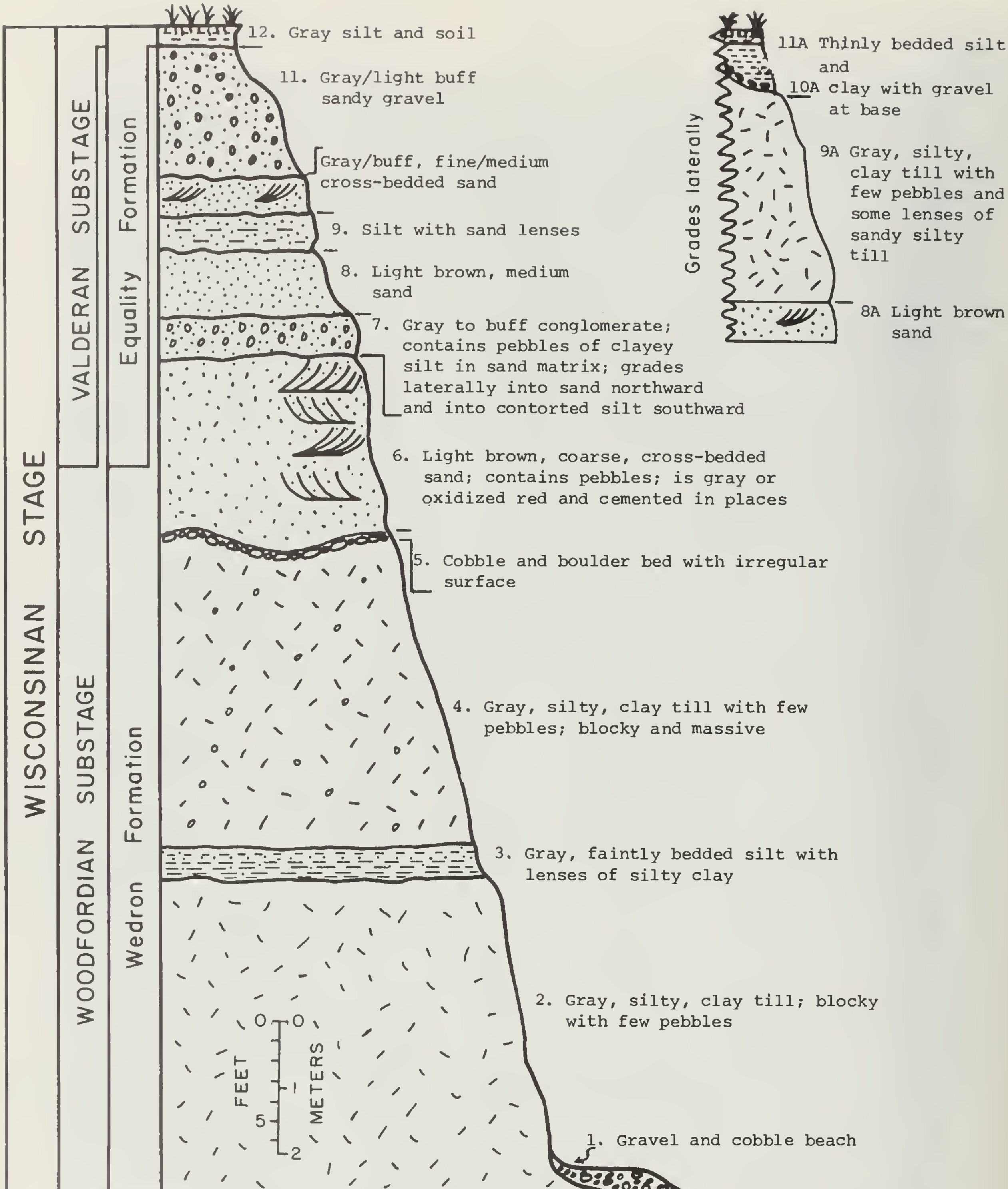


Fig. 6 - Stratigraphic section just south of Lake Bluff Sewage Disposal Plant (SE$\frac{1}{4}$, NE$\frac{1}{4}$, Sec. 21, T. 44 N., R. 12 E., Lake County, Waukegan Quadrangle).

TABLE 9—CUMULATIVE BLUFF RECESSION AT LAKE FOREST NATURE PRESERVE, SOUTH LAKE FOREST, SINCE 1973

Year	Recession at southern profile (ft)	Recession at northern profile (ft)
1973	0	0
1974	12	14
1975	31	35

Lake Michigan and occupies only 568 feet of shore. Unlike the bluff areas between the Great Lakes Naval Training Center and the Lake Forest Waterworks, it may be considered representative of the shore areas south of the waterworks that remained stable through much of the century but are now eroding because of the present and persistent high lake levels.

Two profiles were established to measure the bluff changes that occurred between 1973 and 1975 (fig. 9). The bluff recession measured from known cultural features along both profiles is shown in table 9. Along the southern profile, 31 feet of erosion has taken place since 1973, while along the northern profile 35 feet has eroded, a recession average of 33 feet for the 2 years. Bluff changes from 1872 and 1910 to 1958, measured from lake survey charts and topographic quadrangle maps, are shown in table 10.

Distances were measured from east to west from surveyed longitude lines. The nine measurements were spaced at equal intervals. Because the Waukegan 7.5-minute quadrangle map shows the 1958 bluffline, erosion since 1958 is included in table 11.

The period of relative stability prior to the present transgression is clearly reflected in the average 17.3 feet of bluff recession recorded for the time between the years

TABLE 10—BLUFF RECESSION AT LAKE FOREST NATURE PRESERVE IN SOUTH LAKE FOREST FROM 1872 TO 1958

Profile no. (spacing 70 ft)	Recession 1872 to 1910 (38 years) (ft)	Recession 1910 to 1958 (48 years) (ft)	Recession 1872 to 1958 (86 years) (ft)
1	108	10	118
2	50	43	93
3	42	0	42
4	50	7	57
5	58	0	58
6	42	0	42
7	42	10	52
8	50	33	83
9	42	53	95
	Average 54	Average 17.3	Average 71.1

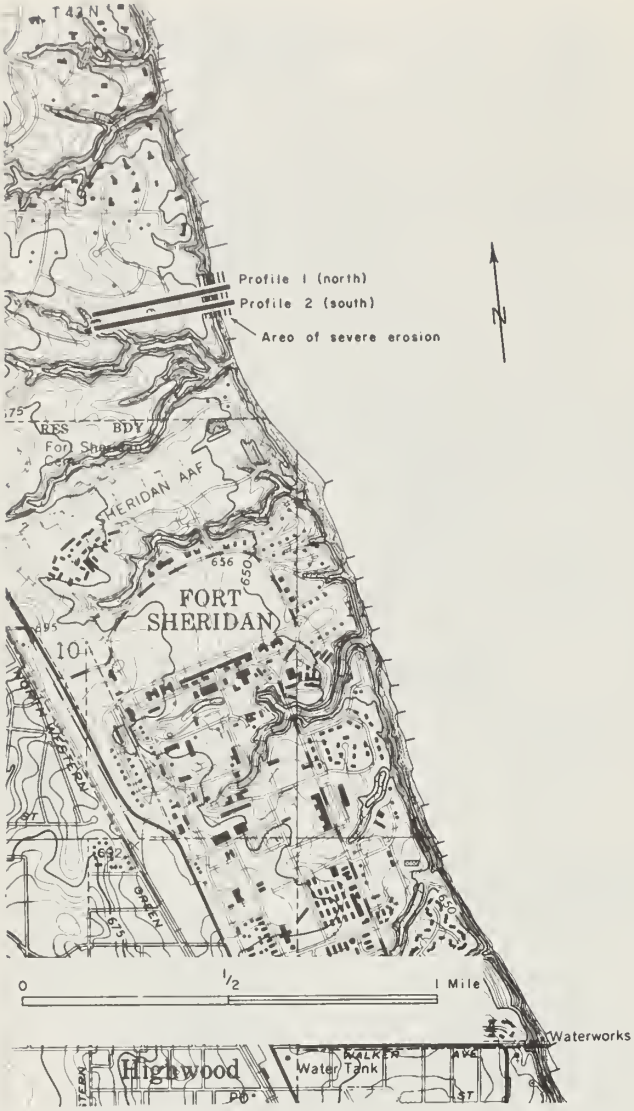


Fig. 9 - Location of profiles used to calculate erosion rates in south Lake Forest.

1910 and 1958. The average calculated for the period 1910 to 1975, however, is higher because of the increase in erosion since 1973, a period for which the average was 33 feet. From 1872 to 1910, an average of 54 feet of this same bluff was eroded owing to the higher lake levels of the 1870s and 1880s. This is the same general pattern of recession that was found along the Lake Forest to Great Lakes bluff—a record of high recession rates prior to

TABLE 11—TOTAL BLUFF RECESSION AT LAKE FOREST NATURE PRESERVE, 1872 TO 1975

Period	Recession (ft)
1910 to 1975	50.3
1872 to 1975	104.1

1910, low rates between 1910 and the early 1970s, and a return to high erosion rates in the middle seventies.

The volume of bluff material removed from this area since 1973 has been about 45,000 cubic yards, leaving 45-degree bluff angles and a bluff height of 65 feet. Since 1872 an average bluff recession of 104.1 feet has removed about 141,000 cubic yards.

Although the Lake Forest erosion area is relatively small, it serves as a model for bluff areas that have recently become subject to erosion. Study of the area has also served to corroborate data and interpretations made at Lake Bluff.

BLUFF EROSION AT HIGHLAND PARK, GLENCOE, AND WINNETKA

Unlike the areas at Lake Bluff and Lake Forest, the bluff shores at Highland Park, Glencoe, and Winnetka suffered most of their erosional losses prior to the turn of the century. At present, the reach is relatively stable, even though in small areas at Highland Park severe erosion is in progress.

Because the reach has a modern history of stability with only small scattered areas of real concern, 16 profiles (fig. 10) were used to measure bluff changes between 1872

Fig. 10 - Location of profiles used to calculate erosion rates in Highland Park, Glencoe, and Winnetka.

and 1975 and between 1964 and 1975 to determine the area's erosion history. Nine profiles were measured in Highland Park, five in Glencoe, and two in Winnetka. In Highland Park, two profiles showed evidence of significant erosion. At profile 1 (fig. 10), near the Highland Park—Fort Sheridan boundary, recession was caused by the slumping of a single 17-foot block during the early 1970s. At the second site (profile 9) at the southern extremity of Highland Park, approximately 15 feet of recession has occurred since 1964 on a 200-foot reach of shore.

Although erosion at Highland Park, Glencoe, and Winnetka is much less spectacular than the erosion now occurring at Lake Forest and Lake Bluff, the volume of material lost to the lake in the three communities since 1872 is considerable. The main difference is that approximately 11 miles of shore edging those communities was involved, whereas less than 2 miles was involved in the Lake Forest—Lake Bluff losses. About 47,000,000 cubic yards of sediment has been lost from the 11-mile reach. At Winnetka, the total recession for all parts of the shore during the past 100 years has been 28 feet, and total sediment loss has been 4,000,000 cubic yards. Recession of the Glencoe shore for the century averaged 21 feet, a loss of 10,000,000 cubic yards of material. Highland Park's shoreline of more than 5 miles receded 43 feet in 100 years, involving a loss of about 33,000,000 cubic yards of material. Although these losses are large, they occurred mainly before 1910 when shore protection measures were much less adequate than at present.

FUTURE LAKE LEVELS AND BLUFF RECESSION

The present high-water transgression of Lake Michigan thus far has been unique (fig. 2). Beginning in 1964, average annual lake levels have gradually increased, and they have remained consistently above 580 feet IGLD from 1973 through 1975. Such consistency has not occurred since the high levels of the 1870s and 1880s. The only other modern transgression that resembles the present one occurred between 1951 and 1955.

If present-day levels should represent a return to persistently high lake levels similar to those of the 1870s and 1880s, bluff and shoreline recession will continue at the present or accelerated rates. Lake levels peaked above 579 feet for 35 separate years between 1872 and 1975. If the average lake level is above 579 feet 35 percent of the time during the next 100 years, bluff recession averages will be similar to those of the 10- and 100-year values given in table 6. Under such lake conditions, if shoreline culture should remain unchanged, those areas now eroding would recede about 260 feet more in 100 years. If lake levels average more than 579 feet annually for only 25 percent of the next 100 years, bluff recession averages would approximate those for a 50-year period and about 85 feet of bluff erosion would be expected. Average annual lake levels between 1925 and 1975 surpassed 579 feet for only 12 years.

Regardless of whether 260 feet or 85 feet of bluff recession occurs during the next 100 years, recession will continue until protective structures or adequate littoral drift sediments are provided and other elements necessary to a shore-management program are added.

ERODED AREAS AND SHORE PROTECTION AT LAKE BLUFF AND LAKE FOREST

Field studies and examination of aerial and ground photos of the Illinois shore indicate that portions of the Illinois bluff having a history of stability also have a history of adequately installed and maintained protection at the foot of the bluff. Almost invariably, the areas now eroding are those that have minimal or no artificial protection or have poorly constructed and/or poorly maintained protective structures.

In Lake Bluff, eight areas have remained reasonably stable from 1947 to 1975: (1) the area immediately south of the Great Lakes jetty (fig. 6); (2) a small promontory about 1000 feet south of the jetty (figs. 6, 11); (3) the seawall-protected Shore Acres Country Clubhouse (figs. 6, 12); (4) a 1200-foot long seawall and groin area 2000 feet north of Blodgett Avenue, Lake Bluff (fig. 6); (5) the bluff to the west and north of the Lake Bluff Sewage Plant (fig. 7); (6) two small seawall-guarded areas about 500 feet south of the sewage plant (fig. 7); (7) a small seawall-protected area just 1100 feet north of the Lake Forest Waterworks (fig. 14); and (8) the area just west and north of the waterworks (fig. 14). All other areas have been subject to erosion at one time or another.

Except for the protected area north of Blodgett Avenue, ineffective groins have permitted serious erosion along much of the Lake Bluff shore. Groins are useful devices for curbing erosion in most areas, but if they are not well designed, properly constructed, and regularly maintained, their usefulness as shore-protectors diminishes.

The groins located between the Lake Forest Waterworks and the Lake Bluff Sewage Disposal Plant have not been entirely effective, as the eroding bluffs show (figs. 15 and 16). The groin field was established in 1949, and, for the most part, served to protect the shore until the high lake levels in 1973 submerged the groins.

In addition to groins not designed to withstand higher lake levels (resulting in submergence of the structures), failure of bulkheads or seawalls has been responsible for severe bluff recession in several places, including (1) the area just south of the clubhouse of the Shore Acres Country Club (figs. 6, 13); (2) a small seawall-protected area about 500 feet south of the Lake Bluff Sewage Disposal Plant (fig. 15); and (3) a small seawall-protected area about 1100 feet north of the Lake Forest Waterworks (fig. 14).

The seawalled area protecting the clubhouse of the Shore Acres Country Club, prior to its partial destruction over a period of years, was at one time nearly twice its present length. About 100 feet of the wall was breached in 1955. The breach remained until 1960, and a small erosional embayment formed behind it (fig. 6). By 1961, approximately 300 additional feet of wall was lost and the erosional embayment enlarged. The formerly protected bluff can now barely be distinguished from the bluff to the south that has been eroding for a longer time.

The second bluff area that has sustained significant erosion because of seawall failure is just south of the Lake Bluff Sewage Disposal Plant (fig.

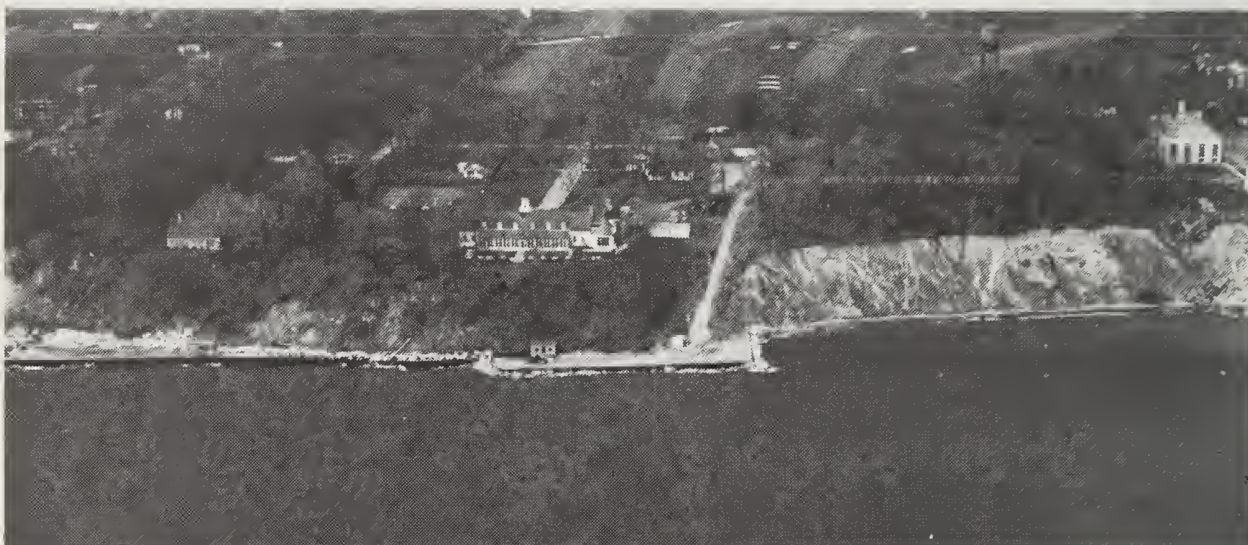


Fig. 11 - Bluff one-eighth of a mile south of Great Lakes Naval Training Center, August 1974, at a lake level near 580 feet. The bluff is more than 70 feet high. The lower part is of homogeneous gray glacial till. Most of the upper half of the bluff consists of weak till, silt, sand, and gravel. The beach house was built before 1947 and has been maintained ever since. Its location indicates the subsequent bluff recession (fig. 5). Numerous seeps can be seen along the entire reach. Fallen trees can be seen on the bluff face and on the narrow beach. More moisture is present below the mouths of truncated gullies than elsewhere. Rubble groins once present along this shore have been damaged and submerged. This location is shown by a vertical aerial view in figure 6.

Fig. 12 - Shore Acres Country Club in Lake Bluff and the adjacent reach of shore northward. The northern part of the bulkhead shown here has been maintained for nearly 40 years. The eroding bluff adjacent on the north has receded nearly 90 feet since 1964, the highest bluff recession rate on the shore. The upper 40 feet of the bluff here is contorted glacial-fluvial sands, silts, and clays that create an unusually weak zone in the upper half of the bluff. The photo was taken in May 1975 when the lake level was near 580 IGLD. The dark areas indicate high moisture content. A vertical aerial view of this location is shown in figure 6.

Fig. 13 - Reach of shore just south of Shore Acres Country Club in Lake Bluff. The bluff intersects ditches and several gullies that show evidence of downcutting at the bluff face. The foot of the bluff is deeply notched by direct wave impact. Large slump blocks with sod still intact can be seen on the bluff face, along with fallen trees. At the north end of the face a large slump block directly in front of the house has settled a few feet. Some blocks slump slowly down the face over a period of time; others fall suddenly. The photo was taken in May 1975 when lake elevation was near 580 IGLD. A vertical view of this location is shown in figure 6.

15). The northernmost portion of the wall was constructed prior to 1947 and is stable; the remaining part was set in 1952 and 1953, and it has been less successful. Bluff erosion became evident following construction of the 1952-1953 section, but the bluff stabilized as vegetation took hold. The bluff remained stable until late 1969 or early 1970 when breaching of the sheet piles occurred, creating an erosional embayment in the bluff. About 60 percent of the 1952-1953 seawall section has now been destroyed, and recession has placed the bluff less than 50 feet from a residence.

The third bluff area, north of the Lake Forest Waterworks, has not suffered as great a loss as the other two, but recession is now occurring behind the bulkhead at accelerating rates. The seawall is about 150 feet long and was constructed between 1947 and 1952. A gradual degradation of the bluff seems to have occurred since construction, partly because of the wall's limited extent. Since about 1973, the bluff has been eroding at accelerated rates because a small breach has been exploited by wave action.

In general, groined shorelines have not prevented bluff erosion along the Lake Bluff shore. Considering the many factors, such as a dearth of littoral drift, weak bluff materials, and substantial ground-water seepage, the groins cannot be entirely blamed. Nevertheless, those few groins set prior to 1937 have proved to be permanent and effective. Inasmuch as the groins were set during an extended period of low lake levels (fig. 2), the vegetation on the bluff may have played an important role in the protection of the shore. Lake levels remained low for more than 15 years during the 1930s and 1940s, permitting the vegetation to become well established on the bluff face. Consequent-


1
2
3
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ly, when high water levels arrived during the 1950s, the bluff was protected not only by groins but by mature vegetation that successfully withstood wave attack. Groins emplaced during or just prior to the high levels of 1952-1953 have proved to be unsuccessful defenses against bluff erosion. Apparently the basic instability of the eroding bluff and the erosion lag create conditions in which the groins are flanked and rendered ineffective. At any rate, groin construction on the Lake Bluff shore suggests that groins built at the beginning of a protracted period of low lake levels survive better than those built during high-water conditions. The record further suggests that an extended period of time is required for natural vegetation to become thoroughly rooted, mature, and truly protective.

CONCLUSIONS

Areas of bluff erosion are distributed along the entire shore north of Winnetka. The areas of severe damage, however, are mainly at Lake Forest (fig. 17), Lake Bluff (figs. 15, 16), and Fort Sheridan (fig. 19). Estimated volumes of material lost amount to 50,000 cubic yards at Fort Sheridan and 45,000 cubic yards at Lake Forest, nearly all of it eroded since 1973. Lake Bluff has had by far the most severe damage, and recession of its shores has been taking place for more than 100 years. Since 1872, an average of 267 feet of recession has occurred, which is a loss of about 6,360,000 cubic yards of material. During 11 years of the present lake-level cycle, the shore has receded an average of 30.5 feet and lost about 636,000 cubic yards. Study of the Lake Bluff shore suggests that the loss is due to such factors as

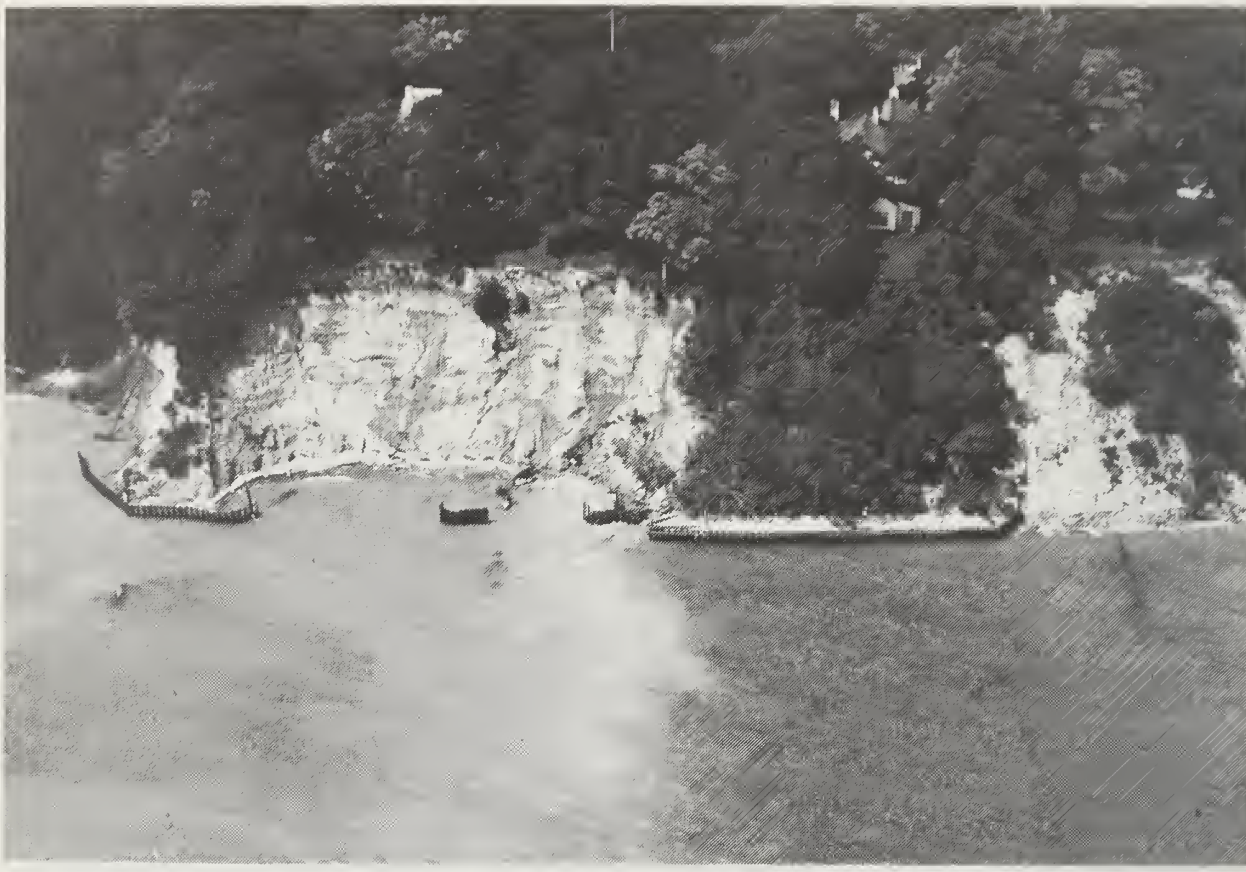
1) High lake levels
2) Loss of vegetation
3) Inadequate shore protection
4) Natural weakness in the bluff materials
5) Oversteep slopes
6) Ground-water seeps and springs in the bluffs
7) Deprivation of littoral drift sediments along the shore by shore structures farther north.

A study of the shore's history by means of photos, maps, and field examinations has suggested several points that may be useful in planning a program to stabilize the bluff.

Fig. 14 - Shore in southern Lake Bluff and northern Lake Forest. The Lake Bluff Sewage Disposal Plant is at the top. The Lake Forest Waterworks is in the center.

1—Area 1100 feet north of the waterworks where a bulkhead has failed and a set of groins that normally protect the shore (shown here in April at low water) have been flanked, topped, and partly submerged by high water. Consequently, the reach from there northward to the Lake Bluff Sewage Disposal Plant has suffered severe erosion during the present high-water cycle.

2 and 3—Shore in Lake Forest where groins and sheet-pile bulkheads have remained throughout high-water levels and have maintained a relatively stable and vegetated bluff.



1. When lake levels are rising, serious bluff erosion from wave attack apparently does not become significant until the 579-foot IGLD level has been exceeded. When this threshold has been passed, erosion progresses rapidly.

2. Bluff erosion generally does not immediately decrease with decreasing lake levels, even when they fall below the 579-foot level. Commonly, there is a lag effect by which recession rates are maintained or accelerated because slopes remain exposed until vegetation can become firmly established.

3. Where lake levels are rising, well developed beaches will delay the onset of maximum erosion until they are depleted. The absence of a contribution of littoral drift from north of the Lake Bluff area and the rapid southward movement of materials generated by local bluff erosion insure the depletion of any beach materials accumulated during low water stages.

4. Groins established during high water periods in Lake Bluff have been generally unsuccessful because of recession of the bluff and flanking of the structures. Groins established during the 1930s, after which a protracted period of low lake levels ensued, have been successful. The

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Fig. 15 - The shore in Lake Bluff just south of the Lake Bluff Sewage Disposal Plant. The bulkhead shown here failed in 1969 or 1970. All recession behind the structure has occurred since that time. On the right, where the bulkhead has been maintained, the bluff has remained vegetated and stable. The houses on the top of the bluff are now less than 50 feet from the bluff edge. Note the submerged groins and debris. The photo was taken in August 1974 when the lake level was at 580.7 IGLD. The geologic section described is shown in figure 8; it is located a few hundred feet north of this area. Unstable sand, silt, clay, and brown silty till compose more than the upper half of the scarp. Homogeneous gray till composes approximately the lower half. Figure 7 shows a vertical view of this location.

Fig. 16 - Seventy-foot bluff scarp in south Lake Bluff. The sharp, dark, irregular line halfway up the face is the contact between the lower gray, homogeneous, glacial till and the weak, irregularly layered, silty till, sand, silt, and clay sediments above. Dark streaks indicate surface seeps that were present during most months of 1974 and 1975. The vertical fluting of the bluff resulted when surface waters drained over the bluff face. The foot of the bluff is deeply undercut and shows fresh slumping. The photo was taken in August 1974 when the lake level was near 581 IGLD and the outer ends of groins were submerged, along with parts of other protective structures. The south groin has been entirely flanked and separated from the shore. The bluff has receded 39 feet since 1964 at this place (fig. 4, profile 2). Note the clouds of clay derived from the bluff that are suspended in the water. See figure 7 for a vertical aerial view at the location.

presence of mature vegetation established during the long low-water period is given primary credit for their success.

Several studies originally planned remain to be made during FY 1976-1977.

1. Distribution of earth materials in the bluff will be determined and the various sediment-size fractions being contributed to the lake will be calculated. Additional data concerning earth materials will also be gathered for the rapidly eroding reach of shore between the south jetty of Great Lakes Naval Training Station and the Shore Acres Country Club. A detailed search for new zones or conditions of special instability, particularly the shore south of Lake Forest, will be included.

2. Ground-water distribution and levels will be monitored from wells drilled on the bluff. The effects of seasonal rainfall and of rainy episodes on bluff recession will be investigated.

3. Specific shore protection measures will be studied and general protection plans developed for providing shore stability. In addition, the rates of denudation and revegetation of the bluff face will be determined in areas that have various types of shore protection.

4. Oblique aerial photographs and ground photographs, taken monthly, will monitor changes in the bluff and shore conditions, such as a significant loss

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Fig. 17 - Bluff in southernmost Lake Forest, part of the former Rockefeller-McCormick estate, Villa Turicum. The ruin of a swimming pool and stairway can be seen. The photograph was made in August 1974 when lake level was more than 580 IGLD. The scarp is the result of erosion during the present high lake-level cycle. In modern times, recession began in 1973. Since then, 33 feet of recession has taken place.

Fig. 18 - Bluff area between Center Avenue and Blodgett Avenue in Lake Bluff. The scarp has approached several houses. The bluff in the center has been stabilized by rubble dumped over the face as well as placed at the foot of the bluff. The groin at the south (left), replaced by a new one in 1975, has been damaged. The groins at the north end are essentially empty, although groins a little farther north are partially full. This reach was photographed in May 1975 when lake level was near 580 IGLD.

Fig. 19 - Eroded reach of bluff at Fort Sheridan just north of Walker Avenue. Although this area has been protected by groins, the three present here have been submerged by high water. The photograph was taken in May 1975 when lake level was near 580 IGLD. The upper part of the bluff has been removed and only homogeneous glacial till remains.

of vegetation caused by downward slumping, a previously undetected area in which the bluff toe has eroded, recognizable changes in the character of the beach, recently submerged groins, and recently damaged seawalls or other shore protection structures. Owners of shore property will be notified of serious adverse changes in the stability of the bluff.

Several additional elements worthy of investigation have been suggested by the present study.

1. A detailed record, based on careful ground control, should be made of recession at several locations on the bluff. Measuring sites should be placed at close intervals in order to monitor the erosion of slump blocks at various localities. The main purpose would be to relate weekly recession rates to seasonal and other weather-induced phenomena. Rainfall, freeze-thaw, humidity, wind and wave storm effects should be analyzed.

2. Experiments in bluff stabilization should be considered. Various methods for de-watering the bluff should be examined, along with methods for reforestation.

3. Multiple plans for diverting littoral drift sediments around the Great Lakes jetties should be considered, and a comprehensive plan should be made for structural protection of the shore.

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