MR 81-2

Coastal Changes, Eastern Lake Michigan, 1970-74

by

William A. Birkemeier

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Bluff recession and volumetric losses at 17 profile lines along the eastern shore of Lake Michigan were measured monthly from August 1970 to December 1974. Average rate of bluff recession for the period equaled 2.5 meters per year per profile line with an average loss of 4.2 meters per year on the most severely eroded line. Bluff recession tended to increase with lake level but the seasonal peak in recession coincided with the storm period
(continued)

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(September to April). Peak recession occurred before ice buildup (between November and December) and just after ice breakup (in the spring, March to April). Lake ice was found to be an effective shore protection agent during the stormiest months of January, February, and March. Till and mixed till bluffs tended to erode less than bluffs composed of sand, but no clear dependence on bluff composition was found.

An analysis of the content and median sand size of 519 sediment samples collected from both the foreshore and the backshore during the final 15 months of surveying shows that backshore sediments are generally finer and more uniform than foreshore sediments. High and low concentrations of gravel, usually found on the foreshore, were characteristic of specific profile lines. Deposits of heavy minerals, predominantly magnetite, were usually found on the backshore.

PREFACE

This report is published to improve the understanding of Great Lakes bluff recession and the factors controlling it. It is the final report of a 4-year study of 17 profile lines located along the eastern shore of Lake Michigan. The work was carried out under the coastal processes program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by William A. Birkemeier, Hydraulic Engineer, under the supervision of C. Galvin, former Chief, Coastal Processes Branch, and C. Mason, Chief, Field Research Facility Group.

The author acknowledges the assistance of many individuals in collecting, editing, and analyzing the data. The first 3 years of data (August 1970 to July 1973) was collected under contract by Dr. R.A. Davis and graduate students of Western Michigan University. The final period of data (October 1973 to December 1974) was collected by E. Tompkins and a surveying party from U.S. Army Engineer District, Detroit. Their efforts are commendable because of the difficulty involved in monthly surveying of the complex and steep terrain which borders Lake Michigan.

P. Pritchett and M. Czerniak (both formerly of CERC) assisted in the data editing and analysis. Reviews by Dr. D.L. Harris, C. Mason, and E.B. Hands of CERC; C. Johnson of the U.S. Army Engineer Division, North Central; the Engineering Division of the Detroit District; C. Kureth of the Traverse Group; and Dr. R.A. Davis of the University of Florida contributed greatly to improving the final report.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

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FIGURES

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angel)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: C = (5/9) (F -32).

To obtain Kelvin (K) readings, use formula: K = (5/9) (F -32) + 273.15.

COASTAL CHANGES, EASTERN LAKE MICHIGAN, 1970-74

by
William A. Birkemeier

I. INTRODUCTION

Dramatic erosional changes along the shorelines of the Great Lakes (Fig. 1), which occurred during a rise in lake level from a low in 1964 to a peak level in 1973, sparked renewed interest in understanding and predicting the processes involved. An investigation of these changes began, under contract with the U.S. Army Coastal Engineering Research Center (CERC), in August 1970 with a series of monthly surveys of the 17 profile lines shown in Figure 2. The investigation continued until December 1974.

Figure 1. Severe bluff erosion undermining lakefront home near Stevensville, Michigan (17 October 1976).

Two reports published by CERC describe the results of the program up to July 1973 (Davis, Fingleton, and Pritchett, 1975; Davis, 1976). Davis, Fingleton, and Pritchett (1975) discuss the period between August 1970 and July 1972 and include background and environmental data, the location of the profile lines, the conditions at each line, the details of the monitoring program, as well as document changes from 1970 to 1972. Davis (1976) discusses the results from August 1970 to July 1973 and includes further background and environmental data, an air photo analysis of shoreline changes at the 17 profile lines from 1938 to 1972, and an analysis of the offshore bar topography at each line.

This report discusses both the final period of study (October 1973 to December 1974) and the combined data collected during the entire study, with primary emphasis on measurements of bluff recession. Section II defines the important terms used in the report. Section III discusses the study area and

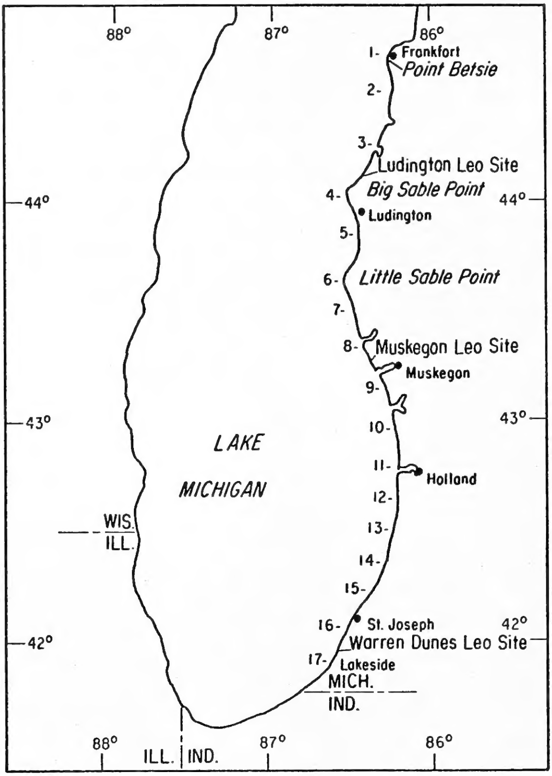


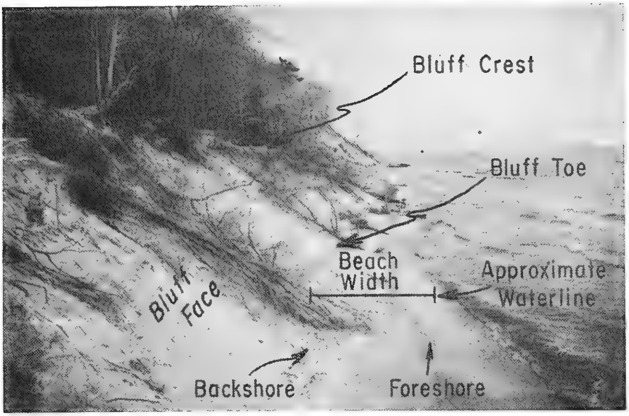
Figure 2. Index map showing profile locations.

the primary processes which affect beach changes; Section IV discusses previous research; Sections V and VI present an analysis of the beach profile and sediment data; and Section VII summarizes the results and presents recommendations for future research. Beach and bluff changes, which were computed for the final period of study only, are discussed in Appendix A. Representative ground photos plus documentation of each bench-mark location and a short discussion of each profile line are given in Appendix B.

II. DEFINITION OF TERMS

The analysis of the data includes discussions of the temporal and spatial changes to certain profile features including the bluff crest, bluff toe, shoreline, and waterline. These features, along with other important terms used are illustrated in Figure 3 and defined below.

(a) Bluff crest - line along the bluff which divides active eroding bluff from stable bluff. Generally well defined in eroding bluffs. It tends to move up the *bluff face*, the steep part of the bluff, during periods of erosion.



Profile line 8, May 1976

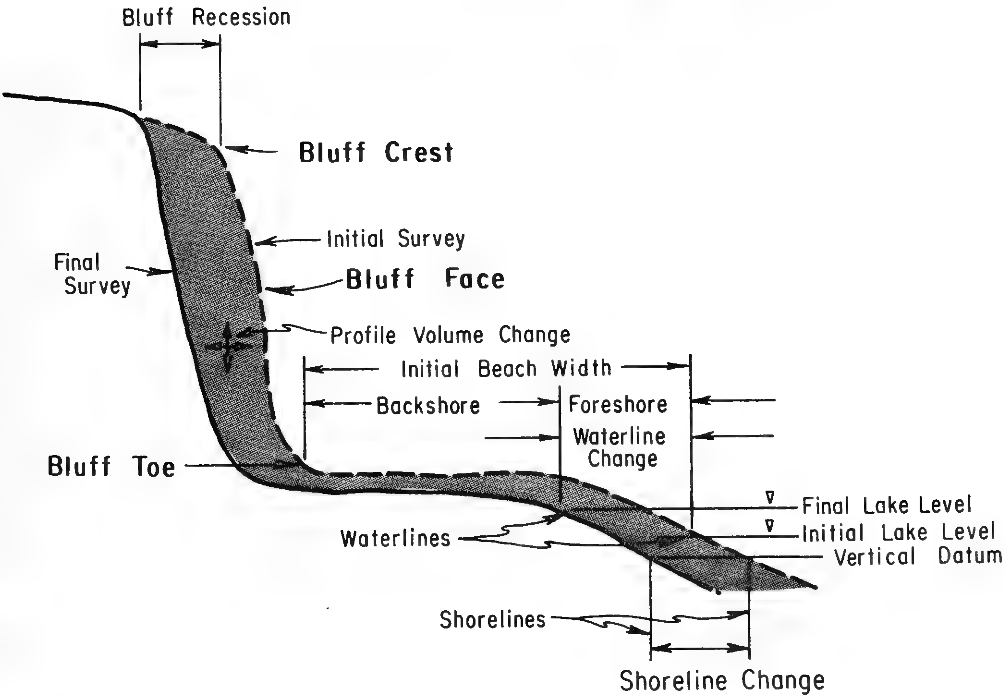


Figure 3. Definition sketch.

(b) Bluff recession - the amount of horizontal retreat of the bluff face (as used in this report; Davis, Fingleton, and Pritchett, 1975; and Davis, 1976). This generally coincides with the movement of the bluff crest. In keeping with the convention used in the two previous reports, the term *bluff recession* implies a negative (landward) movement of the bluff.

(c) Bluff toe - the point of intersection between the steep bluff and flatter beach.

(d) Waterline - the point of intersection between the lake and the beach at any given time. This feature changes with lake level. *Waterline change* refers to the movement of the feature between two surveys.

(e) Shoreline - the point of intersection of the profile line with a constant vertical datum such as low water datum (LWD). *Shoreline change* refers to movement of the shoreline.

Note.--Positive values of shoreline and waterline change indicate lakeward movement of the features; negative values, landward movement.

(f) Beach width - the distance between the waterline and the bluff toe during any one survey.

(g) Foreshore - steep active part of the beach adjacent to the lake.

(h) Backshore - flatter, less active section of the beach between the bluff toe and the foreshore. May be almost nonexistent on narrow beaches.

(i) Profile volume - the volume per unit length of shoreline of the profile cross section above the vertical datum and lakeward of some horizontal point. *Volume change* refers to the change in profile volume between two surveys based on common vertical and horizontal bounds.

(j) Erosion - the removal, by the action of natural forces, of material (negative volume) from the profile or from a section of the profile, e.g., bluff or beach. Similarly, *accretion* is an increase in volume (positive volume).

III. STUDY AREA

The 17 profile lines on the eastern Lake Michigan shoreline (Fig. 2) cover approximately 310 kilometers with an average spacing of 19 kilometers between lines. As indicated in Davis, Fingleton, and Pritchett (1975), profile sites were selected according to location, year-round accessibility, and their variety of coastal morphology and composition. Because of the glacial origins of the Lake Michigan basin, the geology is complex and highly variable along the shore. Consequently, each profile line has a unique combination of beach type, bluff composition, bluff height, wave climate, and shoreline orientation. General characteristics of each profile line are given in Table 1. Figure 4 shows the general shape of each profile line and the changes which occurred during the final study period.

Table 1. General profile line characteristics.

Profile line	Orientation	Bluff height[1] (m above LWD)	Bluff sediment	Beach width[2] (m)	Foreshore slope	Nearby shore protection structures[3]
1	N. 13° E.	3.4	Sand	14 to 37	0.09	Groins (N.)
2	N. 05° E.	7.1	Sand	3 to 13	0.10	None
3	N. 07° E.	6.8	Sand	7 to 9	0.12	Seawall (N.)
4	N. 07° E.	7.3	Sand	19 to 36	0.12	Seawall (N.)
5	N. 07° W.	4.9	Sand, till cap	7 to 13	0.13	Seawall (N., S.)
6	N. 07° E.	6.2	Sand	6 to 13	0.14	None
7	N. 18° W.	3.4	Sand, some till	5 to 13	0.13	None
8	N. 24° W.	9.2	Sand	2 to 14	0.15	Reveted Road (N.)
9	N. 25° W.	5.3	Sand	5 to 10	0.14	None
10	N. 11° W.	2.4	Sand and till	2 to 5	0.12	Seawall (N., S.)
11	N. 03° E.	4.0	Sand	5 to 17	0.13	None
12	N. 16° E.	6.1	Sand	11 to 17	0.13	None
13	N. 15° E.	14.5	Till	5 to 6	0.10	None
14	N. 25° E.	8.6	Sand	12 to 22	0.05	None
15	N. 34° E.	10.7	Till	2 to 4	0.11	Seawall (S.)
16	N. 28° E.	6.2	Sand	3 to 14	0.09	Seawall (N.)
17	N. 43° E.	11.4	Till	8 to 16	0.07	None

[1]Bluff heights changed during the study as the erosion reached higher elevations. Values given were measured in October 1973.

[2]Beach widths varied considerably--low values given occurred during a high lake level (August 1974), high values during a low level (November 1974).

[3]Letters in parentheses indicate direction (north or south) relative to the profile line.

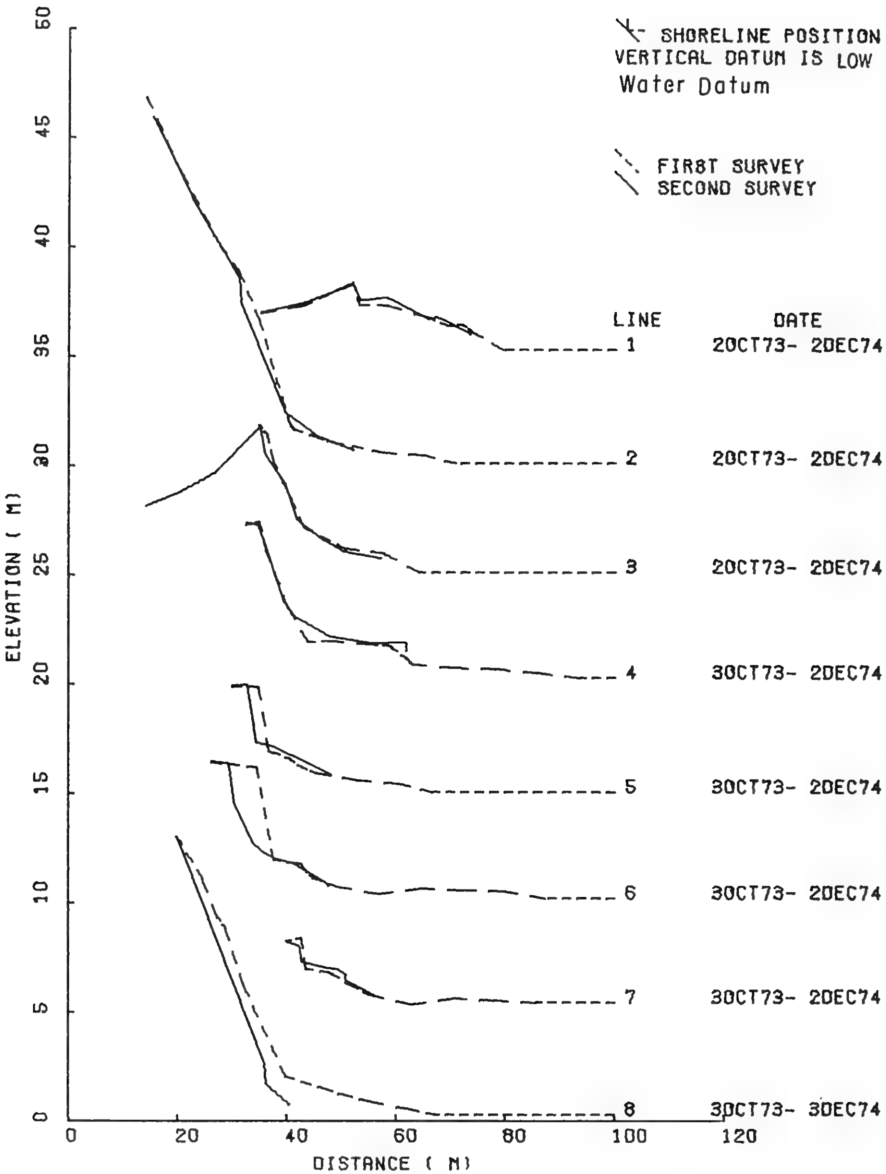


Figure 4. Comparison of profile lines along eastern Lake Michigan, October 1973 and December 1974.

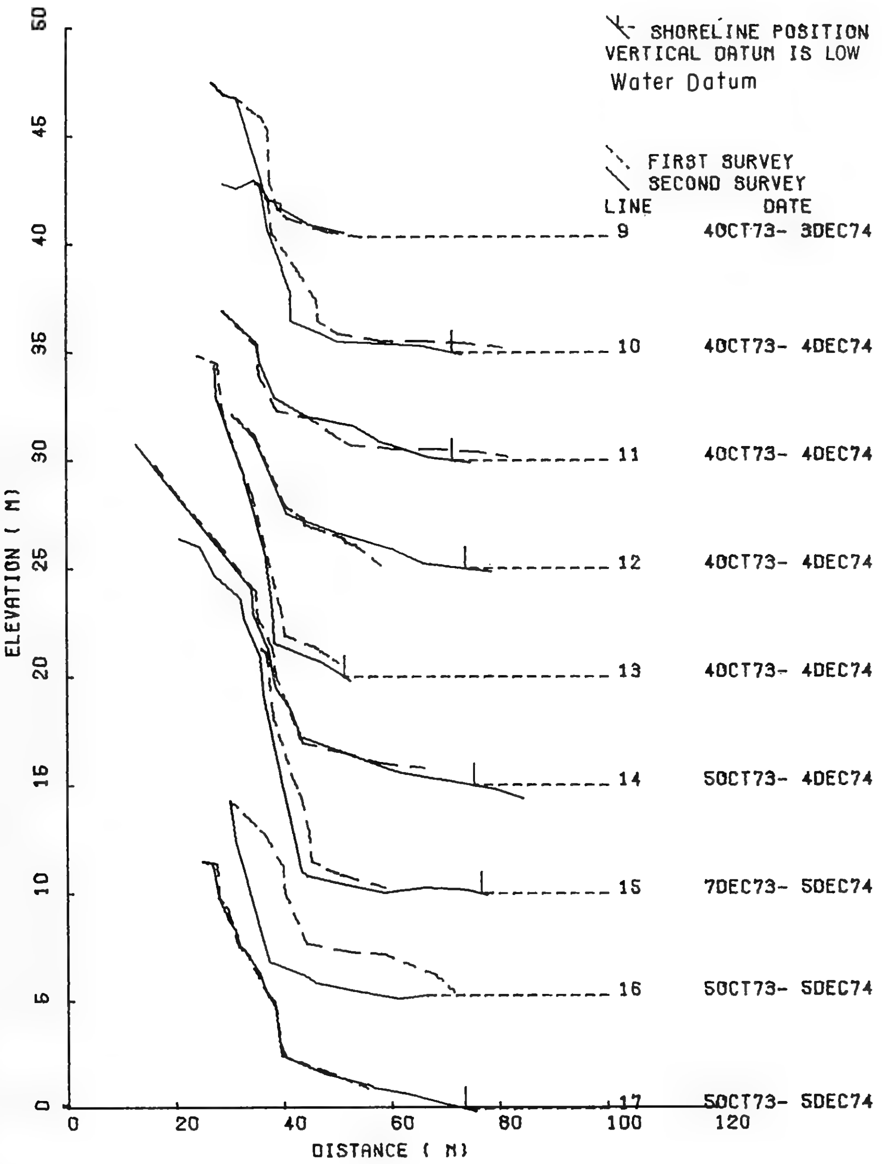


Figure 4. Comparison of profile lines along eastern Lake Michigan, October 1973 and December 1974.--Continued

Because of the large distances between lines and the uniqueness of each line, they cannot be used to measure changes in the alongshore direction. In fact, Birkemeier (1980) found significant variations in bluff recession at points just 30 meters apart. The profile lines do, however, document in detail the temporal changes which occurred at each line.

Important in describing erosion along the Great Lakes are the primary processes involved. These include variations in lake level, wave action, ice cover, and slope failure. The actual effect of each process or of combinations of the processes varies depending on the profile.

1. Lake Level.

The 1.43-meter increase in mean annual lake level from 1964 to 1973 was a primary reason for the initiation of this study. After peaking at 176.92 meters above the International Great Lakes Datum (IGLD) in 1973, the lake level stabilized in 1974. The variation in mean annual lake level from 1950 to 1974 is shown in Figure 5. Long-term fluctuations in water level correlate well with precipitation though there is some phase lag (Seibel, 1972). Because the long-term changes are not cyclic, they are difficult to predict. Cohn and Robinson (1976) attempted to predict lake levels through Fourier analysis of historic records between 1860 and 1970. They were able to determine prominent cycles of 1, 8, 11, 22, and 36 years. The model correctly predicted the rise in lake level between 1970 and 1975 and forecasted a general decrease in levels between 1975 and 1980.

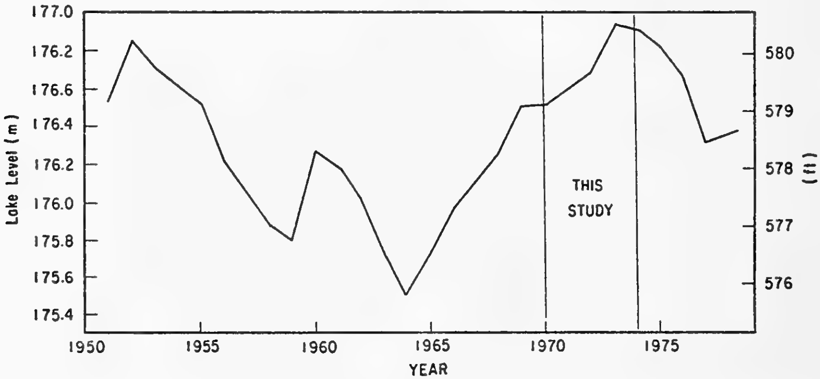


Figure 5. Annual average of Lake Michigan water level as recorded at Ludington, Michigan, from 1951 to 1978 (IGLD).

Seasonal fluctuations are more regular, varying about 0.34 meter from a winter low level to a peak level in the summer. Monthly lake level changes during the study, as well as the maximum and minimum daily levels recorded each month at Ludington, Michigan, are shown in Figure 6. Lake level variations cause an immediate movement of the waterline by either "drowning" or uncovering the beach which, depending on beach slope, can have an important effect on beach width. Moreover, higher lake levels permit wave action to reach higher elevations and to undercut the bluff.

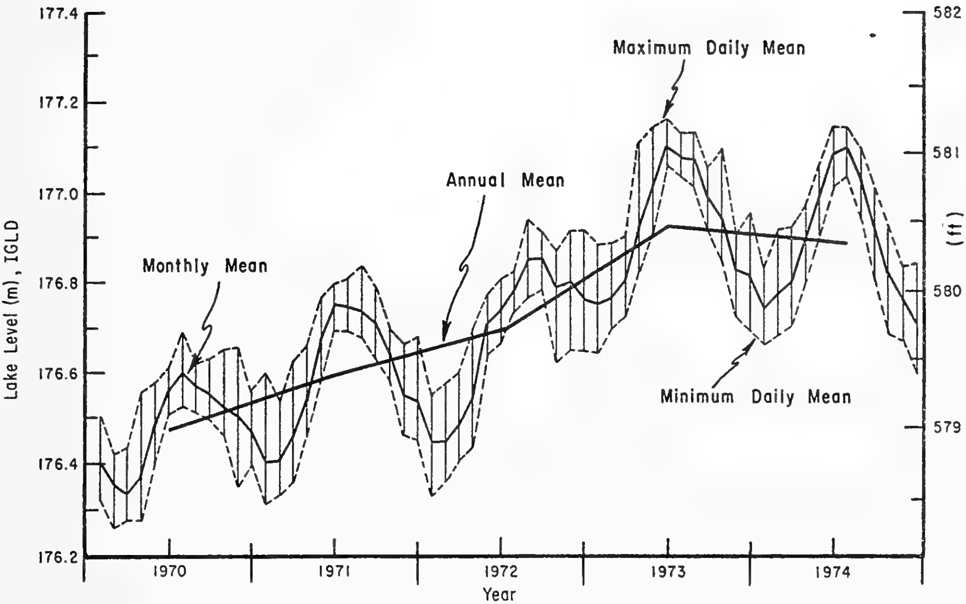


Figure 6. Monthly mean Lake Michigan water levels at Ludington, Michigan.

2. Lake Ice.

Lake ice, which builds up along the shore during the winter months (Fig. 7), provides valuable beach protection which offsets the effects of winter storms. The period and the amount of ice coverage vary both yearly and with location. Ice tends to develop in late December and persists into March.

A thorough analysis of the development, buildup, and eventual disappearance of shore ice during the 1973-74 winter was done by Seibel, Carlson, and Maresca (1975) in conjunction with the construction of the Donald C. Cook Nuclear Power Plant in Berrien County, Michigan. Davis (1973) also discussed lakeshore ice.

3. Storms.

Storms that affect the study area generally move through the Great Lakes from west to east. The combination of this path and counterclockwise circulation produces strong winds from the north and northwest usually following passage of the storm. Seibel (1972), Maresca (1975), Davis (1976), and others have investigated in detail the wind and wave climate of the study area and the characteristics of the storms which affect the eastern shore of Lake Michigan.

Seibel (1972) determined that the average annual number of low-pressure storm systems, regardless of magnitude, was about 43, although the number varied from a low of 31 storms to a high of 67 storms (from 1938 to 1970) with

Figure 7. Shore ice at profile line 11, 4 January 1974. Note the two lines of ice ridges.

most storms occurring between November and April. In determining bluff recession, the number of storms did not appear to be as important as the intensity of individual storms.

One of the most significant storms during the study period occurred on 17 and 18 March 1973. This storm caused some of the highest sustained winds of the study period with winds at Muskegon, Michigan, averaging 41 kilometers per hour from the northwest for 2 days. No severe storms were recorded during the final study period, October 1973 to December 1974 (Johnson and Hiipakka, 1976). This fact had a major effect on the beach changes as is discussed in Section V.

4. Waves.

Visual observations of waves along eastern Lake Michigan were reported in Bruno and Hiipakka (1973) and by Birkemeier (1980). Figure 8 shows the seasonal variations in breaking wave height and period for the three locations identified in Figure 2. The data represent daily visual observations (except for ice cover periods) between November 1971 and October 1975. Data were primarily collected by park rangers with varying consistency (a complete record consists of about 1,100 observations per station). Data collection was discontinued when lake ice developed and was not resumed until some time after ice breakup. Consequently, there were few observations in early spring, particularly during March. This is unfortunate since, as is shown in Section V, the amount of bluff recession peaks both before and after the period of ice cover.

The data show a consistent increase in wave height and period at each location, beginning in late spring or summer and peaking in November or December. A seasonal trend was also found in Resio and Vincent's (1976)

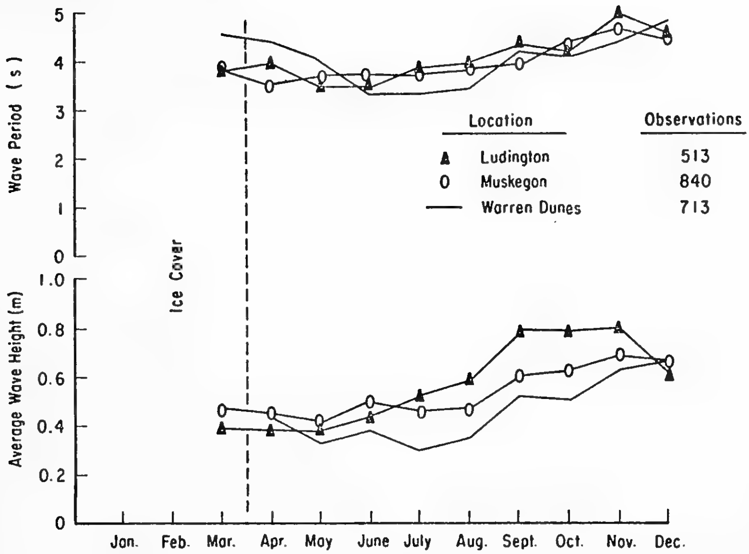


Figure 8. Variation in average monthly breaking wave statistics for three eastern Lake Michigan locations, November 1971 to October 1975.

hindcasted design wave data for the study area. They computed design wave heights and periods for waves from three directions, for each season, and for return periods of 5, 10, 20, 50, and 100 years. The highest calculated waves were found to occur during the winter season (January, February, and March). This indicates that the March data, shown in Figure 8, probably underestimate the actual wave heights. It also underscores the combined importance of storm occurrence and ice breakup on bluff recession.

5. Slope Failure.

Bluff erosion is a two-step process--erosion of the base of the bluff by wave action, followed by gravity failure of the bluff slope. This process results in new material being deposited at the base of the bluff continuing the cycle.

The basic mechanisms for slope failure are falls, rotational slumps, and soil flows (Chieruzzi and Baker, 1958). Falls occur when rocks or blocks of bluff material are undercut enough to drop on the beach. This type of action occurred at profile line 13. Rotational slumps are the result of shear failure along a "slip circle" (Edil and Vallejo, 1976), causing a major movement of the bluff face or some section of it. This type of failure was important at profile line 17 (see photo in App. B). Soil flow generally occurs when ground water saturates a clay bluff, increasing the specific weight and reducing the internal shear stress (Carter, 1976). This mechanism may also be important at profile line 17.

IV. PREVIOUS STUDIES

Powers' (1958) comprehensive study on Lake Michigan classified the entire shoreline according to geomorphology, based on bluff type, composition, and height. Powers also measured bluff recession around the lake. Of 134 measurement stations, 124 eroded an average of 0.45 meter per year; 4 had no change; and the remaining 6 accreted an average of 0.48 meter per year. Forty-four of the measurement points are located within the area covered by the 17 profile lines. Two locations experienced a net accretion while the remaining 42 eroded. The average change for all 44 locations was -0.38 meter per year. Periods of coverage varied from 20 to 127 years with some data as early as 1830. Powers recognized lake level fluctuations, severe storms, and manmade structures as being the primary factors affecting the recession date. However, he noted that his measurements were insufficient to quantify the relationship between lake level and bluff recession. Powers' report also included a summary of studies conducted as early as 1864.

Seven of Powers' eastern Lake Michigan sites were resurveyed in 1973 by Buckler and Winters (1975). Of the seven sites, three had stabilized since 1956, while two were retreating at similar rates and two at higher rates. They found no pattern between retreat rates and bluff composition and hypothesized that other factors were more important.

Seibel (1972) used aerial photos to examine bluff recession since 1938 at four Lake Michigan and two Lake Huron locations. He also examined the relationship between lake level and precipitation and between lake level, storm frequency, and bluff recession. He determined linear relationships between average lake level and bluff recession for each of the six sites. One of the significant conclusions reached by Seibel was the importance of infrequent severe storms in controlling the rate and amount of bluff recession.

Because lakeshore property values and insurance costs may be linked to the recession rate in an area, there is considerable interest in predicting future bluff lines for at least the mortgage life (typically 30 years) of a structure. Jannereth (1974) described the State of Michigan's effort to do this using 1938 and 1974 aerial photos. The results, published by the Michigan Department of Natural Resources (1975), are a series of maps of the Lake Michigan shoreline identifying high-risk erosion areas. A minimum setback line equal to 30 times the annual recession rate was computed for each area. A recommended setback line was also determined by adding 9 meters to the minimum setback value. The highest recession rate (1.9 meters per year) was measured just south of South Haven, Michigan (between lines 13 and 14 in Fig. 2).

Tanner (1975) analyzed air photos of bluff recession in Berrien County near the Donald C. Cook Nuclear Power Plant. He proposed an exponential relationship between bluff retreat and lake level, wave characteristics, and other unspecified parameters. The existence and movement of a series of southward-moving "beach pads" (or rhythmic undulations in the shoreline) was described. The distance between pads averaged 45 meters, and the pads moved 51 meters during the ice-free season. Tanner postulated that the pads serve as a mechanism for offshore sand transport with material being directed diagonally offshore along the edge of the pads.

Fox and Davis (1970a) and Davis and Fox (1971) reported on a 30-day period of monitoring environmental processes and shore response on Lake Michigan near profile line 16. During this period a major storm with maximum breaker heights of 1.8 meters caused significant beach changes (Fox and Davis, 1970b). Fox and Davis (1971) and Davis and Fox (1971, 1972) reported on a similar study at profile line 11 near Holland, Michigan. Results from these two studies were used to develop a computer simulation model of coastal processes (Fox and Davis, 1972, 1973).

Maresca (1975) studied both long- and short-term changes to a shoreline reach south of the present study area. He determined long-term recession rates using aerial photos from 1950, 1955, 1960, 1967, and 1973. Short-term changes were determined by monitoring eight storms between August and December 1973. The data collected included beach and bluff profiles surveyed at 15-meter intervals along the shore. Maresca documented the importance of storms and found considerable variations in recession rate between closely spaced profile lines.

Armstrong, et al. (1975), under contract to the U.S. Army Engineer Division, North Central, prepared an extensive assessment of erosion and flooding damage which occurred during the 1972-74 high water period. The initial study included only Muskegon and Manistee counties, but the study was later expanded to include all Michigan counties.

Berg and Collinson (1976) presented a thorough analysis of bluff recession including volumetric losses for the Lake Michigan shore of Illinois. They determined that a lake level in excess of 176.5 meters IGLD is needed for significant bluff recession. In addition, bluff recession lags behind an increase in lake level because of the protection offered by well-developed beaches and vegetation. Similarly, as lake levels fall, recession continues until the bluffs are revegetated.

A number of studies have also been done on the offshore bar system, an important feature of the lakeshore bathymetry. Davis and McGeary (1965) discussed the nearshore bar system near Stevensville, Michigan, identifying the first two bars and their composition. During a 3-month summer period (June to August 1963) they found bar features relatively stable. The first bar was located at a 1.1-meter depth about 99 meters from shore; the second bar at a 2.4-meter depth was 229 meters from the shoreline.

Saylor and Hands (1970) and Hands (1976) discussed the influence of increasing lake levels on the shoreward movement of the bar system. Hands (1979) presented a linear relationship between increases in water level and mean shore retreat. The relationship is based on observations of shore movement during periods of 2 to 8 years when the lake level rose rapidly then began to decline. Although based on measurements taken along a 50-kilometer stretch of shore in three counties (Mason, Oceana, and Muskegon), the relationship is proposed as an empirical guide for estimating the mean shore retreat which might be expected to occur simultaneously with, and as a result of, water level changes at locations with similar geomorphic and environmental conditions. Hands (1980) presents a more comprehensive model for estimating the ultimate shore retreat necessary to eventually reestablish an equilibrium sand profile, based on conservation of sediment volumes. The approach permits explicit accounting for local sediment characteristics, wave exposure, and geomorphology.

Variations in sediment characteristics along the study area were studied by Hulsey (1962). He collected beach sediments at three locations across the beach at 6-kilometer intervals along 360 kilometers of the eastern Lake Michigan shoreline. Samples were collected in 1960 and 1961 during a minor peak in lake level preceding the 1964 low level (see Fig. 2). Beach and nearshore sediments south of Muskegon were studied by Cote (1967).

Gray and Wilkinson (1979), using bluff recession data from Seibel (1972), examined the effect of nearshore lithology on the rate of bluff recession. They found that alongshore variations in bluff recession rates correlated with alongshore variations in bathymetry and morphology of the nearshore zone. In an area of low long-term recession rates they found an offshore profile devoid of the common two or more longshore bars typical of high erosion areas. Moreover, the surface was composed of coarse sand and large boulders. Gray and Wilkinson also found that lateral variations in the nearshore morphology correlated well with lateral changes in the lithology of the bluff material.

V. PROFILE LINE CHANGES

1. Description of the Data.

Each of the 17 profile lines (Fig. 2) was surveyed at roughly 4-week intervals for a total of 56 surveys. (In October 1973 an additional profile line (15A) was established 67 meters north of profile line 15 because of an adjacent seawall. No surveys were made of profile line 15 between October and December 1973. Both lines 15 and 15A were surveyed until December 1974. Only the original profile line 15 is discussed in this report.) The actual surveying dates are listed in Table 2. The data between August 1970 and September 1973 were collected, using the Emery surveying method (Davis, Fingleton, and Pritchett, 1975; Davis, 1976), and vertically referenced to the lake level during the first survey (176.6 meters, IGLD).

Table 2. Survey dates.

	Date											
Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1970								3–5 28–29	26–27	24–25	21–22	18–20
1971	15–17	12–13	12–14	9–11	9–11	2–4 30–2		2–3 26–28	24–26	22–24	19–20	20–21
1972	15–17	12–13	10–12	7–8	6–7	4–6 30–1	29–30	25–26	29–30	20–21	18–19	28–29
1973	13–14	10–11	9–11	7 14	7–8	7–8	6–7		8–9	2–5	5–7	5–7
1974	2–5 28–31	25–27	21–26	22–24	20–22	17–20	15–17	12–15	9–11	9–11	4–6	2–5

The Emery method is a fast and inexpensive surveying method. Two people use two graduated 5-foot poles and the horizon to measure the distance and the change in elevation between adjacent survey points. Because the accuracy of each survey point in this method depends on the accuracy of the previous point, the accuracy tends to decrease with distance, and large elevation errors are possible (Czerniak, 1973). Each survey began near the bluff crest, so errors should be greater for points on the beach than for those on the bluff line.

Surveying after September 1973 was done by transit and tape. Elevations were recorded to the nearest tenth of a foot, and distances were measured to the nearest foot. Because of the height of the bluffs on profile lines 2, 13, and 14, stadia readings were used to determine both distance and elevation. Vertical datum was changed from that used by Davis (1976) to low water datum (LWD) equal to 175.81 meters IGLD. Each profile line was surveyed from the bench mark, or from a point landward of the bench mark, to wading depth or to the edge of the ice cover.

Because of the severe erosion at some of the profile lines during the study, bench marks were occasionally lost and had to be reset. Usually, this required simply placing an auxiliary bench mark landward of the original one before the loss actually occurred. However, in some instances, the original monument was lost before the auxiliary monument was installed. When this occurred, both horizontal and vertical control had to be reestablished.

Vertical control was established from the lake level the day the auxiliary bench mark was placed. Once the lake level was determined from a nearby gage, the data were corrected to the same datum as the original bench mark. Horizontal control was more difficult to establish. This was accomplished by estimating the distance between the location of the original monument and the auxiliary one.

The accuracy of this procedure was questionable, particularly during the Davis surveys when monuments were placed on the bluff face and the Emery method was used to reestablish control. The problem was most acute between the end of the Davis surveys in July 1973 and the beginning of the U.S. Army Engineer District, Detroit, surveys in October 1973. Although original bench marks were used where possible, the vertical datum was changed and new vertical control was established. Similar problems also existed at some profile lines between the two periods of the Davis surveys (August 1970 to July 1972 and August 1972 to July 1973).

The importance of this surveying problem is that, because of the inaccuracies and the lack of a stable bench mark at some profile lines, there is not a reliable continuous record of profile line changes. Also, the data, which are available at CERÇ, had to be stored in three separate files, one for each study period. Consequently, changes to some of the profile features, such as the shoreline, cannot be examined over the entire study period. Only monthly amounts of bluff recession, which are less sensitive to vertical control errors, are examined in detail over the entire period (August 1970 to December 1974). Annual volume changes are also discussed. Monthly volume and shoreline changes, which can only be examined for October 1973 to December 1974, are discussed in Appendix A.

2. Bluff Recession and Volume Change Measurements.

Monthly amounts of bluff recession for each profile line are tabulated (in feet) and summarized in Table 3. Measurements from August 1970 to July 1973 are from Davis (1976). English units have been used because the data were originally collected to an accuracy of the nearest foot. Figure 9 is a histogram of the data in Table 3.

Table 3. Monthly bluff recession (in feet), eastern Lake Michigan, August 1970 to December 1974.

Profile line	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
	1970								Start		2	1	4	7
	1971										1	6	4	11
1	1972				1						1			2
	1973	1			6	5								12
	1974													0
	Total	1			7	5					4	7	8	32
	1970								Start					0
	1971													0
2	1972											5		5
	1973				4								2	6
	1974	1				3	4		1					9
	Total	1			4	3	4		1			5	2	20
	1970								Start					0
	1971	4										1	4	9
3	1972	1					1	1		3	1	2	2	11
	1973	8			4	9	1			2		1	2	27
	1974					1	2	1						4
	Total	13			4	10	4	2		5	1	4	8	51
	1970								Start					0
	1971				2					7	3	2		14
4	1972				2	8	20		7	5			5	47
	1973				1									1
	1974										2			2
	Total				5	8	20		7	12	5	2	5	64
	1970								Start			7	11	18
	1971					1								1
5	1972							1					4	5
	1973				6									6
	1974			5		1			2					8
	Total			5	6	2		1	2			7	15	38
	1970								Start					0
	1971													0
6	1972									12			2	14
	1973	2			5	10					7		7	31
	1974			1		1		2		3	3			10
	Total	2		1	5	11		2		15	10		9	55
	1970								Start	8			8	16
	1971	10					4					1	5	20
7	1972						1	1		1				3
	1973	5				1		2						8
	1974							1	1					2
	Total	15				1	5	4	1	9		1	13	49
	1970								Start					0
	1971	1					1						1	3
8	1972				1						1		5	7
	1973				2	3								5
	1974			6		2		3				1		12
	Total	1		6	3	5	1	3			1	1	6	27
	1970								Start					0
	1971					3	3						3	9
9	1972												6	6
	1973	5				8		2				11		26
	1974					1		1			3	2	1	8
	Total	5				12	3	3			3	13	10	49

Table 3. Monthly bluff recession (in feet), eastern Lake Michigan, August 1970 to December 1974.--Continued

Profile line	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
10	1970								Start	3	4	14	2	23
	1971									2	2	2	1	7
	1972	1												1
	1973											1		1
	1974	6			1		2	3					1	13
	Total	7			1		2	3		5	6	17	4	45
11	1970								Start					0
	1971												2	2
	1972	2							2			9		13
	1973				3									3
	1974													0
	Total	2			3				2			9	2	18
12	1970								Start		2		1	3
	1971												8	8
	1972	7									8			15
	1973				7									7
	1974													0
	Total	7			7						10		9	33
13	1970								Start					0
	1971												2	2
	1972													0
	1973													0
	1974			1										1
	Total			1									2	3
14	1970								Start					0
	1971													0
	1972											5		5
	1973	2			14	7								23
	1974	1			1				1					3
	Total	3			15	7			1			5		31
15	1970								Start					0
	1971													0
	1972				1		1	1						3
	1973				4									4
	1974					4								4
	Total				5	4	1	1						11
16	1970								Start				4	4
	1971					1		1						2
	1972													0
	1973													0
	1974	10	1	1	4	3		4		3	5		1	32
	Total	10	1	1	4	4		5		3	5		5	38
17	1970								Start			2	1	3
	1971												8	8
	1972							2	1	1	10	10		24
	1973													0
	1974			2	1									3
	Total			2	1			2	1	1	10	12	9	38
Total by year	1970								Start	11	8	24	31	74
	1971	15	0	0	2	5	8	1	0	9	6	12	38	96
	1972	11	0	0	5	8	23	6	10	22	21	31	24	161
	1973	23	0	0	56	43	1	4	0	2	7	13	11	160
	1974	18	1	16	7	16	8	15	5	6	13	3	3	111
Total		67	1	16	70	72	40	26	15	50	55	83	107	602
Mean		3.9	0.6	0.9	4.1	4.2	2.4	1.5	0.9	2.9	3.2	4.9	6.3	35.4

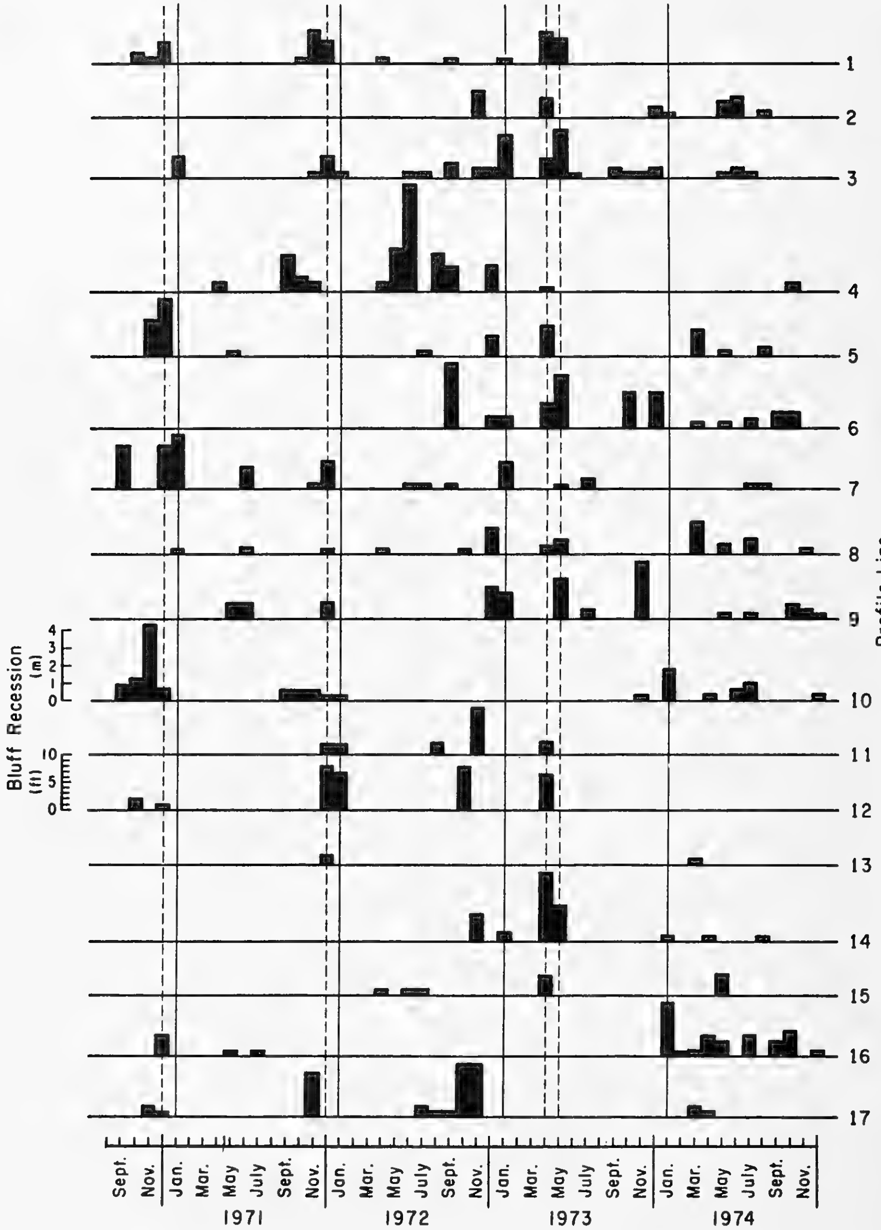


Figure 9. Bluff recession by profile line and survey. Solid vertical lines separate calendar years; dashlines identify months of peak recession for all lines.

During the 52-month study period, the average recession per profile was 10.8 meters for an average recession rate of 2.5 meters per year. The total amount of recession varied considerably between profile lines, as shown in Figure 10. The median amount of recession, 10.1 meters, was slightly less than the mean. Profile line 4, which has a 7-meter-high sand bluff, retreated the most, losing 19.5 meters with most of the loss occurring in 1972. In contrast, the till bluff at profile line 13 lost only 0.9 meter.

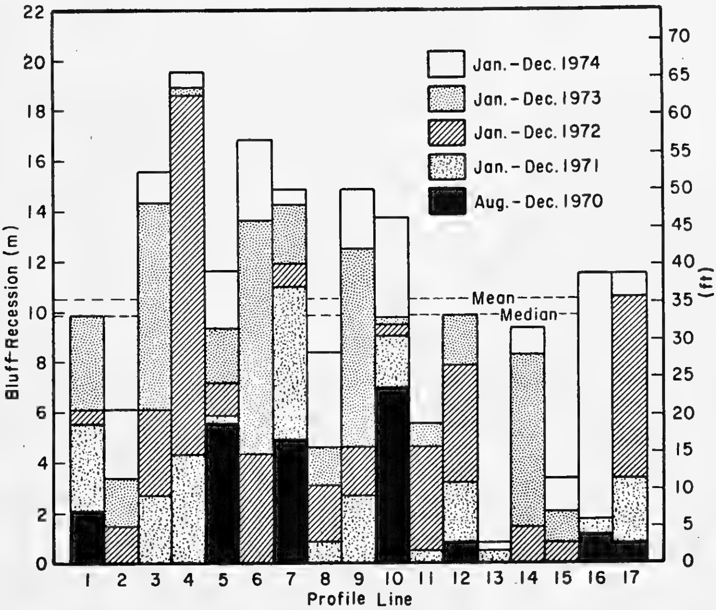


Figure 10. Cumulative amount of bluff recession for each profile line.

It is apparent in Figure 9 that bluff recession occurs in varying quantities over discrete periods of time (shorter in fact than the 1-month period between surveys); however, the data reveal no distinct patterns. Though there was erosion at every profile line during the study, there were no survey periods when every profile eroded. In fact, the greatest number of eroding profiles during any month was 11, between March and April 1973. This coincided with the 17-18 March 1973 storm discussed in Section III. There were, however, two ice-free periods (August 1971 and August 1973) when none of the profile lines eroded, even though lake levels were at or near seasonal peaks.

As mentioned previously, annual bluff and beach volume changes for the first 3 years of study were computed by Davis (1976), relative to the lake level during his first survey (176.6 meters, IGLD). These data are given in Table 4 along with similarly computed data for the year from October 1973 to September 1974 and for the 3-month period from October to December 1974. Total changes are plotted in Figure 11. Average total volume change was −35.0 cubic meters per meter of shoreline. Because of the different bluff heights

Table 4. Annual bluff and beach volume changes (in cubic meters per meter).[1]

Profile line	Aug. 1970 to July 1971	July 1971 to July 1972	July 1972 to July 1973	Oct. 1973 to Sept. 1974	Sept. to Dec. 1974	Total
1	-2.5	-12.5	-20.1	1.3	0.8	-33.0
2	2.5	-2.5	-5.0	-1.4	-6.7	-13.1
3	-10.0	-10.0	-15.1	-4.8	-2.3	-42.2
4	-15.1	-37.6	-45.2	5.6	0.6	-91.7
5	-15.1	2.5	-2.5	-4.2	1.4	-17.9
6	7.5	-5.0	-10.0	-21.0	2.1	-26.4
7	-15.1	0	-2.5	-7.5	8.7	-16.4
8	0	-2.5	-2.5	-31.8	-0.3	-37.1
9	-7.5	-5.0	-17.6	-9.0	0	-39.1
10	-5.0	-7.5	0	-19.8	4.2	-28.1
11	-2.5	-5.0	-10.0	1.2	8.5	-7.8
12	-12.5	-2.5	-17.6	-6.8	8.5	-30.9
13	0	5.0	-5.0	-12.8	-1.1	-13.9
14	2.5	-7.5	-20.1	-4.9	-1.1	-31.1
15	0	-12.5	-10.0	-10.2[2]	-14.2	-46.9
16	-5.0	2.5	-5.0	-63.8	-15.7	-87.0
17	-2.5	-12.5	-17.6	-2.6	2.0	-33.2
Mean	-4.7	-6.6	-12.1	-11.3	-0.3	-35.0
Standard deviation	6.9	9.6	10.9	16.4	6.8	23.2
Median	-2.5	-5.0	-10.0	-6.8	0.6	-31.1

[1]Vertical datum is 176.6 meters IGLD, as used by Davis (1976).

[2]Actual period: December 1973 to September 1974.

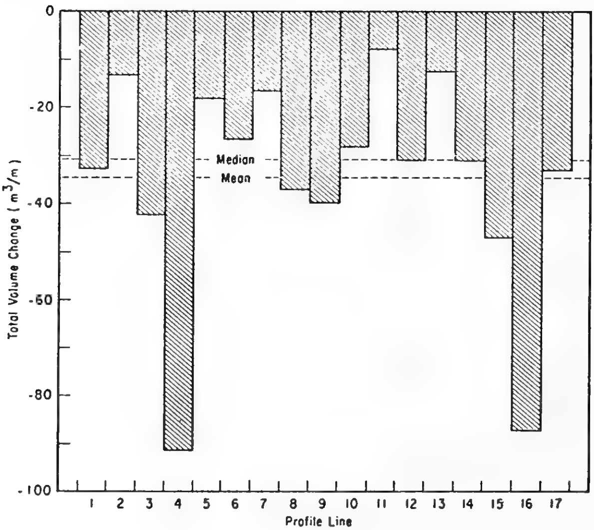


Figure 11. Total volume change for each profile line, August 1970 to December 1974. Vertical datum is 176.6 meters IGLD, as used by Davis (1976).

and beach widths between profile lines, there are some interesting differences between Figures 10 and 11. For example, profile line 16, which was only seventh highest in bluff recession, was second in volume eroded.

Profile lines 4 and 16, which lost the greatest volumes, are both located within the influence of a shore protection structure. Davis, Fingleton, and Pritchett (1975) attributed the high amount of bluff recession in 1972 at profile line 4 to a nearby seawall. The dramatic increase in bluff recession and volume loss in 1974 at profile line 16 was attributed to a 579-meter-long seawall completed during the study (Birkemeier, 1980). Because these two profile lines were locally affected, they were separated from the remaining profile lines and are discussed in Section V, 4.

3. <u>Lake Levels and Storms</u>.

Birkemeier (1980) found that the average rate of bluff recession from November 1970 to November 1974 correlated well with the occurrence of storms and correlated inversely with the seasonal variation in lake level. The study area was a 1.6-kilometer reach of beach located north of profile line 16. This finding is supported by the present study which includes more frequent measurements over a larger area during approximately the same time period. This same relationship is shown in Figure 12, which graphs the combined total bluff recession by year and month for 15 profile lines, excluding lines 4 and 16. Note that peak bluff recession occurs just before and after ice breakup. Minimum recession occurs during the ice cover period and during the summer months.

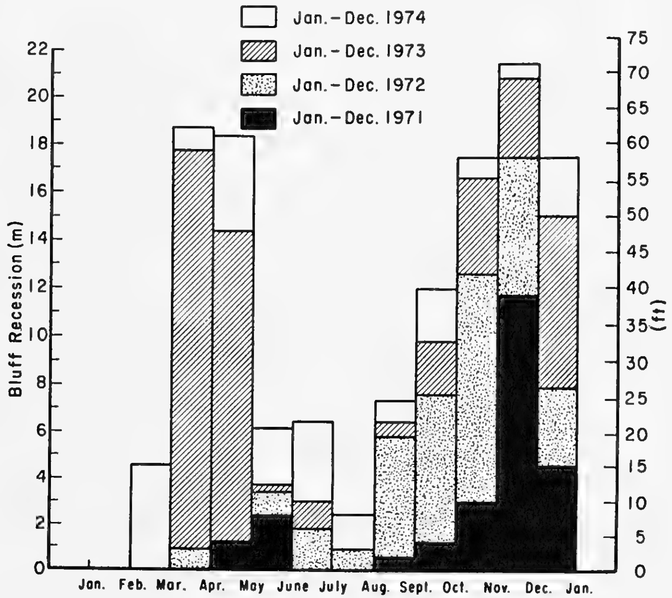


Figure 12. Cumulative bluff recession for 15 profile lines (excluding 4 and 16), by month and year.

The importance of individual storms can be seen in Figure 13, which illustrates with respect to time the variation in (a) total bluff recession (for the 15 profile lines), (b) average and annual lake level, and (c) storminess. *Storminess* is defined as the sum of the average daily windspeed between two surveys when the wind was onshore (wind direction $\leq 10°$ or $\geq 170°$) and greater than 29 kilometers per hour (recorded at Muskegon, Michigan). This definition, though arbitrary, is based on the assumption that most bluff recession occurs during stormy periods with high onshore winds. Note that storminess appears somewhat insensitive to major storms such as the March 1973 storm.

Figure 13 shows that peak amounts of bluff recession occur during periods of seasonal minimum lake levels and maximum storminess. For the 40 ice-free surveying periods (as shown in Table 3, April to January), the correlation coefficient resulting from a simple linear regression between storminess and bluff recession was 0.50 (significant at the 1-percent level). Although the study period was too short to adequately evaluate the effects of long-term lake level changes, the greatest shift in average lake level occurred between 1972 and 1973, which corresponded to the period of greatest bluff recession. The storminess of this period was, however, not significantly different from other storm periods.

4. The Effect of Structures.

As mentioned previously, the anomalously high recession measured at profile lines 4 and 16 appeared to result from the effect of local shore protection structures. Six of the remaining 15 profile lines are also located near structures though the effects were less apparent.

Davis, Fingleton, and Pritchett (1975) attributed their 1972 measurements of high recession (and volume loss) at profile line 4 to the sheet-pile seawall located less than 200 meters to the north; however, this erosion unexplicably stopped in 1973 and the area remained stable through the end of the study (see Fig. 9).

Somewhat more interesting and better documented is the situation which occurred at profile line 16. Until December 1973, this profile line had been one of the most stable, receding only 2 meters since August 1970. Then in 1974, the line lost 9.8 meters of bluff, an amount equal to 28 percent of the total recession recorded for all 17 profile lines during 1974.

Birkemeier (1980) attributed this dramatic increase in recession to the 579-meter seawall constructed 275 meters updrift (north) of profile line 16. After the seawall was completed in November 1971, the rate of erosion increased at the downdrift (south) end of the seawall, eventually forming a crescentic-shaped cut. This cut lengthened, reaching profile line 16, in late 1973. The bluff receded during 8 of the last 12 months of study.

The erosion at profile line 16 has continued. A field trip to the area in October 1976 found two large precast concrete seawalls placed at the base of the bluff across the profile line and a number of sandbag groins placed along the shore farther to the south. Both are evidence of further erosion.

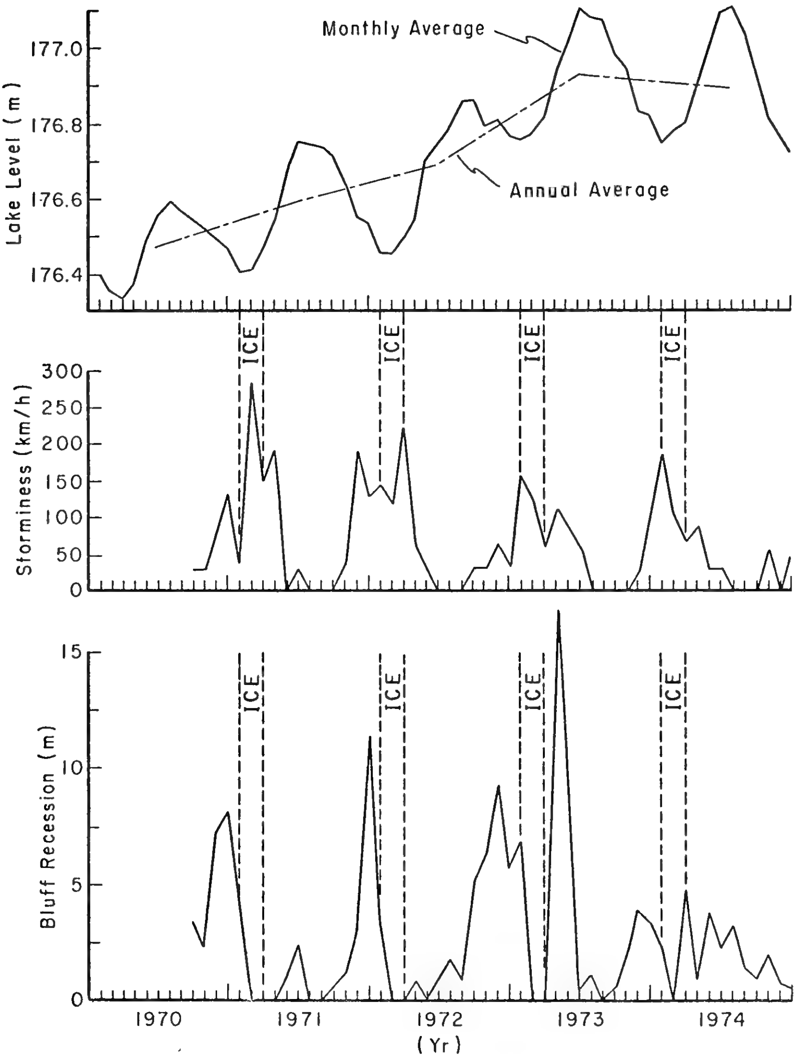


Figure 13. Variation in lake level, storminess, and total bluff recession, with respect to time, for 15 profile lines.

Profile line 8 also experienced relative stability during the early years and considerable recession during 1974 (see Fig. 9). A possible cause was the concrete "road debris" revetment placed just north of the profile line where the road bends very close to the lake. The recession at profile line 8 continued after December 1974, with an additional loss of 4 meters recorded in May 1976 during a field trip to the area.

5. Bluff Composition.

If the average volume changes given in Table 4 are recomputed without profile lines 4 and 16, they provide some insight into the effect of bluff composition. The average volume lost by the 15 profile lines was 27.8 cubic meters per meter, which is almost equal to the median amount of 28.1 cubic meters per meter.

Of the three profile lines with till bluffs (13, 15, and 17), only profile line 13 eroded less than the mean volume, while profile line 15 eroded the most of all 15 profile lines. The three profile lines with mixed sand and till (5, 7, and 10) all eroded an amount nearly equal to or less than the mean.

Although on the average, till or mixed sand and till bluffs appear to erode less than pure sand ones, the data are inconclusive. Profile line 11, which has a low sand bluff, eroded the least of all profile lines, followed closely by the sand bluff at profile line 2. Any clear difference between the erodibility of sand and till bluffs is probably obscured in other factors; e.g., differences in ground waterflow, vegetation, offshore bathymetry, and wave climate between profile lines.

VI. BEACH SEDIMENTS

During the last 15 months of surveys (October 1973 to December 1974), except when ice prevented it, surface sediment samples were collected from the beach face (foreshore) and from the base of the dune or bluff (backshore) at each profile line. Because the beach sediments are glacial derived, they include a wide range of sediment sizes from fine silt to coarse pebbles. This variation in sediment size is obvious in the photo of the beach at profile line 2 (Fig. 14).

In order to better understand the nature of the sediments, an attempt was made to collect representative surface samples. This differed from Davis, Fingleton, and Pritchett (1975) and Davis (1976) who collected and reported only on sand-size sediments. A total of 246 foreshore and 273 backshore samples were collected. The laboratory analysis consisted of (a) wet sieving the silt (less than 0.062 millimeter) from samples with significant silt content, (b) dry sieving the remaining sample into sand (between 2.0 and 0.062 millimeter) and gravel (greater than 2.0 millimeters) fractions, (c) computing the dry weight of each size fraction, and (d) using a visual accumulation tube to obtain the size distribution of the sand. In addition, a visual estimate was made of the percentage of heavy minerals in the sand fraction. The sand-size distribution was plotted to graphically determine the "median sand size." *Median sand size* is defined as the size (in millimeters) that divides the sand fraction so that half, by weight, is coarser than the median size and half is finer.

Figure 14. The beach at profile line 2, showing the wide range of sediments (May 1973). Note bands of pebbles on the foreshore and heavy minerals along the backshore.

Because of the varied nature of the sediments and the difficulty in collecting truly representative samples, the data were interpreted by simple averaging of the sediment data by month and by profile. To eliminate any seasonal bias in the results, annual averages were computed for each profile line by first computing an average for all the samples from the same month (e.g., October 1973 and October 1974) and then by averaging the 12 monthly averages. Table 5 summarizes the sediment statistics for each profile line.

An examination of the median sand size revealed that the foreshore was coarser than the backshore in 92 percent of the available foreshore-backshore sample pairs. This is obvious in Figure 15, which is a histogram of the median sand sizes given in Table 5. The median size of the backshore samples varied more smoothly alongshore than did the foreshore samples. The average median sand size for the foreshore was 0.42 millimeter though it varied from 0.30 millimeter at profile line 9 to 0.68 millimeter at profile line 13. The median for individual samples varied even more, from 0.15 to 1.05 millimeters. The average range in median foreshore sand size between profile lines was 0.30 millimeter.

Backshore samples were more uniform and finer. Average median sand size was 0.29 millimeter (0.13 millimeter less than the foreshore), varying only from 0.24 millimeter at profile line 13 to 0.36 millimeter at profile line 1. The range in average median size of backshore samples (0.11 millimeter) was less than the range for the foreshore samples.

Though it seldom actually occurred, an idea of the typical composition of foreshore and backshore sediments is given in the line of average values at the bottom of Table 5. A composite foreshore sample consists of about 24 percent gravel, 76 percent sand, and less than 1 percent silt. The backshore contains only 2 percent gravel, 84 percent sand, and 14 percent silt. Actual samples similar to these are shown in Figure 16.

Table 5. Sediment statistics summary, eastern Lake Michigan (October 1973 to December 1974).[1]

Profile line	Foreshore					Backshore				
	Sand size (mm)		Composition (pct by weight)			Sand size (mm)		Composition (pct by weight)		
	Median	Std. dev.[2]	Gravel	Sand	Silt	Median	Std. dev.[2]	Gravel	Sand	Silt
1	0.52	0.07	64.9	35.0	<0.1	0.36	0.02	2.3	97.6	<0.1
2	0.41	0.08	32.1	67.9	<0.1	0.32	0.02	0.6	99.3	<0.1
3	0.46	0.09	58.8	41.1	<0.1	0.35	0.03	2.3	97.5	0.2
4	0.33	0.04	0.6	99.4	0.0	0.28	0.01	0.0	100.0	<0.1
5	0.41	0.05	42.1	57.8	0.1	0.31	0.04	9.2	90.1	0.7
6	0.31	0.03	4.0	96.0	<0.1	0.26	0.02	0.0	100.0	0.0
7	0.35	0.05	3.6	96.3	0.1	0.27	0.05	3.2	86.3	10.5
8	0.42	0.14	9.1	90.9	<0.1	0.32	0.04	0.0	99.9	0.1
9	0.30	0.04	0.1	99.9	<0.1	0.26	0.01	0.0	99.9	0.1
10	0.37	0.06	15.8	79.0	5.2	0.25	0.04	2.4	43.1	54.5
11	0.43	0.04	4.2	95.8	<0.1	0.30	0.02	0.1	99.6	0.3
12	0.60	0.20	38.2	61.8	<0.1	0.28	0.02	0.0	99.9	<0.1
13	0.68	0.10	62.4	37.5	0.1	0.24	0.03	6.6	36.3	57.1
14	0.34	0.06	7.7	92.3	<0.1	0.29	0.01	0.0	99.9	0.1
15	0.37	0.05	21.9	76.6	1.5	0.29	0.06	5.8	33.7	60.5
16	0.42	0.09	18.0	81.9	0.1	0.28	0.01	0.0	99.9	0.1
17	0.51	0.15	15.7	84.3	<0.1	0.26	0.02	2.1	39.0	58.9
Average	0.42	0.08	23.5	76.1	0.4	0.29	0.03	2.0	83.6	14.4

[1]All values are annual averages of 12 monthly averages. Data taken in the same month (e.g., October 1973 and October 1974) were first averaged together.

[2]This is the standard deviation of 12 monthly median sand sizes, not the average standard deviation of the sample distributions.

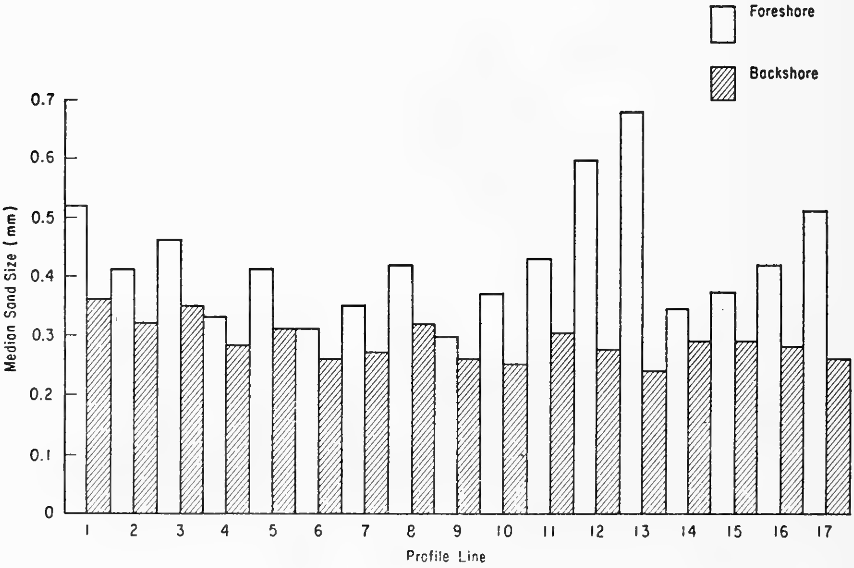


Figure 15. Longshore variation in foreshore and backshore median sand size, eastern Lake Michigan.

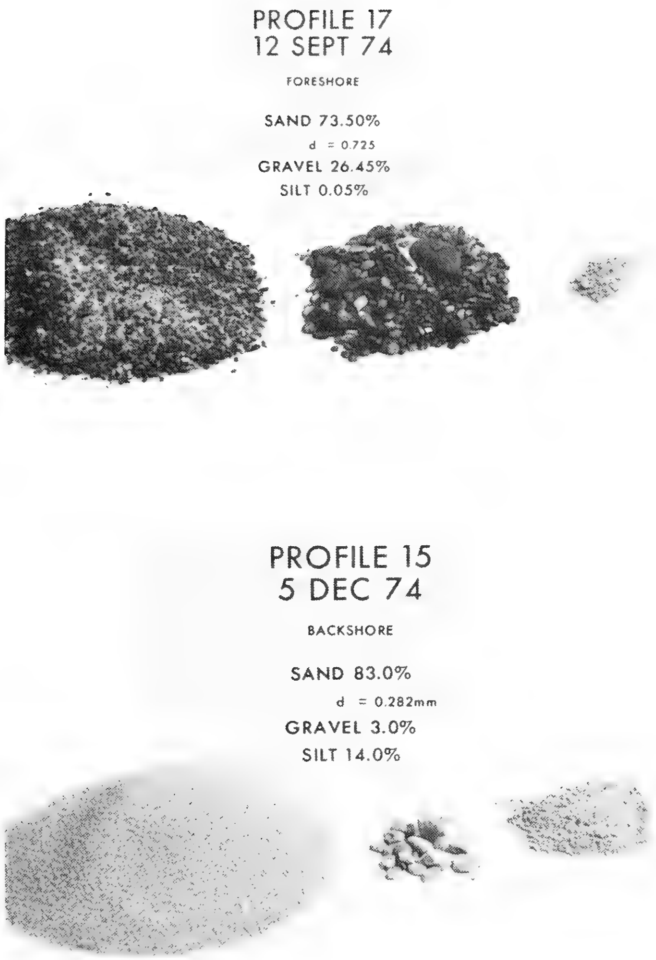


Figure 16. Actual foreshore and backshore samples with content similar to the composite averages given in Table 5.

Sample composition was strongly related to bluff type. Almost pure sand was found on both the backshore and foreshore at profile lines 4, 6, 8, 9, 11, and 14, all of which are backed by sand bluffs. Similarly, only profile lines 10, 13, 15, and 17, which have till bluffs, had high silt concentrations on the backshore (greater than 50 percent).

While gravel was found in varying amounts at all profile lines, high and low concentrations were characteristic of specific lines. High percentages of gravel (geater than 40 percent) were found on the foreshore at profile lines 1, 3, 5, and 13. Gravel concentration was not necessarily related to bluff type. For example, the beach at profile line 1 is covered with pebbles even though it fronts a sandy dune area (Davis, 1976).

A not unexpected finding is the linear relationship between (profile average) sample gravel content and median sand size shown in Figure 17 for both the foreshore and backshore data from Table 5.

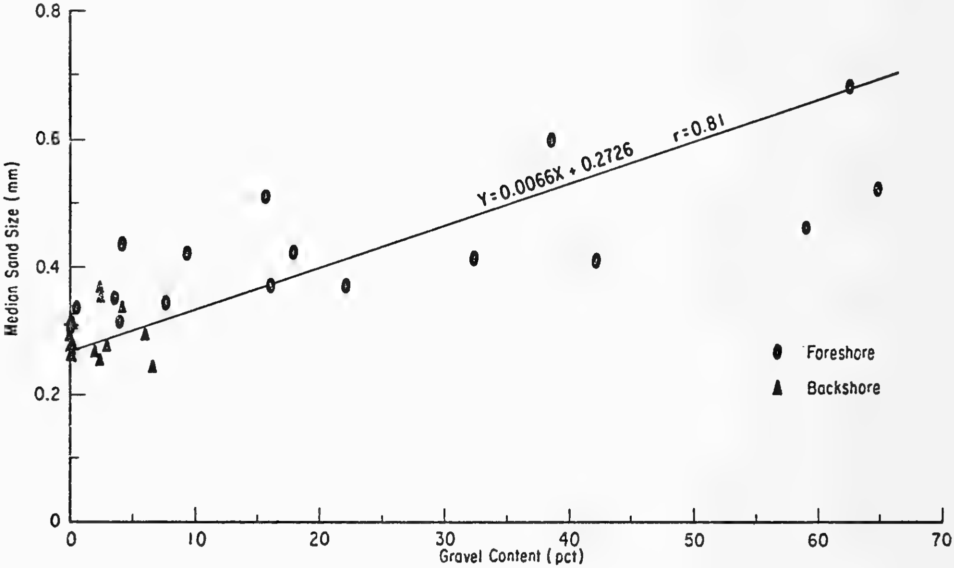


Figure 17. Linear relationship between median sand size and percent gravel by weight.

When the data are averaged monthly, as shown in Figure 18, the backshore median sand size is fairly uniform throughout the year. However, the foreshore shows an increase during the fall months, peaking at 0.48 millimeter. This trend is similar though out of phase with the lake level variations. An examination of the variation for individual profile lines indicated that this seasonal increase occurred to some extent only at profile lines 2, 5, 8, 10, 11, and 12. Seasonal variations in sample content are also shown in Figure 18.

From the visual estimates of heavy mineral content, it was determined that heavy minerals, predominantly magnetite, were most commonly found on the backshore. Only 6 percent of the foreshore samples had significant amounts of magnetite compared with 13 percent of the backshore samples. The average

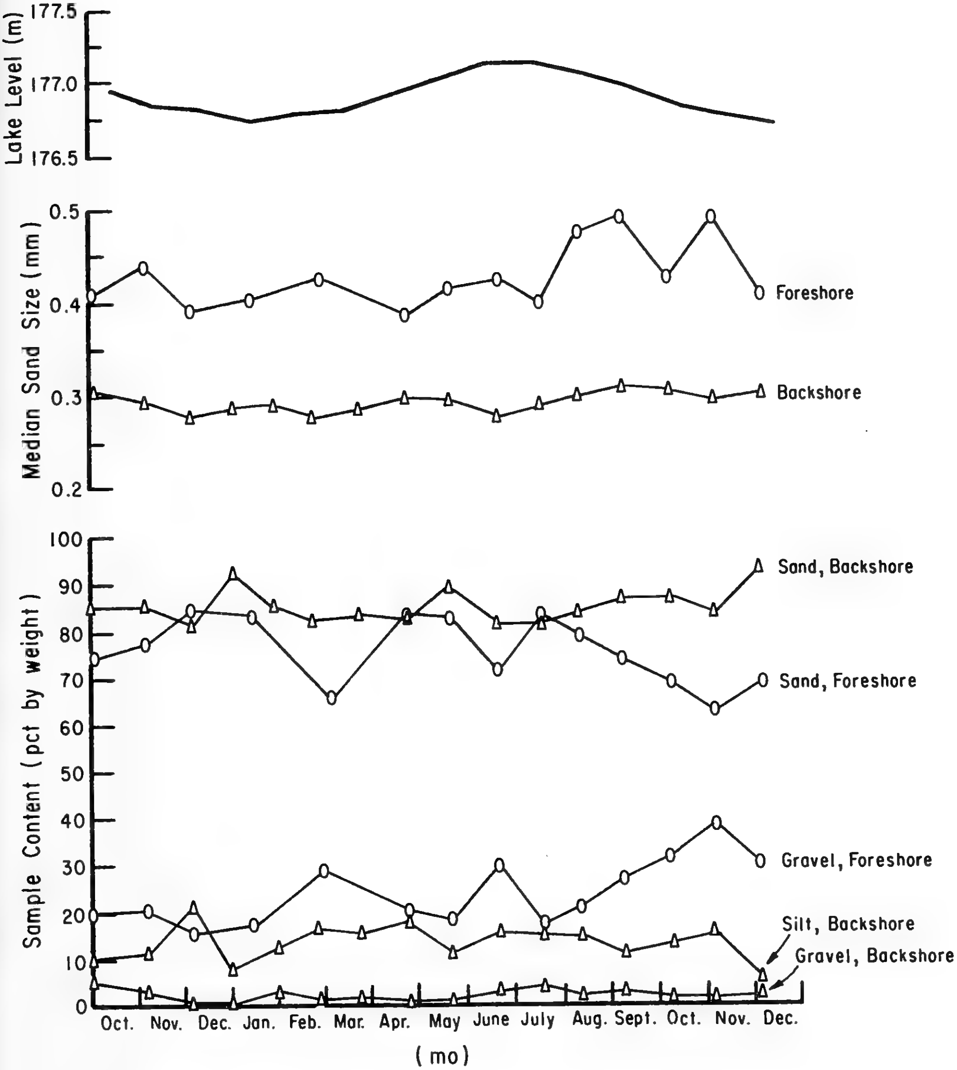


Figure 18. Monthly variation in average median sand size and sample content for the 17 eastern Lake Michigan profile lines, 1973-74.

visual estimated percentage (of the sand fraction) of heavy minerals was 35 percent on the backshore and 17 percent on the foreshore. There were no obvious patterns of occurrence of heavy minerals either among profile lines or seasonally.

This summary of the sediment characteristics does not fully reveal the complex nature of the beach sediments, particularly of individual samples and between profile lines. To facilitate further analysis, the original data have been compiled and placed in the CERC library (Birkemeier, 1981).

VII. SUMMARY AND DISCUSSION

This report has discussed the changes which occurred at 17 unique profile lines located along the east coast of Lake Michigan. Although the report is primarily a data report, the important factors affecting bluff recession, such as lake levels, storms, shore protection structures, and composition, have been analyzed. In general, the bluff line can be expected to respond to the different processes (if these processes could be isolated) as follows:

(a) Lake level--Increasing lake level increases bluff recession. Decreasing lake level decreases bluff recession. Either trend should affect all profile lines. Rate of change may be important.

(b) Storms--High rates of bluff recession during short time intervals, depending on storm duration and intensity, should affect all lines. Expect great variation between lines due to different orientations, compositions, beach widths, and proximity to the storm path.

(c) Shore protection structures--Varied but localized influence which affects individual profile lines.

(d) Bluff composition--Varied but localized influence which affects individual profile lines.

Although the available data are insufficient to isolate and quantify each of these relationships, they do provide some insight into the complexity of the bluff recession phenomena. For example, the dominant factor causing high erosion at profile lines 4 and 16 was their proximity to shore protection structures. The low recession recorded at profile line 13 appears to be due to its till composition. Ground waterflow may be a controlling factor at profile line 17.

1. Summary.

Long-term measurements like those of Powers (1958) and the Michigan Department of Natural Resources (1975) report bluff recession rates of 0.5 to 2 meters (maximum) per year. These low values tend to obscure the fact that the recession actually occurs in cycles of high and low recession rates. As discussed in Section V, 2, the average annual rate of bluff recession per profile between August 1970 and December 1974 was 2.5 meters per year, a value exceeding the highest long-term rate. At individual profile lines, the differences were even more dramatic. Profile line 4 retreated at an average rate of 4.2 meters per year, more than twice the highest long-term average, and in one instance retreated 6.1 meters between two surveys.

The amount of bluff recession increased steadily from the beginning of the study in August 1970 through 1973. Though this coincided with the increase in lake levels, the study period was too short to evaluate long-term lake level effects. Peak amounts of recession as shown in Figure 13 occurred during periods of intense storm activity.

During the final period of surveys (October 1973 to December 1974), the lake levels stabilized, and there were few significant storms. Consequently, most of the profile lines began to stabilize. With respect to the other profile lines, the dramatic changes at profile lines 4 and 16 were anomalous during the study. In both cases, nearby shore protection structures appeared to be affecting the profile lines, dramatically increasing the rate of erosion.

Although there was considerable variation in bluff recession between profile lines, a strong seasonal dependence is shown in Figure 12. Bluff recession is high during late fall and early spring and low during the summer and during periods of ice cover. This variation is interesting because it is out of phase with the seasonal lake level variation but in phase with the annual storm cycle. The effect of storms would probably be greater if they occurred in phase with the seasonal fluctuations in lake level. This is an important consideration in planning lake level regulation, particularly if the current phase relationship between the storm season and seasonal lake levels is changed.

The importance of storms was demonstrated 17-18 March 1973 when a major storm caused the bluffs at 11 of the 17 profile lines (65 percent) to erode an average 1.6 meters. This was not only the highest total amount of recession, but also the highest number of profile lines retreating between any two consecutive surveys.

In terms of volumetric losses, relative to the Davis (1976) datum (Table 4), average change per profile from August 1970 to December 1974 was -35.0 cubic meters per meter. Losses varied from -91.7 cubic meters per meter at profile line 4 to only -7.8 cubic meters per meter at profile line 11. Average volumetric losses followed the same trend as bluff recession, increasing from August 1970 to July 1973 and then decreasing between October 1973 and September 1974. No clear relationship between bluff composition and volume change was identified.

From representative surface sediment samples of the foreshore and backshore it was found that relative to the backshore, the foreshore had a coarser sand fraction and higher gravel concentrations. The foreshore also displayed greater variability in content both between surveys and between profile lines. Average median grain size for the sand fraction of the foreshore samples was 0.32 millimeter versus 0.29 millimeter for the backshore. Other useful sediment statistics are given in Table 5.

2. Discussion.

An important aspect of this and almost every study of Great Lakes erosion is the complexity of the problem and the variability of both the lakeshore and the processes. It appears that for every rule, there is an exception like the sand bluff at profile line 11 which eroded the least of all profile lines, including the seemingly more resistant till or mixed sand and till bluffs, or the six profile lines that did not erode during the 17-18 March 1973 storm. Though some of the anomalous results may be caused by poor profile line selection or by surveying errors, for the most part they are probably real.

The surveying problem is an important one which had considerable impact on this study. A good series of surveys is composed of two parts: a stable system of relocatable bench marks and accurate surveying. Accurate bluff surveying is difficult because, regardless of the method used, small errors in distance or elevation can lead to large errors in bluff and beach volumes. The following guidelines may be useful in planning a similar program of surveying:

(a) Establish a series of bench marks for each line that extend from the most stable point above the active erosion to a primary bench mark about 100 meters inland, or farther. Tie the primary bench mark into local cultural features and into the state coordinate system.

(b) In addition to surveying the active part of the bluff, occasionally survey the stable part of the bluff to the primary bench mark.

(c) Use the most accurate surveying method available. Probably the best method would be to use electronic distance measuring (EDM) equipment and a transit or theodolite. This would give precise distances and elevations without having to either move the instrument or read stadia intervals.

(d) Keep careful notes as to the location of bluff crest, bluff base, waterline, and sand sample locations. Photos are also useful.

It should be realized that although long-term measurements may not be planned, future researchers may want to reoccupy the profile lines.

Two major improvements to the surveying program described here are needed to unravel the complexities of the processes. One is detailed wave data for each profile site, and the other is the inclusion of the alongshore dimension at each site. Instead of single profile lines, carefully selected reaches of lakeshore about 1 kilometer long should be studied. Daily wave and current data should be collected by visual observers. Detailed wave hindcasts would also be useful and would provide uniform wave data.

In addition, detailed information on periods of ice cover is needed to identify when ice prevents erosion. In areas where it is important, some measure of ground waterflow and its effect on the bluff is needed.

Two different sets of data are needed--one which examines long-term changes over a complete lake level cycle, and short-term measurements to quantify the effects of storms. It is not sufficient to monitor beach changes just during peak lake levels. Measurements during transition periods and periods of low lake levels, particularly during major storms, are also needed. Long-term changes may best be studied by a series of regular annual or semiannual surveys or high-quality vertical air photos.

This report and the two previous ones by Davis, Fingleton, and Pritchett (1975) and Davis (1976) have illustrated the complexity of Great Lakes shore processes. They are useful in characterizing the eastern Lake Michigan shoreline and in quantifying the changes expected during a period of peak lake levels. The reports have also identified the difficulties inherent in monitoring lakeshore changes and are therefore useful in planning future studies.

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APPENDIX A

PROFILE CHANGES BETWEEN OCTOBER 1973 AND DECEMBER 1974

Because of the more reliable surveying procedures used, a detailed analysis of the data collected during the final study period (October 1973 to December 1974) was possible. Cumulative changes were computed for beach and bluff positions and volume changes for each profile line. The datum used (176.88 meters, IGLD) was equal to the average monthly lake level for the period. Though the elevation of the beach varied from profile line to profile line, a constant upper elevation of 1.25 meters above datum was selected to facilitate volume computations. To ensure that only bluff face volume changes were being computed, volume computations were terminated at an elevation of 13.75 meters above the datum. All active bluff crests were lower than this value.

Total volume and shoreline changes for the period are given in Table A-1 and plotted in Figure A-1. Average shoreline and volume change values were greatly affected by the changes at profile line 16. During the period, the shoreline of 9 of the 17 profile lines accreted an average of 2.2 meters while the remaining 8 lines eroded 7.3 meters. Average beach volume loss was -2.0 cubic meters per meter but varied from 5.2 cubic meters per meter at profile line 11 to -29.1 cubic meters per meter at profile line 16.

Table A-1. Total shoreline and volume changes: October 1973 to December 1974.[1]

Profile line	Shoreline change (m)	Beach volume (m^3/m)	Bluff volume (m^3/m)	Total volume change (m^3/m)
1	-1.4	0.9	2.4	3.3
2	0.2	1.6	-9.5	-7.9
3	-5.2	-1.0	-2.6	-3.6
4	3.2	4.7	0.8	5.5
5	2.1	2.1	-5.2	-3.1
6	0.3	-0.3	-17.7	-18.0
7	0.6	2.1	-1.1	1.0
8	-13.2	-9.6	-25.8	-35.4
9	1.4	0.7	-10.0	-9.3
10	-3.8	-6.1	-10.3	-16.4
11	6.1	5.2	2.8	8.0
12	4.5	2.8	-2.7	0.1
13	-4.3	-4.7	-8.8	-13.5
14	-1.1	1.1	-6.2	-5.1
15[2]	-5.4	-3.7	-20.2	-23.9
16	-24.3	-29.1	-43.6	-72.7
17	1.5	-0.4	-0.7	-1.1
Mean	-2.3	-2.0	-9.3	-11.3
Standard deviation	7.3	8.0	11.9	19.4

[1]Vertical datum equals 176.88 meters, IGLD.

[2]Actual period: December 1973 to September 1974.

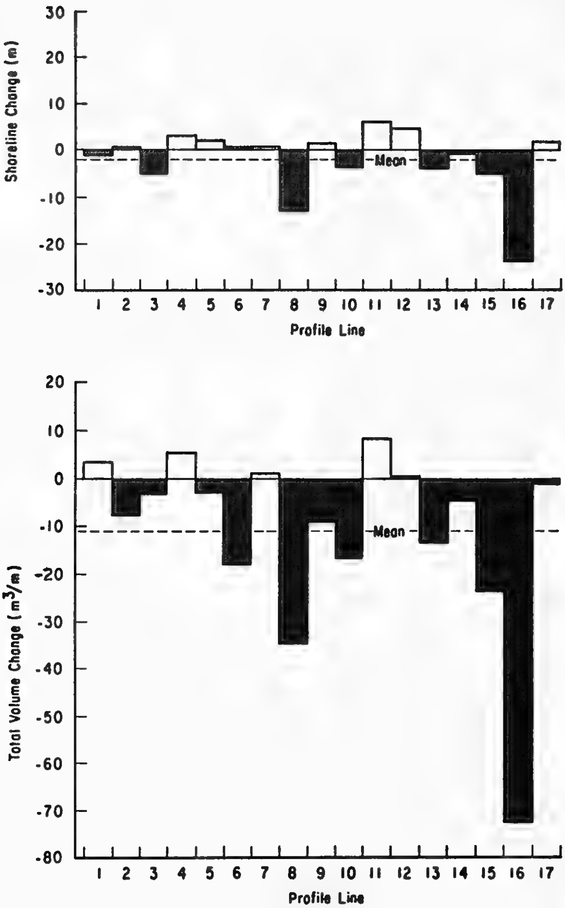
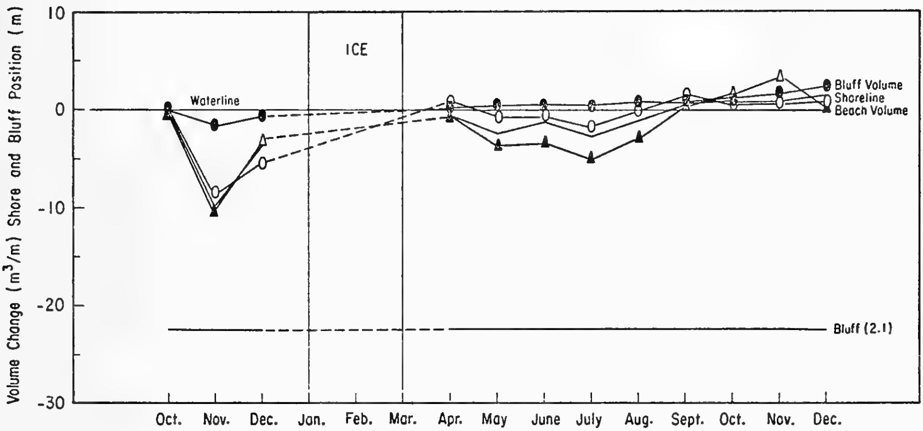


Figure A-1. Total shoreline and volume change by profile line: October 1973 to December 1974. Vertical datum equals 176.88 meters, IGLD.

In terms of bluff erosion, three profile lines (1, 4, and 11) accreted slightly though an amount less than 2.8 cubic meters per meter. This can be seen in Figure 4. The average change was −9.3 cubic meters per meter with profile lines 8 and 16 accounting for 44 percent of the total. Total volume changes averaged −11.3 cubic meters per meter and were well correlated with total shoreline movement (correlation coefficient of 0.93).

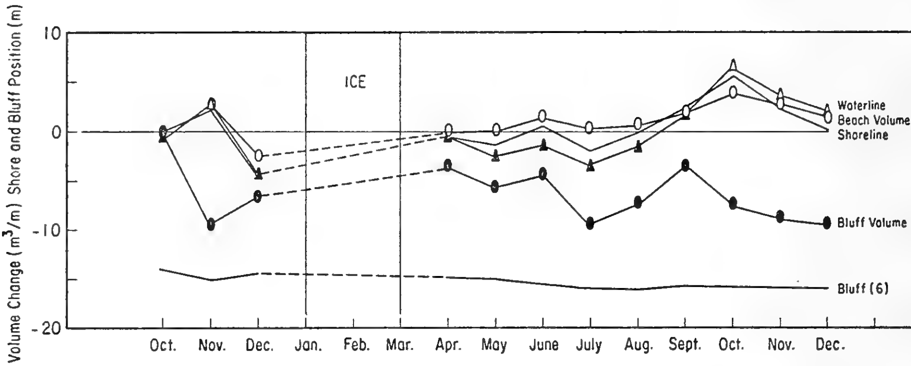
Changes in these parameters with respect to time are shown in the plots in Figure A-2 (profile lines 1 to 17). Because features such as shoreline position could not be determined during the winter, changes for all the parameters during January, February, and March have not been shown.

Key to plots: All data are relative to a vertical datum of 176.88 meters (IGLD) or 1.07 meters above LWD. This datum, which is also the shoreline elevation, represents the average lake level during the period, October 1973 to December 1974. To illustrate the influence of changing lake levels, the distance to the contour equal to the average monthly lake level was computed and plotted as the waterline. Solid triangles represent periods when the beach was narrower or equal to the beach defined by the shoreline. Open triangles indicate wider beaches. The line marked "bluff" indicates the cumulative change in position of an elevation contour (given in parentheses) which represents the bluff crest during the first survey. Plotted positions of the shoreline, bluff line, and lake level are relative to the location of the shoreline during the first survey of each line. Beach volumes were computed above datum and below the 1.25-meter contour (or 177.13 meters IGLD). Bluff volumes were computed above 1.25 meters and below 13.25 meters. Volumes plotted represent cumulative changes. Because of ice cover, data collected between January and March 1974 have been omitted.

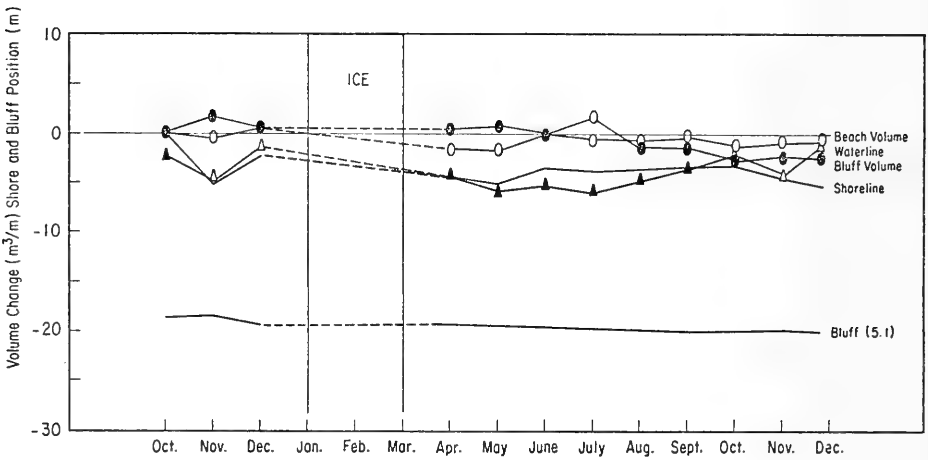


a. Profile line 1

Figure A-2. Plots of cumulative change to the shoreline, waterline, bluff line, beach volume, and bluff volume for the 17 profile lines, October 1973 to December 1974.

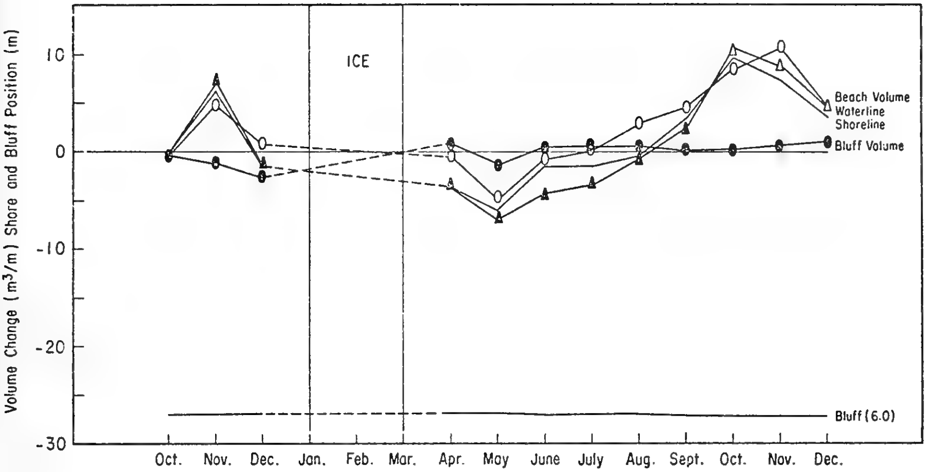


b. Profile line 2

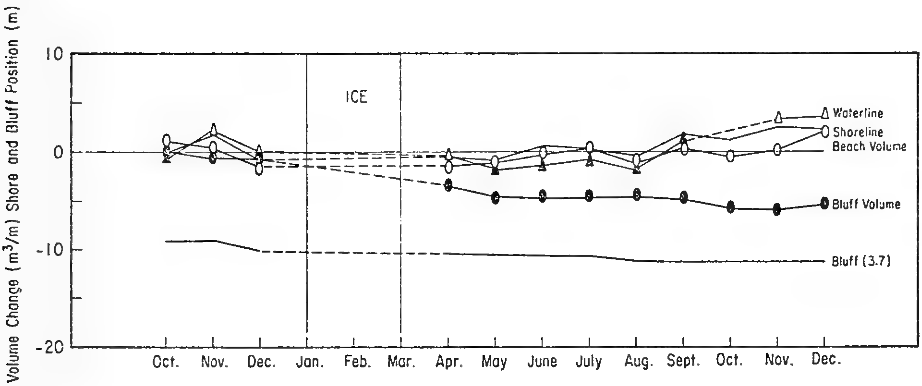


c. Profile line 3

Figure A-2. Plots of cumulative change to the shoreline, waterline, bluff line, beach volume, and bluff volume for the 17 profile lines, October 1973 to December 1974.--Continued

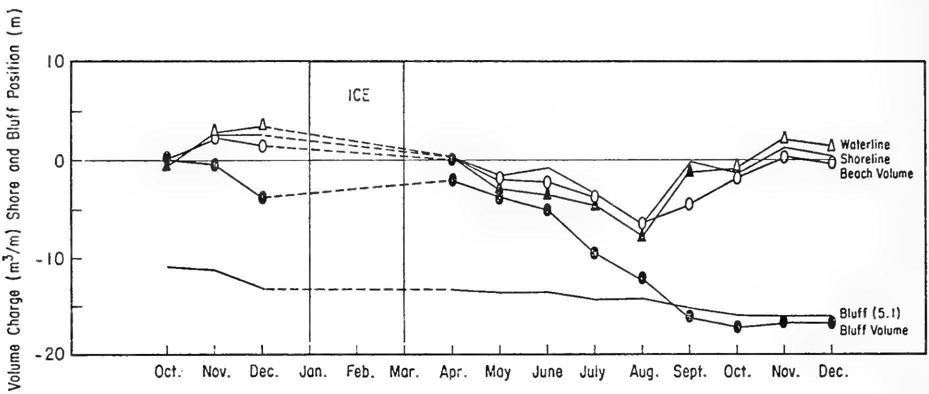


d. Profile line 4

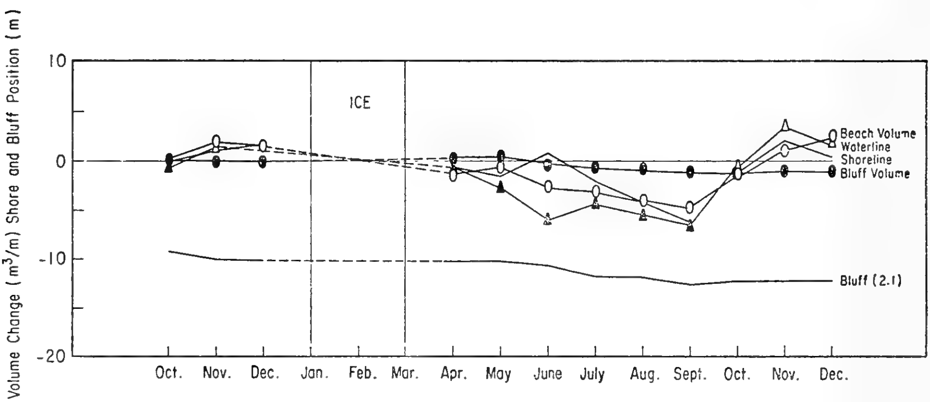


e. Profile line 5

Figure A-2. Plots of cumulative change to the shoreline, waterline, bluff line, beach volume, and bluff volume for the 17 profile lines, October 1973 to December 1974.--Continued

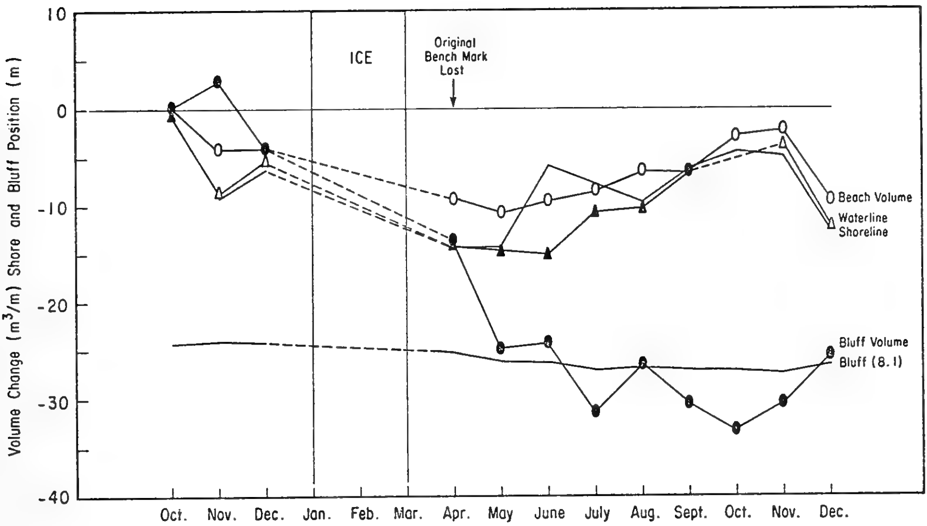


f. Profile line 6

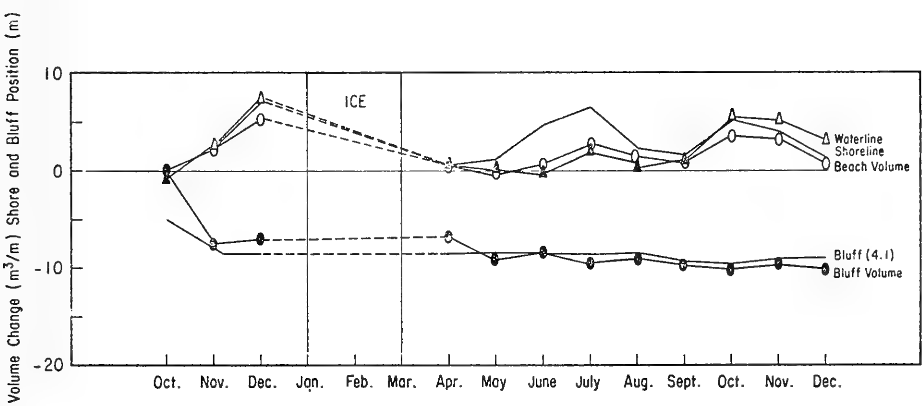


g. Profile line 7

Figure A-2. Plots of cumulative change to the shoreline, waterline, bluff line, beach volume, and bluff volume for the 17 profile lines, October 1973 to December 1974.--Continued

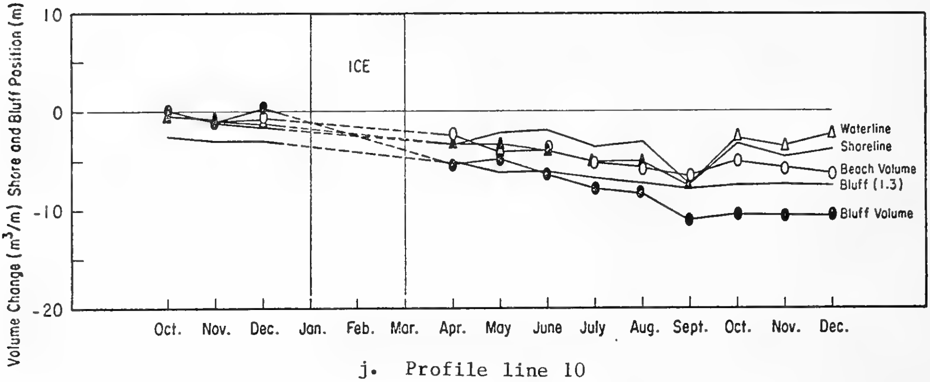


h. Profile line 8

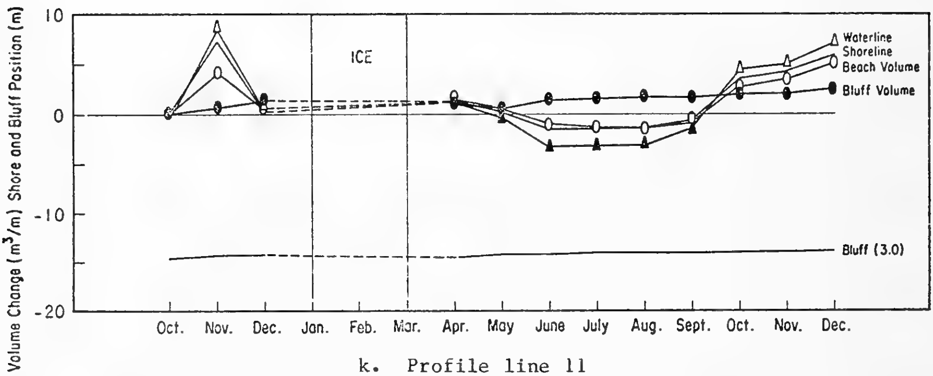


i. Profile line 9

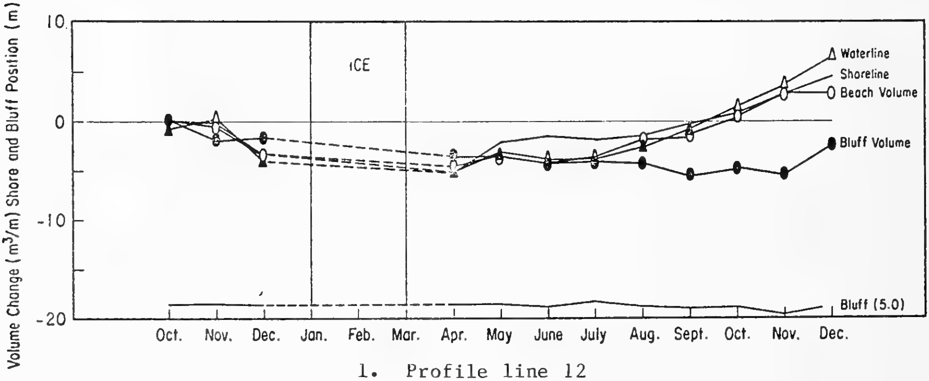
Figure A-2. Plots of cumulative change to the shoreline, waterline, bluff line, beach volume, and bluff volume for the 17 profile lines, October 1973 to December 1974.--Continued



j. Profile line 10

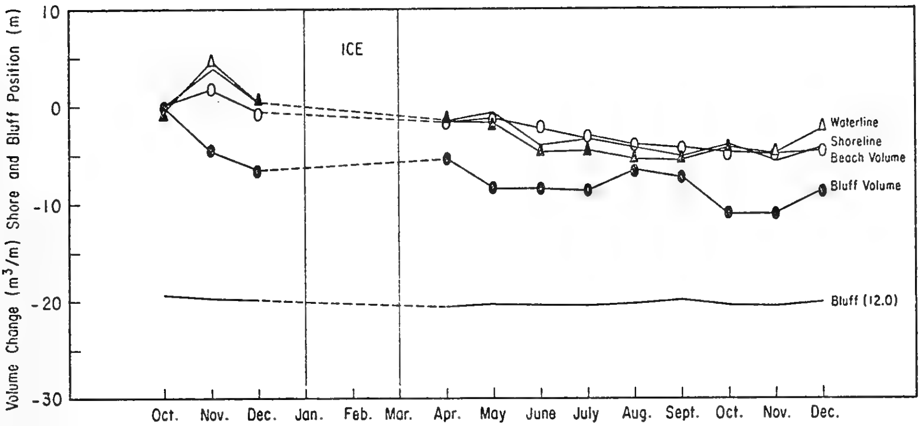


k. Profile line 11

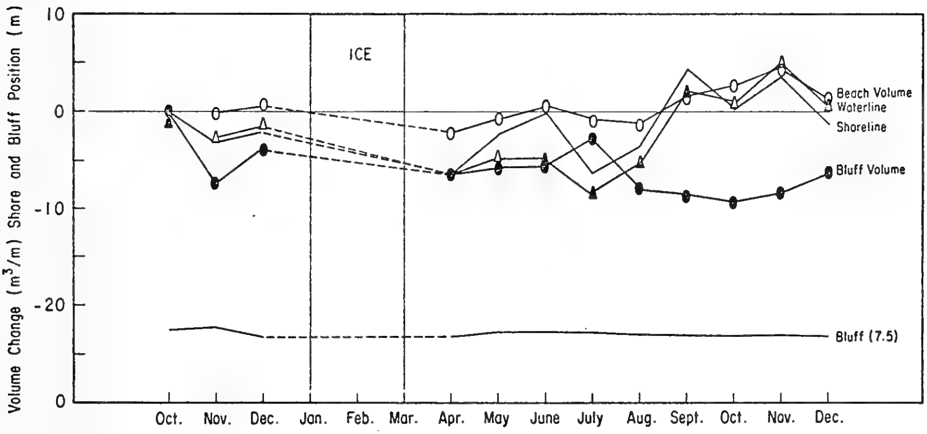


l. Profile line 12

Figure A-2. Plots of cumulative change to the shoreline, waterline, bluff line, beach volume, and bluff volume for the 17 profile lines, October 1973 to December 1974.--Continued

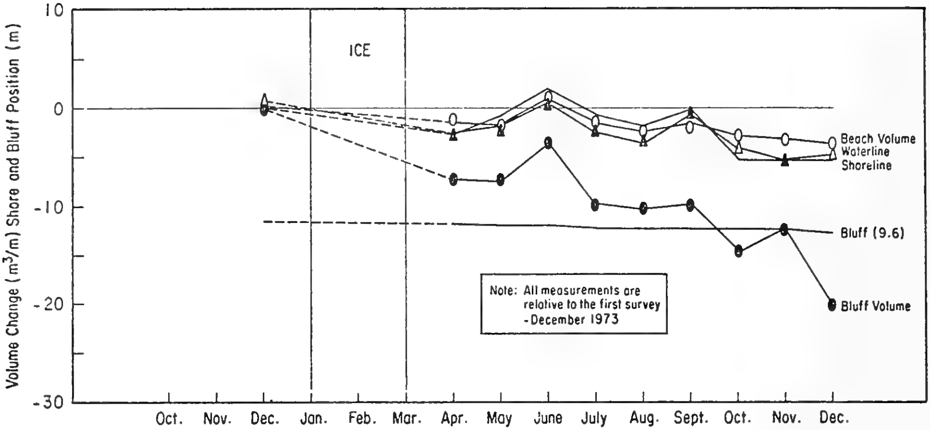


m. Profile line 13

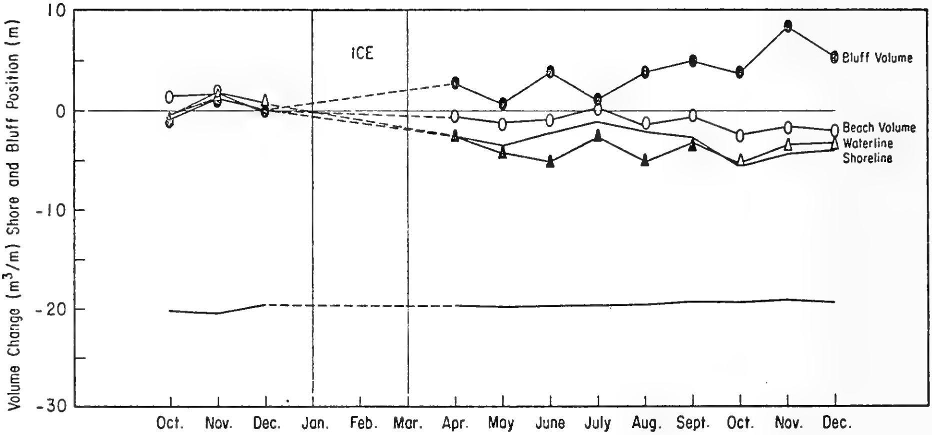


n. Profile line 14

Figure A-2. Plots of cumulative change to the shoreline, waterline, bluff line, beach volume, and bluff volume for the 17 profile lines, October 1973 to December 1974.--Continued

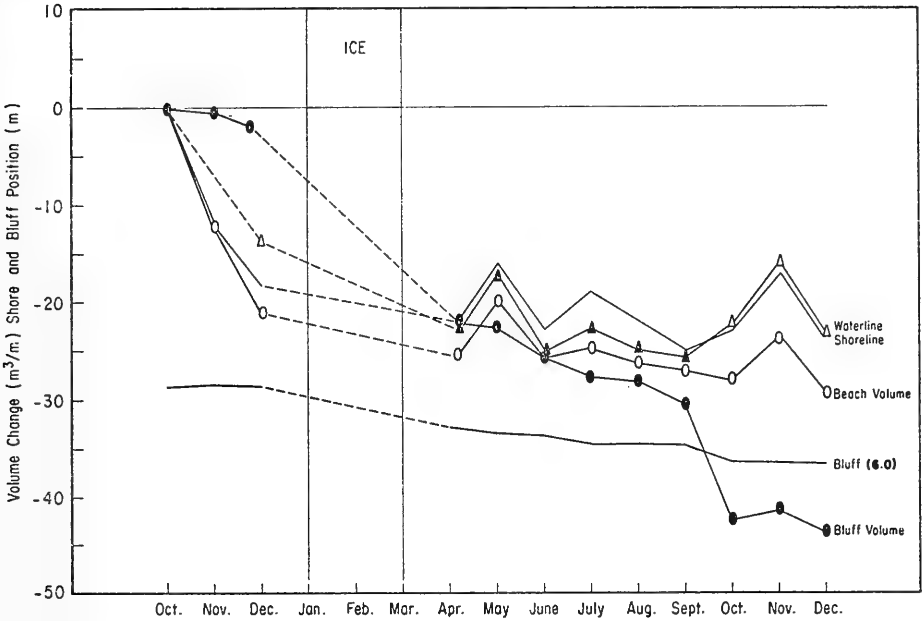


o. Profile line 15

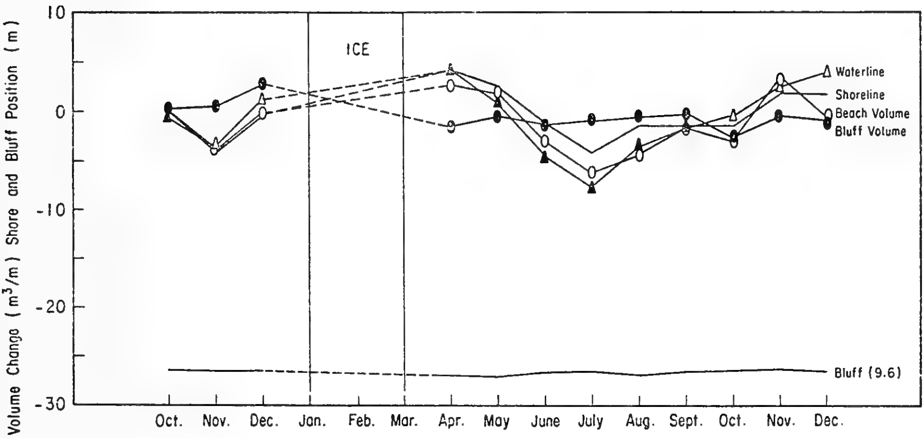


p. Profile line 15A

Figure A-2. Plots of cumulative change to the shoreline, waterline, bluff line, beach volume, and bluff volume for the 17 profile lines, October 1973 to December 1974.--Continued



q. Profile line 16



r. Profile line 17

Figure A-2. Plots of cumulative change to the shoreline, waterline, bluff line, beach volume, and bluff volume for the 17 profile lines, October 1973 to December 1974.--Continued

One important, though not well understood parameter frequently mentioned with respect to Great Lakes coastal processes is beach width. As defined in Section II, beach width refers to the distance from the base of the bluff to the changing waterline, not to the shoreline which refers to a constant elevation regardless of lake level. This distinction can be important, particularly if the datum defining the shoreline is much lower than the lake level. For this reason, the datum was redefined from that used by Davis (1976) to the mean monthly lake level between October 1973 and December 1974. To get some idea of the influence of changing lake levels on the beach width, the distance to the average monthly lake level intercept, relative to the initial position of the shoreline, was computed for each month and profile line. This is plotted as the waterline in Figure A-2 (a to r). Solid triangles along this line indicate that the actual beach was narrower than that defined by the shoreline; open triangles indicate a wider beach. The effect is seasonal with wider beaches during late fall and winter lake levels and narrower beaches during spring and summer. At some of the profile lines, where the foreshore slope is mild, the difference between the shoreline and waterline positions can be significant. As expected, shoreline changes and beach volume changes are well correlated.

The importance of beach width can be clearly seen in Figure A-2 (q). The severe bluff erosion at profile line 16 did not begin until after the fairly wide beach (shown in Fig. 4) eroded. From October 1973 to April 1974, the amount of beach erosion was less than the amount of bluff erosion. After April, the amount of bluff erosion exceeded the amount of beach erosion and continued to increase.

The relationship is not obvious at the other profile lines, possibly because unlike profile line 16, most of the other lines were in transition from a period of severe erosion to one of mild erosion or even accretion. As mentioned previously, this transition is the result of the combination of stabilizing lake levels and no major storms.

APPENDIX B

PROFILE LINE DOCUMENTATION AND PHOTOS

This appendix provides ground photos and monument documentation for each of the 17 profile lines. Also included are short discussions of the changes which occurred between October 1973 and December 1974. Table B-1 gives the position of the bench mark and the last measured bluff crest position for each profile line.

Table B-1. Location of the bench mark and bluff crest at each profile line during the final survey, 2-5 December 1974.

Profile line	Range location of bench mark (ft)	Bluff crest location (ft)
1	0	30
2	-306	12
3	-68	0
4	0	7
5	0	9
6	0	10
7	0	8
8	Lost	
9	-30	-15
10	-20	21
11	0	22
12	16	-3
13	-0	28
14	-20	-3
15	0	40
15A	-50	-1
16	-50	-18
17	0	6, 46[1]

[1]Two distinct bluff crests.

This information complements the information given in Davis, Fingleton, and Pritchett (1975) and Davis (1976). Davis, Fingleton, and Pritchett (1975) provided aerial photos of each line along with a description of the location of each monument. Since many of the original monuments have been replaced, current documentation is included. Also included are comments pertaining to the status of each monument as of May 1976, the date of the last CERC trip to the area.

The ground photos were made from color slides taken during surveys between October 1973 and December 1974 or during the May 1976 field trip. Generally, one photo shows the general characteristics of the profile line including bluff height, beach width, vegetation, local structures, and bluff composition. The second photo illustrates important characteristics not shown in the first photo or a significant change to the characteristics (e.g., a large change in beach width). The entire set of slides, which provides an invaluable record of the profile line changes, is available through the CERC slide library.

The short, descriptive discussions of each profile line are continuations of similar discussions in Davis, Fingleton, and Pritchett (1975) and Davis (1976).

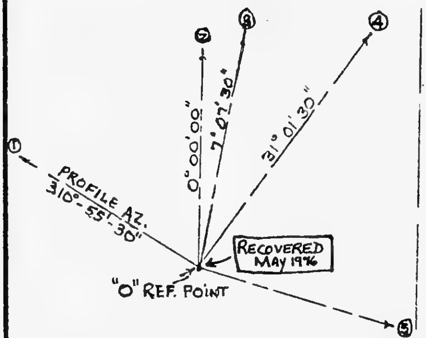
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	1x2" RED STAKE	PROFILE LINE #1	
LOCALITY (Mich.) BENZIE COUNTY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M) 584.81
LATITUDE	LONGITUDE	DATUM	DATUM I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY) NCE
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Oct. 1973 — ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

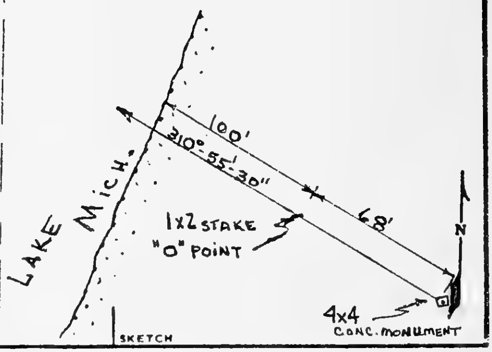
OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

This site is located south of point Betsie lighthouse . Drive north out of Frankfort on M-22 around west shore of Crytal Lake. Turn left at Pt. Betsie sign. Drive to west end of road which ends at lake near the lighthouse. Proceed from there to the south along private drive (unlocked chain across rd.) Stop vehicle as the road begins to swing east to the last house. Walk from there southward for approximately 500' "to a" depressed area. The "0" point for this profile is approximately 100' behind shoreline at this time. It is a 1x2" stake, painted red. The backsite for the profile AZ.(310-55-30) is a 4x4" conc. monument located 68'southeasterly on the side of a sand slope.



① PROFILE LINE
② MAGNETIC NORTH
③ ℄ OF CUPOLA ON DWELLING S. OF LIGHTHOUSE DWELLING
④ RT. EDGE OF CHIMNEY ON LG. YELLOW, GABLE ROOFED HOUSE
⑤ RT. EDGE OF CHIMNEY ON GREY HIPROOFED BUNGALOW - (TO EAST)

BENCH MARKS: TOP OF 1x2" STAKE - 584.81
TOP OF MEDAL PIN ON 4X4 CONC. MONUMENT - 591.75
PROFILE AZ. - 310°-55'-30"



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1958 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

8 May 1973 - Note U.S. Coast Guard station and groins in background; also wide pebble beach.

4 November 1974 - Beach is noticeably wider with more sand than in above photo.

Profile Line 1. Distinctive feature of this profile line is the pebble foreshore. The bluff is actually a vegetated dune. Deposits of heavy minerals are common. The bluff was stable during October 1973 to December 1974, though the beach was active particularly in late 1973. Between October and November, 10.2 cubic meters per meter eroded. This was followed by a long period of accretion. Final profile configuration in December 1974 was similar to October 1973 (see Fig. 9).

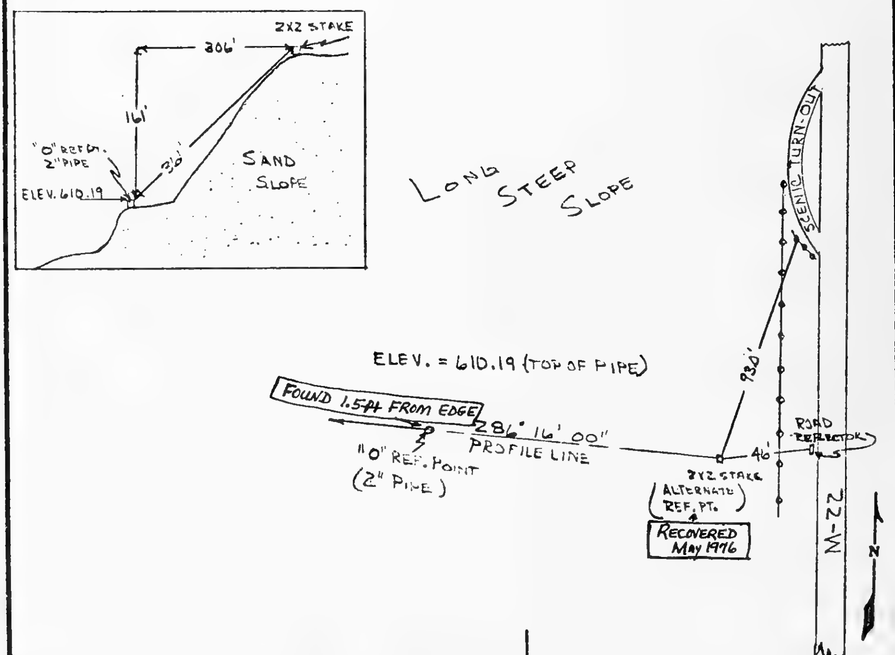
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	2" ORANGE PIPE	PROFILE LINE #2	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
MANISTEE COUNTY (Mich.)	—	—	610.19
LATITUDE	LONGITUDE	DATUM	DATUM
	—	—	I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
—	—		N.C.E.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE / ORDER
—	—	—	Oct. 1973

TO OBTAIN GRID AZIMUTH, ADD ° ′ ″ TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ′ ″ TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ′ ″	° ′ ″		

This site is located adjacent to the south end of the first scenic turn-off north of Arcadia on the west side of M-22.



SKETCH

DA FORM 1959, 1 OCT 64 — REPLACES DA FORMS 1959 AND 1950, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION

For use of this form, see TM 5-237; the proponent agency is U.S. Continental Army Command.

9 May 1976 - Sand and pebble beach decreases in width from the profile line to the south.

12 August 1974 - Beach is almost nonexistent due to high summer lake level.

Profile Line 2. Very steep sand bluff with active erosion below the 8.3-meter contour. Bluff above this contour is well vegetated. Wide range of sand and gravel (almost no silt) found on beach. Bluff relatively stable during Davis (1976) surveys with the greatest amount of retreat, 3.4 meters, occurring after November 1973. Beach also relatively stable between October 1973 and December 1974. The stability of this profile line is perplexing. Davis, Fingleton, and Pritchett (1975) reported that nearby areas had severely eroded.

COUNTRY U.S.A.	TYPE OF MARK 3/4" RE-ROD	STATION PROFILE LINE #3	
LOCALITY (Mich.) MANISTEE COUNTY	STAMPING ON MARK ——	AGENCY (CAST IN MARKS) ——	ELEVATION (FT) (M) 587.44
LATITUDE ——	LONGITUDE ——	DATUM ——	DATUM I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY) N.C.E.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Oct. 1973 / ORDER

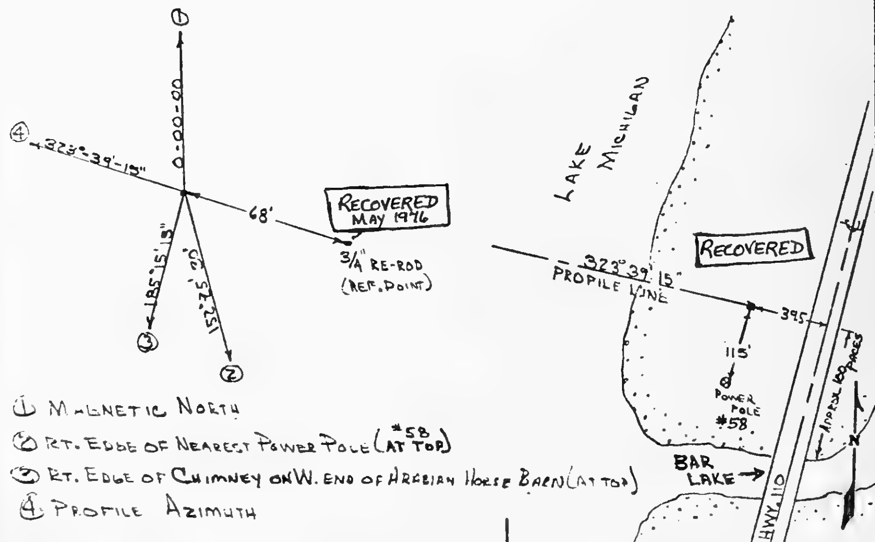
TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

This site is located approximately 2-3/4 miles north of the R.R. track crossing at the north end of Manistee as you follow Hwy. 110 north to Bar lake outlet. The site is approximately 100 paces NORTH of outlet. The reference point is a 3/4" re-rod tied in as shown below. "o" point is 68' lakeward along profile line from re-rod. B.M. is top of re-rod - 587.44

Note: We are currently using the re-rod 68'E as a reference point. Stake at "0" point has been moved. Itwas not replaced since it was so near the edge of the bluff.



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

9 May 1976 - Fresh scarping south of the seawall is evidence of continued erosion after surveying ceased in December 1974.

7 May 1973 - View to the south showing sand beach and bluff, gravel foreshore.

Profile Line 3. Predominantly sand bluff and backshore; gravel found on foreshore. This profile line had retreated significantly during the Davis (1976) surveys. Between October 1973 and December 1974, the crest of the bluff retreated 3.4 meters in increments of 0.6 meter or less. The beach remained stable in the last study period.

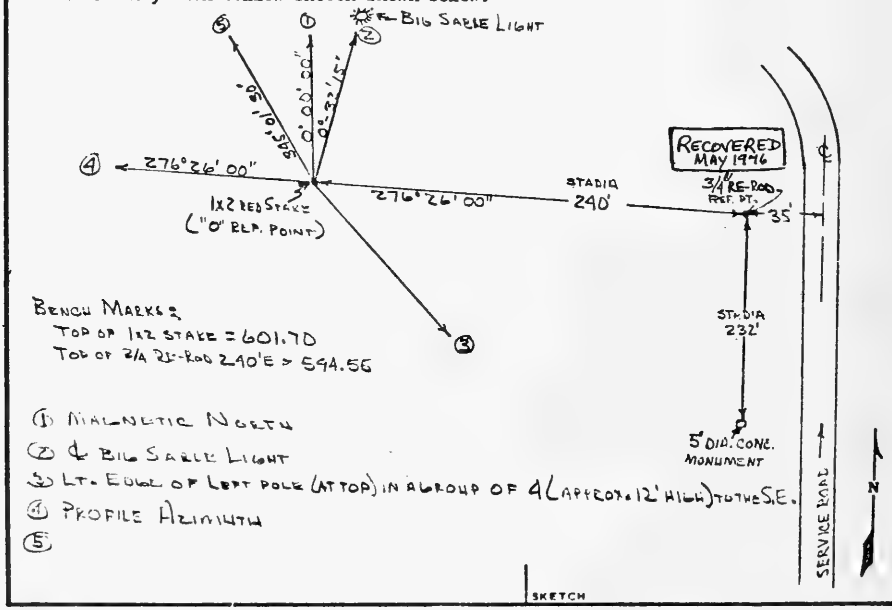
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	1x2 RED STAKE	PROFILE LINE # 4	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
MASON COUNTY (Mich.)	—	—	601.70
LATITUDE	LONGITUDE	DATUM	DATUM
—	—	—	I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
—	—	—	N.C.E.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE / ORDER
—	—	—	Oct. 1973

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

This site is located approximately 1000' south of the Big Sable lighthouse. Drive north out of Ludington along Lakeshore Dr. to Ludington State Park. Directly across the road from the park registration office is Pine campground. Drive north through the campground and continue north through chained off service rd. (obtain key from park office if locked). Approximately 1300' before arriving at lighthouse, look west from road for a 5" dia. concrete monument, then follow sketch shown below:



SKETCH

DA FORM 1959, 1 OCT 64 — REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S. Continental Army Command.

9 May 1976 - View to north showing wide sand beach. Note offset between beach and seawall (to left of white tower).

12 August 1974 - Narrower beach than shown in photo above; well-vegetated dune crest.

Profile Line 4. Davis (1976) speculated that this sand dune profile line may be affected by a seawall located about 100 meters to the north. This is not unlikely as the dune at this profile line retreated more than any of the other profile lines during the study. Only 0.6 of the total 19.5 meters of recession occurred between October 1973 and December 1974. The beach was very active with evidence of both overall beach accretion and erosional scarps appearing in the 4-week interval between surveys. There was a net increase in beach volume between October 1973 and December 1974.

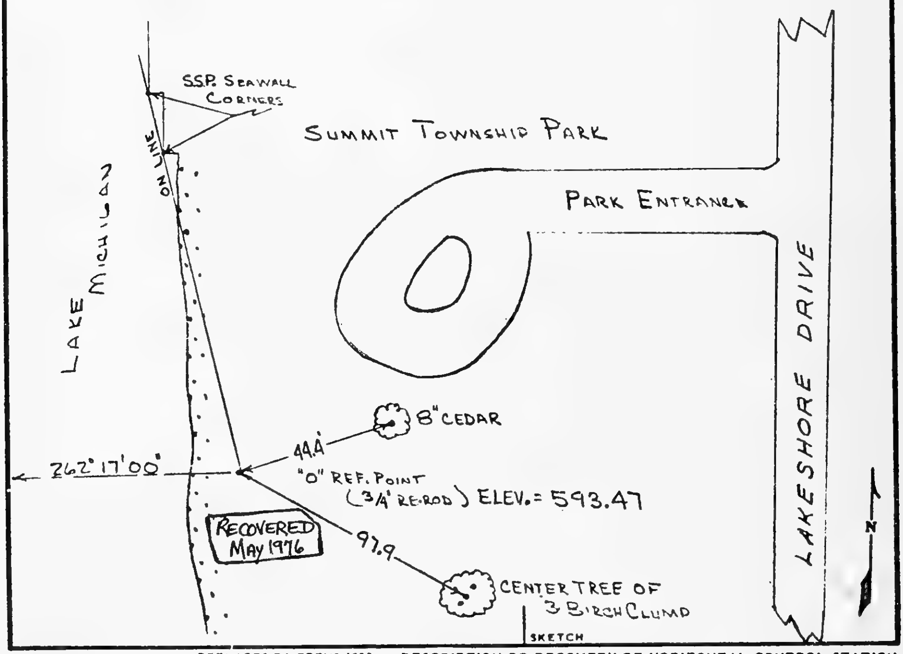
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	3/4" Re. Rod	Profile Line #5	
LOCALITY (Mich.) Mason County	STAMPING ON MARK —	AGENCY (CAST IN MARKS) —	ELEVATION (FT) 593.47
LATITUDE —	LONGITUDE —	DATUM —	DATUM I.G.L.D.
(NORTHING)(EASTING) (FT) (M) —	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE —	ESTABLISHED BY (AGENCY) NCE.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE —	DATE Oct. 1973 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

This site is located near the south end of Summit township park. The park is approximately 2 miles (following Lakeshore Dr.) north of business route 31 going into north end of Pentwater. Profile is approximately 150' south of south end of Summit township park. A 3/4" re-rod is used as "0" reference point see sketch below:



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

9 May 1976 - Wide beach, gravel foreshore; seawall located south of the profile line.

10 September 1974 - View to the north. Beach much narrower than in above photo. A seawall located north of the profile line is behind the surveyor.

Profile Line 5. The sand bluff at this profile line was stable from October 1973 until March 1974 when it retreated 1.5 meters, causing the trees shown above to fall onto the beach. This was followed by an additional 0.3 meter of recession in May 1974 and 0.6 meter in August 1974. For most of the period, the beach was narrow but stable. The beach accreted in the fall of 1974. Beach composition was mostly sand with deposits of gravel on the foreshore and some till found on the bluff.

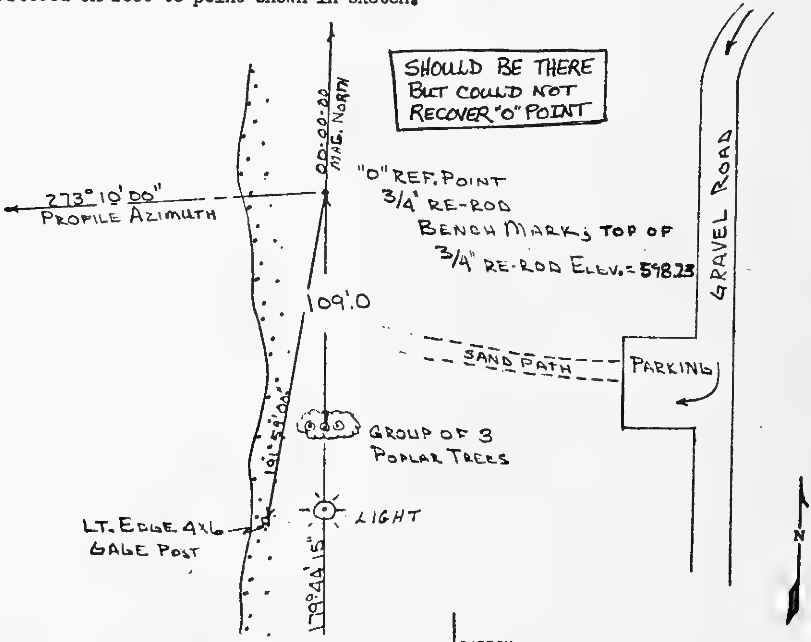
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	3/4" RE-ROD	PROFILE LINE #6	
LOCALITY (Mich.) Oceana County	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M) 598.23
LATITUDE	LONGITUDE	DATUM	DATUM I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY) N.C.E.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Oct. 1973 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ′ ″ TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ′ ″ TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ′ ″	° ′ ″		

This site is approximately 700' north of Little Sable Point lighthouse. Arrived at by driving west along the south bank of Silver Lake Outlet(small creek). As the road turns south it nears Lake Michigan. You continue south to a small parking area on the west side of the gravel road at the lighthouse. Proceed on foot to point shown in sketch.

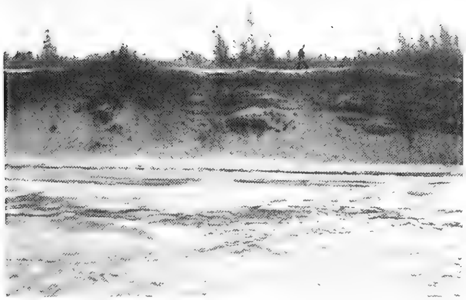


SKETCH

DA FORM 1959, 1 OCT 64 — REPLACES DA FORMS 1958 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

9 May 1976 - Wide beach, mildly sloping dune; compare with photo below.



10 September 1974 - Steep bluff face is evidence of recent erosion. Beach is narrow.

Profile Line 6. The sand bluff at profile line 6 is located north of the lighthouse at Little Sable Point. Though the configuration of the beach was about the same in October 1973 as December 1974, it went through a cycle of accretion in the fall of 1973 and erosion in the summer of 1974. The fall accretion was accompanied by 2.1 meters of bluff recession. The bluff continued to recede during 1974 but in small amounts during March, May, July, September, and October for a total recession of 3 meters. The beach was predominantly sand with only infrequent gravel deposits.

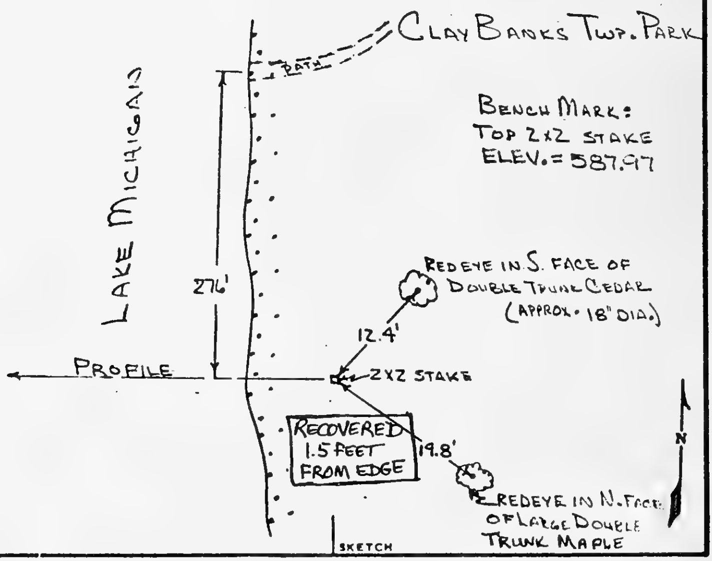
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	2X2 SURVEY STAKE	PROFILE LINE #7	
LOCALITY (Mich.) Oceana County	STAMPING ON MARK ———	AGENCY (CAST IN MARKS) ———	ELEVATION (FT) (M) 587.97
LATITUDE ———	LONGITUDE ———	DATUM ———	DATUM I.G.L.D.
(NORTHING)(EASTING) (FT) (M) ———	(EASTING)(NORTHING) (FT) (M) ———	GRID AND ZONE ———	ESTABLISHED BY (AGENCY) N.C.E.
(NORTHING)(EASTING) (FT) (M) ———	(EASTING)(NORTHING) (FT) (M) ———	GRID AND ZONE ———	DATE Oct. 1973 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ′ ″ TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ′ ″ TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ′ ″	° ′ ″		

To arrive at this site you travel to Claybanks Township Park, approximately 2 miles south of Stoney Lake. Drive to the south end of the park. Follow the pathway down the bank, through the washout and to the beach. From the lower end of the pathway at the beach follow the shoreline 276'south to the profile site. The trees shown in the sketch below are among other trees in a heavily wooded area. Approximate location would be 30'w of shoreline w/+4.0 water gage I.G.L.D.



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

9 May 1976 - Wide beach in this photo is in marked contrast to photo below taken 2 years earlier.

23 April 1974 - Narrow sand beach. Note fallen trees and vegetation on bluff.

Profile Line 7. Most of the bluff recession at this profile line occurred before October 1973. The low bluff is comprised of sand and till and is well vegetated. The beach was slightly erosional from October 1973 to September 1974, but accretion during October to December 1974 resulted in a net increase in beach volume for the period. Except for 0.6 meter of recession in July and August 1974, the bluff was stable.

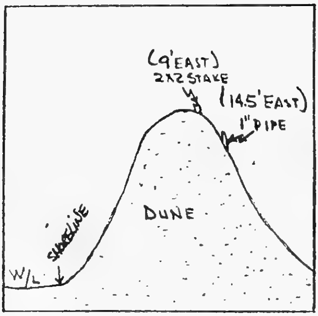
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	1" BLACK PIPE	PROFILE LINE #8	
LOCALITY (Mich.)	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
MUSKEGON COUNTY			617.52
LATITUDE	LONGITUDE	DATUM	DATUM
			I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
			NCE.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: Oct. 1973 / ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ′ ″ TO THE GEODETIC AZIMUTH

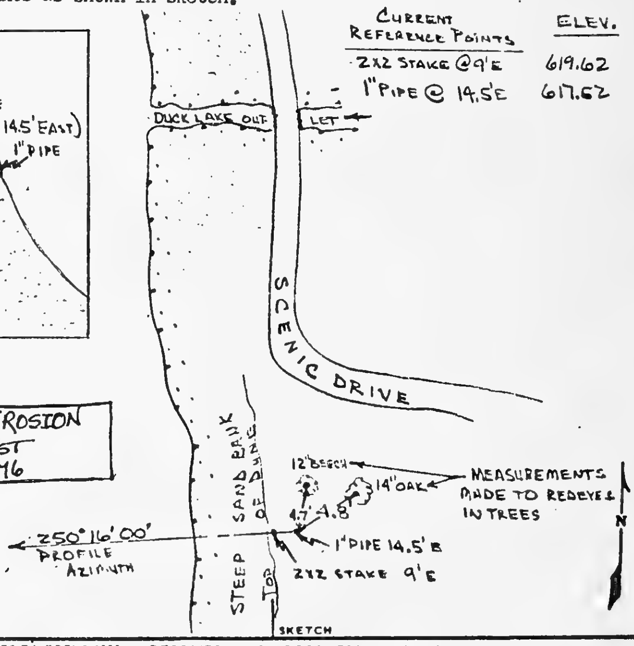
TO OBTAIN GRID AZ. (ADD)(SUB.) ° ′ ″ TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ′ ″	BACK AZIMUTH ° ′ ″	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

This site is located just south of Duck Lake Outlet, on Scenic Drive between White Lake and Muskegon, Mich. Park your vehicle where the road first begins to curve east, as you are headed south. Then proceed on foot along high ridge on dune (approximately 400' south from road curve sign.) Find trees and points as shown in sketch.



SEVERE EROSION
PIPE LOST
MAY 1976



DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION

For use of this form, see TM 5-237; the proponent agency is U.S. Continental Army Command.

9 May 1976 - View from edge of roadway toward profile line (see diagram on facing page). Profile line runs next to the first tree from the left. Note narrow beach and shoreline offset.

23 April 1974 - Relatively wide beach with extensive band of heavy mineral sand.

Profile Line 8. As mentioned in the text, profile line 8 proved to be one of the more interesting lines. Recession of the steep sand bluff had occurred more or less sporadically during the first 3.5 years of surveying. Then in 1974 the beach and bluff eroded significantly. The bluff retreated 10 meters as the active erosion moved upward 4 meters. The dramatic increase in erosion caught the surveyors by surprise and the bench mark was lost in April 1974. The close proximity of the profile line to the reveted roadway may help to explain this severe erosion, which has continued. In May 1976, the bench mark was found lying on the bluff face. This is an indication that an additional 2 to 3 meters of bluff had eroded in the 1.5 years after December 1974.

COUNTRY	TYPE OF MARK	STATION	
U.S.A	3/4 Re-Rod	Profile # 9	
LOCALITY (Mich.) Muskegon County	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) ~~(M)~~ 602.09
LATITUDE	LONGITUDE	DATUM	DATUM I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY) N.C.E.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE Oct. 1973 — ORDER

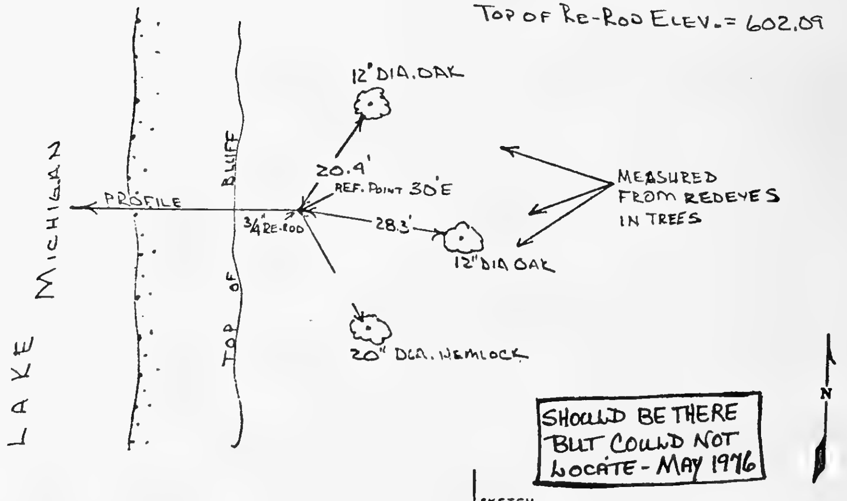
TO OBTAIN GRID AZIMUTH, ADD ° ′ ″ TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ′ ″ TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC) ° ′ ″	BACK AZIMUTH ° ′ ″	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

This site is reached by traveling to P.J. Hoffmaster State Park, located between Muskegon and Grand Haven along Lakeshore drive, a little way north of Pontaluna Rd. Enter the park ,.then drive to the northwest corner where the wooden.steps lead down to the beach. After desending the steps, follow the shoreline for 650' southward. Here the profile crosses the reference point apporximatly 25' east of the top of the nearest bluff paralleling the beach.

Reference Point:
3/4" Re-rod @ 30' East
Top of Re-Rod Elev.= 602.09



SKETCH

DA FORM 1959, 1 OCT 64 — REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION (TM 5-237)

8 May 1976 - This pure sand beach is a dramatic change from the photo shown below taken 2 years earlier.

23 April 1974 - Obvious erosional period following the winter.

Profile Line 9. Between October and November 1973, the sand bluff at profile line 9 receded 3.4 meters. This recession was accompanied by beach accretion which continued until January 1974. Additional recession occurred during 1974 but in amounts less than 0.9 meter. The beach and bluff are almost 100 percent sand. Gravel is uncommon. Final beach configuration was similar to that found in October 1973.

COUNTRY	TYPE OF MARK	STATION	
U.S.A.	3/4" RE-ROD	PROFILE # 10	
LOCALITY (Mich.)	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
OTTAWA COUNTY	—	—	603.37
LATITUDE	LONGITUDE	DATUM	DATUM
—	—	—	I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
—	—	—	N.C.E.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: Oct. 1973 / ORDER: —
—	—	—	

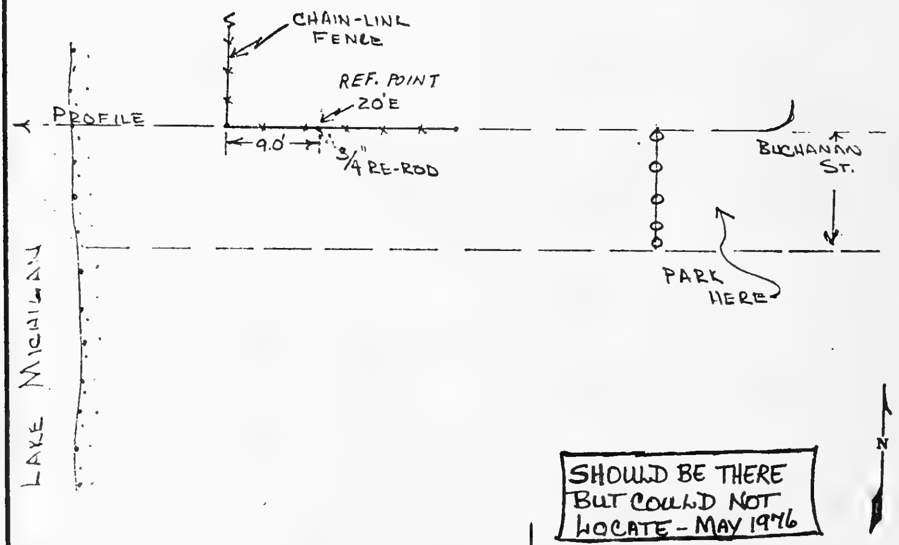
TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		

This site is located at the west end of Buchanan St. Approximately 4 miles south of Robbins Rd. Grand Haven, Mich.

REFERENCE POINT:
3/4" RE-ROD ELEV. = 603.37



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION (TM 5-237)

8 May 1973 - View to north; note lack of beach, steep slope.

17 July 1974 - View north showing seawall. Note gray clay till outcrop in center of photo.

Profile Line 10. The box-type seawalls with permeable sides, located both north and south of this profile line, are evidence of a history of erosion. Severe erosion of 10 meters during the fall of 1970 and 1971 uncovered a bed of clay till below the sand bluff. This tended to stabilize the bluff through 1972 and 1973. However, the near-vertical face of the till layer began to erode during 1974. The absence of any significant beach undoubtedly contributed to the erosion.

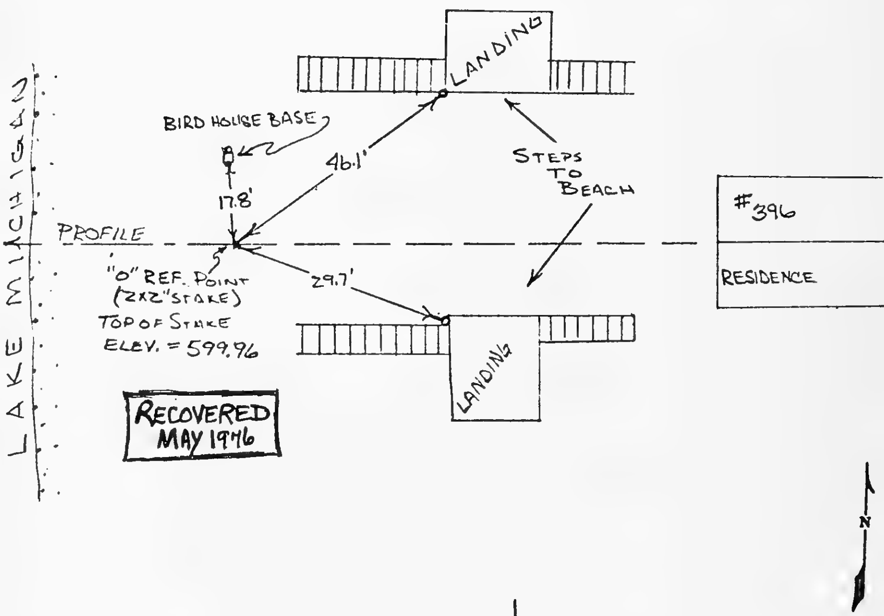
COUNTRY	U.S.A
TYPE OF MARK	2X2 STAKE
STATION	PROFILE # 11
LOCALITY	(Mich.) OTTAWA COUNTY
STAMPING ON MARK	—
AGENCY (CAST IN MARKS)	—
ELEVATION (FT) (M)	599.96
LATITUDE	—
LONGITUDE	—
DATUM	—
DATUM	I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	—
(EASTING)(NORTHING) (FT) (M)	—
GRID AND ZONE	—
ESTABLISHED BY (AGENCY)	N.C.E
(NORTHING)(EASTING) (FT) (M)	—
(EASTING)(NORTHING) (FT) (M)	—
GRID AND ZONE	—
DATE	OCT. 1973
ORDER	—

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

This site is located between Port Sheldon and Holland at 396 Lakeshore DR. Reference point is apporximately halfway down the bank behind the residence.



SKETCH

DA FORM 1959 1 OCT 64 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION (TM 5-237)

8 May 1973 - Wide sand beach, vegetated dune. Shack on beach and steep bluff face are evidence of recent erosion.

8 May 1976 - Wide beach covered with heavy minerals.

Profile Line 11. This profile line is located in a heavily developed area. The line crosses a vegetated dune which accreted between October 1973 and December 1974. This is in contrast to earlier years. The lack of severe storms combined with a substantial beach probably accounted for the reduced erosion. The beach grew significantly between October and November 1973, though much of the accreted sand was removed by December 1973. A general increase in beach volume occurred during 1974. Beach and bluff are composed of predominantly sand, though some gravel was found on foreshore.

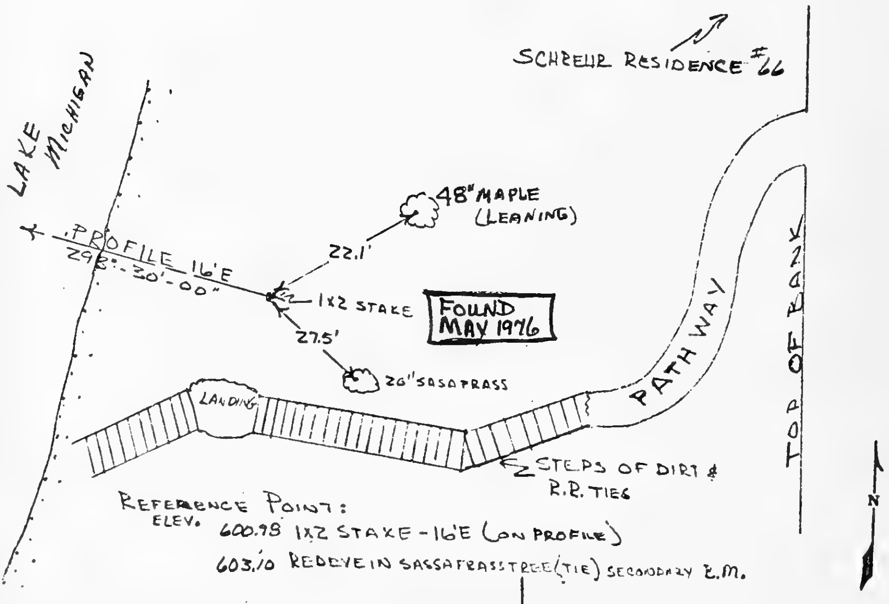
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	1x2 RED STAKE	PROFILE #12	
LOCALITY (Mich.) ALLEGAN COUNTY	STAMPING ON MARK —	AGENCY (CAST IN MARKS) —	ELEVATION (FT) 600.98
LATITUDE —	LONGITUDE —	DATUM —	DATUM I.G.L.D.
(NORTHING)(EASTING) (FT) (M) —	(EASTING)(NORTHING) (FT) (M) —	GRID AND ZONE —	ESTABLISHED BY (AGENCY) N.C.E.
(NORTHING)(EASTING) (FT) (M) —	(EASTING)(NORTHING) (FT) (M) —	GRID AND ZONE —	DATE Oct. 1973 ORDER —

TO OBTAIN GRID AZIMUTH, ADD ° ′ ″ TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ′ ″ TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ′ ″	° ′ ″		

To reach this site, travel to Douglas, Mich. turn west at Center St. (main intersection), and drive to the west end of the street. Then turn north and drive apporximately 300' to Douglas Township Park and public beach. Proceed down the pathway over the bank and down the steps to the last plateau before the beach. The reference point is approximately 25' north of the landing.



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE. DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION (TM 5-237)

8 May 1973 - Wide, mildly sloping beach with gravel foreshore. Note indentation of shoreline in middle of photo.

19 June 1974

Profile Line 12. Like profile line 11, the bluff at profile line 12 was stable between October 1973 and December 1974, and the beach accreted. The low bluff is composed of sand and is vegetated by large trees and brush. Beach accretion began in April 1974 and continued until December 1974.

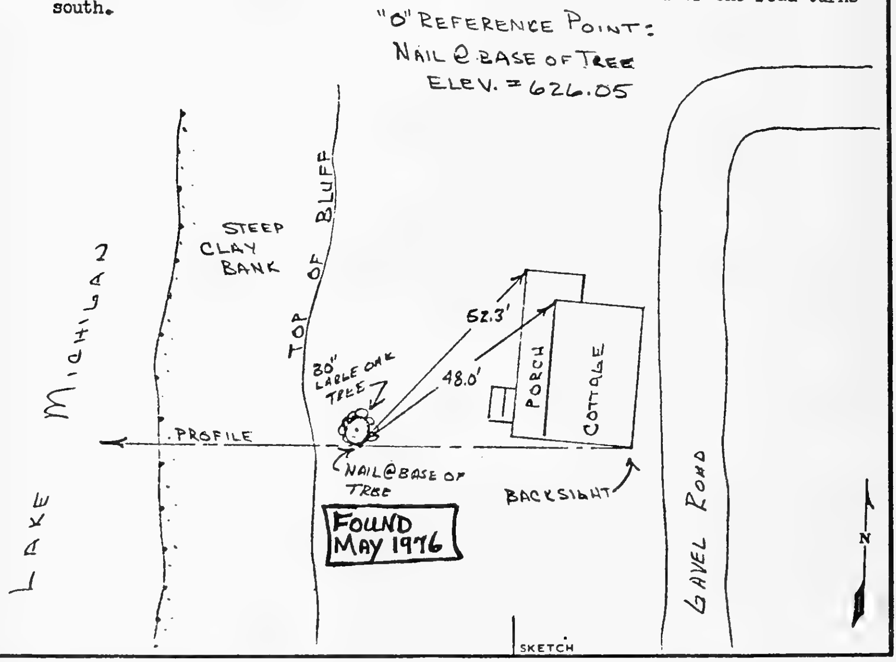
COUNTRY	TYPE OF MARK	STATION	
U.S.A	Nail @ Tree Base	Profile #13	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) ~~(M)~~
Allegan County (Mich.)			626.05
LATITUDE	LONGITUDE	DATUM	DATUM
			I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
			N.C.E.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: Oct. 1973 ORDER

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

. This site is reached by taking Blue Star Highway to Glen Mich. Then turn west at 114 th. st., and proceed to the west end until the road swings to the south. The reference point is a nail w/red cloth driven into the base (south side) of a large oak tree behind the second house after the road turns south.



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE. DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION (TM 5-237)

8 May 1973 - View north toward the profile line. Note width of beach in foreground and indentation near surveyors.

11 September 1974 - Closeup of till bluff. Beach is narrower than in above photo.

Profile Line 13. The till bluff at profile line 13 retreated the least of all 17 profile lines. The stability of the area is primarily a result of the composition of the bluff but may also be due to a coastal protuberance composed of till located to the south. The major change between October 1973 and December 1974 was a small amount of bluff recession of the bluff crest (0.3 meter) and a steepening of the base of the bluff. This steepening was accompanied by erosion of the beach. By May 1976, the area appeared to be seriously eroding. There was almost no beach, and the property owner had placed large concrete blocks just offshore in hopes of dissipating some of the wave energy.

COUNTRY	TYPE OF MARK	STATION	
U.S.A	2X2 STAKE	PROFILE # 14	
LOCALITY (Mich.) VANBUREN COUNTY	STAMPING ON MARK —	AGENCY (CAST IN MARKS) —	ELEVATION (FT) 612.98
LATITUDE —	LONGITUDE —	DATUM —	DATUM I.G.L.D.
(NORTHING)(EASTING) (FT) (M) —	(EASTING)(NORTHING) (FT) (M) —	GRID AND ZONE —	ESTABLISHED BY (AGENCY) N.C.E.
(NORTHING)(EASTING) (FT) (M) —	(EASTING)(NORTHING) (FT) (M) —	GRID AND ZONE —	DATE Oct. 1973 — ORDER —

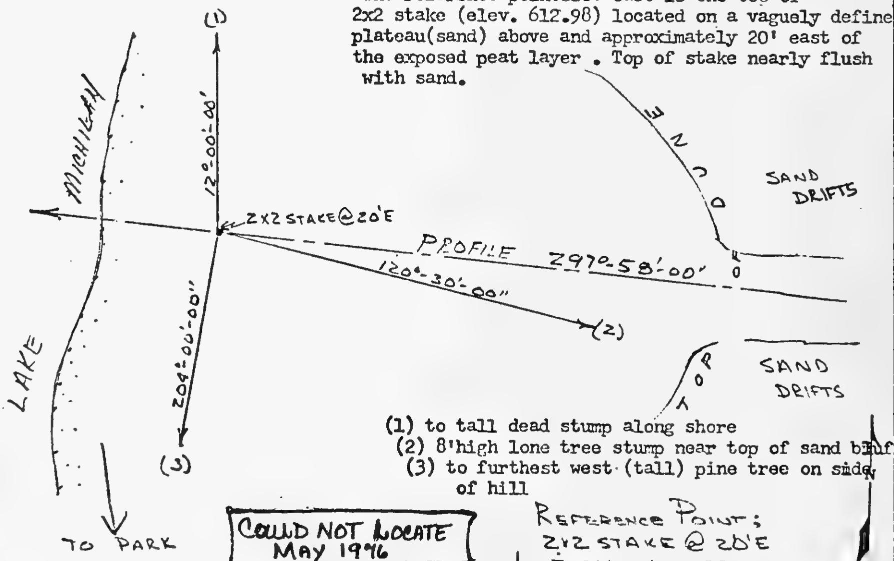
TO OBTAIN GRID AZIMUTH, ADD ° ′ ″ TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ′ ″ TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ′ ″	° ′ ″		

This site is located approximately 1/3 of a mile north of VanBuren State Park, which is just south of South Haven Mich. Approximately 1000' north of the park check station (small guard shack along road), there is a steel bar gate at the entrance to an old road leading to the lake. Follow this old road on foot to the west end at the lake. Directly to the south is a large hollowed out sand dune. The profile goes through this depression at an azimuth of ; 297- 58- 00.

The reference point@20' east is the top of 2x2 stake (elev. 612.98) located on a vaguely defined plateau(sand) above and approximately 20' east of the exposed peat layer . Top of stake nearly flush with sand.



COULD NOT LOCATE MAY 1996

REFERENCE POINT; 2X2 STAKE @ 20'E ELEV. = 612.98

SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE. DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION (TM 5-237)

8 May 1973 - Steep sand bluff face with imbedded peat layers; narrow beach.

15 August 1974 - View onshore showing blowout. For perspective, transit is at an elevation of 9 meters (above the lake level). Dead trees in background are at 40 meters, and are about 80 meters landward of the bluff crest.

Profile Line 14. This profile line is located at the base of a large blowout in some of the highest dunes in western Michigan. As shown in the photos, there are peat and till layers visible across the bluff face. Most of the bluff erosion occurred in the fall of 1972 and the spring of 1973. An additional 1 meter of bluff recession occurred between October 1973 and December 1974. The beach during this time was going through cycles of erosion and accretion. Though significant beach erosion occurred in April, July, and October 1974, there was no net change in beach volume between October 1973 and December 1974.

COUNTRY	TYPE OF MARK	STATION	
U.S.A.	3/4" RE-ROD	PROFILE # 15 & 15A	

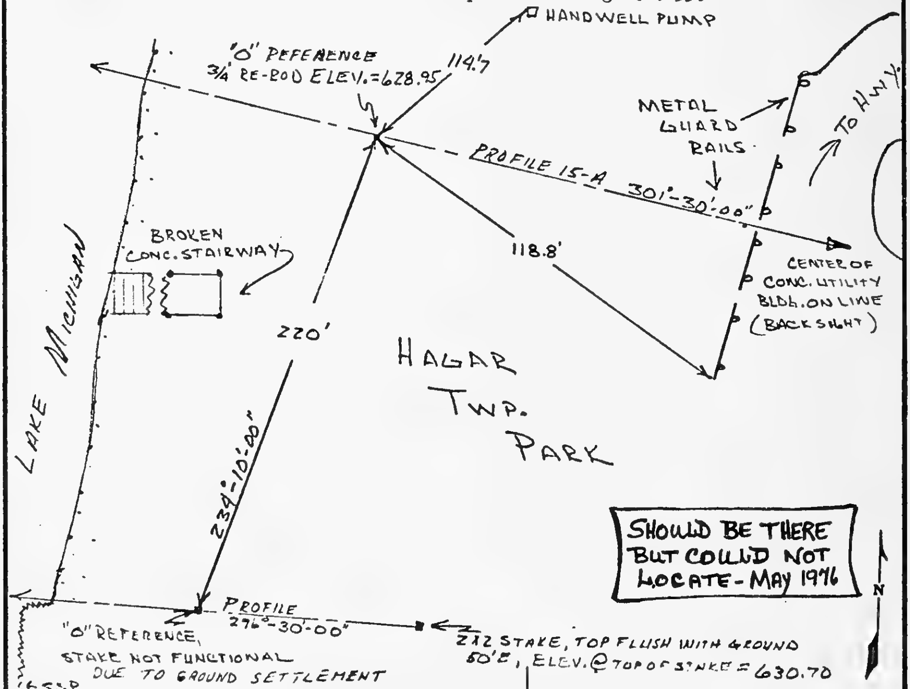
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
BERRIEN COUNTY (Mich.)	———	———	628.95
LATITUDE	LONGITUDE	DATUM	DATUM
———	———	———	I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
———	———	———	NCE.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: OCT. 1973 / ORDER
———	———	———	

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

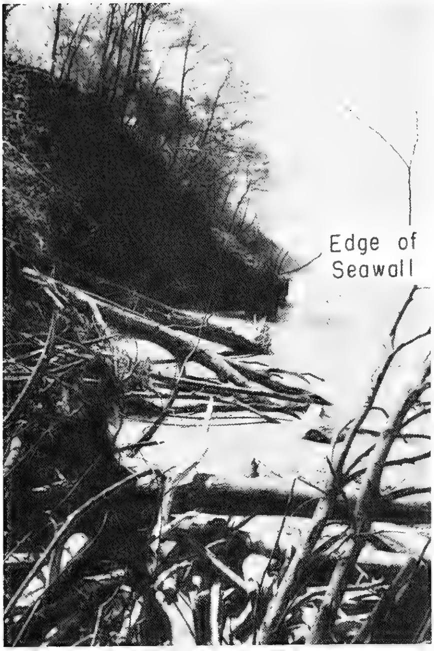
These sites are located in Hagar Township Park. The park is approximately 5 miles north of St. Joseph Mich. along U.S. 33.



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION (TM 5-237)



8 May 1976 - Severe erosion to the area in foreground has caused extensive loss of trees. Note location of seawall.

20 June 1974 - Profile line runs just north of seawall which was constructed in late 1973.

Profile Line 15. Except for a loss of 1.2 meters following the March 1973 storm, and a similar loss in 1974, the till bluff at profile line 15 was relatively stable throughout the study. The top of the bluff is forested and the adjacent areas are developed. The erosion in early 1973 and the lack of a fronting beach probably resulted in the construction of the seawall (pictured above) adjacent to but not in front of the site. The beach continued to be narrow and frequently nonexistent in 1974.

COUNTRY	TYPE OF MARK	STATION	
U.S.A.	2x2 Red Stake	Profile # 16	
LOCALITY (Mich.)	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT)
Berrien County			608.41
LATITUDE	LONGITUDE	DATUM	DATUM
			I.G.L.D.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
			N.C.E.
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: Oct. 1973 / ORDER:

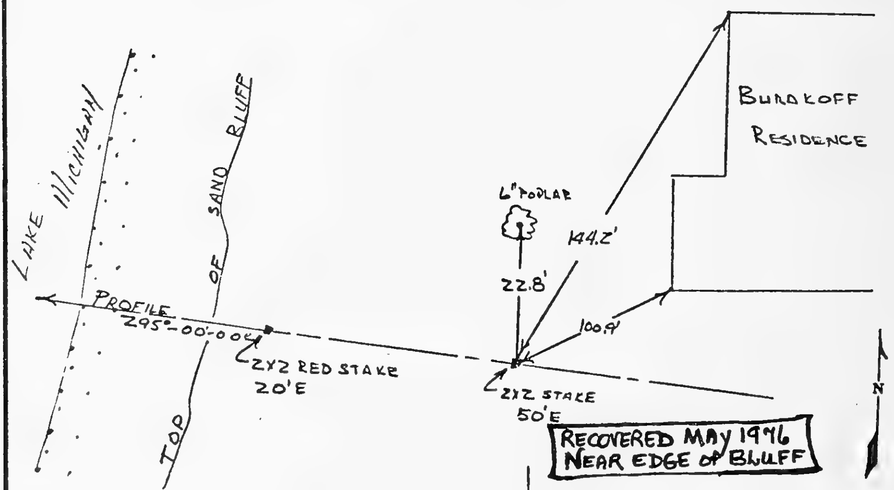
TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

To reach this site, traveling south from St. Joseph, Mich., on business Rte. 94, turn right on the black-top road immediately before the ramp to Interstate 94. Proceed westerly to Notre Dame rd. which runs to the south. Continue to the private drive which is approximately 1/4 mile north of Chalet-on-the-Lake. Follow this drive westerly (bearing left at a fork) to the Burakoff residence. The reference point is south-west of the house.

Reference Points	Elev.
2x2 stake@ 20'E painted red	608.41
2x2 stake@ 50'E unpainted	611.62



SKETCH.

DA FORM 1959, 1 OCT 64 — REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION (TM 5-237)

8 May 1973 - Major feature is width of beach.

8 May 1976 - Similar view as above but 3 years later. Beach is narrow or non-existent; bluff is steep and recently eroded.

Profile Line 16. As mentioned in the text, line 16 is probably the most interesting profile line in terms of changes between October 1973 and 1974. During this time period, the entire profile (both beach and bluff) eroded, losing more than 85 cubic meters per meter of sand. The sequence of events was for severe beach erosion in November and December 1973 followed by recession of the bluff beginning in January 1974. Except for a period of bluff stabilization and beach building in May 1974, the erosion continued through all of 1974. Field trips in May and October 1976 found narrow beaches and an assortment of concrete and sandbag shore protection devices along the shore southward from profile line 16. The cause of this erosion is discussed in Section V, 4 and in Birkemeier (1980).

COUNTRY	TYPE OF MARK	STATION	
U.S.A.	3/4" RE-ROD	PROFILE #17	
LOCALITY: BERRIEN COUNTY (Mich.)	STAMPING ON MARK: —	AGENCY (CAST IN MARKS): —	ELEVATION (FT): 614.90
LATITUDE: —	LONGITUDE: —	DATUM: —	DATUM: I.G.L.D.
(NORTHING)(EASTING) (FT) (M): —	(EASTING)(NORTHING) (FT) (M): —	GRID AND ZONE: —	ESTABLISHED BY (AGENCY): N.C.E.
(NORTHING)(EASTING) (FT) (M): —	(EASTING)(NORTHING) (FT) (M): —	GRID AND ZONE: —	DATE: Oct. 1973 — ORDER: —

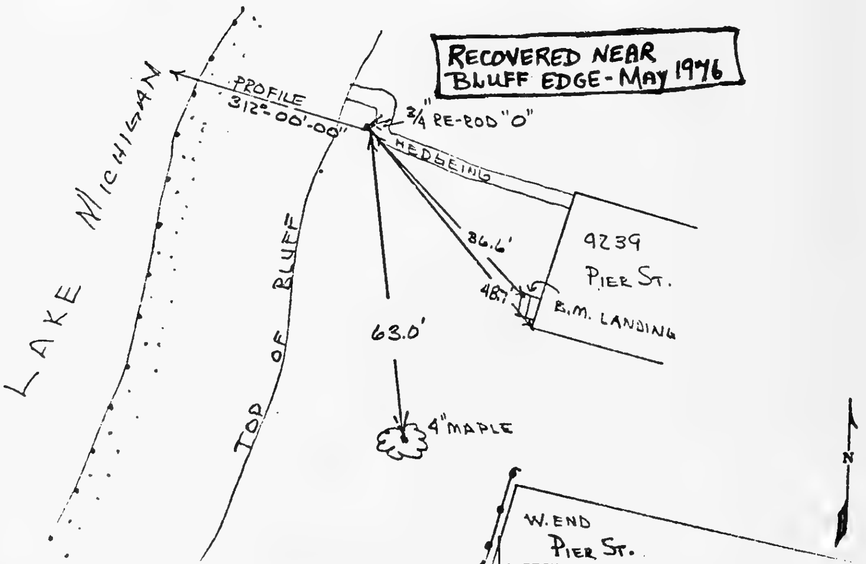
TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)

This site is located at Lakeside, Mich. Proceed to the west end of Pier St. The reference point is west of the northwest corner of the last residence on the north side of Pier St.

Reference Points	Elev.
3/4 re-rod(dist.=o)	rod top= 614.90
B.M."Landing" @ N.W. corner of conc. landing	616.04



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION (TM 5-237)

8 May 1973 - Large-scale slump of upper part of till bluff.

16 August 1974 - Note failing bluff line and accretionary beach ridge. Dark patches on the foreshore are periodic gravel deposits.

Profile Line 17. As mentioned in the text, the till bluff at profile line 17, unlike the till bluffs at profile lines 13 and 15, suffered serious erosion during the study. Total recession equaled 38 meters, of which only 1 meter occurred in the spring of 1974. Movement of the bluff occurs through large-scale slumping which moves trees and grass down the bluff face. The higher erosion here than at profile lines 13 and 15 may be explained by examining the ground waterflow at each profile line. It is likely that there is a greater ground water effect at profile line 17.

Birkemeier, William A.

Coastal changes, eastern Lake Michigan, 1970-74 / by William A. Birkemeier -- Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical Information Service, 1981.
[89] p. : ill. : 27 cm. -- (Miscellaneous report -- U.S. Coastal Engineering Research Center ; no. 81-2)
Includes bibliographical references.

This report is published to improve the understanding of Great Lakes bluff recession and the factors controlling it. It is the final report of a 4-year study of 17 profile lines located along the eastern shore of Lake Michigan.

1. Beach profile. 2. Beach sediments. 3. Erosion. 4. Lake levels. 5. Lake Michigan. I. Title. II. Series: U.S. Coastal Engineering Research Center. Miscellaneous report no. 81-2.

TC203 .U581mr no. 81-2 627

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