STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Horace R. Collins, Chief

Report of Investigations No. 99

LAKE ERIE SHORE EROSION, LAKE COUNTY, OHIO: SETTING, PROCESSES, AND RECESSION RATES FROM 1876 TO 1973

by

Charles H. Carter

Columbus
1976

DEPARTMENT OF NATURAL RESOURCES

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LAKE ERIE SHORE EROSION, LAKE COUNTY, OHIO: SETTING, PROCESSES, AND RECESSION RATES FROM 1876 TO 1973

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ABSTRACT

The 30-mile-long Lake County shore is made up of 30- to 40-foot high bluffs and slopes composed of till overlain by glaciolacustrine deposits. Lakeward of the shore are narrow sand beaches (generally several tens of feet wide) and gentle nearshore slopes (about one degree within 500 ft of the shoreline). Along this shore wave erosion is the crucial process. Erosion of in-place or slumped material by storm-generated surface waves reduces the resisting moment at the base of the bluff or slope, leading to and perpetuating shore recession.

Study of maps and aerial photographs of Lake County shows major shoreline changes between 1876 and 1973. In 1876 the Lake County shore had a fairly even outline and was fronted by a continuous beach and several manmade structures; in 1973 the shore had an uneven outline and was fronted by discontinuous beaches and about 400 manmade structures. These changes in outline, beaches, and manmade structures are reflected in recession rates, determined from a 1:4,800 recession-line map of the entire county shore. The principal rate of recession decreased from slow (1-3 ft/yr) in the 1876-1937 period to very slow (<1 ft/yr) in the 1937-1973 period; however, the range of recession rates increased from very slow to moderate (3-5 ft/yr) to very slow to very rapid (7-9 ft/yr).

The manmade structures are the principal cause of these changes in recession rates. The increased number of structures has helped protect the shore from wave erosion by trapping sand (groins) or by directly armoring the shore (seawalls). On the other hand, the few large jetties and large groins, by significantly disrupting the longshore drift, have caused a downdrift increase in nearshore slope and a decrease in beach width, leading to accelerated wave erosion of the shore downdrift of these structures.

INTRODUCTION

PURPOSE

This report on erosion along the Lake County shore is the first of a series of reports that will cover the entire Ohio shore of Lake Erie. The primary purpose of these reports is to provide a basis for intelligent decisions related to shore erosion; such decisions are required because of increased development along the shore and the associated greater probability of increased damage. These reports are concerned also with the long-range problems of shore land and soil lost to the lake and of lake sedimentation. The Ohio Division of Geological Survey hopes that these reports will be broad enough in scope yet detailed enough in nature to serve a useful purpose.

PROBLEM

Shore erosion can be a major problem at times along the lake. For example, in the fall of 1972 and the spring of 1973, storms caused property damage measured in the tens of millions of dollars, and vast amounts of irreplaceable land and soil were lost to the lake. Furthermore, this is just part of the total problem; sedimentation of silt and clay derived from erosion of the shore is contributing to the eutrophication of Lake Erie.

APPROACH

Aside from trying to understand the how and why of shore erosion we have tried to get an idea of the rate at which the shore is receding. Because of the many natural and cultural differences along the shore, the rates are not uniform. Therefore, to get a better idea of recession rates as well as the reason(s) for the nonuniformity in rates, we have used an historic approach to monitor and to map the evolution of the shore. By comparing topographic maps and aerial photographs from different years the natural and cultural changes can be observed, measured, and recorded. The record of these changes can then be used to help decipher the how and why of erosion along the shore.

Maps and photographs from three years—1876, 1937, and 1973—were selected for use in making the recession-line map (table 1). The 1876 maps are the first detailed maps of the entire Ohio shore of Lake Erie, the 1937 photographs are one of the first series of aerial photographs taken of the entire Ohio shore of Lake Erie, and the 1973 photographs

TABLE 1.—*Sources of map and aerial photographic coverage for Lake County*

MAPS

1876 U.S. Army, Corps of Engineers Lake Survey field sheets (scale about 1:10,000)

I-685 to I-690

AERIAL PHOTOGRAPHS

1937-38 U.S. Agricultural Adjustment Administration (scale about 1:7,900)

West	
1 May 38, QC-25-1969	23 Sep 37, QC-10-925
10 Nov 37, QC-19-1543	23 Sep 37, QC-9-843
1 May 38, QC-25-1969	23 Sep 37, QC-9-838
11 Apr 38, QC-21-1639	23 Sep 37, QC-9-758
23 Sep 37, QC-11-1007	22 Sep 37, QC-8-755
23 Sep 37, QC-11-1006	22 Sep 37, QC-8-667
4 Nov 37, QC-15-1155	22 Sep 37, QC-7-663
23 Sep 37, QC-10-928	22 Sep 37, QC-7-569
	East

1973 Ohio Department of Transportation (scale about 1:4,800)

Flight number	Photograph numbers
5196	143-206
5196	223-280

are one of the latest series. The 1876-1937 and 1937-1973 periods were the longest time intervals for which records were available for comparison of recession rates; the lengthy periods eliminate as much as possible the bias of profound changes within a few years time caused primarily by the combination of high lake levels and wind storms. Even these periods may not be long enough. For example, recession rates closely parallel changes in lake level. Within the 1876-1937 period there were 11 years when the mean annual lake level was above 571.0 ft (table 2); during the 1937-1973 period there were 10 years when the mean annual lake level was above 571.0 ft. In other words, if lake level has as important an effect on shore recession rates as we suspect, then the shorter time interval between 1937 and 1973 should show greater recession rates because of the

TABLE 2.—*Annual Lake Erie lake-level averages greater than 571.0 ft above IGLD (1955) at Cleveland since 1875*[1]

1876-1936	Level (ft above IGLD, 1955)	1937-1973	Level (ft above IGLD, 1955)
1876	571.8	1951	571.3
1878	571.3	1952	572.0
1882	571.5	1953	571.3
1883	571.3	1954	571.2
1884	571.4	1955	571.4
1885	571.3	1969	571.5
1886	571.4	1970	571.1
1887	571.4	1971	571.3
1890	571.1	1972	571.9
1929	571.3	1973	572.7
1930	571.1		

[1] Lake Survey Center.

greater frequency of high lake levels within a given period.

Changes in shoreline shape, in beach size and distribution, and in type, size, and distribution of manmade structures can be observed on the maps and photos; the study of these natural and cultural changes through time has proved to be an invaluable tool in the interpretation of recession rates along the Lake County shore.

Terms used throughout the report are defined here:

Erosion.—The general process(es) whereby shore land is lost to the lake. *Wave erosion.*—Erosion that takes place because of the action of surface waves.

Recession.—The landward movement of the shore.

Recession line.—The line along the shore formed by the break in slope between the upland surface and the vertical or sloping surface that fronts the lake.

Recession rate.—The average retreat of the recession line within a given period.

STUDY AREA

Lake County, one of eight Ohio counties that border the southern shore of Lake Erie, lies along the eastern part of the Ohio shore and is bordered on the lake by Ashtabula County to the east and Cuyahoga County to the west. The shoreline length of Lake County is about 30 miles (48 km).

The shore can be divided into two geographic areas, which are separated by the Grand River. The shore west of the river is for the most part urban and built up, whereas the shore east of the river is more sparsely settled and there is some agricultural and forest land. The more densely populated centers include Willowick, Eastlake, Mentor-on-the-Lake, Mentor Headlands, Fairport Harbor, and Madison-on-the-Lake (pl. 1).

Headlands Beach State Park is the only major park along the shore, although there are several (fewer than 10) small city and township parks. The Mentor Marsh State Nature Preserve is located west of Grand River, and there are popular recreational boat harbors at Mentor-on-the-Lake and at the mouth of the Chagrin River in Eastlake.

Three highways, Ohio Rte. 283, Ohio Rte. 44, and Ohio Rte. 535, cut into the shore zone. Major industries located in the Grand River mouth area are the Diamond Shamrock Corporation and the Morton Salt Company. I.R.C. Fibers Company has a plant four miles east of Fairport Harbor, and the Cleveland Electric Illuminating Company has a power plant just west of the Chagrin River mouth.

PREVIOUS WORK

There have been several studies related to the shore and shore processes in Lake County (table 3). However, for the most part these studies have been too general, too local, or too narrow in scope to contribute much to our knowledge of the how and why of shore erosion. Among these reports, those by Christopher (1959), Pincus (1961), and the U.S. Army, Corps of Engineers (1950, 1952, 1954) are probably the best. The report by Stanley Consultants (1969) is also important; even though the report covers only a four-mile stretch of the Lake County shore and much of the report pertaining to shore erosion and shore processes was taken from previous studies, the group did present recession-rate maps based on aerial photographs from 1937 to 1968 as well as a projected recession line for the year 2000.

The well-done study by Christopher (1959) emphasizes geography, geomorphology, and geology. Of particular merit

TABLE 3.—*Reports on shore erosion and shore processes, Lake County*

Author(s)[1]	Date	Area of study
Chieruzzi and Baker	1958	Perry Township Park
Christopher	1955	Mentor Harbor to Fairport Harbor
Christopher	1959	Fairport Harbor to Pennsylvania state line
Gordon	1956	Lakeline to Mentor-on-the-Lake
Pincus	1961	Lake County
Read	1873	Lake County
Stanley Consultants	1969	Cuyahoga-Lake County line to Chagrin River
U.S. Army, Corps of Engineers	1950	Chagrin River to Fairport Harbor
U.S. Army, Corps of Engineers	1952	Fairport Harbor to Ashtabula
U.S. Army, Corps of Engineers	1954	Euclid to Chagrin River

[1] See references cited for specific title.

are the sections on shore stratigraphy and mass wasting. The report is strongly shore oriented, although there is a short section on littoral processes.

Pincus' study (1961), which covers the entire Ohio shoreline, includes aspects of geography and geology related to engineering geology. The report is general (the map scale is about 1:78,000) yet broad in scope and serves as a valuable frame of reference for most shoreline studies of Lake Erie.

The U.S. Army, Corps of Engineers (1950, 1952, 1954) studies were done in cooperation with the state of Ohio. The reports are fairly comprehensive from a geographic-geologic point of view, but are not very detailed except for local areas. Of particular value are the structure inventories and profiles. In addition, general plans for protecting the shore are proposed.

The most specific report done on shore erosion in Lake County is that by Stanley Consultants (1969). Probably the most important aspects of this study are the economic analysis and the photo mosaics, which show the recession of the shore.

GENERAL PROCEDURE

Field studies

Field studies were made in the spring and summer of 1970 and the summer of 1973. The 1970 season, under the direction of Charles E. Herdendorf, consisted primarily of establishing range locations and profile lines, working up the stratigraphy at the range locations, determining the nature of the deposits and the depth to bedrock along the profile lines, and making the 1970 structure inventory.

The 37 profile lines were run from U.S. Army, Corps of Engineers shore points (pl. 1). One additional location, range 18a, was established in 1973 in the Grand River area for horizontal control, but no profile was run. Bluff measurements were made with a hand level or steel tape; a recording echo sounder was used to survey the nearshore bottom. The resulting echograms (fig. 1) indicated bottom relief and type of surface material. Jetting, to determine thickness and type of bottom deposits and depth to bedrock, was done about 500 ft (152 m) from the shoreline. Cores were taken about every 5 ft (1.5 m) during the jetting procedure. Surface samples were taken at about 500 ft (152 m), 1,000 ft (305 m), 1,500 ft (457 m), and 2,000 ft (610 m) from the shoreline with a LaFond-Dietz snapper sampler.

The 1973 season consisted primarily of reconnaissance surveys and spot checks of the stratigraphy and profiles.

Office studies

Office work has consisted primarily of map and photographic studies. Because the maps and the photographs used to prepare the recession-line map (pl. 4) are at different scales (the 1876 maps have a scale of about 1:10,000, the 1937 photographs have a scale of about 1:7,900, and the 1973 photographs have a scale of about 1:4,800), the smaller scale maps and photos were projected and enlarged by means of a Map-O-Graph Model 55 to the 1973 photo scale.

Preparation of the map was essentially a three-stage process: (1) preparation of an overlay map on acetate from the 1973 photographs; this overlay map shows the position of the 1973 recession line as well as certain roads, water towers, houses, and prominent geographic features that can be used to insure accurate correlation and alignment of the overlapping aerial photographs; (2) projection and enlargement of the 1876 maps to the same scale as the 1937 photographs and transfer of the 1876 recession line to the 1937 aerial photographs; (3) projection and enlargement of the 1937 aerial photographs (with the 1876 recession line) to the same scale as the 1973 aerial photographs and transfer of the 1876 and 1937 recession lines to the 1973 acetate base map.

Accurate horizontal control between the 1876 maps

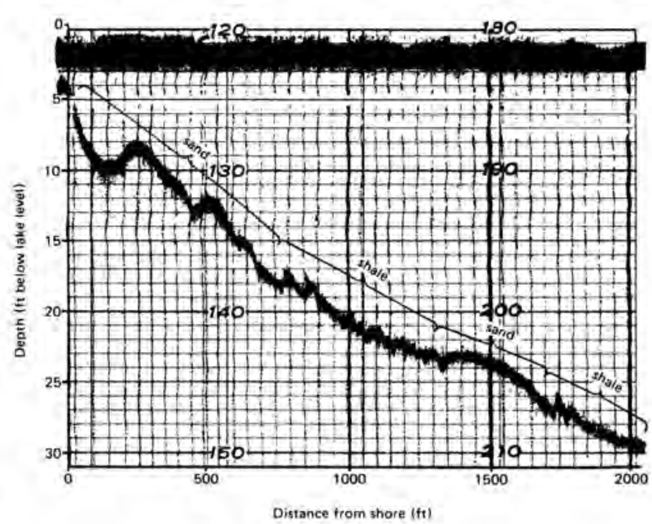


FIGURE 1.—Echogram of range profile 2.

and the 1937 photographs and between the 1937 photographs and the 1973 photographs during projection and enlargement was maintained by correlation of geographic control points and lines. Fortunately the Ohio shore of Lake Erie was sufficiently developed by the 1870's so that the control points and lines found on the 1876 maps were adequate for correlation with the 1937 photographs. For example, on the 1876 maps 79 control points and lines (table 4) could be correlated with control points and lines on the 1937 photographs. Because of increased shore development since 1876, a greater number of control points and lines are present on the 1937 photographs to correlate with control points and lines on the 1973 aerial photographs. Once control points on the map and photo or photo and photo were matched up, many other natural and cultural features could be used to give more precise correlation.

TABLE 4.–*Control-point density, 1876 and 1937*

Reach	Number of control points	Length of reach (1876) (ft)
Cuyahoga-Lake County line-Chagrin River	13	22,400
Chagrin River-Mentor Harbor	15	22,350
Mentor Harbor-Grand River	8	18,050
Grand River-Camp Roosevelt	13	33,000
Camp Roosevelt-Redbird	20	26,450
Redbird-Lake-Ashtabula County line	10	21,250

The recession rate at a given location can be determined by measuring the distance between recession lines for two different years and dividing this distance by the period defined by the recession lines. In measuring recession rates along the shore a scale that showed the map distance for the specific recession-rate classes within a given time period was used. In this way the scale could be moved between two recession lines, and the breaks between the recession-rate classes could be marked off for later measurement of the distance along the shore. The recession-rate classes are: very slow, 0-1 ft/yr; slow, 1-3 ft/yr; moderate, 3-5 ft/yr; rapid, 5-7 ft/yr; very rapid, 7-9 ft/yr. Rates greater than very rapid are given in ft/yr.

Recession volumes (fig. 2) above a lake elevation of 570.0 ft were determined by multiplying the midpoint of

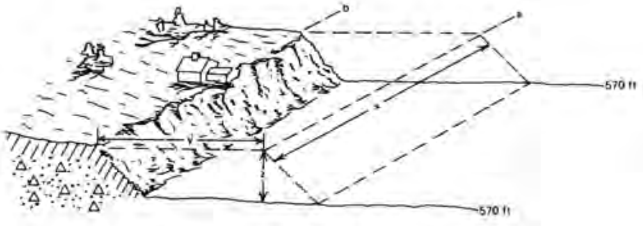


FIGURE 2.–Measurements used in determination of recession volumes.

the recession-rate class (for example, very slow, 0.5 ft/yr, slow, 2 ft/yr) by the stretch length, x (the distance parallel to the shore which receded at that rate), by the thickness, z, of till and/or glaciolacustrine clay along the shore. In practice, because the thickness of till and/or clay differs along the shore, stretch lengths receding at a given rate were subdivided into lengths corresponding to the thickness of the till and/or clay, and recession volumes were computed for these subdivisions.

Accuracy of position of the recession lines is unknown. However, there is much indirect evidence that suggests that the lines are accurate to within a few tens of feet at a given location. Moreover, the greatest source of possible error appears to be human; if this is so, then errors in drawing the recession lines will probably be random so that deviations will tend to even out along the shoreline.

Overall, the map and photograph scales were quite consistent, and the transfer of the recession line from the 1876 maps to the 1937 photographs and from the 1937 photographs to the 1973 photographs was done at essentially the same amount of enlargement.

The base map was more accurate than we expected. East-west and north-south field measurements were made between well-defined points at 11 different locations along the Lake County shore (table 5). Then independently the distances between the same points were measured from the 1973 photographs; the absolute mean of the differences was 4.8 ft, with a range of -11 to +11 ft. The even relief of the lake plain surface along the shore has undoubtedly contributed to the accuracy of the aerial photographs because the pilot could easily maintain a constant elevation. The camera

TABLE 5.–*Field check of 1973 aerial photograph scale*

Station	Direction of measurement	Field measurements, to nearest foot	Photo measurements, to nearest foot	Difference between measurements, to nearest foot
1	EW	418	423	-5
	NS	220	226	-6
2	EW	342	346	-4
	NS	270	273	-3
3	EW	334	323	11
	NS	290	280	10
4	EW	323	326	-3
	NS	294	293	1
5	EW	375	376	-1
	NS	199	190	9
6	EW	296	293	3
	NS	300	303	-3
7	EW	386	383	3
	NS	236	233	3
8	EW	449	460	-11
	NS	331	336	-5
9	EW	380	376	4
	NS	345	350	-5
10	EW	313	313	0
	NS	275	276	-1
11	EW	301	306	-5
	NS	257	266	-9

used to take the photographs was a Zeiss RMKA with a focal length of 152.64 mm (Lloyd Herd, Ohio Dept. Transportation, personal communication, 1975).

One check was used to determine the accuracy of position of the recession lines—surveys were run along the same 37 profiles in 1948 (U.S. Army, Corps of Engineers) and in 1970 (Ohio Division of Geological Survey). These profiles could be located approximately on the aerial photographs and the positions of the profiles then could be transferred to the recession-rate map. The differences in recession lengths between the field measurements of the 1948-1970 period and the map measurements of the 1937-1973 period are shown on table 6. Although the periods are not the same nor of the same length, there is a striking similarity between the two. Of the 27 profiles which can be compared, along 25 the recession-rate classes of the 1937-1973 period are the same (20) or greater than (5) the recession-rate classes derived from the 1948 and 1970 field measurements. Moreover, in spite of the many physical and cultural factors that affect the shore processes, the greater recession rates in the 1937-1973 period than in the 1948-1970 period are to be expected; lake level was extremely high in the early 1970's and above the long-term average level in the early 1940's. The two exceptions, profiles 15 and 16, are not readily understandable; the most likely cause for the difference is a slight error in locating the profile lines on the map. Both profiles are adjacent to stretches undergoing recession at a moderate rate.

Lastly, the overall recession-rate determinations are consistent with historical and modern field investigations and measurements along the Lake County shore.

Laboratory studies

The percentage of gravel and sand in the surficial shore samples was determined by: (1) air drying and weighing of

TABLE 6.—*Measurement of recession distances in the field and from the recession-line map*

Profile no.	1948-1970		1937-1973	
	Field measurements (ft)	Rate[1]	Map measurements (ft)	Rate[1]
1	24	slow	62	slow
2	18	very slow	80	slow
3	78	moderate	144	moderate
4	19	very slow	12	very slow
5	indeterminable[2]			
6	floodplain		floodplain	
7	50	slow	98	slow
8	48	slow	104	slow
9	10	very slow	10	very slow
10	68	moderate	120	moderate
11	61	slow	92	slow
12	floodplain		floodplain	
13	floodplain		floodplain	
14	26	slow	148	moderate
15	106	moderate	78	slow
16	80	moderate	104	slow
17	17	very slow	0	very slow
18	floodplain		floodplain	
19	0	very slow	14	very slow
20	169	very rapid	272	very rapid
21	140	rapid	280	very rapid
22	floodplain		floodplain	
23	70	moderate	200	rapid
24	25	slow	86	slow
25	indeterminable			
26	12	very slow	14	very slow
27	12	very slow	0	very slow
28	18	very slow	0	very slow
29	floodplain		floodplain	
30	3	very slow	38	slow
31	11	very slow	0	very slow
32	16	very slow	0	very slow
33	indeterminable			
34	4	very slow	14	very slow
35	12	very slow	0	very slow
36	2	very slow	34	very slow
37	indeterminable			

[1]Very slow, <1 ft/yr; slow, 1-3 ft/yr; moderate, 3-5 ft/yr; rapid, 5-7 ft/yr; very rapid, 7-9 ft/yr.

[2]Indeterminable means that generally a manmade change in the slope or bluff has made it impossible to make a meaningful measurement.

the samples, (2) wet sieving of the silt- and clay-size particles through a 0.062-mm sieve, and (3) weighing of the gravel and sand caught in the sieve.

Mineralogical determinations were made by x-ray diffraction. Two sets of samples were run, a bulk sample and a 2-micron particle-size sample. The 2-micron samples were run air dried, glycolated, and heated.

ACKNOWLEDGMENTS

Dr. Charles E. Herdendorf and Mr. Lawrence L. Braidech initiated the field part of this study in 1970. Dr. Herdendorf, assisted by Mr. James Daubenspeck, did the sediment sampling, jetting, and coring along the profile lines; Mr. Braidech, assisted by Mr. David B. Gruet, established the profile lines, worked up the shore stratigraphy at the profile locations, and made the 1970 structure inventory. The 1970 echo-sounder profiles were done collectively by these people. Mr. Donald E. Guy, Jr. assisted the writer in the field and office; Mr. Guy's principal contribution was the preparation of the recession-line maps. He also made the 1876 and 1937 structure inventories and did the drafting for the photographs and recession-line maps (pl. 4) as well as performing various and sundry tasks associated with preparation of the report. Mr. Walter R. Lemke, the *GS-1* captain, handled the logistics of the offshore operation and helped with the profiling. Mr. Dale L. Liebenthal, the first mate, helped with the data collection and drafting. Mr. Terry VanOfferen helped in the field in 1973. The staff of the geochemistry laboratory, Ohio Division of Geological Survey, did the mineralogical analyses.

Mr. David Gilmer of the Lake County Planning Commission provided some ideas for topics to be included in the report. Mr. F. G. Haskins of Painesville kindly lent us his copies of the 1937 Lake County aerial photographs until we obtained our own, and, last but not least, the people along the Lake County shore were friendly and helpful toward us in our work.

PHYSICAL SETTING

To facilitate description of the Lake County shore, the shoreland area has been divided into three geomorphic zones: shore, beach and shoreline, and nearshore. The shore zone lies landward of the beach; the beach and shoreline zone lies between the shore zone and the lake; and the nearshore zone lies between the shoreline and about 2,000 ft (610 m) offshore.

METEOROLOGY

Meteorologic processes affect the overall physical setting in the three zones. The following meteorologic information was taken from a report by the Environmental Science Services Administration (1969).

The climate of Lake County is marked by large annual, daily, and day to day ranges in temperatures. West to northerly winds blowing off Lake Erie tend to lower daily high temperatures in summer and raise temperatures in winter. When winds are from directions other than those mentioned above the presence of the lake has little effect upon temperatures within the rolling to hilly portions of Lake County. Summers are moderately warm and humid in this part of Ohio but temperatures rarely climb higher than 90°F. Winters are reasonably cold and cloudy but the relatively warm waters of Lake Erie temper the air temperatures of on shore winds. Because of this tempering effect subzero temperatures occur in only 3 of 5 winters. Weather changes occur every few days from the passing of cold or warm fronts and their associated centers of high and low pressures.

As is characteristic of continental climates, precipitation varies widely from year to year, however, it is normally abundant and well distributed throughout the year with winter being the driest season. Painesville's average annual precipitation of 35.68 inches is slightly more than 1 inch below the mean for northeast Ohio. Showers and thundershowers account for most of the rainfall during the growing season. Thunderstorms occur on about 35 days each year. Most of these occur April through August. Over the level terrain of Lake County, most precipitation during the winter months comes from rain but this is not the case 4 to 7 miles southeast of the Lake as this area is a part of Ohio's "snow belt." Average annual snowfall within Lake County varies from about 55 inches along the Lake Erie shoreline to more than 90 inches along the Geauga-Lake County line. As is typical of all of Ohio, seasonal snowfall in Lake County is subject to wide variations from the annual means.

Winds

Onshore winds along the Lake County shore come from the southwest (the prevailing wind), northwest, and northeast quadrants. Because of the orientation of the lake, the strongest winds come most frequently from the westerly quadrants, with a secondary maximum from the northeast (U.S. Weather Bureau, 1959, p. 13). Winds recorded at Fairport Harbor for a 10-year period are shown on table 7.

TABLE 7.—*Measurement of onshore winds at Fairport Harbor (1 Feb 1932-31 Jan 1942)*[1]

	Direction of wind (percent of total yearly average)				
	SW	W	NW	N	NE
Speed					
0-12 mph	18	7	7	3	9
13-24 mph	5	4	5	2	4
>24 mph	1	2	2	<1	1
Duration	24	13	14	5	14
Movement	22	17	20	6	16

[1] U.S. Army, Corps of Engineers, 1950, pl. 1.

Storms

The following information, which is consistent with the wind data, is from the U.S. Weather Bureau (1959, p. 4).

The more destructive storms on the Great Lakes usually come from a southwesterly direction. These LOWS originally form in three areas: 1) Texas and New Mexico; 2) the Central Rocky Mountains and Great Plains; and 3) the Pacific Southwest. The movement of storms from all three regions is similar, from the Middle West to the Great Lakes. The season for storms from these regions is generally from October through May.

LIMNOLOGY

Limnologic processes also affect the three shoreland zones.

Waves

Because of the prevailing westerly winds and the orientation of the shoreline relative to the lake, most of the surface waves striking the Lake County shore come from the northwest quadrant. Wave height (table 8), determined from weather maps, is greatest from the northwest quadrant.

TABLE 8.—*Wave height data for ice-free period, 1 April to 1 December*[1]

	Height (ft)	Direction of wave (percent)							
		WSW	W	WNW	NW	NNW	N	NNE	NE
Cleveland[2]	0.5-3		1	2	2	3	3	3	2
	3-6		<1	1	1	1	<1	1	<1
	>6		<1	<1	<1	<1			<1
Erie, Pennsylvania[3]	0.5-3	2	3	1	3	3	2	3	2
	3-6	<1	1	<1	1	<1	<1	1	<1
	>6	<1	<1	<1					<1

[1] Saville, 1953, p. B15, C17.
[2] Lake calm or wave height less than 0.5 ft 79 percent of the time.
[3] Lake calm or wave height less than 0.5 ft 77 percent of the time.

Longshore drift

The longshore drift is primarily from southwest to northeast. Reversals in longshore drift do take place from time to time, especially during northeast storms, but, because of the shoreline orientation and the greater fetch for onshore winds from the west, the overall result is a net drift to the northeast. Evidence for this west-to-east movement is seen most readily on the windward (west) side of large structures such as the intake jetties at Chagrin River, the Mentor Harbor jetties, and the Grand River jetties, where large amounts of sand have been trapped by the structures.

Because of the somewhat northerly orientation of the shore from the Cuyahoga-Lake County line to Grand River, the longshore drift along this part of the shore is probably more unidirectional than it is from Grand River to the Lake-Ashtabula County line, where the shore has a more easterly orientation and is less sheltered from easterly winds.

Lake-level changes

Natural lake-level changes can be divided into three types: short term (changes within a few days or less), medium term (changes within a year), and long term (changes over a few years or more).

The short-term changes due to wind-stress buildup, barometric pressure changes, and seiche activity are most pronounced at the confined ends of the lake near Buffalo and Toledo. Because the Lake County shoreline is near the middle of the lakeshore and unconfined, these changes do not have as significant an effect on the lake level along Lake County in comparison to shoreline stretches nearer the ends of the lake.

Medium-term (seasonal) changes are lakewide in effect and are caused primarily by differences in rates of runoff, evaporation, and evapotranspiration. A typical seasonal cycle for Lake Erie shows a high in June-July and a low in January-February; the mean difference in elevation between the high- and low-water stages is about 1.2 ft (Lake Survey Center, 1973).

Long-term changes are caused by: (1) major changes in the weather within the Great Lakes basin, and (2) glacio-isostatic rebound. Weather changes affect precipitation, which, along with secondary factors such as evaporation and runoff, can cause long-term changes in the level of Lake Erie. These changes can be quite pronounced; for example, in December 1934 the mean lake level was about 567.6 ft, whereas in December 1972, after several long-term up-and-down cycles, the mean lake level was about 572.4 ft—a difference of 4.8 ft (Lake Survey Center, 1973). Figure 3 shows the fluctuation of lake level for the interval from 1876 to 1973. The other natural long-term effect, glacio-isostatic rebound, has raised the shore at Port Colborne, Ontario, Canada, relative to the shore at Cleveland, Ohio, an estimated 0.37 ft/century (U.S. Army Engineer Division, 1965, Appendix A, p. A-19). However, the rebound rate is based on water-level measurements made solely within the past 100 years.

The effect of manmade structures and modifications on the level of Lake Erie has been the subject of lively debate, especially during extreme high- and low-water stages. However, data (Great Lakes Basin Commission, 1975, p. 55) indicate that the water level of Lake Erie has been lowered about 3 inches by manmade diversions within the Great Lakes basin.

SHORE ZONE

Geography

The Lake County shore has a flat glaciated appearance that is interrupted here and there by small hills or stream valleys (pl. 1). From the Cuyahoga-Lake County line to Redbird this appearance changes abruptly at the shoreline, where 30- to 40-ft (9- to 12-m) bluffs and/or irregular hummocky slopes commonly mark the interface between the land and the lake. At Redbird and east to the Lake-Ashtabula County line the landscape is much less precipitous, and banks and gentle slopes less than 15 ft (5 m) high are common.

Aside from the shore-lake interface, the most noticeable topographic breaks are the river valleys. Both the Chagrin and Grand Rivers have cut wide deep channels into the surficial deposits; the Mentor Harbor-Mentor Marsh depression is an abandoned Grand River channel. East of Fairport Harbor, the valley of Chapel Creek in Madison Township is the most noticeable topographic break.

Geology

There are four principal deposits that make up the Lake County shore: shale (the bedrock), till, glaciolacustrine clay, and glaciolacustrine sand (pl. 3). These deposits are best exposed along the lakeshore bluffs, although exposures can be found in and along the stream channels.

Shale underlies the entire Lake County study area (pl. 3). The shale contains thin resistant siltstone beds and has a northeast strike and a gentle southeast dip.

Till, which unconformably overlies the shale, is exposed at or near lake level in the bluffs along the entire Lake County shore. The till, which ranges in thickness from 3 ft (1 m) at the Lake-Ashtabula County line to more than 45 ft (14 m) west of Painesville-on-the-Lake, is tough, compact, gray when fresh, and yellow brown when weathered. Joints are common. On the basis of included lake deposits, red clay

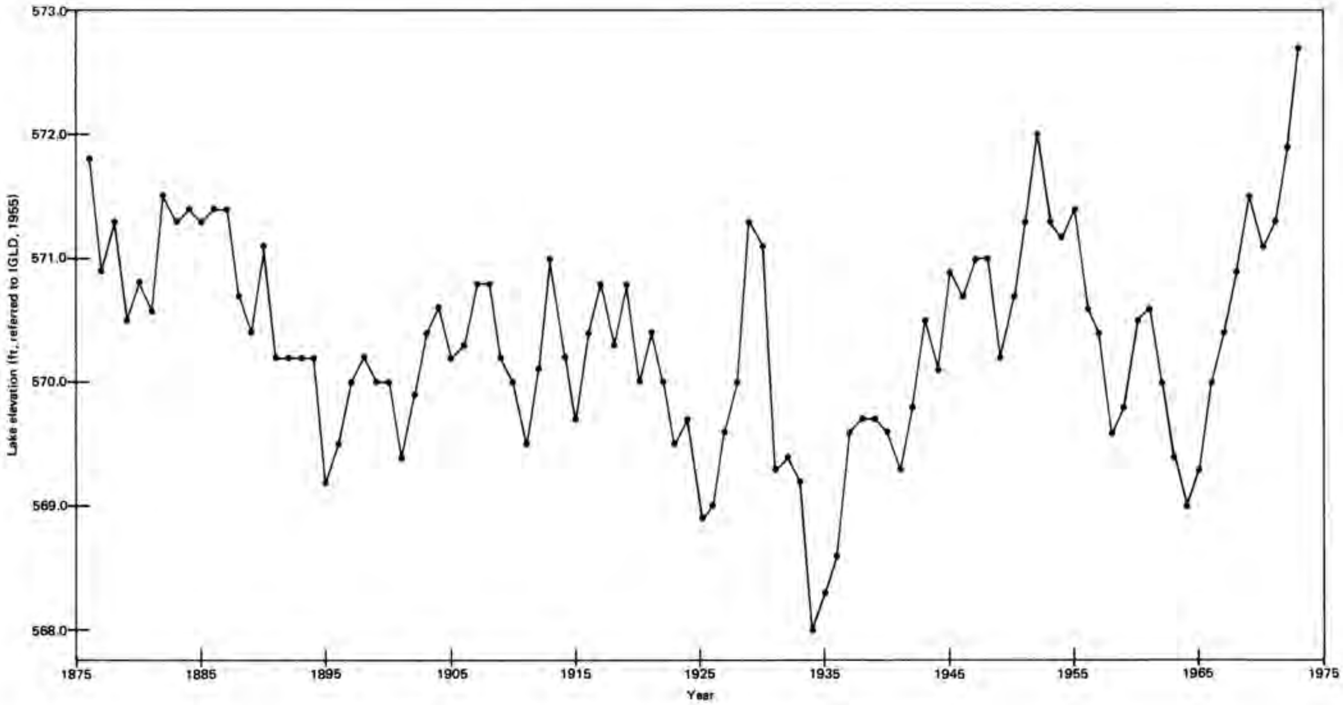


FIGURE 3.–Average water level for Lake Erie, 1876-1973.

lenses, and boulder pavement, Christopher (1959, p. 52, 53) has divided the till into two members. In general the till contains about 80 percent silt and clay, 15 percent sand, and 5 percent gravel (table 9). The clay is illite with minor chlorite (D. L. Streib, Ohio Div. Geological Survey, written communication, 1973).

Lake clay commonly overlies the till; the contact is generally fairly sharp. The clay is thinly laminated, gray to brown, and well sorted; near the till contact stratification is commonly poorly defined and the clay is poorly sorted. In places the clay is deformed. The best exposures of the deposit, which reaches a thickness of 23 ft (7 m), are in the bluffs between McKinley Creek and Chapel Creek. This clay

TABLE 9.–*Grain-size analysis of till*[1]

Range	Grain size (weight percent)		
	Gravel	Sand	Silt and clay
1	5	18	77
2	5	15	80
3	4	13	83
9	7	17	76
10	5	16	79
11	3	16	81
15	1	16	83
19	1	22	77
21	5	12	83
22	4	14	82
23	5	13	82
24	1	14	85
26	3	17	80
27	5	19	76

[1] L. L. Braidech, written communication, 1973.

TABLE 10.–*Grain-size analysis of bluff sand*

Range	Grain size (weight percent)[1]							
	gravel		sand					silt and clay (<0.062 mm)
	pebble (4-16 mm)	granule (2-4 mm)	very coarse (1-2 mm)	coarse (0.5-1 mm)	medium (0.25-0.5 mm)	fine (0.125-0.25 mm)	very fine (0.062-0.125 mm)	
8			1	2	5	31	51	10
11			1	7	18	38	27	8
24	1	1	2	11	11	12	30	31
26				1	5	50	39	4
29				15	27	35	19	4

[1] To nearest one percent.

has the same mineralogy as the clay in the till: illite with minor chlorite (D. L. Streib, written communication, 1973).

Capping the clay is a well-sorted stratified fine- to very fine-grained quartz sand (table 10). The thickest–up to 43 ft (13 m)–exposures of the sand are in the eastern part of the area, especially immediately east of Chapel Creek. Unlike the till-clay contact, the clay-sand contact is commonly gradational.

Pedology

The soils, as expected, mirror the underlying geology. A general soil map of Lake County (Reeder and Sobol, 1973) shows one principal soil association (Conneaut-Painesville) along the shore west of Grand River and two principal soil associations (Conneaut-Painesville and Stafford-Elnora) along the shore east of Grand River. The Conneaut-Painesville soil association has developed primarily on till or glaciolacustrine clay, whereas the Stafford-Elnora soil association has developed on glaciolacustrine sand. The other soils mapped along the Lake County shore are the Orrville-Fitchville (low terrace), Tyner-Otisville, and Marsh. Concise descriptions of these soils as well as some of their agricultural and engineering aspects also are given on the map by Reeder and Sobol (1973).

Ground water

Ground-water measurements show yields of less than five gallons per minute along the Lake County shore (Ohio Division of Water, 1959, 1961). This low yield is directly related to the low porosity and permeability of the underlying clay, till, and shale.

BEACH AND SHORELINE ZONE

Beaches

Sand beaches, which differ greatly in size, form a discontinuous ribbon along nearly the entire Lake County shoreline. The longest continuous stretch of moderate-to-large—greater than 50 ft (15 m) wide—beaches is from North Perry Park to the Lake-Ashtabula County line. Other sizeable beaches are present on the windward (west) side of the jetties at Chagrin River, Mentor Harbor, and Grand River.

The beaches are composed of medium- to very coarse-grained subangular to subrounded well-sorted sand composed largely of rock fragments and quartz (table 11). The beaches from the Cuyahoga-Lake County line to Grand River have an average thickness of about 5 ft (1.5 m), whereas the beaches east of Grand River to the Lake-Ashtabula County line have an average thickness of about 3 ft (1 m). Most of the beaches west of Grand River lie on till; the beaches east of Grand River lie on shale (pl. 3).

Shoreline

The Lake County shoreline has a regular even form on a small scale. The shoreline between the Cuyahoga-Lake County line and Grand River is slightly convex and has an overall orientation of about 230 degrees, whereas the shoreline between Grand River and the Lake-Ashtabula County line is nearly straight and has an overall orientation of about 245 degrees. On a larger scale there are several shoreline irregularities. Most of these are at the mouths of rivers, near bedrock highs, or on the windward side of major manmade structures, where the shoreline is a positive feature and extends out into the lake. On the lee side of major manmade structures the shoreline is a negative feature.

Manmade structures

Manmade structures as well as sand beaches are a significant part of the Lake County shoreline. Almost without exception such structures have a direct effect on the physical processes operating along the shoreline. The structures can be divided into four basic types: breakwaters, jetties, groins, and seawalls; locations are shown on the aerial photographs (figs. 5-70) and descriptions are given in the Appendix. Included in the 402 structures described are 26 breakwaters, 13 jetties, 200 groins, 46 groin fields, and 81 seawalls. The structures range in size from a few feet wide and several feet long to several feet wide and several hundred feet long. Groins and seawalls are distributed along the entire shoreline, whereas breakwaters and jetties are located primarily at the mouths of rivers and harbors. The number of structures is directly proportional to land development.

TABLE 11.—*Grain-size analysis of beach sediment*

Range	Grain size (weight percent)[1]							
	gravel		sand					
	pebble (4-16 mm)	granule (2-4 mm)	very coarse (1-2 mm)	coarse (0.5-1 mm)	medium (0.25-0.5 mm)	fine (0.125-0.25 mm)	very fine (0.062-0.125 mm)	silt and clay (<0.062 mm)
1	1	8	65	25				
2	1	10	40	44	4			
3		7	86	7				
4		4	59	36	1			
5		12	86	2				
6	6	9	10	53	21			
7	24	76						
8	4	18	62	15				
9		12	84	4				
10			51	48				
11	1	2	22	65	9	1		
12		1	42	56				
13		2	9	31	54	5		
14		5	30	62	3			
15	9	64	16	10	2			
16		6	75	19				
17		1	4	18	64	14		
18	1	26	73					
19		10	31	44	14			
20		1	7	34	44	14		
21		2	60	36	1			
22		2	11	34	46	7		
23	5	8	48	38	1			
24	1	4	19	47	23	5	1	
25	1	3	23	66	6			
26		3	11	13	62	11		
27	1	2	5	60	31			
28	2	38	58					
29		6	29	53	11			
30	5	13	43	38	1			
31	4	14	32	50				
32	1	2	35	61				
33	1	1	1	24	69	5		
34		1	20	32	40	7		
35		12	54	32				
36	4	5	17	30	38	6		
37	3	9	4	10	68	6		

[1] To nearest one percent.

The 195 structures located west of Grand River are fairly evenly distributed along the built-up shoreline. Along the sparsely populated shore between Grand River and the Redbird area there are only 79 structures; however, between the Redbird area and the Lake-Ashtabula County line, a much more built-up shoreline only about half the length of the Grand River to Redbird shoreline, there are 128 structures.

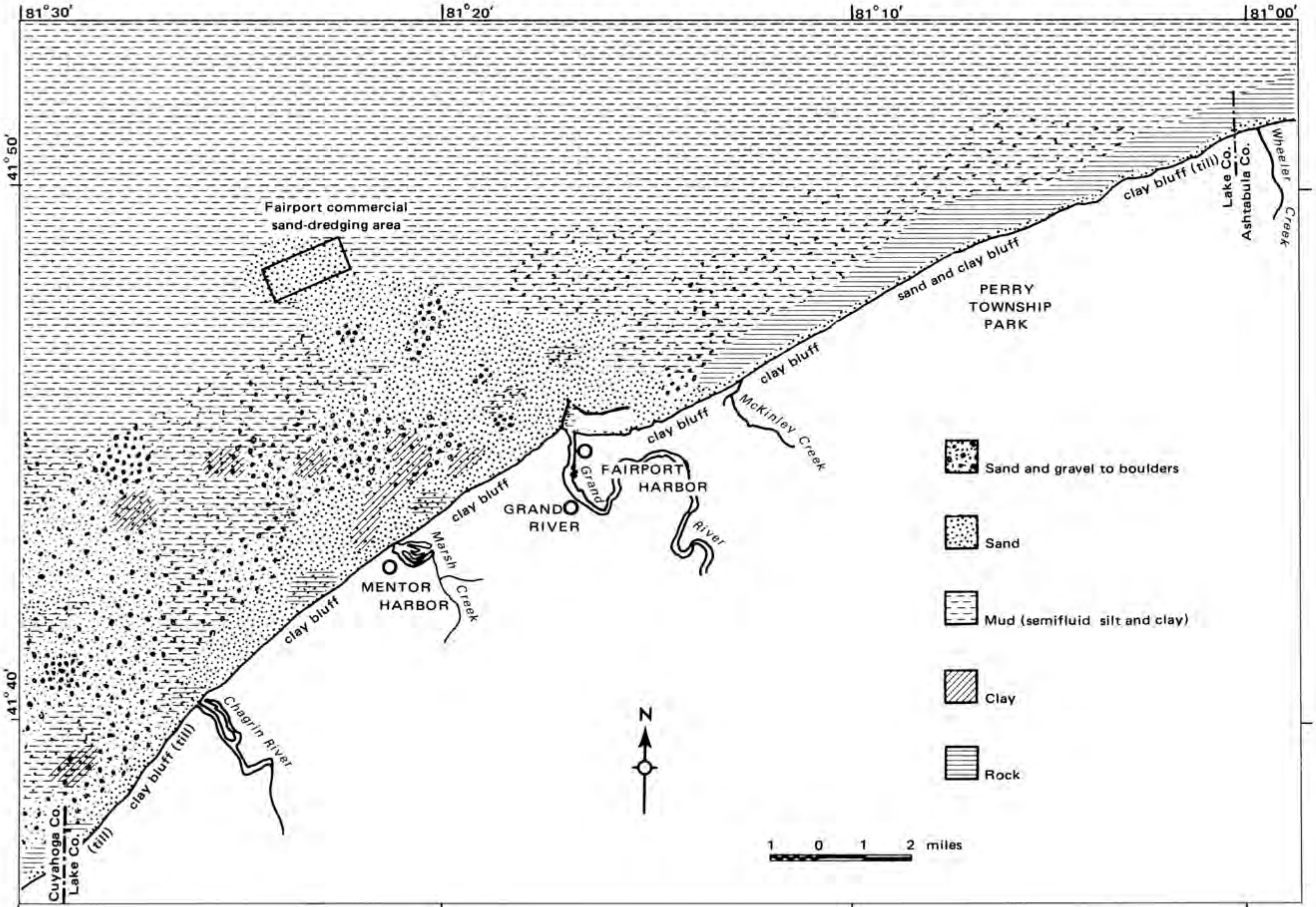


FIGURE 4.–Bottom deposits of Lake Erie along the Lake County shore (after Hartley, 1961).

NEARSHORE ZONE

Bottom deposits

The bottom deposits in the nearshore zone can be divided into two groups on the basis of areal distribution and thickness. West of Grand River, sand extends continuously in most places from the shoreline to more than 1,800 ft (550 m) offshore (pl. 3, fig. 4). The sand forms ripples, dunes, and/or bars and grades from medium to coarse sand at the beach into fine sand and silt offshore. Sand thickness decreases offshore from the beach and shoreline zone. Till generally underlies the sand in the beach and shoreline zone, but in places pinches out lakeward. In the nearshore zone till or shale underlies the sand.

East of Grand River the sand generally is confined to a narrow–less than 300-ft (92-m)–ribbon adjacent to the beach. The sand here forms ripples and dunes; sand bars are uncommon. The grain size of the sand decreases offshore along this stretch also. Offshore from the sand ribbon, shale makes up the bottom in most places.

Nearshore slopes

Along the entire county shoreline the bottom surface to about 2,000 ft (610 m) offshore has a slope of less than one degree (table 12). However, the slope is not constant; in general the slope decreases from the western border to the eastern border of the county. For example, the mean water depth 2,000 ft (610 m) from the shoreline along 17 ranges west of Grand River was 24 ft (7 m), with a range of 14.5 to 30 ft (4 to 9 m), whereas the mean water depth 2,000 ft (610 m) from the shoreline along 18 ranges east of Grand River was 21 ft (6 m), with a range of 17 to 24 ft (5 to 7 m). (Profiles of ranges 8 and 22 did not extend to 2,000 ft offshore.) Within 500 ft (152 m) of the shoreline–in the zone where most of the wave energy is expended on the bottom–the mean water depth is less than 13 ft (4 m).

TABLE 12.–*Nearshore slope and bars*

Range	Slope[1] (water depth/distance from shoreline in ft/ft)	Bars[2]	
		Distance from shoreline to approximate bar crest (ft)	Shape
1	28/2,000	150	poorly defined
2	28/2,000	250	poorly defined
		500	poorly defined
		1,400	poorly defined
3	28/2,000	200	poorly defined
		800	moderately well defined
		1,250	well defined
4	28/2,000	450	moderately well defined
5	30/2,000	200	moderately well defined
		650	moderately well defined
6	27/2,000	600	poorly defined
		1,800	moderately well defined
7	27/2,000	950	moderately well defined
		1,700	poorly defined
8	22/1,600	200	poorly defined
		900	moderately well defined
9	27/2,000	400	well defined
		1,050	moderately well defined
10	25/2,000	200	poorly defined
		700	well defined
		1,450	well defined
11	22/2,000	600	moderately well defined
		900	well defined
		1,400	moderately well defined
12	24/2,000	800	moderately well defined
13	23/2,000	500-1,100	moderately well defined
		1,500	well defined
14	22/2,000	600	poorly defined
		1,050	well defined
		1,650	poorly defined
15	22/2,000	250	moderately well defined
		1,250	well defined
		1,850	poorly defined

Range	Slope[1] (water depth/distance from shoreline in ft/ft)	Bars[2]	
		Distance from shoreline to approximate bar crest (ft)	Shape
16	16/2,000	250	moderately well defined
		700	moderately well defined
		1,350	well defined
		2,000	moderately well defined[3]
17	17/2,000	150	poorly defined
		350	moderately well defined
		1,100	moderately well defined
		2,000	moderately well defined[3]
18	14.5/2,000	150	poorly defined
		550	well defined
		1,000	poorly defined
		1,400	moderately well defined
		1,950	well defined
19	24/2,000		
20	23/2,000		
21	23/2,000		
22	22/1,600	Seawall shore face	
23	23/2,000	140	poorly defined
		500	poorly defined
24	24/2,000	Riprap shore face	
25	21/2,000		
26	20/2,000		
27	20/2,000		
28	20/2,000	250	moderately well defined
29	19/2,000		
30	19/2,000		
31	21/2,000		
32	20/2,000	200	poorly defined
33	18/2,000		
34	17/2,000		
35	19/2,000		
36	23/2,000		
37	20/2,000	700	poorly defined

[1] Lake level was between 2.7 ft and 3.1 ft above Low Water Datum (568.6 ft) when survey was done. A slope of one degree would equal 36 ft/2,000 ft.
[2] Poorly defined, 1-2 ft relief; moderately well defined, 3-4 ft relief; well defined, 5 ft or more relief.
[3] Bar continues offshore beyond 2,000 ft on echogram.

At 500 ft (152 m) the depth of the water decreases from about 13 ft (4 m) along the westernmost reach to about 9 ft (3 m) along the easternmost reach. Structures have influenced the slope in places. The natural slope of ranges 16 to 18 west of Grand River has been reduced because of sand accumulation on the windward side of the west jetty at Grand River; just to the east of the Grand River a scarcity of sand has contributed to a steeper slope.

Nearshore bars

Nearshore bars are most common west of Grand River because of the thicker and more extensive sand deposits. West of the river, 46 bars ranging from poorly defined to well defined (table 12) were picked from the echograms of 18 profiles; east of the river, 5 bars ranging from poorly defined to moderately well defined were picked from the echograms of 19 profiles. Of the 51 bars, 19 are poorly defined (relief of 1 to 2 ft or <1 m above the adjacent bottom), 21 are moderately well defined (relief of 3 to 4 ft or 1 m above the adjacent bottom), and 11 are well defined (relief of at least 5 ft or 1.5 m above the adjacent bottom). The bars have a scattered nearshore distribution, although they are concentrated in three general zones: (1) within 100 to 300 ft (30 to 92 m) of the shoreline, (2) within 500 to 1,100 ft (152 to 336 m) of the shoreline, and (3) more than 1,200 ft (366 m) from the shoreline. Distribution along the shoreline is much clearer: the best defined and most numerous bars are located adjacent to and updrift from the major harbor structures at Chagrin River (range 5), Mentor Harbor (range 13), and Grand River (range 18) (table 12).

SHORE EROSION PROCESSES AND RATES

Shore erosion, the loss of shore land, can be related to many processes, but along the Lake County shore, as along most of the shore of Lake Erie, there are two principal shore erosion processes: wave erosion and mass wasting; of the two processes, wave erosion is by far the more significant. These processes erode the Lake Erie shore at different rates because of two primary factors: the physical setting and the weather. Variation in recession rates among different reaches along the shore and through time generally can be related to these two factors.

PROCESSES

Wave erosion

Surface waves, which are generated by wind blowing across the lake, are the principal cause of recession along the Lake Erie shore because waves contain a great deal of energy that is released when the waves deform and break. Although some of the energy is returned to the lake through reflection and other types of wave-related movement, much of the energy is expended in wave erosion of the nearshore, beach and shoreline, and shore zones.

The effect of nearshore slope on wave energy can be looked at in this general way: (1) wave energy is related directly to wave height; (2) waves deform and break (lose their height) when the water depth is about one to two times the wave height; (3) therefore the gentler the nearshore slope, the farther offshore waves break and the greater the decrease in wave energy reaching the shoreline. Once the waves reach the shoreline a wide beach will absorb most of the wave energy, but along stretches with narrow beaches a much greater proportion of the wave energy will reach the shore.

Lastly, because of the nearly continuous removal of slumped or in-place material, which acts as a resisting moment at the base of the slope or bluff, the shore bluff or slope does not at any time reach a long-term equilibrium. Therefore recession is continuous.

Mass wasting

Mass wasting is basically the downslope movement of material by gravitational stress. The underlying cause of mass wasting in most cases is an unbalanced condition commonly

> . . . brought about by . . . (a) an increase in the weight of the overlying material due to the absorption of water; (b) a decrease in the resisting mass due, for example, to undercutting a slope; (c) a decrease in shear strength of the material itself, which may be caused by the absorption of moisture (Leopold and others, 1964, p. 340).

Along the Ohio shore of Lake Erie the principal mass-wasting processes are block falls, rotational slumps, debris flows, and piping.

Block falls, which are the relatively free-falling movement of coherent material, are caused by wave erosion undercutting the base of a bluff. Rotational slumps, which are a shearing and rotary movement of material along a curved slip surface, appear to be controlled by laminated clay zones within or above the till. When a clay zone becomes lubricated, either from water updip or from surface water percolating down along joint planes, the zone acts as a slip plane upon which the shore material slumps. Debris flows, which are the downward movement of a mass of incoherent material, are most pronounced where there are interbedded sands. Water percolating down from the overlying sands and/or running along the sand-clay interface saturates the clay. This increase in moisture reduces the internal shear resistance of the clay and this, as well as the weight of the overlying sand, causes the clay to deform and flow. Piping, which is erosion by percolating water, is common along sand-clay contacts. Water flowing through an overlying sand layer is concentrated at the clay contact; the consequent decrease in the shear strength of the sand at the contact causes the sand to collapse.

Block falls are common along the high till bluffs east of Painesville-on-the-Lake; rotational slumps are common along most of the Lake County shore, especially between Mentor Harbor and Camp Roosevelt; debris flows are common in the thick clays east of Camp Roosevelt; and piping is common in the thick sands east of Camp Roosevelt.

RATES

Physical setting

The geology of the shore has a direct effect on recession rates. The type of shore deposit, whether rock, till, or glaciolacustrine clay or sand, is most important. A rock-bound shore, for example, generally will erode at a much slower rate than a shore composed of clay or sand, primarily because of the difference in resistance to erosion. Along the

Ohio shore the recession rates increase from rock to till to glaciolacustrine clay to sand.

Wide beaches with associated shallow nearshore slopes and bars afford excellent protection against wave attack because bars and gentle nearshore slope cause the waves to deform and break offshore; at the same time the wave energy reaching the shoreline is absorbed on the beach and not at the base of the slope or bluff. Even during periods of high lake level the combination of nearshore bars, gentle nearshore slope, and a wide beach greatly reduces the recession rate. During a storm, for example, when the nearshore and beach sand is easily eroded, the sand body generally will remain partially intact and will build up again during nonstorm periods.

Shoreline orientation and fetch distance, which essentially determine the exposure to waves, are also important elements in any analysis of recession rates. All other factors in the physical setting being equal, the more normal the shoreline orientation and the longer the fetch distance with respect to the strongest most persistent winds, the greater the recession rate. However, because most of the Lake County shore has about the same shoreline orientation, and fetch distances are approximately equal, shore geology and the hardy triumvirate of beach width, nearshore slope, and nearshore bars have a much more important effect on the recession rates.

Weather

The weather has a direct influence on recession rates. Lake level, which is controlled largely by the weather, is probably the most important factor in recession rates along the Lake Erie shore. Given similar wind conditions, the lower the lake level, the lower the recession rate, because wave energy is expended farther from shore. This relationship can be demonstrated by comparing recession rates during high-water periods and during low-water periods (Benson, 1974).

Wind storms, especially during periods of high lake level, greatly accelerate the normal day-to-day erosion processes. When storm-generated waves several feet high break along the shore tremendous amounts of wave energy are expended in wave erosion. For example, a single severe storm of a few days duration during a high-water period on Lake Erie can directly contribute to removal of as much land as is normally eroded within a period of several years or in some cases an even longer period. Moreover, because of variability of wind-storm intensity, combined with fluctuations in lake level, recession rates over a period of a few years may vary greatly.

The effect of storms, however, can be greatly modified by ice. Because ice generally covers the nearshore and beach and shoreline zones of Lake Erie during the winter months and because most of the intense storm activity in the lake region commonly takes place during the winter, storms do not cause as much damage as they might. Prior to development of lake ice, ice buildup from spray and wave splash helps armor the shore against wave attack.

The weather is important also to mass-wasting processes. When precipitation saturates the unconsolidated easily eroded shore deposits the shear resistance of the deposits decreases and they become more susceptible to failure. Furthermore, the increased weight of the shore deposits accelerates the mass-wasting processes.

Other land-based processes related to the weather include the freeze-thaw and wet-dry cycles that contribute to accelerated erosion, particularly in unprotected areas, by disrupting the surficial deposits.

SHORE EROSION REACHES

The Lake County shore has been divided into six reaches on the basis of physical geography and geology. The reaches are (1) Cuyahoga-Lake County line to Chagrin River, (2) Chagrin River to Mentor Harbor, (3) Mentor Harbor to Grand River, (4) Grand River to Camp Roosevelt, (5) Camp Roosevelt to Redbird, and (6) Redbird to the Lake-Ashtabula County line. For each reach the following topics are discussed: natural setting, natural processes, historic perspective, recession history, interpretation of recession, and recession forecast. A summary and erosion-control suggestions conclude the discussion of each reach. The text for each reach is followed by tables listing nearshore depths, land use, type and number of stickout structures (structures which affect the longshore drift of sand), size and distribution of beaches, and recession rates. Aerial photographs with superimposed 1876, 1937, and projected 2010 bluff lines complete the coverage of each reach.

Within the section on natural setting, the three geomorphic zones (nearshore, beach and shoreline, and shore) are discussed; in the natural processes section the principal erosion processes are discussed; in the historic perspective section, changes in land use, in the number, type, and distribution of stickout structures, in beach size[1] and distribution, and in shoreline shape are chronicled. The section on recession history documents shore recession within two periods, 1876-1937 and 1937-1973; the section on interpretation of recession was written to try to tie together the different natural and cultural features, processes, and influences so that the reasons for the recession rates within a given reach can be explained. The recession forecast is a prediction of where the shore is likely to be in the next 30 to 40 years. The forecast is based on the assumption that recession rates will be about the same as they were in the past 36 years—an uncertain assumption.

For a comparison of erosion processes and recession rates among the six reaches, see p. 89.

CUYAHOGA-LAKE COUNTY LINE TO CHAGRIN RIVER REACH

This is the most densely populated Lake County reach; the shore is nearly completely built up, making recession of any magnitude a serious property-damage problem.

[1] Because beach width at a given time is dependent upon lake level, it is necessary to know the approximate lake-level elevation at the time a survey was done or aerial photographs were taken so that meaningful correlations can be made. The lake level in the summer of 1876 (when field surveying for the map was done) at Cleveland ranged from about 572.0 ft to 572.5 ft; in September-October of 1937 (when photos were taken) the lake level ranged from about 569.3 to 569.9 ft, and in April-May of 1938 (when photos were taken) the lake level at Cleveland was about 570.2 ft; on 15 April 1973 (when the 1973 photos were taken) the lake level at Cleveland ranged from 573.3 to 573.4 ft (Lake Survey Center, 1973). Because of the sizeable difference between the lake levels of 1937-38 and both 1876 and 1973, comparisons of beach size and distribution were not made. However, the much smaller difference between the 1876 and 1973 levels allowed beach size and distribution in those years to be roughly compared. Beach lengths are based on shoreline measurements.

Natural setting, *circa* 1973

Nearshore zone.—Several feet (1 to 2 m) of sand overlie shale or till near the shoreline (pl. 3); 1,500 ft (455 m) offshore the bottom surface is sand or shale. The bottom has a well-defined slope of 5 to 7 degrees within 50 ft (15 m) of the shoreline; offshore the slope is quite gentle, especially beyond 100 ft (30 m) (table 13). The slope is interrupted here and there by sand bars. The best developed bars are located along range profiles 3, 4, and 5 (table 12, table 13, pl. 3).

Beach and shoreline zone.—Beaches front about 70 percent of this reach. The one long natural beach, between range 2 and range 3, is about 2,600 ft (788 m) long and has an average width of about 40 ft (12 m). In addition, there are a few small natural beaches in shallow embayments on the lee side of stickout structures. With the exception of the large—70 ft (21 m) wide by 2,800 ft (855 m) long—beach west of the intake jetty west of Chagrin River, the other beaches are small and have formed on the updrift (west) side of groins. Overall, the beaches have a patchwork distribution that is controlled mainly by stickout structures.

Shore zone.—Till makes up almost all of the shore in this reach. However, a thin—less than 3 ft (1 m) thick—laminated clay unit occurs in places near the base of the bluff, and east of range 3 the till is capped by a thin—less than 10 ft (3 m) thick—clay unit. The recession line is in general well defined; the line is irregular and has an orientation of about 040 degrees.

Natural processes, *circa* 1973

Till falls and rotational slumps are the most apparent results of erosion along this reach. The falls are initiated by wave erosion at the base of the bluff, whereas the rotational slumps, which are indirectly related to wave erosion, result from slipping along the clay unit near the base of the bluff.

Historic perspective: 1876, 1937, 1973

Land use.—This reach shows a steady increase in development from 1876 to 1973 (table 14). In 1876 the shoreland was intensively farmed; by 1937 there was little agricultural land, range, or forest left; by 1973 the shore had become moderately to densely populated. A large power plant was built at the east end of the reach in the 1950's.

Stickout structures.—No manmade structures, except for a pier at the mouth of the Chagrin River, are shown on the 1876 map. By 1937 a large number of stickout structures (groins, breakwaters, and jetties) had been built, and, in general, the number, type, and distribution of these structures have not changed appreciably from 1937 to 1970 (table 15). There is one notable exception—the approximately 1,200-ft (366-m) intake jetties, built in the early 1950's, in front of the power plant at the east end of the reach. Groins make up nearly 90 percent of the structures.

Beaches.—The most apparent difference between the beaches of 1876 and 1973 is the distribution of sand (table 16). The 1876 map shows a continuous ribbon of sand along the entire reach, whereas the 1973 photos (figs. 5-13) and field observations show that the sand now is sporadically distributed along the reach. Commonly the sand is concentrated on the windward (west) side of stickout structures and in places within the embayments in the shadows of these structures. The biggest local change between 1876 and 1973 is formation of the large beach on the west side of the power-plant intake jetties near the Chagrin River.

Shoreline shape.—The shoreline shape was most even and regular in 1876 (pl. 4). In 1937 the overall shape was the same, but in local areas erosion at the ends of closely spaced drain tiles created a sawtooth appearance along the top of the bluff. By 1973, several headlands, particularly along the western half of the reach, give the shoreline a much more uneven form. The headlands represent structurally protected segments of the shore, whereas embayed areas, especially to the east (downdrift) of the headlands, are (or were) structurally unprotected.

Recession history

1876-1937.—The recession rates were quite consistent in this period (table 17). A slow (1-3 ft/yr) rate was exceeded only in a 650-ft (198-m) stretch that had a moderate (3-5 ft/yr) recession rate. This stretch receding at a moderate rate was unprotected by structures in 1937; however, there were stickout structures on either side of the stretch.

1937-1973.—The recession rates in this period were mainly very slow (<1 ft/yr) and slow, although two stretches, with a combined length of over one-half mile (over 800 m), receded at a moderate rate (table 17). Both of these stretches were structurally unprotected and lay adjacent to and east of substantial stickout structures (structures 25 and 60). In general, areas that have a high structure density have lower recession rates than areas with a low structure density. For example, the stretch from structure 27 (between range 3 and range 4) to structure 60 (between range 4 and range 5), a distance of about one mile (about 1,600 m), has receded at slow to very slow rates; this stretch has about 60 structures. The stretch from structure 25 (between range 2 and range 3) to structure 27, a distance of about one-half mile (about 800 m), receded at a moderate rate; this stretch has no structures. No stretches in this reach receded at slow to very slow rates without being fronted by manmade structures.

Interpretation of recession

The best approximation for a natural (pre-structure) recession rate is the rate during the 1876-1937 period; the modal recession rate in this period was slow. In the 1937-1973 period the modal rate was very slow, although there was a sizeable length (15 percent) of the reach that receded at a moderate rate. The greater variability in the recession rates in the 1937-1973 period than in the 1876-1937 period resulted from the manmade structures. Seawalls and similar structures help protect the shore immediately landward of the structures. Groins and similar stickout structures, by trapping sand on the updrift side, reduce the nearshore slope and widen the beach to help protect the updrift shore. At the same time, however, these types of structures deprive the downdrift shore of sand, increase the nearshore slope, narrow the beach, and thus contribute to accelerated recession rates downdrift. This is particularly true along structurally unprotected areas immediately downdrift of substantial structures such as the structure 25 groin field and the structure 12 jetty. Further evidence of this influence can be seen in the more irregular shoreline shape in the 1937-1973 period (figs. 5-13; pl. 4), especially in areas protected by stickout structures adjacent to unprotected areas. Overall, the recession rates have been reduced by these structures from slow to very slow in some areas and have been increased from slow to moderate in other areas.

Recession forecast (2010 A.D.)

Even though this reach has no stretches that have receded at rapid (5-7 ft/yr) or very rapid (7-9 ft/yr) rates, the built-up nature of the land along this shore makes recession a serious property-damage problem. There is one long (nearly 8,500 ft or 2,600 m) stretch, nearly unprotected, that could be a major problem area along this reach: the stretch from between range 1 and range 2 to between range 3 and range 4 (figs. 6-10). The reason for the potential hazard is threefold: (1) the two headlands (one behind structures 10-12 and the other behind structure 25), (2) the scarcity of sand in the longshore drift system available to form protective beaches, and (3) the almost complete lack of structural shore protection.

Summary and erosion-control suggestions

Shoreline structures have had a beneficial effect on some stretches of this reach and an adverse effect on others. Because the principal cause of erosion along this reach is waves, the most likely solution for the erosion problem is toe protection. Because of the scarcity of sand, groins are not advisable. Landscaping to include adequate drainage, tough cover, and toe protection in the form of a wall or armored slope could enhance the natural beauty of the area as well as reduce or eliminate erosion.

TABLE 13.—*Nearshore depths, Cuyahoga-Lake County line to Chagrin River*

Range profile	Nearshore depth (ft)								
	50 ft[1]	100 ft	200 ft	300 ft	400 ft	500 ft	1,000 ft	1,500 ft	2,000 ft
1	5	8	8.5	10.5	12	13	21	25	28
2	4	8.5	8[2]	9[2]	11	12.5[2]	20	23[2]	28
3	7	8	7[2]	10.5	14	16	19.5	24.5	28
4	5.5	8.5	10.5[2]	10[2]	8.5[2]	10.5[2]	21	27	28
5	5.5	7.5	7[2]	11.5	12.5	14	16[2]	23[2]	30

[1] Distance from shoreline in all cases; shoreline is defined as the contact between the lake and the beach. See table 12 for lake level.
[2] Depth to sand bar (crest or limb).

TABLE 14.—*Land use, Cuyahoga-Lake County line to Chagrin River*

Location	Land use[1]		
	1876	1937	1973
County line-R1	agricultural, urban(s)[2], range	urban(s)	urban(d)
R1-R2	agricultural, urban(s), range	urban(s)	urban(m)
R2-R3	agricultural, urban(s), range	urban(s), agricultural	urban(m-d)
R3-R4	agricultural, urban(s), range	urban(s)	urban(m-d)
R4-R5	range, forest, agricultural, urban(s)	urban(d), forest	urban(m)
R5-Chagrin River	forest, range, agricultural, urban(s), wetland	urban(s), agricultural, wetland(fp)	industrial

[1] Land uses for a given year are arranged from left to right in order of amount of land used, largest land use to the left.
[2] (s), sparsely populated, less than one house/acre; (m), moderately populated, one to three houses/acre; (d), densely populated, four or more houses/acre; (fp), floodplain.

TABLE 15.–*Inventory of stickout structures, Cuyahoga-Lake County line to Chagrin River*

Location	Structure no.[1]	Type and number of structures[2]			
		1876	1937	1954	1970
County line-R1	1			x	GF(5)
	3				G
	4			x	GF(12)
			G east of 5		
	5				P
R1-R2	7		x	x	S
	8				G
	9				GF(5)
	10		x	x	B
	11		y	x	G
	12			x	J
			GF(3)	x	
	13			GF(6)	
	14				G(2)
	15		x	G	
	16		x	GF(3)	
	17		y	x	G(2)
	18		x	x	G
	19		x	P	
	20		y		G
	21		y	x	G
	22		x	GF(3)	
R2-R3	23				G
			GF(4)		
	24		y	x	P
	25		x	x	G/B(7)
			GF(3) in area of 26 G between 26 and R3		
R3-R4	27			x	GF(12)
	28			x	GF(4)
	29				J
	30		x	x	P/S
	31			x	G
	32			GF(3)	
	33		y	x	G(2)
	34		y	x	G(2)
	36		y	x	G
	37		y	G(2)	
	38		y		J
	39		y	x	G
	40			G	
	41		y	x	B
	42		y	G	
	43		y	x	G/S
	44		y	G(2)	
R4-R5	45			G	
	46		y	x	G
	47		y	G	
	48		y	G	
	49		y		GF(7)
	50		y	GF(3)	
	51		y		GF(7)
	52		y	B	
	54		y	x	G
	57		y	x	G
	58		y	x	GF(4)
	59		y	x	B/S
	60		y		GF(9)
	61			x	B
	64				G/P
R5-Chagrin River	65		G and G/B 1,000 ft east of R5		G
	66				G
	68		GF(10)	GF(7)	J
	70	P		x	J

[1] Structure numbers correspond to numbers in the Appendix, which is a compendium of information on all structures along the shore of Lake County. Some early (1876-1937) structures, which are not described in the Appendix, are included in the stickout structure table, but are not numbered (for example, the groin field between structure no. 23 and structure no. 24).

[2] B, breakwater; G, groin; GF, groin field; J, jetty; P, pier; S, seawall; (5), number of structures included under one inventory number; x, structure described in a later year is most likely the same structure observed on map or aerial photograph; y, structure described in a later year is possibly the same structure shown on map or aerial photograph; (1924), year the structure was built, if known.

TABLE 16.—*Beaches, Cuyahoga-Lake County line to Chagrin River*

Location	1876			1937			1973		
	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]
County line-R1	700	natural	moderate				400	trapped	small
				1,300	natural	small	500	–	
	500	natural	small				500	trapped and natural	small-moderate
R1-R2							400	–	
							500	trapped	small
							300	–	
	4,800	natural	small	5,000	trapped	small-moderate	400	trapped	small
							300	–	
							2,600	natural	small
							600	–	
R2-R3	2,200	natural	small				1,900	trapped and natural	small
	200	natural	moderate	4,000	trapped	small-moderate	300	–	
	1,600	natural	small-moderate				1,900	natural	small
R3-R4							800	natural	small
	2,100	natural	small	1,800	natural	small-moderate	300	–	
							1,100	trapped and natural	small
	1,600	natural	moderate	1,800	trapped	small-moderate	700	–	
							900	trapped	small
R4-R5							500	trapped	small
							600	–	
				2,500	trapped	small-moderate	500	trapped and natural	small
	3,800	natural	small-moderate				400	–	
				1,300	natural	small	300	trapped	small
							1,300	trapped	moderate
R5-Chagrin River							1,500	trapped	large
	2,850	natural	small-moderate	2,800	trapped	small	1,400	–	

Summary

Width of beach[3]	Beach length (ft)[1]		
	1876	1937	1973[4]
Small	9,600	5,400	11,800
Small-moderate	8,250	15,100	500
Moderate	2,500		1,300
Large			1,500

[1] Measured to nearest 100 ft.

[2] *Natural,* the development of the beach has not been caused by manmade structures; *trapped,* the development of the beach has been caused by manmade structures; –, no beach.

[3] *Small,* less than 50 ft wide; *moderate,* 50 to 100 ft wide; *large,* greater than 100 ft wide.

[4] In 1973 there was 5,800 ft of shore without any beach.

TABLE 17.—*Recession rates, Cuyahoga-Lake County line to Chagrin River*

Location	1876-1937		1937-1973	
	Recession rate[1]	Length (ft)[2]	Recession rate[1]	Length (ft)[2]
County line-R1	very slow	500	slow	1,450
	slow	800		
R1-R2			very slow	300
	slow	1,100	slow	550
			very slow	1,000
	very slow	1,500	slow	1,300
			very slow	1,150
	slow	2,600	slow	500
			very slow	550
R2-R3	slow	3,950	very slow	2,300
			moderate	1,900
R3-R4	slow	550	moderate	600
	moderate	650	slow	1,000
	slow	2,750	very slow	2,400
R4-R5			very slow	1,100
			slow	1,150
	slow	3,750	moderate	800
			slow	500
			very slow	300
R5-Chagrin River	slow	500	very slow	2,800
	very slow	2,650		
	floodplain (1,100 ft)		*floodplain (1,100 ft)*	

Summary

Recession rate[1]	Length in each recession class (ft)[2]	
	1876-1937	1937-1973
Total very slow	4,650	11,900
Total slow	16,000	6,450
Total moderate	650	3,300

[1] Very slow, <1 ft/yr; slow, 1-3 ft/yr; moderate, 3-5 ft/yr; rapid, 5-7 ft/yr; very rapid, 7-9 ft/yr.
[2] Measured to nearest 50 ft.

**AERIAL PHOTOGRAPHS,
CUYAHOGA-LAKE COUNTY LINE TO CHAGRIN RIVER REACH**

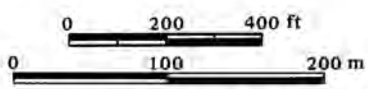
Aerial photography of the Lake County shore was done in 1973 by the Ohio Department of Transportation. The photographs for this reach are reproduced here with superimposed 1876, 1937, and projected 2010 recession lines. The 1876 line is farthest lakeward; the 2010 line is the heavy dashed line farthest landward; the 1876 and 1937 lines are dashed where approximate. The recession lines for the different years coincide where there has been no change.

Range and structure locations also are shown (see Appendix for description of the structures). The following symbols are used:

Range location and number

Structure location and number; dashed line indicates that structure was not found in 1970 survey

Scale on all photos:



Scale distorted toward edges of photos

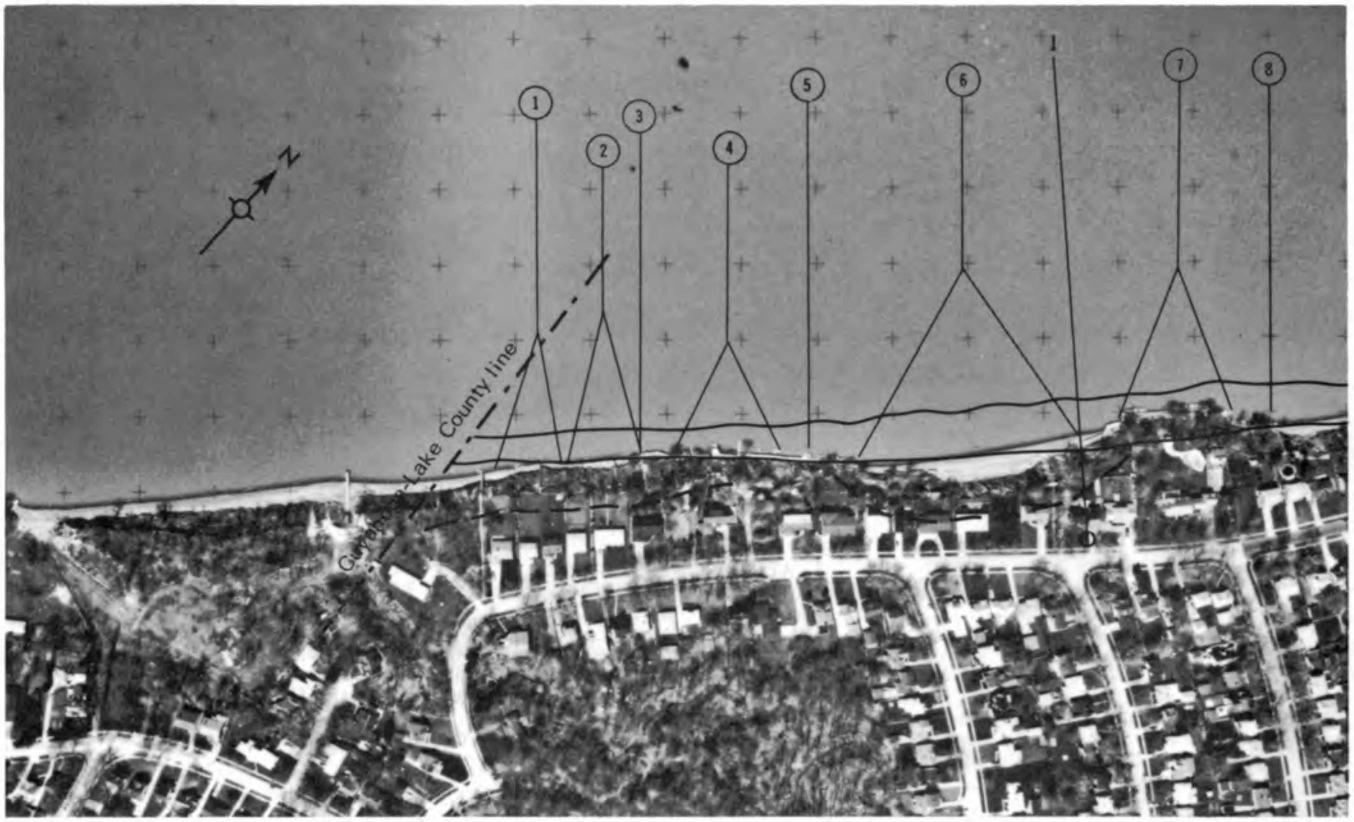


FIGURE 5

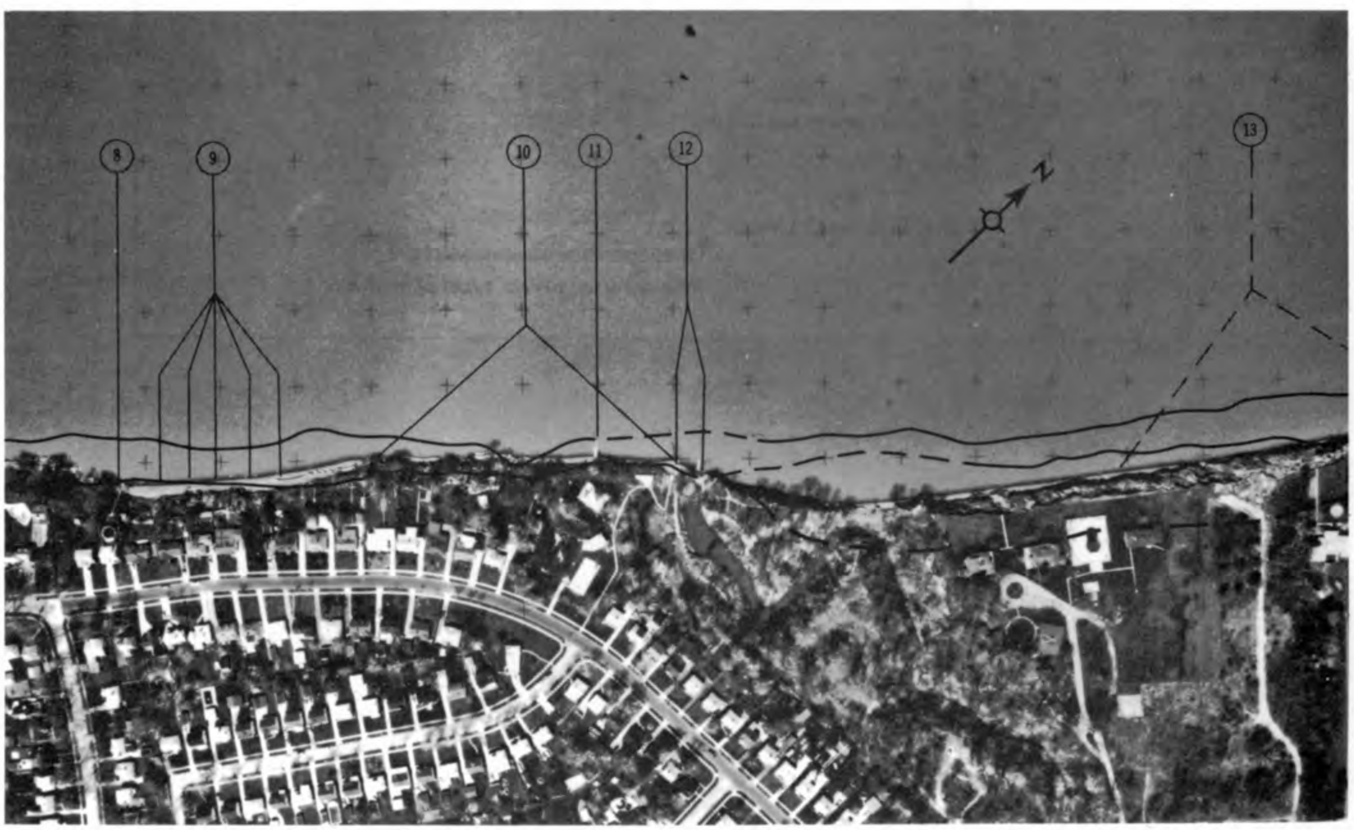


FIGURE 6

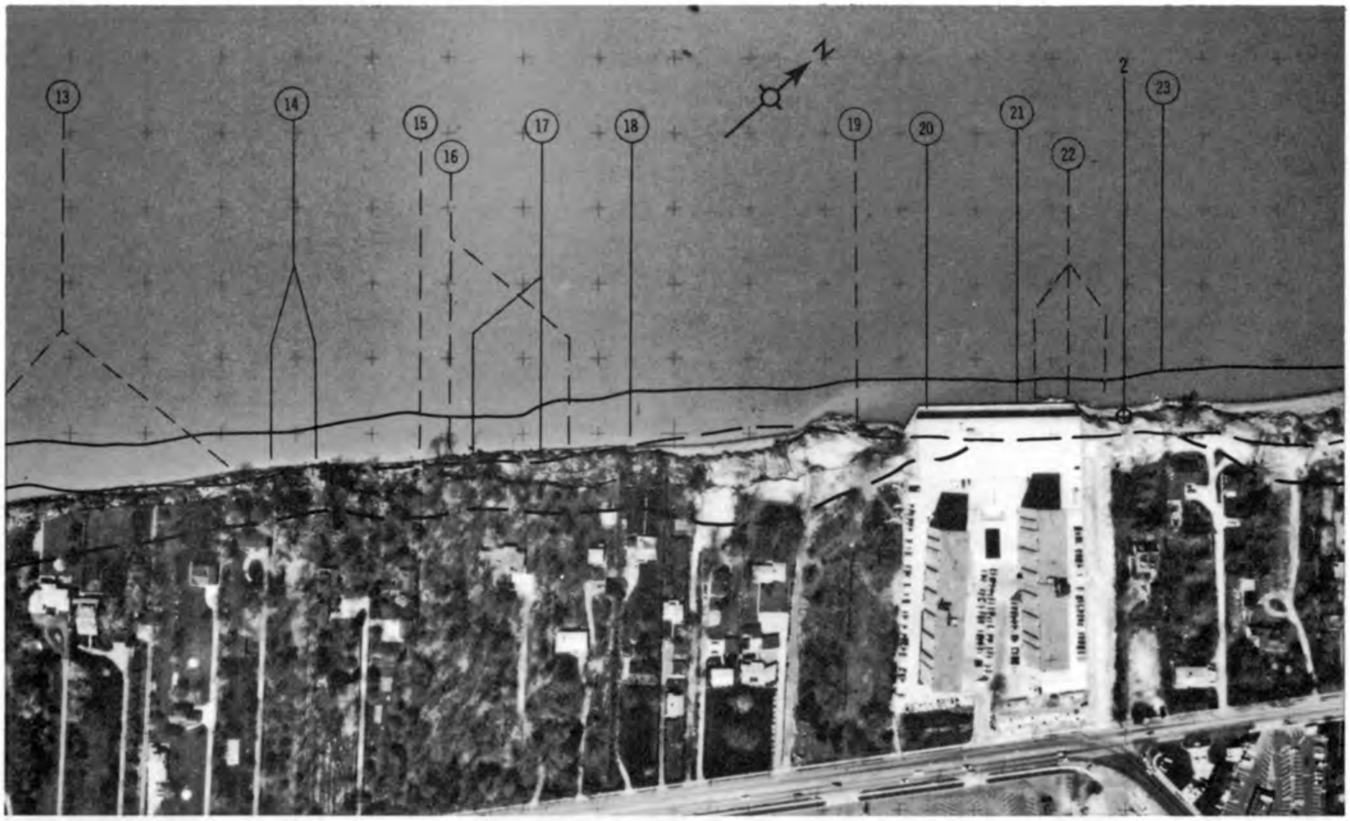


FIGURE 7

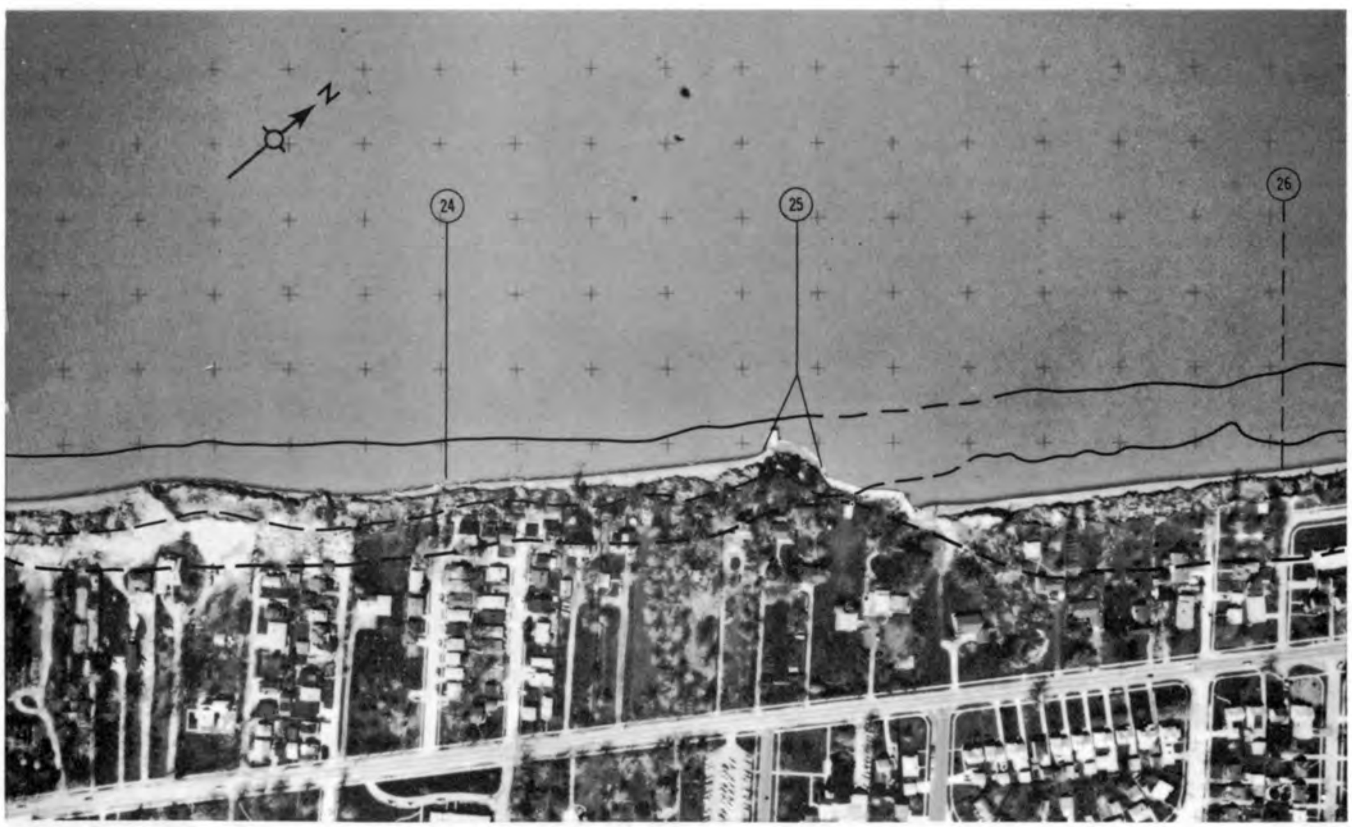


FIGURE 8

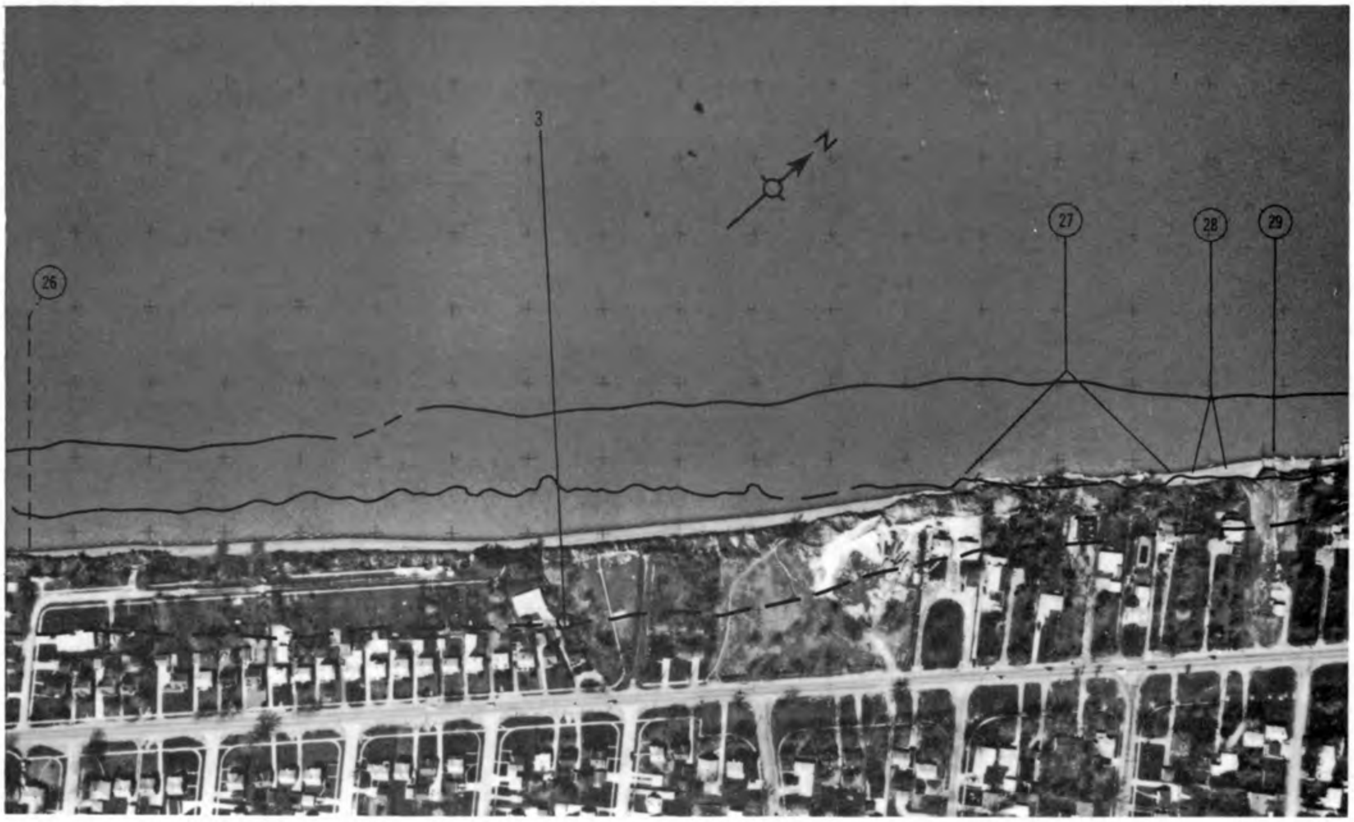


FIGURE 9

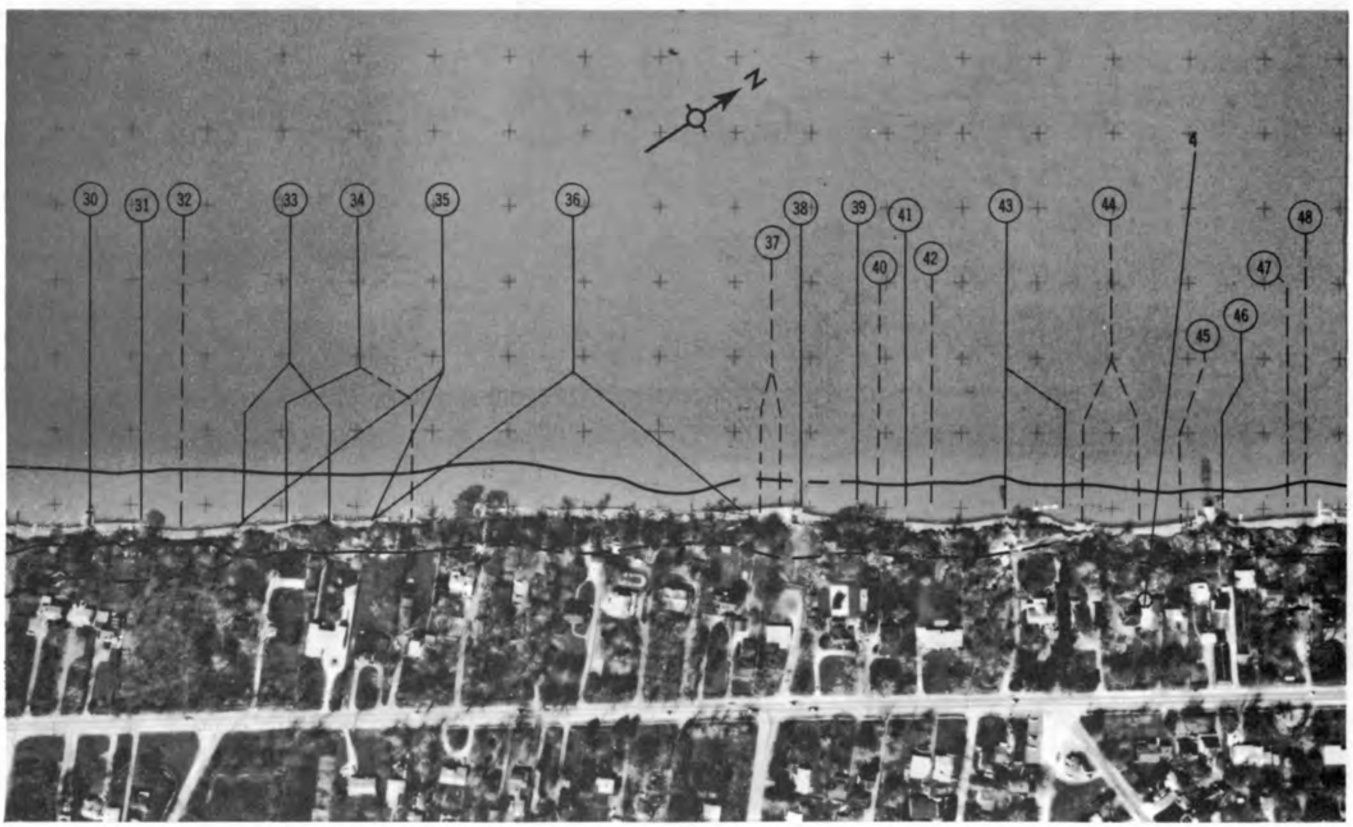


FIGURE 10

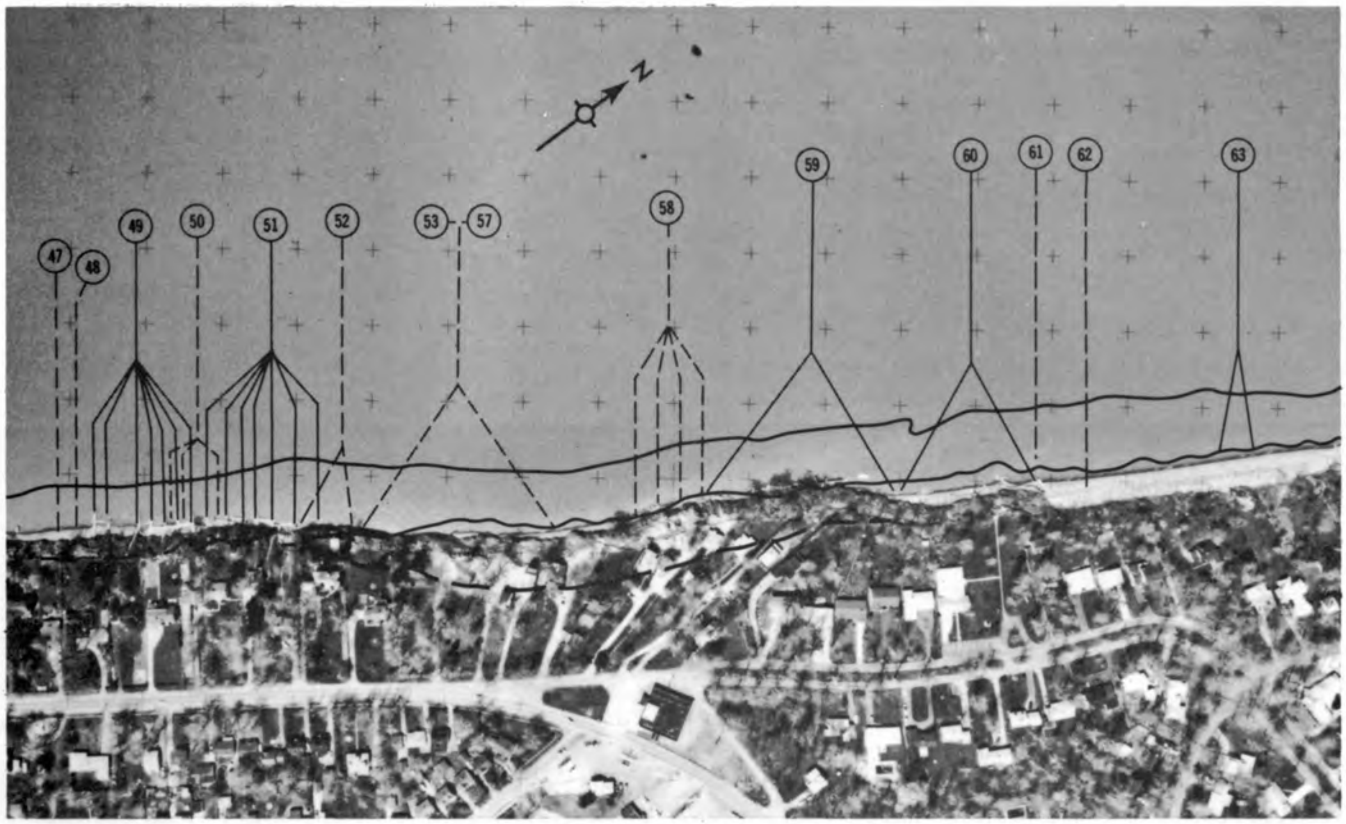


FIGURE 11

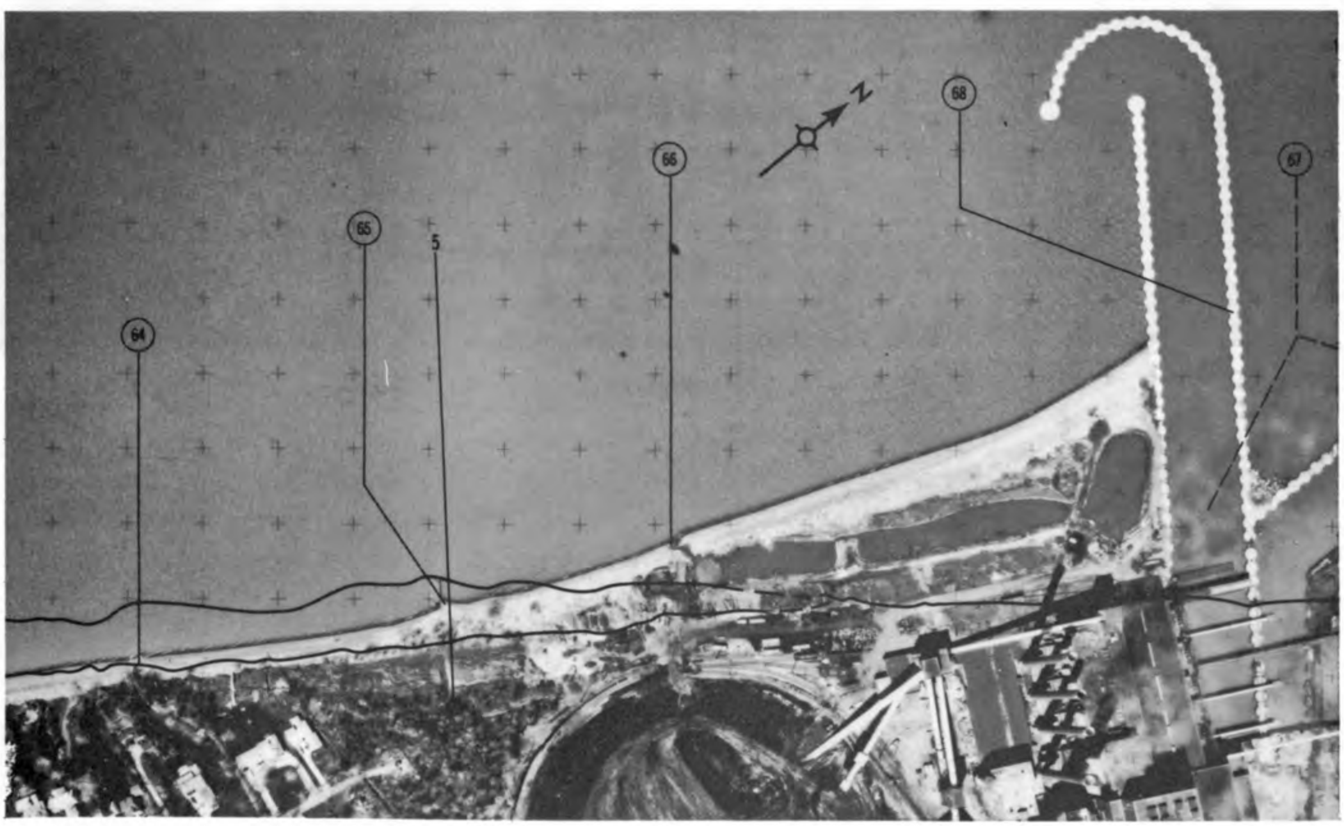


FIGURE 12

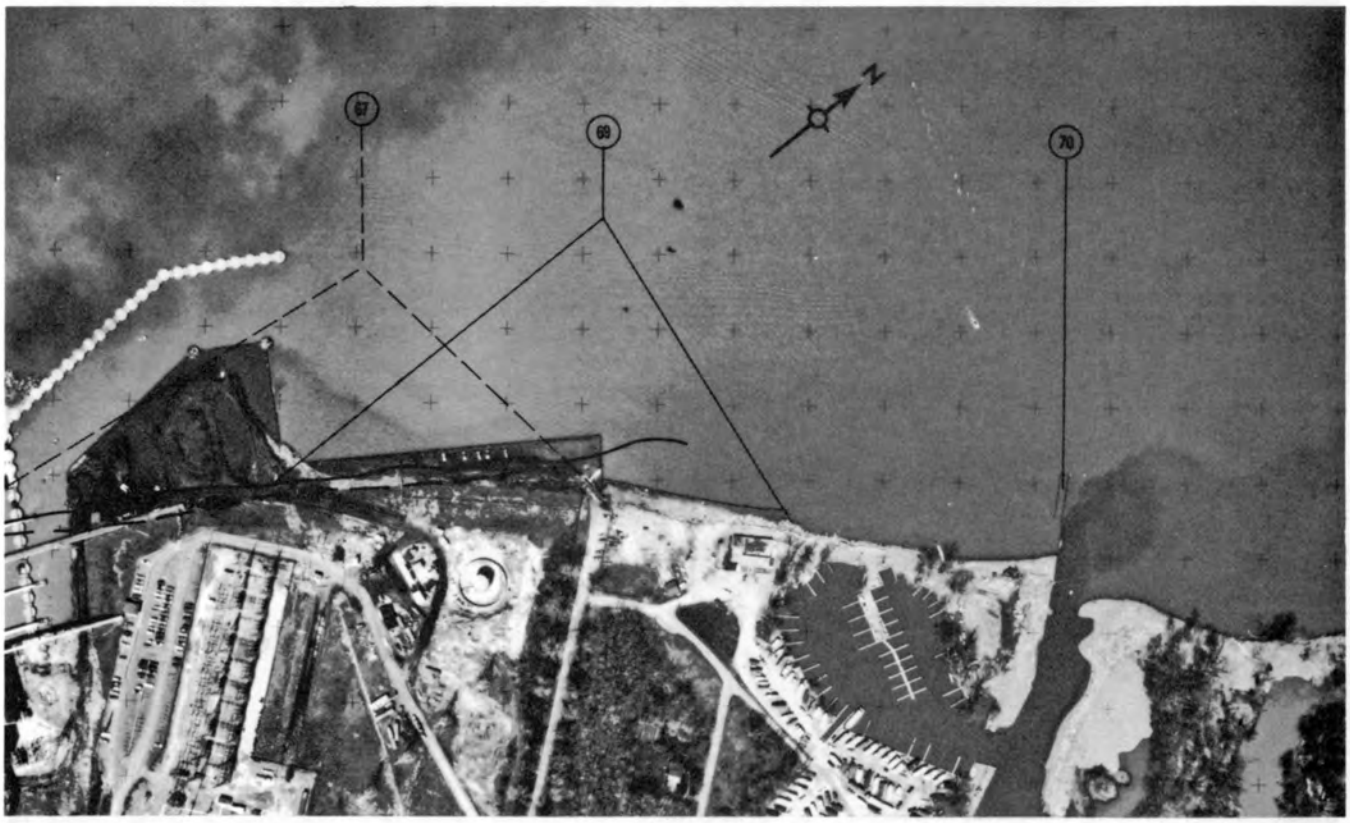


FIGURE 13

CHAGRIN RIVER TO MENTOR HARBOR REACH

This reach is second to the Cuyahoga-Lake County line to Chagrin River reach in amount of built-up land. Private homes front most of the shore; therefore recession is a serious property-damage problem here also.

Natural setting, *circa* 1973

Nearshore zone.—Sand ranging in thickness from a few feet (1 m) to several feet (2-3 m) overlies till in most places along this reach (pl. 3). The sandy bottom has a well-defined slope of between 3 and 9 degrees, with a mean of about 5 degrees, within 50 ft (15 m) of the shoreline; beyond 200 ft (61 m) of the shoreline the slope is a gentle less-than-1-degree surface (table 18). The slope is interrupted here and there by sand bars. The best developed bars are located along range profiles 10, 11, and 13, although each of the other range profiles (6, 7, 8, 9, and 12) has at least one moderately well-developed bar (table 12, table 18, pl. 3).

Beach and shoreline zone.—Beaches front about 72 percent of this reach. Most of the beaches lie to the west (updrift) of stickout structures; for this reason the distribution of the beaches appears to be controlled largely by the stickout structures. The beaches are primarily small; for the most part the larger ones are located along the eastern half of the reach. The largest beach, which fronts the Marsh Creek (Mentor Harbor) floodplain, has been trapped by the Mentor Harbor west jetty. This beach is about 4,400 ft (1,340 m) long and has an average width of about 200 ft (61 m).

Shore zone.—Till overlain by laminated clay with sandy interbeds and capped by well-sorted sand makes up the bluffs in this reach (pl. 2). The clay thickens from a featheredge near the Chagrin River to about 12 ft (4 m) west of Mentor Harbor; the sand has a more irregular distribution.

The recession line (pl. 4) is in general well defined except for the floodplains at the mouth of the Chagrin River and at the entrance to Mentor Harbor. The line has a wavelike irregularity along the central half of the reach, with gentle windward (west) slopes and steep lee (east) slopes; the recession line is more even adjacent to the Chagrin River and Marsh Creek (Mentor Harbor) floodplains at the ends of the reach.

Natural processes, *circa* 1973

Wave erosion, which leads to till falls and slides, is, as along the Cuyahoga-Lake County line to Chagrin River reach, the most significant type of erosion along this reach. Rotational slumps are common and take place near the contact between the till and the clay or within the till near irregularly distributed zones of laminated clay. Piping at the sand-clay contact and debris flows in the laminated clay are common where there are thick sand zones.

Historic perspective: 1876, 1937, 1973

Land use.—This reach shows a more gradual increase in urbanization (table 19) than does the Cuyahoga-Lake County line to Chagrin River reach. However, agricultural land is now virtually absent and there are few undeveloped areas.

Stickout structures.—No manmade structures are shown on the 1876 map, but by 1937 a fairly large number of stickout structures had been built. In general the type and distribution of the structures have not changed appreciably from 1937 to 1970 (table 20), although, parallel to the increased development of the shore zone, there has been a small increase in number of stickout structures. This change is especially noticeable between ranges 10 and 11; between ranges 6 and 7 there has been a decrease in the number of stickout structures since 1937. Groins make up more than 90 percent of the structures. The one large structure, the Mentor Harbor jetty system, was built in 1931 (U.S. Army, Corps of Engineers, 1950, pl. 7).

Beaches.—The beaches in 1973 are distributed sporadically along the reach, whereas the 1876 beaches formed a continuous sand ribbon (table 21). Moreover, some of the stretches that lack beaches in 1973 had moderate to large beaches in 1876. Beaches in 1973 are conspicuously lacking along the front of promontories stabilized by stickout structures. However, sand is concentrated on the windward (west) side of the structures and in places within the embayments in the shadows (east) of these structures. The greatest local change from 1876 to 1973 is along the Chagrin River floodplain (Chagrin River to range 6); a large beach fronted this stretch in 1876, but in 1973 there is no beach, although there are small beaches immediately to the east in the range 6 to range 7 area. In 1937, at a lower lake level, the size of the beach in front of the floodplain still exceeded the size of the beaches immediately to the east in the range 6 to range 7 area.

Shoreline shape.—The shoreline shape was fairly even and regular in 1876 (pl. 4). However, by 1937 a prominent headland had developed near range 8 (fig. 17), and the shoreline was more irregular. By 1973 a prominent headland had developed west of range 10 (fig. 20), and the shoreline had become even more irregular than in 1937. The headlands represent structurally protected segments of the shore, whereas the embayments, especially to the east of the headlands, are (or were) structurally unprotected. The increase in unevenness of the shoreline with time indicates the increasing influence of manmade structures.

Recession history

1876-1937.—The recession rates in this period were slow and very slow except for two stretches between ranges 8 and 9 where the shoreline receded at a moderate rate (table 22). These stretches are directly to the east of a headland; this headland was protected by a large seawall-groin field constructed in 1928 (U.S. Army, Corps of Engineers, 1950, pl. 7). By 1937, 17 groins fronted the shore between ranges 8 and 9.

1937-1973.—The recession rates in this period were mainly very slow and slow (table 22). However, three stretches receded at a moderate rate. Two of the stretches lie immediately adjacent to range 10 and between range 10 and range 11 and are directly east of a headland. This headland is protected by a large seawall-groin field constructed in 1926 (U.S. Army, Corps of Engineers, 1950, pl. 7). The third stretch which receded at a moderate rate in this period is between range 6 and range 7. The structure density along and to the west of this stretch has stayed about the same from 1937 to 1973; there is a small structurally protected headland immediately to the west.

Interpretation of recession

The best approximation for a natural (pre-structure) recession rate is the rate during the 1876-1937 period; the recession rate in this period was primarily slow. In the 1937-1973 period the recession rate was largely very slow, although about 20 percent of the reach had a moderate rate.

The major cause of the moderate rate between ranges 8 and 9 in the 1876-1937 period appears to be the structural headland near range 8. This man-influenced feature has deprived the immediate downdrift shore of sand by either trapping sand and/or forcing sand far enough offshore so that the sand could not enter the nearshore system until much farther downdrift (east). The very slow recession rate in the 1937-1973 period along this stretch is probably due to the increased number of structures downdrift, although the structural headland now partially shelters the stretch from waves from the west.

The increased structural protection which slowed the recession rates between range 8 and range 9 in the 1937-1973 period may have caused an increase in recession rates in the two stretches near range 10. In the 1876-1937 period these stretches receded at very slow to slow rates, probably because recession of the updrift shore (range 8 to range 9) put more sand into the longshore drift system. This sand was incorporated into beaches within the range 10 to range 11 stretch, and the larger beaches helped reduce the recession rates. However, with increased structural protection along the range 8 to range 9 stretch the amount of sand derived from this stretch decreased, and the recession rates in the range 10 area increased.

The moderate recession rate in the stretch between range 6 and range 7 in the 1937-1973 period is probably due to a decrease in sand supply; the type and density of structures have stayed about the same in this area since 1937, while the beach size has changed drastically. The water-intake jetties along the west side of the Chagrin River are probably the cause of the loss of sand to this area.

The most significant recession-rate factor then appears to be the stickout structures. Overall, the rate of recession has decreased from slow to very slow west (updrift) of the structures and has increased from slow to moderate east (downdrift) of the structures. Further evidence of the influence of stickout structures can be seen in the increasing irregularity of the shore with time, particularly in areas protected by stickout structures adjacent to unprotected areas. Another major factor contributing to a lower recession rate along this reach, in contrast to the Cuyahoga-Lake County line to Chagrin River reach, is the beaches. These beaches, which are made up of sand derived principally from erosion of the shore and/or from sand in the nearshore zone, appear to have greatly retarded the recession rate. For example, even in areas downdrift of substantial structures, erosion of the bluffs and formation or buildup of a beach has helped protect the shore from wave erosion and in so doing has retarded the recession rate.

Recession forecast (2010 A.D.)

Recession will continue to be a problem along this reach, particularly along the stretches that underwent recession at a moderate rate in the 1937-1973 period. The reason is threefold: (1) the natural and/or man-influenced headlands, (2) the water-intake jetties along the west side of the Chagrin River, and (3) the scarcity of structural protection along the stretches undergoing recession at a moderate rate.

Summary and erosion-control suggestions

As in the reach to the west, shoreline structures have had a beneficial effect on the land behind and/or updrift of them and an adverse effect on unprotected stretches downdrift of them.

One measure that could be used to reduce the recession rates, especially in the areas receding at moderate and slow rates, is construction of properly designed groins and/or breakwaters, which, by trapping sand or breaking down waves, would reduce the effect of wave erosion and the resultant mass wasting. The moderate sand supply along this reach and the short length of the unprotected areas relative to the overall reach length would support this measure.

Landscaping, in conjunction with adequate drainage, tough cover, and toe protection, in areas such as Willoughby Park that do not have houses along the edge of the bluff is probably the best overall plan for reducing or eliminating shore erosion along this reach. In addition, interceptor drains at the sand-clay contact would reduce piping and increase the shear resistance of the underlying clay, thus increasing stability of the slope above the till.

A system to bypass sand around the large intake jetties on the west side of the Chagrin River, or modification of the structure to allow sand to pass through it, would reduce wave erosion to the stretch adjacent to and east of the river. This, however, would affect the harbor entrance.

TABLE 18.–*Nearshore depths, Chagrin River to Mentor Harbor*

Range profile	Nearshore depth (ft)								
	50 ft[1]	100 ft	200 ft	300 ft	400 ft	500 ft	1,000 ft	1,500 ft	2,000 ft
6	8.5	10.5	12.5	14	14.5	14.5	19.5	25	27
7	4.5	6.5	9	13	14.5	14.5	17[2]	21.5[2]	27
8	5.5	7.5	6[2]	10	12	13.5	14.5[2]	21.5	[3]
9	6.5	9	10.5	10[2]	7[2]	10[2]	17[2]	18.5	27
10	5	8.5	8[2]	9.5[2]	11[2]	13	15.5	14[2]	25
11	4	8	11	11.5	13	14	13.5[2]	19[2]	22
12	5	7	10.5	13	14	14	14.5[2]	19	24
13	3	5	10	11	13	12.5[2]	15.5[2]	16.5	23

[1] Distance from shoreline in all cases; shoreline is defined as the contact between the lake and the beach. See table 12 for lake level.
[2] Depth to sand bar (crest or limb).
[3] Profile did not extend to 2,000 ft offshore.

TABLE 19.–*Land use, Chagrin River to Mentor Harbor*

Location	Land use[1]		
	1876	1937	1973
Chagrin River-R6	range, wetland	urban(s)[2], wetland	urban(m), wetland
R6-R7	agricultural	urban(s), agricultural	urban(s-m)
R7-R8	range, agricultural, urban(s)	urban(s), agricultural	urban(s-m)
R8-R9	agricultural, range, urban(s)	urban(s-m), agricultural	urban(s-d)
R9-R10	agricultural, forest, range	urban (s), agricultural	urban(m), range
R10-R11	range, forest, agricultural	urban(s), agricultural, forest	urban(s-m)
R11-R12	forest, range	forest, urban(s)	urban(s), forest
R12-R13	range, wetland, agricultural	wetland, forest, urban(s)	wetland, forest, urban(s)
R13-Mentor Harbor	wetland	wetland	wetland

[1] Land uses for a given year are arranged from left to right in order of amount of land used, largest land use to the left.
[2] (s), sparsely populated, less than one house/acre; (m), moderately populated, one to three houses/acre; (d), densely populated, four or more houses/acre.

TABLE 20.–*Inventory of stickout structures, Chagrin River to Mentor Harbor*

Location	Structure no.[1]	Type and number of structures[2] 1876	1937	1950	1970
Chagrin River-R6					
R6-R7	72		x	G	
			P		
	73				J
			GF(3) between 73 and 75		
	75		x	G(2)	
	76		x(1924)	x	G(2)
	77		y,G	G(2)	
			G		
	78				G(3)
	79				G/B
R7-R8	80				J
	81				GF(3)
	82		y,GF(7)	GF(6)	
	85		x	x	GF(4)
	87		x(1928)	GF(12)	
R8-R9	89		x	G	
			GF(4)		
	90		x	G	
			G(1)		
	91				G
	92		x(1922)	G	
	93				G
	94		x(1925)	x	G
	95		x	x	G
	96				G
	97		y		G
	98		y		G
	100		x(1927)	G	
	101				G
	102		y		G(2)
	103		y(1922)	G	

Location	Structure no.[1]	Type and number of structures[2] 1876	1937	1950	1970
	105		y		G
	106				G
	107		x	x	G
R9-R10	108		x	x	G
	109		y		G
	110		x	x	G
	111		x	GF(3)	
	114				G
	116		y		G
	118		y(1926)	x	GF(7)
R10-R11	121				GF(6)
	124				GF(10)
	125				G
	126				G
	127				G
	129				GF(6)
	130				G(2)
	131				GF(5)
	132				GF(4)
	133		G		
	135				GF(3)
R11-R12	136				G
	138		x	x	GF(5)
			G(2) between 140 and 141		
	141				G
	142		x	G	
			G between 142 and 143		
	143		x	GF(3)	
R12-R13	144		x	GF(3)	
	145		x(1931)	x	J(2)
R13-Mentor Harbor					

[1] Structure numbers correspond to numbers in the Appendix, which is a compendium of information on all structures along the shore of Lake County. Some early (1876-1937) structures, which are not described in the Appendix, are included in the stickout structure table, but are not numbered (for example, the groin field between structure no. 23 and structure no. 24 on table 15).
[2] B, breakwater; G, groin; GF, groin field; J, jetty; P, pier; S, seawall; (5), number of structures included under one inventory number; x, structure described in a later year is most likely the same structure observed on map or aerial photograph; y, structure described in a later year is possibly the same structure shown on map or aerial photograph; (1924), year the structure was built, if known.

TABLE 21.–*Beaches, Chagrin River to Mentor Harbor*

Location	1876			1937			1973		
	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]
Chagrin River-R6	2,000	natural	large	2,000	natural	large	2,000	–	
R6-R7	1,500	natural	large	1,500	natural	moderate-large	1,000	–	
							600	trapped	small
	700	natural	large	400	trapped	small-moderate	600	trapped	small
	400	natural	moderate	700	–		1,600	–	
	1,900	natural	small	1,400	trapped	small	800	natural	small
				600	trapped and natural	moderate			
R7-R8	3,800	natural	small-moderate	2,300	trapped and natural	small-moderate	2,600	trapped	small
				1,400	–		1,000	–	
R8-R9							200	–	
	4,000	natural	small	4,000	trapped	small	1,600	natural	small
							2,100	trapped	small-moderate
R9-R10	300	natural	small	1,300	trapped	small-moderate	200	trapped	small
							800	–	
	3,100	natural	moderate-large	800	trapped	moderate	1,400	trapped	small
							900	–	
	400	natural	small-moderate	1,500	trapped	small	500	trapped	small
R10-R11							1,100	trapped	small
							800	trapped	small-moderate
				700	natural	small	1,000	trapped	small
	4,900	natural	small				1,000	trapped	small-moderate
				4,200	natural	moderate-large	800	–	
							200	trapped	small
R11-R12	2,300	natural	small-moderate	700	trapped	small-moderate	2,300	trapped	small
				1,500	trapped	small			
R12-R13	200	natural	moderate	500	trapped	small	500	trapped	small-moderate
	4,100	natural	large	3,900	trapped	large	3,800	trapped	large
R13-Mentor Harbor	500	natural	large	500	trapped	large	500	trapped	large

Summary

Width of beach[3]	Beach length (ft)[1]		
	1876	1937[4]	1973[4]
Small	11,100	9,600	12,900
Small-moderate	6,500	4,700	4,400
Moderate	600	1,400	
Moderate-large	3,100	5,700	
Large	8,800	6,400	4,300

[1] Measured to nearest 100 ft.

[2] *Natural,* the development of the beach has not been caused by manmade structures; *trapped,* the development of the beach has been caused by manmade structures; –, no beach.

[3] *Small,* less than 50 ft wide; *moderate,* 50 to 100 ft wide; *large,* greater than 100 ft wide.

[4] In 1937 there was 2,100 ft and in 1973 8,300 ft of shore without any beach.

TABLE 22.–*Recession rates, Chagrin River to Mentor Harbor*

Location	1876-1937		1937-1973	
	Recession rate[1]	Length (ft)[2]	Recession rate[1]	Length (ft)[2]
Chagrin River-R6	*floodplain (2,050 ft)*		*floodplain (2,050 ft)*	
R6-R7	*floodplain (1,450 ft)*		*floodplain (1,450 ft)*	
	very slow	1,800	slow	2,050
	slow	1,400	moderate	1,150
R7-R8			very slow	1,150
	slow	3,750	slow	1,100
			very slow	1,700
R8-R9	moderate	1,700		
	slow	1,500	very slow	4,150
	moderate	800		
R9-R10			very slow	400
	slow	2,200	slow	1,100
	very slow	1,600	very slow	2,050
			moderate	350
R10-R11	very slow	1,050	moderate	300
			slow	750
	slow	3,100	moderate	2,800
			very slow-slow	700
	very slow	800	slow	550
R11-R12	very slow	800	slow	700
	slow	1,650	very slow	1,800
R12-R13	slow	400	very slow	500
	floodplain (3,900 ft)		*floodplain (3,800 ft)*	
R13-Mentor Harbor	*floodplain (500 ft)*		*floodplain (500 ft)*	

Summary

Recession rate[1]	Length in each recession class (ft)[2]	
	1876-1937	1937-1973
Total very slow	6,050	11,750
Total very slow-slow		700
Total slow	14,000	6,250
Total moderate	2,500	4,600

[1] Very slow, <1 ft/yr; slow, 1-3 ft/yr; moderate, 3-5 ft/yr; rapid, 5-7 ft/yr; very rapid, 7-9 ft/yr.
[2] Measured to nearest 50 ft.

**AERIAL PHOTOGRAPHS,
CHAGRIN RIVER TO MENTOR HARBOR REACH**

Aerial photography of the Lake County shore was done in 1973 by the Ohio Department of Transportation. The photographs for this reach are reproduced here with superimposed 1876, 1937, and projected 2010 recession lines. The 1876 line is farthest lakeward; the 2010 line is the heavy dashed line farthest landward; the 1876 and 1937 lines are dashed where approximate. The recession lines for the different years coincide where there has been no change.

Range and structure locations also are shown (see Appendix for description of the structures). The following symbols are used:

Range location and number

Structure location and number; dashed line indicates that structure was not found in 1970 survey

Scale on all photos: 0 200 400 ft; 0 100 200 m

Scale distorted toward edges of photos

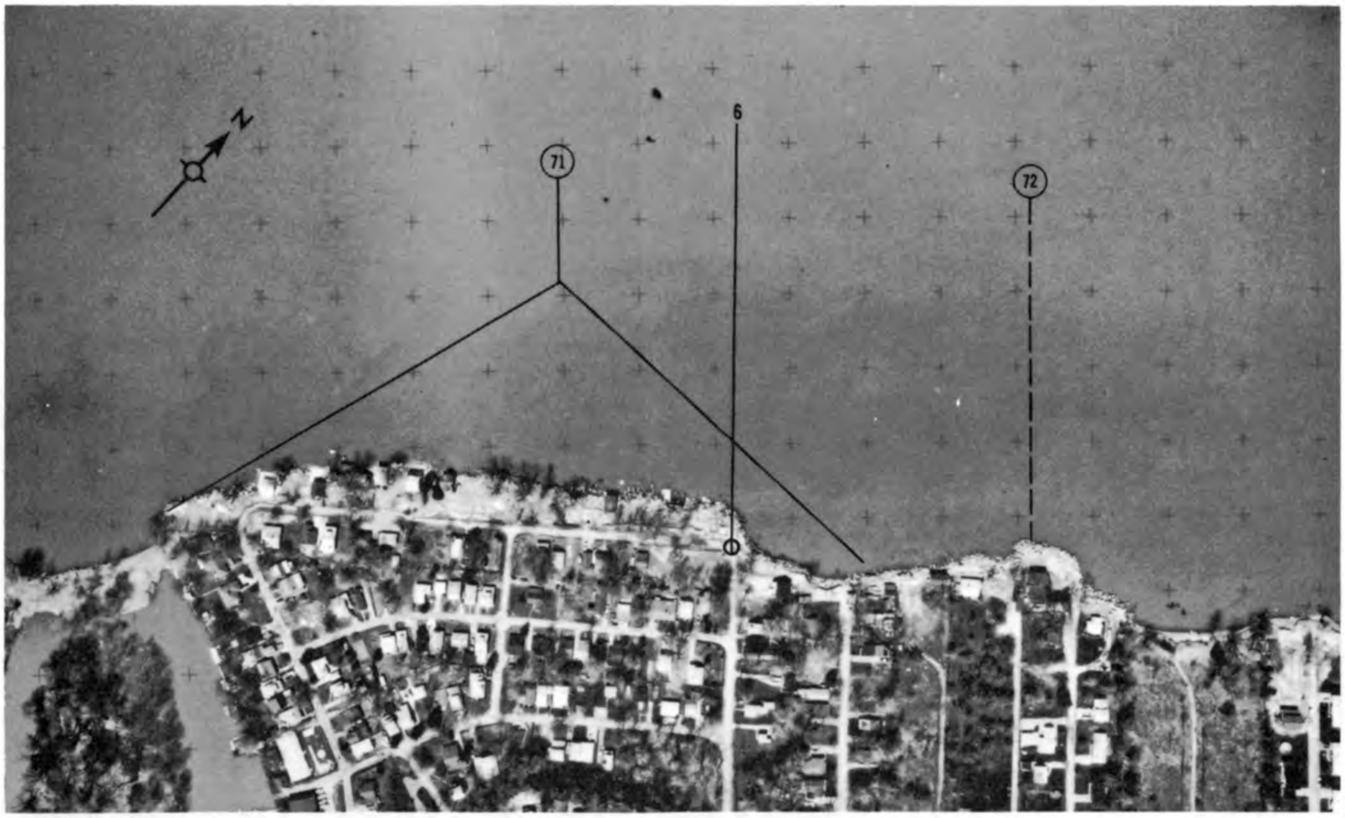


FIGURE 14

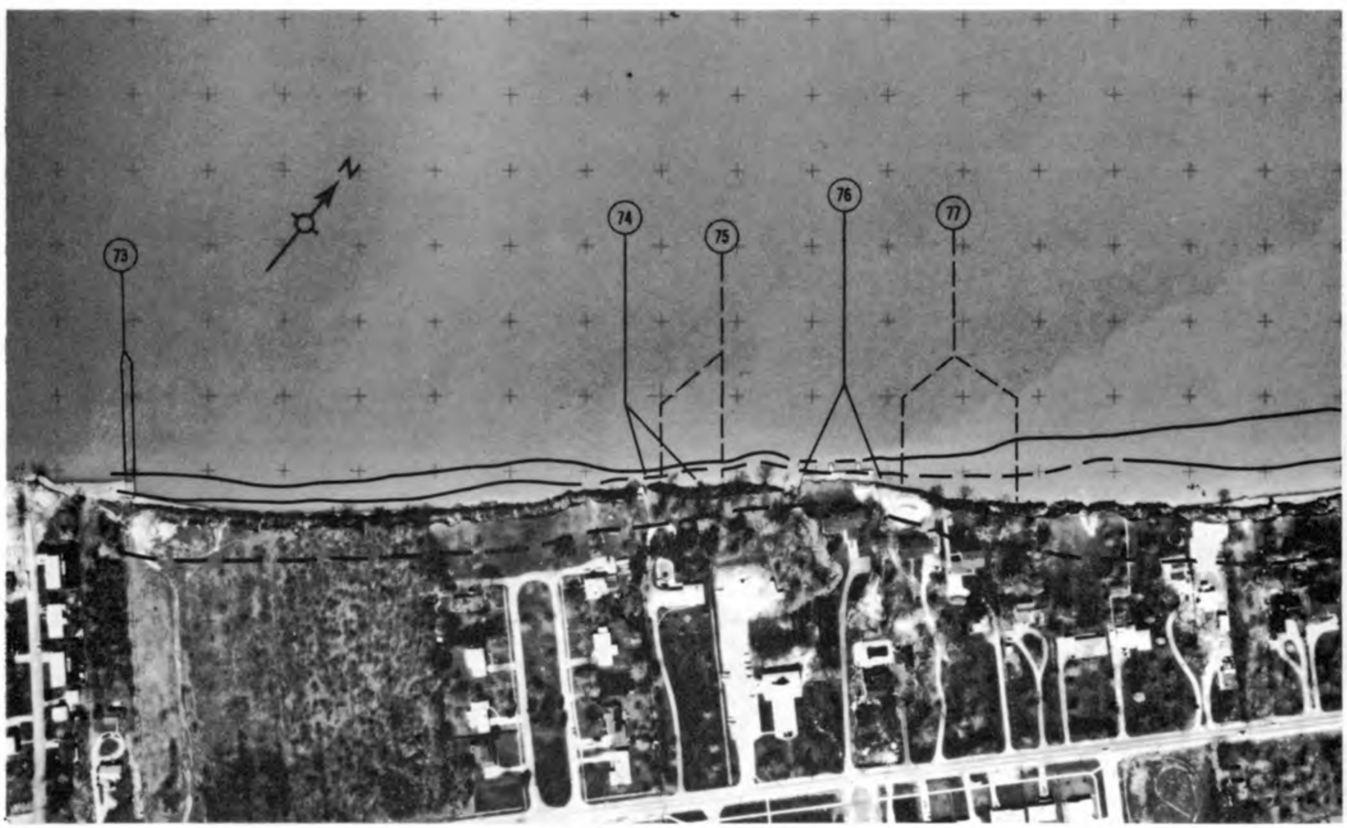


FIGURE 15

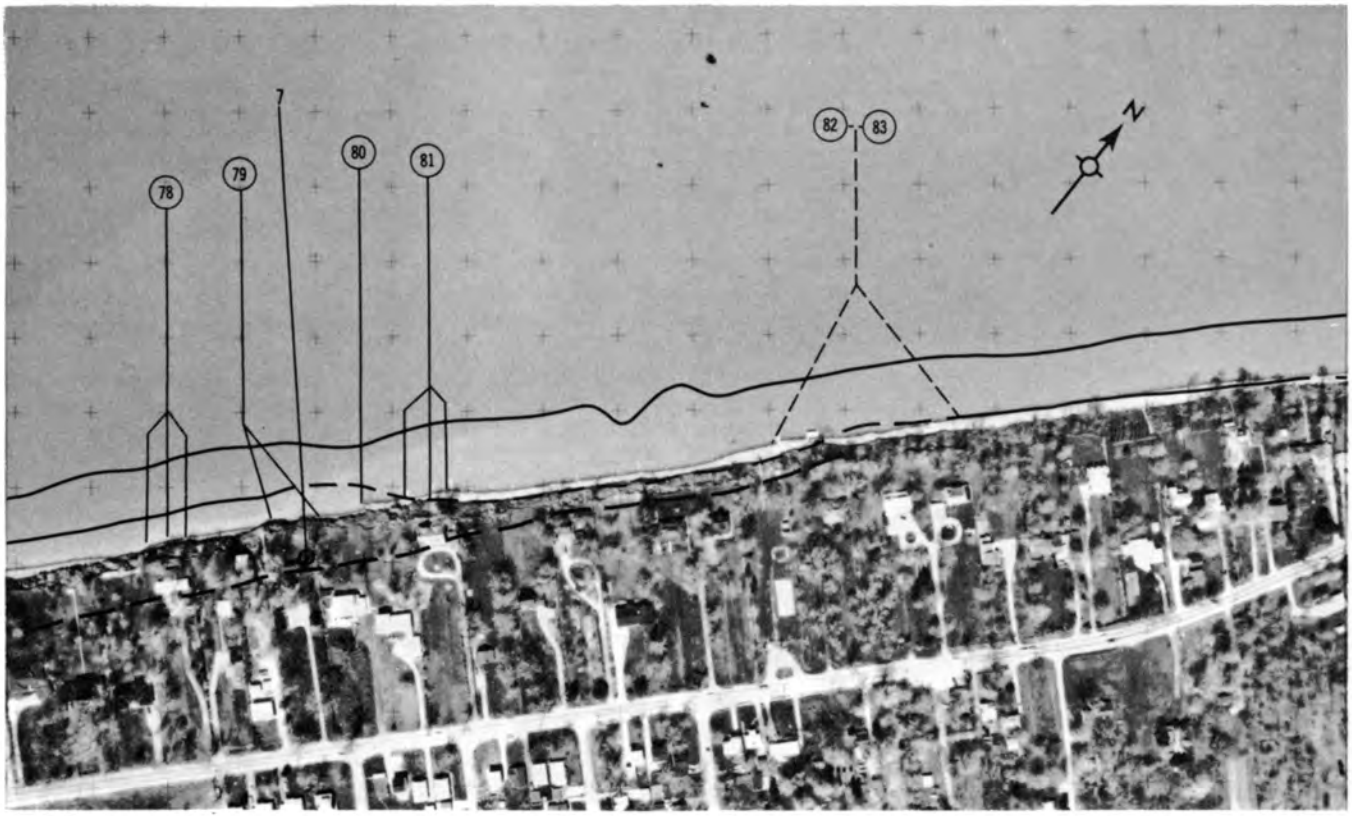


FIGURE 16

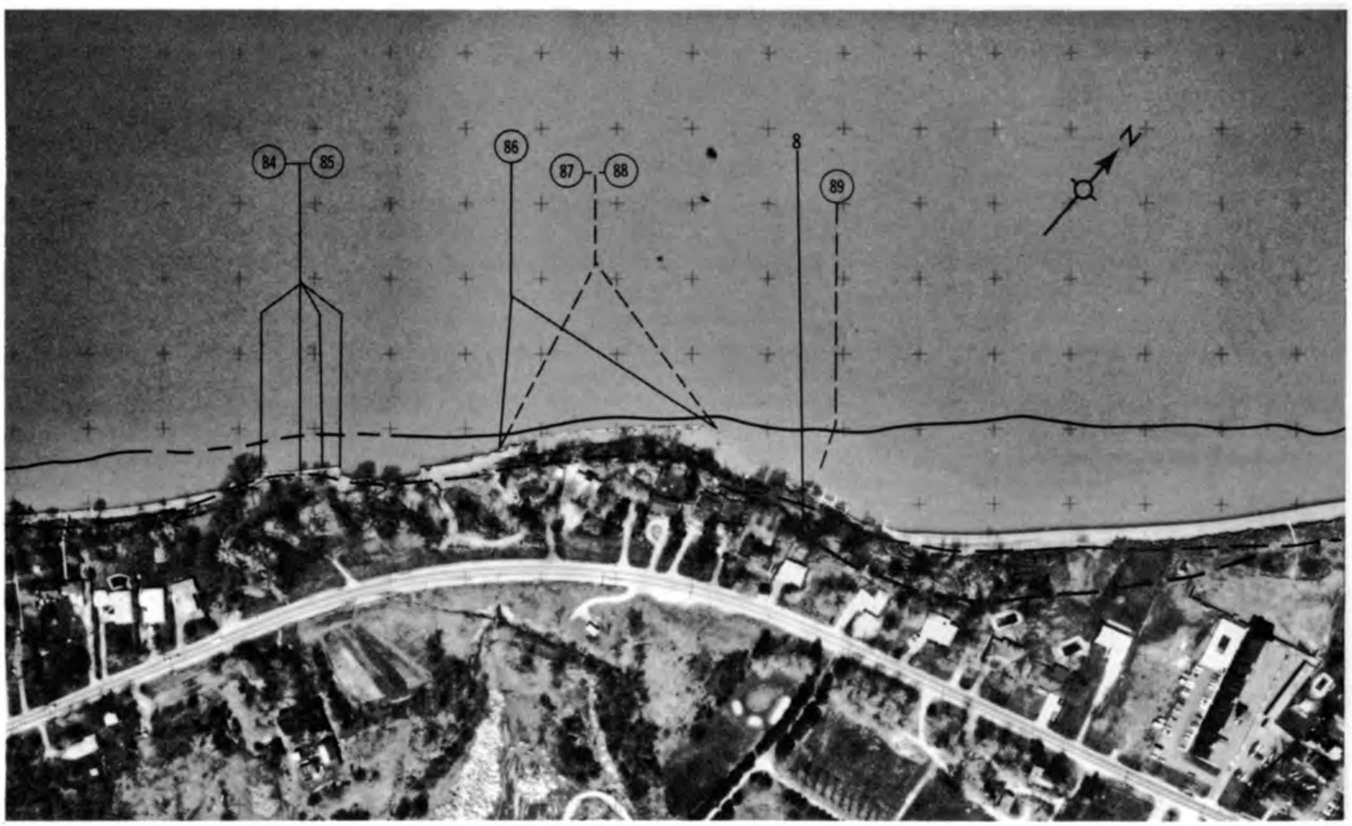


FIGURE 17

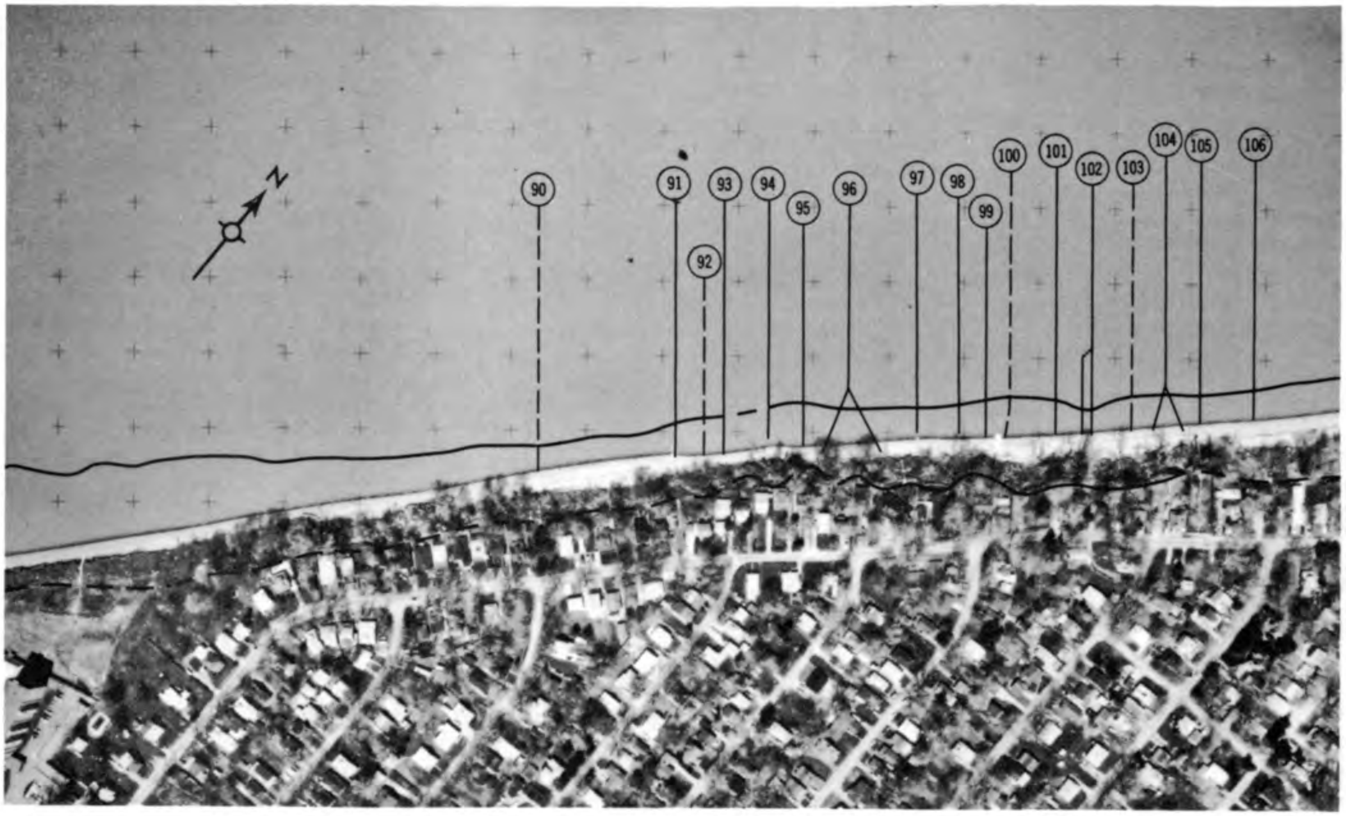


FIGURE 18

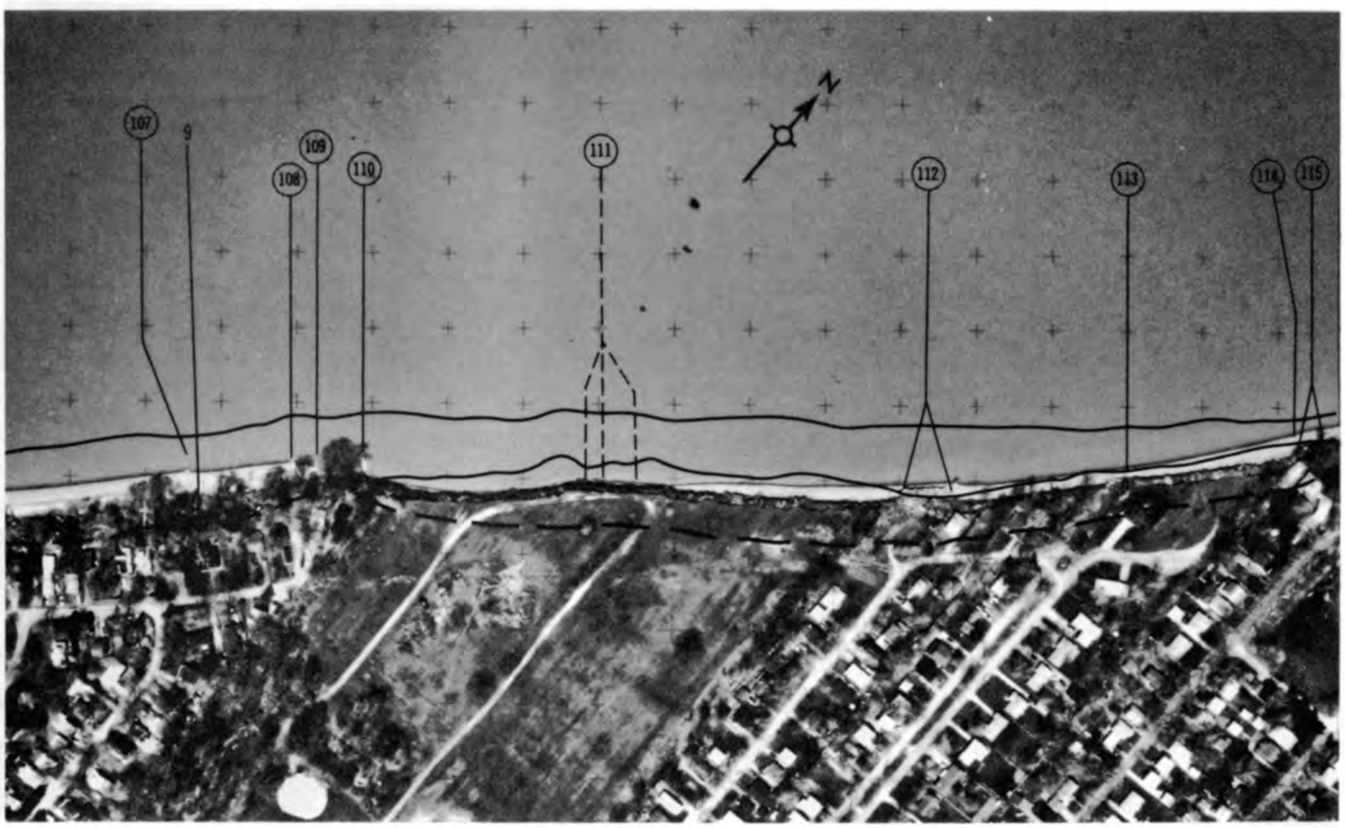


FIGURE 19

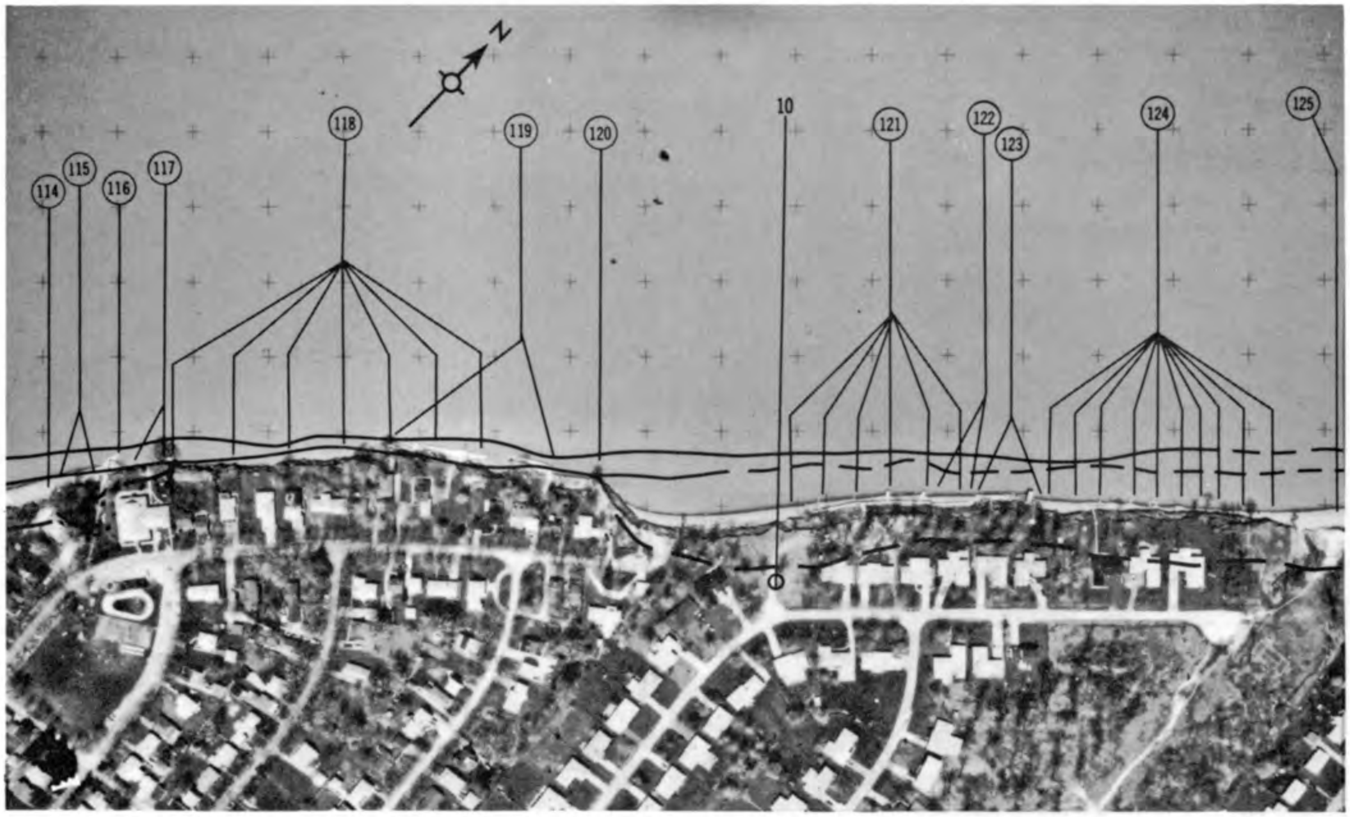


FIGURE 20

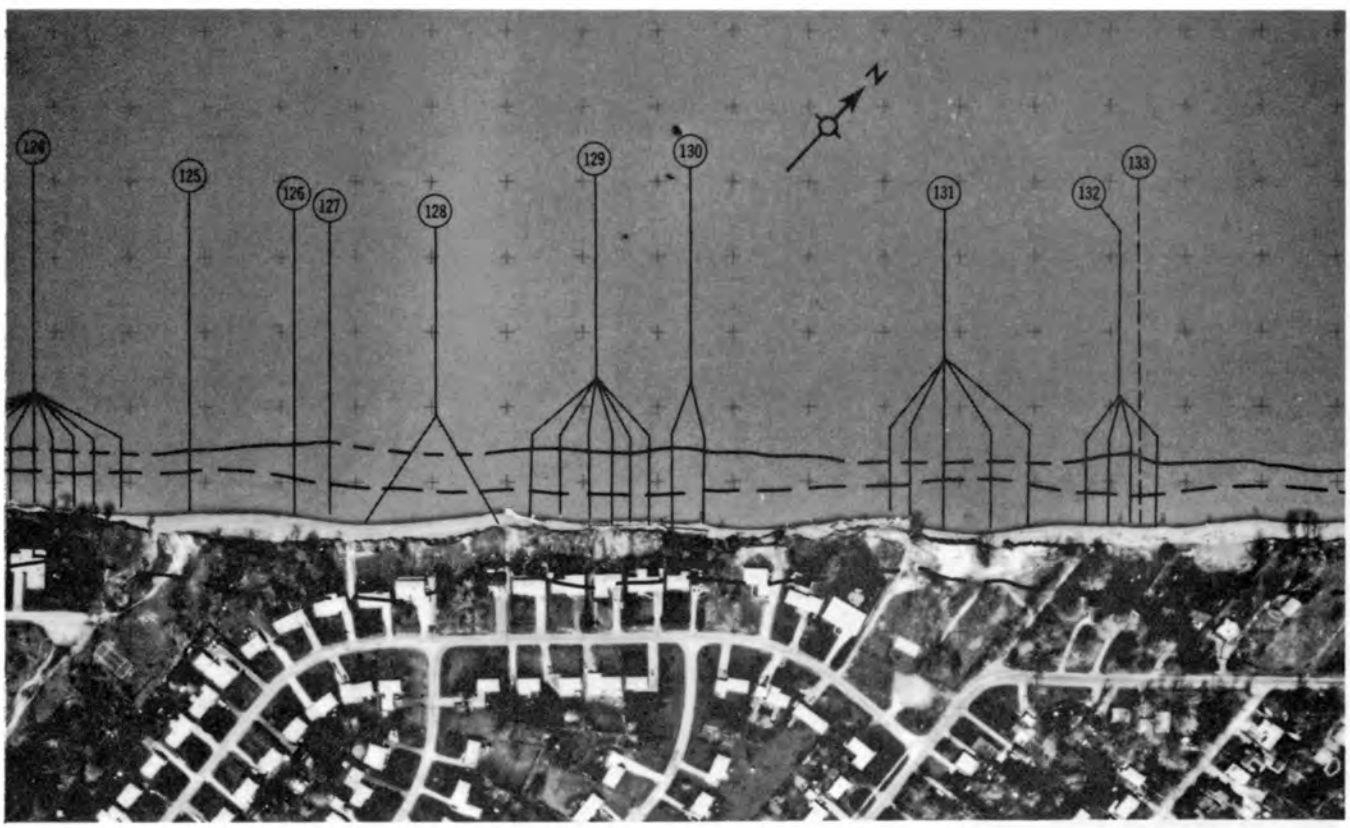


FIGURE 21

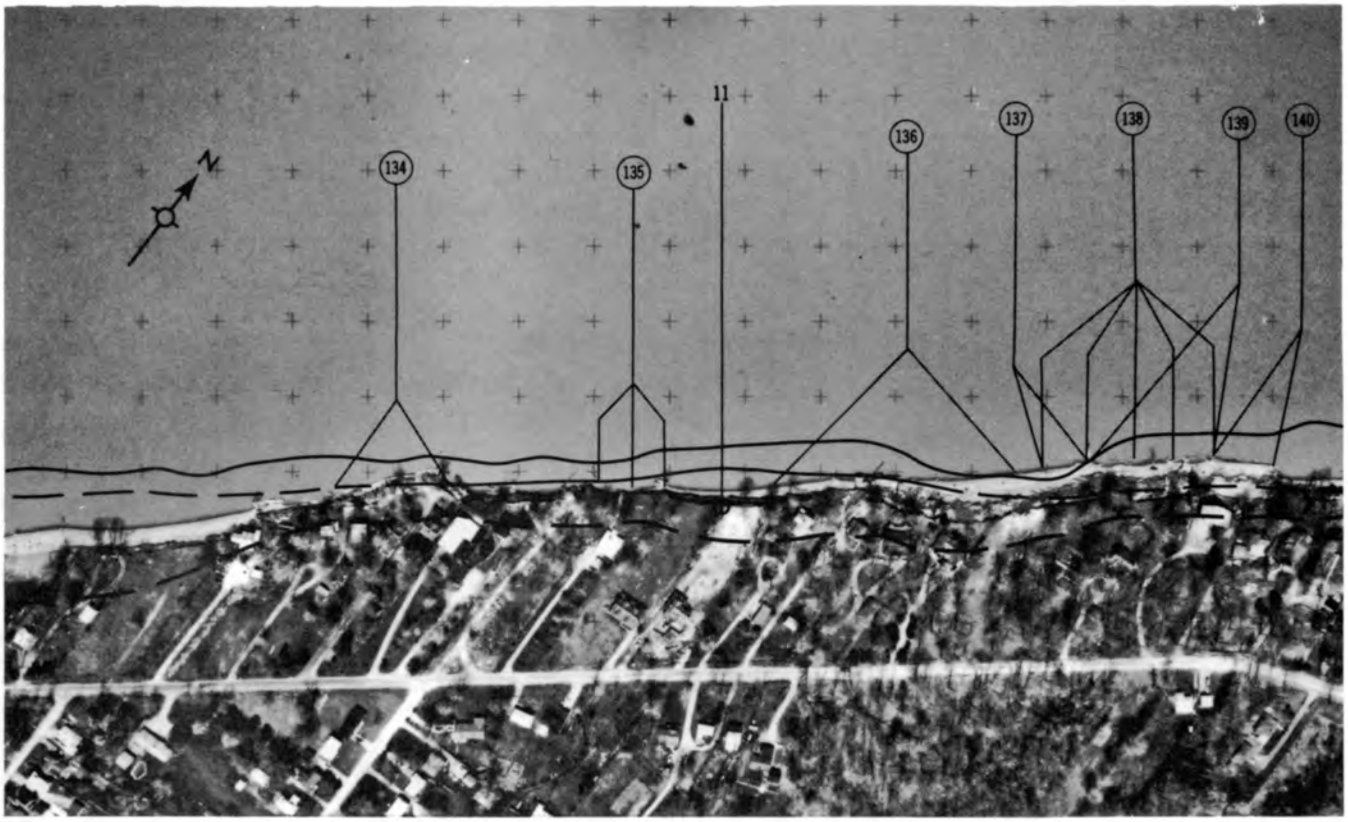


FIGURE 22

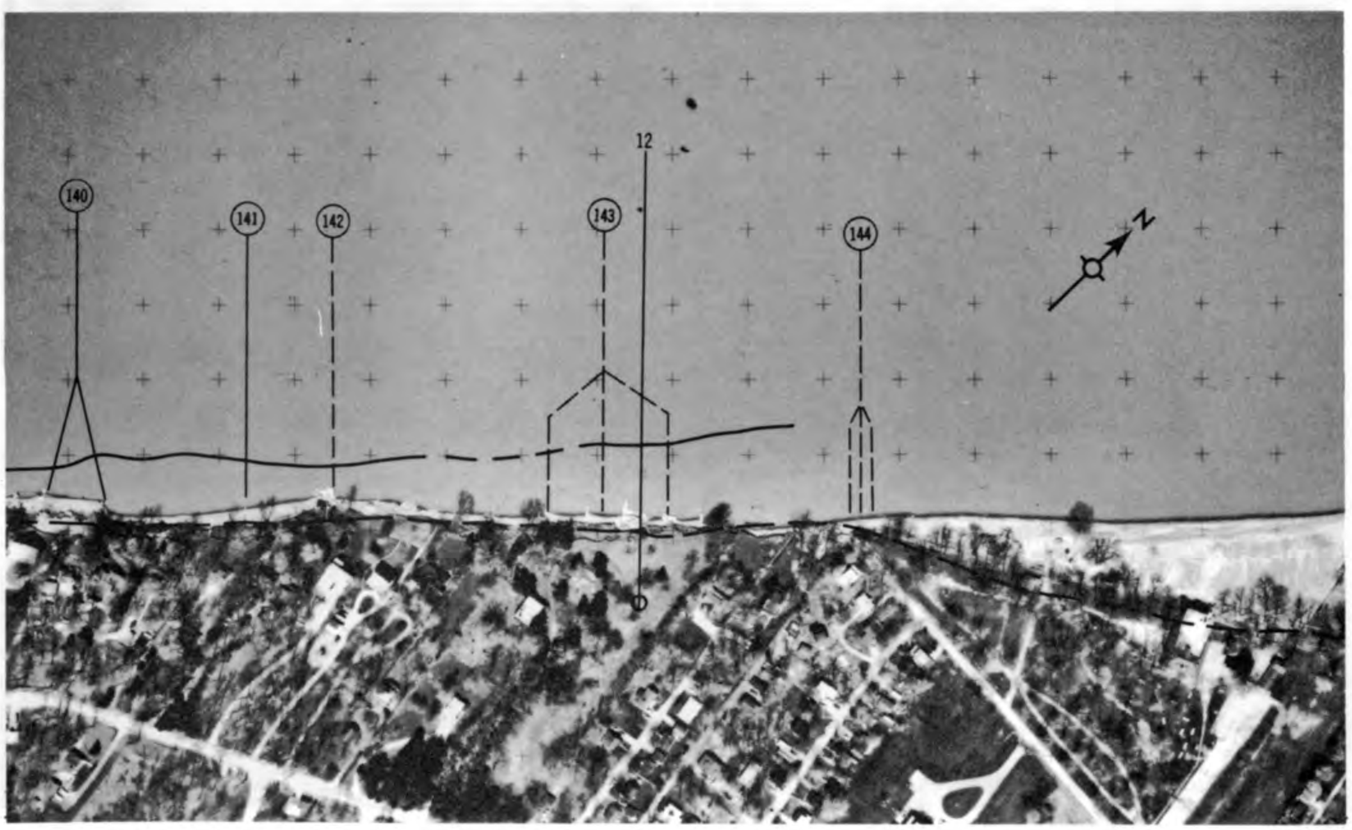


FIGURE 23

FIGURE 24

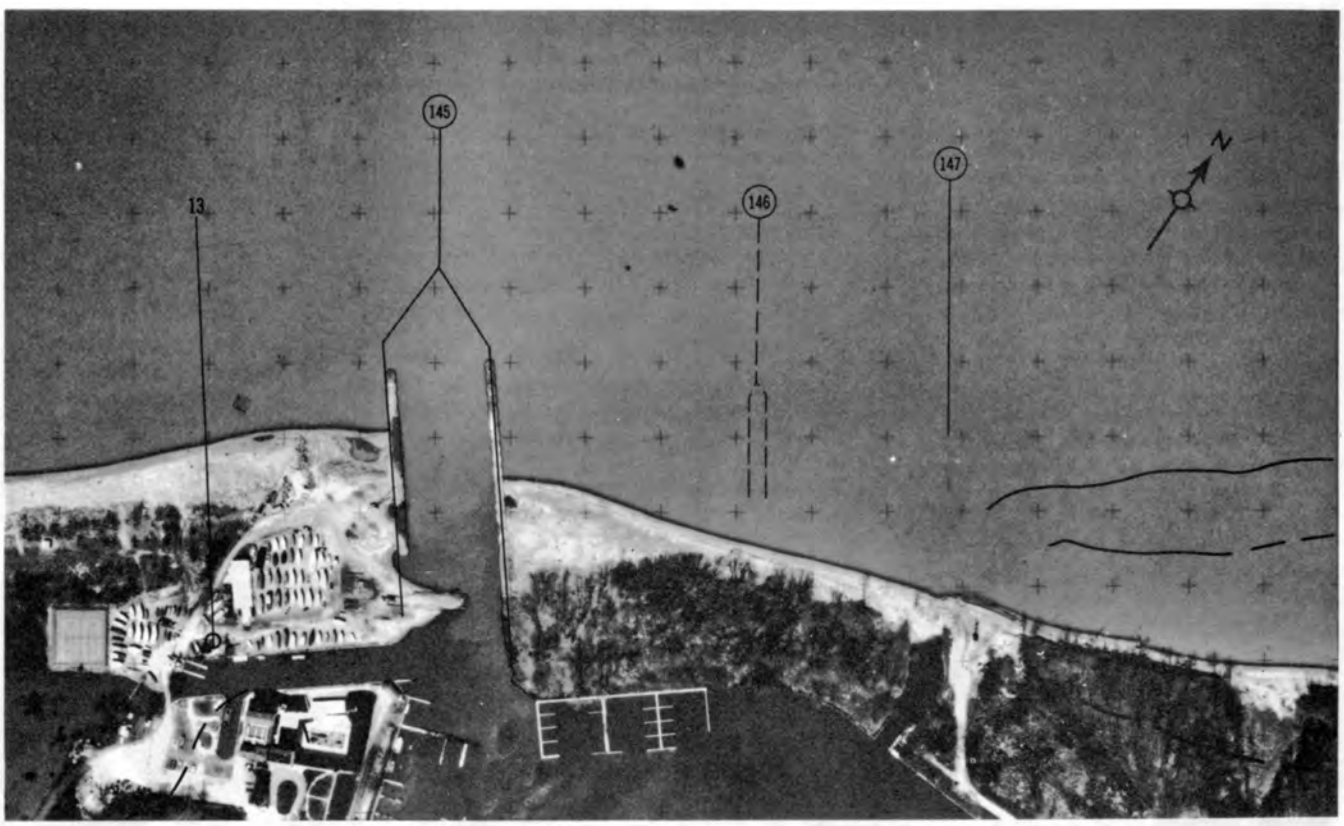


FIGURE 25

MENTOR HARBOR TO GRAND RIVER REACH

This reach lies between the Mentor Harbor jetties to the west and the Grand River jetty-breakwater complex to the east. The reach is sparsely settled in comparison to the two reaches to the west; the Mentor Headlands area, near the center of the reach, is the only population center. Headlands Beach State Park is located at the northeast end of the reach, and to the south the Mentor Marsh State Nature Preserve borders the reach. There is a serious erosion problem along the western one-third of the reach; however, the remainder is fairly stable.

Natural setting, *circa* 1973

Nearshore zone.—Sand, which ranges in thickness from a few feet (1 m) to more than 10 feet (3 m), overlies till throughout this reach (pl. 3). The sand increases in thickness from west to east (range 14 to range 18). The sandy bottom has a slope of 3 to 5 degrees from the shoreline to 50 ft (15 m) offshore; farther offshore the overall slope is generally less than 1 degree (table 23). Sand bars are located along each of the range profiles (tables 12, 23, pl. 3) and increase in number and definition from west to east.

Beach and shoreline zone.—Beaches front about 97 percent of this reach. The beaches are largely trapped, with the principal exception of the beaches from Mentor Harbor to range 15, where the beaches appear to be both trapped and natural. The largest beach, which is the largest one along the Lake County shore, lies adjacent to and west of the Grand River jetty-breakwater complex. This beach, which is more than a mile and a half long (2,500 m), fronts more than one-third of the reach.

Shore zone.—Two tills separated by laminated clay with sandy interbeds make up most of the shore along this reach except at the western end, where well-sorted sand overlies the laminated clay that in turn overlies the basal till (pl. 2). The laminated clay thins to the east but is persistent enough to be recognized at the base of rotational slumps as far east as range 15 and probably extends along the entire reach.

The recession line is well defined along the western one-third of the reach; however, along the remaining two-thirds of the reach the recession line is poorly defined because of development in the Mentor Headlands area and the low relief along the Grand River floodplain. The shoreline has a gentle wavelike shape. The crest is east of range 15, and shallow embayments on either side of the crest extend to the jetties at either end of the reach. There is a smaller wavelike shape within the shallow embayment to the west (Mentor Harbor to range 15).

Natural processes, *circa* 1973

Rotational slumps are the most significant result of wave erosion along this reach. The slumps take place along the contact between the till and the laminated clay, with the clay acting as a slip plane for the overlying till. The clay is lubricated by surface water seeping downward along joints in the till and/or by ground water from updip. Erosion of the slumped material by waves eliminates the resisting moment and helps stimulate new slumps. Debris flows in the laminated clays and piping at the clay-sand contact are a problem between range 13 and range 14.

Historic perspective: 1876, 1937, 1973

Land use.—Of the three reaches west of the Grand River this reach has undergone the least amount of change between 1876 and 1973 (table 24). The principal changes have been an increase in development in the Mentor Headlands area (range 15 to range 17) and establishment of the state park at the east end of the reach.

Stickout structures.—Three structures are shown on the 1876 map: a groin or pier between range 14 and range 15 and two large jetties at the mouth of the Grand River. Aside from the area around the mouth of the Grand River, the only other area in this reach that had more than a few stickout structures in 1937 was the stretch between Mentor Harbor and range 15. For example, there were 26 groins between Mentor Harbor and range 14 in 1937. By 1970 a large number of groins had been built in the Mentor Headlands area (range 15 to range 17); at the same time the groins between range 14 and range 15 were not kept up and were eventually destroyed (table 25). In general, structural development proceeded in three stages along this reach: (1) construction of harbor structures at the mouth of the Grand River in the early 1800's and early 1900's, (2) construction of the Mentor Harbor jetties and downdrift groins in the early 1930's, and (3) construction of the stickout structures in the Mentor Headlands area in the 1950's and 1960's.

Beaches.—In contrast to the two reaches to the west, the 1876 beaches and the 1973 beaches here have about the same distribution. Moreover, they are about the same size, although the 1876 beaches were slightly larger (table 26). The small stretch (between range 15 and range 16) without a beach in 1973 is directly in front of a seawall complex; waves have probably scoured the sand to a greater-than-normal depth by reflection off the seawall.

Shoreline shape.—The shoreline shape was fairly even and regular in 1876, although there was a gentle headland between Mentor Harbor and range 15 (pl. 4). By 1937 the stretch between Mentor Harbor and range 15 was nearly straight, and the remainder of the reach had the same overall appearance as it did in 1876. By 1973 the stretch between Mentor Harbor and range 15 is a shallow embayment, although there is a prominent headland near the center of it. Farther east, between ranges 15 and 17, the shore is more irregular, probably because of the construction of more shoreline structures. The dramatic change in shape between Mentor Harbor and range 15 can be tied in directly with the evolution of the jetties at Mentor Harbor and the destruction of the groin field to the east of the harbor.

Recession history

1876-1937.—The recession rates in this period were slow and very slow along about 80 percent of the reach; however, a 3,900-ft (1,190-m) stretch between Mentor Harbor and range 15 receded at moderate to rapid rates (table 27). This stretch is directly east (downdrift) of the Mentor Harbor jetties; in 1937 this stretch had 36 groins, most of them in poor condition, fronting it.

1937-1973.—The recession rates in this period were bimodal—very slow and very rapid. About 60 percent of the reach receded at very slow to slow-moderate rates, whereas the remaining 40 percent of the reach underwent recession at moderate to very rapid rates (table 27). The stretches with moderate to very rapid recession rates are located between Mentor Harbor and range 15; the stretches with very slow to slow recession rates are located between range 15 and the Grand River. As in the 1876-1937 period, the stretches that have undergone the most rapid recession are directly east (downdrift) of Mentor Harbor. By 1950, in the area between Mentor Harbor and range 15, only 7 of the 36 groins observed in the 1937 photographs were reported by the Corps of Engineers (U.S. Army, Corps of Engineers, 1950, pl. 7), and by 1970 only 5 of the groins remained. Four of the groins are clustered in front of a headland (at range 14) that is almost equidistant between Mentor Harbor and range 15. In the stretch directly lakeward of the headland, which is about 300 ft (92 m) long, the rates from 1937 to 1973 have been moderate to slow.

The remainder of the reach, which has receded at very slow to slow rates, has had a moderate structure density (range 15 to range 17) or has been protected by the sand trapped by the west Grand River jetty (range 16 to Grand River).

Interpretation of recession

This reach, in contrast to the two reaches to the west, had only a short stretch (range 15 to range 17—the Mentor Headlands area) in the 1876-1937 period that had a rate that could be considered as a good approximation for a natural (pre-structure) recession rate; the recession rates along this stretch in this period were very slow to slow. However, buildup of protective sand in front of this stretch since the construction of the Grand River jetties has probably caused a decrease in these rates, and therefore the rates are not entirely natural.

The major cause of the moderate to rapid recession rates between Mentor Harbor and range 15 in the 1876-1937 period appears to be the Mentor Harbor jetties. These structures, constructed in 1931, have trapped a considerable volume of sand: from 1967 to 1973 the mean annual volume of sand dredged from the harbor entrance and removed from the lake was 11,000 cu yd (6,900 cu m). In addition, it is likely that the structures force the sand which remains in the longshore drift system to be transported too far offshore to enter the immediately adjacent longshore drift system, thus contributing to accelerated recession downdrift. After construction of the jetty system, sand in the beaches between the harbor and range 15 moved to the east with longshore drift, and, because there was a lack of replacement sand, the beaches became smaller, the nearshore slope became steeper, and the shore became more vulnerable to wave erosion.

In addition to the effect of the jetty system, the increased rates of recession and the greater length of shoreline undergoing moderate to very rapid recession in the 1937-1973 period in the Mentor Harbor to range 15 area can be attributed directly to the destruction of a large number of groins along this stretch. When the groins were not maintained, less and less sand was held in the beach and nearshore area, and the recession rates increased. Maintenance of the groins in the range 14 area resulted in decreased recession, and a headland developed behind and immediately to the west of the structures. However, the development of this new barrier along the stretch has probably contributed to increased rates of recession to the east.

The remainder of the reach shows no appreciable change between 1937 and 1973 from the very slow to slow natural rate, even though a large number of stickout structures has been built in the Mentor Headlands (range 15 to range 17) stretch. The structures have protected the shore updrift of them, and downdrift (from range 17 to Grand River) the shore, two-thirds of which is floodplain, is protected by the gentle nearshore slope and huge beach at Headlands Beach State Park.

The most significant factor, then, contributing to increased recession rates along this reach has been the Mentor Harbor jetty system. These jetties, by trapping sand from the longshore drift system or by forcing sand farther offshore, have increased the rates of recession within the Mentor Harbor to range 15 stretch by a factor in some places as great as 10. However, as in the Chagrin River to Mentor Harbor reach, the plentiful supply of sand, derived either from shore erosion to the west and/or from the sandy nearshore zone, has undoubtedly reduced recession rates by decreasing the nearshore slope and through beach buildup along this reach, particularly east of range 15.

Recession forecast (2010 A.D.)

The recession rates should be significantly lower along this reach in the 1973-2010 period because, as of 1974, sand dredged from Mentor Harbor is, by directive of the Ohio Department of Natural Resources, to be placed back into the longshore drift system. However, there are other problems, such as the headland at range 14, the unprotected stretches along the Mentor Headlands shore (downdrift of stickout structures), and the laminated clay zone near the base of the bluff or slope. The rates of recession will decrease with time in the more rapidly receding embayed areas because the deeper an embayment becomes the more protected it is from waves. Also, in 1973 the embayed areas had wider beaches than did the adjacent areas; the wider beaches and associated shallower nearshore slopes will help protect these areas from wave erosion.

Summary and erosion-control suggestions

This reach can be divided into three stretches: (1) the Mentor Harbor to range 15 stretch, (2) the Mentor Headlands (range 15 to range 17) stretch, and (3) the Headlands Beach stretch (range 17 to Grand River). The Mentor Harbor to range 15 stretch has undergone accelerated recession because of the Mentor Harbor jetties. Neither the Mentor Headlands stretch nor the Headlands Beach stretch changed much from 1876 to 1973. The Headlands Beach stretch has been protected further by the accumulation of sand on the west (updrift) side of the Grand River jetties.

The major problem area, therefore, is the Mentor Harbor to range 15 stretch. Because sand dredged from the harbor is now being put back into the longshore drift system, the recession rates should decrease along this stretch. Also, the deeper the embayments on either side of range 14 become, the more protected they become, and the recession rates should decrease.

In both the Mentor Harbor to range 15 area and the Mentor Headlands area standard shore-protection measures can be undertaken to further reduce the recession rate. Because of the relatively abundant sand supply along this reach, short (less than 50 ft or 15 m) groins can be used to trap sand and help protect the base of the shore. Also, a combination of landscaping, adequate drainage, and toe protection in the form of seawalls in areas that do not have houses along the edge of the bluff could reduce or eliminate recession along this reach. Moreover, if water can be kept from the laminated clay between the tills, there will be a significant increase in slope stability. This might be accomplished through a system of inexpensive interceptor drains.

TABLE 23.—*Nearshore depths, Mentor Harbor to Grand River*

Range profile	Nearshore depth (ft)								
	50 ft[1]	100 ft	200 ft	300 ft	400 ft	500 ft	1,000 ft	1,500 ft	2,000 ft
14	3	4.5	8	11.5	12[2]	12[2]	12.5[2]	20[2]	22[2]
15	3.5	5	7	6.5[2]	10.5	14	15.5[2]	16[2]	22
16	4.5	5	6.5[2]	7.5[2]	11.5	13	15.5	14[2]	16.5[2]
17	4.5	5.5[2]	6[2]	5.5[2]	6[2]	10[2]	14[2]	19[2]	17[2]
18	4	4[2]	4.5[2]	10	9.5[2]	8[2]	13[2]	13.5[2]	14.5[2]

[1] Distance from shoreline in all cases; shoreline is defined as the contact between the lake and the beach. See table 12 for lake level.
[2] Depth to sand bar (crest or limb).

TABLE 24.—*Land use, Mentor Harbor to Grand River*

Location	Land use[1]		
	1876	1937	1973
Mentor Harbor-R14	wetland, forest, urban(s)[2]	wetland, forest, urban(s)	wetland, forest, urban(s)
R14-R15	agricultural, urban(s), range	range, forest	forest
R15-R16	agricultural, urban(s)	urban(s), agricultural	urban(s-m), agricultural
R16-R17	agricultural, urban(s), forest	urban(s), agricultural	urban(s-m)
R17-R18	urban(s), wetland, agricultural, forest	urban(s), forest, wetland	urban(s), forest, wetland
R18-Grand River	forest, wetland	forest, wetland	state park

[1] Land uses for a given year are arranged from left to right in order of amount of land used, largest land use to the left.
[2] (s), sparsely populated, less than one house/acre; (m), moderately populated, one to three houses/acre.

TABLE 25.–*Inventory of stickout structures, Mentor Harbor to Grand River*

Location	Structure no.[1]	Type and number of structures[2]			
		1876	1937	1954	1970
Mentor Harbor-R14					
	146		x	G(2)	
	147		x	x	G
			G and GF(22) between 147 and 148		
R14-R15	149		y, GF(5)	x	GF(4)
		G or P between 150 and R15	G, G(2), and G(2) between 150 and R15		
R15-R16	151		y		G
	152				G(2)
	153				G(2)
	155		y		GF(3)
	156				G
	157				G
	158			G	
	160		x	x	G
	161		y	x	GF(3)
	162				GF(4)
	164				G
	165			x	G(2)
	166				G(2)
	167			x	GF(5)
	169		x	G	
	170				GF(11)
	171			G	
R16-R17	172				GF(4)
	173			G	
	174				G
	175			x	G(2)
	176			x	G
	177			x	G
	178				G
	179			x	G
	180			x	G
	181			x	G(2)
	182				GF(4)
	183				G(3)
	184				G
	185				G
	186			G(2)	
	187		y(1929)	x	G
R17-R18					
R18-Grand River	188		x(1908)	x	B
	189		x(1911)	x	B
	190		x(1901)	x	B
	191		x(1936)	x	B
	192		x(1914)	x	B
	192a	x(1827)	x	x	J
	192b	x(1827)	x	x	J
	192d				G

[1] Structure numbers correspond to numbers in the Appendix, which is a compendium of information on all structures along the shore of Lake County. Some early (1876-1937) structures, which are not described in the Appendix, are included in the stickout structure table, but are not numbered (for example, the groin field between structure no. 23 and structure no. 24 on table 15).

[2] B, breakwater; G, groin; GF, groin field; J, jetty; P, pier; S, seawall; (5), number of structures included under one inventory number; x, structure described in a later year is most likely the same structure observed on map or aerial photograph; y, structure described in a later year is possibly the same structure shown on map or aerial photograph; (1924), year the structure was built, if known.

TABLE 26.–*Beaches, Mentor Harbor to Grand River*

Location	1876			1937			1973		
	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]
Mentor Harbor-R14	3,400	natural	small-moderate	3,300	trapped	small-moderate	3,100	trapped and natural	small-moderate
R14-R15	3,400	trapped and natural	small-moderate	1,800	trapped and natural	small-moderate	3,600	trapped and natural	small
				1,700	trapped	moderate			
R15-R16	3,900	natural	small-moderate	2,700	trapped	small-moderate	300	trapped	small
				1,200	trapped	moderate-large	500	–	
							3,100	trapped	small
R16-R17	3,700	natural	small-moderate	3,800	trapped	moderate-large	3,900	trapped and natural	small
R17-R18	3,000	trapped	small-moderate	3,100	trapped	moderate-large	1,500	trapped	small-moderate
							1,600	trapped	large
R18-Grand River	1,700	trapped	large	1,700	trapped	large	1,700	trapped	large

Summary

Width of beach[3]	Beach length (ft)[1]		
	1876	1937	1973[4]
Small			10,900
Small-moderate	17,400	7,800	4,600
Moderate		1,700	
Moderate-large		8,100	
Large	1,700	1,700	3,300

[1] Measured to nearest 100 ft.

[2] *Natural,* the development of the beach has not been caused by manmade structures; *trapped,* the development of the beach has been caused by manmade structures; --, no beach.

[3] *Small,* less than 50 ft wide; *moderate,* 50 to 100 ft wide; *large,* greater than 100 ft wide.

[4] In 1973 there was 500 ft of shore without any beach.

TABLE 27.—*Recession rates, Mentor Harbor to Grand River*

Location	1876-1937		1937-1973	
	Recession rate[1]	Length (ft)[2]	Recession rate[1]	Length (ft)[2]
Mentor Harbor-R14	*floodplain (1,100 ft)*		*floodplain (1,200 ft)*	
	slow	1,150	rapid	300
	moderate	1,300	very rapid	2,150
	rapid	800	rapid	750
			slow-moderate	50
R14-R15			slow-moderate	250
	rapid	300	rapid	100
	moderate	1,500	very rapid	2,500
	slow	1,950	rapid	400
			moderate	500
R15-R16			slow	300
	very slow-slow	3,900	very slow	3,550
			slow	150
R16-R17			slow	450
	very slow	3,450	very slow	1,250
	slow	650	slow	450
			very slow	1,950
R17-R18	slow	2,800	very slow	3,150
	very slow	400		
	floodplain (1,950 ft)		*floodplain (1,950 ft)*	
R18-Grand River	*floodplain (1,700 ft)*		*floodplain (1,700 ft)*	

Summary

Recession rate[1]	Length in each recession class (ft)[2]	
	1876-1937	1937-1973
Total very slow	3,850	9,900
Total very slow-slow	3,900	
Total slow	6,550	1,350
Total slow-moderate		300
Total moderate	2,800	500
Total rapid	1,100	1,550
Total very rapid		4,650

[1] Very slow, <1 ft/yr; slow, 1-3 ft/yr; moderate, 3-5 ft/yr; rapid, 5-7 ft/yr; very rapid, 7-9 ft/yr.
[2] Measured to nearest 50 ft.

AERIAL PHOTOGRAPHS,
MENTOR HARBOR TO GRAND RIVER REACH

Aerial photography of the Lake County shore was done in 1973 by the Ohio Department of Transportation. The photographs for this reach are reproduced here with superimposed 1876, 1937, and projected 2010 recession lines. The 1876 line is farthest lakeward; the 2010 line is the heavy dashed line farthest landward; the 1876 and 1937 lines are dashed where approximate. The recession lines for the different years coincide where there has been no change.

Range and structure locations also are shown (see Appendix for description of the structures). Structures 189, 190, 191, and 192, part of the Grand River jetty-breakwater complex, are located offshore from the mouth of the Grand River and are not within range of the photographs. The following symbols are used:

Range location and number

Structure location and number; dashed line indicates that structure was not found in 1970 survey

Scale on all photos: 0 200 400 ft; 0 100 200 m

Scale distorted toward edges of photos

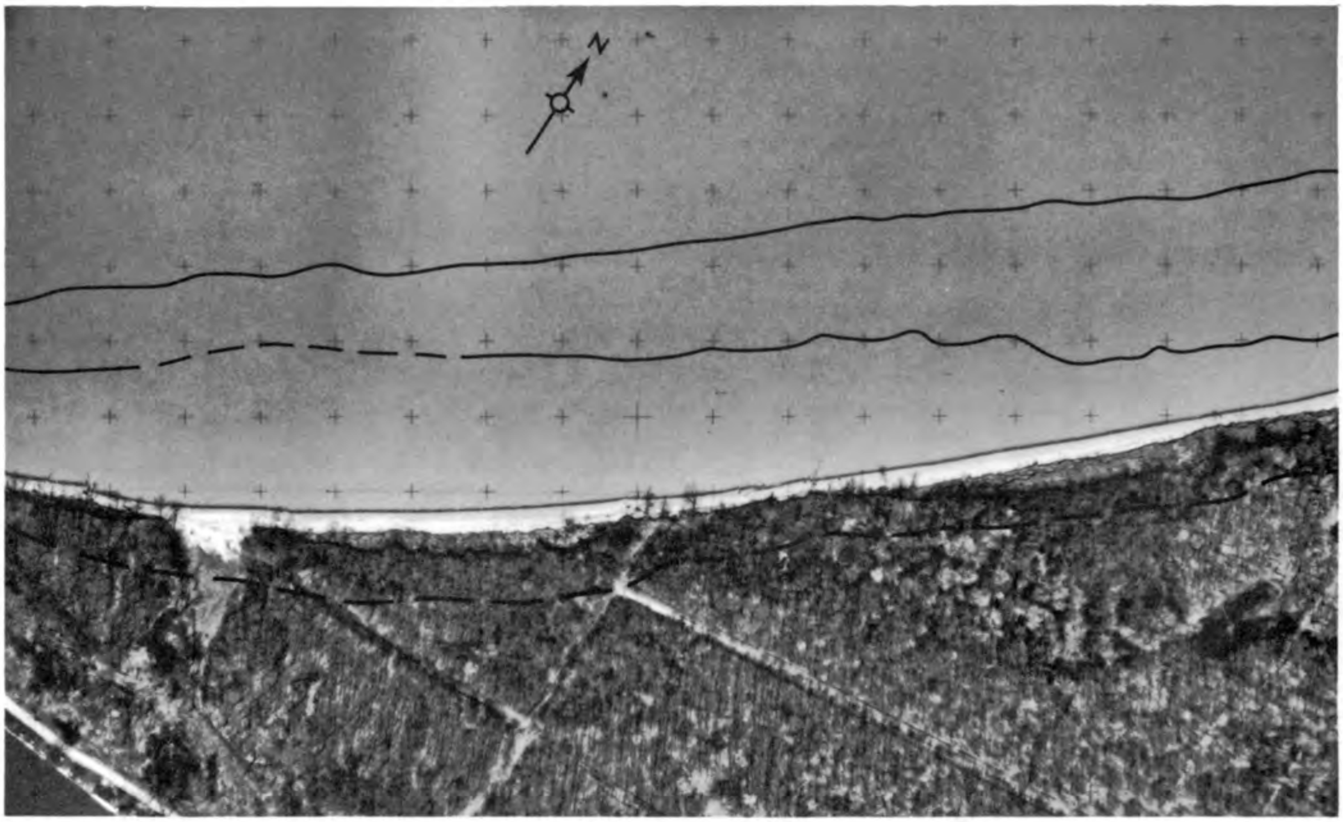


FIGURE 26

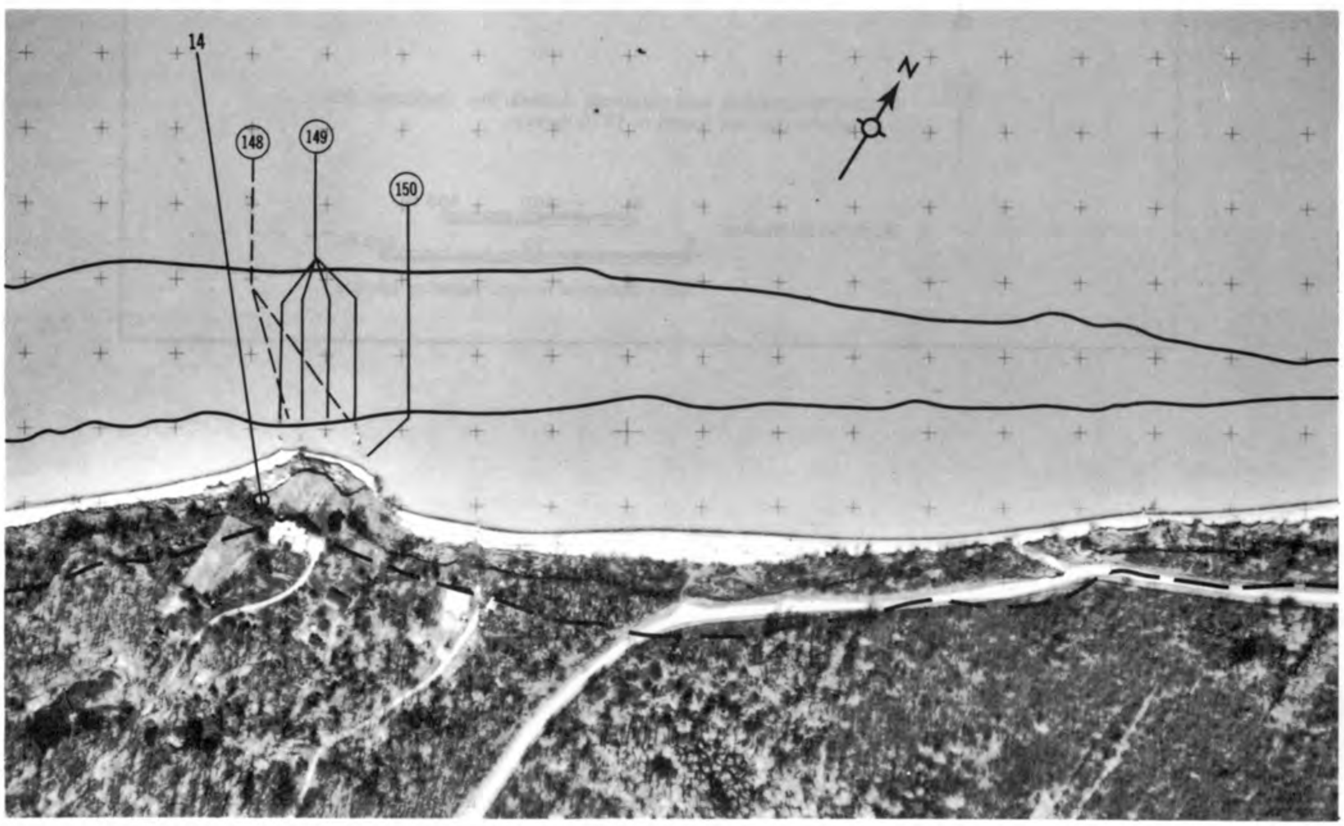


FIGURE 27

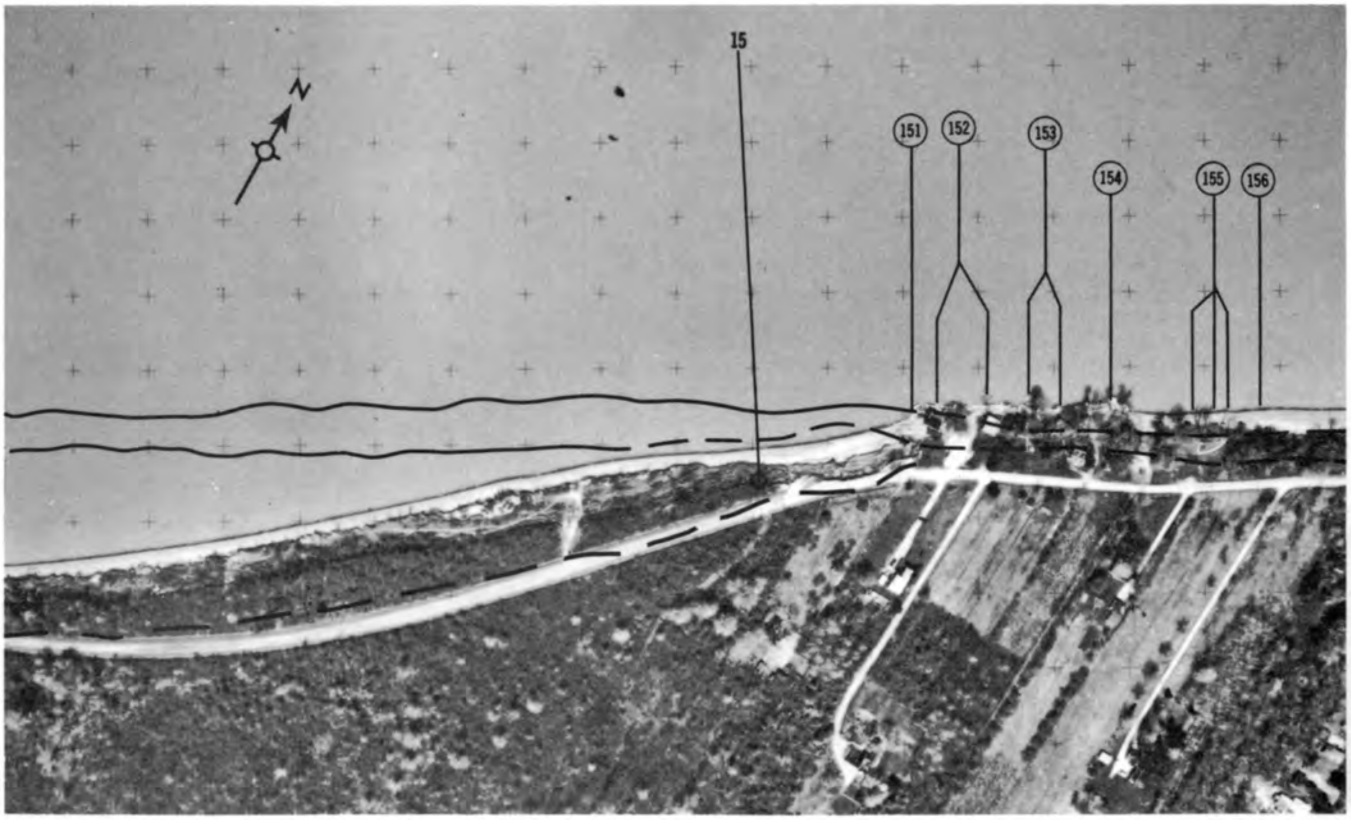


FIGURE 28

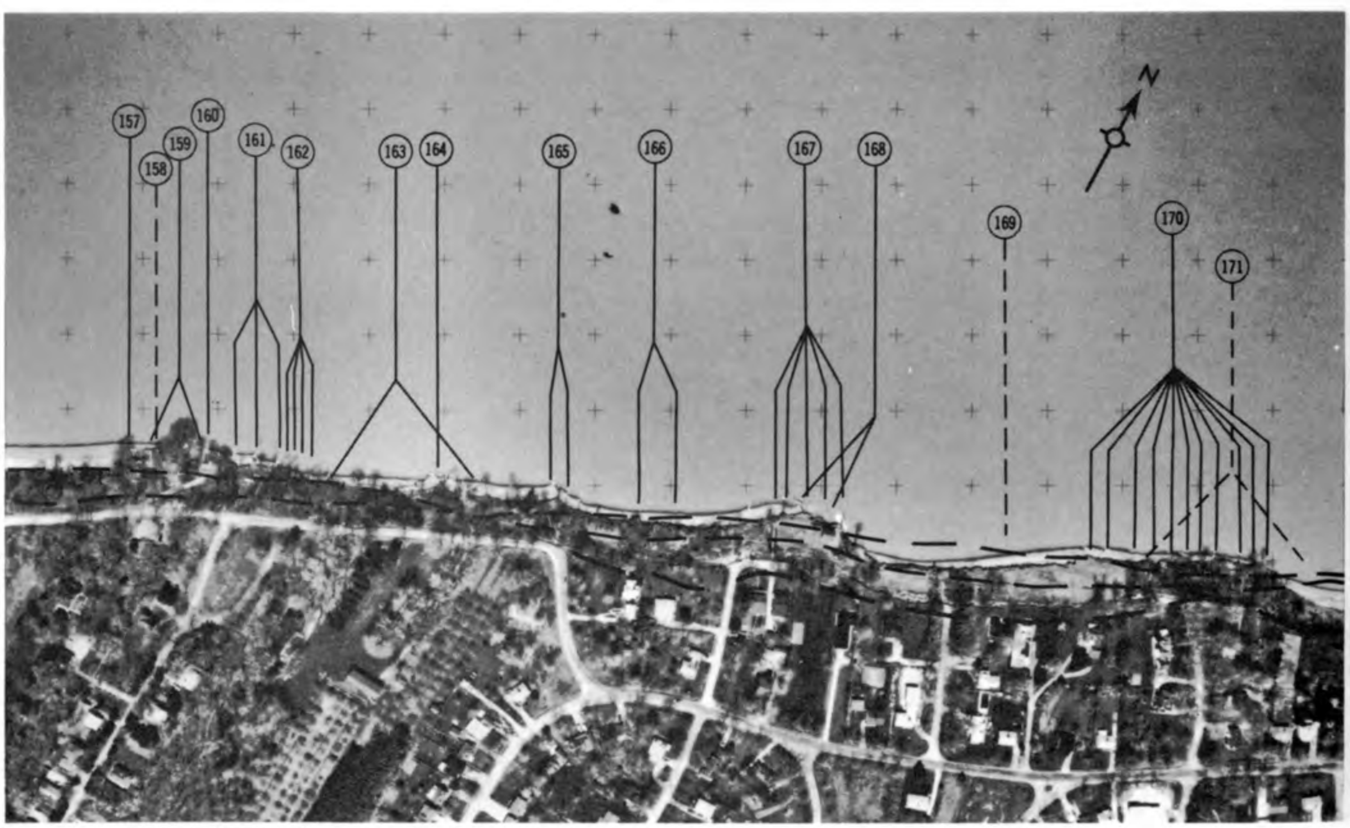


FIGURE 29

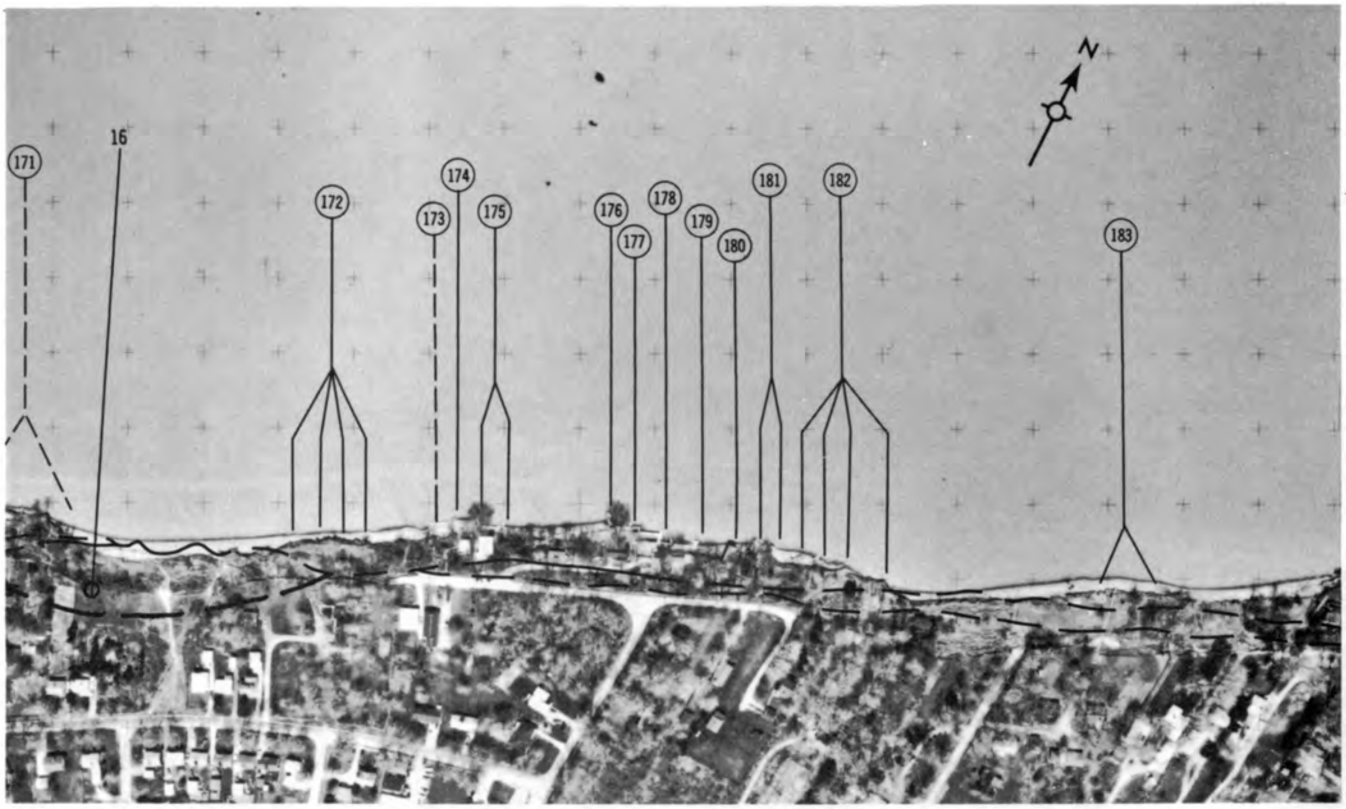


FIGURE 30

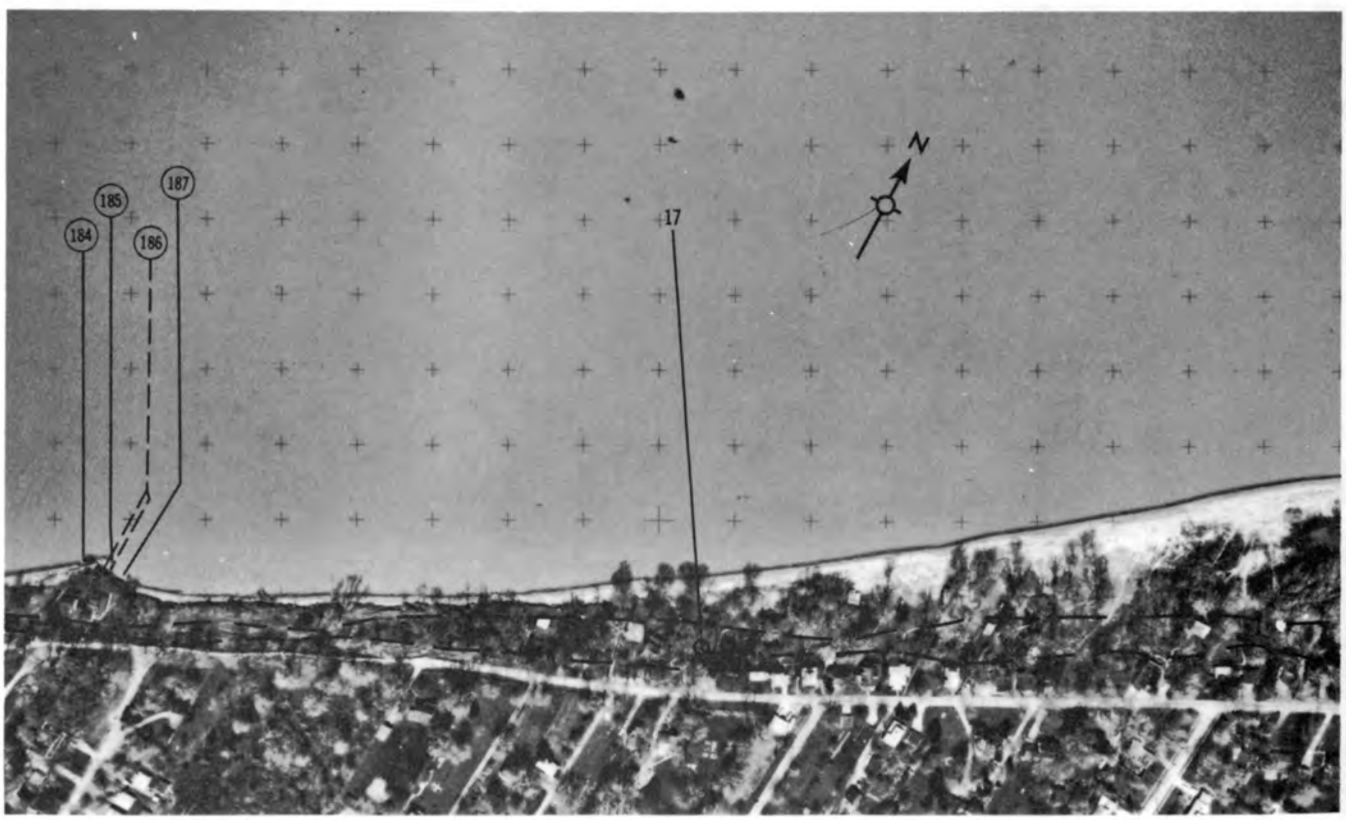


FIGURE 31

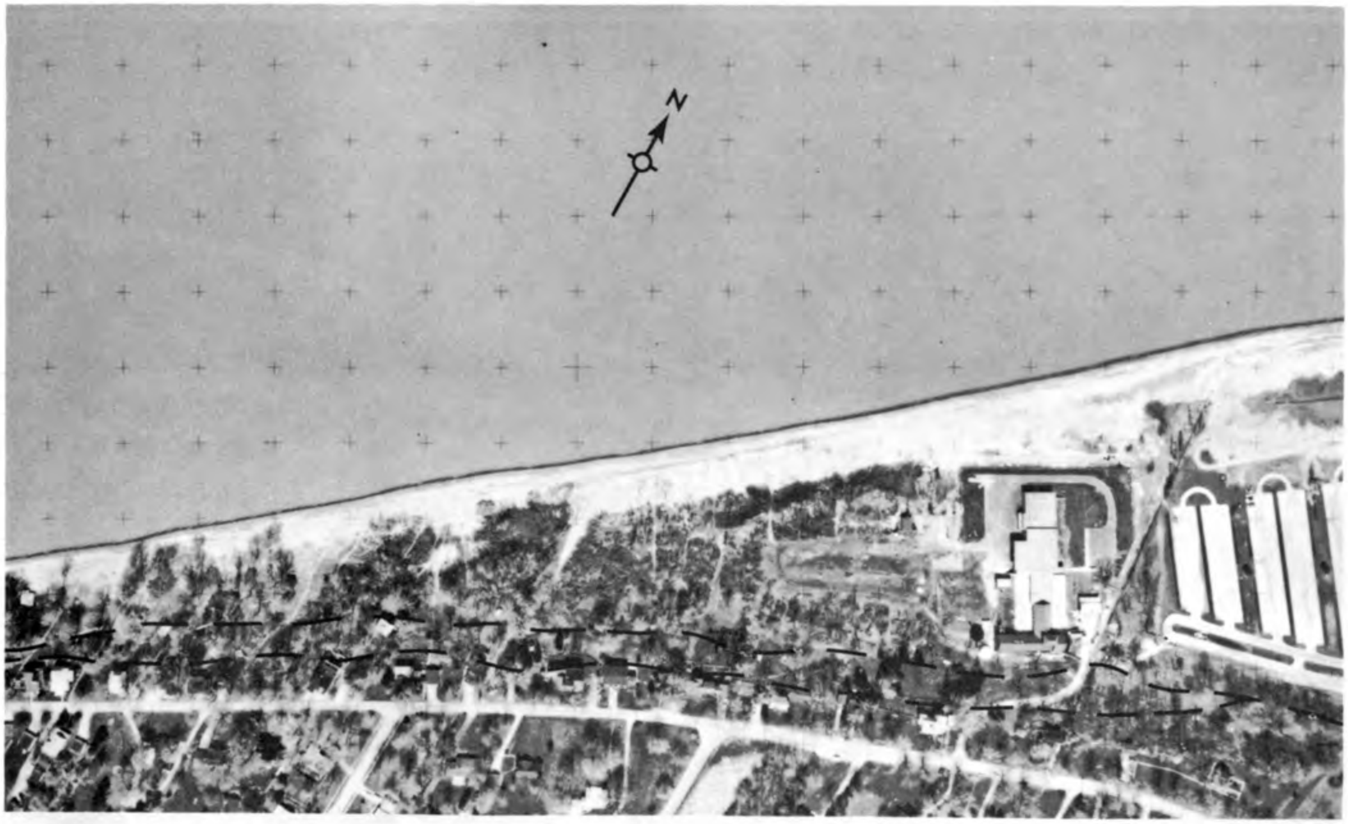


FIGURE 32

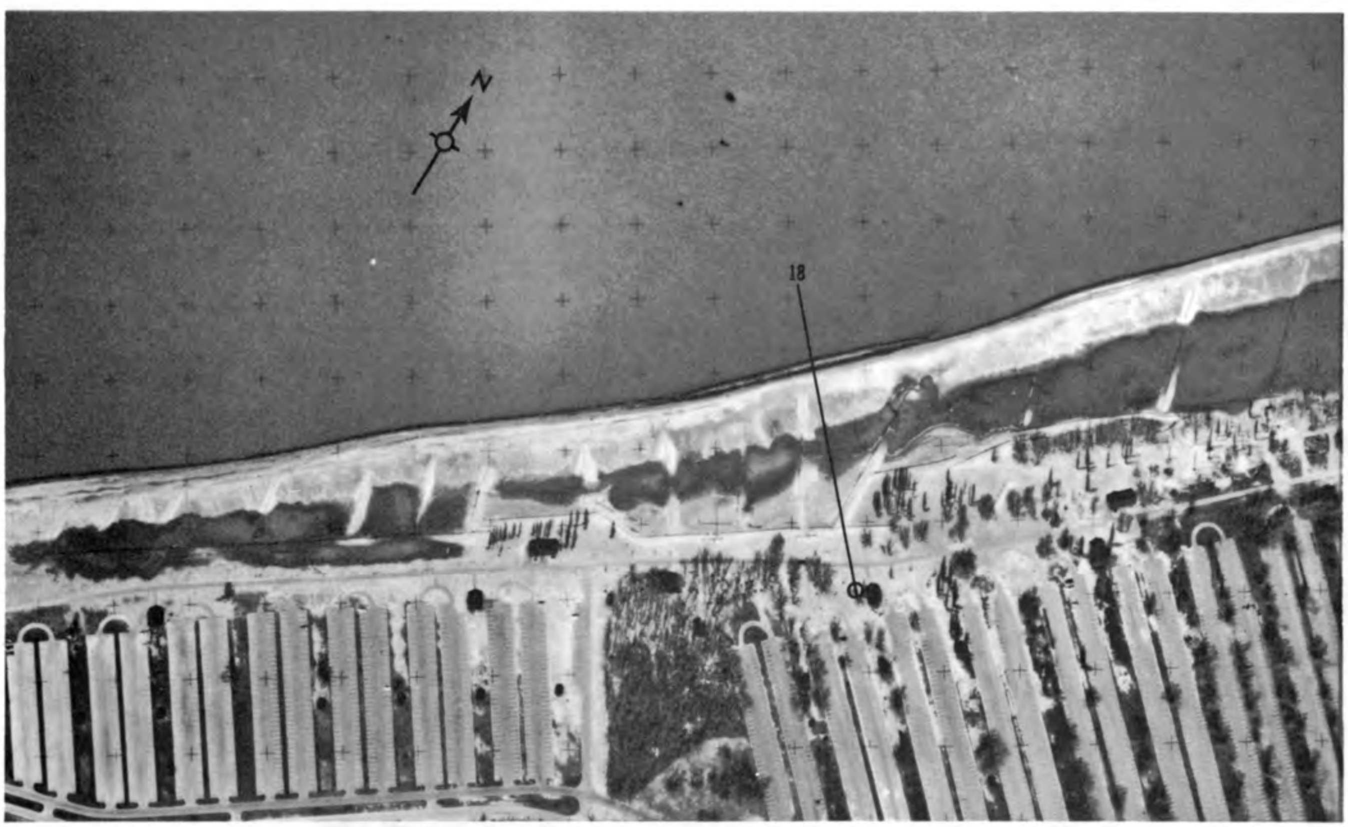


FIGURE 33

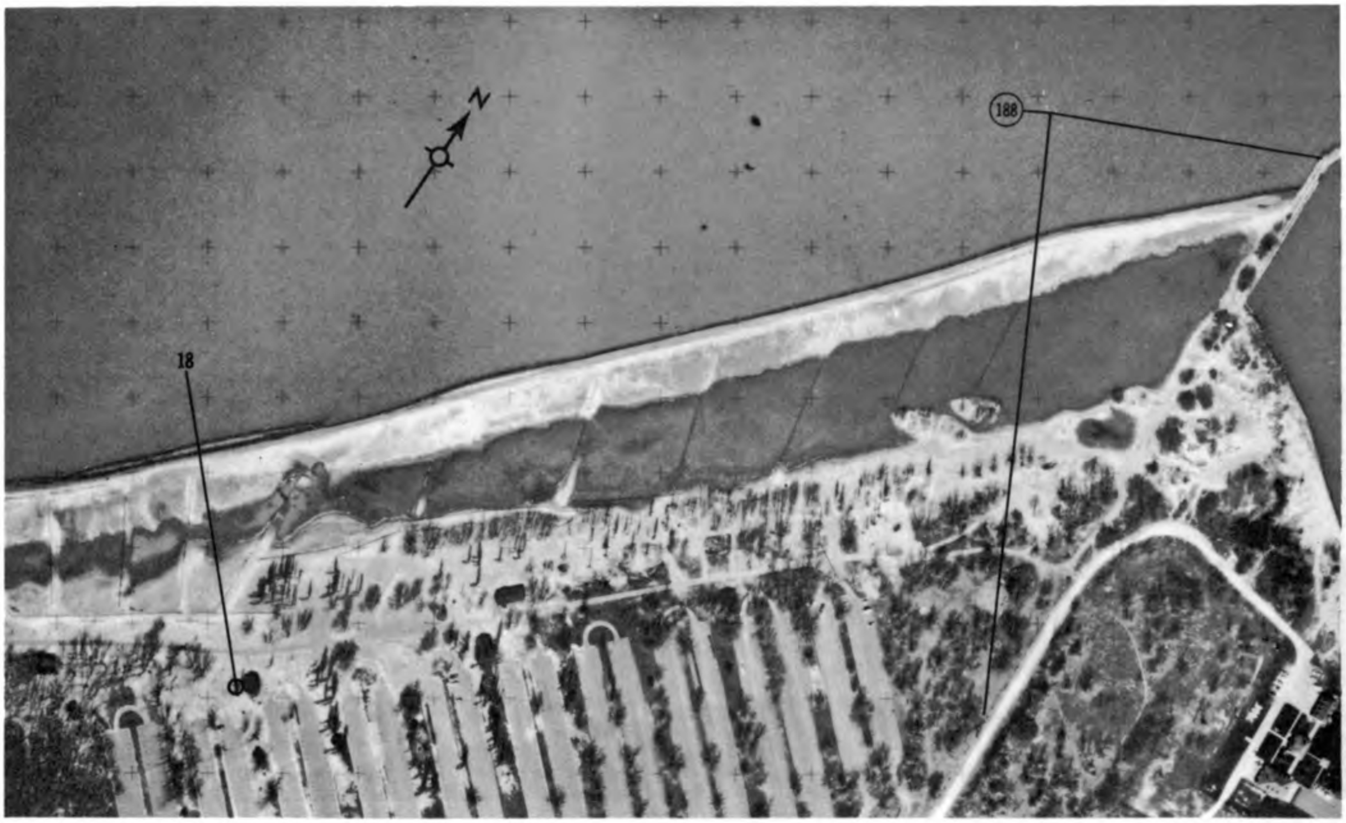


FIGURE 34

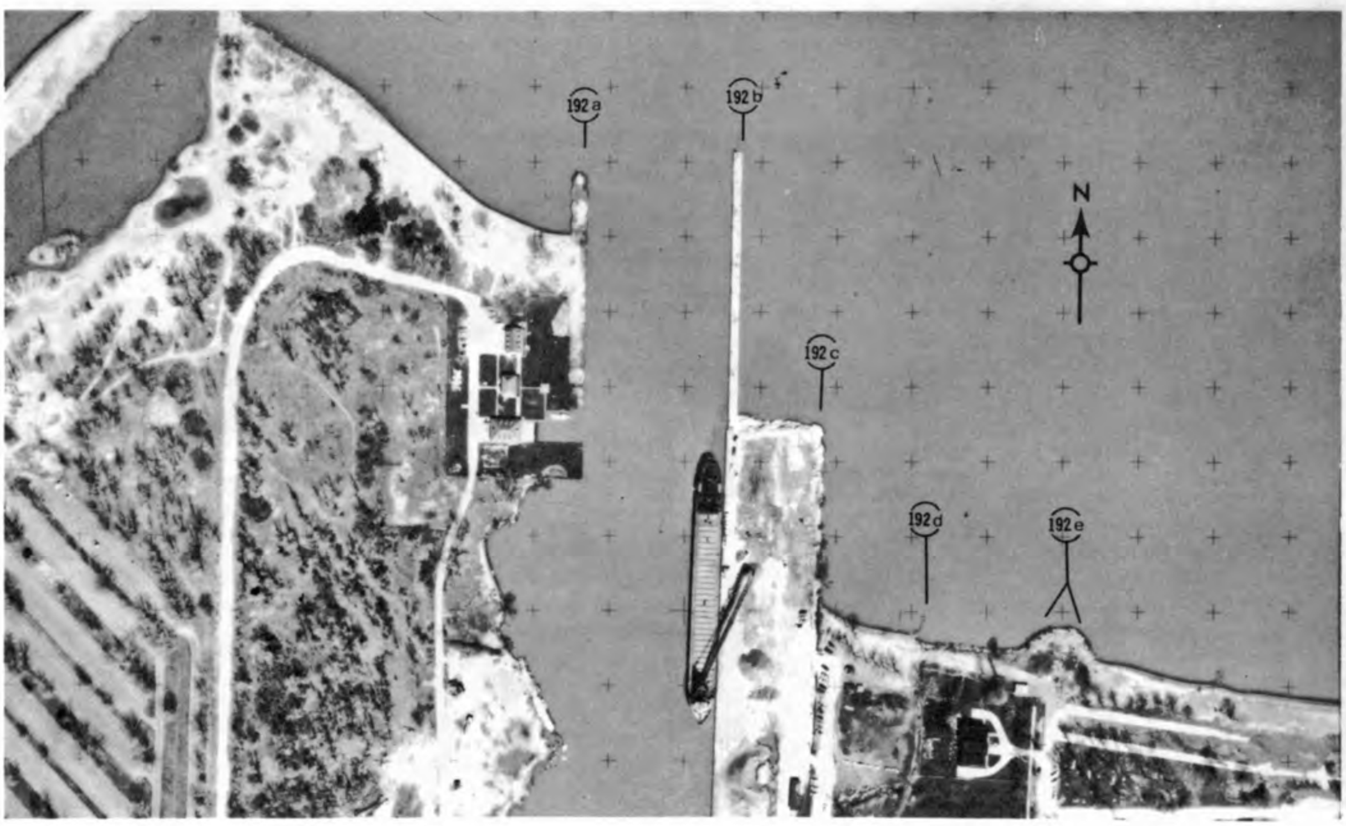


FIGURE 35

GRAND RIVER TO CAMP ROOSEVELT REACH

This reach is the most sparsely populated, yet the most highly industrialized, reach along the Lake County shore. Because of the low population density there has not been much property damage except to the village of Painesville-on-the-Lake; however, along this reach there has been a tremendous amount of erosion with a consequent loss of land and soil and an increase in lake sedimentation.

Natural setting, *circa* 1973

Nearshore zone.—Shale is at or very near the bottom surface along this reach (pl. 3). Profile 19, which is updrift of a headland fronted by long groins, has the greatest amount of sand in the nearshore zone. The sand is 4 to 5 ft (about 1.5 m) thick near the shoreline, but thins lakeward; shale is at the surface 550 ft (167 m) from the shoreline. The bottom along this reach has a well-defined slope of 5 to 6 degrees within 50 ft (15 m) of the shoreline; farther offshore, the slope is much less steep (table 28). Nearshore bars are uncommon along this reach; bars were noted only along the range 23 profile (table 12, table 28, pl. 3).

Beach and shoreline zone.—Beaches front about 70 percent of this reach. The beaches are small to moderate in size and are natural and trapped; most of them fill shallow embayments between headlands. However, the largest natural beach, which lies between range 22 and range 23, fronts a natural headland.

Shore zone.—Well-defined bluffs front the shoreline along this reach except in front of the industrial complex east of Grand River and behind the large beach between ranges 22 and 23.

The bluffs are composed largely of till. Near the base of the till there is a thin (less than 5 ft, or 1.5 m, thick) laminated clay unit that thins to the east (pl. 2). East of Painesville-on-the-Lake another laminated clay unit, which thickens to the east, caps the till. This clay is as much as 15 feet (4.6 m) thick and is overlain in places by a thin (less than 5 ft, or 1.5 m, thick) sand layer.

The shoreline is marked by a broad shallow embayment that extends along almost all the reach. Within this embayment there are three headlands with associated embayments on the downdrift (east) side; these headland-embayment couples have a wavelike form. The headlands are located near range 19, near range 22, and between ranges 22 and 23.

Natural processes, *circa* 1973

Rotational slumps are the most significant result of wave erosion along the western half of the reach (Grand River to range 21). To the east (range 21 to Camp Roosevelt) the laminated clay that acts as a slip plane below the till is too thin to have much effect; as a result the deposits are internally much more stable and maintain a vertical face. Till falls, initiated by wave erosion, are the most significant erosional process here.

Historic perspective: 1876, 1937, 1973

Land use.—The major changes in land use from 1876 to 1973 have taken place along two stretches (Grand River to range 19 and range 21 to range 22) where sparsely populated agricultural areas evolved into industrial areas (table 29). Along the rest of the reach there has been an overall loss of agricultural and forest land from 1876 to 1973.

Stickout structures.—Two manmade structures—the large jetties at the mouth of the Grand River—are shown on the 1876 map. By 1937 there were about 20 structures along this reach. From 1937 to 1970 the type, number, and distribution of the structures changed little (table 30). Probably the greatest change has taken place from Hardy Road, between range 19 and range 20, to range 22; in 1937 there were at least 8 groins/groin-breakwaters along this stretch, while in 1970 there were none. Other principal changes include the jetties that were built in 1937 adjacent to range 22 and the change from stickout-structure protection in the Grand River to range 19 stretch in 1937 to seawall-revetment protection by 1970. In general most of the structures were built in clusters, located at the Grand River industrial complex, at Painesville-on-the-Lake, and along the Camp Wise-I.R.C. Fibers plant stretch.

Beaches.—The beaches of 1876 were larger and more continuous than the 1973 beaches (table 31). For example, 35 percent of the 1876 beaches were moderate in size or larger, whereas only 12 percent of the 1973 beaches are that size. The basic difference, however, is distribution. In 1876, from range 20 to Camp Roosevelt, the beaches, although only small to small-medium in size, formed a continuous ribbon along the shore; in 1973, although the beaches are still small, they are not continuous, but are separated for the most part by small promontories and shoreline irregularities that were not present in 1876. For example, in 1876 only one stretch did not have a beach, whereas in 1973 10 stretches had no beach.

Shoreline shape.—The shoreline shape was fairly regular and uniform in 1876, being marked by a broad shallow embayment from Grand River to midway between range 19 and range 20 and then by a broad headland from this location to Camp Roosevelt. By 1937 the embayment was deeper and the headland was not as prominent. Furthermore, the shore was becoming more irregular in places because of the effect of manmade structures. By 1973 the embayment-headland couple of 1876 and 1937 has become an irregular embayment because of recession in the range 19 to range 22 stretch. Moreover, a few of the irregularities present in 1937 have been accentuated by differential erosion and form headlands, such as the headland between range 19 and range 20 (at Painesville Township Park) and the headland at range 22. The headlands represent protected segments of the shore.

Recession history

1876-1937.—The major portion (64 percent) of the reach receded at very slow to slow rates (table 32). However, there were three long stretches with a moderate recession rate: (1) adjacent to range 18a, (2) between range 20 and range 21 and adjacent to range 21, and (3) between range 21 and range 22. The stretch adjacent to range 18a is 5,700 ft (1,740 m) long and lies about 3,200 ft (976 m) downdrift of the Grand River jetties; the stretch was unprotected in 1876. The stretch between range 20 and range 21 and adjacent to range 21 is 3,800 ft (1,160 m) long and lies about 2,400 ft (732 m) downdrift of the Painesville Township Park headland; the stretch was unprotected in 1876 and 1937. The third stretch, between range 21 and range 22, is 1,900 ft (579 m) long and lies almost immediately downdrift of the 34 stickout structures that fronted Camp Wise in 1937; the stretch was unprotected in 1876.

1937-1973.—The major portion (57 percent) of the reach receded at very slow to slow rates (table 32). However, four long stretches receded at moderate or greater rates. The first stretch, between range 18a and range 19, had a moderate recession rate and is 2,250 ft (686 m) long. This stretch is close to and downdrift of the Grand River jetties and in 1937 was immediately downdrift of a substantial groin field/breakwater structure. The second stretch, between range 19 and range 22, had moderate to very rapid, primarily very rapid, recession rates, and is 6,000 ft (1,830 m) long. This stretch is immediately downdrift of the Painesville Township Park headland. The third stretch, between range 22 and range 23, had moderate to rapid recession rates and is 2,000 ft (610 m) long. This stretch is immediately downdrift of the I.R.C. Fibers Company jetty. The fourth stretch, adjacent to range 23 and between range 23 and Camp Roosevelt, had moderate to rapid recession rates except for 500 ft (152 m) that had a slow recession rate. The stretch is 4,750 ft (1,450 m) long and is immediately downdrift of a natural headland.

The principal areas that have undergone recession at very slow to slow rates have been in part protected by manmade structures. The major exception is between range 22 and range 23, where a natural headland has trapped sand from the longshore drift system, thus helping to protect the updrift shore but accelerating the recession rates downdrift.

Interpretation of recession

The best approximation for a natural (pre-structure) recession rate is the rate of the 1876-1937 period; however, this approximation must be tempered by the fact that the Grand River jetties were emplaced in 1827. The effect of these jetties on the recession rates of this reach is not well known, but it is likely that these structures have had a pronounced effect on the recession rates because of the sizeable quantity of sand they have trapped. The amount of sand trapped by these structures was 124,000 cu yd/yr (94,700 cu m/yr) in the 1911-1945 period and 88,000 cu yd/yr (67,300 cu m/yr) in the 1945-1958 period (Bajorunas, 1961, p. 333, 334). The recession rates in the 1876-1937 period ranged from very slow to moderate; the mode was slow. In contrast, the recession rates in the 1937-1973 period ranged from very slow to very rapid; the mode was very slow. These data are consistent with data from the three reaches to the west. Compared to recession rates of the 1876-1937 period, the recession rates of the 1937-1973 period have decreased at the very slow-slow end of the spectrum and increased at the moderate-very rapid end of the spectrum.

The stretch adjacent to range 18a probably receded at a moderate rate in the 1876-1937 period because of the Grand River jetties. The jetties trapped sand from the longshore drift system to the west, thus depriving the east (downdrift) shore of sand; the resultant steepening of the nearshore slope and narrowing of the beach is probably the cause of the moderate recession rate. This stretch has since been stabilized by a revetment-seawall system and between 1937 and 1973 receded at a very slow rate. Furthermore, the Grand River east breakwater was built to reduce the recession problem in this stretch (Bajorunas, 1961, p. 334). The stretch between range 20 and range 21 and adjacent to range 21 was also on the lee side of two groups of structures near range 19 and range 20. These structures trapped sand (probably derived from the accelerated recession updrift) from the longshore drift system and caused accelerated recession downdrift. It is interesting to note that the short—200 ft (61 m)—section that underwent slow recession within this stretch was protected by stickout structures in 1937. The third stretch, between range 21 and range 22, also was downdrift of a group of stickout structures; entrapment of sand by these structures caused accelerated recession downdrift. This stretch subsequently has been stabilized by a large beach that developed from the buildup of sand on the windward side of the jetty to the east as well as from a groin field directly in front of the stretch.

The stretch between range 18a and range 19 probably has undergone accelerated recession in the 1937-1973 period because of the destruction of the groin field/breakwater system that partially fronted and protected this stretch in 1937. The stretch between range 19 and range 22, the most rapidly receding stretch along the Lake County shore, has undergone accelerated recession for two reasons: (1) the stretch is on the lee side of a structural headland (Painesville Township Park), the same headland that caused accelerated recession by trapping sand during the 1876-1937 period, and (2) all (there were at least 8) stickout structures along this stretch were destroyed between 1937 and 1973. The stretch between range 22 and range 23 has undergone accelerated recession because of the jetties at range 22. This fairly long (more than 170 ft, or 56 m) stickout structure has trapped sand as well as forced sand farther offshore so that the downdrift area is deprived of sand. In 1937 sand from the natural headland between range 22 and range 23 extended nearly to range 22; by 1973 sand from the headland was more than 3,600 ft (1,100 m) to the east. The accelerated recession along the stretch adjacent to range 23 and between range 23 and Camp Roosevelt appears to be the result of natural processes related to the construction of the jetties at range 22. The jetties upset the equilibrium between the headland and the shore to the lee of the headland by causing accelerated recession downdrift. Sand bypassing the jetties was forced farther offshore and deposited in front of the headland. The headland built lakeward, forcing sand yet farther offshore; as a result the downdrift shore did not get the normal supply of sand, and accelerated recession took place.

Recession forecast (2010 A.D.)

Recession will continue to be a major problem along this reach, particularly along the stretches that receded at moderate to very rapid rates in the 1937-1973 period. The reason is fourfold: (1) the scarcity of sand in the longshore drift system, (2) the natural and/or man-influenced headlands, (3) the laminated clay zone near the base of the bluff along the western half of the reach, and (4) the almost complete lack of structural protection east of the industrial complex.

Summary and erosion-control suggestions

The most significant recession-rate factor is the stickout structures. These structures have reduced recession rates updrift (west) of them, while they have increased recession rates downdrift (east) in areas with a scarcity of structures. Moreover, once the updrift shore is stabilized, accelerated recession downdrift places the shore farther from the longshore drift of sand, assuming that sand is able to bypass the structure(s). Further evidence of the influence of stickout structures can be seen in the more irregular shoreline within the 1937-1973 period, especially in areas protected by stickout structures and adjacent to unprotected areas. Overall, the rates of recession have been reduced from slow to very slow in some areas because of these structures and have been increased from slow-moderate to rapid-very rapid in other areas. The Grand River harbor structures have had the most significant influence on this reach. The tremendous quantity of sand trapped on the west side of the jetty-breakwater complex gives some indication of the effect of the structures in trapping sand. Accelerated recession along this reach probably began immediately after emplacement of the harbor jetties in 1827. The accelerated recession on the east side of the jetties prior to the emplacement of shore structures and the breakwater probably is responsible for the pronounced embayment east of Grand River.

To reduce the recession rate the following points might be considered: (1) reduction in the length of the large structures at Painesville Township Park and at the I.R.C. Fibers plant, (2) landscaping–drainage, slope reduction, and toe-support–at the above-named areas as well as at the range 23 area and the stretch east of range 18a, (3) beach nourishment, especially in areas undergoing moderate to rapid recession (short–less than 50 ft, or 15 m, long–groins could be built in these areas to try to hold this sand; the area west of range 23 is a good example of how a gentle landscaped slope and sufficient sand can protect a shoreline), and (4) a sand bypass system to transfer sand around the Grand River harbor structures to reduce wave erosion downdrift.

TABLE 28.–*Nearshore depths, Grand River to Camp Roosevelt*

Range profile	Nearshore depth (ft)								
	50 ft[1]	100 ft	200 ft	300 ft	400 ft	500 ft	1,000 ft	1,500 ft	2,000 ft
19	4.5	8	12	13.5	14	15.5	16.5	21	24
20	5	6.5	8.5	8.5	4	6.5	19.5	21	23
21	5	8.5	10	10	11.5	11	15	16	23
22	6	7.5	9.5	10	10	11	16	20	[3]
23	5	5.5[2]	5.5[2]	7.5	8.5	7[2]	13.5	19	23.5

[1] Distance from shoreline in all cases; shoreline is defined as the contact between the lake and the beach. See table 12 for lake level.
[2] Depth to sand bar (crest or limb).
[3] Profile did not extend to 2,000 ft offshore.

TABLE 29.–*Land use, Grand River to Camp Roosevelt*

Location	Land use[1]		
	1876	1937	1973
Grand River-R18a	range, urban(s)[2], agricultural	urban(m), industrial	urban(m), industrial
R18a-R19	range, agricultural, forest, urban(s)	range, forest, industrial	range, forest, industrial
R19-R20	range, agricultural, forest, urban(s)	urban(s), range	urban(s), range
R20-R21	range, agricultural, forest, urban(s)	range, urban(s), agricultural	range, urban(s), agricultural
R21-R22	agricultural, forest, urban(s)	range, agricultural, forest, industrial	agricultural, range, forest, industrial
R22-R23	agricultural, forest, range	agricultural, forest, range	agricultural, forest, range
R23-Camp Roosevelt	agricultural, range, forest	agricultural, forest, range	agricultural, forest, range

[1] Land uses for a given year are arranged from left to right in order of amount of land used, largest land use to the left.
[2] (s), sparsely populated, less than one house/acre; (m), moderately populated, one to three houses/acre.

TABLE 30.–*Inventory of stickout structures, Grand River to Camp Roosevelt*

Location	Structure no.[1]	Type and number of structures[2]			
		1876	1937	1954	1970
Grand River-R18a	192i		G(2), G/B, GF(3), G/B	x	B
R18a-R19	192j		x	GF(6)	
	192k		x	x	G/B
	192l		x	G	
R19-R20	193		x	x	G
	194		x	x	G
	195		x	x	G
	196		x(G/B)	x(G/B)	G
	198				G
	199		x(G/B)	x(G/B)	G
			G		
			G		
			G		
			G/B		
R20-R21	200		x	G(2)	
	201		x	G(2)	
R21-R22	203		x	x	GF(24)
	204		y	x	G
	205		y	x	G
	206		x	x	G
	208		x	x	J
	209		x	x	G
	210			x	G
			x	GF(3)	
	212		x	x	G
	214		y	y	GF(16)
	215		x(1937)	x	J
R22-R23					
R23-Camp Roosevelt	216				G

[1] Structure numbers correspond to numbers in the Appendix, which is a compendium of information on all structures along the shore of Lake County. Some early (1876-1937) structures, which are not described in the Appendix, are included in the stickout structure table, but are not numbered (for example, the groin field between structure no. 23 and structure no. 24 on table 15).

[2] B, breakwater; G, groin; GF, groin field; J, jetty; P, pier; S, seawall; (5), number of structures included under one inventory number; x, structure described in a later year is most likely the same structure observed on map or aerial photograph; y, structure described in a later year is possibly the same structure shown on map or aerial photograph; (1924), year the structure was built, if known.

TABLE 31.–*Beaches, Grand River to Camp Roosevelt*

Location	1876			1937			1973		
	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]
Grand River-R18a	700	trapped	large	700	trapped	moderate	700	trapped	small-moderate
				2,200	trapped	moderate-large	1,600	trapped	moderate-large
	2,900	trapped	large	1,200	trapped	small	3,100	–	
	3,900	natural	moderate-large	1,500	–		600	trapped	moderate
				1,900	trapped	small	1,400	trapped	small
R18a-R19	1,600	natural	small				1,200	natural	small
	1,300	natural	moderate	5,400	trapped	small	300	–	
	2,600	natural	moderate-large				3,700	trapped and natural	small
R19-R20	1,000	natural	small-moderate	1,500	trapped	small-moderate	700	trapped	small
	1,200	natural	no beach-small	600	–		700	–	
				100	trapped	small	700	natural	small
R20-R21							200	natural	small
							400	–	
				400	trapped	small	400	natural	small
	3,200	natural	small-moderate	600	–		400	–	
				1,000	trapped	small	300	natural	small
				900	–		900	–	
							500	natural	small
R21-R22				1,500	–				
				1,100	trapped	small	300	natural	small
	4,900	natural	small	200	–		1,700	–	
				1,200	trapped	small			
				700	–		2,800	trapped	small
				200	trapped	small			
R22-R23							200	–	
							3,000	trapped and natural	small
	6,100	natural	small-moderate	6,100	natural	moderate-large	200	–	
							1,000	natural	small
							1,800	natural	moderate-large
R23-Camp Roosevelt				1,700	–				
	3,500	natural	small	400	natural	small	1,200	natural	small
				600	–		2,700	–	
				800	natural	small			

Summary

Width of beach[3]	Beach length (ft)[1]		
	1876	1937[4]	1973[4]
No beach-small	1,200		
Small	10,000	13,700	17,400
Small-moderate	10,300	1,500	700
Moderate	1,300	700	600
Moderate-large	6,500	8,300	3,400
Large	3,600		

[1] Measured to nearest 100 ft.

[2] *Natural,* the development of the beach has not been caused by manmade structures; *trapped,* the development of the beach has been caused by manmade structures; –, no beach.

[3] *Small,* less than 50 ft wide; *moderate,* 50 to 100 ft wide; *large,* greater than 100 ft wide.

[4] In 1937 there was 8,300 ft and in 1973 10,600 ft of shore without any beach.

TABLE 32.–*Recession rates, Grand River to Camp Roosevelt*

Location	1876-1937		1937-1973	
	Recession rate[1]	Length (ft)[2]	Recession rate[1]	Length (ft)[2]
Grand River-R18a	*floodplain (750 ft)*		*floodplain (750 ft)*	
	very slow	900		
	slow	600		
	very slow	1,000	very slow	7,250
	slow	350		
	moderate	4,250		
R18a-R19			very slow	300
			slow	700
	moderate	1,450	slow-moderate	400
	slow	1,300	very slow	400
	very slow	800	slow	550
	slow	2,000	moderate	2,250
			slow	700
			very slow	500
R19-R20			very slow-slow	1,050
	slow	2,000	moderate	200
	moderate	250	rapid	150
			very rapid	900
R20-R21	slow	350	very rapid	300
	moderate	1,300	rapid	200
	slow	200	very rapid	2,200
	moderate	1,350	rapid	150
			very rapid	600
R21-R22	moderate	1,150	very rapid	150
	slow	1,100	rapid	250
	very slow	400	moderate	900
	slow	200	slow	900
	moderate	1,900	very slow	350
	slow	300	slow	350
			very slow	2,300
R22-R23			very slow-slow	300
			moderate	250
	slow	1,850	rapid	850
	very slow	250	moderate	900
	slow	900	slow	800
	very slow	500	very slow	2,600
	slow	2,900	slow	150
			moderate	700
			rapid	100
R23-Camp Roosevelt	very slow	900	rapid	550
	slow	2,600	moderate-rapid	300
	moderate	200	moderate	700
	slow	150	slow	500
			moderate	1,900

Summary

Recession rate[1]	Length in each recession class (ft)[2]	
	1876-1937	1937-1973
Total very slow	4,750	13,700
Total very slow-slow		1,350
Total slow	16,800	4,650
Total slow-moderate		400
Total moderate	11,850	7,800
Total moderate-rapid		300
Total rapid		2,250
Total very rapid		4,150

[1] Very slow, <1 ft/yr; slow, 1-3 ft/yr; moderate, 3-5 ft/yr; rapid, 5-7 ft/yr; very rapid, 7-9 ft/yr.
[2] Measured to nearest 50 ft.

AERIAL PHOTOGRAPHS, GRAND RIVER TO CAMP ROOSEVELT REACH

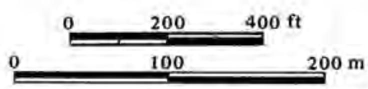
Aerial photography of the Lake County shore was done in 1973 by the Ohio Department of Transportation. The photographs for this reach are reproduced here with superimposed 1876, 1937, and projected 2010 recession lines. The 1876 line is farthest lakeward; the 2010 line is the heavy dashed line farthest landward; the 1876 and 1937 lines are dashed where approximate. The recession lines for the different years coincide where there has been no change.

Range and structure locations also are shown (see Appendix for description of the structures). Structure 192f was too far offshore to be considered a shore-protection structure; structure 192l could not be located on the aerial photograph. The following symbols are used:

Range location and number

Structure location and number; dashed line indicates that structure was not found in 1970 survey

Scale on all photos:



Scale distorted toward edges of photos

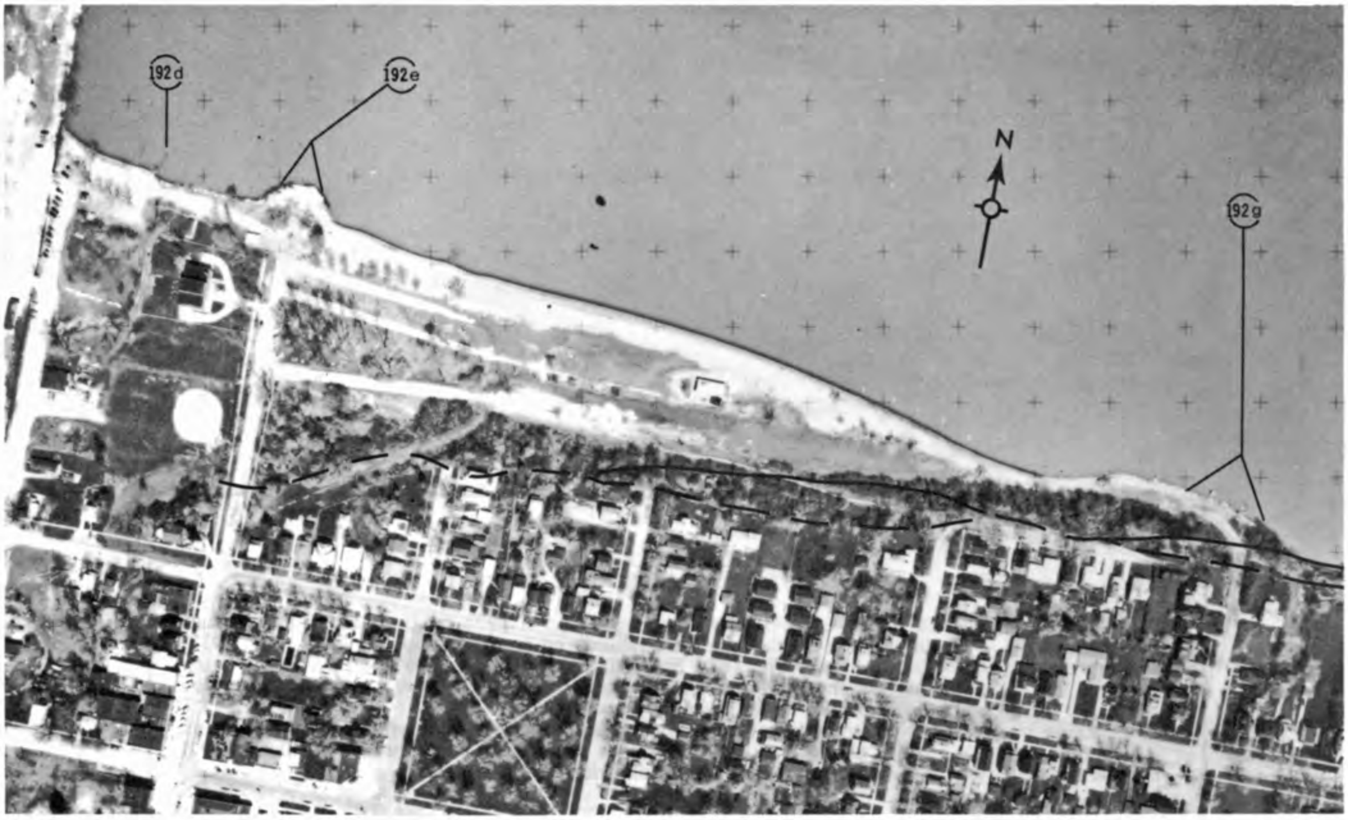


FIGURE 36

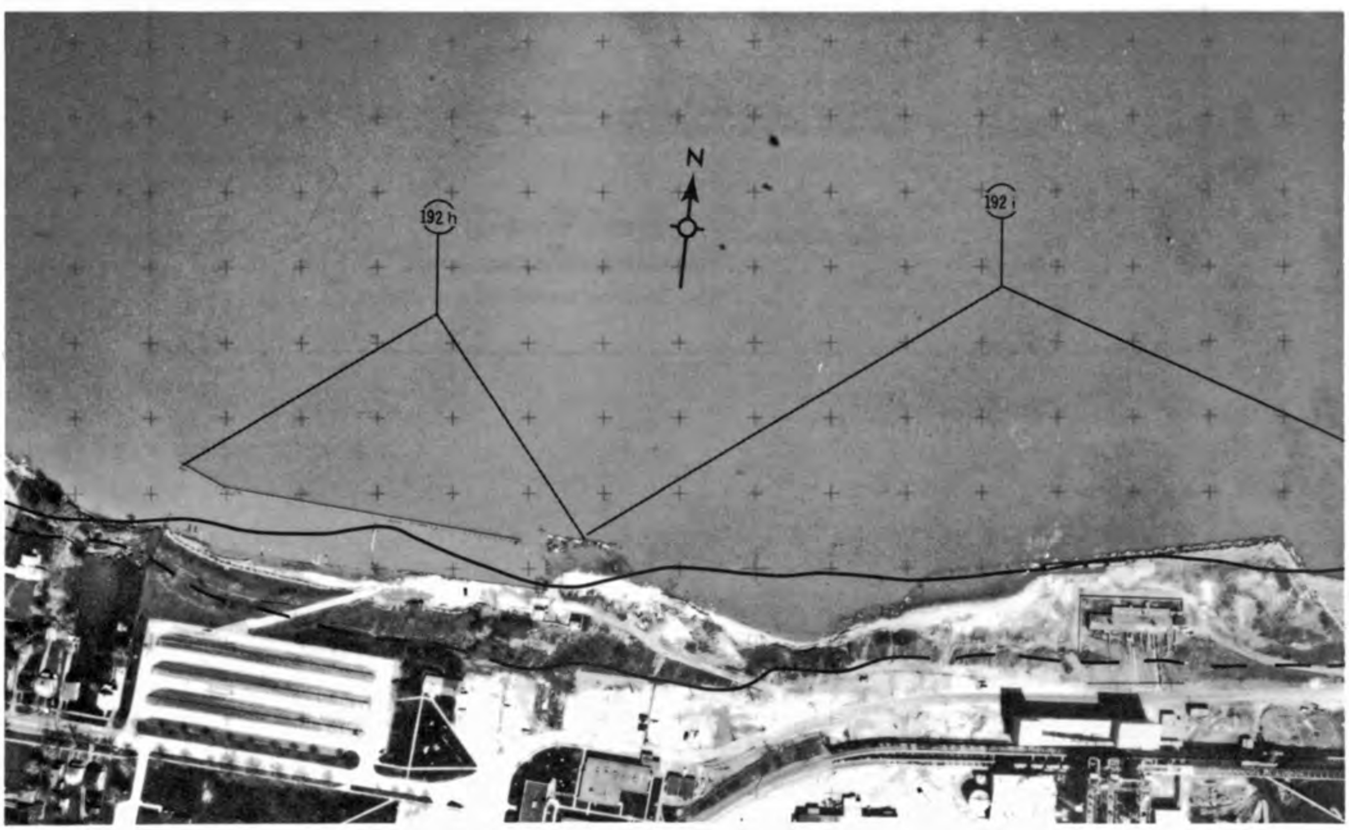


FIGURE 37

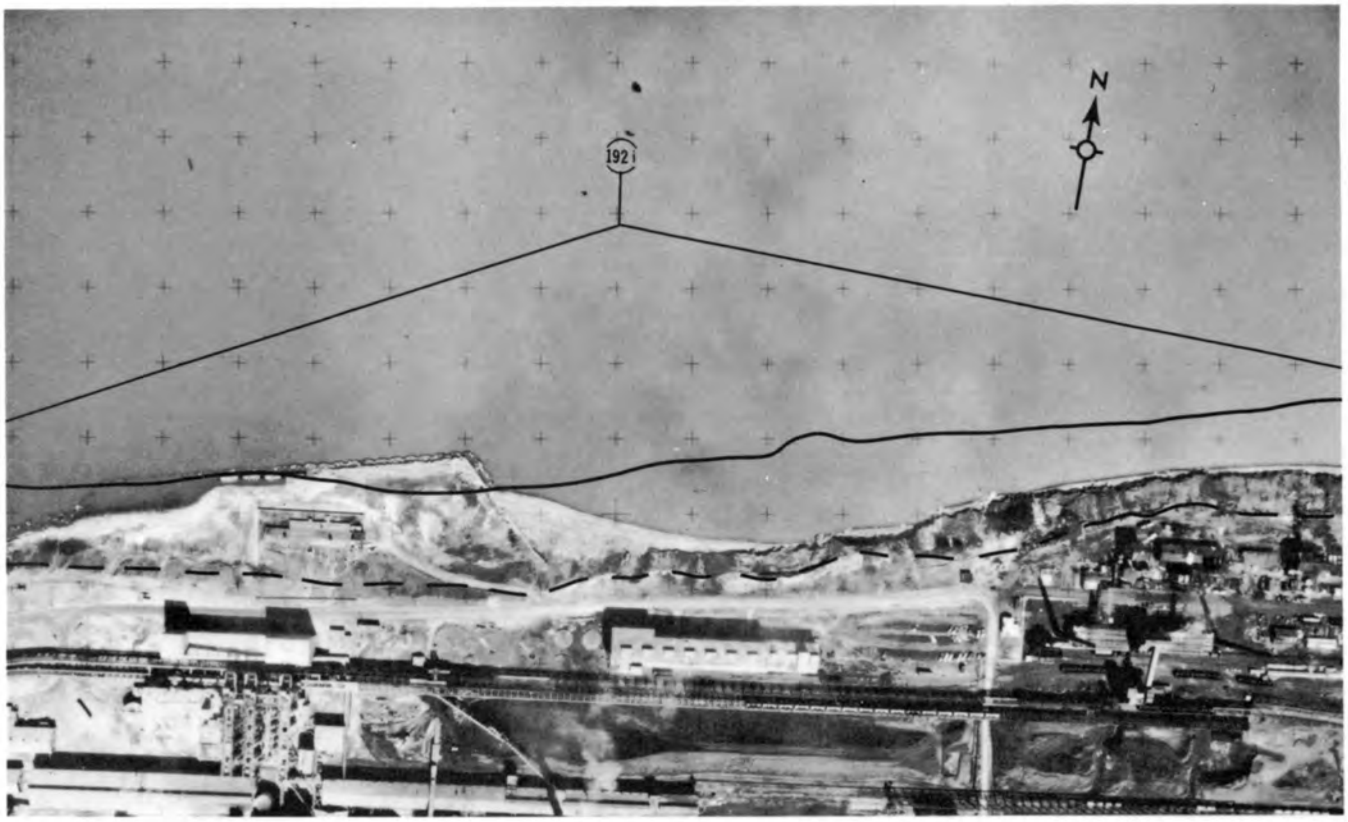


FIGURE 38

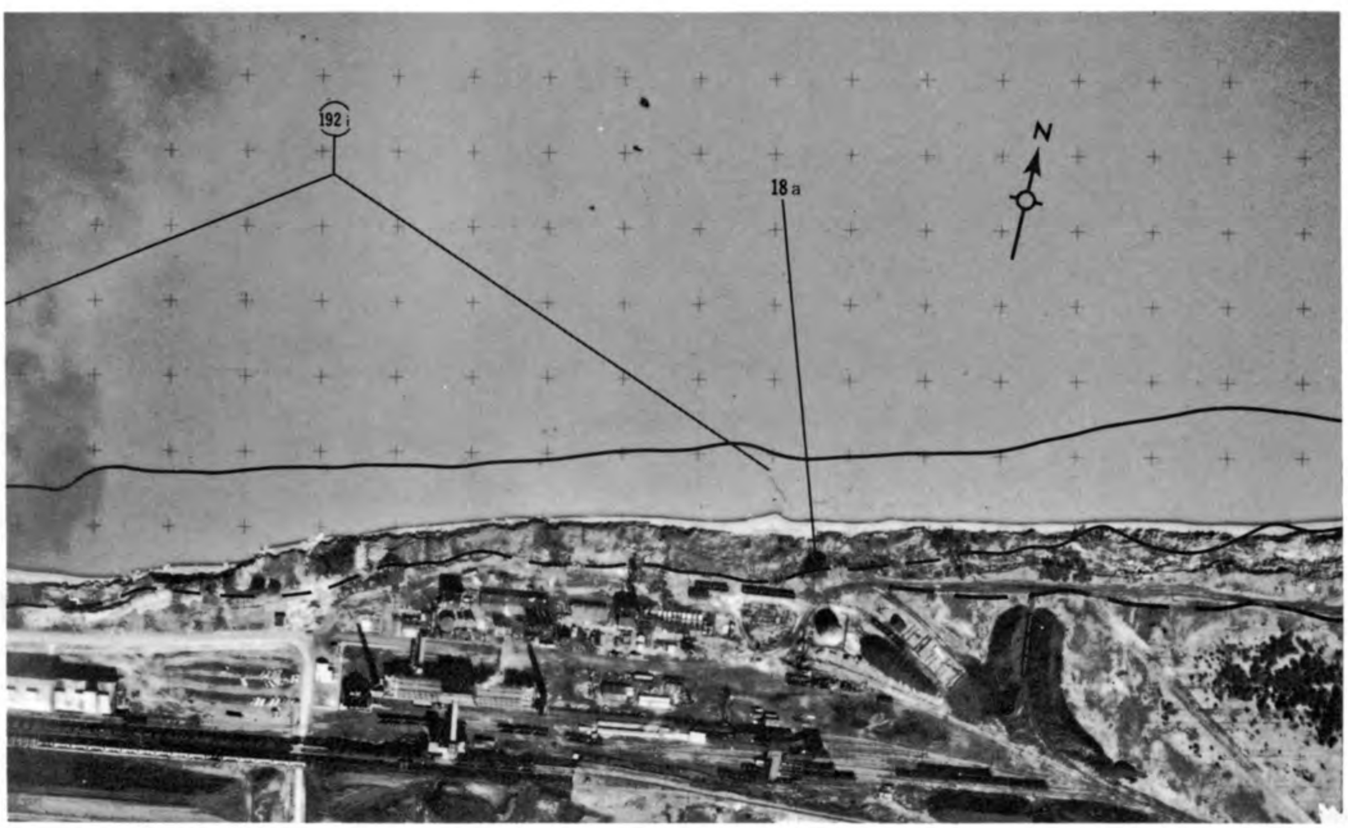


FIGURE 39

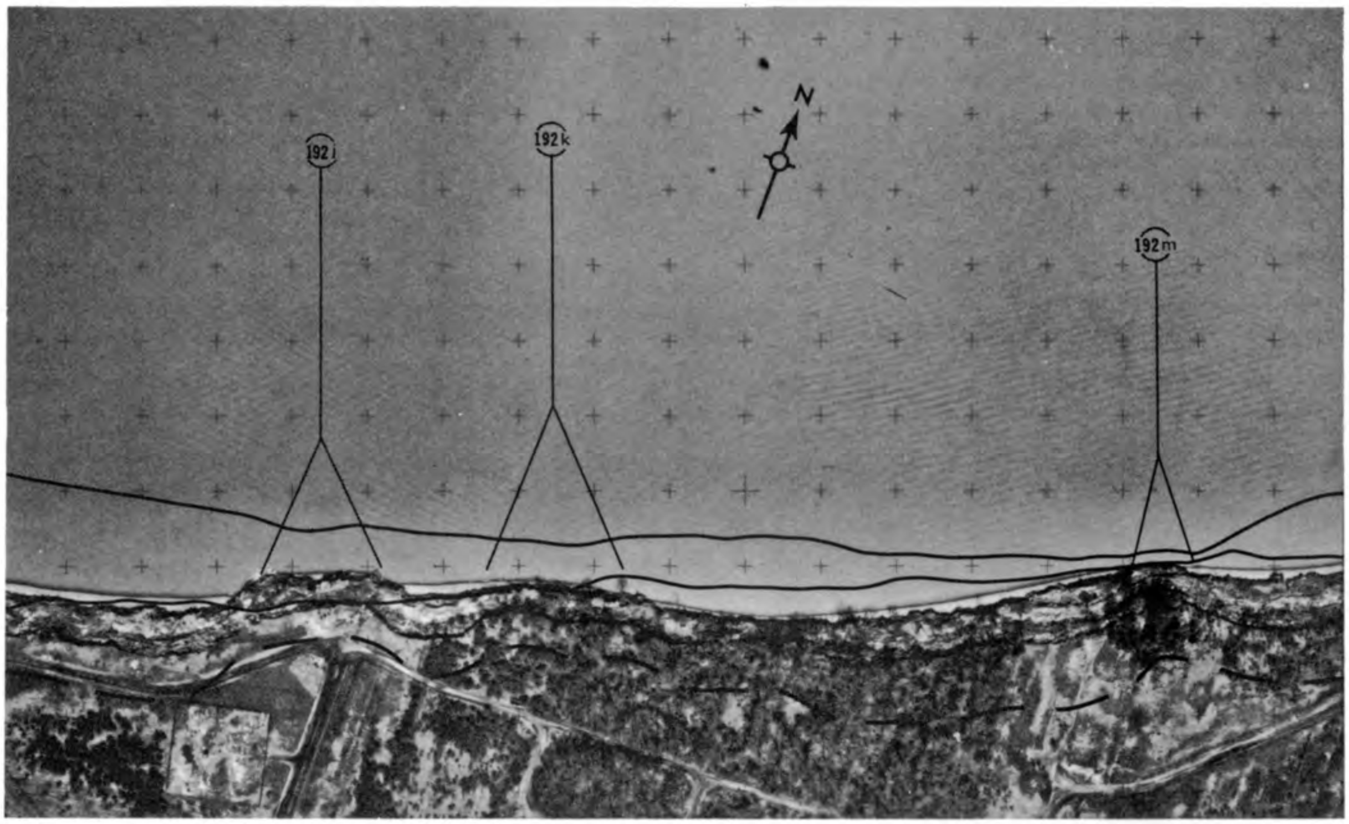


FIGURE 40

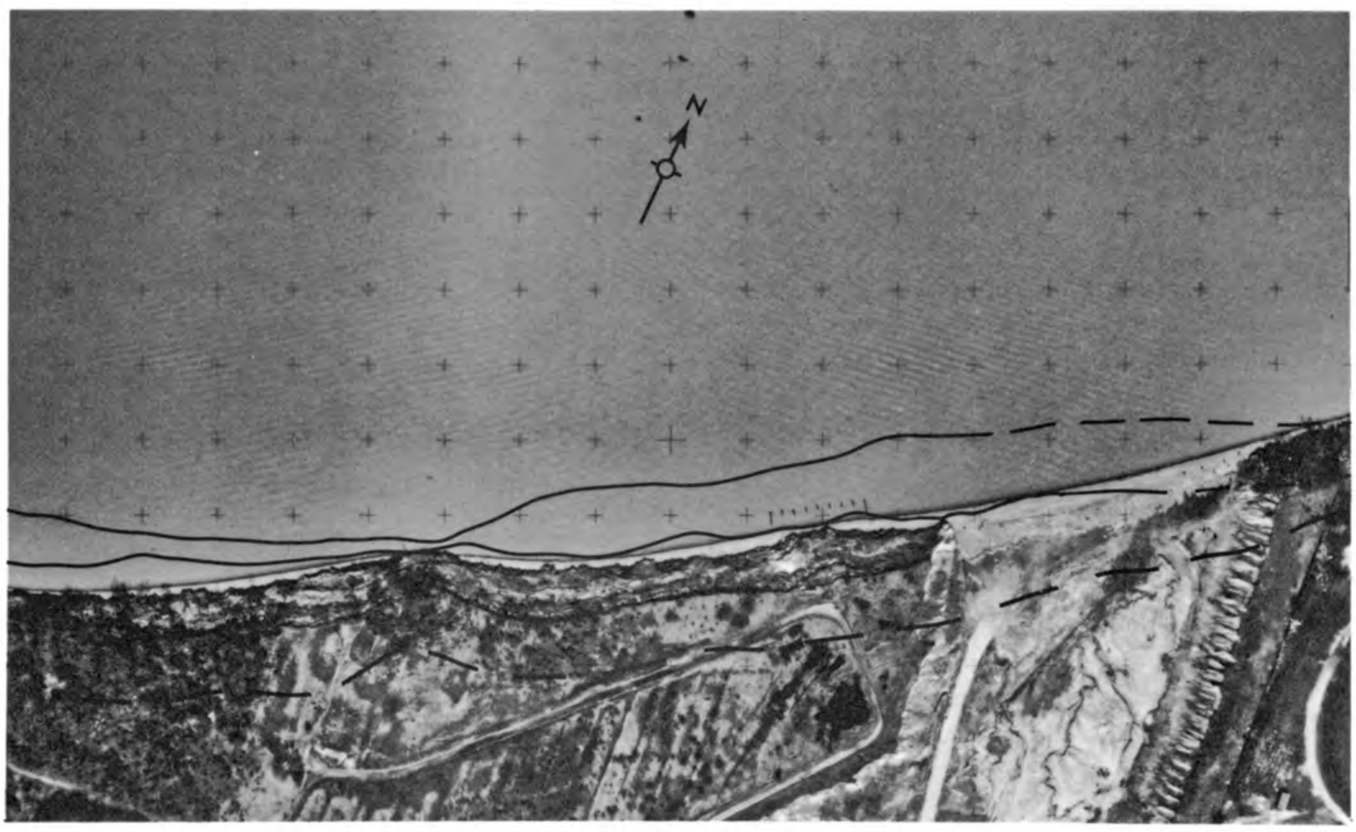


FIGURE 41

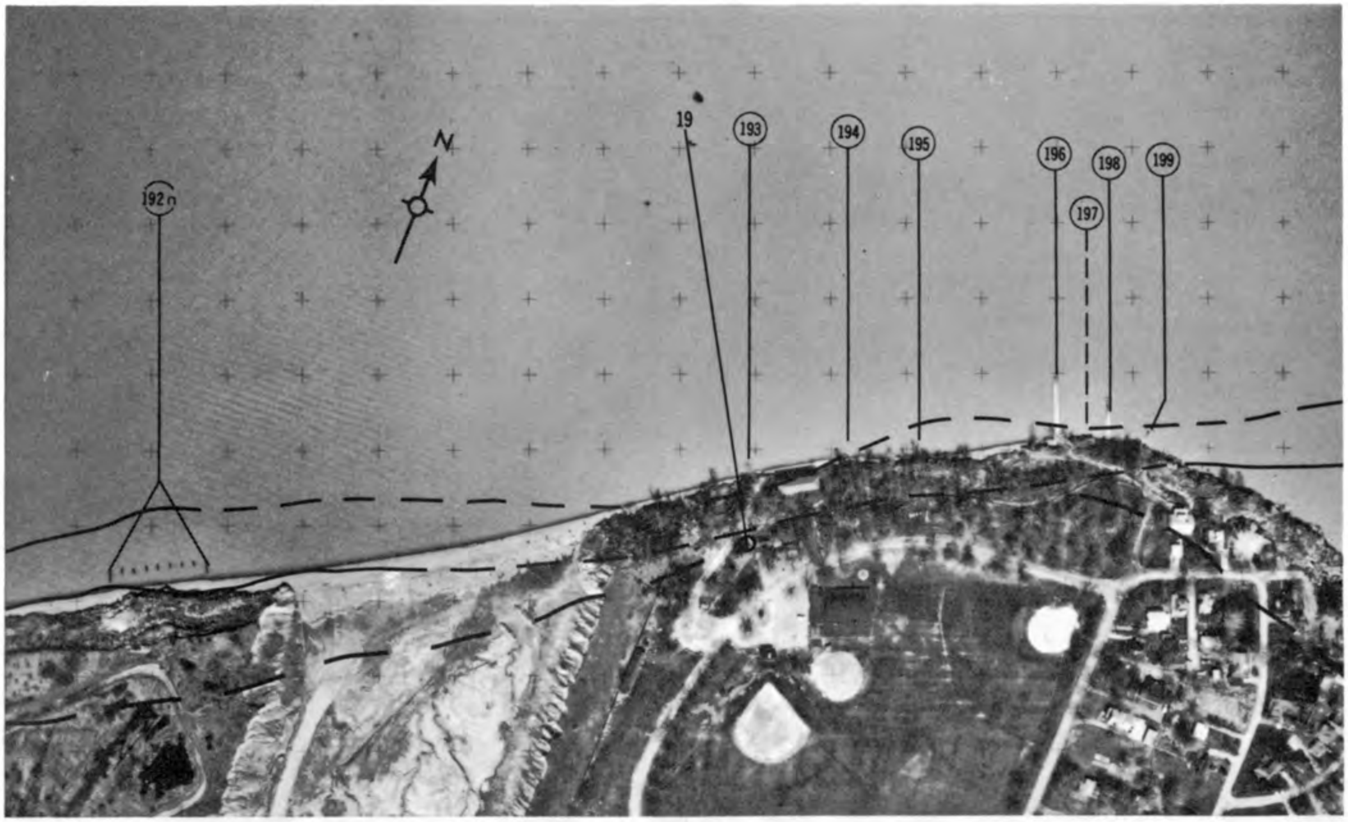


FIGURE 42

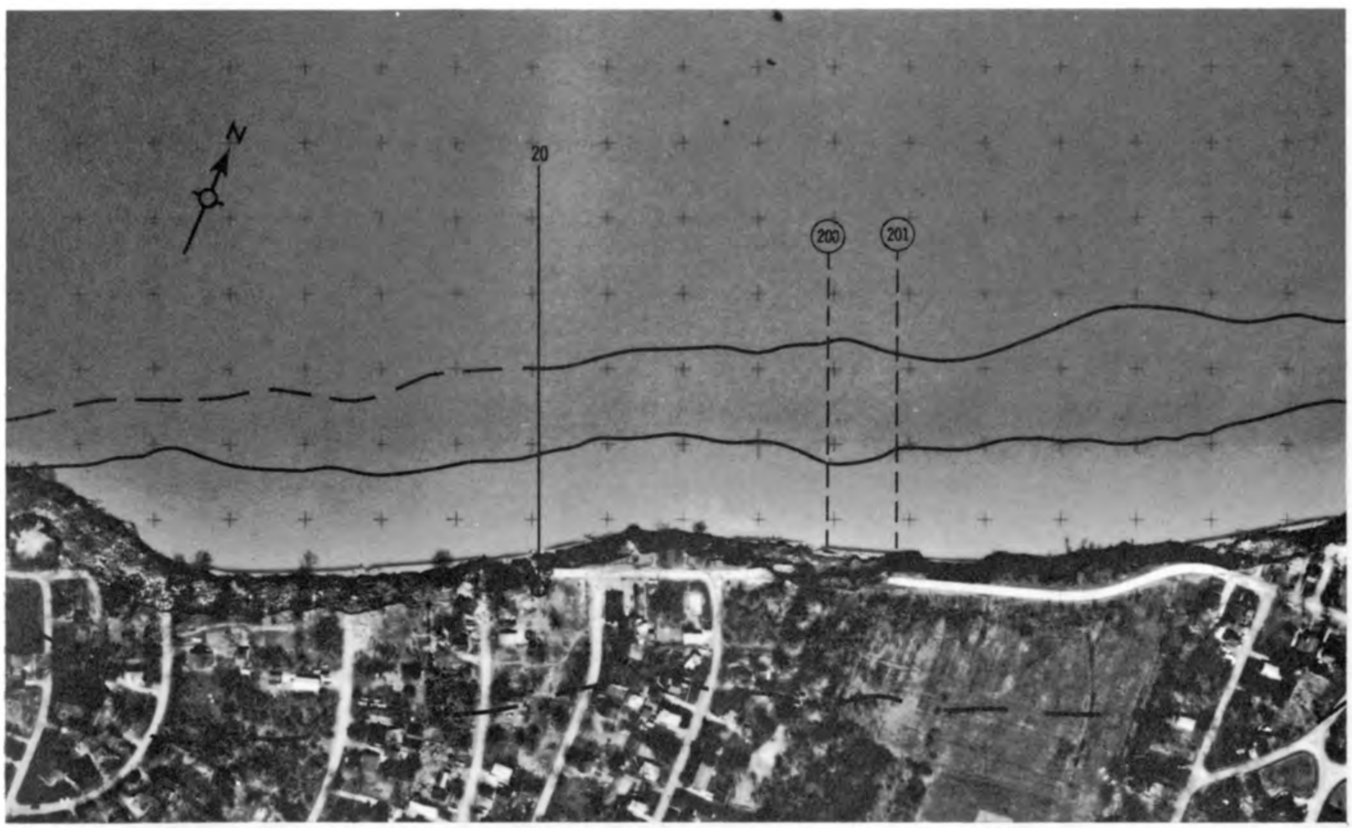


FIGURE 43

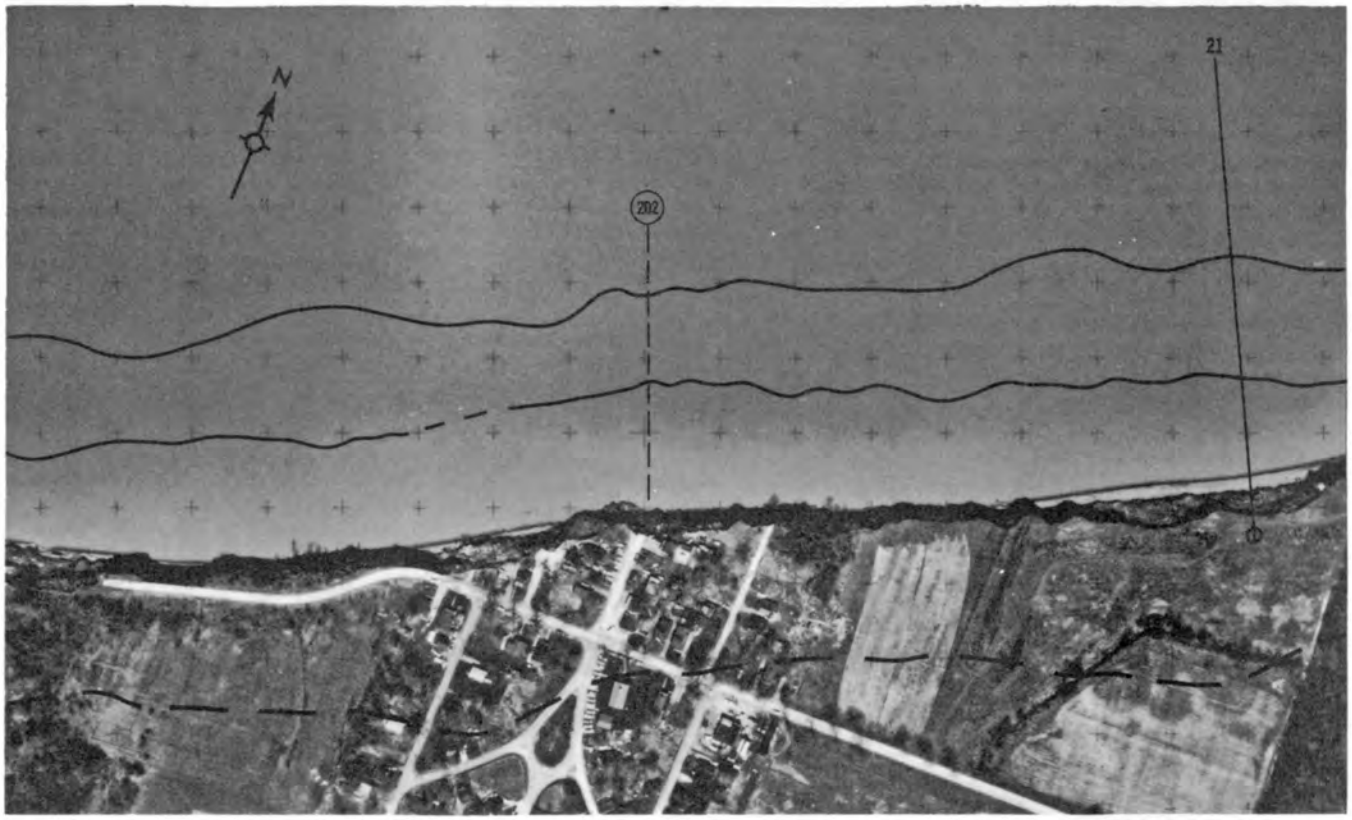


FIGURE 44

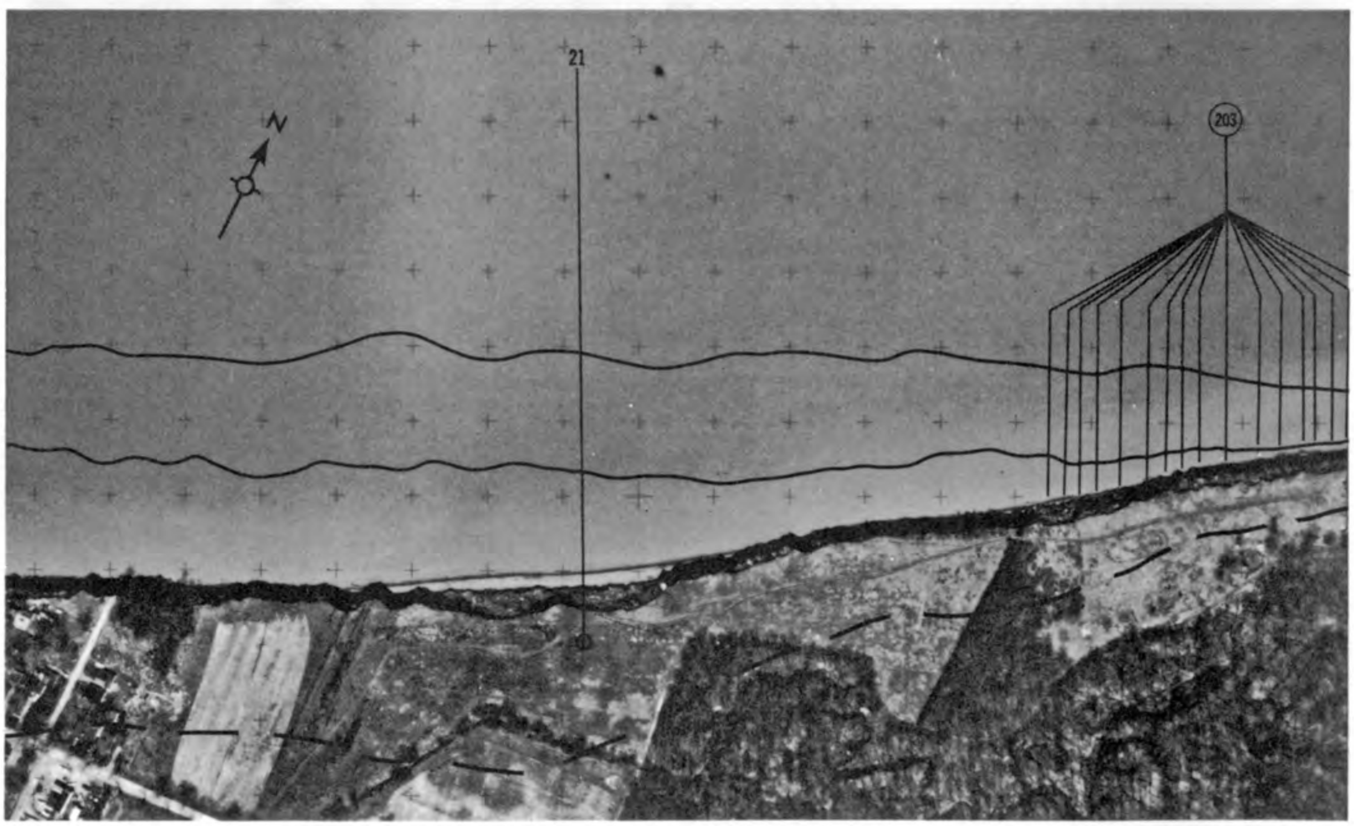


FIGURE 45

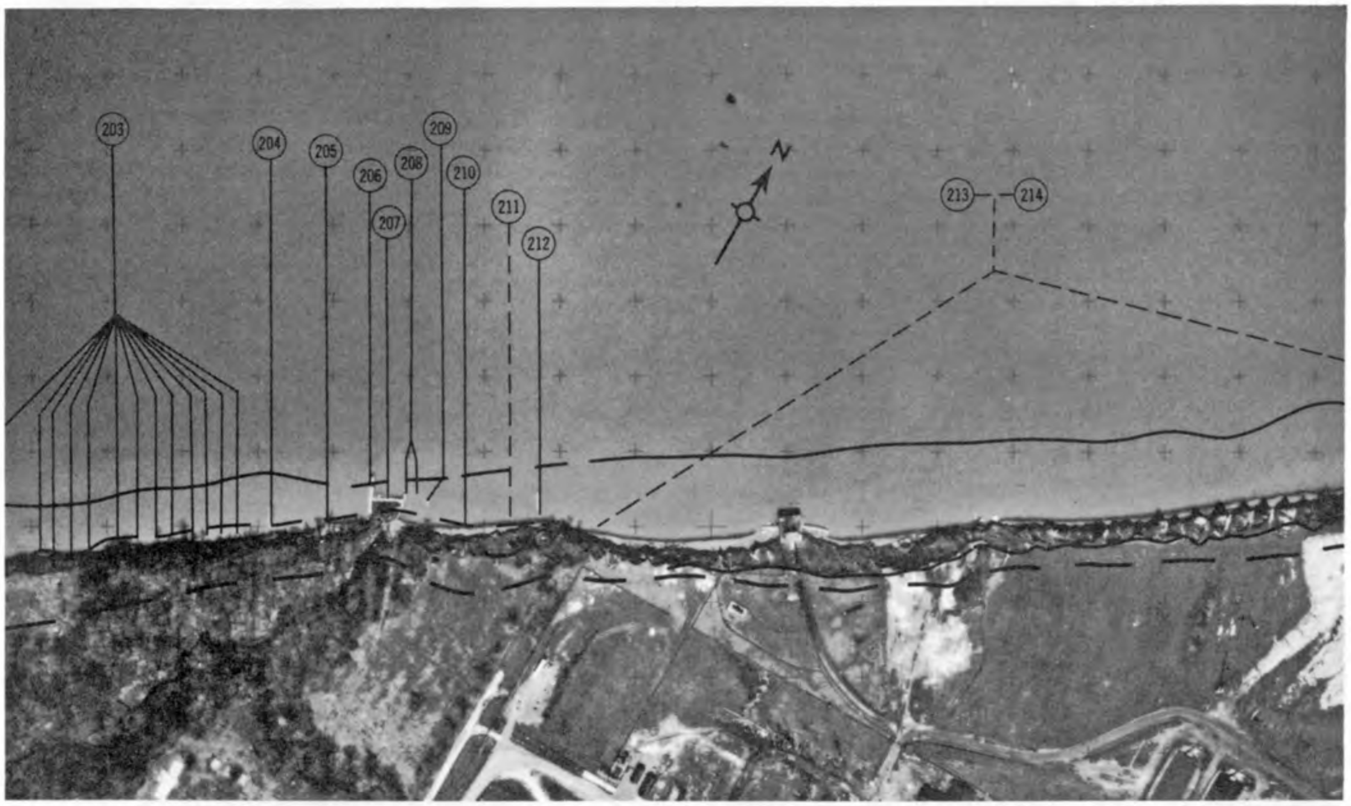


FIGURE 46

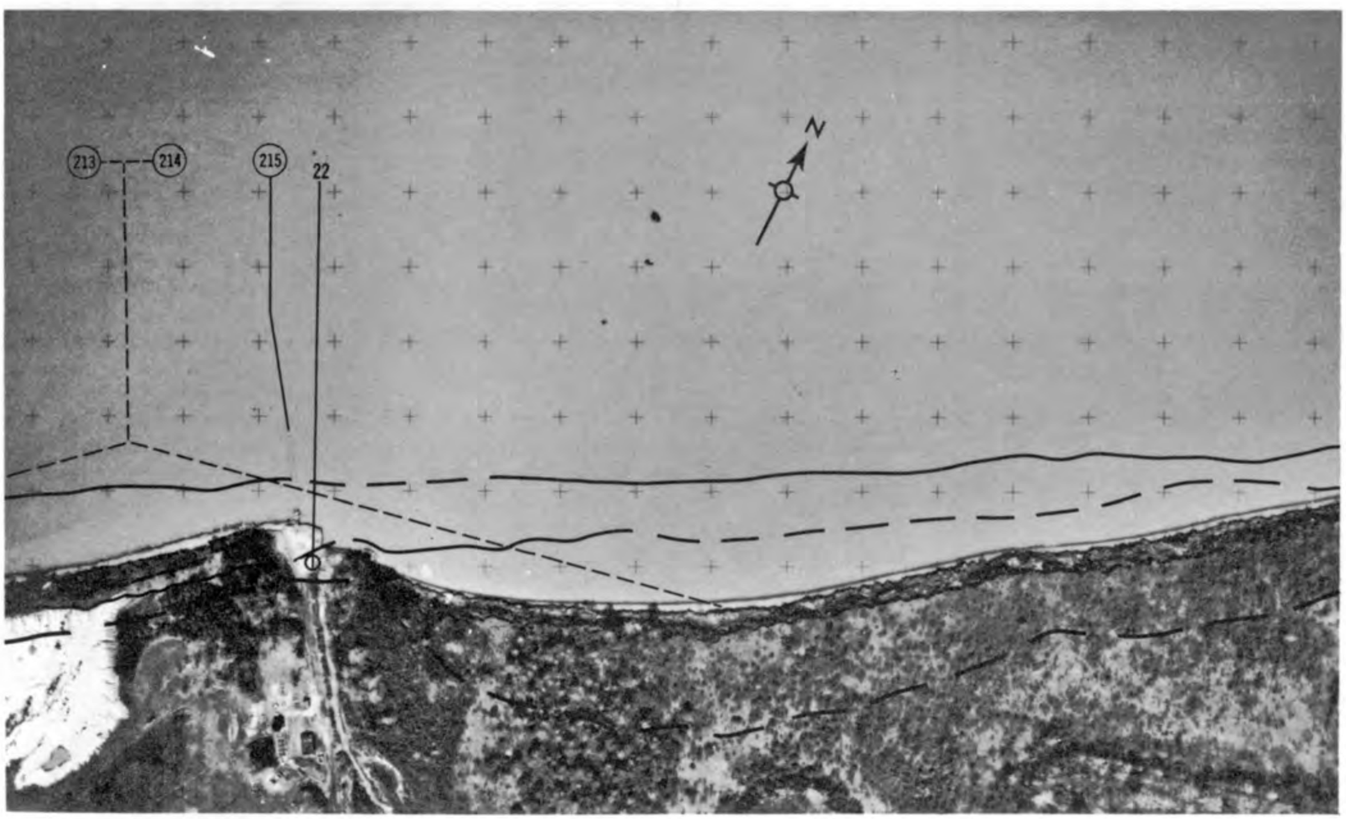


FIGURE 47

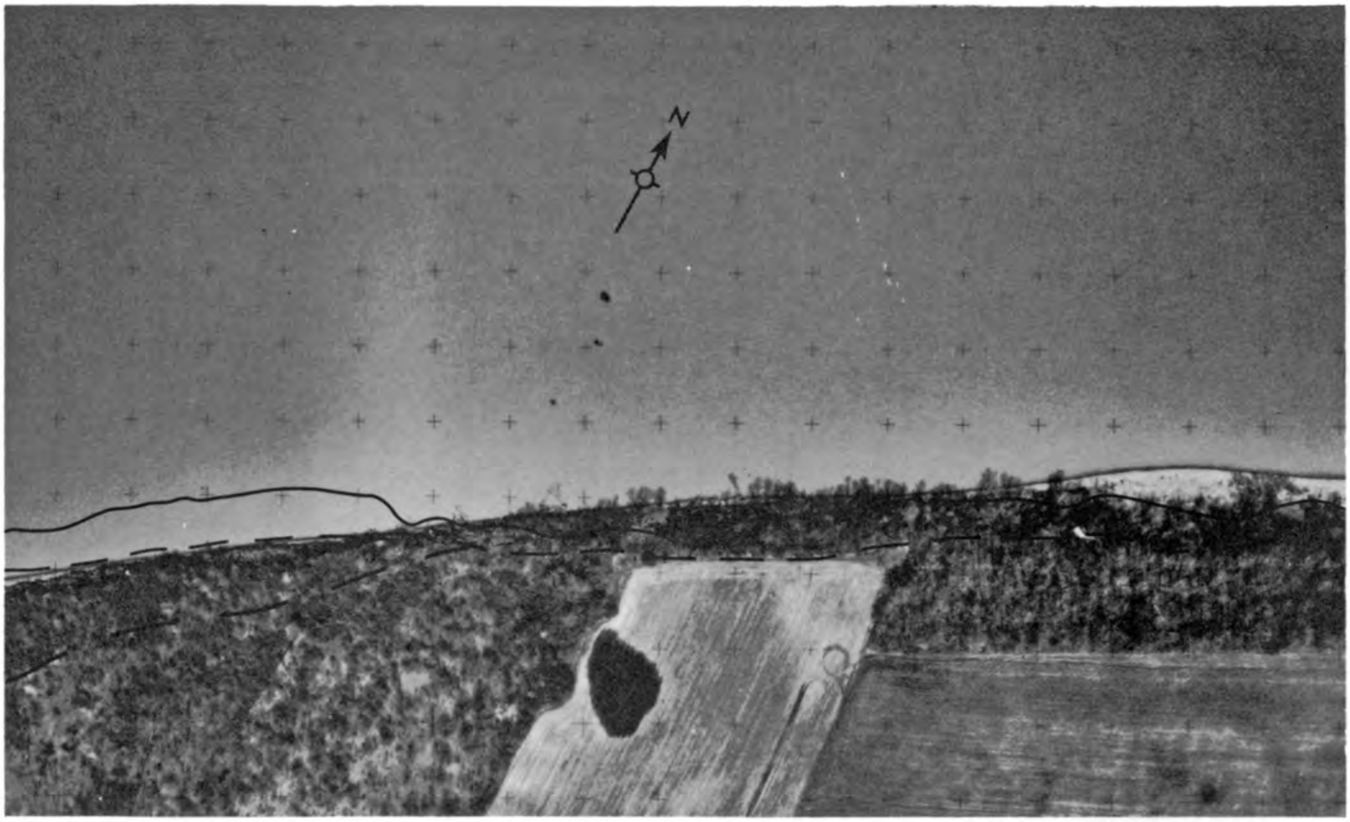


FIGURE 48

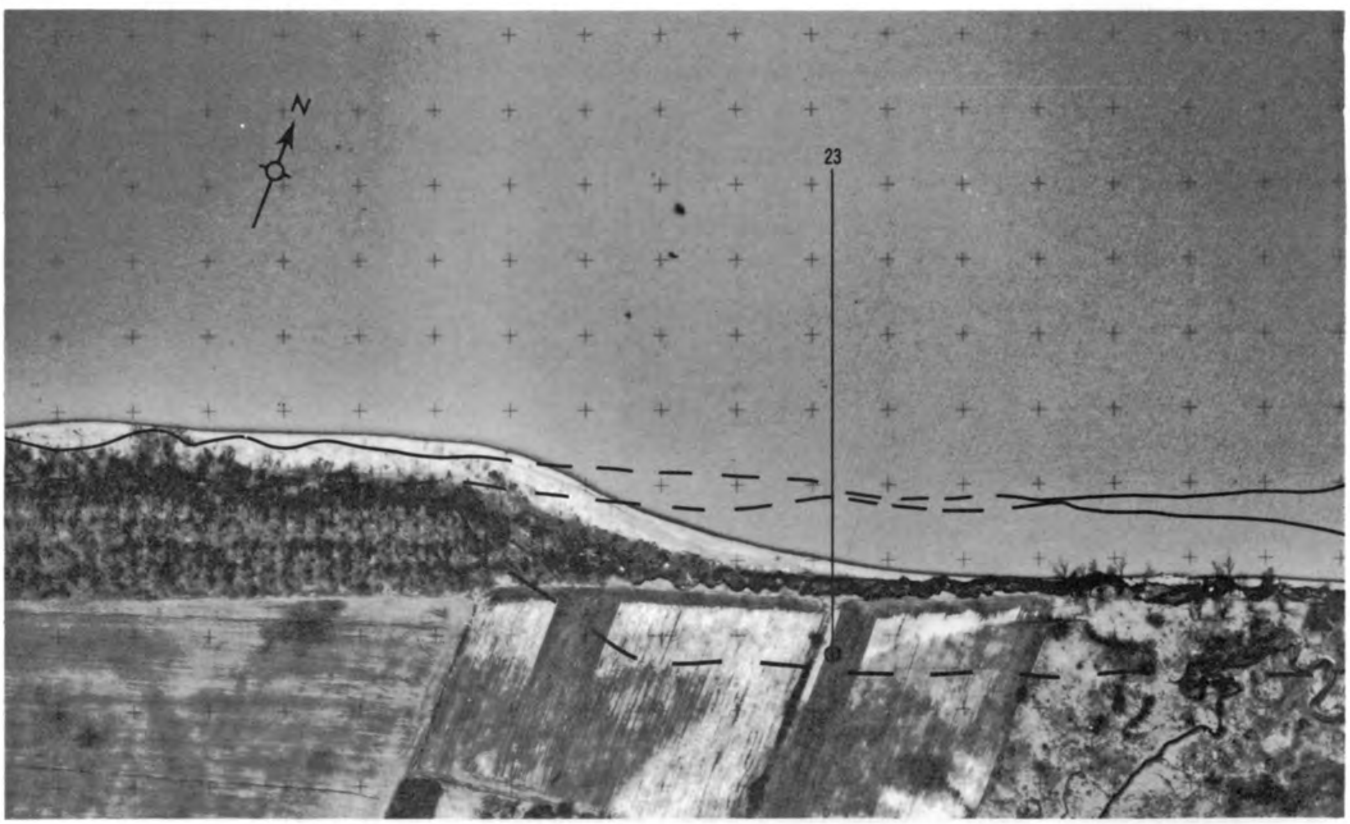


FIGURE 49

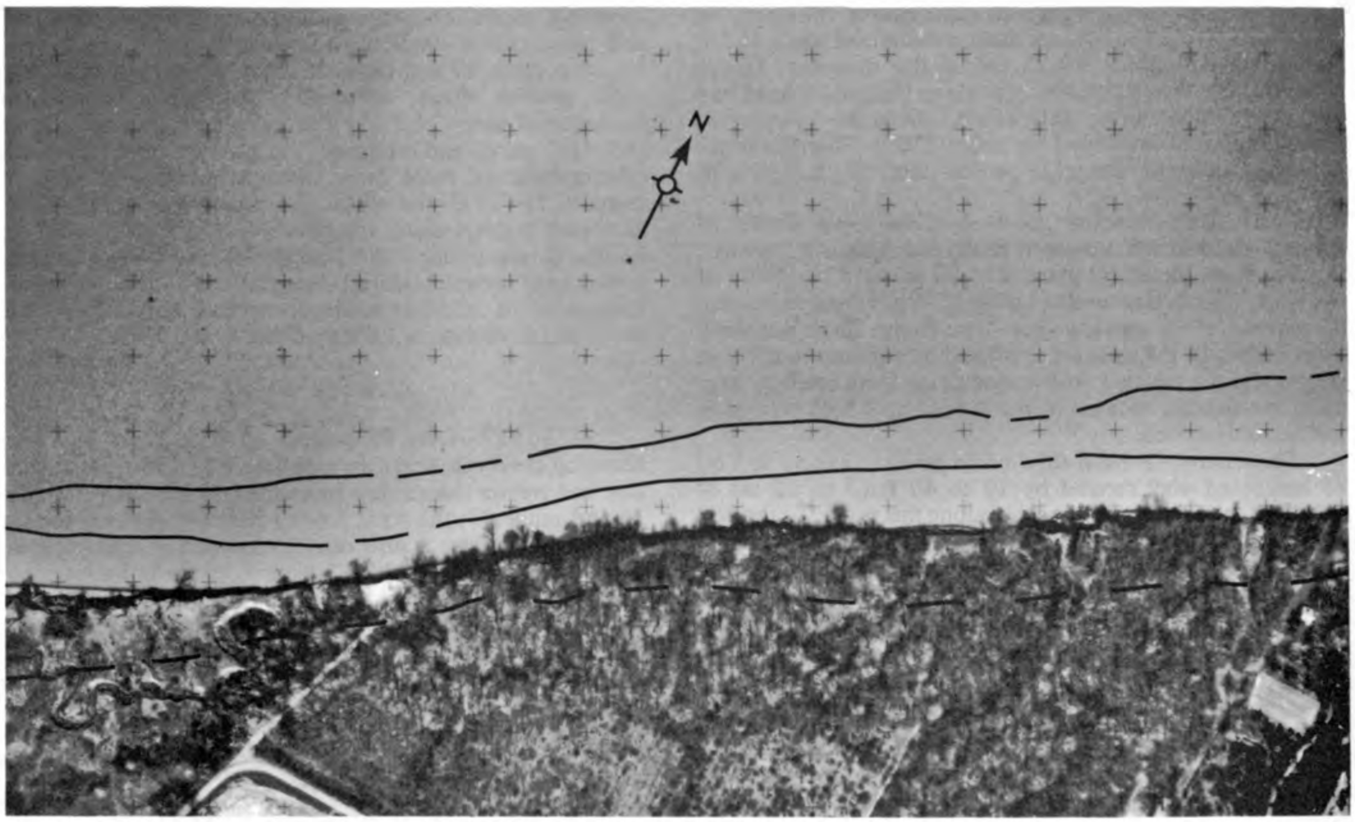


FIGURE 50

CAMP ROOSEVELT TO REDBIRD REACH

This reach is an extension of the rural-agricultural land to the west. The gently rolling sparsely settled shore has only one principal population center, the Redbird area at the eastern edge of the reach. Two summer camps, Camp Roosevelt and Camp Wingfoot, as well as a light industrial plant, are located along the shore. In addition, a nuclear power plant is being built at North Perry (between range 25 and range 26). As along the Grand River to Camp Roosevelt reach, there are few serious property-damage problems, but there are significant erosion problems, especially along the western two-fifths of this reach.

Natural setting, *circa* 1973

Nearshore zone.—Shale is exposed along most of the bottom except for a wedge of sand and/or till along the shoreline (pl. 3). The bottom has a well-defined slope of 3 to 4 degrees within 50 ft (15 m) of the shoreline; farther offshore the slope is not nearly as steep (table 33). Sand bars are uncommon along this reach; there is, however, a moderately well-developed bar about 250 ft (76 m) from the shoreline along the range 28 profile (table 12, table 33, pl. 3).

Beach and shoreline zone.—Beaches front about 70 percent of this reach; however, beach distribution is irregular. Beaches front about 50 percent of the western two-fifths of the reach (Camp Roosevelt to range 27), but front more than 90 percent of the eastern three-fifths (range 27 to Redbird). The beaches to the west are small and lie adjacent to stickout structures; the beaches to the east range from small to large and have formed because of the influence of both manmade and natural barriers.

Shore zone.—A basal till overlain by 20 to 25 ft (6 to 8 m) of laminated clay capped by 10 to 40 ft (3 to 12 m) of stratified sand makes up the shore along this reach. To the east the till thins and the sand thickens (pl. 2).

The physiography of the shore parallels the distribution of the beaches. Along the western two-fifths of the reach, well-defined bluffs characterize the landscape; along the eastern three-fifths of the reach, tree-covered slopes are characteristic.

The shoreline shape is irregular, with subdued headlands separated by shallow embayments. The headlands in general appear to reflect underlying bedrock highs. These highs act as barriers to the longshore drift of sand. However, headlands also are located behind clusters of stickout structures, such as those at Perry Township Park and near Camp Wingfoot.

Natural processes, *circa* 1973

Till falls are the most significant result of wave erosion along this reach. However, debris flows and slumps in the laminated clay are a major problem when the shore deposits become saturated with water. Piping at the sand-clay interface is also a problem during extremely wet periods.

Historic perspective: 1876, 1937, 1973

Land use.—There have been no widespread changes in land use along this reach from 1876 to 1973 (table 34). The biggest changes have been the buildup of the Redbird area and the construction of the light industrial plant in Perry Township. In general there has been a slight increase in population density that is reflected in the loss of forest and range land.

Stickout structures.—No structures are shown on the 1876 map. By 1937, there were several stickout structures between range 28 and range 29 and several stickout structures within the range 30 to Redbird stretch. By 1970 a few stickout structures were scattered along the reach (table 35). However, about 55 percent of the structures are concentrated at two locations—Camp Roosevelt-Perry Township Park and Camp Wingfoot.

Beaches.—Beaches were smaller and more sporadically distributed in 1973 than they were in 1876 (table 36). The largest beaches in both 1876 and 1973 fronted the eastern three-fifths of the shore (range 27 to Redbird).

Shoreline shape.—The shoreline shape was fairly regular and uniform in 1876. In general the form was that of a broad headland, much like today, with two more distinct headlands and associated downdrift embayments near range 27 and between range 29 and range 30. In 1937 the shore had the same general shape, although construction of stickout structures at range 24, Perry Township Park, at range 25, the industrial park, and at range 26, North Perry, led to the development of three more distinct headland-embayment couples. By 1973 the shape had changed relatively little; increased erosion along the embayments downdrift of the headlands accentuated the wavelike shape of the headland-embayment couples. Local irregularities in the shoreline, because of the influence of structures on shore processes, are much more common in 1973 than they were in 1937.

Recession history

1876-1937.—Over 99 percent of this reach underwent recession at very slow to slow rates (table 37). The only stretch that had greater than a slow recession rate was between range 26 and range 27; the stretch was 150 ft (46 m) long and the rate was moderate. A slow rate of recession characterized 37 percent of the reach; of this 37 percent, 73 percent was west of range 27 along the part of the shore fronted by small discontinuous beaches. There were three major stretches with a slow recession rate: (1) between Camp Roosevelt and range 24, (2) between range 24 and range 26, and (3) between range 26 and range 27. These stretches were downdrift of natural and/or structurally protected headlands.

1937-1973.—The major portion (73 percent) of this reach has receded at very slow to slow rates (table 37). However, there are five stretches, each several hundred feet (>100 m) long, that have receded at moderate or greater rates in this period. From west to east, the first stretch, which is adjacent to Camp Roosevelt, is the continuation of the stretch which receded at moderate to rapid rates at the east end of the Grand River to Camp Roosevelt reach. This stretch is east of a natural headland and is 1,500 ft (457 m) long. The second stretch is between range 24 and range 25; this stretch, which is 1,150 ft (351 m) long and shows a moderate rate of recession, is directly downdrift of the structurally protected headland at Perry Township Park. The third stretch is between range 25 and range 26; this stretch, which is 700 ft (213 m) long and receded at a moderate rate, is directly downdrift of a 150-ft (45-m) stickout structure (structure 234). The fourth stretch, which is the longest and most rapidly receding one, is between range 26 and range 27; this stretch receded at moderate to rapid rates except for 300 ft (92 m) that had a slow rate. The stretch is 3,300 ft (1,006 m) long and is immediately downdrift of a natural headland and a few stickout structures. The fifth stretch showing a greater than slow recession rate lies between range 29 and range 30. This stretch has receded at a moderate rate and is 650 ft (198 m) long. The stretch lies within the pronounced embayment to the east of the structures that front Camp Wingfoot.

Overall, stretches which are receding most rapidly are located along the western two-fifths of the reach, which is discontinuously fronted by small beaches.

Interpretation of recession

The best approximation for a natural (pre-structure) recession rate is the very slow to slow rates—the mode is very slow—of the 1876-1937 period. However, the modal rate in the 1937-1973 period is also very slow. Furthermore, the more rapidly receding—slow rate—stretches in the 1876-1937 period were also the more rapidly receding—moderate rate—stretches in the 1937-1973 period.

The principal stretches (between Camp Roosevelt and range 27) that had slow and moderate recession rates in the 1876-1937 period probably receded at greater rates than comparable stretches to the east of range 27 because sand that should have protected the shore was trapped or forced farther offshore by updrift structures or headlands.

The situation in the 1937-1973 period is similar: the stretches receding at moderate or greater rates are downdrift of natural and/or manmade headlands. For example, the stretch at the western margin of the reach is downdrift of a natural headland that has trapped sand and/or modified its movement. The stretch between range 24 and range 25 also is downdrift of a headland, but this headland developed because of structural protection. The result is the same—accelerated recession downdrift. However, manmade structures appear to have had the most influence on the increase in recession rates. In four of the five stretches with moderate or moderate-rapid recession, stickout structures were (or are) an integral part of the headland. In the stretch (adjacent to Camp Roosevelt) that is apparently without structural protection the headland is directly downdrift of a groin field and jetties that probably have had a direct effect on the equilibrium of the headland.

Recession forecast (2010 A.D.)

Recession will continue to be a problem along this reach as it will along the Grand River to Camp Roosevelt reach, particularly along the stretches that receded at moderate to rapid rates in the 1937-1973 period. The reason is threefold: (1) the scarcity of sand in the longshore drift system along the western half of the reach, (2) the natural and/or man-influenced headlands, and (3) the almost complete lack of structural protection.

Summary and erosion-control suggestions

The very slow and slow recession rates along this reach in the 1876-1937 period provide a reliable baseline from which to monitor subsequent recession rates. As in the reaches to the west, the most significant recession-rate factor is the stickout structures. These structures have increased the rate of recession downdrift by depriving the downdrift beach and nearshore zone of sand, yet at the same time they have decreased the rate of recession updrift by trapping sand. Even though there are stretches of very slow recession in the 1937-1973 period comparable in length to those in the 1876-1937 period, increased recession along other stretches from slow in 1876-1937 to moderate in 1937-1973 can be linked directly to the evolution of manmade structures.

Shore deposits also may be a factor in recession rates along this reach. An appreciable thickness (15 ft, or 4.6 m) of sand is exposed from range 26 to the eastern limit of the reach. When eroded from the shore, this sand is added to the longshore drift system. Although the fine bluff sand does not have enough mass to stay in the beach zone, but is carried offshore, this sand nevertheless contributes to a gentler nearshore slope, which is probably one of the principal causes of the very slow and slow recession rates along the eastern three-fifths of the reach. However, stickout structures, such as those at Camp Wingfoot, can still cause accelerated recession. In general, because of the abundant sand supply (sand probably derived from erosion of the till within the Grand River to Camp Roosevelt reach), the small stickout structures along the eastern three-fifths of the reach have had little detrimental effect on the downdrift shore. However, if structures are large, as they are at Camp Wingfoot, or are built in areas where there is little sand in the longshore drift system, accelerated recession results.

The recession rates could be reduced along the western two-fifths of the reach by toe protection, because the major problem is wave erosion. In addition to toe protection, landscaping including adequate drainage and tough cover could reduce the recession problem. A reduction in size or a design modification of the jetties between range 25 and range 26 would reduce recession downdrift of the structure; this solution also could be applied to the structures at Camp Wingfoot to reduce the downdrift recession rate. In areas of slumps or slides drains should be installed; they are inexpensive and can significantly increase the stability of the shore deposits above the shore zone affected by waves.

TABLE 33.–*Nearshore depths, Camp Roosevelt to Redbird*

Range profile	Nearshore depth (ft)								
	50 ft[1]	100 ft	200 ft	300 ft	400 ft	500 ft	1,000 ft	1,500 ft	2,000 ft
24	3.5	6.5	8.5	9	9.5	9.5	15	21	24
25	3	3.5	7	8	8.5	9.5	13.5	17	21
26	4	4.5	6.5	7	7.5	8.5	14.5	19	17
27	4	5.5	7.5	8	10	12	17	18	20
28	4	5.5	4.5[2]	6[2]	8.5	9	16	17.5	20
29	4	6	8	9	8	8.5	12.5	17	19
30	4.5	5	5.5	6	6.5	7.5	12.5	15.5	19
31	3.5	5	8.5	8.5	9.5	9.5	13	20	21

[1] Distance from shoreline in all cases; shoreline is defined as the contact between the lake and the beach. See table 12 for lake level.
[2] Depth to sand bar (crest or limb).

TABLE 34.–*Land use, Camp Roosevelt to Redbird*

Location	Land use[1]		
	1876	1937	1973
Camp Roosevelt-R24	agricultural, range	agricultural, urban(s)[2]	agricultural, forest, urban(s)
R24-R25	agricultural, range	agricultural, forest	forest, agricultural, industrial
R25-R26	agricultural, forest, range, urban(s)	agricultural, forest, urban(s)	agricultural, forest, urban(s)
R26-R27	agricultural, forest, range, urban(s)	agricultural, forest, urban(s)	agricultural, forest, urban(s)
R27-R28	agricultural, range, urban(s)	agricultural, urban(s)	agricultural, urban(s)
R28-R29	agricultural, forest, range, urban(s)	agricultural, forest, urban(s)	agricultural, forest, urban(s)
R29-R30	agricultural, range, forest, urban(s)	agricultural, forest, urban(s)	forest, agricultural, urban(s)
R30-R31	agricultural, range, forest, urban(s)	agricultural, urban(s)	agricultural, urban(s)
R31-Redbird	agricultural, forest, range, urban(s)	agricultural, urban(s)	urban(m)

[1] Land uses for a given year are arranged from left to right in order of amount of land used, largest land use to the left.
[2] (s), sparsely populated, less than one house/acre; (m), moderately populated, one to three houses/acre.

TABLE 35.–*Inventory of stickout structures, Camp Roosevelt to Redbird*

Location	Structure no.[1]	Type and number of structures[2]			
		1876	1937	1954	1970
Camp Roosevelt-R24	217		stretch between		G
	218		Camp Roosevelt		G
	219		and R25 is		G
	220		obscured by	x	G
	221		trees in	x	P
			1937 photos		
	223			G	
	224			G	
	225				G
	226				G
	227			G	
	228				G
R24-R25	229			x	G/P
	230			x	G
			G		
	232				G
	234				J
R25-R26	235		y		G(2)
	236		y		GF(3)
R26-R27	237				G
	238				G
	239				G
	240				G
	241				GF(3)
			G(2)		
R27-R28					
R28-R29	242		x(1935)	x	B
	243		x	B	
	244		x	B	
	245		x	x	B
	246		x	x	B
	247		x	G	
	248		x	G	
			G		
	249		x	G	
			G(2)		
			G		
R29-R30	250				G(2)
	251				G(2)
	252			G	
	254			P	
	255				G(3)
R30-R31	256			G	
	257		x	x	GF(3)
	259		x		G(2)
			G		
			G		
	260		x	x	P
			GF(3)		
	261				GF(6)
R31-Redbird	263		x	x	G
			G		

[1] Structure numbers correspond to numbers in the Appendix, which is a compendium of information on all structures along the shore of Lake County. Some early (1876-1937) structures, which are not described in the Appendix, are included in the stickout structure table, but are not numbered (for example, the groin field between structure no. 23 and structure no. 24 on table 15).

[2] B, breakwater; G, groin; GF, groin field; J, jetty; P, pier; S, seawall; (5), number of structures included under one inventory number; x, structure described in a later year is most likely the same structure observed on map or aerial photograph; y, structure described in a later year is possibly the same structure shown on map or aerial photograph; (1924), year the structure was built, if known.

TABLE 36.—*Beaches, Camp Roosevelt to Redbird*

Location	1876			1937			1973		
	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]
Camp Roosevelt-R24				400	–		200	–	
	2,400	natural	small	2,000	trapped and natural	small	600	trapped	small
							1,600	–	
R24-R25							300	–	
	2,000	natural	small-moderate	300	trapped	small	1,200	natural	small
				1,800	–		400	–	
							300	trapped	small
R25-R26							400	natural	small
	4,500	natural	small-moderate	700	natural	small	2,500	–	
				3,600	natural	small-moderate	1,000	trapped and natural	small
							200	–	
R26-R27				1,000	natural	small			
	1,700	–		1,300	–		2,400	–	
	1,900	natural	small-moderate	600	natural	small	1,700	trapped	small
				800	natural	moderate			
R27-R28	1,400	natural	moderate-large	2,000	natural	moderate-large	1,800	natural	small
	400	natural	small-moderate	1,400	trapped and natural	small-moderate	500	natural	moderate
	1,600	natural	small				900	natural	small
R28-R29	2,300	natural	small	2,100	trapped	moderate-large	2,200	trapped	small-moderate
	2,000	natural	small-moderate	2,200	trapped	small-moderate	2,200	trapped and natural	moderate-large
R29-R30	400	natural	moderate				800	trapped	small
	2,800	natural	large	2,900	trapped and natural	small-moderate	300	–	
							1,200	trapped and natural	small
							1,000	trapped and natural	small-moderate
R30-R31	3,700	natural	small-moderate	2,100	trapped	small	1,500	trapped	small
				1,600	trapped	moderate	600	–	
							1,800	trapped and natural	small
R31-Redbird	1,400	natural	small-moderate	2,200	trapped	moderate	2,200	trapped	small
	900	natural	small						

Summary

Width of beach[3]	Beach length (ft)[1]		
	1876[4]	1937[4]	1973[4]
Small	7,200	6,700	15,400
Small-moderate	15,900	10,100	3,200
Moderate	400	4,600	500
Moderate-large	1,400	4,100	2,200
Large	2,800		

[1] Measured to nearest 100 ft.

[2] *Natural,* the development of the beach has not been caused by manmade structures; *trapped,* the development of the beach has been caused by manmade structures; –, no beach.

[3] *Small,* less than 50 ft wide; *moderate,* 50 to 100 ft wide; *large,* greater than 100 ft wide.

[4] In 1876 there was 1,700 ft, in 1937 3,500 ft, and in 1973 8,500 ft of shore without any beach.

TABLE 37.–*Recession rates, Camp Roosevelt to Redbird*

Location	1876-1937		1937-1973	
	Recession rate[1]	Length (ft)[2]	Recession rate[1]	Length (ft)[2]
Camp Roosevelt-R24			moderate	1,500
	slow	1,750	very slow-slow	500
	very slow	700	moderate	200
			slow	300
R24-R25			slow	100
	very slow	300	moderate	1,150
	slow	1,950	slow	500
			very slow	700
R25-R26			very slow	100
	slow	1,250	slow	400
	very slow	2,750	moderate	700
			slow	700
			very slow	2,200
R26-R27	very slow	500	very slow	150
	slow	500	slow	150
	very slow	200	moderate	1,000
	slow	500	moderate-rapid	700
	moderate	150	slow	300
	slow	900	moderate	1,300
	very slow	150	slow	200
	slow	300	very slow	400
	very slow	800		
R27-R28	very slow	2,600	very slow	3,500
	slow	900		
R28-R29	slow	400	very slow	1,100
	very slow	750		
	floodplain (3,100 ft)		*floodplain (3,100 ft)*	
R29-R30	*floodplain (200 ft)*		*floodplain (500 ft)*	
			moderate	650
	very slow	3,100	slow	450
			very slow	2,000
R30-R31	very slow	2,400		
	very slow-slow	650	very slow	3,900
	very slow	900		
R31-Redbird	very slow	900	very slow	2,100
	slow	1,300		

Summary

Recession rate[1]	Length in each recession class (ft)[2]	
	1876-1937	1937-1973
Total very slow	16,050	16,150
Total very slow-slow	650	500
Total slow	9,750	3,100
Total moderate	150	6,500
Total moderate-rapid		700

[1] Very slow, <1 ft/yr; slow, 1-3 ft/yr; moderate, 3-5 ft/yr; rapid, 5-7 ft/yr; very rapid, 7-9 ft/yr.
[2] Measured to nearest 50 ft.

AERIAL PHOTOGRAPHS, CAMP ROOSEVELT TO REDBIRD REACH

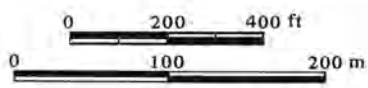
Aerial photography of the Lake County shore was done in 1973 by the Ohio Department of Transportation. The photographs for this reach are reproduced here with superimposed 1876, 1937, and projected 2010 recession lines. The 1876 line is farthest lakeward; the 2010 line is the heavy dashed line farthest landward; the 1876 and 1937 lines are dashed where approximate. The recession lines for the different years coincide where there has been no change.

Range and structure locations also are shown (see Appendix for description of the structures). The following symbols are used:

Range location and number

Structure location and number; dashed line indicates that structure was not found in 1970 survey

Scale on all photos:



Scale distorted toward edges of photos

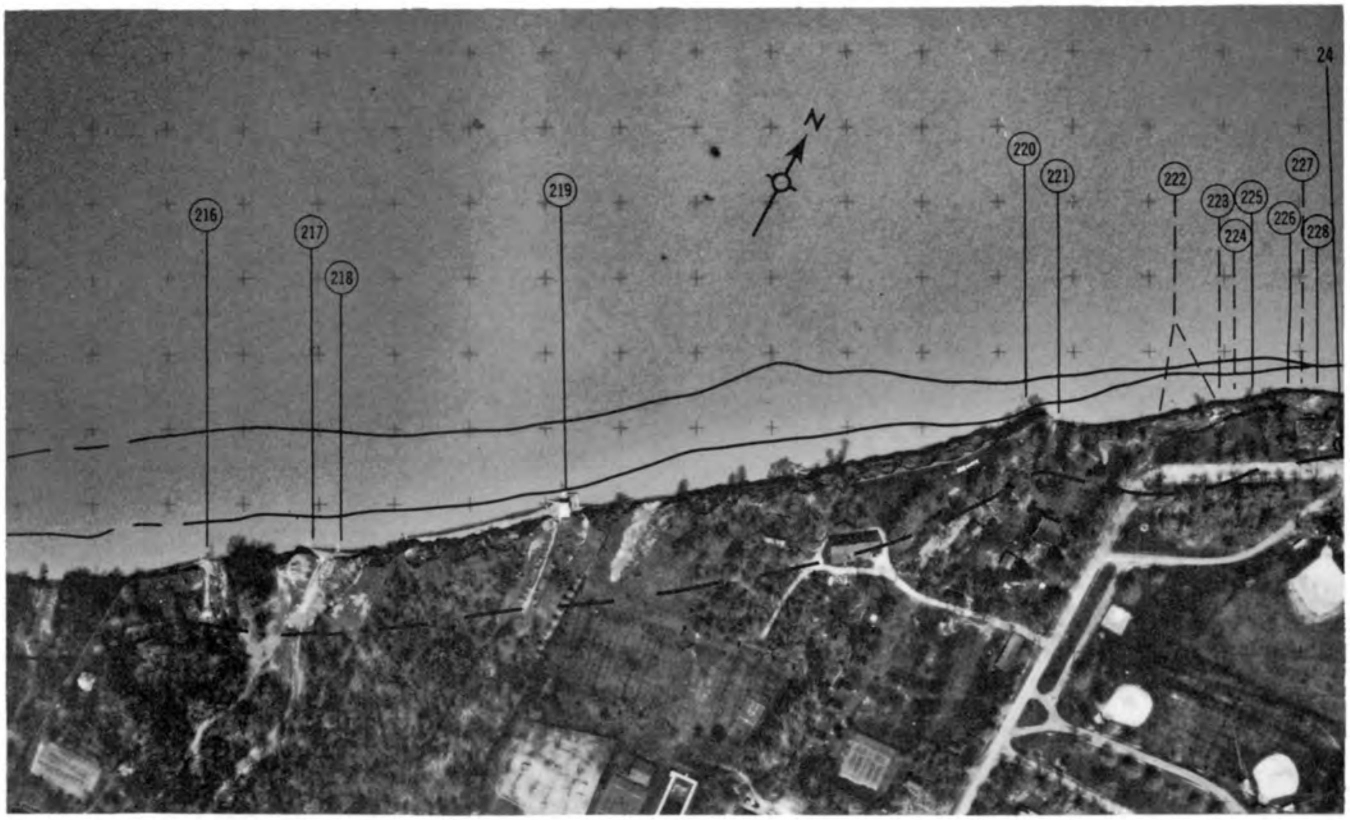


FIGURE 51

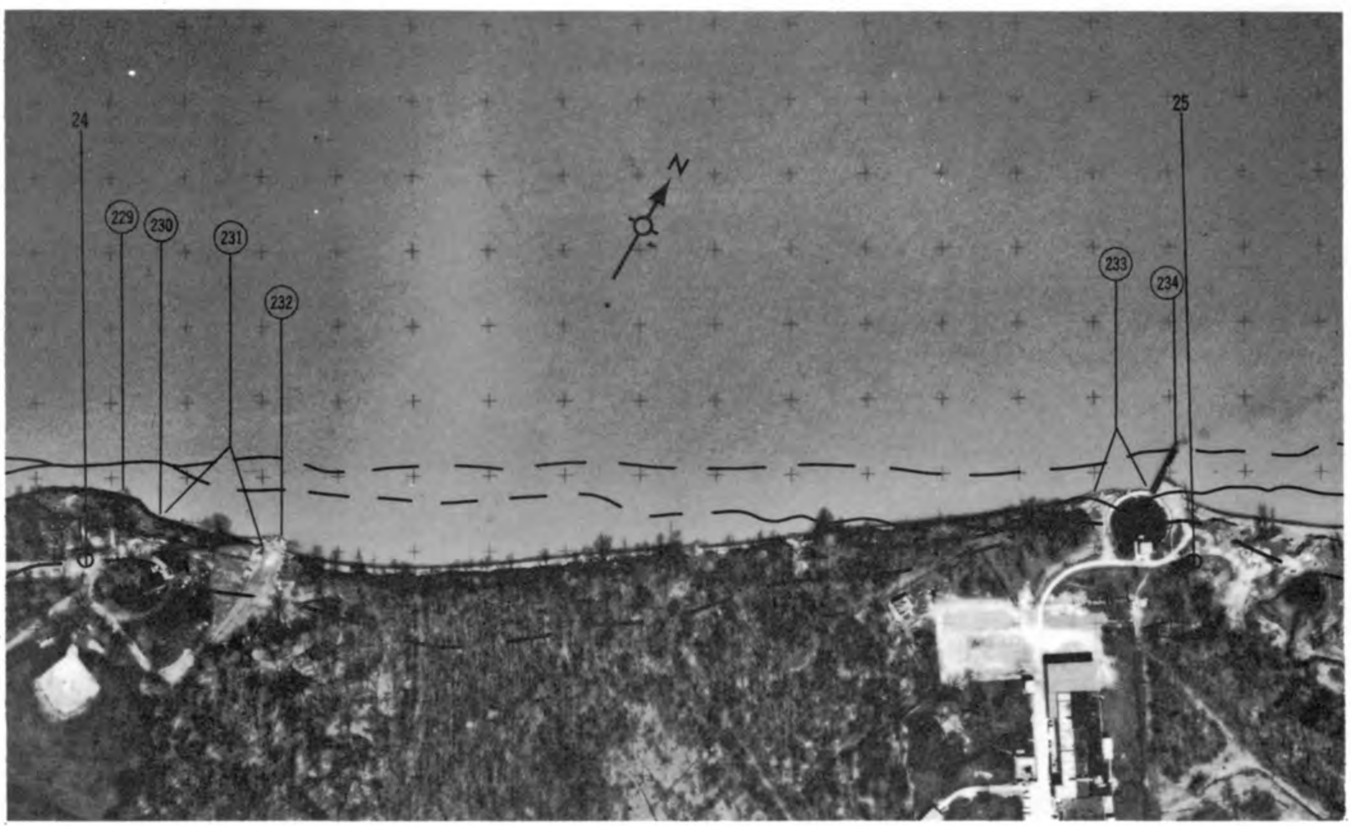


FIGURE 52

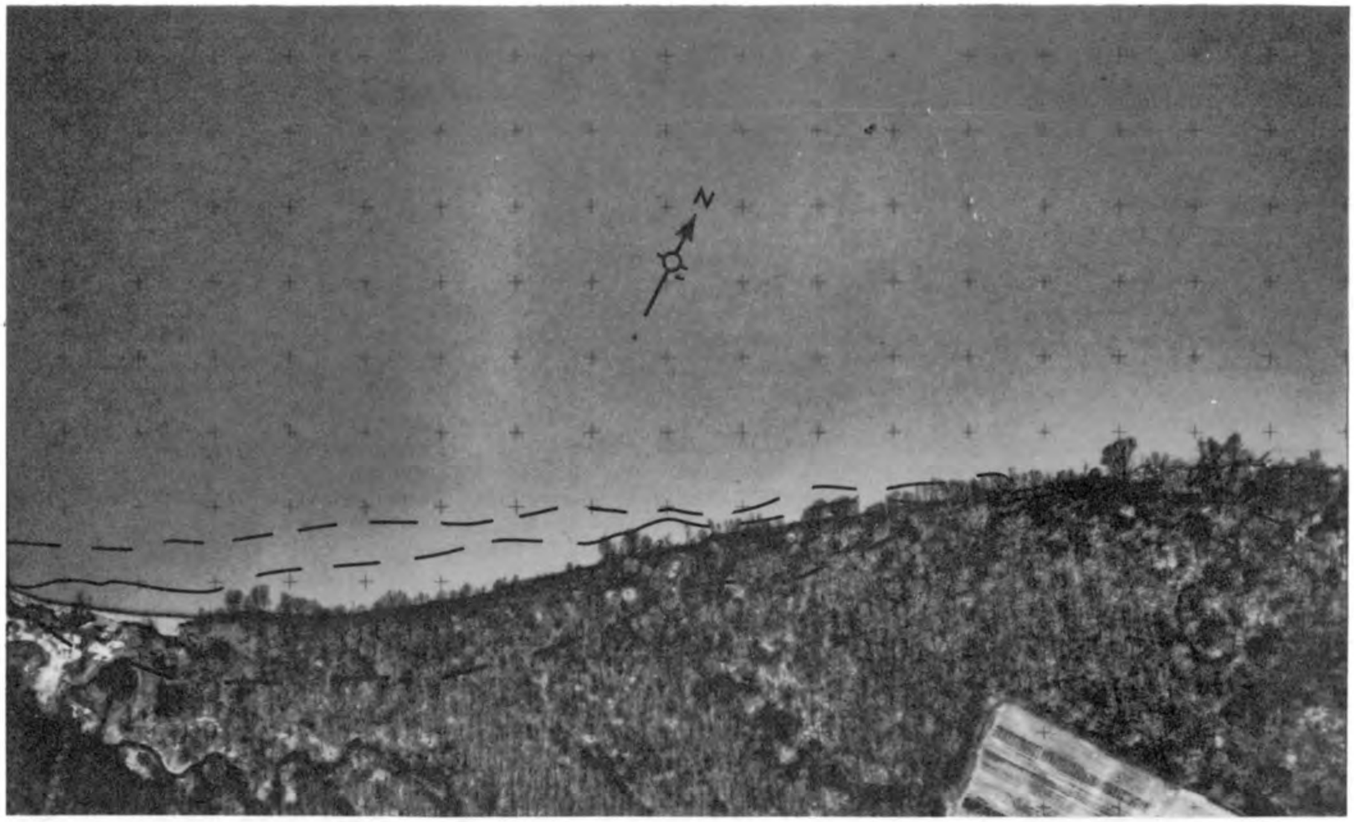


FIGURE 53

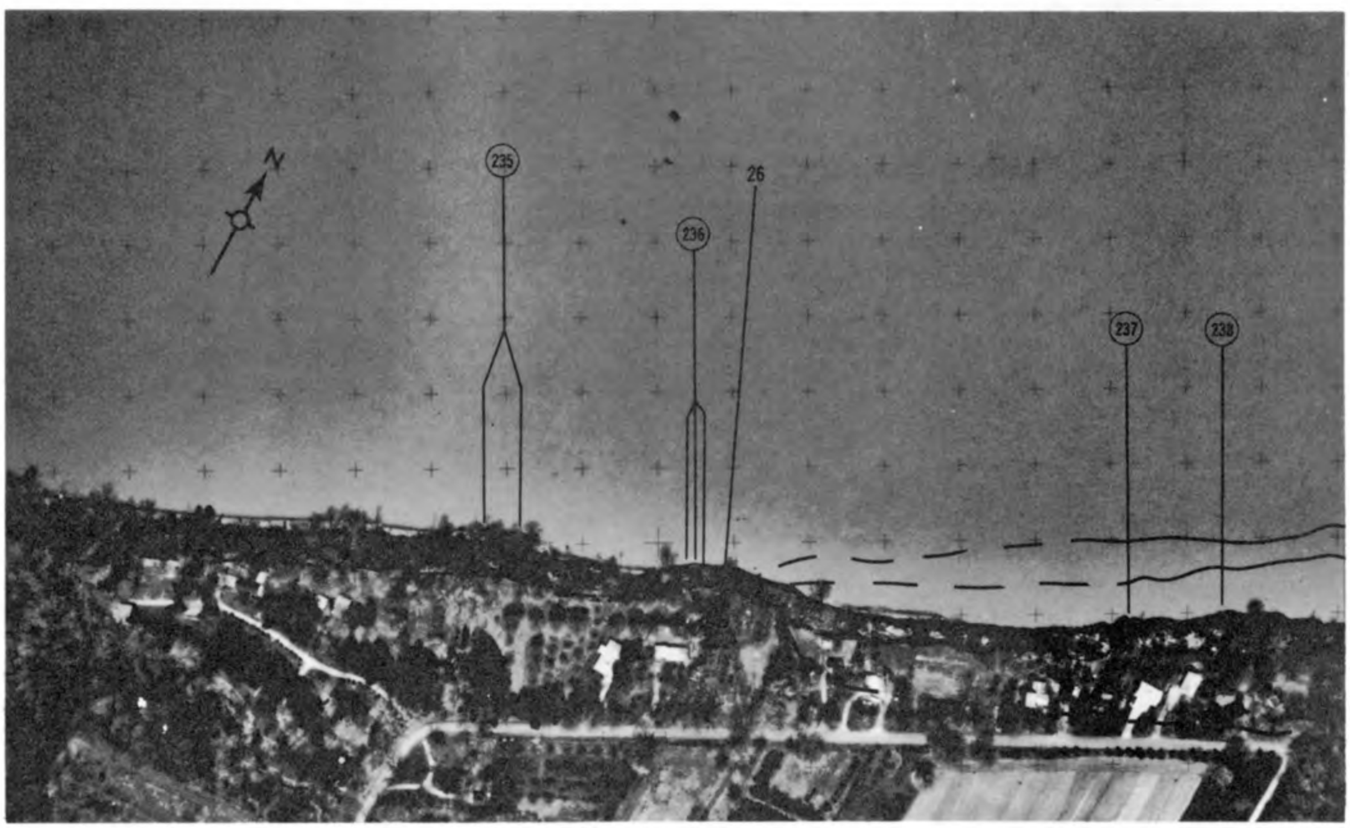


FIGURE 54

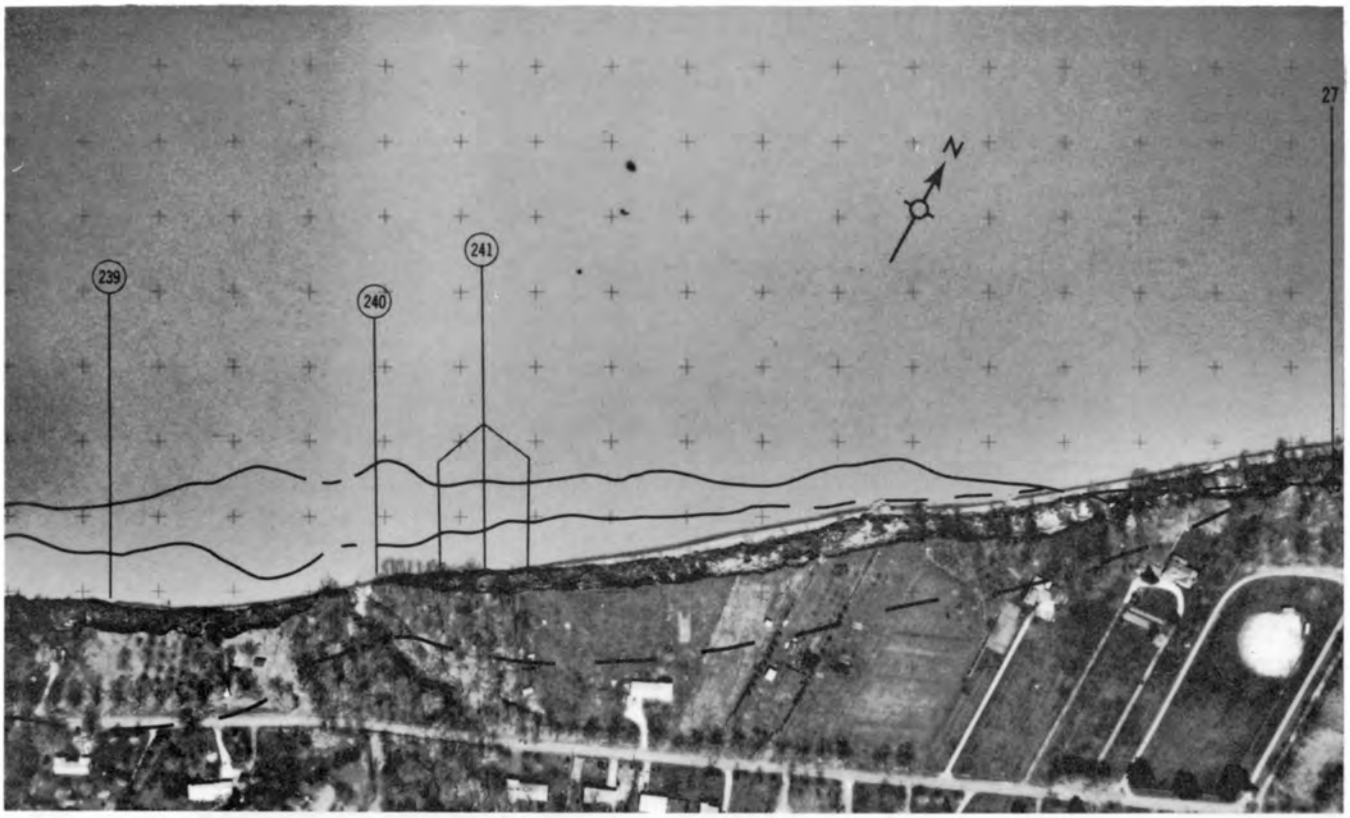


FIGURE 55

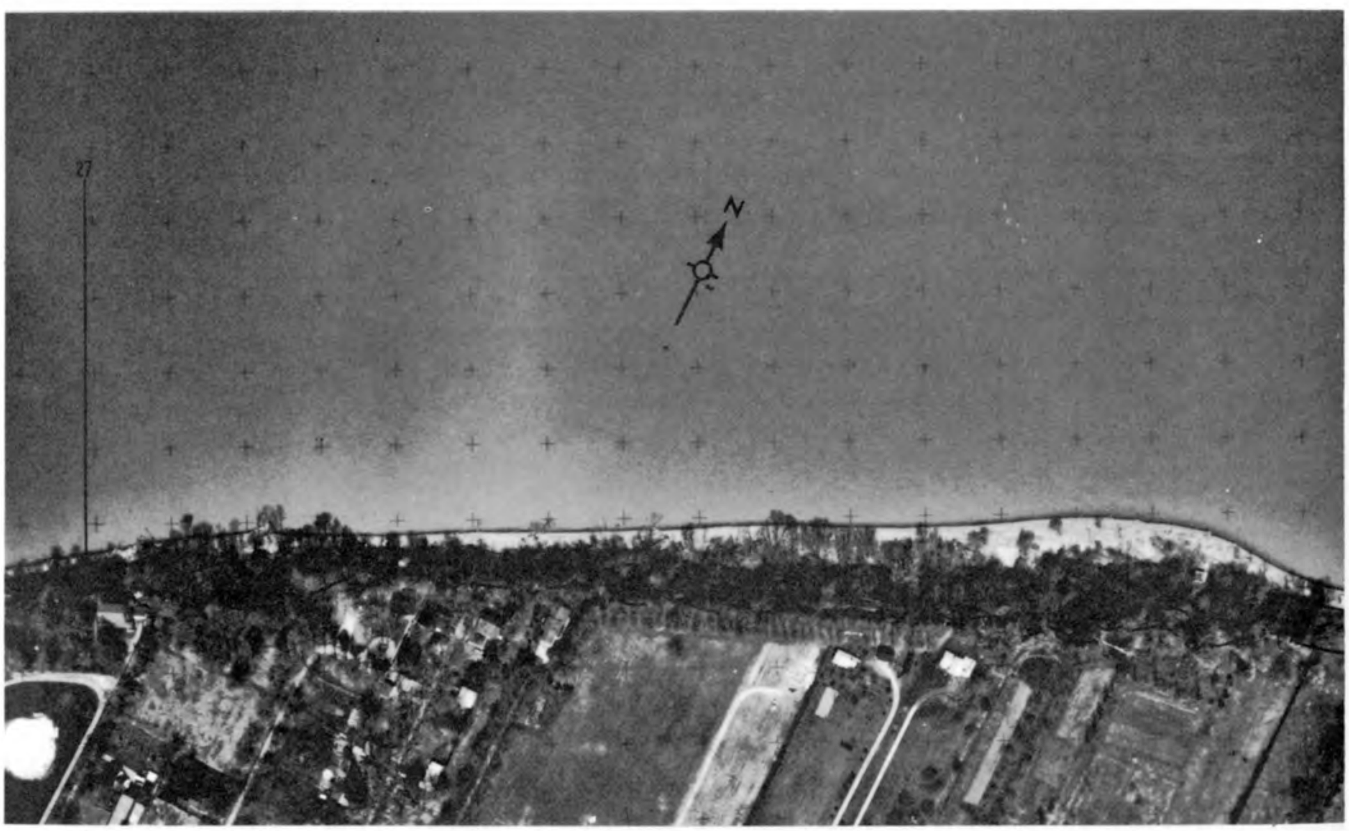


FIGURE 56

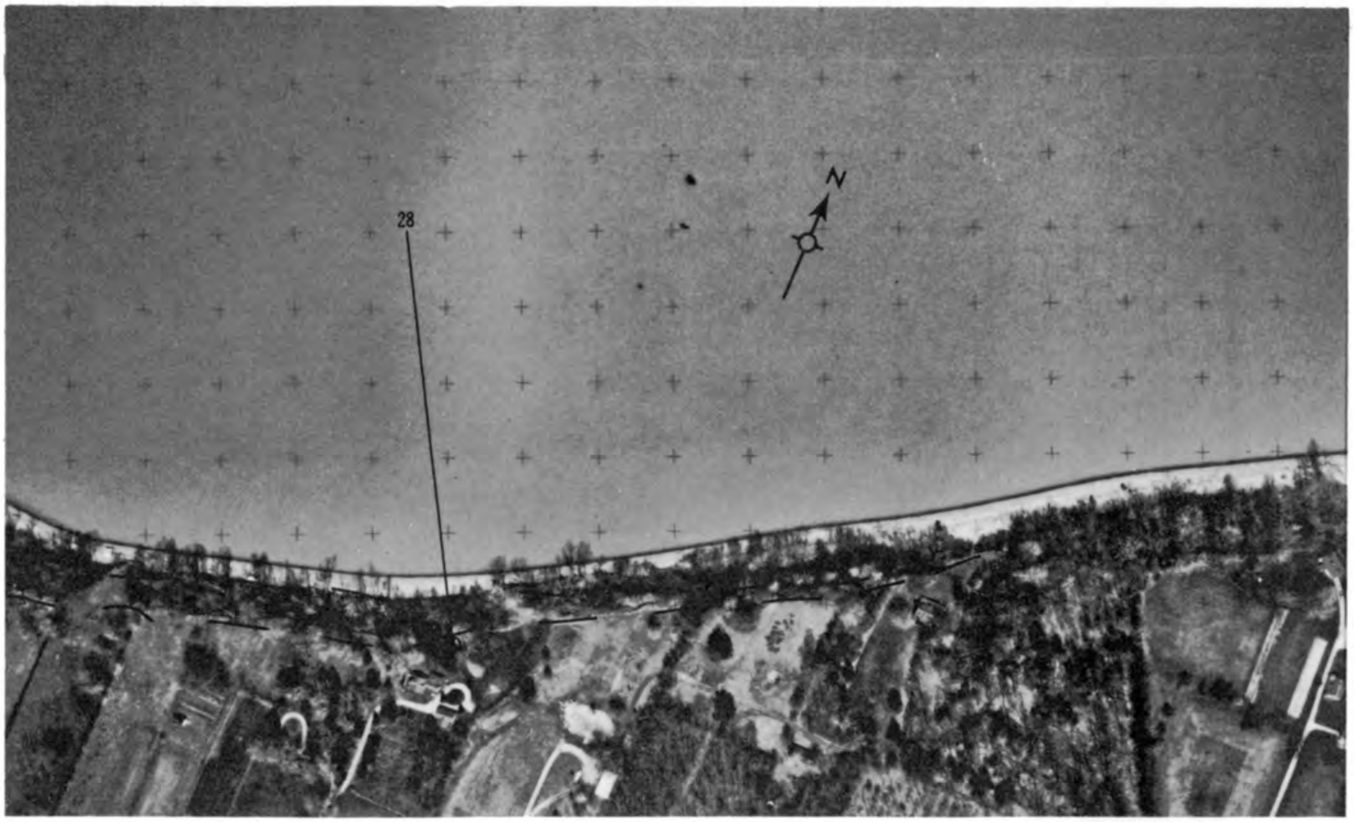


FIGURE 57

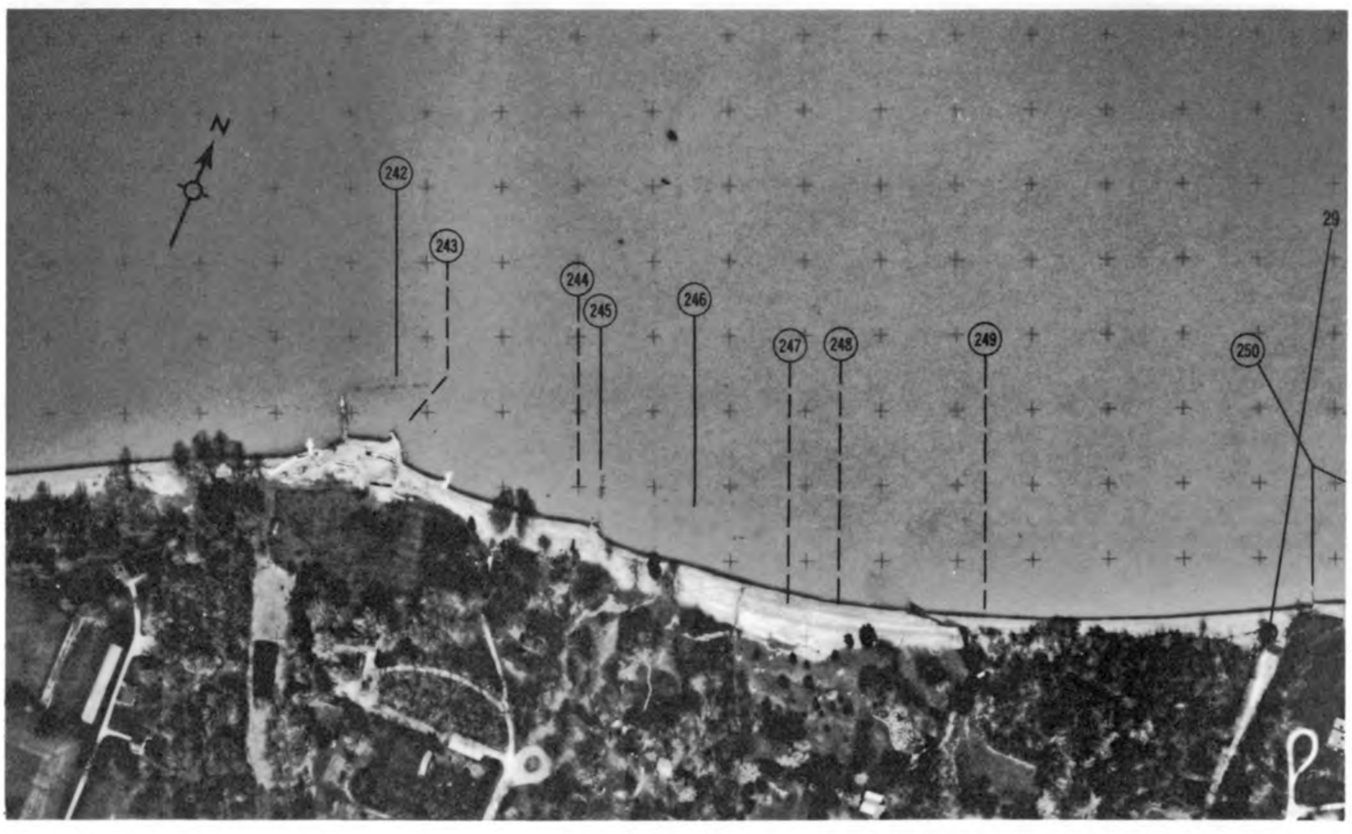


FIGURE 58

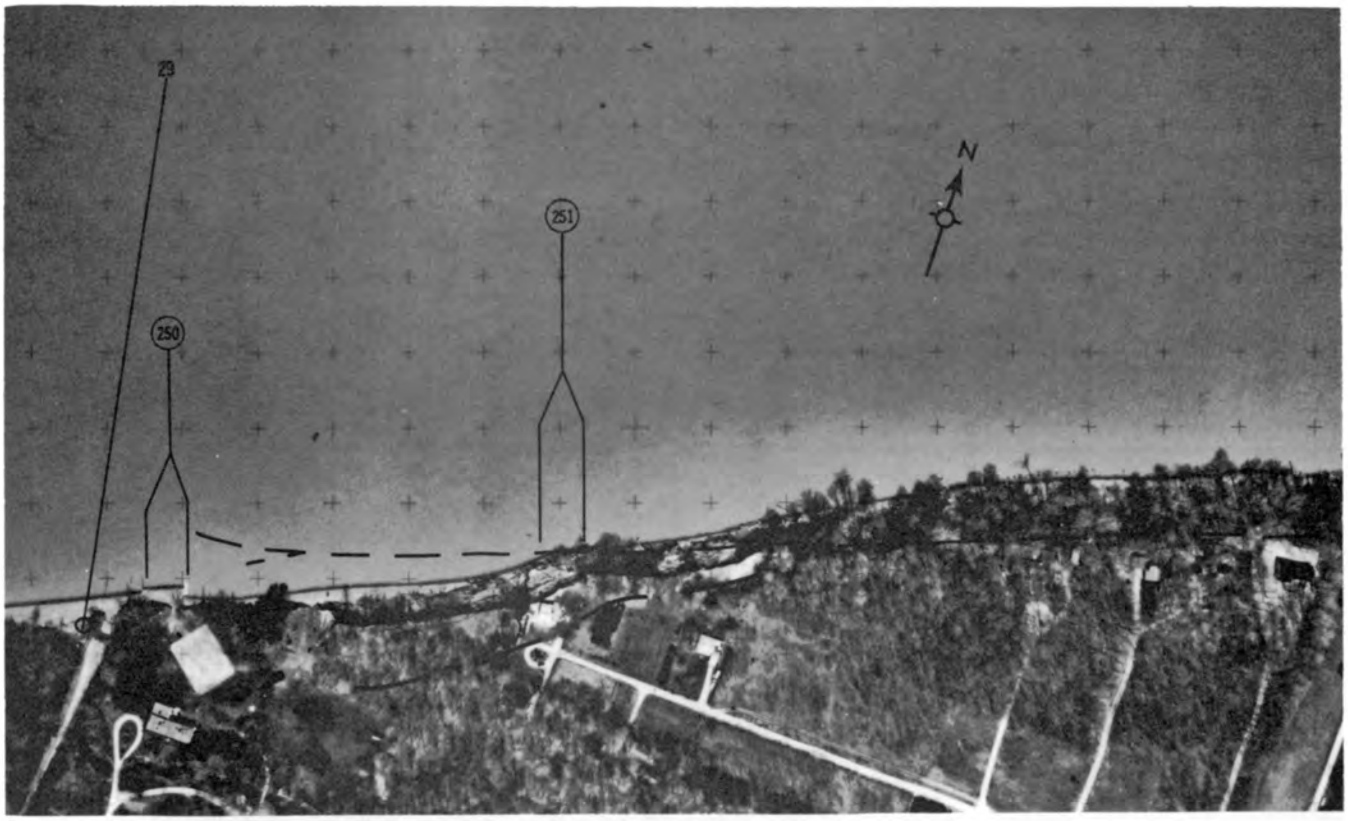


FIGURE 59

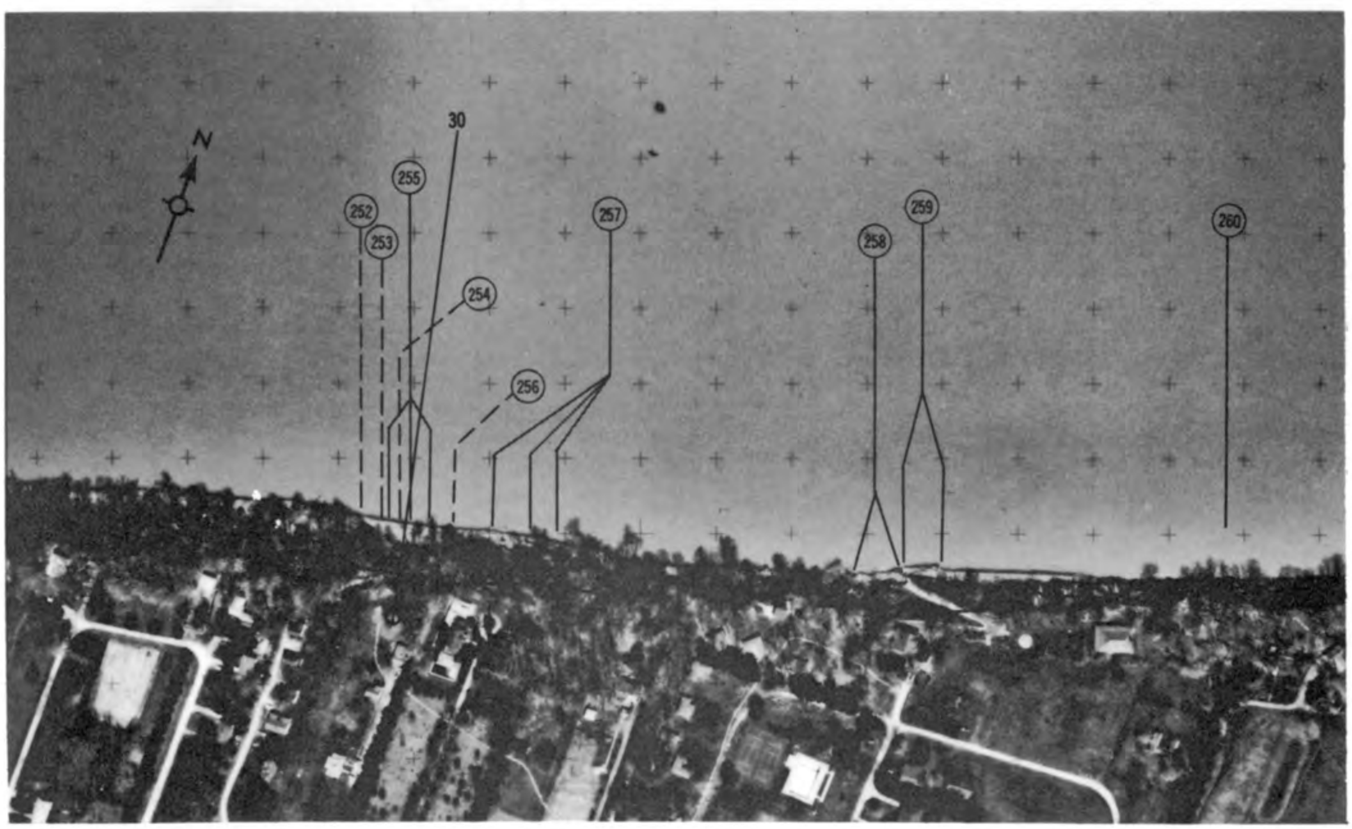


FIGURE 60

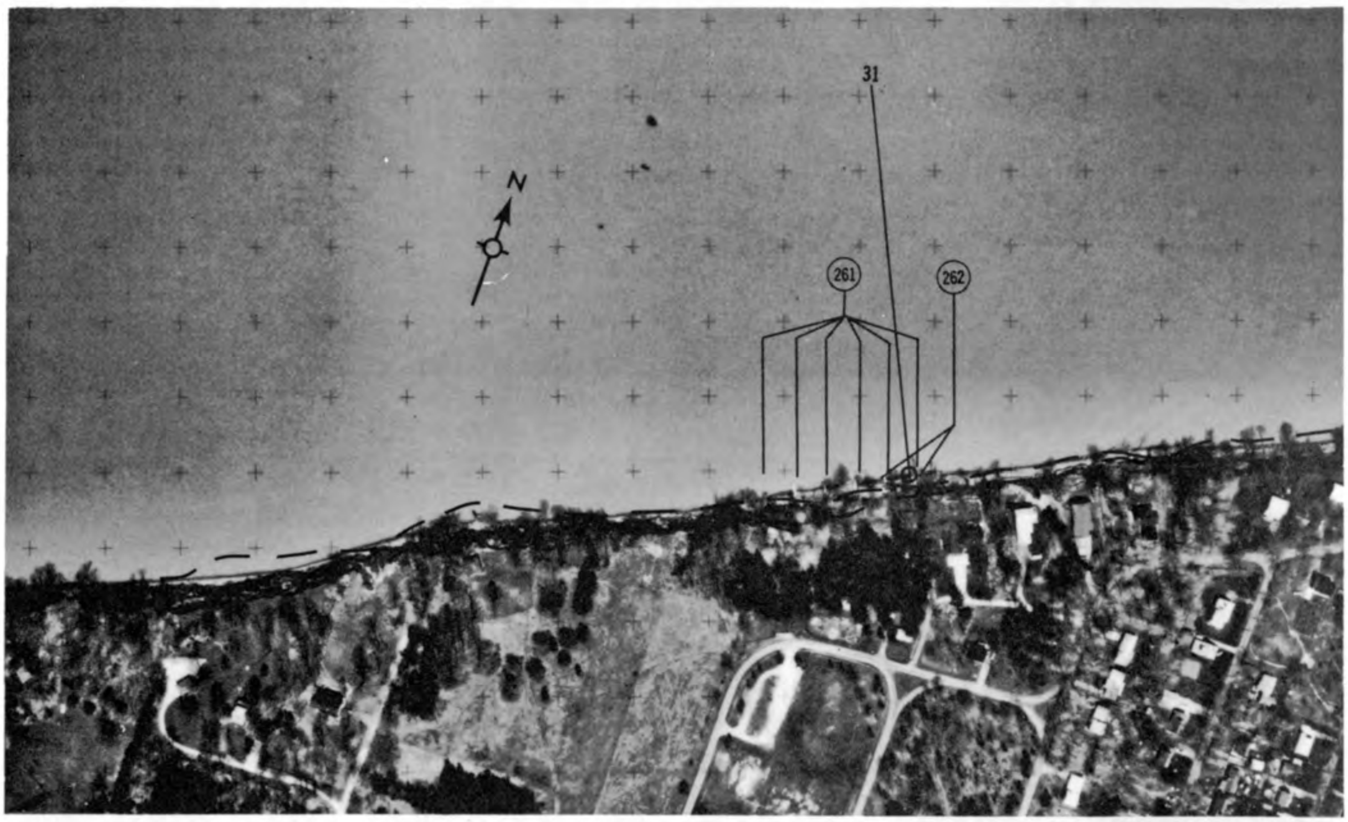


FIGURE 61

REDBIRD TO LAKE-ASHTABULA COUNTY LINE REACH

This reach includes the community of Madison-on-the-Lake and part of the community of Redbird. The remainder of the area is largely rural. This reach has lower relief, more continuous beaches, and lower recession rates than the five reaches to the west.

Natural setting, *circa* 1973

Nearshore zone.–Shale is at or very near the bottom surface everywhere along this reach (pl. 3). The bottom has a well-defined slope of 4 to 5 degrees within 50 ft (15 m) of the shoreline; farther offshore the slope is much less steep (table 38). Two poorly developed sand bars, one along profile 32 and the other along profile 37, were noted on the echograms; these are the only appreciable bodies of sand mapped in the nearshore zone (table 12, table 38, pl. 3). Topographic breaks, which are probably ancient channels, cut the shale along ranges 32 and 35. However, in general, the rocky bottom is fairly even.

Beach and shoreline zone.–Well-developed beaches front nearly 90 percent of the reach. The largest beaches front headlands, whereas the smallest beaches are located in the embayments adjacent to and east of the headlands. Many of the beaches appear to have a natural origin, although stickout structures, which have trapped sand on the west (updrift) side, are common along the shoreline.

Shore zone.–A basal till overlain by 10 to 15 ft (3 to 4.6 m) of laminated clay capped by a thin–generally less than 5 ft (1.5 m)–layer of well-sorted sand makes up the shore along this reach (pl. 2). The till and clay have a constant thickness along the reach, but the sand thins to the east.

Poorly defined banks and landscaped slopes front the shoreline along nearly all of this reach. In places seawalls and similar structures form the interface between the beach and the upland area.

Natural processes, *circa* 1973

Small rotational slumps and debris flows within the laminated clay are the most apparent result of wave erosion along this reach. Where unprotected banks are exposed, as at Madison-on-the-Lake (east of range 34), wave erosion has undercut the banks, and the banks have failed. In areas protected by seawalls and similar structures, waves overtopping and outflanking the structures along the low-lying shore have caused erosion.

Historic perspective: 1876, 1937, 1973

Land use.–Between 1876 and 1937 there was a slight increase in population and a decrease in the amount of agricultural land (table 39). However, between 1937 and 1973 there was a pronounced increase in development of the shore. The shore zone in 1973 for the most part is moderately populated and shows a decided decrease in agricultural and range land since 1937.

Stickout structures.–No structures are shown on the 1876 map. By 1937 there were several stickout structures between Redbird and Madison-on-the-Lake and on either side of range 37, as well as a few others scattered along the shoreline. By 1970 nearly the entire shore was fronted by stickout structures (table 40). There were about 31 stickout structures along this reach in 1937; in 1970 there were 115. In general, the distribution of structures has remained nearly the same except between ranges 35 and 37, where there was an increase in stickout structures from 5 in 1937 to 44 in 1970, and along the eastern half of the range 32 to range 33 stretch, where there was an increase from none in 1937 to 18 in 1970. The structures, as along the other Lake County reaches, are clustered. The major cluster is between Redbird and Madison-on-the-Lake (ranges 32 to 34), and there were smaller clusters between ranges 35 and 37, east of Madison-on-the-Lake.

Beaches.–Beaches in 1973 are slightly smaller and not as continuous as they were in 1876 (table 41). This difference in beach size and distribution may be due to the higher lake level in 1973. However, the relative sizes of the beaches have stayed the same between the 1876-1937 period and the 1937-1973 period.

Shoreline shape.–The shoreline shape remained basically the same from 1876 to 1973. Four prominent headlands separated by three embayments give the reach a definite wavelike appearance that is similar to that of the headland-embayment couples along the Camp Roosevelt to Redbird reach. The headlands in general appear to reflect underlying bedrock highs. Between 1876 and 1937 there were two recognizable changes: (1) the embayment between range 32 and range 33 deepened appreciably, and (2) the embayment between range 36 and range 37 deepened. Between 1937 and 1973 the embayment east of range 34 deepened appreciably. These changes are reflected in the recession-line map (pl. 4).

Recession history

1876-1937.–The recession rates were quite uniform; along the entire reach, rates were very slow (77 percent) or slow (table 42). Two long stretches receded at a slow rate: (1) the 3,200-ft (975-m) stretch on either side of range 33, and (2) the 1,200-ft (366-m) stretch between ranges 36 and 37. These stretches are located in embayments.

1937-1973.–The recession rates within this time period were even more uniform than the rates within the 1876-1937 period–94 percent of the reach had a very slow recession rate (table 42). The poorly defined banks are mute evidence of this; where more rapid recession is taking place, as east of range 34, the banks have steep well-defined edges. The 1,000-ft (305-m) stretch east of range 34 is the only area that has receded at greater than very slow rates (slow, moderate). This stretch is located east of the prominent headland at Madison-on-the-Lake between structures 335 and 337 (figs. 65, 66). There are several groins along the headland that have trapped sand to protect the shore; however, in the more rapidly receding stretch east of the headland only one structure was present in 1950, and this structure had been destroyed by 1970.

There are no severe erosion problems along this reach, with the possible exception of the short stretch east of range 34. In general, the more rapidly receding stretches lie within embayments, whereas the more slowly receding stretches lie along or updrift of headlands.

Interpretation of recession

The best approximation for a natural (pre-structure) recession rate is the very slow to slow rates (the mode is very slow) of the 1876-1937 period. However, the modal rate in the 1937-1973 period is also very slow. In contrast to most of the more rapidly receding stretches of the Camp Roosevelt to Redbird reach, the most rapidly receding stretch here in the 1937-1973 period is at a different location than the two most rapidly receding stretches in the 1876-1937 period. The recession rates stayed about the same (very slow) between 1876-1937 and 1937-1973 throughout the remainder of the reach. An interesting aspect of this reach is that where there are small- or moderate-sized beaches–as along 2,000 ft (610 m) west of range 32 and 1,900 ft (576 m) west of range 37–there has been little or no recession, even in the absence of structures.

The two stretches with a slow recession rate in the 1876-1937 period appear to have receded more rapidly than the rest of the reach because of the headlands immediately updrift of them. The headland at range 32 formed a natural barrier to the longshore drift of sand; sand was trapped on the updrift side and/or forced far enough offshore so that it could not enter the longshore drift system until much farther downdrift. This loss of protective sand to the downdrift beach and nearshore area caused accelerated recession by allowing waves refracted toward the headland to break nearer the shore. The headland near range 35 and the small headland at range 36 may have had an effect on the net longshore movement of sand to the east, but the proximity of stickout structures between the small headland and the stretch with the slow recession rate probably has contributed to the greater than average recession between ranges 36 and 37. On the other hand, the large number of manmade structures that have been built since 1937 along both of these more rapidly receding stretches apparently has had a beneficial effect on the shore–these areas have receded at a very slow rate since 1937.

The only stretch (east of range 34) in the 1937-1973 period that underwent greater than very slow recession also is on the lee side of a headland. This headland, which is protected by sand trapped by groins, forces sand that bypasses the groins far enough offshore so that the immediate downdrift beach and nearshore area is deprived of protective sand, and accelerated recession results. The groins at the end of the headland seem to be the exacerbating factor, because this area underwent very slow recession within the 1876-1937 period.

Recession forecast (2010 A.D.)

Barring extremely unusual lake conditions this reach should have no significant erosion problems in the near future. Furthermore, since the 1970 structure inventory, seawalls have been constructed in front of the short stretch between range 34 and range 35 that underwent recession at a moderate rate between 1937 and 1973. The seawalls should retard the recession rate.

Summary and erosion-control suggestions

In comparison to the other Lake County reaches this reach does not have a significant erosion problem. There are two primary reasons for this: (1) an abundant supply of sand that forms beaches and contributes to a gentle nearshore slope, and (2) the lack of large stickout structures. The gentle slopes and beaches cause waves to break and expend their energy away from the vulnerable base of the shore. The lack of large stickout structures means that the natural transport of sand will not be too severely interrupted, thereby insuring a continuous protective beach along the shore.

Sand holds the key to erosion protection along this reach. As long as there is an ample supply of sand along the shoreline and if other factors do not change appreciably, erosion will continue to be a minor problem along this reach. Well-built seawalls appear to be a good means of shore protection along this low-relief reach. In stretches such as the one east of range 34, elimination of the groins at the tip of the headland and construction of seawalls should stabilize the shore. The same method probably could be followed along most if not all of the more rapidly receding areas in this reach.

TABLE 38.–*Nearshore depths, Redbird to Lake-Ashtabula County line*

Range profile	Nearshore depth (ft)								
	50 ft[1]	100 ft	200 ft	300 ft	400 ft	500 ft	1,000 ft	1,500 ft	2,000 ft
32	4.5	4.5	4.5[2]	6	7	7.5	12	17	20
33	4.5	6	9	11.5	12.5	13.5	16.5	18	18
34	3.5	4.5	5.5	7	7.5	8	10	14	17
35	3.5	4.5	6	6.5	7	8	12	16	19
36	3	4.5	6.5	7.5	8.5	10	13.5	17	23
37	3	5	8	12	13	14	16[2]	21	20

[1] Distance from shoreline in all cases; shoreline is defined as the contact between the lake and the beach. See table 12 for lake level.

[2] Depth to sand bar (crest or limb).

TABLE 39.–*Land use, Redbird to Lake-Ashtabula County line*

Location	Land use[1]		
	1876	1937	1973
Redbird-R32	agricultural, range, urban(s)[2]	urban(s), range, agricultural	urban(m), agricultural
R32-R33	agricultural, range, forest, urban(s)	urban(s), range, agricultural	urban(m), agricultural, forest
R33-R34	agricultural, range, urban(s)	urban(s), agricultural	urban(m)
R34-R35	agricultural, range, forest, urban(s)	urban(s), agricultural, forest	urban(m), forest
R35-R36	agricultural, range, urban(s), forest	urban(s), agricultural	urban(m), agricultural, range
R36-R37	agricultural, forest, range	urban(s), range, agricultural, forest	urban(s-m), agricultural, forest
R37-county line	urban(s), agricultural, wetland	urban(s), forest, wetland	urban(s), forest, wetland

[1] Land uses for a given year are arranged from left to right in order of amount of land used, largest land use to the left.
[2] (s), sparsely populated, less than one house/acre; (m), moderately populated, one to three houses/acre.

TABLE 40.–*Inventory of stickout structures, Redbird to Lake-Ashtabula County line*

Location	Structure no.[1]	Type and number of structures[2]			
		1876	1937	1950	1970
Redbird-R32					
R32-R33	264			x	G
	265			x	G
	266			x	G/P
	267			G	
	270		x(1929)	x	G
	271			x	G
	273			x	G
	274			x	G
	275		x	x	G
	278		x	x	G
	280			x	G
	282		x	x	G
	284			x	G
	286		x	x	G
	288		x	x	G
	289		y	x	G
	291			x	G
	292				G
	293			G	
	294			x	G
	295				GF(4)
	297				GF(3)
	301				G
	303				GF(3)
	304			x	G
	306				G
	309				G(2)
R33-R34	312		y		GF(5)
	313				G
	315		y		G
	318				GF(3)
	319		x	x	G
	321		x	x	P
	322			x	G
	323				G
	324			G	
	325				G
	326				G
	327			G	
	328				G
	329				G
	330		y		G
	331				G
	332				G
	333				GF(5)
R34-R35	334				G
	335				G/B
	336			G/B	
	338				G
	339		y	G	
	340		x	x	G
	342				GF(4)
	343			x	G(2)
R35-R36	344				G(2)
	345				GF(5)
	346				G(2)
	347				G(2)
	349				G(2)
	351				G(2)
	352				GF(5)
	353				P/G
	354			G	
	355				G
	356				G
	357			x	G(2)
	359				G
	360				G
R36-R37			G		
	362				G
	363				G
	364			x	G
	365			x	G
	367			x	G
	368				G
	369				G
	370				G
			G		
	372				G
	373				G
	375				G
	377				G
	378				G
	379				G
	380				G
	381				G
	382				G
			G(2)		
			G		
R37-county line	383		x	G	
	384		x	G	
			G		
	387		x	G	
	388			G	
	389				G
	390		y		G
			G		
			G(2)		

[1] Structure numbers correspond to numbers in the Appendix, which is a compendium of information on all structures along the shore of Lake County. Some early (1876-1937) structures, which are not described in the Appendix, are included in the stickout structure table, but are not numbered (for example, the groin field between structure no. 23 and structure no. 24 on table 15).

[2] B, breakwater; G, groin; GF, groin field; J, jetty; P, pier; S, seawall; (5), number of structures included under one inventory number; x, structure described in a later year is most likely the same structure observed on map or aerial photograph; y, structure described in a later year is possibly the same structure shown on map or aerial photograph; (1924), year the structure was built, if known.

TABLE 41.–*Beaches, Redbird to Lake-Ashtabula County line*

Location	1876			1937			1973		
	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]	Beach length (ft)[1]	Type of beach[2]	Width of beach[3]
Redbird-R32	2,100	natural	small-moderate	2,100	natural	moderate-large	2,000	natural	small-moderate
R32-R33	4,000	natural	small-moderate	4,000	trapped	moderate	4,000	trapped	small
R33-R34	800	natural	small	1,200	trapped	small	300	trapped and natural	moderate
	1,900	natural	moderate	1,500	trapped	moderate	1,900	trapped	small
							500	–	
R34-R35	3,500	natural	small-moderate	3,900	trapped and natural	moderate	600	–	
							3,200	trapped	small
R35-R36	3,500	natural	small-moderate	3,500	trapped and natural	moderate	1,200	trapped	small
							400	–	
							1,900	trapped	small
R36-R37	1,800	natural	small-moderate	300	trapped	large	1,400	trapped	small
				900	trapped	small-moderate	2,000	trapped and natural	moderate
	1,700	natural	large	2,300	trapped and natural	small			
R37-county line	1,500	natural	large	2,000	natural	small-moderate	1,500	trapped and natural	small-moderate
	500	natural	small-moderate				600	–	

Summary

Width of beach[3]	Beach length (ft)[1]		
	1876	1937	1973[4]
Small	800	3,500	13,600
Small-moderate	15,400	2,900	3,500
Moderate	1,900	12,900	2,300
Moderate-large		2,100	
Large	3,200	300	

[1] Measured to nearest 100 ft.

[2] *Natural,* the development of the beach has not been caused by manmade structures; *trapped,* the development of the beach has been caused by manmade structures; --, no beach.

[3] *Small,* less than 50 ft wide; *moderate,* 50 to 100 ft wide; *large,* greater than 100 ft wide.

[4] In 1973 there was 2,100 ft of shore without any beach.

TABLE 42.–*Recession rates, Redbird to Lake-Ashtabula County line*

Location	1876-1973		1937-1973	
	Recession rate[1]	Length (ft)[2]	Recession rate[1]	Length (ft)[2]
Redbird-R32	very slow	2,000	very slow	2,000
R32-R33	very slow	1,200	very slow	3,900
	slow	2,700		
R33-R34	slow	500	very slow	2,700
	very slow	2,150		
R34-R35			very slow	500
			slow	200
	very slow	3,700	moderate	300
			slow	500
			very slow	2,350
R35-R36	very slow	300		
	slow	250	very slow	3,400
	very slow	2,900		
R36-R37	very slow	550		
	slow	1,200	very slow	3,450
	very slow	1,700		
R37-county line	very slow	500	very slow	500
	floodplain (800 ft)		*floodplain (800 ft)*	
	very slow	900	very slow	150
			slow	200
			very slow	500

Summary

Recession rate[1]	Length in each recession class (ft)[2]	
	1876-1937	1937-1973
Total very slow	15,900	19,450
Total slow	4,650	900
Total moderate		300

[1] Very slow, <1 ft/yr; slow, 1-3 ft/yr; moderate, 3-5 ft/yr; rapid, 5-7 ft/yr; very rapid, 7-9 ft/yr.

[2] Measured to nearest 50 ft.

AERIAL PHOTOGRAPHS, REDBIRD TO LAKE-ASHTABULA COUNTY LINE REACH

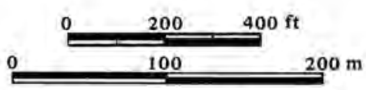
Aerial photography of the Lake County shore was done in 1973 by the Ohio Department of Transportation. The photographs for this reach are reproduced here with superimposed 1876, 1937, and projected 2010 recession lines. The 1876 line is farthest lakeward; the 2010 line is the heavy dashed line farthest landward; the 1876 and 1937 lines are dashed where approximate. The recession lines for the different years coincide where there has been no change.

Range and structure locations also are shown (see Appendix for description of the structures). The following symbols are used:

Range location and number

Structure location and number; dashed line indicates that structure was not found in 1970 survey

Scale on all photos:



Scale distorted toward edges of photos

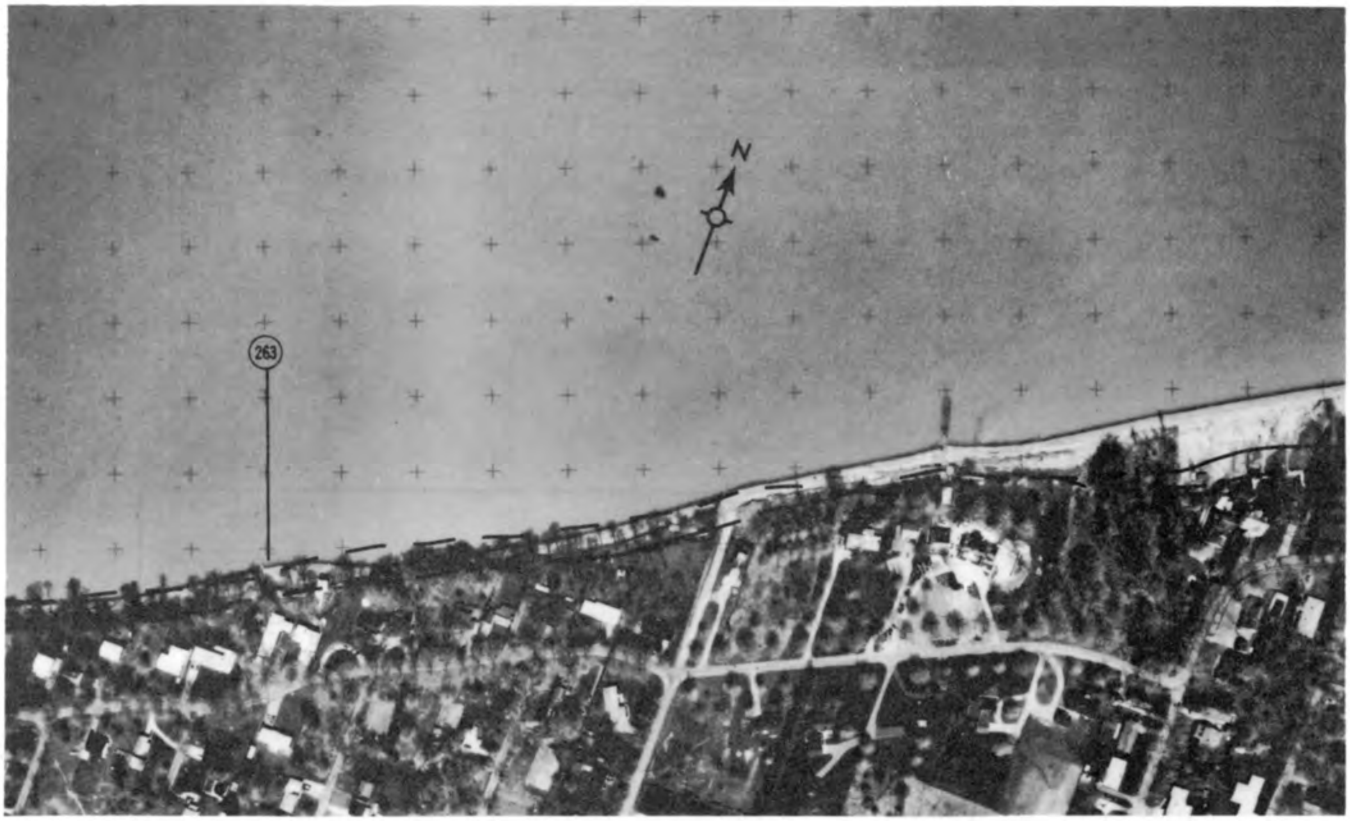


FIGURE 62

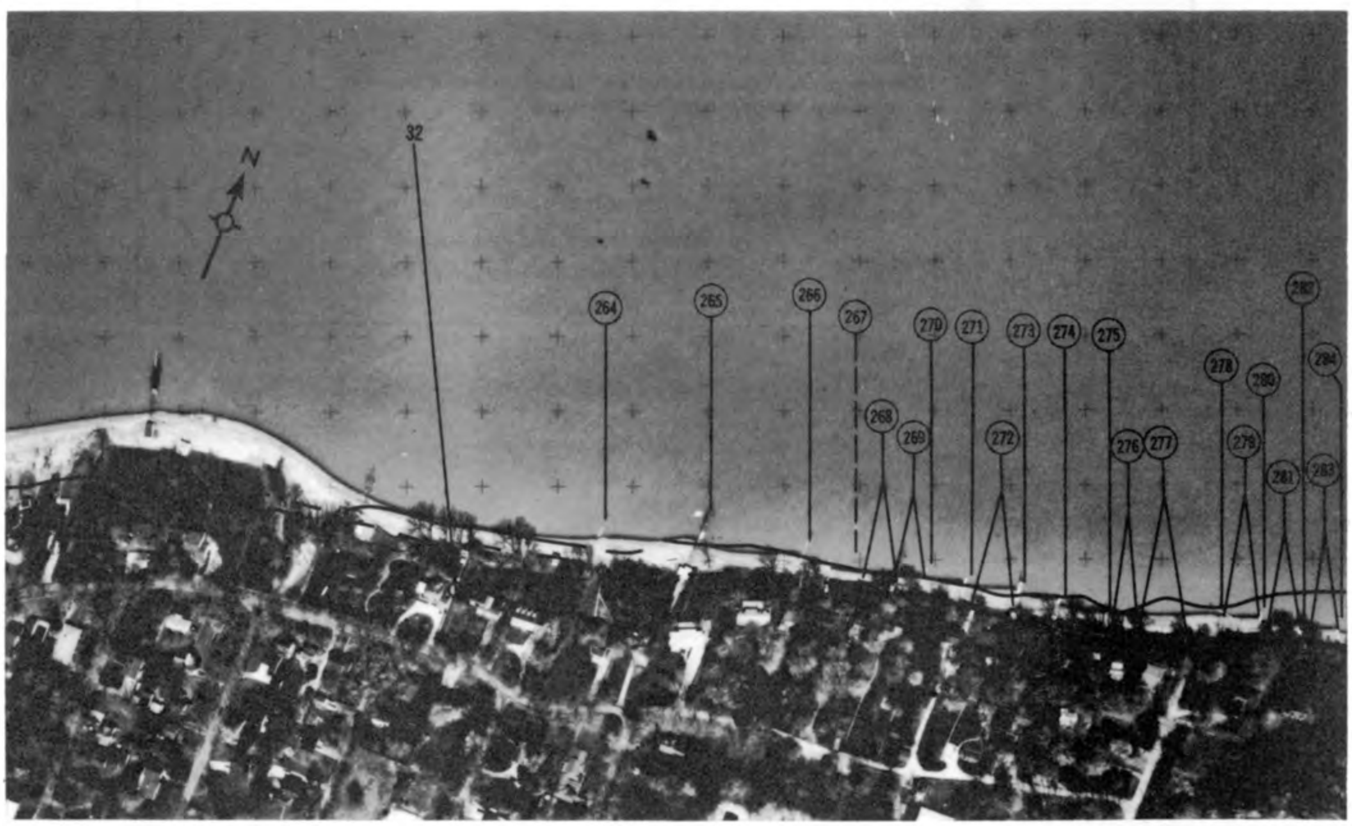


FIGURE 63

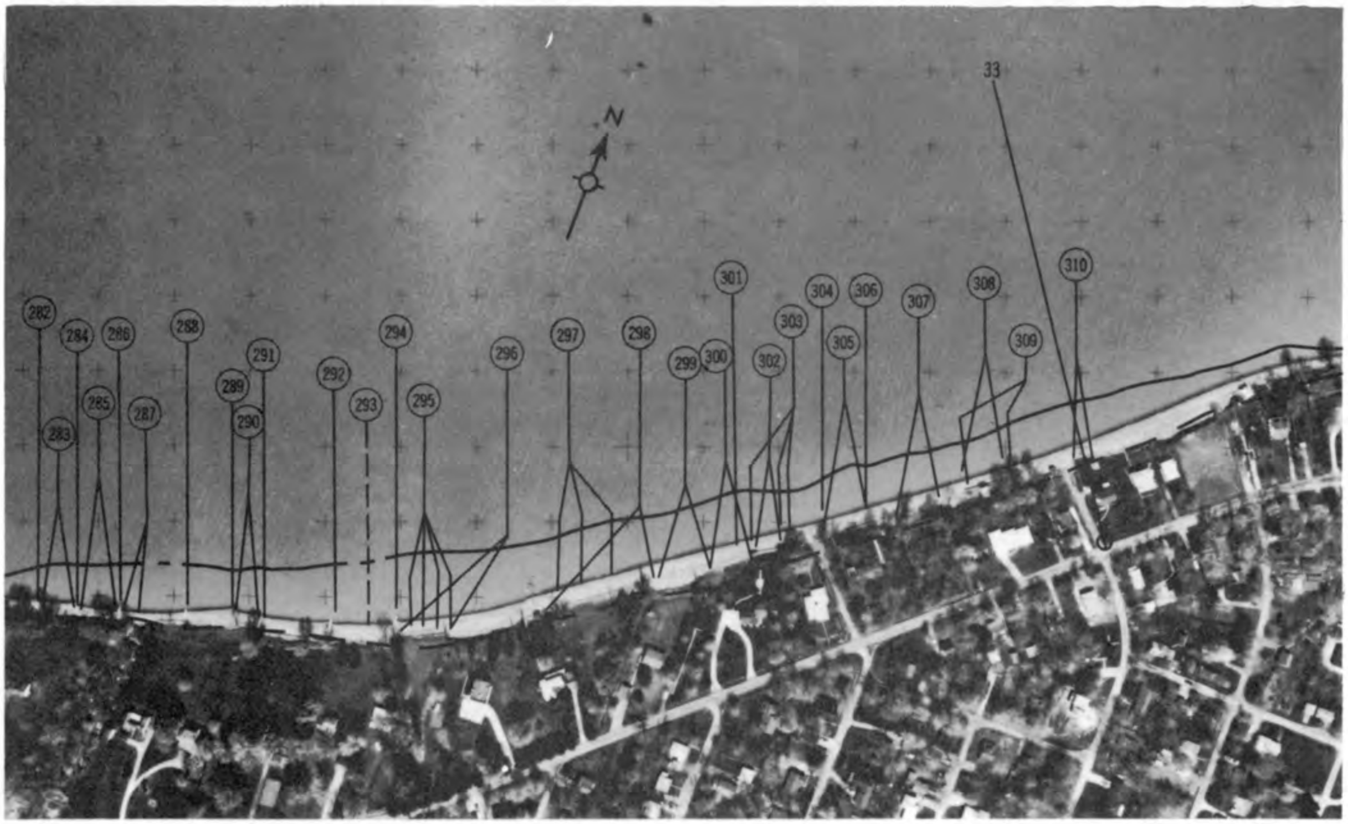


FIGURE 64

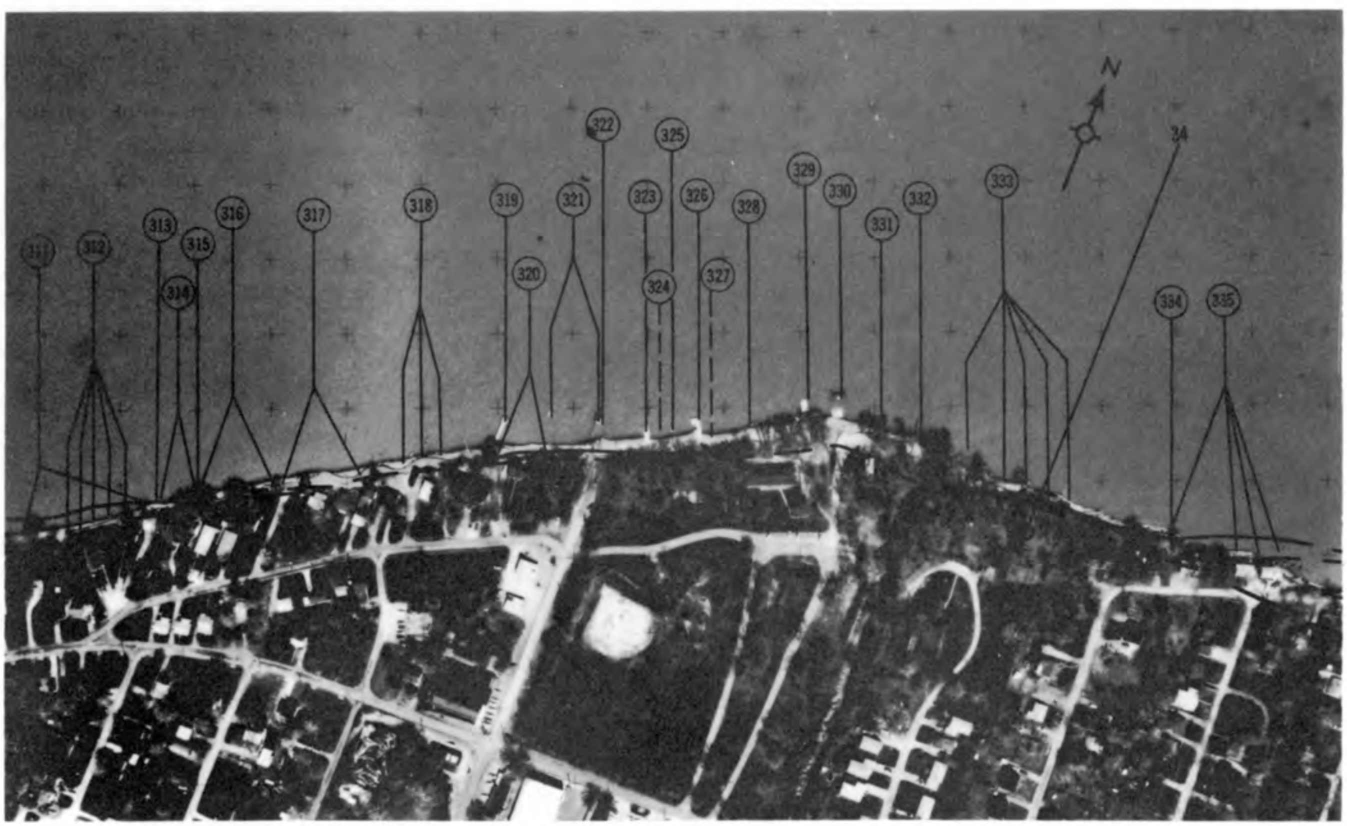


FIGURE 65

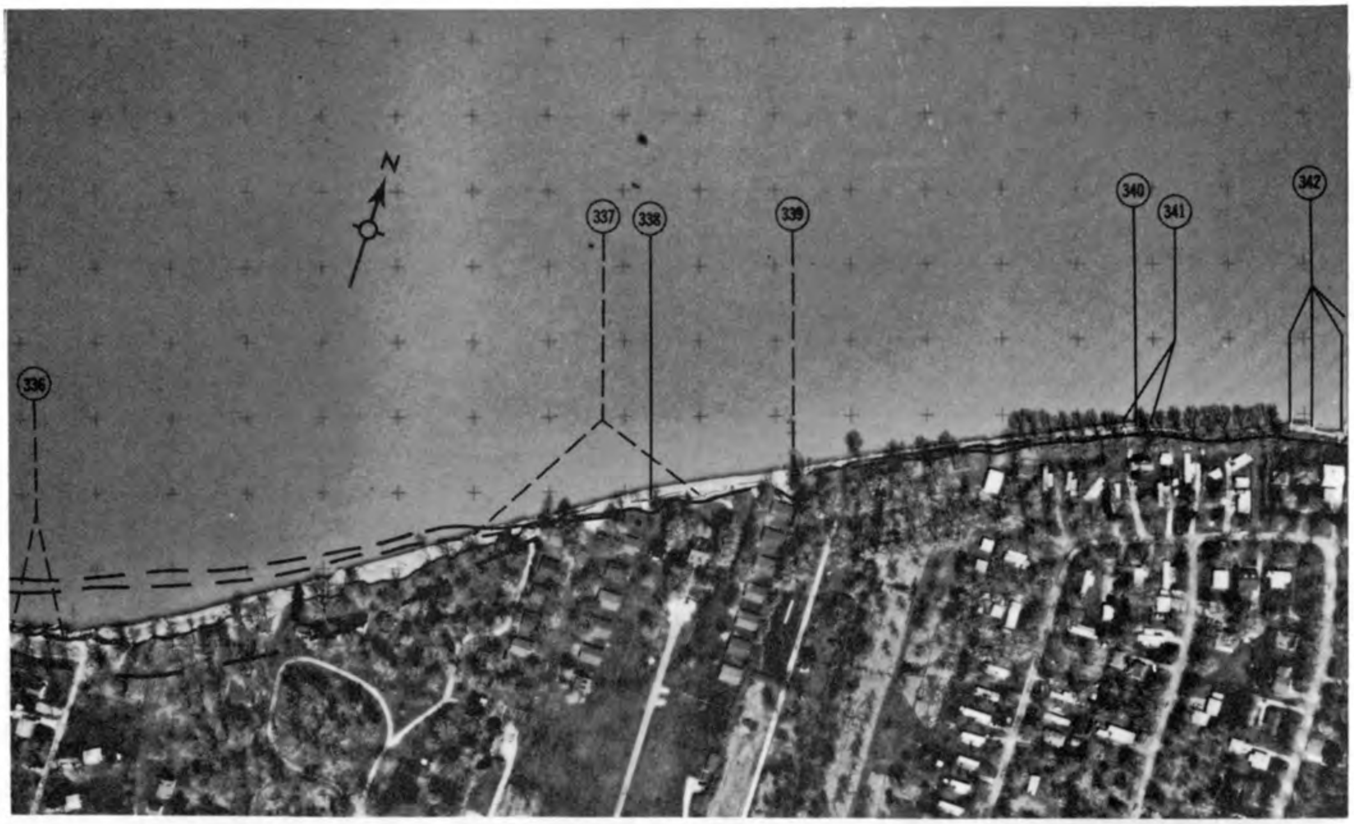


FIGURE 66

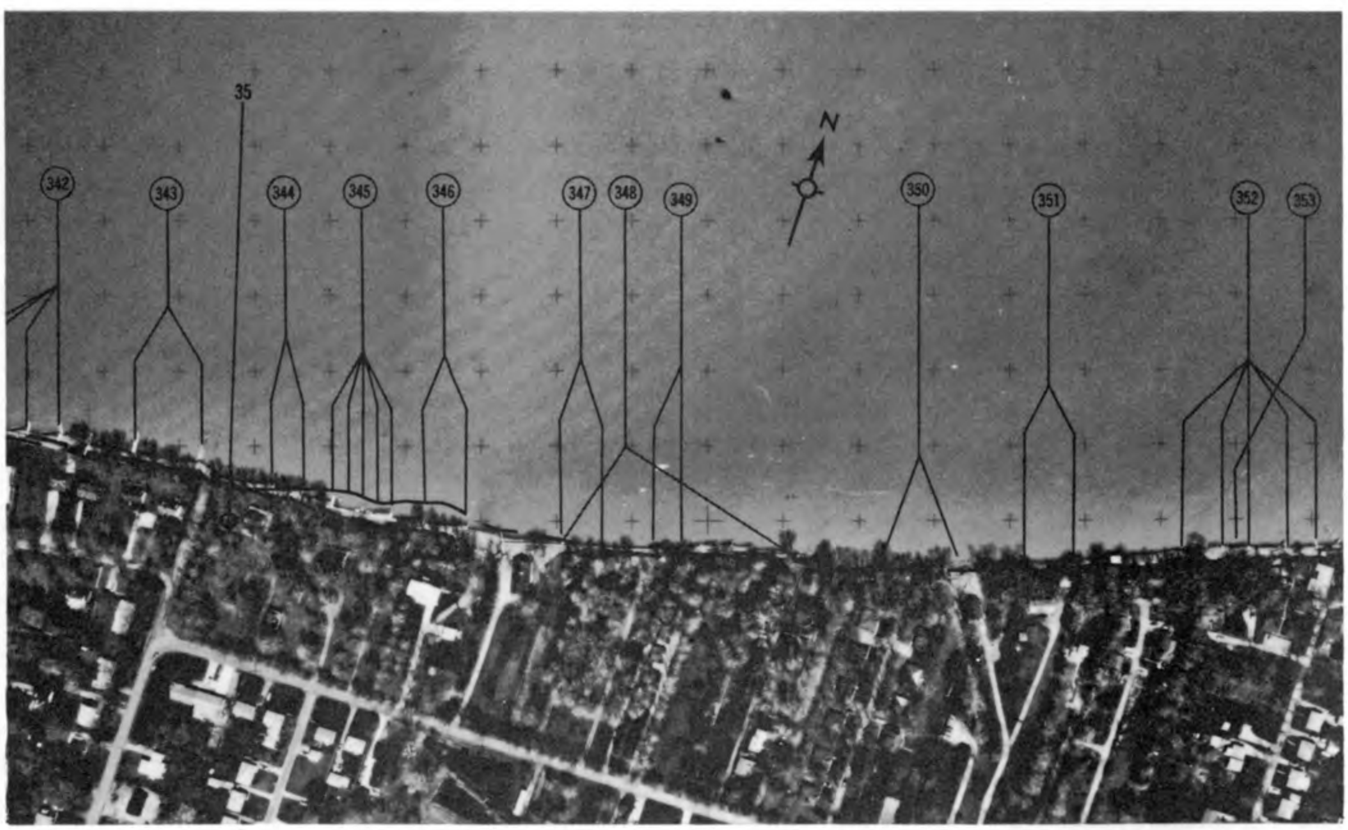


FIGURE 67

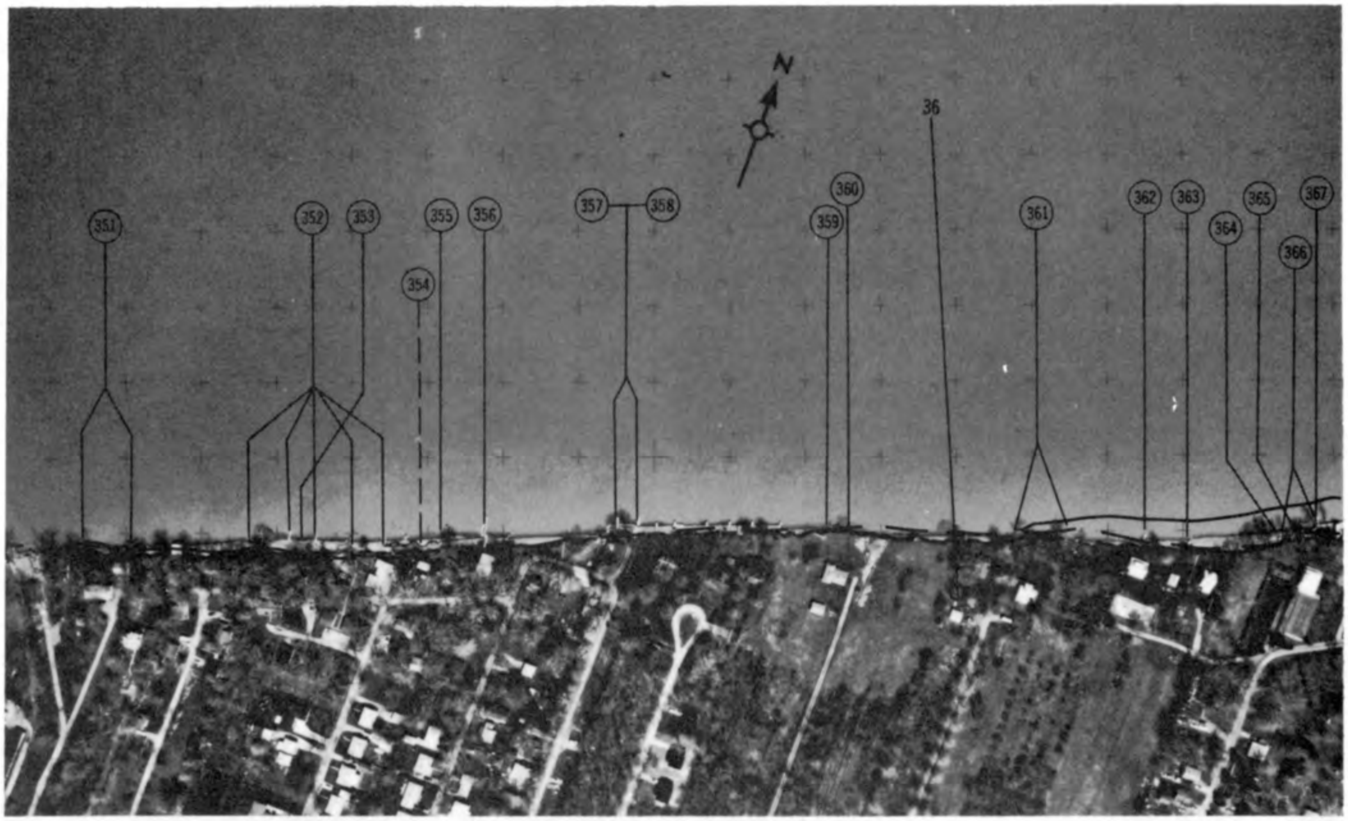


FIGURE 68

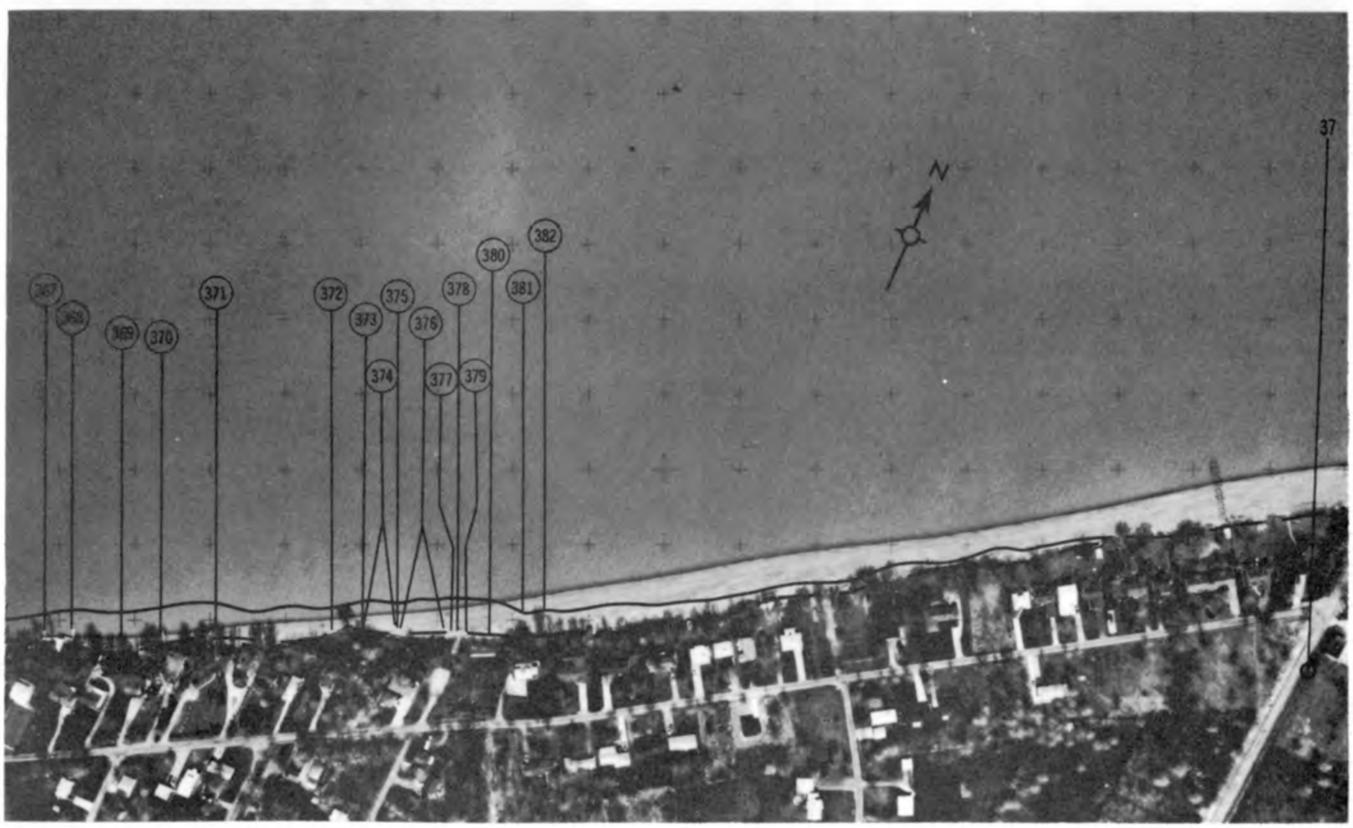


FIGURE 69

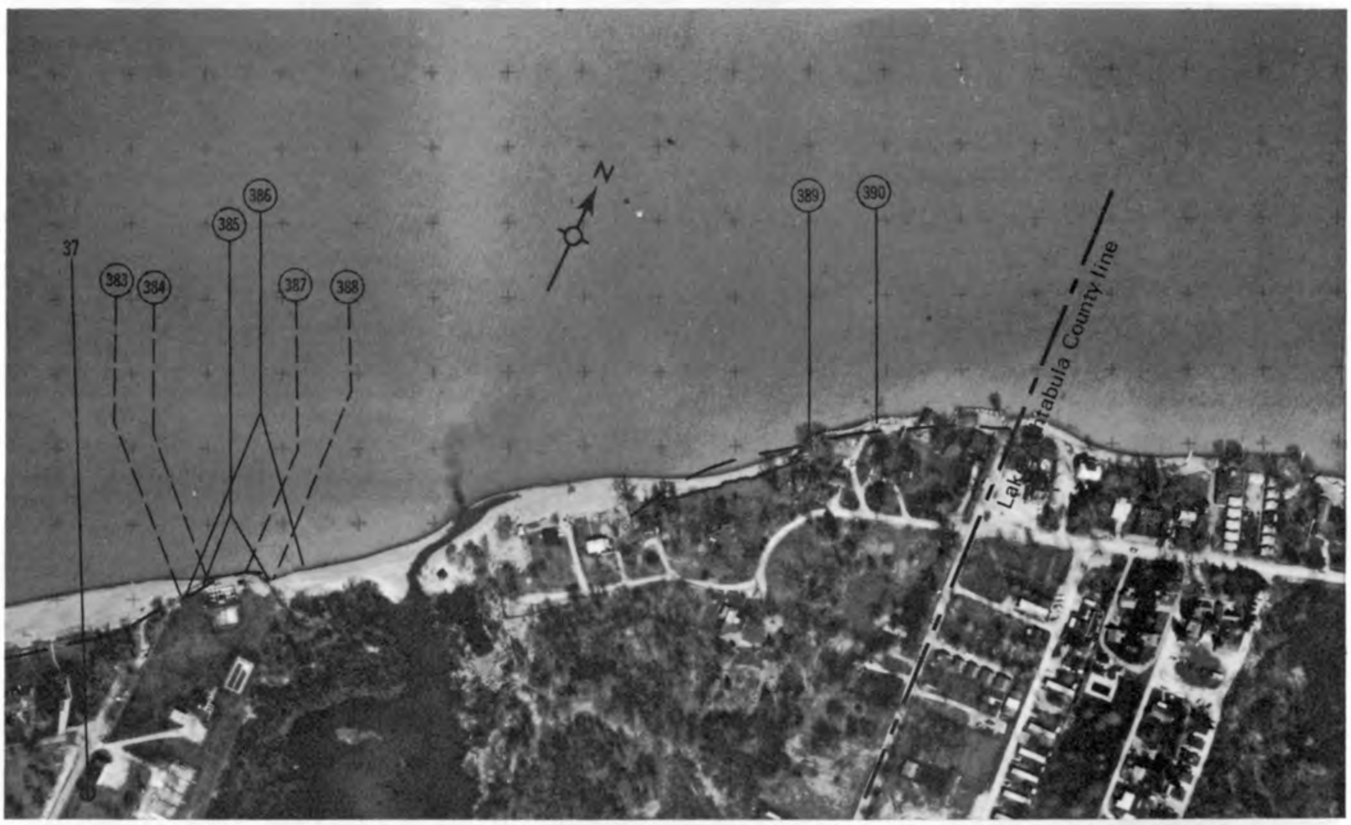


FIGURE 70

REACH COMPARISONS–A COUNTY PERSPECTIVE

Comparisons of the reaches are necessary to better understand the effects of the different factors that play roles in recession along the Lake County shore. For, although studies of the individual reaches can help in our understanding of the more local, large-scale causes and effects along the shore, the understanding of the broader, small-scale causes and effects requires comparisons among the reaches. For example, nearshore slope, distribution of beaches, and the general nature of manmade structures are factors which may differ little within a given reach, but which may differ to a great degree among the reaches. This section will attempt to tie together the large-scale changes into a small-scale overall picture by comparing the reaches with respect to: (1) principal recession-rate factors and their changes through time, (2) differences in recession rates among the reaches for the 1876-1937 and 1937-1973 periods, and (3) interpretation of the why and wherefore of the recession rates for each period and the differences between the two periods.

RECESSION-RATE FACTORS

Precipitation, lake level, storms, fetch distance, shoreline orientation, geology, manmade structures, beach size and distribution, nearshore slopes, and nearshore bars are factors that can have a significant effect on recession rates. However, in considering a relatively short shore length, such as along Lake County, that has a fairly straight even shoreline, several of these factors can be considered as constants in an analysis of recession rates within a given period. The variability of precipitation, lake level, storms, fetch distance, and shoreline orientation with respect to different portions of the Lake County shore is comparatively low. For instance, the intensity of a three-day northeaster will be about the same along the entire county shore, although factors such as nearshore slopes and beaches will affect the way storm waves act on the shore.

The geology along the Lake County shore also is considered a constant, for, even though there are changes in the geology along the shore, the critical erosion zone near lake level along nearly the entire Lake County shore is made up of till. Furthermore, although detailed geological surveys were not made along this shore until the 1940's, it is probable that the land-water interface was fronted by till in both 1876 and 1937 because of the areally extensive nature of the till along the present shore. Moreover, the topographic expression of the slope or bluff along a specific stretch is the same on the 1876, 1937, and 1973 maps and photos, indicating that the lateral and vertical distribution of the till and glaciolacustrine deposits have stayed about the same. Therefore, by assuming precipitation, lake level, storms, fetch distance, shoreline orientation, and geology to be constants, the following factors are considered to be the most important variables in a comparison and analysis of recession rates among the different Lake County reaches: beaches, nearshore slopes, and manmade structures (more specifically stickout structures). These variables generally are interrelated; stickout structures, for example, have a direct influence on the size and distribution of beaches. Nearshore bars are not considered separately because of their close association with beaches; the largest number of and the best defined bars are located in association with the largest beaches, *e.g.*, west of the Mentor Harbor jetties (profiles 10 through 13) and west of the Grand River jetties (profiles 15 through 18). Because of this relationship it is difficult to separate the effect of a large beach from that of a large bar on the recession rate along a given stretch. In the following discussion, beaches, nearshore slopes, and stickout structures will be considered separately where possible for 1876, 1937, and 1973; the factors then will be considered in the context of recession rates within the periods 1876-1937 and 1937-1973, and between the 1876-1937 and 1937-1973 periods.

Beaches

The size and distribution of beaches have changed in a fairly orderly pattern with time along all the reaches (table 43). And, although changes in lake level have affected the size of beaches, there are overall patterns in beach size and distribution in a given year and from year to year, indicating

TABLE 43.–*Beach size*

Reach	Beach size[1]	Reach length (percent)		
		1876	1937	1973
Cuyahoga-Lake County line to Chagrin River	no beach			28
	small	47	26	56
	small-moderate	40	74	2
	moderate	13		6
	large			7
Chagrin River to Mentor Harbor	no beach		7	28
	small	37	32	43
	small-moderate	22	16	15
	moderate	2	5	
	moderate-large	10	19	
	large	29	21	14
Mentor Harbor to Grand River	no beach			3
	small			56
	small-moderate	91	40	24
	moderate		9	
	moderate-large		42	
	large	9	9	17
Grand River to Camp Roosevelt	no beach		26	32
	no beach-small	4		
	small	30	42	53
	small-moderate	31	5	2
	moderate	4	2	2
	moderate-large	20	26	10
	large	11		
Camp Roosevelt to Redbird	no beach	6	12	28
	small	25	23	52
	small-moderate	54	35	11
	moderate	1	16	2
	moderate-large	5	14	7
	large	10		
Redbird to Lake-Ashtabula County line	no beach			10
	small	4	16	63
	small-moderate	72	13	16
	moderate	9	60	11
	moderate-large		10	
	large	15	1	

[1] *Small*, less than 50 ft wide; *moderate*, 50 to 100 ft wide; *large*, greater than 100 ft wide.

TABLE 44.—*Reach length with small-moderate or greater beach size*

Reach	Reach length (percent)		
	1876	1937	1973
Cuyahoga-Lake County line to Chagrin River	53	74	15
Chagrin River to Mentor Harbor	63	61	29
Mentor Harbor to Grand River	100	100	41
Grand River to Camp Roosevelt	66	33	14
Camp Roosevelt to Redbird	70	65	20
Redbird to Lake-Ashtabula County line	96	84	27

that specific cause-and-effect relationships operated along the reaches.

1876.—In 1876 there was a nearly continuous beach along the entire county shore except for a short (1,700 ft, 518 m) stretch along the Camp Roosevelt to Redbird reach (table 43). The majority of the beaches were small-moderate in size, and two reaches (Mentor Harbor to Grand River and Redbird to the Lake-Ashtabula County line) were fronted almost entirely by beaches of this size (table 43).

1937.—By 1937, there were three reaches (Chagrin River to Mentor Harbor, Grand River to Camp Roosevelt, and Camp Roosevelt to Redbird) that were partially without beaches, although in general the overall size of the beaches did not change much between 1876 and 1937. The beaches along the Grand River to Camp Roosevelt reach did show a decrease in beach size (tables 43 and 44). However, beach size probably changed more than indicated: the lake level when the 1937 photographs were taken was 2 to 3 ft (<1 m) below the 1876 level.

1973.—By 1973 all the reaches had stretches without beaches and, in general, the beaches showed a decrease in size (tables 43 and 44). Most of the changes can be attributed to record-high lake levels; however, within three reaches there were unnatural changes in the size and distribution of beaches. Along the Cuyahoga-Lake County line to Chagrin River reach the range in beach size changed from small to small-moderate in 1937 to no beach to large in 1973; along the Chagrin River to Mentor Harbor reach the range (small to large) in beach size stayed the same, but beaches of moderate and moderate-large size were not present in 1973; along the Mentor Harbor to Grand River reach one stretch of large beach increased in length from 1,700 ft in 1876 and 1937 to 3,300 ft in 1973.

Nearshore slopes

A comparison of water depths along the same profiles in 1876 and in 1970 shows a general increase in the nearshore slope with time along most of the reaches (table 45). The reaches with the gentlest slopes in 1876 were the reaches with the gentlest slopes in 1970. The Mentor Harbor to Grand River reach showed the least increase in slope within 500 ft (152 m) of the shoreline, and the Chagrin River to to Mentor Harbor and the Grand River to Camp Roosevelt reaches showed the greatest increases in slope within 500 ft (152 m) of the shoreline.

1876.—The gentlest slopes within 500 ft (152 m) of the shoreline were located along the three reaches east of Grand River, and the steepest slopes within 500 ft (152 m) of the shoreline were located along the three reaches west of Grand River (table 45). In general, there is an overall decrease in slope from the west edge of the county to the east edge, probably because of the increase in bedrock elevation from west to east.

1970.—The gentlest slopes within 500 ft (152 m) of the shoreline in 1970 also were located along the three reaches east of Grand River, and the steepest slopes were located along the three reaches west of Grand River (table 45).

The most pronounced changes in slope within 500 ft (152 m) of the shoreline—the very slight increase in slope

TABLE 45.—*Nearshore depths, 1876 and 1970*[1]

Distance from shoreline (ft)	Depth (ft)											
	Cuyahoga-Lake County line to Chagrin River (5 profiles)		Chagrin River to Mentor Harbor (8 profiles)		Mentor Harbor to Grand River (5 profiles)		Grand River to Camp Roosevelt (5 profiles)		Camp Roosevelt to Redbird (8 profiles)		Redbird to Lake-Ashtabula County line (6 profiles)	
	1876	1970	1876	1970	1876	1970	1876	1970	1876	1970	1876	1970
50	2.1	5.4	3.1	5.2	2.1	3.9	2.1	5.1	2.3	3.8	2.3	3.7
100	4.0	8.1	5.4	7.8	4.2	4.8	4.0	7.2	3.9	5.2	3.6	4.8
200	7.1	8.2	7.2	9.7	7.0	6.4	6.4	9.1	6.4	7.0	5.2	6.6
300	9.5	10.3	9.0	11.5	8.9	8.2	7.6	9.9	7.6	7.7	6.3	8.4
400	11.9	11.6	10.0	12.4	10.1	9.9	8.6	9.6	8.6	8.5	7.0	9.2
500	12.3	13.2	11.0	13.2	11.4	11.4	9.7	10.2	9.4	9.2	7.9	10.1
1,000	18.4	19.5	13.4	15.9	12.9	14.1	17.5	16.1	14.2	14.2	13.0	13.3
1,500	24.9	24.5	18.5	19.4	14.2	16.5	21.4	19.4	18.0	18.1	16.8	17.2
2,000	29.6	28.4	23.6	25.0	18.6	18.4	24.5	23.4	21.4	20.1	19.5	19.5

[1] See individual reach sections for complete listing of nearshore depths. The 1970 profile lines are the same as the 1876 profile lines.

along the Mentor Harbor to Grand River reach and the significant increase in slope along the Grand River to Camp Roosevelt reach–between 1876 and 1970 are probably due to the same factor. The slightness of the increase in slope along the Mentor Harbor to Grand River reach reflects the tremendous amount of sand trapped by the Grand River west jetty, whereas the increase in slope along the Grand River to Camp Roosevelt reach reflects a net loss of sand, primarily because of the same jetty.

The overall increase in slope from 1876 to 1970 between the shoreline and 500 ft offshore apparently is due to one principal factor–sand supply. With increased shore protection to the west (Cleveland to the Cuyahoga-Lake County line) and along the Lake County shore, an insufficient quantity of sand is entering the longshore drift system to replace the sand transported to the east. However, two other factors–change in lake level and crustal rebound–also may have affected the nearshore slope. Lake level rose from about 571.0 ft in the summer of 1875 to about 572.5 ft in the summer of 1876–when the 1876 profiles were made–and it is possible that this change could have increased the average nearshore slope because the nearshore slope may not have yet reached equilibrium. In a parallel situation, lake level dropped from about 572.5 ft in the summer of 1969 to 571.5 ft in the summer of 1970–when the 1970 profiles were made–and it is possible that this change could have decreased the average slope. If these inferences are correct, the increase in slope between 1876 and 1970 would be greater than is indicated.

On the other hand, because the south shore of the lake is rebounding from the glacial load at a slower rate than the northern shore, with time the nearshore slope along the south shore could increase because of the increase in water depth. The extrapolated difference in vertical movement, based on automatic water-level gage records from about 1900 with respect to Port Stanley, Ontario, Canada, is about -0.20 ft/century at Cleveland, -0.63 ft/century at Fairport Harbor, and -0.34 ft/century at Ashtabula (Donald Rondy, Lake Survey Center, personal communication, 1974). Therefore the actual increase in slope between 1876 and 1970 may represent more than a loss of sand to the nearshore area, particularly along the reaches east of Grand River, where rock lies at or close to the bottom surface.

TABLE 46.–*Stickout structures*

Reach	Stickout structures (no.)		
	1876	1937	1970
Cuyahoga-Lake County line to Chagrin River	1	44	44
Chagrin River to Mentor Harbor		39	39
Mentor Harbor to Grand River	3	22	38
Grand River to Camp Roosevelt		24	19
Camp Roosevelt to Redbird		23	30
Redbird to Lake-Ashtabula County line		25	79

Stickout structures

The number of stickout structures increased greatly from 1876 to 1937 along all of the reaches, whereas from 1937 to 1973 the number of stickout structures did not change much except along the Redbird to Lake-Ashtabula County line reach (table 46). The increase from 1876 to 1937 roughly parallels the change in land use from agricultural and range land to urban (sparse) and agricultural land (table 47).

The largest and most significant structures–the jetties at the mouth of the Grand River–however, were built long before 1876, in the mid-1820's. Other structures, significant because of their size and consequent disruption of longshore drift, are the jetties at Mentor Harbor and at the Cleveland Electric Illuminating Company Chagrin River plant.

1876.–Only 4 stickout structures, including the Grand River jetties, are shown on the 1876 maps (table 46).

1937.–One hundred and seventy seven stickout struc-

TABLE 47.–*Principal land use*

Reach	Land use		
	1876	1937	1973
Cuyahoga-Lake County line to Chagrin River	agricultural	urban(s)[1]	urban(m-d)
Chagrin River to Mentor Harbor	range, agricultural	urban(s)	urban(s-m)
Mentor Harbor to Grand River	agricultural	urban(s)	urban(s-m)
Grand River to Camp Roosevelt	range, agricultural	range, agricultural, urban(s)	agricultural, range, urban(s)
Camp Roosevelt to Redbird	agricultural	agricultural	agricultural, forest
Redbird to Lake-Ashtabula County line	agricultural	urban(s)	urban(m)

[1] (s), sparsely populated, less than one house/acre; (m), moderately populated, one to three houses/acre; (d), densely populated, more than four houses/acre.

tures were observed on the 1937 photographs (table 46). Most of the structures lay along the most densely populated reaches, Cuyahoga-Lake County line to Chagrin River and Chagrin River to Mentor Harbor. The Mentor Harbor jetties were constructed in 1932.

1970.–In 1970, 249 stickout structures were inventoried (table 46). From 1937 to 1970 there was a marked increase in the number of stickout structures (25 to 79) along the Redbird to Lake-Ashtabula County line reach. There was an increase from 22 stickout structures in 1937 to 38 in 1970 along the Mentor Harbor to Grand River reach, an increase from 23 stickout structures in 1937 to 30 in 1970 along the Camp Roosevelt to Redbird reach, and a decrease from 24 stickout structures in 1937 to 19 in 1970 along the Grand River to Camp Roosevelt reach. The Cleveland Electric Illuminating Company jetties west of the Chagrin River were constructed in the early 1950's.

RECESSION RATES

1876-1937

The principal recession rate for the four westernmost reaches (Cuyahoga-Lake County line to Camp Roosevelt) was slow (table 48). The range in recession rates measured along these four reaches, with the exception of the Mentor Harbor to Grand River reach, was very slow to moderate. Recession rates in the Mentor Harbor to Grand River reach ranged from very slow to rapid.

The principal recession rate for the two eastern reaches (Camp Roosevelt to the Lake-Ashtabula County line) was very slow (table 48). The range in recession rates along these two reaches was very slow to slow except for a 150-ft (46-m) stretch between Camp Roosevelt and Redbird, where recession took place at a moderate rate.

1937-1973

The principal recession rate for all of the Lake County reaches during this period was very slow (table 48). Recession rates from the Cuyahoga-Lake County line to Mentor Harbor and from Camp Roosevelt to the Lake-Ashtabula County line ranged from very slow to moderate except for a relatively short–700 ft (214 m)–stretch along the Camp Roosevelt to Redbird reach that receded at moderate-rapid rates. However, from Mentor Harbor to Camp Roosevelt recession rates ranged from very slow to very rapid; moreover, there was an appreciable (several thousand feet, or a few thousand meters) stretch along each of the two reaches that receded at rapid-very rapid rates.

INTERPRETATION OF RECESSION RATES

Recession rates form a logical starting point from which to interpret the why and wherefore of erosion because the rates reflect the physical and cultural factors that affect the erosion processes. The most apparent differences in recession rates between the two time periods (1876-1937 and 1937-1973) can be related directly to the most important recession-rate variables along the Lake County shore: nearshore slopes, beaches, and stickout structures.

1876-1937

Comparison of recession rates from 1876 to 1937 along the six reaches shows two principal differences: (1) the principal recession rate for the two easternmost reaches is very slow, whereas the principal recession rate for the four reaches to the west is slow, and (2) there are higher (moderate and rapid) recession rates for greater percentages of the Mentor Harbor to Grand River and Grand River to Camp Roosevelt reaches. Measurements of nearshore slope in the 1876-1937 period are available only for 1876; the gentlest slopes within 500 ft (152 m) of shore in 1876 were located along the three reaches east of Grand River. The nearshore slope along the Grand River to Camp Roosevelt reach was still changing because of the effect of the Grand River jetties.

Beach size and distribution were about the same in 1876 and in 1937, although from 1876 to 1937 there was an overall increase in beach size along the Mentor Harbor to Grand River reach and an overall decrease in beach size

TABLE 48.–*Recession rates*

Reach	Rate[1]	Reach length (percent) 1876-1937	Reach length (percent) 1937-1973
Cuyahoga-Lake County line to Chagrin River	very slow	22	55
	slow	75	30
	moderate	3	15
Chagrin River to Mentor Harbor	very slow	27	50
	very slow-slow		3
	slow	62	27
	moderate	11	20
Mentor Harbor to Grand River	very slow	21	54
	very slow-slow	21	
	slow	36	7
	slow-moderate		2
	moderate	15	3
	rapid	6	9
	very rapid		25
Grand River to Camp Roosevelt	very slow	14	40
	very slow-slow		4
	slow	50	13
	slow-moderate		1
	moderate	35	23
	moderate-rapid		1
	rapid		6
	very rapid		12
Camp Roosevelt to Redbird	very slow	60	60
	very slow-slow	2	2
	slow	37	11
	moderate	1	24
	moderate-rapid		3
Redbird to Lake-Ashtabula County line	very slow	77	94
	slow	23	4
	moderate		1

[1] *Very slow,* <1 ft/yr; *slow,* 1-3 ft/yr; *moderate,* 3-5 ft/yr; *rapid,* 5-7 ft/yr; *very rapid,* 7-9 ft/yr.

along the Grand River to Camp Roosevelt reach. The largest beaches fronted the Mentor Harbor to Grand River reach and the Redbird to Lake-Ashtabula County line reach.

The two westernmost reaches had the greatest number of stickout structures per shore length.

The contrast in recession rates between the two eastern reaches and the four reaches to the west is probably due to one factor–nearshore slope. For example, although the Camp Roosevelt to Redbird reach had beach sizes comparable to those to the west (with the exception of the Mentor Harbor to Grand River reach) as well as similar structure density (with the exception of the two westernmost reaches), the gentler nearshore slope was the most likely cause of the slower recession rate. The Grand River to Camp Roosevelt reach, which was similar to the Camp Roosevelt to Redbird reach, receded at a more rapid rate because of the Grand River harbor structures; the continual disruption and entrapment of sand from the longshore drift system from before 1876 to 1937 deprived the adjacent downdrift shore of sand, leading to an increase in nearshore slope, a decrease in beach width, and an increase in the recession rates. However, sand derived from the accelerated recession along this reach probably has helped protect the shore along the two eastern reaches.

The higher recession rates for greater percentages of the Mentor Harbor to Grand River and Grand River to Camp Roosevelt reach lengths are probably due more to local changes (see individual reach descriptions). The one stretch that receded at moderate and rapid rates along the Mentor Harbor to Grand River reach is directly downdrift of the Mentor Harbor jetties. A similar situation appears to account for the four long stretches that receded at a moderate rate along the Grand River to Camp Roosevelt reach; in each case, the more rapidly receding stretch is downdrift of a large stickout structure or group of stickout structures.

1937-1973

Comparison of recession rates from 1937 to 1973 along the six reaches shows two principal differences: (1) the much greater percentage of reach lengths which receded at rapid and very rapid rates along the Mentor Harbor to Grand River and Grand River to Camp Roosevelt reaches, and (2) the much greater percentage of reach length which underwent recession at very slow and slow rates along the Redbird to Lake-Ashtabula County line reach.

The gentlest slopes within 500 ft of shore in 1970 were along the Mentor Harbor to Grand River reach and the two easternmost reaches (table 45).

Comparison of beach size in 1937 and 1973 (table 43) shows a marked decrease, which probably is due mainly to the higher lake level in 1973. The general distribution of sand is about the same. The large amount of sand trapped by the three large stickout structures (Chagrin River, Mentor Harbor, and Grand River jetties) is evident, for in 1973 the only large beaches along the Lake County shore were those adjacent to and updrift of these structures.

The Redbird to Lake-Ashtabula County line reach had the largest number of stickout structures per shore length in 1970, and the Grand River to Camp Roosevelt and Camp Roosevelt to Redbird reaches had the smallest numbers (table 46).

By the 1970's the Mentor Harbor to Grand River reach had a gentle nearshore slope, the largest beaches, and a moderate stickout structure density; these factors should have greatly reduced the recession rate. However, compared to the other reaches, a much greater percentage of reach length receded at rapid and very rapid rates along this reach, as well as along the Grand River to Camp Roosevelt reach. The reason for this is a local problem which is not reflected in the overall perspective. The stretches along the Mentor Harbor to Grand River reach which receded at rapid and very rapid rates are unprotected and immediately downdrift of the Mentor Harbor jetties (see the discussion of the 1876-1937 period).

The Grand River to Camp Roosevelt reach has a similar interpretation; the one long (several thousand feet, a few thousand meters) stretch that receded at rapid and very rapid rates is largely unprotected and is downdrift of substantial structures (see the discussion of the 1876-1937 period). Moreover, the overall slope along this reach is steeper than those of four other reaches, including the Mentor Harbor to Grand River reach.

The high percentage (94) of reach length which receded at a very slow rate along the Redbird to Lake-Ashtabula County line reach probably is due primarily to the gentle nearshore slope. In addition to the gentle slope, the much greater number of stickout structures has had an influence. These structures, built along this reach since 1937, have trapped sand derived from the more rapidly receding areas west of the Grand River jetties. However, the gentle nearshore slope and an adequate amount of sand in the longshore drift system appear to be the principal factors for the low recession rates along this reach.

1876-1937 to 1937-1973

A comparison of the recession rates between the two periods shows two main differences: (1) the principal recession rate for all six reaches in the 1937-1973 period was very slow, whereas the principal recession rate for the four westernmost reaches in the 1876-1937 period was slow, and (2) although the principal recession rate decreased from 1876-1937 to 1937-1973, the range in recession rates increased along four of the six reaches.

In general, from 1876 to 1970 there has been an increase in water depth of ½ ft to 2½ ft (0.2 to 0.75 m) and a corresponding increase in slope within 500 ft (152 m) of the shoreline; the nearshore slope increased least along the Mentor Harbor to Grand River reach and increased most along the Chagrin River to Mentor Harbor reach and the Grand River to Camp Roosevelt reach.

Beach sizes in general reflect the water level, with the greatest percentage of reach length with small and no-beach classes mapped during the record-high lake levels of 1973. The distribution of beaches, however, is more irregular with time. For example, even during the comparatively low lake level of 1937 there were reaches that were fronted by stretches without beaches, whereas in 1876 only one reach, Camp Roosevelt to Redbird, had a stretch with no beach. Moreover, even during the high lake level of 1973 the three westernmost reaches had stretches with large beaches, although the percentage of reach length without beaches was much greater than in 1876 and 1937.

From 1876 to 1937 there was an overall marked increase in the number of stickout structures, but from 1937 to 1973 there has been little change, with the exception of the Redbird to the Lake-Ashtabula County line reach, which had about a threefold increase. The Cleveland Electric Illuminating Company jetties, built in the early 1950's, are the only large structures added since 1937.

Although beaches are more irregularly distributed and there has been an overall increase in nearshore slope, the principal recession rate along the Lake County shore has decreased rather than increased from the 1876-1937 period to the 1937-1973 period. The reason for the decline is probably manmade structures. The increased number of stickout structures, as well as the increased number of seawalls and seawall-like structures adjacent and parallel to the shore, has protected the shore enough to have caused the principal recession rate to decrease. Moreover, this decrease took place within a period that had two intervals (early 1950's and early 1970's) of unusually high lake levels and in which there were major storms (Carter, 1973, p. 4).

If the principal recession rate decreased from the 1876-1937 period to the 1937-1973 period, why then did the range in recession rates increase? The principal reason for this dichotomy appears to be the manmade structures; even though the structures most likely have been the primary factor in causing a decrease in the overall recession rate, in local areas, particularly unprotected areas downdrift of large structures (especially the Grand River and Mentor Harbor jetties), the recession rate has increased. A sufficiently large number of structures along the shore can cause a decrease in the principal recession rate, but where there are few structures or no structures, a large structure may disrupt the longshore drift and cause higher recession rates. These higher rates along some stretches in the 1937-1973 period are reflected in the greater range in recession rates as well as in the greater percentage of reach lengths with high recession rates.

SUMMARY AND CONCLUSIONS

SETTING

The moderately built-up Lake County shore lies along Lake Erie in northeastern Ohio. Bluffs and slopes, composed largely of till, that have an average relief of about 40 ft (12 m) make up the shore. Discontinuous sand beaches, commonly 50 to 100 ft (15 to 30 m) wide, front the shore, along with a variety of shore-protection structures. There are over 400 structures along the shore, three of which are large jetties that extend out into the lake perpendicular to the shore for several hundred feet (a few hundred meters). Nearshore slopes differ along the shore, but in general the slopes west of Grand River are steeper than the slopes east of Grand River. The average water depth 500 ft (152 m) offshore at a lake-level elevation of 570.0 ft is about 13 ft (4 m) west of Grand River and 9 ft (3 m) east of Grand River. From the western edge of the county to Grand River the bottom to at least 2,000 ft (610 m) offshore is covered by sand of various thickness; the sand overlies till or shale. From Grand River to the eastern edge of the county, the nearshore (within a few hundred feet or 100 m of shore) bottom is covered by a thin (a few feet or <1 m) layer of sand, which is underlain by shale; farther offshore to at least 2,000 ft (610 m) the bottom is shale.

SHORE PROCESSES

Storm waves appear to be the principal cause of erosion along the Lake County shore. Wave erosion removes in-place and slumped material near lake level, thus maintaining an unstable bluff or slope. Lake level is a major factor in this process. The higher the lake, the closer the waves break to the shore and the greater the wave energy expended on the shore deposits; consequently, the greater the recession rates.

Mass wasting accompanies wave erosion. Slides, flows, and slumps are most severe where there are stratigraphic differences, particularly zones of laminated clay within till. Because of the cohesive nature of the shore deposits, failure of a bluff or slope may take place weeks or months after wave erosion at the base of the bluff or slope.

SHORELINE CHANGES

The principal change in the Lake County shore from 1876 to 1973 has been the increase in unevenness of the shore. The 1876 shore, with the exception of the Grand River area, had an even, uniform outline, whereas the 1973 shore had an uneven, nonuniform outline. Directly associated with this change in outline are changes in manmade structures, beaches, and nearshore slopes. There were only a handful of structures in 1876; in 1973 there were over 400. In 1876 there was a continuous ribbon of sand fronting the shore; in 1973 this sand ribbon was broken in places by stretches of shore without a beach. Since 1876 the nearshore slope within 500 ft (152 m) of the shoreline generally has increased; for example, within 500 ft of the shoreline the water is generally 1-2 ft (<1 m) deeper. In most places these changes can be related to recession rates.

Structures

In 1876 waves impinged upon a largely natural Lake County shore. Wave erosion and subsequent mass wasting of the unprotected shore provided sand and gravel to form a nearly continuous ribbon of coarse-grained sediment along the shore in the beach and shoreline and nearshore zones. Wave erosion and mass wasting are continuing today, but, because of the manmade structures that have been built along the shore, the effect of the waves has been altered. The structures, largely by disrupting the longshore drift of sand and/or by armoring the shore, have caused a decrease in the recession rates along some stretches and at the same time have caused an increase in the recession rates along other stretches.

Stickout structures—largely groins and jetties—by modifying the longshore drift of sand, have had the greatest influence on shoreline changes and recession rates. Entrapment of sand on the updrift side of a structure results in a wider beach and a gentler nearshore slope; loss of sand to the adjacent downdrift shore results in a narrower beach and a steeper nearshore slope (fig. 71). The increase in beach width and decrease in the nearshore slope on the updrift side reduce the amount of wave energy impinging upon the shore and cause a decrease in the recession rate; on the downdrift side the decrease in beach width and increase in nearshore slope increase the amount of wave energy impinging upon the shore, causing an increase in the recession rate. Moreover, the large structures (the Grand River, Mentor Harbor, and Chagrin River jetties) appear to have had a much greater effect on recession rates than did many of the small structures; the only stretches along the Lake County shore that underwent recession at a rapid or very rapid rate are just downdrift of either the Mentor Harbor jetties or the Grand River jetties.

Parallel structures—seawalls and breakwaters—have re-

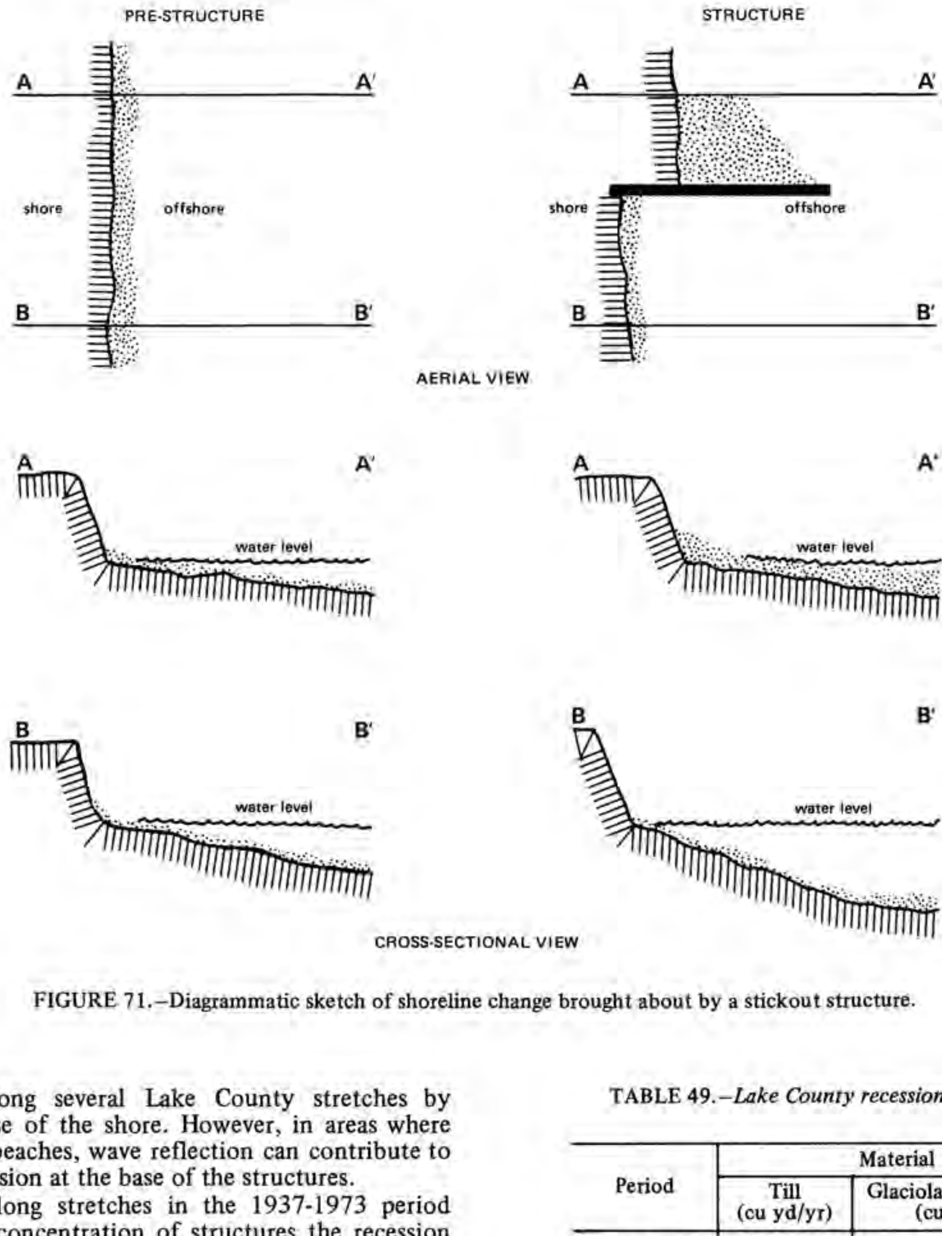


FIGURE 71.–Diagrammatic sketch of shoreline change brought about by a stickout structure.

duced erosion along several Lake County stretches by protecting the base of the shore. However, in areas where there are narrow beaches, wave reflection can contribute to increased wave erosion at the base of the structures.

In general, along stretches in the 1937-1973 period where there is a concentration of structures the recession rate is slower than that of the 1876-1937 period, when there were fewer structures. Interestingly enough, the manmade structures do not appear to have had much effect on the total amount of land lost along the Lake County shore (table 49); even though the principal recession rate decreased from the 1876-1937 period to the 1937-1973 period, the increased recession rates along some stretches in the 1937-1973 period more than compensated for the reduction in the principal rate. A study (Carter, 1975, p. 21) of the amount of sediment lost to the lake from shore erosion found that of the eight Ohio counties on the lake, the Lake County shore contributes the greatest amount of sediment.

TABLE 49.–*Lake County recession volumes*[1]

Period	Material	
	Till (cu yd/yr)	Glaciolacustrine clay (cu yd/yr)
1876-1937[2]	247,306	103,296
1937-1973[3]	265,627	123,396

[1] Volumes include only material eroded above a lake elevation of 570.0 ft; see p. 4 and figure 2 for explanation of how recession volumes were determined.

[2] Ohio Division of Geological Survey, unpublished data.

[3] Carter, 1975, p. 22.

Beaches

In stretches along the Lake County shore where there were wide (>100 ft) beaches, for example, the large beaches on the updrift (west) side of the jetties at Grand River, Mentor Harbor, and Chagrin River, within a given period the recession rate was very slow. The updrift beaches have become larger because of the structures, and a direct correlation can be made between beach size and recession rate. The recession rate updrift of each of the three large structures decreased from the 1876-1937 period to the 1937-1973 period (see tables 17, 22, and 27) because there are now larger beaches (and shallower nearshore slopes) than there were before the structures were constructed (Chagrin

River and Mentor Harbor) or were mapped (Grand River).

Nearshore slopes

Lastly, there is a correlation between gentle nearshore slopes and low recession rates. For example, in the 1876-1937 period the two easternmost reaches, which had the gentlest slopes but not necessarily the largest most continuous beaches or the most shore protection, each had a principal recession rate that was very slow; in contrast the four reaches to the west had a principal recession rate that was slow.

RECESSION RATES

The increased range in recession rates from the 1876-1937 period to the 1937-1973 period has caused the shore to become more uneven; the protected segments are characterized by headlands and the unprotected segments are characterized by embayments.

1876-1937

The principal recession rate was slow (1-3 ft/yr), and the range in recession rates was very slow (<1 ft/yr) to rapid (5-7 ft/yr) within this period. Of the three major factors (nearshore slopes, beaches, and manmade structures) directly related to wave erosion along the Lake County shore, nearshore slopes and manmade structures appear to have had the greatest effect on the variation in recession rates in this period. The gentle nearshore slopes along the two easternmost reaches helped protect the shore, and as a result these reaches had the lowest principal recession rate (very slow). Stickout structures, especially the jetties at Grand River and Mentor Harbor, in depriving the downdrift shore of sand and thereby increasing nearshore slope and reducing beach width, contributed to higher recession rates downdrift.

1937-1973

The principal recession rate was very slow (<1 ft/yr), and the range in recession rates was very slow to very rapid (7-9 ft/yr) within this period. Manmade structures appear to have had the most significant effect on wave erosion and hence recession rates in this period. In comparison to the 1876-1937 period the much greater number of structures along the shore has caused a decrease in the principal recession rate along the four westernmost reaches, although along unprotected stretches of these reaches the recession rates generally increased. This is particularly true, as it was in the 1876-1937 period, of the stretches downdrift of the Mentor Harbor and Grand River jetties.

1876-1937 to 1937-1973

The decrease in the principal recession rate and the increase in the range of recession rates from the 1876-1937 period to the 1937-1973 period can be related directly to the manmade structures; the increased number of manmade structures along most of the Lake County shore is responsible for the decrease in the principal recession rate, and the addition of a few large stickout structures and the absence of protection downdrift of these structures are responsible for the abnormal increase in the range of recession rates.

FUTURE CONSIDERATIONS

In light of the recession rates along the Lake County shore, what can be done to reduce shore erosion, particularly along the more rapidly receding stretches? There are at least two ways of looking at this question, one from a local point of view and the other from a countywide point of view.

Local considerations

Areas with shore lengths of a few hundred feet (<100 m) or less can probably be most easily protected by manmade structures, particularly if the stretch is between protected areas. The type of protection naturally will depend on the physical setting.

Countywide considerations

Stretches with shore lengths of several hundred feet (>100 m) or more can be protected by either a nonstructural method such as increasing the supply of sand along the stretch (beach nourishment) or a combination nonstructural and structural method such as increasing the supply of sand as well as building structures to retain it. The importance of sand cannot be taken lightly; wherever the recession rate increased along the shore from the 1876-1937 period to the 1937-1973 period, the increased rate could be traced to a diminished supply of sand that in turn caused an increase in the nearshore slope and a decrease in beach width.

It is noteworthy that corrective measures are being considered or are being undertaken for the two major problem areas along the Lake County shore—the stretch downdrift of the Mentor Harbor jetties and the stretch downdrift of the Grand River jetty-breakwater complex. Sand dredged from the Mentor Harbor entrance is now being deposited on the east (downdrift) side; this should reduce the recession rate downdrift of the structures by putting more sand into the longshore drift system. However, this procedure will need to be carried out on a regular basis to insure a continuous supply of sand. The Buffalo District office of the U.S. Army, Corps of Engineers has undertaken a study of the Grand River area at the request of the Ohio Department of Natural Resources. The Corps is authorized under section 111 of Public Law 483, U.S. 90th Congress, to

> investigate, study, and construct projects for the prevention or mitigation of shore damages attributable to Federal navigation works. The cost of installing, operating, and maintaining such projects shall be borne entirely by the United States. No such project shall be constructed without specific authorization by Congress if the estimated first cost exceeds $1,000,000 . . . (U.S. Dept. of the Army, 1970, Appendix 1, p. 1-9).

It is hoped that within the next few years a solution can be worked out to reduce the effect of the Grand River jetty-breakwater complex on the downdrift shore.

If one assumes that the Lake County shore will one day be reasonably well protected from storm waves, there will then be another problem—that of beach sand. Evidence points to the shore as the source of the sand in the longshore drift system (Carter, 1975, p. 2); if the natural supply is not maintained by recession and the sand in the longshore drift system continues to be transported along the shore to the east, then the beaches will decrease in size, the nearshore slope will increase, and the shore will be subjected to greater wave energy. Therefore, if by protecting the shore we lose the source of the sand, but we want beaches and gentle nearshore slopes for shore protection as well as for recreational pursuits, then we are going to have to either recycle the sand that we are now trapping, perhaps within cells defined on the downdrift side by major stickout structures, or nourish our beaches with sand from an outside source, presumably offshore deposits.

Last but not least in any consideration of solutions for shore protection is lake-level regulation. A decrease in the level of the lake would reduce the amount of wave energy reaching the shore; the greater the decrease in lake level, the greater the decrease in wave energy reaching the shore. Perhaps in the distant future, if shoreland becomes dear enough and lake sedimentation becomes a tangible problem, this solution will be considered with the others to help protect the Lake County shore as well as the entire Lake Erie shore.

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APPENDIX.–STRUCTURE INVENTORY OF LAKE COUNTY (1970)

The following symbols are used in the table below to describe the types and compositions of the structures along the shore of Lake Erie in Lake County:

Type of structure

B	breakwater	LG	L-groin
G	groin	P	pier
GF	groin field	R	ramp
G/B	groin/breakwater	S	seawall
G/S	groin/seawall	TG	T-groin
J	jetty		

Composition

1	concrete	8	steel sheet pile
2	concrete pile	9	steel sheet pile cells
3	concrete block	10	concrete rings
4	timber pile	11	steel plate crib
5	timber crib	12	concrete cone and wedge
6	stone block	13	Armco bin-type crib
7	stone rubble	14	gabion

Please note:

Type of structure, number preceding letter indicates the number of structures if more than one are present. *Elevation,* measurements are to the nearest 0.5 ft above Low Water Datum (LWD) for Lake Erie; LWD = 568.60 ft above the 1955 International Great Lakes Datum (IGLD). Average Lake Erie level during the period of structure inventory (1970) was 3.0 ft above LWD. Elevations given for G/S combinations are for highest shore and lowest lake points of entire structure. *Width/length,* measurements for G/B combinations are B measurements only; measurements for G/S combinations are G measurements unless otherwise indicated; where two distances are given for groin length, the second number indicates length of T or L.

Structure 192f was too far offshore to be considered as a shore protection structure and was omitted in the table.

Structure number	Type of structure	Composition	Elevation (ft above LWD)		Width/length (ft)	Condition	Construction date	U.S. Army Corps of Engineers number	Remarks
			Shore	Lake					
1	5 G/B	6	3.0	2.0	5/100	fair	pre-1950	XI-57	
2	S	1	7.0		2/150	good	post-1950		
3	G	1	3.0	3.0	4/40	good	1962		
4	12 G/B	6	3.0	2.0	5/240	fair	pre-1950	XI-58	
5	P	1	5.0	3.0	4/35	fair	1962		
6	S		4-6.0		-/450	poor-good	post-1950		different heights and materials
7	S	1, 6	10.0		7/250	fair-good	pre-1950	XI-59	
8	G	1	5.0	3.0	1/30	good	post-1950		filled
9	5 GF	12	4.5	2.5	5/40	good	post-1950		filled
10	B	6		2-3.0	6/600	poor-fair	pre-1950	XI-60	
11	G	1	5.0	3.5	6/60	good	post-1950		filled
12	J	3, 6	5.5	3.0	5/80	fair	post-1950		twin jetties at creek mouth
13	6 GF	5			6/40		pre-1950	XI-61	not found in 1970
14	2 G	1	4.5	3.5	1/110	good	post-1950		outflanked
15	G	5			6/100		pre-1950	XI-62	not found in 1970
16	3 GF	5			6/50		pre-1950	XI-63	not found in 1970
17	2 G	1	5.0	2.0	1/40	fair	post-1950		outflanked
18	G	1, 6	4.0		1-5/40	poor	pre-1950	XI-64	outflanked
19	P	1			15/30		pre-1950	XI-65	not found in 1970
20	G	1	3.0	2.0	3/30	poor	post-1950		
21	G	8	3.0	3.0	-/30±	poor	post-1950		outflanked
22	3 GF	5			6/50		pre-1950	XI-66	not found in 1970
23	G	1	4.5	4.0	2/20	good	post-1950		filled
24	P	1				poor	post-1950		
25	7 G/B	1, 6	2-5.0		-/350	fair-good	pre-1950	XI-67	concrete seawall built at base of bluff in 1969; 4 shore returns
26	S	3	4.0		5/100		pre-1950	XI-68	not found in 1970
27	12 G/B	6	2.0	2.0	5/370	poor	pre-1950	XI-69	
28	4 GF/S	3	3.5	3.0	5/30	poor	pre-1950	XI-70	
29	J	8	9.0	5.5	1/60	good	post-1950		filled
30	P/S	1, 8	6.0		15/40	good	pre-1950	XI-71	

Structure number	Type of structure	Composition	Elevation (ft above LWD)		Width/length (ft)	Condition	Construction date	U.S. Army Corps of Engineers number	Remarks
			Shore	Lake					
31	G	1	5.0	3.0	4/30	good	post-1950		filled
32	3 GF/S	1			2/25		1948	XI-72	not found in 1970
33	2 G	3	4.0	3.5	4/40	good	pre-1950	XI-73	partially filled
34	2 TG	1	5.0	3.0	3/40, 30	fair-poor	pre-1950	XI-75	east groin not found in 1970
35	S	1	5-6.0		2/285	poor	1929	XI-74	modified in 1965
36	3 G/B/S	1	6.0	3.0	G 2/30 S 2/750	fair-good	1929	XI-76-80	filled; modified in 1965
37	2 G	5			4/40		pre-1950	XI-81	not found in 1970
38	J	8	9.0	6.0	1/82	good	post-1950		twin jetties 25 ft apart
39	G	1	6.0	3.0	5/60	fair	post-1950		partially filled
40	G/S	5			6/50		pre-1950	XI-82	not found in 1970
41	B	1	6.0	3.0	1-3/60	poor-fair	pre-1950	XI-83	
42	G	5			8/40		pre-1950	XI-84	not found in 1970
43	G/S	1, 6	6.0	3.0	G 5/50 S 5/150	G-good S-poor	pre-1950	XI-85	
44	2 G	5			6/50		pre-1950	XI-86	not found in 1970
45	G	1, 4			4/20		pre-1950	XI-87	not found in 1970
46	G	1, 4	4.0	2.0	5/50	poor	pre-1950	XI-88	
47	G	5, 1			4/100		pre-1950	XI-89	not found in 1970
48	G	5, 7			4/100		pre-1950	XI-90	not found in 1970
49	7 GF	1	6.0	4.0	5/20-30	good	1962		filled; groins tied to 200-ft concrete seawall
50	3 GF	5			4/30		pre-1950	XI-91	not found in 1970
51	7 GF	1	6.0	4.0	3/30	good	1958		filled; groins tied to cone seawall
52	B	1					pre-1950	XI-92	not found in 1970
53	S	13			-/30		1950	XI-93	not found in 1970
54	G	5, 1			3/50		pre-1950	XI-94	not found in 1970
55	S	1			3/150		pre-1950	XI-95	not found in 1970
56	S	13			-/50		pre-1950	XI-96	not found in 1970
57	G	5, 1			5/40		pre-1950	XI-97	not found in 1970
58	4 GF	6			5/20-150		pre-1950	XI-98	not found in 1970
59	B/S	1, 6	3.0	2.0	3/450	poor	pre-1950	XI-99	
60	9 GF/S	1, 3	4.0	2.0	G 4/30 S 4/300	fair-good	post-1950		filled
61	B	1			-/40		pre-1950	XI-100	not found in 1970
62	S	1			2/100		pre-1950	XI-101	not found in 1970
63	S	7			-/80	fair	post-1950		
64	G/P	1	6.0	4.0	2/25	good	post-1950		filled
65	TG	8	6.0	6.0	1/140, 30	good	post-1950		
66	TG	8			1/140, 30	good	post-1950		
67	B	1			3/1,600		pre-1950	XI-102	structure removed
68	J	9			30/1,080, 1,280	good	post-1950		twin jetty intake-outfall structure; holds large beach to west
69	S	8	9.0		-/1,000	good	post-1950		
70	J	8	7.0		16/150	good	1947		
71	see remarks				-/1,500	poor	post-1950		entire shoreline fronted by rubble
72	G	5			4/30		pre-1950	IX-3	not found in 1970
73	J	8	9.0	6.0	1/78	good	post-1950		twin jetties 20 ft apart
74	S	1	8.0		1/150	poor	post-1950		not completed
75	2 G	6			4/30		pre-1950	IX-4	not found in 1970
76	2 G/S	8, 6	7.0	6.0	G 10/10 S -/165	good	1924	IX-5	modified in 1970
77	2 G	6			8/30		pre-1950	IX-6	not found in 1970
78	3 G	1			10/20		post-1950		buried below sand beach
79	G/B	6	4.0	3.0	6/60	good	1966-67		
80	J	8	6.0	6.0	1/52	good	post-1950		twin jetties 20 ft apart; filled
81	3 GF	6	4.0	3.0	6/30	good	post-1950		filled
82	6 GF	1			6/30		pre-1950	IX-7	not found in 1970
83	S	1			1/380		pre-1950	IX-8	not found in 1970
84	S	1	7.0		2/280	good	pre-1950	IX-9	
85	4 GF	6			4/10-30	good	pre-1950	IX-10	

Structure number	Type of structure	Composition	Elevation (ft above LWD)		Width/length (ft)	Condition	Construction date	U.S. Army Corps of Engineers number	Remarks
			Shore	Lake					
86	S	1, 6	8.0		9/460	fair-good	1928	IX-12	
87	12 GF	6			4/20		1928	IX-11	not found in 1970
88	B	4			-/250			IX-13	not found in 1970
89	G	6					pre-1950	IX-14	not found in 1970
90	G	1			6/40		pre-1950	IX-15	not found in 1970
91	TG	1	6.0	4.0	3/60, 18	good	post-1950		filled
92	G	6			4/30		1922	IX-16	not found in 1970
93	G	1	6.0	6.0	4/35	good	post-1950		filled
94	G	6	4.0	3.0	5/50	fair	1925	IX-17	partially filled
95	G	1	2.0	2.0	7/70	poor-fair		IX-18	partially filled
96	G/S	1, 6				poor	post-1950?		
97	G	6	5.0	2.0	6/30	poor	post-1950		partially filled
98	G	3	6.0	4.5	9/40	poor-fair	post-1950		partially filled; outflanked
99	S	1			2/50	poor	1927	IX-19	
100	G	1			6/30		1927	IX-20	not found in 1970
101	G	6	3.5	2.5	4/12	poor	post-1950		partially filled
102	2 G	1	2.5	2.5	6/30	poor	post-1950		outflanked
103	G	5			6/40		1922	IX-21	modified in 1946; not found in 1970
104	S	1			2/60	poor	post-1950		
105	G	6	5.5	2.0	6/50	poor	post-1950		partially filled
106	G	1	7.0	4.0	3/25	fair	post-1950		filled
107	G	1	6.5	3.0	8/60	fair	pre-1950	IX-22	partially filled
108	G	1	5.0	4.0	8/60	good	pre-1950	IX-23	filled
109	G	1	5.0	4.0	4/20	good	post-1950		filled; tied to concrete seawall
110	G	1	6.0	4.0	8/40	good	pre-1950	IX-24	filled
111	3 GF	6			4/30		pre-1950	IX-25	not found in 1970
112	S	3	15.0		1/80	good	1967		modified in 1970
113	S	6	11.0		-/70	good	post-1950		
114	G	3	6.0	4.0	3/30	poor-fair	post-1950		filled
115	S	1, 3, 6, 7			-/100	poor-fair	post-1950		
116	G	1	4.0	2.0	3/20	fair	post-1950		filled
117	S	1	9.0		2/100	fair	1926	IX-26	
118	7 GF	6	5.0	3.5	6/30+	poor-good	1926	IX-27	
119	S	1	5.0		1/300	poor	1926	IX-28	
120	S	7			-/80	fair	post-1950		
121	6 GF	1	4.0	2.5	1/20	fair-good	1967		filled
122	S	14	2-4.0		3/75	good	1968-69		
123	S	1	6.0		2/200	good	post-1950		
124	10 GF	1	3.5	2.5	1/20	good	1967		
125	G	1	3.5	3.5	6/18	good	post-1950		filled; outflanked
126	G	1	4.0	4.0	6/12	good	post-1950		filled; outflanked
127	G	1	4.0	3.0	3/20	fair	post-1950		partially filled
128	S				-/340	poor	post-1950		rubble
129	6 GF	1	4.5	4.5	2/24	good	1968		filled; outflanked
130	2 G	5	4.0	4.0	8/40	good	1968-69		filled
131	5 GF	1	4.0	3.0	3/20	fair	1968-69		filled
132	4 GF	5	5.0	3.0	8/32	fair	1969		outflanked
133	G	2			-/150		pre-1950	IX-29	not found in 1970
134	S	1	7.0		2/300	fair	1968		
135	3 GF	5	5.0	4.0	8/32	good	1969		placed along front of graded and seeded bluff with timber crib seawall
136	G	5		1.0	8/24	poor	post-1950		outflanked
137	S	1	4-6.0		1/120	poor	1931		
138	5 GF	1	5.0	3.5	6/20-60	fair-good	1931	IX-31	repaired in 1953; partially filled
139	S	1	7.0		-/300	fair-good	pre-1950	IX-30	
140	S	8	7.0		1/126	good	1969		
141	G	5	5.0	4.0	8/40	fair	post-1950		partially filled
142	G	1			3/20		pre-1950	IX-32	not found in 1970
143	3 GF	1			4/60		pre-1950	IX-33	not found in 1970
144	3 GF	5			5/40		pre-1950	IX-34	not found in 1970
145	J	8	8.0		18/400	good	1931	IX-35, 36	twin jetty harbor structure; holds large beach to west

Structure number	Type of structure	Composition	Elevation (ft above LWD)		Width/length (ft)	Condition	Construction date	U.S. Army Corps of Engineers number	Remarks
			Shore	Lake					
146	2 G	4			-/100		pre-1950	IX-41	not found in 1970
147	G	8	3.5		-/200	poor	pre-1950	IX-42	outflanked
148	B	6			-/200		pre-1950	IX-43	not found in 1970
149	4 GF	6	5.0	3.0	6/50-120	fair-good	pre-1950	IX-45	
150	S	6	5.0		6/80	good	pre-1950	IX-44	
151	G	1	4.5	3.5	4/25	good	post-1950		filled
152	2 G	1	4.0	5.0	4/40	fair-good	post-1950		partially filled; outflanked
153	2 G	1	4.5	2.0	1/70	fair	post-1950		
154	S	1	7.0		-/60	fair	post-1950		
155	3 GF/S	1	6.0	3.0	1/35	fair	post-1950		
156	TG	1	5.0	3.5	4/30, 10	poor	post-1950		outflanked
157	G	1	5.0	3.0	4/52	good	post-1950		filled
158	G	1			3/30		1945	IX-46	not found in 1970
159	S	1, 3	5.0		-/100	poor	pre-1950	IX-47	
160	G	1			5/50	poor	pre-1950	IX-48	
161	3 GF	5, 1	5.0	4.0	8/20	good	1945	IX-49	partially filled
162	4 GF	5	5.0	5.0	8/8	fair	post-1950		outflanked
163	S	1	6.5		2/340	poor	post-1950		
164	TG	1	5.0	3.0	2/25	poor	pre-1950		
165	2 G, S	1	6.0	2.0	G 2/40 S 2/40	poor	post-1950	IX-50	
166	2 G	1	4.0	2.0	1/30	poor	post-1950		partially filled; outflanked
167	5 GF	6	5.0	2.0	6/50	fair	1946	IX-51	
168	S	1, 3	4.0	3.0	2/150	poor	1946	IX-52	
169	G	1, 4			-/100		pre-1950	IX-53, 54	not found in 1970
170	11 GF	1			1/28-35	fair-good	1957		filled
171	G/B/S	1, 6			G 3/20-50 S 2/100		1946	IX-55-58	not found in 1970
172	4 GF	1	4.0	3.0	1/40	good	post-1950		filled
173	G	1			3/60		pre-1950	IX-59	not found in 1970
174	G	1	4.0	3.0	4/35	good	post-1950		filled
175	2 G	1	6.0	1.5	4/40	fair-poor	pre-1950	IX-60	filled
176	G	1	7.0	4.0	5/60	good	1946	IX-61	modified in 1970; filled
177	G	1	7.0	1.5	3/55	fair	post-1950		filled
178	G	1	6.0	2.0	6/20	fair	post-1950		filled
179	G	1	6.5	3.0	6/20	good	pre-1950	IX-62	filled
180	G/P	1	4.5	3.0	8/38	poor	pre-1950	IX-63	filled
181	2 G	1	6.0	3.0	3/20	fair	1947	IX-64	outflanked
182	4 GF	1	5.0	2.0	1/30	fair	post-1950		outflanked
183	3 G/S	1, 10	3.0	3.0	8/60	poor	post-1950		
184	G	1	5.5	1.5	1/70	good	1955		filled
185	G	1	5.0	2.0	3/30	good	1955		
186	2 G	1			3/30		pre-1950	IX-65	not found in 1970
187	G	5, 7	3.0	2.0	5/30	poor	1929		
188	B	6, 7	10.5		10/1,500	good	1908	IX-66	structures 188 to 192b are part of the Grand River jetty-breakwater complex; these structures have trapped an enormous quantity of sand to the west
189	B	6, 7	10.5		10/1,040	good	1911	IX-69	
190	B	6, 7	10.5		10/840	good	1901	IX-67	
191	B	9, 1	8.5		30/500	good	1936	IX-68	
192	B	6, 7	8.3		10/6,750	good	1914	IX-70	
192a	J	1, 9	8.0		-/500	fair-good	1827	III, VII, XII-73	rebuilt in 1941
192b	J	1, 8	8.3		-/580	fair-good	1827	III, VII, XII-74	rebuilt in 1941
192c	S	7			-/340	fair-good			
192d	G	5			-/70	fair-good			
192e	S	7			-/180	fair-good			
192g	S	7			-/240	fair-good			
192h	B	1, 8	3.5		-/730	fair-good	1939-1943	III, VII, XII-2	
192i	B	9, 7	3.5		-/4,000	see remarks	1939-1943	III, VII, XII-2	condition varies from ruins to good; in 1938, beach protected by 2 groins, a groin/breakwater, 3 groin fields, and a second groin/breakwater

Structure number	Type of structure	Composition	Elevation (ft above LWD)		Width/length (ft)	Condition	Construction date	U.S. Army Corps of Engineers number	Remarks
			Shore	Lake					
192j	6 GF	6			-/80	ruins		III, VII, XII-4, 5, 6, 7, 8	
192k	G/B	6			80/500	ruins		III, VII, XII-9, 10, 11	
192l	G	6			3/50	ruins		III, VII, XII-12	not located on aerial photo
192m	B	6			-/200	ruins		III, VII, XII-13	
192n	B	9	2.0		-/210	fair-good			
193	LG	6	4.0	3.0	6-10/80	poor	pre-1950	III-14	
194	TG	6	4.0	2.0	6/90, 40	poor	pre-1950	III-15	outflanked
195	TG	6	4.0	2.0	6/70, 50	poor	pre-1950	III-16	outflanked
196	G	1, 3	8.0	7.0	5/120	good	1950		a groin/breakwater existed prior to 1950
197	B	6			6/330		pre-1950	III-17	not found in 1970
198	G	3	7.0	2.0	4-10/85	good	post-1950		
199	G	6	4.0	2.5	8/88	fair	pre-1950	III-18	
200	G	1			2/20		pre-1950	III-19	not found in 1970
201	G	1			2/20		pre-1950	III-20	not found in 1970
202	B	6			4/50		pre-1950	III-21	not found in 1970
203	24 GF	1, 6	4-5.0	3-2.0	2-5/25	fair	pre-1950	III-22-46	
204	G	1, 6	6.9	5.5	6/45	fair	pre-1950	III-47	outflanked
205	LG	1, 6	5.0	3.0	4/50, 10	poor	pre-1950	III-48	outflanked
206	G	1, 6	6.0	4.0	8/80	poor	pre-1950	III-49	outflanked
207	B	1, 3, 6	5.0		16/65	fair	pre-1950	III-50	
208	J	1	4.0	4.0	2-3/55-10	good	pre-1950	III-51, 52	twin jetties; partially filled
209	G	1, 6	3.5	5.0	5/50	poor	pre-1950	III-53	outflanked
210	TG	1, 6	3.5	2.5	4/40, 25	poor	pre-1950	III-54	outflanked
211	B	6			3/100		pre-1950	III-55	not found in 1970
212	G	1	6.0	5.0	8/45	fair-good	pre-1950	III-56	outflanked
213	S	6			5/3,000		pre-1950	III-57	not found in 1970
214	120 GF	6	3.5	3.5	5/35	fair	pre-1950	III-58	sixteen groins found; remainder either buried by beach or below water level
215	J	8	4.0		20/170+	good	1937	III-59	filled
216	G	1	4.5	3.0	8/45	good	post-1950		filled
217	G	1	4.0	4.0	6/40	good	post-1950		filled
218	G	1, 3	4.5	3.0	4-8/16	good	post-1950		
219	G	1	4.5	4.0	6-16/55	good	post-1950		filled
220	G	1, 3	4.0	3.0	3-5/35+	fair	pre-1950	III-60	modified in 1970; filled
221	S/P	3	4.0	2.5	8/100	fair-poor	pre-1950	III-61	
222	S	6			-/150		pre-1950	III-62A	not found in 1970
223	G	1			1/30		pre-1950	III-62	not found in 1970
224	G	1			4/20		pre-1950	III-63	not found in 1970
225	G	3	3.0	3.0	4/40	poor	post-1950		
226	G	3	3.5	3.0	4/50	poor	post-1950		
227	G	1			2/30		pre-1950	III-64	not found in 1970
228	G	3	3.0	3.0	4/40	poor	post-1950		outflanked
229	G/P	6	3.5	3.0	4/40	poor	pre-1950	III-65	
230	G	3	3.5	3.0	4/30	poor	pre-1950	III-66	outflanked
231	S	10	3.0	3.0	5-10/170	poor	post-1950		outflanked
232	R/G	1, 10	6.0	1.5	20/35	fair	post-1950		
233	S	8	8.0	8.0	-/140	good	post-1950		
234	J	8	7.0	7.0	20/150	good	post-1950		double-walled intake jetty; filled
235	2 G	1	5.0	3.5	2/35	fair	post-1950		outflanked
236	3 GF	1	4.0	2.5	2/35	poor	post-1950		outflanked
237	G	1	3.0	3.0	5/35	poor	post-1950		outflanked
238	G	1	3.0	3.0	5/30	poor	post-1950		outflanked
239	G	1	3.5	2.5	1/20	poor	post-1950		outflanked, but filled
240	G	1	4.0	2.0	3-5/35	poor	post-1950		outflanked, but filled
241	3 GF	1	4.0	2.0	1/30	poor	post-1950		outflanked
242	B	6, 7	6.0		12/230	poor-fair	1935	III-67, 67A	
243	B	6, 7			8/200		pre-1950	III-67B	not found in 1970
244	B	6, 7			6/70		pre-1950	III-68	not found in 1970
245	B	6, 7	4.0	1.5	6/100	poor	pre-1950	III-68A	

Structure number	Type of structure	Composition	Elevation (ft above LWD)		Width/length (ft)	Condition	Construction date	U.S. Army Corps of Engineers number	Remarks
			Shore	Lake					
246	B	6	3.0	3.0	4/100	poor	pre-1950	III-69	
247	G	5, 7			5/50		pre-1950	III-70	not found in 1970
248	G	6			4/70		pre-1950	III-71	not found in 1970
249	G	1, 6			4/30		pre-1950	III-72	not found in 1970
250	2 G	1	5.5	3.5	5/40	poor-fair	post-1950		outflanked
251	2 G	1	4.0	3.0	1/35	poor-fair	1955		outflanked
252	G	1			3/30		pre-1950	XII-73	not found in 1970
253	S	1			1/100		pre-1950	XII-73A	not found in 1970
254	P	1			4/4		pre-1950	XII-74	not found in 1970
255	3 G	10	6.0	2.0	5/25	poor-fair	post-1950		
256	G	5, 7			5/70		pre-1950	XII-75	not found in 1970
257	3 GF	1	4.5	2.5	1/24-40	poor	pre-1950	XII-76	outflanked, but filled
258	S	12	5.0		-/100	good	post-1950		
259	2 G	1	6.0	3.5	1/50	good	post-1950		filled
260	P	1				poor	pre-1950	XII-77	
261	6 GF	1, 5	5.5	3.0	4/40	fair	post-1950		filled
262	S	1	5.5		2/100	good	pre-1950	XII-78	
263	G	6	4.0	4.0	6/150	fair	pre-1950	XII-79	
264	G	3	5.0	3.5	8/140	good	1945	XII-80	filled
265	G	1	5.0	3.5	8/120	good	1945	XII-81	filled
266	G/P	3	5.0	4.5	4-8/70	good	1945	XII-82	filled
267	G	1			4/40		pre-1950	XII-83	not found in 1970
268	S	1	9.6		2/80	good	pre-1950	XII-84	
269	S	1	6.6		3/70	fair-good	pre-1950	XII-85A	
270	G	1	5.0	4.0	4/45+	good	1929	XII-85	filled
271	G	5, 1	6.0	5.0	5/50	fair-good	pre-1950	XII-86	filled
272	S	1	7.6		2/130	good	pre-1950	XII-86A	
273	G	1, 3	6.5	5.0	10/65+	good	pre-1950	XII-87	filled
274	TG	1, 3	5.5	4.0	4/60, 8	good	pre-1950	XII-88	
275	G	11, 1	8.0		12/50	good	pre-1950	XII-89	
276	S	13	10.5		1.5/75	good	pre-1950	XII-89A	
277	S	1	9.5		1.5/120	good	pre-1950	XII-89B	
278	G	1	6.0	4.0	3/80	good	pre-1950	XII-90	
279	S	1	8.6		1/100	good	pre-1950	XII-90A	
280	G	1	5.0	4.0	2.5/40	good	pre-1950	XII-91	filled
281	S	1	4.6		1/100	fair-good	pre-1950	XII-91A	
282	G	1	5.0	4.0	2.5/50	fair	pre-1950	XII-92	partially filled
283	S	1	8.5		1/100	fair-good	pre-1950	XII-92A	
284	G	1	5.0	3.5	2.5/60	good	pre-1950	XII-93	filled
285	S	1	8.5		1/100	fair-good	pre-1950	XII-93A	
286	G	1, 5	5.0	4.0	2.5/60	good	pre-1950	XII-94	filled
287	S	1	4.5		1/60	fair-good	pre-1950	XII-94A	
288	G	1	5.0	3.5	3/40	good	pre-1950	XII-95	filled
289	G	1	6.0	3.5	4/60	good	pre-1950	XII-96	filled
290	S	1	9.5		1/50	good	pre-1950	XII-96A	
291	G	1	5.5	3.5	3/45	good	pre-1950	XII-97	filled
292	G	1	8.0		5/50	good	post-1950		
293	G	1			8/15		pre-1950	XII-98	not found in 1970
294	G	1	5.5	4.0	3/50	good	pre-1950	XII-99	
295	4 GF	1	7.0	4.0	3/12	good	post-1950		
296	S	1	9.4		1/150	good	pre-1950	XII-100	
297	3 GF	1	5.5	3.0	1.5/30	good	post-1950		filled
298	S	1	7.0		2/220	good	pre-1950	XII-101	
299	S	1	7.0		2/100	poor	pre-1950	XII-101	
300	S	1	7.0		2/130	good	pre-1950	XII-101	
301	G	1	6.0		1/25	fair-good	post-1950		filled
302	S	1	9.5		1/100	good	pre-1950	XII-102	
303	3 GF	1	5.0	3.0	1/40	fair-good	post-1950		
304	G	1	4.5	2.0	1/30	good	pre-1950	XII-103	partially filled
305	S	1	9.0		1/70	good	pre-1950	XII-103A	
306	G	1	4.5	2.0	1/50	good	post-1950		partially filled
307	S	4, 5	9.0		1/120	fair	pre-1950	XII-104	
308	S	1	9.0		1/100	good	1948	XII-105	

Structure number	Type of structure	Composition	Elevation (ft above LWD)		Width/length (ft)	Condition	Construction date	U.S. Army Corps of Engineers number	Remarks
			Shore	Lake					
309	2 G	1	4.5	2.5	1/35	good	post-1950		
310	S	3	9.5		1/75	fair	pre-1950	XII-106	
311	S	1	7.5		1.5/250	good	1948	XII-107	
312	5 GF	1	5.0	2.5	1/20	poor	post-1950		
313	G	1	3.5	2.0	1/40	good			
314	S	5	11.0		-/70	fair	pre-1950	XII-108	
315	G	10	3.0	2.0	8/15	poor-fair	post-1950		
316	S	3	7.5		1/100	fair	pre-1950	XII-109	
317	S	1	8.0		1/225	good	1948	XII-110	
318	3 GF	12	4.0		3/20	fair	post-1950		
319	TG	1	8.0	7.5	8/80, 11	good	pre-1950	XII-111	filled
320	S	5	8.0		-/100	fair-good	pre-1950	XII-111A	
321	P	1	6.5		20/20	fair-good	pre-1950	XII-112, 113	
322	G	5, 7	7.0	4.5	8/48	poor	1950		
323	G	1	6.0	6.0	10/40	good	1955		outflanked
324	G	5			6/30		pre-1950	XII-114	not found in 1970
325	G	1	4.5	3.5	4/25	good	1955		filled
326	LG	1	5.5	5.5	10/50, 22	good	1955		
327	G	5			6/30		pre-1950	XII-115	not found in 1970
328	TG	5	5.5	5.5	7/51, 38	poor	1953		
329	G	1	5.0	5.0	12/23	good	1955		
330	R/G	1, 8	5.0	1.0	50/80	good	post-1950		
331	TG	5, 7	5.0	4.0	9/35, 27	poor	post-1950		
332	G	5, 7	5.0	4.0	9/59	poor	post-1950		
333	5 GF	1	6.0	2.0	1/50	fair-good	post-1950		
334	G	10	4.0	3.0	5/30	poor	post-1950		
335	G/B	3	5.0		3/200	good	post-1950		
336	G/B	5			4/60		pre-1950	XII-116, 116A	not found in 1970
337	S	1			1/450		pre-1950	XII-117	not found in 1970
338	TG	1	5.0	3.5	5/100, 20	fair	post-1950		
339	G	1			2/20		pre-1950	XII-118	not found in 1970
339a	see remarks							XII-119	no information available
340	G	1	7.0	7.0	4/50	good	pre-1950	XII-120	partially filled
341	S	1	11.0		1/60	good	pre-1950	XII-120A	
342	4 GF	1	7.5	4.5	3/44	good	post-1950		
343	2 G	3	5.5	3.0	8/54	good	1948	XII-121, 122	filled
344	2 G	1	5.0	4.0	2/42	good	post-1950		filled
345	5 GF	3	7.0	4.5	5/30	good	post-1950		
346	2 G	1	7.0	3.0	1.5/40	good	post-1950		filled
347	2 G	1	5.0	3.0	3/18	good	post-1950		filled
348	S	1	11.0		1.5/550	good	pre-1950	XII-123	
349	2 G	1	5.0	3.0	1/45	fair	post-1950		filled
350	S	1	9.5		1/200	good	pre-1950	XII-124	
351	2 G	1	5.0	3.0	1/50	fair	post-1950		filled
352	5 GF	1	5.0	3.0	1/50	fair	post-1950		filled
353	P/G	1	3.0	3.0	2.5/30	fair	post-1950		
354	G	5						XII-125	not found in 1970
355	LG	1	9.0	4.5	1.5/35, 16	good	post-1950		filled
356	G	3	7.0	5.5	6/42	good	post-1950		filled
357	2 G	1	7.0	7.0	4/20	good	pre-1950	XII-126, 127	
358	S	1	10.0		3/40	good	pre-1950	XII-126A	
359	G	3	4.5	3.0	3/18	poor	post-1950		filled
360	G	3	4.5	2.5	3/18	poor	post-1950		filled
361	S	3	3.0		3/120	poor	post-1950		
362	G	3	5.0	2.5	3/44	fair	post-1950		
363	G	3	5.0	3.0	3/40	fair	post-1950		
364	G	1	4.5	4.0	3/20	fair	pre-1950	XII-128	
365	G	1	4.5	4.0	3/20	good	pre-1950	XII-129	
366	S	1	11.5		1/90	good	pre-1950	XII-128A	
367	G	1	5.0	4.0	3.5/25	good	post-1950	XII-130	partially filled
368	G	1	5.0	4.0	3.5/30	good	post-1950		
369	G	1, 8	6.0	3.5	2.5/44	good	1960		
370	G	1, 8	6.0	4.5	3.5/40	good	1960		

Structure number	Type of structure	Composition	Elevation (ft above LWD)		Width/length (ft)	Condition	Construction date	U.S. Army Corps of Engineers number	Remarks
			Shore	Lake					
371	B	3	4.0	4.0	4/80	poor	post-1950		
372	G	1	5.0	2.0	2/40	good	post-1950		filled
373	G	1	5.0	3.0	2/44	good	post-1950		filled
374	S	1, 3	5-9.0		2/80	good	post-1950		
375	G	1	5.0	3.5	3/34	fair	post-1950		filled
376	S	1, 3	5-10.0		2/120	good	post-1950		
377	G	1	4.0	3.0	1/40	good	post-1950		filled
378	G	1	4.0	3.0	2/50	good	post-1950		filled
379	G	1	4.0	3.0	1/60	good	post-1950		filled
380	G	1	4.5	3.5	1/60	good	post-1950		filled
381	G	1	4.0	3.5	1/60	good	post-1950		filled
382	G	1	4.0	3.0	1/50	good	post-1950		filled
383	G	6			5/20			XII-131	not found in 1970
384	G	6			5/20			XII-132	not found in 1970
385	S	8	9.5		200	good	pre-1950	XII-131A	
386	S	1, 3	3.5	3.5	3/600	fair-good	post-1950		
387	G	8	7.1		4/20		pre-1950	XII-133	not found in 1970
388	G	6			5/20		pre-1950	XII-134	not found in 1970
389	TG	1	2.0	2.0	3/75, 20	poor	post-1950		outflanked
390	TG	1	2.0	2.5	3/50, 12	poor	post-1950		outflanked

Contours on bedrock surface by Joel D. Vormelker

Cartographer: Donald R. Camburn

575 — Contour on bedrock surface, contour interval 25 feet

(23) Range location

2 1.5 1 .5 0 1 2 miles

2 1.5 1 .5 0 1 2 kilometers

CONTOUR INTERVAL 10 FEET

DOTTED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES AND SOUNDINGS IN FEET - DATUM IS LOW WATER 570.5 FEET

BASE COMPILED FROM THE FOLLOWING 7½-MINUTE U.S. GEOLOGICAL SURVEY TOPOGRAPHIC QUADRANGLE MAPS:

Eastlake	Mentor
Madison	Painesville
Mayfield Heights	Perry

PLATE 1. MAP OF LAKE COUNTY SHORE SHOWING ELEVATION OF BEDROCK SURFACE

R-1 Range 1 (see plate 1 for locations of ranges)

Sand

Laminated clay

Till

Laminated clay smears

CHC Stratigraphic section measured by C. H. Carter

DSF Stratigraphic section measured by D. S. Fullerton

DWG Stratigraphic section measured by D. W. Gordon

HJP Stratigraphic section measured by H. J. Pincus

LLB Stratigraphic section measured by L. L. Braidech

PRS Stratigraphic section measured by P. R. Shaffer

50 ft

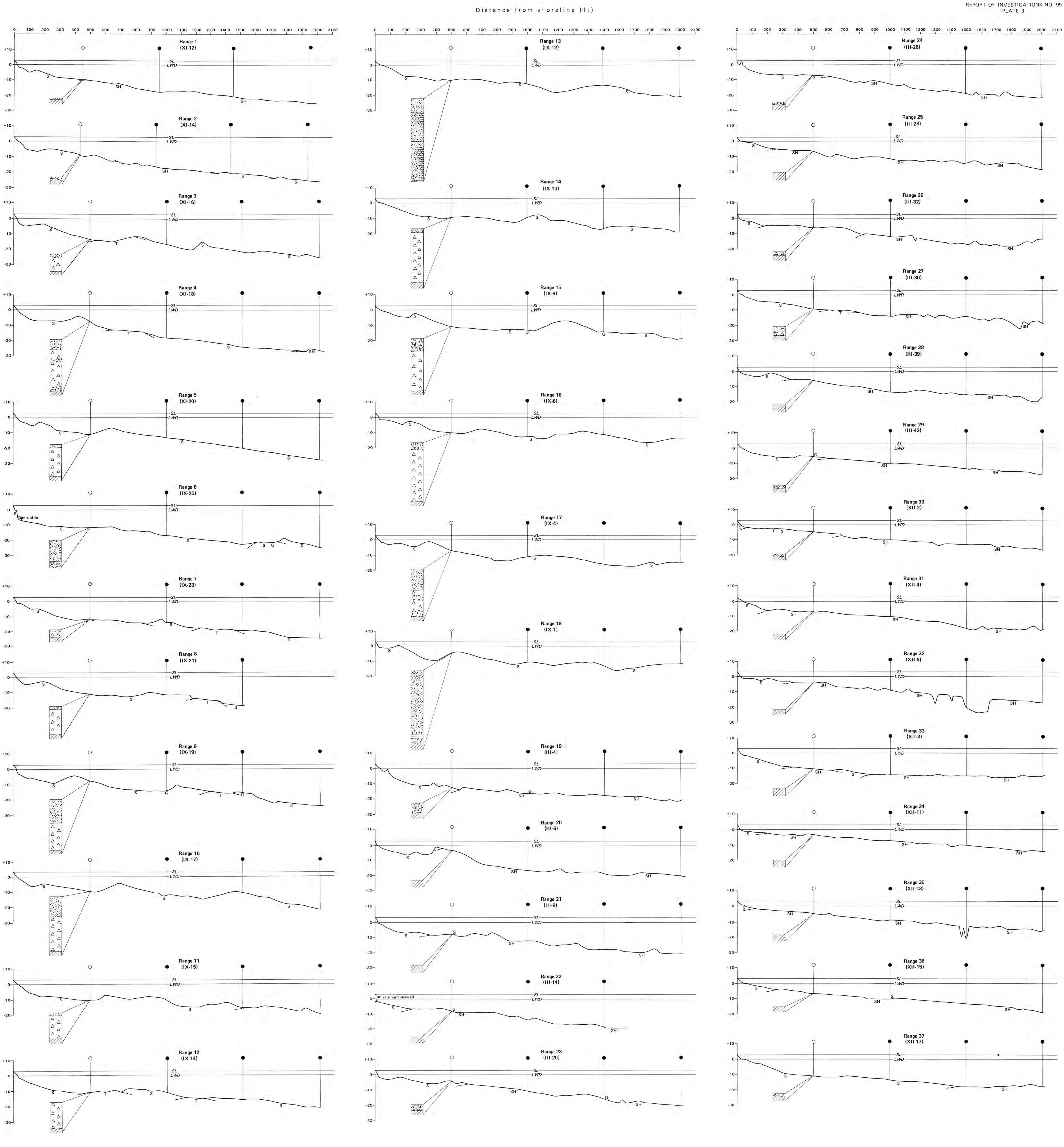
2000 ft

0 .5 1 kilometer

Datum is 570.0 ft above IGLD (1955)

Cartographer: Donald R. Camburn

PLATE 2. CROSS SECTION OF SHORE STRATIGRAPHY, LAKE COUNTY



EXPLANATION

G Gravel

S Sand

SH Shale

T Till

SL Lake level at the time of survey

LWD Low Water Datum (568.60 ft above IGLD, 1955)

Approximate contact between materials

Jetting station

Snapper station

See plate 1 for locations of ranges. Numbers in parentheses refer to U.S. Army Corps of Engineers (1950, 1952, 1954) profile numbers. Profile and surface material information based upon echograms and snapper and jetting samples. A sand (S) or gravel (G) symbol at the surface or immediately below a sample station indicates that sand or gravel was recorded at the station site, but the lateral extent is not known. Vertical exaggeration 10X.

EXPLANATION FOR CORES

Gravel

Sand

Clay

Interbedded sand and clay

Till

Shale

Scale of cores is 1 inch equals 10 feet

Cartographer: Donald R. Camburn

PLATE 3. NEARSHORE PROFILES AND BOTTOM DEPOSITS, LAKE COUNTY

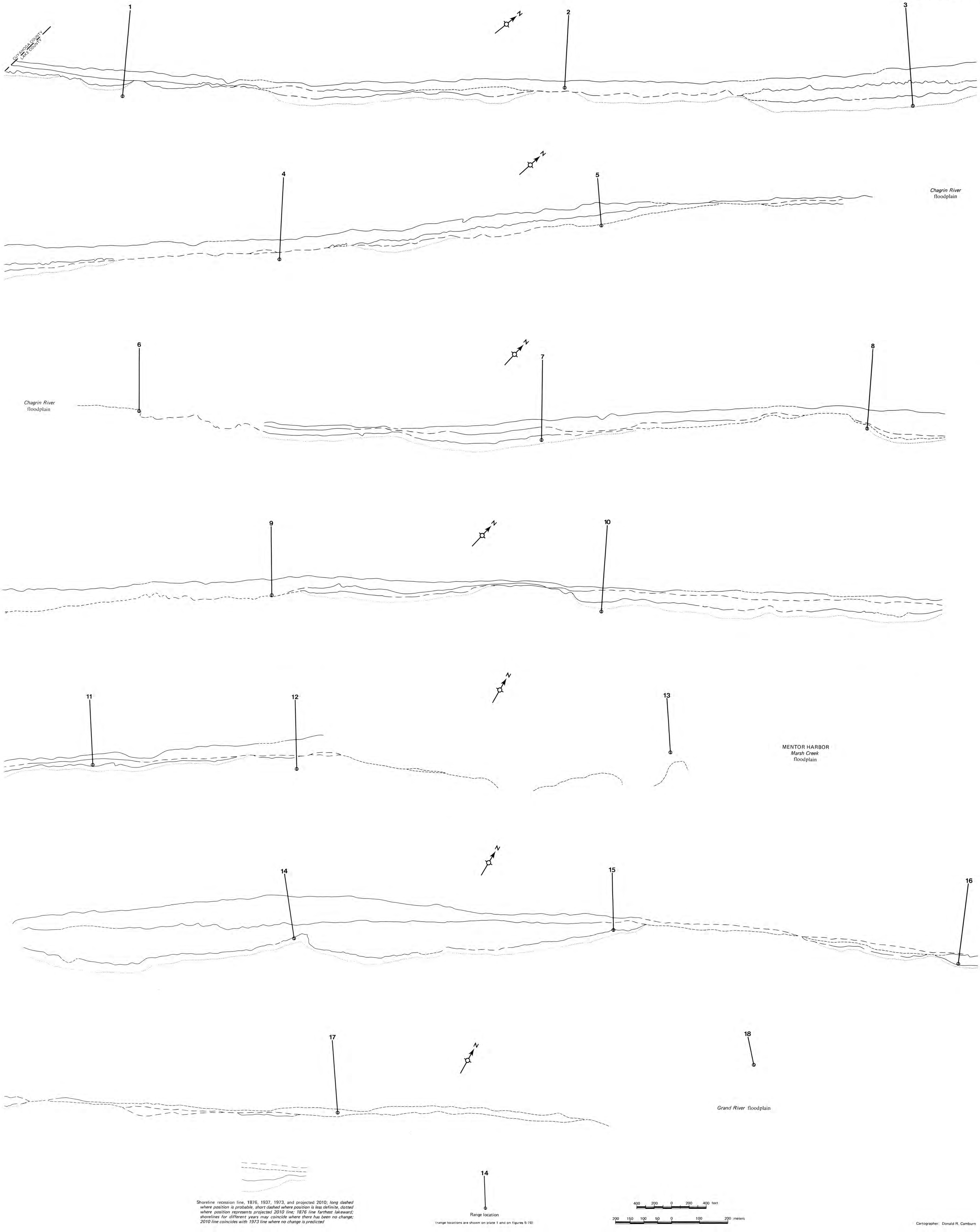


PLATE 4, SHEET 1. RECESSION-LINE MAP OF LAKE COUNTY

PLATE 4, SHEET 2. RECESSION-LINE MAP OF LAKE COUNTY