SENIOR THESIS

A REVIEW OF THE GEOLOGIC HAZARDS ALONG THE LAKE ERIE SHORE OF OHIO FROM CLEVELAND TO ASHTABULA

by

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INTRODUCTION

The hazards along the shore of a large body of water are many, the most important are erosion and flooding. The Lake Erie shore between Cleveland and Ashtabula (fig. 1) is mostly high (up to 18m) bluffs of shale, glaciolacustrine clay, and till. In this area, therefore, erosion is a much greater problem. Mass wasting and, more importantly, wave erosion have increased recession rates in some areas, but overall these rates have decreased. This general decrease in recession rates despite record high lake levels is due to an increase in man-made shore protection structures. Man-made structures while protecting some shores have caused other areas to become more susceptible to erosion by cutting off sand supplies and leaving some areas without beaches. The principle geomorphic change in the Lake Erie shore line from 1876 to the present is a change from a uniform, regular shore to one more irregular and nonuniform (Carter et. al., 1982). Unfortunately much of the property that is being lost at increasing rates is owned by homeowners who may not know how best to protect their land.

EROSION PROCESSES

The two main processes of shore erosion are wave erosion and mass wasting. Of the two wave erosion is much more important. Acting on its own mass wasting would soon produce an equilibrium slope that would be relatively stable. Wave erosion, in reality, acts in concert with mass wasting to produce constantly unstable bluffs. The waves remove the slumped as

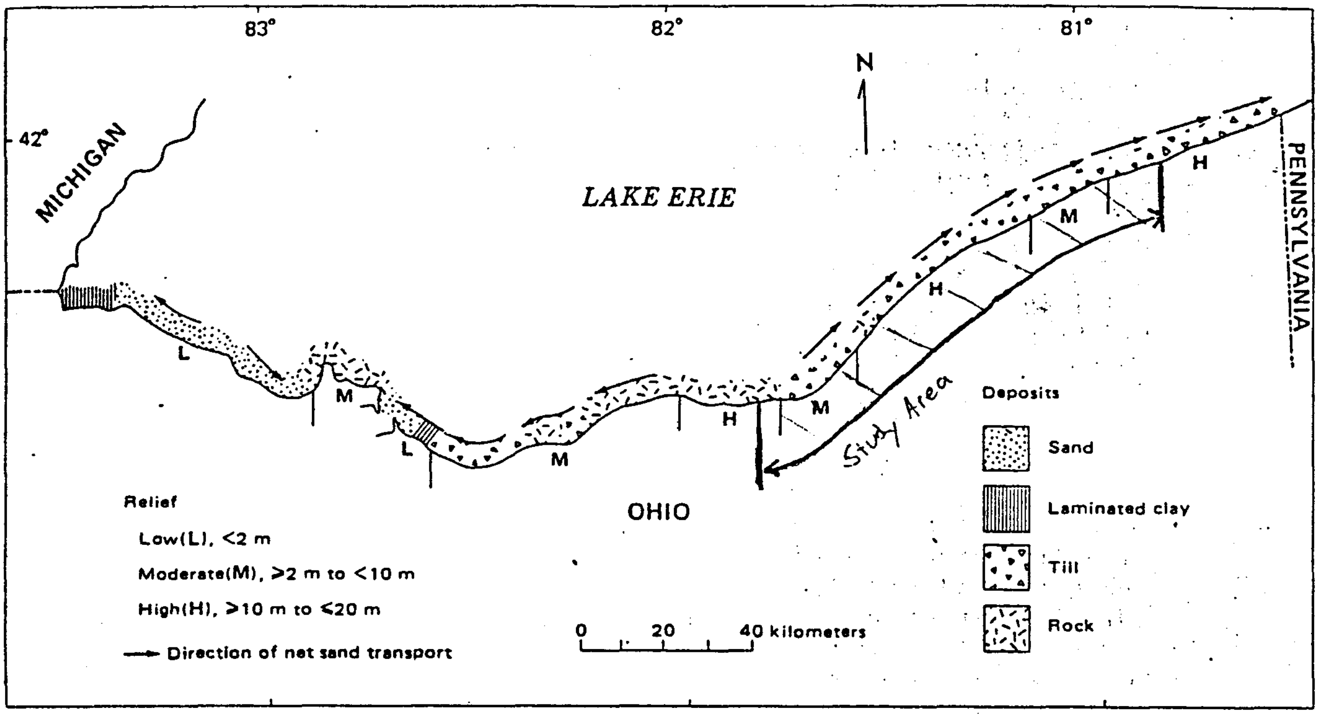


Figure 1.—Generalized map of shore deposits in the wave erosion zone, relief, and net sand transport directions (from Guy and Fuller, 1990)

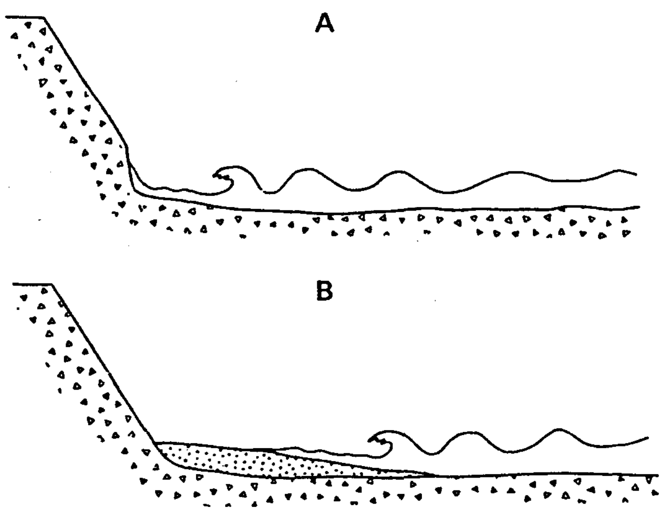


Figure 2a

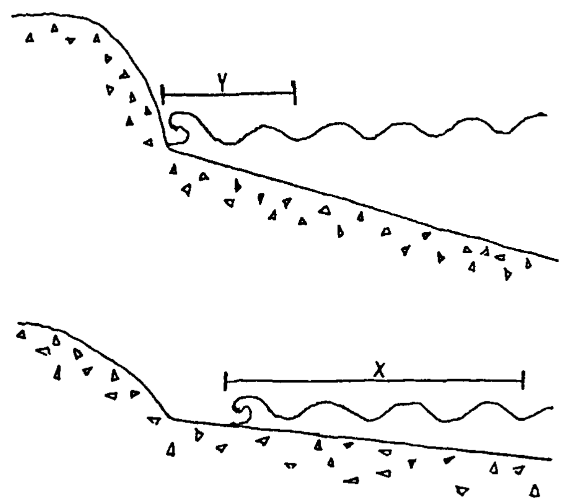


Figure 2b

Figure 2a.--Diagram of the effect of a beach on wave energy. A, no beach, wave energy transferred directly to shore materials; B, wide beach, wave energy absorbed before waves reach shore materials. (from Carter and Guy, 1983)

Figure 2b.--Diagram of the effect of the nearshore slope on wave energy. With a more shallow nearshore slope, the waves feel greater friction from the bottom because of the increased distance (X>Y).

well as the in situ material from the base of the bluff or bank which causes instability in the material. The cohesive forces of the bank then give way to gravity. In this way the shore is kept in constant disequilibrium.

The type of shore deposits found at a particular site along the shore in part controls the recession rate and the process of mass movement at this site. Recession rates increase from rock (shale in the study area) to till to clay (Carter et. al., 1982). Mass wasting occurs as block falls, rotational slumps, and debris flows. Block falls occur where shale or till bluffs have been undercut by waves, causing individual blocks to break away along fracture surfaces. Rotational slumps occur in the till and glaciolacustrine sediments; typically the slip surface is a porous saturated zone in the lower part of the bluff. Debris flows occur when glaciolacustrine sediments or sands in the upper bluff become saturated with ground water and lose their shear strength (Guy and Fuller, 1990, p10).

Wave related erosion depends on several variables, including shoreline orientation, beach width, nearshore slope and shore composition. The orientation of the shoreline changes the angle of incidence of the waves thereby changing the amount of wave energy. With a wider beach, the waves break against the sand and rarely reach the bluff (fig. 2a). The nearshore slope also affects where a wave breaks and how much energy it carries. A wave begins to "feel" the effects of the lake bottom when the water depth is about one half the wavelength. A shallow slope causes the wave to lose energy due to friction over a longer distance and therefore decrease its energy (fig. 2b). The effect of shore composition is stated above. For a given physical setting and wave climate, shorefast ice and lake level are the most important factors in shore erosion. Ice cuts down on wave erosion by damping the waves or by directly armoring the shore. Lake level affects wave erosion by influencing the distance from shore at which the waves break. For a given wave, a higher lake level will cause the wave to break nearer to the shore. In this way more wave energy reaches the shore. Carter and Guy determined an annual slope cycle typical of the Quaternary deposits (fig. 3). Spring thaws trigger mass wasting in the form of block falls, rotational slumps and debris flows. The resultant debris, which fronts the bluff toe, forms a 30-60 degree slope that can extend two-thirds of the way up the bluff. The debris slopes are eroded during spring storms leading to steeper slopes. Then the smaller summer waves at higher water levels attack the bluff toe creating vertical or undercut slopes. Undercutting and enlargement of the joints by wave erosion leads to block falls in the late summer and fall. This process leads to a steeper, smoother overall slope that persists through the winter as shorefast ice shields the coast from waves and freezing temperatures maintain the internal shear strength of the material. The slope processes then begin again in the late winter - early spring (Carter and Guy, 1988, p4). Much to the good fortune of Lake Erie shore land owners the largest waves and therefore greatest wave energy occurs when the lake level is lowest (late fall to early spring) and when shorefast ice helps protect the shore (from about mid December to mid March) (fig. 4).

LAKE LEVEL FLUCTUATIONS

Lake-level fluctuations of Lake Erie can be divided into three types: short term, annual, and long term. Annual and long term fluctuations are caused by changes in the net volume of water in the lake whereas short term changes are due solely to tilting of the water surface (Guy and Fuller, 1986).

Short-term fluctuations

Short-term fluctuations in lake level can last for a few hours to a few days

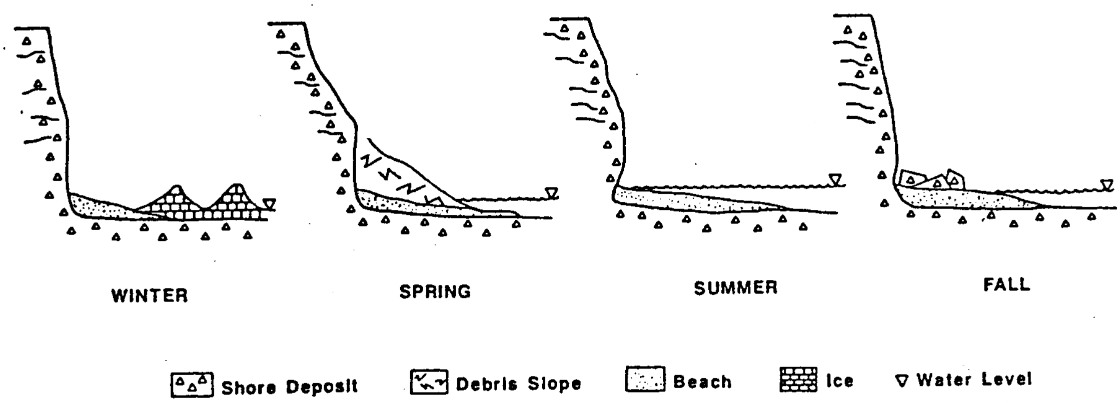


Figure 3.--Seasonial variations in bluff and beach profiles (from Carter and Guy, 1988).

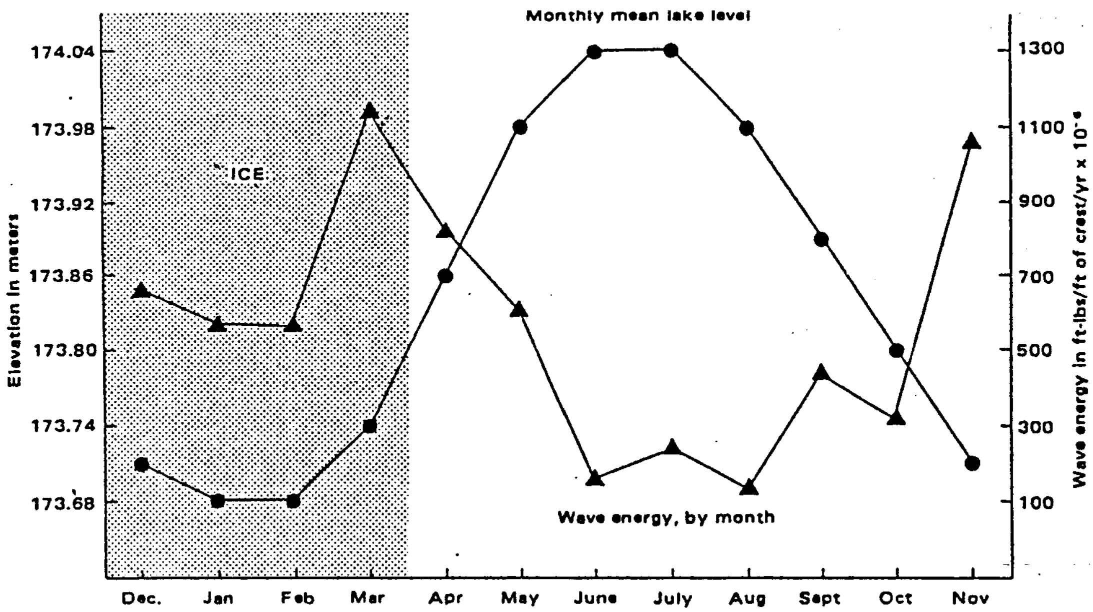


Figure 4.--Wave energy, lake level, and ice (from Guy and Fuller, 1990).

and are caused by wind tides, changes in barometric pressure, and inertial surges of water called seiches (fig. 5c). The most important short-term fluctuations are the wind tides because they cause the most local setup of lake level and are accompanied by storm waves. The lake level at the confined ends of the lake can be set up or down and much as 2m. The wind setup in the study area usually reaches a maximum of 0.6m. Carter and Guy (1988) determined that 77-90 percent of bluff toe erosion occurs during lake storms. Changes in barometric pressure cause similar, but less important surges. A seiche occurs when the lake level drops to its normal level after one of the previous phenomenons has caused setup (Guy and Fuller, 1986).

<u>Annual fluctuations</u>

Annual lake-level fluctuations are caused by the seasonal changes in the hydrologic cycle. In the spring, increased rainfall and decreased evapotranspiration and evaporation cause the lake level to rise reaching its annual high point in June - July. During the summer and fall decreased rainfall and increased evapotranspiration and evaporation bring the lake level down to its annual low in January - February (fig. 5b). The average annual range in lake level from mid-summer high to mid-winter low is about 0.4m. The greatest range in monthly average lake levels are a high of 174.9m in June 1986, and a low of 173.0m in February 1936 (Guy and Fuller, 1990).

<u>Long-term fluctuations</u>

As stated above, most short-term erosion occurs during storms, but mean lake level (long-term lake level changes) rather than storm surge (short-term lake level changes) is the dominant variable controlling erosion rates. The affect of lake level on erosion is best exemplified by the Lake Erie

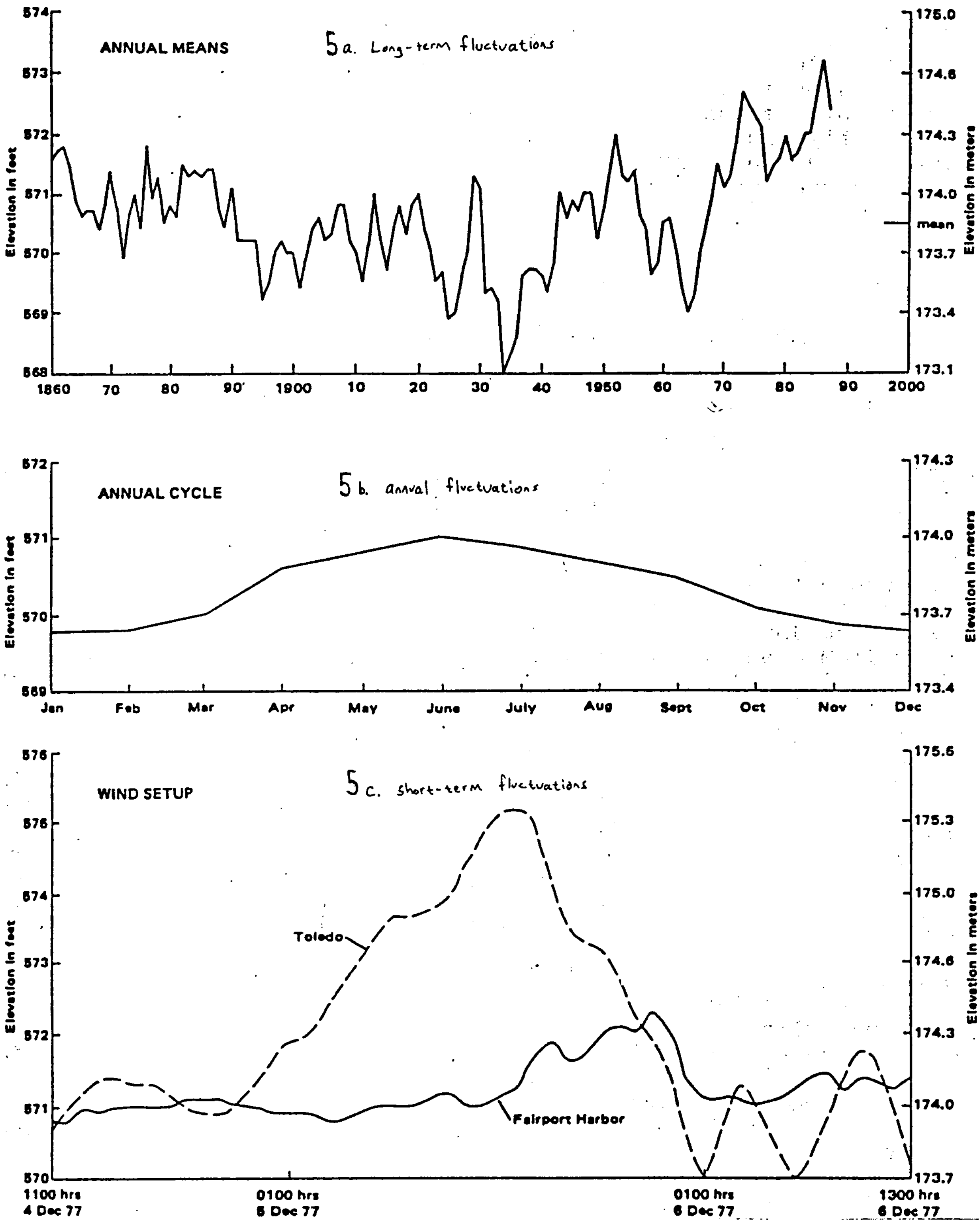


Figure 5.--Lake-level fluctuations (from Guy and Fuller, 1990).

shore of Lucas County. From 1957 to 1968, the mean lake level was 173.7m and the mean erosion rate was 0.8m and from 1968 to 1973 the mean erosion rate was 2.9m with a mean lake level of 174.2m. The erosion rate increased in the later period despite the fact that the frequency and magnitudes of storms was greater in the earlier period. For example, in the period from 1957 to 1968 there were six storms with a setup of 0.9-1.2m, no storms with a setup of 1.2-1.5m, and one storm with a setup of 1.5-1.8m. During the period from 1968 to 1973 there were two storms with a setup of 0.9-1.2m and no storms with a greater setup (Carter, Monroe, and Guy, 1986).

Long-term lake level fluctuations are caused primarily by changes in precipitation in the Great Lakes Basin. The record high- water levels of 1985, 1973, 1952, and 1943 were all preceded by several years of high precipitation. On the other hand the record low-water levels of 1964 and 1934 were caused by years of below normal precipitation. An example of the volume of water that changes in Lake Erie due to long term effects can be seen in the fluctuation between 1964 and 1973. The annual mean lake level was 0.7m above the long-term mean in 1974 and 0.4m below the long-term mean in 1963. With this change in lake level of 1.1m over 11 years the volume of water in Lake Erie increased by 29km^3. From 1974 to 1984 lake levels stayed at about 0.5m above its long-term mean (fig. 5a). Due to an increase of precipitation in 1985 (26% above normal) the monthly average lake levels rose to 0.9m above the long term average and remained high through 1986. Since 1986, the annual mean level of the lake has declined about 0.6m caused by decreased precipitation and increased evaporation. The increased evaporation is believed to be caused by warmer weather, less ice cover, and more sunshine. The evaporation of Lake Erie water was 7 percent above normal in 1987 and early 1988.

MAN-MADE STRUCTURES AND RECESSION RATES

The most important geomorphic change along the shoreline from 1876 to 1973 has been its change in outline from a relatively smooth, uniform shape to a more irregular, nonuniform outline. Along with the overall changes in the shoreline uniformity is the decrease in size and abundance of beaches. These changes are directly related to the increase in man-made structures along the shore. The Ohio Geological Survey, using 1876 shore maps and air photos from 1938 and 1973, have created recession-line maps for all of Ashtabula and Lake Counties (Carter, 1976, Carter and Guy, 1983). The maps also contain projected recession lines for 2010. Cuyahoga County is one of three Lake Erie counties for which there is not yet a complete report of investigations on shore erosion.

Types of structures

There are two main types of shore protection structures; shore parallel structures such as seawalls and breakwaters and shore perpendicular structures such as groins and jetties. Seawalls protect the shore by directly blocking the movement of waves and therefore help reduce or even eliminate recession behind them, but recession continues on either side of the structure. This difference in recession causes the shore to become more irregular. Groins trap sand on their updrift side (to the west in the study area) allowing the sand to accumulate. The resultant beaches protect the updrift shore while the downdrift shore, starved of sand, loses its protective beach. Once again this creates a more irregular shore. Hartley (1964) estimated that the length of eroding shore is about five times that of the length of shore protected by buildup. The general changes in shoreline shape caused by groins, jetties, and breakwaters can be seen in figures 6 and 7.

Effects of structures

The manmade structures have caused the shore to become more irregular, but have decreased the overall recession rates even during a period of high lake levels. For example, in Lake County, 67 percent of the shore receded at less than 0.3 m/yr. in an early period (1876-1938) and 71 percent of the shore receded at this rate during a late period (1938-1973). One percent of the shore receded at greater than 1.5 m/yr. in the late period while rates this high were not found during the early period. The cause of the increased range in recession rates lies in the disturbance of the supply of sand to the littoral system. The contrast between deposition on the updrift side of a groin and the erosion on the downdrift side can be startling (fig. 11). The seawalls and breakwaters do not directly block sand from traveling downshore, but they do reduce the amount of sand in the littoral system.

The rivers emptying into the lake have very low gradients because their lower reaches were drowned by a post- glacial rise in lake level. For this reason the rivers do not supply a substantial amount of sand to replenish the beaches. Most of the sand in the system is derived from erosion of the shore. Seawalls, by protecting the shore from erosion, help deplete the sand supply and decrease the number and size of beaches which are the shores natural defense against erosion. The relationship between the number of structures, beach widths, and recession rates for Ashtabula, Lake,

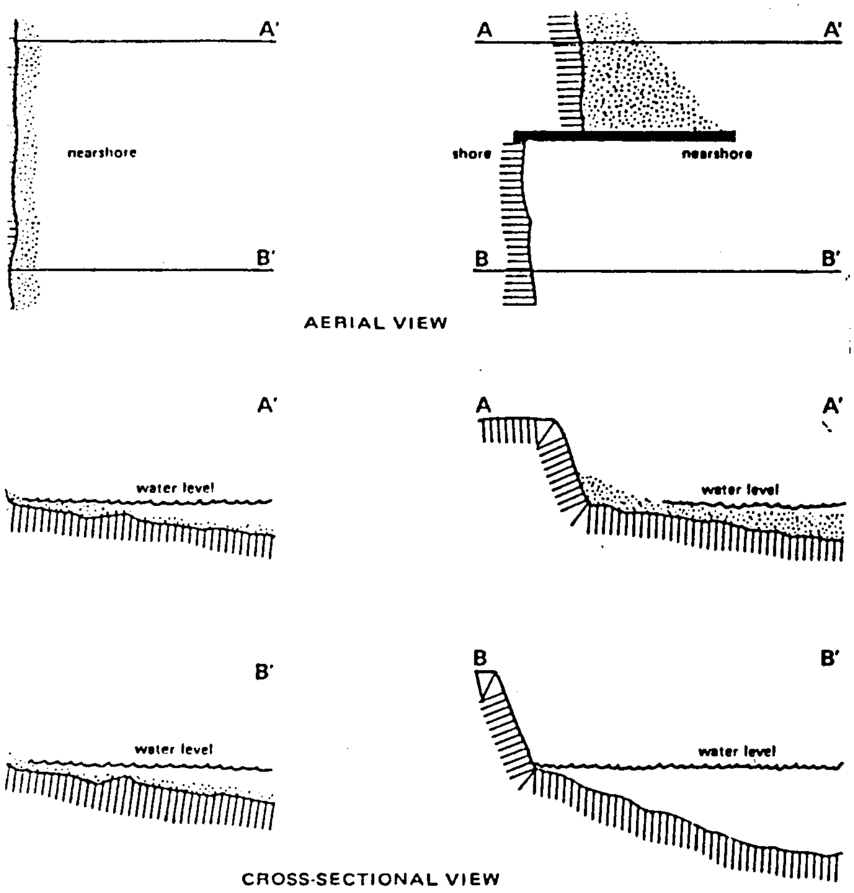
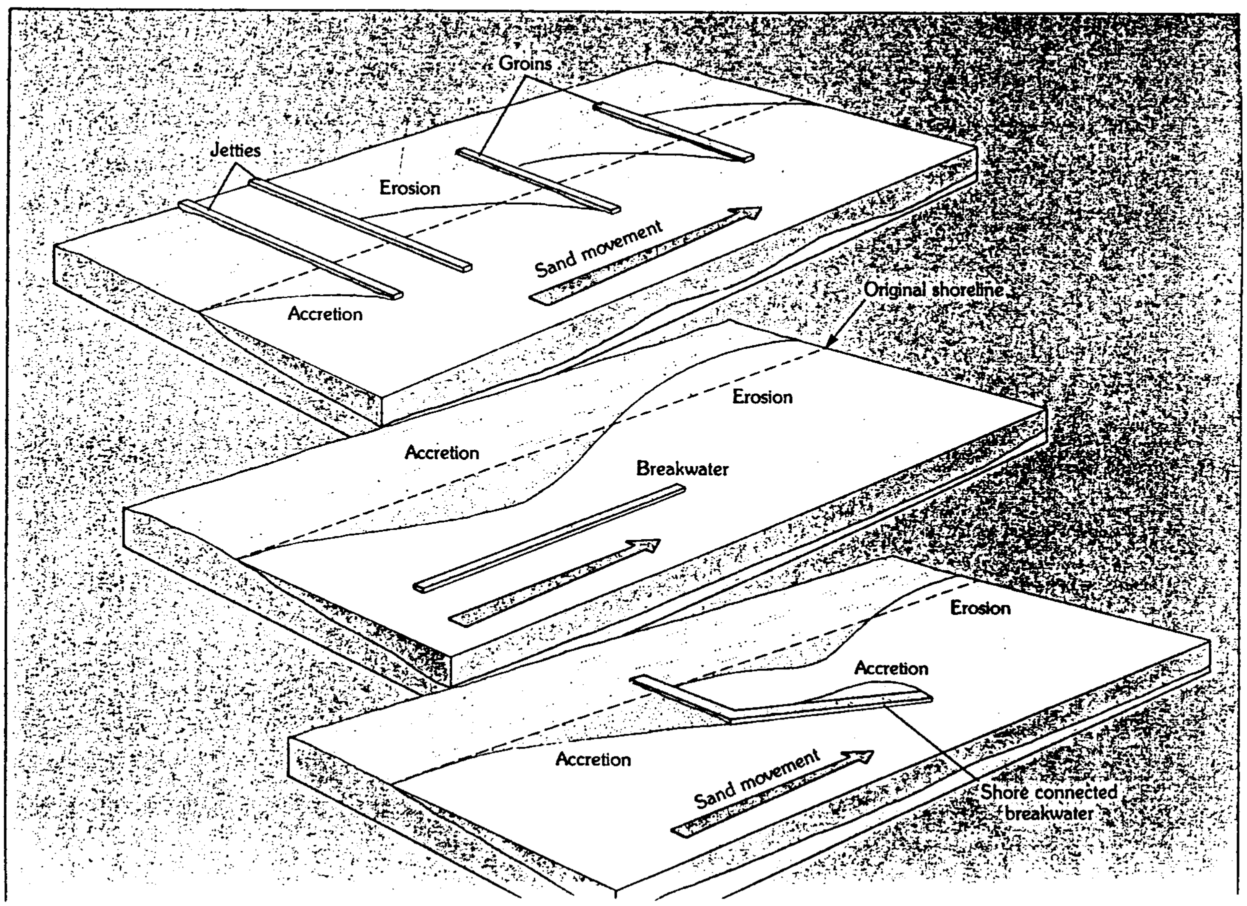
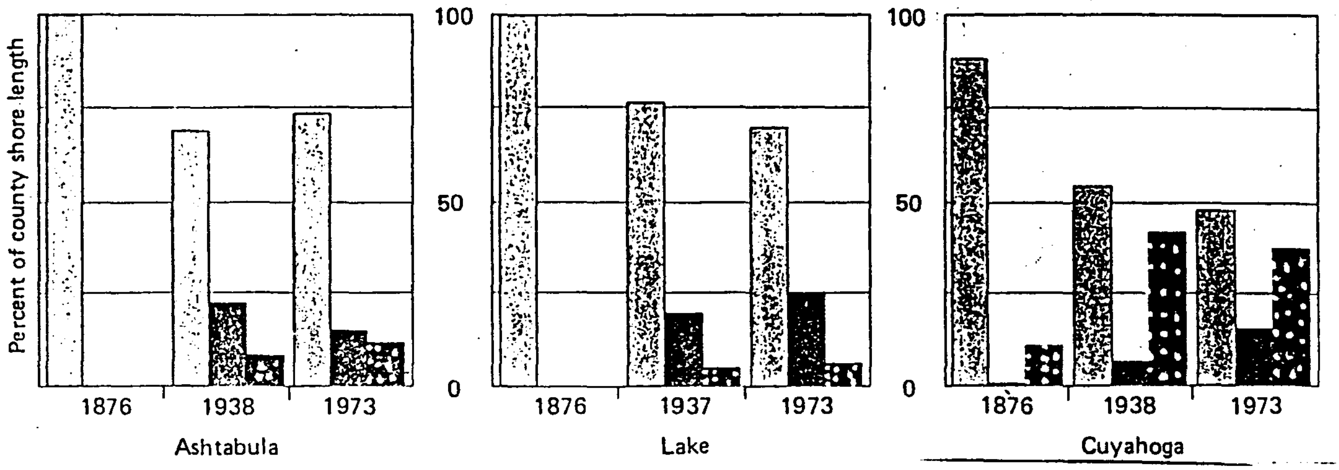


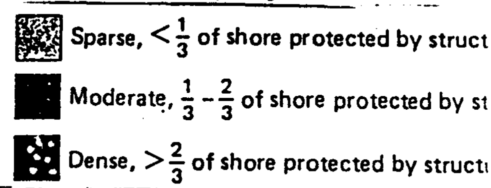
Figure 6.--Diagrammatic sketch of shoreline change brought about by a stickout structure (from Carter and Guy, 1983)

Figure 7.--The effects on a shoreline brought about by the construction of groins and breakwaters (from Tarbuck and Lutgens, 1987)

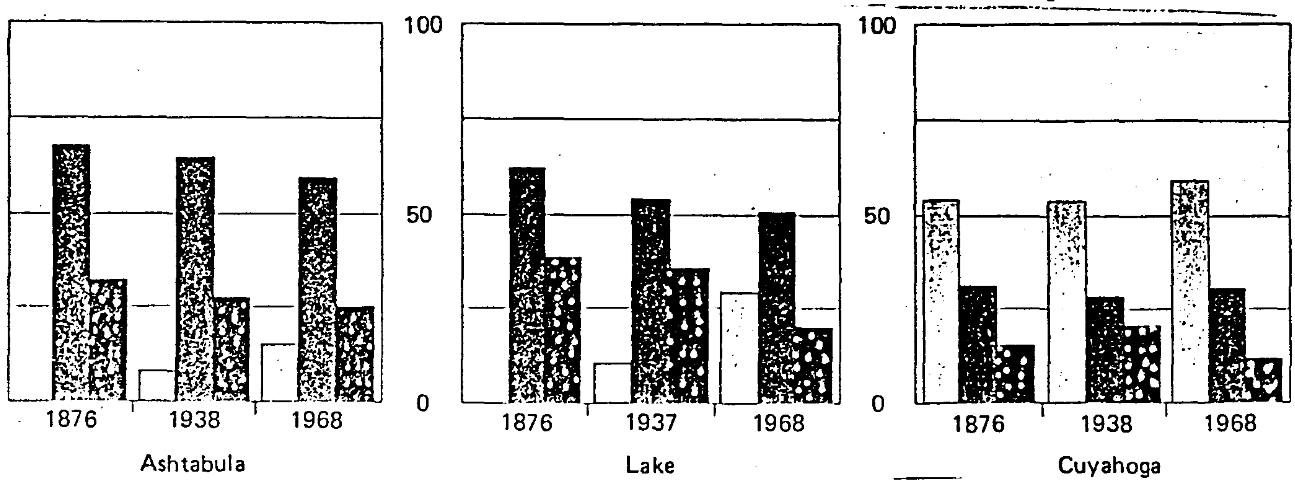


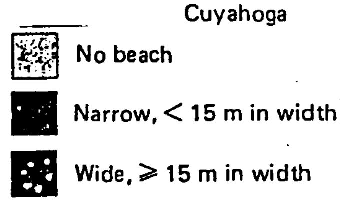
(from Carter, Benson, and Guy, 1981).



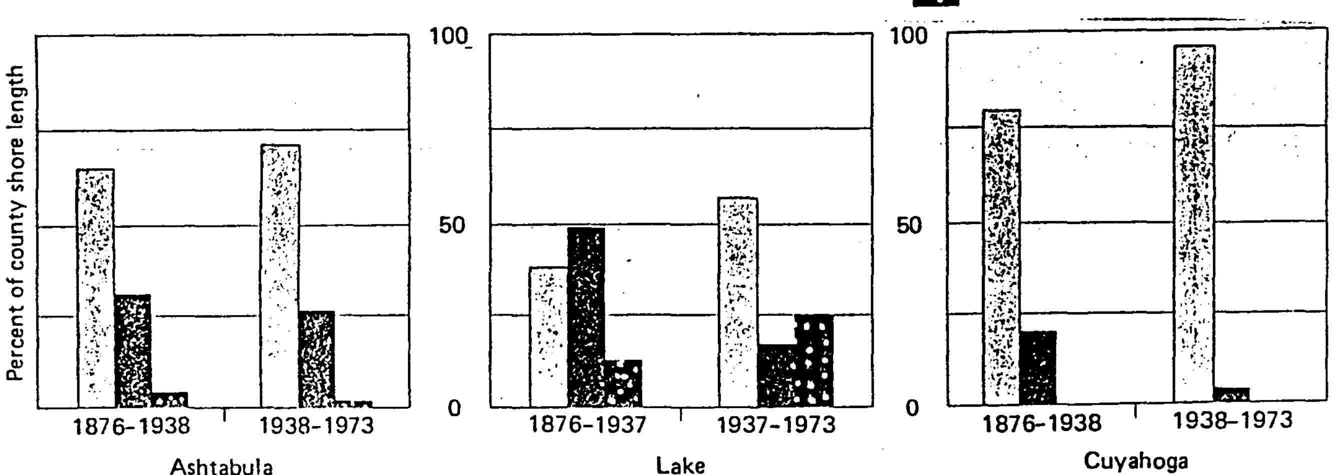


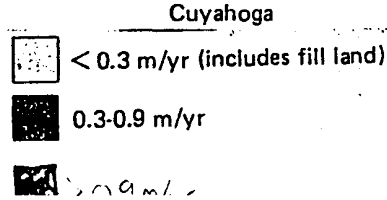
Structure density by county. Structures are defined as seawalls or seawall-like structures or closely spaced groins with trapped-sand beaches.





Beach widths by county.





Recession rates by county.

and Cuyahoga Counties is illustrated in figure 8 for the time period between 1876 and 1973.

POINTS OF INTEREST

Two specific sites are presented here; One illustrates the depositional effects of shore protection structures (Headlands Beach State Park) and the other shows the erosional effects of disturbing the littoral system (Painesville-on-the-Lake).

Headlands Beach State Park

Headlands Beach has advanced lakeward as much as 600m since the mid-1820s as a direct result of the Fairport Harbor structures (figs. 9, 10). Beach widths have increased for about 1.4km to the west of the structures and shoreline orientation has changed from east-west to northeast-southwest. The west jetty was first constructed in the mid-1820s and was lengthened so that by 1876 it was over 600m long. Breakwaters were then constructed in the early 1900s. The present length of the west breakwater is about 1.2km. These structures had to be lengthened to keep pace with the enormous amount of sand building up from the eastward moving littoral system. Bajorunas calculated a deposition rate of about 110,000 m^3/yr. at the park (Carter, 1987). Some sand made it past the jetty and into the harbor. Hartley calculated that approximately 535,000 m^3 of sand was removed by dredging from outer Fairport harbor between 1932 and 1947. This sand was dumped back into the lake, but at too great a distance from the shore to supply beach sand. If this sand had been returned to the littoral system, it could have supplied enough sand to make a beach 23m

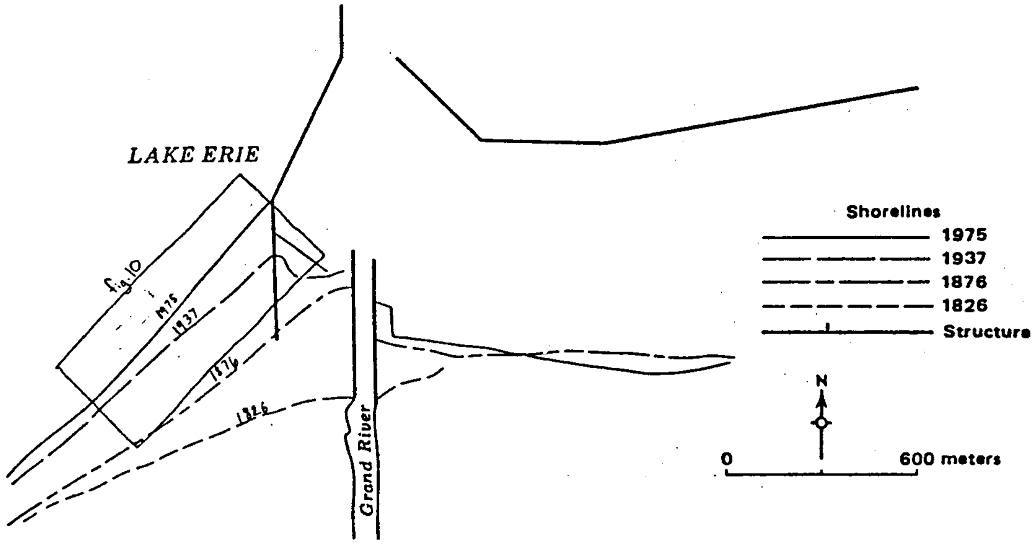


Figure 9.--Historic shorelines updrift (west) of the Fairport Harbor jetties (from Guy and Fuller, 1990)

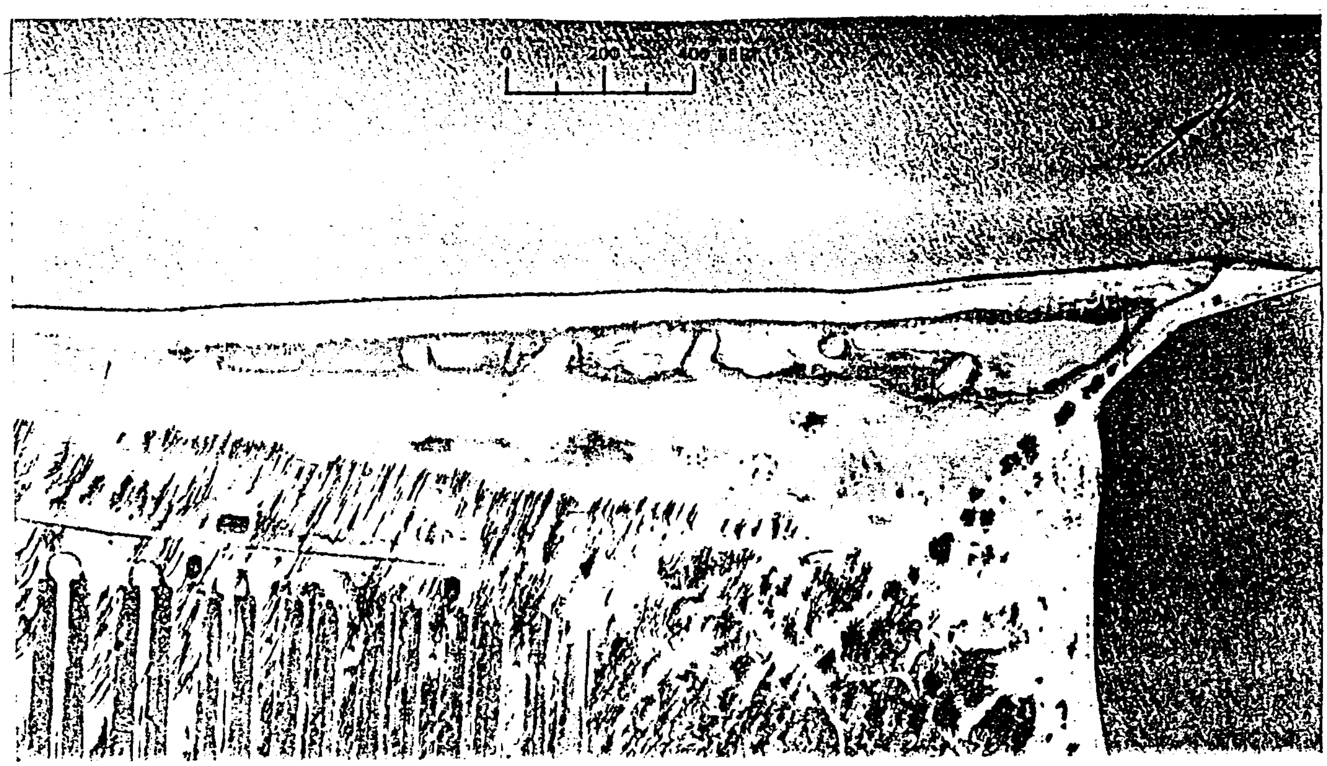


Figure 10.--Headlands Beach State Park (from Carter, 1973).

wide to protect a 14km eroding stretch of shore (Carter, 1973, p.32). The beach sand, being derived from the till bluffs to the west, is poorly sorted and compositionally immature with abundant shale clasts. The dunes, located landward, are well developed and are composed of finer, better sorted sands.

Painesville-on-the-Lake

The Fairport Harbor structures (3.2km to the west of this site) and the groins at Painesville Township Park have greatly affected this portion of shore line (fig. 11). This site lies in the middle of the 6km stretch of shore affected by the Fairport Harbor structures. By blocking the longshore transport of sand, these structures have stripped the beaches away from shores to the east. The groins located in Painesville Township Park accentuated this problem. The recession rates along the parks frontage and along Painesville-on-the-Lake were uniform (about 0.6m/yr.) before the groins were built. After their construction in the early 1940s, the recession rates west of the groins were about 0.2 m/y while the rates to the east were about 2.2 m/y. The 18m high till bluff at this site has retreated over 100m, taking with it a portion of highway and several homes.

HELP FOR HOME OWNERS

Private homeowners have lost a substantial amount of land to erosion, some have even lost their homes like those in Painesville-on-the-Lake. The U.S. Corps of Engineers has published a brochure entitled "Help Yourself - A discussion of the critical erosion problems of the Great Lakes and

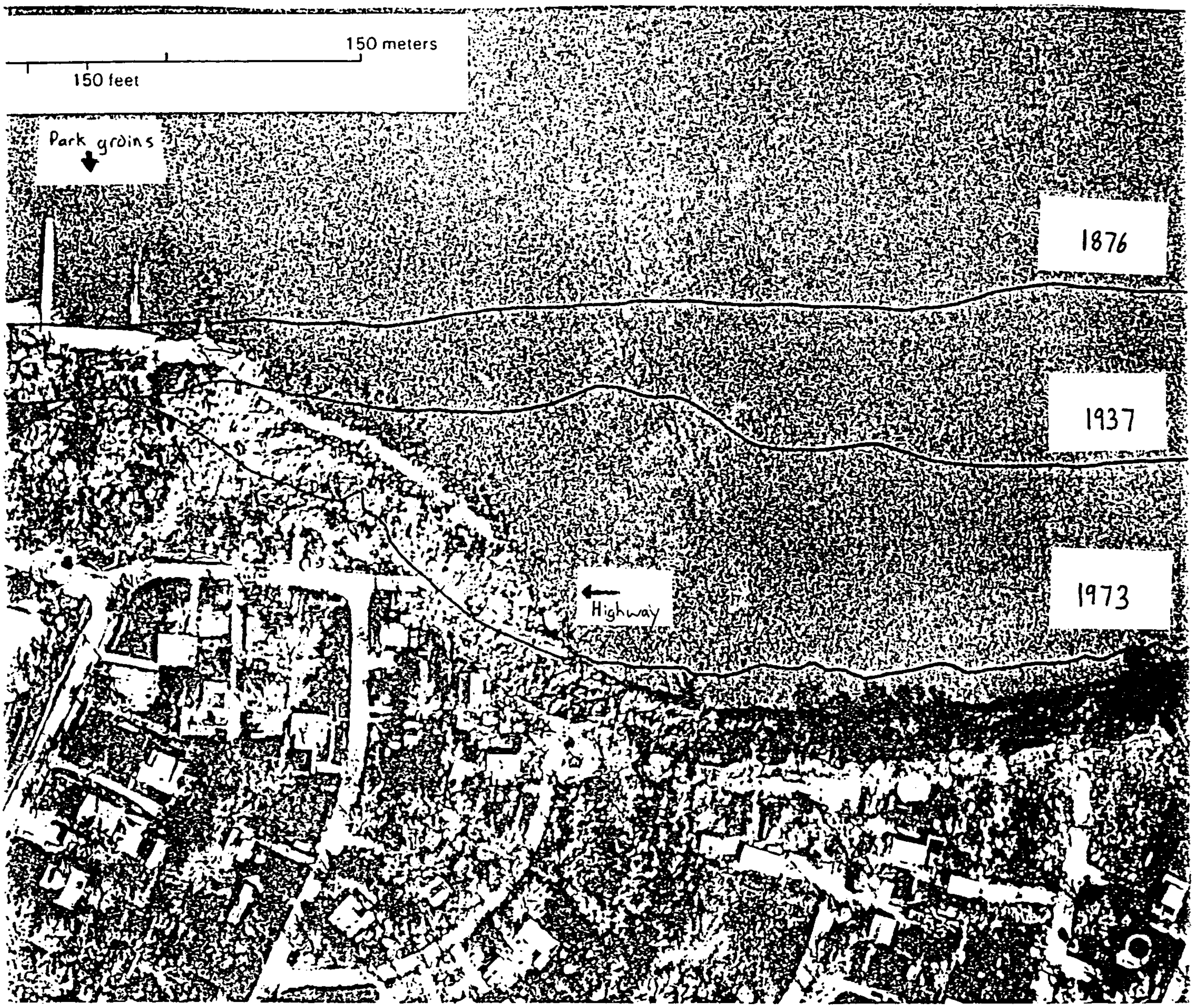


Figure 11.--Recession line map for Painesville-on-the-Lake. Recession lines determined from 1876 U.S. Lake Survey field sheets, 1937 Agricultural Adjustment Administration aerial photographs, 1973 Ohio Department of Transportation aerial photographs. These recession lines have been projected onto a 1990 Ohio Department of Transportation photograph (from Guy and Fuller, 1990)

alternative methods of shore protection " (U.S. Army Corps of Engineers, 1973). This publication covers all aspects of shore protection structures including organizing the effort with neighbors and getting a permit to defining the problem and deciding on which structure is best. A homeowner determines the scale of protection needed based on nearshore slope, expected increase in lake level, average storm setup value, and height and size of shore material. The brochure indicates which structures are appropriate for each problem and how much, per linear foot, each one costs.

Another publication , "Coastal erosion and the residential property market", deals with the economics of shore erosion, and can help homeowners determine the value of shore protection structures (Kriesel and Lichtkoppler, 1989). The general idea is that as erosion causes a house to be more visibly at risk, prospective buyers will pay a lower price for it. A homeowner (or realtor) first calculates a variable called GEOTIME which is the amount of time until the house is at the edge of the bluff. This variable is based on the houses present distance from the bluff, the number of feet lost from the property from 1876-1973, and the estimated useful lifetime of an erosion control device. This variable is then used along with the the characteristics of the house, to determine its value. The presence of an erosion control device can substantially increase house value. For example the calculated value of a particular house without erosion control is $96,062 whereas the same house, with an erosion control device expected to last twenty years, would be worth $105,684. With these two publications a homeowner can at least determine the initial cost and estimated property value gains expected of an erosion control device.

SUMMARY

The principle hazard along the Lake Erie shore from Cleveland to Ashtabula is shore erosion. While the average rate of shoreline recession has decreased, some unprotected stretches have seen a major increase in the amount of land being lost. For any given wave climate and physical setting, including the amount of sand supplied by long shore drift, lake level is the most important variable. But since humans began building structures into the lake, the natural balance of erosion and deposition has been altered. Now the most important variable in shore erosion is the presence of shore protection structures. Human beings have always found it necessary to invent solutions to remedy the problems caused by their previous inventions. For example, when we lived in caves we found them cold and uncomfortable so we invented houses. Houses were warm and comfortable, but we missed the outdoors so we invented windows. With these new windows we felt we lost our privacy so we invented curtains, shades and blinds. Now that the natural cycle of the shore has been disrupted a solution must be found. Many cities, businesses and homeowners have constructed shore protection structures to protect separate stretches of land, but there is no comprehensive shore-wide plan. As more short reaches of shore are protected, less sand enters the littoral system and the remaining unprotected reaches recede at an even greater rate. The options for a solution are very limited. Could the entire shore be adequately protected at an acceptable cost? Even if this could be financed it would greatly diminish the appearance of the lake's natural shoreline and its usefulness as a place of recreation. Perhaps the lake level could be controlled. This could be very expensive and could disturb the natural balances of the Great Lakes. Probably the best solution for now is beach nourishment. Sand supply does not appear to be a problem. There are large offshore sand deposits off Fairport Harbor (about 320×10^6 m^3) and Lorain-Vermilion (about 100×10^6 m^3) (Carter, Benson, and Guy, 1982). Ironically, the irregular shore may help to reduce the longshore flow of sand and therefore reduce the frequency of nourishment.

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