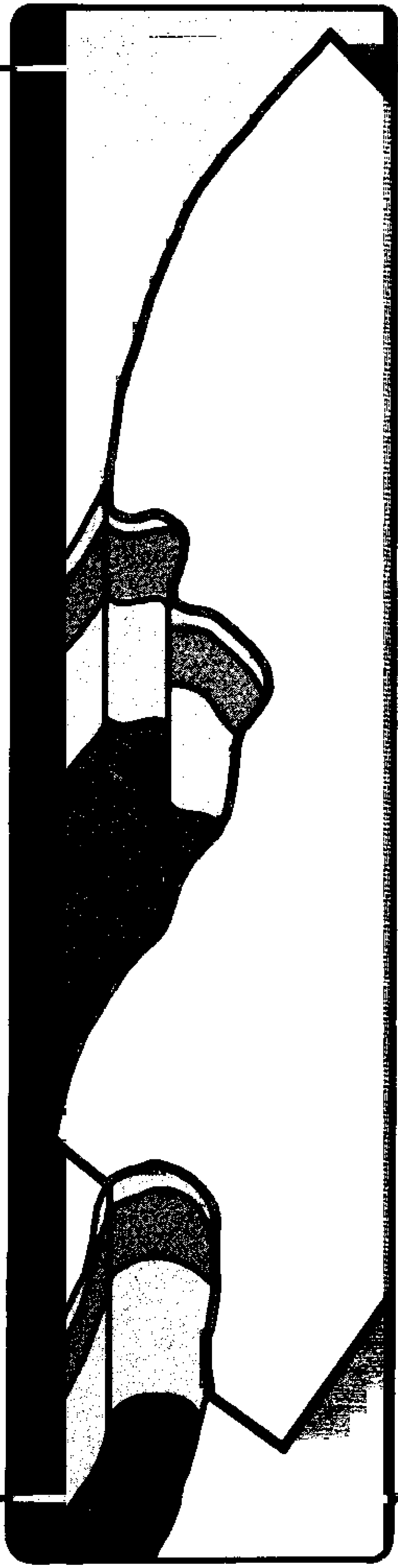

Great Lakes Coastal Geology

Historic Bluff Recession Along the Lake Ontario Coast, New York

Thomas Drexhage and Parker E. Calkin

New York Sea Grant Institute

HISTORIC BLUFF RECESSION ALONG THE LAKE ONTARIO COAST, NEW YORK

Thomas Drexhage and Parker E. Calkin
Department of Geological Sciences
State University of New York at Buffalo

New York Sea Grant Institute
Albany, New York

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ABSTRACT

HISTORIC BLUFF RECESSION ALONG THE LAKE ONTARIO COAST, NEW YORK

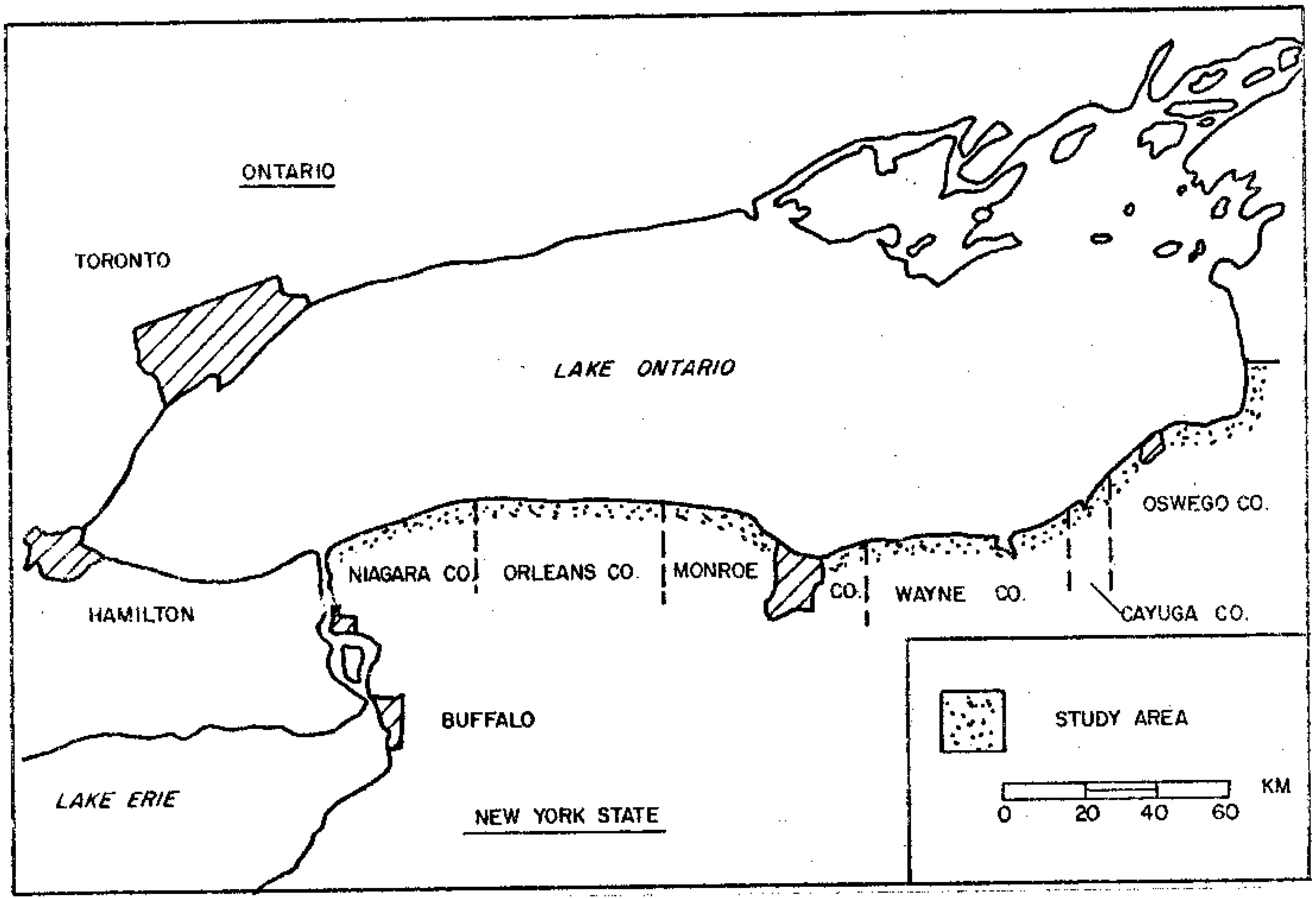
by Thomas Drexhage and
Parker E. Calkin

Department of Geological Sciences
State University of New York at Buffalo

Coastal erosion along lakes and oceans significantly affects coastal activities, resources, and property values. Conservation of coastal resources requires effective methods for controlling erosion. At this time, however, amounts or locations of coastal erosion cannot be precisely predicted. Experience shows that attempts to control natural forces (such as erosion) based on partial knowledge are sometimes disastrous. Therefore, scientists are trying to establish a workable model of the forces (for example, wind, waves, sediment size, topography) involved in natural erosion before attempting large experimental projects in erosion control. This paper measures and analyzes one component of coastal process: bluff recession. We measured rates of bluff line recession at 250 sites in six counties along the coast. Long-term recession rates were determined for the 99-year period from 1875 to 1974 by comparing a 1875 Corps of Engineers Lake Survey with US Army Corps of Engineers aerial photographs taken in 1938 and in the 1950s. Mean short-term rates were generally 100 percent higher than mean long-term rates; at 15 sites, more than 90 percent of the recession occurred during the short term. Short-term recession rates ranged from 0.0 to 3.7 m (0.0 to 12.1 ft) per year; the mean short-term recession rate was 0.8 m (2.6 ft) per year. Long-term recession rates ranged from 0.0 to 1.3 m (0.0 to 4.3 ft) per year; the mean long-term rate was 0.4 m (1.3 ft) per year. To help establish a model of bluff recession, we compared long-term recession rates with field data on bluff height, bluff composition, bluff orientation, beach width, beach material, beach slope, and bluff face slope. This comparision yielded the following conclusions:

- Bluffs greater than 6.1 m (20 ft) high have the highest mean recession rate.
- Bluffs composed of clayey/silty till have higher recession rates than bluffs composed of other materials.
- Areas of the coast that face northwest have the highest recession rates.
- Wide beaches have a significant positive correlation with high bluff recession.
- Bluffs fronted by cobble beaches may have the highest recession.

FIGURE 1 Study area--recession measurements were made on the New York State Lake Ontario coast



BACKGROUND

Introduction

Lake Ontario was formed approximately 11,000 years ago (Prest 1970). Since then the south coast of the lake has undergone constant erosion. Cartographic and photographic records compiled over the past 100 years document the loss of land that has been taking place at varying rates and intensities along the shore, causing major difficulties for coastal landowners. However, there has been little or no analysis undertaken on the areal distribution or intensities of erosion: when erosion is highest, why it takes place, and what losses can be expected in the future.

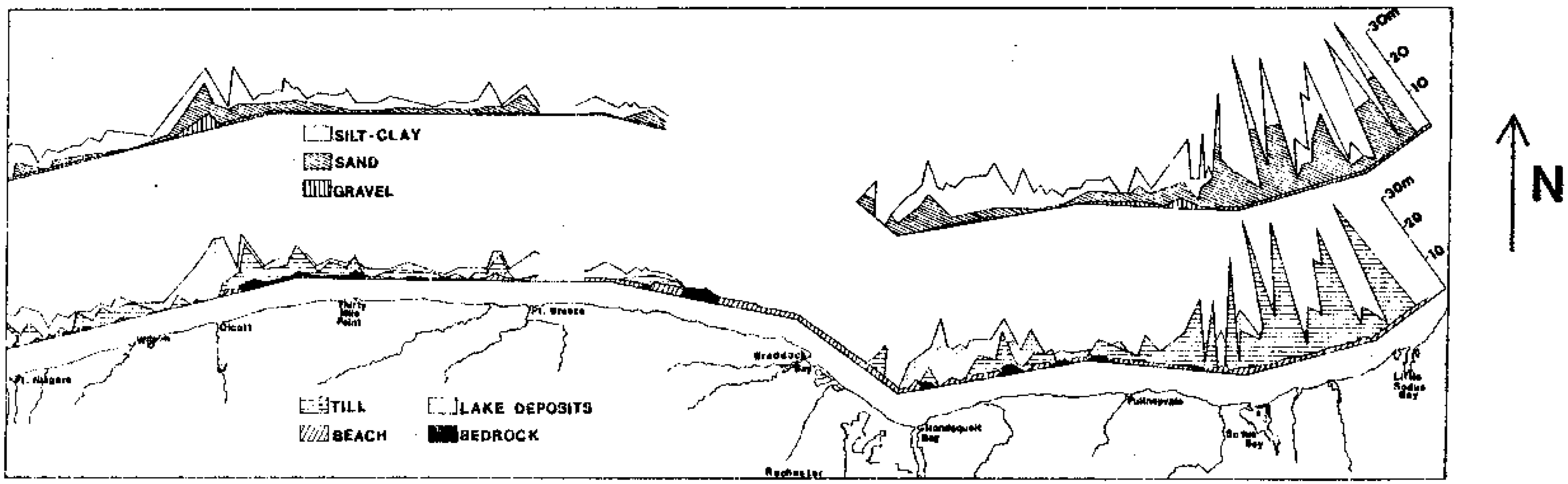
Levels of Lakes Erie and Ontario reached record highs between 1973 and 1976 resulting in accelerated recession of their bluffs as well as extensive flooding and changes in sedimentation patterns at embayments. This, together with the paucity of scientific information on the Great Lakes in New York, was a stimulus for a study of the over 400 km (250 mi) of coast begun in 1973 at the State University of New York at Buffalo. Researchers at SUNY colleges at Oswego, Brockport, Geneseo, and Fredonia, and from Syracuse University, have also contributed to this project. The basic goal and direction of the project has been: (1) to establish baseline geologic information on bluff composition, mechanics, and rates of bluff failure and erosion along the coasts of Lakes Erie and Ontario, and (2) to measure the sediment contributions from bluff erosion and stream flow to the lakes and to analyze the beach and nearshore sediment movement at selected embayments.

This study was undertaken to determine the historic rates of recession along the New York coast of Lake Ontario; how they are distributed spatially and temporally; and to attempt to isolate some of the factors that influence local differences in recession rates. With this information coastal areas can be accurately defined for the benefit of coastal planners as well as private landowners.

Our analysis involved making erosion measurements along 279 km (173 mi) of coast, stretching from the mouth of the Niagara River to North Pond at the eastern end of the lake (Figure 1). Six counties are in the study area: Niagara, Orleans, Monroe, Wayne, Cayuga, and Oswego counties. Coastal problems along Lake Ontario are usually dealt with in terms of county boundaries. Since physiographic variations between counties are sometimes great, each county will be considered in detail.

Refer to the glossary on page 117 for definitions of terms.

FIGURE 2 Generalized topographic section along the south coast of Lake Ontario with areal distribution of bluff sediments (above) and genetic components of coast (below) (The topography and genetic composition is based on measurements at approximately 1 km intervals; bluff texture is estimated from scattered textural data.)



Source: Modified from Calkin et al 1976

Geology of the Study Area

Continuous bluffs 4 to 18 m (13 to 59 ft) high occur along the coast from the Niagara River to Hamlin (Figure 2). This region consists of relatively smooth lake plain with most relief due to postglacial stream dissection. From Hamlin to Irondequoit Bay, drumlins of till up to 30 m (98 ft) high separate low wetlands fronted by barrier beaches. Bluffs are generally less than 1.5 m (4.9 ft) high and good exposures of bluff material are few. From Irondequoit Bay to Sodus Bay the coast consists mainly of bluffs 4 to 8 m (13 to 26 ft) high, reaching maximum heights of 18 m (59 ft). Eastward from Sodus Bay to Oswego, bluffs up to 38 m (125 ft) high are cut in drumlins with lower bluffs and wetlands between (Figures 2 and 3). Few drumlins reach the coast between Oswego and Selkirk where hummocky till and ice contact stratified drift, modified by post-Iroquois lake stages (above present lake level), form most of the surface. The eastern coast consists primarily of sand beaches greater than 24 m (79 ft) wide and partially stabilized dune complexes fronting ponds and inlets.

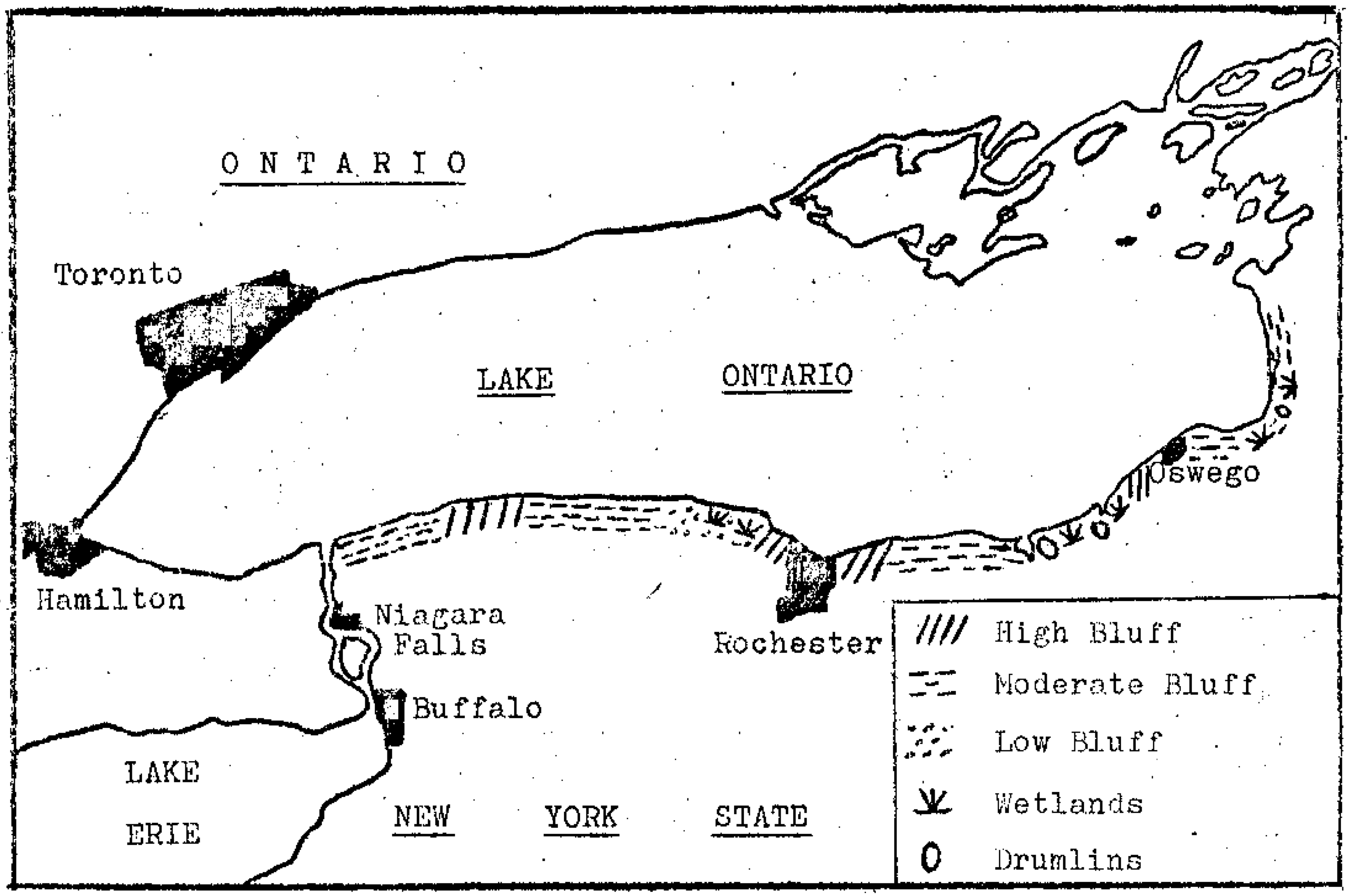
Lake Ontario is the smallest of the Great Lakes in surface area approximately 19,000 km (7,336 mi). It fills a glacially scoured basin of an average depth of 85 m (279 ft) and a maximum depth of 245 m (804 ft) below the low water datum of 74.01 m (242.8 ft), above mean sea level (International Joint Commission 1972). The long axis of the lake trends east-west, parallel to the strike of the bedrock exposed along the coast.

A sequence of Middle and Upper Ordovician sandstones, siltstones, and shales underlies the study area. This forms a major homocline striking east-west and dipping southward approximately 7.5 m/km (40 ft/mi). The rocks include, from oldest to youngest, 61 to 183 m (200 to 600 ft) of red shale and sandstone of the Queenston Shale formation overlaid by up to 290 m (951 ft) of units of the Loraine Group including the Oswego and Pulaski sandstones, and siltstone of the Whetstone Bluff Formation (Fisher 1977). The Queenston Shale crops out discontinuously between the Niagara River and Southwest Oswego, with the longest continuous exposure near Thirtymile Point (Figure 2). In this region the Queenston consists of red to dark red, laminated, fine- to very fine-grained sandstone, siltstone, and shale, becoming coarser in an easterly direction (Kindle and Taylor 1913; Fisher 1966). Members of the Loraine Group, principally the Oswego and Pulaski sandstones, underlie the region from Oswego eastward. These are gray to dark gray, medium- to fine-grained sandstones. Exposures are intermittent, but occur principally near Ninemile Point (Figure L-58).

Small anticlinal folds with axes roughly parallel to the regional dip appear to form many of the points of land projecting into the lake. In addition, researchers have documented tight anticlinal structures of less than 10 m (33 ft) amplitude near Thirtymile Point (Figure 2) and west of Olcott (Gilbert 1899; Kindle and Taylor 1913). Kindle and Taylor also described small faults in the same region (1913). The well known Clarendon-Linden Fault crosses the study region near Hamlin Beach State Park (Figures L-24, 25) in Monroe County (Chadwick 1920; Hutchinson et al 1979).

Overlying the bedrock in the study region are Pleistocene glacial deposits of late Wisconsin age (Muller 1977a; Calkin, in preparation). The

FIGURE 3 Physiography of various reaches along study area coast



bluffs along the Lake Ontario coast provide one of the most interesting and continual displays of glacial drift in the northeast. A simplified stratigraphic section would include, in stratigraphic order (Calkin, in preparation):

- an upper unit consisting variably of glaciolacustrine sand, silt, or clay;
- an underlying silty gray till with an upper waterlaid facies; and
- a lower, compact, red stony and/or sandy till.

The thickness and extent of these units is variable along the coast and the Pleistocene glacial stratigraphy may be locally complex. Figure 2 shows the vertical and linear extent of these units in bluff exposures. Exposures of the individual units is often discontinuous and variability within them is great. The following researchers have attempted to correlate these units: Calkin, Brennan, and Adams (1976); Solomon (1976); Calkin, Drexhage, and Brennan (1978); Brennan (1980); Calkin (in preparation).

The region lies within the plain of glacial Lake Iroquois, a much higher lake than the present Lake Ontario, which was dammed by the receding Wisconsin ice margin on the north. Formation of Lake Iroquois started approximately 12,400 years before present (BP) (Muller 1977b; Calkin and Brett 1978). Lake Iroquois drained to a lower stage between 11,000 and 12,000 BP before reaching the present level (Prest 1970; Karrow et al 1975). Evidence for several post-glacial lake stages in the Ontario basin has been presented by various researchers including recent studies discussed by Prest (1970); Sutton, Lewis, and Woodrow (1972); Muller (1977b); Gorman, Frape, and Johnston (1978).

Previous Work

Coastal recession of the Great Lakes lends itself to qualitative and quantitative studies. Researchers in this area include: Davis, Siebel, and Fox (1973); Gelinas and Quigley (1973); Berg and Collinson (1976); Carter (1976); Siebel, Armstrong, and Alexander (1977). However, only a few researchers have treated the New York coast of Lake Ontario. The US Army Corps of Engineers (1945, 1954, 1955, 1970, 1973) has undertaken most of the work here. The first four of these references deal mainly with specific areas and problems of beach erosion. However, the 1973 study is more comprehensive, including shoreland use and classification along the entire New York coast. Palm (1975) assessed erosion rates and recent high water damage along the coast of Oswego County. Computing rates for the 1938-1974 period, he used a method of comparing bluff positions on air photos different from that of this study. There have been no published studies involving determination of rates for longer periods.

THE PROJECT

Methods and Procedures

Recession Measurements

Our study used two methods of measuring recession: one involved determining short term changes over a 13- to 17-year period; another obtained changes over a 99-year period. For measuring short-term changes, we referred to two sets of photographs from the US Department of Agriculture: one set taken in 1938 and another between 1951 and 1955. A Bausch and Lomb optical micro-rule enabled us to directly measure distances between fixed points on land and the bluff line (Figure 4). We indicated places where we took measurements on the most recently available US Geological Survey (USGS) 7.5 minute topographic maps (Table 1). We next computed distances along the east side of a convenient road leading to the shore from a road intersection to the bluff line (Figure 4). When there was no road available leading to the shore, we substituted farm, field lines, or other recognizable lines as a baseline. Since the micro-rule contains a built-in straight line, our baseline consisted of any two landmarks aligned perpendicular to the bluff and identified on both sets of photographs. We then measured the distance from a landmark to the bluff line.

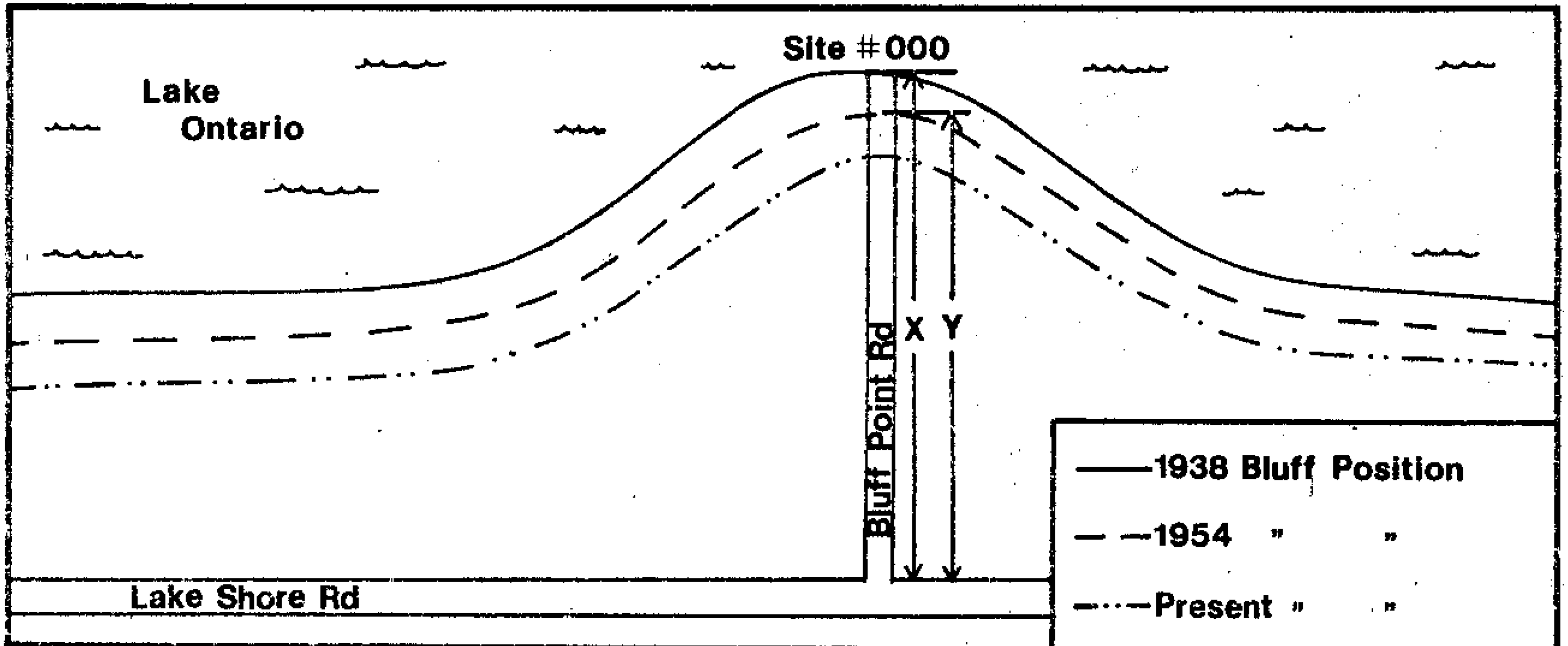
According to the scale of the photographs, we converted the distances determined from coincident points on the two respective photographs to true distances in meters. Our next step was to determine the difference between distances and divide it by the number of years between photographs to give a mean recession rate at that point.

The average scale of the 1938 and 1950s photos was about 1:20,000. In the scale or time period conversions, we accounted for small differences in scale on the photos due to flight height changes and varying dates of flight that would affect the recession values.

We determined long-term changes through the use of 22 1874-1875 US Army Corps of Engineers Lake Survey sheets which used together covered the coast at a scale of 1:10,000 (Chief of Engineers 1874 and 1875). We used these with the 1974 US Army Corps of Engineers aerial photographs at a scale of 1:9,000. From the 1875 maps we traced the bluff line onto a transparent overlay. We then projected and traced the bluff line from the air photos to scale on the overlay using a Saltsman Overhead Projector. Sufficient development of the Lake Ontario coastal area by 1875 made correlation with present landmarks for scale matching relatively easy. We transferred sites with short-term measurements from the topographic maps onto the overlay and then converted the recession rate for the 1875-1974 period at these points.

FIGURE 4 A. Hypothetical bluff lines--- and ——— from superimposed photos taken in 1938 and 1954 to illustrate how short-term recession was measured

B. Method of computation used to derive recession rate



$$\left(\underset{(in)}{X} \times \begin{matrix}\text{SCALE}\\ 1938\\ (m/in)\end{matrix} \right) - \left(\underset{(in)}{Y} \times \begin{matrix}\text{SCALE}\\ 1954\\ (m/in)\end{matrix} \right) \div \underset{(yrs)}{16} = \begin{matrix}\text{SHORT TERM}\\ \text{RECESSION}\\ \text{RATE AT}\\ \text{SITE 000}\\ (m/yr)\end{matrix}$$

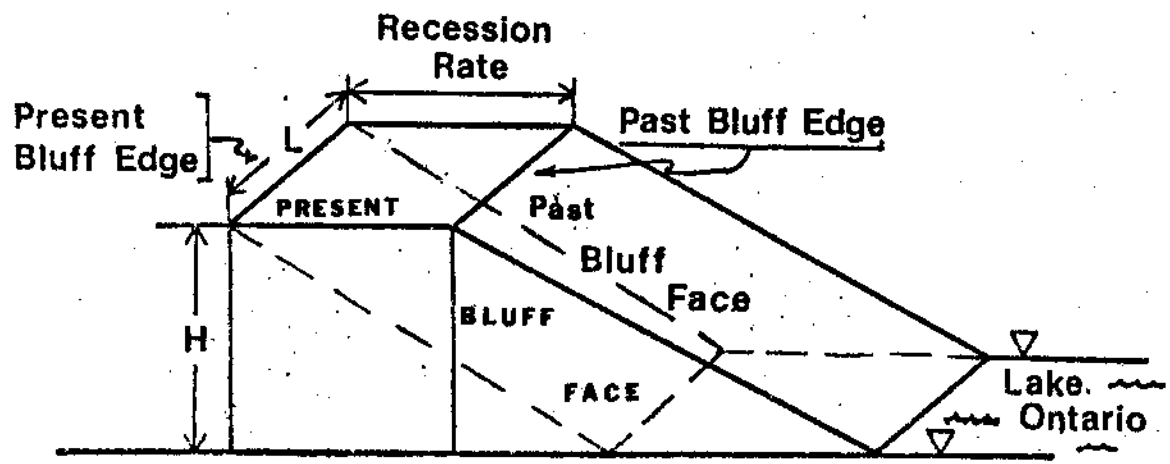
METHOD OF DETERMINING RECESSION RATE

TABLE 1

List of US Geological Survey topographic maps used in this study

Name of quadrangle	Sites included	Year compiled
Ft. Niagara, NY - Ontario	1-11	1965
Sixmile Creek, NY	12-31	1973
Wilson, NY	32-53	1965
Newfane, NY	54-59	1965
Barker, NY	60-72	1965
Lyndonville, NY	73-85	1951
Ashwood, NY	86-95	1950
Kent, NY	96-103	1951
Kendall, NY	104-108	1951
Hamlin, NY	109-119	1971
Hilton, NY	120-129	1971
Braddock Heights, NY	130-137	1971
Rochester East, NY	138-143	1971
Ninemile Point, NY	144-159	1971
Furnaceville, NY	160-173	1952
Pultneyville, NY	174-182	1952
Salmon Creek, NY	183-197	1952
Sodus Point, NY	198-203	1953
North Wolcott, NY	204-209	1953
Fair Haven, NY	210-214	1954
West Ninemile Point, NY	215-218	1954
Oswego West, NY	219-226	1954
Oswego East, NY	227-230	1954
West of Texas, NY	231-238	1955
Texas, NY	239-245	1955
Pulaski, NY	246-250	1954

FIGURE 5 Diagram of method used for determining mean annual erosion volumes (the volumes of the prism defined by the past bluff face and the present bluff face and recession rate would equal the amount of material eroded annually.)



$$H_{(m)} \times L_{(m)} \times \begin{matrix}\text{RECESSION}\\ \text{RATE}\\ (m/yr)\end{matrix} = \begin{matrix}\text{ANNUAL}\\ \text{EROSION}\\ \text{LOADING}\\ (m^3/yr)\end{matrix}$$

Source: After Siebel et al 1977

Erosion Volumes

We calculated the erosion volumes using the method illustrated in Figure 5. The following formula calculates the volume of eroded material (Siebel et al 1977):

$$\text{Mean Bluff Height (m)} \times \text{Length of Shore of County (m)} \times \text{Mean Recession Rate of County (m/yr)} = \text{Annual Erosion Volume } (m^3/yr)$$

This next formula determined the mean bluff height for each county:

$$\frac{\Sigma l_i h_i}{\Sigma l_i} = \text{Mean Bluff Height}$$

where l_i = reach length in meters and h_i = mean bluff height of reach in meters as taken from data presented by Siebel and associates (1977).

Field Study

During summer 1977 we undertook field work to correlate geologic and geographic factors at the various sites with our laboratory-determined recession. During five days of investigation we gathered data at 101 sites along the coast. Our intention was to clarify whether some types of bluffs are more susceptible to erosion than others and to determine which areas are of critical importance in terms of land use and recession rate. We recorded the following information in the field: degree of fracturing, height of bluff above the water level, vegetation, composition, orientation, beach type, beach width, beach slope, and bluff face slope.

We chose these parameters because of their probable influence on recession rate and because they were easily obtained in the field. With the help of a preprinted data sheet two workers were able to gather data in about five to ten minutes after reaching each site. Workers also photographed each site for documentation.

Some of the critical dimensions that we could not evaluate in the time available for this study included: lake level, offshore slope, wave fetch, and sheer strength of the bluff material (Quigley and Tutt 1968; Davis et al 1973; Great Lakes Basin Commission 1975).

Other Determinations and Methods

Land Use. We obtained land use percentages within each county from the US Army Corps of Engineers National Shoreline Study (1973). Where no actual figures were available, we interpreted land use from the shoreland use maps included with the study. Next, we measured the length of shore for each land use type (commercial, agricultural, residential) in each county and divided this value by the length of shore in that county. Then, we converted the values to percentages.

Nearshore Slopes. Depth contours indicated on the USGS topographic maps provided the nearshore slopes (Table 1). We measured the distance from the shoreline out to the 9.1 m (30 ft) depth contour to the nearest 0.5 mm (0.02 in) at each site. Following this, we calculated the slope in feet/mile and converted the value to meters/kilometer. We determined slopes along the same orientation (azimuth) as recession measurements at each of the sites.

Recession Categories

Tables 4, 7, 11, 15, 19 and 23 list the recession rates as follows:

very slow	<0.3 m/yr (<1 ft/yr)
slow	0.3 to 0.6 m/yr (1 to 2 ft/yr)
moderate	0.6 to 0.9 m/yr (2 to 3 ft/yr)
fast	0.9 to 1.2 m/yr (3 to 4 ft/yr)
very fast	>1.2 m/yr (>4 ft/yr)

This grouping method probably yields the most realistic picture of the data. Limitations of the measuring technique may cause small differences in recession rate.

Limitations

Selection of Measuring Sites. The available air photo coverage limited the selection of sites for determining short term recession rates. Flight lines for the 1938 and 1950s photographs ran north-south yielding an overlap in photo coverage along the field. The location of the recession sites in the center area of the photograph served to minimize scale distortions. Also limited was the selection of measurement sites to the location where landmarks had not changed during the interval between photos. For example, in undeveloped wooded regions we encountered difficulties in finding landmarks that had not changed. Thus, we had to space the measurement sites farther apart and the recession sites are unevenly distributed along the coast. The amount of land included in each single photo print was also a factor in measurement. If the photo included only a narrow coastal band, we found it difficult to find roads parallel to the bluff that could be used as landmarks for measurement.

Accuracy. We used a micro-rule divided into increments of 0.025 mm (0.001 in). This enabled the repetition of photographic measurements to within 0.05 mm (0.002 in). Checks showed that on the photos we could measure a mile on the ground within ± 0.9 m (3 ft). Most distances measured for determining recession (Figure 4, X or Y) were much less than 1.6 km (1 mi), allowing for greater accuracy.

Bluff Line. Interpretation of the bluff line position is a possible source of error. The abrupt change in slope of the land, marked by a dark shadow on the photographs, is the bluff line identifier. When trees obscured the bluff line, in about 20 percent of the cases, we took the bluff line to be 33 percent of the tree's diameter inland.

Long term measurements were subject to similar sources of error in placement of the bluff lines. The 1875 maps were quite detailed in that they showed field lines, buildings, and roads that could be matched with about 90 percent of the 1974 photos. Where the 1875 maps indicated no bluff line, we assumed that the bluff generally paralleled the shore and was at the landward edge of the beach. The maps clearly indicated the latter. Therefore, the 1875 bluff position is approximate; however, we assume that errors in its position are slight and random.

Field Study. Time and the size of the area under study limited the field study. Hence, we gathered data in subcategories representing ranges of quantity for each parameter investigated. Since the primary purpose of this study was investigation of historic rates of erosion rather than present parameters, this method proved adequate; it allowed for the maximum acquisition of data in a short time span.

Changes over Time. Physical conditions of the present are not necessarily those of the past. Natural and man-made changes may occur frequently at many stations. This is particularly the case for structures or materials placed to protect the shore from erosion. They may be absent or present for various lengths of time during the interval of measurement spanned by the two sets of photographs. The effects of these changes may be apparent and dramatic over short periods, yet they tend to average out over long periods along a given reach of coast. Taking this into consideration, we compared the long term recession rates with the present physiography.

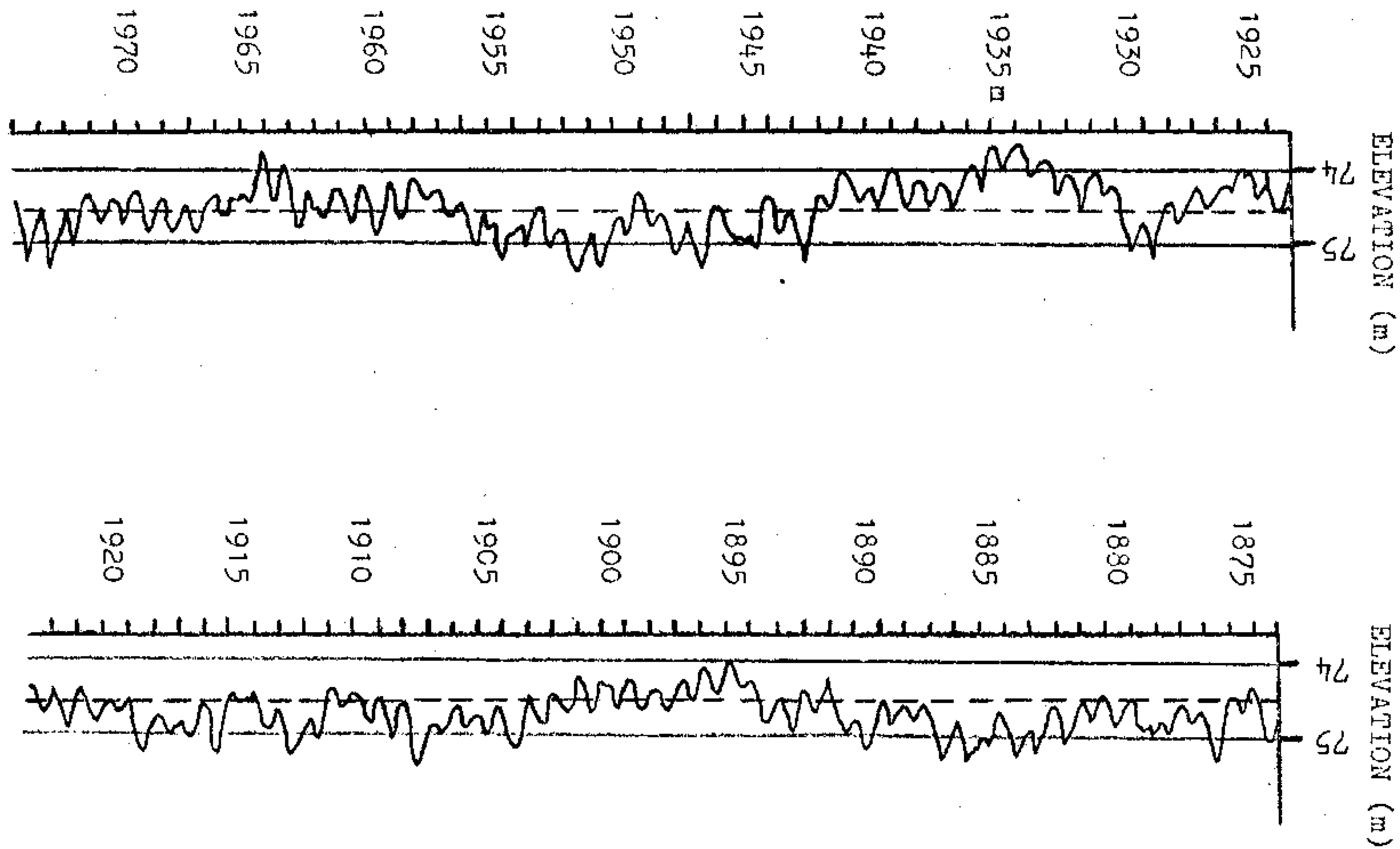
Lake Levels

The approximate elevation of the water surface of Lake Ontario plays an important role in erosion of the bluffs. High water levels rapidly increase the rate of recession (Davis et al 1973). As lake level rises, beaches become inundated and narrower, allowing direct wave attack against the bluffs. The removal of beach sediment from the shore further decreases bluff protection. In areas along the south coast of Lake Ontario where bedrock is present, it is usually exposed less than 2 m (6.5 ft) above the water surface. Therefore, rises in lake level allow waves to impact directly onto the more erodible tills and lacustrine deposits above the rock.

The completion of the St. Lawrence Seaway in 1958 (International Joint Commission 1972) made possible the regulation of the level of Lake Ontario. However, such regulation is only paritally effective in controlling water levels and their various changes. Variations in lake level occur on three time scales (Laidley 1962).

(1) Short-term changes in water level from day to day. These are usually the result of weather conditions and prevailing winds. The magnitude and duration of such changes is dependent upon the velocity of the wind, the wind direction, and the length of the storm. The effects on erosion of the bluffs by short-term changes may be considerable (Fox and Davis 1973; Maresca 1974); however, these effects are impossible to relate to recession rate in our study

FIGURE 6 Graphical representation of mean water levels for Lake Ontario between 1875 and 1974 (Dashed line indicates mean of 74.6 m for the 1875 to 1974 period.)



Source: National Oceanic and Atmospheric Administration 1971, 1979 due to their relatively short duration.

(2) Medium-term changes over the course of a year. These result from the continued cumulative effects of weather conditions within the Great Lakes basin. These changes in level may be drastic, depending on the inflow through the Niagara River, precipitation, local inflow, evaporation, and degree of winter ice retention. Extended periods of abnormally high precipitation have marked effects in higher lake levels.

(3) Long-term changes over many years. Results of these changes would be those most detectable in this study. Such changes are due to variations in runoff and precipitation over several years. Figure 6 and Table 2 show mean annual lake levels for the time periods for which recession was measured in this study.

Davis and associates (1973) discussed the cyclic fluctuations of the Great Lakes' water levels, indicating a period of between 8 and 14 years. Using mathetical analysis, Cohn (1975) determined cycles of 8, 11, 12, and 36 years.

TABLE 2

Mean lake levels of Lake Ontario for the various periods over which recession was measured in this study

Time period	Mean lake level (meters above mean sea level)	Mean lake level (feet above mean sea level)
1875-1974	74.58	244.69
1938-1951	74.64	244.88
1938-1954	74.72	245.15
1938-1955	74.72	245.26

Source: National Oceanic and Atmospheric Administration 1979

BLUFF RECESSION BY COUNTY

Niagara County

Geography

Location

Niagara County extends eastward for 49.9 km (31 mi) along the coast of Lake Ontario from the Niagara River to a point just east of Thirtymile Point at Somerset (Figure 1). We determined recession rates at 75 sites in Niagara County as shown on Figures L-1 through L-11.

Land Use

The Niagara County coastline is primarily used for residential purposes (51.9 percent); agricultural and undeveloped lands account for 27.9 percent; parks and recreational areas, 19.6 percent; and industrial and commercial uses account for less than 1 percent of the land (US Army Corps of Engineers 1973). Two small boat harbors with jetties are located along the coast at Wilson and at Olcott. Four state parks are also within the region: Fort Niagara, Fourmile Creek, Wilson Tuscarora, and Golden Hill.

Geology

Bluffs

The Niagara County coast is in the plain of what was Lake Iroquois during the glacial period. Except in areas of post-glacial stream dissection, the relief is less than 1 to 5 m (3 to 16 ft). Bluffs 4 to 15 m (13 to 49 ft) are continuous along the coast and are variably composed of red fine-grained sandstone of the Queenston formation sometimes covered with varying thicknesses of glaciolacustrine sand, silt, and clay from glacial Lake Iroquois. The longest exposed reach of bedrock along the Lake Ontario coast in New York lies in Niagara County beginning east of Olcott and reaching past Thirtymile Point when it rises to a maximum of 2.5 m or 8.2 ft (Leverett 1902; Kindle and Taylor 1913; Muller 1977a; Calkin, in preparation). The silt and clay content of the bluff materials increases and lacustrine deposits over the till become thicker west of Olcott. East of Olcott, glaciolacustrine deposits over the till are less continuous and sand and gravel contents of the bluff material are higher (Figure 2).

Beaches

Beaches in Niagara County are discontinuous and 1 to 6 m (3 to 19 ft) wide. East of Olcott (site 56), beaches are usually located between higher exposures of bedrock. To the west of site 56, beaches are more continuous and wider. Most are found west (prevailing drift) of small creeks entering the lake and are composed of coarse cobbles. Sand beaches, particularly those held by groins, are common at Olcott and Fort Niagara; however, in general, sand-sized material (particularly fine sand) does not remain on beaches.

Streams

The major tributary in the county is the Niagara River. Most of the Niagara River's sediment load is carried west (downdrift) off the coast or is deposited at its mouth (Sutton, Lewis, and Woodrow 1970; Pluhowski 1975). This is suggested by the scarcity of well-developed sandy beaches along the shore. Several other smaller streams enter the lake in Niagara County but most have insufficient discharge to carry appreciable amounts of sediment to the lake.

Nearshore Slopes

The slopes lakeward from the shoreline were determined at sites 1 through 67. Slopes from sites 67 through 75 could not be measured because the maps compiled in 1951 showed no depth contours. Slopes ranged from 1.8 to 17.0 m/km or 9.5 to 90 ft/mi (Table 3). The low slopes at the western end of the county are probably attributable to deltaic sedimentation at the mouth of the Niagara River (Sutton et al 1970; Pluhowski 1975). Steeper slopes occur from sites 52 through 67 where bedrock crops out near lake level.

Recession Rates

Recession History

We determined long- and short-term recession rates at the 75 sites indicated in Figures L-1 through L-11 and Table 4. The data show that 52 percent of the sites showed increased recession from the long term to the short term; 13.3 percent showed a decrease; 28 percent remained the same; and 6.7 percent could not be determined. The distribution of rates in each recesssion category is shown in Table 5. The mean recession rate for Niagara County from 1938 to 1951 was 0.79 m/yr (2.6 ft/yr). Long-term rates have a mean of 0.46 m/yr (1.5 ft/yr) and range from 0.00 m/yr at site 58 to 1.28 m/yr (4.2 ft/yr) at sites 34 and 35 (Figure L-4). Short-term losses in Niagara County amounted to nearly 0.5 km^2 (0.2 mi^2) of land while long-term losses amounted to approximately 2.3 km^2 (0.88 mi^2) from 1875 to 1974 over the county.

Erosion losses appear to be episodic; large amounts of recession take place during relatively short periods of time. Major increases or decreases in rates of recession may be related to episodic causes such as lake level and climatic phenomena (Davis et al 1973; Maresca 1974).

TABLE 3

Nearshore slopes: Niagara County

Site number*	Slope (m/km)	Site number	Slope (m/km)
1	1.9	35	6.7
2	1.8	36	8.5
3	1.8	37	8.8
4	1.9	38	7.6
5	2.6	39	7.5
6	2.6	40	7.5
7	3.2	41	7.3
8	3.7	42	6.5
9	5.7	43	6.4
10	7.5	44	6.5
11	7.0	45	6.8
12	6.9	46	6.6
13	6.3	47	6.0
14	6.8	48	5.9
15	7.7	49	6.5
16	8.6	50	6.2
17	7.0	51	7.1
18	7.4	52	12.3
19	7.9	53	14.7
20	8.2	54	13.4
21	7.7	55	13.9
22	8.3	56	8.6
23	8.6	57	12.1
24	8.5	58	13.4
25	8.6	59	17.0
26	8.2	60	15.0
27	8.2	61	14.7
28	8.1	62	11.4
29	8.2	63	12.9
30	7.9	64	13.4
31	7.5	65	13.2
32	7.4	66	13.4
33	6.7	67	14.7
34	6.3		

*Sites located on Figures L-1 through L-11

TABLE 4

Recession rates: Niagara County

Site number	Long-term recession rate (1875-1974)	Short-term recession rate (1938-1951)	Site number	Long-term recession rate (1875-1974)	Short-term recession rate (1938-1951)
1	---	Very slow*	38	Slow	Very slow
2	Slow*	Very fast*	39	Moderate	Very slow
3	Slow	Very fast	40	Slow	Slow
4	Slow	Very slow	41	Slow	Slow
5	Slow	Fast*	42	Moderate	Moderate
6	Moderate*	Very fast	43	Fast	Very slow
7	Moderate	Very fast	44	Fast	Very fast
8	Moderate	Very fast	45	Moderate	Moderate
9	Slow	Very fast	46	Slow	Slow
10	Slow	Very fast	47	Slow	Moderate
11	---	---	48	Slow	Slow
12	Moderate	Very fast	49	Moderate	Slow
13	Very slow	Very fast	50	Slow	Slow
14	Slow	Very slow	51	Slow	Moderate
15	Slow	Very fast	52	Slow	Slow
16	Very slow	Moderate	53	Slow	Fast
17	Slow	Fast	54	Slow	Very slow
18	Very slow	Moderate	55	Slow	Very slow
19	Very slow	Fast	56	Very slow	Very slow
20	Very slow	Slow	57	Very slow	Very slow
21	Slow	Slow	58	Very slow	Very slow
22	Very slow	Very slow	59	Very slow	Very slow
23	Very slow	Very slow	60	Very slow	Very slow
24	Very slow	Slow	61	Very slow	Very slow
25	Slow	Fast	62	Very slow	Fast
26	Slow	Slow	63	Slow	Very Fast
27	Slow	Moderate	64	Very slow	Very slow
28	Slow	Fast	65	Very slow	Slow
29	Slow	Fast	66	Very slow	Slow
30	Slow	Very fast	67	Slow	Very fast
31	Slow	Very fast	68	Slow	Very fast
32	Moderate	Very fast	69	Very slow	Moderate
33	Moderate	Very fast	70	Very slow	---
34	Very fast	Very fast	71	Very slow	---
35	Very fast	Very slow	72	Very slow	Very slow
36	Moderate	Very fast	73	Very slow	Slow
37	Moderate	Very slow	74	Very slow	Moderate
			75	Very Slow	---

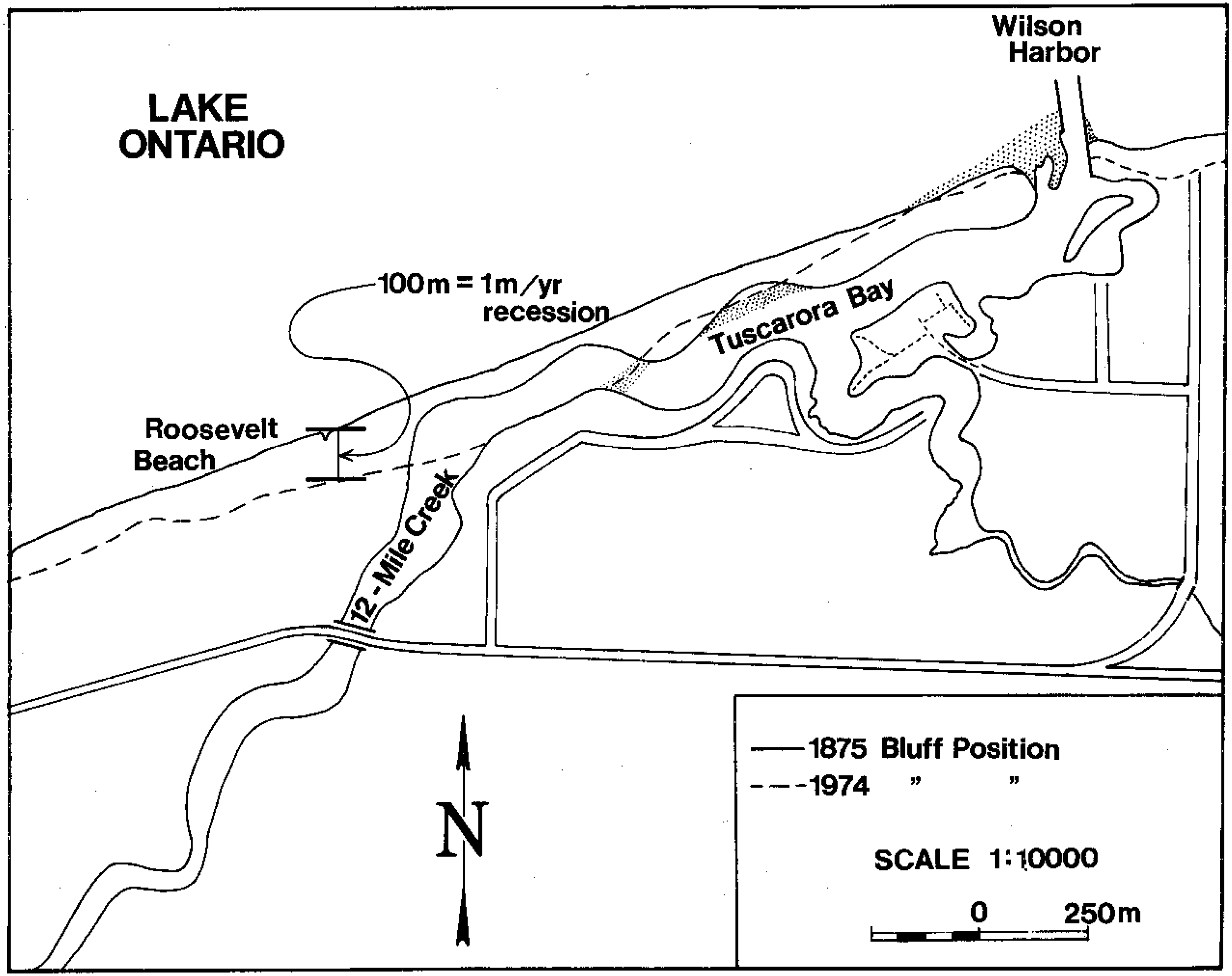
*Very slow=< 0.3 m/yr; slow=0.3-0.6 m/yr; moderate=0.6-0.9 m/yr; fast=0.9-1.2 m/yr; very fast=>1.2 m/yr.

TABLE 5

Distribution of Niagara County recession rates among the recession categories for the long and short term

Recession category	Long-term % of total sites	Short-term % of total sites
Very slow	33.7	26.7
Slow	42.7	18.7
Moderate	16.0	12.0
Fast	2.7	10.7
Very fast	2.7	26.7
Indeterminate	2.7	5.3

FIGURE 7 Twelvemile Creek in Wilson, NY area, showing 1875 and 1974 bluff positions (Note the change in location of the mouth of the creek during the 99-year period; for detailed location, see Figure L-4, Site 34 to Site 37.)



Recession rates are not uniformly distributed in the county, but rather decrease from west to east along the coast. Highest recession occurs in the West Branch/Twelvemile Creek area. Erosion in this area has been so severe (Figure 7) that the West Branch of Twelvemile Creek, which once entered Lake Ontario through Tuscarora Bay, has now been cut off (Fortune 1980).

Erosion Volumes

Material eroded from the bluffs is a significant source of sediment. However, little material from the bluffs, other than pebble to boulder sized rocks, appear to remain on the beaches (Fortune 1980). This helps explain the lack of well-formed beaches in Niagara County (US Army Corps of Engineers 1973).

Detailed calculations of annual erosion volumes for Niagara County for the periods 1875 to 1974 and 1938 to 1951 are shown in Table 6.

During the 13-year period, 1938 to 1951 (13.1 percent of the time), 22.5 percent of the total erosion losses occurred. In many short reaches, particularly in high recession areas such as near sites 3, 10, 15, and 29, greater than 50 percent of the total losses occurred between 1938 and 1951.

Interpretation of Recession

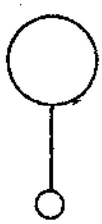
Distribution of recession throughout the county may be related to a number of factors. West of site 52, bedrock is not exposed near the water line. Moreover, there is a general lack of vegetation on the bluff face as most bluffs are steep and between 75° and 90° in slope. We first find exposed bedrock in Niagara County just east of Olcott near site 57; and bedrock exposures generally rise toward Thirtymile Point, site 75. Bluffs in the eastern parts of the county have lower slopes, greater vegetation, and bedrock toes, all of which help to explain the easterly decrease in recession rate. Between sites 57 and 75 recession episodes relate to periods of storminess, highwater levels, and high waves that increase erosion of the unconsolidated till and glaciolacustrine deposits above the bedrock. In addition, there are fewer protective structures in the western portion of the county, which must contribute to higher recession losses in these areas (US Army Corps of Engineers 1945, 1970).

FIGURES L-1 to L-11

LOCATION MAPS FOR

NIAGARA COUNTY

Scale on all maps: 1:24,000 or 1 inch = 2000 ft.



Indicates site and number where recession was measured.

North is always at the top of the figure.

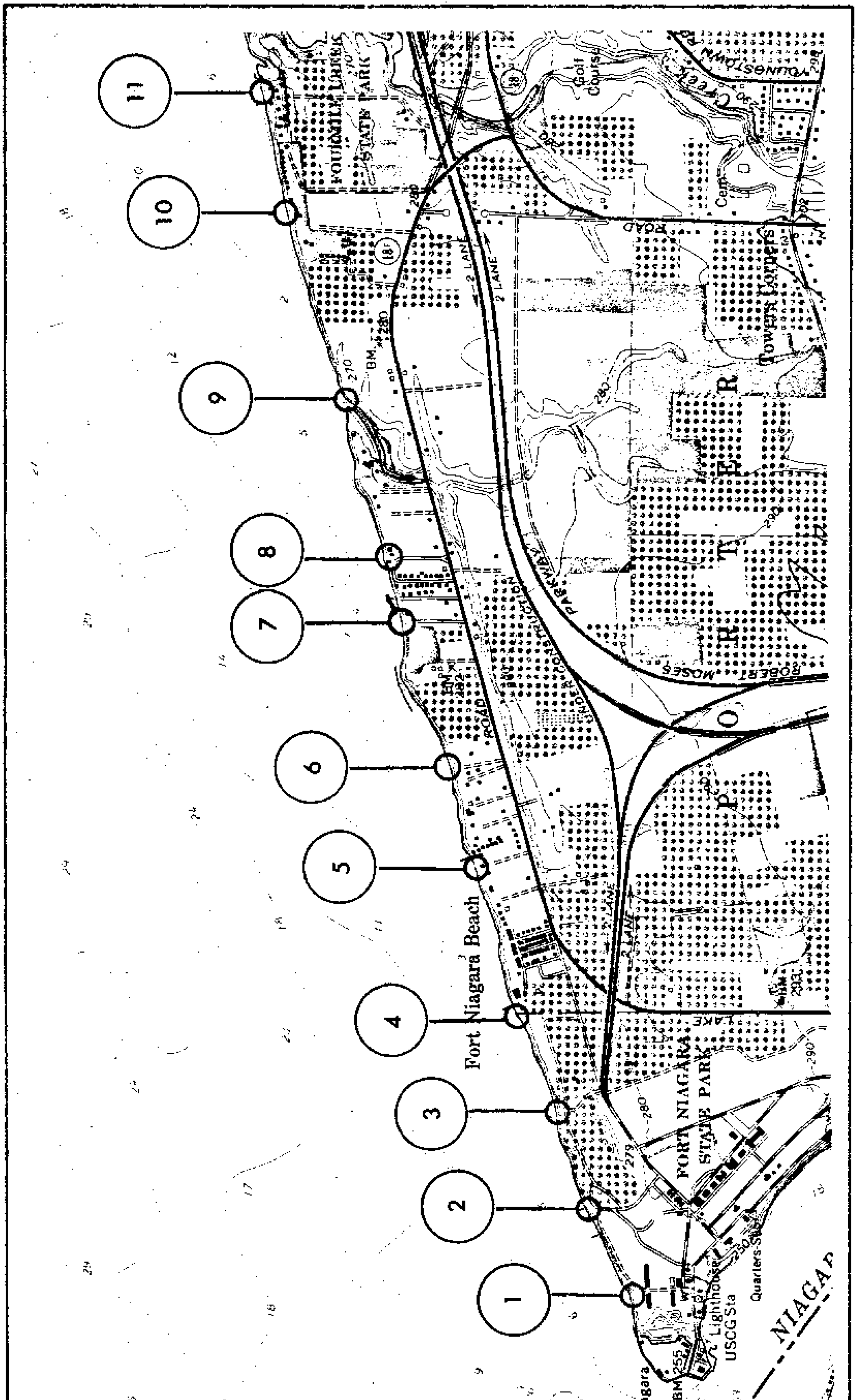

1
2
3
4
5
6
7
8
9
10
11
Fort Niagara Beach
FORT NIAGARA
STATE PARK
Towers Corners
ROBERT MOSES
PARKWAY
Lighthouse
USCG Sta
Quarters
Golf Course

Figure L-1

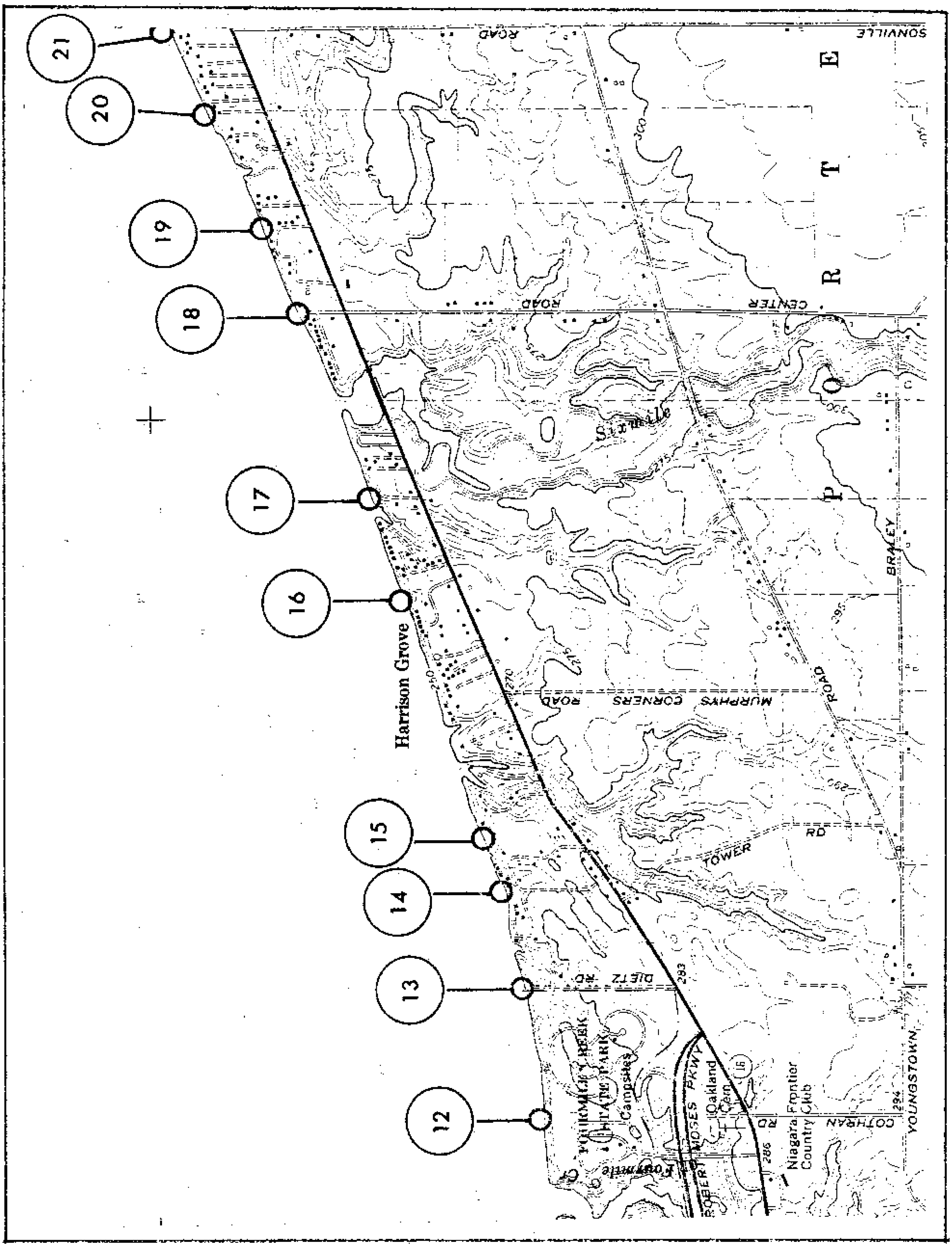
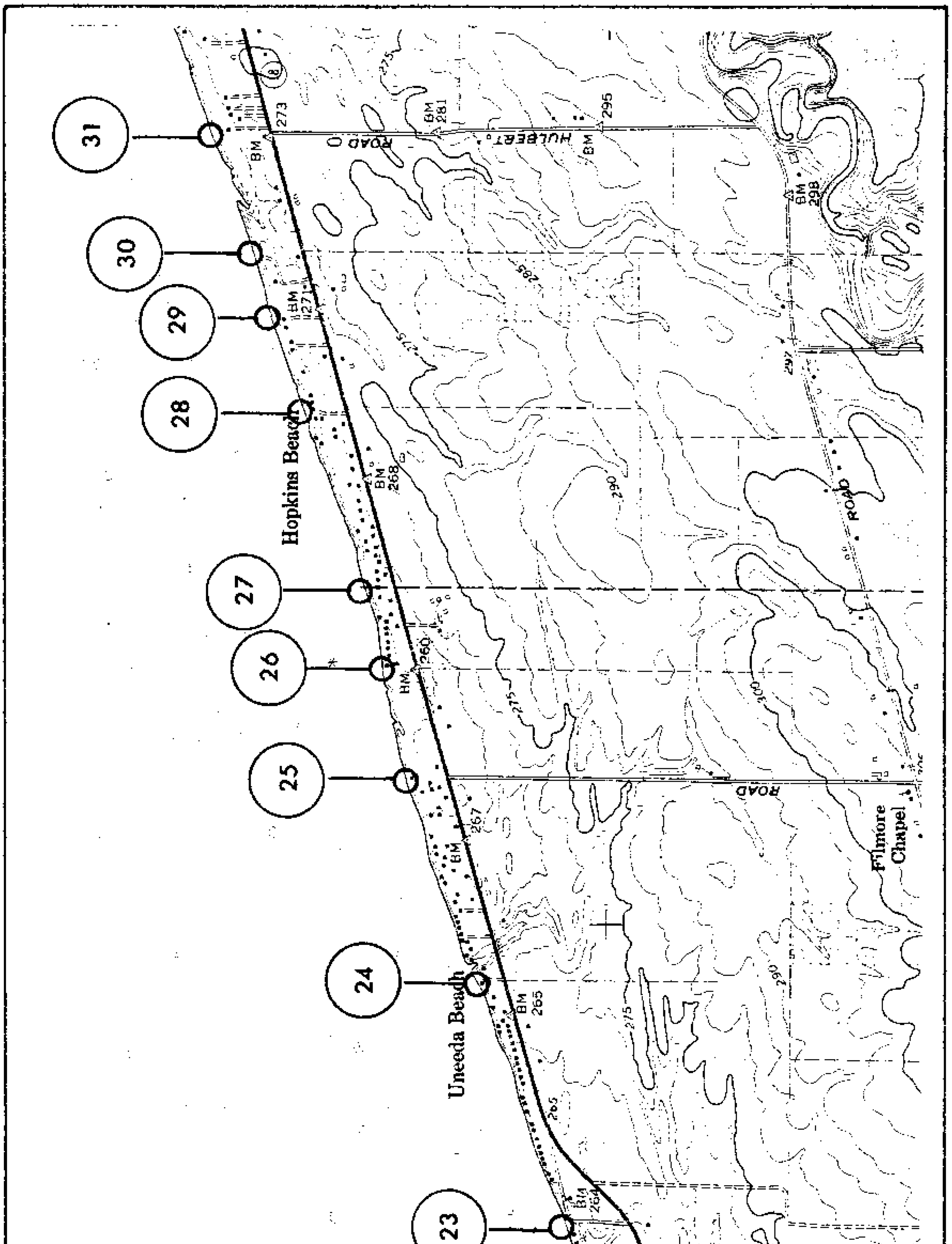
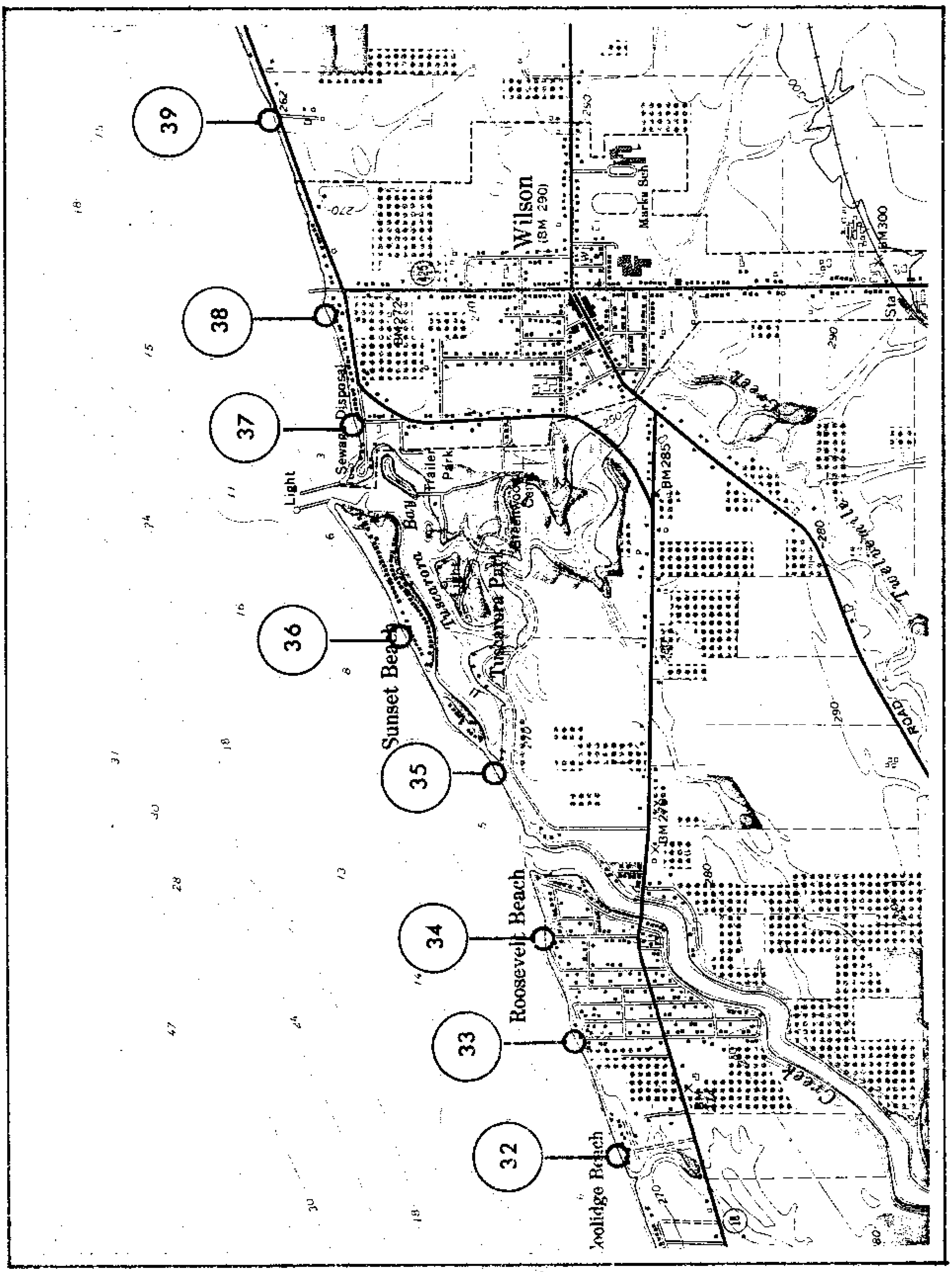

12
13
14
15
16
17
18
19
20
21
Harrison Grove
Sixmile
MURPHYS CORNERS ROAD
TOWER RD
DIETZ RD
CENTER ROAD
BRALEY
YOUNGSTOWN
COTHRAN RD
Niagara Frontier Country Club
Oakland Cem
ROBERT MOSES PKWY
Campsites
R
T
E
P
O

Figure L-2



31
30
29
28
27
26
25
24
23
22
Hopkins Beach
Uneeda Beach
Filmore Chapel
HULBERT ROAD
ROAD

Figure L-3



32
33
34
35
36
37
38
39
Wilson
(BM 290)
Sunset Beach
Roosevelt Beach
Tuscarora Bay
Tuscarora Park
Trailer Park
Sewage Disposal
Light
BM285
ROAD

Figure L-4

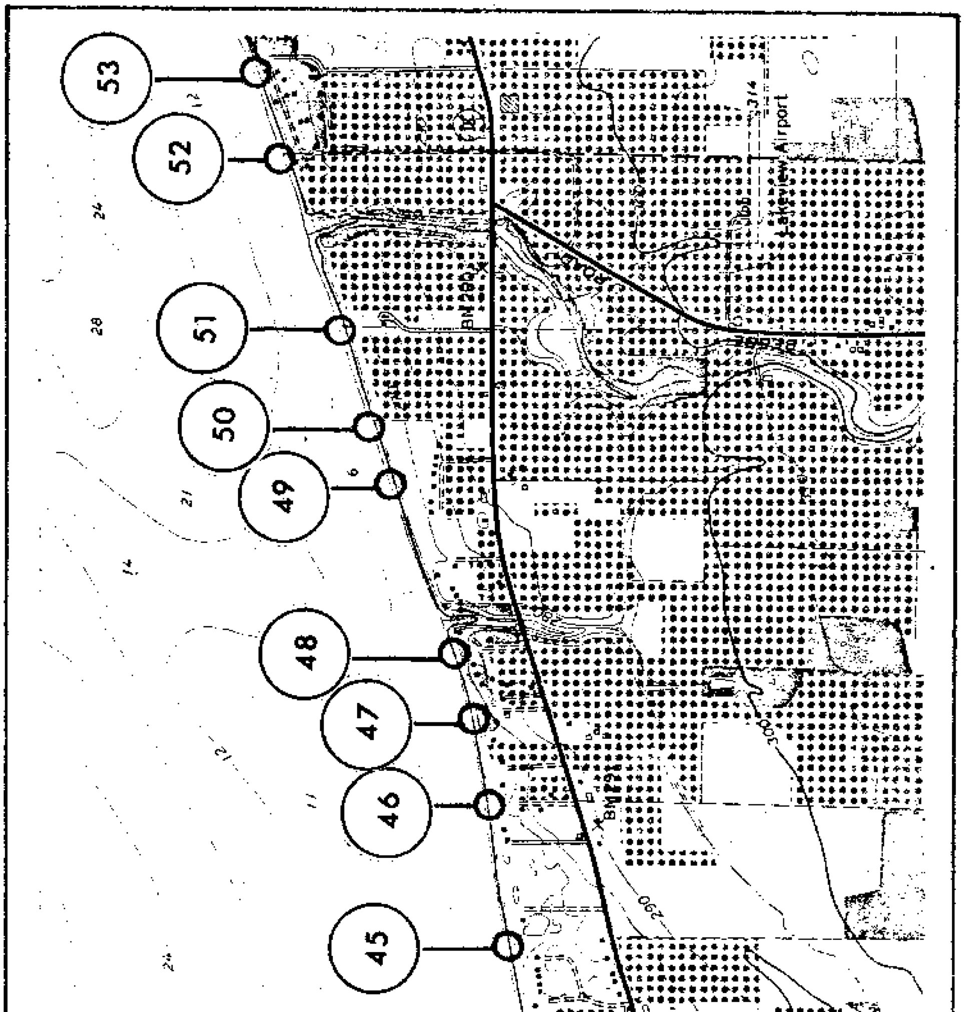


Figure L-5

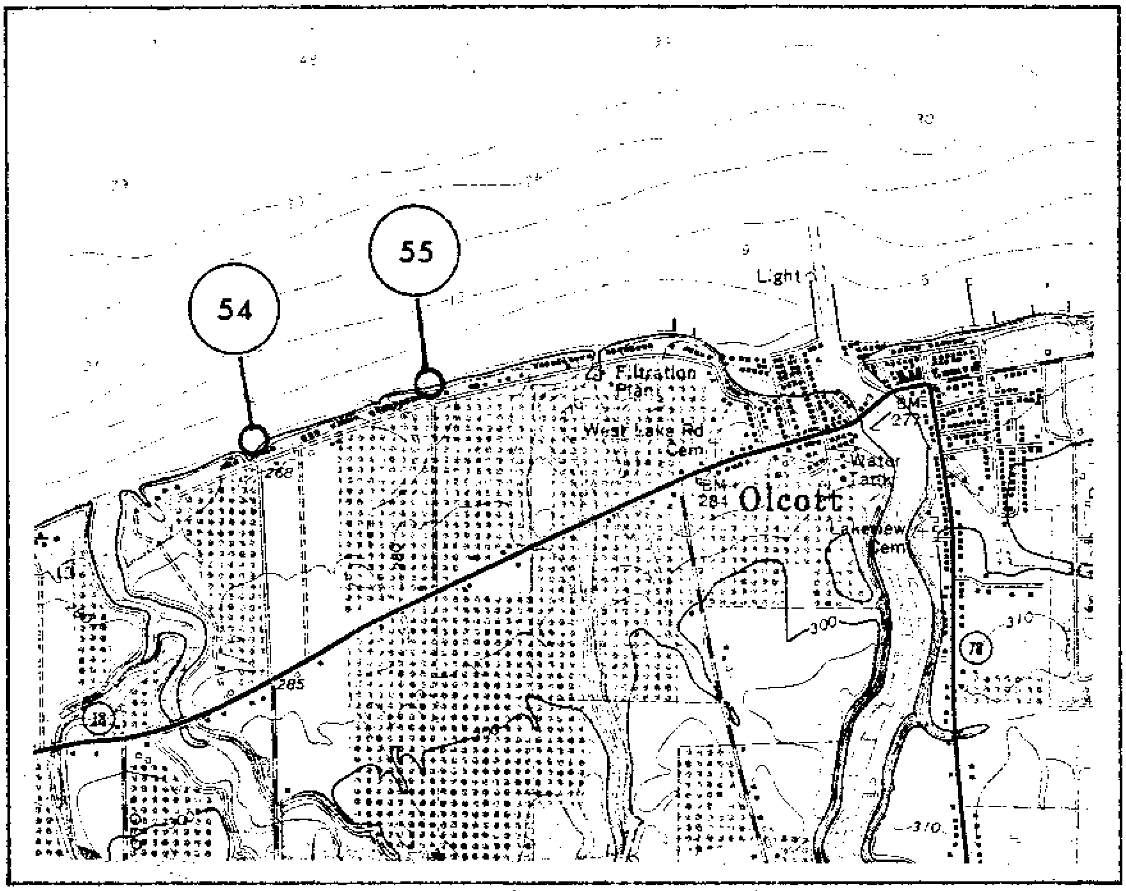


Figure L-6

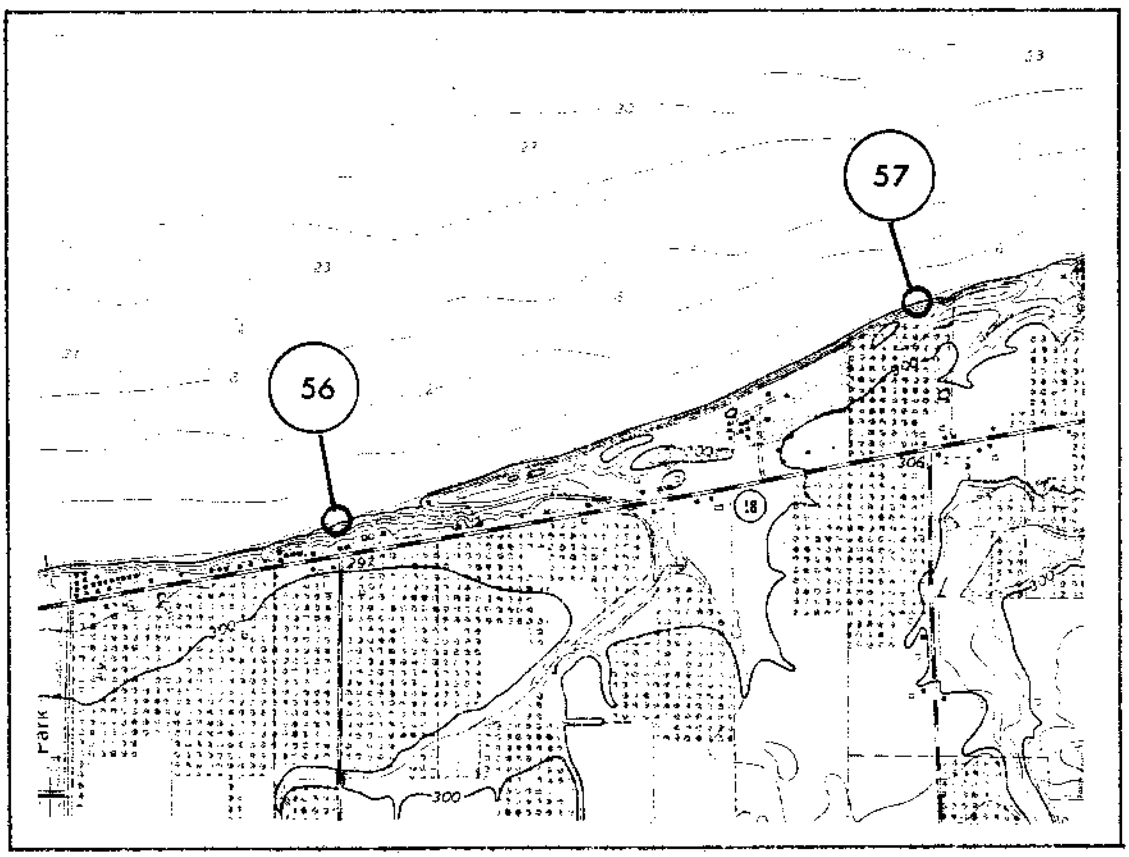
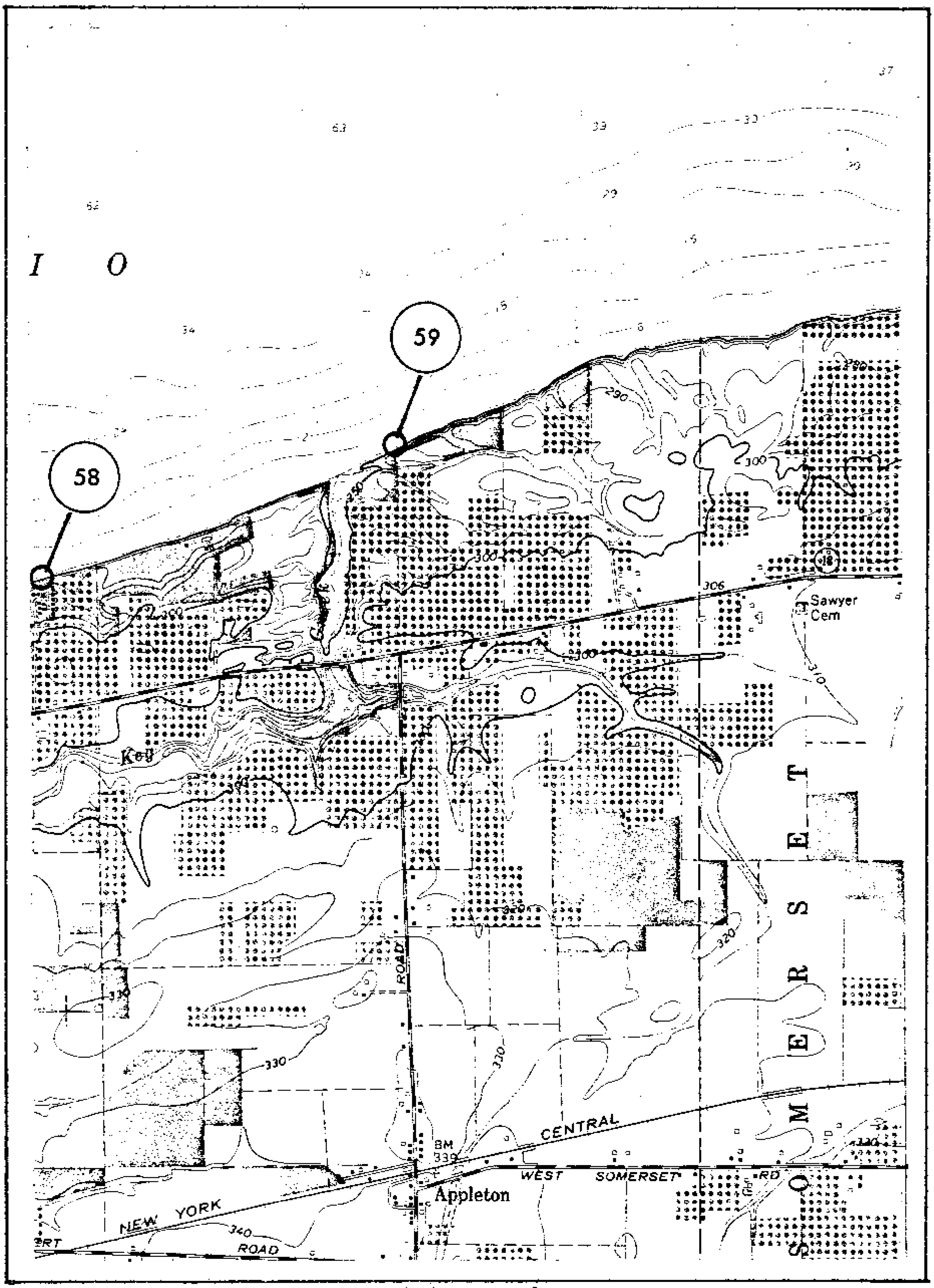


Figure L-7



O
59
58
Sawyer
Cem
Keg
ROAD
S O M E R S E T
CENTRAL
BM
339
WEST
SOMERSET
RD
Appleton
NEW YORK
ROAD

Figure L-8

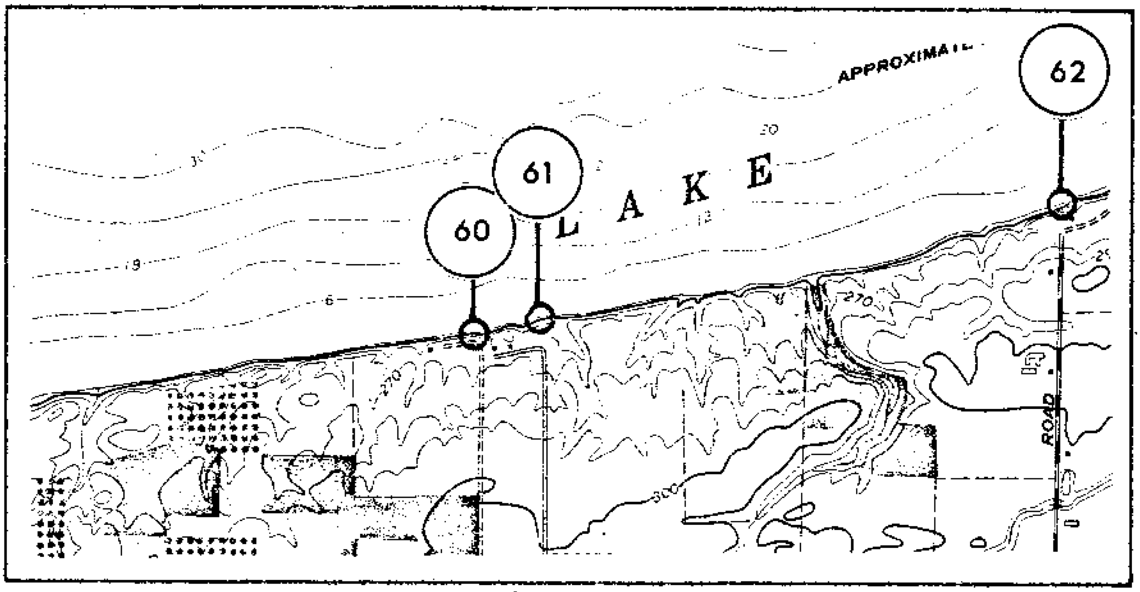


Figure L-9

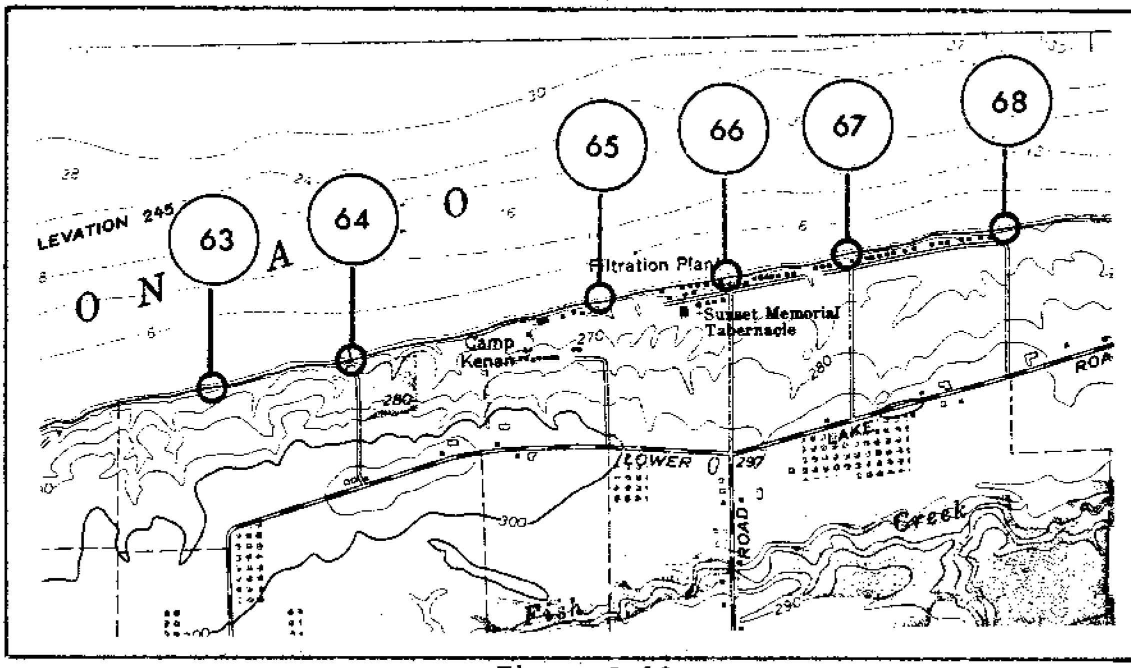


Figure L-10

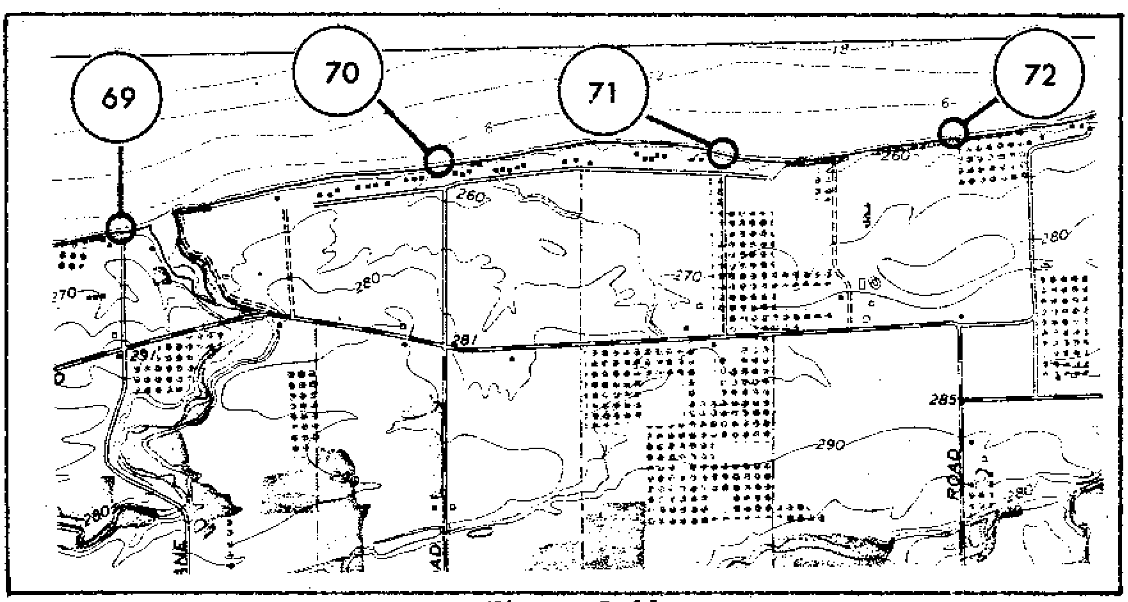


Figure L-11

TABLE 6

Mean annual erosion volumes in Niagara County for the periods 1875-1974 and 1938-1951

Term	Average bluff height	x	Length of shore	x	Mean recession rate	=	Mean annual erosion volume
1875-1974	9 m		49,900 m		0.46 m/yr		2.07×10^5 m^3/yr
1938-1951	9 m		49,900 m		0.79 m/yr		3.55×10^5 m^3/yr

Orleans County

Geography

Location

Orleans county, with 40 km (24.9 mi) of coast on Lake Ontario, stretches from Thirtymile Point on the west, to an eastern boundary near Troutburg (Figure 1). We measured recession at 34 sites along the coast as indicated on Figures L-12 through L-23. Because Orleans County is less developed and has fewer roads or other landmarks for measurement sites, we found fewer locations here for measurement than we found in Niagara County.

Land Use

Residential uses occupy approximately 57 percent of the Orleans County coast. Housing density is low; perhaps 20 to 30 percent of the homes are only used seasonally. Agricultural lands occupy approximately 35 percent of the coast; public and recreational lands about 8 percent. Two parks are in this region: a portion of Golden Hill State Park at Thirtymile Point and Lakeside Beach State Park near Knuckville (Figures L-12 and L-17). Because population density is low along the coast, erosion is a critical factor only in limited areas (Dobson and Henderson 1976).

Geology

Bluffs

The coast of Orleans County trends uniformly east-west, with five sharp protrusions of land into the lake near sites 86, 93, 99, 100, and 107 (Figures L-15, -16, -17, -19, -20, -23). Bluffs 2 to 6 m (7 to 20 ft) high are composed of Queenston bedrock overlain first by 1 to 3 m (3 to 10 ft) of purplish-gray till and then by 0.5 to 3 m (1.6 to 10 ft) of lacustrine deposits (Calkin, in preparation). The Queenston fine sandstone bedrock is exposed only near Shadigee and east of Thirtymile Point; it is usually less than 1 m (3 ft) above lake level. The bedrock above the lake reaches a maximum height of 2 m (6.6 ft) at Golden Hill. In most locations, sand and gravel make up about half the bluff material, but near Point Breeze (site 99) and the eastern border of the county (Brennan 1980), sand and gravel make up over half the bluff material. Toward the eastern portion of the county (sites 98 to 109), till thickness decreases until bluffs are composed almost entirely of glaciolacustrine deposits (Figure 2). Streams entering the lake flow east-northeast, paralleling the direction of the last glacier movement.

Beaches

Beaches, consisting largely of cobbles, occur only intermittently along the coast, and are less than 6 m (20 ft) wide. There are few sources of beach-sized sediment within the area. The greatest accumulation of beach material occurs from sites 95 to 97 and from 99 to 109, east of Johnson Creek and Oak Orchard Creek (Figures L-19 and L-20).

Streams

Tributaries are few and their discharges too small to contribute significant volumes of coarse sediment.

Recession Rates

Recession History

We determined recesssion rates at the 34 sites shown on Figures L-12 through L-23. These rates are shown in Table 7. We could not determine long-term rates for sites 96 to 99 because not enough coastal landmarks matched both the 1974 photos and the 1875 survey. Table 8 indicates the percentage of sites in each recession category for both the long and the short term. An increase in recession rates from the long term to the short term appeared in 41 percent of the sites measured; 35 percent remained the same; 12 percent decreased; and 12 percent was indeterminable due to missing data. Short-term recession rates reached a maximum of 1.70 m/yr (5.6 ft/yr) at site 93. Mean recession along the Orleans County coast was 0.44 m/yr (1.4 ft/yr) from 1938 to 1954. Long-term rates were lower, ranging from 0.00 m/yr at site 83 to 0.56 m/yr (1.8 ft/yr) at sites 101 and 109. Mean recession between 1875 and 1974 was 0.29 m/yr (0.95 ft/yr) along the Orleans County coast.

Between 1875 and 1974 approximately 1.2 km^2 (0.46 mi^2) of land were lost as a result of recession; between 1938 and 1954 approximately 0.28 km^2 (0.1 mi^2) were lost. Recession rates for the short term are nearly 200 percent higher than those for the long term. Sites 76, 93, 101, and 109 show radical rate increases from the long term to the short term. Between 1938 and 1954, site 93 had the highest recession rate: 1.70 m/yr (5.6 ft/yr). This site also had the second highest rate, 0.50 m/yr (1.6 ft/yr) between 1875 and 1974. Highest long-term rates are at sites 101 and 109, with rates of 0.60 m/yr (1.97 ft/yr).

Erosion Volumes

In Orleans County, the average bluff height is low, approximately 2.12 m (6.96 ft) and erosion of the bluffs is slow. As a result, little sediment derives from bluff erosion. Annual erosion volumes for the periods between 1875 and 1974 and between 1938 and 1954 are shown in Table 9. Approximately 25 percent of the total erosion losses for 99 years occurred between 1938 and 1954, 16.2 percent of the time.

Interpretation of Recession

Long-term recession is fairly uniform along the coast; all sites had less than 0.60 m/yr (1.97 ft/yr) recession. Two factors probably account for this: the regularity of the coast line, with few large protrusions of land into the lake, and the relatively uniform height and continuity of the bluffs.

TABLE 7

Recession rates: Orleans County

Site number	Long-term recession rate (1875-1974)	Short-term recession rate (1938-1954)	Site number	Long-term recession rate (1875-1974)	Short-term recession rate (1938-1954)
76	Slow*	Very fast*	93	Slow	Very fast
77	Slow	Fast*	94	Slow	Moderate
78	Very slow*	Slow	95	Slow	Very slow
79	Very slow	Moderate*	96	---	Moderate
80	Very slow	Slow	97	---	Very slow
81	Very slow	Slow	98	---	Slow
82	Very slow	Very slow	99	---	Very slow
83	Very slow	Very slow	100	Very slow	Very slow
84	Very slow	Slow	101	Slow	Very fast
85	Very slow	Very slow	102	Slow	Very fast
86	Very slow	Moderate	103	Slow	Moderate
87	Very slow	Very slow	104	Slow	Slow
88	Slow	Very slow	105	Very slow	Very slow
89	Very slow	Very slow	106	Slow	Very slow
90	Very slow	Very slow	107	Slow	Slow
91	Very slow	Very slow	108	Very slow	Very slow
92	Very slow	Moderate	109	Slow	Very fast

*Very slow=<0.3 m/yr; slow=0.3-0.6 m/yr; moderate=0.6-0.9 m/yr; fast=0.9-1.2 m/yr; very fast=>1.2 m/yr.

TABLE 8

Distribution of Orleans County recession rates among the recession categories for the long and short term

Recession category	Long-term % of total sites	Short-term % of total sites
Very slow	50.0	44.1
Slow	38.2	20.6
Moderate	0.0	17.6
Fast	0.0	2.9
Very fast	0.0	14.7
Indeterminate	11.8	0.0

TABLE 9

Mean annual erosion volumes in Orleans County for the periods 1875-1974 and 1938-1954

Term	Average bluff height	x	Length of shore	x	Mean recession rate	=	Mean annual erosion volume
1875-1974	2.12 m		40,400 m		0.29 m/yr		2.48×10^4 m^3/yr
1938-1954	2.12 m		40,400 m		0.44 m/yr		3.77×10^4 m^3/yr

Short-term rates are less uniform, indicating that erosion is episodic. For example, at site 93, 55 percent of the total 99-year losses occurred in only 16 years. As a result, areas with lower rates between 1938 and 1954 may, either since 1954 or at some future time, undergo greater erosion to maintain uniform long-term recession rates.

Greatest recession, 0.60 to 1.70 m/yr (1.97 to 5.6 ft/yr) along the coast of Orleans County is confined to a limited number of reaches. Highest recession appears to be in the following four areas (Figures L-12 through L-23): (1) western county line to Marshall Road, sites 76-82; (2) Morrison Road to Rock Ledge Beach, sites 91-96; (3) Brighton Cliff to Peter Smith Road, sites 100-104; and (4) near the eastern county line, sites 108 and 109.

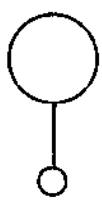
The areas between sites 76 and 79 and between 80 and 82 are of particular concern because a number of residences are located in these areas.

FIGURES L-12 to L-23

LOCATION MAPS FOR

ORLEANS COUNTY

Scale on all maps: 1:24,000 or 1 inch = 2000 ft.



Indicates site and number where recession was measured.

North is always at the top of the figure.

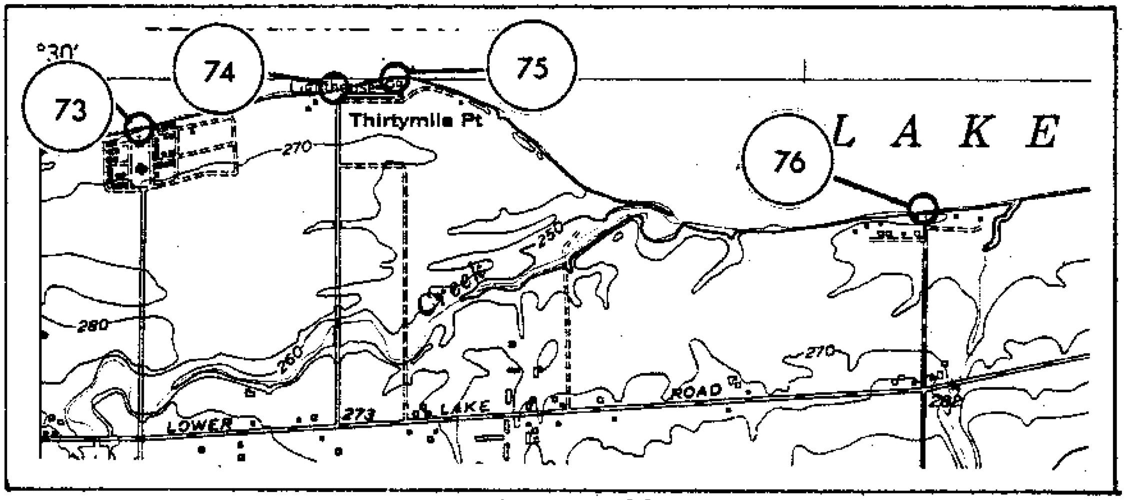


Figure L-12

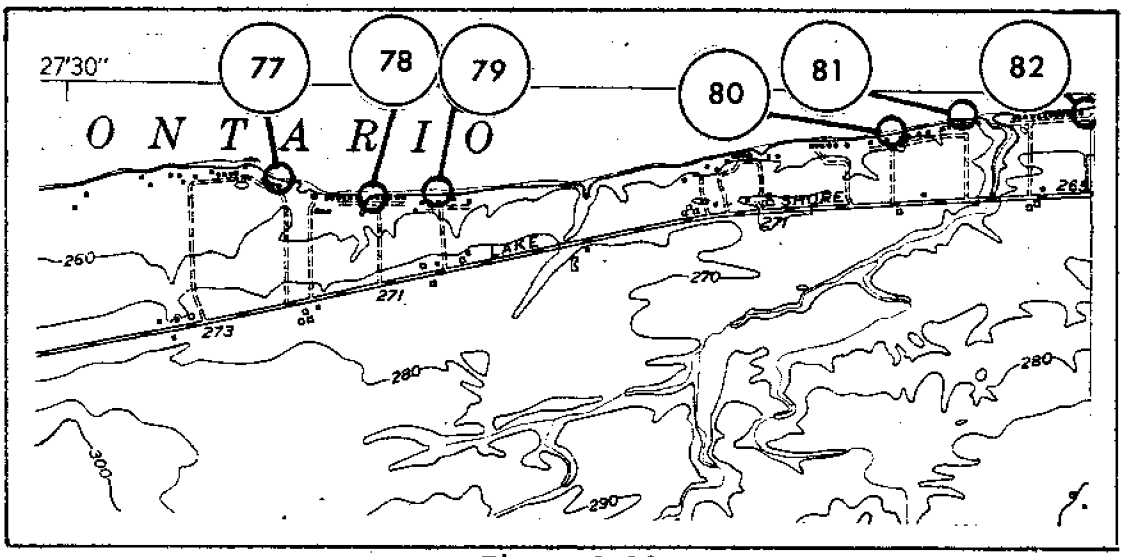


Figure L-13

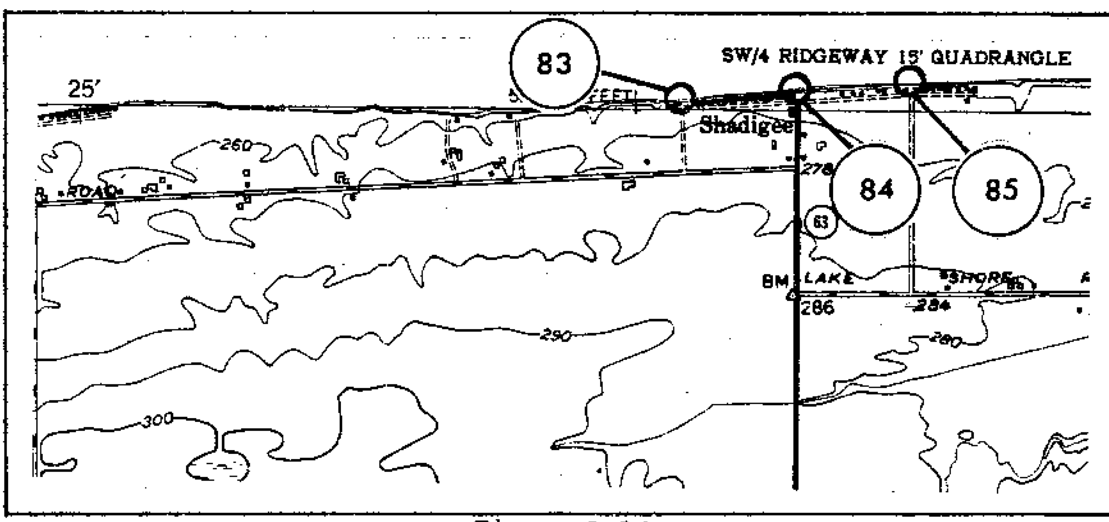


Figure L-14

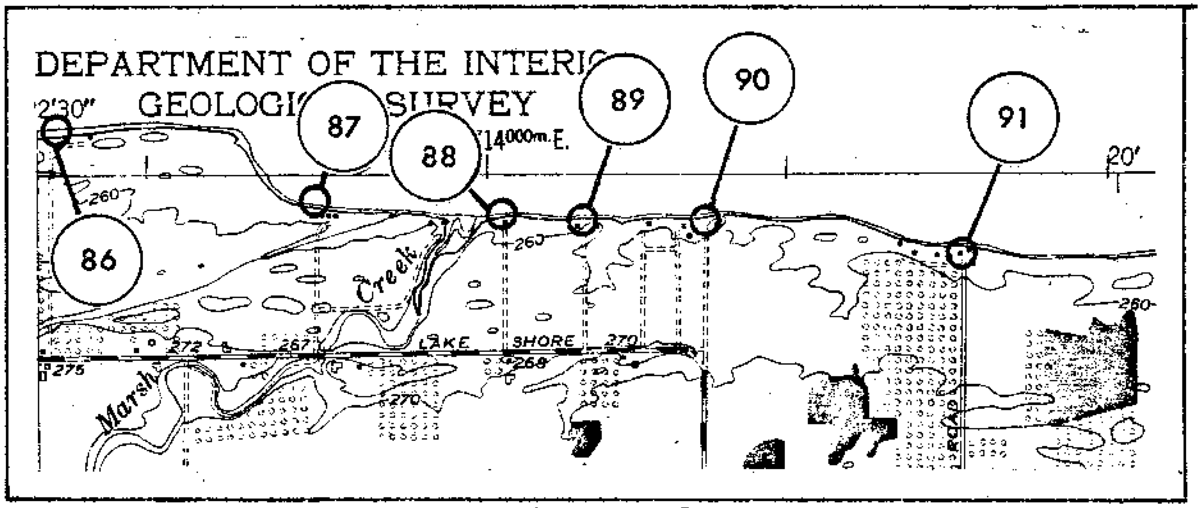


Figure L-15

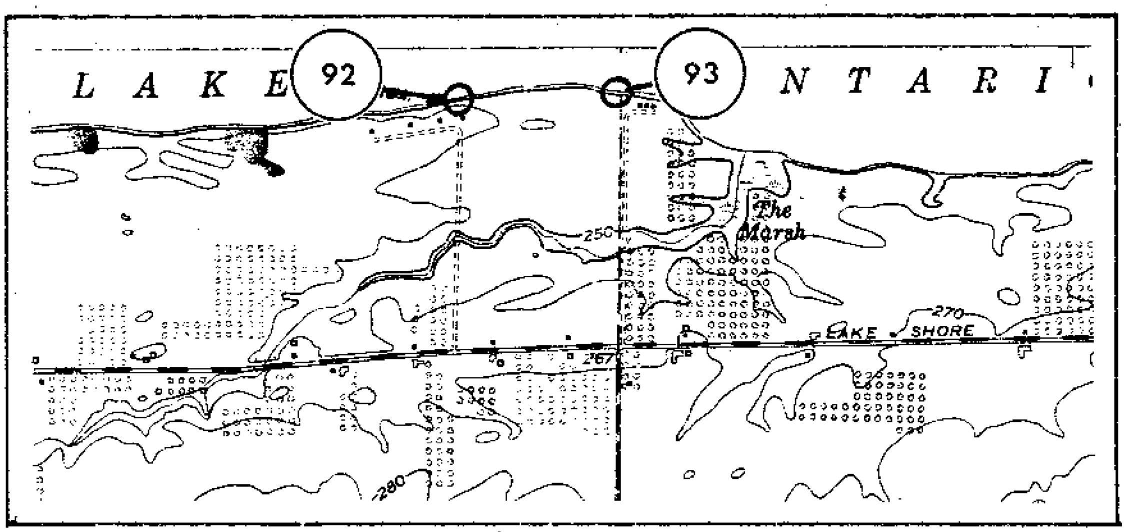


Figure L-16

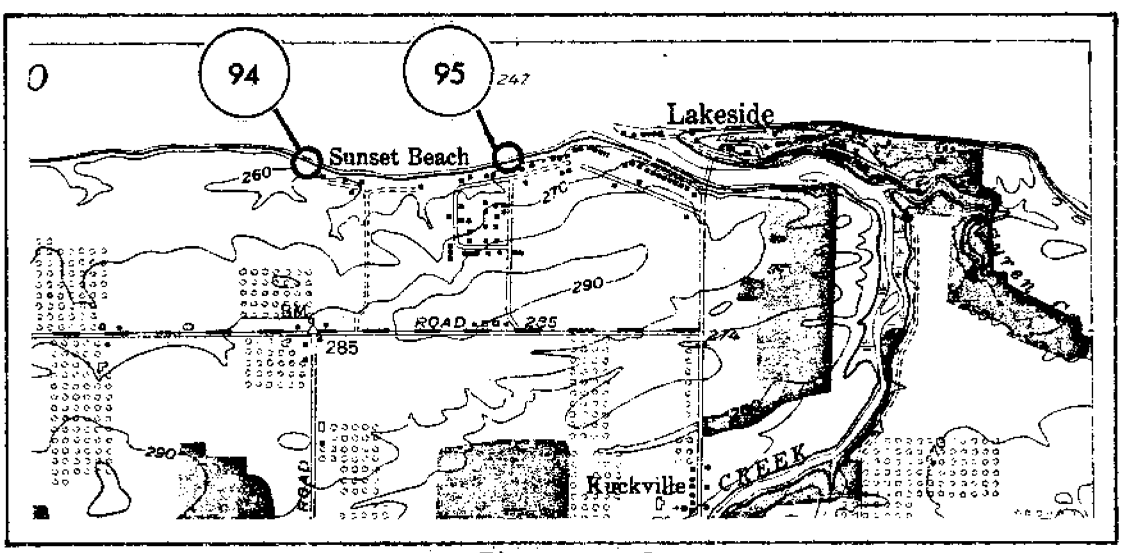


Figure L-17

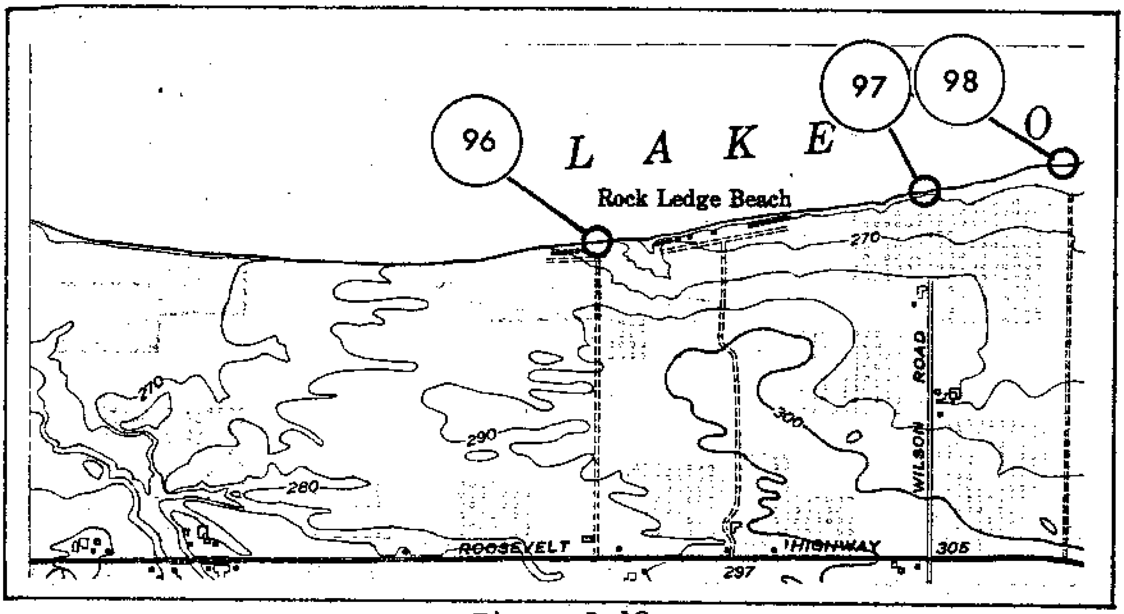


Figure L-18

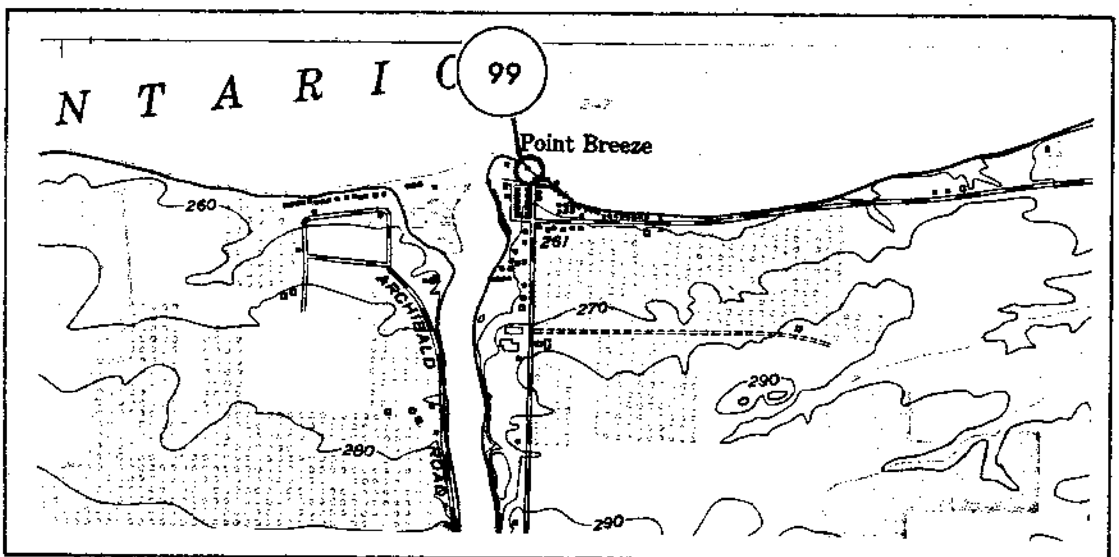


Figure L-19

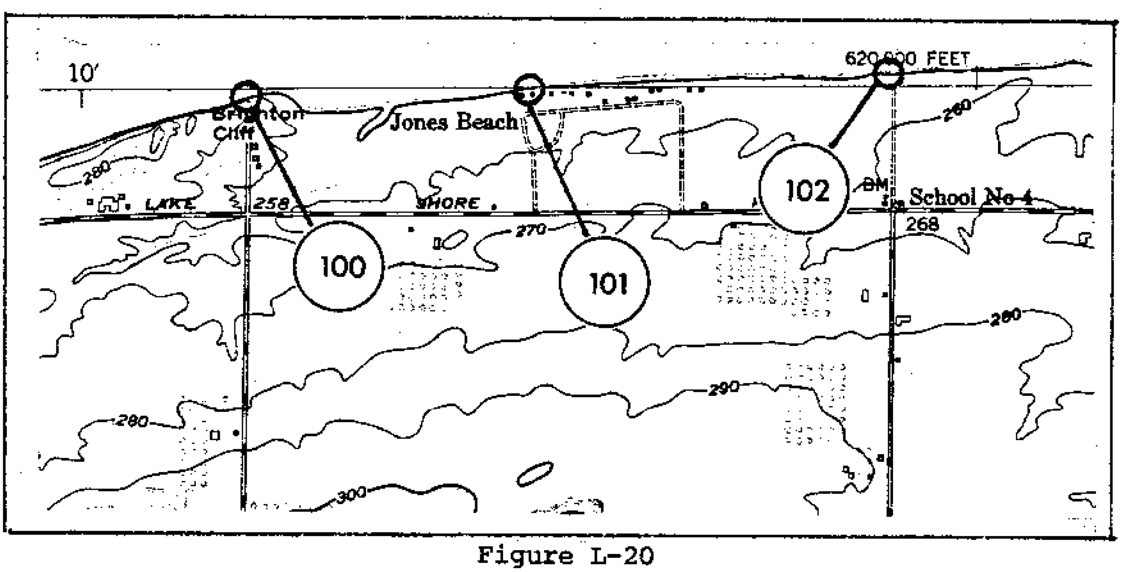


Figure L-20

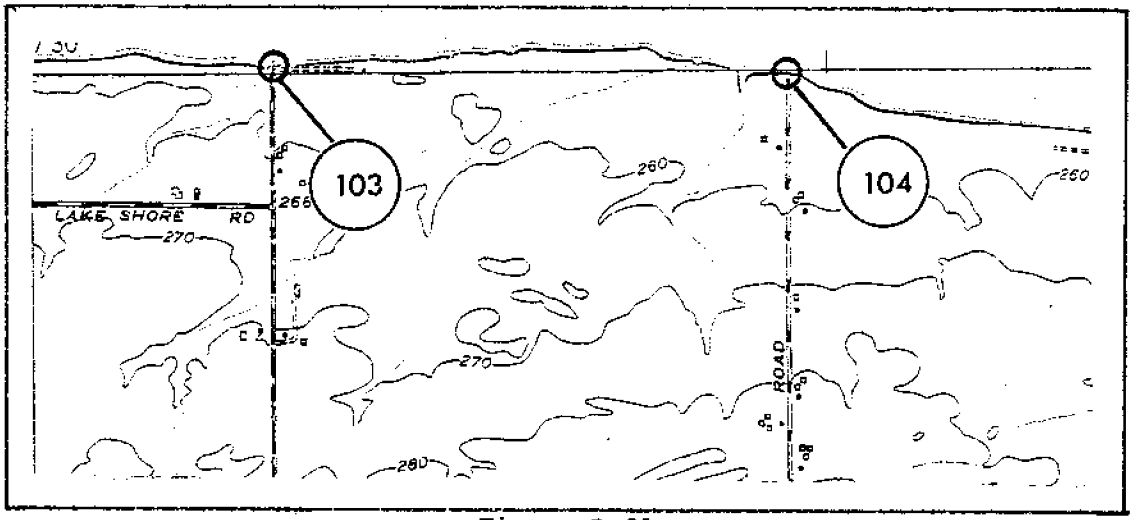


Figure L-21

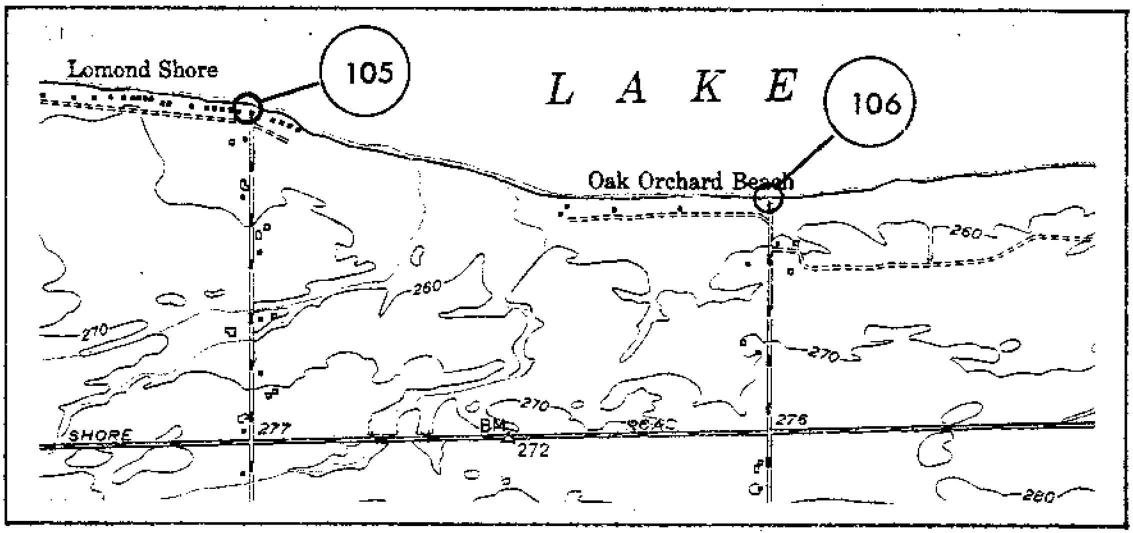


Figure L-22

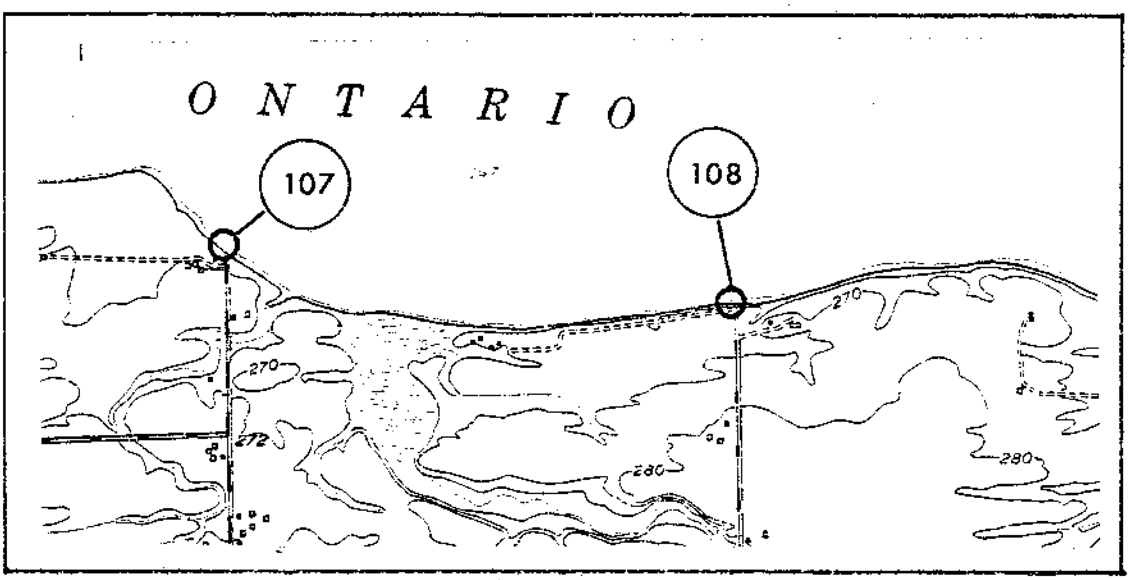


Figure L-23

Monroe County

Geography

Location

From a western boundary near Troutburg, Monroe County stretches eastward 60 km (37.3 mi) to the county line northeast of Webster. We measured recession rates at 50 locations indicated on Figures L-24 through L-37.

Land Use

Monroe County is the most developed region of the Lake Ontario coast in New York State (Dobson and Henderson 1976). Residential and commercial purposes account for nearly 51 percent of coastal land use in this region; agricultural uses account for 26 percent; and recreational about 23 percent (US Army Corps of Engineers 1973). The City of Rochester and its associated suburban development are responsible for the relatively high land use intensity along the coast of Monroe County. The Monroe County coastline includes five parks: parks at Hamlin Beach, Braddock Bay, and three other parks--Ontario Beach, Durand Eastman, and Webster Park.

Much of the coast was developed by 1875; since then the coast has been protected to various degrees and by various methods. Stone revetments and seawalls are common and are reflected in lower recession rates.

Geology

Bluffs

The coastal region west of the Genesee River (Figure 3) consists primarily of low lake plains and wetlands fronted by cobble barrier beaches. Bluffs in this region are generally less than 2 m (6.6 ft) high but reach maximum heights of 24 m (79 ft) at Devil's Nose (Figure L-24). Bluff material is rarely exposed; most is covered by protective structures. The bluffs are composed of lacustrine silts and sands with a few isolated regions of glacial till near Hamlin Beach and drumlins at Braddock Bay (Figures L-25, L-30, L-31). Pebble- and cobble-size material is scarce except at the high bluff of Devil's Nose composed of well-sorted sands with more resistant cemented gravels at the base.

Wetlands comprise a large portion of the coast. The largest wetland area is at Braddock Bay; it consists of ponds separated by drumlins, the most prominent is Rigney Bluff (Figure L-32). Bedrock is exposed about 1 m (3 ft) above lake level 3 km (1.9 mi) east of Hamlin Beach, although the remainder of the region lacks rock exposures.

East of the Genesee River the bluffs rise 12 to 18 m (39 to 59 ft) above lake level. Depositional relief is moderate to low; most relief is due to post-glacial stream dissection. The bluff material consists primarily of lacustrine sands and silts. Sand content of the bluff materials decreases as we move east from Irondequoit Bay and sandy clay contents increase (Figure 2). In much of this area, red stony till is overlaid by a gray clayey till. A large drowned valley forms Irondequoit Bay, fronted by a wide barrier beach composed of sand to pebble-size materials.

Beaches

Beaches west of Rochester are poorly developed and narrow, usually less than 10 m (33 ft) wide. Most have steep profiles (about 12 to 16 percent gradient), and are composed of coarse cobbles 80 to 100 mm (3 to 4 in) in diameter. Wide sand beaches held in place by groins occur at Hamlin Beach and Braddock Bay (Figures L-25 and L-31). Sand has also accumulated on the western side of the jetty at the Genesee River, forming Ontario Beach (Figure L-33) approximately 24 m (78 ft) wide. Natural beaches are usually confined to barrier beaches that cross inlets into swamps and marshes. Many beaches, such as Shore Acres and Braddock Point (Figures L-27 and L-30), are without beach protection and rely entirely on man-made structures to resist erosion.

East of Rochester, beaches are wider and more fully developed. Sand beaches greater than 24 m (78.7 ft) wide are found between the Genesee River and Irondequoit Bay. Beyond Irondequoit Bay, beaches tend to narrow in an eastward direction. These beaches are composed mostly of pebbles; because of this they are steeper than the wider beaches to the west (Coch 1961).

Streams

Of some 15 major tributaries entering Lake Ontario in Monroe County (Figures L-24 through L-37), six enter Lake Ontario through ponds and marshes, preventing the coarse sediment they carry from entering the littoral zone.

The Genesee River is the most significant tributary; sediment yield equals 76,000 tons/year (Upchurch 1973). Jetties are at the mouth of the river; however, enough sediment is in the shore zone to maintain sand beaches east of the river (Woodrow, Sutton, and Rukavina 1967).

Nearshore Slopes

Slopes of the nearshore zone ranged from 5.1 to 21.4 m/km or 27 to 113 ft/mi (Table 10). The steepest slopes are in the vicinity of Benedict Beach and Shore Acres (Figure L-27) and east of Irondequoit Bay (Figures L-35 through L-37). No apparent trend of the slopes exists within the county except that beaches are poor in regions with steep slopes.

Recession Rates

Recession History

We measured recession rates at the 50 sites indicated on Figures L-24 through L-37. Results are shown in Table 11. The distribution of rates in each recession category is shown in Table 12. The short-term rate is higher than the long-term rate at 40 percent of the sites; rates are the same at 50 percent of the sites; and long-term rates are greater than short-term at 8 percent of the sites. Rates could not be determined at site 153 because of man-made changes. Short-term rates ranged from 0.00 m/yr at sites 141 to 146 to 1.10 m/yr (3.6 ft/yr) at site 116. Mean recession between 1938 and 1951 was 0.41 m/yr (1.3 ft/yr) along the Monroe County coast. Mean recession for the long term, 0.21 m/yr (0.7 ft/yr), is much lower and ranged from 0.72 m/yr (2.4 ft/yr) at sites 133 and 114 to 0.00 m/yr at sites 141 to 146.

Erosion Volumes

Little sediment derives from erosion of the bluffs; highest recession mean rate of 0.52 m/yr (1.7 ft/yr) between 1938 and 1951 is found west of Rochester from sites 110 to 139 (Figures L-24 to L-33). This area consists mainly of wetlands that contribute little sediment from erosion. Along the eastern portions of the county, from sites 143 to 159, erosion is confined to points of land that protrude into the lake. Little sediment derives from such erosion. Calculated erosion volumes are as shown in Table 13. The area between the Genesee River and Irondequoit Bay was not considered since no detectable recession was found there for either the short or long term.

Interpretation of Recession

Recession rates are higher in the region west of Rochester than in the region to the east. This is documented by the average recession rates shown in the erosion volumes calculated in Table 13. Some conditions that may be responsible for the high erosion in the western region of the county are the following:

- Most of the region consists of easily eroded low bluffs or wetlands.
- The higher bluffs in this region are composed largely of easily eroded sands.
- Regions of higher sand bluffs protrude into the lake and are more subject to wave attack.
- Beaches are scarce and poorly developed west of Rochester.

Erosion in Monroe County is uniform over time as shown by the low rates for both the short and the long term (Table 11). A possible explanation for this is that regions where recession measurements were made were developed 100 years ago and the sites have been protected for long periods.

TABLE 10

Nearshore slopes: Monroe County

Site number*	Slope (m/km)	Site number*	Slope (m/km)
109	9.4	134	5.2
110	10.3	135	6.0
111	11.1	136	8.4
112	8.8	137	7.9
113	8.8	138	N/A
114	9.5	140	N/A
115	10.1	141	N/A
116	8.9	142	N/A
117	8.4	143	21.4
118	9.5	144	10.7
119	9.4	145	9.1
120	10.0	146	7.2
121	11.7	147	7.5
122	10.1	148	6.3
123	9.7	149	6.7
124	8.5	150	6.9
125	10.0	151	8.0
126	5.1	152	7.5
127	8.7	153	7.5
128	8.3	154	7.1
129	8.3	155	11.9
130	7.1	156	14.1
131	7.9	157	13.6
132	6.1	158	9.8
133	5.2	159	10.0

N/A = Nearshore slope unable to be determined at the site.

*Sites located on Figures L-24 through L-37

TABLE 11

Recession rates: Monroe County

Site number	Long-term recession rate	Short-term recession rate	Site number	Long-term recession rate	Short-term recession rate
110	Moderate*	Moderate	135	Very slow	Very slow
111	Moderate	Moderate	136	Very slow	Slow
112	Slow*	Moderate	137	Very slow	Moderate
113	Slow	Very slow	138	Very slow	Very slow
114	Moderate	Very slow	139	Very slow	Very slow
115	Very slow*	Very slow	140	Very slow	Very slow
116	Slow	Fast*	141	Very slow	Very slow
117	Very slow	Moderate	142	Very slow	Very slow
118	Very slow	Moderate	143	Very slow	Very slow
119	Very slow	Very slow	144	Very slow	Very slow
120	Very slow	Very slow	145	Very slow	Very slow
121	Very slow	Moderate	146	Very slow	Very slow
122	Very slow	Slow	147	Very slow	Very slow
123	Very slow	Slow	148	Very slow	Slow
124	Moderate	Moderate	149	Very slow	Slow
125	Moderate	Moderate	150	Very slow	Very slow
126	Moderate	Slow	151	Slow	Very slow
127	Very slow	Moderate	152	Very slow	Slow
128	Very slow	Slow	153	---	---
129	Very slow	Moderate	154	Very slow	Slow
130	Slow	Slow	155	Very slow	Very slow
131	Slow	Slow	156	Very slow	Slow
132	Very slow	Slow	157	Very slow	Moderate
133	Moderate	Moderate	158	Very slow	Very slow
134	Slow	Moderate	159	Very slow	Slow

Very slow=<0.3 m/yr; slow=0.3-0.6 m/yr; moderate=0.6-0.9 m/yr; fast=0.9-1.2 m/yr; very fast=>1.2 m/yr.

TABLE 12

Distribution of Monroe County recession rates among the recession categories for the long and short term

Recession category	Long-term % of total sites	Short-term % of total sites
Very slow	70.0	40.0
Slow	14.0	28.0
Moderate	14.0	28.0
Fast	0.0	2.0
Very fast	0.0	0.0
Indeterminate	2.0	2.0

TABLE 13

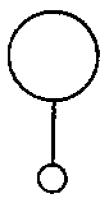
Mean annual erosion volumes in Monroe County for the periods 1875-1974 and 1938-1951

Term	Average bluff height	x	Length of shore	x	Mean recession rate	=	Mean annual erosion volume
West of Genessee River							
1875-1974	3.1 m		37,000 m		0.29 m/yr		3.33×10^4 m^3/yr
1938 1951	3.1 m		37,000 m		0.52 m/yr		5.96×10^4 m^3/yr
East of Irondequoit Bay							
1875-1974	10.4 m		15,800 m		0.10 m/yr		1.64×10^4 m^3/yr
1938-1951	10.4 m		15,800 m		0.30 m/yr		4.93×10^4 m^3/yr
Totals for Monroe County							
1875-1974							4.97×10^4 m^3/yr
1938-1951							1.09×10^5 m^3/yr

FIGURES L-24 to L-37

LOCATION MAPS FOR MONROE COUNTY

Scale on all maps: 1:24,000 or 1 inch = 2000 ft.



Indicates site and number where recession was measured

North is always at the top of the figure.

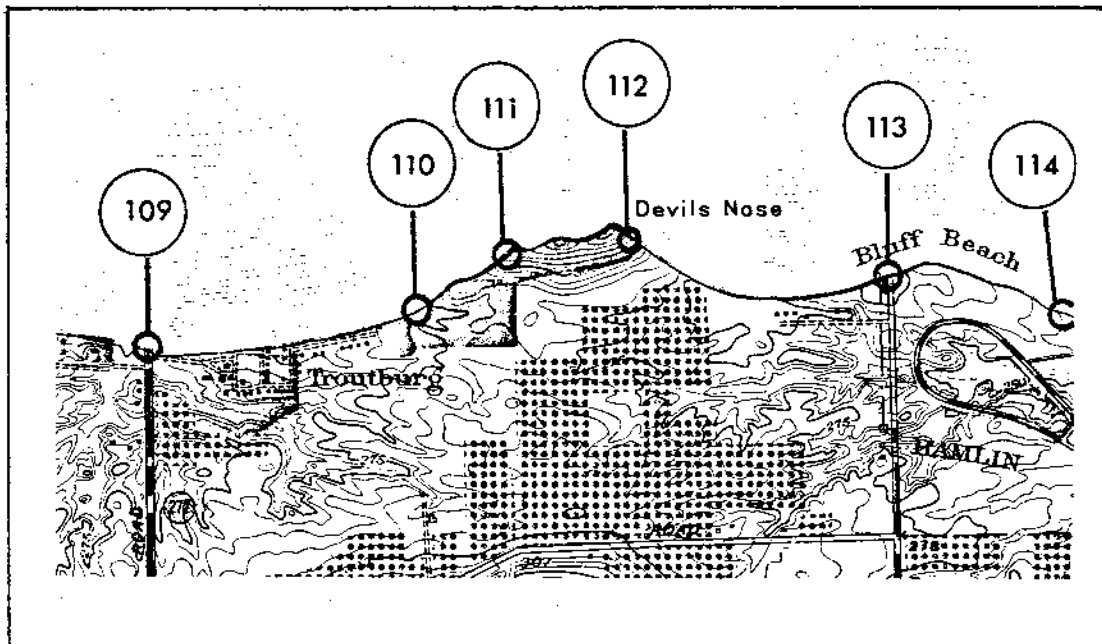


Figure L-24

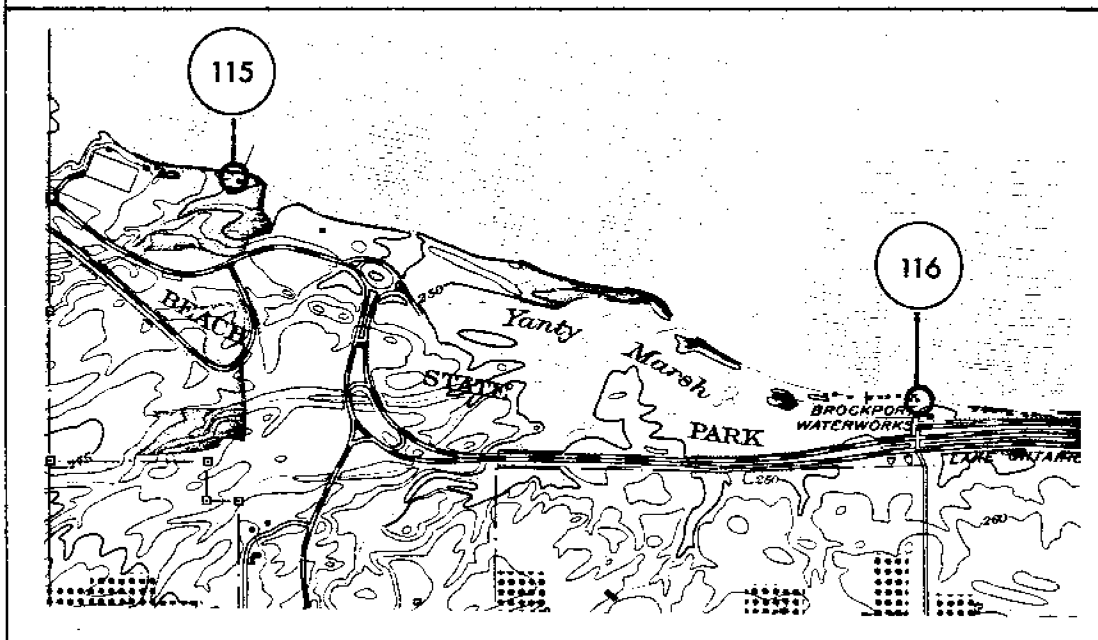


Figure L-25

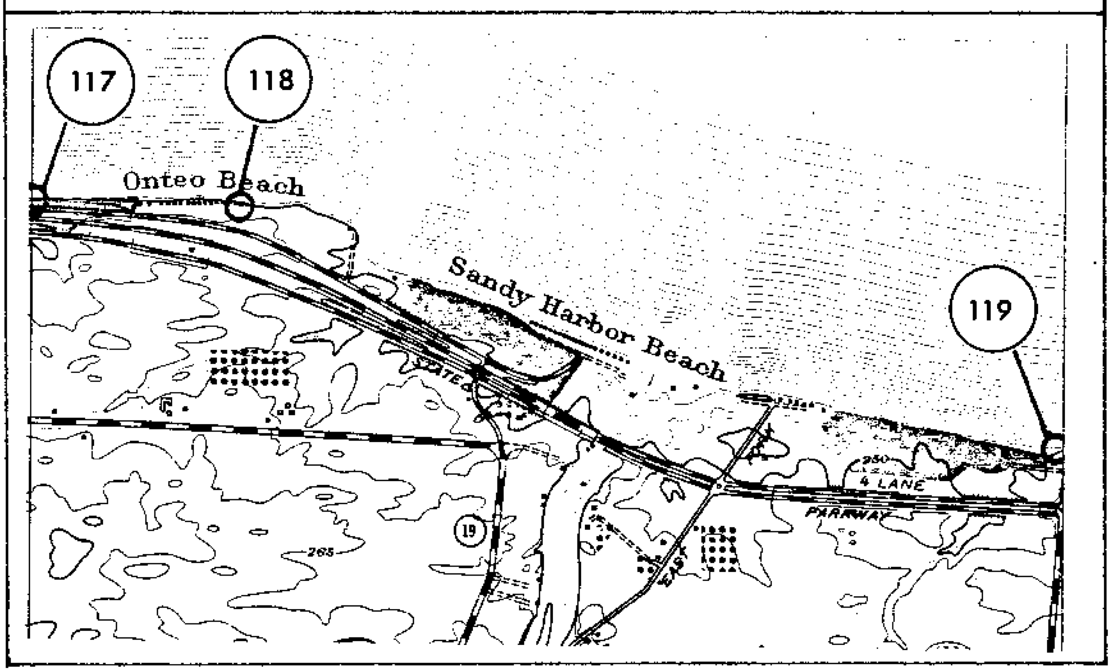


Figure L-26

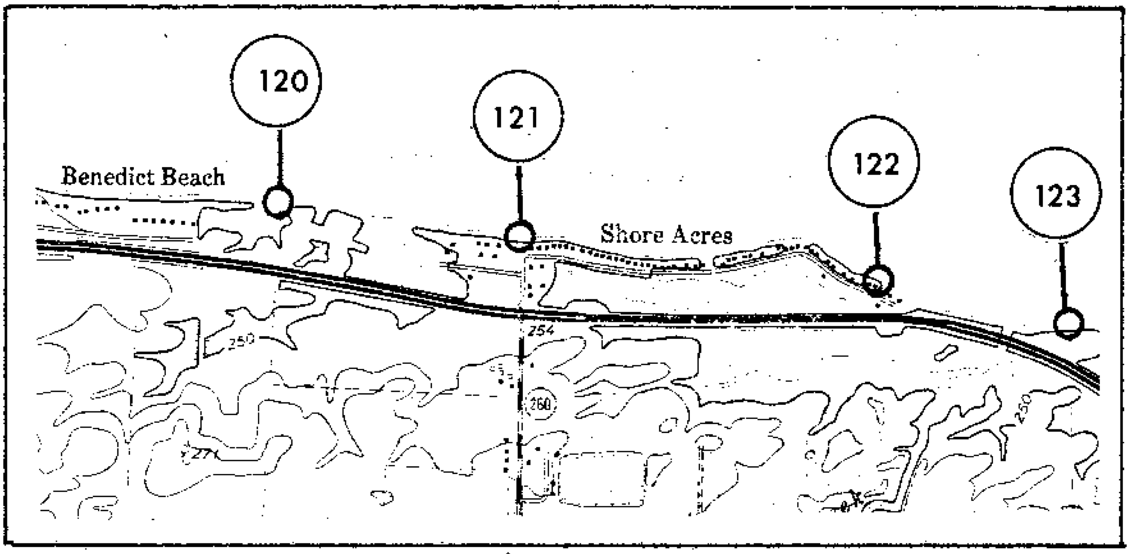


Figure L-27

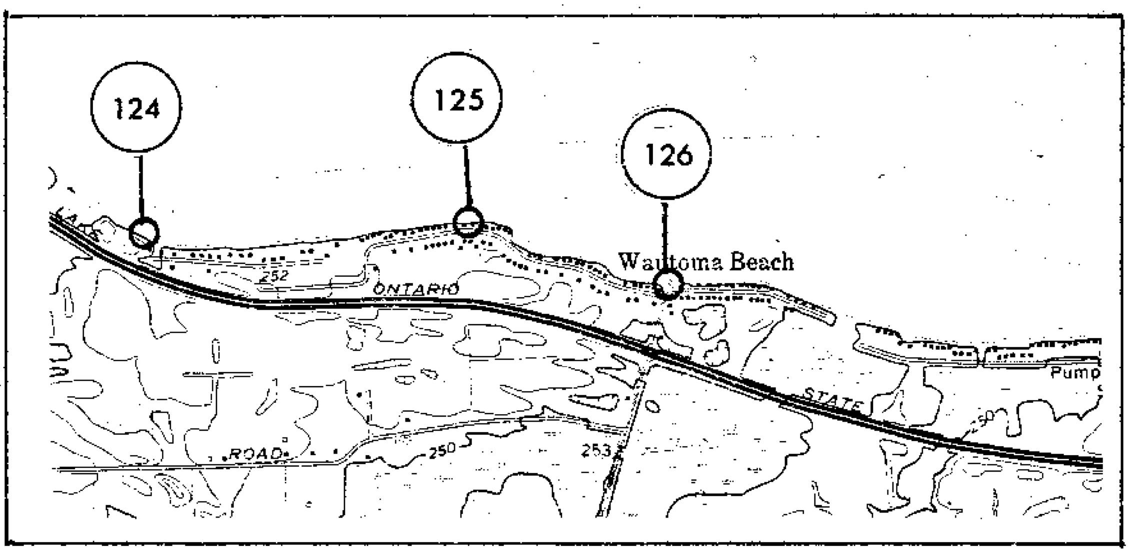


Figure L-28

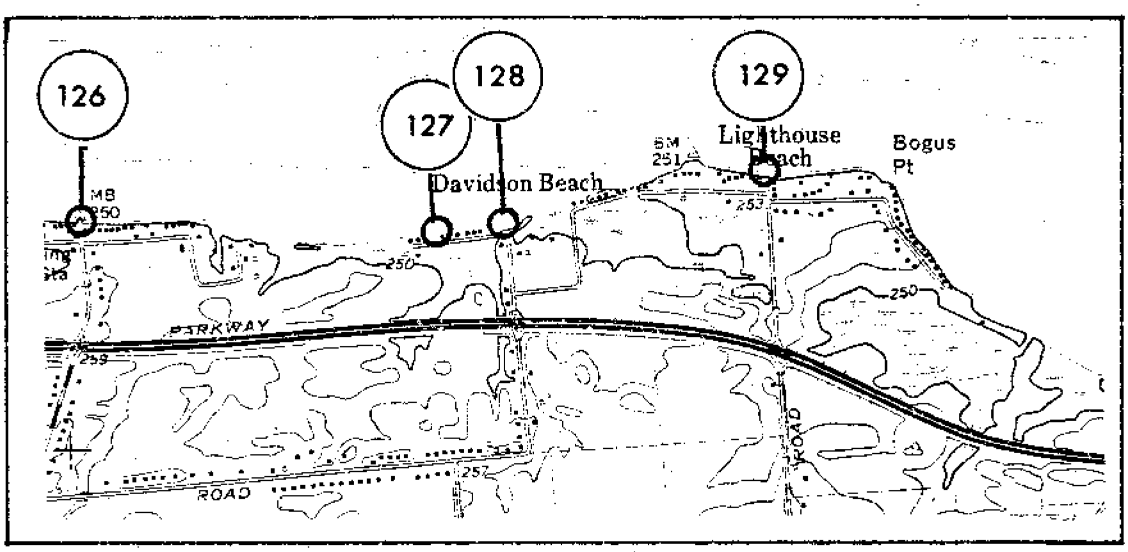


Figure L-29

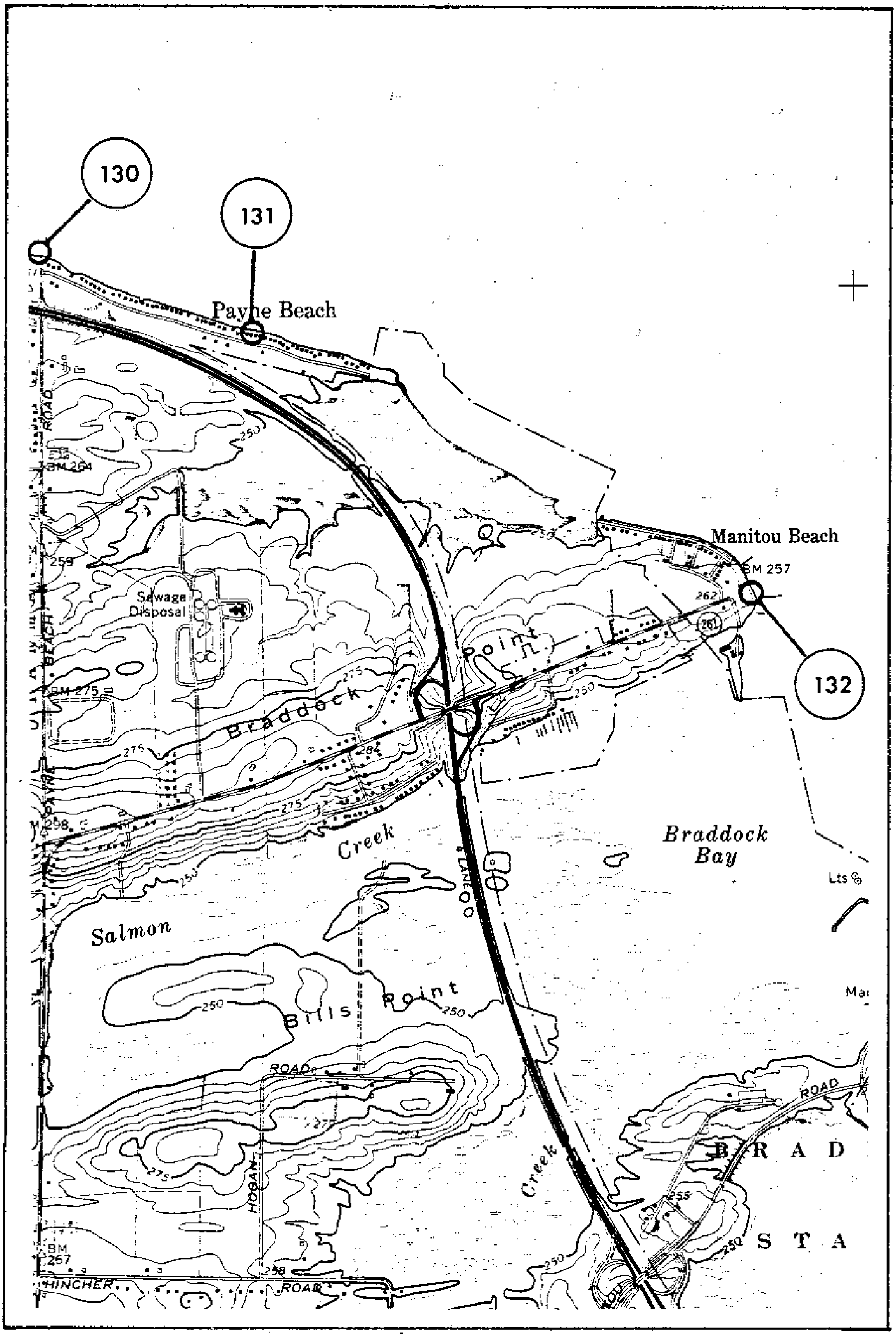

130
131
132
Payne Beach
Manitou Beach
BM 257
262
261
Sewage Disposal
BM 264
259
BM 275
Braddock Point
Braddock Bay
Creek
Salmon
Bills Point
250
275
282
ROAD
HOGAN
HINCHER ROAD
BM 267
258
B R A D
S T A
Lts

Figure L-30

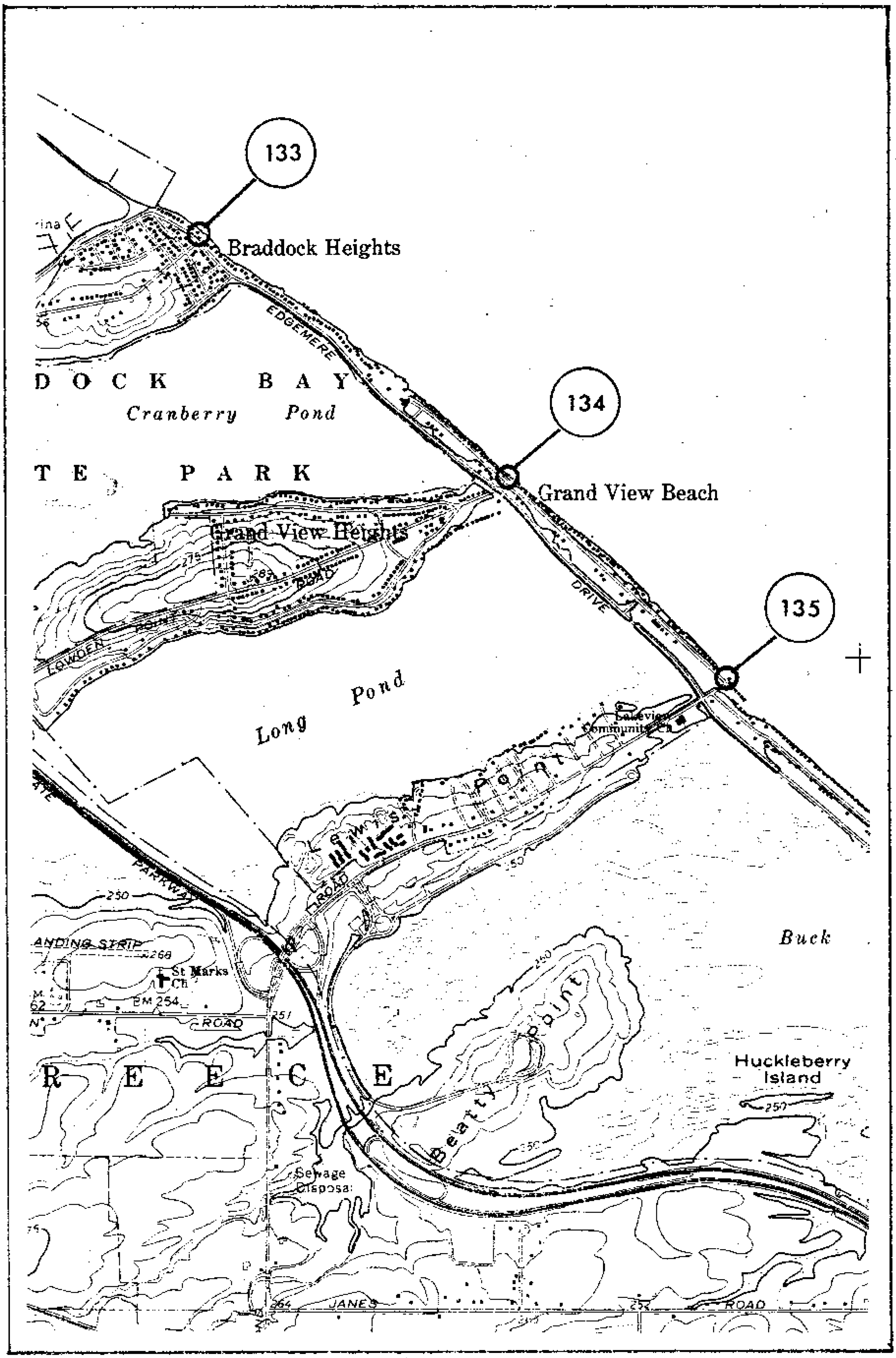
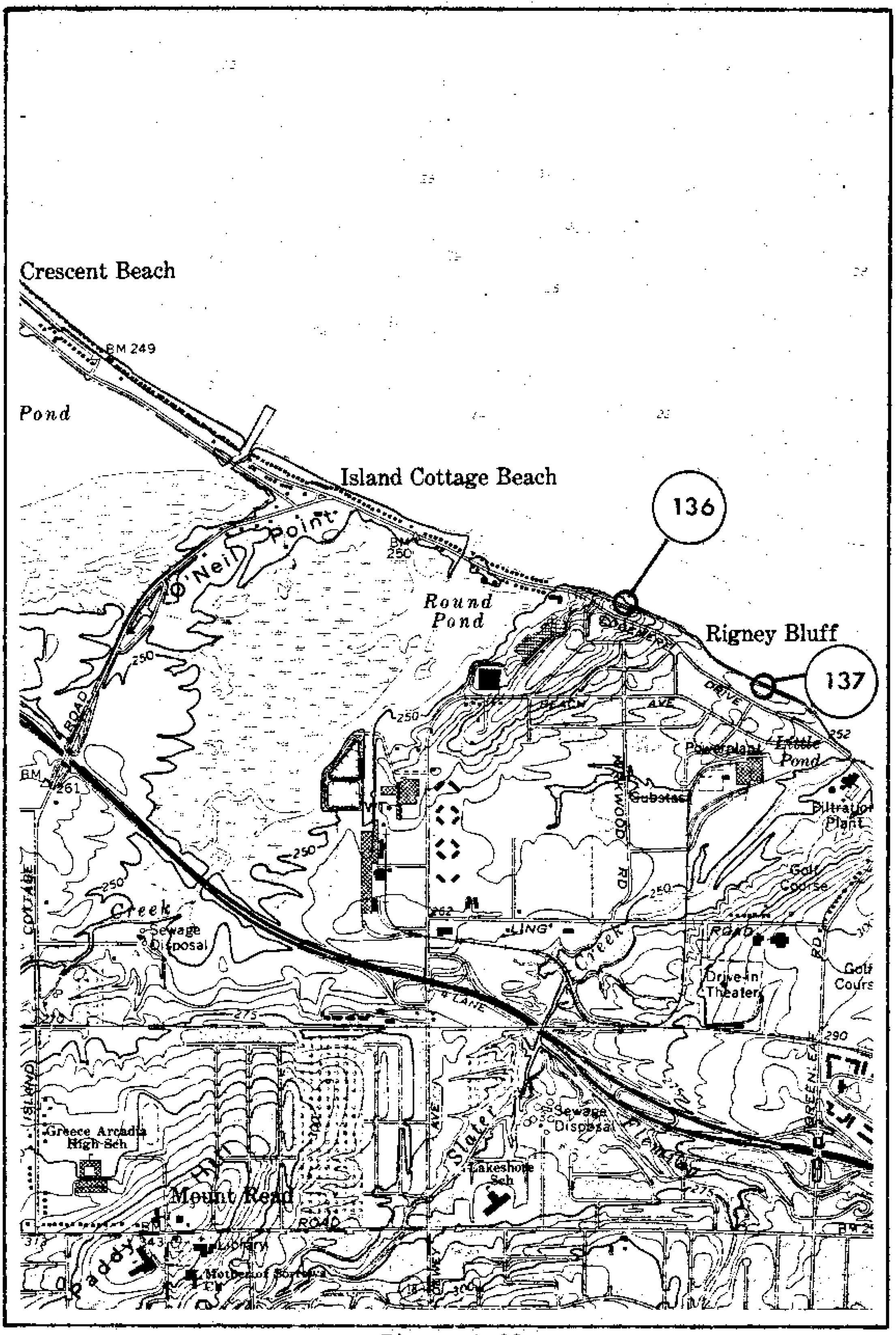

133
Braddock Heights
EDGEMERE
DOCK BAY
Cranberry Pond
134
TE PARK
Grand View Beach
Grand View Heights
ROAD
LOWDEN POINT
DRIVE
135
Long Pond
PARKWAY
ROAD
ANDING STRIP
St Marks Ch
BM 254
ROAD
Buck
Huckleberry Island
R E E C E
Beatty Point
Sewage Disposal
JANES
ROAD

Figure L-31



Crescent Beach
BM 249
Pond
Island Cottage Beach
136
O'Neil Point
Round Pond
Rigney Bluff
137
Powerplant
Little Pond
Substa
Filtration Plant
Golf Course
Creek
Sewage Disposal
Drive-in Theater
Greece Arcadia High Sch
Mount Read
Lakeshore Sch
Slater Creek
Library
Mother of Sorrows

Figure L-32

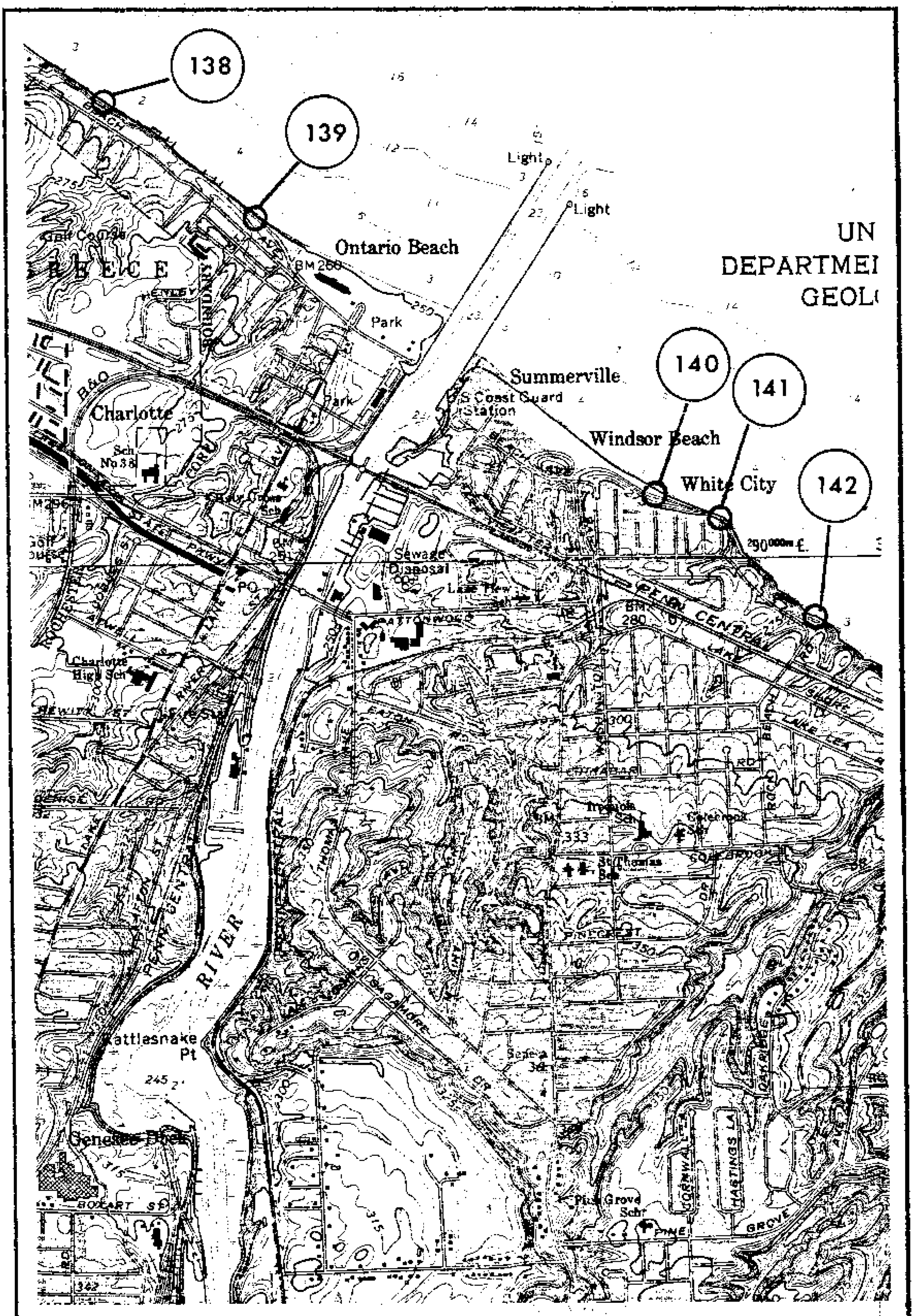

138
139
140
141
142
Ontario Beach
Park
Summerville
U S Coast Guard Station
Windsor Beach
White City
Charlotte
Light
UN
DEPARTMEI
GEOL
RIVER
Rattlesnake Pt
Genesee Dock

Figure L-33

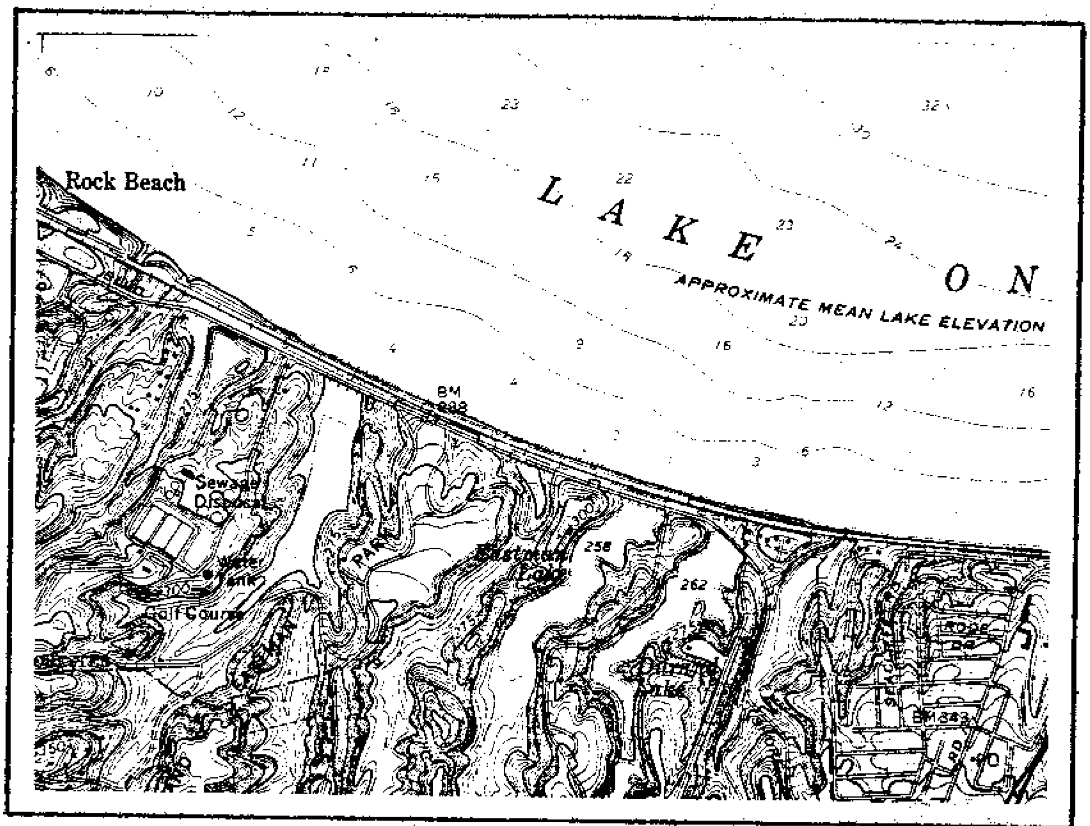


Figure L-34

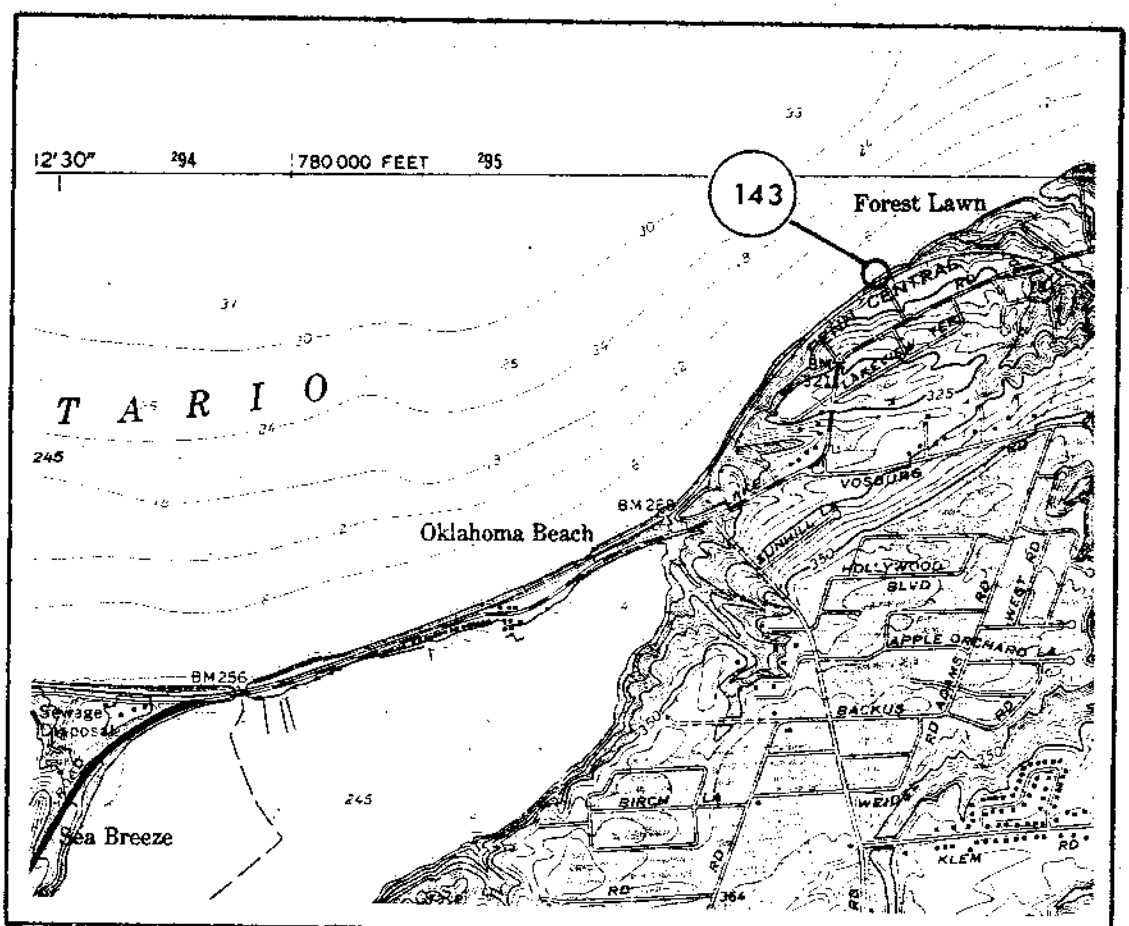


Figure L-35

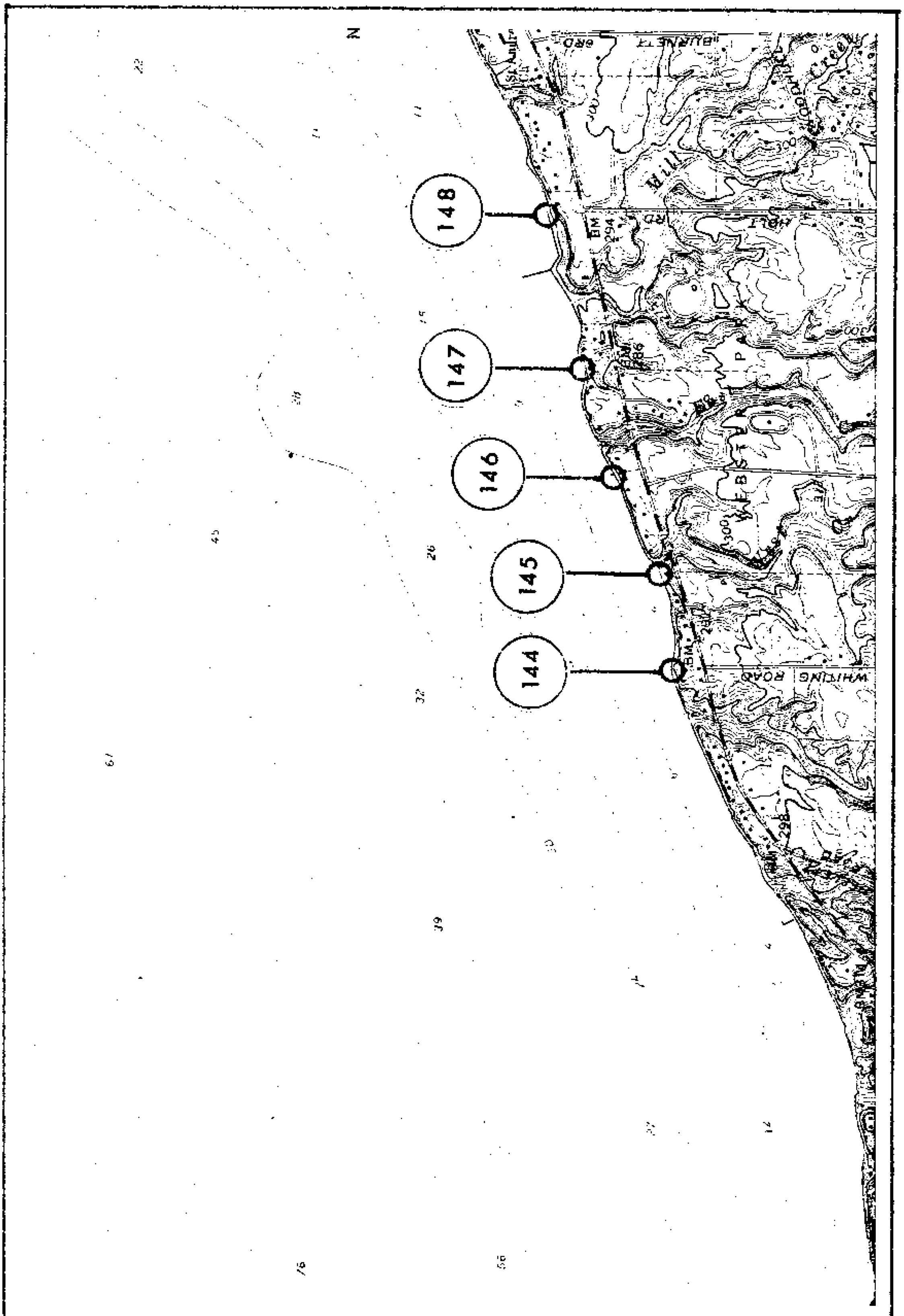


Figure L-36

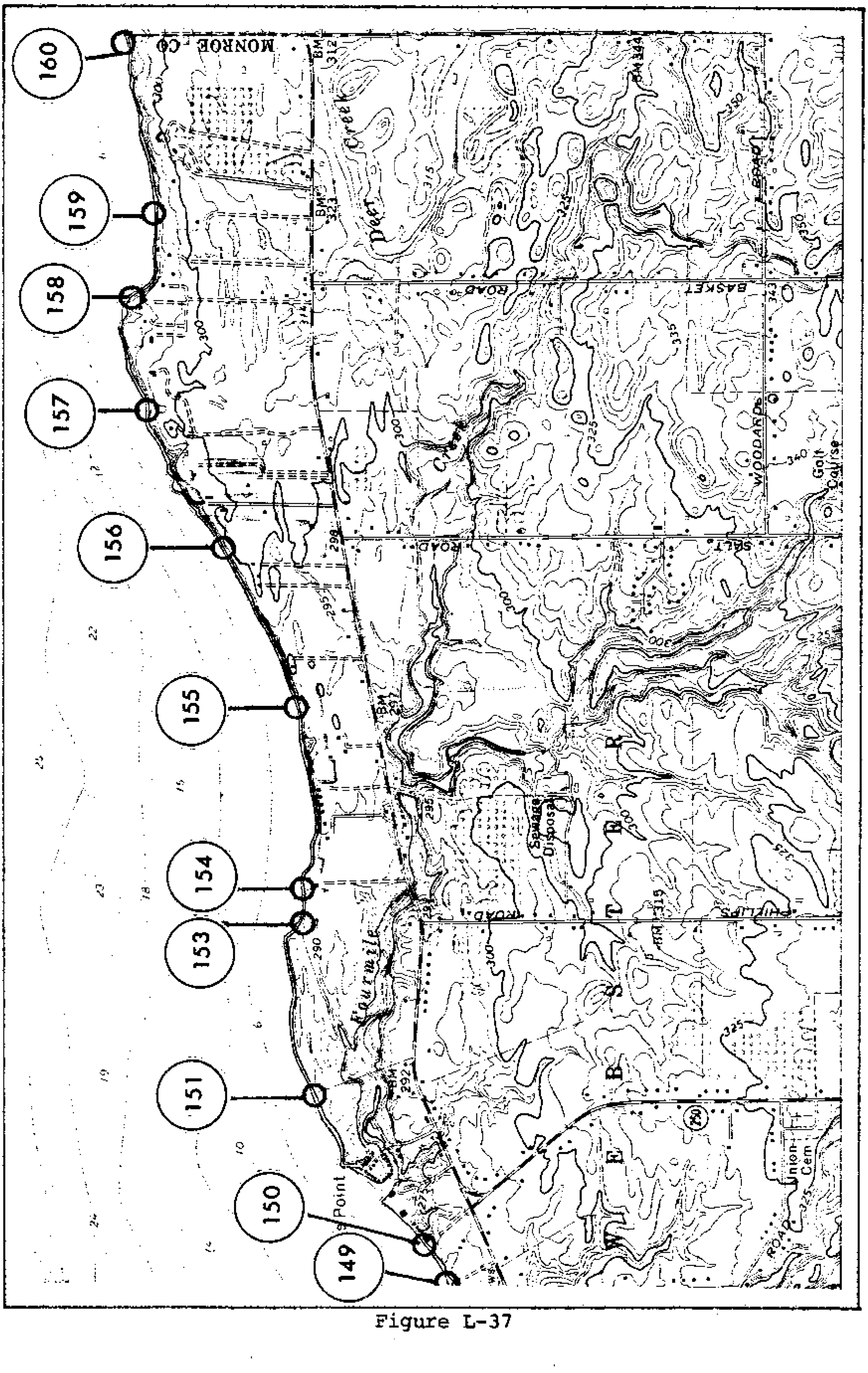

160
159
158
157
156
155
154
153
151
150
149
MONROE CO
Deer Creek
BASKET
SALT
ROAD
PHILLIPS
WOODARD
Golf Course
Sewage Disposal
Fourmile
Point
Union Cem

Figure L-37

Wayne County

Geography

Location

Wayne County contains approximately 60.5 km (37.6 mi) of Lake Ontario coastline: from a western boundary near Webster reaching east to the county line near Fair Haven (Figure 1). We determined recession rates at the 50 locations indicated on Figures L-38 through L-48.

Land Use

Approximately 50.5 percent of the Wayne County coast is agricultural and undeveloped land; 32 percent is used for commercial and residential purposes; and 17.5 percent is recreational land (US Army Corps of Engineers 1973). An undeveloped state park is located at Chimney Bluffs near Sodus Bay (Figure L-46); numerous other town and county parks are scattered along the coast. High recession rates in Wayne County pose problems to residential and commercial development.

Geology

Bluffs

The Wayne County coast is one of the most physically interesting and variable along Lake Ontario. To simplify our discussion, we divided the coastline into three areas (Figures L-38 to L-48): (1) the western county line to Pultneyville; (2) Pultneyville to Maxwell Bay; and (3) Maxwell Bay to the eastern county line.

Western County Line to Pultneyville. From the Monroe County line to Pultneyville the coastline is a fairly smooth lake plain with occasional higher drumlins. The bluffs average about 8 m (26 ft) high; the maximum height is 17 m (55.7 ft). They are composed of glacial till from 0 to 9 m (29.5 ft) thick overlaid in most reaches with 1 to 5 m (3 to 16.4 ft) of glaciolacustrine deposits. Two till sheets are distinguished here. The lower consists of compact stony and sandy red till; the upper consists of a gray clayey till with an upper waterlaid facies. We find red, fine-grained Queenston sandstone exposed in a few short reaches just east of the western county line and near Pultneyville. The bedrock reaches a maximum height of 2 m (6.6 ft) above the lake (Dames and Moore 1974; Calkin et al 1976, 1978; Brennan 1980). Predominant particle size is silt and clay. Local areas of high sand and gravel in regions of stony till and lacustrine deposits increase in an eastward direction (Figure 2).

Pultneyville to Maxwell Bay. From Pultneyville to Maxwell Bay the coast consists of wave-cut drumlins projecting into the lake with regions of lower lake plain between them (Fairchild 1929; Slater 1929) (Figure 2). The drumlins are higher in this region than in the region to the west, reaching heights of approximately 20 m (65.6 ft). The lowlands between them have bluffs 6 to 10 m (20 to 33 ft) high. The drumlins west of Maxwell Bay face north-northeast, parallel to the direction of the glacial ice movement. The bluffs are composed almost entirely of glacial till. We found a low exposure of Queenston fine sandstone of limited extent about 3.2 km (2 mi) west of Maxwell Bay. Sand and gravel content of the bluff material is higher in this region than in the west although the bluffs are predominantly clayey till that displays a pinkish-grey surface color. The coast is less uniform in this reach, trending east-northeast from Pultneyville to Bootleggers Point and then east-southeast to Maxwell Bay (Figure L-44).

Maxwell Bay to Eastern County Line. The reach from Maxwell Bay to the eastern county line is composed of high drumlins interspersed with large bays and wetland regions (Martin 1901). The drumlin bluffs average about 25 m (82 ft) high and reach a maximum height of about 30 m (98 ft). Few low bluffs lie between the drumlins; most of the drumlin bluffs are fronted by pebble and cobble barrier beaches. They are composed entirely of pinkish-grey glacial till (Solomon 1976). Sand content of the bluffs in this region is much higher than in regions to the west (Figure 2).

Beaches

Most of the beaches east of Pultneyville are 1 to 9 m (3 to 29.5 ft) wide and occur intermittently in small embayments along the coast. The beaches are composed of coarse cobble to pebble sized material. They have gradients of 12 to 20 percent.

Beaches are wide from Putlneyville eastward; they range from 3 to 24 m (10 to 79 ft) wide. The beaches are composed of smaller stones and have lower slopes than those to the west; many cross marshes and embayments between drumlins.

Streams

Twelve small tributaries enter the lake in Wayne County; they are shown on Figures L-38 through L-48. Three enter the lake through bays preventing much sediment from entering the littoral zone.

Nearshore Slopes

Slope of the lake bottom in the nearshore zone ranges between 4.0 and 23.4 m/km or 21 and 123 ft/mi (Table 14). The slopes generally decrease from west to east; an abrupt eastward decrease in slope begins east of Maxwell Bay near site 194 (Figure L-44).

Recession Rates

Recession History

We determined recession at the 50 locations indicated in Figures L-38 through L-48; the rates are shown in Table 15. Table 16 indicates the distribution of rates in each category for both the long and the short term. At 76 percent of the sites, the short-term rate was higher than the long-term rate; at 14 percent of the sites it was the same; at only 2 percent of the sites was the short-term rate lower than the long term rate. We could not determine a difference at 8 percent of the sites because we were unable to obtain reliable data. This inability resulted from either man-made changes along the coast and/or other factors interfering with the proper determination of bluff position. Between 1875 and 1974 approximately 2.45 km^2 (0.94 mi^2) eroded and between 1938 and 1954, 1.60 km^2 (0.61 mi^2) eroded.

The highest short term rates computed for the entire study area were in Wayne County. We found greater than 3.00 m/yr (9.8 ft/yr) at nine sites. At site 190 (Figure L-43) we measured recession at 3.7 m/yr (21.5 ft/yr). We found higher rates at sites 199, 204, and 205 (Figures L-46 and L-47) located on barrier beaches across bays and marshes rather than bluffs. However, during the plotting of the bluff lines we observed that retreat of such beaches tended to parallel the recession of the bluff areas on either side of them and beach width often remained constant.

Erosion Volumes

Most sediment in the shore zone of Wayne County derives from erosion of the bluffs (Coch 1961). Little beach-making sediment seems to be carried into the county from the Genesee River suggested by the diminishing beach size toward the eastern boundary of Monroe County (US Army Corps of Engineers 1955; Pluhowski 1975). Annual erosion volumes for the periods 1875 to 1974 and 1938 to 1954 are shown in Table 17. Approximately 64 percent of the total 99-year losses occurred in 16 years. The large amount of sediment eroded is a result of the high average bluff height and the rapid recession.

Interpretation of Recession

The short-term rates determined in this study are generally much higher than the long-term rates; at many sites the total recession seems to have occurred between 1938 and 1954. In fact, because of a mapping error on the 1875 survey or because of difficulties in measuring the recession rate, the long-term rates may actually be greater than they appear. Since the bluff was often high and steep, the 1875 cartographer may have moved the bluff line landward to fit in the numerous contour lines on the bluff face. In our measurements we often had to match farm field lines because no other landmarks could be found on the 1875 maps. The accuracy of these lines is questionable since relief is considerable and much of the area is wooded.

The short term rates are extemely high and are not based on the 1875 survey. These high rates may be the result of geologic conditions along the coast. We found the highest rates in the eastern portion of the county on drumlin bluffs (sites 199 to 209). Because the bluffs are unprotected and often lack vegetation, subaerial erosion and wave attack easily remove great amounts of material from these bluffs. From 1938 to 1954 the mean lake level was 74.72 m (245.16 ft), 0.14 m (0.46 ft) higher than the 99-year mean (Table 2). This may be one factor in the higher short-term rates.

TABLE 14

Nearshore slopes: Wayne County

Site number*	Slope (m/km)	Site number*	Slope (m/km)
160	14.4	185	14.2
161	17.4	186	9.9
162	11.7	187	15.0
163	12.9	188	13.4
164	12.7	189	12.5
165	15.3	190	14.2
166	11.4	191	9.9
167	13.9	192	12.9
168	10.4	193	16.3
169	8.8	194	7.9
170	10.7	195	6.6
171	10.5	196	5.7
172	11.9	197	5.6
173	10.5	198	7.8
174	12.9	199	4.8
175	14.4	200	6.0
176	11.2	201	10.0
177	11.5	202	7.4
178	10.4	203	6.3
179	16.7	204	5.9
180	13.9	205	5.2
181	14.4	206	4.6
182	7.5	207	4.0
183	11.4	208	4.4
184	23.4	209	4.7

*Sites located on Figures L-38 through L-48

TABLE 15

Recession rates: Wayne County

Site number	Long-term recession rate	Short-term recession rate	Site number	Long-term recession rate	Short-term recession rate
160	Very slow*	---	185	Slow	Very fast
161	Very slow	Very fast*	186	Slow	Fast
162	---	Fast*	187	Slow	Very fast
163	Very slow	Fast	188	Slow	Very fast
164	Very slow	Slow	189	Slow	Very fast
165	Slow*	Fast	190	Slow	Very fast
166	Slow	Fast	191	Slow	Very fast
167	Slow	Fast	192	Slow	Very fast
168	Slow	Slow	193	Fast	Very fast
169	Very slow	Moderate*	194	Fast	Very fast
170	Very slow	---	195	Slow	Very fast
171	Very slow	Fast	196	Slow	Moderate
172	Very slow	Slow	197	Very slow	Slow
173	Very slow	Very slow	198	Very slow	Moderate
174	Very slow	Very slow	199	Fast	Very fast
175	Very slow	Slow	200	Very fast	Very fast
176	Very slow	Fast	201	Fast	Very fast
177	Very slow	Very fast	202	Slow	Very fast
178	Moderate	Moderate	203	Slow	Very fast
179	Very slow	Very slow	204	Slow	Very fast
180	Slow	Moderate	205	---	Very fast
181	Slow	Very fast	206	Slow	Very fast
182	Slow	Moderate	207	Slow	Very fast
183	Slow	Very fast	208	Fast	Very slow
184	Slow	Very fast	209	Slow	Moderate

*Very slow=<0.3 m/yr; slow=0.3-0.6 m/yr; moderate=0.6-0.9 m/yr; fast=0.9-1.2 m/yr; very fast=>1.2 m/yr.

TABLE 16

Distribution of Wayne County recession rates among the recession categories for the long and short term

Recession category	Long-term % of total sites	Short-term % of total sites
Very slow	32.0	8.0
Slow	50.0	10.0
Moderate	2.0	14.0
Fast	10.0	16.0
Very fast	2.0	48.0
Indeterminate	4.0	4.0

TABLE 17

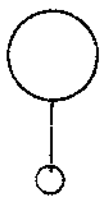
Mean annual erosion volumes in Wayne County for the periods 1875-1974 and 1938-1954

Term	Average bluff height	x	Length of shore	x	Mean recession rate	=	Mean annual erosion volume
1875-1974	8.2 m		60,500 m		0.41 m/yr		2.03×10^5 m^3/yr
1938-1954	8.2 m		60,500 m		1.69 m/yr		8.38×10^5 m^3/yr

FIGURES L-38 to L-48

LOCATION MAPS FOR WAYNE COUNTY

Scale on all maps: 1:24,000 or 1 inch = 2000 ft.



Indicates site and number where recession was measured

North is always at the top of the figure.

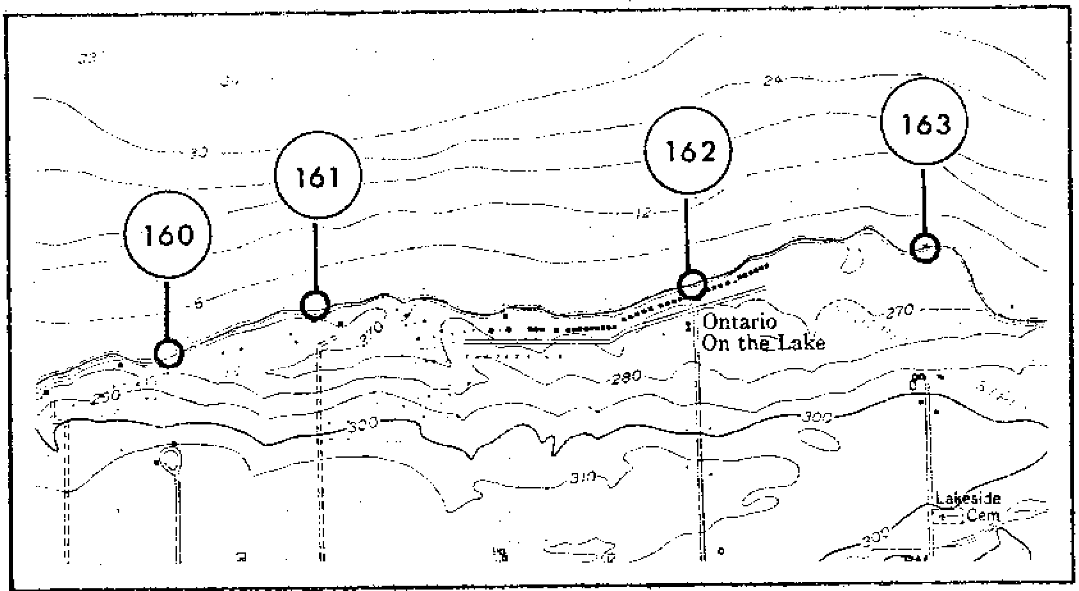


Figure L-38

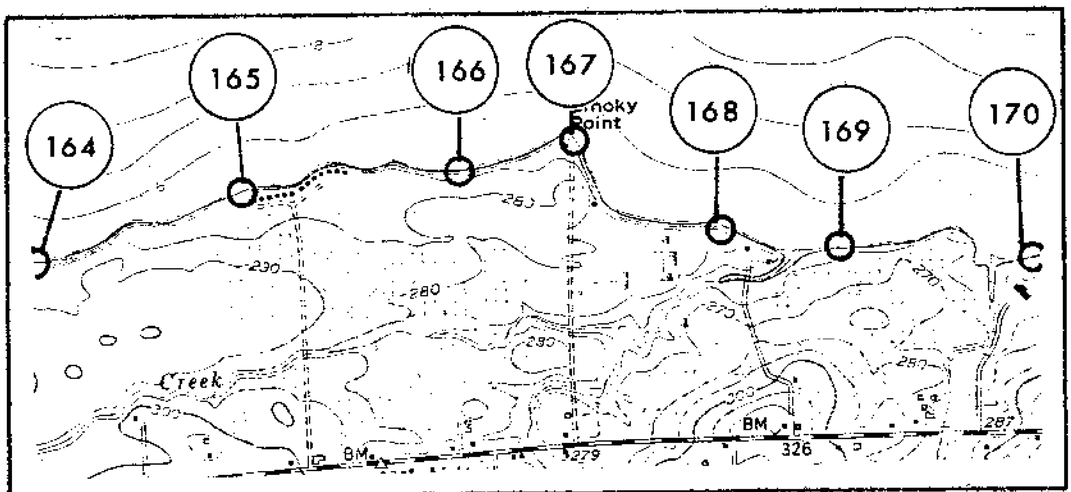


Figure L-39

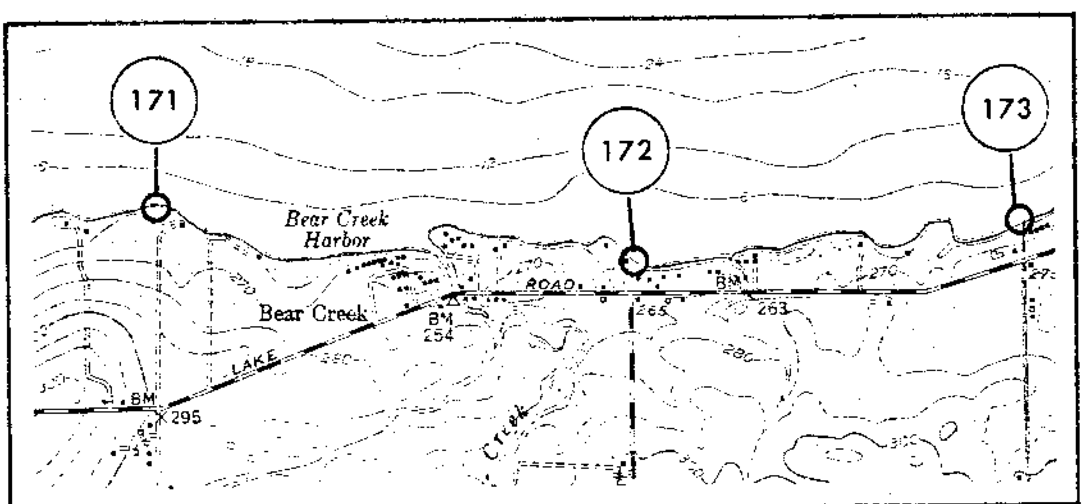


Figure L-40

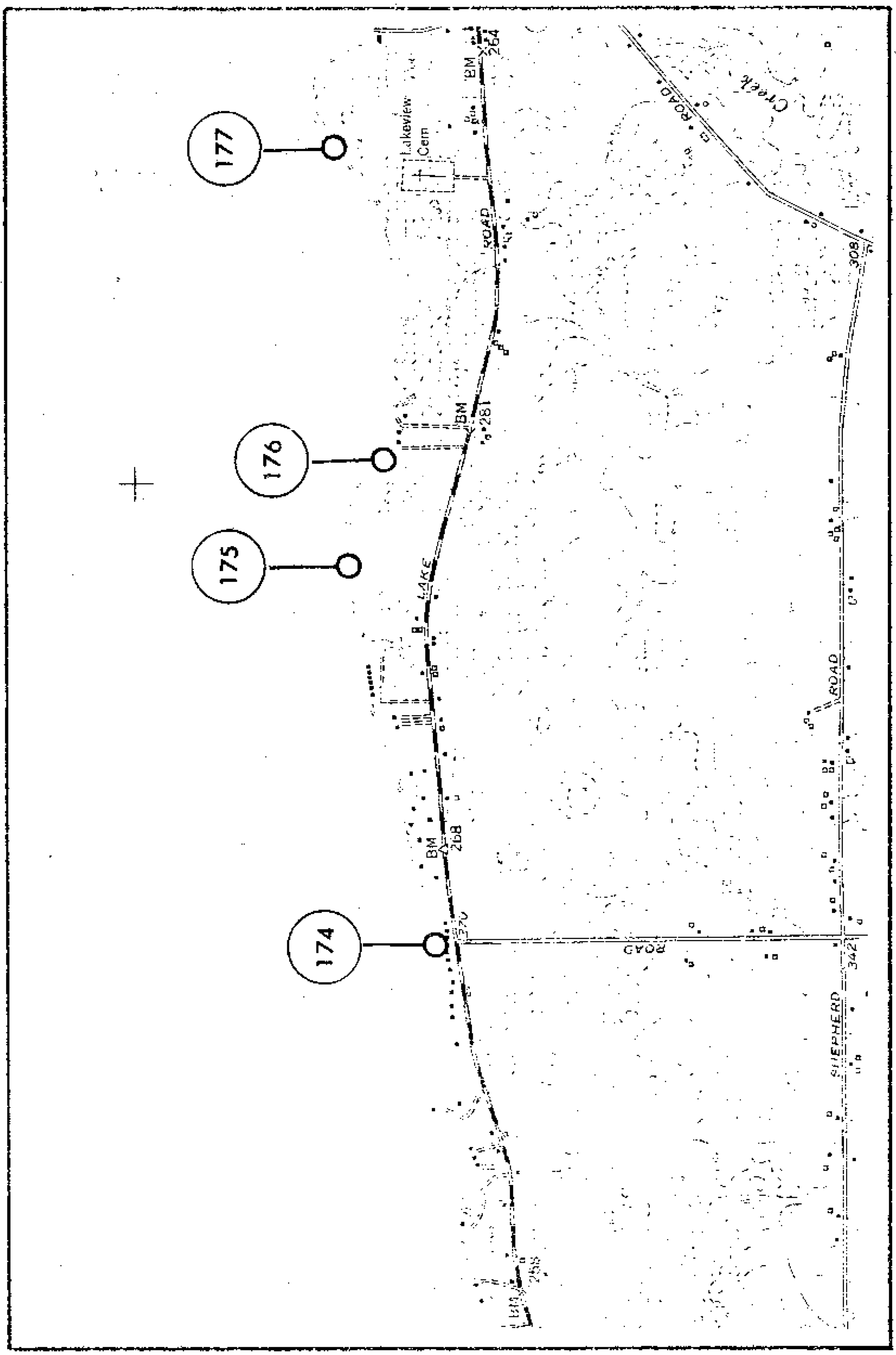

177
176
175
174
Lakeview Cem
LAKE
ROAD
SHEPHERD
ROAD
Creek
BM 281
BM 268
342
308

Figure L-41

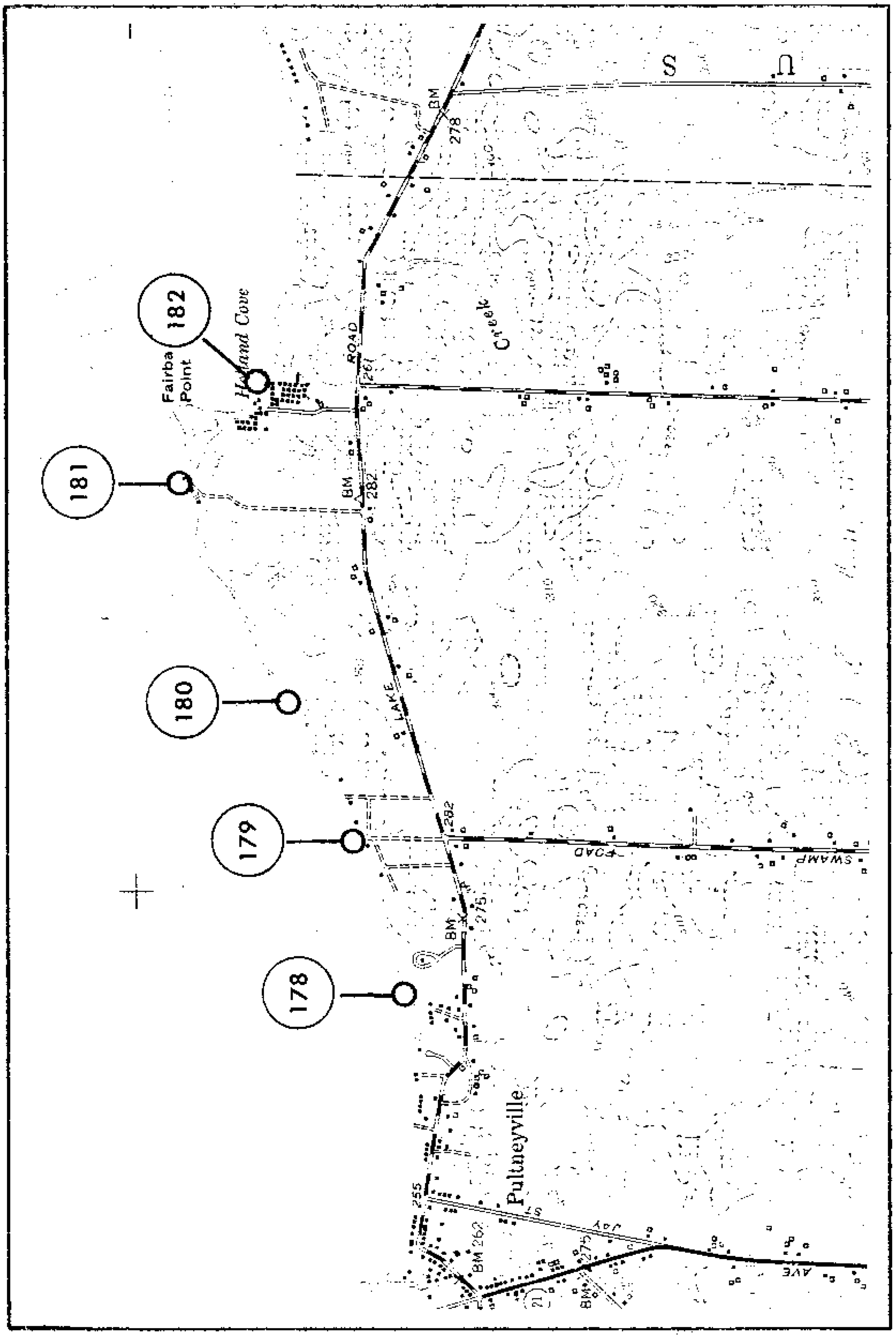

178
179
180
181
182
Pultneyville
LAKE
ROAD
SWAMP
ROAD
JAY
ST
AVE
Creek
Fairba
Point
Holland Cove
BM
278
261
282
275
255
BM 262

Figure L-42

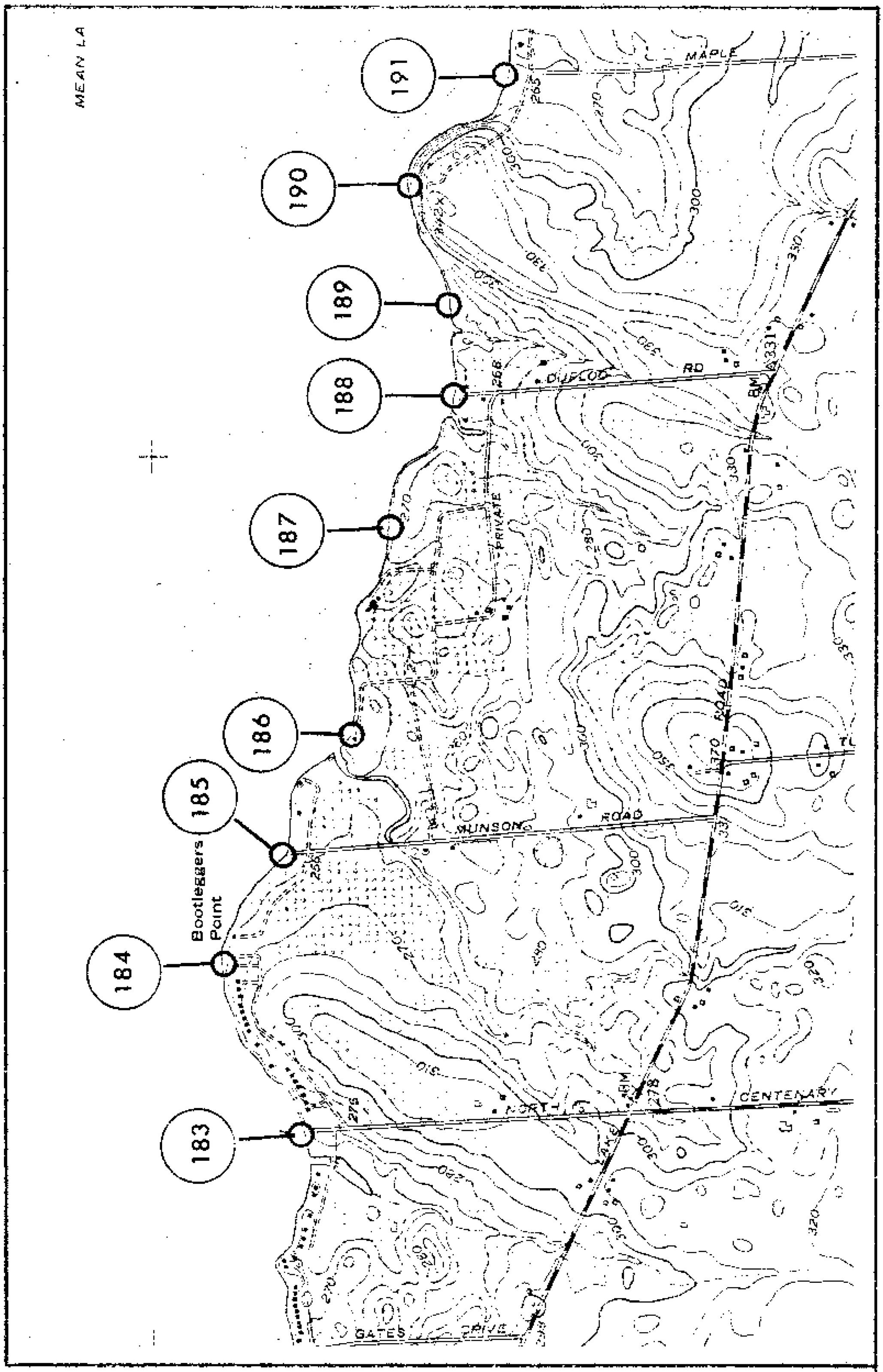

MEAN LA
183
184
185
186
187
188
189
190
191
Bootleggers Point
MUNSON
ROAD
MAPLE
PRIVATE
RD
CENTENARY
GATES
DRIVE

Figure L-43

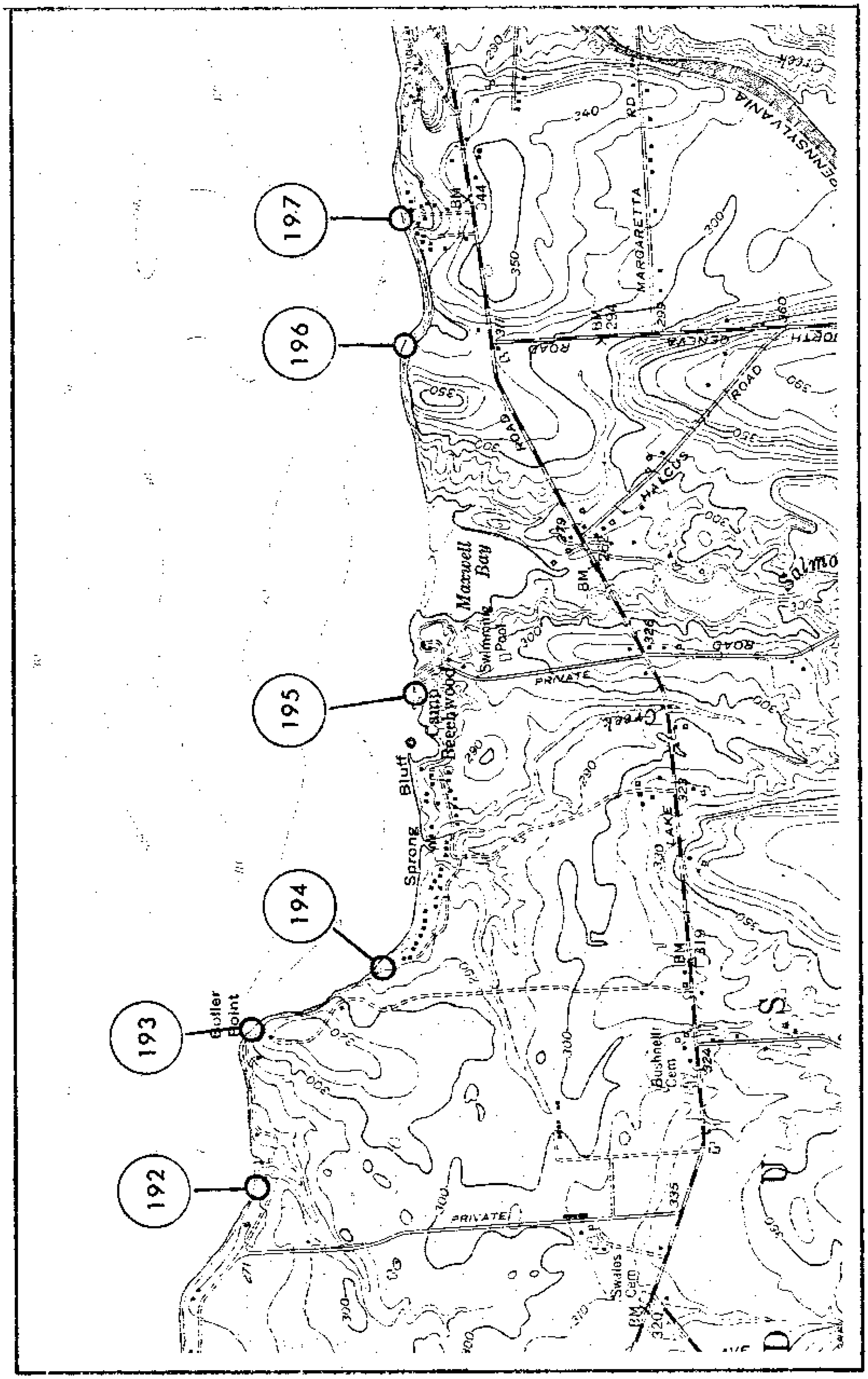

192
193
194
195
196
197
Butler Point
Sprong Bluff
Camp Beechwood
Maxwell Bay
MARGARETTA
HALCUS
ROAD
LAKE
PRIVATE
PENNSYLVANIA
Bushnell Cem

Figure L-44

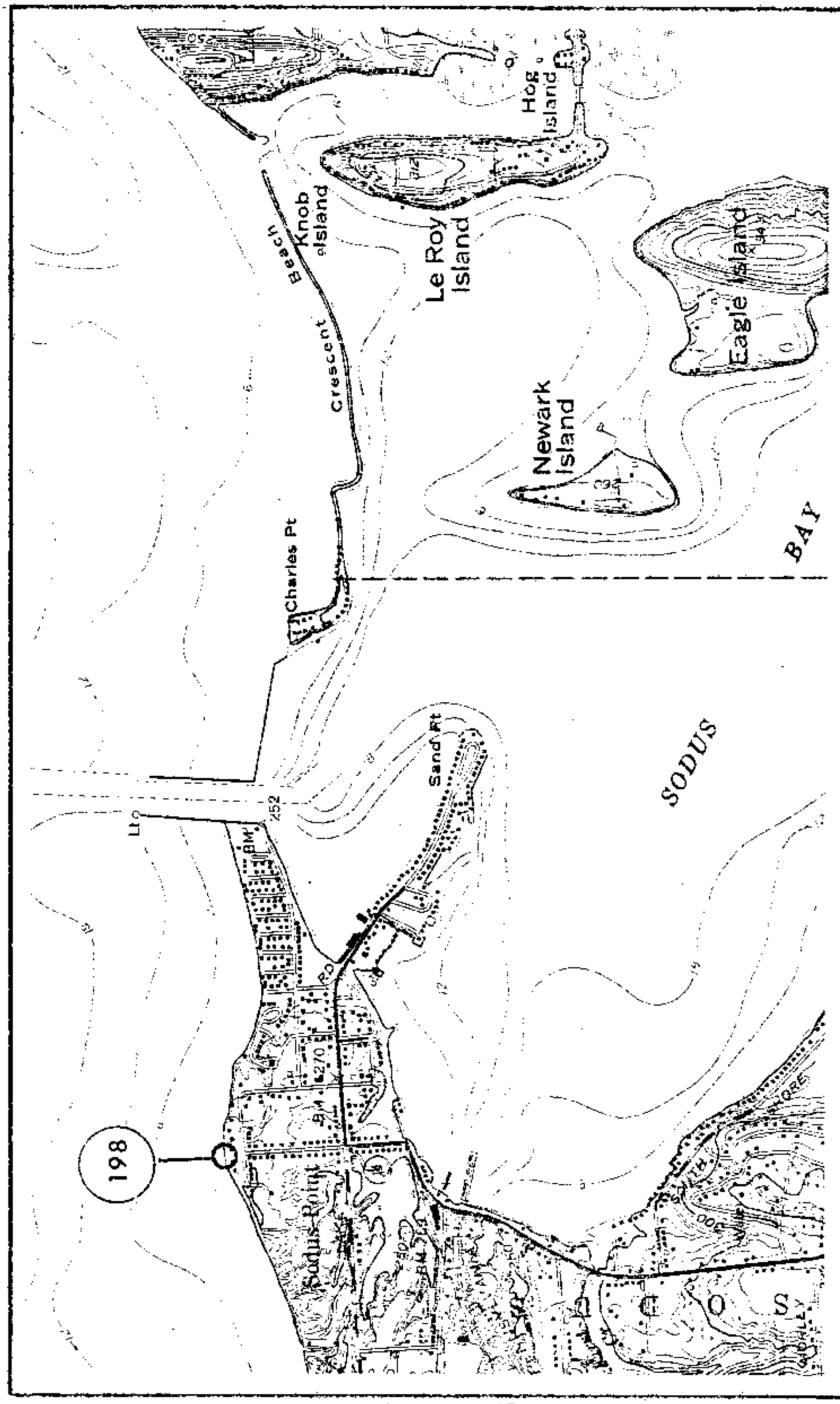

198
Sodus Point
Lt
Sand Pt
Charles Pt
Crescent Beach
Knob Island
Le Roy Island
Hog Island
Newark Island
Eagle Island
SODUS
BAY

Figure L-45

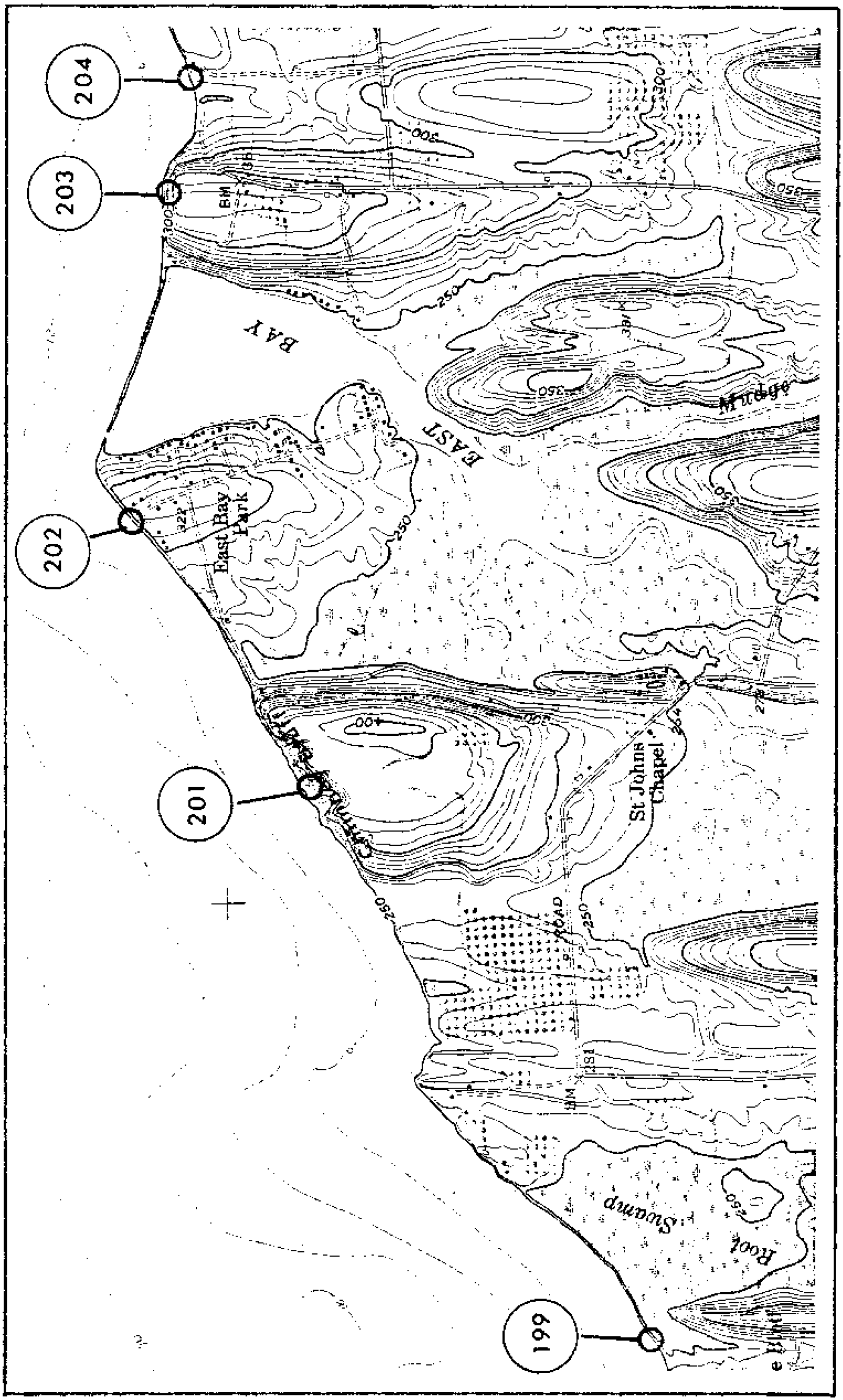

204
203
202
201
199
EAST BAY
East Bay Park
St Johns Chapel
Root Swamp
Mudge
ROAD

Figure L-46

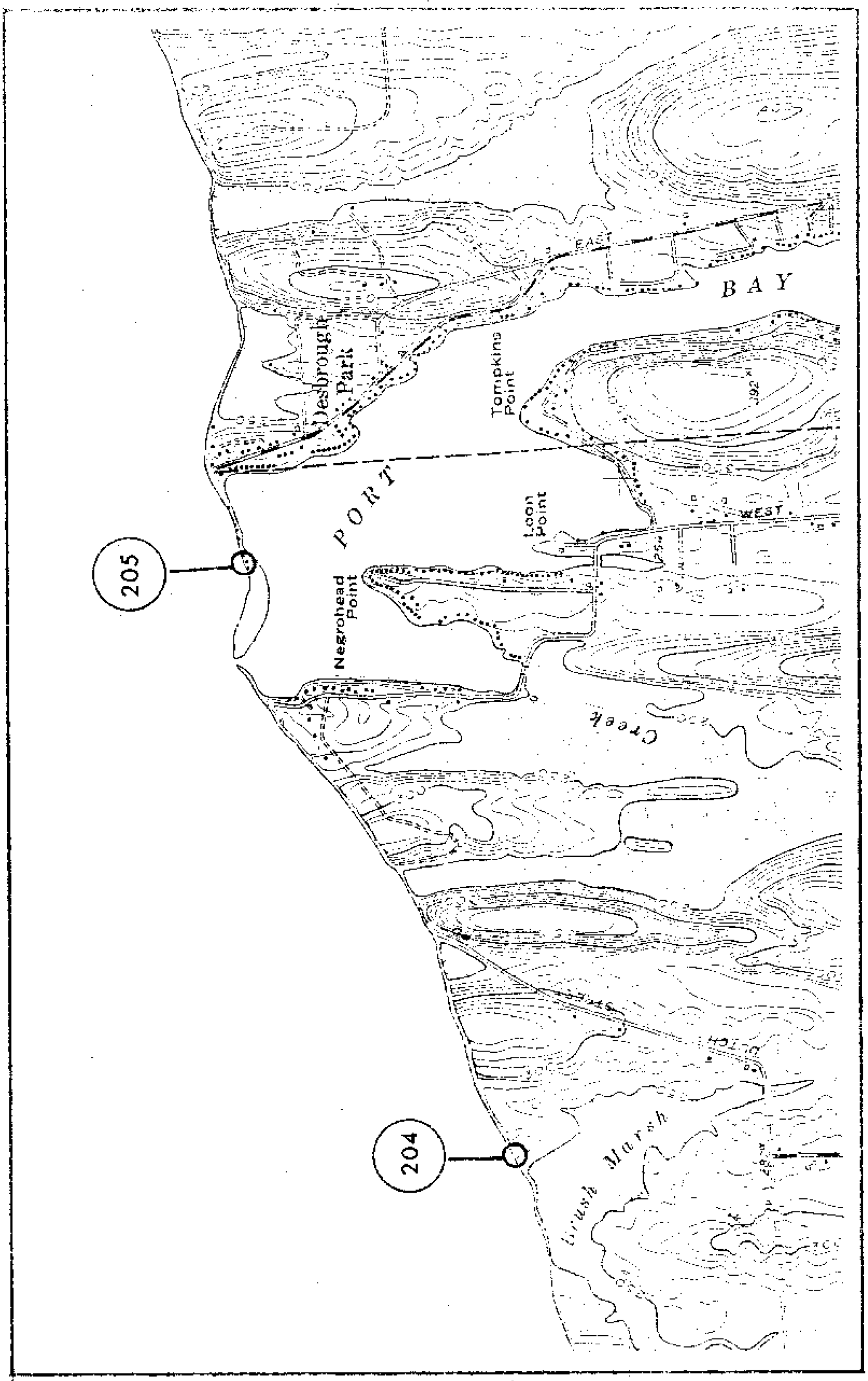

205
204
PORT
BAY
Desbrough Park
Tompkins Point
Loon Point
Negrohead Point
EAST
WEST
Creek
Marsh

Figure L-47

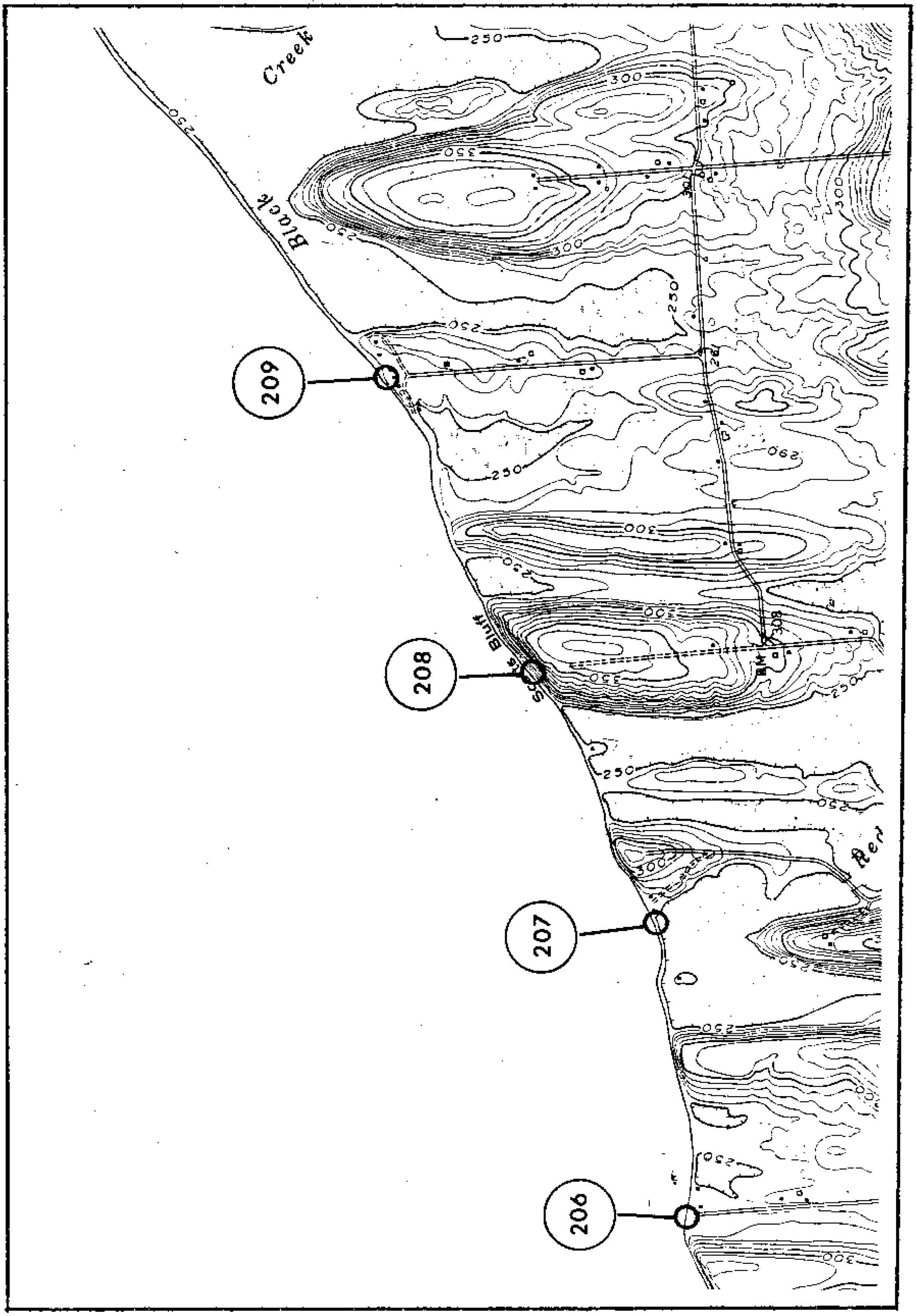


Figure L-48

Cayuga County

Geography

Location

A short stretch of Lake Ontario coastline approximately 12.9 km (8.0 mi) long lies within Cayuga County extending in a northeast direction from a point near Sterling Valley to another point near Blind Sodus Bay (Figure L-49). We measured recession at 10 sites in the area as indicated on Figures L-49 through L-51. Because the coast is short and bluff areas are intermittent, few sites were suitable for measurements.

Land Use

Agricultural uses account for approximately 63 percent of the coastal region; commercial and residential uses account for 30 percent of the region; and recreational purposes, 7 percent (US Army Corps of Engineers 1973). Population is sparse except near Fair Haven (Dobson and Henderson 1976).

Geology

Bluffs

Drumlins approximately 25 to 30 m (82 to 98 ft) high characterize the coast of Cayuga County (Fairchild 1929). The drumlins are composed of stony till with 30 to 50 percent sand and coarser material (Brennan, 1980). The bluffs have steep faces of 75° to 90° slope that are poorly vegetated and highly subject to subaerial erosion. Orientation of the drumlins is north-south while the coast trends northeast, resulting in wave-cut faces diagonally across the drumlins. Low wetlands and ponds fronted by cobble barrier beaches occur between the drumlins. No bedrock is exposed along the Cayuga County coast. A detailed description of the surface and subsurface geology in the Sterling area of Cayuga County is provided by Rochester Gas and Electric Corp (1973).

Beaches

Steep cobble beaches with gradients of 12 to 20 percent occur along most of the shore except in a region near Little Sodus Bay (Coch 1961). Sand has accumulated on the west side of the jetty here and at Fair Haven State Park (Figure L-50) (US Army Corps of Engineers 1955). Otherwise, small sandy areas occur locally within the generally cobble-bearing beaches that front the eroding drumlins. These beaches are less than 15 m (49 ft) in most places. Many of the beaches are narrower, approximately 5 to 7 m (16 to 23 ft) wide, and are composed of cobbles and coarse sand.

Streams

Only three tributaries of significant size enter the lake in Cayuga County.

Nearshore Slopes

Slopes in the nearshore zone varied from 4.1 to 13.6 m/km (22 to 72 ft/mi). Lowest slopes were near Little Sodus Bay; they increase uniformly in slope in the direction toward the eastern county line. The slopes are given in Table 18.

Recession Rates

Recession History

We measured recession rates at the 10 sites indicated in Figures L-49 through L-51; the rates are shown in Table 19. The distribution of rates in each recession category is shown in Table 20 for both long and short terms. We found higher short-term rates at 50 percent of the sites; at 30 percent of the sites short- and long-term rates were the same; and at 20 percent short-term rates were lower than long-term rates. Short-term rates ranged from 0.12 m/yr (0.4 ft/yr) to 1.37 m/yr (4.5 ft/yr); the mean rate was 0.65 m/yr (2.1 ft/yr). We found the highest short-term recession at site 212. Long-term rates ranged from a maximum of 1.10 m/yr (3.6 ft/yr) at site 211 to 0.11 m/yr (0.36 ft/yr) at site 219. Mean recession from 1875 to 1974 was 0.49 m/yr (1.6 ft/yr).

Erosion Volumes

The jetty at Little Sodus Bay (Figure L-49) traps much coarse sediment in the littoral zone. This sediment must be derived from bluff erosion. Erosion volumes for the long and the short term are shown in Table 21. These volumes are large compared to the length of the coast and appear to be the result of erosion of the high drumlin bluffs.

Interpretation of Recession

The high rates found may in fact be related to the orientation of the coast, which is westerly facing. Prevailing westerly winds have a long fetch distance and wave action may be intense. We measured recession on high drumlins where erosion is concentrated. High percentages (30 to 50 percent) of sand and gravel in the till of these drumlins make them less cohesive and increases the erosion potential of the bluffs. The lack of vegetation on the bluff face allows rill wash and other processes of mass wasting to continue at a rapid rate.

Recession decreases in an eastward direction from the Wayne/Cayuga County line. Bluffs in the eastern region are lower and more highly vegetated. These lower bluffs are less subject to subaerial erosion and most recession is the result of wave attack. Periods of wave erosion are episodic, relating to high water and storms. Recession of the eastern bluffs (sites 215 to 219), which are 1 to 3 m (3 to 10 ft) high, occurs during discrete episodes whereas the higher bluffs in the western portion recede continually through the combined action of subaerial erosion and wave attack. This may partly account for the decrease in recession rate from east to west along the coast.

Most rapid recession is concentrated on high bluff regions. Rapid recession may be a problem near Fair Haven State Park and Moon Beach (Figures L-50 and L-51). Other areas of the coast undergo considerable recession; however, the land is either undeveloped or agricultural and recession poses fewer or at least less costly problems than in other more developed areas along the coast.

TABLE 18

Nearshore slopes: Cayuga County

Site number*	Slope (m/km)
210	7.8
211	4.6
212	4.1
213	5.2
214	6.0
215	7.1
216	7.8
217	8.2
218	13.6
219	13.4

*Sites located on Figures L-49 through L-51.

TABLE 19

Recession rates: Cayuga County

Site number	Long-term recession rate	Short-term recession rate
210	Very slow	Very slow
211	Fast	Very fast
212	Moderate	Very fast
214	Moderate	Moderate
215	Slow	Very slow
216	Very slow	Very slow
217	Moderate	Slow
218	Very slow	Slow
219	Very slow	Moderate

TABLE 20

Distribution of Cayuga County recession rates among the recession categories for the long and short term

Recession category	Long-term % of total sites	Short-term % of total sites
Very slow	44.4	33.3
Slow	11.1	22.2
Moderate	33.3	22.2
Fast	11.1	0.0
Very fast	0.0	22.2
Indeterminate	0.0	0.0

TABLE 21

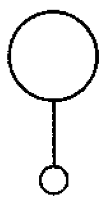
Mean annual erosion volumes in Cayuga County for the periods 1875-1974 and 1938-1954

Term	Average bluff height	x	Length of shore	x	Mean recession rate	=	Mean annual erosion volume
1875-1974	7.9 m		12,900 m		0.5 m/yr		5.10×10^4 m^3/yr
1938-1954	7.9 m		12,900 m		0.7 m/yr		7.14×10^4 m^3/yr

FIGURES L-49 to L-51

LOCATION MAPS FOR CAYUGA COUNTY

Scale on all maps: 1:24,000 or 1 inch = 2000 ft.



Indicates site and number where recession was measured

North is always at the top of the figure.

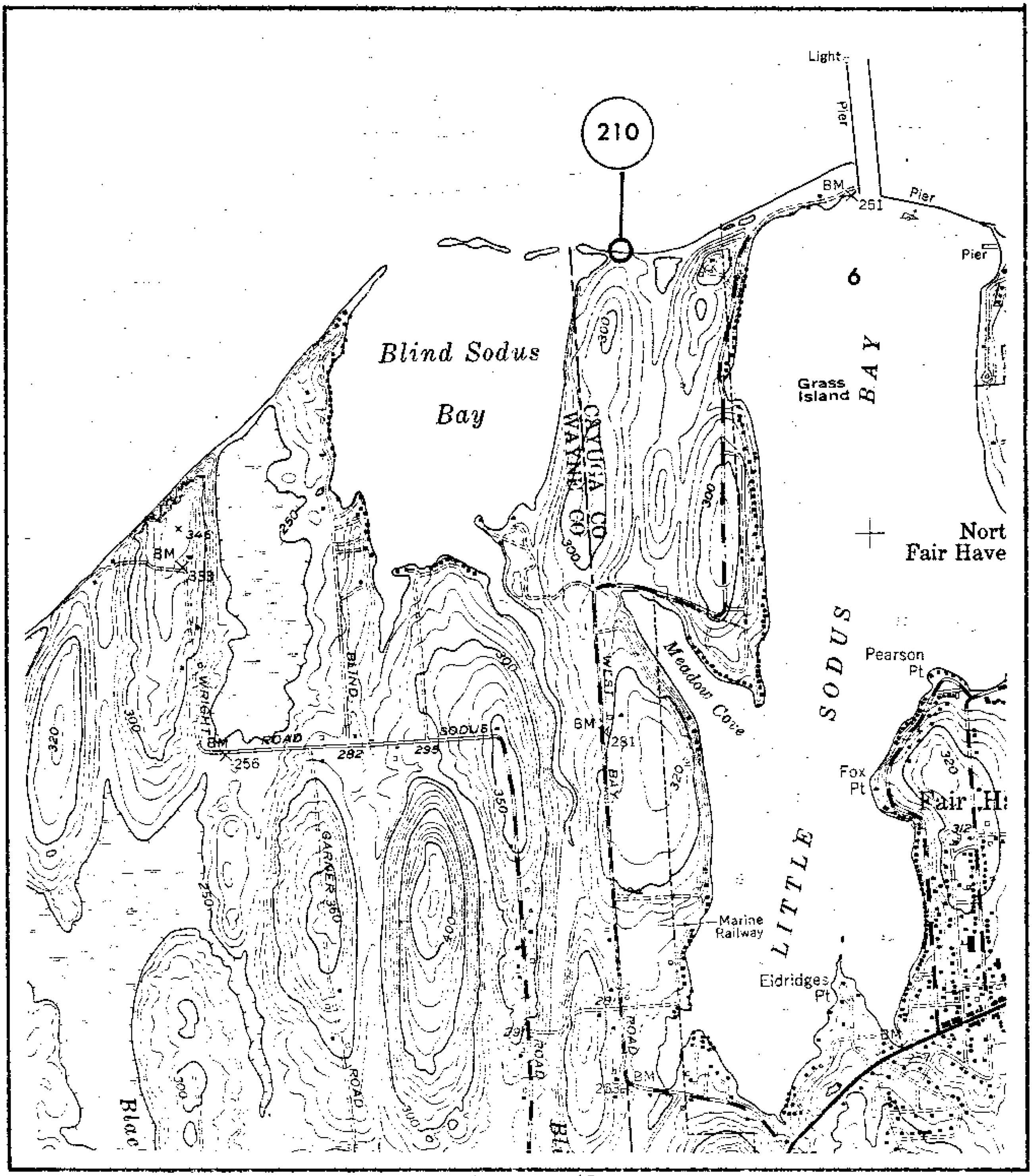

210
Light
Pier
BM
251
Pier
Pier
6
Blind Sodus
Bay
Grass Island
BAY
CAYUGA CO
WAYNE CO
North Fair Haven
SODUS
Meadow Cove
Pearson Pt
Fox Pt
Fair H
LITTLE
Marine Railway
Eldridges Pt
WRIGHT
ROAD
SODUS
BLIND
BM
256
282
295
BM
281
BAY
WEST
GARNER
ROAD
BM
353
346

Figure L-49

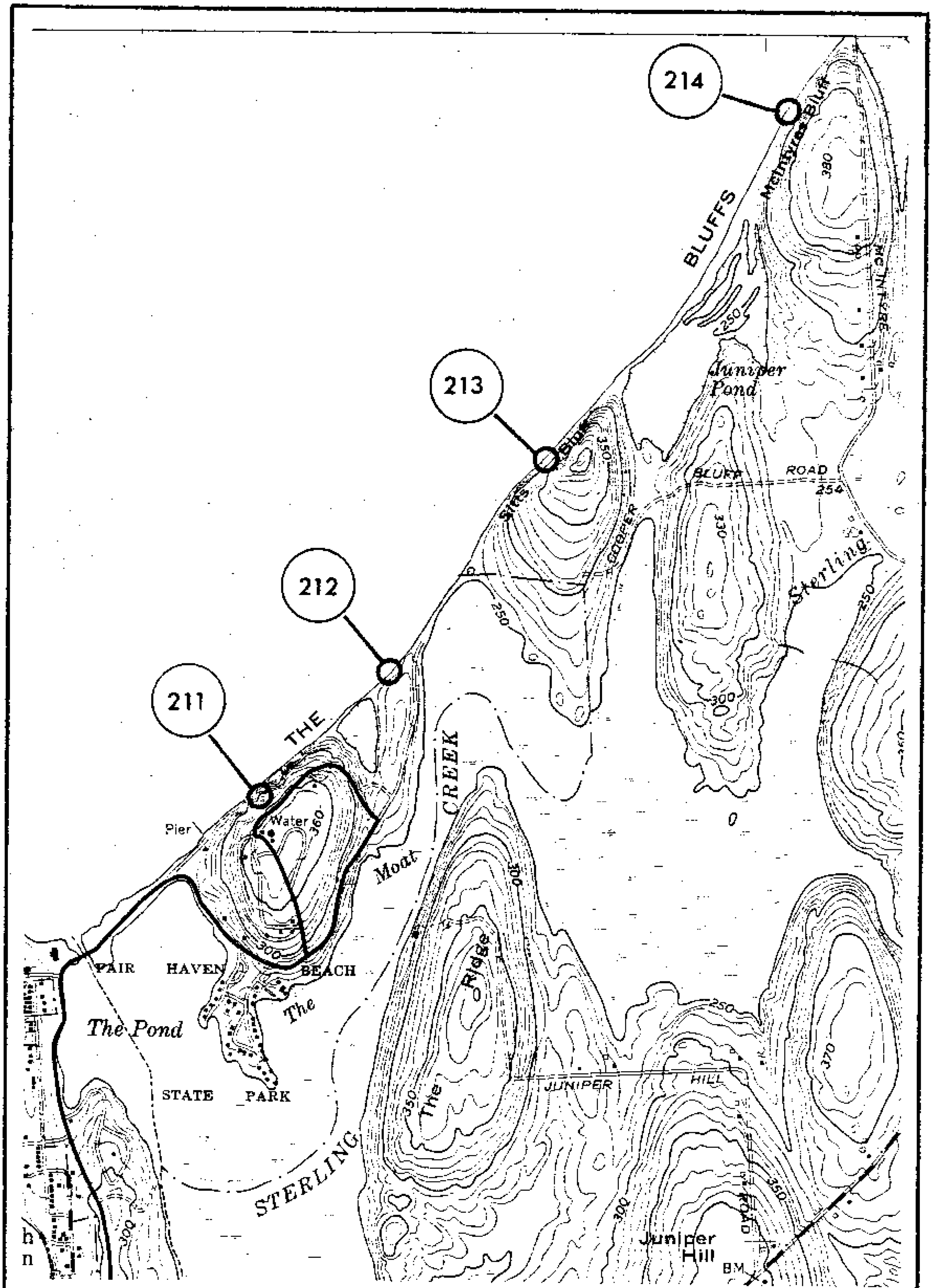
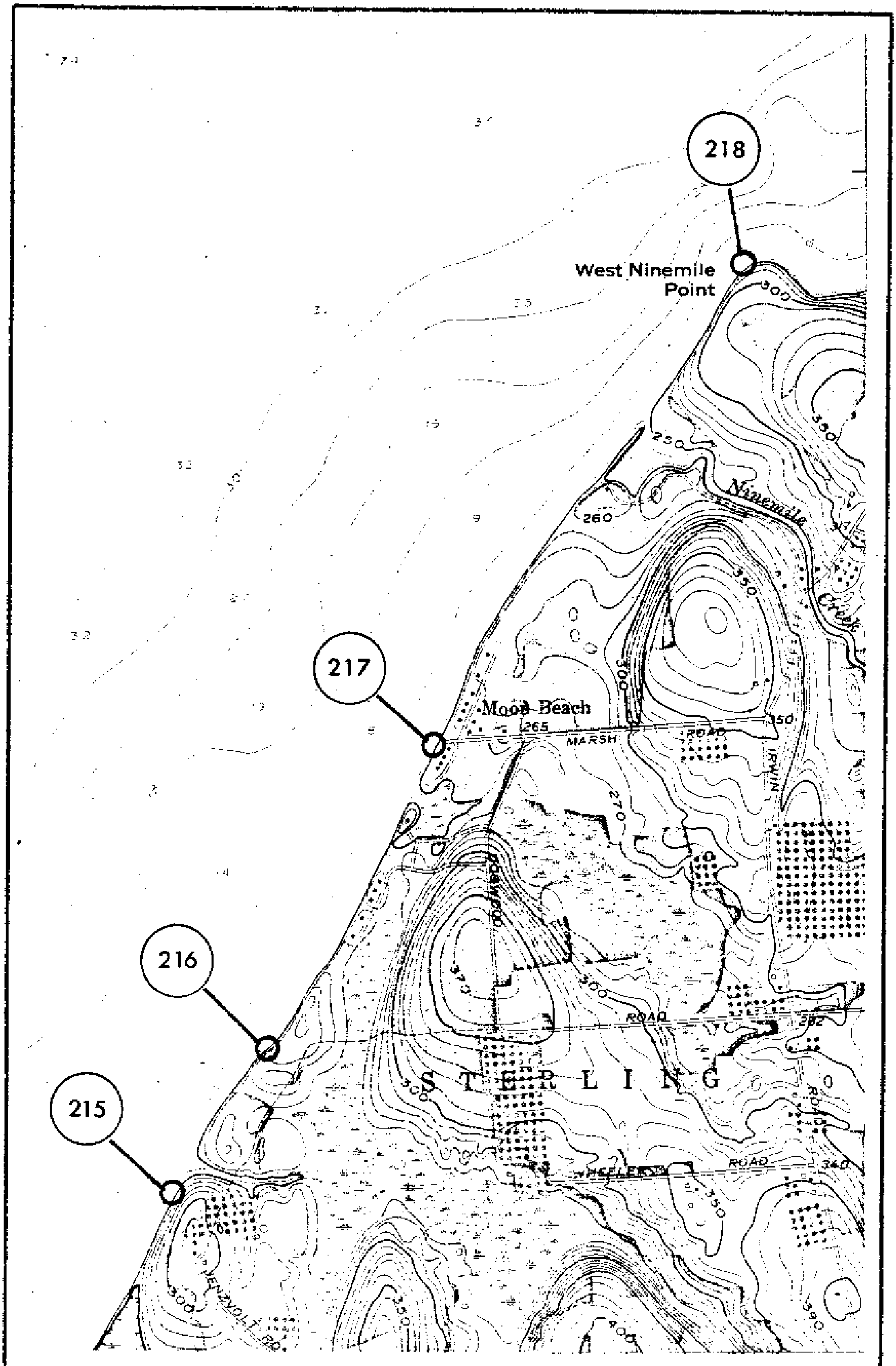

214
213
212
211
BLUFFS
THE
McIntyres Bluff
Juniper Pond
BLUFF ROAD
COOPER
Sterling
CREEK
Moat
Water
Pier
FAIR HAVEN BEACH
The Pond
STATE PARK
The
STERLING
The Ridge
JUNIPER HILL
ROAD
Juniper Hill
BM

Figure L-50


218
West Ninemile
Point
217
Mood Beach
MARSH
ROAD
IRWIN
216
215
STERLING
ROAD
WHEELER
ROAD
Ninemile
Creek
Figure L-51

Oswego County

Geography

Location

Oswego County, at the eastern end of the study area, contains 55 km (34.2 mi) of Lake Ontario coastline, from Eighteenmile Creek (Figure L-52) to North Pond (Figure L-62). We measured recession at 32 sites indicated on Figures L-52 through L-62. We measured only a few sites at the eastern end of the county because the photos and maps included strips of coast too narrow to measure, making selection of measurement sites difficult.

Land Use

Commercial, residential, and industrial development occupy approximately 57 percent of the coastal area; agricultural purposes account for 33 percent; and recreation 10 percent (US Army Corps of Engineers 1973). A state park is located at Selkirk Shores along the eastern portion of the coast. Since much of the region is developed, recession in such areas poses significant problems.

Geology

Bluffs

Most of the Oswego County coastline from the western county line to just east of Oswego, is made up of bluffs 3 to 12 m (10 to 39 ft) high interspersed with occasional drumlins up to 35 m (115 ft) high (sites 220 to 228, Figures L-52 through L-55). These bluffs are composed of gray stony till; moving east, the sand content of the till increases. Low continuous bluffs 6 to 10 m (20 to 33 ft) high extend from near Ninemile Point to Mexico Bay (sites 230 to 243). The bluffs are occasionally broken by wetland regions. These bluffs are composed of sandy till and lacustrine sands that are less consolidated than those in the western portions of the county (Kaiser 1962). Gray Oswego Sandstone is intermittently exposed above the waterline in an area west of the town of Selkirk (Figure L-61); it reaches a maximum height of 5.6 m (18.4 ft) above lake level west of Ninemile Point (Calkin, in preparation).

From Mexico Bay to North Pond (sites 244 to 250) the coast is composed of partially stabilized dune complexes and higher drumlin bluffs fronting ponds and wetlands. The bluffs are composed mostly of sand and are highly susceptible to erosion (Calkin, in preparation). Higher drumlin areas are composed of till with clay contents higher than surrounding areas.

Beaches

Beaches between the Cayuga/Oswego County line and Texas (Figures L-52 through L-59) are narrow or absent. Most are composed of coarse cobbles (above

20 cm or 7.9 in) and lie between bedrock exposures. Widths are usually less than 8 m (26.2 ft). Beach material becomes generally finer-grained northward of the Mexico Bay region, resulting partially from the sandier composition of the bluff material, but particularly from the littoral drift regime of the region (Sutton et al 1970; Trask 1976; Weir 1977).

Along the eastern section (sites 244 to 250) of the coast, beaches are more fully developed and made of fine-grained sand. Sand beaches wider than 24 m (78.7 ft) with inlets and overwash channels occur in this region (Sutton et al 1970; Weir 1977). Recession here involves somewhat different processes than along the south coast of Lake Ontario. Beach erosion, dune migration, and inlet formation and closure are processes that alter shoreline configurations and bluff positions (US Army Corps of Engineers 1954; Cohn 1973).

Streams

Sixteen streams flow into Lake Ontario in Oswego County, three enter through North Pond. They contribute little sediment to the littoral zone (Leetaru 1978). The most significant tributary is the Oswego River (Pluhowski 1975); its sediment load of 136,500 tons/yr contributes significantly to the littoral environment (Upchurch 1973).

Nearshore Slopes

Slopes of the nearshore zone ranged from 5.2 to 28.9 m/km or 28 to 153 ft/mi (Table 22). The highest slopes in the county are from sites 231 to 240, where bedrock is at or near lake level. The lowest slopes are in the eastern part of the county, from sites 241 to 250, and are probably caused by offshore sand sheets (Sutton et al 1970, 1972).

Recession Rates

Recession History

Table 23 shows the recession rates for the 32 sites indicated in Figures L-52 through L-62. Table 24 gives the distribution of recession rates in each recession category. Forty percent of the sites had higher rates for the short term than for the long term; 16 percent had lower short-term rates; 16 percent had the same rates; and 28 percent had indeterminable rates. We could not compute long-term rates at many locations because too few landmarks were available to allow superimposition of the 1974 photos onto the 1874 survey. Short-term rates reached up to 2.96 m/yr (9.7 ft/yr) at site 221 with a mean rate of 0.55 m/yr (1.8 ft/yr). The long-term mean rate was 0.26 m/yr (0.9 ft/yr) and rates reached to 0.56 m/yr (1.8 ft/yr) at sites 234, 236, and 237.

Erosion Volumes

We calculated erosion volumes for the portion of the county along the southern lake coast between sites 220 and 246. We decided to eliminate the eastern coastal section from sites 247 to 250 from these calculations since

TABLE 22

Nearshore slopes: Oswego County

Site number*	Slope (m/km)
219	13.4
220	6.3
221	5.3
222	10.0
223	15.0
224	7.7
225	8.7
226	15.3
227	6.7
228	6.8
229	7.3
230	7.4
231	13.4
232	15.0
233	15.3
234	17.1
235	25.9
236	26.8
237	25.9
238	19.2
239	28.9
240	10.4
241	8.8
242	8.5
243	7.5
244	5.2
245	5.2
246	6.7
247	8.4
248	8.6
249	7.5
250	6.5

*Sites located on Figures L-52 through L-62.

TABLE 23

Recession rates: Oswego County

Site number	Long-term recession rate	Short-term recession rate
219	Very slow*	Very fast*
220	Very slow	Very fast
221	Very slow	Very fast
222	Very slow	Slow*
223	Very slow	Slow
224	---	Very fast
225	Very slow	Moderate*
226	Very slow	Moderate
227	Very slow	Very slow
228	Very slow	Very slow
229	Slow	Very slow
230	---	Very slow
231	---	Very slow
232	---	Very slow
233	---	Very slow
234	Slow	Very slow
235	Slow	Very slow
236	Slow	Very slow
237	Slow	Very slow
238	Very slow	Slow
239	Very slow	Moderate
240	Very slow	Very fast
241	Very slow	Fast*
242	Slow	Slow
243	Very slow	Slow
244	---	Very slow
245	Slow	---
246	Very slow	Very slow
247	Very slow	Very slow
248	Very slow	Moderate
249	---	Very slow
250	---	Slow

*Very slow=<0.3 m/yr; slow=0.3-0.6 m/yr; moderate=0.6-0.9 m/yr; fast=0.9-1.2 m/yr; very fast=>1.2 m/yr.

TABLE 24

Distribution of Oswego County recession rates among the recession categories for the long and short term

Recession category	Long-term % of total sites	Short-term % of total sites
Very slow	53.1	46.9
Slow	21.9	18.8
Moderate	0.0	12.5
Fast	0.0	3.1
Very fast	0.0	15.6
Indeterminate	25.0	3.1

littoral processes here tend to compensate for erosion with accretion in adjoining areas, resulting in no net increase in sediment in the littoral zone (Weir 1977). The erosion volumes are shown in Table 25. Thirty-six percent of the erosion occurred in the 17 years after 1938.

Interpretation of Recession

We found no apparent trend within the long-term rates; all are slow to very slow. Because much of Oswego County was wooded and undeveloped at the time of the 1874 Survey, the bluff positions we used in our study may not have been accurate; hence, this long term rate may be questionable.

Short term rates often were higher and did illustrate some trends. We found higher short term rates west of Oswego than east of it. The western region is composed of intermittent drumlin bluffs which are more susceptible to erosion. Rates are very low in the reach between Oswego and Ninemile Point (Figures L-55 to L-59). This may in part be due to the frequent exposure of bedrock along this area. We found high recession rates in the Mexico Bay region (sites 239-248). Beaches here are finer-grained and less steep and provide less protection against wave attack. The bluff material is sandier and less cohesive, and the bluffs are generally lower than those to the west. Hence they may be subject to higher erosion. The long wave fetch and unconsolidated sand in the eastern section subject the area to high recession. Separate intensive studies by Weir (1977) and Cohn (1973) document erosion in the North Pond and Selkirk areas using different techniques than the ones we used. Since few sites in this area were available for our recession measurements, the high erosion rates are not apparent in our results presented here.

TABLE 25

Mean annual erosion volumes in Oswego County for the periods 1875-1974 and 1938-1954

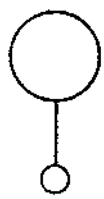
Term	Average bluff height	x	Length of shore	x	Mean recession rate	=	Mean annual erosion volume
1875-1974	3.1 m		43,770 m		0.26 m/yr		3.53×10^4 m^3/yr
1938-1955	3.1 m		43,770 m		0.55 m/yr		7.46×10^4 m^3/yr

FIGURES L-52 to L-62

LOCATION MAPS FOR OSWEGO

COUNTY

Scale on all maps: 1:24,000 or 1 inch = 2000 ft.



Indicates site and number where recession was measured.

North is always at the top of the figure.

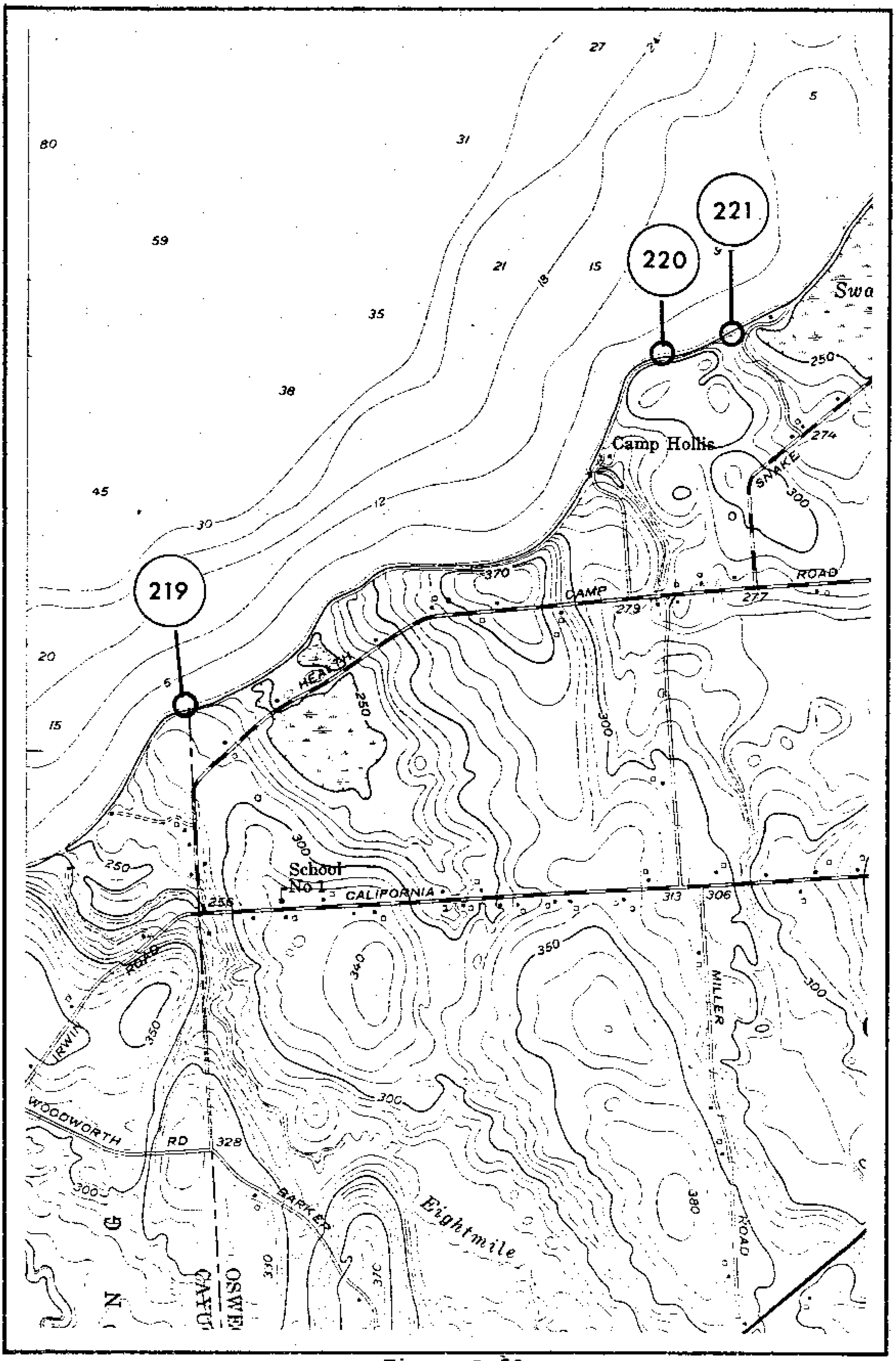

219
220
221
Camp Hollis
School
No 1
CAMP
ROAD
HEALTH
SNAKE
CALIFORNIA
IRWIN
ROAD
WOODWORTH
RD
BARKER
MILLER
ROAD
Eightmile
OSWE
CAYU
Swa

Figure L-52

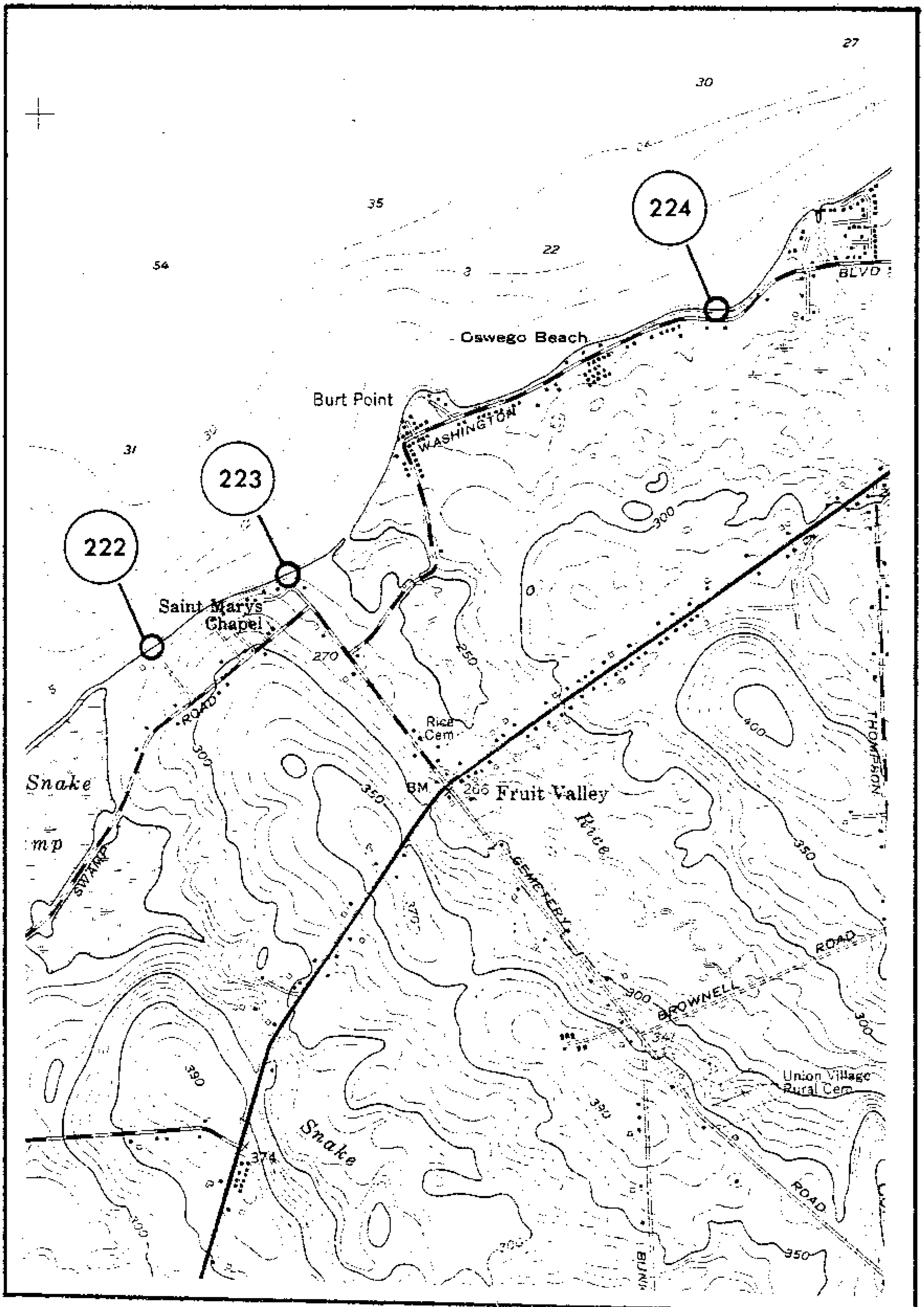

224
223
222
Oswego Beach
Burt Point
WASHINGTON
BLVD
Saint Marys Chapel
ROAD
Rice Cem
BM
Fruit Valley
Snake
SWAMP
CEMETERY
THOMPSON
ROAD
BROWNELL
Union Village Rural Cem
Snake
ROAD
Rice

Figure L-53

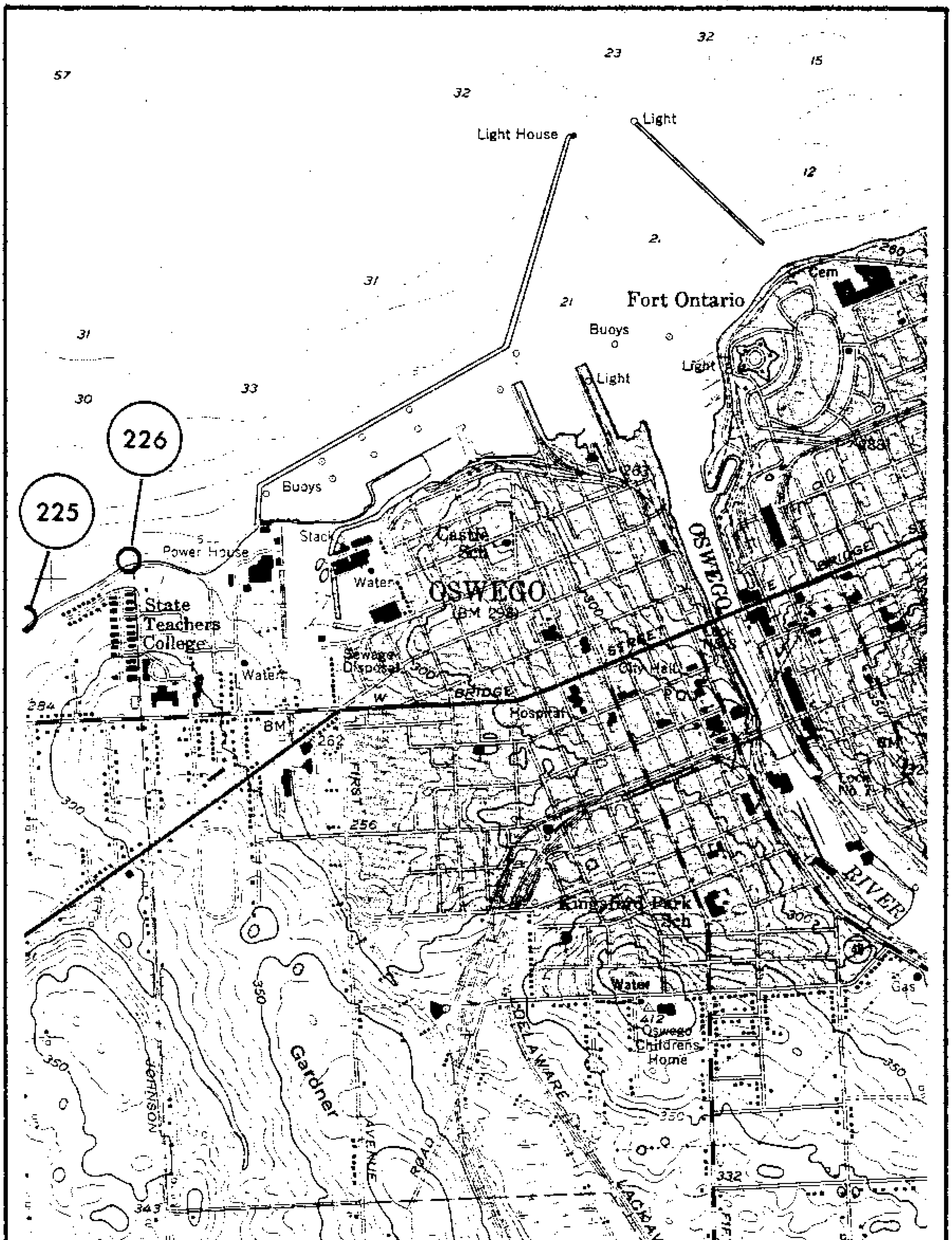
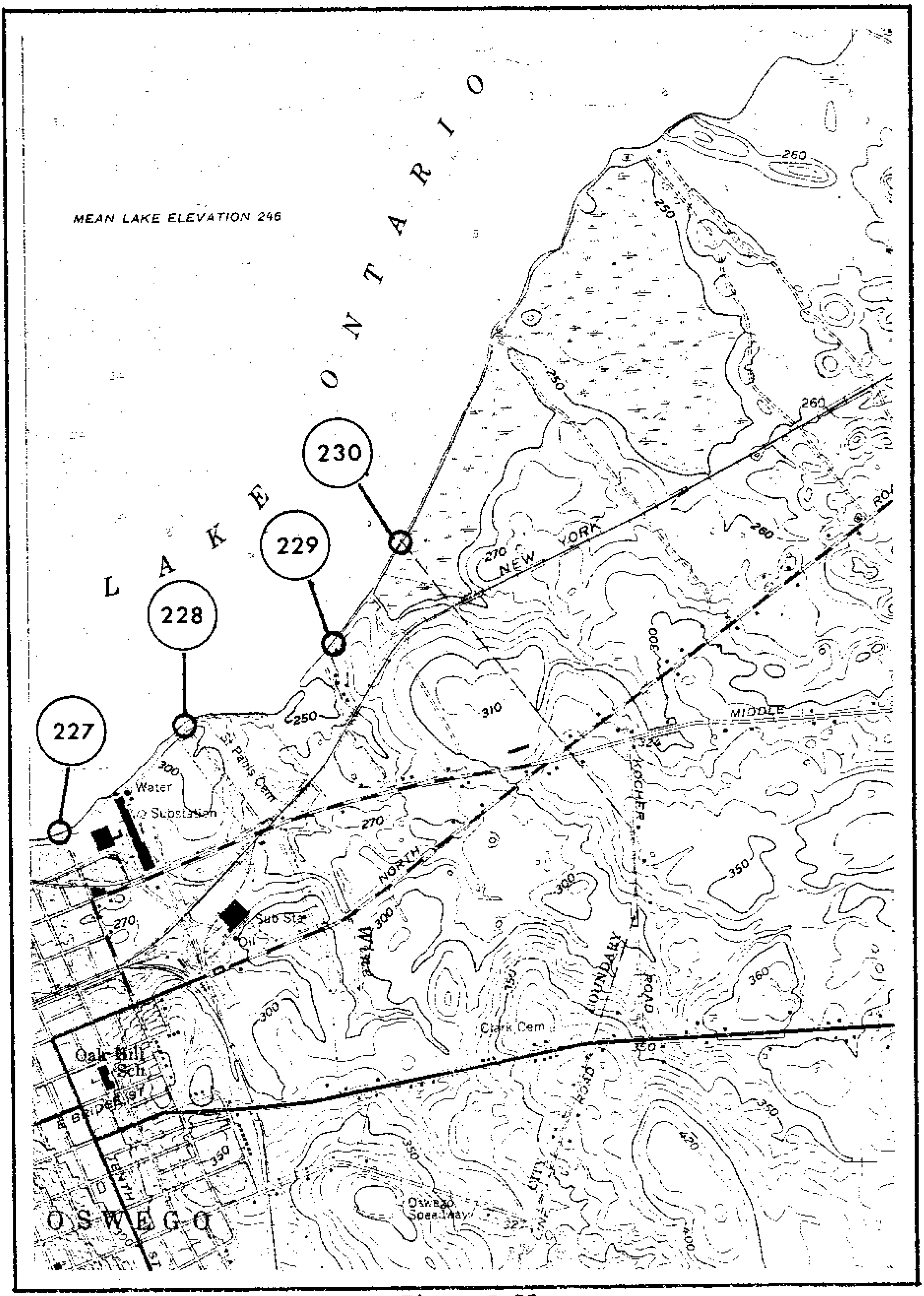

226
225
Light House
Light
Fort Ontario
Buoys
Light
Buoys
Power House
Stack
Water
Castle Sch
OSWEGO
(BM 298)
State Teachers College
Water
Sewage Disposal
BRIDGE
STREET
City Hall
Hospital
OSWEGO
RIVER
Kingsford Park Sch
Water
Oswego Childrens Home
Gardner
JOHNSON
FIRST
AVENUE
ROAD
DELAWARE
LACKAWANNA
FIFTH
Cem
Gas

Figure L-54



MEAN LAKE ELEVATION 246
LAKE ONTARIO
227
228
229
230
Water
Substation
Sub Sta
Oil
Oak Hill Sch
NEW YORK
MIDDLE
NORTH
KOCHER
BOUNDARY
ROAD
CITY
Clark Cem
Oswego Speedway
OSWEGO
BRIDGE
TENTH ST

Figure L-55

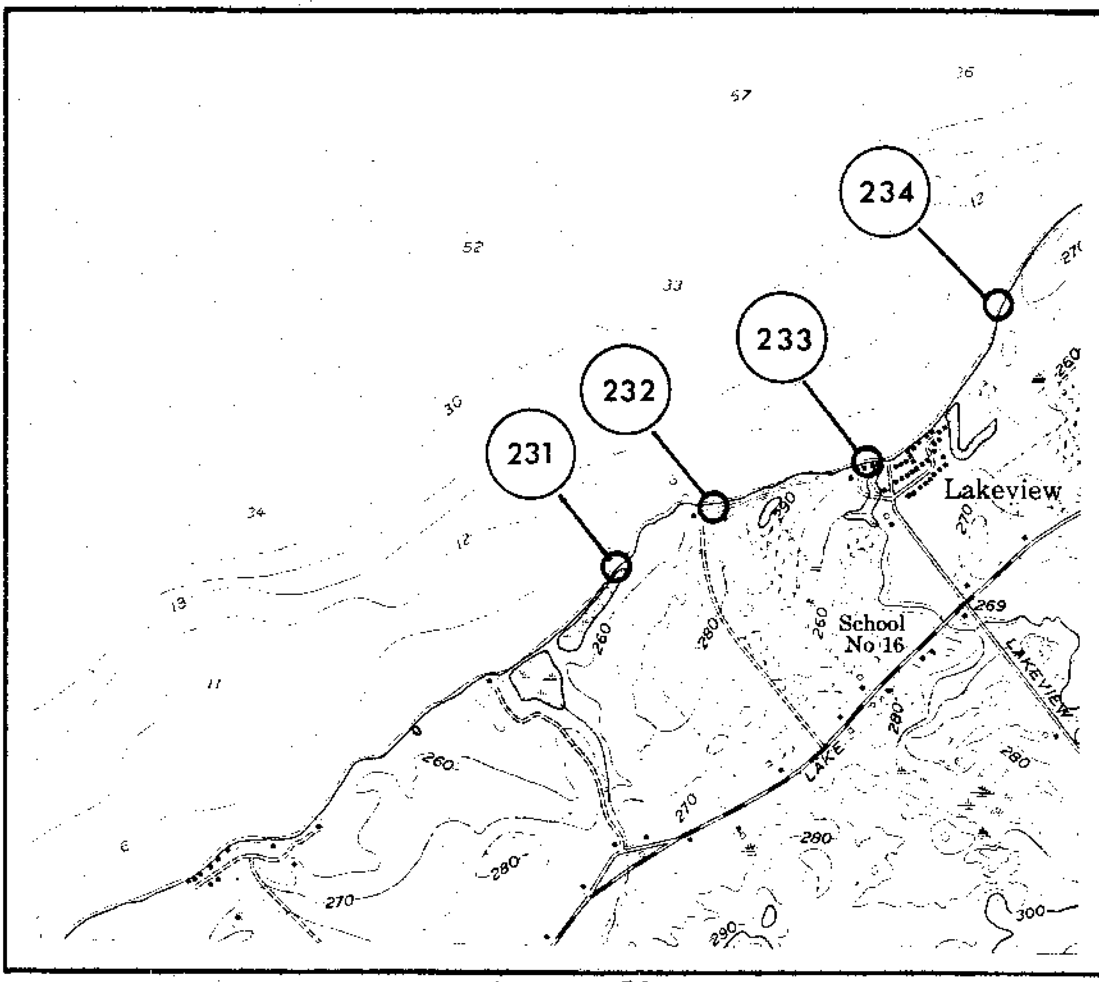


Figure L-56

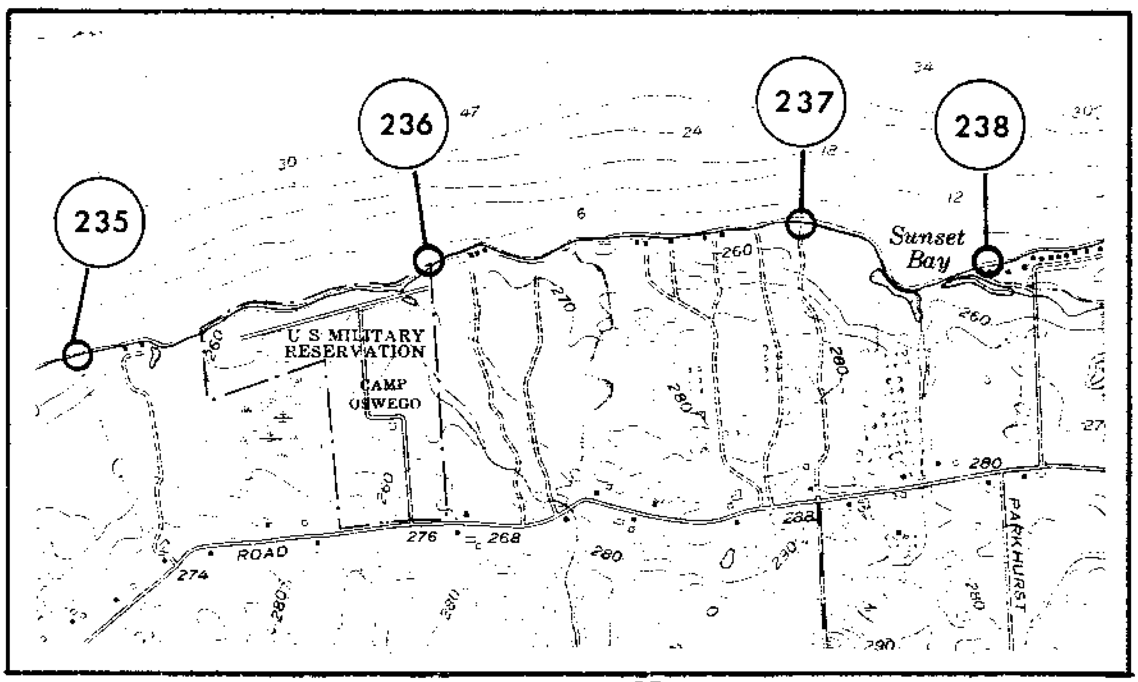


Figure L-57

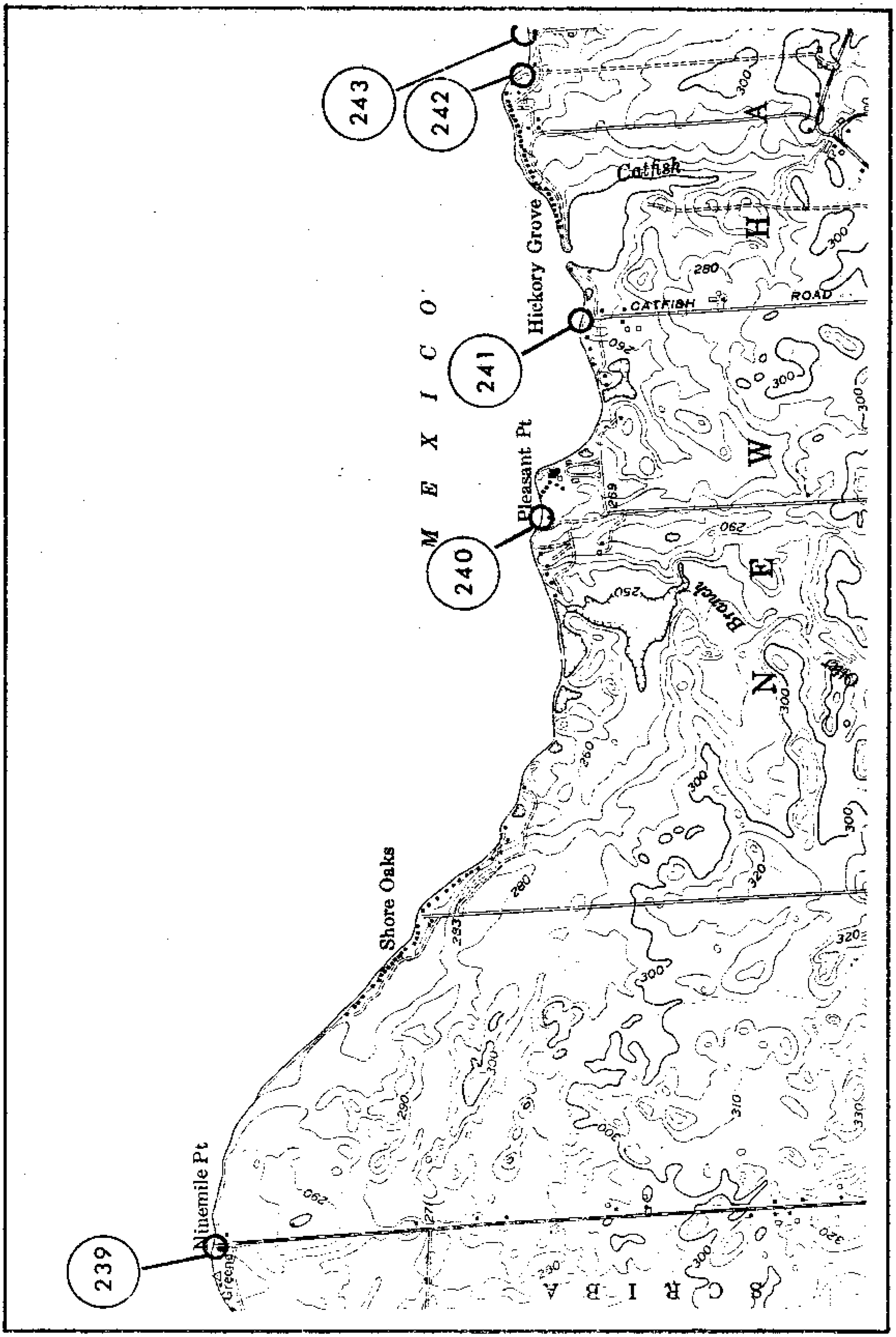

239
240
241
242
243
Ninemile Pt
Shore Oaks
Pleasant Pt
Hickory Grove
M E X I C O
Catfish
CATFISH ROAD
Branch
N E W H A
S C R I B A

Figure L-58

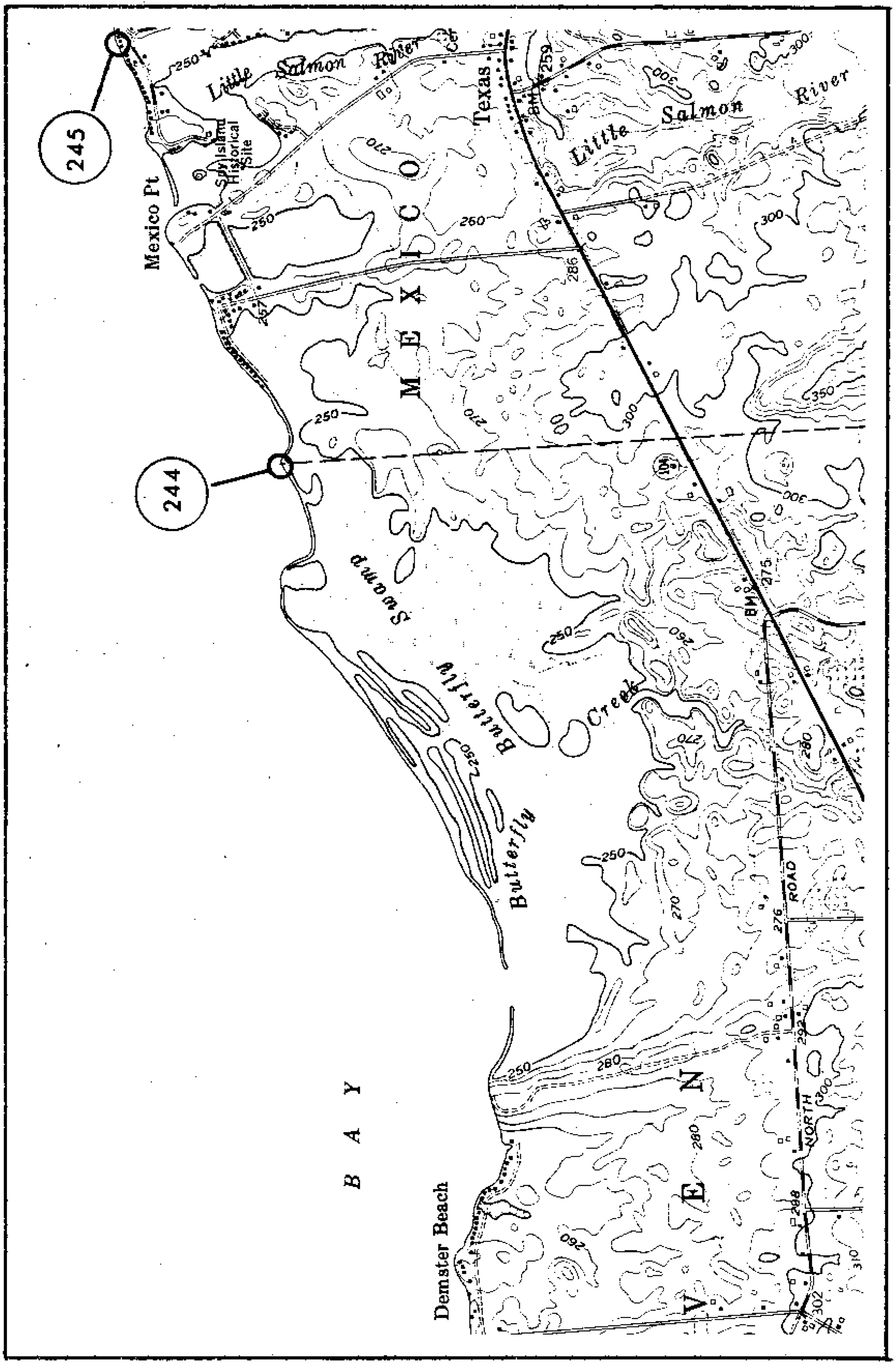

245
244
Mexico Pt
Spy Island Historical Site
Little Salmon River
Texas
Little Salmon River
M E X I C O
Swamp
Butterfly
Butterfly
Creek
B A Y
Demster Beach
NORTH ROAD
V O E N

Figure L-59

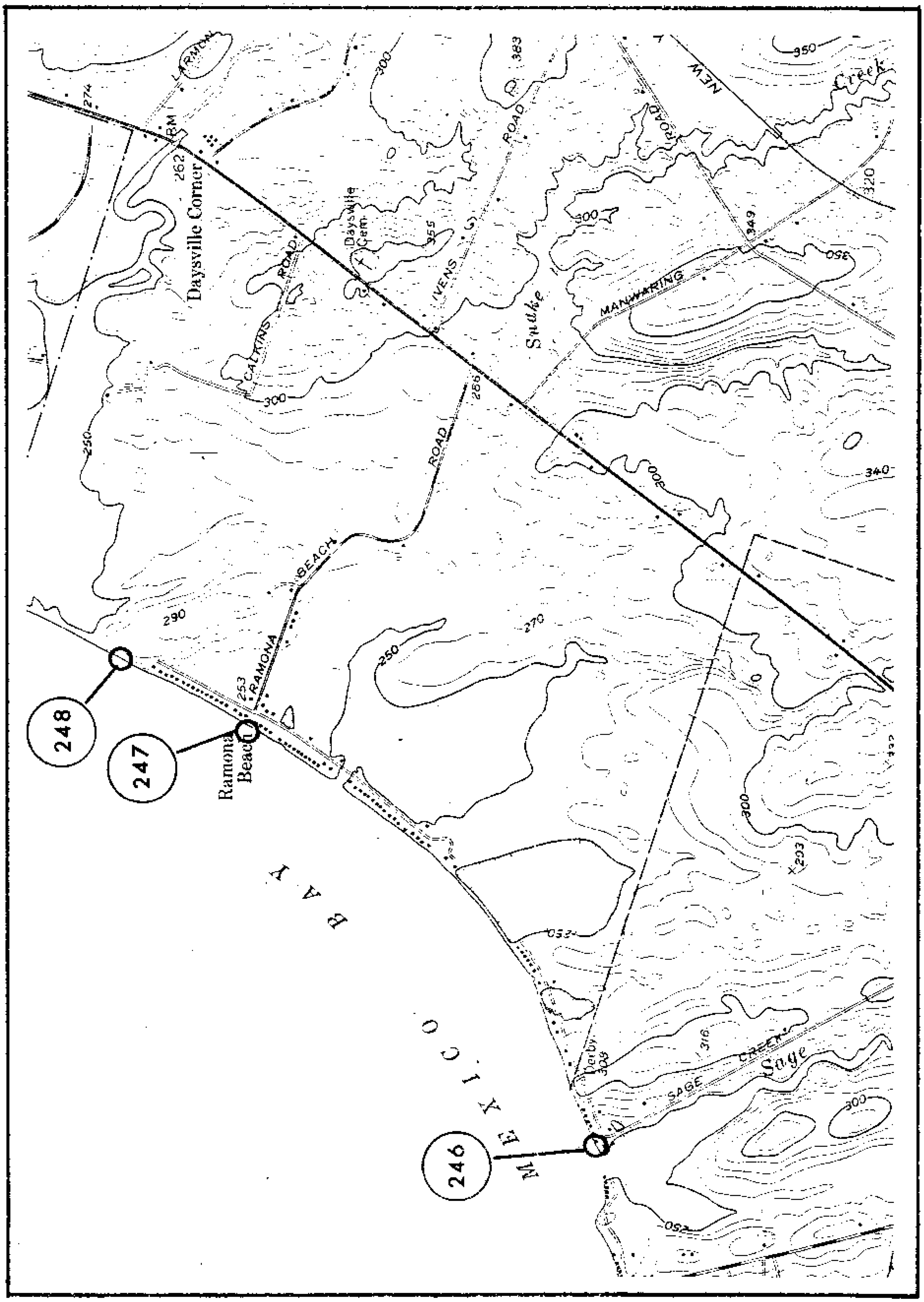

Daysville Corner
Ramona Beach
LARMON
CALKINS ROAD
IVENS ROAD
RAMONA BEACH ROAD
MANWARING
NEW ROAD
SAGE CREEK
Sage
Creek
Snake
Derby
Daysville Cem
MEXICO BAY
248
247
246

Figure L-60

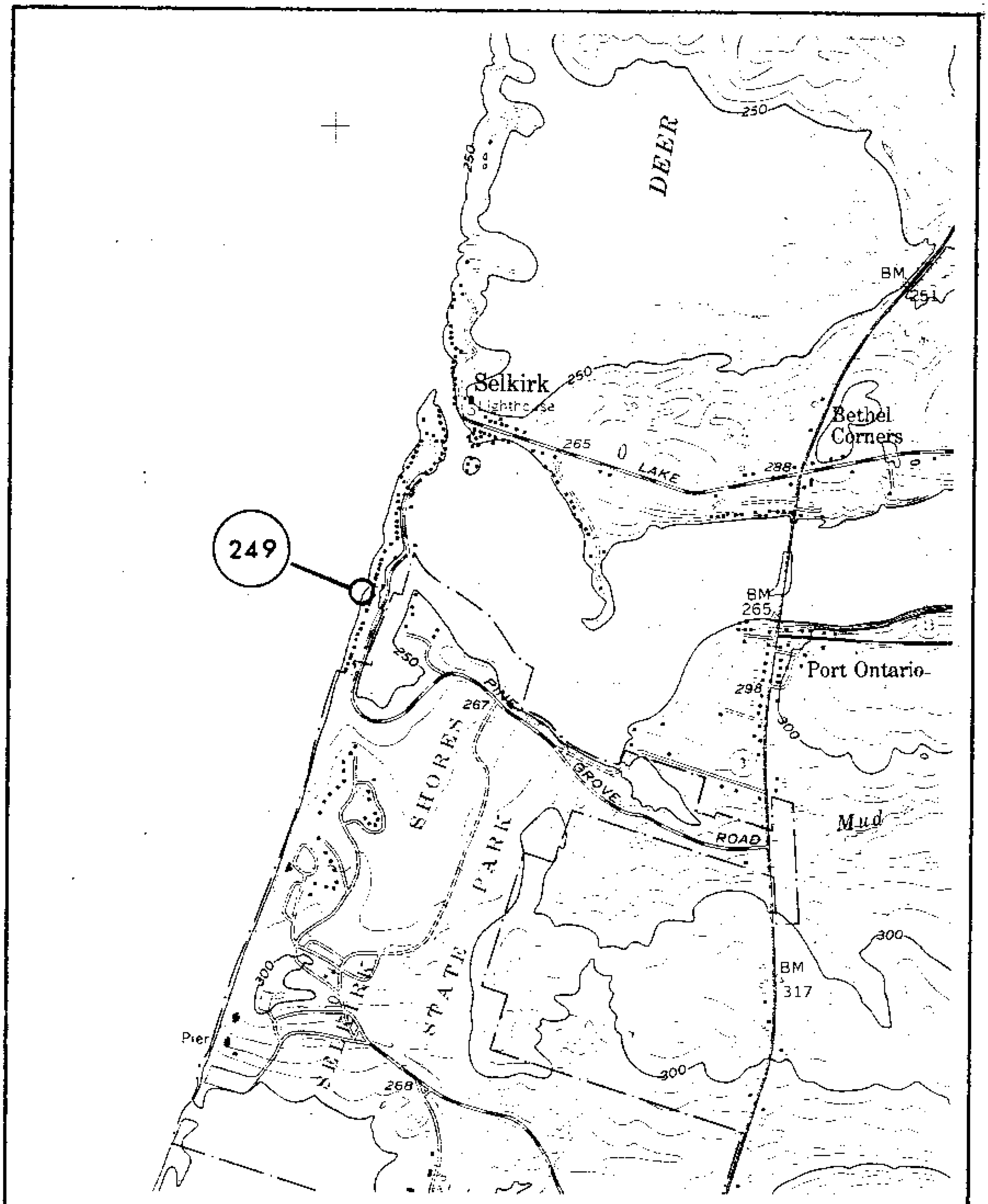

DEER
250
BM
251
Selkirk
Lighthouse
Bethel
Corners
265
LAKE
288
249
BM
265
Port Ontario
250
PINE
267
298
300
SHORES
GROVE
ROAD
Mud
PARK
STATE
300
BM
317
Pier
300
268
300

Figure L-61

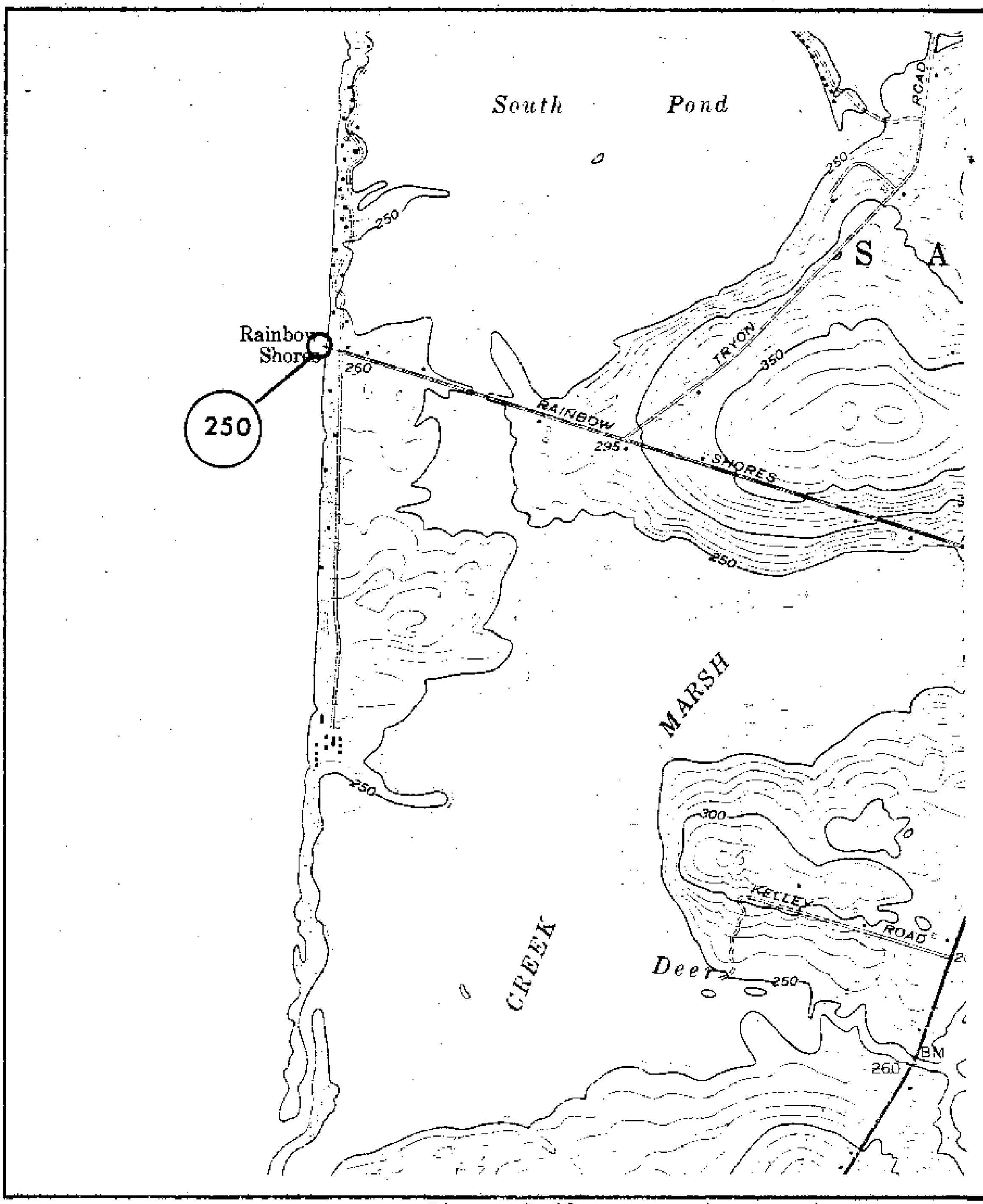

South
Pond
ROAD
250
S
A
Rainbow
Shores
250
260
TRYON
350
RAINBOW
295
SHORES
250
MARSH
300
KELLEY
ROAD
CREEK
Deer
250
BM
260

Figure L-62

ANALYSIS OF RECESSION RATES

Introduction

In undertaking analysis of bluff recession rates along the south coast of Lake Ontario, we linked geologic and physiographic conditions to recession rate. We took data in the field at 101 of the sites where recession was measured (Table 26). A preprinted data sheet contained the recession information. At each site, nine parameters were recorded including bluff height, bluff composition, bluff orientation, bluff face slope, beach width, beach composition, degree of bluff fracturing, vegetation type, and beach slope. Each parameter was divided into several subcategories. We then analyzed the information to determine the relationship of each parameter to the long-term recession rate.

Determination of the frequency distribution for each parameter showed the dominant subcategory, if any, of the parameter along the coast (Davis 1973). In addition, we calculated the mean recession rate for each subcategory. This was intended to demonstrate which subcategory of the parameter was associated with the highest recession rates along the coast, as well as which subcategories were conducive to low recession. Table 27 shows the results of these calculations. We found no significant relationship of the degree of fracturing, vegetation type, or beach slope to bluff recession rate and therefore they are not included in the table. The six parameters listed plus beach slope may serve as variables in future predictive models of recession for the Great Lakes (Davis 1974; Hiipakka 1974); therefore, some discussion of these is presented below.

Discussion of Significant Recession Parameters

Bluff Height

We took the vertical distance from the base of the cliff at the back of the beach to the break in slope at the top as the bluff height. Bluffs in the subcategory greater than 6.1 m (20 ft) high had the highest mean recession rate, 0.53 m/yr (1.7 ft/yr). Sites where no bluff was present had the second highest mean rate, 0.41 m/yr (1.3 ft/yr). Low to moderate bluffs displayed the least recession (Table 27).

Highest recession on bluffs greater than 6.1 m (20 ft) may correlate with their tendency to be subject to greater mass wasting than lower bluffs (Quigley and Tutt 1968). Coastal regions with no bluff (bluff height <0.3 m or 1 ft) usually display beaches or lowlands where the beach grades up directly to the coastal land (US Army Corps of Engineers 1973). Recession in these areas has been recorded as the landward retreat of the line marking the break in vegetation. The higher recession of this subcategory needs no explanation.

TABLE 26

List of sites where data were gathered in the field. Sites are located on Figures L-1 through L-62

Site number	Site number	Site number
4	108	182
11	109	185
12	110	188
13	111	190
23	112	198
34	113	199
35	114	200
37	115	201
38	116	202
60	119	203
61	121	205
62	122	206
66	126	208
67	128	209
68	129	217
70	130	221
71	132	223
74	133	224
75	134	225
76	136	226
82	140	227
83	141	228
84	147	229
91	148	230
92	149	232
93	150	233
95	162	234
98	171	235
99	174	238
100	178	239
104	179	240
105	180	241
107	181	242

TABLE 27

Parameters investigated in the field, subcategories, mean recession rates, standard deviation, maximum and minimum values, and number of samples

Parameter	Subcategory	Mean rate (m/yr)	Standard deviation	Max	Min	n
Bluff height	Low, 1-5	0.23	0.16	0.51	0.00	11
	Medium, 5-12	0.30	0.27	0.81	0.00	21
	High, 12-20	0.28	0.21	0.61	0.00	19
	Very high, >20 ft	0.53	0.43	1.28	0.00	16
	No bluff	0.41	0.33	1.28	0.00	18
Bluff composition	Sandy till and sand	0.34	0.25	0.97	0.00	16
	Clayey/silty till	0.39	0.34	1.28	0.00	42
	Bedrock toe with sand	0.17	0.06	0.25	0.00	4
	Bedrock toe with clay	0.06	0.08	0.20	0.00	6
	No bluff	0.41	0.32	1.28	0.00	17
Bluff orientation	$285^{\circ}-325^{\circ}$	0.53	0.27	0.91	0.18	5
	$325^{\circ}-5^{\circ}$	0.34	0.34	1.28	0.00	59
	$5^{\circ}-45^{\circ}$	0.35	0.21	0.72	0.00	18
	$45^{\circ}-85^{\circ}$	0.43	0.34	0.12	0.05	3
Bluff face slope	Nearly vertical, $75^{\circ}-90^{\circ}$	0.37	0.31	1.27	0.00	44
	Steep, $45^{\circ}-75^{\circ}$	0.39	0.25	0.77	0.00	8
	Medium, $20^{\circ}-45^{\circ}$	0.22	0.41	1.28	0.00	9
	Low, $<20^{\circ}$	0.29	0.13	0.41	0.15	3
	No bluff	0.37	0.32	1.28	0.00	21
Beach width	None	0.31	0.31	1.28	0.00	22
	Narrow, <10 ft	0.33	0.28	1.11	0.00	35
	Medium, 10-30 ft	0.38	0.32	1.27	0.00	25
	Wide, >30 ft	0.84	0.39	1.28	0.51	3
Beach composition	Sand	0.40	0.26	0.71	0.00	7
	Pebbles	0.29	0.36	0.91	0.00	6
	Cobbles	0.49	0.37	1.28	0.00	26
	Coarse cobbles	0.27	0.21	0.77	0.00	18
	Boulders	0.28	0.31	0.81	0.00	7
	No beach	0.30	0.31	1.28	0.00	21

Low and medium bluffs (0.3 to 3.6 m or 0.9 to 11.8 ft) are not as subject to mass failure; most recession is the result of direct wave erosion. Episodes of high recession are discrete short-term events.

Bluff Composition

Many variations and combinations of bluff composition exist along the Lake Ontario coast; however, only five major subcategories (Table 27) existed at the sites visited. We took the composition of the unconsolidated bluff material as the portion with a vertical extent greater than 50 percent of the height.

Sites with bedrock toes had the lowest mean recession (Table 27). In comparison, such sites had less than half the recession of sites without bedrock protection. Sites composed of sand and sandy till had a mean rate of 0.34 m/yr (1.1 ft/yr), while sites composed of clayey/silty till receded still faster with a mean rate of 0.39 m/yr (1.3 ft/yr). The high mean recession found at the sites composed of clayey/silty till may relate to a number of factors:

1. Only a small percent of the eroded material remains to build a protective beach.

2. When mass failure occurs, the arc of failure is farther landward from the bluff face and more recession is produced (Edil and Vellejo 1976).

3. Growth of vegetation is difficult on very clayey material.

4. Highest recession is often on high drumlin bluffs which, by their origin, are most often composed of sandy or clayey/silty till.

Bluff Orientation

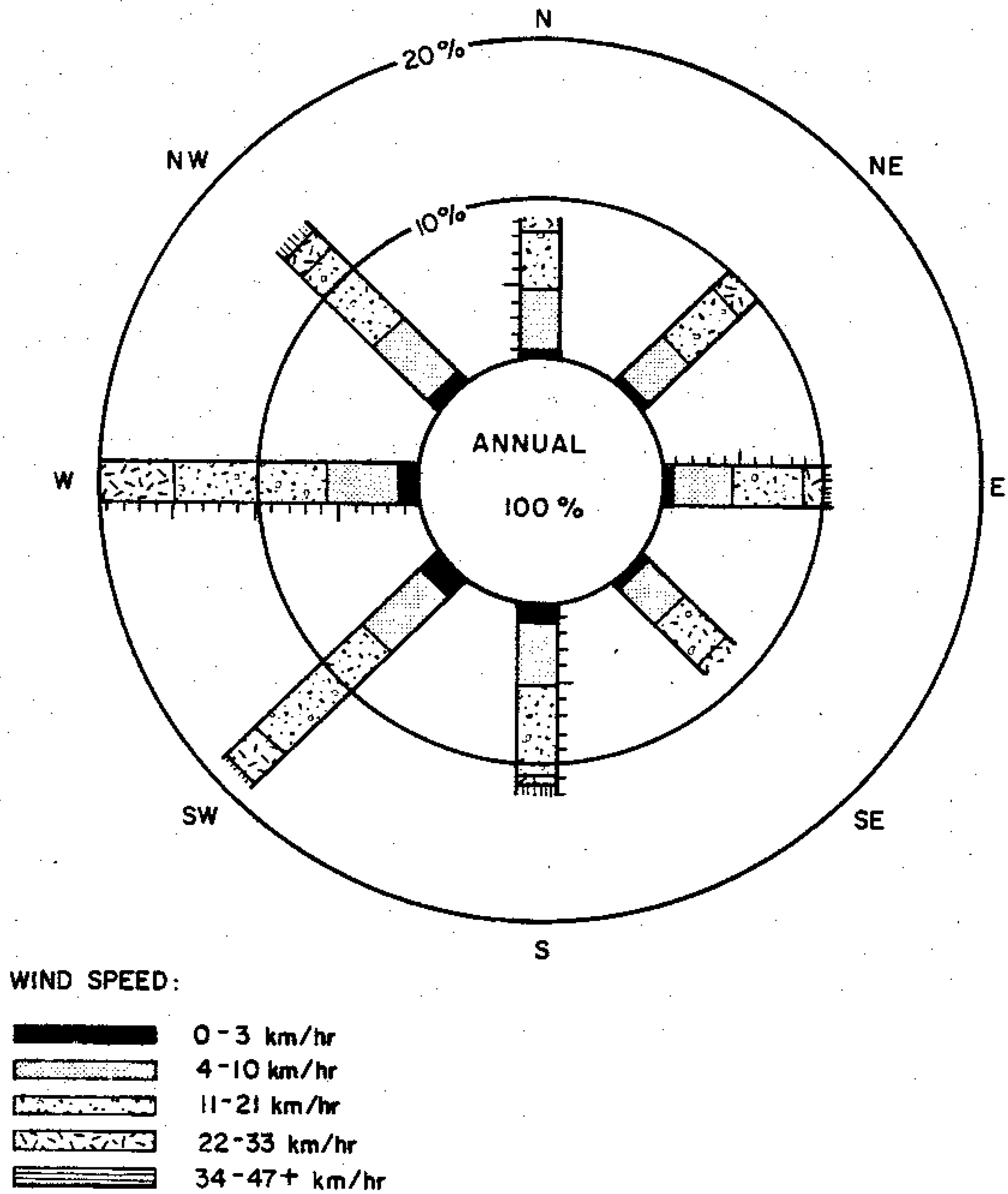
We determined the bluff face orientation as the azimuth of a line drawn perpendicular to the bluff line. Most bluffs were oriented in a northerly direction, that is, between 325° and 45°. However, those with orientations between 285° and 325° showed the highest mean recession (Table 27). Bluffs oriented between 45° and 85° had the second highest recession, while those between 325° and 45° showed the slowest recession.

Highest recession on westerly facing bluffs relates to the prevailing westerly winds (Figure 8). Waves generated by such winds impact more directly on portions of the coast facing west, resulting in higher energy concentrations conducive to erosion (Coakley and Cho 1973). Most of the bluffs oriented between 45° and 85° are in Monroe County. Storm waves generated by northeasterly storms may cause the higher mean recession of these bluffs.

Bluff Face Slope

We determined the bluff face angle as the slope of the bluff face at the midpoint of the bluff height. Bluffs steeper than 45° had higher mean recession than those less than 45° (Table 27). Some 52 percent of the sites

FIGURE 8 Annual wind rose diagram for Lake Ontario (Data obtained from summary of synoptic meteorological observations from 1960 to 1972. The diagram indicates, for example, that during 20% of the year, winds blow from the west. This 20% period is made up of winds with the following speeds: 1.5% at less than 3 km/hr; 4 to 5% at 4 to 10 km/hr; 9.5% at 11 to 21 km/hr; and 4.5% at 22 to 33 km/hr.)



Source: Siebel et al 1977

visited had faces steeper than 75°, while only 4 percent had slopes less than 20°. This indicates that recession was relatively active at most sites visited. Of the bluffs steeper than 75°, only 7 percent showed no recession, while 44 percent of those between 20° and 45° showed no detectable recession in the 99-year period.

The steepness of the face is a measure of its susceptibility to mass failure (Quigley and Tutt 1968) and an indication of how active recession is occurring in a given area. Subaerial erosion will usually reduce the bluff to a stable slope (Edil and Vallejo 1976). However, loss of the protective talus by wave erosion will maintain steep slopes and perpetuate recession.

Beach Width

The relationship between beach width and recession appears to be unusual; the wider the beach, the higher the recession (Table 27). At most of the study sites, sediment derived from eroding bluffs nourishes the beaches. In general, we conclude that wider beaches result from higher recession unless nourished by other sediment sources. A few areas where we did not take data in the field have wide beaches that receive nourishment from other sediment sources. In these areas of wide beaches, recession was very slow.

Beach Composition

Most beaches along the south coast are composed of cobble to coarse cobble material (US Army Corps of Engineers 1973). We found no uniform relationship between beach composition and recession rate (Table 27). Sites with coarse cobble beaches had the highest mean recession, 0.48 m/yr (1.6 ft/yr). Sites with sand beaches had the second highest mean recession, 0.40 m/yr (1.3 ft/yr). This is in part related to the beach width relationship considered above. As sand beaches are generally wider than other types of beaches, they have the highest recession.

Beach Slope

We collected beach slope data because we believed it to be an indirect measure of wave energy reaching the shore (Kemp 1961). Beach slope directly relates to grain size; therefore, steeper beaches are associated with coarser grain size and absorb wave energy better (Bascom 1964; Komar 1976). Medium gradient beaches had the highest mean recession of 0.59 m/yr (1.9 ft/yr). Sites with steep beaches and without beach protection had similar mean recession, approximately 0.30 m/yr (1 ft/yr). Areas without beaches were usually below bluffs protected by seawalls, revetments, riprap, or by a bedrock toe. Such protection would tend to slow recession.

GLOSSARY

Anticlinal: the convex folding of beds.

Armor (of shore or coast): any manmade device or scheme to reduce the loss of coastal land by wave erosion, including revetments, seawalls, riprap, and pilings.

Bedrock: any solid rock exposed at the earth's surface or overlaid by uncemented and/or unpacked material.

Bluff: the steep cliff or abrupt break in slope at the landward edge of the shore zone.

Bluff height: the vertical distance from the base of the bluff to the break in slope at the top.

Bluff line: (1) the line defined by the abrupt break in slope of the land, marked by a dark shadow on the photographs; (2) the landward edge of the beach where no cliff exists; (3) the line defined by the lakeward edge of the break in vegetation, chosen according to the situation existing at the measuring site. The bluff line was considered to extend 8 m (26 ft) in either direction from the measuring site.

Breakwater: a structure protecting a shore area or harbor by breaking the force of waves.

Coast: the strip of land extending from the shore landward to the first major change in terrain features.

Drumlin: an inverted spoon-shaped hill of gravel and/or till deposited beneath a glacier and elongated in the direction of its flow.

Erosion: the wearing away and loss of land due to subaerial and littoral processes.

Groin: a shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift of sand or gravel or retard erosion.

Homocline: a condition where beds dip uniformly in one direction.

Lacustrine: of or pertaining to lakes.

Littoral: of or pertaining to a shore.

Loraine Group: a group of rock strata too thick to be considered a formation and including sandstones and siltstones of the Oswego, Pulaski, and Whetstone Bluff formations.

Middle and Upper Ordovician Sandstones: sandstones deposited approximately 480 to 430 million years ago during Middle and Late Ordovician time.

Protection: any natural or manmade scheme or situation that tends to reduce recession including beaches, groins, breakwaters, vegetation, and bedrock.

Queenston Shale: a rock formation of Late Ordovician age.

Recession: the landward movement of the position of the bluff line.

Recession rate: the average annual rate of retreat (in meters/year) of the bluff line position determined by dividing the number of years in the period of study into the recession during the same period.

Revetments: any manmade device or scheme composed of masonry or other materials to protect a mass or bank of earth, including facings, sheathings, and retaining walls.

Riprap: any foundation or sustaining wall composed of stones thrown together without order.

Shore: the common margin of dry land and Lake Ontario.

Subaerial: anything formed, existing, or taking place on the land surface.

Whetstone Bluff Formation: a formation of siltstone and shale belonging to the Loraine Group of rocks, of Middle Ordovician age.

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Department of Technical Communication
Rensselaer Polytechnic Institute

New York Sea Grant Institute
State University of New York
and Cornell University
411 State Street
Albany, NY 12246