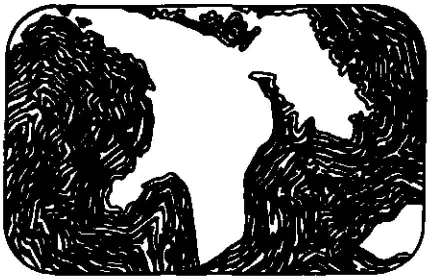

Methods for Recording Great Lakes Shoreline Change

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Abstract
Presently available methods and techniques for monitoring changes of certain geophysical aspects of the Great Lakes shoreline can be classified in two groups:
1) Historical records dating back to early exploration days exist in the form of navigational charts, old survey records and photographs. However they were not intended for the purpose of monitoring changes in the coastal zone processes. Hence the value is limited in recording these phenomena.
2) Scientific observations ranging from synoptic overview (satellite) to ground measurement (erosion profile) are examined and discussed in general with a closer look at the nature and concentration of suspended loads, bathymetry and currents, wave climate, erosion and accretion rates. Site specific studies of the coastal processes are also discussed.

Résumé
Les méthodes et les techniques actuellement disponsibles pour surveiller les changements de certains caractères géophysiques de la bordure des Grands Lacs sont examinées et classeés en deux groupes.
1) Des donneés historiques, datant du début de la période d'exploration, existent sous forme de cartes de navigation, de notes prises lors d'anciennes campagnes de mesures et de photographies aériennes. Mais comme ces donneés n'ont pas été recueillies dans le but d'enregistrer les changements de la bordure, leur valeur est limitée.
2) Des observations scientifiques allant de vues synoptiques (satellite) à des mesures au sol (profile d'érosion) sont examinées et discutées dans un context général en accordant cependant une importance particulière - à la nature et à la concentration des matières en suspension - à la bathymetrie et aux courants, - au régime des vagues, - à l'érosion et aux vitesses d'accumulation. Des études spécifiques de sites portant sur les processus costaux sont aussi présentées dans ce papier.

Introduction
The morphology of the Great Lakes Shoreline is influenced by a number of dynamic processes. The techniques available for the monitoring and analysis of such phenomena vary from ground measurements at a specific site to a synoptic overview of an entire lake basin by satellite imagery. The selection of the appropriate combination of these techniques depends upon the nature of the problem, the objectives to be achieved and the economic constraints.

This paper reviews and discusses, in general terms the available techniques for monitoring changes of some geophysical aspects of the coastal zone and, by example, shows application to the Great Lakes Shoreline. The reader is directed to the literature for detailed explanations of both the nature of shoreline change and the techniques which are employed in their measurement.

The principal changes which affect shorelines are related to the following:
1) Erosion (regression)
2) Accretion (advance)
3) Flooding (inundation)

The rates at which shoreline response takes place are, to a large degree, under the direct control of both continuous and catastrophic changes associated with both climate and meteorological conditions.

Techniques employed by Marine Sciences, Central Region, in gathering information on these processes include:

a) The development of shore profile networks.
b) The *in situ* measurement of lake currents by current meters, and drogues etc.
c) Photogrammetric techniques utilizing aerial photography and ground control points.
d) remote sensing techniques such as those involving high altitude photography and satellite imagery.

Historical Records
Meaningful information on the Great Lakes shoreline can be traced to the archives of navigation charts, early land survey records of first riparian settlers and original township or county maps.

Figure 1 shows an example of a navigation chart dated 1818. Such charts were prepared for the sole purpose of navigation without any intention of recording shoreline changes and quantitative measurements cannot be extracted from them. The general configuration of the shoreline at that time can be observed, however, giving qualitative evaluation of the changes when compared to present maps or aerial photographs.

Figure 2 shows a photomosaic of a section of the area shown in Figure 1 compiled from the 1973 aerial photographs. Differences in shoreline configuration are obvious, when comparing these two figures.

Historical records which could be applied to quantitative measurements began with the early land surveys around 1850 (Fig. 3). Subsequent development patterns, such as county road networks, which generally follow the original concession and lot lines layout, provide common reference points in documenting shoreline changes. However, once again the intended purpose was not to record changes in lake shoreline, but to indicate size and location of the property on land. Nevertheless, some crude quantitative evaluation can be derived from them, providing the survey lines terminated at the water's edge. Unfortunately, in most cases, it is difficult to determine whether these survey lines ended at the edge of bluff, the water's edge or the high water mark. Considerable error has also been introduced because of widely varying standards of accuracy in these measurements and the effect of unknown (until 1860) differences in lake levels.

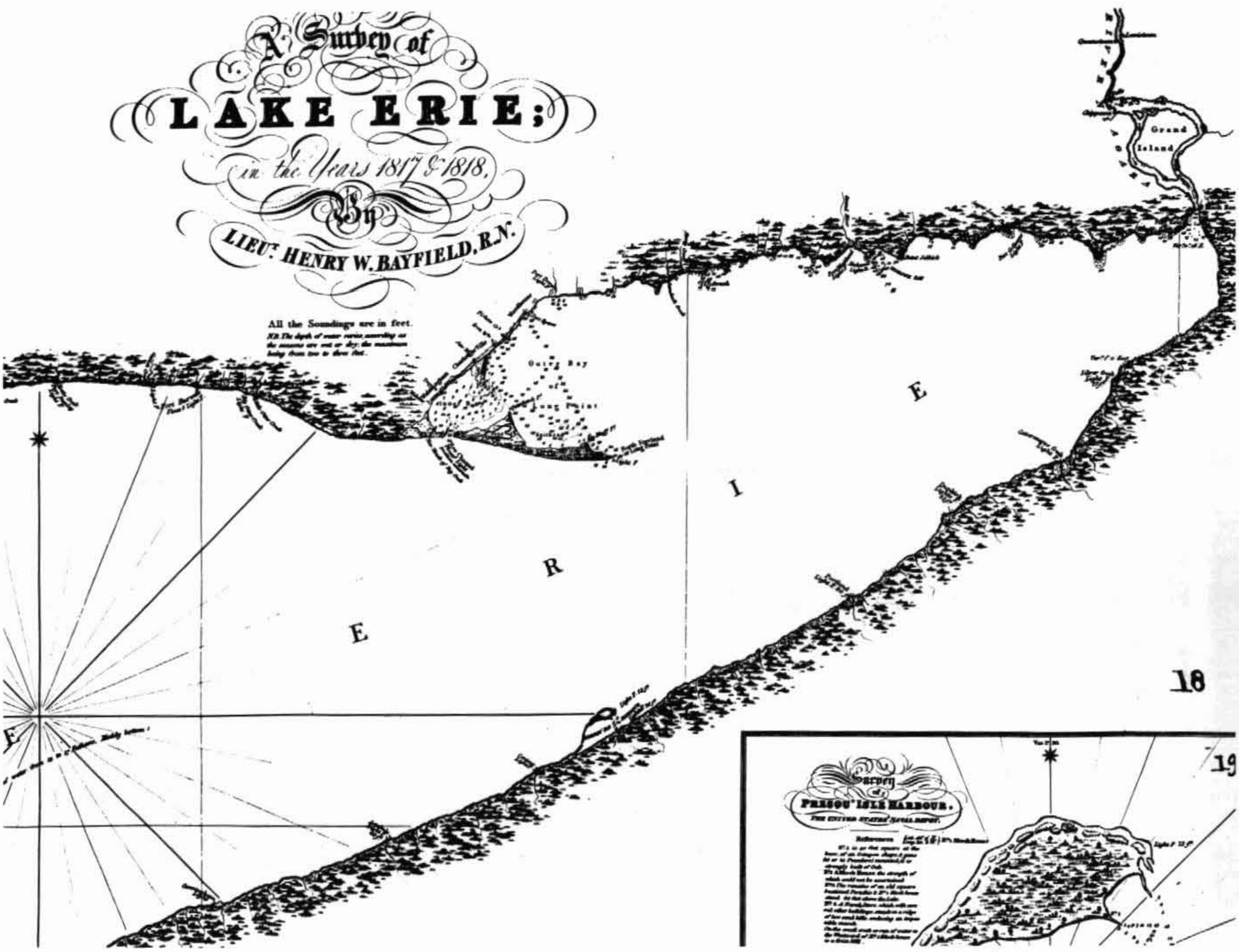


Figure 1
1818 Navigation Chart.

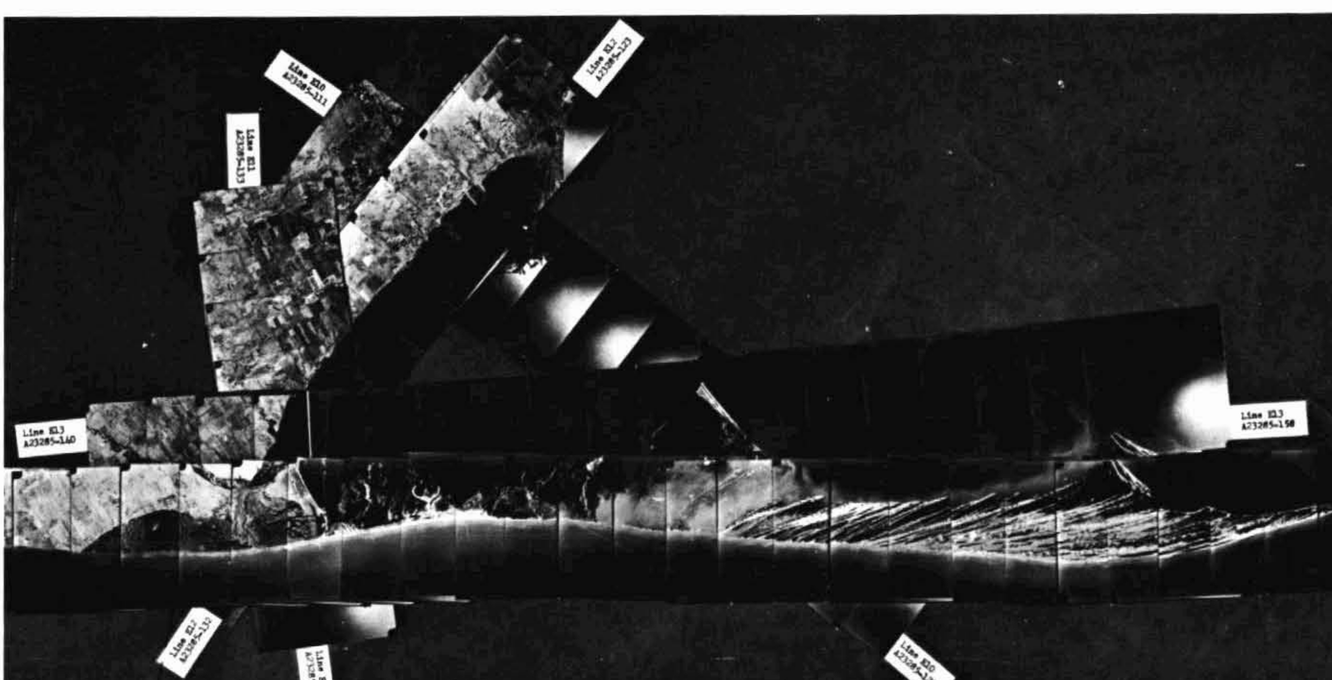


Figure 2
Photomosaic of a section of the area shown in Figure 1 (1973 Aerial Photos).

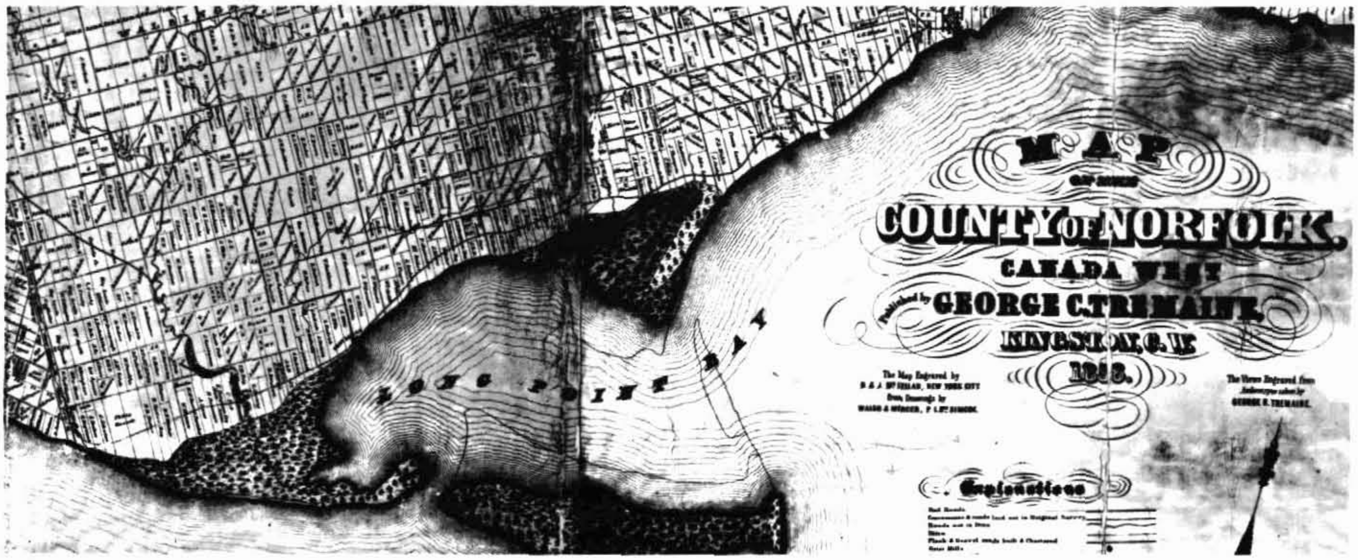


Figure 3
Early land surveys.

Scientific Observations

Photogrammetry. The province-wide aerial photographic coverage flown in 1952-1955 provided another means of quantitatively comparing the shoreline at that time with the present shoreline, photographed in 1973. A segment of this comparison is shown in Figure 4 (a) and 4 (b). An added benefit in comparing these periods resulted from the fact that they both represented occurrence of generally high lake levels and thus documented shoreline changes occurring over a complete high-low-high water level recurrence. Traces of the edge of bluff were delineated from both series of aerial photographs and superimposed in a horizontally rectified manner. In many respects, the data obtained by this technique were relatively reliable and, allowing for the standard errors inherent in using aerial photography, provided meaningful values for regression or advance along continuous stretches of shoreline, as well as point locations.

An example of the changes in edge of bluff position for the 20 year interval is shown in Figure 5.

Profiles were extracted from stereo models of 1952-55 and 1973 aerial photographs, at approximate intervals of 1.60 km, along the erodible part of the shoreline. Profile locations were chosen to coincide exactly on both the old and new aerial photographs and in such a way that they could be readily identifiable. In order to show changes in the shore profile itself, digitized cross sections at the same locations were extracted for both photographic series and were superimposed to show the changes that had occurred. An example of such digitized photogrammetry is presented in Figure 6. By using the above techniques, an accurate assessment of rates in recession and advance was obtained, which served both to complement historical rates data and to highlight the interaction of water level variations with shoreline response.

Shore Profile Network. Each erosion or accretion station was selected to represent a typical reach of shoreline having similar physical characteristics of bluff height and composition, beach material, width of beach, angle of wave approach and any other characteristics which could be associated with the erosion process along a particular stretch of shoreline. Profile lines were established with their reference points at permanent or semi-permanent land marks, such as the intersection of road centrelines or limits, property boundaries, or existing survey monuments or buildings. Points along the profile line were then selected and their elevations referenced to International Great Lakes Datum (1955) using conventional leveling techniques, as illustrated in Figure 7.

By comparing earlier profile data with those of 1973, annual net volumes of erosion and accretion were calculated in m^3 by applying the planimetric values to the corresponding stretch of shoreline. These annual net erosion rates are depicted in Figure 8.

A computer program was written to facilitate volume calculations in both metric and English units whereby mean, net and sub-total, erosion or accretion, figures are given for each of the reaches along with a grand total for each lake. The calculated volumes represent quantitative changes in the shoreline material of beaches and bluffs from the top of the bluff or beach to low water datum.

In addition to the onshore profile, the offshore portion to a depth of 20 m was obtained using echo sounding and electronic distance measurement techniques. Figure 9 illustrates a three dimensional computer plot, based upon such data, at the southern part of Point Pelee.

To aid in a comparative analysis of regression/advance rates, values of short term changes were calculated from these profiles and the rates represented in histograms, as shown in Figure 5.

Along with the establishment of the erosion station network, a qualitative record of shoreline changes is being developed through collection of sequential oblique colour slides taken from an airborne platform at low altitude.

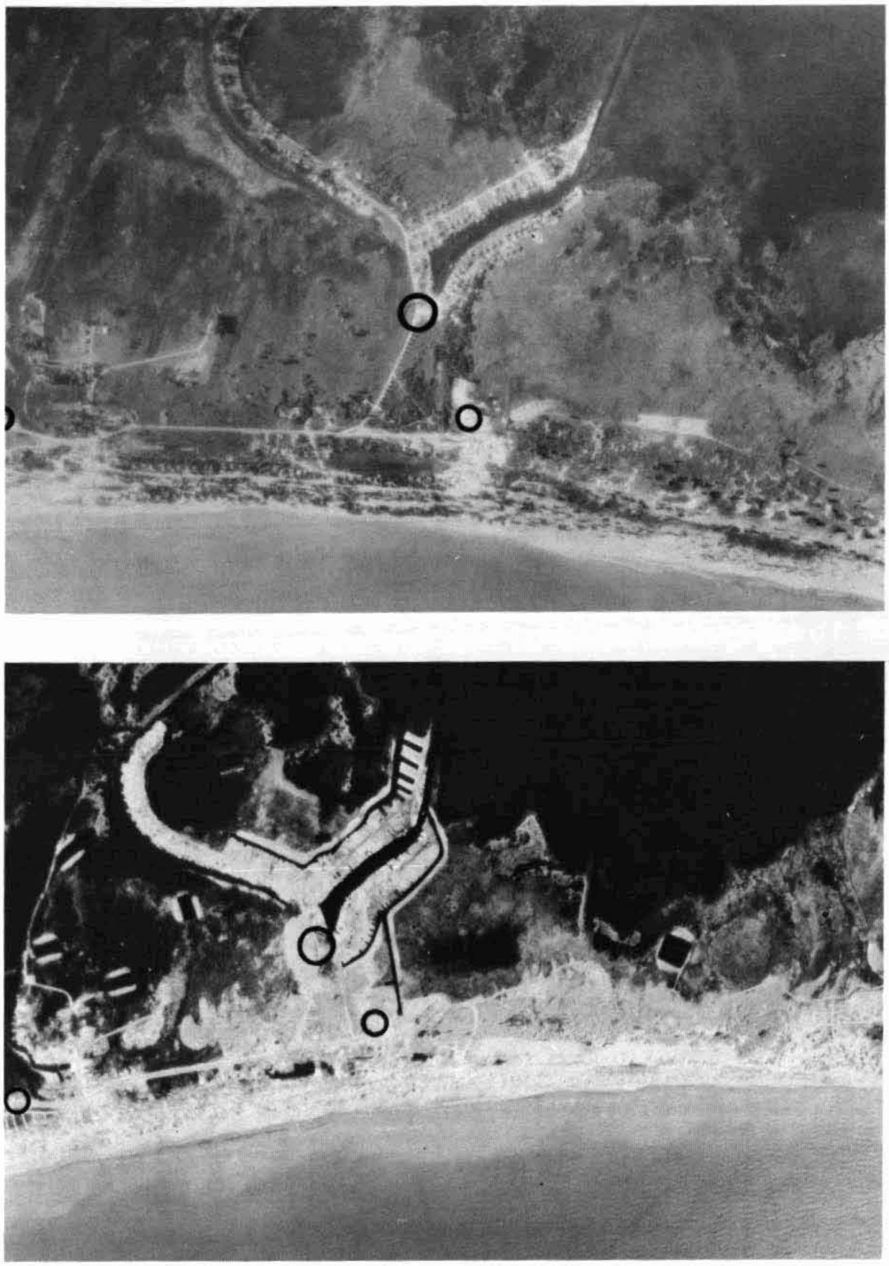


Figure 4
A - Aerial Photo flown in 1952-1955
B - Aerial Photo flown in 1973.

This in time will provide valuable data showing possible interrelation between the land use patterns, vegetation cover and shoreline processes.

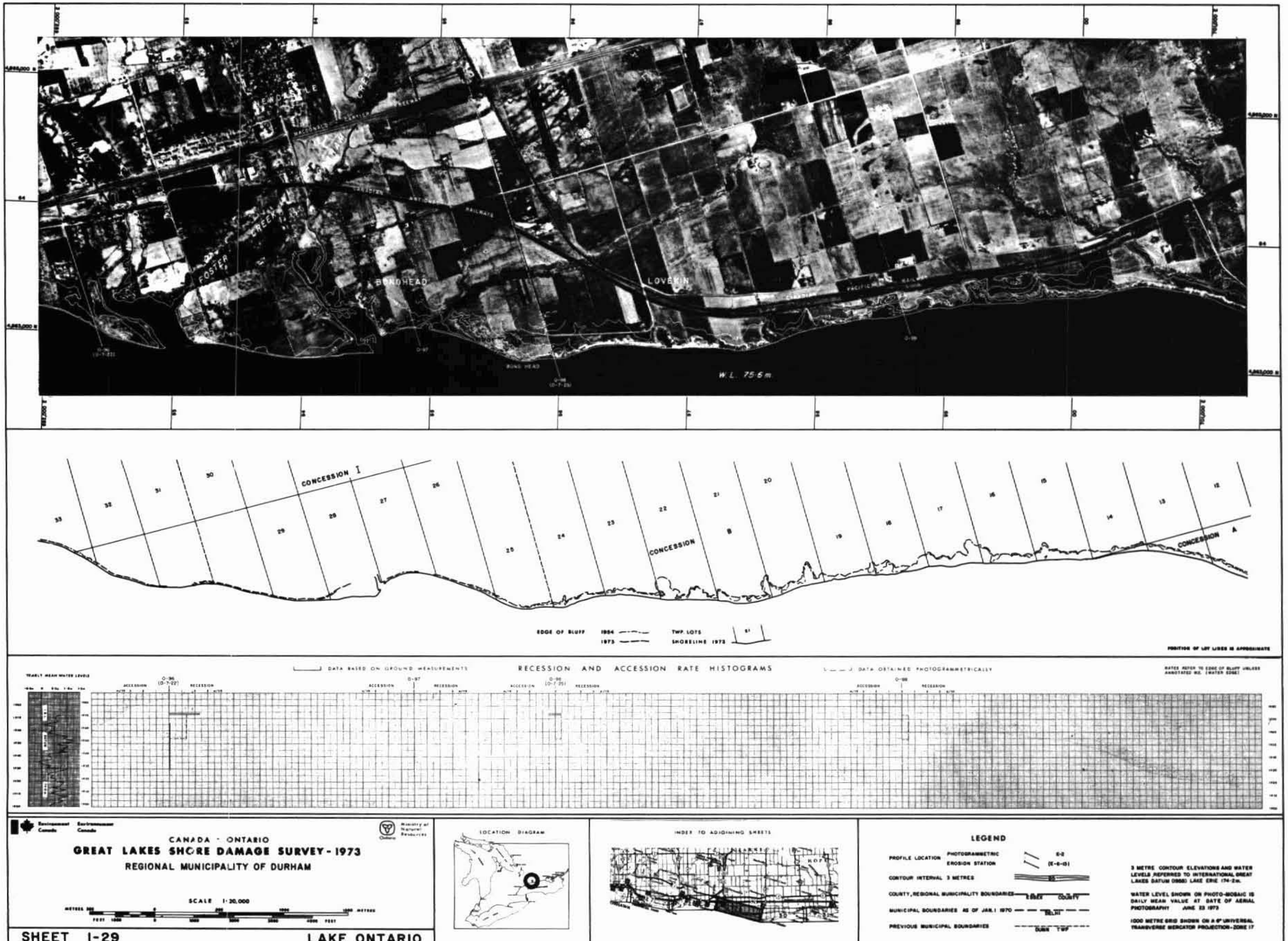
Current Measurements. Nearshore current measurement is an integral part of studying sediment transport phenomena. The methods of measuring current include self-recording electromagnetic current meters, drogues and tracers (radioactive and dyes). Figure 10 shows the current flow around Point Pelee, determined by tracing the movement of drogues, and corresponds to observations based upon satellite and high altitude photography.

Remote Sensing. The recent advent of remote sensing techniques for both acquiring and analyzing optical data, collected in the form of reflected energy return from the earth's surface, has enabled geophysical phenomena to be studied in terms of synoptic spatial overviews. In addition to conventionally flown multiband aerial photography, which may be applied to nearshore zone studies of shoreline changes, remote sensing from environmental satellites, such as ERTS-1, may be used to effectively monitor shoreline change on an 18-day repetition cycle. The ERTS-1 data have been used to study the sediment transport phenomena present in the Lake Huron-Lake St. Clair-Lake Erie waterway. These data are in accord with the accretion/erosion results obtained from the shore profiling network, and are of particular value in determining the effects of spring runoff on the morphology of the Great Lakes shoreline. Figure 11 illustrates an ERTS-1 image collected over the Lake Huron-Lake St. Clair-Lake Erie portion on March 27, 1973. The sediment transport avenues are readily apparent, as is the applicability of such high altitude photography to environmental mapping.

A graphic illustration of how the ERTS data may be used to infer the geophysical processes which govern the evolution of shorelines is presented in Figure 12. In this are shown the digital data collected by the satellite over Point Pelee on April 14, 1973, and clearly delineated are the computer classifications of the surface flow of sediment-laden waters around the tip of the Point and the resulting Archimedes spiral/vortex current flow patterns. Figure 13 illustrates a colour-infrared vertical aerial photograph of Point Pelee taken within 10 minutes of the satellite overpass. The agreement between observations at 10,000 feet and at 500 nautical miles is indeed striking. Data of this nature have been used to derive a model for the temporal evolution of Point Pelee and Rondeau as "mirror-image" landforms resulting from bifurcated sediment transport along the northern shoreline of western Lake Erie. These results are in agreement with the data displayed in Figure 10.

Satellite data may be applied as a global mapping device and may be used to provide a record of the seasonal advances and recessions of flood plains, littoral drift, near-shore zone dynamics and, in cases of relatively non-turbid waters, the changes in the hydrography of the nearshore area. Clearly, great potential exists for future evaluations by these methods.

Figure 5 *Changes in edge of bluff position for the 20 year interval.*



DIGIT.SECT.E-22 1955 FLIGHT

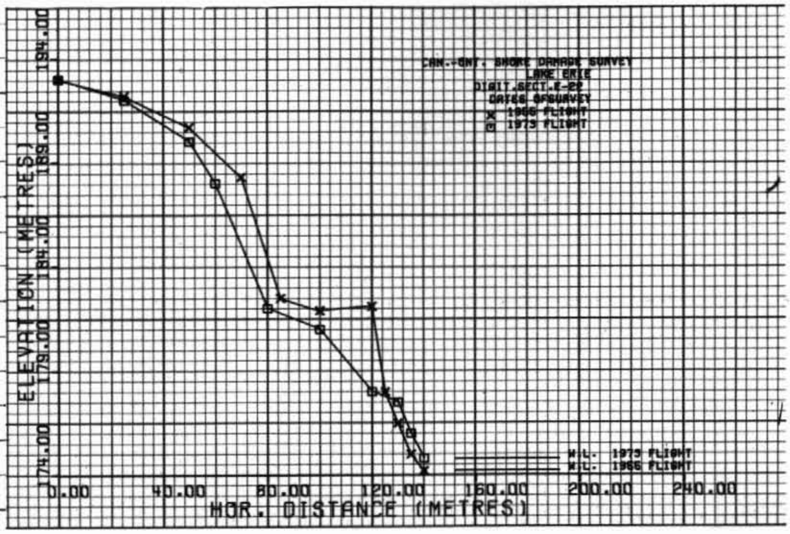
WATER LEVEL AT 174.40 METRES.

DISTANCE (METRES)	ELEVATION (METRES)
0.00	193.00
25.00	192.20
50.00	190.70
70.00	188.30
85.00	182.50
100.00	181.90
120.00	182.10
125.00	178.00
130.00	176.50
135.00	175.00
140.00	174.20

DIGIT.SECT.E-22 1973 FLIGHT

WATER LEVEL AT 174.70 METRES.

DISTANCE (METRES)	ELEVATION (METRES)
0.00	193.00
25.00	192.00
50.00	190.00
60.00	188.00
80.00	182.00
100.00	181.00
120.00	178.00
130.00	177.50
135.00	176.00
140.00	174.80



THERE WAS A NET LOSS OF 0.149E+03 CUBIC METRES/METRE OF BEACH FACE ABOVE THE WATER LEVEL OF THE SECOND SURVEY.
THERE WAS A NET GAIN OF 0.781E+00 CUBIC METRES/METRE OF BEACH FACE BELOW THE WATER LEVEL OF THE SECOND SURVEY.

Figure 6

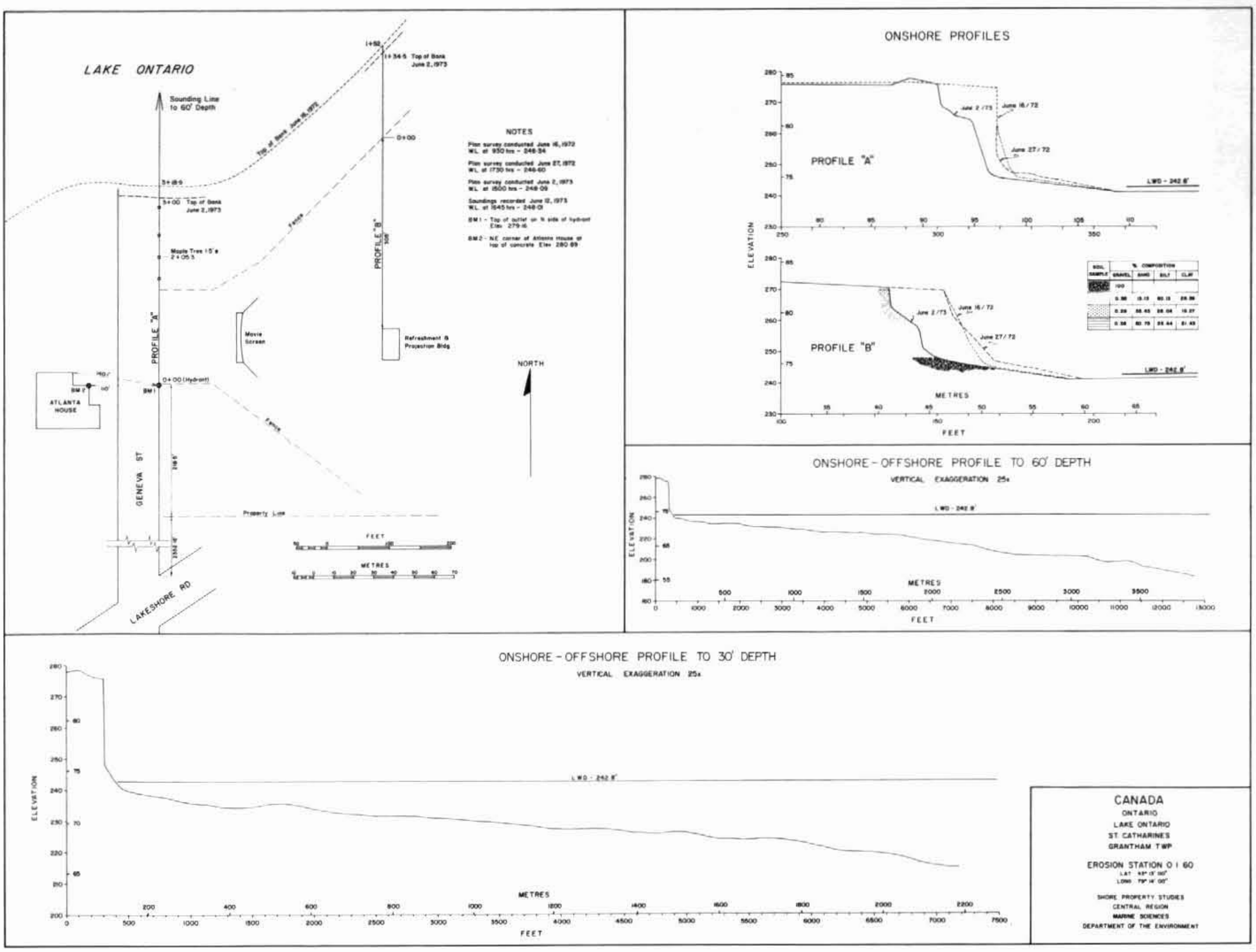


Figure 7 *Shore property studies.*

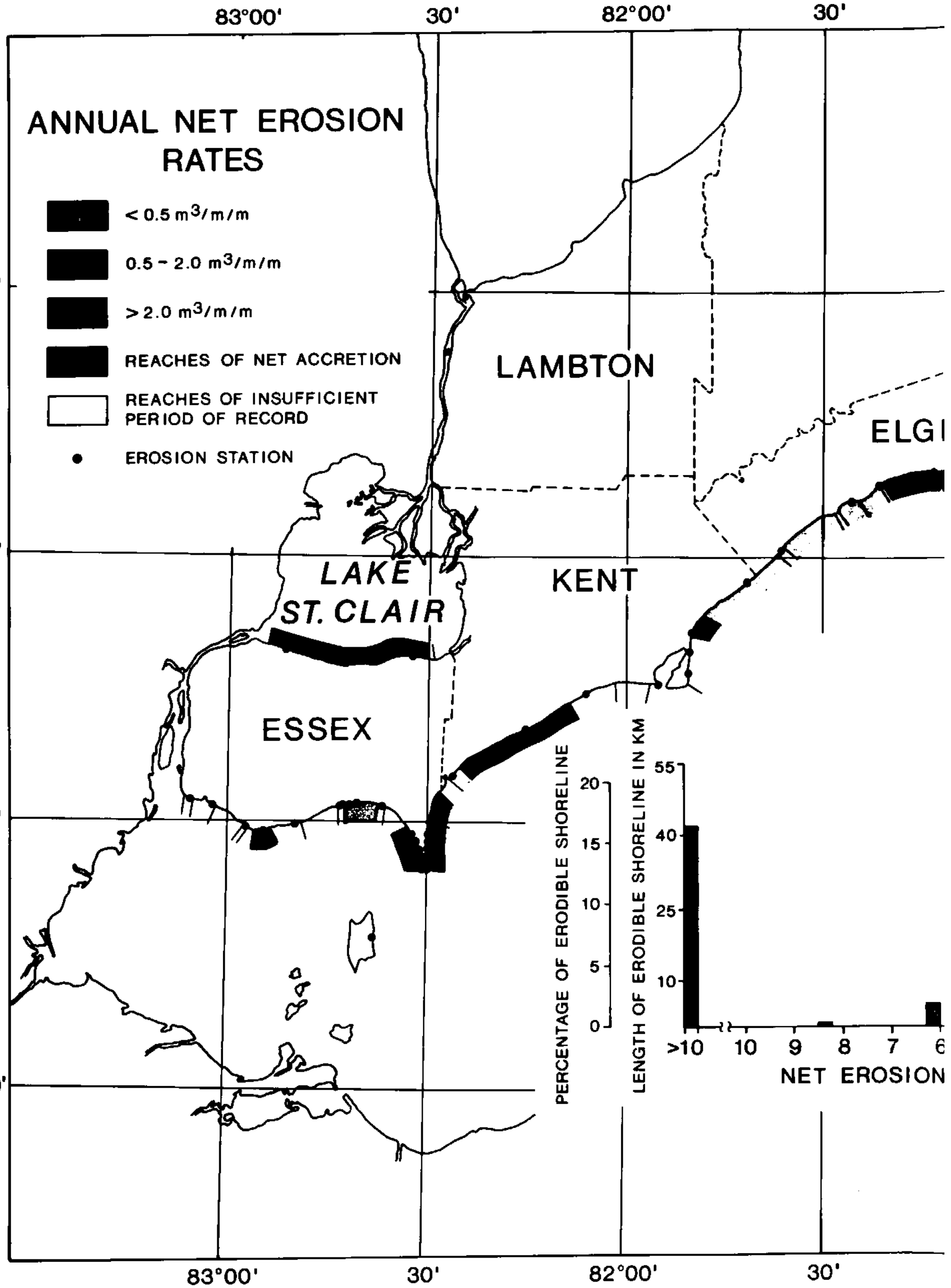
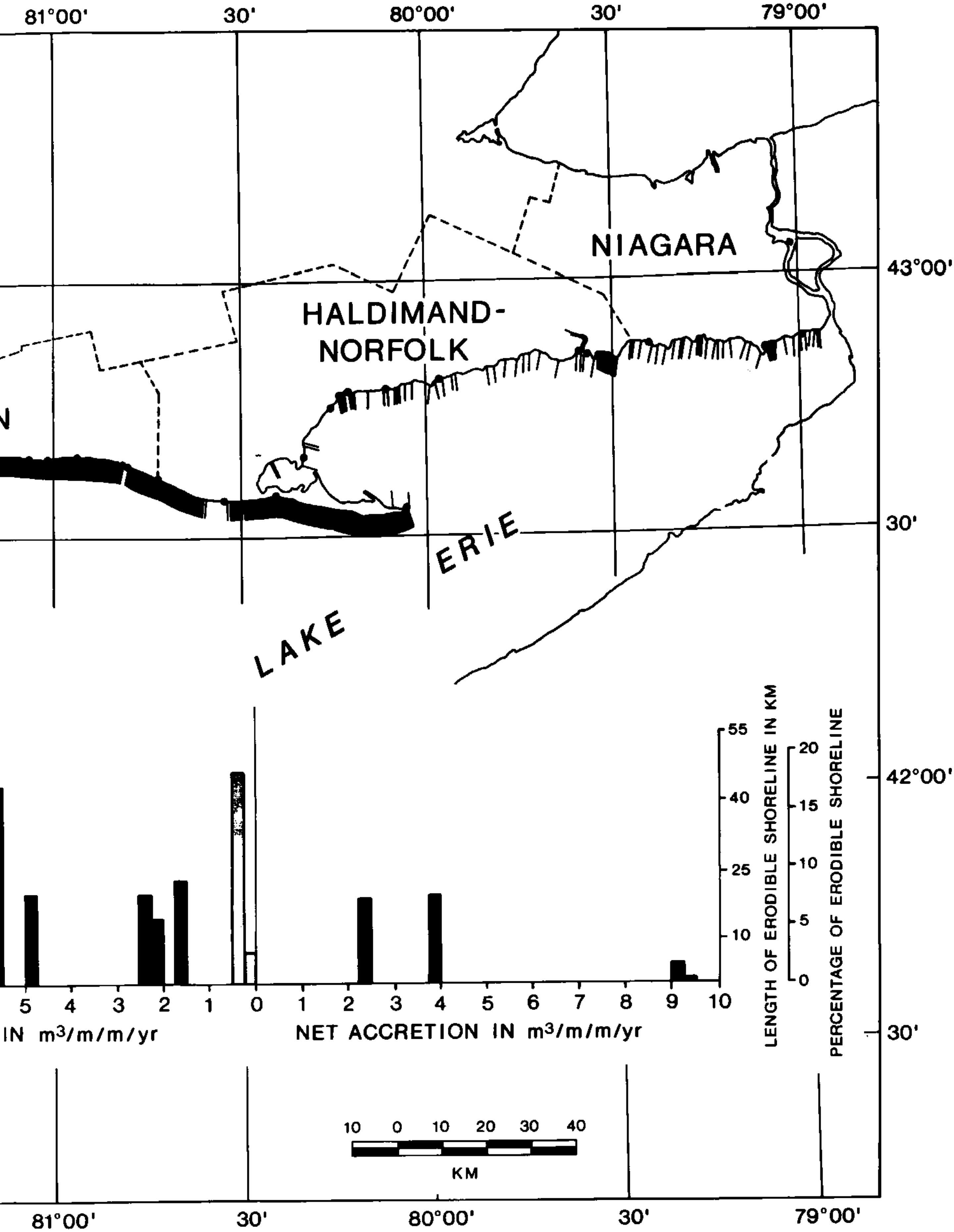


Figure 8
Annual net erosion rates.



81°00'
30'
80°00'
30'
79°00'
NIAGARA
HALDIMAND-
NORFOLK
43°00'
30'
42°00'
30'
LAKE
ERIE
55
40
25
10
20
15
10
5
0
5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 10
IN m3/m/m/yr
NET ACCRETION IN m3/m/m/yr
LENGTH OF ERODIBLE SHORELINE IN KM
PERCENTAGE OF ERODIBLE SHORELINE
10 0 10 20 30 40
KM

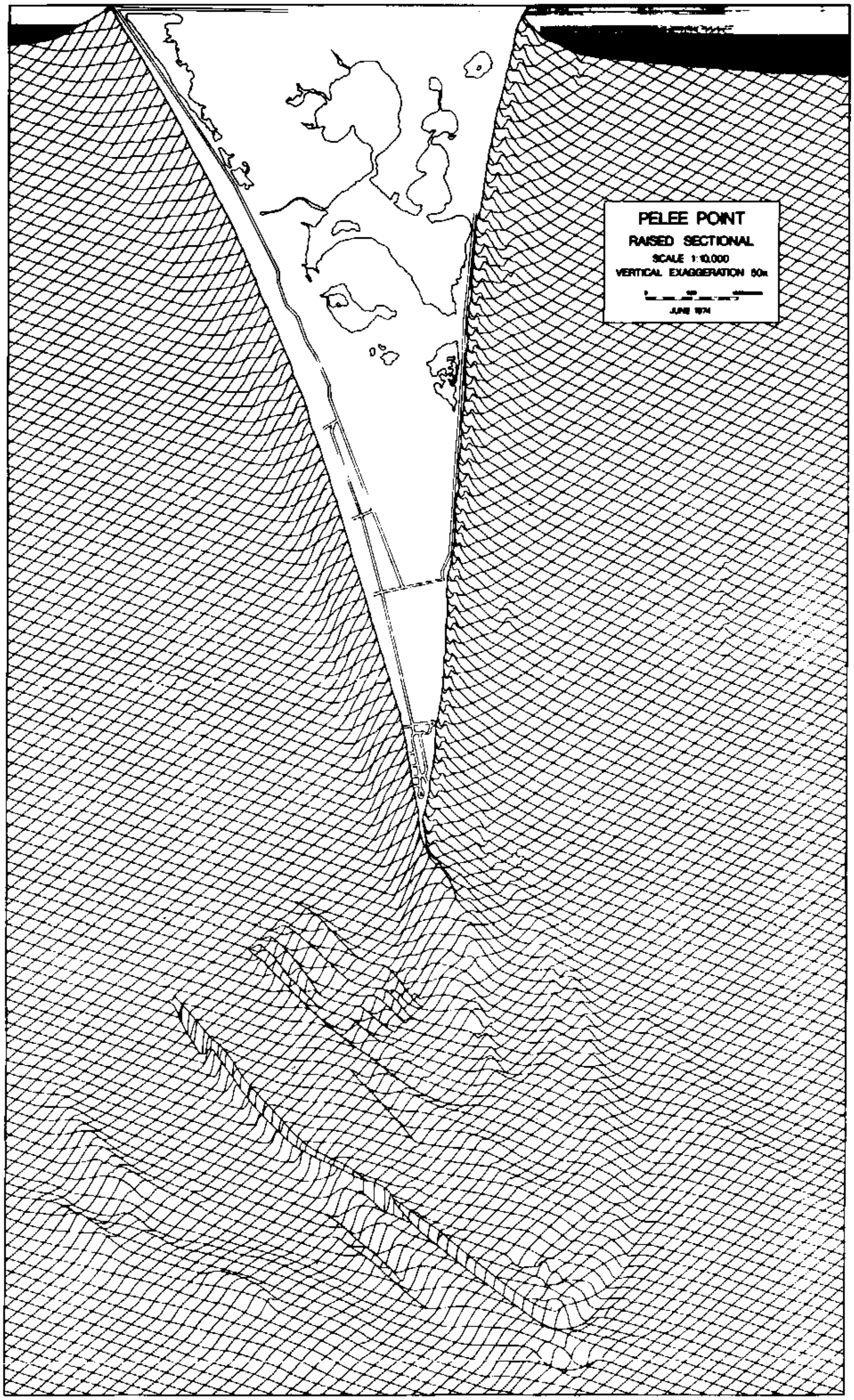


Figure 9

Suggested Reference Material

More detailed discussions of the material presented in this communication may be found in the following references:

Bukata, R, P., W. S. Haras and J. E. Bruton, 1975, The Application of ERTS-1 Digital Data to Water Transport Phenomena in the Point Pelee-Rondeau Area: Verh. Internatl. Verein. Limnologie, v. 19, p. 168-178.

Bukata, R. P., W. S. Haras and J. E. Bruton, 1974, Space Observations of Lake Coastal Processes in Lake Huron and Lake St. Clair: Proc. Second Can. Symposium on Remote Sensing, v. 2, p. 531-549.

Bukata, R. P., W. S. Haras, J. E. Bruton and J. P. Coakley, 1976, Satellite, Airborne and Ground-based Observations of Storm-induced Suspended Sediment Transport off Point Pelee in Lake Erie: Warsaw, Poland, Proc. Internatl. Conf. (1974) on Human Environment Conservation, in press.

Coakley, J. P., W. S. Haras and N. G. Freeman, 1973, The Effect of Storm Surge on Beach Erosion, Point Pelee: Proc. 16th Conf. Great Lakes Research.

Freeman, N. G. and W. S. Haras, 1971, A Study of the Lake Huron Storm Surge of August 22, 1971: Unpublished Report, Can. Dept. Environment, Marine Sciences, Central Region.

Haras, W. S., 1974, Recession Rate Measurement Techniques - A Critique: Ann Arbor, Michigan, U.S., Great Lakes Basin Commission, Proc. Recession Rate Workshop, p. 169-179.

Haras, W. S. and K. K. Tsui, eds., 1976, Canada-Ontario Great Lakes Shore Damage Survey Coastal Zone Atlas: Can. Ministry of Supply and Services, 637 p.

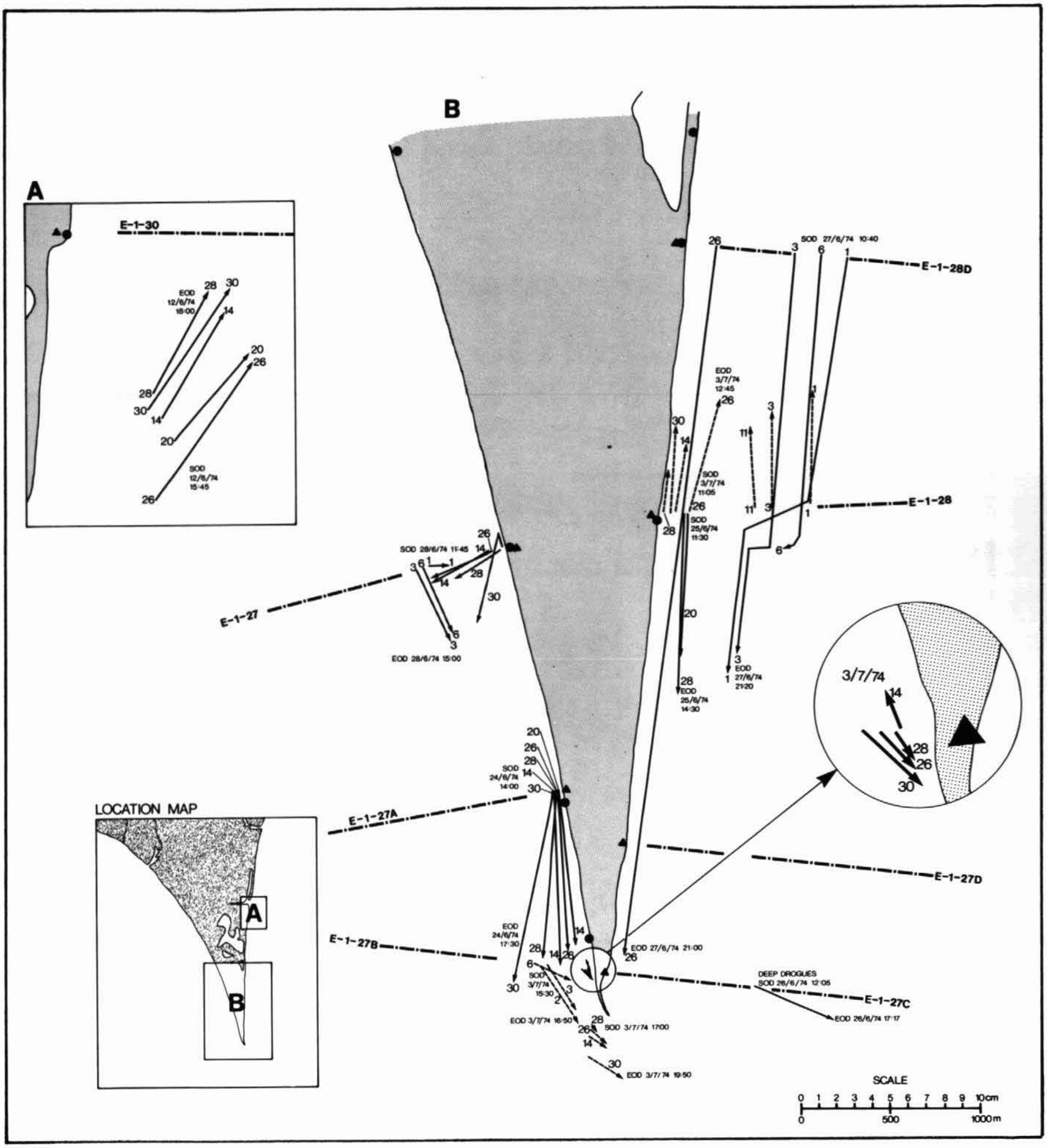


Figure 10
Drogue movements at Point Pelee, 1974.

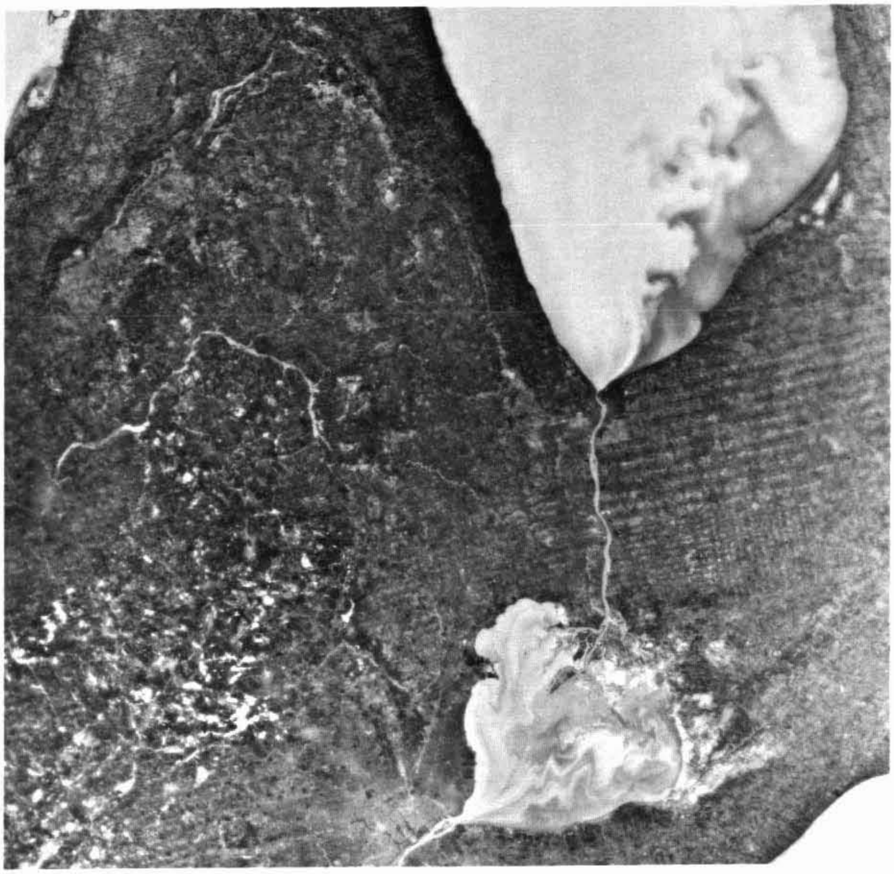


Figure 11
ERTS-1 image collected over the Lake Huron-Lake St. Clair-Lake Erie portion on March 27, 1973.

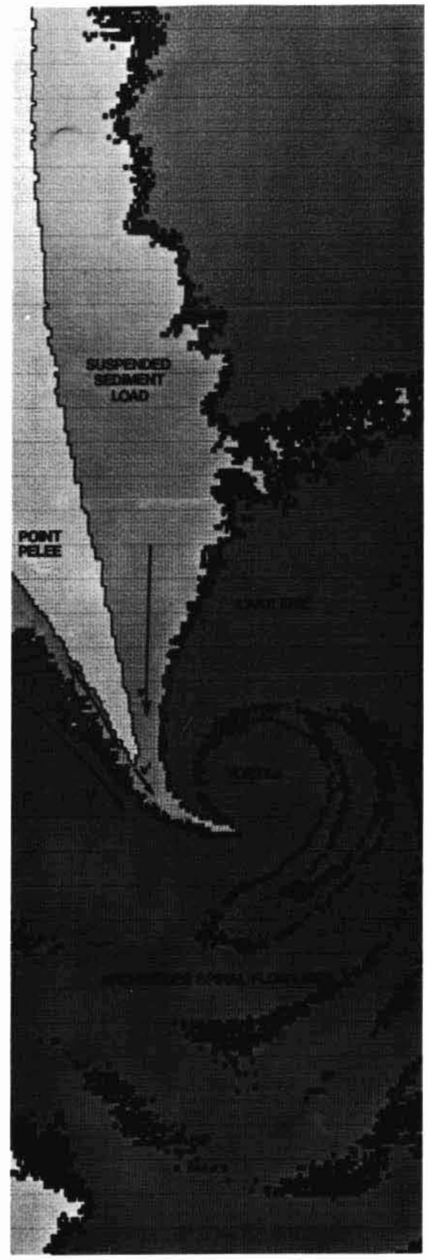


Figure 12
Graphic illustration of how the ERTS data may be used to infer the geophysical processes which govern the evolution of shorelines.

Figure 13
Colour-infrared vertical aerial photograph of Point Pelee.