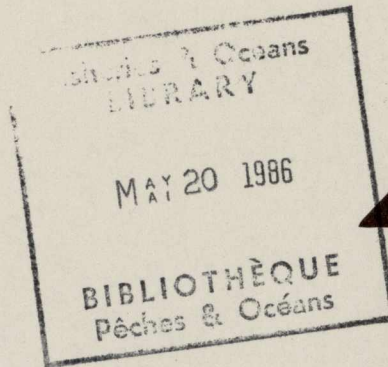




A VOLUMETRIC ANALYSIS OF EROSION

Using Photogrammetric Contour Maps
Scarborough Bluffs, Lake Ontario

R. K. Weaver



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OF EROSION

Using Photogrammetric Contour Maps
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by

R. K. Weaver

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Shore Properties Studies
Research and Development Division
Ocean and Aquatic Sciences
Central Region
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Burlington, Ontario

ABSTRACT

This project deals with the validity of utilizing a computer processing technique to reduce data from contour mapping. The tabular data produced from this methodology is used to determine erosion and accretion rates. The technique is useful specifically in high bluff areas.

Bluffer's Park, a 2.41 km reach of Lake Ontario shoreline in the Borough of Scarborough, was used as a case study. The erosion rate, being an annual measure of a volume of material eroded from a linear metre of shoreline having a bluff height of 1 metre ($\text{m}^3/\text{m}/\text{yr}$), was found to be $0.34 \text{ m}^3/\text{m}/\text{yr}$. This rate is an average over the face of the bluff and is in the same range as the rates normally associated with other areas of Scarborough Bluffs.

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INTRODUCTION

The southern Great Lakes region tends to be sensitive to shoreline changes due to the socio-economic impact that occurs in the event of the slightest change in the shoreline. The planners of metropolitan areas and all owners of property now bordering on the lakes have become increasingly aware of the problems associated with being on the waterfront. This concern has prompted developments in shoreline management and control policy which automatically increases public awareness and public involvement in the problems of abating shore erosion and assessing the shore's stability.

In the Metropolitan Toronto region, the impact of shoreline changes has generated considerable interest in the management of the 'Waterfront'. The beauty of Bluffer's Park is highlighted by continuing erosion and has been jeopardized by offshore landfill. As a recreational development however, this site has encouraged an increase in public involvement, residential interests and further regional planning. Important parameters to be considered when planning further developments of a waterfront site are erosion and accretion rates. High bluff reaches such as the Scarborough Bluffs are very difficult to monitor for the purpose of obtaining these rates. In this report, however, a methodology for monitoring shoreline changes in such areas was accomplished by examining survey maps from various years in the past. This is a qualitative approach but by a data reduction procedure of digitizing and numerically calculating the areas and consequently the volumes, quantitative information is produced for the entire reach of the bluff.

A specific application of the data-reducing technique involved contour maps of the bluff at Bluffer's Park reach in Scarborough. The data has been reduced for contour maps representing shore and bluff configurations for the years 1947, 1956, 1966, and 1977.

THE SITE

The site is the high bluff reach on the north shore of Lake Ontario in the Borough of Scarborough located at the foot of Brimley Road. The gradual descent of Brimley Road ravine provides easy access to the lake and is the access for a Metro Waterfront offshore landfill development known as Bluffer's Park. The Needles Bluffs on the west side of the site and the Cathedral Bluffs on the east side are the significant bluff features for this park development.

The major geological components of the bluff are the Scarborough Clay, Scarborough Sand, and Sunnybrook Till formations from the Wisconsin Stage. A brief description of the geological stages and formations is listed in Table 1 as taken from Scarborough Lakefront Development Study (1970). One of the contributing factors of erosion at Scarborough Bluffs is that of subsurface water movement. This movement is through the geological formation of deltaic beds (Scarborough Clay), on top of which are four layers of glacial deposits separated by layers of stratified clay and sand.

<u>Stage</u>	<u>Formation or Event</u>	<u>Lithology</u>
Wisconsinian (10-50,000 years ago)	Lake Iroquois Sand	Sand and gravel
	Leaside Till	Silty sand till
	Thorncliffe Formation	Varved clay, sand
	Meadowcliffe Till	Silty clay till
	Thorncliffe Formation	Sand, silt
	Seminary Till	Clayey sand till
	Thorncliffe Formation	Sand, silt
	Thorncliffe Formation	
	- Bloor member	Varved clay
	Sunnybrook Till	Silty clay till
Sangamonian (interglacial stage)	Scarborough Sand	Sand, silt, wood
	Scarborough Clay	Clay, silt, wood
	Don Formation	Clay, silt, wood
Illinoian (300,000 years ago)	York Till	Clayey sand till

Table 1: Geological Formations and Events

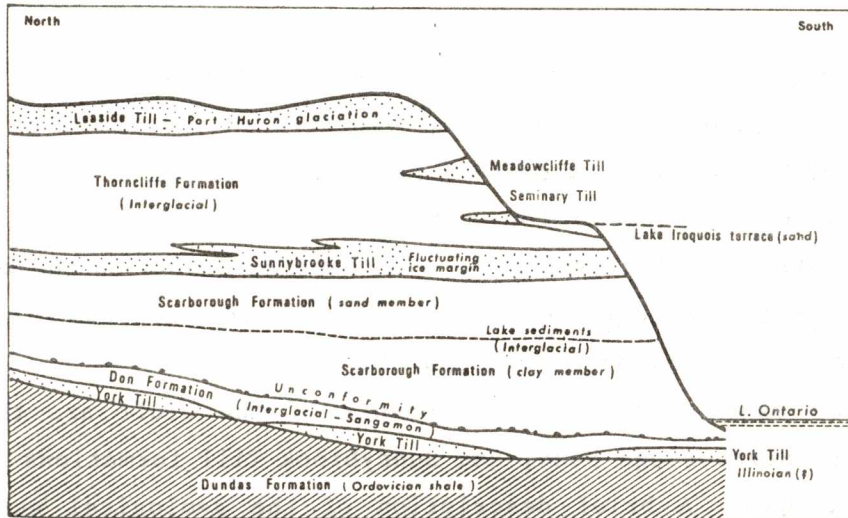


Figure 1: Changes of environmental conditions in the Pleistocene period shown by sediments in southern Ontario (after Karrow)

Although ground water seepage is one of the major elements of erosion there are other major contributors: i.e. wave action, surface runoff, lake levels, lake current, littoral drift, and ice action. All of these factors are active components of this one continuous geomorphic process in shoreline dynamics.



Figure 2: Bluffer's Park, offshore landfill development site

The study area was divided into ten sections of varying length, each section delineating significant shoreline characteristics. Figure 3 illustrates the geographical position of these sections and Table 2 summarizes the characteristics of each of the ten sections.

Section	Length (m)	Height (m)	Slope	Gully	Vegetation	Location
1	83.9	45	45°	-	B1	
2	179.2	38	59°	lg	R1	Needles Bluffs
3	244.0	45	37°	sm	R1	
4	289.8	45	34°	-	R1, B1	
5	228.8	45	31°	lg	B3 excluding road allowance	Brimley Road Ravine
6	415.6	45	37°	sm	R1, R2, B2, B3	
7	194.4	69	37°	lg	R2	Sunny Point Ravine
8	129.6	69	37°	-	B1	Cathedral Bluffs
9	404.1	76	42°	lg	R2, R1	Broadmead Ravine
10	205.9	84	29°	-	B1, B2	Cathedral Bluffs

Table 2: Site Characteristics

Notes on Vegetation (from Project Planning Associates Environmental Study, 1976).

R1: Ravine: Young trees, shrubs, herbaceous. Species: Willow, Poplar, Chokecherry, Sweet Clover, Sumac, Grape Grass, Coltsfoot, Golden Rod, Cattails.

R2: Ravine: Larger and more matured trees. Species: Poplar, Elm, Ash, Locust, Birch.

B1: Bluff: Bare to lightly vegetated. Mainly herbaceous species, few shrubs.

B2: Bluff: Shrubs, small trees, herbaceous plant material.

B3: "Forest", mostly large matured trees, closed canopy. Species: Sugar Maple, Ironwood, Yellow Birch, Hemlock, Aspen, Red Oak, Cherry, Hazel, Dogwood.

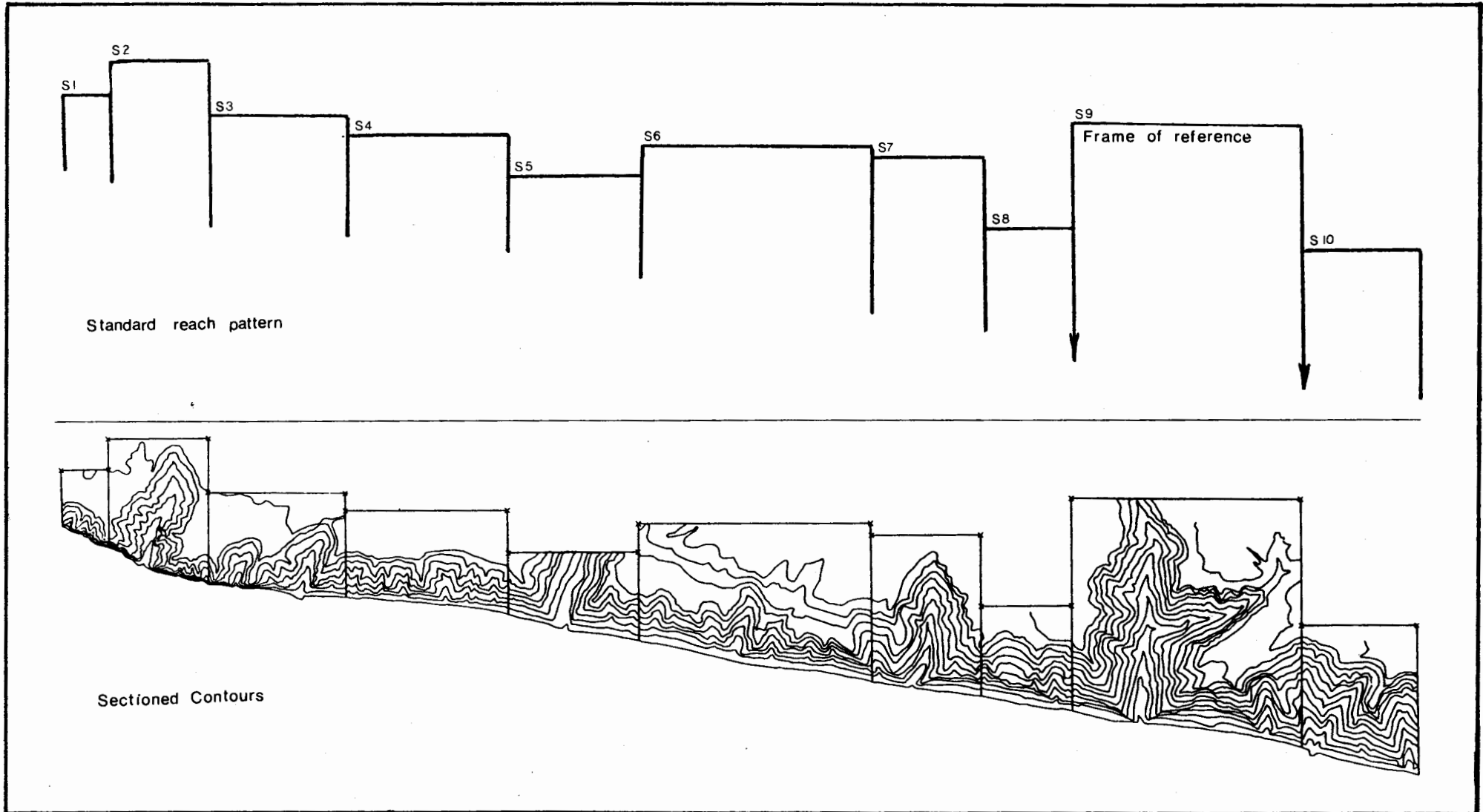


Figure 3: a) Standard reach pattern, b) Bluffer's Park 1956 (sectioned)

METHOD OF ANALYSIS

Maps at a scale of 1" = 200' with contours at 5 foot intervals were obtained from Northway Survey Corporation Limited. These maps were produced from aerial photographs taken from flights in 1947, 1956, 1966 and 1977.

The following section describes the procedure in determining volumetric erosion and accretion rates from contour maps.

1. Contour maps: Establish maximum contour interval at which data will be reduced.
2. Specify a standard reach pattern: This is a collection of standard frames of references established to section off the reach into specific and prominent shoreline characteristics (Figure 3b). The frame of reference allows three of the four sides to be consistently represented at all times for all maps with the contour line forming the final closure needed to calculate the relative area at that contour.

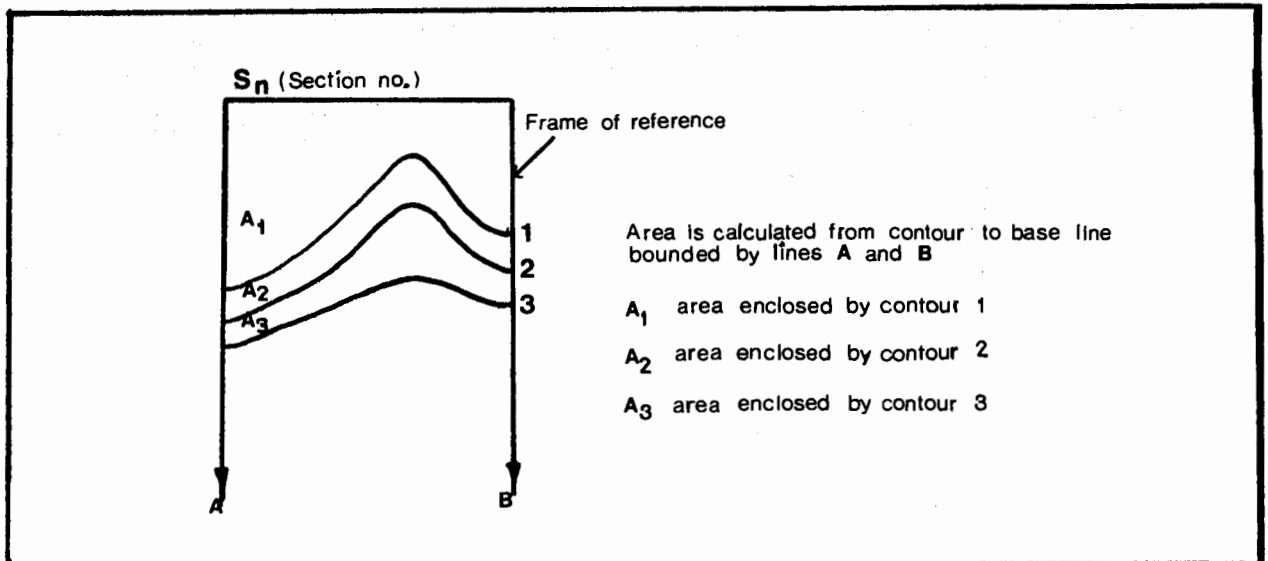


Figure 4: Section and frame of reference configuration

3. Use each frame of reference and digitize all contours within its bounds: Digitizing is a process used to convert continuous (analog) information to discrete (digital) information so that the resulting transformed data will be compatible for computer processing. Digitizing a contour (analog or continuous information) is essentially the representation of the contour using a number of discrete points having x and y coordinates, (x_i, y_i) ; where $i=1,N$. The distance between points is user specified, but is typically 0.03 in, $x_i - x_{i-1} = 0.03$.

4. Calculate the relative area: A straight line simulates the contour over the distance of 0.03 in and forms a small trapezoid, the area of which is calculated using the following equation:

$$A_i = \frac{1}{2}(Y_i + Y_{i-1}) * (X_i - X_{i-1}) \quad (1)$$

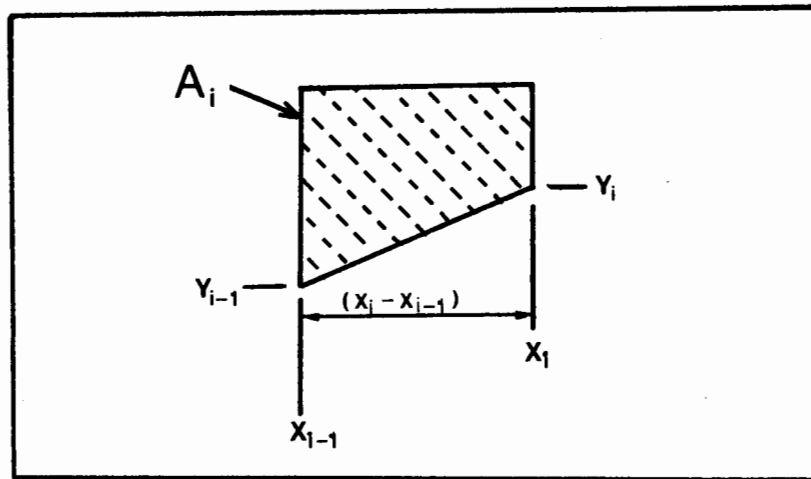


Figure 5: Increment of Area: A_i

Each area is summed over the length of the section which is bound by the frame of reference.

$$\text{Area} = \sum A_i$$

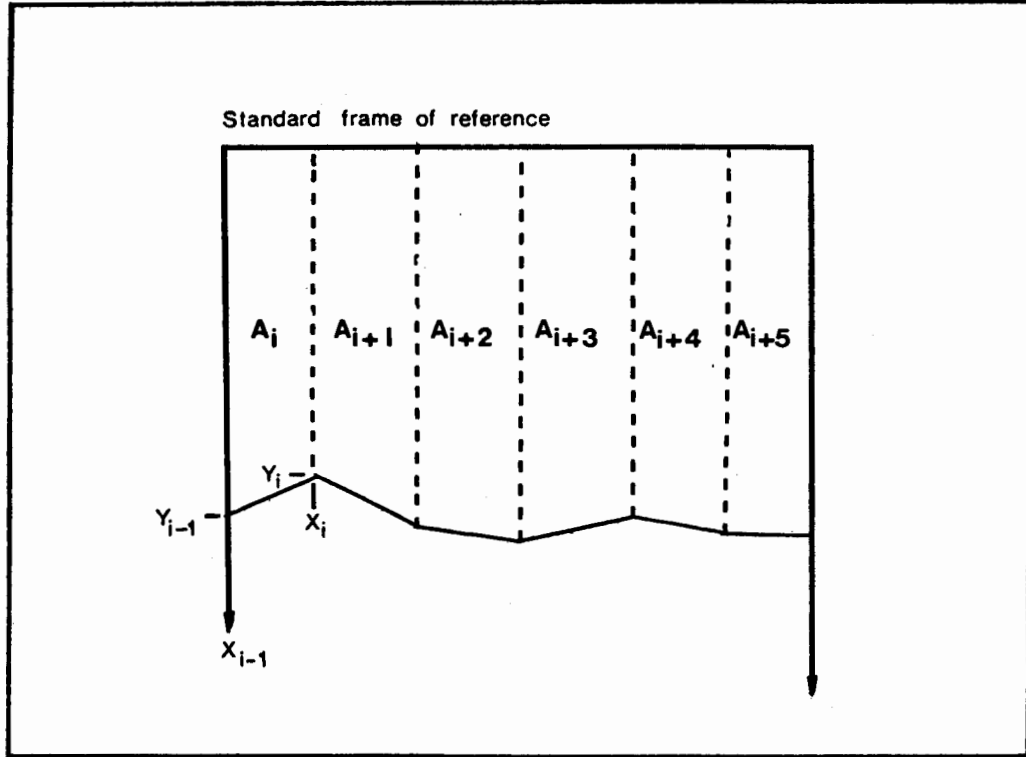


Figure 6: Area within a frame of reference

The result is an approximated area for the contour line being considered, calculated numerically by the technique known as "the trapezoidal rule for integration".

5. Calculate the volume between contour intervals.

$$\text{VOL} = \frac{1}{2}(A_2 + A_1) * \text{FACT}^2 * \text{ABS}(C_2 - C_1) * \text{METRE} \quad (2)$$

where

- METRE = 0.305
- FACT = 60.96
- A_1 = Area 1
- A_2 = Area 2
- $C_2 - C_1$ = contour interval.

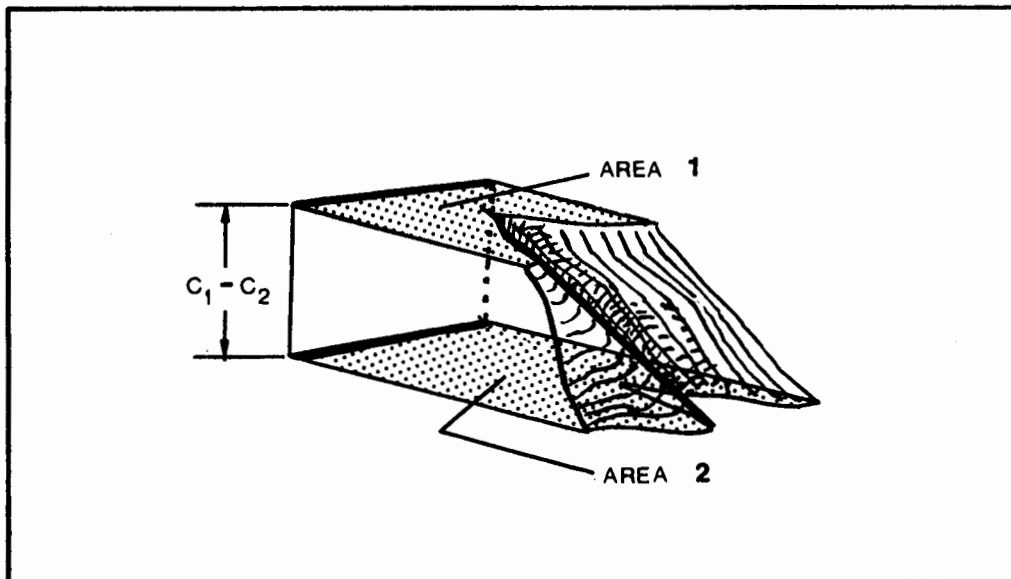


Figure 7: Volume between contours

The change in volumes between years demonstrates accretion or erosion.

ERROR FACTORS

Error may be introduced in varying degrees by:

- 1) inherent inaccuracies of original maps.
- 2) digitization of contours.
- 3) computations required for area and volume calculations.

1) Inaccuracies in mapping can be attributed to many factors. This is mainly due to difficulties in transposing contours from aerial photographs where ground level elevation is obscured by treed areas. Large areas of shadow, as well as areas of excessive contrast are other factors which present a deceptive, uneven appearance, making it difficult to delineate the contours.

Although these factors may present problems, a certain level of standards is expected for the production of contour maps from aerial photographs. The maps used in this project were produced with five foot contour intervals. The suggested associated error (commonly used standard) could be half of the contour interval, which means that any given contour should agree vertically to within ± 2.5 ft or ± 0.76 m of the elevation it is representing.

2) Errors are more apparent and quantifiable in the digitization of the contour maps. Based on a sample of 38 pairs of trials - 76 individual contour closures (see Appendix A) - the average difference between pairs of area calculations in Section 4 is 0.073 in^2 , in Section 5 is 0.082 in^2 , in Section 6 is 0.052 in^2 , and in Section 7 is 0.024 in^2 . These differences for one contour interval amount to 2070 m^3 , 2320 m^3 , 1500 m^3 , and 680 m^3 of material respectively.

The length of the reach does not appear to influence the degree of error and the difference in the area calculation tends to be constant over the length of the contours in any given reach.

The error in digitizing, however, can be reduced by the operator. This is accomplished by moving the cursor at a slow steady rate allowing the sampling rate to be more consistently. Each sample is

taken when the distance between it and the last sample is greater than the distance specified by the user (typically 0.03 in).

3) The computational error in the area calculation is relatively small because of the operation of the trapezoidal rule for integration and the interval distance of the sampling rate. By using the trapezoidal rule for integration rather than following the contour exactly, the contour is approximated by straight lines in small increments. In theory, if the increments are small enough, the straight lines can change directions instantaneously simulating a smooth curve.

Calculating volumes may result in either a positive or negative error depending on the configuration of the actual bluff between the contours. Over the 7.63 m (25 ft) contour interval, a straight line slope is assumed. If the actual slope is concave to the assumed straight line slope, calculations will yield an overestimate of the volume for that bluff configuration. A convex slope will result with an underestimate of the volume. This relationship is shown in Figure 8.

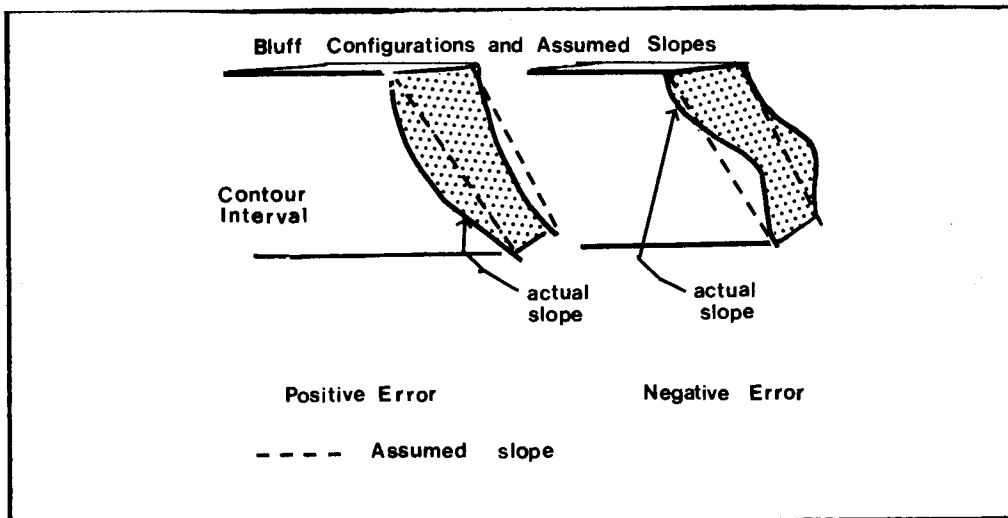


Figure 8: Straight line slope

However, over the length of the reach the slope may vary between the two configurations many times. The assumption of a straight line slope is an approximation of the mean. If an error is present, it may be decreased by increasing the number of contour lines to be digitized, thereby decreasing the contour interval.

The accuracy in producing and digitizing the contour maps is the most important attribute influencing the validity of this derived data, and consequently the reliability of the erosion or accretion rate.

ASSUMPTIONS

In order to reduce and analyze the data, it is necessary to state the following assumptions.

- 1) Net changes in volume are incurred at water's edge:
although changes may have occurred at different rates over the height of the bluff, the net volume gained or lost will be incurred at water's edge.
- 2) The top of the bluff (TOB) can only recede:
because of the nature of the study reach, the top of bluff cannot retain any landfill which would be the only method of accretion.
- 3) Toe elevation (250 ft contour) remained constant for the length of the reach:
since the elevation of the transition from a bluff profile to a beach profile is not specifically defined on the maps.
- 4) Height of the bluff varies only because of TOB:
the height of bluff is from TOB to the lower limit of 250 ft contour elevation (TOE).
- 5) The original contour maps are correct:
the original maps were produced by a reputable aerial photography survey agency.
- 6) The slope between contours is constant:
the bluff slope is represented with a straight line between contours.
- 7) Area and volumetric errors average to 0.0 over the height and reach of the bluff:
the data reduction will result in having a positive or negative error and one will compensate for the other.

ANALYSIS

The data listed in Appendix B is reduced to volumetric changes of bluff material between the years 1947 and 1977 and is entered in Appendix C. From this data, erosion and accretion rates are calculated for approximate 10 year periods (Tables 3 and 4).

	<u>Erosion Rates (10 yr period)</u>			<u>Average</u>	<u>Average*</u>
	<u>66-77</u>	<u>56-66</u>	<u>47-56</u>		
Section 1	-.75	-.34	-.06	-.38	-.38
Section 2	-.57	-.25	-.14	-.32	-.32
Section 3	-.48	-.41	-.28	-.39	-.39
Section 4	-.22	-.40	-	-.31	-.31
Section 5	-	-.08	-	-.08	
Section 6	-.11	-.48	-	-.30	-.30
Section 7	-.43	-.36	-.57	-.45	
Section 8	-.64	-.30	-.29	-.41	-.41
Section 9	-.44	-.34	-	-.39	-.39
Section 10	<u>-.26</u>	<u>-.09</u>	<u>-</u>	<u>-.18</u>	<u>-.18</u>
	-.43	-.31	-.27	-.32	-.34*
				Weighted Average:	-.31**

Table 3: Erosion rates in $m^3/m/m/yr$.

* Average - $0.34 m^3/m/m/yr$; average using eight averages excluding high and low samples (Sections 5 and 7).

** Weighted Average - 0.31 ; weighted average is the sum of percentage contribution of each section given the individual averages.

ACCRETION RATES (10 yr periods)

	<u>1956-47</u>	<u>1966-56</u>	<u>1977-66</u>
Section 1	-	-	-
Section 2	-	-	-
Section 3	-	-	-
Section 4	.09	-	-
Section 5	.16	-	.34
Section 6	.58	-	-
Section 7	-	-	-
Section 8	-	-	-
Section 9	.16	-	-
Section 10	.12	-	-

Table 4: Accretion Rates in $m^3/m/m/yr.$

Four of the ten sections are defined as bluff reaches and four are defined as gullies. Sections 5 and 6 are excluded from both categories since Section 5 is affected by the Brimley Rd. access and Section 6 is a long reach with characteristics of both categories.

	Section #	Reach Length (m)	Yearly Erosion Rates 30 year average
Bluff	1	83.9	-0.38 ($m^3/m/m/yr$)
	4	289.8	-0.31
	8	129.6	-0.41
	10	205.9	<u>-0.18</u>
		Bluff average	-0.32
		weighted average	-0.30
Gully	2	179.2	-0.32
	3	244.0	-0.39
	7	194.4	-0.45
	9	404.1	<u>-0.39</u>
		Gully average	-0.39
	weighted average	-0.39	

Table 5: Erosion Rates for Bluff Sections vs. Gully Sections

Based on the previous analysis and reduction of data from Appendix B and C, a generalized chronological order of coastal changes for Bluffer's Park reach are:

Section 1	1947-56	Stable top of bluff, erosion and slumping at toe
	56-66	erosion over height of bluff
	66-77	increased erosion over height of bluff
Section 2	1947-56	erosion top of bluff, stabilizing, erosion toe
	56-66	erosion over height of bluff
	66-77	increased erosion over height of bluff
Section 3	1947-56	erosion top of bluff, slumping, toe erosion
	56-66	erosion over height of bluff
	66-77	increased erosion over height of bluff
Section 4	1947-56	erosion top of bluff, slumping and accretion
	56-66	erosion over the height of bluff
	66-77	decreased erosion over height of bluff
Section 5	1947-56	minimal accretion over height of bluff
	56-66	top of bluff erosion, slumping at toe
	66-77	stable top of bluff, accretion (fill for Brimley Road extension)
Section 6	1947-56	excessive accretion for height of bluff, minimal toe erosion
	56-66	erosion over height of bluff
	66-77	top of bluff accretion, erosion for remainder of bluff
Section 7	1947-56	erosion over height of bluff, 50% accounts for near toe erosion
	56-66	decreased erosion over height of bluff
	66-77	increased top of bluff erosion, erosion over height of bluff

Section 8	1947-56	accretion at top half of bluff, erosion for bottom half of bluff
	56-66	erosion over height of bluff
	66-77	erosion over height of bluff
Section 9	1947-56	accretion over height of bluff to erosion for near toe of bluff
	56-66	erosion over height of bluff
	66-77	erosion over height of bluff
Section 10	1947-56	accretion over height of bluff, erosion at toe
	56-66	erosion for top portion of bluff, slumping, continue erosion and slumping at toe
	66-77	erosion for top of bluff, slumping, erosion

DISCUSSION

The landfill site influenced Sections 4 to 9 at the 250 ft contour line by showing definite accretion. This accretion is not regarded as being part of the natural process of erosion-accretion cycles and was taken into account in the analysis. The moderation of the slope in the Brimley Road ravine was another specific area in which the data reduction required some discretion.

Appendix C demonstrates accretion near the top of the bluff. In a bluff area most accretion can be attributed to slumping. Special cases of accretion are sediment transport and deposition or beach accretion; however, both are found in the region of the toe and water's edge. It is inappropriate to have natural accretion at the top of the bluff especially when the Scarborough Bluff reach is not conducive to retaining any accretion on the bluff face. Historical data (1955 aerial photos) show a clean bluff face in contrast to the accretion which is documented by the contour maps. Some of the area is tree covered making the delineation for contour maps difficult for the years 1947 and 1956.

The results of the initial testing of digitizing error can be decreased with more experience. The operator can improve the digitizing such that the difference between samples fluctuates in the range of ± 0.06 in² per contour per section. This error accounts for a maximum volume of ± 700 m³ of material over a contour interval of 7.63 m (25 ft); improved somewhat over the initial trials done at the beginning of the study and documented in Appendix A. When volumes are within this range the bluff is assumed to be stable (having no erosion or accretion).

The average rate of erosion for gullies is 0.08 m³/m/m/yr greater than the average rate of erosion for a bluff area. Groundwater seepage, runoff, precipitation, and weathering make gullies more susceptible to increased erosion since the surface area exposed by a gully is larger than the surface area of a bluff, per shoreline length.

Many factors (water levels, wave action, littoral drift, etc.) influence the rate of erosion in bluff areas in varying degrees and in different ways. The effect of the offshore landfill on the site's vegetation, rate of erosion and rate of recession is inevitable. If the

landfill eliminates erosion at the toe and does not influence the present recession rate at the top of bluff, then moderation and stabilization of the slope will result.

The cycle normally associated with bluff recession is wave erosion of toe → landslide (sheet wash) → talus → removal of talus due to wave action → wave erosion of toe (Horikawa, 1967). If, however, there is an intervention in the process, as in this case (offshore landfill), the cyclic period is then disrupted and prolonged. The removal of the talus due to wave action cannot be initiated and the process is essentially short-circuited to landsliding due to ground water seepage and surface runoff. The material on the face of the bluff above water level slumps until the slope of the bluff becomes stabilized.

The rate of erosion is expected to decrease due to the fact that wave action (a major factor associated with shoreline dynamics) in the landfill portion of the site has been almost eliminated.

In bluff areas high lake levels moisten, undercut and generally weaken the base of the bluff (Canada/Ontario, 1975) as well as facilitating the transfer of dislodged material offshore and alongshore. Any detrimental influence such fluctuations may have on the site is abated by landfill. Although offshore landfill may be a means of protecting this reach, rates of erosion to either side of the site may change significantly. Depending on the configuration of the offshore landfill site, sediment transport, littoral drift, wave refraction and energy will be influenced, ultimately having the effect of changing the shoreline.

Presently there are erosion monitoring stations in the Scarborough reach (Figure 9) which are used to measure shoreline changes. Figure 10, a plot of cross-sectional profiles, illustrates the apparent differences between ground surveys for two consecutive years (1977-78).

For a volumetric comparison, assume the profile line represents a one metre reach. The associated volume lost over the height of the bluff (57 m) is 140 m^3 and can be reduced to an average annual recession rate of $2.45 \text{ m}^3/\text{m}/\text{yr}$. Similar rates are reduced from other erosion stations within the Bluffer's Park reach. They are $3.06 \text{ m}^3/\text{m}/\text{yr}$, and $1.88 \text{ m}^3/\text{m}/\text{yr}$ for stations 0-05-025 and 0-05-023 respectively. In comparison to these short term rates (1 yr period), other studies over a longer period (up to 30 yr) have been done.

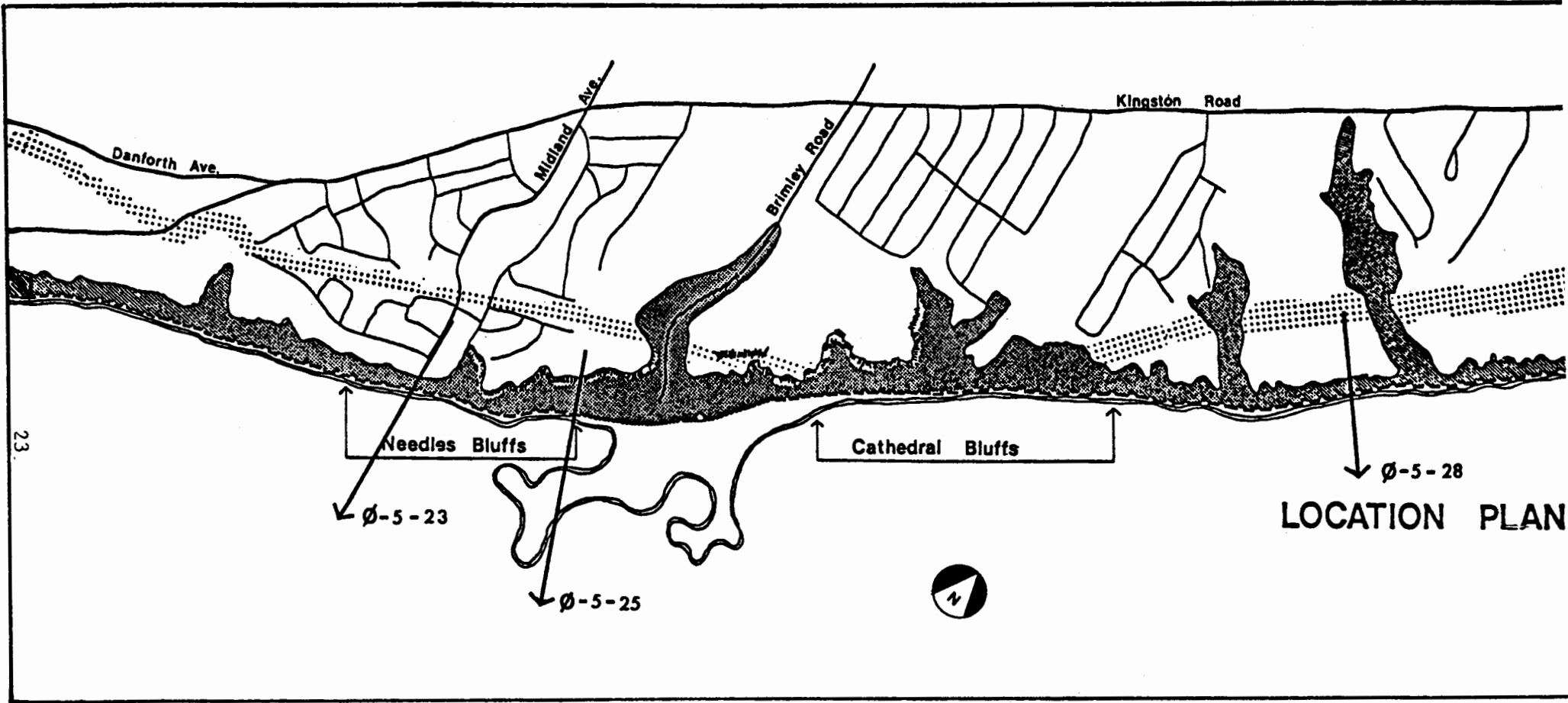


Figure 9: Erosion Station Location Plan

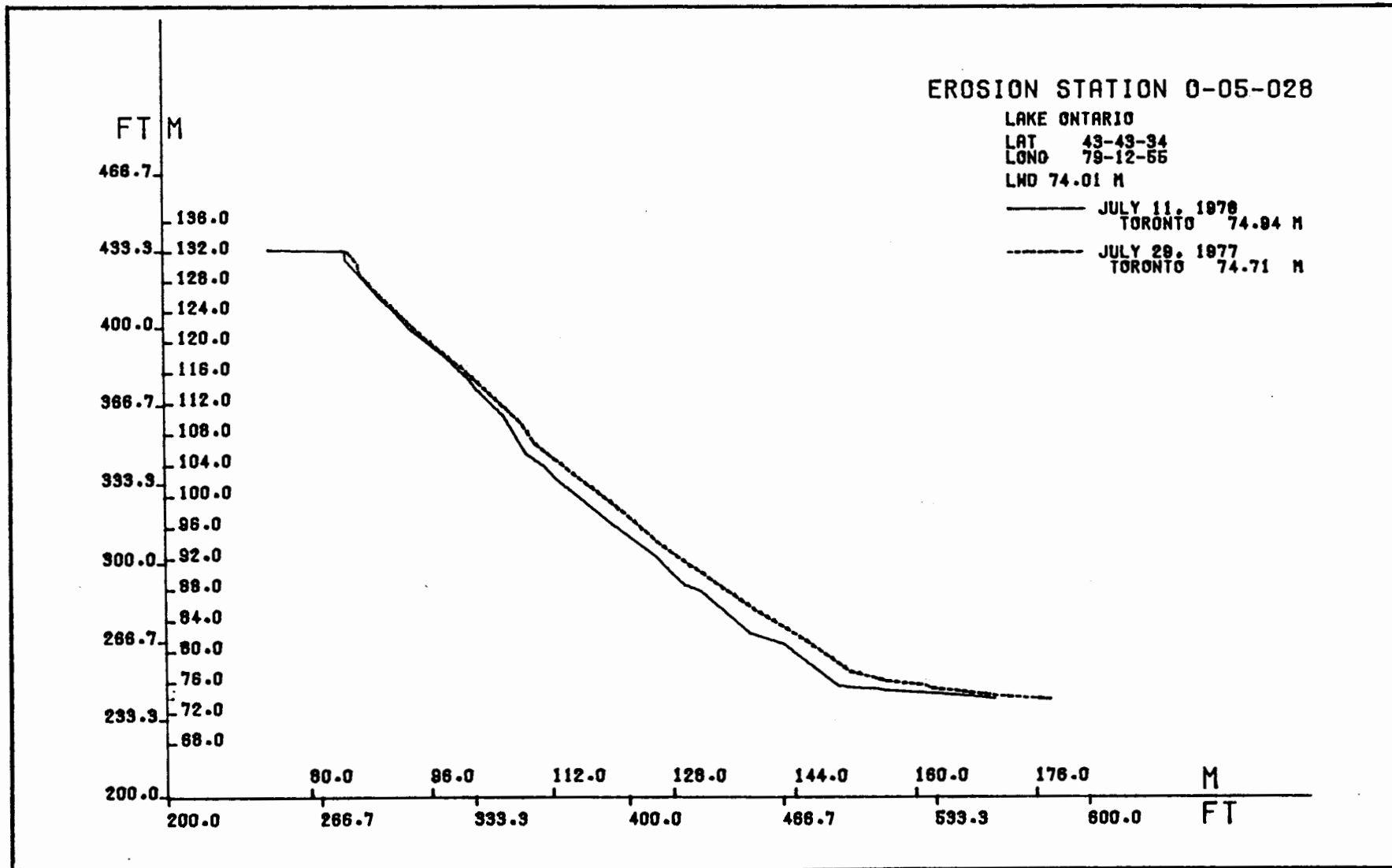


Figure 10: Erosion Station Profile

The recession rates for the Bluffer's Park area are commonly reported to be in the range of 0.30-0.60 m/yr. Langford suggests the range 0.38-0.49 m/yr while Baird's study (1922-1952) demonstrated a recession rate averaged between top of bank and toe of bluff measurements of approximately 0.56 m/yr.

An average recessional rate over the whole face of the bluff (rate of erosion in $\text{m}^3/\text{m}/\text{m}/\text{yr}$) used in this study is comparable to the linear measures of recession by Langford and Baird. Another study by Fricbergs stated "over 9.5 miles of reach an average of 380,000 yd^3 of material was lost". If a few generalizations such as

- erosion is constant for length of reach
- average height of bluff in Bluffer's Park reach is 55 m
- length of Bluffer's Park reach is 16% of Fricbergs' reach

are made, the calculated rate of erosion is $0.35 \text{ m}^3/\text{m}/\text{m}/\text{yr}$. The results of this study demonstrated for the small reach of 2.41 km that the rate of erosion over a 30 year period is $0.34 \text{ m}^3/\text{m}/\text{m}/\text{yr}$. The average rates between sections ranged from 0.18 - $0.41 \text{ m}^3/\text{m}/\text{m}/\text{yr}$ (Table 3) and the weighted average erosion was $0.31 \text{ m}^3/\text{m}/\text{m}/\text{yr}$ for the period from 1947 to 1977.

CONCLUSIONS

It is therefore concluded that:

- 1) Some of the mapping was in error.
- 2) Digitizing errors are unavoidable but the overall magnitude is not appreciable.
- 3) 10 yr rates from 1947-1977 varied appreciably:

1947-1956:	0.27	$\text{m}^3/\text{m}/\text{m}/\text{yr}$
1956-1966:	0.31	$\text{m}^3/\text{m}/\text{m}/\text{yr}$
1966-1977:	0.43	$\text{m}^3/\text{m}/\text{m}/\text{yr}$
- 4) 30 yr rates 1947-1977: $0.34 \text{ m}^3/\text{m}/\text{m}/\text{yr}$.
- 5) Gullies eroded at a rate of approximately $0.08 \text{ m}^3/\text{m}/\text{m}/\text{yr}$ faster than bluff areas over a 30 yr period.
- 6) The methodology produces rates comparable to any other procedures for calculating erosion/accretion rates.

RECOMMENDATIONS

Maps should be scanned visually for possible errors such as varying map scales, improper contour intervals, incorrect labelling of contours and large changes of contours between years.

Initial points taken, when digitizing, could be standardized by inking reference points on the frame of reference for each section.

Digitizing error could be minimized by operator's experience.

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APPENDIX A

SUPPORT MATERIAL FOR
DETERMINING DIGITIZING ERROR

Notes: 1) areas in square inches

OBS ₁	OBS ₂	ΔOBS	$\overline{\text{OBS}}$	$ \overline{\text{OBS}} - \Delta\text{OBS} $
(Area)	(Area)	(ΔArea)	(Average Area)	
5.403	5.472	.069		.004
6.381	6.465	.076		.003
7.829	7.872	.043		.030
8.989	9.056	.067		.006
9.938	10.011	.073		.000
10.802	10.843	.041		.032
11.645	11.729	.084		.011
27.252	27.385	.133		.060
			<u>.073</u>	
0.974	0.901	.073		.009
1.929	1.820	.091		.009
2.766	2.662	.104		.022
3.738	3.643	.095		.013
4.751	4.691	.060		.022
6.552	6.420	.132		.050
8.293	8.217	.076		.006
24.790	24.762	.028		.054
			<u>.082</u>	
7.936	7.939	.003		.049
10.913	10.874	.039		.013
13.826	13.830	.004		.048
17.569	17.571	.002		.050
19.279	19.209	.070		.018
20.485	20.457	.028		.024
21.780	21.704	.076		.024
23.113	23.056	.057		.005
24.321	24.266	.055		.003
25.775	25.688	.087		.035
32.317	32.168	.149		.097
			<u>.052</u>	
4.537	4.574	.037		.013
5.483	5.475	.008		.016
6.264	6.289	.025		.001
7.450	7.508	.058		.034
8.775	8.754	.021		.003
9.765	9.794	.029		.005
10.814	10.839	.025		.001
11.740	11.722	.018		.006
12.611	12.642	.031		.007
13.453	13.457	.004		.020
16.908	16.885	.013		.011
			<u>.024</u>	

Let $\overline{\text{OBS}} = 0.5 * (\text{A(N)} + \text{A(N-1)})$

$\text{FACT} = 60.96$

$\text{ABS}(\text{CD(N)} - \text{CD(N-1)}) = 25$

$\text{METRE} = .305$

$\therefore \overline{\text{OBS}}$ represents $\text{VOL} = \overline{\text{OBS}} * \text{FACT}^2 * 25 * .305$

$.073$ represents $\text{VOL} = 2068\text{m}^3$

$.082$ represents $\text{VOL} = 2324\text{m}^3$

$.052$ represents $\text{VOL} = 1473\text{m}^3$

$.024$ represents $\text{VOL} = 680\text{m}^3$

APPENDIX B

TABULATED VOLUMES

1947 - 1977

- Notes:**
- 1) volumes in cubic metres**
 - 2) contour ID ranges from**
250 ft - 400 ft: Section 1 (S1)
to 250 ft - 575 ft: Section 10 (S10)

	<u>1977</u>	<u>1966</u>	<u>1956</u>	<u>1947</u>
S1	25445.21	25416.88	24056.78	
	43310.70	45917.56	49544.49	50139.54
	50281.22	53908.15	57365.07	57648.43
	56911.71	61431.21	65043.97	65143.15
	61530.38	66829.11	69492.64	71107.75
	63499.69	70597.72	71306.10	74281.32
	65029.81	73218.74	73232.91	76633.16
S2	102191.72	104713.57	98748.96	102772.59
	152671.28	159131.76	164628.83	165946.43
	198588.84	202442.46	206990.30	207287.82
	237408.38	242182.90	247226.60	246560.72
	265956.32	273266.86	277120.48	276610.44
	284544.36	292109.92	295255.15	296091.05
	294674.28	304931.70	305880.94	308927.00
S3	105960.33	113965.09	114999.33	134352.43
	168822.48	176118.85	185412.87	191150.79
	208492.07	217332.73	223764.87	224969.12
	244308.05	253219.55	260799.27	258957.47
	270957.52	277743.86	286272.82	285026.06
	287930.44	295439.33	303472.43	303954.13
	301163.09	311930.55	315628.32	319311.93
S4	166824.83	173795.34	185370.36	186645.46
	201649.07	207571.17	215703.44	216029.30
	238655.14	242664.60	250513.51	248218.34
	268704.86	272827.66	280634.07	276808.79
	293498.35	299335.45	307496.06	303373.25
	317229.28	322017.96	330249.40	328280.09
	549749.79	346669.78	348369.91	349120.80
S5	38748.70	39471.25	41908.10	40973.03
	63669.70	62989.65	67806.68	64703.95
	89242.43	86635.57	92203.48	89525.78
	118626.27	114687.64	117011.15	116926.14
	159060.92	149526.05	147344.22	144850.70
	209143.79	186872.14	182607.66	177039.75
landfill		235793.26	217771.93	216553.50

	<u>1977</u>	<u>1966</u>	<u>1956</u>	<u>1947</u>
S6	263717.82	256931.49	267401.43	238187.60
	346570.61	343864.58	353002.75	330376.91
	441947.66	439595.82	449513.22	428261.65
	518935.01	520082.60	530212.51	517050.71
	560970.62	564300.03	574784.14	567232.75
	594746.45	605202.22	617258.95	612229.41
	631880.03	639360.58	653329.94	650397.23
	669126.95	674269.83	683861.37	684994.78
	705552.14	712395.14	715837.90	718713.94
landfill	818582.16	754274.90	753552.35	756442.56
S7	141478.79	147060.87	149285.20	156510.73
	165422.22	174121.20	176628.89	179717.45
	193105.94	203023.34	205403.51	207216.98
	228822.74	237592.56	241347.00	244407.23
	261833.52	269328.24	276468.76	279670.67
	290508.97	296813.60	308431.13	311349.67
	318121.84	323732.26	335873.99	342136.12
	345054.66	350225.88	356743.03	367397.15
	368969.77	374452.67	374325.16	389187.09
	427170.73	398537.78	391241.41	406939.24
S8	55494.93	55112.41	55254.08	51924.67
	80415.94	85714.67	84467.91	82172.74
	91565.93	98607.29	99910.72	98210.59
	106342.86	113058.35	115707.72	114616.80
	120751.42	128642.84	131915.58	131873.08
	133289.85	142102.17	147769.25	148661.82
	145134.06	154994.79	161908.63	163948.78
	159726.80	167037.34	174107.03	177379.77
	174857.92	179788.29	184222.78	190300.73
	188784.78	194097.68	193530.97	203320.86
		208407.07	205984.39	215816.78
S9	317880.99	316365.04	350608.41	292931.65
	494113.18	519105.03	529985.83	517121.55
	595001.47	611903.55	618123.18	615417.14
	685745.67	694501.32	699587.53	693027.88
	767677.56	776390.71	782624.50	774860.59
	850317.83	863380.47	869741.77	864924.75
	933298.13	946969.98	954592.21	952467.05
	1007834.47	1021633.83	1032132.10	1030743.67
	1067664.73	1080288.16	1094045.01	1096991.90
	1123598.86	1134125.47	1143192.81	1154484.48
	1174545.96	1187821.11	1187537.75	1206012.45
	1220463.52	1233441.15	1228142.42	1247212.16

	<u>1977</u>	<u>1966</u>	<u>1956</u>	<u>1947</u>
S10	64774.79	80628.46	82201.07	73077.07
	101426.66	104911.92	110352.32	108538.85
	124463.36	127226.07	131958.08	128827.02
	150772.81	150659.47	153620.52	152572.11
	174886.26	173129.46	174730.41	173880.35
	201139.03	199155.55	199495.58	197072.90
	228893.58	228426.05	228227.70	225550.00
	252766.18	256308.11	255458.04	253927.93
	277828.86	281455.80	281795.82	280024.86
	303075.73	304605.84	306688.50	305115.88
	326084.10	327189.18	329215.16	328690.96
	343057.02	348922.45	348384.08	350055.87
	355439.60	370797.40	366178.73	372058.33

APPENDIX C

TABULATED CHANGE IN VOLUMES

1947-56; 1956-66; 1966-77

- Notes:
- 1) volumes in cubic metres
 - 2) any contour interval having a volume change greater than -700 and less than +700 is assumed to be stable and is denoted with an asterisk
 - 3) contour interval is 25 ft (7.63 m)

* Stable
- Loss

	<u>1977-66</u>	<u>1966-56</u>	<u>1956-47</u>
S1	28*	1361	
	- 2607	- 3627	- 595*
	- 3627	- 3457	- 287*
	- 4520	- 3613	- 99*
	- 5299	- 2664	- 1609
	- 7098	- 708*	- 2975
	- 8189	- 14*	3400
	<u>- 31312</u>	<u>- 12722</u>	- 2161
S2	- 2522	5965	- 4024
	- 6460	- 5497	- 1318
	- 3854	- 4548	- 297*
	- 4774	- 5044	666*
	- 7310	- 3854	510*
	- 7565	- 3146	- 836
	<u>- 10257</u>	<u>- 949</u>	<u>- 3047</u>
	- 42742	- 17073	- 8346
S3	- 8005	- 1034	- 19353
	- 7296	- 9294	- 5738
	- 8840	- 6432	- 1205
	- 8911	- 7580	1842
	- 6786	- 8529	1246
	- 7509	- 8033	- 482*
	<u>- 10767</u>	<u>- 3698</u>	<u>- 3683</u>
	- 58114	- 44600	- 27373
S4	- 6971	- 11575	- 1275
	- 5922	- 8132	- 326*
	- 4009	- 7849	2295
	- 4123	- 7807	3826
	- 5837	- 8161	4123
	<u>- 4788</u>	<u>- 8232</u>	<u>1969</u>
	- 31650	- 51756	10612
landfill	<u>(203080)</u>	<u>- 1700</u>	<u>- 751</u>
	171430	- 53456	9861

* Stable
- Loss

	<u>1977-66</u>	<u>1966-56</u>	<u>1956-47</u>
Road Allowance			
S5	- 732*	- 2437	935
	680*	- 4817	3103
	2607	- 5568	2678
	3939	- 2324	85*
	9534	2182	2494
	<u>22271</u>	<u>4265</u>	<u>5568</u>
	38299	- 8699	14863
S6	6786	- 10470	29214
	2706	- 9138	22626
	2352	- 9918	21252
	- 1147	- 10130	13162
	- 3330	- 10484	7552
	- 10456	- 12056	5029
	- 7480	- 13969	2932
	- 5143	- 9592	- 1133
	- <u>6843</u>	- <u>3442</u>	- <u>2876</u>
	- 22555	- 89199	97750
S7	- 5582	- 2225	- 7225
	- 8699	- 2507	- 3089
	- 9918	- 2380	- 1813
	- 8770	- 3755	- 3060
	- 7495	- 7140	- 3202
	- 6305	- 11618	- 2918
	- 5611	- 12141	- 6263
	- 5171	- 6518	- 10654
	- 5483	127*	- 14862
landfill	<u>(28633)</u>	<u>(7296)</u>	- <u>15698</u>
	- 63034	- 48157	- 68784
S8	382*	- 142*	3330
	- 5299	1247	2295
	- 7042	- 1303	1700
	- 6716	- 2649	1091
	- 7891	- 3273	42*
	- 8813	- 5667	- 892
	- 9860	- 6914	- 2040
	- 7311	- 7070	- 3272
	- 4931	- 4434	- 6078
	- <u>5313</u>	567*	- 9790
	- 62794	<u>2423</u>	- <u>9832</u>
		- 27215	- 23446

* Stable
- Loss

	<u>1977-66</u>	<u>1966-56</u>	<u>1956-47</u>
S9	1515	- 34243	57677
	- 24992	- 10880	12864
	- 16902	- 6220	2706
	- 8756	- 5086	6560
	- 8713	- 6234	7764
	- 13063	- 6361	4817
	- 13671	- 7623	2125
	- 13799	- 10499	1389
	- 12624	- 13757	- 2946
	- 10527	- 9067	- 11292
	- 13276	284*	- 18475
	- 12978	5299	- 19070
	<u>-147786</u>	<u>-104387</u>	<u>44119</u>
S10	- 15854	- 1573	9124
	- 3485	- 5441	1814
	- 2763	- 4732	3131
	113*	- 2961	1048
	1757	- 1601	850
	1984	- 340*	2423
	467*	199*	2677
	- 3542	850	1531
	- 3627	- 340*	1771
	- 1530	- 2083	1573
	- 1105	- 2026	525*
	- 5865	538*	- 1671
	- 15358	4619	- 5880
	- 48808	- 14891	18916