U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SHORE AND LAKEBED EROSION; RESPONSE TO CHANGING LEVELS OF LAKE ERIE AT MAUMEE BAY STATE PARK, OHIO

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A Cooperative Study of Lake Erie Coastal Erosion by the U.S. Geological Survey, Woods Hole, MA and the Ohio Geological Survey, Sandusky, Ohio

Open-File Report 95-662
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ABSTRACT

The shore and nearshore area of Maumee Bay, at the western end of Lake Erie, was studied in detail to document the role of water levels on shore and lakebed erosion. Maumee Bay is bordered by a low escarpment composed of sand-poor glacial lacustrine silt and clay. Three regimes of lake level occurred during this nine-year study, each reflected by a change in the character and rate of erosion. During stable lake levels the erosion occurred as bank and shore recession and also as nearshore lakebed downcutting. During rising/high lake levels, bank and shore recession continued, but nearshore downcutting slowed except at the transgressed shoreline. During falling levels, bank recession ceased, the shoreline moved lakeward due to the falling levels, and nearshore downcutting resumed. Over the nine years of this study, total bank recession averaged about 20 m and nearshore downcutting averaged about 0.5 m. The hypothesis that a lower lake level stops erosion turns out to be false in this area because erosion of the lakebed continues to deepen the nearshore; therefore, when higher lake levels return, waves have an even greater impact on the bank.

INDEX WORDS: Lake Erie, erosion, water levels, downcutting, nearshore processes

INTRODUCTION

Purpose

The original goal of this study was to track littoral movement of a tracer-sand (Fuller, 1982) in response to a request for sand drift rates prior to design and placement of an artifical beach in the Maumee Bay State Park. The study area was revisited when Lake Erie was at record high water levels and afforded an excellent opportunity to document changes in the erosion rates (Fuller, 1986). Subsequently, the area was again revisited after lake levels fell during 1987 and 1988. Overall, the study lasted 9 years.

Setting

Geology-

The study area is at the southwestern end of Lake Erie, 8 km east of Toledo, Ohio, at Maumee Bay State Park (Fig. 1). At the present time, water depths in Maumee Bay are shallow, averaging <2m except in the maintained navigation channel.

The park is located on the flat-lying plain of glacial lacustrine sediments that were deposited between 14,000 and 12,000 years BP when deep proglacial lakes dominated the area (Lewis, 1969). The plain is ~0.6 m above average lake level; much of it, therefore, is within the open lake flood elevation for the 100-year storm (2.32 m above LWD, U.S. Army Corps of Engineers, 1977). Along the shore, wave-built sand washover fans have coalesced to form a low ridge on top of the flat plain (Fig. 2a). The crest of the sand ridge is ~1.2 m above average lake level and forms a low barrier between the plain and the lake.

Glacial lacustrine sediments are commonly exposed along the shore in a low (8-20 cm) erosional scarp (Fig. 2b). This highly-erodible, unprotected bank is sand poor (<5%) and, as a result, insufficient material is available to build wide, protective sand beaches; in addition, offshore sand bars are poorly developed with troughs starved of sand (Fig. 2d and Fig. 3). Thus, in many areas lakeward of the scarp, a wave-eroded sloping clay surface makes up the shallow, nearshore lake bottom (Fig. 2c).

Hydrology-

Water level fluctuations in Lake Erie occur over three time scales (Fig. 4). The first two, long-term and annual, reflect changes in the volume of water within the lake basin, whereas the third, short-term change, reflects tilting of the lake surface. Long-term changes are the result of precipitation/evaporation changes in the basin and the upper lake (Superior, Michigan, Huron) basins. Short-term changes are the result of transient external forces such as winds or barometric pressure. At the study area, winds from the north or northeast increase the lake level, and therefore increase nearshore water depths "setting up" the lake surface. The set-up is occasionally enough to flood the flat plain, but more importantly, the rise allows storm waves to break over the still water shoreline. Waves built on a raised water level increase the effective peak water level of storms.

Stillwater levels (without waves) during the 5-6 April 1982 storm provide an example of the impact of raised levels (Fig. 5). During this storm, the Toledo lake level was set up 2.2 m above LWD to 175.5 m above datum [International Great Lakes Datum (IGLD), 1955, U.S. Department of Commerce]. This rise in water level was ~1.1 m above the average local lake level for the month, and was caused by the stress of strong northeast winds. An even higher level of 175.7 m was reached during the 30-31 March 1985 storm.

Much of the shore along Maumee Bay has been diked to protect it from flooding and to reduce shore erosion. Where the shore is unprotected, even with the shallow water depths and relatively short fetch, erosion rates can be high. Benson (1978) reported that short-term, top-of-the-bluff recession rates for the study area ranged from 3.4-7.1 m/y, and the long-term (1877-1973) average rate was 4.4 m/y.

Previous Work

Many of the shoreline studies of the area were carried out by the U.S. Army Corps of Engineers (1945, 1961, 1983, 1988). State of Ohio government-agency reports covering the area include Pincus,1960; Ohio Division of Shore Erosion, 1961; and Benson, 1978. Benson's 1978 report provides an historical look at shore-recession data for the area. The U.S. Army Corps of Engineers (1983, 1988) reports includes a detailed description of the area and a discussion of the physical processes at Maumee Bay State Park. These studies suggests possible shore-protection measures, calculate wave conditions, and include a copy of the Ohio Geological Survey's Open-File Report (Fuller,1982) concerning the results of the tracer-sand study. Another report by Fuller (1986) presented the results of the first two years of this study and was part of the 1986 Associate Committee for Research on Shoreline Erosion and Sedimentology (ACROSES) Conference sponsored by the Canadian National Research Council.

The ACROSES conference in Burlington, Ontario focussed on erosion of cohesive shores. Many papers discussed nearshore downcutting and are pertinent to this study. Maximum water depths for lake bottom erosion were reported to be shallower than 12 m for much of the north shore of Lake Erie (Philpott, 1986). Pinchin and Nairn (1986), and Kamphuis (1986) reported that the recession rate of a bluff is directly related to the amount of downcutting in the nearshore. If, for example, downcutting does not occur, the bluff toe will not be cut back and the bluff will not retreat due to shore erosion. Davidson-Arnott (1986) noted that the vertical lowering of the nearshore needs to keep pace with bluff recession for the system to remain in dynamic equilibrium. Nearshore downcutting rates for three water depths in his study area at the the west end of Lake Ontario at Grimsby, Ontario were: 6 m of water=1.5 cm/y; 2 m of water=3.5 cm/y; and <1m of water= >10 cm/y.

Boyd (1986) used the same Lake Ontario location (Grimsby) to develop the following model. The area has a shoreline recession rate of 1 m/y; therefore, a point 45 m from the present shore was the shore 45 years ago. Given the existing water depth at 45 m from shore of 3.5 m, means that average downcutting rate over the period is 7.8 cm/y. Boyd's model used the 45 m distance and the profile shape to arrive at various downcutting rates along the profile. These rates range from 15 cm/yr at the shoreline to 0.3 cm/y at a depth of 3.5 m. He then projects rates for an offshore slope of 3:100 with a bluff recession 1 m/y. To keep up with erosion, an average annual downcutting rate of 3 cm would be required, but to maintain the profile shape, a 5 cm/y rate at the shore would be required, but only 0.04 cm/y rate at the maximum depth of 3.5 m.

METHODS

The study area (Fig. 6) encompassed a rectangle about 300 m parallel to shore and 120 m offshore that included the 1981 shoreline. The original baseline lay approximately parallel to and 9 m landward of the 1981 fall shoreline. Steel pipes were set along the original baseline to mark the landward end of each profile. Due to erosion, a secondary baseline had to be established which was located 30.5 m further inland. Elevations of the pipes were surveyed from a Corps of Engineers benchmark on Cedar Point Road (Fig. 1). All elevations for the study have been converted to the International Great Lakes Datum (IGLD, 1955). Because the original baseline was lost to erosion early in the study, all distances have been referenced to the secondary baseline.

Over the 9-year period, thirteen profiles extending about 120 m into the lake, at right angles to the baseline (Fig. 6), were monitored. The profiles were spaced at 30 m intervals along the baseline, except for five near the center of the baseline that were spaced 15 m apart. Location, alignment, and elevation for the profile lines were referenced to steel pipes driven into the clay along the baseline

During a site visit, level-line surveys were run along each of the 13 profiles using a transit and stadia rod. Elevation of the lake bottom was measured to the nearest 3 cm at either 3 or 6 m intervals along each profile (Fig. 6). Horizontal control was maintained by alignment of range poles and a measured tag line anchored at the baseline.

DATA ANALYSIS

Two types of lake level fluctuations need to be considered to interpret the field data: 1) short-term changes due to wind set-up (Figs. 2, 5) long-term changes due to evaporation and precipitation (Fig. 7).

Storm waves provide much of the energy for erosion of the clay slope (Carter and Guy, 1988). Short-term water level fluctuations allow storm waves to focus more wave energy on the shore and the shallow nearshore area. The impact of short-term water-level variations, due to storm-induced tilting of the lake surface, can be illustrated by data from the following two storms: the first, on November 20, 1981 set the Toledo lake level up 0.7 m from the previous 7-day mean. Wave activity associated with this storm stripped the sand from most of the nearshore portion of the study area. A site visit on November 25 showed some landward movement of the washover fans and an emergent and submergent clay slope. Another northeast storm on April 5-6, 1982 allowed waves built on a raised water surface (1.4 m above the previous 7-day mean) to alter the area significantly (Fig. 5). For example, nearly all the sand at the shoreline was transported onto the flatplain to rebuild the washover fans landward of their pre-storm position. These reformed fans were about 0.5 m thick. The offshore bars were totally removed exposing the underlying clay.

Variations in the lake's annual mean levels were used to break the study into 3 periods (Fig. 7). The first period from 1981 to 1984, was characterized by water level stability; the second period, from 1985 to 1986, was characterized by rising and high annual lake levels; and the third period, from 1987 to 1990, by falling and relatively lower average levels.

During the first period, erosion was characterized by both landward movement of the bank face and downcutting of the nearshore lake bottom. This produced a nearly classic example of parallel profile retreat (Fig. 8). The second period was characterized by flooding of the previous shoreline and rapid erosional retreat of the bank face (loss of shore material). Rapid changes were obvious and were due to a combination of flooding and erosion. Sand, accumulated on the nearshore clay slope, provided some protection to the nearshore lake bottom effectively eliminating downcutting (Fig. 8). The locus of downcutting was inshore in an area that had previously been subaerially exposed (landward of the previous period's shoreline). In the third period (falling and low levels), little or no landward retreat of the shoreline occurred. In fact, it moved lakeward by emergence due to falling lake level. All of the accumulated nearshore sand was stripped away exposing the clay slope where downcutting resumed (Fig. 8). Thus the third period can be characterized by a stable bank, emergent shoreline, and reactived nearshore downcutting especially near the new shoreline.

To quantify the changes seen in this study, a starting point was needed. This fixed reference point is defined by the intersection of the average water level for the first period (1981-84) and the clay slope. All measurements of backcutting were made from this point along its elevation (174.3 m) and all downcutting was measured as vertical change from this elevation (Fig. 8). There are inherent problems in characterizing erosion by measuring progressive changes from a fixed reference point (along a fixed elevation and downward in a fixed vertical plane). For example, during high water the reference elevation may be totally submerged and during low water it may subaerially exposed. This, therefore, represents a different technique for measuring erosion from that previously used by other researchers working in the area (see Benson, 1978; Carter and Guy, 1988, who measured the retreat of the bluff crest. This method documents dramatic changes in energy level along the profiles because the downcutting environment changes radically especially near the initial fixed reference point. Boyd (1986) and Davidson-Arnott (1986) both suggest that there is rapid downcutting at the shoreline and progressively less downcutting as water depth increases. This relationship is required if the profile shape is to be maintained, but it means that as soon as there is erosion at the starting fixed reference point there will also be a reduction in the downcutting rate.

RESULTS

During the 9-year study, the shoreline at the fixed reference points (Fig. 8, "O") receded an average of 20 ± 2.3 m along the length of the study area (Table 1). Recession was greater at the east end, closer to the center of the embayment. Recession rates ranged from 2.0 to 2.7 m/y and averaged 2.3 ± 0.25 m/y.

Downcutting from the original fixed reference points averaged 48.8 cm ± 9.1 cm or an average rate of 5.4 ± 1.0 cm/y during the study period. Total downcutting ranged from 37.5 to 64.0 cm and was greatest during the first period (3 years of stable water level). This may, in part, reflect the fact that the fixed reference point was originally defined at the locus of maximum energy. The first period rates averaged 3.3 m/y for backcutting and 12.4 cm/y for downcutting. A decrease in downcutting rate during the second period (rising lake level) was expected because the water depth nearly doubled. The deeper water allowed the transfer of energy available for erosion inshore toward the new shoreline. In fact, sand accumulated at the fixed reference points along the west end of the study area (see Lines 15+00 through 17+00, Table 1).

For the most part, downcutting at the fixed reference points was reactivated through the third period (falling and lower lake levels), but since the water depths had already been increased, due to the initial downcutting, the fixed reference points had become offshore sites where downcutting rates remained somewhat below the average rates during the nine-year study. The downcutting measured in this study almost doubled the nearshore depth within 15 m of the shore. This nearshore deepening allowed larger waves to act directly on the new shoreline and bank. Tables from the Shore Protection Manual U.S. Army Corps of Engineers, 1973) suggest that a 0.3 m increase in wave height, from 0.6 to 0.9 m, nearly doubles the energy available at the shoreline. Although a 0.6 m wave is not possible in only 0.6 m of water, 0.6 m waves can develop when short-term lake levels are elevated by storms, exactly the conditions that cause most of the damage to the shore. Thus, deepening of the nearshore during lower levels sets the stage for major losses during storms in the next period of high levels.

The shoreline downcutting rates calculated during this study fall within the range of values (5-15 cm/y) predicted by Boyd (1986) for the Lake Ontario study site. The rapid shoreline downcutting in the first period mimic Davidson-Arnott's 1986 measured values, and the trend of decreasing downcutting with increasing depth can be seen in the general decrease in rate during the later periods.

SUMMARY

A stretch of shore on Maumee Bay, at the west end of Lake Erie, was the site for this nine-year study that spanned three regimes of lake levels. The site is located in the flat-lying plain of glacial lacustrine sediments consisting mostly of silt and clay. These sediments, when unprotected, are subject to rapid erosion. Because of their sand-poor nature, protective beach deposits are lacking. Throughout the course of the study, the shoreward retreat of the bank/shoreline was about 20 m while downcutting in the nearshore increased the water depth by 37 to 64 cm.

Bank recession and nearshore downcutting occurred during the period of stable lake level. During rising lake level, bank recession accelerated and shoreline retreat was due both to flooding and erosion. Nearshore downcutting all but ceased, except at the prograded shoreline; in some areas the nearshore became protected by minor sand deposits on the clay slope. During falling and lower lake levels, bank recession all but ceased. The shoreline moved lakeward due to the falling water level, and nearshore downcutting, which is always greatest just lakeward of the new shoreline, was reestablished. The falling lake level reduced the shoreline erosion associated with the previous high water levels, but downcutting was renewed nearshore. Thus the stage is set for more rapid bank erosion with the return of higher lake levels.

ACKNOWLEDGMENTS

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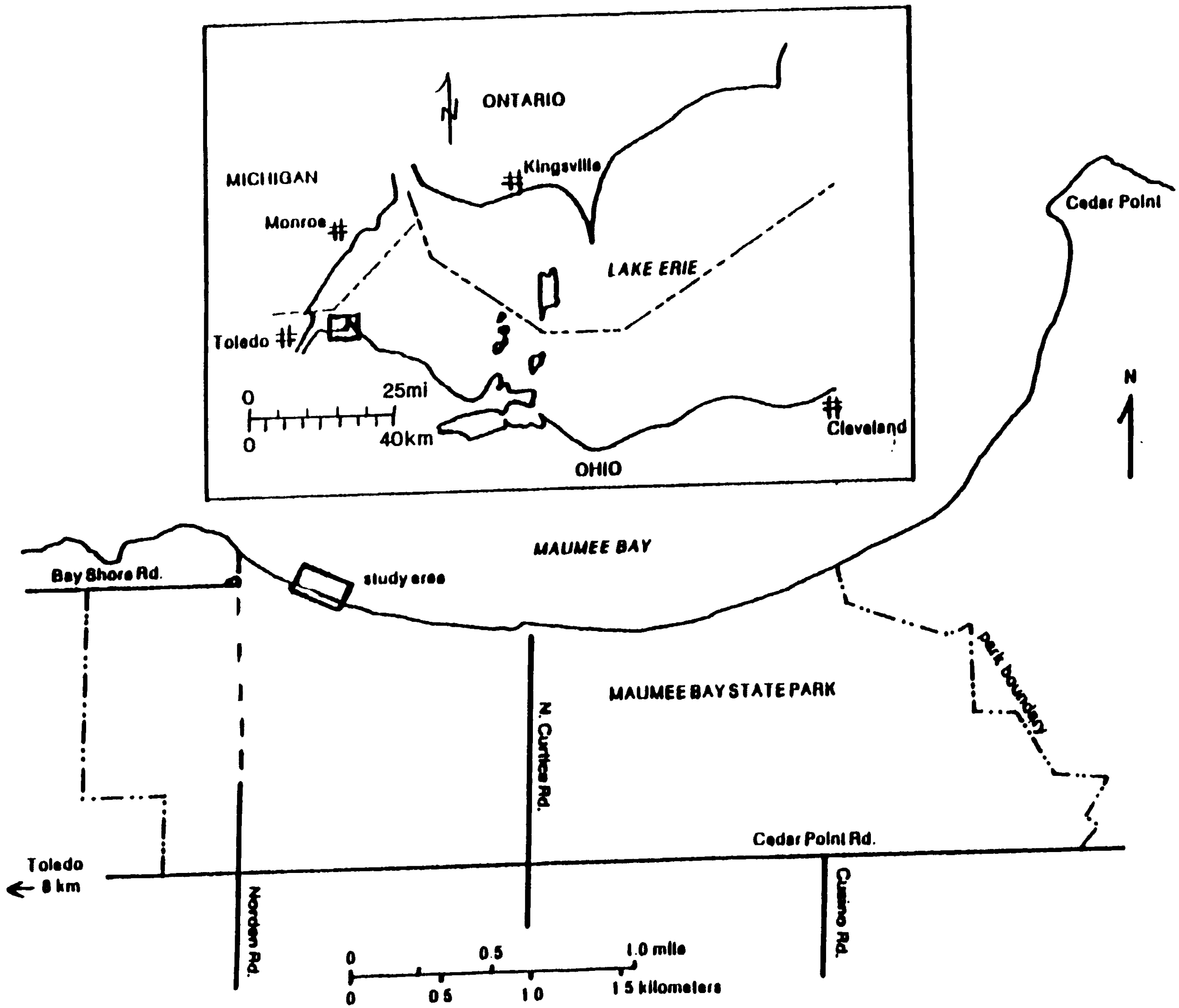


FIG. 1. Location of study area at Maumee Bay State Park (from Fuller, 1986).

a Erosion scarp (clay notch) cut by waves in clay shell. Looking east from survey line 15+00 at 6 meters from base line; date 6-7-82, water level = 174 4 meters

b Landward edge of sand washover fan building onto flat glacial-lake-clay low-lands. Looking west from 19+00 at 18 meters from base line, date 4-12-82

c Erosion scarp filled with sand. Note nearshore clay slope exposed at low water. Looking east from 15+00 at 15 meters from base line; date 11-20-81, water level = 173 1 meters

d Starved first sand bar exposed at low water, nearly starved second bar with third bar partly exposed. Looking east from 0 25 km west of study area; date 11-20-81, water level = 173 1 meters

FIG. 2. Geomorphic features of Maumee Bay State Park Study area (modified from Fuller, 1986).

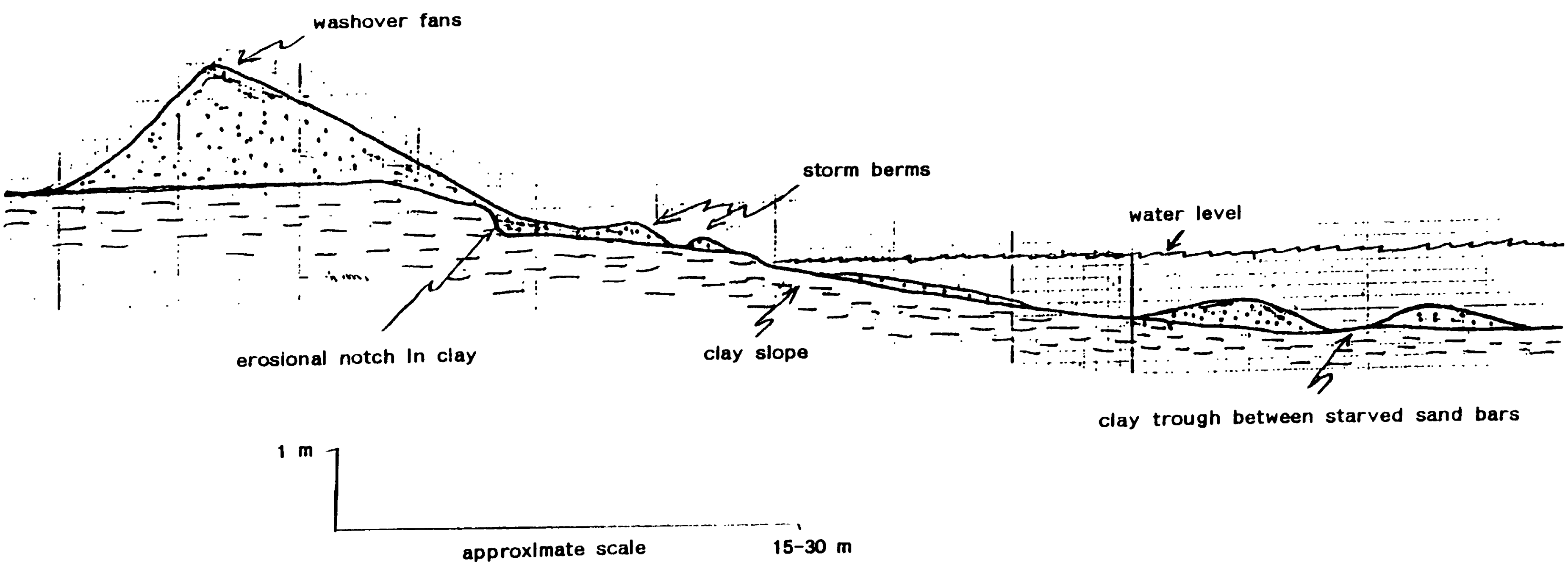
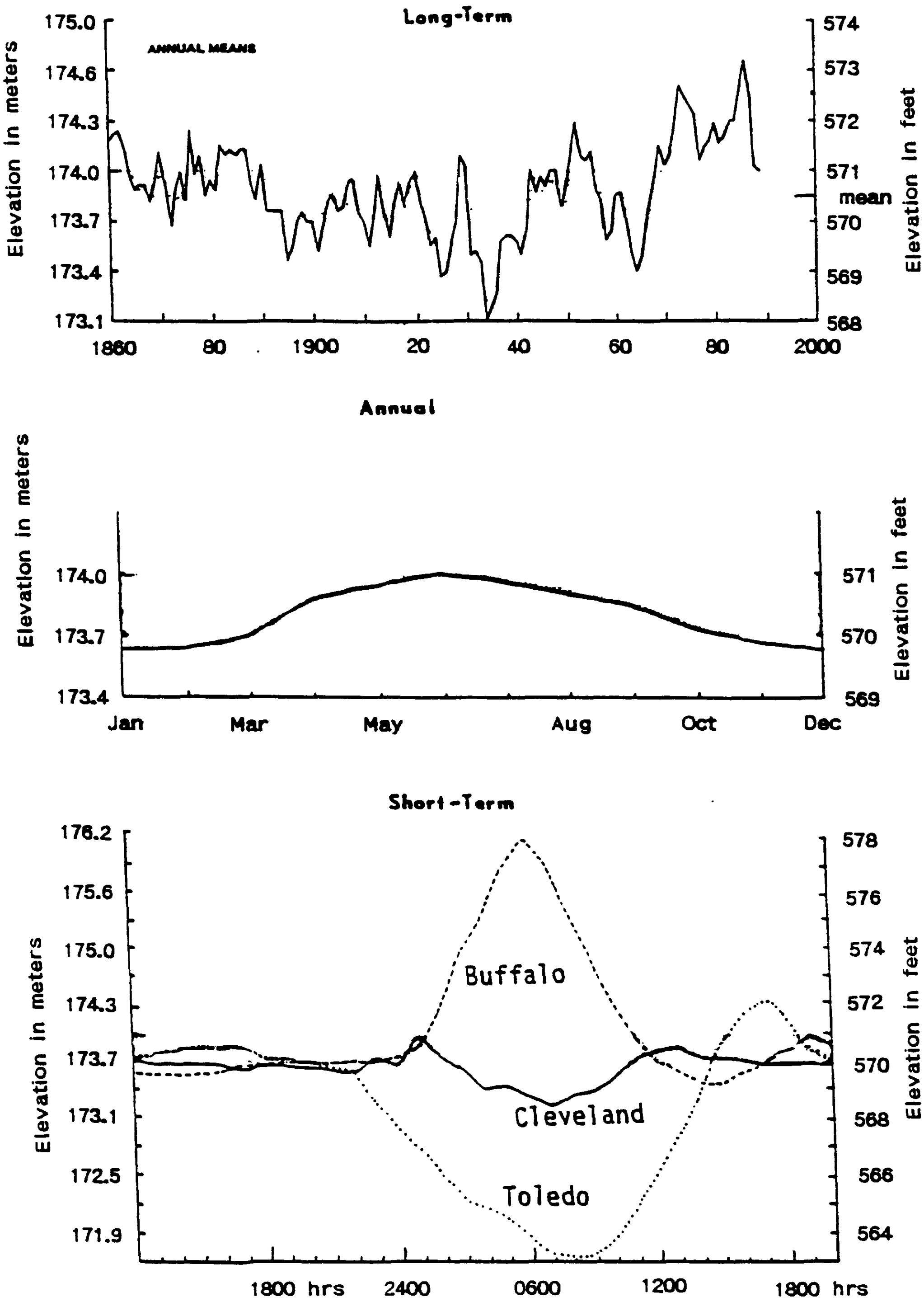


FIG. 3. Idealized cross-section of Maumee Bay study area showing sand washover fan perched on glaciolacustrine sediments and sand-starved bar troughs. Vertical scale greatly exaggerated.



Datum = IGLD(1955)

FIG. 4. Water level variations on Lake Erie.

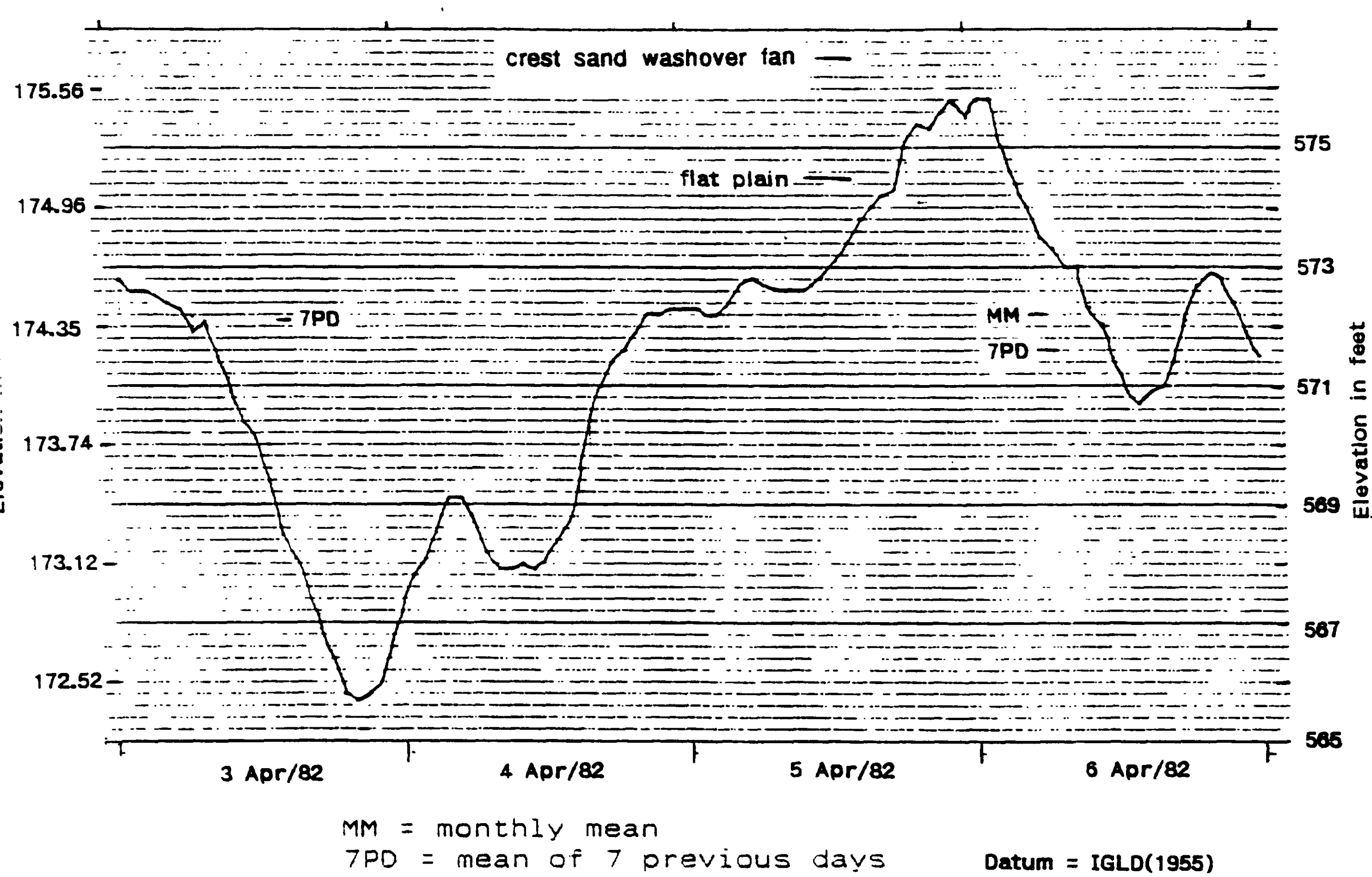


FIG. 5. Hourly water levels at NOAA's Toledo gauge for 5-6 April 1982 storm.

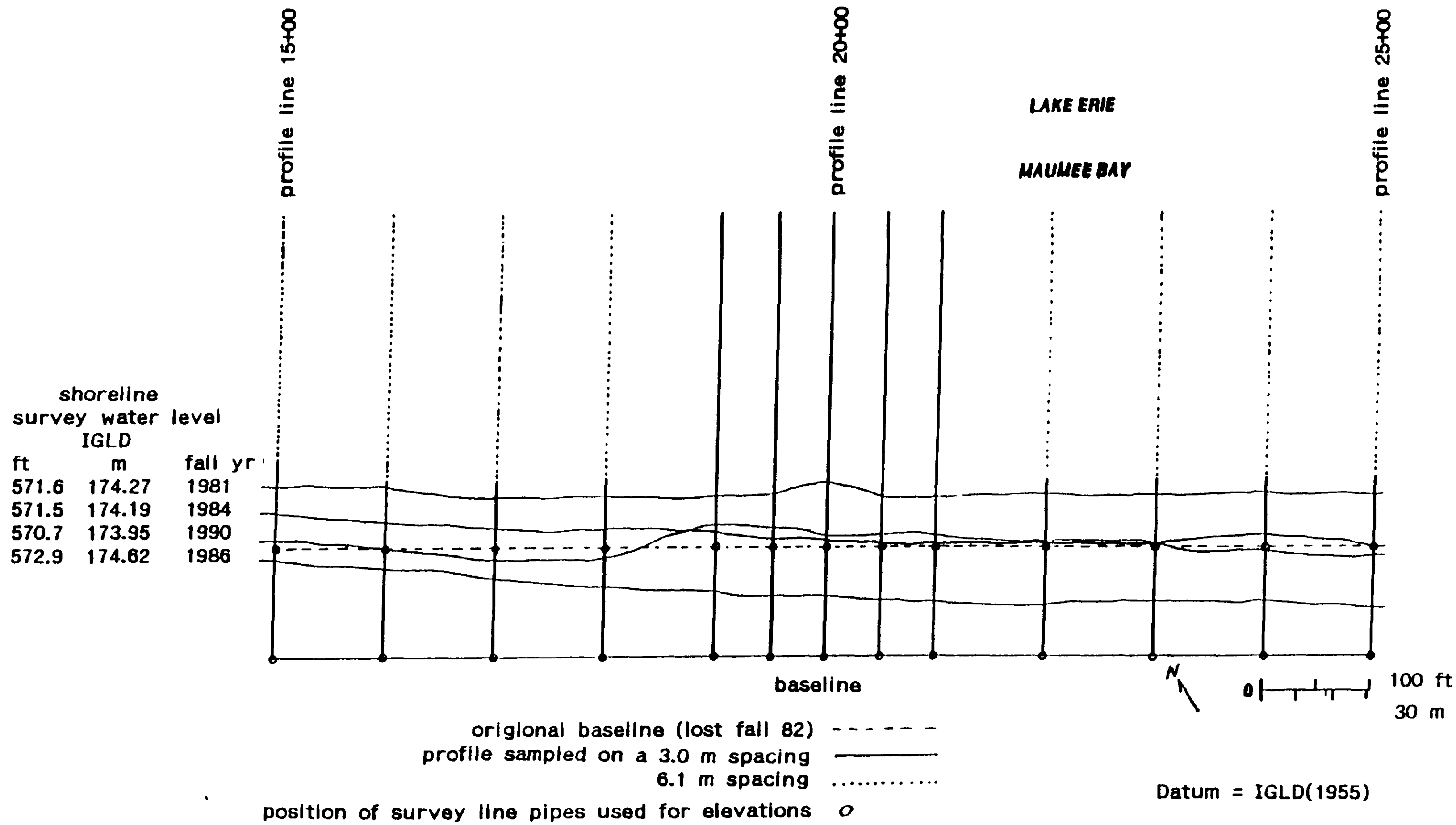
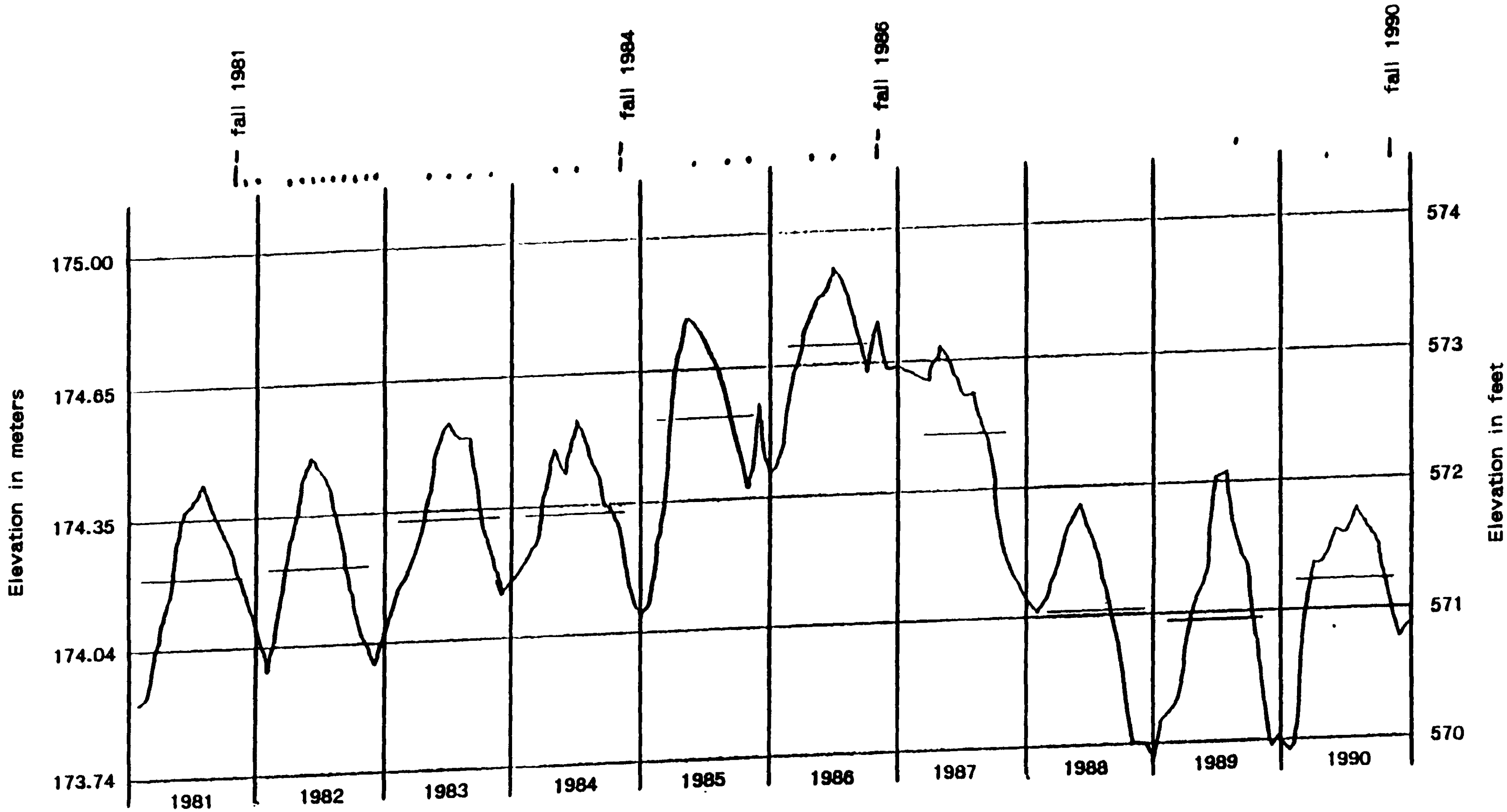


FIG. 6. Survey grid for study area with baselines, profile lines, and survey shorelines.



notation of site visits across top . = site visit
| = site visit used

mean annual water level shown as bar across year

Datum = IGLD(1955)

FIG. 7. Monthly and annual water levels at NOAA's Toledo water level gauge during study.

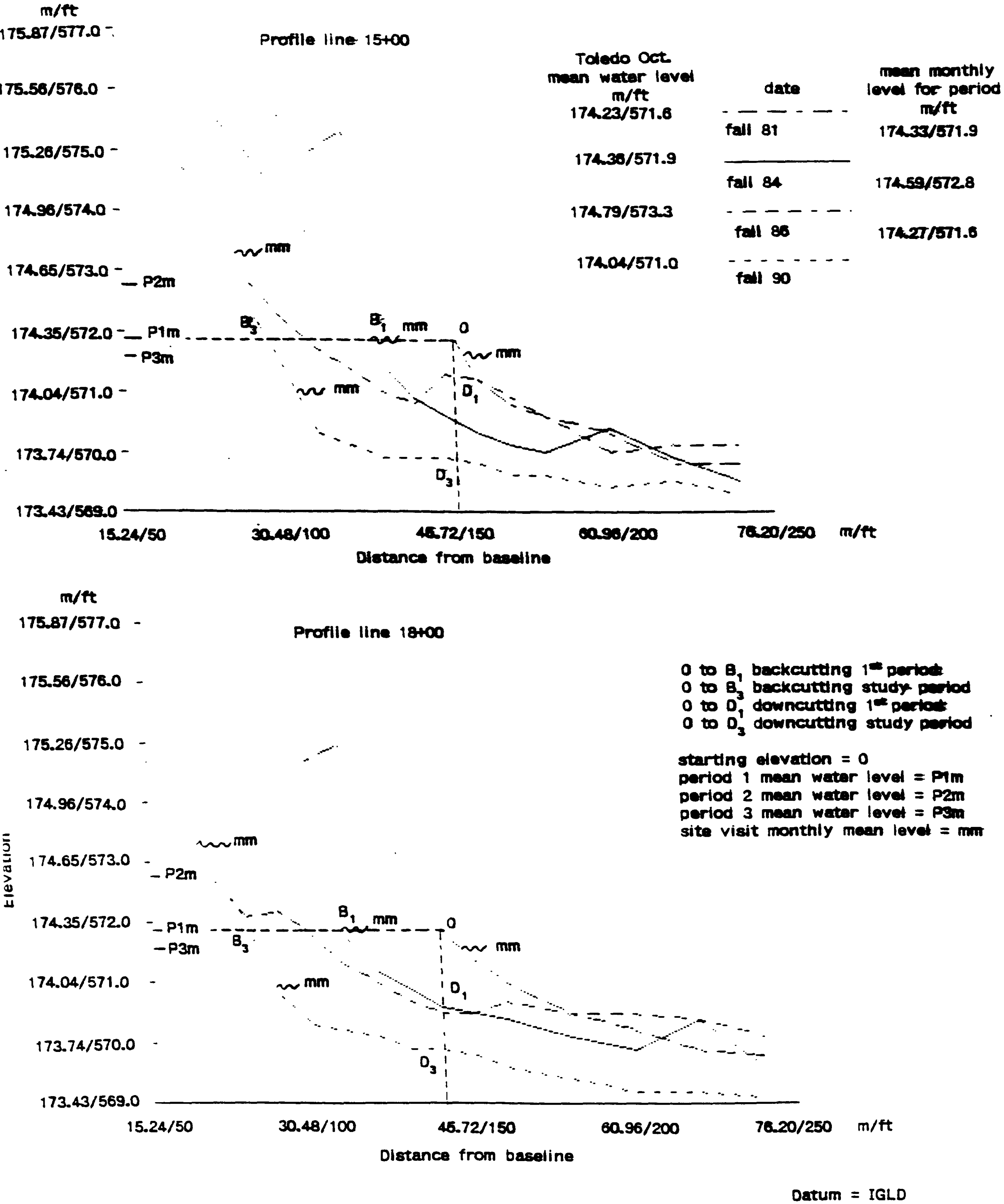


FIG. 8. Comparative nearshore profiles from study area showing bluff retreat and nearshore downcutting (see Fig. 6 for profile location).

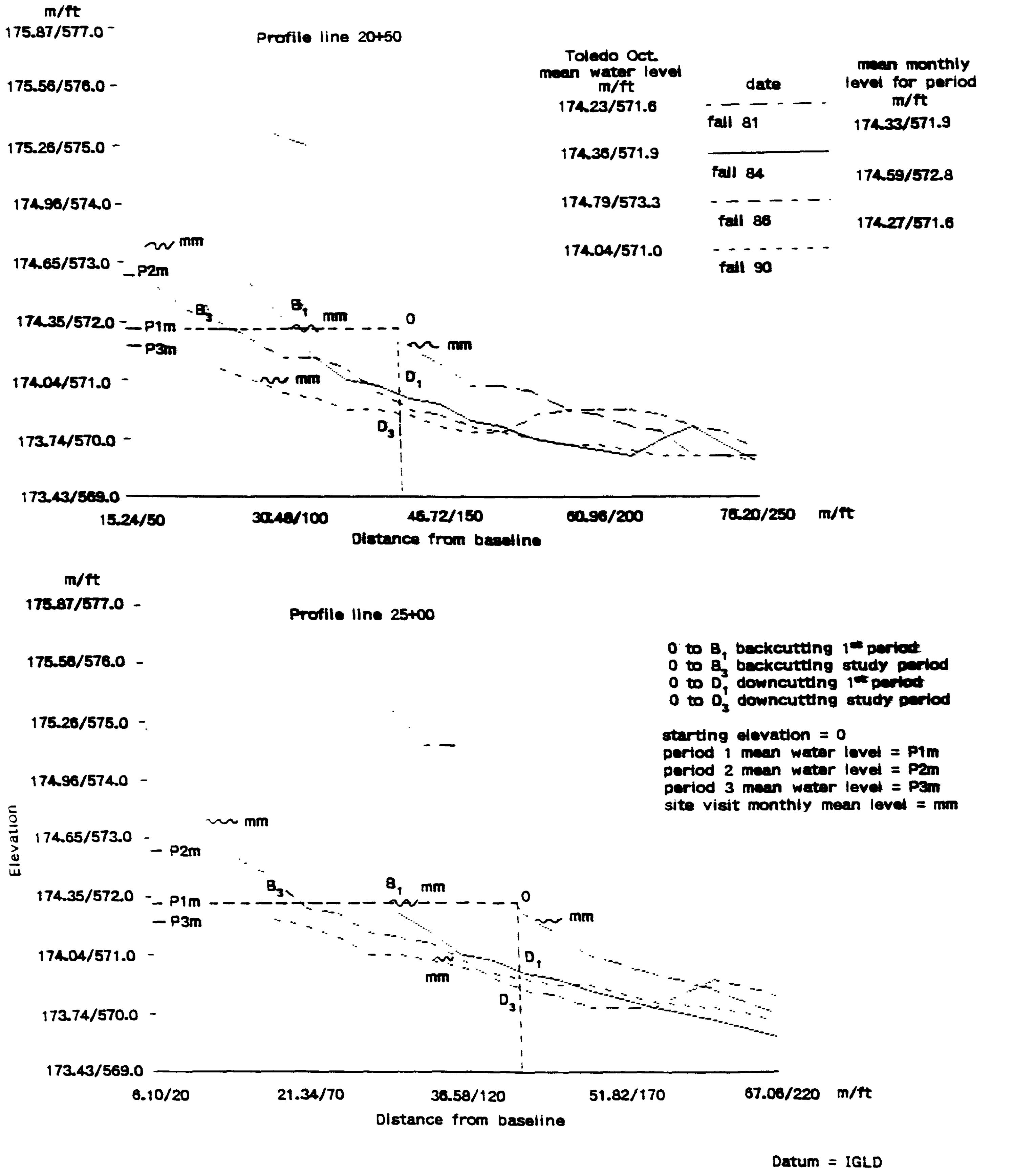


FIG. 8. Comparative nearshore profiles from study area showing bluff retreat (cont.) and nearshore downcutting (see Fig. 6 for profile location).

Table 1. Erosion and downcutting values for Maumee Bay study area
All measurments from "0" at land and average water level of period 1 (174.36 m). See Fig. 8.

Profile line	STUDY erosion meters O-B3 1981-90	TIME PERIODS erosion meters O-B1 1981-84	erosion meters B1-B2 1984-86	erosion meters B2-B3 1986-90	STUDY erosion rate 9y O-B3 1981-90	TIME PERIODS erosion rate 3y O-B1 1981-84	erosion rate 2y B1-B2 1984-86	erosion rate 4y B2-B3 1986-90
west								
15+00	17.68	7.92	6.25	3.51	1.96	2.64	3.12	0.88
16+00	18.59	8.99	5.33	4.27	2.07	3.00	2.67	1.07
17+00	20.12	9.60	5.49	5.03	2.24	3.20	2.74	1.26
18+00	17.98	9.45	3.20	5.33	2.00	3.15	1.60	1.33
19+00	17.68	9.45	4.11	4.11	1.96	3.15	2.06	1.03
19+50	18.14	9.14	5.64	3.35	2.02	3.05	2.82	0.84
20+00	18.90	9.75	7.16	1.98	2.10	3.25	3.58	0.50
20+50	19.81	10.52	5.64	3.66	2.20	3.51	2.82	0.91
21+00	20.27	9.75	6.40	4.11	2.25	3.25	3.20	1.03
22+00	21.34	9.14	7.77	4.42	2.37	3.05	3.89	1.10
23+00	21.95	11.13	6.25	4.57	2.44	3.71	3.12	1.14
24+00	24.38	11.89	6.25	6.25	2.71	3.96	3.12	1.56
25+00	24.69	12.50	8.84	3.35	2.74	4.17	4.42	0.84
east								
average	20.12	9.94	6.03	4.15	2.24	3.31	3.01	1.04
std. dev.	2.29	1.21	1.39	1.02	0.25	0.40	0.70	0.25

Profile line	STUDY downcut cm O-B3 1981-90	TIME PERIODS downcut cm O-B1 1981-84	downcut cm B1-B2 1984-86	downcut cm B2-B3 1986-90	STUDY downcut rate 9y O-B3 1981-90	TIME PERIODS downcut rate 3y O-B1 1981-84	downcut rate 2y B1-B2 1984-86	downcut rate 4y B2-B3 1986-90
west								
15+00	62.18	42.06	-23.77	43.89	6.91	14.02	-11.89	10.97
16+00	60.66	42.98	-24.38	42.06	6.74	14.33	-12.19	10.52
17+00	64.01	40.23	-16.46	40.23	7.11	13.41	-8.23	10.06
18+00	60.96	39.32	3.05	18.59	6.77	13.11	1.52	4.65
19+00	44.50	42.67	2.44	-.61	4.94	14.22	1.22	-0.15
19+50	44.50	39.32	3.35	1.83	4.94	13.11	1.68	0.46
20+00	45.72	33.53	4.57	7.62	5.08	11.18	2.29	1.91
20+50	43.59	33.53	4.57	5.49	4.84	11.18	2.29	1.37
21+00	44.50	33.53	4.57	6.40	4.94	11.18	2.29	1.60
22+00	37.49	29.87	9.45	-1.83	4.17	9.96	4.72	-0.46
23+00	39.32	35.97	3.35	0.00	4.37	11.99	1.68	0.00
24+00	42.67	35.97	0.30	6.40	4.74	11.99	0.15	1.60
25+00	43.89	35.05	4.27	4.57	4.88	11.68	2.13	1.14
east								
average	48.77	37.23	-1.9	13.43	5.42	12.41	-0.95	3.36
std. dev.	9.07	3.99	11.07	16.44	1.01	1.33	5.53	4.11

Negative number is accretion during time period