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COASTAL ENGINEERING AND EROSION PROTECTION

Report for the Year 1976-77

by

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and
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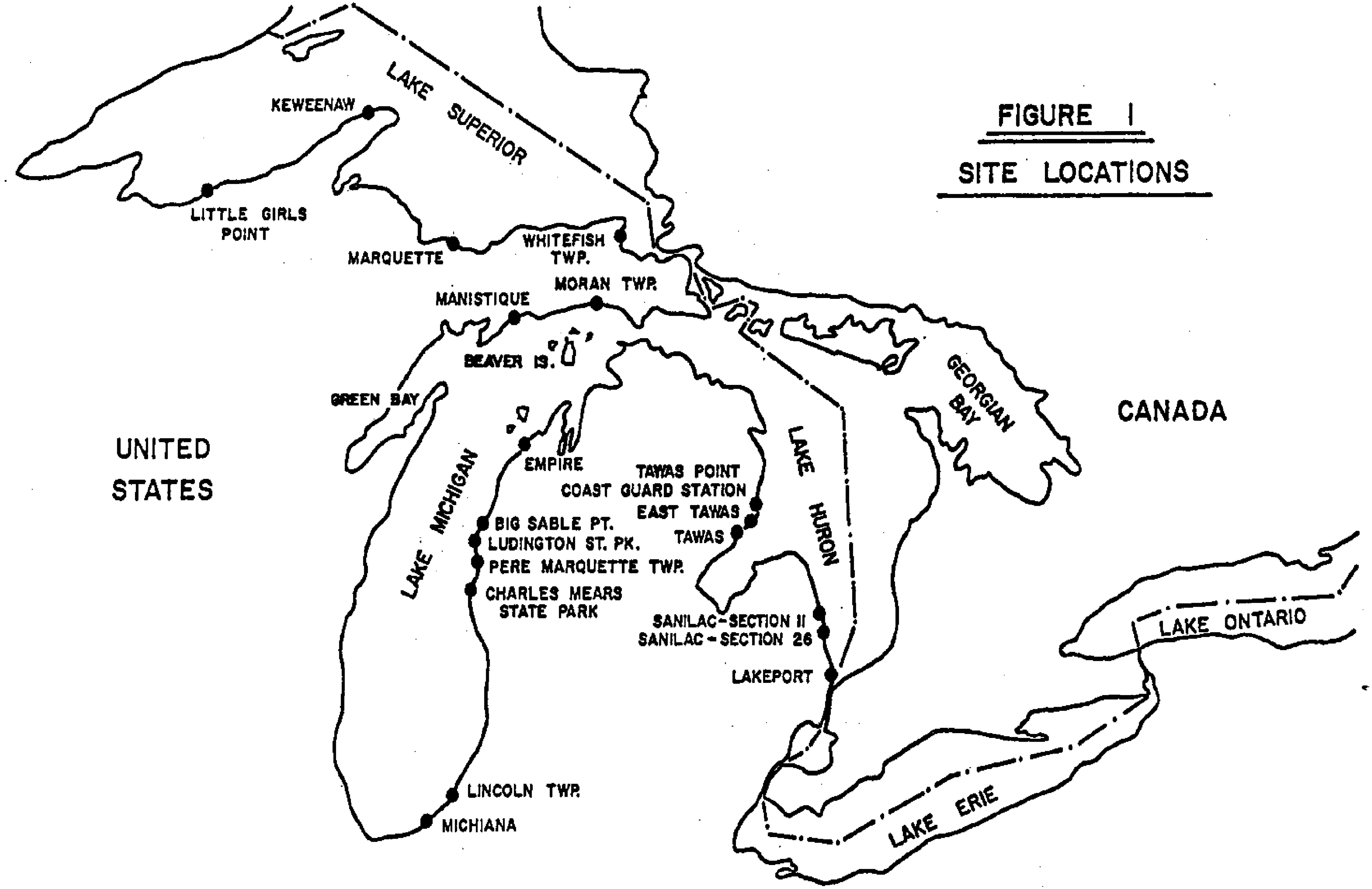
FIGURE 1

SITE LOCATIONS



COASTAL ENGINEERING AND EROSION PROTECTION

Report for the year 1976-77

The feasibility of low cost shore protection for the Great Lakes is being studied by means of observation on 18 demonstration projects located on Lakes Huron, Michigan and Superior. These field installations include a variety of protective procedures and construction materials. This project is a study of the effectiveness and durability of these field installations, along with the study of related laboratory models which supplemented and extended the field observations.

The observation program, which began in 1973, has been financed by the Michigan Sea Grant Program, the Michigan Department of Natural Resources, and the U.S. Army Corps of Engineers. During one year there were some funds made available through a cooperative effort with a project at the University of Wisconsin financed by a grant from the Rockefeller Foundation. The original funding for these projects was a $300,000 grant from the Michigan legislature to the Michigan Department of Natural Resources.

This report extends the observations through three full years for most of the projects. A major effort during 1976-77 was the analysis of wind data to determine a history of the height and duration of waves during major storms at the various demonstartion sites for the three year period 1974-76.

The names and locations of the projects are shown on the map in Fig. 1 and in Table 1 where the projects are grouped according to the lake on which they are located. Table 1 also shows the type of protective procedure used at each location as well as information on the scope of the project, the type of materials used, the cost, the date of installation and a summary of storm wave height data for the three years 1974-76. All but two were completely new installations. The exceptions are Ludington and Big Sable Point. At Ludington steel groins installed by the DNR Parks Division are being monitored, and at Big Sable Point a steel sea wall had been installed by the Coast Guard. In the laboratory investigation some of the procedures included in the field project were modelled to determine the causes of damage at one of the projects and to determine the effects of variations in the groin systems at others. Some devices which were not included in the field program were also investigated by means of models. The model studies also provided information on the effect of various protective measures on the rate of littoral drift. No quantitative values of littoral drift are available from the field projects. During the past year the effort of the laboratory staff was devoted to hindcasting the wave heights during the major storms which have occurred during the three years 1974-76. This information is essential for evaluating the effectiveness and durability of the field demonstration projects.

The cost of materials and installations of these projects varied from 15 to 70 dollars per foot of shoreline. This cost included the preparation of some construction drawings but did not include designing the structures, which would add about 10 per cent. It is quite certain that the present construction costs, after an interval of 3 or 4 years, would be considerably higher. Perhaps some of the more expensive installations will reach $100 per foot in 1978. Such "low cost" procedures can be expected to reduce the rate of bluff recession for moderate storms on exposed shore lines. However, during major storms, those which might be exceeded in intensity only once

TABLE 1

SHORE PROTECTION PROJECTS

Summary of Pertinent Data

Name and Location	Type of Protection	Installation Date	Cost ($/ft)	Number of(1) Storms	Hours(1)
	LAKE MICHIGAN				
MICHIANA	Toe protection	9/73		18	246
Berrien County South of New Buffalo at end of Seminole Street	Asphalt mastic and rock revetment 300 ft. long		70		
LINCOLN TOWNSHIP	Two groins	11/73		22	329
Berrien County One mile north of Stevensville	Wooden groin Longard tube		50 30		
MEARS STATE PARK	Three groins	9/73		24	321
Oceana County at Pentwater	Inner ends are gabions and outer ends are sand filled bags		(2)		
PERE MARQUETTE TOWNSHIP	Off-shore breakwater	11/73	70	24	321
Mason County South of Ludington Buttersville Park	Three segments of zig-zag concrete walls with 50 foot gaps				
LUDINGTON STATE PARK	Two groins	11/73		24	355
Mason County North of Ludington at State Park Building	Steel		(2)		

TABLE 1 Continued

Name and Location	Type of Protection	Installation Date	Cost ($/ft)	Number of Storms[1]	Hours[1]
	LAKE MICHIGAN				
BIG SABLE POINT	Steel Wall	10/74		24	355
Mason County North Ludington State Park	Gabion cutoff groins installed behind existing wall		(2)		
EMPIRE	Toe Protection	9/73		24	355
Leelanaw County Empire Village	40 inch Longard tube, 300 feet long		30		
MORAN TOWNSHIP	Toe Protection				
Mackinac County Two miles east of Brevort	Three 40 inch Longard tubes stacked one on two (300 ft)	10/73	56.50	8	82
	Three layers of sand filled bags (250 ft)	10/73-4/74	60		
MANISTIQUE[3]	Revetment	7/74		(3)	
Schoolcraft County Three miles west of Manistique	Gabion mats		20	(3)	
	LAKE SUPERIOR				
WHITEFISH TOWNSHIP	Revetment and groins	7/74	45	(4)	(4)
Chippewa County Five miles south of Paradise at Roadside Park	Rock revetment with wooden groins extending to low bluff				

TABLE 1 Continued

Name and Location	Type of Protection	Installation Date	Cost ($/ft)	Number of(1) Storms	Hours(1)
	LAKE SUPERIOR				
MARQUETTE	Sand nourishment	9/73		21(5)	77(5)
Marquette County Shiras Park in Marquette	Waste sand from local industry		(2)		
KEWEENAW	Revetment	8/74		2(5)	77(5)
Keweenaw County at Sand Bay N.E. of Eagle Harbor	Waste rock from local mines		20		
LITTLE GIRLS POINT	Revetment	8/74		3(5)	77(5)
Gogebic County North of Ironwood	Concrete rings (Nami Rings) 2.5 feet in diameter and one foot high		63		
	LAKE HURON				
TAWAS POINT COAST GUARD STATION	Revetment	7/74		0	0
Iosco County at Coast Guard Station, north of East Tawas	Part dumped rock and part placed in two layers		50		
EAST TAWAS	Sand nourishment	4/74		0	0
Iosco County at East Tawas City Park	3000 yds^3 placed along 400 ft. of open shoreline		15		

TABLE 1 Continued

Name and Location	Type of Protection	Installation Date	Cost ($/ft)	Number of[(1)] Storms	Hours[(1)]
	LAKE HURON				
TAWAS CITY	Sand nourishment with groin	2/74		0	0
Iosco County Tawas City Park	4350 yds^3 placed between new wooden groing and existing pier along 400 ft. of shore line		26		
SANILAC-SECT. 11	Toe protection	9/74		3	30
Sanilac County Four miles south of Port Sanilac at roadside park	69 inch Longard tube 400 feet long		65		
SANILCA-SECT. 26	Groin system. Six groins			3	30
Sanilac County Five miles south of Port Sanilac at roadside park	Two 40 inch longard tubes	10/73	30		
	One 60 inch longard tube	4/74	25		
	Gabions	9/74	30		
	Sand filled bags	10/73	30		
	Rock and asphalt mastic	10/73	45		
	Timber crib	9/75	30		
LAKEPORT	Off-shore barrier	4/74		3	30
St. Clair County Lakeport State Park North of Port Huron	40 inch Longard tube placed on off-shore bar		25		

in 5 to 15 years, they are likely to be relatively ineffective and might even be destroyed. This is in contrast to the more expensive higher quality procedures which, if properly selected and designed, can be expected to be quite permanent and to provide protection during major storms. Generally such high quality protection can be expected to cost more than $300 per foot. The costs of all types of shore protection vary not only with time but they depend very much on the availability of construction materials and knowledgeable contractors and on the length of shore line which is being protected.

The degree of excellence of shore protection is judged by its effectiveness and durability relative to its cost and its compatibility with shore use. In locations where the shore line is used for recreation, the maintenance of the shore line for bathing and the preservation of scenic values are important characteristics of good protective procedures. In this latter regard, sand nourishment must be considered as the best procedure followed by the combination of sand nourishment with groin systems and then by groin systems which capture and hold some of the natural littoral drift. Revetments, sea walls and offshore breakwaters are usually considered to be less desirable from the recreational and aesthetic points of view.

The effectiveness and durability of protective procedures cannot be fully judged until the structure has survived long enough to justify its construction costs. This would probably never be for a period less than about 10 years. However, time alone cannot be the basis for evaluation of durability because of the irregular occurrence pattern of major storms and the variability of water levels. It is quite possible to have a ten year period without without a real severe storm and at other times several such storms might occur within a year or two. Furthermore, on the Great Lakes the spectrum of storms which are potentially damaging is larger during high lake levels than during lower levels. It is therefore essential to determine the number and severity of storm waves which have attacked each installation to provide a basis for evaluating its effectiveness. For this reason, a major part of the effort of the laboratory group has been used to determine the storm wave history at each demonstration site. The procedure for estimating wave heights will be presented in the next section and the current evaluation of the various protective measures based on performance to this time wil be presented in the following section.

Wave Height Histories

Storms having winds greater than a selected critical intensity were analyzed to estimate average overwater wind direction, velocity and duration. These data were then used along with the corresponding fetches to estimate deep water wave heights and periods. The waves were then projected shoreward to shallow water taking into account refraction and diffraction in order to estimate the magnitude and location of the breaking waves.

The critical storm magnitude was selected on the basis of generalized curves, prepared by the laboratory staff, which showed the wind velocities and durations which might be expected to create six foot breaking waves at each site.[1] The principal purpose of these curves was to quickly alert field personnel when a potentially damaging storm was in progress. These criteria were based on generalized conditions and provided an estimate of the minimum winds needed to produce six foot breakers. The estimation of the actual breaker heights during various portions of the storm requires a much more detailed study of actual wind velocities and directions.

Winter storms were checked for ice cover and only those occurring during open water conditions were included in the study. Data on ice cover were supplied by the Great Lakes Environmental Research Laboratory.[2,3,4]

The wind velocity was determined from wind records near the sites. Two or three land stations were available within fifty miles of the various installations. The wind velocities were modified to represent over-water conditions on the basis of observations made from a research vessel on the Great Lakes.[5] For long storms the wind data were grouped into periods of relatively consistent direction and velocity in such a manner as to produce the maximum wave height. The deep water wave height was then determined from the relations developed by Bretschneider.[6] The breaker height and depth were determined by taking into account the refraction and in some cases the diffraction as the waves approached the breaking zone. The water depths shown on the charts were modified to include the current lake elevation and the wind set-up for each storm. In some locations the bottom topography was sufficiently uniform so that the wave conditions at the breaker zone could be computed by numerical methods using successive approximations. At such sites some storms were checked with refraction diagrams to assure that the simpler method was satisfactory.[7] At some locationns it was necessary to draw complete refraction diagrams for each storm and at two Tawas sites and the Moran Township site the waves were also affected by diffraction.

The most difficult problem was at the Moran Township site where the effect of shoal areas and islands made it difficult to predict the wave height at the site. As shown in Fig. 1 this project is located at the north end of Lake Michigan and therefore southerly or southwesterly storms which cover large areas might generate waves over a fetch nearly 300 miles long. However, such waves would have relatively long wave lengths and the refraction would reduce their size greatly before reaching the site. Therefore the most damaging conditions at the Moran site are caused by waves generated by southerly winds in a fetch from the vicinity of the Grand Traverse Bay area or from a westerly wind in a fetch extending from the vicinity of the Green Bay area (Fig. 1). The waves from the south had to pass through the extensive shoal area between Waugoshance Point and the Beaver Island group. This problem was resolved by first determining the characteristics of the waves generated in the reach south of the shoals. The waves were then carried through the reach of shoal water taking into account the effect of refraction and shoaling.[8,9,10,11] Finally a third fetch is considered which takes the wave to the breaking zone. The wave characteristics of each fetch interval depend on those generated in the previous interval and they are related by equating the energies at the beginning of the last two fetches to those at the ends of the previous reaches. Shoal areas were also crossed by waves generated by westerly winds in the fetch between Sturgeon Bay and the site. When southwesterly waves approach this site the orthogonal lines cross and two wave fronts are formed which follow the directions of the crossed orthogonals.[12] The wave heights beyond the crossed orthogonals must be estimated and their exact values are subject to question. The computations at the other sites are quite straight forward. However, there is some uncertainty due to the fact that wind data are not available exactly on the line of fetch and then only on the land at the downstream end of the fetch. Nevertheless, the computed breaker heights can be considered to have the right order of magnitude and provide a good history of the wave energy exerted on the various projects.

The storms which occurred at each demonstration site are tabulated in Table 2. This table gives the date of each storm, the direction, velocity and duration of the wind, the fetch, the wave period and the significant deep water wave height. The significant wave height is the average of the highest one third of a group of waves. It is the most used wave height parameter during a storm. Under most conditions, this wave height is about 60 per cent larger than the average of the group but about the same amount smaller than the largest waves in the group. The last two columns in Table 2 give the breaker height and depth at the breaking location.

An interesting and important factor in evaluating the projects shown in Table 2 is the large number of storms which produced critical waves which occurred at the sites located on the east side of Lake Michigan compared with the number which occurred at the Lake Huron sites. This is because the prevailing winds in this region are from the west. Summarized in Table 1 are the number of storms and total duration of breaking waves with significant heights equal to or greater than five feet. It will be seen that the number of hours during which such waves occurred during the three years varied from 246 to 355 at the Lake Michigan sites compared with 30 hours at the Sanilac sites on Lake Huron. The conditions at the Tawas sites were even milder than at Sanilac due to the effect of refraction and diffraction.

During the three years 1974-76 for which these records have been taken the levels of the Lakes Michigan-Huron varied from 0.6 feet to 2.3 feet above the long term average. On Lake Superior the lake levels varied from 0.4 feet below average to 0.9 feet above average.

TABLE 2

WAVE DATA AT FIELD PROJECTS

1 Date	2 Wind Direction Degrees	3 Av. Wind Velocity Knots	4 Wind Duration Hours	5 Fetch Miles	6 Wave Period Seconds	7 Deep Water Wave Height Feet	8 Breaker Height Feet	9 Breaker Depth Feet
				LAKE MICHIGAN **Michiana**				
Nov. 20-21, 74	306	22	31	81	5.5	6.5	6.5	8.5
Jan. 10-12, 75	248	24	24	24	5.0	4.5	2.5	3.5
Jan. 18-19, 75	315	23	12	72	5.5	6.5	6.5	8.5
Jan. 29, 75	260	23	6	28	5.0	5.0	3.5	4.5
Feb. 25, 75	243	18	7	12	3.5	2.5	1.0	1.5
Mar. 22, 75	320	20	10	102	5.0	5.5	5.5	7.0
Mar. 24-25, 75	235	15	27	24	3.5	2.5	.5	.5
	320	20	5	102	5.0	5.5	5.5	7.0
Mar. 30, 75	280	23	8	45	5.5	5.5	5.0	6.5
Apr. 3-4, 75	350	23	8	120	5.5	6.0	6.0	8.0
	310	21	36	81	5.5	6.5	6.5	8.5
Sep. 12-13, 75	320	20	32	102	5.5	6.0	6.5	8.0
Nov. 10, 75	269	25	14	45	5.5	6.5	5.0	6.5
Nov. 13, 75	348	25	15	119	6.5	8.5	8.5	11.0
Jan. 2-4, 76	266	21	7	36	4.5	4.5	3.5	4.5
	280	20	39	38	4.5	4.5	4.0	5.0
Jan. 20-21, 76	334	23	11	110	6.0	7.0	7.0	9.0
Jan. 28-29, 76	336	21	10	112	5.5	6.0	6.0	7.5
Mar. 5, 76	264	33	7	45	6.5	9.0	7.0	9.0
May 4-5, 76	233	21	14	24	4.5	4.0	Land Wind	
Sep. 21, 76	317	26	10	102	6.5	8.5	8.5	11.0
Sep. 23, 76	330	25	10	102	6.0	8.0	8.0	10.0
Oct. 13-15, 76	310	22	12	81	5.5	6.5	6.5	8.5
Oct. 15, 76	290	27	13	45	6.0	7.0	6.5	8.5
Nov. 3, 76	282	28	9	45	6.0	7.5	6.5	8.5

TABLE 2 Continued

WAVE DATA AT FIELD PROJECTS

1 Date	2 Wind Direction Degrees	3 Av. Wind Velocity Knots	4 Wind Duration Hours	5 Fetch Miles	6 Wave Period Seconds	7 Deep Water Wave Height Feet	8 Breaker Height Feet	9 Breaker Depth Feet
				<u>Lincoln Township</u>				
Nov. 13, 75	348	25	15	142	6.5	9.0	7.5	10.0
Jan. 2-4, 76	266	21	7	64	5.0	5.0	5.0	6.5
	280	20	39	64	5.0	5.5	5.5	7.0
Jan. 20-21, 76	334	23	11	120	6.0	7.0	6.5	8.5
Jan. 28-29, 76	336	21	10	120	5.5	6.0	5.5	7.0
Mar. 5, 76	264	33	7	64	7.0	10.0	10.0	12.5
May 4-5, 76	233	21	14	46	5.0	5.0	4.0	5.0
Sep. 21, 76	317	26	10	119	6.5	8.5	8.5	10.5
Sep. 23, 76	330	25	10	119	6.0	7.5	7.5	9.5
Oct. 13-15, 76	310	22	12	98	6.0	7.0	7.0	9.0
Oct. 15, 76	290	27	13	64	6.0	8.0	8.0	10.5
Nov. 3, 76	282	28	9	64	6.5	8.5	8.5	10.5
Nov. 20-21, 74	306	22	31	98	6.0	7.0	7.0	9.0
Jan. 10-12, 75	248	24	24	49	5.5	6.0	5.5	7.0
Jan. 18-19, 75	225	18	18	20	4.0	3.0	2.0	2.5
	315	23	12	88	6.0	7.0	7.0	9.0
Jan. 29, 75	260	23	6	52	5.0	5.5	5.0	6.5
Feb. 25, 75	243	18	7	37	4.5	4.0	3.5	4.5
Mar. 22, 75	320	20	10	210	5.0	5.5	5.5	7.0
Mar. 24-25, 75	235	15	27	46	4.0	3.5	2.5	3.5
	320	20	5	119	5.5	6.0	6.0	7.5
Mar. 30, 75	280	23	8	142	5.5	6.0	6.0	8.0
Apr. 3-4, 75	350	23	8	142	5.5	6.0	5.0	6.5
	310	21	36	98	5.5	6.5	6.5	8.5
Sep. 12-13, 75	320	20	32	119	5.5	6.5	6.5	8.5
Nov. 10, 75	269	25	14	64	6.0	7.0	7.0	9.0

TABLE 2 Continued

WAVE DATA AT FIELD PROJECTS

1 Date	2 Wind Direction Degrees	3 Av. Wind Velocity Knots	4 Wind Duration Hours	5 Fetch Miles	6 Wave Period	7 Deep Water Wave Height Feet	8 Breaker Height Feet	9 Breaker Depth Feet
				Mears State Park				
Oct. 21-22, 74	207	22	30	Land Wind				
Jan. 10-12, 75	248	27	18	78	6.0	8.0	7.5	10.0
Jan. 18-19, 75	225	18	24	94	5.0	5.5	4.5	5.5
	293	18	10	62	5.0	5.5	5.5	7.0
Jan. 29, 75	260	23	7	64	5.5	6.0	6.0	7.5
Feb. 25, 75	243	18	7	82	4.5	4.0	4.0	5.0
Mar. 24-25, 75	220	15	22	108	4.5	4.0	3.0	3.5
	310	15	12	67	4.0	3.5	3.5	4.5
Apr. 19, 75	190	20	7	Land Wind				
	240	20	23	84	5.5	6.0	5.0	6.5
Sep. 12-13, 75	300	20	30	60	5.0	5.5	5.5	7.0
Nov. 10, 75	256	23	14	69	5.5	6.5	6.5	8.0
Jan. 2-4, 76	214	25	7	8	4.0	3.0	2.5	3.0
76	236	19	19	88	5.0	5.5	5.0	6.5
Jan. 16, 76	332	21	13	76	5.5	6.0	5.5	7.0
Jan. 20-21, 76	224	22	7	12	4.0	3.0	2.5	3.5
	340	26	7	80	6.0	8.0	7.0	9.0
Jan. 28-29, 76	236	22	10	88	5.5	6.5	6.0	7.5
	333	21	9	76	5.5	6.0	5.5	7.0
Jan. 31-Feb. 1, 76	217	25	9	8	4.0	3.0	2.5	3.0
	343	29	12	80	7.0	9.5	8.0	10.5
Mar. 5, 76	235	28	7	88	6.0	8.0	7.0	8.0
Mar. 23-24, 76	197	26	26	Land Wind				
May 4-5, 76	203	23	12					
Sep. 21, 76	319	25	10	74	6.0	7.5	7.5	9.5
Sep. 23, 76	323	24	10	76	6.0	7.0	7.0	9.0
Oct. 13-15, 76	305	25	13	63	6.0	7.0	7.0	9.0
	290	26	16	62	6.0	7.5	7.5	9.5
Oct. 28-30, 76	250	24	12	74	6.0	7.0	6.5	8.5
	230	30	12	90	7.0	10.0	8.0	10.5
	235	24	20	88	6.0	7.5	6.5	8.5
	235	17	8	88	5.0	4.5	4.0	5.0

TABLE 2 Continued

WAVE DATA AT FIELD PROJECTS

1 Date	2 Wind Direction Degrees	3 Av. Wind Velocity Knots	4 Wind Duration Hours	5 Fetch Miles	6 Wave Period Seconds	7 Deep Water Wave Height Feet	8 Breaker Height Feet	9 Breaker Depth Feet
Pere Marquette Township								
Oct. 21-22, 74	207	20	30	130	6.0	6.5	6.0	7.5
Jan. 10-12, 75	248	27	18	72	6.5	8.0	8.0	10.5
Jan. 18-19, 75	225	18	24	96	5.0	5.5	5.0	6.5
	293	18	10	56	5.0	5.5	5.0	6.5
Jan. 29, 75	260	23	7	62	5.5	6.0	6.0	7.5
Feb. 25, 75	243	18	7	76	4.5	4.0	4.0	5.0
Mar. 24-25, 75	220	15	22	80	4.5	4.0	3.5	4.5
	310	15	12	50	4.0	3.5	3.0	4.0
Apr. 19, 75	190	20	7	110	5.0	4.5	3.5	4.5
	240	20	23	60	5.0	5.0	5.0	6.5
Sep. 12-13, 75	300	20	30	45	4.5	4.5	4.5	6.0
Nov. 10, 75	256	23	14	50	5.5	6.0	6.0	7.5
Jan. 2-4, 76	214	25	7	120	5.5	6.5	6.0	8.0
	236	19	19	80	5.0	5.5	5.5	7.0
Jan. 16, 76	332	21	13	50	5.0	5.5	4.0	5.0
Jan. 20-21, 76	224	22	7	80	5.0	5.5	5.5	6.5
	340	26	7	60	6.0	7.5	4.5	6.0
Jan. 28-29, 76	236	20	10	80	5.5	6.5	6.5	8.0
	333	21	9	55	5.0	5.5	4.0	5.5
Jan. 31-Feb. 1, 76	217	25	9	80	6.0	7.5	7.0	9.0
	343	29	12	55	6.0	8.0	4.5	6.0
Mar. 5, 76	235	28	7	65	6.0	8.0	8.0	10.0
Mar. 23-24, 76	197	26	26	100	6.5	9.0	7.0	9.0
May 4-5, 76	203	23	12	100	6.0	7.5	6.5	8.0
Sep. 21, 76	319	25	10	50	5.5	6.5	5.5	7.0
Sep. 23, 76	323	24	10	50	5.5	6.0	5.0	6.5
Oct. 13-15, 76	305	25	13	45	5.5	6.5	6.0	7.5
	290	26	16	40	5.5	6.5	6.0	8.0
Oct. 28-30, 76	250	24	12	60	6.0	6.5	7.2	6.5
	230	30	12	84	7.0	10.0	6.2	10.0
	235	24	20	80	6.0	7.5	12.0	7.5
	235	17	8	80	4.5	4.5	6.4	4.5

TABLE 2 Continued

WAVE DATA AT FIELD PROJECTS

1 Date	2 Wind Direction Degrees	3 Av. Wind Velocity Knots	4 Wind Duration Hours	5 Fetch Miles	6 Wave Period Seconds	7 Deep Water Wave Height Feet	8 Breaker Height Feet	9 Breaker Depth Feet
				Ludington State Park - Big Sable Point - Empire				
Oct. 21-22, 74	207	22	30	140	6.0	8.0	6.0	7.5
Jan. 10-12, 75	248	27	18	71	6.5	8.0	8.0	10.5
Jan. 18-19, 75	225	18	24	96	5.0	5.5	5.0	6.0
	293	18	10	52	5.0	5.5	5.0	6.5
Jan. 29, 75	260	23	7	60	5.5	6.0	6.0	7.5
Feb. 25, 75	243	18	7	70	4.5	4.0	4.0	5.0
Mar. 24-25, 75	220	15	22	102	4.5	4.0	3.5	4.5
	310	15	12	57	4.0	3.5	3.5	4.0
Apr. 19, 75	190	20	7	166	5.0	4.5	2.5	3.0
	240	20	23	72	5.0	5.5	5.5	7.0
Sep. 12-13, 75	300	20	30	54	5.0	5.0	5.0	6.5
Nov. 10, 75	256	23	14	60	5.5	6.0	6.0	8.0
Jan. 2-4, 76	214	25	7	130	5.5	6.5	5.5	7.0
	236	19	19	82	5.0	5.5	5.5	7.0
Jan. 16, 76	332	21	13	61	5.0	5.5	4.0	5.5
Jan. 20-21, 76	224	22	7	95	5.0	5.5	5.0	6.5
	340	26	7	65	6.0	7.5	5.0	6.5
Jan. 28-29, 76	236	22	10	82	5.5	6.5	6.0	8.0
	333	21	9	61	5.0	5.5	4.0	5.5
Jan. 31-Feb. 1, 76	217	25	9	95	6.0	7.5	6.5	8.0
	343	29	12	61	6.5	8.5	5.5	7.0
Mar. 5, 76	235	28	7	82	6.0	8.0	7.5	9.5
Mar. 23-24, 76	197	26	26	162	7.0	10.5	6.5	8.5
May 4-5, 76	203	23	12	148	6.0	7.5	5.5	7.0
Sep. 21, 76	319	25	10	59	6.0	7.0	6.0	7.5
Sep. 23, 76	323	24	10	61	6.0	7.0	5.5	7.5
Oct. 13-15, 76	305	25	13	56	6.0	7.0	6.5	8.5
	290	26	16	51	6.0	7.0	7.0	8.5
Oct. 28-30, 76	250	24	12	62	5.5	6.5	6.5	8.5
	230	30	12	90	7.0	10.0	9.5	12.0
	235	24	20	82	6.0	7.5	7.0	9.0
	235	17	8	82	5.0	5.0	4.5	6.0

TABLE 2 Continued

WAVE DATA AT FIELD PROJECTS

1 Date	2 Wind Direction Degrees	3 Av. Wind Velocity Knots	4 Wind Duration Hours	5 Fetch Miles	6 Wave Period Seconds	7 Deep Water Wave Height Feet	8 Breaker Height Feet	9 Breaker Depth Feet
Moran Township								
Jan. 10-12, 75	202	28	4		5.0	6.0	5.0	6.0
	248	28	14		5.0	5.5	4.0	5.0
Jan. 18-19, 75	135	15	24		Ice Cover			
	315	15	18		Ice Cover			
Jan. 29, 75	40	10	7		Ice Cover			
	360	15	6		Ice Cover			
Mar. 29, 75	260	20	10		Ice Cover			
Apr. 19, 75	260	21	14		5.5	6.0	6.0	7.0
Nov. 10, 75	215	21	5		4.5	14.5	5.0	6.0
	275	32	10		7.5	12.0	11.0	14.0
	275	20	4		5.5	6.0	5.5	7.0
Jan. 2-4, 76	240	22	9		4.5	4.0	3.0	4.0
	290	19	3		3.5	3.0	2.0	2.5
May 4-5, 76	190	24	16		4.5	4.5	4.0	5.0
Oct. 11-12, 76	190	23	9		4.5	4.0	4.5	3.5
	190	27	9		5.0	5.0	4.5	5.5
	205	16	7		4.0	3.0	3.0	3.5
Oct. 28-29, 76	240	25	15		5.0	5.0	4.0	5.0
	215	33	7		7.0	10.0	10.5	13.5
	225	23	25		5.0	5.5	5.0	5.0
	240	13	5		3.0	2.0	1.5	2.0
Nov. 1-2, 76	200	26	13		5.0	6.0	5.0	6.0
	265	16	5		4.5	5.0	4.5	5.5
Nov. 5-6, 76	230	25	10		5.0	5.0	3.5	4.5
	275	14	6		4.5	4.0	3.5	4.4

TABLE 2 Continued

WAVE DATA AT FIELD PROJECTS

1 Date	2 Wind Direction Degrees	3 Av. Wind Velocity Knots	4 Wind Duration Hours	5 Fetch Miles	6 Wave Period Seconds	7 Deep Water Wave Height Feet	8 Breaker Height Feet	9 Breaker Depth Feet
LAKE HURON								
Tawas Point Coast Guard Station								
Jan. 10-11, 75	135	20	3	24	4.0	3.5	3.5	4.5
	202	25	9	16	4.0	4.0	3.0	3.5
Tawas City								
Jan.10-11, 75	135	20	3	26	4.0	3.5	3.0	4.0
	202	25	9	3	2.5	1.5	1.5	1.5
East Tawas								
Jan. 10-11, 75	135	20	3	1	2.0	1.0	<.5	<.5
	202	25	9	15	3.5	2.5	2.5	3.0
Sanilac - Section 11 and Section 26								
Jan. 10-12, 75	156	22	7	26	4.5	4.5	3.0	4.0
	203							
Jan. 18-19, 75	225							
	293							
Jan. 29, 75	130	10	5	28	2.5	1.5	1.5	1.5
	270							
Oct. 17-18, 75	45	23	9	53	5.5	6.0	5.5	7.0
Apr. 24-25, 75	63	23	7	42	5.0	5.5	5.5	7.0
	47	23	14	53	5.5	6.0	5.5	7.0

TABLE 2 Continued

WIND DATA AT FIELD PROJECTS

1 Date	2 Wind Direction Degrees	3 Av. Wind Velocity Knots	4 Wind Duration Hours	5 Fetch Miles	6 Wave Period Seconds	7 Deep Water Wave Height Feet	8 Breaker Height Feet	9 Breaker Depth Feet
				LAKE SUPERIOR				
				Keweenaw				
Oct. 13-14, 76	295	25	6		5.5	6.0	5.5	7.0
	295	20	8		5.5	5.5	5.0	6.5
Nov. 2-3, 76	255	27	9		6.5	8.5	1.5	2.0
	255	40	3		8.0	12.5	2.5	3.0
	270	27	8		7.0	10.0	6.0	8.0
	285	25	16		6.5	9.0	7.0	9.0
	315	20	4		5.0	4.5	4.5	6.0
				Little Girls Point				
Oct. 13-14, 76	295	25	6		5.0	5.0	5.0	6.5
	295	20	8		4.5	4.0	4.0	5.0
Nov. 2-3, 76	255	27	9		4.0	4.0	3.0	4.0
	255	40	3		5.5	5.5	4.5	5.5
	270	27	8		5.5	6.5	6.0	7.5
	285	25	16		5.0	5.5	5.5	7.0
	315	20	4		5.0	4.5	4.5	6.0

Evaluation of the Field Projects

This presentation of discussions of the individual projects has been organized according to the type of protection in the following order; sand nourishment, sand nourishment with groins, groin systems, toe protection, sea walls and off-shore breakwaters. This arrangement is in accordance with the desirability of the various procedures on preserving the recreational use of the shore line. The locations of the projects are shown by the map in Fig. 1 as well as in Table 1.

Sand Nourishment

The creation of an artificial beach protects the bluffs behind the beach by causing the waves to break farther from shore and thus reduces the wave energy which will reach the toe of the bluff. This procedure usually improves the recreational use of the area.

East Tawas. A small sand fill was placed along 400 feet of shore line at East Tawas in Tawas Bay. The area is sheltered to some extent by Tawas Point to the north. No storms during the three years, 1974-76, produced waves larger than three feet at this location. Nevertheless, the small waves and littoral currents began to move the sand soon after it was placed and within a year it was nearly all removed from its original location. A year later there was evidence that some of the sand had shifted back to the original location. It appears that if a much longer reach of beach had been filled, sand nourishment would have been a useful procedure in this relatively sheltered location.

Marquette. A massive sand fill was placed on a point at Shiras Park in Marquette. The sand had a much higher percentage of fine material than the natural beach. Even though it was expected that the finer material would be easily carried away by the littoral currents the nourishment project was undertaken because the sand was clean and it was supplied at no cost by a local industry. This area is exposed to northerly storms but the site has some protection from four small islands located several hundred feet offshore. Quantitative values of the volume placed have not yet been supplied by local agencies who have made some measurements. The University of Michigan program has observed and photographed the area several time each year. It appears that most of the sand, perhaps 80 per cent, has been moved away from its original location but there is still sand beach in front of and covering the broken rock bluff protection which had been placed on the most vulnerable erosion area prior to the placing of the sand. Therefore, the sand nourishment has provided local protection for four years. It is probable that much of the sand has been distributed along the coast and is therefore providing additional benefit. The wind data have not yet been obtained for 1974 and 1975 but there were two large storms in 1976. Although the direction of these storms was more parallel to the shore than on-shore, refraction would have created considerable wave action at the site and the currents would have been very strong.

This project would probably not have been considered to be economically feasible if it had been necessary to purchase the sand. However, judging by the length of time during which the sand provided protection, the use of a groin system would have made this a durable and very effective project.

Sand Nourishment with Groins

When groins are included with a sand fill program the groins tend to protect the sand from removal by wave action and littoral currents. The presence of the groins detracts some from the recreational use of the area. The sand fill causes the waves to break farther from shore and thus prevent or decrease erosion at the toe of the bluffs.

Tawas City. The sand fill project at Tawas City has provided a good recreational beach for 3 1/2 years. Very little sand has been lost. The low cost of $26 per foot includes the cost of a wooden groin at the north end of the 400 foot reach. An old pier was already in existence at the south end. Until this time the easterly storms have been so affected by the protection from Tawas Point to the north that no waves over three feet high have attacked this project. However, even if it is eventually necessary to replace some of the sand, this appears to be an ideal type of protection for this area.

Ludington State Park. Two steel groins at Ludington State Park have helped to slow down the erosion which was threatening the buildings and parking area. The beach is filled each spring with wind blown sand which is removed from the parking area. So far it has not been possible to get estimates of how much sand is added each year. Prior to the installations of the groins the sand fill alone was not preventing the progressive recession of the low bluff. This area has been attacked by 24 storms having significant breaker heights of five feet or more during the three years, 1974-76. Three of these storms produced breaking waves having a significant height in excess of 7.5 feet. During one storm the breaker height was 8 feet for 18 hours. During the first year one of the steel groins was severely damaged and the outer end had to be replaced. The costs are not known because the construction was done by the State Parks Division. However it can be assumed to be near $100 per foot based on a beach length of 250 feet. The annual maintenance adds to this cost.

Mears State Park. A system of three groins at Mears State Park has nearly the same history as was described for Ludington State Park. The inner ends of the groins are Gabions and the outer ends are sand filled bags. Sand fill is placed each spring as the adjacent parking lots are cleared of wind blown sand. The number of storms with significant breaker heights of five feet or more was 20. There were four storms during which the breaker height was equal to or greater than 7.5 feet. The combination of the groins and sand fill has prevented damage to the adjacent buildings and parking area. There has been some settling of the groins at their outer ends, some of the sand filled bags have been destroyed as the result of punctures, and others have been moved from their original location. However, the groins are still functioning. Because of the participation of the State Parks Division in the construction and maintenance, costs cannot be determined. But the original cost based on a 300 foot reach of beach would be within the range of the other projects. The cost of annual filling might well bring the total cost for 4 years up to $100 per foot.

Groin Systems

Groins are frequently used in locations where the littoral drift is sufficient so that some of the natural sand can be expected to be collected between groins and thus create a beach. The presence of the beach material then provides protection as previously described.

Lincoln Township. Two groins were installed at the Lincoln Township site in a reach of about 55 feet. The groins divide the reach into three segments about 185 feet long. Massive steel or concrete walls are installed on the properties to the north and south of the site. One groin is a 40 inch sand filled tube, 125 feet long, and the other is a wooden groin 90 feet long. Assuming that the length of beach being protected is 370 feet, the cost per foot is about $40. These groins have maintained a beach and kept a low rate of bluff recession under very severe conditions. During the three years 1974-76 there have been 22 storms covering a time span of 329 hours during which the significant breaker height has been equal to or greater than five feet. During one storm a breaker height of seven feet continued for 31 hours. The highest breakers were 10 feet with a duration of 7 hours. During the past year most of the large storms have come from a north-westerly direction and have created a beach on the north side of the timber groin which has covered the Longard tube. To the south of the timber groin the beach has receded and there is considerable bluff recession particularly at the steel wall at the south end of the 555 foot beach. This steel wall is being flanked and there is considerable bluff recession at that location. Areas to the north of the site are suffering severe damage. The wooden groin is in its original condition but the sand filled tube has suffered some damage and has settled about three feet. Until being covered it was still holding some sand.

Sanilac - Section 26. A system of six groins of different types of construction were installed at Sanilac - Section 26. The groins vary in length from 50 to 100 feet and are spaced at 200 foot intervals. Because of the clay bottom at this site, pile type construction had to be avoided.

The following types of construction were used:

Two adjacent 40 inch sand filled tubes

One 60 inch sand filled tube

Rock covered with asphalt mastic

Rock filled timber crib

Gabions

Sand filled bags.

During the three years 1974-76 this site had only three storms with a total duration of 30 hours during which the significant breaker height was equal to or greater than five feet. The groins created a beach soon after they were installed and the beach has been maintained until the present time. There has been some slumping of the nearly vertical bluff but the toe of the bluff has receded very little. Except for the sand filled bag groins, the structures have remained in good condition. One of the 40 inch Longard tubes has settled about a foot and some damage has occurred on one side of the rock-mastic groin. The outer end of the Gabion groin has settled a small amount. Some of the sand filled bags were lost or damaged soon after this groin was built. There appears to be no more damage this past year. This groin has lost some of its effectiveness. Because of the small number of easterly storms this groin system has not yet been well tested. The average cost of this groin system was about $32 per foot of beach.

Toe Protection

There are nine projects in this category. The objective of this type of protection is to prevent the waves from removing the bluff material at the toe of the bluff and thus enable the bluff to become stable once it has reached a slope which is flat enough to resist erosion from wind, rain, thawing and freezing and usage by man. The first five to be described are revetments, four are sand filled tubes or bags and one is a Gabion.

Tawas Point Coast Guard Station. The rock revetment at Tawas Point Coast Guard Station is 400 feet long placed on a 10 foot bluff. The cost was $50 per foot. The rock was obtained locally and varies in size from 3 to 10 inches. The north half of the revetment has an additional upper layer of 11 to 16 inch rock. This site is protected from southeasterly storms by the point and no major northeasterly storm has occurred. The two largest storms produced significant breaker heights of 3.0 and 3.5 feet respectively. The moderate waves which have attacked the structure have done no damage but there is considerable evidence of damage at adjacent sea walls.

Whitefish Point. A rock revetment 350 feet long was installed at a roadside park on Whitefish Point on Lake Superior. There are three wooden groins spaced at 150 feet which extend inward to a land fill. The rocks obtained locally varied in size from about 2 inches to 8 inches. The low bluff (3 to 4 feet) had eroded so badly that the Department of Natural Resources roadside park had lost considerable area. This park area was replaced by filling at the time the revetment and groin system were built. The site is exposed to easterly storms but the fetch from this direction is only 20 miles. However, damage has also been caused by long waves which are generated by westerly storms on the main part of Lake Superior and are then diffracted around Whitefish Point. Wind data which apply specifically to this site have not yet been obtained but it is known that several very large westerly storms have occurred. The site is only about 15 miles from where a large ore carrier was sunk during a storm in November, 1975. No damage has occurred to the revetment or to the fill which is being protected. However, erosion is continuing on either side of the installation.

Keweenaw Peninsula. A rock revetment was constructed on the west side of the Keweenaw Peninsula from waste material from local mines. The stones varied in size from 3 inches to 24 inches. The material was not sorted but it was well placed including the excavation and filling of a trench at the toe of the revetment. The cost was $20 per foot. This site was selected because the eroding bluff was threatening the highway and had become a continuous maintenance problem for the county. At this time only the 1976 wind data are available. Two major westerly storms occurred, one of which caused the sinking of the ore carrier Fitzgerald at the east end of Lake Superior. This storm created breaker heights greater than 5 feet contiuously for 52 hours at this site. There was no noticeable damage to the revetment or to the bluff which was being protected. There is a submerged rock ledge about 300 feet off-shore which provides some protection.

Michiana. An innovative rock and asphalt mastic revetment was installed at the toe of a 30 foot bluff located at Michiana at the southern end of Lake Michigan. In the spring of 1975, about 1 1/2 years after installation, a series of large storms attacked this site. The final storm produced significant breaker heights of over 5 feet for 42 hours. These storms undermined this structure and caused it to settle. Its presence still provides some measure of protection but its effectiveness has been greatly reduced. The storms which caused the failure of this revetment destroyed steel and concrete walls and other shore structures in that vicinity.

Little Girls Point. A revetment consisting of Nami rings was placed along 300 feet of shore line at Little Girls Point on Lake Superior. These concrete rings are 2 1/2 feet in diameter, one foot high and weigh 265 pounds. They were placed so that they formed a pattern of contiguous circles. Only the 1976 wind data have been obtained up to this time but it was learned from local observers that at least one severe storm occurred in 1975 which damaged some of the rings and caused some bluff erosion. However, it appears that the bluff erosion is slightly less severe than on either side of the revetment. This project is more of a test of the durability of the rings than of their effectiveness to prevent erosion. This is because the revetment was placed on the upper portion of the beach rather than on the lower portion of the bluff as had been intended.

Moran Township. Toe protection consisting of Longard tubes and sand filled bags was installed at the base of a 30 foot sand bluff in Moran Township on the north shore of Lake Michigan. Three 40 inch Longard tubes were stacked one on two for 300 feet of shoreline. The sand filled bags were stacked in three layers in different arrangements for a length of 280 feet. There have been 8 storms which produced significant breaker heights of 5 feet or more for a total of 82 hours. The Longard tubes are in their original stacking arrangement but have been moved lakeward about 3 feet and have settled about a foot. The contractor who installed these tubes has provided some maintenance. It is possible that the upper tube would have been pushed off of the two lower tubes at some locations without this maintenance. The sand bags have settled considerably, some have been moved from the original stacking arrangement and some have been destroyed. The top of the bluff has continued to recede but now the slope of the bluff is about 1 to 1 and may be reaching a relatively stable condition. These structures have kept the toe of the bluff from receding. However, the number of hours of attack by large waves is only about one third to one fourth as much as for the sites on the western shore of the lower peninsula.

Sanilac - Section 11. Toe protection was supplied by 69 inch Longard tubes placed at the base of a 30-foot clay bluff at a roadside park on Lake Huron at the site designated as Sanilac - Section 11. The total length is 400 feet, installed in two 200 foot sections. Three storms having significant wave heights greater than 5 feet for a total of 30 hours have attacked this site. This is only about one tenth as much wave energy as has been expended on the Lake Michigan sites. During the first year the tubes were undamaged but had been moved lakeward about 5 feet at the north end. Since then the northern 200 feet has been progressively damaged and moved lakeward until now it is nearly completely destroyed. The southern 200 feet is still in good condition. The presence of this toe protection has slowed the bluff recession rate as compared with the bluff to the north and south. However it appears that this type of protection is not economically feasible.

Empire. A 40 inch Longard tube was installed as toe protection for a low bluff at Empire on Lake Michigan. This tube was damaged and caused to settle very soon after installation. It was completely inadequate for the extreme wave conditions at that location which are similar to those shown for Ludington State Park.

Manistique. This project was initiated in cooperation with the Michigan Department of State Highways which wished to test Gabions as bluff protection at a roadside park located at the north end of Lake Michigan. However, the Highway Department changed its plans shortly after the Gabions were installed and expanded the size of the park, completely covering the installation. It is probable that the Gabions will eventually be uncovered at which time it would be of interest to monitor the effectiveness of this installation.

Sea Walls

Several of the projects listed in the previous section as "toe protection" might also be called sea walls. This is particularly true of the single Longard tube at Sanilac - Section 11. However, it was decided that the term sea wall should refer to vertical or near vertical wooden, steel or concrete walls. No such structure was built as a demonstration project. However, one such wall which had been previously built by the U.S. Coast Guard became part of the monitoring program when the Big Sable Point Lighthouse was given to the State of Michigan. The sea wall is 200 feet long and placed so that in plan it is concave toward the shore. The top of the wall was about 4 feet above the still water level during the high level of 1973. This is a very high wave energy location. The waves during the period 1974-76 are as described for Ludington State Park. Foundations of previous heavy wall installations provide ample evidence that erosion has long been a problem at this site. These efforts have created a peninsula at the lighthouse which extends more than 100 feet into Lake Michigan. The wall had been providing some protection for the site. However, the presence of the wall has created deep water at the front of the wall which permits some waves to reach the wall without breaking. These waves over-top the wall and the strong littoral currents carry material from behind the wall. The steel wall had been flanked when it was taken on as an observation project. By this time the original demonstration program funding ws nearly exhausted. However, an effort was made to hold fill behind the wall by constructing

Gabion groins to tie the wall into the bluff using materials left over from another project. Because of the lack of foundation and rather poor construction the Gabions were soon undermined and became quite ineffective. The wall itself is now beginning to lean lakeward at one end.

Off-Shore Breakwaters

This method of erosion control provides some direct protection by shielding portions of the shoreline from wave attack. However, its most important effect is to create a region of quieter water behind the walls so that any littoral drift tends to settle out and create a beach. This action is much the same as that of a groin system.

Pere Marquette Township. A massive zig-zag concrete wall was constructed 50 feet off-shore at Buttersville Park in Pere Marquette Township. The walls were in three sections of which two are 70 feet long and one is 56 feet long with 50 foot gaps between the sections. The walls are of reinforced concrete panels one foot thick bolted to form a series of V's such that the distance from the lakeward end of a V to the shore end is 18 feet. Each V covers a distance of 12 feet parallel to shore. The walls were set on the sand bottom at a water depth of about five feet so that there was one foot of freeboard during high water. Prior to the winter of 1975 the walls provided protection and beach material was accumulated behind the walls, however the walls started to settle at some locations. In the winter of 1975 there were six storms producing breaking waves larger than 5 feet for a total period of 89 hours. These storms caused more settlement, broke three panels, and there was extensive erosion behind the walls. Laboratory tests showed that when the still water level reached the top of the walls their effectiveness was greatly reduced. It is believed that during these storms the wind tide was at least one foot, thus creating the conditions tested in the laboratory. The walls have sustained some additional damage and settlement in the last year. Bluff erosion is still continuing.

Lakeport State Park. A 40 inch Longard tube was placed offshore on a sand bar at Lakeport State Park on Lake Huron in the fall of 1974. The erosion at that location was threatening a building. However, soon after the installation sand accretion occurred on the beach at this location as well as to the north and south for a considerable distance. The tube is now covered with sand and its effectiveness cannot be evaluated until the sand shifts away from the area and exposes the tube to wave action.

Conclusions

In most cases, the three or four years of records now available do not provide sufficient information of the economic effectiveness of the field projects. However, a number of results and trends can be summarized.

Sand nourishment has been very effective at sites that have some protection and especially when combined with a groin system.

One pair of groins in a high energy area has collected beach material and has provided considerable protection under severe conditions. Another system of groins has collected some sand but has not yet been tested with a larger number of storms.

Rubble revetments have provided excellent protection with relatively small and inexpensive stones. However, two of the three installations have not been tested under severe storm conditions.

Those structures which have been constructed without a foundation in order to keep them in the "low cost" category have settled from their original positions. Such structures are sand filled tubes, sand filled bags, Gabions, a concrete wall and an asphalt mastic revetment. In contrast, a wood pile groin, which provides its own foundation, has remained intact so far under very severe conditions.

Sand filled bags have suffered damage at all locations where they have been installed on this project. At several locatons, the sand filled tubes have also suffered damage.

An offshore breakwater with its crest at about the elevation of the water level did not prevent severe erosion of the bluff during a major storm.

The construction of experimental sites on Lake Michigan, where they are subject to attack by the prevailing westerly winds, will provide information on effectiveness and durability many years sooner than those built on Lake Huron where the on-shore direction is from the east.

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