CHAPTER 16

FILLING PATTERN OF THE FORT SHERIDAN GROIN SYSTEM

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ABSTRACT

An analysis of the action of a groin system through the 14 months following construction is reported herein. Six surveys were made during this period which included onshore elevations to the bluff line and offshore soundings to approximately the seven foot depth contour. Wind records during the period of record were studied and hindcasts of wave conditions made. Analysis of the basic data reveals that the cumulative volume of impoundment at the system may be expressed approximately by $K(I \cos B)^{0.97}$.

GENERAL

The groin system under consideration is located on the shoreline of Lake Michigan within the reservation of the Fort Sheridan Army Post. Fort Sheridan is located along the west shore of Lake Michigan between Lake Forest and Highland Park in Lake County, Illinois about 30 miles north of Chicago and 45 miles north of the south end of the Lake. The area is a part of the Highland Park Lake Border Moraine. The bluffs which vary in height from 50 to 70 feet above the beach are composed of glacial till and contain about 10 to 15 percent, by weight, of beach building material. Bluffs of this general composition are typical throughout the general area.

The reservation occupies about 1-3/4 miles of shore with the beach alongshore ranging up to 150 feet wide at low water datum. (Low water datum is a plane of reference 578.5 feet above mean tide at New York and is referred to herein after as LWD.) LWD is about 2 feet below mean lake level. In the area protected by the groin system the present development along the beach includes a water pumping station, an officer's beach, and an enlisted men's beach. The area along the top of the bluff behind the groin system contains family quarters and other post buildings.

Lake Michigan is the third largest of the Great Lakes and has a water area of approximately, 22,400 square miles (see fig. 1). The Lake has a maximum length of 307 miles with the major axis lying in a north-south direction. The maximum width, which lies in an east-west direction, is about 118 miles. Maximum deep-water wave height, as determined by hindcast methods and use of the Bretschneider (1)* curves, is considered to be about 25 feet. Information concerning Lake Michigan and Fort

* Numbers in parenthesis throughout this paper refer to references at end of paper.

Sheridan is given in other chapters of the proceedings of this conference and in references (2, 3, 4, 5). General information in regard to the variations in Lake Michigan levels during the period of record 1860 - 1952 is tabulated below.

TABLE 1

VARIATIONS IN LEVEL OF LAKE MICHIGAN

	DATE	ELEVATION*	FEET
Highest Monthly Mean Stage (1860 - 1953)	June 1886	583.68	
Lowest Monthly Mean Stage (1860 - 1953)	Feb. 1926	577.35	
Mean Stage (1860 - 1953)		580.58	
Maximum Temporary Rise:			
at Milwaukee			2.3
at Calumet Harbor			2.8

* Referred to mean tide at New York.

The general alignment of the shore line at Fort Sheridan is in a north-south direction and permits waves from the north through east to south-southeast to affect the shore. The available fetches in nautical miles are approximately 110, 210, 90, 75, 60, 60, 45 and 40 from North, NNE, NE, ENE, East, ESE, SE and SSE, respectively.

In the fall of 1950 in a report by the District Engineer, Chicago District, Corps of Engineers to the Chief of Engineers, based on information gathered for a Cooperative Beach Erosion Control Study with the State of Illinois of the Illinois Shore of Lake Michigan (4), it was recommended that the shore within the reservation of Fort Sheridan could best be protected by a system of 21 groins. However, it was also pointed out that the rate of erosion and the degree of development of the shore at that time justified only the protection of the central portion by the construction of 10 groins. After consideration of the volume of available drift it was decided that the initial phase of the construction should include not more than five groins. Five groins were constructed and comprise the system discussed herein.

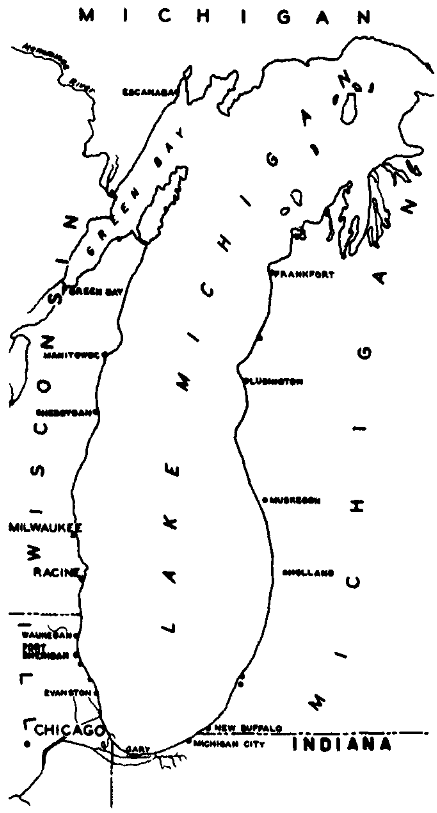

Fig. 1. Lake Michigan

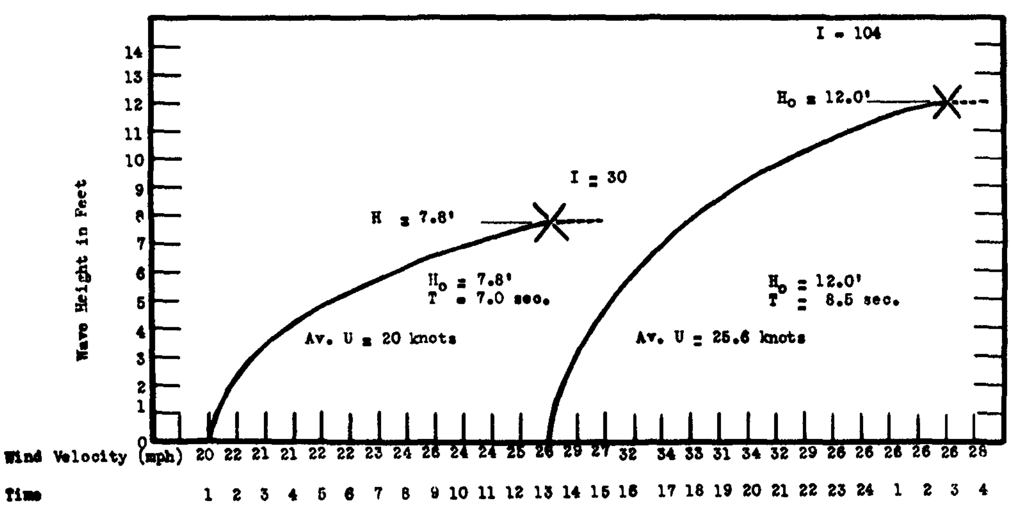

Fig. 2. Computation index for storm on October 23-24, 1951.

The groins of the comprehensive system are identified by consecutive numbers, the most southerly or downdrift numbered 1 and the most northerly or updrift numbered 21. The five groins under consideration in this paper are numbered 9 to 13 and will be referred to by number. Construction of groin 9 was begun on May 26, 1951, construction of groin 13, and therefore this system, was completed on August 8, 1951. The initial plans included the construction of groins 14-18 during the spring of 1952. However, due to the small amount of impoundment at groins 9 and 10 at that time, further construction was posponed until October 1952, following the final survey considered in this paper.

The groins are of cantilever type construction consisting of singlerow, interlocking steel sheet piling. The shoreward ends of the groin extend into the bluff or past the line of considered maximum erosion of the backbeach. The tops of the groins at their shoreward ends are 5.5 feet above LWD and extend horizontally from the bluff to about 100 to 150 feet lakeward thereof, then slope on a 1 on 30 slope to an elevation of 0.5 feet above LWD at their outer ends. The groins are so designed that the breaks in elevation of the top edges form a smooth convex curve and are coincident with the crest of the design forebeach. The groins are 250 to 300 feet in total length and are spaced from 350 to 390 feet apart.

SURVEYS

On August 14, 1951 following the groin construction, a sounding survey was made by Chicago District, Corps of Engineers. However, the observations were taken only from the forebeach to the lakeward end of the groins and the space between observations was too great to furnish sufficient information for true evaluation of the action of the groins. Beginning with the survey of October 12, 1951 the program of observations was extended and remained consistent throughout the remaining surveys.

Observations were taken on lines adjacent to each side of the groins, from the outer ends of the groins lakeward to approximately the 6.5 foot depth contour, and midway between each groin from a point shoreward of the forebeach crest to the 6.5 foot depth contour. Except for those lines adjacent to the groins the observations were taken at 20 foot intervals. The surveys were plotted and submitted in map form. Contour maps prepared from these data are presented herewith as Plates 1, 2, 4, 6, 8 and 10. Maps were also made showing change in bottom elevation between surveys and are presented as Plates 3, 5, 7, 9 and 11. Discussion of the pattern of filling of the groins is presented in a later section of this paper. By use of a planimeter and the Plates showing change in bottom elevation the volume of accretion or scour that occurred between the surveys was obtained. Table No. 2 presents a summary of impoundment to the ends of the groins and to the 6 foot depth contour.

TABLE 2

VOLUME OF IMPOUNDMENT BY GROIN SYSTEM

VOLUME - Bluff to 6-foot depth in Cubic Yards

AREA OF IMPOUNDMENT GROIN NUMBER	10/12/51 to 12/4/51	12/4/51 to 4/18/52	4/18/52 to 5/28/52	5/28/52 to 8/12/52	8/12/52 to 10/8/52	TOTAL Per Area
200 ft. North of 13 to 13	- 400	-1,820	- 970	+1,380	+ 680	-1,130
13 to 12	+6,100	+ 740	- 320	+ 250	+ 790	+7,560
12 to 11	+2,690	+2,140	+4,850	+1,120	- 630	+10,170
11 to 10	- 780	+3,360	+ 380	+ 50	+1,440	+4,450
10 to 9	-1,240	+ 890	+2,030	-1,680(1)	+2,120	+2,120
9 to 200 ft. South of 9	- 440	- 590	- 30	- 600(1)	+ 90	-1,570
TOTAL	+5,930	+4,720	+5,940	+ 520	+4,490	+21,600

VOLUME - Bluff to End of Groins in Cubic Yards

AREA OF IMPOUNDMENT GROIN NUMBER	10/12/51 to 12/4/51	12/4/51 to 4/18/52	4/18/52 to 5/28/52	5/28/52 to 8/12/52	8/12/52 to 10/8/52	TOTAL Per Area
200 ft. North of 13 to 13	+ 400	-2,790	- 640	+ 730	+ 260	-2,040
13 to 12	+6,660	- 870	- 430	+ 240	-2,120	+3,480
12 to 11	+1,030	+3,460	+5,300	+ 420	- 200	+10,010
11 to 10	- 570	+3,460	+ 120	+ 200	+1,180	+4,390
10 to 9	-1,370	+ 140	+ 490	-1,080(1)	+1,200	- 620
200 ft. South of 9 to 9	- 720	- 590	- 60	- 600(1)	+ 60	-1,910
TOTAL	+5,430	+2,810	+4,780	- 90	+ 380	+13,310

(1) Groin 9 Flanked during this period.

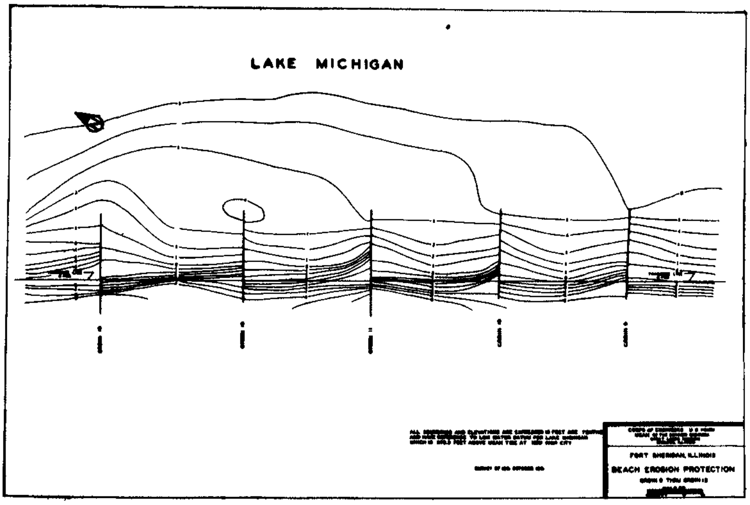

Plate 1

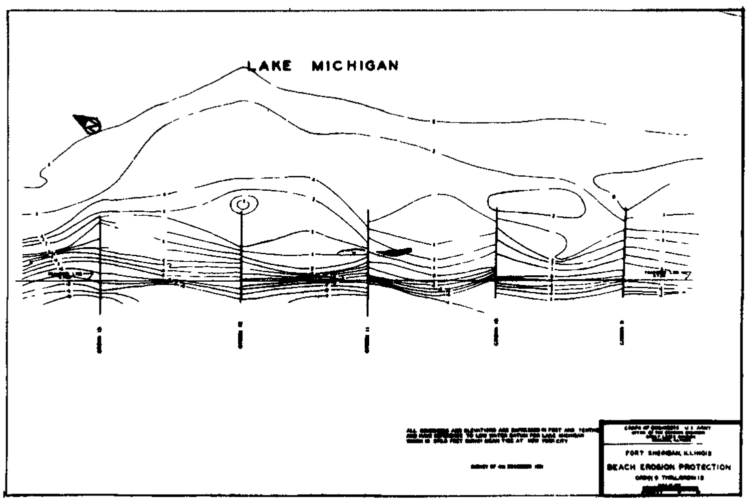

Plate 2

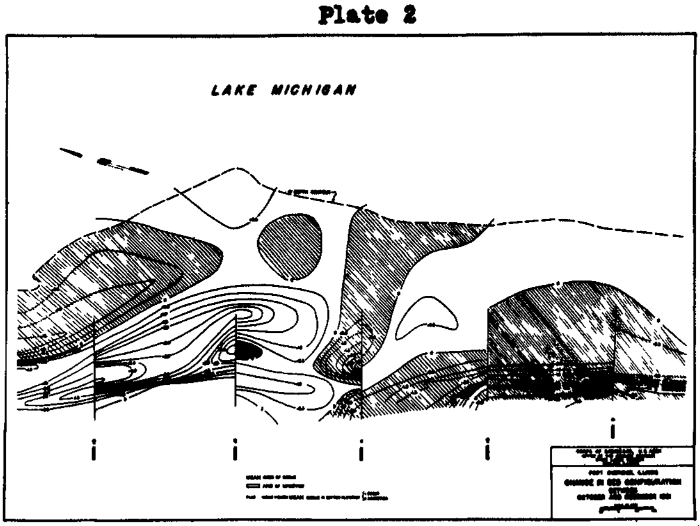

Plate 3

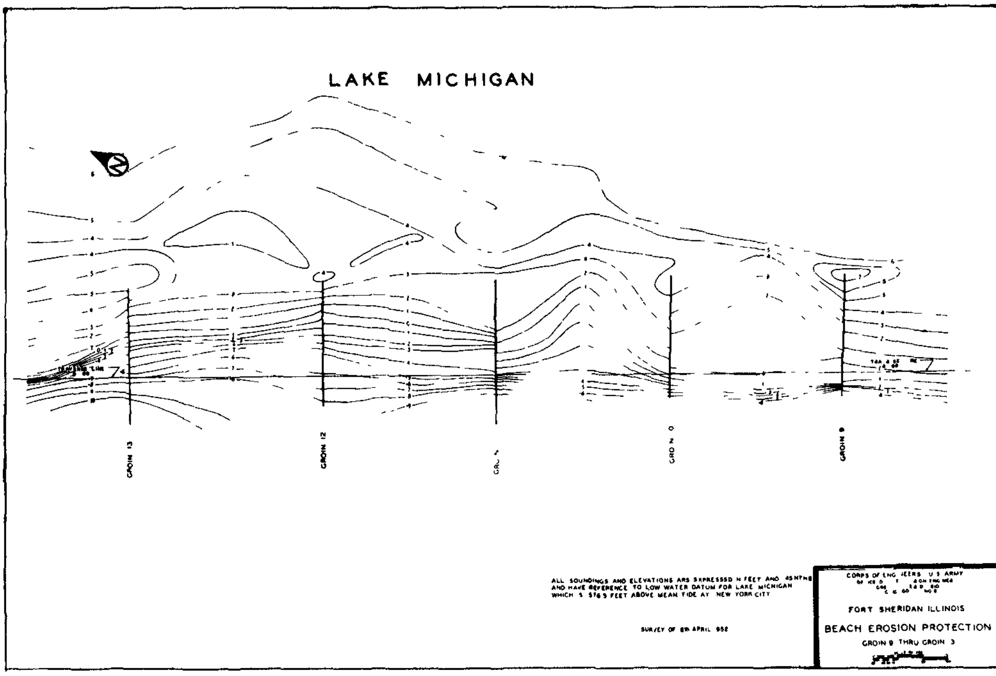

Plate 4

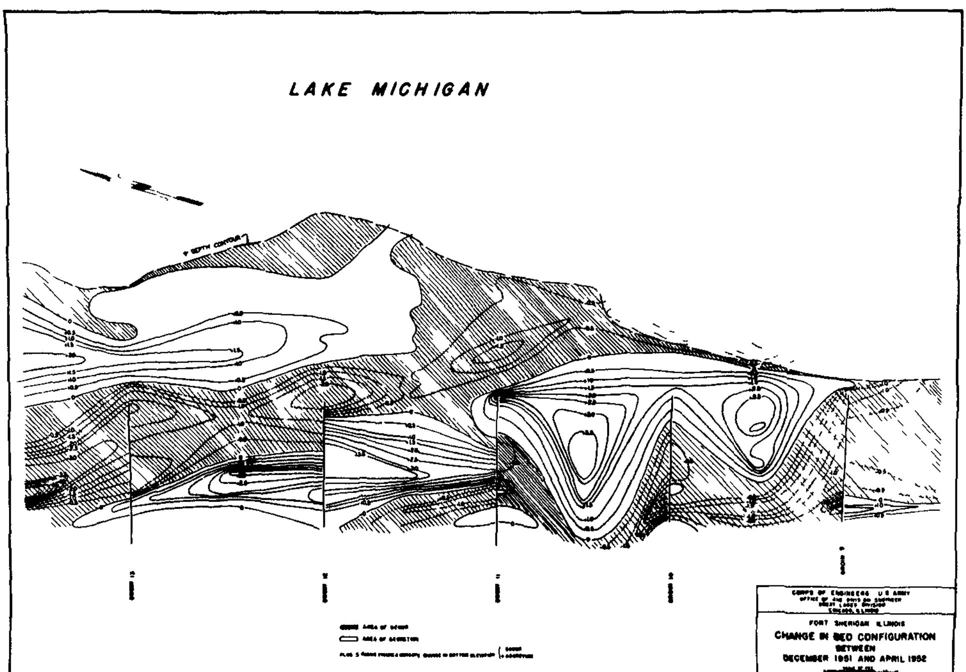

Plate 5

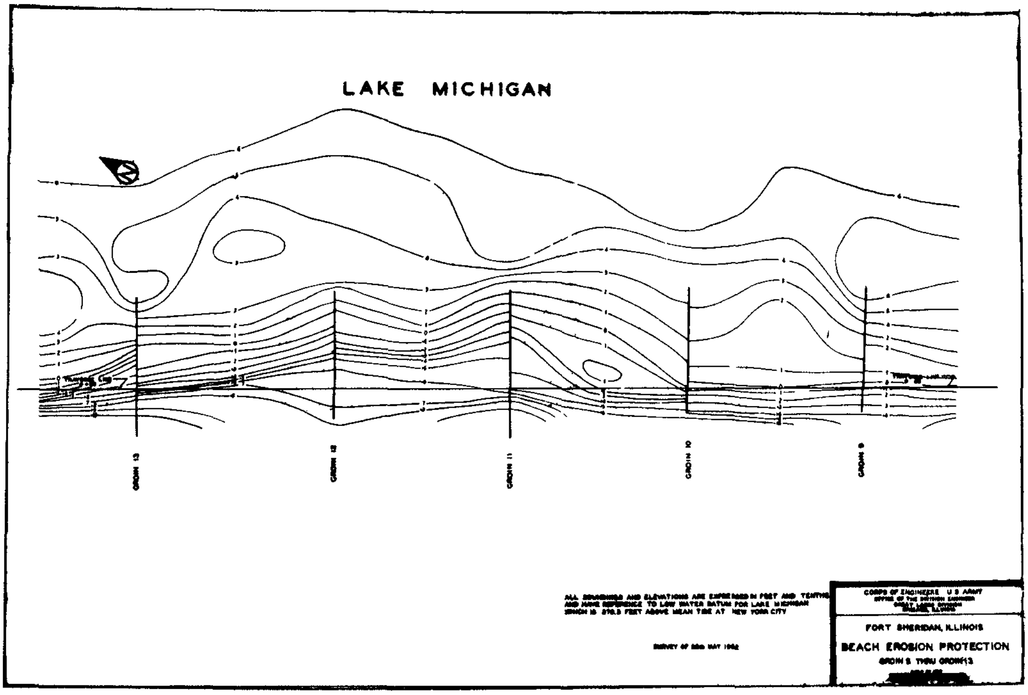

Plate 6.

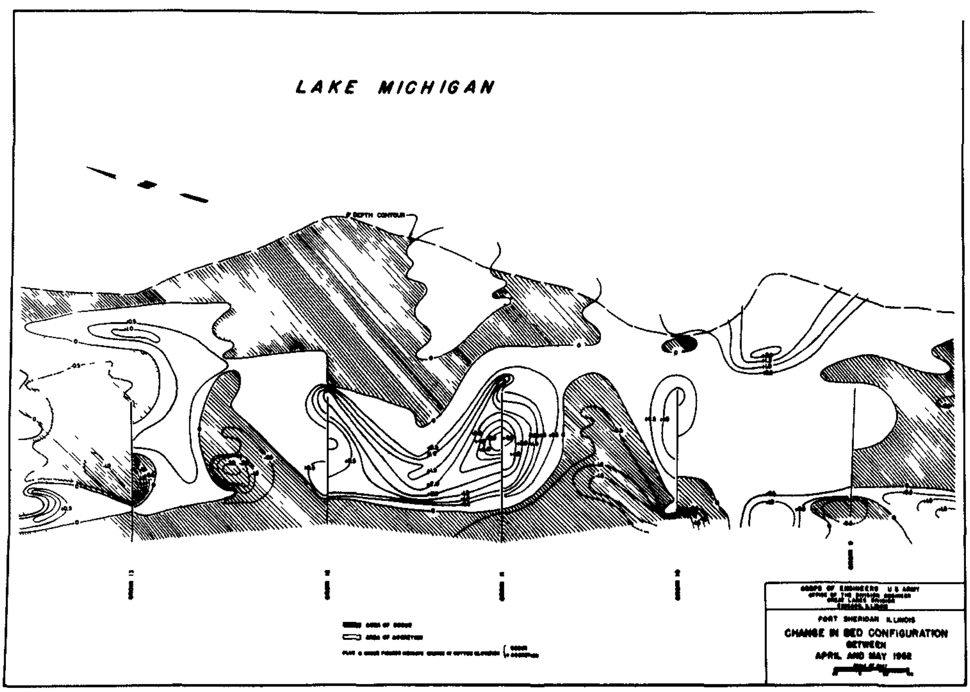

Plate 7.

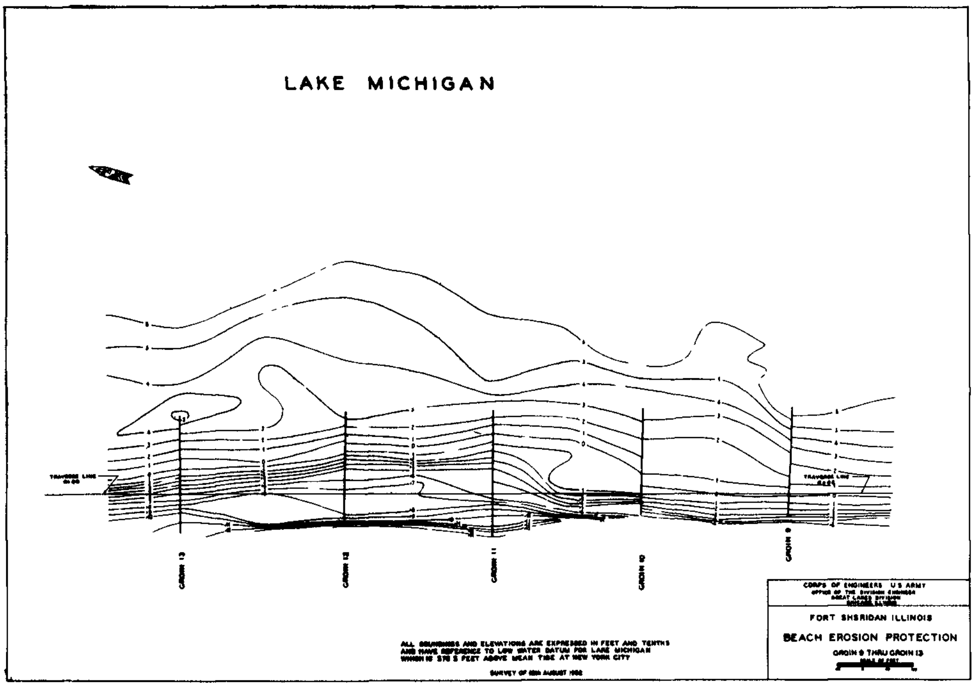

Plate 8.

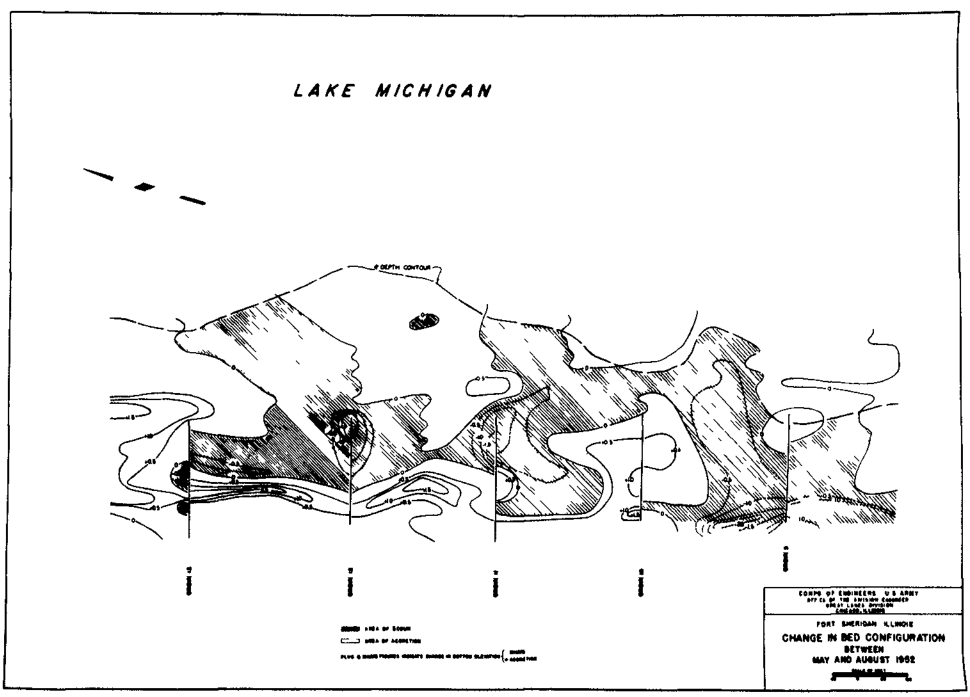

Plate 9.

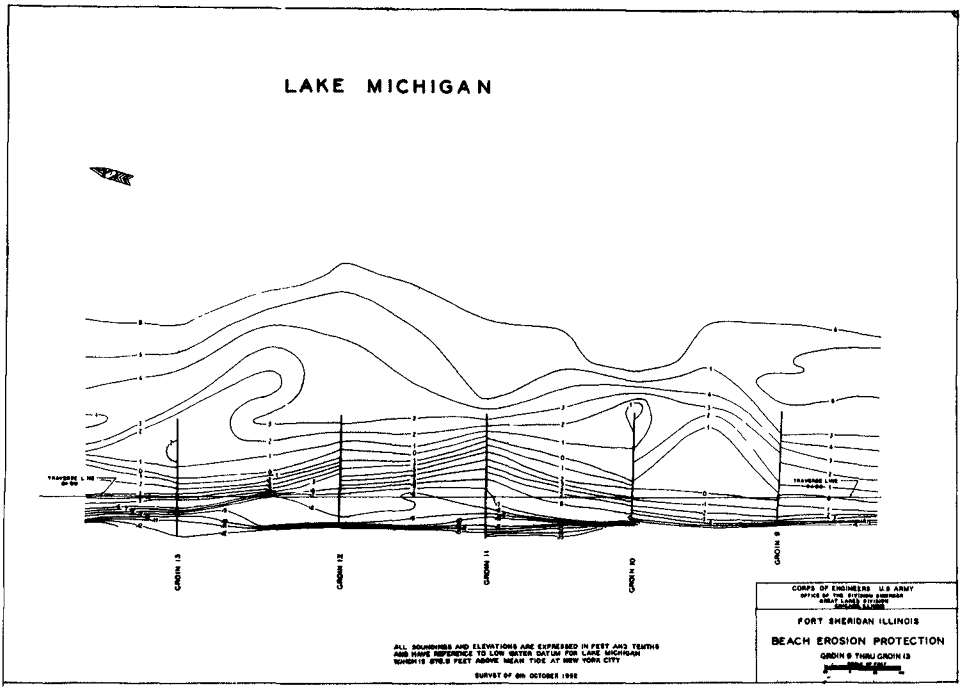

Plate 10.

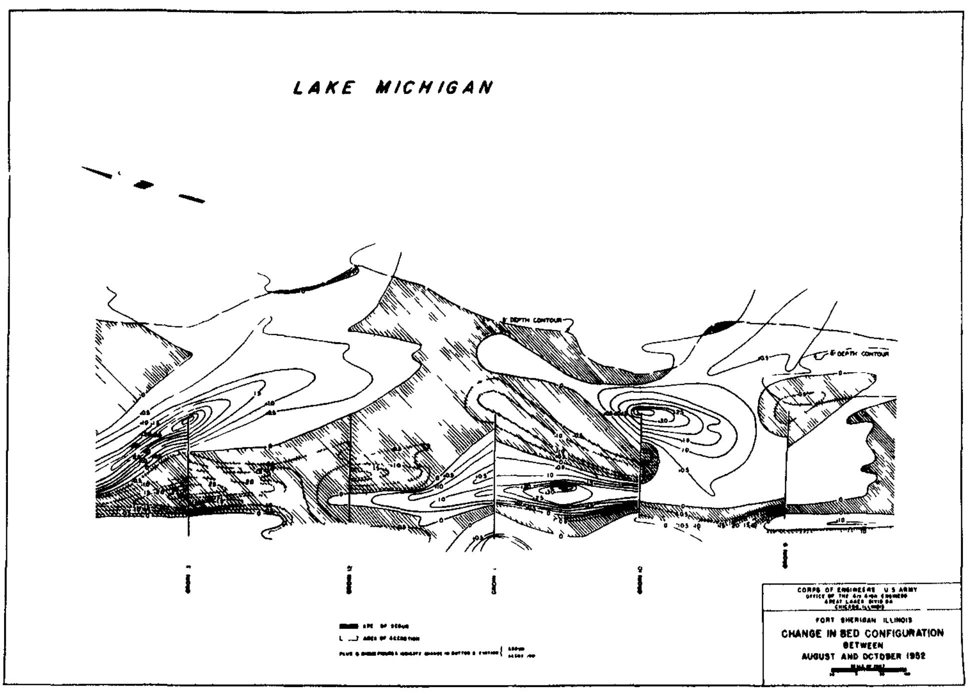

Plate 11.

ENERGY INDEX

It was considered possible to express impoundment of the littoral drift by the groin system in terms of an index derived from a combination of the effects of the various pertinent meteorological factors. It was also considered that such a description could be an index of the energy transmitted along the water surface. This index would therefore be an adaptation of the equation for total energy in a unit length of wave front. The equation for total energy in deep water may be written:

$$E_t = \frac{W \frac{g}{2\pi} T^2 H^2}{8} \left(1 - 4.93 \frac{H^2}{L^2}\right)$$

in which E_t = total energy, W = specific weight of water in pounds per cubic foot, g = accelleration of gravity in feet per second per second, T = wave period in seconds, H = wave height (trough to crest) in feet, and L = wave length in feet.

The shape term, $\left(1 - 4.93 \frac{H^2}{L^2}\right)$, is negligible in such an approximation and of the remaining terms of the formula, $\frac{W \frac{g}{2\pi}}{8}$, are constant. Therefore, it is considered that the principal variables, T^2H^2, of the energy formula would provide an adequate approximate measure for comparative purposes.

The energy index was computed for each storm throughout the period October 12, 1951 through October 8, 1952 in which a deepwater wave height of 3 feet, or more, was generated. The wave characteristics were determined by hindcast methods (1) from wind data recorded at automatic recording gages located at Navy Pier, about 30 miles south of the area, for 1951 and at the South Side Filtration Plant, about 35 miles south of the area, for 1952. The wind data were supplied by the Division of Water Purification, City of Chicago.

In order to assure a consistent evaluation, the wind record for each storm was divided in such a manner that a maximum value is obtained as the index for the storm. The divisions are of two general classes. First is the principal portion, or that part of the storm which could, by itself, generate a wave height equal to the maximum of the entire storm; and, second are the remaining portions as delimited by the principal portion or by the effective fetch. The $H^2 T^2$ is computed for the significant wave of each portion, summed, and divided by 100 to obtain the index of the storm. The duration of the storm is thus given recognition in the index since the energy transmitted to the water by the portions of the storm superfluous to that theoretically necessary for production of the maximum wave height is included in the index as additional H^2T^2. Figure 2 is a graphic evaluation of the storm which occurred on October 23-24 1951.

In figure 2, U = wind velocity in knots and I = energy index. The principal portion of the storm, e.i. from hour 1400 to hour 0300, would generate a deepwater wave 12 feet high at Fort Sheridan; also, preceding this portion of the storm, the wind occurring from hour 0 to hour 1400 would produce a wave 7.8 feet in height. After hour 0300 on October 24 the velocity of the wind decreased rather rapidly and the direction changed to northwest, which is an offshore direction. The wind after hour 0300 was therefore not effective. The energy index for the storm would then be:

$$H^2T^2 = I = \frac{(7.8)^2\ (7.0)^2 + (12.0)^2\ (8.5)^2}{100} = 134$$

Energy index, I, referred to throughout this paper was determined thus.

RELATIONSHIP OF ENERGY INDEX TO VOLUME OF IMPOUNDMENT.

The index as described in preceding paragraphs was determined for the period of time between surveys and tabulated according to date and direction of propagation of the wave.

TABLE 3

SUMMARY OF ENERGY DATA

PERIOD COVERED	ENERGY INDEX I BY DIRECTION									
	NORTH	NNE	NE	ENE	EAST	ESE	SE	SSE	TOTAL	I cos E
Oct.12, 1951 Dec. 4, 1951	320 (52%)	247 (40%)	-	-	16 (3%)	-	13 (2%)	19 (3%)	615	584
Dec. 4, 1952 - Apr. 18, 1952	319 (17%)	688 (38%)	113 (6%)	91 (5%)	229 (12%)	193 (11%)	101 (6%)	90 (5%)	1824	1680
April 18, 1952 - May 28, 1952	3 (1%)	167 (76%)	10 (4%)	15 (7%)	26 (12%)	-	-	-	221	212
May 28, 1952 - Aug 12, 1952	4 (6%)	22 (32%)	-	-	19 (28%)	14 (20%)	8 (14%)	-	67	64
Aug 12, 1952 - Oct 8, 1952	70 (32%)	46 (21%)	72 (33%)	19 (9%)	11 (5%)	-	-	-	218	198
TOTAL	716 (24%)	1170 (40%)	195 (7%)	125 (4%)	301 (10%)	207 (7%)	122 (4%)	109 (4%)	2945	

The percentages shown in parenthesis are the portion of the total index for the survey period that the value for the specific direction comprises.

However, in order to relate the index to impoundment it was necessary to resolve the index value to the direction of wave travel which would produce maximum transport. This direction in which maximum drift will occur is assumed to be when the deep water waves approach the generalized shore line at an angle of 45°, since maximum drift will occur when the combination of the velocity of littoral current and the erosion of updrift bluffs and beaches is maximum. Saville (6,7) determined that maximum littoral transport occurred along an infinitely long straight beach when deepwater waves approach at an angle of 43° to the beach. Bruun (8) estimated that maximum transport occurs when the waves approach at an angle of 40° to 50°. Figure 3 shows the relative location of the maximum drift producing directions M_1 and M_2 with respect to the recorded wind directions, when M_1 and M_2 are at an angle of 45° with the generalized shore line.

On the figure 3, B is the angle between a line parallel to the actual direction of wave propagation and a line parallel to the direction of propagation which would produce maximum transport. The corrected energy index value was obtained by calculation according to the formula:

$$I \text{ corrected} = I \cos B$$

A study of the values of the energy index and the impoundment of the groin system measured between the bluff and the 6 foot depth contour indicates direct relationship. A plot was made in which impoundment and 10 (I cos B) was compared. Inspection indicated that a fractional exponent of 10 (I cos B) would approximately reproduce the impoundment curve except for irregularities due to other variables.

In addition to energy considerations the measures deemed necessary to consider in describing the filling of the groins would be elevation of the lake surface during the storms, the capacity of the groins to impound the available drift, and ice effect on erosion and accretion on the shore. From the available basic data it appears that cumulative volume of impoundment at a 5 groin system at Fort Sheridan may be expressed,

$$\text{Cum. Imp.} = 10C_1 \, (I \cos B)^{0.97} \, C_2 \, C_3.$$

and simplified to,

$$K \, (I \cos B)^{.97}$$

wherein $K = 10C_1 \, C_2 \, C_3$.

The three coefficients, C_1, C_2 and C_3 are discussed in the following paragraphs.

The coefficient C_1 gives consideration to the ability of the groins to impound a constant portion of the drift passing the area, and is variable with time. Throughout the period of record of the groins C_1 is assumed to equal unity. However, as the system fills the retaining ability decreases and therefore C_1 would decrease.

C_2 is a coefficient to correct for the effect of ice on erosion of, and accretion on the shore line. Usually in the latter part of December ice begins to form and the spray freezes on the shore, both having the effect of decreasing the erodibility of the source of the drift. Also as the ice thickens and windrows form, waves cannot attack the shore. The ice also forms a barrier to the shoreward movement of littoral drift. Usually in the latter part of March or early in April the ice melts and the necessity for this correction is nullified. Inspection of the available data indicates that a value of 0.7 for C_2 is appropriate for the ice effect on the shore during January - April 1952.

C_3 is the coefficient to adjust the energy index to conditions of change in Lake level. The monthly lake level in October 1951 was 581.54 feet above mean tide at New York, rising slightly to 581.66 in March 1952. From March to August 1952 the level rose rapidly to 582.69, then declined to 581.91 in October 1952. Since the higher elevation could only have the effect of increasing the amount of littoral drift made available by energy acting on the shore, the shape of the curve reveals no appreciable effect caused by the higher lake level. Therefore, C_3 is considered to be unity for the specific conditions during this study. However, if at a later date the lake level decreased appreciably so that the waves could not progress inland to erode the bluffs it appears that this coefficient would decrease to reflect the loss of efficiency of the energy index.

Considering the above evaluation of the coefficients the formula expressing the cumulative impoundment for the period January-April may be reduced to $7\ (I \cos B)^{.97}$ and for the remaining portion of the record is expressed by $10(I \cos B)^{.97}$. Figure 4 indicates that these values reproduce the cumulative curve within about 10%.

DISCUSSION OF PATTERN OF GROIN SYSTEM FILLING

Considering the survey of October 12, 1951 as a base, the patterns of filling of the system as shown by the surveys are discussed. Assumptions are also made as to the causes of the particular patterns.

Survey of December 4, 1951. During the period of 12 October to 4 December 1951 the monthly average level of Lake Michigan varied from 581.54 to 581.58, a very small change. The energy factor for the period was 616 with 320, or 52 percent from the north and 247, or 40 percent from the north-northeast. The groins impounded a total of 5930 cu. yds., an average of 3120 cu. yds. per month. The area of greatest accretion was between groins 13 and 12 where 6100 cu. yds. were impounded. The greatest loss occurred between groins 10 and 9 and amounted to about 1240 cu. yds. All volumes of accretion given herein are measured between the bluff and the 6-foot depth contour unless otherwise indicated.

As indicated above, the action of the groins was generally positive in nature (see Plate 3). The greater bulk of the accretion formed a

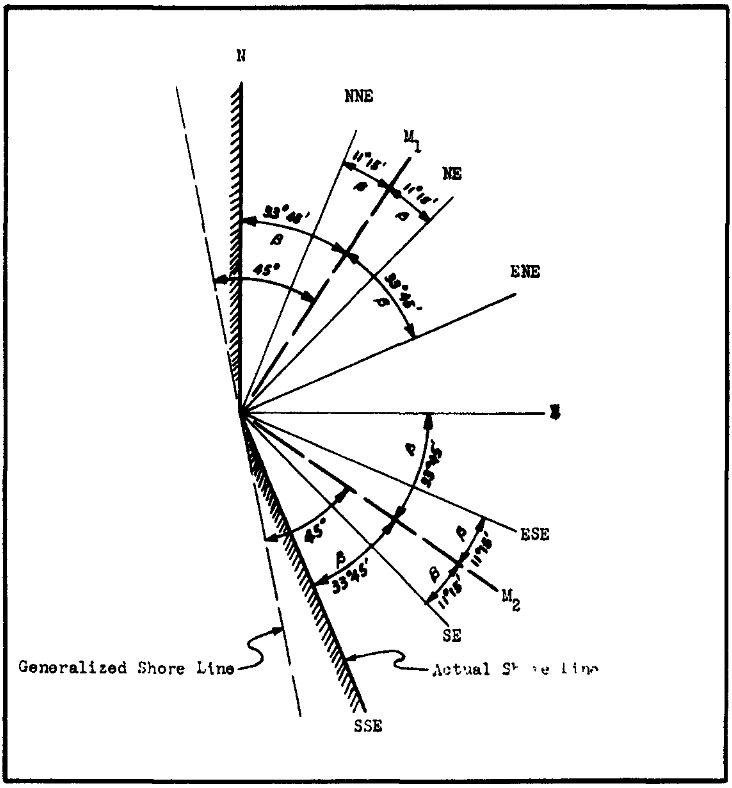

Fig. 3. Relationship of direction of maximum drift production, M_1 and M_2, to direction of wave propagation.

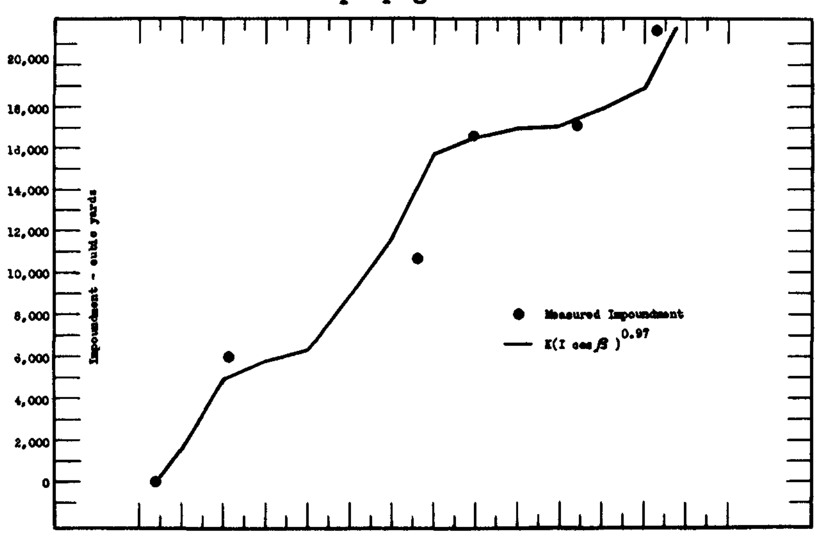

Fig. 4. Comparison of computed to measured impoundment.

finger shaped area beginning near the inner end, and north of groin 13, and extending in a slightly eastward direction past 13 and 12 to about 3/4 the distance between 12 and 11. The maximum depth of impoundment was 4.7 feet and was adjacent to the south side of groin 13. The depth of impoundment decreased to 3.2 feet at the lakeward end of groin 12, and to zero 290 feet southward of the groin. It would appear that the predominance of southward moving wave energy moved a considerable amount of material from the north. This material formed a beach north of groin 13 with a berm 10 feet above low water datum or about 8.5 feet above the average lake level with the forebeach extending lakeward with a 1 on 16 slope. The sand was impounded about 4.5 feet above the top of the groin therefore spilling over the groin and piling on the south side. Since the predominant wave was diffracted by groin 13 much less energy was expended on this impoundment. The circulation (9) between groins 13 and 12 distributed the sand in a south-southeast direction around the end of groin 12, then diffraction around the end of groin 12 directed it in a south direction. It is evident that the portion of the energy from the east (3%) was of sufficient intensity to distribute a portion of the shoal farther onto the shore.

From about 120 feet north of groin 11 to the south end of the study area the principal action was negative. The cause is assumed to be a paucity of material reaching the downdrift groins, due to the simultaneous construction of the five groins. The points of maximum erosion and the points of minimum accretion, where there is accretion adjacent to the north side of the groins, occurs between 100 and 200 feet landward from the outer ends of the groins. Specifically, the points adjacent to groins 13, 12, 11, 10 and 9 occur at a distance of 120, 100, 150, 190 and 200 feet, respectively, shoreward from the lakeward ends. It would appear then that this is the point of maximum energy impingement on the groin. It would also appear that a rip action occurs along the updrift side of the groin during this particular predominent direction of wave approach. The variance in distance of the erosion points from outer ends of the groins is apparently due to local refraction characteristics.

At the time of this survey, the beaches appeared to be rather straight and sloping without noticeable bar formation as the impoundment of material generally flattened the beach gradient. This is especially apparent between the 1 and 5 foot depth contours in the area from groin 13 to groin 10. The elevation of the beach berms decreased from $+$ 10 feet at groin 13 $+$ 5 feet south of groin 9. The beach slopes formed by groins 13, 12, 11, 10 and 9, between the berm and the flatter offshore gradient were about 1 on 16, 1 on 14, 1 on 10, 1 on 8 and 1 on 12, respectively, the slope south of groin 9 was about 1 on 10.

<u>Survey of April 18, 1952</u>. The period December 4 to April 18 includes that portion of the year in which ice forms a barrier on the shore. This decreases the effect of the large energy index of 1324 for the period. Several rather severe storms occurred during this period

which generated maximum wave heights of 9.8 feet, 15 feet and 13 feet from north-northeast, and one storm from the north which developed a maximum wave height of about 10.5 feet. The energy index was distributed as follows: North 319 (17.5%); North-Northeast 688 (38%), Northeast 113 (6%), East-Northeast 91 (5%), East 229 (12.5%), East-Southeast 193 (10.5%), Southeast 101 (5.5%), and South-Southeast 90 (5%). The elevation of the lake level varied from 581.58 to 582.06 during the time period. The greatest impoundment occurred between groins 11 and 10 where a volume of 3360 cu.yds. was impounded, and between groins 12 and 11 where a volume of 2140 cu.yds. accreted. Loss of volume occurred north of groin 13 by an amount of 1820 cu.yds. and south of groin 9 by an amount of about 600 cu.yds. The total increased volume in the system amounted to 4720 cu.yds. during this period of time, an average 1020 cu.yds. per month.

In examining the patterns of change in bottom elevation, it is of interest to note the resemblance between the band of accretion from north of groin 13 to groin 11 on the map of the October-December change (Plate 3) and the band of erosion on the map of the December-April change (Plate 5). Referring to Table 2 and Plates 3 and 5, it would appear that the large volume of material impounded between groins 13 and 12 during the period October-December 1951 migrated to the area between groins 12 and 11. Assuming this to be the manner in which the large accretion occurred between groins 12 and 11, the areas of maximum influx were in the 3 to 6 foot depths lakeward of groins 13 and 12, between groins 11 and 10 and between 10 and 9. The geometrical designs formed by the impoundment between groins 11 and 10, and 10 and 9 indicate that a reverse circulation may have been set up which caused erosion adjacent to the groins and deposits in the center of the area. However, no observations were made during storm periods to substantiate such an assumption. It also appears that a considerable littoral current was produced which moved material from the area immediately north of groin 13 and near and beyond the outer ends of the remaining groins. Considerable scour may be noted near the outward extremity of each groin. Continued erosion is noted south of groin 9.

At the time of the April survey the beach was more irregular than at the time of the December survey. This is accredited to the fact that the predominant direction of energy approach changed from north to north-northeast and that a greater number of easterly and southerly storms occurred.

Survey of 28 May 1952. The fourth survey of the study was completed on May 28, 1952. Therefore, the period of time covered by this survey was 1.3 months. The monthly mean lake level for April was 582.06 and for May was 582.32. By reference to Table 3 it may be noted that $I = 221$ and $I \cos B = 212$. It may also be noted that 76% of the energy index was from NNE which is an angle of approximately 34° with the shoreline, therefore, approaching closely the direction of maximum littoral transport.

The highest rate of impoundment that occurred during the period of study took place between the April and May surveys. The groins accumulated 5940 cubic yards of material, which is 4570 cubic yards per month for the 1.3 month period. The major portion of the accumulation, 4850 cubic yards, occurred between groins 12 and 11. Groin 9 collected 2030 cubic yards, which was the first large impoundment at that groin. Possibly a considerable portion of the groin 9 accumulation is migration from groin 10.

The general pattern of change in the bottom configuration was one of smoothing. The predominance of short period waves had the effect of slight erosion in the deeper water beyond the lakeward ends of groins 13 through 10. The ridge of sand midway between groins 11 and 10 was eroded, and filling occurred adjacent to the groins. There was also some filling downdrift of groin 10, but the general configuration remained constant. Gentle erosion continued downdrift of groin 9, probably due to a paucity of littoral drift. The accretion occurring below groin 9, landward of the LWD shoreline, is evidently migration from the north side of the groin. The slight erosion along the berm may have been caused by the westerly, or offshore, wind movement which consisted of approximately 10,000 miles of the 22,000 miles occurring during the months of April and May.

Survey of 12 August 1952. This increment of the time was the least productive of any portion of the study as the total gain in impoundment was only 520 cubic yards, which is an average of 210 cubic yards per month. There are two principal reasons for the small impoundment, the small amount of energy developed and the fact that groin 9 was outflanked. The energy index for the period was 67, an average of 27 per month.

The date of the actual flanking of the groin is not known but it appears reasonable to assume that the storm of June 11-12 may have culminated the action following the constant erosion of the toe of the bluff on the south side of the groin. The storm of June 11-12 was the most severe of this time increment. The computed maximum wave height and period was 7.1 feet and 6.2 seconds, respectively, from the east. This direction of propagation would mean that waves approached perpendicular to the shore causing severe erosion and little littoral current.

The wave action was sparse consisting of low, short period waves which varied from about 4 to 7 feet in height and 5 to 6 seconds in period. It is also of interest to note that 62% of the energy index came from the southerly direction, opposite to the predominant direction of littoral drift.

The general pattern of bottom change was to further smooth the beach except in the vicinity of groin 9 where an exceptional amount of erosion occurred because of the outflanking of the groin. In the area bounded by the bluff and the 6-foot depth contour, and lines 200-feet north and 200-feet south of groin 9, a loss of about 2280 cubic yards was experienced. In the remainder of the system the beach prograded. The area of largest accretion was north of groin 13 where approximately 1380 cubic yards accumulated. The prograding of this area is accredited to the smaller waves occuring during the period which would cause less turbulence and also would cause less overtopping of the groin. The greatest depths of accretion, exclusive of that near the shoreline, was at the lakeward end of groin 13 and about 80 feet lakeward of the outer end of groin 11, where in both cases a depression in the lake bottom had previously existed. The areas of greatest erosion were along the lakeward ends of groins 12 and 11 where small mounds of sand had existed at the time of the May survey.

The lake level during the period June through August varied from elevation 582.48 to elevation 582.69. The monthly mean elevation for August was the highest that had occurred since June 1886. This high lake level would tend to make the smaller waves more effective in eroding the shore than if they had occurred at a lower level.

Survey of October 8, 1952. This is the final survey under consideration in this paper and completes one year of study of the five-groin system. The energy index for this period was 218, an average of 109 per month. The north component comprised 32% and the NE 33 % of the index. The system impounded 4490 cubic yards, an average of 2245 cubic yards per month.

The wave heights contained in the index were greater than for the preceding two surveys. The wave heights varied from about 5 to 10.5 feet and the wave periods from about .5 to 8 seconds. There were two rather severe storms, one occurring on August 21-22 that generated a maximum wave height of about 10 feet with a 7.5 second period, the second occurring on September 6th produced a wave 10.6 feet high with a period of about 8 seconds.

The larger waves involved were evidently in part responsible for the irregular beach configuration existing at the time of the survey. A formation very similar to that observed on the plot of the December 1951 survey is evident. The formation consists of a cigar-shaped impoundment beginning north of groin 13 and extending southward and lakeward, forming an angle of about 60° with the groin. The maximum depth of the accretion was 4 feet, occurring at the lakeward end of groin 13. The other points of maximum depth of accretion were midway between groins 11 and 10, about 60 feet lakeward of the landward end of groin 10, and at the lakeward end of groin 10, both deposits were about 4 feet deep. In noting the similarity in the impoundment formations at the time of the December 1951 survey and the October 1952 survey, it may also be noted that at only these two survey times were there a larger portion of the energy index resulting from waves from the north rather than north-northeast. The reason is not apparent for the clearly defined erosion and accretion areas. For instance, at the lakeward ends of groins 13, 12 and 10 there is definite accretion while at the lakeward ends of groins 11 and 9 there is definite erosion.

Groin 9 was not tied back to the bluff prior to this survey. Therefore, erosion along the base of the bluff, and between the landward end of the groin and the bluff continued. However, debris and bluff material closed the breech to the extent that accretion in amount of about 2120 cubic yards occurred between groins 10 and 9.

SUMMARY OF FINDINGS

It has been attempted herein to follow the filling of a five groin system, to point out some of the major patterns in bottom changes caused by the groins, theorize as to elements of the cause of the patterns, and to develop an empirical expression to describe the volume change in the system. It may be noted that impoundment is related to an index of energy and no attempt is made to separate the effect of the various characteristics of the waves which contain the energy. The waves considered are storm-generated, deep-water waves whose generation occurred during 993 hours of the 8,760 hours comprising the study time period, or about 11% of the total time.

It is interesting to note that groin 13, which is the extreme updrift groin, did not accumulate the largest impoundment. One feature of the filling characteristics of the system was the initial action of this groin. For the first month or so after construction a prograding of the beach updrift occurred, thereafter retrogression followed for about 7 months. Rapid prograding did not occur until after the completion of this study when a short groin was constructed to the updrift. This feature is considered characteristic since following construction of additional groins to the system updrift, the area north of groin 13 began rapid prograding and the new extreme updrift groin is following a pattern of retrogression. This pattern of action indicates that the extreme updrift groin acts as a wave disipator for the system and that diffraction of the waves and currents by this groin aids in the filling of those downdrift.

Groin 12 impounded considerable material between the surveys of October and December 1951 and the flow of material was directed around to groins 11 and 10 thereafter. Both groins 11 and 10 collected a sizeable impoundment between the surveys of December 1951 and April 1952, and groin 11 was very effective between the surveys of April and May 1952. It is believed that groin 9 would have accreted beach between the surveys of May and August 1952 had not the flanking of the groin occurred. The first positive action of groin 9 occurred between the surveys of August and October 1952.

The filling of a groin system is not necessarily a persistent smooth filling process but is generally one of pulsating movement forming areas of alternate accretion and erosion. The actual configuration of the bottom at any specific time depends largely on the condition of the sea existing for an undetermined period of time preceeding the survey. The data analyzed for this study indicates that the larger, longer period waves form a very irregular beach configuration while the short period waves smooth the contours and form a regular-shaped beach. The irregular beach pattern caused by the larger waves is assumed to be related to two apparent characteristics of the impinging wave. First, the larger waves contain greater energy which causes the suspension of a larger quantity of sand thereby making it available for distribution, and second, the larger waves transport a larger quantity of water to the beach resulting in more intense rip currents which, together with circulation between the groins causes confused patterns of deposition. Such an assumption appears consistent with the findings of Bruun (9).

It may also be seen that the accretion is not confined to the area shoreward of the lakeward ends of the groins. It is true that in the initial stages the majority of available material is impounded within the limits of the groins, but as the system fills the accretion extends outward into deeper water. Between the surveys of October and December 1951 92% of the impoundment occurred within the groin confines, between December 1951 and April 1952 the amount was 60%, from April to May 1952 80%, May to August 1952 a loss of 20%, August to October 1952 a gain of 8%. On the basis of cumulative amount of impoundment the amount within the groins confines at the respective survey times listed previously was 92%, 77%, 78%, 75% and 62% of the total impoundment. Therefore 38% of the total impoundment as of October 1952 was lakeward of the groin system and was generally in a crescent shaped area extending from approximately groin 13 to groin 11.

It is considered that comparison of detail prototype studies of other groin systems are necessary to determine identities of the process of groin action. Also, it is hopes that further study of this system can be made. The recently constructed groins updrift of the five reported on herein will allow study of the effect of simultaneous groin construction on a somewhat stabilized system downdrift. Further study is also necessary to substantiate the validity of direct relationship between a storm wave energy index and volume of impoundment.

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