FINAL PROJECT REPORT

EVALUATION OF GREAT LAKES SHORE PROTECTION STRUCUTRES

Report UMCEE 88-8

By

Steven J. Wright
Timothy D. Finley

THE UNIVERSITY OF MICHIGAN
DEPARTMENT OF CIVIL ENGINEERING
ANN ARBOR, MICHIGAN

December, 1988

For

Michigan Department of Natural Resources
Coastal Management Program
Land and Water Division

December, 1988

INTRODUCTION

This project report presents the results of a survey performed during the summer and fall of 1988 in which a variety of shore protection structures recently installed on Lakes Michigan and Huron were examined to determine various aspects of their performance. Specific objectives of the evaluation include:

- Determine whether or not the structures were built as permitted
- Determine whether or not they have been effective
- Determine any adverse impacts associated with the installation

The sites were selected by the Michigan Department of Natural Resources. Employees involved in the permitting process in the various MDNR field offices were requested to identify specific sites to be included in the evaluation. Copies of permits were forwarded and these were used to establish the study sites. There were 36 such permits transmitted (some sites had more than one permit) including one site for which the permit application had been denied. All of these permits were issued between 1985 and 1988. Figure 1 presents a map of the lower peninsula of Michigan and approximate site locations are identified. A labeling system was used for record keeping purposes that identified the sites alphabetically going around the state of Michigan clockwise starting at the Indiana - Michigan border. Table 1 provides a brief description of the type of construction permitted at each of these sites. A more detailed description of each site presented in Appendix A includes the permit numbers, an identified applicant, and the month and year that the permit was issued. Of the sites in which the construction had actually been performed, a general classification by structure type includes:

- Groins and related structures - 22 sites
- Groins with an offshore sill - 2 sites
- Stone revetments - 4 sites
- Wavebusters - 2 sites
- Vertical retaining wall - 2 sites
- Others - 2 sites (one revetment of large cubical concrete blocks, one wall of manufactured concrete units with sloping face)

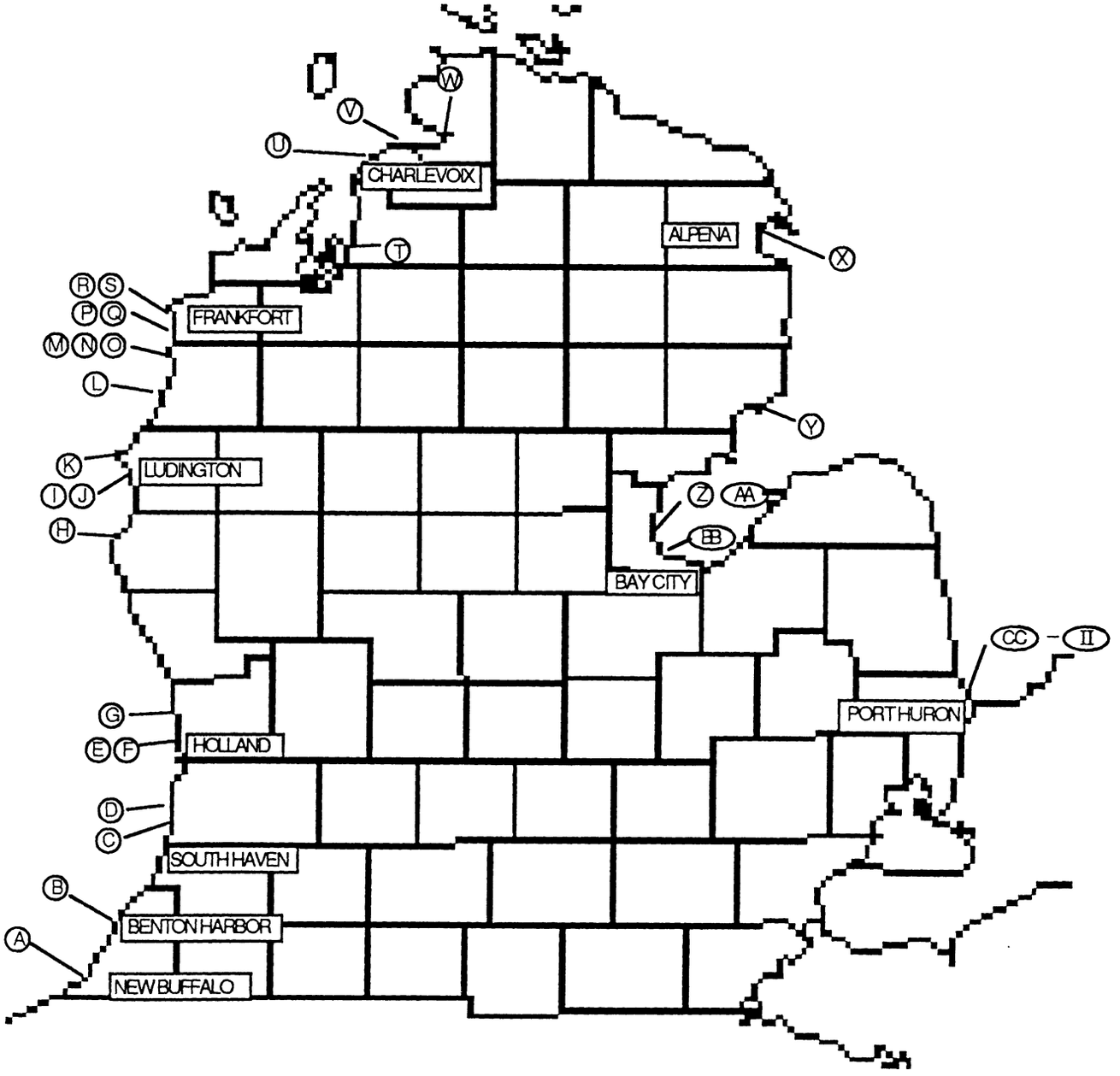


Figure 1. Location Map for Shore Protection Sites.

TABLE 1

Description of Individual Sites

Site ID	Location	Type of Structure
A	New Buffalo	Concrete filled tube groin system
B	Benton Harbor	Concrete block revetment/seawall
C	Glenn	Modular seawall
D	Saugatuck	Wooden retaining wall/groin
E	Holland	Low profile wooden sill and groin system
F	Holland	Two low profile wooden groins
G	Grand Haven	Corrugated metal pipe groin, concrete filled
H	Pentwater	Wavebusters
I	Ludington	Concrete filled tube sill and groin system
J	Ludington	Repair stone revetment
K	Ludington	Two extensive wooden groin fields
L	Bar Lake	Low profile wooden sill and groin system
M	Arcadia	Wooden groin system
N	Arcadia	Stone revetment, behind existing shore protection
O	Arcadia	Two stone revetments
P	Elberta	Concrete filled tube sill and groin system
Q	Elberta	Two concrete filled tube groins
R	Frankfort	Wavebusters (not installed)
S	Frankfort	Retaining wall at toe of bluff
T	Elk Rapids	Two rock filled timber crib jetties (not installed)
U	Charlevoix	Concrete filled tube sill and groin system
V	Charlevoix	Three sets of concrete filled tube groins
W	Bay View	Stone revetment

X	Alpena	Wavebuster system (incomplete)
Y	Tawas Point	Wooden pole retaining wall (incomplete)
Z	Linwood	Sandgrabber wall (not constructed)
AA	Linwood	Two wooden groins
BB	Bay City	Wooden groin (part of groin system)
CC	Port Huron	Extend existing steel groins, install new ones
DD	Port Huron	Extend existing steel sheetpile groin
EE	Port Huron	Steel sheetpile groin
FF	Port Huron	Steel sheetpile groin
GG	Port Huron	Steel sheetpile groin
HH	Port Huron	Steel sheetpile groin
II	Port Huron	Steel sheetpile groin system

Most of these permits were issued in 1986 and 1987. During this time period, the Great Lakes system was in a phase of extraordinarily high lake levels. The extreme high average monthly lake level for the Lake Michigan-Huron system was established during the calendar year 1986 for each month except for the January high which occurred in 1987. Therefore, many of the shore protection measures were undertaken as a response to these unusually high water levels. Since the extreme high monthly average level recorded in October, 1986 average lake levels have declined almost continuously and by the beginning of July, 1988 (at which time the evaluation project commenced) had returned to levels approximately equal to the 1900 - 1987 average and about 2.5 feet lower than the recorded extremes in 1986 (from *Monthly Bulletin of Lake Levels for the Great Lakes, October, 1988* U.S. Army Corps of Engineers, Detroit District). This variation in lake levels has had a decided effect on the response of the shoreline and presumably upon the response to the emplacement of specific structures. In some cases, structures installed in late 1986 have probably had little impact on the shoreline because they have been completely out of the water much of the time and in the summer of 1988, there were several sites in which the shoreline was further offshore than the end of the structure. Finally, a number of the structures requested in the permit applications were not constructed or completed, apparently because the decline in lake levels resulted in some cases in a decrease in perceived need to take corrective action. We have attempted to consider the probable effects of the lake level variations on the performance of the various structures in our evaluation.

EVALUATION METHODOLOGY

After the copies of the permits were received, all private landowners were contacted to obtain permission to visit the site, preferably at a time when someone with some knowledge of the structure was present. The objective, in addition to gaining access to the site, was to try to establish exactly when the structure was completed, their impressions of its function, and any other additional information that might help interpret observations made during the site visit. After diligent effort, all property owners were contacted and permission granted to visit all sites. Due to difficulties in scheduling, landowners were present at somewhat less than half the sites.

All sites were visited during the months of July and August, 1988. A site visit consisted of making a working sketch to identify the general state if the shoreline in the immediate vicinity of the structure. That is, the locations of other nearby shore protection structures were noted, evidence relating to the direction of littoral drift, the general type of material that composed any beach present, etc. Also any information obtained from the landowner was recorded. An attempt was made to reconcile the existing structure with that described in the permit to determine whether or not the structure was installed as permitted. For those sites at which the structure had not yet been constructed, the same procedures were followed in anticipation that there will be a chance to visit the sites in the future after construction has been completed.

Photographs were then taken at the site. These included several different views of the structure and also of the surrounding shoreline to the extent that this might prove useful in the interpretation of results. A total of approximately 400 black and white photographs and about 100 color slides were taken at the various sites. Appendix B contains several of these photographs.

On August 29, 1988, a small aircraft flight was made from the Indiana - Michigan border up to Petoskey to obtain aerial photographs of the same sites and other locations of interest along the shoreline, and to obtain additional perspective of the overall shoreline in the vicinity of the structures. A similar flight for the Lake Huron shoreline was planned, but was never made because of scheduling difficulties and the rainy weather during the fall of 1988. Consequently, aerial photographs were obtained for only about two-thirds of the total sites.

It was recognized from the outset that a potential difficulty with the study was the acquisition of information from a single point in time. In order to circumvent this problem, other sources that provided visual records of the shoreline were investigated. These included aerial photographs that were taken for the U.S. Army Corps of Engineers, Detroit District office. The aerial photographs that proved most useful were at a scale of 500 feet to one inch and were taken in the vicinity of various Corps harbor projects. In many of the projects, aerial photographs were taken over distances of approximately one mile on either side of the harbor entrance. Generally, the more recent sets of photographs covered a greater shoreline length, and older ones were useful only if a site was within about a half mile of a harbor entrance. There were seven sites that could be located in these aerial photographs Coverage in

time was somewhat spotty and in some cases, only two aerial photographs were available, while at other sites, as many as six or seven were available. In specific cases, this information was invaluable to determine the nature of the shoreline response.

Similar aerial photographs were available in the MDNR office in Lansing except that the aerial coverage was more extensive. In general, all of the sites were included in the aerial coverage, but in most places, the most recent photographs were from the early 1980's. The dates of aerial coverage varied from site to site, but typically there was always information available from the previous high water period around 1973 and also from around 1980. These aerial photographs were examined for those sites in which it was felt that they would provide potentially useful information.

The Detroit District office of the Corps of Engineers also took some videotapes of the shoreline at various times. The quality of these videotapes is quite variable and in some cases, it is difficult to make out sufficient detail and their value is somewhat marginal. The best quality video was taken in September, 1987 and covers the Lake Huron shoreline from Port Hope to Port Huron. This was the only tape of the Lake Huron shoreline and thus only the Port Huron sites are included. Videotapes of the Lake Michigan shoreline were taken in October and November of 1986 and in March and November of 1987. The 1987 tapes were most valuable for the purposes of the present study. These covered different sections of the shoreline so not all of the sites on Lake Michigan are on the tapes, particularly those in the northern part of the lower peninsula. More recent videotapes have been taken, but these were not viewed. Copies of most of these tapes were made and were viewed as part of the site assessment process.

FINDINGS

In response to the study objectives, the project findings are separated into three subareas.

I. Compliance with Permit

There were a few cases in which the exact language of the permit was unclear and compliance was not possible to precisely assess. This difficulty existed primarily

with respect to length of permitted structure for a number of groin systems. Situations in which this difficulty arose are for the present purposes judged to be in compliance with the permit unless there was no question that the structure was much longer than intended. Nor were issues associated with groin height considered when they were specified in terms of height above existing lake level although this effect could have been approximately considered. Using these criteria, there are 12 permits that appear to have been violated to some extent. A list of them by site is as follows:

A, C, D, I, L (2 permits violated, violations observed due to complaint of neighbor and since corrected), P, Q, U, V, FF, GG

Not counting existing sites in which construction has not been initiated or those for which the permit application was made after construction was complete, there are 30 permits from which these twelve violations occurred. Thus forty percent of the sites examined are in violation of some aspect to their permit. The most frequent problem was with respect to groin length and in several cases (at least four), the installed groins were at least twice the value specified in the permit. Other problems included groin height, groin location, and position of structure relative to the bluff. In this latter regard, other sites could potentially be added to the list of violations, but only those that were obvious were included in the above list. At least three permit violations (sites P, Q, and V) may be associated with a different interpretation of the terms of the permit by the contractor than what we read it to be (see the discussion under the **General Comments** section below).

II. Structure Effectiveness

In this regard, there are some potential difficulties due to the dramatic decline in lake levels over the last two years. However, attempts will be made to generalize the discussion associated with specific structures presented in Appendix A.

The relative effectiveness of groin systems appeared to vary considerably at the time of the site visits and the aerial flight. In the southern end of both Lakes Michigan and Huron, the groin systems appeared to be fairly effective in accreting littoral material on their updrift side. In Lake Huron, this appeared to be due to the

generally coarse material that was found along the shoreline while at New Buffalo, it may have been attributable to the beach nourishment project at the harbor to the north. Nevertheless, in both locations, there appeared to be a significant accumulation of coarse material on the updrift sides of the groins with fairly steep beaches that would be expected with that size of littoral material. It is possible that the coarse nature of this material has prevented significant rearrangement during periods of lower wave activity with the result that a well-defined fillet was present on the updrift side of the groins.

Farther to the north in Lake Michigan, between about Holland and somewhat north of Ludington, there was less evidence of trapping of littoral drift by the groin systems at the time of our site visits. Whether this was due to the generally fine littoral material or the particular wave climate is unclear, but sand generally appeared to be filled relatively uniformly across groin compartments. The prevailing littoral drift was variously estimated to be south or north depending upon the particular site. Inspection of the aerial photographs at different times sometimes indicated drift in the opposite direction. In trying to understand these observations, the various videotapes of this portion of the shoreline were reviewed. The following general observations were made:

- The videotape taken on March 7, 1987 indicated that most groins along this section of the shoreline had well defined fillets on their updrift (northern) side.
- Videotapes in November 1987, October 1986, and the August 1988 aerial flight did not generally indicate a significant accumulation of sand on the updrift side of most groins in this area.

An interpretation of these observations is possible in light of the fact that most of the large storms that would transport a fair amount of sediment occur during the fall and winter months (*Design Wave Information for the Great Lakes, Report 3, Lake Michigan*, D.T. Resio and C.L. Vincent, U.S. Army Engineer Waterways Experiment Station Report H-76-1, November, 1976). Thus gross transport should be most clearly defined at the end of the winter season. Transport during the spring and summer months may only represent minor perturbations to the sand deposition patterns developed during those months of peak storm activity. Furthermore, the

same report indicates that south of about Holland, the prevalence of design waves is either from the northerly or directly offshore directions with much smaller design waves from the south. This is, of course, due to the limited southern fetch in this region. It should also be kept in mind that the information presented in the report has a minimum return period of five years and therefore may not be representative of the more frequent storms. However, the same report indicates that north of Big Sable Point, design waves predominately originate from the southerly direction as compared to a northerly one. Along the shoreline in between these locations, or in the region in question above, there is no clear difference in the design wave heights for waves from either the southerly or northerly directions. This would indicate that a strong possibility exists for more back and forth transport along the shoreline with less net transport than either farther to the south or the north.

The above interpretation would be more or less consistent with the observations in the long (58 groins) groin field north of Ludington (site K) in which it is observed that the compartments within the groin field are filled more towards either end than in the center (Figs. B29 and 30). Since the original groin system also never filled at the center in the 25-plus year period of time after it was constructed, it would support the general conclusions drawn above. All of the other groin systems (including the 13 groin system just to the south) investigated were considerable shorter and the same features were not observed and conclusions are more difficult.

One feature appeared to be present at a number of sites with clay bluffs in the vicinity of Holland. Apparently during the high water period, waves scoured away a fair amount of material at the toe of the bluff. It appears as if there is a clay ledge or sill that extends out from the toe of the bluff in several of these locations and that sand has been left on these ledges as a fairly uniform beach. The presence of groin systems appears to have little influence on beach width at present and we suspect has little or no influence on shoreline protection. This interpretation is somewhat speculative, but reasonable consistent with observations made by others (C. Johnson, Chicago District, U.S. Army Corps of Engineers, personal communication) regarding this section of the shoreline. The sand beach at the present time is both fairly deep and wide and most groin systems in the area are completely filled, so it is not entirely clear what the process was by which most of the filling took place. In March 1987, clearly defined fillets were present on the north sides of many groins in

this area and so it is possible that the groins were fairly effective until the water levels dropped far enough to isolate the groins from the zone of littoral drift.

A problem was noted with many groin and sill systems in which the groin length to spacing ratio was small (approximately less than one-half or so). We are primarily referring to sheet pile or timber sills in this case. In a large number of these installations, the groin compartments do not appear to have ever filled unless the sill was located so far shoreward that it is not impacted by waves. The obvious explanation is that wave reflection off the sill has prevented the deposition of sand within the groin compartments. In the present study, site H is probably the best example of this situation, but even there, the groin length to spacing ratio is about one except at the southern edge of the property where it is smaller. However, the southern groins have clearly been less successful in creating a beach. The other example on Lake Michigan is site M. There however, the sill is of low enough height that it is completely buried on the south end of the property. Differences in filling of the groin compartments at this site may be due to the fact that littoral drift is from south to north here and the very long concrete groins near the center of the groin field block off drift for the northernmost groins (a similar sort of argument could be made at site H). In any case they have very little sand in them. Many other sites of this sort are visible in the videotapes of the Lake Michigan shoreline and indicate that more attention should be paid to the design of this type of system. It may well be also that a minimum groin length for this type of system is required, regardless of the spacing.

The groin systems at Port Huron on Lake Huron were on relatively steeper beaches and a well defined fillet was nearly always present on the northern side of the groin. For those systems that also had a high seawall, the fillet sometimes did not extend across the entire property and it was clear that the relationship between the groin length and property width was important. At these sites, longer groins were more effective in building a beach than shorter ones, but the beach material was considerably different (more coarse) than at nearly all of the Lake Michigan sites and fairly steep beaches formed.

The different types of groin construction did not appear to be as significant a factor as other details of the installation and location along the shoreline. There were, however, no sites in which adjacent groin systems were radically different

from each other. If there was a difference, it was typically associated with whether or not a sill connecting the onshore ends of the groins was present or not and this matter is discussed above. The concrete tube groins appear to be an evolution from earlier attempts at simply filling fabric bags with sand (*Low-Cost Shore Protection Final Report on the Shoreline Erosion Control Demonstration Program* (Section 54), U.S. Army Corps of Engineers, August 1981). In those earlier installations, ripping of the fabric bag and loss of the sand fill was a common problem, which the replacement by a cement-sand mixture is obviously intended to alleviate. With regards to the effectiveness in trapping littoral transport, however, at least some of the systems appeared to function fairly well. All systems had at least two rows of bags at the onshore end and were typically about two feet high but were shorter at the offshore end which was only one bag high. The installations at sites A, J, P, Q, and U appeared to have trapped a reasonable amount of sediment. However, site V which is located in an area of very coarse bottom material is unlikely to be very successful, as it appears as though there is very little littoral material to trap. However, the installation has not been in place long enough to validate that assessment.

A problem that was noted with several of the concrete filled tube groins was damage to the groin surface (Fig. B25). There were five sites inspected where this type of groin had been installed sometime between July and November of 1987 and thus had been in place only a year at most at the time of the site inspection. Of these, three sites (considering the tube groin system on the Epworth and Reid properties, sites I and J, as one because they were installed at the same time) had already experienced some degree of damage, in all cases on the tops of the offshore ends of the groins. Because of the very short time since the installation at these sites, this raises some question about the long term integrity of the structures. Additional site visits in another year or two would be very valuable in determining the durability of this type of groin.

The stone revetments that were inspected appeared to be functioning fairly well in protecting the shoreline. It also seems as though the ability to make a partial repair to a damaged revetment by the placement of more armor stones is a more palatable course of action and is less likely to lead to a situation where a structure is allowed to completely fail before replacing it with something else. In the sites (sites O

and Y) where too small of armor stone was used, a fair amount of it has ended up in the lake in front of the structure and it appears that armor stones must be heavier than 1-2 tons before they will be stable to the wave climate that they are exposed to in the Great Lakes. Further investigation at other sites is required to define this in more detail and of course the local wave climate will also be variable at different sites. A singular phenomenon was that beaches do not normally form in front of stone revetments and this may be a big drawback to the recreational use of the lakefront resource. There are numerous locations, however, in the videotapes where sections of shoreline that have been protected with revetments and seawalls protrude much further into the lake than surrounding shorelines, either unprotected or with other types of shore protection. In particular, the top of the bluff often extends much farther lakeward with a much steeper bluff face and thus it is apparent that this type of shore protection may be necessary in those situations in which buildings that are very close to the edge of the bluff are to be protected.

The heavier concrete units such as wavebusters, etc. appeared to have foundation problems in many cases. It appears as though more attention needs to be paid to this aspect of the installation of such a structure. Most of the structures that we investigated of this type had not been in place long enough for a thorough assessment to be made but this is something that should be watched carefully for this type of installation. Neither of the wavebuster installations inspected were particularly well suited for determining their effectiveness since they were used in conjunction with some other major shore protection system. The subjective opinion of the property owners at site H was that they were not very useful, but Mr. Ohmart at site X was fairly well satisfied with his installation.

Finally, although we did not specifically investigate structures of this type, vertical seawalls were observed in a number of locations along the shoreline during the aerial survey. In many of the older structures, at least a portion of the seawall had slumped, apparently due to scour at the structure toe. Also, there was seldom any beach in front of such a structure unless it was also protected by long groins. Even in many of those cases, water was fairly deep right at the seawall. However, as noted above, there are many places where the bluffs behind seawalls extend much farther lakeward of adjacent properties and it is clear that with regards to the prevention of bluff erosion, they must be fairly effective.

III. Adverse Impacts

Included in this area are issues such as erosion of adjacent properties and questions of esthetics. Both of these are somewhat subjective, but our perceptions are presented.

With respect to shoreline erosion on adjacent properties, there were no sites where this was obvious. This is probably logical due to the 2.5 foot drop in lake levels, so perhaps a more carefully framed question would be with regards to the rate of shoreline recovery. It was clear that there was a significant accumulation of sediment in some groin systems and that narrower beaches existed on the downdrift side in some cases. Perhaps the best examples of these were found at sites P and Q where the long tube groins had apparently trapped a fair amount of littoral material as evidenced by the broader beaches between the groin compartments compared to both updrift and downdrift. However, the beach downdrift (north) from the Diebel groins were narrower than that updrift from the Blackwell ones and this could possibly be attributed to less littoral material being available there. However, these tube groin systems were essentially filled and further disruption of the littoral drift should not be expected at these sites. As noted in Appendix A in the discussion of the individual sites, the relative width of the shoreline in the vicinity of these two groin systems has not remained constant over time and definite conclusions are difficult.

A major factor in many cases was the location of adjacent shore protection structures immediately downdrift from many groin systems and the effect of erosion or at least reduced accretion could not be readily assessed.

The steel sheet pile groins at Port Huron could possibly be expected to have created local erosion on their downdrift side due to the highly reflective nature of these groins. However, there was no real indication of this unless the property on the downdrift side was also protected by a high seawall. In these cases, beaches were minimal, but it is expected that the seawall and its wave reflection characteristics was more important than the groin itself.

The issue of esthetics is a very subjective one, but the most unattractive shoreline protection structures were those timber structures that were combination retaining wall and groin systems. Short groins in these configurations required small groin spacings in order to hold any littoral material. Coupled with the fact that the wood

deteriorates relatively quickly in the adverse environment made many of these structures particularly unattractive especially if they were more than a few years old. In several cases, lower profile wooden groins may have been more satisfactory as they would not have protruded so far out of the the sand. Clearly, time of installation with respect to the recent high water cycle was important in this regard at many of the sites as at several locations, the wood groins still stand three feet out of the beach due to the fact that they were installed during the very high water conditions.

The low profile tube groins were often nearly buried in the sand and did not seem nearly as unattractive. Finally, the steel sheet pile groins were long enough that they were typically placed at property boundaries and did not seem as out-of-place as other more closely spaced groin systems in the same vicinity.

Since most of the stone revetments did not have any beach fronting them, their value as a recreational facility is clearly limited. This is especially true with the consideration that very large armor stones are required in most wave climates. This would appear to be a major drawback to their use in many locations as they would interfere with the intended use of the beach.

The one sandgrabber wall that had been previously installed in Lake Huron (site Z) was not a very satisfactory arrangement in its particular location (Figs. B65 and 66). However, it was located on Saginaw Bay and this may have had a major influence. Apparently no significant amounts of sand were able to be transported through or over this wall. The site location, however, is such that very large waves are not likely at this site because of the location within Saginaw Bay and due to the shallow water for a fair distance offshore. Thus, this wall never functioned as should be intended with sand accumulating behind it. Furthermore, it was apparently possible during high water episodes for floating debris to pass over the top of the wall and be trapped behind as there was a fair amount of driftwood, etc. behind the wall. This installation seemed to be generally less satisfactory than the seawalls on either side.

General Comments

In addition to the comments noted above, a few observations were made primarily during the study of the permit applications. Various difficulties were

noted in trying to assess the extent of permit compliance and it appears that a few changes in the permitting procedure might be helpful in some cases. Following is a brief discussion of these issues.

- Several of the permits were expressed in terms such as "Lakeward end of existing and proposed structures shall be no more than one foot above existing lake levels."; "The western end of the permitted wall shall be placed no closer than 80 feet from the ordinary high water mark..."; etc. Although this type of terminology was not present in most permits, the possibility for difficulty in interpretation is readily apparent. With respect to the first statement, it is obvious that the water elevation is different now than at the time the permit was granted and this could be accounted for by determining the differences in mean lake levels between the two dates. However, the contractor may have placed the structure at still another lake level and it is not clear how to figure out what this may have been. Perhaps this issue is not as critical as the second type of statement. Since the shoreline changes over time, especially if the shore protection is effective, it is not clear that it would be possible at a later date to define a location for the shoreline at the ordinary high water mark, or with respect to any other specified water level.

A second difficulty that was often encountered in the interpretation of permits was associated with the fact that sketches in the permit application were so minimal or often inaccurate that it was not possible to get a sense of the shoreline from the information provided and in one case, we could not precisely establish exactly what structures were associated with the permit (site M). This could also be a problem in the decision on the permit application if the agency person did not visit the site to inspect it personally.

An additional observation was that in areas where the existing shoreline has been subjected to a variety of shore protection efforts over the years, there is a considerable variation in the relative position of the shoreline as one goes along the beach. As an example, most of the permits at the Port Huron sites, which are relatively close together, are for 50 foot long groins. However, because of the variable shoreline position, these protrude varying distances into the lake. Some adjacent ones that are approximately the same length protrude an extra 40 feet or so into the lake. A more logical procedure would appear to be to try to maintain a relatively

constant lakeward position of the groin ends. This would only be possible, however, if accurate drawings were provided in the permit application, a site visit was performed prior to the decision on the permit, or if aerial photographs were used to help guide the permit decision. This latter step may well be the only feasible way to develop this regulatory approach.

A final comment was with regard to interpretation of several of the permit applications. It is impossible to discern intent in this regard, but it is noted that several permit applications ask to install groins that extend, e.g., 40 feet offshore from the existing shoreline. As the permit was granted, the wording was revised to read that 40 foot long groins were permitted. It then appears that the contractor then constructed a much longer groin that perhaps met the intent of the original application and not the permit as granted. From reading through the permits, it is not clear exactly what was intended, but the potential for confusion exists at the least and that more explicit communication is necessary if these systems are not being constructed as intended.

RECOMMENDATIONS FOR FUTURE STUDIES

It would be useful to perform followup studies on at least some of these sites since many of them had not been in place for even a year at the time of the site visits and none have been installed for longer than three years. It would appear that about a two year inspection interval would yield sufficient detail to draw some better conclusions regarding structure performance. The value of such an effort at specific sites will depend upon the future trends in lake levels since many of the structures were completely out of the water during the summer of 1988 and all of them have been performing in an environment that had been associated with continuously declining lake levels that are not representative of the long term state of the lake system.

Some specific issues that could not be adequately addressed in the present study include:

* The issue of damage to the concrete filled tube groins to see if they have as long a useful life as some of the other possible groin systems.

* The deposition patterns within a groin system over several seasons to see if seasonal variations in wave climate have any effect on the apparent effectiveness of the structure.

* The effectiveness of the tube groins in an environment where the bottom material is largely cobble.

* The long term stability of heavy concrete units, such as wavebusters.

* The ability of the tube groins at the Epworth property to hold a sand beach with the entire shoreline protected by a revetment.

* The continued evolution of the shoreline at sites P and Q to more clearly define any possible adverse impacts.

If a followup study or studies are to be performed, it would be useful to reevaluate the sites that are to be investigated to delete some that appear to be of marginal value and to add some additional ones that might yield more useful information. With respect to additional sites that might be included in a future evaluation, the following thoughts come to mind:

- Other wavebuster systems should be evaluated than the ones included in the present study to better define the performance of this type of structure. Both sites included in the present study involved so many other shore protection structures that it is not possible to separate the various influences.
- We noticed a fair number of timber zig-zag offshore breakwaters, especially in the southern part of Lake Michigan. Some of them appeared to be in poor condition, but others were not; presumably this was due to the age of the structure but we did not have any specific information.
- No beach nourishment programs were investigated
- We noticed a large number of seawalls, many of which were in disrepair. It would be of interest to know how long some of them have been in place and to compare their useful life with that of other structures.
- A closer look at the issue of groin systems backed by vertical sills would be warranted.

With respect to the sites investigated in the present study, some of them did not yield very useful information because of the presence of surrounding structures that

dominated the shoreline response in the vicinity or for various other reasons. If an additional study is conducted in the future, it is recommended that the following sites be dropped from the study list:

- D - Not really a shore protection system and not effective as such where located.
- F - Site is dominated by adjacent higher and longer groins on both sides.
- I - Site is dominated by the shore protection to the north.
- L - This site is influenced strongly by adjacent properties that project considerably further lakeward, unless the shoreline as a system is to be considered.
- R - Wavebuster system was not constructed and probably won't be.
- S - Wall is buried in the sand and will not be impacted unless extreme water levels return.
- T - Groin system was not constructed and probably won't be.
- Z - Old sandgrabber wall did not accumulate much sand behind it and new one is to be constructed farther onshore.
- BB (and possibly also AA) - Will be out of water unless increases in water level occur.
- DD, EE - Probably dominated by longer groins on adjacent property.
- HH - Redundant information, other similar structures in immediate vicinity.

There are other sites that may be of marginal value, but the ones listed above are least likely to prove useful. Other sites are fairly similar, e.g. there are a lot of tube groin systems. Elimination of the sites listed above from further studies would cut the current group by one-third and allow the addition of several additional sites that would potentially yield more useful information. If a reduced investigation effort was visualized, then the original list could be pared even further.

APPENDIX A

DETAILED DESCRIPTIONS OF INDIVIDUAL SITES

Site A - Permit # 87-12-533G: Warwick Shores Condominiums, New Buffalo

The permit was to install seven groins constructed from concrete filled fabric bags approximately 100 feet long. The permit was issued in October of 1987 and the groins were installed that fall.

The original permit requested the installation of nine groins spaced at approximately 110 feet along the property line. This was amended during the permitting process so that the northern two groins were removed and no groins were to be constructed closer than 240 feet from the northern property line. As inspected, there were nine groins constructed and the most northern one appeared to be closer than allowed to the property boundary. Groin length was as permitted. The groins were constructed of concrete filled tube bags placed on filter fabric. The bags were approximately 3 feet wide and in some locations, two bag widths were used with an additional tube stacked on top of them. These are primarily at the shoreward end of the groins.

There is a small revetment that projects lakeward farther than the surrounding beach; it is apparently located at the property boundary to the northeast (Figs. B1and B2). This revetment protects a small building very close to the water's edge and has been there since at least the early 1970's. Aerial photographs over the last few years have generally indicated a shoreline that is relatively straight in the general vicinity except right at the revetment. In photographs from the years 1974, 1976, and 1980 the beach was always narrower on the downdrift (southern) side of the revetment than either farther to the south or on the north side of the revetment. In 1980 there was a fairly broad beach on the order of 100-200 feet wide all the way from the New Buffalo harbor to some additional revetments much farther to the south. The only irregularity in the shoreline is a small (about 200 feet long and 50 feet wide) indentation in the beach just to the south of the revetment.

The permit for this site was issued on October 22, 1987, and the groins are visible in the Army Corps of Engineers videotape taken on November 6, 1987. At this time, the shoreline is clearly recessed in the area of the northernmost groins in much the same fashion as indicated in the preceding paragraph. Since this must have been close to the time of construction, this shoreline state is considered to represent the condition from which the effectiveness of the system is judged. That is, although the beach at the groins is only a little wider in August, 1988 than surrounding locations, the system has apparently been effective.

The groins are installed perpendicular to the beach immediately to the south of this revetment and in the region where the beach appeared to be adversely affected previous to their installation. The littoral drift in this part of Lake Michigan is towards the south. The site is approximately one-half mile south of the New Buffalo harbor and is apparently being influenced by the coarse beach nourishment that was previously placed in that vicinity. There is a fair amount of coarse material on the beach here and the transport has clearly been from the north. The northernmost groins are nearly completely filled on the beach and sand extends to about 20 feet from the end of the groin. The beach slope is relatively steep (which we found for most beaches with coarse material) and the water depth is about 4.5 feet at the end of

the groin. About halfway up the beach, the littoral material is about 20 inches deeper on the north side of the groin than on the south (Fig. B3). Coarse material is more abundant on the north sides of the groins. It is reasonable to expect that these seven most northerly groins will be subject to little additional filling if there are no further drops in lake level.

The southern two groins have probably not yet filled. This is a little unclear since at the time of the site visit (8/8/88) and the aerial flight (8/29/88), there was an eight inch drop in the berm in this area, indicating that some recent event with waves from the west or southwest had probably scoured out some of the littoral material held in these groins (Fig. B1). Nevertheless, the shoreline is closer to the bluff in the southern two groins and it is likely that these will continue to fill with time. The last groin in the system at the southwest side of the property has been damaged towards its offshore end.

Site B - Permit # 86-12-464G: Warren Residence, north of Benton Harbor

The permit was to place two rows of concrete blocks along about 350 feet of shoreline. There were three rows of similar blocks that had been previously placed along the same shoreline around 1980. One of the new rows of blocks was to be placed at the toe of the bluff while the other row approximately 30 feet lakeward. The block dimensions were to be 4 ft by 4 ft by 4 ft and weigh about 10,000 pounds. The permit was issued in January, 1987

These blocks are sufficiently heavy that they would not be moved under almost any conceivable wave that could be expected at this site. They are of such a size that they act basically as a seawall. Of the previous three rows of similar blocks placed, one was at the toe of the bluff two additional rows spaced approximately 20 feet apart in the seaward direction. Of the new rows of blocks, one was to be placed at the toe of the bluff just offshore of the existing row and the second one was to be located between the two outer rows. It is not clear whether these two rows of blocks have been placed or not, and those visible on the beach appear to be present from the placement in the early 1980's.

The beach at this location is mostly composed of fine sand with very little cobble. The bluff is clay with vegetation (shrubs, trees, etc) nearly all the way down to the toe of the bluff, indicating that very little bluff erosion has occurred at this site in the last several years. There is also clearly clay below the beach and the concrete blocks have sunk through the sand down to the clay which can support them. Near the bluff toe, the blocks protrude up through the beach only about one foot on average, with a few sticking up as much as about two feet. Of the seaward rows, only the tops of some of the blocks are visible (Fig. B5). In fact, it is not obvious that the second row of blocks had actually been installed. In any case, it is clear that the weight of the blocks is responsible for the sinking of the blocks into the sand, probably during periods of high wave activity.

A key factor at this particular site is the presence of a large foundation block (Fig. B4) which serves as an anchor for an aerial tramway that provides transport to the top of the bluff. This foundation block is perhaps 15 by 20 feet in plan dimension and is located at the southern side of the Warren property. The farthest landward portion of this foundation is located approximately 60-70 feet seaward from the toe of the bluff. The beach is nearly 75 feet wide on the north side of the foundation block and there is essentially no beach to the south, so this is clearly acting as a groin in this region where the littoral transport is generally towards the south. This conclusion was reinforced by the inspection of aerial photographs at the Detroit District U.S. Army Corps of Engineers office. The foundation block was present in 1977, but there is almost no beach to the north with a somewhat broader beach to the south. Water is present behind the foundation block. This condition holds up to April of 1980 at which time the foundation block was approximately 100 feet offshore. No aerial photographs were available from then until April of 1986, at which time the concrete blocks are present on the shoreline and the foundation block is attached to the shoreline. Between April and October of 1986 (during which time the lake levels continued to rise) the beach increased in width and that trend has continued up to the present. It is fairly apparent that the placement of the original rows of concrete

blocks in the early 1980's stabilized the shoreline in the immediate vicinity of the foundation block and this resulted in a blockage of the southerly littoral drift at the site. This in turn has built a fairly broad beach for several hundred feet up the shoreline to the north.

It is concluded that the presence of this foundation block dominates the beach processes at the particular location. It has served as a fairly long groin and has stabilized the beach over the same location that the concrete blocks were intended to protect. Therefore, it is not possible to determine whether or not they have been effective. However, the one thing that is obvious is that on a sand beach, they would sink into the beach relatively rapidly and not be particularly useful. It is quite possible that even on the clay foundation that the blocks are apparently resting on, the absence of the sand trapped by the "groin" would result in erosion at the blocks and further undermining. This statement is made in light of the observations of beaches in front of sea walls at various locations along the Great Lakes shorelines.

Site C - Permit # 88-12-18G: Kasten property, near Glenn.

The breakwater was to be constructed of concrete units with a face that slopes downwards towards the lake. The units are about eighteen feet long and 7.5 feet high. The permit was issued March, 1988.

A condition of the permit is that the lakeward side of the breakwater be located no further than 25 feet from the toe of the bluff. There has been substantial bluff slumping in this particular area and the owner's residence is very close to the edge of the bluff (about 15 to 20 feet). The owner has dumped fill material on the face of the bluff in an attempt to stabilize it (Fig. B6). This is obvious from the fact that the bluff face has a different color than the bluffs on adjacent properties. As the bluff presently exists, the lakeward side of the breakwater is closer to fifty feet from the toe of the bluff. Also, apparently some gravel has been placed behind the breakwater to fill to the top of the breakwater and attempt to prevent further bluff slumping. It appears that decisions were probably made to not fulfill the specific requirements of the permit to provide additional protection for the residence at the top of the bluff.

The individual concrete units were reported to weigh about 4000 pounds apiece. They are resting on the clay underneath the beach in this area. Flanking protection is provided by curving the ends of the breakwater around (with the same units) so that they attach to the toe of the bluff. They extend lakeward about as far as the shoreline was in August, 1988. There are no other shore protection devices in the immediate vicinity of this property.

In view of the short length of time that this system has been in place, it is not clear that any specific conclusions are warranted. A key issue would be with respect to the stability of the foundation upon which the concrete units are resting and whether they will settle with time. Since the lakeward face has a slope of about 1:3 (vertical:horizontal), there should not be as significant a problem as occurs with vertical seawalls. It would appear possible that wave runup could be significant, especially if the lake levels come back up. A vertical concrete slab has been placed along a portion of the top of the sloping wall to deflect the runup and these may be sufficient to prevent significant overtopping of the breakwater. It is also possible if lake levels go down more that the waves will erode the clay at the forward face of the breakwater and pitch the units forward.

Site D - Permit # 87-12-598G: Tilton property, south of Saugatuck.

The permit was issued for a wood timber retaining wall. This wall is not actually along the lakeshore, but instead along Plummerville Creek, a small waterway that drains into Lake Michigan. The permit was issue in February of 1988.

The only conditions on the permit were that the wall not extend lakeward beyond a position that is within 80 feet of the shoreline at ordinary high water. In August of 1988, the end of the retaining wall was approximately 25 feet from the shoreline (Fig. B9) and clearly beyond this 80 foot limit. The original permit application was also obscure with respect to the actual site conditions. In the submitted sketch, a retaining wall was indicated as currently existing on the south side of the creek. In August of 1988, there was a groin projecting perpendicular to this wall which extended out into the creekbed. Also not indicated on the sketch were two wooden groins and a retaining wall along the lakeshore that tie into the southern retaining wall (Fig. B8 and B10).

The purpose of including this particular structure in this study is not entirely clear. If the wall had been constructed as permitted, it should have had no influence on protection from the wave climate of Lake Michigan. It is possible that waves run up the creek mouth and cause some erosion. However, at the time of the site visit, there was a very large amount of coarse gravel deposited around the creek mouth. It is possible that this has been artificially placed at some time in the past but does not seem likely. In particular, there is about 40 feet of material between the retaining wall and the creek. It is somewhat curious why the retaining wall would have been placed where it was if the purpose was to prevent additional erosion and there is some 40 feet of unprotected property between the creek and the retaining wall.

In this area, the retaining wall and the similar one along the south side of the creek along the with groin system extend farther lakeward than the surrounding shoreline and a relatively broad beach has formed, (Fig. B8) especially just to the north of this system of structures. This was apparent even during the extreme high water in 1986 at which time, it is one of the few examples of a beach along the entire southern Lake Michigan shoreline. Since this condition existed prior to the issuance of the permit, it is concluded that the structure has had no significant influence on the shoreline in the vicinity.

Site E - Permit # 86-9-644G: Goodrich property, north of Holland.

The permit is for the installation of a low profile wooden sill and groin system. The permit also allowed for the dredging of a small volume of sand from offshore to provide some beach fill. The permit was issue in October, 1986 and construction was completed that fall.

The purpose of the sill was to stabilize the toe of the bluff. One can see the lower 25 to 30 feet of the bluff has been subjected to relatively recent slumping (Fig. B11) and presumably this preceded the construction of the sill. The sill seems to be holding against the further sliding of this material. In August 1988, there was a fairly high berm built up on the shoreline and there was approximately 90 feet between the sill and the shoreline. The low profile groins constructed under the permit were completely buried and were not visible at all (Fig. B12) . In November of 1986, there was little beach visible in aerial photographs obtained for the U.S. Army Corps of Engineers all along the shoreline in this vicinity. It appears that the beach recovery is mainly due to the fall in water levels between November, 1986 and the present, rather than the particular shore protection system employed. This entire section of shoreline is extensively protected with similar sill and groin systems, however and no specific conclusions are possible.

Site F - Permit # 87-9-491G: Hierlwimmer property, north of Holland

The permit was for two low profile wooden groins and was issued in August of 1987. The groins were apparently constructed as permitted. There is an extensive groin system all along the entire shoreline in this area with at least four or five groins to either side of the ones in question (Figs. B14 and 15) . In fact, these two groins are lower and shorter than the surrounding ones and were completely buried in August of 1988 (Fig. B131). It appears probable that they are largely ineffective due to the presence of the surrounding (larger) groins and no definite conclusions are possible. There is a sandbar that has formed just beyond the end of the groins but there is no obvious reason for its formation at this particular location.

In inspecting other groins in the immediate vicinity, many of them have filled more on the southern side as compared to the northern side, indicating a reversal of littoral transport compared to those sites further to the south on Lake Michigan. Of the surrounding groins, those that are impermeable appear to be doing a much better job of holding the beach compared to those which have openings. A number of medium size boulders (on the order of 12-18 inches) have been placed near the shoreline just to the north of the groins in this permit (Fig. B14) . It appears likely that they will be rapidly lost (buried in the sand) as they are not large enough to be stable under large waves. They are not present in aerial photographs taken in 1987, so have apparently only recently been placed there.

Site G - Permit # 87-9-576G: Ehlert property, near Grand Haven.

The permit was issued in September, 1987 for the installation of a four foot diameter, forty foot long corrugated metal pipe that was filled with sand, sealed with grout, and installed as a groin. Other similar groins were installed to the south of this location. The system was apparently installed as permitted.

Aerial photographs of the area indicate a fair number of groins existing along the shoreline. At the time of the site visit in August, 1988, there was no obvious shore protection to the north of the site. However, the aerial photographs in 1986 and 1987 indicate a sill structure that either failed completely during the high water during the winter of 1986-87 or was buried by the rebuilding of the beach. The former is suspected, since the structure is no longer present in an aerial photograph taken in May, 1987 even though the total beach width has not significantly changed. Fairly recent slumping of the bluff is apparent from the site visit. The bottom appears to be composed of clay and as the lake levels have receded, they have left a sand berm on top of the clay. This has almost entirely covered the groin in question (Fig. B16) and those immediately to the south (Fig. B17) . The shoreline configuration has not significantly changed from the earlier aerial photographs, so it appears that the major effect at this location is the building of the berm due to the drop in lake levels. A sketch in the permit application indicated a narrower beach to the north of the location where the groin was to be installed compared with farther south. At the time of the site visit and the aerial inspection, this same condition existed (Fig. B18) . Therefore it is concluded that the placement of this groin has had very little effect on the shoreline at this location and point in time.

Site H - Permit # 86-6-332G: Dutch Boys Landing, south of Pentwater.

The permit was for the placement of approximately 1750 lineal feet of *wavebusters* to be placed along a section of shoreline that already had a system of groins as well as a steel *sandgrabber* wall. The permit was issued in October, 1986. Some of the wavebusters were placed closer to the shoreline than indicated in the permit drawings; it is assumed that this was done because the water depths were greater than anticipated in those locations. The wavebusters were not placed in all groin compartments, so the entire length of shoreline was not covered. It was our understanding that there was no intention to do any additional installation of wavebusters on the property as the owners were not particularly impressed with their effectiveness.

The wavebusters are a cast concrete unit approximately triangular in cross section with three horizontal slots distributed along the sloping face. The slot opening is greater on the lakeward face and the intention is to pass sand and water through the slots under wave advance, thereby dissipating wave energy. The wavebusters are four feet high and seven feet along the base. Some of them are clearly sinking into the sand (some are completely buried with sand) and it would be of interest to observe if further sinking occurs over time.

The littoral material at the site is primarily fine sand, with the drift being primarily to the south. No clear indications of large littoral drift rates are present. There is very little beach in the unprotected area just to the north of this project. Immediately to the south, there appears to have been a major fill at the toe of the bluff which is fronted by concrete rubble. Further to the south are a series of revetments, some of which are fronted by seawalls. In none of these locations is there a significant beach, whereas the project site has a beach of up to nearly 100 feet in width in some locations.

This is a site that is fairly complicated by the presence of a variety of structures. During the high water in 1986, the shoreline was at the toe of the bluff and further onshore than the sandgrabber wall which is a row of low profile sheet piling driven between the groins 50 feet or more lakeward of the bluff (Figs. B19-21). The wavebusters were installed farther offshore from the sandgrabber wall. The groin system is variable as well. There are a total of 24 wood or steel sheet pile groins along the shoreline with a spacing of a little less than 100 feet. The steel groins were placed between 1980 and 1982. Going from the north side of the property, the groins are: (1-3) wooden groins about 90 feet long; (4-8) wooden groins 90 - 120 feet long; (9) a 125 foot long wooden groin; (10) a 125 foot long steel groin; (11-13) steel groins about 100 feet long; and (14-24) steel groins about 65 feet long). The wave busters were to have been installed approximately 50 feet offshore or nearly to the ends of the southern groins. In the actual installation, the wavebusters were placed only about 15 feet from the sandgrabber wall along most of those southern groins. There is only a minor difference in the location of the shoreline in adjacent groin compartments that do not have the wavebusters present, and more differences are present between nonadjacent groin compartments than between adjacent ones with and without wavebusters. It is therefore assumed that they have played a relatively minor role in protecting the shoreline at this site.

Aerial photographs have served to reinforce this conclusion. To the south of this location, there are a whole series of revetments/seawalls that extend along the entire shoreline all the way to Silver Lake State Park. There is no beach in front of any of these structures. Approximately 1 mile north of the site, there is a groin system consisting of 5 groins that also seems to have built a much broader beach than the surrounding shoreline. In this particular installation, groins number 9 - 11 (counting from the north end) project further lakeward than any of the others. This is apparently due to irregularities in the existing bluff line. However, the groins to the north of these are basically filled with sand while those farther to the south have considerably less sand in them. The groins on the north side of the property have been in place since at least 1973, while the ones along the south were not present at that time. However, they were installed sometime between 1973 and 1978 and have filled only little in that time. This we attribute to relatively small net littoral transport at the site and trapping of much of this in the northernmost groins.

The wave busters are nearly completely buried along the first ten groins (Figs. B19-20) and in some locations not visible at all as the beach has built beyond them. Towards the south, water may stand all the way back to the sandgrabber wall and in most locations, water was observed on the shoreward side of the wall. There is no major pattern of filling on the north side of the groins. Groin length appears to be the major factor controlling the beach width at the site and it appears logical to conclude that the groins are the single most important component to the shore protection in place at this site. The sand grabber wall was placed only along the southern groins and the combination of the vertical face along with the shorter groins appears to have been much less effective than the longer groins in building a beach as the lake levels have receded.

Apparently during the high water in 1986, the groins were not high enough to protect the toe of the bluff. In some places, there is a wooden retaining wall that has been placed at the toe of the bluff while in others there is a revetment of *flex blocks* that has been installed (Fig. B19) . The flex blocks are a series of concrete blocks through which cables have been threaded so that the entire system is tied together as a flexible cover. There are gaps between blocks through which vegetation is growing at the present time. The owners are convinced that this system saved some houses during the high water. At the present time, it would not be impacted by waves.

Site I - Permit # 85-6-419G: Reid property at Ludington

The permit issued was for the construction of a low profile grout filled tube to act as a sill approximately 40 feet lakeward from the existing shoreline. Also permitted was the construction of a 60 foot long grout filled tube groin to be placed just north of the north property line and the extension of an existing wood groin on the south property line by the placement of a 75 foot grout sandbag along it. The permit was issued in July, 1986 and is immediately adjacent to the site J - Epworth Assembly property also included in this study.

In the site visit of August, 1988, the grout filled sill was not visible nor was the tube groin at the south property line. The tube groin on the edge of the Epworth property was in place; this is discussed in more detail in the next section since there are a series of tube groins along the south end of the Epworth property. An additional concrete filled tube groin was observed in the center of the property (Fig. B22) or considerable farther north than permitted if this was to correspond to the tube groin at the south property line. Only the very top of this tube groin is visible. The wooden groin at the south property line was the length of the one indicated as existing at the time of the permit application. The beach was about 90 feet in width at this time, so it is possible that the additional items associated with the permit application were completely buried. In May of 1987, the two groins (the central tube groin and the wood groin) were present in an aerial photograph by the Corps of Engineers during a time in which there is much less beach width and no sign of the sill or the extended groin is present. It is concluded that something quite different than permitted has been installed.

The tube groin on the Epworth Assembly property line projects lakeward at least 125 feet beyond the location of the proposed sill. The littoral drift is obviously towards the north in the vicinity from observations on the Epworth site. In May, 1987 and earlier, there was a sea wall structure (timber plank construction) at the south side of the Reid property with water standing behind it perhaps 50 feet. The Reid property projects at least 50-75 feet lakeward of the shoreline immediately to the south. By April, 1988 the seawall to the south is either completely gone or else has been buried in the sand and the shoreline has filled to a position about level with the wood retaining wall that is at the landward end of the two groins. By August of 1988, the beach had grown even wider and in front of the Reid property the shoreline is beyond the location of the edge of the Epworth Assembly property (Fig. B24) and clearly controlled by the tube groin at that location. It is concluded that the edge of the revetment and the tube groin on the Epworth Assembly property provide most of the shore protection at this site and this effect probably extends farther south than the Reid property which is only 183 feet wide. Apparently, the beach to the south is also strongly influenced by lake levels, since there was a fairly broad beach at this location in 1978 and the shoreline to the south of the Reid property was approximately 50 feet lakeward of its position in 1987. In 1973 and 1980, the beach to the south is reasonably wide, but there is no beach in front of the Reid property. This is probably due to the fact that the Reid property extends farther lakeward than the property to the south and also due to the fact that the Epworth property has a seawall (prior to the installation of the revetment) along the south boundary and this results in much wave reflection onto the Reid property.

Site J - Permit # 85-6-333G: The Epworth Assembly property, north of Ludington harbor

The permit was to place 2667 cubic yards of stone along 4000 feet of shoreline. The permit was issued in February, 1985. This stone armor was to supplement existing stone revetments already in place. So far as can be determined, the installation was according to conditions specified in the permit. There is a concrete filled tube groin system at the south end of the property that was installed during the summer of 1987 (at the same time as at site I), but no information was provided on a permit for this activity.

A variety of shore protection structures have been implemented along the shoreline in this location over the last ten to twenty years. There are the remains of a timber bulkhead (Figs. B25 and 26) that are present in the lake just offshore of the current shore protection with some portions of it being incorporated into the stone revetment. This system probably goes back at least fifteen years. Two steel groins were installed at the north end of the property, probably about the same period of time. Very little is still standing at present and these contribute nothing to the shore protection. A steel sheet pile bulkhead was installed along most of the shoreline approximately ten years ago. This is not regular and there are a couple of projections that jut out into the lake beyond a straight shoreline. After the placement of the sheet pile bulkhead, no beach developed on the lakeward side as the littoral material was scoured from in front. Sometime prior to 1982 (judging from aerial photographs, it was probably not long before that year) four rock groins were constructed out into the lake in an attempt to build some beach. Two were located near the southern property boundary while the other two were a considerable distance north (more than 1000 feet so the two sets do not influence each other). In April of 1982, an aerial photograph indicates that the two northerly groins had some deposition on the northern sides, but this was fairly limited in extent, perhaps 50 feet or less. By 1985, the southern two groins are scarcely visible in an aerial photograph of the site. In 1983 or 1984, the stone was initially added along the outside edge of the steel bulkhead (Figs. B26 and 27) and this was added to in 1986 under the conditions of this permit. Finally, in the fall of 1987, undercurrent stabilizers, concrete filled tube groins were installed near the southern property boundary. A total of six tube groins were installed in the first few hundred feet of shoreline from the south property line. These had been in place for about a year at the time of the site visit.

In the Corps of Engineers aerial photographs of April, 1988 there was no visible beach anywhere along the property. However, by August, fine sand was accumulating into a beach at several of the tube groins at the south end (Fig. B25). The beach was up to about 40 feet wide in August and is only significant between the first three groins. In particular, the southernmost groin, which is at the property boundary had accumulated a three foot higher sand beach on the south side; this beach is actually on the Reid property to the south, see site I. A sand beach had also formed on the north side of the groin, apparently due to the next most southern tube groin. Three of these tube groins are along a lakeward projection of the shoreline that is fixed by the bulkhead. Immediately to the north, the bulkhead, and thus the shoreline, moves landward about 30 feet and the other three tube groins are located directly to the north. These groins have also accumulated some sand, mainly in the

first two compartments, but the amounts are much less than the first three. It is presumed that these may continue to fill over time and eventually the beach would provide some measure of shore protection, at least at the present lake levels. Elsewhere along the property boundary, there is still no beach present. In one section towards the north end of the property, the stone was placed as a seawall with no bulkhead behind it to straighten out the shoreline in that vicinity. There is sand and a beach 20 to 40 feet wide behind the seawall, but not in front.

With respect to the items of the particular permit, it appears that the placement of the stone has served to adequately stabilize the shoreline although it is probable that the steel bulkhead would have served the same purpose. It is likely that the stone has served to prevent scour in front of and possible failure of the bulkhead, but this is only conjecture. It is presumed that the additional placement of stone was to replace some that had been displaced by wave motion over the last five years or so and it is realistic to expect a certain amount of maintenance with such an installation. However, the system appears to be very solid and it looks like the addition of the tube groins along with the lower lake levels will finally build a beach in front of the structure. It is likely that rising water levels could scour much of this beach material again.

Site K - Permit # 85-6-250G: Ludington State Park.

The permit was to construct two timber groins fields along the shoreline at Ludington State Park. These were constructed to protect the state highway M-116 at these two locations. The southern groin field (Fig. B28) had 13 groins while the northern groin field had 58 groins (Figs. B29 and 30). These groin fields basically replaced similar ones that had been constructed in the same location in the early 1950's. So far as is apparent, the construction was according to permit specifications. The remnants of the older groin system project further offshore than the new groins as part of a concession to reconstruct of the groin fields to a shorter length (Fig. B31). Also, the end groins in the fields are shorter and of lower profile as required in the permit.

The littoral drift in this particular area is apparently variable over the course of the year and there is probably not a major net component on a long term basis. From aerial photographs taken in April of 1988, the 13 groin south field appears to be filling from the northern end. A similar conclusion was drawn from inspection of the aerial photographs of the northerly groin field. However, during the site visit, the southerly groin field appeared to be slightly more filled on the south sides of the groins with a maximum of about six inches higher of sand as compared to the north side of the same groin. Aerial photographs at other times indicate a fillet on either side of the individual groins with no clear indication of filling from a particular direction. There were no obvious elevation differences in the beach material across the groins at the time of the site visit in the northern groin field. The littoral material is fine sand at both locations.

Since the present groin system is basically a replacement of the older groin fields, it is of some interest to compare the deposition patterns within the northerly group of 58 groins. Aerial photographs were available for both April, 1978 and April, 1988 from the Corps of Engineers. According to Corps of Engineers records, the mean lake levels were about 0.9 feet higher in 1988 compared to 1978. In the aerial photographs, the southernmost 12 to 15 groins were nearly filled at both time periods. Near the center of the groin field at both times, the compartments are largely unfilled. Towards the northern end of the groin field, the compartments are almost entirely filled and the similarities in patterns are striking (Figs. B29 and 30). In April of 1978, the beach in the central portion of the groin system is slightly wider than in 1988 and this is consistent with the lower water levels at that time. Unfortunately, there do not appear to be Corps of Engineers photographs available for the intervening years to observe the impacts of lake levels on the groin system.

MDNR aerial photographs were available for October 1973, 1974, and April, 1980. The same general trends as noted above were observed in nearly all cases. In 1973, the northernmost groins in the long groin field were not significantly filled, apparently due to the structure just to the north of the creek which may have been trapping littoral drift from the north. The general sedimentation patterns in the long groin field may be interpreted to indicate alternate filling from either end and the effect does not extend all the way to the center of the groin field. In any case, the beach on either side of both groin fields is no different in width than within the groin fields so it is not obvious that they are serving as an effective shore protection system.

Site L - Permits # 85-6-1761G and # 86-6-354G: Robert Johnson property, north of Manistee

Two permits were issued for this site. The first was to construct two 25 foot long timber groins. Since these were not extended to the existing bluff, a second permit to construct a low profile wooden sill behind them and terminating into neighbor's retaining walls on both sides was issued (a copy of this permit was not transmitted, but the correspondence associated with the first permit indicates the general details). The first permit was issued in August, 1985 and the second in July, 1986. Apparently, the groins were recognized early on as not being constructed in accordance with the permit and in particular, the southern groin was only 20 feet from the south property line instead of the required fifty feet. However, the total lot width was only 100 feet and the construction was allowed to remain. The wooden sill was specified to be constructed to tie perpendicularly into the retaining walls on either side (Fig. B33) and apparently this was not done on the south side where the sill sloped onshore back to the corner of the adjacent property owner's retaining wall. This was corrected and at the time of the site visit in August, 1988, the sill appeared to have been constructed according to the permit requirements. The groins are closer to 35 feet in length than the specified 25 feet in the permit application.

The shoreline in the vicinity of this property is a hodgepodge of short groins and retaining walls and it is difficult to imagine that most serve any useful purpose. For example, the property immediately to the south (Fig. B35) has a series of eight to ten foot long groins projecting out from the timber seawall at spacings of about ten feet. Both adjacent property owners have high retaining walls approximately six or seven feet above the water level that front the shoreline and then bend in towards the Johnson property. These walls must have surely focused a large amount of wave energy into the shoreline and it seems somewhat ironic that at least one of these property owners expended considerable energy in forcing his neighbor to solve a problem that he in large part created. Considerable erosion has clearly occurred in this area in the past as the bluff is considerably farther landward on this property than on the two adjacent lots.

The property immediately to the south has apparently been successfully protected over the years so that now it extends much farther lakeward than surrounding properties (Fig. B33). The groin system to the north was installed sometime between 1980 and 1984. While this system has not built a beach, it has apparently prevented further bluff erosion as the bluff on the Johnson property has receded further since then and has reached its present configuration.

In August, 1988 the beach which was composed mainly of sand with some small cobble extended just over half the length of the groins. The water depth at the end of the groins was only about six inches. The compartment in between the two groins had slightly less beach than the compartments on either side which were bounded on the outside by the neighbor's retaining walls. Since the retaining wall on the south side runs in towards the groin and there is about a three foot gap between the back of the groin and the sill, it would not be surprising to see that waves would be reflected back to the sill and at least part of the water passing through the gap and out between the two groins with sand left on the south side. A similar phenomenon may be

happening on the north side of the property line except that there is only a one foot gap and the waves probably spill over the groin, resulting in sand deposition on the north side of the groin.

Site M and N - Property of Lutheran Camp Association, Camp Arcadia at Arcadia

There were several permits issued for this property. One issued in March, 1985 (Permit 85-6-6G) was for a 230 foot low profile seawall with six 30 foot groins. These were extended from a similar construction under a permit (83-56-99) (U.S. Army Corps of Engineers) issued the previous summer. A second permit was for the construction of four 25 foot groins. (85-5-310G) This permit was amended to request the placement of 13,00 cubic yards of material dredged from the Arcadia harbor for beach nourishment. Modifications to an existing permit (85-56-004) (U.S. Army Corps of Engineers) were requested to add additional groins in the same general area. Finally, a permit (86-6-289G) issued in June, 1986 was to install a 225 foot long quarrystone revetment. Most of these permit applications were submitted with only minimal sketches and it is essentially impossible to correlate all structures requested in the various permits with the over thirty groins that currently exist along this section of shoreline.

The site consists of approximately 30 groins along the beach front. Moving from the south of the property, there are: five 25 foot long timber groins, four approximately 50 foot long groins (Fig. B37), three 40 foot timber groins, a 100 foot long concrete groin (Fig. B38), seven 30 foot timber groins, a 100 foot long concrete groin, and twelve 25 foot timber groins (Fig. B39). A steel sheet-pile sill exists between the concrete groins and this apparently corresponds to the request for modification to Permit 85-56-004 because most of the other requests were for timber seawalls. The revetment is installed behind the northernmost four or five of these groins. There is a revetment along the shoreline to the north of this site that belongs to the Arcadia Cottage Association (Site O) that is attached to the revetment on this site (Fig. B40).

In 1984, there were approximately 60 groins along the shoreline here, including the ones to the north that are now covered by the revetment installed by the Arcadia Cottage Association. In 1980, there were only three of these groins to the south of the most southerly long concrete groin so apparently the construction at the site has been carried out on a piecemeal basis over the last ten years or more.

The littoral drift at the site appears to be to the north as most groins had more sand on the south side of them (also, there is a significant fillet on the south side of the jetty at the Bar Lake inlet). The differences were not great, but the trend is clear. The short groins at the south end of the system had beach up to about five feet from the lakeward end of the groin. The longer groins north of them project further into the lake. North of the concrete groins, very little beach has accreted and the shoreline gets closer to the sill at the back of the groins at the northern end of the groin field. At the time of the aerial survey on August 29, there appeared to be a maximum beach width of about 10-15 feet immediately north of the northern concrete groin with all other beach compartments having no more than five feet of beach. The shoreline seems to be fairly regular compared to the irregular lengths of the various groins in this area. Further observations over a longer period of time will be required to see if these areas fill in further. No beach had existed in front of the sill during the high water of 1986 and only recently has much beach been present.

Site O - Permit # 86-6-137G: Arcadia Cottage Colony Association, at Arcadia

This permit was for the placement of a revetment along an existing timber seawall and groin system along a total of 920 feet of shoreline. There is an 800 foot length of revetment a 350 foot stretch of shoreline to the north and then an additional 120 feet of revetment. The permit was issued in June, 1986.

The revetment was over the top of an existing timber seawall which had short revetments projecting lakeward from the seawall. These groins are visible projecting through the revetment (Fig. B40). Along the 800 foot revetment, there is a short bluff and the armor stones were specified as weighing 4000-5000 pounds each. They were to be placed both in front of the seawall and up the front slope of the bluff on about a 1.5:1 slope (horizontal:vertical). The revetment is placed on smaller stones which are in turn placed on filter fabric. The 120 foot revetment design specified 4000-5000 pound stones in front of the seawall with 1000 pound stones behind it (after two rows of the heavier armor stones) to fill up to the existing grade. 4000 pound stones would be roughly 3.5 - 4 feet in dimension. Some of them are actually that large but there are also smaller ones present in the revetment. It appears that the stone is generally smaller than stated in the permit. There is also a fair number of stones that have toppled into the lake and are visible just offshore from the revetment. The seawall is visible along most of the 120 foot long revetment indicating that a significant amount of stone movement has occurred in this area.

A revetment was present in the vicinity in a November, 1984 aerial photograph, apparently located on the property between the two separate revetments constructed in 1986. In 1988, very little of that revetment is still visible and apparently almost total failure of it occurred during the recent high waters.

There is no beach existing anywhere along the front of the revetment. A key question is whether or not erosion in front of the revetment will create additional lakeward movement of the revetment stones. There has apparently been a significant loss of stone in the two years since the placement of the revetment. This appears to be due to the placement of too small of stones and the lack of sufficient material on the front side of the seawall. Even the design sketches indicate only a couple of rows of stone to be placed on top of graded 1/2 to 3 inch stones. There is too much size difference between these and the cover stones and the design seems to be inadequate.

The shoreline immediately to the north of the 120 foot long revetment has little shore protection (Fig. B42) and considerable shoreline retreat occurred, both between the years 1980 -84 and 1984 - 88. Also, shoreline retreat in the region where the older revetment had been located indicates that the shore protection is responsible for maintaining the shoreline position in this vicinity.

Site P - Permit # 87-6-301G: Blackwell property, at Elberta

The permit was to install two forty foot tube groins (undercurrent stabilizers) and 80 feet of "revetment" (actually another tube groin) along the existing shoreline. The permit was issued in July, 1987. In the permit application, the exact statement is to install the tube groins 40 feet into the lake from the existing shoreline, but design sketches and the permitted activity both appear to indicate tube groins of 40 feet total length, indicating that the shoreline was just off the toe of the bluff at the time of the permit request. As installed, the tube groins are approximately 100 feet long. The proposed spacing between the tube groins was 80 feet, but as installed, it is about 110 feet.

The tube groins are two bags high closer to the bluff and only one bag high further offshore. The revetment is basically the same height as the onshore sections of the groins and located just off the toe of the bluff. Nearly the entire groins have been covered with sand. The onshore, higher sections have a maximum of six to ten inches exposed above the sand. The offshore segment is completely buried at the onshore end and only the last ten to twenty feet of the offshore end is exposed (Fig. B45). This lies in the region of wave runup as the shoreline is located right at the end of the groins.

The beach is broader at this location than at the adjacent shoreline, so the systems appears to be fairly effective. There is no other shore protection on adjacent properties. To the north, there is a similar installation (site Q) about 600 feet further up the beach along with another set of tube groins between the two sites. There is no clear pattern of littoral drift at the site, although there are indications that the drift is generally to the north.

Aerial photographs of the site from years prior to the installation of the groin system indicate a relatively complex situation that is difficult to interpret. In 1974, the beach was fairly narrow in front of the Blackwell property and broader in both directions along the shoreline. In 1980, the same general situation is found, but in 1984 the beach is broader at the Blackwell property and narrower for approximately 1500 feet farther north after which a broader beach is again found. Thus, a number of changes have occurred along the shoreline over time during periods when there was no shore protection present and specific conclusions may not be possible from observations at a single point in time. At the present time, the beach becomes narrower about 200 feet north of the most northern Diebel groin and remains so for some distance up the shoreline, perhaps at least 500 - 1000 feet. A similar situation exists to the south of the most southern Blackwell groin (Fig. B45). Thus one is left with the impression that sand has been trapped by the groin systems with a tendency for littoral transport from south to north. Finally, it is noted that bluff slumping has occurred recently along the shoreline in this vicinity and that much of the sand close to the toe of the bluff could have come from that source.

Site Q - Permit # 87-6-302G: Diebel property, at Elberta

This permit is for the installation of three 40-foot undercurrent stabilizers or concrete filled tube groins. The permit was issued July, 1987 and the site is just to the north of the site P discussed above. Again, the actual groin length is about 100 feet compared to the permitted 40 feet. The actual permit language in one place implies that 50 foot total length is allowed with 40 feet of groin offshore from the existing shoreline. At this particular location, there are five of the tube groins. It is presumed that the northernmost three are the ones described in this permit and that the southerly two are from some other permitted activity. All five groins are spaced approximately 100 to 150 feet apart and the southerly two have a tube sill (similar to site P) up against the toe of the bluff.

The general state of this groin system is similar to the description for site P and the discussion for that site also considers this site as well. The onshore sections of the groins are two bags high and are nearly covered while the offshore section which is only one bag high has been nearly completely covered. Looking at the beach in this entire stretch of shoreline, one is led to the conclusion that these systems are working fairly effectively. As mentioned above, the northerly groin at site P and the most southerly of the five groins at this location are about 600 feet apart. The beach is narrowest about midway between this two groin groups (Fig. B44). Looking to the north from this site, the beach immediately narrows to about 40-50 feet (about half the beach width at the groin system) (Fig. B47) and continues at this width or less for a considerable distance up the shoreline where there are no shore protection structures present. Some of this may be due to erosion created by the interruption of littoral transport at the groin system, but the beach width at the time of the permit application was small because of the higher water levels. and the natural beaches have not recovered as quickly as the protected beaches here.

Site R - Permit # 86-6-437G: Congregational Summer Assembly property, at Frankfort

The original permit application requested the placement of a system of wavebusters at an offshore distance of 50 feet in seven 150 foot long segments with a 60 foot gap between them. The permit was amended to allow the placement of these 30 feet offshore. The permit was issued in December, 1986. These were never actually installed. It is presumed that the falling water levels in the spring of 1987 convinced the property owners to take no action at that time.

Site S - Permit # 87-6-23G: Hayes and Gosnell property, at Frankfort

The permit is for the construction of a 300 foot long timber retaining wall about 15 feet from the toe of the bluff. The permit was issued in July, 1987, at which time the construction had already been completed. The retaining wall was located at the shoreline that existed during the high water in the fall of 1986. It was constructed with short five foot long "groins" projecting lakeward at 20 foot spacings along the front of the wall; these are indicated in the permit application. This system was obviously constructed as permitted, since the permit was requested after the construction was completed in December, 1986 or January, 1987.

As early as December, 1986, the beach width was indicated to be 60 feet according to the permit application. At the time of the site visit in August, 1988, the beach width had increased to 90 feet. The top of the retaining wall projects at most about eight to ten inches above the beach on the Gosnell property (Fig. B48) (at the outer edge of the short groins) and the wall is scarcely visible on the Hayes property. In light of the fact that construction was undertaken during the time of extreme high water levels and due to the low profile of the retaining walls, it is concluded that these have had no effect at all on shoreline erosion or beach protection in this area. The adjacent shoreline location and condition is essentially equivalent to that in front of these two properties. Perhaps if the water levels in the lakes return to their 1986 highs, the walls will be tested to determine their effectiveness.

Site T - Permit # 86-5-309G: Inwood Harbor Property Owners Association, at Elk Rapids

The permit was to place two timber crib rock-filled groins at the harbor entrance and to dredge the entrance. The two activities were separated, apparently for administrative purposes. The dredging permit was issued in March, 1987. The groins were to be 50 feet in length and project 50 feet lakeward from the toe of the bluff, apparently to prevent sedimentation in the harbor entrance channel. At the time of the site visit, there was only loose stone along the north side of the harbor entrance that presumably was associated with an activity sometime in the past. There has been no construction activity at the site and no plans for anything at present. Apparently, a decision has been made to continue dredging the mouth of the harbor whenever required, and this seems to be a reasonable choice.

Site U - Permit # 86-5-81G: LaCroft Condominiums, at Charlevoix

The permit was to construct a grout-filled bag seawall fronted by seven 45 foot long, grout-filled bag groins. The permit was issued in June, 1986. It was constructed during the summer of 1987. The groin length is a little longer than permitted. The major deviation from the permit application is the placement of a second tier of bags approximately 25 feet offshore from the permitted one (Fig. B49-52). This is composed of a two bag base topped by an additional bag. The onshore bag wall is at least four tiers high (Fig. B52), rather than the permitted three. It is not present in the last groin compartment on the eastern end of the system. Also, apparently only six groins were actually constructed. In the permit, only a single bag is indicated for the cross section of the groin whereas the actual cross section is a two bag wide base topped by a single bag crest.

This system is located approximately 800 feet northeasterly along the shoreline from the (approximately) 750 foot long jetty at the Round Lake inlet and this would appear to have a major influence on the system in which the prevailing drift is in the northeasterly direction. In 1980, the beach width in the lee of the jetty is clearly narrower than the surrounding shoreline, but this is not the case in 1973 aerial photographs.

The system is more filled with fine sand in the southwestern end than in the eastern end (Fig. B49). A beach exists just offshore of the offshore sill in the two southwesterly groin compartments and has filled behind up to the top of the sill. Littoral drift is clearly southwest to northeast in this location and the deposition patterns are consistent with this. Sand has filled to the top of the most southerly groin on the west side except at the offshore end. The lower row of base bags is visible on the east side of this groin along the two offshore bags. A similar state exists in the second groin compartment, but the third and fourth are much less filled (Fig. B50) and the offshore sill is much more exposed in those and no sand beach is visible offshore from the sill. The shoreline location in the last groin compartment which has no outer sill is about equivalent to the sill location in the adjacent compartment. This whole system has a much higher beach profile than most of the other groin systems investigated and it is concluded that more time will be required before the system is completely filled.

The top bag at the outer end of the most southwesterly groin is already beginning to deteriorate as is the corresponding bag on the most northeasterly groin.

Site V - Permit # 88-5-127G: US 31 shoreline east of Charlevoix

The permit was for the placement of 12 tube groins (undercurrent stabilizers) along the shoreline in various locations where shoreline recession is threatening the state highway. There were three sets of tube groins, one with three, another with four, and the third with five groins. The permit was issued in June, 1988. The tube groins were permitted to be forty feet long with seventy foot spacing in all cases. The set closest to Charlevoix (set 1) is the five groin group (Figs. B53-55) and the middle three groins are approximately seventy feet long. The second group is the four groin group while the third which is farthest from Charlevoix has three groins. These latter two groups were apparently installed as permitted.

The onshore ends of the tubes do not extend all the way the the highway embankment, but are terminated above the present water level. At their onshore end, there are shorter bags stacked to make a large "bulb" (Figs. B55-56). The tubes at their offshore ends are typically either just below or just above the present water surface (Figs. B54-56); this varies with the particular groin set and the individual groin. Thus, they are relatively low profile.

Since the groins were only recently installed, there is insufficient time to draw any conclusions regarding their effectiveness in protecting the shoreline. In all three locations, the groin groups are installed in small bays from which rocky points projects into the lakes at both ends. The littoral material is mostly flat cobble four inches or less in dimension. However, there are also some larger stone over one foot in dimension. Very little sand is visible in the region. Observations of these systems will have be continued into the future before any reasonable conclusions may be drawn.

Site W - Permit # 86-5-372G: Bay View Association, at Bay View

The permit is for the placement of 1415 cubic yards of stone riprap along 370 feet of shoreline to construct a 19.5 foot wide revetment. One ton stone was specified for the armor layer with 200 pound filter stone beneath. The permit was issued in October, 1986. So far as is apparent, the system was constructed as permitted. The armor stones are approximately of the specified size.

At the time of the site visit the water levels had dropped to the point where the revetment is completely above the existing shoreline. Some of the armor stones have been displaced lakeward especially along the northeastern end of the revetment. The beach is very coarse cobble at this location with very little sand (Fig. B59). Beyond the revetment to the east, some sandy beaches are present.

It is not entirely obvious why this structure was constructed. It appears as though it is not necessarily a shore protection problem so much as a wave runup problem. It appears as though the relatively flat shoreline (Fig. B57) may have been subject to extensive wave runup during the last high water period and that the structure may have been constructed to control this.

Site X - Permit # 86-5-154G: Ohmart property, at Alpena

The permit is for the installation of wavebusters along 1300 lineal feet of shoreline. Four 30 foot gaps were to be installed along the structure and it was to be located 50 feet off the existing shoreline. The permit was issued in October, 1986 and construction was completed that fall. The major discrepancy between the permit application and the actual construction was that most of the proposed length of structure was never completed. Two types of wavebusters were used, (Figs. B60-62), the standard one used on all Lake Michigan sites considered, and a taller (six foot) "Normandy Wavebuster" which has two vertical slots as compared to the three horizontal ones in the others.

The wavebusters were installed on four properties: 240 S. State, 250 S. State, 430 S. State, and 442 S. State. Each property is on the order of 80 to 100 feet in width. The first two are adjacent properties with the other two further south and with one property in between the two southern installations. Of the two northern ones, the installation on 240 S. State was the Normandy style, while the other three were the shorter type with horizontal slots. The two northern ones were installed in a continuous line. The ones at 442 S. State were installed farther offshore and in deeper water than those at 430 S. State.

The situation along this shoreline is complicated by the various existing shore protection systems and their relative success. The property at 240 S. State extends much farther lakeward than the surrounding properties. This property has riprap behind the wavebusters (Fig. B60) and no beach is being restored there. In fact, the wavebusters are barely offshore here as this property projects farther lakeward than any other in this vicinity. Also the revetment to the south of 250 S. State holds the shoreline farther offshore than surrounding properties. Consequently, the Ohmart property (250 S. State) is tucked between two revetments and probably protected from further erosion (albeit at a more shoreward position) even with no shore protection. The beach on the Ohmart property has shifted over the years with the variation in lake levels but generally is stable in accordance with the above conclusion. Therefore, it is questionable whether the wavebuster systems serve any functional value at the particular locations.

The wavebusters at the south side of the property line at 250 S. State appear to be sinking into the lake bottom (Fig. B61) and property owners report that rearrangement of individuals units has occurred due to settlement. The bottom does not appear to be changed too much in the immediate vicinity of the structures. The shoreline location at the two southern wavebuster installations has not yet responded to the installation of the units. That is, the property on either side of 430 and 442 S. State has a shoreline position that is about equivalent to those properties (Fig. B62). However, since the two properties are only about 100 feet apart and there are revetment within a couple of hundred feet on either side of the wavebuster systems, it is not clear that a conclusion regarding the effectiveness of the wavebuster systems is possible. It is unfortunate that of the three sites with wavebuster installations included in this study (with one not being constructed), not one was really installed in a situation where the effectiveness of the system could properly be judged.

Site Y - Permit # 87-7-232G: Various properties, Tawas Point

The permit was to install a new wooden pole wall 1700 feet long in front of a similar deteriorating structure and to fill behind this wall with rock. Pile "icebreaker" clusters offshore of this wall were also included in the permit. The permit was issued in April, 1988.

The site is characterized by existing structures similar to that described above (Fig. B63), except that the existing pole wall is in fairly poor condition. An additional problem is that the previous construction was undertaken in a piecemeal fashion with some walls extending farther lakeward than others, The plan as presented in the permit application proposed to tie the whole lakeshore together in a more continuous fashion with an overall plan presented for a whole stretch of shoreline. However, it appears that a good number of the property owners will not be participating in the project and the shore protection will again be undertaken in a piecemeal fashion here. The existing wall is about sixteen years old at present and appears to have been reasonably stable although there is no beach in front of the wall and water depths are typically 3-5 feet at the walls.

In August of 1988, only a few residents were installing their walls. In particular, the Shaw and Heller residences were in the process of installing their walls (Fig. B64). This site should be investigated again in a couple of years to see what has been done on the site and the structure performance.

One problem that was apparent at this site associated with the existing structure was related to the rock fill behind the pole wall. The stones were shale or limestone and were relatively flat. Some of these had been broken by the wave action and had then fallen lakeward. Also, the front face of the fill was too steep and even some unbroken stones were sliding into the lake. This occurrence was associated with the deterioration of the pole wall, but indicates that both components of the system need to be in good condition in order for it to be effective. Larger and stronger stone would have been required at this site had not the pole wall been present.

Site Z - Permit # 86-8-347G: Fair property, at Linwood

The permit was to remove an old *sandgrabber* wall and to replace it with a similar system along the 128 feet of lakefront. The new seawall was to be constructed generally fifteen feet onshore from the old wall. The permit was issued in July of 1987 and has not yet been constructed.

The old wall was attached to a sheetpile seawall on the north side and tied into a dock on the south. It was about fifteen years old and beginning to fail in a few locations. Seawalls in the vicinity may up a fairly straight shoreline in this area with the sandgrabber wall extending slightly farther lakeward (Fig. B65). Apparently, this is the reason that the permit specified that the new sandgrabber wall be placed further onshore. The old wall did not accumulate much sand behind it (Fig. B66). This is apparently due to the fact that the water is fairly shallow for a considerable distance offshore here and no large waves could wash over the structure here and carry sand behind it. What did happen is that floating debris could be lifted over the wall and trapped behind it. At this site, the use of a sandgrabber did not appear to be a good choice at all for shore protection and it is not clear why the owner chose to attempt to construct a second one.

Site AA - Permit # 86-8-222G: Gregoire property, at Linwood

The permit was to construct two 50 foot wooden jetties lakeward of an existing seawall. The permit was issued in October, 1986 and constructed that fall. The installation appears to have been made according to the permit specifications.

Sand is accumulating to a minor extent on the north side of the groins. The beach is composed of sand. The shoreline in late July, 1988 was approximately 40 feet lakeward of the offshore ends of the groins (Fig. B67). During the high water in 1986, the water were overtopping the seawall. It appears that the major influence at this site has been associated with declining water levels and the fairly flat nearshore slope has resulted in a large change in the shoreline position.

Site BB - Permit # 86-8-126G: Dwan property, at Bay City

The permit was to construct a low profile timber groin tied into a concrete block wall on the landward side. The specified wall length was 36 feet. The permit was issued in June, 1986. The wording of the permit with respect to groin length is so vague that it is not possible to determine the actual intent. The groin, as constructed, is about fifty feet long.

There have been in this time period, four groins of approximately the same length constructed at approximately 50 foot spacings. The whole system seems to be working fairly effectively. In July, 1988 the groins were entirely out of water so changes in lake level have also been important. These groins project lakeward farther than the sandgrabber wall on the north and the shoreline is in front of the sandgrabber wall and the lakeward ends of the groins approximately an equal distance. During the spring of 1988, there was no shoreline in front of the sandgrabber wall and the shoreline was at the lakeward end of the groins. During the high water of 1986, before the installation of the groins, there was only about fifteen to 20 feet of beach in front of the block walls. One property owner reports that most of the sand has been accumulated during storm events.

At this site, as in the two previous ones, there is a lot of sand in the offshore region (Fig. B68) and the water depths are fairly shallow for a considerable distance offshore. It seems likely that it was only the problem of the extremely high water and the wind seiche on Saginaw Bay that may have caused problems at these sites. A very broad beach naturally exists to the south of the site in locations where little, if any, shore protection is present. It is concluded that most of the changes at this site are associated with changes in lake levels and not the effectiveness of a particular shore protection system.

Sites CC - II Various properties, north of Port Huron

These are all included in one general discussion because they are all in the same general area of the shoreline and in each case, the permit was to construct steel sheet pile groins. Specific details of each permit follow (properties are listed north to south along shoreline):

CC - Permit # 87-11-614G: Uligian, October, 1987; extend 2 existing jetties and install three new ones, all jetty ends to be aligned at offshore end, jetty lengths are variable

DD - Application # 87-11-733G: Sharpe extend existing steel jetty

EE - Permit # 86-11-473G: Cole, July, 1986 Install 50 foot steel jetty

FF - Permit # 87-11-483G: O'Connor September, 1987; install 50 foot steel sheetpile jetty

GG - Permit # 87-11-443G: Durand July, 1987; install 60 foot steel sheetpile jetty

HH - Permit # 87-11-187G: Wine, April, 1987; install 50 foot steel sheetpile jetty

II - Permit # 86-11-744G: Shumaker, Fall, 1986 Install three 50 foot steel sheetpile jetties

Of these above structures, the Uligian jetties have not yet been constructed (as of July, 1988). The information provided on the Sharp jetty was that a permit had been denied to extend the existing 42 foot steel jetty an additional 21 feet. This denied extension has not been constructed. The Cole jetty has been constructed as permitted. The O'Connor and Durand jetties are approximately 100 feet long. The Wine and Shumaker jetties have been built as permitted.

There have been several other of these steel sheet pile groins installed along this stretch of shoreline. Various other jetties (including some very long ones farther to the north) have been in place over the years and generally appear to be effective in trapping the littoral drift. This shoreline is composed of fairly coarse gravel and cobble and the prevailing littoral drift is from north to south (Figs. B69, 70, and 72). Beach slopes are relatively steep as could be expected with this coarse material. A series of older gabion groins that are rock filled have been along the shoreline (at least some were installed in 1973 during the previous period of high water) and are largely deteriorating. Also many people have put up high steel sheetpile retaining walls to hold their property on the lakeward side. In nearly all cases, the lake is right up against the retaining walls in those areas where groins do not presently exist; a good example is the Uligian property. Where the steel sheet pile groins have been installed next to a seawall, for example, the next property south of Sharpe, a fillet has built up in corner of the northern side of the groin but this does not extend all the way across the property due to the steep beach slope (Fig. B69). Sharpe's have a similar situation except that the fillet extends entirely the way across their lot with

about a 20 foot wide beach on the north side of their property and a 45 foot one one the south side.

No sign of significant erosion on the downdrift side of these groins is apparent, perhaps because of the response to the falling lake levels. A significant amount of accretion has occurred on the north side of most of these groins. For example, the shoreline on the north side of the O'Connor groin is about fifteen feet further lakeward than the shoreline on the south. Just onshore from the water line, the beach is about 20 inches higher on the north side of the groin and this differential extends most of the way up the beach. A similar situation exists at the Durand groin which is just south of this one (Fig. B72). Both of these groins were constructed in late summer, 1987 so that much littoral material has accumulated in one year. Although the situation is perhaps a little more pronounced at these groins because of their length, similar behavior was noted at most of the other groins. The one major exception was the Cole groin and very little material appeared to be accumulating on the updrift side of it. There is a 75 foot long groin just north of the Cole property and possibly this intercepts enough littoral drift to prevent accretion in the Cole groin. In any case, this beach is much more uniform north to south (although the beach is slightly wider on the south side of the property) and is the exception in this vicinity. This beach is also composed of finer material than everything else in the area.

In most cases, the material on the north sides of the groins is much coarser than on the south side (Fig. B76). However on the south side, the material is a fairly uniform coarse gravel. On many lots the north side appears to be sandy, (Fig. B71) but if one digs down a short distance, cobble in the range of 2-5 inches is encountered. Thus it appears that very coarse material is being retained by the groins and some of the relatively finer material is bypassing them.

APPENDIX B

PHOTOGRAPHS OF INDIVIDUAL SITES

Figure B1. Site A: Aerial view of entire project. Note revetment in upper left of photograph, on northern side of property. Six to eight inch slump in beach visible as dark line in southerly two groin compartments in lower right side of photograph.

Figure B2. Site A: Looking along beach in a southerly direction from revetment just north of property. What appears to be groin ends is actually the end of the second tier of bags and groins extend into the water.

Figure B3. Site A: Third groin from northern side of property, looking only at end that is one bag high. Note significant filling of cobble on north side of groin with beach level on southern side nearly 18 inches lower.

Figure B4. Site B: Aerial photograph of concrete foundation block for tramway, at southern edge of property. The shoreline is at the outside edge of block on the north side and at the landward edge to the south.

Figure B5. Site B: View of concrete blocks towards southern side of property. Note row of blocks at right, located at toe of bluff A second row is almost completely buried in the sand to the left of the first row and a few random blocks such as those in upper left have been recently placed on existing beach.

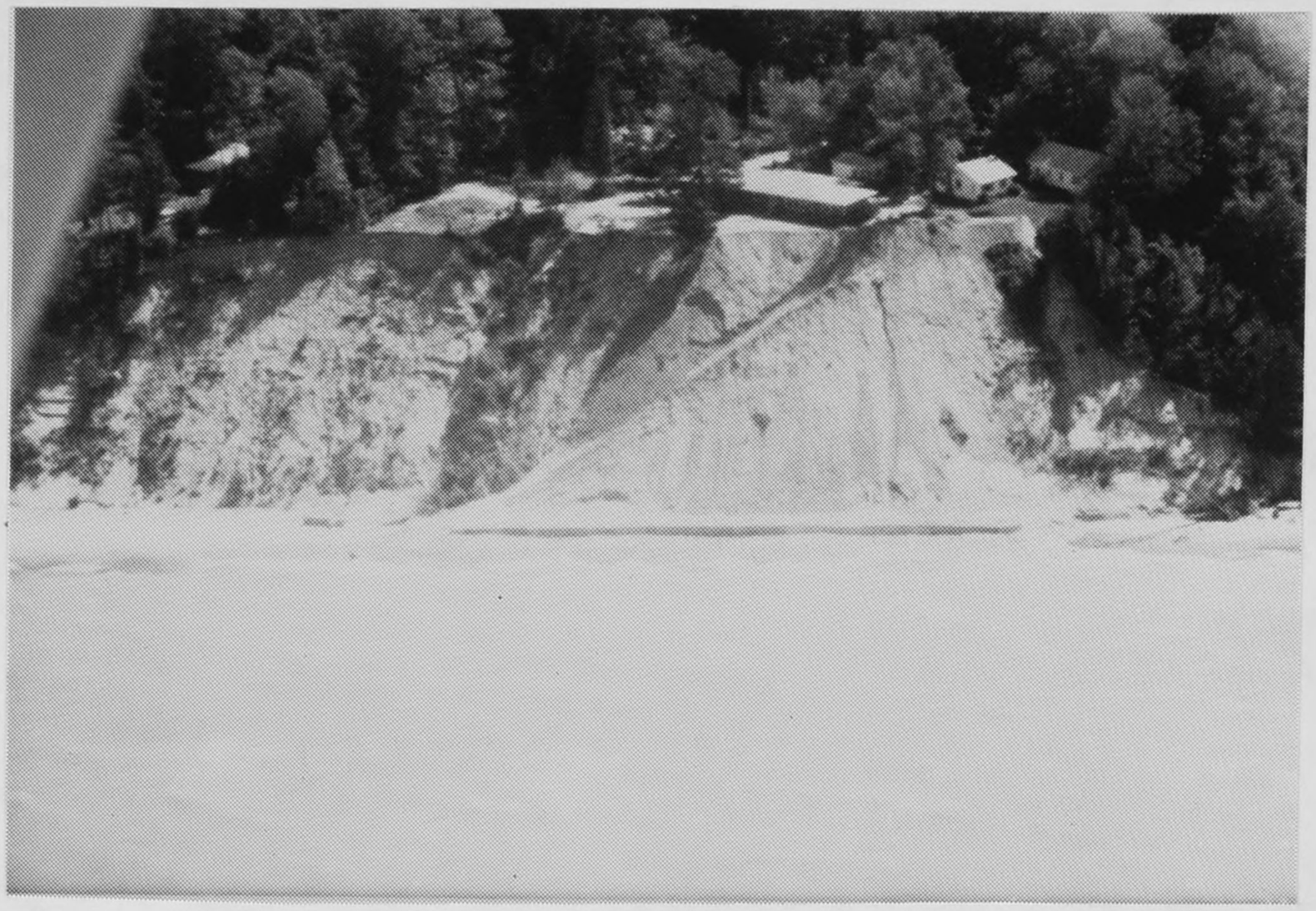


Figure B6. Site C: Aerial view of structure. Kasten property is that with diagonal path down to the left. Dark line above water's edge is the vertical sections of the modular units.

Figure B7. Site C: View of modular units looking from offshore onto the structure.

Figure B8. Site D: Aerial view of site. Retaining wall is dark line on north side of creek which enters lake in center of photo. Note greater width of beach compared to either side of photo, also groin and sill system on property to south of creek.

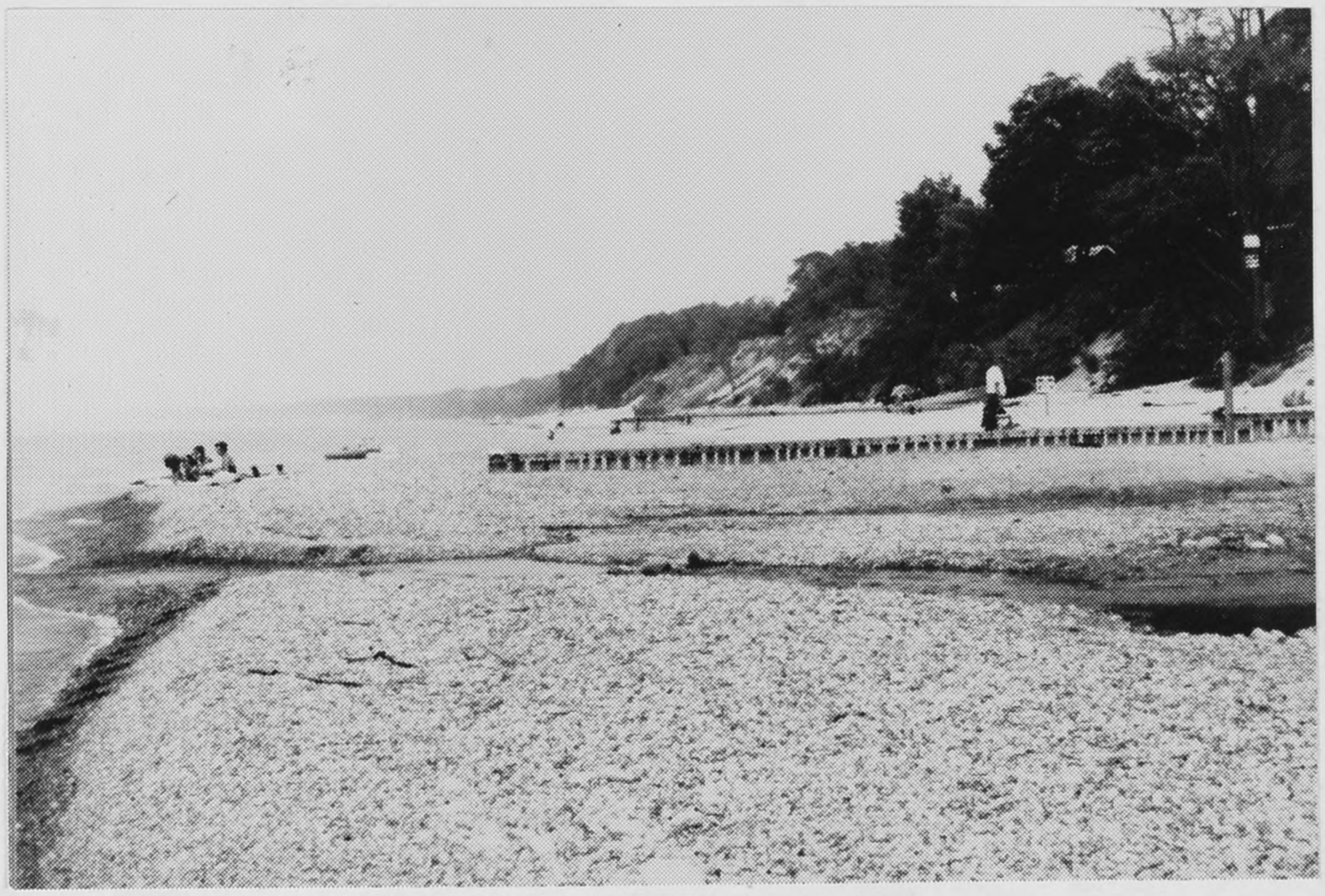


Figure B9. Site D: View of retaining wall from the south side of creek. Decrease in beach width to the north is possible to make out from photograph.

Figure B10. Site D: View of groin system on south side of creek. Decrease in beach width to the south is fairly clear in this photograph.

Figure B11. Site E: Top of retaining wall is visible at toe of bluff. Straight line in foreground is where beach level drops immediately at shoreline with beach perched more than 12 inches above water level. View is towards south.

Figure B12. Site E: Looking to the north from southern edge of site. Shoreline is more visible in this photograph. Top of retaining wall is barely visible at right center of photo.

Figure B13. Site F: Looking offshore along top of nearly completely buried groin. Horizontal members are not visible.

Figure B14. Site F: Looking south towards site from two properties to the north. Top of buried groin is immediately behind stone filled groin compartment in foreground.

Figure B15. Site F: Looking north towards the site. Buried groin is to the north of the four groins in the foreground. Note longer and higher groins on either side of property.

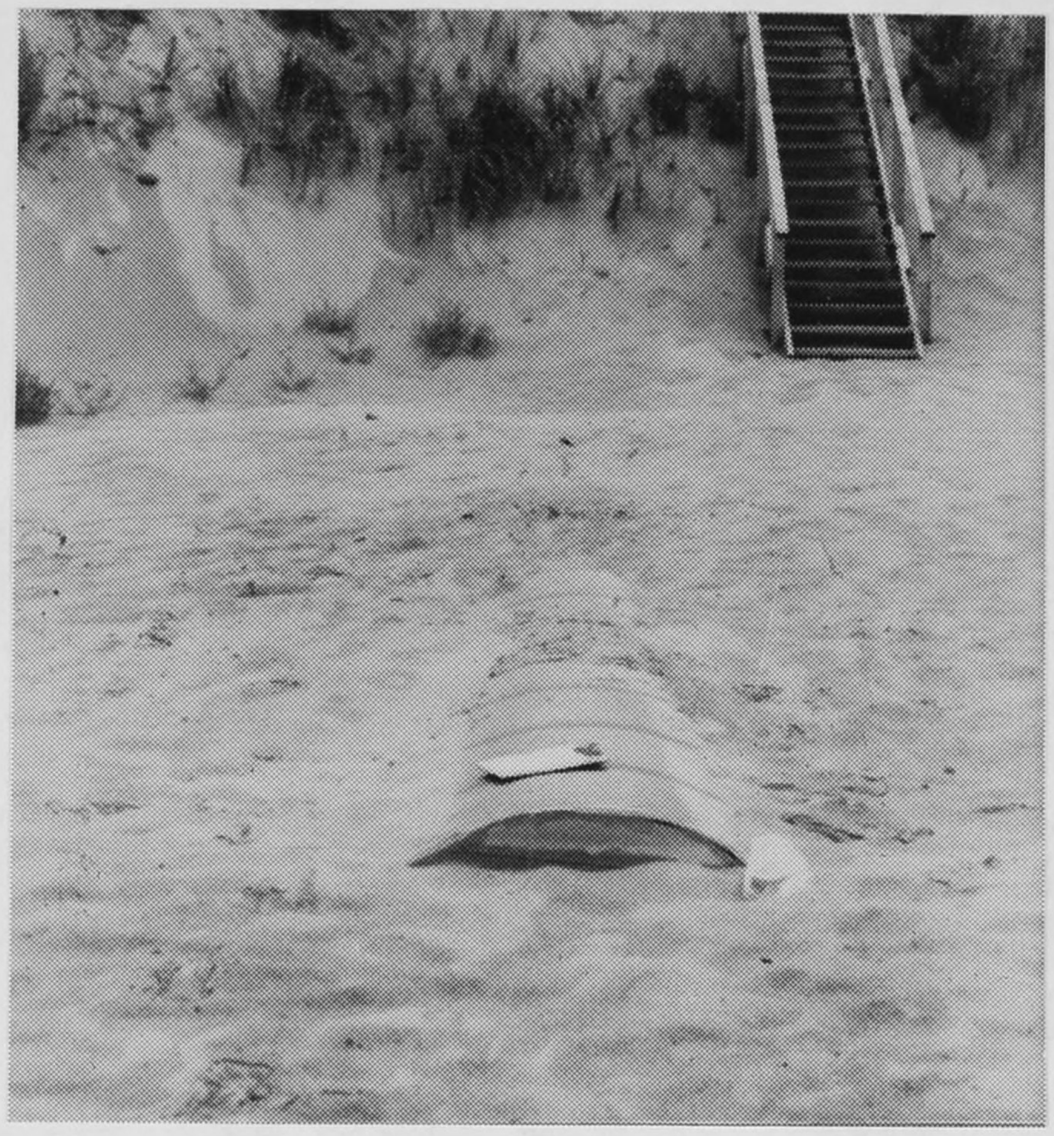


Figure B16. Site G: Looking directly onshore from beyond end of groin, Note that groin is almost completely buried with no beach elevation difference across groin.

Figure B17. Site G: Looking south at groin. Both end of groin are visible in center of photograph.

Figure B18. Site G: Aerial view of property. End of groin is visible in upper center of photograph. Beach is slightly narrower just to north of groin end.

Figure B19. Site H: View towards the north of the last eight groins at the northern side of the system. Tops of wavebusters are visible at lower left side of photograph. Flex-blocks are visible in foreground at toe of bluff.

Figure B20. Site H: View of tops of wavebusters between groins 8 - 10 from north end of site. Wavebusters in center are also visible in Fig. B19. Note sills onshore from wavebusters.

Figure B21. Site H: Looking towards southern end of property from approximately the middle of the groin system. Note that southernmost groins are shorter than the two closest ones. Wavebusters are present in lower right of photo.

Figure B22. Site I: Looking south across Reid property, standing on Epworth property (site J). Tube groin on south side of Epworth property is in foreground, Light colored tube groin at center of property is barely visible below and right of sign. Timber groin at south side of property is also visible and note lack of beach farther o south.

Figure B23. Site I: Looking north across property. Timber groin at south property boundary is present at center right and end of tube groin on Epworth property is also visible below edge of line of trees. Epworth property is on other side of sailboat.

Figure B24. Sites I and J: Tube groin (part of Reid permit) on south boundary of Epworth property. Note accumulation of beach on south side of groin and slight accumulation behind other tube groins to north (in vicinity of old timber retaining wall).

Figure B25. Site J. Tube groin just to north of one in Fig. B24. Note damage to groin top and sand accumulation on south side.

Figure B26. Site J: Aerial view of northern part of Epworth property. Revetment is visible along shoreline with remnants of old shore protection systems.

Figure B27. Site J: Closer view of revetment at location where it is backed by a retaining wall.

Figure B28. Site K: Aerial view of 13 groin field. Note remnants of old groin system.

Figure B29. Site K: Aerial view of southern end of long groin field. Note that groins in southern portion of groin field at lower right are completely filled.

Figure B30. Site K: Aerial view somewhat to the north of Figure B29. Northern end of groin field only is visible. Note that some groins are almost completely filled.

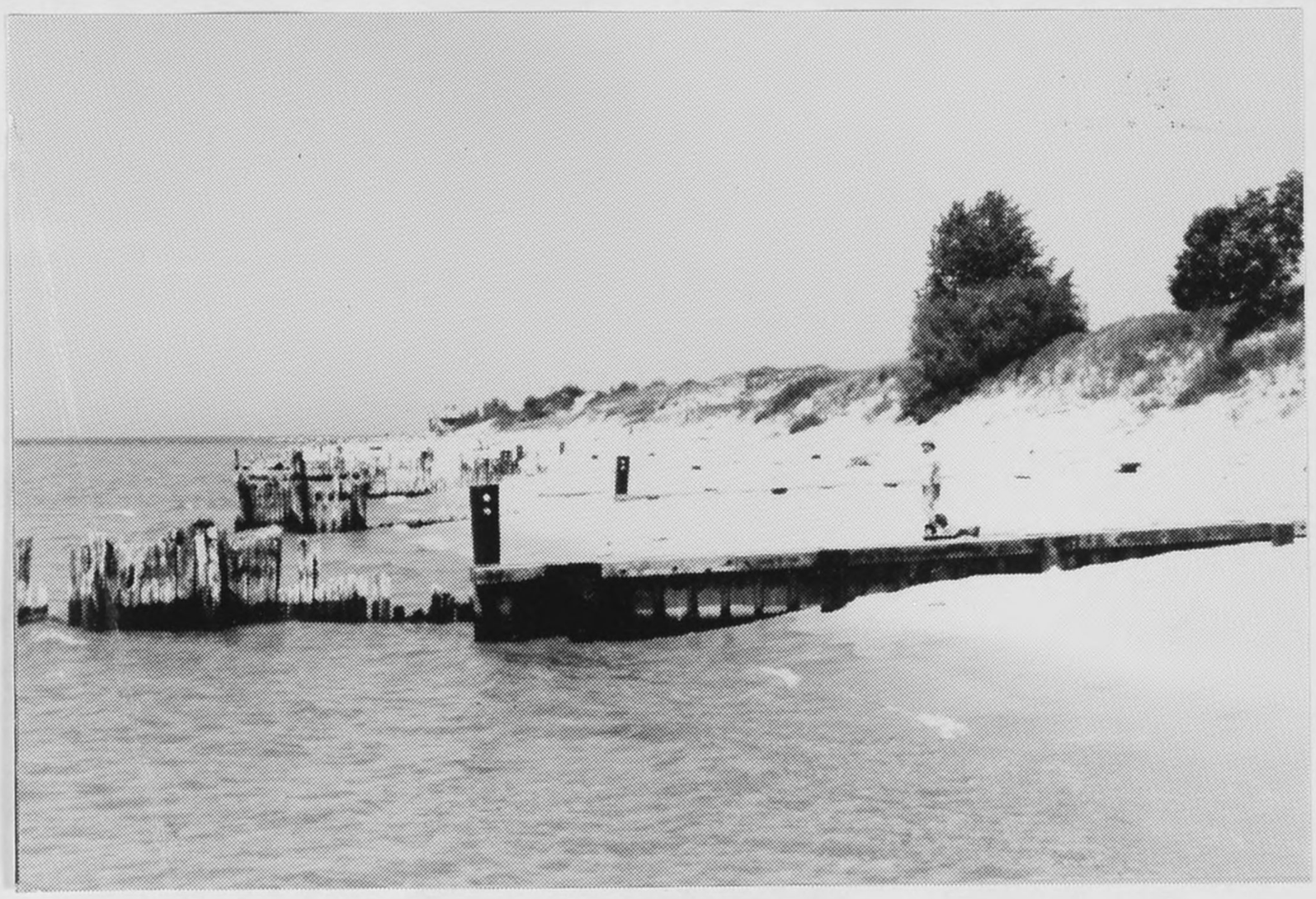


Figure B31. Site K: Looking north across southerly groin field. First groin is the seventh one from south side. Note that new groins are shorter than remnants of old system.

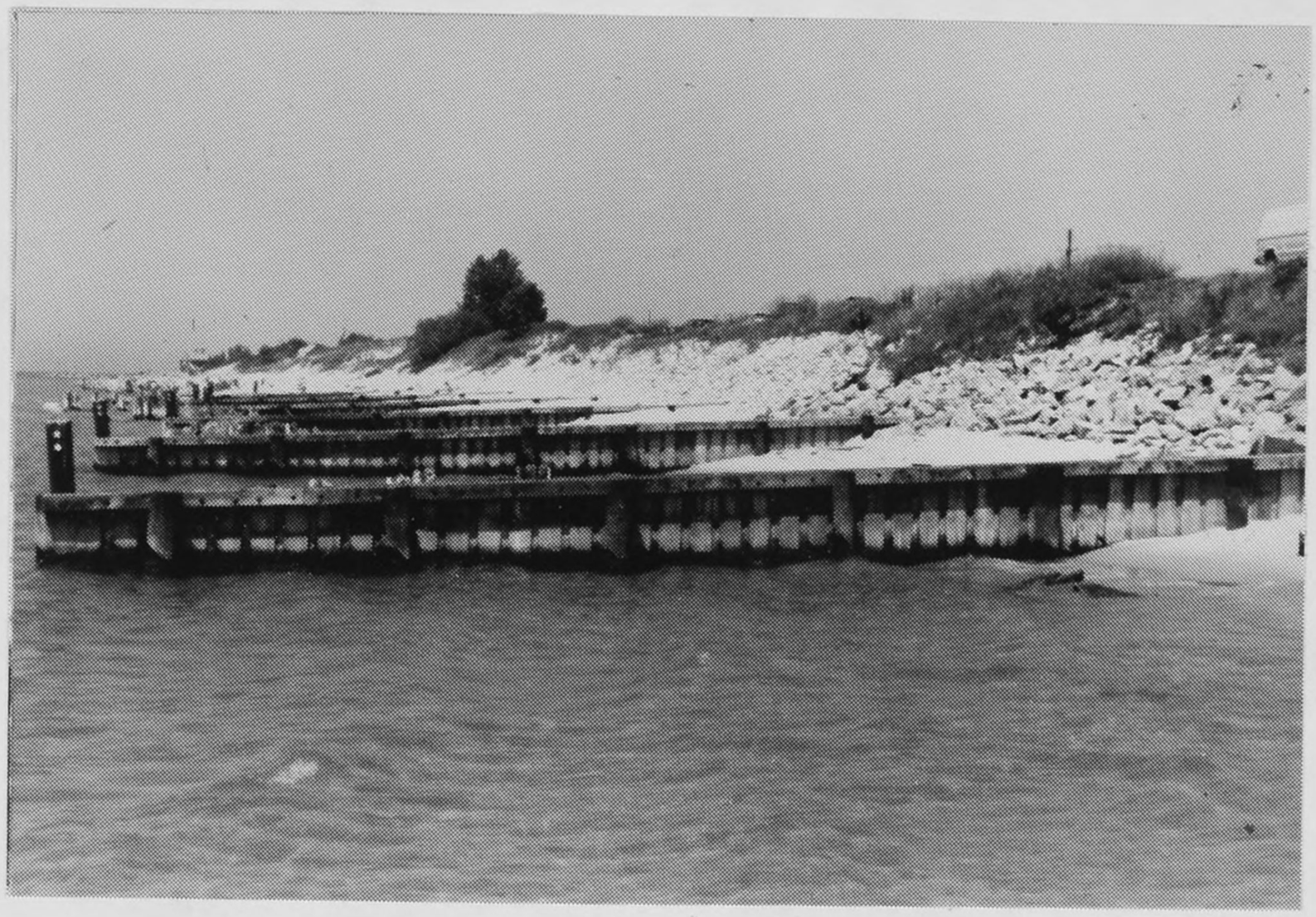


Figure B32. Site K: Looking north across long groin field. Groin in foreground is 50th from southern end of system or close to northern end.

Figure B33. Site L: Aerial view of property which is just to the left of the high retaining wall on the right side of photograph. Note considerable bluff recession compared to property to the south.

Figure B34. Site L: Looking north across site from the property to the south. Two groins and low retaining wall beyond high retaining wall are part of this system. Note other shore protection along shoreline.

Figure B35. Site L: property just to south of site. Note closely spaced short timber groins projecting from retaining wall.

Figure B36. Site M and O: Aerial view of shoreline in general vicinity. Photograph indicates series of groins near center of photo. Long revetment at site O exists just south of where shoreline shifts to the right beyond the point. Two long concrete groins are barely visible in photo.

Figure B37. Site M: Looking northwards from beyond southern edge of groin system.

Figure B38. Site M: Looking north from southernmost long concrete groin, second one is visible parallel to horizon.

Figure B39. Site M: Looking south from 8th groin north of second long concrete groin.

Figure B40. Site N and O: Looking north towards the long revetment on site O from Site M and N property. Revetment on site N is just visible to the right and well up above the existing water level. Also groin and sill system exists between revetment and shoreline. Note old groins within revetment on site O.

Figure B41. Site O: Looking south along revetment from location in Fig. B36 where abrupt turn in shoreline occurs.

Figure B42. Site O: Aerial view of short revetment at north side of property. Recession of shoreline to north of revetment is visible at left center of photo.

Figure B43. Site P: Aerial view of site, visible parts of groins are second tier of tubes.

Figure B44. Site P: Looking north across site. Slight recession in beach to north of site is between this site and site Q. Still farther north, shoreline recedes again at far right of photo.

Figure B45. Site P: Looking to south across site. Beach becomes narrower to the south. Also note groin end at water's edge,

Figure B46 Site Q: Aerial view of site, (3) groins are barely visible on right side of photograph.

Figure B47. Site Q: Looking to the north from the southern side of the site. Note reduction in beach width immediately north of most northern groin in system.

Figure B48. Site S: Looking north at retaining wall just visible at toe of bluff.

Figure B49. Site U: Aerial view of site.

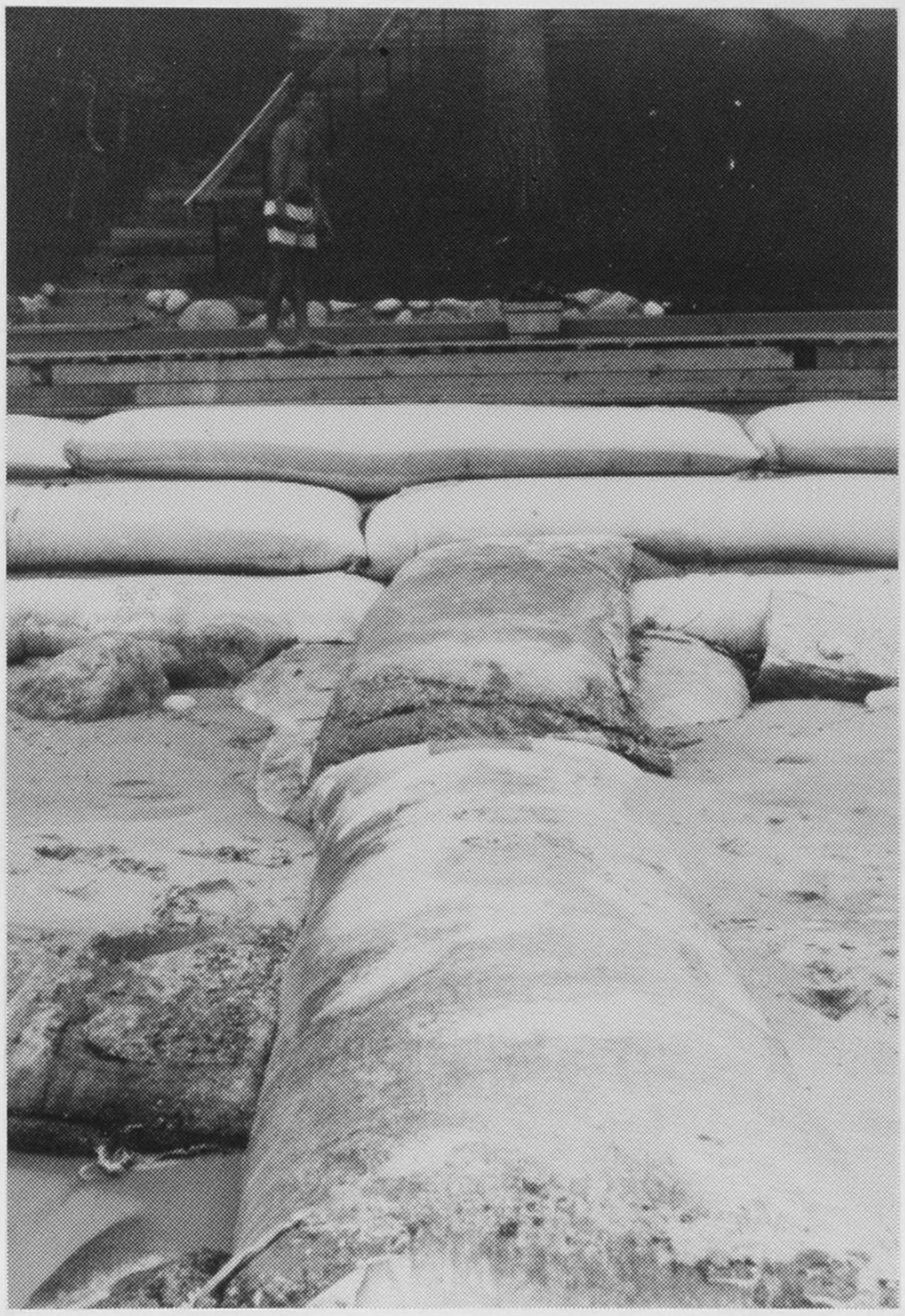


Figure B50. Site U: Looking onshore from third groin from southwest end. Note higher filling on right side of groin

Figure B51. Site U: Looking northeasterly from same point as Fig. B50. Note sand filling behind offshore sill. Beach is beyond sill to the south of this location.

Figure B52. Site U: Looking towards the southwest from the most northerly groin in the system. Beach is higher behind bathers, may be due to artificial filling or littoral drift from the southwest.

Figure B53. Site V: Aerial view of 5 groin system.

Figure B54. Site V: View looking towards the southwest over the top of the 5 groin system.

Figure B55. Site V: Same location as Fig. B54 except looking offshore along tube groin.

Figure B56. Site V: Four groin system, looking southwest. Note coarse beach material at this site.

Figure B57. Site W: Aerial view of site, looking towards the south.

Figure B58. Site W: looking at southwestern side of revetment.

Figure B59. Site W: Looking at coarse beach in front of revetment.

Figure B60. Site X: Normandy type wavebusters in front of 240 S. State. Note revetment almost immediately behind wavebusters.

Figure B61. Site X: Looking generally onshore towards 240 S. State (right) and 250 S. State (left). Trees, seawall, etc. are on 240 S. State property.

Figure B62. Site X: Looking south at wavebusters at 430 S. State. Note shore protection allows property to south to project farther lakeward.

Figure B63. Site Y: Looking south from Philip's property.

Figure B64. Site Y: New wall construction at Heller property.

Figure B65. Site Z: Existing sandgrabber wall at site. Note lakeward displacement relative to seawall to north. Also note that only half of lower block is buried.

Figure B66. Site Z: Backside of sandgrabber wall, sand level behind slightly higher than in front. Also note tree trunk washed over wall during high water.

Figure B67. Site AA: Looking north towards groin. Note shoreline considerably beyond end of groin. Also note similar structure to south at left side of photo.

Figure B68. Site BB: Looking south towards site. Property is between two groins between catamaran and sandgrabber wall in foreground. Note sand spit offshore.

Figure B69 Site DD: Looking south across Sharpe property. Existing groin with large boulder in front is their groin. Note small sand fillet in corner of seawall-groin system immediately to the south. Also note that Sharpe groin does not project as far lakeward as the groin to the south or the groin from which the photo was taken.

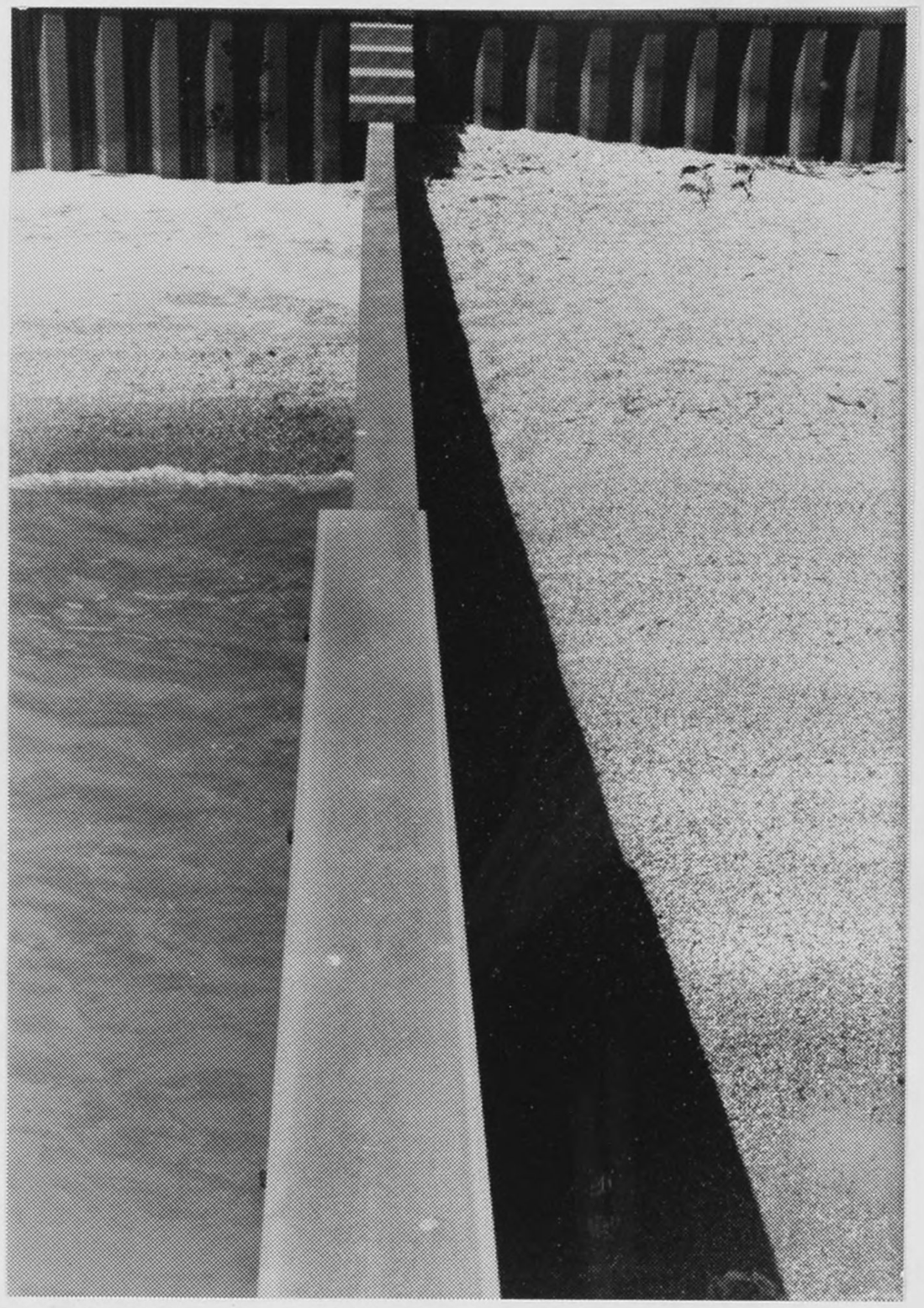


Figure B70. Site DD: Looking shoreward along groin on north side of Sharpe property. Littoral drift is right to left. Total groin length is about 50 feet.

Figure B71. Site GG: Looking south at Durand groin. Sand on beach is just a fine layer with coarse cobbles underneath.

Figure B72. Site GG: Looking offshore along Durand groin. Littoral drift is left to right.

Figure B73. Site HH: Looking towards the southeast from north corner of Wines' beach. Remnant of old concrete groin extends beyond steel groin.

Figure B74. Site HH: Looking onshore from end of old concrete groin (Fig. B73) towards new steel groin and beach.

Figure B75. Site II: Looking north across system of groins from just south of property. Note beach nearly fills groin compartments and general coarse littoral material.

Figure B76. Site II: Looking offshore along most southern groin. Littoral drift is left to right. Note coarse cobble on updrift side of groin.

AIIM SCANNER TEST CHART # 2

Spectra

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz:'',./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

Times Roman

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

Century Schoolbook Bold

4 PT **ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789**

6 PT **ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789**

8 PT **ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789**

10 PT **ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789**

News Gothic Bold Reversed

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

Bodoni Italic

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

Greek and Math Symbols

4 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓'',. / ≦±=≠°><⊁⊀⩾⩽≡

6 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓'',. / ≦±=≠°><⊁⊀⩾⩽≡

8 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓'',. / ≦±=≠°><⊁⊀⩾⩽≡

10 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓'',. / ≦±=≠°><⊁⊀⩾⩽≡

White

Black

Isolated Characters

e	m	1	2	3	a
4	5	6	7	o	°
8	9	0	h	I	B

A4 Page 6543210

MESH HALFTONE WEDGES

65

85

100

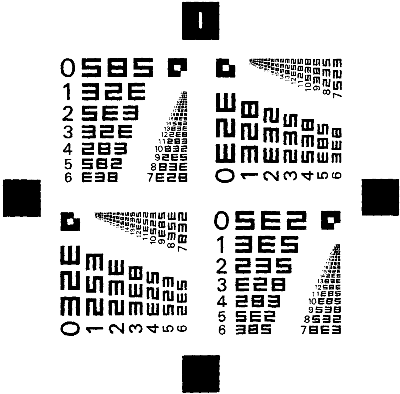
110

133

150

A4 Page 6543210

RIT ALPHANUMERIC RESOLUTION TEST OBJECT, RT-1-71



PRODUCED BY GRAPHIC ARTS RESEARCH CENTER

ROCHESTER INSTITUTE OF TECHNOLOGY, ONE LOMB

MEMORIAL DRIVE, ROCHESTER, NEW YORK 14623