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SHORELAND AND FLOOD PLAIN ZONING ALONG THE WISCONSIN SHORE OF LAKE MICHIGAN

by
A. R. STRIEGL - CIVIL ENGINEER

STATE OF WISCONSIN
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF ENVIRONMENTAL PROTECTION

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SHORELAND AND FLOOD PLAIN ZONING
ALONG THE WISCONSIN SHORE
OF LAKE MICHIGAN

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Shoreland and Flood Plain Zoning

Along the Wisconsin Shore of Lake Michigan

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EXHIBITS

Exhibit No.	Subject
1	Map of Wisconsin Shoreline of Lake Michigan Vulnerable to Erosion
2	Typical Riprap Revetment Lake Michigan Shore
3	Plan for Typical Rubble Mound Seawall, Lake Michigan Shore
4	Plan for Typical Rubble Mound Groin, Lake Michigan Shore

Shoreland and Flood Plain Zoning

Along the Wisconsin Shore of Lake Michigan

AUTHORITY

1. This report on "Shoreland and Flood Plain Zoning along the Shore of Lake Michigan" has been prepared under authority of a contract dated April 13, 1967, with the Wisconsin Department of Resource Development for engineering services with respect to shoreland and flood plain zoning along the shore of Lake Michigan from the Illinois state line north along the eastern side of Door County up to, but not including, Washington Island.

Legislative Requirement for Zoning of Shorelands

2. Section 59.971 of the Wisconsin Statutes, as created by Chapter 614, Laws of 1965, the Water Resources Act, provides that to aid in the fulfillment of the state's role as trustee of its navigable waters, and to promote public health, safety, convenience, and general welfare, "counties may zone all lands (referred to herein as shorelands) in their unincorporated areas within the following distances from the normal high-water elevation of navigable waters ***: 1,000 feet from a lake, pond or flowage; 300 feet from a river or stream or to the landward side of the flood plain, whichever distance is greater." Ordinances enacted under this authority do not require approval and are not subject to disapproval by any town or town board. If an existing town ordinance relating to shorelands is more restrictive than an ordinance later enacted under this section (59.971) affecting the same shorelands, it continues as a town ordinance in all respects to the extent of the greater restrictions, but not otherwise. Ordinances enacted under this authority shall be consistent with any comprehensive zoning plan or general zoning ordinance applicable to the enacting counties, so far as practicable. If any county does not adopt an ordinance by January 1, 1968, or if the Department of Resource Development (now Division of Resource Development of the Department of Natural Resources, Chapter 75, Laws of 1967), after notice and hearing, determines that an ordinance adopted fails to meet reasonable minimum standards for accomplishing the shoreland protection objectives, the Department is to adopt such an ordinance.

Shorelands Included in Study

3. This study is limited to the shorelands and flood plains along the Lake Michigan shoreline of Wisconsin from the southern state boundary to the northern end of Door County, excluding Washington Island. Flood plains directly affected by the waters of Lake Michigan when at high stages are included.

Description of Lake Michigan Shorelands of Wisconsin

Kenosha County Shorelands

4. The Lake Michigan shoreline in Kenosha County is 12 miles in length. From the Wisconsin-Illinois state line to the south city limits, a distance of about 4-1/2 miles, the shoreline direction is almost north and south, the shore at the south end being only about 3/8 mile east of the shore about 3 miles north. The bluffs along the southerly 3 miles of the shoreline average about 11 to 13 feet high and are of sandy, easily erodable material. The foreshore where the bank has not been protected varies from sandy to gravel and coarse stones and is from 20 to 130 feet wide back to the high water erosion line. Bluffs in unprotected areas generally are steep and often caving banks show evidence of rapid erosion by wave action. (See photograph No. 1, appendix A). In a study by the Corps of Engineers in 1954 (reference 6) it was found that the bluff erosion from 1872 to 1953 between the south limit of Kenosha and the State line was about 6.8 feet per year. The average rate probably is somewhat slower now because of a predominantly lower lake level, but during high stages such as occurred during the 1929-1930 and 1951-1955 periods the erosion is very rapid. Houses built close to the lake shore have been protected with heavy stone or concrete riprap, in some instances supplementing old pile bulkheads that have been destroyed. Beach erosion between these protected points has cut the shoreline back 50 feet or more since the protection was placed.

5. Along the shoreline for about 1.5 miles south of the south city limits of Kenosha the lake bank generally is about 17 to 18 feet high with sand to a depth of about 10 feet underlain by a brown clay. The foreshore is 15 to 50 feet wide and composed of sandy materials mixed with considerable gravel and stones. The banks are caving off and show evidence of recent erosion by wave action where the foreshore is relatively narrow. Some of the banks are almost vertical except for loose deposits at the base that have caved off of the upper banks as the underlying clay was eroded by wave action. These deposits generally are easily washed away by further wave action again exposing the bank to undercutting. Where the foreshore is wider and has considerable slope apparently due to a larger proportion of coarser gravel and stone, the banks show evidence of erosion during period of higher lake levels, but weed covered slopes at the base of the banks indicate there has been no recent bank cutting by wave action. At various points the shore erosion has been checked by heavy stone riprap placed to protect houses built close to the bank, but some of this protection has been only partially effective and erosion continues right up to the buildings. At some points broken concrete and other building debris is being dumped over the banks in an attempt to check the rapid erosion. (See photo No. 2, App. A). For about 1/2 mile south of the sewage treatment plant at the south city limits, or south of 80th Street, the bank is about 18 feet high and is caving off at about a 45 degree slope with only a narrow foreshore. (See photo No. 3, App. A). Records show that this bank has been eroding at the rate of almost 4 feet per year for over 100 years. At the sewage treatment plant fill is being dumped and protected with broken concrete riprap to check this loss.

6. Most of the lake frontage through the city of Kenosha has been protected by rubble mounds at the base of the bank, concrete seawalls, timber seawalls, or jetties, or combinations of these types. For 3240 feet south of the harbor fill has been deposited along shore for a width of about 600 feet out to about the 6-foot depth contour and is protected on the lake side by rubble stone placed between two rows of round piles. The northerly 1030 feet is occupied by an industrial plant, and the remainder is public park. All this city frontage was subject to severe erosion before it was protected.

7. North of Kenosha Harbor the Simmons Island Park extends to about 44th Street, a distance of about 2,750 feet and has a good sandy beach formed by accretion and artificial fill. This beach is about 125 feet wide. A precast concrete block jetty located about 1,100 feet north of the harbor pier has held the sand deposited south of the jetty at a shoreline about 20 feet lakeward of that on the north side. A concrete walk along the bank line shoreward of the beach extends about 625 feet north of the jetty and there has been some erosion at the northerly end where the beach width decreases to about 50 feet. The remainder of the frontage north to 44th Street has been protected by placing large stones along the shoreline. Along this frontage of approximately 1000 feet there is no beach or foreshore. The bank slopes up gradually to an elevation about 12 feet above lake level. A bulkhead of rows of wood piles with stone fill protects the shoreline from 44th to 38th Street, about 1/2 mile, and artificial fill has been placed shoreward of the bulkhead for public park use as part of John F. Kennedy Memorial Park (formerly Lake View Park). This fill extends about 250 feet lakeward from the shoreline to the south and north.

8. Penoyer Park extends along the lake from 38th Street north to the mouth of Pike River, about 1700 feet. Along this frontage there is a sand beach about 50 feet wide that has been partially protected from erosion by five stone jetties. These are now in poor condition from settlement and displacement of stone so that the tops of the stone are only slightly above or below water level. The lake bank along this section slopes up from the high water line gradually to an elevation about 11 feet above lake level. For about 1/2 mile north of the mouth of Pike River the sand beach continues with a width of 50 feet or more and has been partially protected with several precast concrete block jetties. These have been fairly effective in holding the beach but have not caused any major accretion on either side. The bank here is sandy and slopes up to about 14 feet above lake level. This frontage is in Alford Park. The remaining park frontage north to 18th Street, about 1/2 mile, also has a sandy beach 50 to 175 feet wide with fairly steep banks up to 32 feet in height. North of the city limit the high steep bank continues close to the lake shore with little or no beach at the base of the banks. Houses have been built close to the top of the slope and attempts have been made to check erosion by placing heavy stones or broken concrete at the foot of the banks. (See photo No. 8, App. A). However, there is evidence of severe bank erosion. This condition of steep clay banks 25 to 30 feet high close to the lake shore with very narrow sand or gravel beaches extends north to the Racine-Kenosha County line. At various

points heavy concrete walls built to protect the banks have been destroyed by wave action. Broken concrete, logs, brush and debris of many kinds has been dumped over the banks at various points to retard the erosion. Short jetties or groins of rock at intervals along parts of the frontage are in poor condition and appear to have had only minor effect on the beach erosion.

Racine County Shorelands

9. The lake bank for about one mile north of the Racine-Kenosha County line is generally about 35 feet high above the lake level and located close to the shore. Beaches are only 15 to 40 feet wide and beach materials are mixtures of sand, gravel and stones. Banks are steep, with about 4 on 5 slope, but are generally brush covered with little recent bank caving. (See photo No. 5, appendix A). This frontage has been protected by a series of about 26 groins constructed approximately perpendicular to the shoreline. These jetties vary in length from 30 to 174 feet, with many 100 to 135 feet long, and are spaced at intervals of about 80 to 300 feet. Top elevations vary from 1 to 7 feet above low water datum. Many of the groins were timber piling with wood sheeting built about 45 years ago by Racine County and these are largely destroyed. A few jetties of precast concrete blocks, broken concrete, or rock are in fair condition. Timber or concrete retaining walls built at the bottom of the sloping lake bank along about 450 feet of the frontage generally are in poor to fair condition, with walls overturning or bank materials sliding over the top of the walls. The jetties appear to have checked the rate of bank erosion but have had little effect in building beaches.

10. The bank for about three-fourths mile from Chicory Road north to the J. I. Case plant continues about 40 feet high with steep slope close to the lake shore. Most of this reach was protected about 45 years ago by the County with two rows of round wood piles about 10 feet apart with stone fill between the rows. Much of this has been destroyed by wave action. The banks have caved off extensively during high water periods. The present beach is about 15 to 20 feet wide and generally strewn with rocks. Scattered old wood piles about 50 to 75 feet off shore appear to be the remains of a bulkhead structure built about 45 years ago to protect the shore from erosion. Most of the wood piles are now gone and the stone fill buried in the lake bottom. Large stones have been placed at the base of the bank near the present shoreline but the erosion generally has progressed up to 15 to 20 feet shoreward from these large stones and most of them are nearly buried in the sand.

11. Just south of the Racine city limit the J. I. Case industrial plant occupies about 3,225 feet of lake frontage, from Larson Avenue north to 24th Street. About 900 feet of this frontage was bulkheaded by the County in 1922 with a double row of round piles with fill between these rows, but this structure has been destroyed by wave action and erosion and the remains are some distance off shore and of no present value as a shore protective structure. The shore recession has been quite rapid along this frontage with an estimated loss of 511,000 cubic yards of materials in a 77 year period, or the equivalent of about 1.75 feet of bank per year. Part of this frontage has been protected by a steel sheet pile bulkhead, but where there is no protection rapid erosion continues.

12. North of the Racine Harbor breakwater North Beach is a wide sand beach with a width of about 450 feet near the breakwater gradually decreasing to about 100 feet at Lake View Park, about 3,000 feet north. The glacial till bluff is about 40 feet high and has a steep slope of 40 to 70 degrees. In 1948 following several high water years the city built a concrete retaining wall at the base of the bluff extending from about 800 feet to about 2590 feet north of the harbor. This wall with top level about 5 feet above low water datum served to check the rapid erosion of the bluff by wave action. In the next 2.5 miles north the height of the bluff gradually decreases to about 25 to 30 feet to the south side of Shoop Park, about one mile south of Wind Point. The bluff along this reach of shoreline is steep and the beach of sand and fine gravel is generally narrow. Along this frontage some 43 groins were built by the county, city and private interests during the period from 1920 to 1949 to check the bluff erosion. These groins were of various types including wood piling, rubble mounds, large stones laid flat, precast concrete sections, and mass concrete. They varied in length from 25 to 191 feet and in top elevation. The wood pile groins first constructed by the county have generally decayed and largely disappeared. The stone and concrete groins are in various states of repair, with many sections settled or displaced by wave action, with loss of effectiveness as bluff protection. About 500 feet of concrete retaining wall near the north city limits was constructed by private interests. At Wind Point the shore is flat and from 5 to 10 feet above low water datum. Along the Shoop Park frontage south of Wind Point the city of Racine, in 1939, built four permeable concrete groins 104 to 375 feet long with tops 4.5 to 5.5 feet above datum. These have been fairly effective in checking the bank erosion near the south end of the park.

13. The beach around Wind Point is fairly wide and is composed of gravel with ledge rock exposed at various points at about lake level. The lake bluffs north of Wind Point increase from about 30 feet high 2000 feet north of the Point to about 100 feet high at the Milwaukee County line about 5 miles farther north. Numerous houses have been built relatively near the top of the bluffs for about 1.5 miles north of Wind Point and there are many homes along the next 3 miles north. Old records show that this shoreline has been subject to rapid erosion in the past, and similar erosion is continuing although at a somewhat slower rate due to the generally lower prevailing lake level. In a report on "The Physical Geography of Wisconsin" issued by the Wisconsin Geological and Natural History Survey in 1916 the following statement on the wave-cut bluffs is made: "The bluffs along Lake Michigan are still being cut back. It is well shown *** at various places between Milwaukee and Racine, where wave-cut cliffs retreated one to six feet a year along the whole coast lines of two counties between 1836 and 1874. *** This cutting helps keep the bluffs steep. The beaches at the cliff base are narrow, for the lake currents carry the eroded material away." The Corps of Engineers, U. S. Army, in a 1952 report on "Racine County, Wis., Beach Erosion Control Study" published as House Document No. 88, 83rd Congress, 1st session (Reference 8), reported on this lake frontage as follows: "From a half mile north of Wind Point to within 1.5 miles of the Racine-Milwaukee County line, the top of the bluffs averages 40 feet above low-water datum. For the northerly 1.5 miles to the county line the bluffs are

from 60 to 100 feet in elevation. The bank profiles are very steep as the result of heavy undercutting and eroding of the banks and average a 1 on 1 slope. The beach has an approximate width of 50 feet and an average slope of about 1 on 10. Available data indicate a lakeward movement of offshore contours, and the lake bottom profiles range in slope from 1 on 40 to 1 on 50. *** the extent of bank recession may be derived with fair accuracy by measurement along section lines from the nearest section corner to the lake bank as shown on maps prepared in the years 1836 and 1874, and from aerial photographs taken in 1946."

The recession of the bluff at various section lines was given as shown in the following Table No. 1

Table - 1

Bluff Recession in Racine County, Wis., 1836-1946

Section corner to bluff crest	Locality	Annual loss, in feet 1836-'74	1874-1946
Township of Caledonia:			
North line of sec. 6	Racine-Milwaukee County line	4.17	4.07
North line of sec. 7	(	2.14	2.87
West line of sec. 8	)Between Racine-Milwaukee	0.83	0.74
North line of sec. 17	(County line and	3.09	1.34
West line of sec. 16	) Wind Point	1.93	0.50
North line of sec. 21	(	1.88	1.43
West line of sec. 22	)	1.67	2.41
North line of sec. 27	Wind Point	.00	1.31
North line of sec. 34	Three-Mile Road	0.99	1.68
West line of sec. 34	East side Vincenne's Circle	2.61	2.78
South line of sec. 33	Melvin Ave.	2.66	0.31
Township of Mount Pleasant:			
North line of sec. 4	Melvin Ave.	2.66	0.31
North line of sec. 9	St. Patrick St.	1.42	-
North line of sec. 16	Seventh Ave.	10.77	-
North line of sec. 21	Between 16th and 17th Sts.	5.64	0.62
North line of sec. 28	Durand Road	1.84	1.98
West line of sec. 28		10.99 (1)	-
North line of sec. 32	Chickory Road	4.26	0.72
South line of sec. 32	Racine-Kenosha County line	3.25	2.92

(1) Equivalent to about 2.5 feet normal to shoreline.

Adjusting the annual losses as given in the table above to indicate bluff recession normal to the bluff crest the Corps of Engineers reported the following average annual rates:

Table - 2

Bluff Recession Normal to Bluff Crest

Racine County, Wis. 1874-1946

Section of lake shore	Average rate per year. Linear Feet
Milwaukee-Racine County line to Wind Point	1.6
Wind Point to North Breakwater, Racine Harbor	0.8
South Breakwater to Racine-Kenosha County line	1.2
Entire Racine County bluff line	1.2

The yearly average losses by the bluff erosion indicated in the above Table No. 2 amount to about 8,500 square feet of area and about 19,500 cubic yards of volume per year per mile for the lake shore of about 5.25 miles from the Milwaukee-Racine County line to Wind Point. The loss from the lake shore south of Racine, from about 2 miles of frontage between Durand Road and the south county line was about 2,200 square feet of area and 10,500 cubic yards of volume per year per mile.

Milwaukee County Shorelands

14. The entire area of Milwaukee County is in incorporated municipalities and the statute requiring shoreland zoning noted in paragraph 2 does not apply to such areas. For that reason no description of the lake shore in Milwaukee County is included in this report. Much of the county shoreline has been protected from rapid erosion by wave action by off-shore breakwaters; revetments, bulkheads, land fills, etc., along the shoreline. Just north of the south county line an electric power plant has been constructed with a bulkheaded land fill extending about 900 feet lakeward from the shoreline and shoreline revetment extending about 2,000 feet to the south. These structures may have some deleterious effect on the northerly part of the Racine County shoreline by preventing a continued supply of littoral drift material.

Ozaukee County Shorelands

15. The southerly 6 miles of lakeshore in Ozaukee County is in the incorporated city of Mequon. The high steeply sloping lake bank varies from about 90 to 140 feet in height and generally slopes at 35 to 45 degrees. The beach varies from about 20 to 150 feet in width. Along many sections any appreciable wave action causes rapid erosion at the base of the bluffs and causes numerous local land slides from materials higher up the slope. The bluff for about 4 miles north of the Mequon city limit is about 120 feet high and has a very steep slope of about 30 to 45 degrees. The beach is 20 to 50 feet wide and stony with wave action cutting at the base of the high bank at many points. Most of the slopes are covered by brush or small trees, but there are areas showing evidence of fairly recent slides and frequent small benches on the slopes showing evidence of older land slides. With easterly winds and only moderate wave action against the shore the lake water is discolored by red clay in suspension for several hundred feet off shore, evidence of continuing bank erosion. The high bluffs are cut by many deep gulleys extending inland for 1/4 to 1/2 mile. Banks of these gullies are usually overgrown with brush and trees. The steep bank continues about 100 feet high with narrow beach for about 3 miles to the south limit of Port Washington.

16. For about 2.5 miles north of Port Washington the red clay lake bluff continues about 100 feet high and with slope of about 1 on 2 (26° 34') or steeper. The beach generally is narrow and most of the bluff is brush covered, but there are areas of freshly caving bank and evidence that slides and erosion of the bank were common when the lake level was at a high stage. About 2.5 miles north of the city at the outlet of Sucker Creek the high bank is back about 200 to 300 feet from the lake shore for about 1,500 feet and there is a fairly level terrace about 14 feet above lake level on which several cottages have been built both north and south of the creek. North of this terrace the high bluff is again close to the lake shore, and about 70 to 80 feet high, for about 1.75 miles, with a beach about 30 feet wide and numerous boulders scattered on the beach and in shoal water off shore. (See photo No. 6, App. A). About 3/4 of a mile south of the north line of Port

Washington township (T II N) the steep bluff again recedes from the lake shore and there is a fairly level terrace about 14 feet above lake level and 200 to 500 feet wide back to the bluff, which here is about 50 feet high and moderately steep, and extends about a mile. Beginning near the north end of the Port Washington Golf Club grounds and continuing about 2 miles north to near the old quarry in Section 19 of Belgium Township (T 12 N) there is a sand beach about 125 feet wide with a sloping sandy lake bank 10 to 15 feet high with a fairly level terrace extending back 400 to 800 feet to a second sloping bank about 30 feet high beyond which is a second fairly level terrace.

17. The lake frontage along Section 19, 1.5 miles east of Lake Church, has a gently sloping beach of fine sand about 125 feet wide with the lake level at low-water datum, with an off-shore under-water slope of less than 1.0 to about 1.5 feet per 100 feet. There are scattered large boulders in the water. (See photo No. 7, App. A). The sand bank slopes up gradually to about 12 to 15 feet above lake level. Near the center of the section an old stone quarry is water filled, forming a 23 acre lake about 200 feet back from the Lake Michigan shore. In the area around the quarry the ledge rock is within 3 or 4 feet of the surface. Most of the area around the quarry is covered with trees and brush. East of the quarry an old timber crib, stone and earth filled pier extends out about 200 feet from the shoreline. This pier, formerly used for barge shipments of stone, has been abandoned for many years. Some large boulders are scattered along the sand beach. Except for some old buildings at the quarry and an old lime kiln at the north end of the section, there are no cottages along this frontage. Development of a State Park along this lake frontage has been authorized.

18. The remaining 3 miles of lakefront north to the Ozaukee-Sheboygan County line has a fine sand beach about 40 to 80 feet wide with a gradual sandy slope for an additional 75 to 100 feet to about 8 to 10 feet above lake level with a fairly level terrace 600 to 1000 feet wide back to a fairly steep bluff about 30 feet high. Numerous cottages and homes have been built along this frontage close to the top of the lakeward slope. (See photo No. 8, App. A).

Sheboygan County Shorelands

19. The shoreline for about 3.5 miles north of the south line of Sheboygan County has a sand beach about 30 to 50 feet wide to the weed line with continuing gradual sand slope for about 100 feet to a level about 14 feet above the lake with a fairly flat terrace from that bank back about 800 to 1000 feet to a second steep bank about 30 feet high. The beach sands are porous, wind blown fine sands easily moved by waves or winds. The lower terrace soils vary considerably but consist generally of mixtures of fine sand, silt loams, or silty clay loams. In some low or pocketed areas they are poorly drained, with high water tables. The lower flat terrace is occupied by many lakefront homes and cottages generally built within 50 to 100 feet of the top of the outer lake bank. (See photo No. 9, App. A).

20. Between Idlewild Beach, 4 miles north of the county line, and the south end of Terry Andrae State Park, about 4 miles, the sand beach slopes

up gradually to an outer bank about 10 to 12 feet above lake level with a gradual rise to some gravel and sand ridges about 20 feet above lake level and 700 to 1400 feet back from the lake shore. Beyond these ridges the level drops again to the Black River Valley, where the river flows northeast nearly parallel to the lake shore and about 2000 feet inland. Many cottages and homes are built on the outer ridges along the lake shore.

21. Between Terry Andrae State Park and the mouth of the Black River, about 3.5 miles, the sand beach is generally 20 to 50 feet wide to the wave-wash or weed line, slopes up gradually to irregular sand ridges 10 to 15 feet above lake level 100 to 200 feet back from the shoreline, and uneven slope with scattered sand ridges back 200 to 1400 feet to a level 20 feet above the lake. From Black River Point to the Black River the lake bank and most of the adjacent higher sand ridges are occupied by substantial homes. North of the Black River for about 0.5 mile to the Edgewater Electric Power Plant near the south limits of Sheboygan the lake shore area is fairly flat and poorly drained, the flat area extending back one-half mile or more from the lake at a level about 10 feet above lake level. The soil here is a silty clay loam.

22. From Sheboygan northward for about 9 miles to the village of Hika, east of Cleveland, fresh red clay bluffs from 40 to 60 feet high are close to the lake shore. (See photos Nos. 10 and 11, App. A). The sand or mixed sand and gravel beaches are generally narrow, about 10 to 25 feet wide, with some additional flat slope in 40 to 80 feet to the base of the steep bluff which generally slopes 35 to 45 degrees. There are many evidences of fresh earth slides due to erosion at the base of the bluff, with indications that bank failures were more frequent during years when the lake level was higher, allowing wave impact directly at the base of the bluff. Shoreward from the top of the bluff the land is generally quite level, permitting cultivation to within a few feet of the bluff crest. Frequently cracks or depressions can be noted in the surface near the bluff indicating pending bank failures following saturation by heavy rains or additional erosion at the bottom of the bank.

Manitowoc County Shorelands

23. At Hika in Manitowoc County 1.5 miles north of the south county line the high bank recedes to about 800 to 1000 feet from the lake shore for about one mile and there is a lower bank about 12 to 14 feet above lake level along the lake front with a fairly level terrace between the two banks. For a short distance south from the mouth of Centerville Creek there is a wide beach area, about 100 feet wide with lake at low-water datum, of sand and gravel with a scattering of larger stones. This beach slopes up to the high water and wave-wash line at the base of the low gradual sloping lake bank. A number of homes and cottages have been built on the level terrace, some of them quite near the lakefront bank. At the westerly limit of the level terrace there is a steep clay bluff rising to about 50 feet above lake level.

24. Beginning about one mile north of Hika and extending for about 9 miles to the south limits of Manitowoc the steep freshly cut lake bluff closely follows the lake shore with only a narrow beach usually only 20 to 40 feet wide at normal stages. Wave action during storms and at high lake levels extends to the base of the high bank in many places so there is continuing bank erosion and undercutting of the slopes. The bank is cut by fine cracks and numerous deep gulleys cut back several hundred feet from the main bank face. The debris eroded from these gulleys is carried along shore by wave action and forms sloping deposits at the base of the steep banks extending to about the up-wash line of high water wave action at about 8 to 10 feet above lake level. (See photos Nos. 12 and 13, App. A). The main banks are usually from 30 to 60 feet above the lake level, increasing to about 80 feet 3 miles south of Manitowoc. (See photo No. 14, App. A). Sand frequently occurs at the top of the bank, above the red clay formation and the surface is quite rolling. Near Northeim, at about the center of this 9 miles of lake frontage, the stratified sands are from 3 to 20 feet thick and the surface topography is decidedly morainic. At the highest bank section south of Manitowoc the lake is cutting back into the red till ridge, and boulders are abundant. The height of the bank decreases slightly to about 70 feet at Silver Creek Park at the south city limits. Along much of this frontage the high banks have slopes of about 45 degrees and are eroding at many points.

25. The lake front bank along the three miles of frontage between Manitowoc and Two Rivers is generally 9 to 20 feet high. The southerly half is generally clay loam and the remainder dune or fine sand. Much of this frontage has been protected from erosion by rubble stone revetments, (See photo No. 15, App. A), to protect the adjacent highway. The Corps of Engineers in a study of beach erosion for Manitowoc County in 1955 (reference 9) made a comparison of survey data available for the period from 1870 to 1953 and determined that for this reach of lakefront between Manitowoc and Two Rivers the entire shoreline had receded, the maximum recession amounting to about 200 feet. The average rate of recession was estimated as 1.0 foot per year, with a total volume of material eroded of about 10,400 cubic yards per year. A Wisconsin Geological Survey report in 1907 (reference 10) estimated the average rate of bluff recession for the red clay bluffs north of Manitowoc Harbor as being over 5 feet per year. This was reduced to 1.0 foot or less per year after the construction of 4,800 feet of offshore wood piling northward from the harbor in 1905. This has been supplemented by additional pile shore protection and permeable concrete groins and bank revetment in the vicinity of Little Manitowoc River, about 0.75 mile north of the harbor, in 1925 and 1940. Artificial fill also was placed to reclaim shore area. About 2.25 miles of this 3-mile lake shore is owned by the county. For most of the distance state highway 42 is close to the top of the bank which has been protected with stone as noted above to stop continued erosion. Areas between the highway and lake bank have been landscaped as park areas, or improved as waysides and parking areas where travelers may stop and view the lake.

26. Northeast of Two Rivers to Rawley Point Lighthouse, a distance of about 4.5 miles, the lake shore area is a series of sand dunes extending

back to the highway 2,000 to 3,000 feet from the lake. These dunes range from 10 to 20 feet in height above lake level and most of the area is covered by forest growth. Fine sand beaches along this frontage vary from about 200 feet wide just north of the city to about 60 feet wide at Rawley Point with the lake level about one foot above datum. Sand dunes slope up unevenly for 100 to 300 feet to a level generally 10 to 15 feet above lake level. (See photo No. 16, App. A). Similar sand beach and banks extend about 1.25 miles north of Rawley Point. With the exception of about 0.8 mile north of the City this entire frontage is in the Point Beach State Forest. The Corps of Engineers study noted previously (reference 9) found an average recession of the shoreline for about 3.6 miles north of Two Rivers of about 0.7 foot per year during the 1870-1954 period. The 1907 report (reference 10) noted rapid cutting back into the sand banks north of the lighthouse. The recession continues although at a somewhat slower rate because of generally lower lake levels.

27. For about three miles north of the Point Beach State Forest the generally sandy banks, mixed with silt loams, continue in irregular ridges near the lake shore with tops generally 10 to 20 feet above lake level. Beaches are sand and fine gravel and generally about 30 to 50 feet wide to the wave wash line and some additional slope for 20 to 50 feet to the base of the main bank. The banks have fairly flat slopes and are usually weed or brush covered, although in some areas caving banks and bare wind-blown sands are visible. (See photos Nos. 17 and 18, App. A). At some points there is a level beach or terrace several hundred feet wide from the lakeward bank back to the base of a second bank about 10 feet high. A few scattered buildings are generally 75 feet or more back from the top of the outer lake bank.

28. About two miles south of Two Creeks and continuing about 3.5 miles to the north line of Manitowoc County the lake bank close to the lake shore is about 20 feet high and has slopes of nearly 45 degrees at many points. The sand and gravel beaches slope quite rapidly to the wave wash line in a width of 20 to 50 feet. Material caving off the slopes is usually found along the base of the bluffs, although rapidly eroded by wave action during major storms or at high lake stages. South of Two Creeks a buried forest bed is found in the freshly eroded lake cliff. This bed is found above laminated red clay extending about three feet above the water. Above this is a distinct bed of peat, logs, stumps and other forest materials, which are covered by a layer of stony red till about 12 feet thick. The caving of the lake banks due to erosion at the base is clearly evident in photos Nos. 19 and 20, Appendix A. A nuclear powered electric generating plant is being erected on the lake shore about 2 miles south of Two Creeks.

Kewaunee County Shorelands

29. At the south line of Kewaunee County the lake shore is an eroding clay bluff about 40 feet high with beds of sand at various levels. The top portion of the bluff is almost vertical, indicating recent slides. The average bank slopes exceed 45 degrees. Materials sliding from the bluff are

banked at the base of the steep slopes and in places are being rapidly eroded by wave action. The sandy beach, with some gravel, is about 30 feet wide. Bluffs of this kind continue north about one mile and then are cut in the next mile by two drainage channels and a creek outlet at Sandy Bay, with stream terraces at the outlets of these channels, and the high banks back several hundred feet from the lake shore. The bluff along the remaining six miles to the south city limit of Kewaunee is close to the lake shore and increases in height from about 40 feet to 80 feet as it approaches the city. Several small but deep drainage outlets cut through the bank along this reach. The banks are very steep, probably approaching slopes of 1 to 1 or steeper. Sand beaches vary from 20 to about 75 feet wide at mean lake stage and generally are quite flat so that at high lake stages and during severe storms wave action may reach the base of the bluffs causing rapid erosion. At some points there are level berms along the high lake bluffs at a level about 15 feet above the lake, probably the remains of old shorelines at higher lake stages. Some of the smaller benches on the slopes may be the lowered surface after massive earth slides occurring as the result of rapid erosion during periods of high lake levels. A few houses have been built within 50 to 100 feet from the top of the bluff. (See photos Nos. 21 to 24, App. A).

30. The lake bluff for about two miles north of the Kewaunee city limit is a steep bank of a mixed sand, gravel, clay glacial till 50 to 60 feet high, with numerous large boulders in the bank and along the beach. (See photos Nos. 25 and 26, App. A, showing a typical bluff). Beaches are very narrow and stony. Banks slope at nearly 45 degrees and are generally eroding. Masek Creek cuts through the 40-foot bluff two miles north of the city with terraces along about one-half mile of frontage at about 17 and 35 feet above lake level. North of this for about 4 miles to Threemile Creek the bluff is close to the lake shore and from 40 to 60 feet high and slopes at about 35 to 40 degrees with near vertical faces near the top of the slope at some points. (See photo No. 25, App. A). Gravel beaches along most of this frontage are narrow, or about 20 feet wide to the wave-wash or weed line with additional slope of 3 or 4 feet in about 20 feet to the base of the bluff where erosion undermining the slope obviously has occurred during storms and high water periods.

31. For about one-third mile north of Threemile Creek, which is about 3 miles south of Algoma, there is a coarse gravel beach sloping up about 3 feet in 20 feet to the base of the steep bank which slopes at about 45 degrees to a height of 20 feet or more. (See photo No. 26, App. A). The bank is of stratified sands and gravel mixed with red clay. North of this for about 1.75 miles to the south limits of Algoma the coarse gravel or stony beach slopes about 3 feet in 20 feet to the weed line and about 5 feet additional in 60 feet to a fairly level terrace about 8 or 9 feet above lake level and 225 feet, more or less, wide back to an 8 to 10 feet steep slope just east of the highway. (See photo No. 27, App. A). Several cottages are located close to the top of the lower lake bank. Filling along the shore and for the highway has altered natural conditions in this area. Until recent months a portion of the terrace just south of the city was used as a city dump.

32. The beach for about 0.5 mile south from the south city limit of Algoma is narrow and stony but the banks are about 25 feet high and steep, sloping at about 45 degrees, and show evidence of recent erosion with little brush cover. The adjacent land is fairly level cultivated fields.

Just north of the city limit of Algoma the lake bank is close to the shore, and there is a relatively narrow beach about 15 feet wide with 2 to 3 feet of slope between the present shoreline and the base of the bank. The beach material is heavily mixed with broken stone, gravel, and boulders. A deep gully cuts through the bank near the city limit at Bay Road. Banks increase in height from about 15 feet adjacent to this drain to about 25 feet in the next 200 feet and then continue north at about that level with some minor variations. The banks to the north slope at about 35 degrees and are generally brush covered. (See photo No. 28, App. A). The surface soil is a grayish-brown loam containing considerable silt with some organic matter, some rock fragments, and a small amount of gravel in some areas. The subsoil consists of brownish-red clay loam containing rock fragments, with some gravel deposits and a large number of boulders. Apparently there has been no substantial bank erosion in recent years due to wave action; although there are some eroded banks along the minor drainage channels leading to the lake.

33. The lake bank for about 1/2 mile north of Algoma is similar to that just described. In the next 1.5 miles to the north to the mouth of Silver Creek the higher bank gradually swings back to about 700 feet from the lake front and lower sand dune type banks about 6 to 10 feet high follow close to the shore. The area between the immediate lake bank and the higher banks is irregular sand dunes and peat deposits with scattered brush cover. The gravel beach that is now about 15 to 20 feet wide to the base of the outer sand dune ridges apparently is subject to erosion by wave action depending on stage of the lake and direction and severity of storms. Similar shoreland extends for about 3/4 mile north of Silver Creek and the bank about 25 feet high then returns to near the lake shore for about one-half mile north to an intermittent drain cutting through to the lake. The outlet of this gully has been blocked at the lake bank line with a dam of large loosely placed boulders to check the continued enlargement of the gully and undermining of cottages placed close to its banks. Several short stone jetties have been built for shore protection to the south of this gully. Along the next mile north to the mouth of Stony Creek the high bank is back 300 to 500 feet from the lake with the immediate lake bank only about 8 to 15 feet high. The beach is 15 to 50 feet wide and composed of sand, but there are many large boulders in the water offshore. Several cottages have been built near the lake shore along this section and the base of the bank has been partially protected by loose stone riprap in front of the cottages. The banks slope at about 45 degrees and appear to have eroded during high water periods. Tree cover generally extends lakeward to the top of the bank slope. Some cottages are built well back from the lake shore near the top of the higher bank. About 1/4 mile south of the county line and just south of the mouth of Stony Creek there is a caving bank about 10 feet high and a beach of coarse gravel only about 10 feet wide.

Door County Shorelands

34. About 1/4 mile north of the Kewaunee-Door county line there is a narrow stony beach only about 10 feet wide to the high water line and the base of a stony bank about 6 feet high and sloping at about 25 degrees. A cottage is located about 100 feet from the lake shore. The main lake bank for about one-half mile is again back as far as 700 feet from the shoreline with a fairly level bench between the two banks. At La Salle Park a mile north of the county line the sand beach, with scattered large boulders, is about 40 feet wide to the high water line at the base of a bank about 10 feet high and sloping at about 45 degrees. From the top of this low bank the level ground extends back about 250 feet to the base of a steep bank about 50 feet high with timbered slope. This flat terrace continues north for about one mile to the mouth of Bear Creek. The northerly one-half mile of this frontage is occupied by about a dozen small summer cottages built generally about 75 feet back from the lake shore. The fore-shore is about 25 feet wide back to the high water line and is covered with stones up to about 6 inches in size. The low bank slopes up 6 to 8 feet in about 25 feet to the general flat terrace area extending back to the high bluff. A few country homes are built back some distance from the lake shore on this flat area.

35. At Clay Banks, between Bear and Schuyler Creeks, most of the lower terrace has been cut away by wave action eroding the red clay bank. The high bluff line is close to the lake shore and has a height of about 70 feet above lake level with only a narrow remainder of the lower level terrace at the base. North of Schuyler Creek the high lake bluff again recedes to several hundred feet from the lake shore and is from 70 to 90 feet high and very steep. At about one mile north of Schuyler Creek the bank is cut through by Woodard Creek. North of this creek for about 2.5 miles the distance from the lake shore to the main high bank gradually increases to about one mile. There are fairly continuous ridges with top elevations about 24 and 27 feet above the lake at about 800 and 1500 feet back from the shoreline, with a peat bog about ten feet above the lake between the outer ridge and the shore. A sandy beach with some fine gravel slopes up to the high water line in about 50 feet from the shoreline. Banks are tree and brush covered. There is very little use of this area for cottage sites or other development.

36. Rocky Point is about 1.75 miles south of the entrance to the Sturgeon Bay Canal. At this point ledge rock is exposed at the shoreline and top of the ledge is about 10 feet above lake level. (See photo No. 29, App. A). The tree covered bank slopes up to 20 feet above lake level in about 500 feet and then remains fairly level back nearly a mile. South of Rocky Point for about 1.5 miles the lake bank is about 10 feet above lake level and slopes up to about 20 feet above lake level in 1500 to 2000 feet. The beach of coarse gravel and stones is about 60 feet wide. A group of cottages occupies about one-half mile of the frontage about 1.5 miles south of the Point. For about one-half mile north of Rocky Point the ledge rock is at or near the surface along the lake shore with the top of the ledge a little above the high water level and only a thin covering of glacial drift. The beach which gradually widens north of the Point, consists chiefly of gravel and limestone chips,

except for about one mile south of the piers at the canal entrance where sand accreting has formed a sand beach up to 125 feet wide at mean lake stage. North of the Point for about a mile and one-half to the Canal the shore back of the lakeward sand ridge is occupied by a continuous row of cottages. This outer ridge is about 8 feet above lake level and the adjacent land rises very gradually to the west to an elevation about 20 feet above lake level in about 1000 to 2000 feet. This area is timber covered.

37. North of the easterly entrance to the Sturgeon Bay Canal for about two miles to Portage Point the lakeshore is generally sandy with beaches 15 to 25 feet wide and gradual slopes up sand banks to about 8 feet above lake level in about 75 feet. The lakeshore continues sandy for about 6 miles between Portage Point and Whitefish Point with sand beaches 20 to 30 feet wide and sandy slopes 75 to 100 feet back to sand dunes 10 to 30 feet high. (See photo No. 30, App. A). Much of this frontage is occupied by about 160 summer homes or all-year homes built 50 to 100 feet back from top of the outer slope of the sand dunes. Most of the area back from the principal lake bank is tree covered and swampy. About 2 miles of this frontage, in sections 31, 32 and 33 from 1 to 3 miles southwest of Whitefish Point, have recently been subdivided into about 170 lakefront lots generally 60 feet wide and varying in depth from about 250 to 550 feet. Two parallel rows of lots 60 feet wide have been platted west of the lake front highway T, or Glidden Drive, providing a total of about 490 lots along this two mile frontage.

38. North of Whitefish Point near the south line of section 22 in Sevastopol Township there is a small sand beach between two points about 1000 feet apart where ledge rock outcrops at the shoreline. From near the north line of section 22 and continuing for about 1.5 miles around the shore of Whitefish Bay there is a sand beach generally about 75 feet wide to the weed line and an additional 100 to 125 feet to the top of the sand dunes at 12 to 15 feet above lake level. This frontage is almost completely occupied by cottages built near the top of the dunes. (See photo No. 31, App. A). At Sevastopol Town Park near the southeast corner of section 3 south of Clark Lake there is a fine sand beach 100 feet or more in width with fairly steep slope up into sand dune hills 30 feet or more above the lake. (See photo No. 32, App. A). About three-fourths mile west of the easterly end of Cave Point ledge rock outcrops at the shoreline and a nearly vertical rock face about 15 feet high is at the shoreline. (See photo No. 33, App. A). Farther east toward Cave Point the rock ledge is about 10 feet high and there is a narrow foreshore about 20 feet wide. Near the township line about one-half mile north of Cave Point ledge rock is at or near the water surface with a thin sand cover on a narrow beach 15 to 20 feet wide to the high water line and bank slopes up steeply to about 8 feet above lake level. The area is quite densely wooded with only a few scattered cottages. This frontage around Cave Point south of the township line is in the Whitefish Bay State Park planned by the Conservation Division.

39. At the end of Jorns Road near the center of section 26 about one mile south of Jacksonport rock ledge in approximately horizontal strata is exposed at the shoreline and rock banks about 6 feet high are about 20 feet shoreward from the August, 1967, shoreline. (See photo No. 34, App. A). At

Jacksonport near the north line of section 23 there is a sand beach with sandy weed-covered foreshore about 140 feet wide back to the high-water shoreline at a sand ridge about 6 feet high. Cottages are built along or back of this ridge along about 1.5 miles of shoreline.

40. About two miles northeast of Jacksonport, near the center of section 12, the beach is fine sand about 20 feet wide to the weed line with gravel slope up to the top of the sand bank about 8 to 10 feet above lake level. Many cottages are located near the top of the bank with boats beached on the sand. The lake shore for about two miles between Heins Creek, the outlet from Kangaroo Lake and Boynton Chapel at the north line of section 32 is generally rock with only a light cover of 1 to 3 feet of gravelly loam frequently mixed with rock. Most of the area is covered with trees and brush. From Boynton Chapel north for about one-half mile there are several cottages along the lake bank. From near the center of section 29 north about one-half mile to the County Park at the south end of Baileys Harbor the shoreline is ledge rock with near vertical face at the shoreline and a roadway close to the top of the bank which is 8 to 10 feet above lake level. The west side of the road is completely occupied by cottages. The county park near the south limit of Baileys Harbor has a few hundred feet of sand beach north of an old timber, stone and earth pier, and between this main pier and a shorter pier about 300 feet south. Just west of the highway at the county park at about 400 feet from the lake shore there is a ledge rock bluff about 15 feet high and ledge rock is close to the surface out to the shoreline. At about the center of the village at Baileys Harbor, near the center of section 20, there is a near vertical ledge rock bluff about 10 feet high at the lake shore. From the north side of the village for about a mile around the north end of the bay there is a sandy beach, with portions at a county park and a private motel and cottage improvements well maintained. The banks slope up gradually to 8 to 10 feet above lake level and a relatively flat brush and tree covered peat area apparently overlying ledge rock at a shallow depth. The northeast corner of the bay at Baileys Harbor is weedy and has loose rock scattered in the water and along shore, with ledge rock apparently near the surface over the entire peninsula between Baileys Harbor and Moonlight Bay. On the east side of Baileys Harbor three small islands are located 1000 to 1200 feet offshore and the surrounding area is shallow, weedy and obstructed by scattered boulders. Several fishing piers have been built on fills or as open structures along shore. Almost the entire shoreline of Baileys Harbor is occupied with cottages built near the top of the sloping banks or rock outcrops at distances from a few feet to about 300 feet from shore.

41. On the west side of Moonlight Bay ledge rock outcrops at the shoreline for about one-half mile or more in Section 15. At the north end of the Bay there is a shallow surface layer of peat over ledge rock. The easterly side of the Bay has ledge rock in nearly horizontal strata exposed at the shoreline with the banks stepped up gradually in about 100 feet to an elevation 10 to 12 feet above lake level. The north end of the Bay is generally shallow and weedy with many boulders scattered in the water.

42. Ledge rock is to be found near the surface throughout most of the peninsula between Moonlight Bay and Cana Island. The easterly half of the

peninsula is rough and stony, with tree and brush cover. At the north end of the small bay west of Cana Island ledge rock is exposed at the shoreline. (See photo No. 35, App. A) except at the northeast corner of the bay where there is a sand beach extending along shore several hundred feet in an area reserved as a county park. The east side of the bay is rocky. Both sides of the peninsula leading out to Cana Island are rocky and the narrow fill carrying a roadway out to the Island is only a foot or so above high water.

43. At a small point near the center of section 35 at the southwest corner of North Bay ledge rock is exposed at the shoreline and at the north end of the point stands with a vertical face about 10 feet high at the lake shore. Cottages on the point are built close to the top of the ledge. The bottom is gravel along shore and in shallow water to the west and a weedy area extends a considerable distance off shore. On the west side of North Bay near the middle of section 22 there is no beach but a muddy shoreline with weeds throughout the north half of the Bay. The banks slope up gradually to an elevation about 6 feet above lake level in about 50 feet. Cottages of medium class have been constructed near the top of the bank along most of the south and west shores of North Bay. The east shore of North Bay is generally gravel or stony, with muddy reaches at various points. Ledge rock is near the surface. (See photo No. 36, App. A). The banks slope up gradually to about 15 feet above lake level and are generally wooded. Water off-shore is shallow, with weed patches extending several hundred feet off-shore. There are very few cottages along this shore.

44. The lake shore along the east side of the point east of North Bay has ledge rock exposed along shore much of the way (See photo No. 37, App. A) and adjoining areas are wooded and generally unsettled for about 2.5 miles north from the point. About one mile of frontage north from about 1000 feet north of the south limit of section 12 is partly occupied by three groups of 5 or 6 small cottages each. Ledge rock is exposed along the shoreline but there are small amounts of sand along the shore in short reaches. The banks are generally only 5 or 6 feet above lake level.

45. At Sand Bay Town Park south of the village of Rowleys Bay there is a sloping sand beach about 40 feet wide to the tree line and possibly 500 feet long. A number of irregular low stone jetties have been built along shore to the south, but are poorly maintained and apparently rather ineffective in holding sand along shore. The off-shore area is weedy south to piers near the center of section 36 used as a base by several commercial fishing boats. Sand at the Town Park may have been hauled in, and has been graded (or possibly recently scraped to remove heavy deposits of dead alewives). The shore north of the improved sand beach is weedy and stony. The wooded area back from the shore is generally a sandy loam mixed with many stones and generally 8 to 10 feet above lake level.

46. A Fishermen's pier about 290 feet by 40 feet and constructed of timber, rock and earth east of Sand Bay, on the southwest side of the point south of Rowleys Bay, is used by commercial fishing boats. Four storage sheds for the fishing operations are on shore near the pier. The shore

around the point east of the pier is rocky and slopes up to the tree line in a short distance. East of the point north to Rowleys Bay settlement the off-shore area is weedy and strewn with rocks. At the Rowleys Bay settlement a small basin for outboard motor boats has been built on the south shore of a small bay that is shallow and generally weed covered. The shore is generally quite irregular and rocky. At the settlement ledge rock is exposed at the shore and in the bank near the road which is about 10 feet above lake level. Two private fishing piers are located on the northeast side of the point east of the end of the public road.

47. The shoreline around the north end of Rowleys Bay is generally swampy and rocky and the offshore waters shallow and weedy. Near the south line of section 19 at the northeast corner of the Bay the shore is covered with coarse boulders and slopes up about 8 feet in 50 to 75 feet and more slowly for another 100 feet to about 12 feet above lake level. The entire point east of Rowleys Bay is heavily wooded and practically unoccupied. The shore at the north end of the small bay at the south end of the point east of Rowleys Bay is exposed ledge rock except for a short reach of sand beach at the northerly end of the bay. There is one old cottage and two small sheds near this beach area, and a stone filled crib boat landing constructed about 50 feet off shore is connected to shore by a small stone mound in poor condition. A ledge rock shoreline apparently bounds most of the point with little cover over the rock. This entire point from the northeast corner of Rowleys Bay to the north side of Section 16 near the middle of Europe Bay, with about 4 miles of shoreline including Newport Bay, is in Europe Bay State Park.

48. The west shore of Newport Bay along the south half of section 21 has a sand beach sloping up from the shoreline to the tree line in 30 to 40 feet, with a steeper bank slope up to about 10 feet above lake level and then a gradual slope to the west. The main point in section 28 south of Newport Bay appears to be ledge rock near the surface with shoreline exposure along much of the frontage. A rocky reef extends lakeward from the point for about one-fourth mile. Along the north shore of Newport Bay ledge rock is exposed to 6 to 10 feet above water at the lake shore with little or no beach and trees overhanging the rocky lake bank.

49. At Ferdinand Hotz Park on the west shore of Europe Bay near the north line of section 16 there is a sand beach about 50 feet wide sloping up gradually to the high water and tree line. The sandy lake bank is about 10 to 12 feet high. The shore appears about the same for about one-half mile north and about three-fourths mile south.

50. The shoreline east of Europe Lake from about the middle of section 9 northeast for approximately one mile to the most easterly point of the peninsula is exposed ledge rock in nearly horizontal strata. The shore is strewn with large blocks of loose rock and slopes up at about 30 degrees from horizontal to an elevation about 10 feet above lake level.

51. About three-fourths mile south of Northport the rock ledge at the shoreline is 12 to 15 feet high and vertical or overhanging. (See photo No. 38, App. A). The lakeshore around the point has been subdivided and several

cottages are located close to the lake shore. About one-half mile south of the Northport pier there is a sand beach about 70 feet wide with slope of about 5 or 6 feet to the tree line and an additional 6 feet to the top of the first sand ridge. (See photo No. 39, App. A). About one-fourth mile south of the Northport pier the beach is sandy mixed with coarse stones to the high water line about 20 feet from waters edge. The beach with a mixture of sand and fine gravel continues north to the pier. The outer sand ridge is about 9 feet above lake level and 75 to 100 feet back from the water's edge.

52. The Northport pier near the south line of section 33 is an alternate landing from the ferry boats normally operating from Gills Rock to Washington Island. The stone filled steel sheet-pile pier with concrete and asphalt deck is about 325 feet long and 30 feet wide. North of the pier the shoreline is stony and slopes up about 3 feet in 30 feet to the tree line, and about 10 to 12 feet in 100 feet along the lake bank. (See photo 40, App. A). About 2000 feet north of the pier the rock ledge approaches close to the shoreline. Along the north shore of the Door County peninsula in section 33 west to Kenosha Park and beyond the ledge rock cliffs 25 to 30 feet high and almost vertical form the shoreline with numerous rock obstructions along the shore. There are a few cottages along the half mile of shore north of the Northport pier and an occasional cottage along the north shore.

Changes in Lake Level Affecting Shorelands

53. The water level of Lake Michigan fluctuates from year to year and also from month to month depending upon general weather conditions and other factors. Stages vary from day to day and even from hour to hour at any particular point along the lake shore due chiefly to winds and differential barometric pressures. The annual and seasonal variations amount to several feet, and the short period changes may range up to several feet depending on the extent or severity of the causative factors and geographic conditions at the locality involved. Complete records of Lake Michigan levels have been kept by the United States Lake Survey since 1860, and other earlier non-continuous records are available beginning in 1836. Evidence from early years indicates that the lake was as low in the period 1815 to 1830 as it has been since. About 1830 the level rose approximately 2 feet and fluctuated around the higher level for about 60 years. The following Table No. 3 shows the principal high and low monthly mean stages of the lake in the 107 years of continuous records. The maximum range has been 6.59 feet between the high of June, 1886, and the low of March, 1964. The greatest range in monthly average levels in one season has been a drop of 2.23 feet from July to December in 1871, with an added drop of 0.35 foot in the following 3 months, and a rise of 2.21 feet from January to August in 1943. The lake level rose 4.97 feet in the period from February 1926 to July 1929 (3 years, 5 months), and 4.45 feet from December 1949 to August 1952 (2 years, 8 months). The average seasonal range is about 1.1 feet with the lowest and highest months usually in February and July, respectively. Storms or seiches may cause temporary changes in the lake level along a particular shore of several feet. For example, on July 19, 1963, seiches and violent thunderstorms

caused a reported rise of more than 6 feet at Waukegan, Illinois, and Holland, Michigan, above the general level prevailing at that time. Rises of about 1.5 feet were reported at Kenosha and Milwaukee at that time. Fluctuations of the latter amount above or below the prevailing stage are not uncommon at points along the Lake Michigan shore of the state. Such high stages, even of relatively short duration, if accompanied by violent wave action may cause very rapid erosion of exposed banks, or the flooding of large areas of low lying lake shore lands. According to studies made by the Corps of Engineers, U. S. Army, based on a 1903-1952 record, a rise of 1.5 feet above the general Lake Michigan level prevailing at the time may be expected to occur at Milwaukee about once in 31 months, and a rise of 2.0 feet about once in 212 months. A similar study of the 1945-1952 record for Sturgeon Bay Canal indicated that a rise of 1.5 feet above the prevailing level may be expected as often as once in 21 months. (Reference 5, Fig. 12).

54. One of the principal natural conditions that control the effects of wave action on shorelands is the condition of the beach area in the foreshore part of the area between the upper limit of wave wash and the ordinary low water shoreline, and the inshore under-water zone between that shoreline and the lakeward limit of the breaker zone. Since the upper limit of wave wash would be greatly affected by the prevailing lake stage, and since a wave breaks in a depth of water approximately 1.3 times the wave height, the lake level and the slope of the beach have a major effect on the wave action that can reach the toe of the bluff to cause erosion and bank recession. The slopes of the foreshore and inshore areas vary widely with the character of the beach building materials; foreshore slopes for sand beaches varying from 1 in 10 to 1 in 30, and inshore bottom slopes of 1 in 20 to 1 in 50 being rather common. Obviously with such bottom slopes a change in the lake stage of 6 feet might make a difference of 120 to 300 feet in the distance from the shore at which waves break, and also a change in the height of wave wash up the bank. There are many places along the lake shore where a rise of 5 or 6 feet in the lake level would bring the still water shoreline inshore to the base of the main lake bank and permit erosive wave action directly on the bank slope. In such cases some type of protective structure or armoring of the bank is necessary to prevent erosion and gradual recession of the bank.

Effects of Lake Level on Flood Plains

55. High water levels of Lake Michigan aggravated by wind and wave action and by temporary local rises superimposed upon the prevailing lake level result in overflow of low areas. The flooded areas are generally the low lying areas near the outlets of tributary streams, where low relatively flat areas many extend some distance back from the lake shore and upstream along the channel. In many cases these areas have been developed as part of urban communities, or as rural residential or resort areas, when lake stages were at the low side of their range and without a full realization of the probability of recurring high stages. Some areas are subject to inundation from the general high stages of the lake alone, while flooding is aggravated and extended to other areas by local temporary rises and the uprush of storm waves.

(continued on page 24)

Table - 3

Lake Michigan High and Low Water Levels
One Month Averages, in feet

Year	High Stage		Low Stage	
	Month	Elevation	Month	Elevation
1861	Aug.	581.79		
1869			March	578.46
1871	July	581.10		
1872			March	578.52
1876	July	581.86		
1880			March	579.18
1886	June	581.94		
1895			Dec.	577.29
1908	July	580.01		
1912			March	577.47
1918	June	580.17		
1926			Feb.	575.61
1929	July	580.58		
1934			March	575.65
1943	Aug.	579.75		
1949			Dec.	576.50
1952	Aug.	580.95		
1959			Feb.	575.93
1960	Aug.	579.26		
1964			March	575.35

Average level for 107 years (1860-1966) of record 578.69 feet.

Range between highest (June, 1886) and lowest (March, 1964) monthly mean stages of record 6.59 feet.

Low Water Datum, the plane of reference used by the Corps of Engineers for harbor work on Lake Michigan, is at elevation 576.8 feet.

All levels are in feet above mean water level at Father Point, Quebec, on International Great Lakes Datum (1955).

The elevations shown are the major high and low monthly mean stages. There have been numerous minor peak and low stages between these principal points of reversal in the stage trend.

Many residences or cottages along the lake shore are close to the water's edge and at an elevation such that they might be flooded at high lake stages, or at least surrounded by water if built on a raised foundation or fill. Even though these structures may not suffer any major structural damage due to flooding, there may be considerable hazard to health due to flooding of septic tanks and seepage fields, flooding of wells or basements, etc. Generally building in such areas should be prohibited or strictly limited with adequate flood proofing required. Generally along the Wisconsin shore of Lake Michigan the low areas at the outlets of tributary streams are occupied by urban improvements and the low areas generally have been filled to a level above any but the most exceptional high water. However, in many cases high lake stages cause backups in storm sewers, and during major storms some backup onto streets and overflows into sanitary sewers through manholes or by infiltrating due to faulty sewer lines. This may overload sewage treatment plants or sewer mains causing basement floodings, by-passing of polluted sewage and attendant health hazards. In the 1952 study by the Corps of Engineers (Reference 3) it was found that a high water level of 580.3 feet (IGLD datum 1955) had caused most of the waterfront area near the city of Sturgeon Bay to be inundated from a few inches up to a foot or more in depth. This level is below 6 of the 10 high water mean monthly stages listed in Table 3, and temporary local rises due to seiches and storms would increase the areas flooded and the depth of flooding. At Kewaunee the low marshy flats along the river are quite broad, stretch inland for several miles, and are subject to flooding at high lake stages. Little damage results as these marsh areas are generally unoccupied. Other small areas near the mouths of minor streams are subject to flooding for some distance inland but usually the damage from flooding is small because improvements in these areas have been limited.

Effects of Wave Action and Currents on Shorelands

56. Storm waves have the most noticeable short-time effect on the shoreline because of their destructive force and encroachment beyond the still water shoreline to erode the banks beyond the foreshore. However, other smaller waves continuing over a longer time may have an even greater effect on the stability of a shore line. Wave-generated currents transport beach material, when such material is available, and are an important factor in beach stability. Material is moved along the beach as littoral drift, as bed load and suspended load, by wave generated currents. The direction of littoral drift is determined by the angle of wave approach and the direction of the along-shore currents. The predominant direction of the littoral drift usually depends, over a long period, on non-storm waves which contain more of the energy that infringes on a shore than is contained in storm waves of shorter duration. Waves affecting the Lake Michigan shore of Wisconsin have a fetch of about 270 miles to the north-northeast, 80 miles to the east, and 70 miles to the southeast at the southern state boundary; and about 250 miles to the south, 55 miles to the southeast, and 70 miles to the northeast at the northerly end of Door County. Wave observations for a continuous period of about 18 months (2 summers and one winter during 1931-1932) at a station

2 miles east of the Milwaukee Harbor entrance recorded wave heights that exceeded 3 feet for 38 percent of the time, 5 feet for 15 percent of the time and 10 feet for one percent of the time. The maximum wave height observed was 14 feet (Reference 7). In a study completed in 1953 by the Beach Erosion Board (Reference 5), the characteristics of waves occurring at Milwaukee were determined from synoptic weather charts by hind-casting for the 3-year period 1948-50. The highest wave computed was in the range of 15-16 feet and occurred in March, 1948. The study indicated that a wave of this height should occur with an average frequency of once in two to three years. An analysis of this hindcast of wave data, together with the wave observations at Milwaukee previously mentioned, and a 12-year (1939-50) hindcast of storms producing waves greater than 8 feet in height indicated frequency of occurrence of waves as shown in the following table. Waves of 7 feet or more can be expected at any time of year, although those of greatest height are most common in fall and winter.

Table 4

Frequency of Occurrence of Waves at Milwaukee

Frequency of Wave Occurrence	Wave height in feet	
	During full year	During ice-free period Apr. 1 - Dec. 1
Once each month	8	6
Twice each year	12	8.5
Once each year	13	10
Once each 2 years	15	11
" " 3 "	16	11.5
" " 5 "	17	12.5
" " 10 "	19	13.5

The probable period range of the once-a-year maximum waves would be 4-5 seconds, the probable direction of approach from the east, and the probable duration of the storm occurrence 5 hours.

57. The continued action of waves against beaches and lake banks which, at lower lake levels, would be exposed only to the higher storm waves is the principal cause of erosion accompanying high lake levels. High lake levels by increasing the water depth at or near the lake bank or bluff face, permit higher waves to impinge on the bank or bluff. If the waves reach and impinge on bluff faces composed of soft or easily erodible materials, undercutting of the bank may be expected, along with slides making more material accessible to the waves and resulting in marked recession of the unprotected bank or beach.

58. The prevailing directions of the wind at Milwaukee, by months, and the mean and extreme wind records, are shown in the following Table 5.

Table 5

Mean and Extreme Wind Records
General Mitchell Field, Milwaukee, Wis. (c)

Month	Mean Hourly Speed m.p.hr.	Prevailing Direction	Fastest Mile		
			Speed m.p.hr.	Direction (b)	Year
(a)	26	14	26	26	
Jan.	12.9	WNW	62	W	1950
Feb.	12.9	WNW	58	NE	1960
March	13.6	WNW	73	SW	1954
April	13.5	NNE	72	SW	1950
May	12.4	NNE	72	SW	1950
June	10.5	NNE	57	S	1953
July	9.6	SW	59	W	1952
Aug.	4.6	SW	50	W	1949
Sept.	10.8	SSW	62	S	1941
Oct.	11.6	SSW	60	S	1949
Nov.	13.2	WNW	72	W	1955
Dec.	12.7	WNW	62	SW	1948
Year	11.9	WNW	73	SW	1954

(a) Length of record, years.
(b) to 8 compass points only.
(c) Means and extremes are from the existing location, from record through the year 1966.

This record shows that the prevailing wind direction at Milwaukee for the months of April, May and June is north-northeast. This is the direction of greatest exposure of the shoreline from about Manitowoc south and storms from that direction result in maximum wave disturbances along the shore with resultant heavy erosion of the beaches and lake banks. The surface currents on Lake Michigan are primarily wind driven. Studies of the currents were made in 1894 by Mark W. Harrington for the United States Weather Bureau (Reference 1). Additional current surveys were made in 1955 by John C. Ayers,

et. al., University of Michigan, and E. Bennette Henson, University of Maryland, for the Great Lakes Research Institute (Reference 2). These studies indicate that the currents tend to circulate in a cyclonic or anti-clockwise direction. Currents in Lake Michigan are divided into two cyclonic cells, one generally south of an east-west line approximately through Sheboygan, and the other between that line and an east-west line through Beaver Island. The general pattern of these primary currents seems to persist with little change. The northern cell is not as intense and the currents along the northwestern shores of the lake are weak. There is a marked southward drift on the west side generally from near Two Rivers Point south. Temporary changes do occur in connection with seiches and, in the case of the weaker currents, with wind direction. Even the well marked currents are modified when strong winds blow for extended periods from a direction other than the prevailing one. There frequently are minor circulation patterns near shore along the frontage between Wind Point near Racine and Port Washington, and between Sheboygan and Two Rivers Point, resulting in northward currents in the shallower areas near shore. However, the predominant currents along the shore are southward.

59. Based on hindcast studies of synoptic weather charts made in connection with a report on Property Damage on the Great Lakes Resulting from Changes in Lake Levels (Reference 3), the Corps of Engineers, U.S. Army, calculated the amount of energy incident on a coast over a long period of time, and the directions from which this energy comes. Since the direction of incident energy determines the predominant direction of the along-shore current, these data in conjunction with data on the subject contained in prior reports enabled qualitative conclusions to be drawn concerning the directions of drift along the shores of Lake Michigan. These studies showed that along the western shore in the vicinity of the north half of Door County Peninsula, the direction of drift varies to such an extent that its up-coast and down-coast components are practically equal. North of Two Rivers to the vicinity of Sturgeon Bay the drift is predominantly northward, and to the south of Two Rivers it is predominantly southward. In the vicinity of Milwaukee the drift has a much stronger component to the south.

60. The effects of littoral drift are important to the preservation and use of the lake shore. With any given lake level, over an extended period of time, there will be a balance of forces tending to move material to and from the beach. Beach sand or eroding bluff material is carried either offshore or down drift by wave generated currents or forces. The material moved out of an area by littoral forces is balanced by materials similarly moved into the area, assuming there is a source of supply on the up-drift side and no interfering obstruction to the littoral forces moving the materials. A groin, for example, might interrupt the alongshore drift and cause accretion on the updrift side, at least for a period after construction, and might cause erosion on the downdrift side by obstruction the supply of nourishing material. A rise in lake levels, upsetting the established balance of forces, might cause more rapid erosion of bluffs and beaches and increase the amount of beach material available. However, increased wave action on the beach also would increase the rate of littoral drift. The first factor would create a tendency toward beach accretion, and the second toward beach erosion. If the

higher level is maintained for some time the beach would reform with a new equilibrium slope, but the foreshore would be moved landward with the new berm at a correspondingly higher level, and an accompanying loss of shoreland.

Ice Effects on Shorelands

61. The detrimental effects of lake ice on lake shores are due generally to the wind-driven on-shore movement of floating ice fields broken away from larger fields by thawing or wave action. The drifting ice can damage shore structures and destroy vegetation, move sand or stones from beaches, or dump sand, rock, or other debris on beaches. At high lake levels the ice cakes churned by wave action, or driven ashore by strong winds may gouge out sand or other erodable materials from the base of high lake banks at considerable distances from the shoreline, causing steep banks to become unstable and subject to land slides when the ice disappears. This hastens the recession of shorelines. The outlets of small streams may be blocked by ice jams so that the confined backwater builds up a hydrostatic head that may cause a breach in the stream bank or cut a new outlet through the lake bank, with possible damage to structures built near the stream or lake bank. Ice jams blocking stream outlets also may cause backwater with resulting inundation of low-lying inland areas. However, the net effects of ice formations along the lake shorelines are beneficial. Spray thrown by wind and wave action often freezes on lake bluffs, beaches, and shore structures coating them with a protective layer of ice. Ice formations along shore, often taking the form of windrows up to 15 feet high running generally parallel to shore, provide further protection to the shore itself. Ice cover extending lakeward for a considerable distance may dampen or practically eliminate wave action along the shoreline.

Shorelands Vulnerable to Erosion by Wave Action

62. The lakeshore from the south city limit of Kenosha to the Illinois state line, about 4.5 miles, is subject to rapid erosion at high lake stages, except where individual properties have been protected by bulkheads or heavy stone armor, with an average bank recession of 4 to over 6 feet per year as noted in paragraphs 4 and 5. During the high-water period in 1951-1952 maximum erosion of up to 100 feet within a year was recorded along this frontage (reference 3). Approximately 3 miles of shoreline in Kenosha County north of the city also is subject to rapid erosion averaging about 2 feet per year since 1872 (reference 6). About one mile of shoreline north of the Racine-Kenosha County line has receded at a rate slightly less than 2 feet per year during the period 1874-1946, and at about twice that rate prior to 1874 (reference 8). However, this frontage has been partially protected by about 26 groins of various lengths and types, most of them built about 45 years ago and in poor condition. However, they have checked erosion to some extent where maintained or supplemented by later construction. The remaining shoreline of about 1.25 miles south of Racine has been subject to an average erosion of about 1.25 feet per year. The southerly 0.75 mile of this frontage continues subject to rapid erosion although protected about 45 years ago by a bulkhead now generally destroyed with the remains a considerable distance lakeward from the shoreline. (see par. 9). Along the J. I. Case plant just south of Racine rapid erosion has occurred and continues where the frontage has not been protected by substantial bulkheads. (see par. 11).

63. North of Racine Harbor about 1.25 miles of shoreline between the city limit and Shoop Park at Wind Point has been subject to recession of about 0.8 foot per year due to erosion. About 30 years ago the rate of erosion was reduced by the construction of about 25 groins 60 to 100 feet long, with a few shorter groins and some short sections of retaining wall, along this frontage. These must be maintained to prevent continued serious erosion. At high lake stages considerable erosion is to be anticipated since the top elevation of many of the groins as constructed was only 2.5 to 5 feet above low water datum and many of them have settled to still lower elevations, so that storm waves at high lake stages would over-top the groins with sufficient energy to cause severe erosion. As noted in paragraph 13 and Tables 1 and 2 bluff recession from Wind Point to the north line of Racine County during the period 1874 to 1946 averaged 0.50 to over 4 feet per year at various points along this frontage, averaging about 1.6 feet per year. Little shore protective work has been done along this frontage and similar erosion continues, with the major losses occurring during years of high lake levels.

64. Evidence of active erosion and undercutting of the lakefront bluffs is common between Milwaukee and Port Washington. The Geological Survey report on the shoreline published in 1907 (reference 10) noted that along this section of the lake shore "the active retreat of the clay bluffs has removed almost all the old shore records. In the freshly cut cliffs of the Milwaukee district a complex structure of laminated clays, till, and stratified sands and gravels is extensively exposed." Such erosion has continued at high lake stages to the present time except where the base of the bluff has been protected by substantial bulkheads or heavy stone armor. There are many instances of well built retaining walls or bulkheads that have been destroyed by wave forces, earth and hydraulic pressures from the retained bank, or

undermining by wave and current action. In Ozaukee County approximately 7 miles of shoreline between the north limit of the city of Mequon and the south limit of the city of Port Washington is subject to severe erosion. A report with photographs of a typical bank failure near the north boundary of mequon was given in the Ozaukee Press, Port Washington, issue of August 31, 1967, as follows: "A sheer wall of clay offers dramatic evidence of the unexplained collapse of thousands of tons of earth in front of the lake shore home *** (at 233 E. Pioneer Road, 144 N., Mequon) at the northern edge of Mequon. A section of lawn and trees several hundred feet wide *** dropped out of sight with a roar at about 6:30 A.M., Friday (August 25). Little of the fallen material could be seen, though layers of muddy clay spread out on the beach far below. In the last few years other instances of lakefront property collapsing have been reported ***." In this case the chunk of earth breaking away from the bluff was reported to be about 75 feet deep and large pine trees were carried down the bank still remaining upright. For a depth of about 30 feet near the top of the bluff the break was nearly vertical. It was necessary to move a large residence located only about 15 feet from the brink of the bluff back about 250 feet to a new foundation. Many slides of this character have been reported and continue to occur, and are caused primarily by erosion undermining the base of the bluff, although frequently accompanied by water saturation of strata of material in the bank causing it to become unstable. In the Corps of Engineers study of the northern part of Milwaukee County (reference 7) where conditions are very similar to those in the southern part of Ozaukee County it was estimated that the average rate of bluff recession from 1836 to 1941 was about 1.2 feet per year. Since most of the frontage remains unprotected it is considered that this rate of recession would be fairly representative for the frontage between Mequon and Port Washington.

65. The lake shore from Port Washington to the north line of Ozaukee County is subject to erosion and recession at high lake stages for most of the frontage. As noted in paragraph 16 a high and steep lake bank follows close to the lake shore for about 4.25 miles, except for a short distance near the mouth of Sucker Creek. Beginning about 0.75 mile south of the north boundary of T. 11 N., and continuing about 6.75 miles to the north county line, the high bank is generally back several hundred feet from the shoreline, with a lower terrace between, and the fairly wide sand beaches and foreshore slope up gradually to the terrace level. At high lake levels there is considerable erosion except for a short section at Harrington Park (Sec. 19, T 12 N, R 23 E) where ledge rock is near the surface.

66. Between the south line of Sheboygan County and the city of Sheboygan, about 11.5 miles, the sand beaches and sandy banks sloping up to terrace levels 10 to 15 feet above lake level are subject to erosion damage at high lake stages. Along the 4 miles of shoreline north of the county line there are about 80 cottages and residences built close to the lake shore on the sandy terrace. During the highwater year 1951-1952 the Corps of Engineers reported (see reference 3) that this frontage had eroded an average of about 60 feet. A number of the cottages had to be moved to save them from undermining, and a variety of protective structures were built along the shoreline to save others. The Corps of Engineers in the study reported total damages to private property along the Sheboygan to Port Washington lakefront of $835,000 and damages to public property of $42,000. Retreat of the lake

bank at Sheboygan 100 years ago was reported as 6.25 feet per year (reference 10). However, this was after a series of several years with levels 3 to 5 feet above the present low water datum and is believed to be much higher than the present average rate of recession. At the same time the shoreline retreat at Port Washington was reported as 2.3 feet per year. Probably a recession of 1.5 to 2.0 feet per year would reasonably represent the average annual retreat over a long period of high and low water years for the unprotected shoreline between Port Washington and Sheboygan.

67. The main lake bank from Sheboygan to the Village of Hika, about 9 miles, is steep clay bluffs close to the shoreline and these bluffs are subject to rapid undercutting by wave action during storms, especially during periods of high lake levels. Many evidences of recent earth slides are found. Sand strata and beds of peat and pre-glacial forest materials in the clay banks hasten the bank failures and shoreline recession.

68. In Manitowoc County from about one mile north of Hika north to silver Creek near the south limit of Manitowoc, about 9 miles, the high lake bank generally follows close to the lake shore with a narrow beach at lower lake levels but with little or no protective beach at high lake stages, when the waves undercut the banks rapidly. A Corps of Engineers beach erosion study in 1955 (reference 9) reported the rate of recession for about 2.5 miles of frontage south of the south city limit near Silver Creek as 0.7 mile per year for the period 1870 to 1954. This probably is fairly representative of the average recession for the remaining frontage south to Hika. The Corps of Engineers 1952 report (reference 3) estimated the average shoreline loss during the high water years, Spring 1951 to Spring 1952, between Sheboygan and Manitowoc as 15 feet. Property losses for this period were estimated as $242,000 to private property and $58,000 to public property.

69. The Corps of Engineers beach erosion study (reference 9) reported the average recession rate for the shoreline between the city limits of Manitowoc and Two Rivers as 1.0 foot per year for the 1870-1954 period. A maximum recession of 200 feet, or about 2.4 feet per year for this period was noted. A Geological Survey report in 1907 (reference 10) noted a report of recession of at least 150 feet in three or four years prior to 1905 in spite of attempts to check the erosion along the lake shore road between these cities. At that time the lake level had been about 3 feet above low water datum for two summers. Nearly all of this frontage has now been protected by bulkheads or heavy stone riprap along the bank so that most of the erosion has been checked.

70. Along the 3.6 miles of shoreline northeast of Two Rivers to the Point Beach State Forest the sand beaches are fairly wide and bank erosion is fairly slow. The Corps of Engineers (in reference 9) reported average recession from 1870 to 1954 of about 0.7 foot per year. Generally lower mean lake levels since 1954, except in 1955 and 1960, probably have reduced this rate of recession and no major losses have been noted recently.

71. In general the sand and gravel beaches for about 3 miles north of the Point Beach State Forest are relatively narrow and wave wash extends to the base of the Irregular sand dunes and ridges along the shore. Shoreline

recession, although continuing when high lake stages permit waves to reach the banks, apparently is rather slow. From two miles south of Two Creeks north about 3.5 miles to the county line beaches are quite narrow. Banks are about 20 feet high and steep and clay beds in some places are mixed with strata of peat, buried forest debris, and glacial till. Many of the banks show definite evidence of recent caving due to undercutting by wave action, and bank recession is continuing.

72. Near the south limit of Kewaunee County the lake bluffs are about 40 feet high and are being undercut by wave action with materials from bank slides at the base of the bluffs being washed away by wave action. Banks slope at about 45 degrees and are clay with strata of sand at various levels. The bluff for about six miles south of Kewaunee is 40 to 80 feet high, slopes at about 1 to 1, and is very close to the lake shore most of the way. Beaches are narrow and erosion is rapid. Bluffs are composed of red till laminated with clays and with the beds of sand at various levels, making the banks subject to easy erosion. Deep gulleys cut through the banks at various points, and debris washed from these gulleys is usually carried away by wave action and currents in a short time. In a 1952 report (reference 3) the Corps of Engineers estimated the average bank erosion loss between Kewaunee and Manitowoc in the one-year high water period Spring 1961 to Spring 1962 as 15 feet. Private property lost along this shore was estimated at $142,000, and public property at $144.000.

73. For two miles north of the Kewaunee city limit the beach is very narrow and stony, making the base of the high bluff subject to undercutting by wave action. Banks of mixed materials with many embedded boulders are 50 to 60 feet high and about 1 on 1 slope and bank slides are common. Along about 0.5 mile near the mouth of Mashek Creek there is a fairly level terrace about 17 feet above lake level. The gravel beach is only about 15 feet wide with an additional gradual slope for about 20 feet to an elevation of about 5 feet above datum at the base of a fairly steep bank about 10 feet high. The bank has been eroded while the lake level was high but at present moderate lake stage the coarse gravel beach appears to retard recession of the bank. North of Mashek Creek for about 4 miles the narrow coarse gravel beach permits erosion of the steep bank which is about 15 feet high. Slow recession of the lake bank appears to be continuing with most of the erosion occurring while the lake is at its higher stages. South from Algoma for about 1.75 miles there is a coarse gravel beach and stony foreshore sloping up to a level terrace about 8 or 9 feet above lake level. Construction of some bulkheads and filling along the shore has changed natural conditions, but where the coarse gravel beach and sloping bank has not been changed by such work there is evidence of considerable erosion at high lake stages.

74. Between Algoma and Sturgeon Bay the lake bank, as described in paragraphs 32 to 36, is quite variable. Frontage where the high clay banks are close to the shore, including about 1.5 miles northeast from Algoma and about one-half mile at Clay Banks, about 2 miles north of the Kewaunee-Door County line, there is evidence of considerable erosion when the water level was high. Other low banks also have suffered some erosion, although the stony beaches reduce erosion at lower lake stages. Around Rocky Point about

one to 2.5 miles south of the Sturgeon Bay Canal entrance ledge rock is exposed or near the surface and there is substantially no bank recession due to erosion. Between Rocky Point and the canal there is some accretion of sand to the beaches along frontage partially protected by the harbor structures at the canal entrance. The Corps of Engineers in 1952 report (reference 3) estimated the average erosion along the 28 miles of shore between Sturgeon Bay and Kewaunee to be about 15 feet for the one year high water period from Spring 1951 to Spring 1952. During this period the lake level rose 1.68 feet, or from 1.84 to 3.52 above low water datum, with an additional rise of 0.63 feet by July, 1952. Total damages to private property for this section of lake shore due to the high water were estimated at $95,000 to private property and $65,000 to public property.

75. North of Sturgeon Bay for about 8 miles to Whitefish Point the sandy beaches are generally 15 to 50 feet wide with bank slopes of about 1 to 3 feet in 10 feet to top of sand dunes and ridges 8 to 30 feet above lake level. The shoreline is subject to considerable change with the water level because of a flat underwater slope, and appears to have receded in about 10 years, 1954-1964, as much as 50 feet or more toward the northerly end of this reach in sections 32 and 33 of Sevastopol Township. Cottages and homes are built along the lake front occupying much of this frontage as noted in paragraph 37.

76. On the easterly side of Whitefish Point ledge rock is at or near the surface and there is very little erosion. The west side of Whitefish Bay has wide sand beaches and there is no important recession of the lake banks. Around Cave Point ledge rock is exposed at the shoreline as noted in paragraph 38 and there is no appreciable loss of lake banks. Rock is generally exposed along much of the shoreline from Cave Point for about two miles north. At Jacksonport and northeast to the outlet from Kangaroo Lake the sand and gravel beach and foreshore back to the outer lake bank is generally quite wide and overgrown with weeds and there apparently is no erosion problem. Most of the shoreline from Heins Creek, the lake outlet, north to Baileys Harbor Village is ledge rock. Ledge rock is close to the surface around the bay at Baileys Harbor and erosion is not a problem. The same condition exists around the point east of the harbor, around Moonlight Bay, and around the point between Moonlight Bay and Cana Island. The lake bank north from Cana Island is generally ledge rock, with near vertical rock cliffs 10 feet or more high near the south entrance to North Bay. The Offshore areas around North Bay are generally weedy and muddy and ledge rock is near the surface. Bank erosion is not a problem. Ledge rock is exposed in the banks east of North Bay and around the point east of the Bay. At Sand Bay Park south of the village of Rowley Bay there is some sand along shore and attempts have been made to retain it by groins that are poorly maintained. Most of the shore area in the vicinity is weedy and stony and there is no appearance of an erosion problem. The lake shore around the north end and east shore of Rowley Bay, and the point east of the Bay is generally rocky or exposed ledge rock and bank erosion is not a problem. Europe Bay State Park includes the east shore of Rowley Bay, the point to the east, and the shores of Newport Bay and Europe Bay to the north side of section 16, about one-half mile south of Europe Lake. About 0.5 mile of shoreline of Europe Bay north of the State Park has a sand beach and sand

banks but no serious erosion is evident. About a mile of lake shore around the point east of Europe Lake has ledge rock exposed at the shoreline. Just south of the center of section 4 the rock cliff is about vertical and 12 to 15 feet high, with a small amount of sand at the base of the rock with the lake level about 1.6 feet above datum.

77. Around the northeast tip of Door County there is no general erosion problem because ledge rock is either at or very near the surface. Rock is exposed along shore for about one-half the distance north of the point east of the north end of Europe Lake to the Northport pier. Some sand covers the ledge south of the pier for about one-half mile but is mixed with rock fragments. North of the pier for about 2000 feet the shore is a bed of broken rock not subject to rapid erosion by wave wash. Around the north shore of the Door County Peninsula in the vicinity of Kenosha Park beds of ledge rock extend to well above the lake level with nearly vertical faces and no appreciable recession of the shoreline is caused by wave action.

Criteria for Shoreland Zoning

78. "Shorelands" as considered in this report, include lands within 1,000 feet of the normal high-water shoreline of Lake Michigan. The normal high-water shoreline is conisdered to be the shoreline as it would exist with the stage of the lake at the highest monthly mean stage recorded during the period of record since 1860, this being the stage recorded in June 1886, elevation 581.94, or 5.14 feet higher than the low water datum used as a plane of reference by the Corps of Engineers for the preparation of navigation charts and plans for navigation improvements. The shorelands considered also are limited to those areas within 1,000 feet of the normal highwater shoreline of Lake Michigan that are outside of incorporated city and village areas. The shoreland protective regulations suggested are proposed under the authorization contained in Sections 59.07(51), 59.97, 59.971, 87,30, 144.26 and 236.45 of the Wisconsin Statutes. The purpose of these regulations is to further the maintenance of safe and healthful conditions; prevent and control water pollution; protect fish and aquatic life; control building sites, placement of structures and land use; and preserve shore cover and natural beauty.

Permits for Construction in Shoreland Area

79. The following conditions shall apply to zoning of the shorelands unless expressly excluded by the provisions of the zoning regulations. No structure shall hereafter be located, erected, enlarged or reconstructed within the shoreland zoned area, and no private water supply or sewage disposal system shall be constructed in that area, without a permit from the Zoning Administrator and without full compliance with the provisions of these regulations and all other applicable local, county and state regulations. No land shall be used or structure erected for human occupancy where the land is held unsuitable for such use by the Zoning Administrator by reason of flooding, concentrated runoff, inadequate drainage, adverse soil

or rock formation, unfavorable topography, low percolation rate or bearing strength, erosion susceptibility, or any other feature likely to be harmful to the health, safety, or general welfare of the community. The particular facts forming the basis for the conclusion that the land is not suitable for certain uses shall be recited in writing. The applicant shall have an opportunity to present evidence contesting such unsuitability which shall be considered by the Plan Commission which may affirm, modify, or withdraw the determination of unsuitability.

Minimum Lot Area and Frontage

80. In any district where public sewerage serivce in not available, the width and area of all lots shall be sufficient to permit an on-site sewage disposal system designed in accordance with Section H-65 of the Wisconsin Administrative Code. In any district where a public water service or public sewerage service is not available, the lot width and area shall be determined in accordance with Section H-65 of the Wisconsin Administrative Code, but for one-family dwellings shall be no less than 100 feet at the building site and 20,000 square feet, respectively. All lots shall abut upon a public street or highway and each lot shall have a minimum frontage of 30 feet. All lots that abut the lake shore shall have a minimum lake frontage of 100 feet. Only one principal structure shall be located on a lot.

Waste Disposal Requirements

81. No discharge of liquid wastes into Lake Michigan or any other surface waters or natural water courses within the shorelands zoning area shall be permitted, subject to the provisions of Section 144.555 and other appropriate provisions of the Wisconsin Statutes. Industrial waste treatment disposal systems shall be subject to approval by the Division of Resource Development prior to construction pursuant to Section 144.555 Wisconsin Statutes and Section RD 8.02 of the Wisconsin Administrative Code. It shall be unlawful to throw, discard, or discharge into any navigable water any can, bottle, or rubbish. Junkyards, dimps, and sanitary fills may be allowed upon issuance of a Special Exemption Permit in conformance with the provisions of these regulations and State Law.

Sewage Disposal

82. All premises intended for human occupancy shall be provided with an approved method of sewage disposal, such as a connection with a public sewer, privy, or septic tank and soil absorption system. The applicable rules, regulations, and laws as set forth in Chapters 145 and 146 of Wisconsin Statutes and Sections RD 12, RD 13, H 61, H 62, and H 63 of the Wisconsin Administrative Code are incorporated in these regulations by reference and shall apply, except that the provisions of these regulations shall apply where more restrictive. All plumbing fixtures shall be connected to a public

sanitary sewer system where such connection is available within 500 feet of the structure served. Where such a public sewer system is not available a private sewage disposal system may be used. Privies shall be discontinued and replaced with water-flush toilets within one year after a public sewer system becomes available in accordance with Section Ind. 22.12 of the Wisconsin Administrative Code.

83. Structures or facilities requiring private sewage disposal facilities shall not be constructed within the shoreland zoning area until a sanitary permit has been issued by the Zoning Administrator. No septic tank system shall be installed or structurally altered without a sanitary permit. No septic tank shall be purchased or installed until a Septic Tank Permit required by Section 144.03, Wisconsin Statutes (Section 38, Chapter 614, Laws of 1965) has been issued. Only septic or treatment tanks as described in Section H 62.20(1)(d), Wisconsin Administrative Code, shall be installed or constructed. The septic tank size shall be based on the number of persons using the building to be served or upon the nature of use and type of waste, as specified in Section H 62.20(1), Wisconsin Administrative Code, except that the minimum tank capacity below the outlet shall be 750 gallons. No septic tank shall be located within the following distances measured horizontally of the items noted:

10 feet of any building used for human occupancy; 10 feet of a lot line; 10 feet of any cistern; 25 feet of the high water mark of any lake or watercourse; 25 feet of a well or other source of water supply used for domestic purposes; 25 feet from the exposed surface of any earth bank having a slope greater than 1 on 4 (14deg. 3 min.). Where feasible septic or treatment tanks shall be located downslope from wells and shall be floodproofed if located in any area subject to periodic flooding.

84. The effluent from septic or treatment tanks shall be disposed of by soil absorption in a seepage pit or drainage field, or by some other method approved by the Division of Health. Soil absorption disposal units shall be constructed in accordance with requirements of Section H 62.20 of the Wisconsin Administrative Code. The type of soil absorption system to be used for effluent disposal shall be determined by percolation tests made in accordance with Section H 65.06(4), Wisconsin Administrative Code. No site for a private sewerage system shall be approved where there is less than 3 feet of soil between the bottom of the proposed tile field or seepage pit and high groundwater or bed rock; or where the percolation rate in any test hole is slower than one inch in 60 minutes. No storm water or clear water drains shall discharge into a private sewage disposal system. Soil absorption systems shall not be constructed where land slopes are 12 percent or more or where there are slopes of more than 12 percent downgrade from the proposed system within 25 feet of the proposed system. Soil absorption systems shall not be constructed where bedrock or high groundwater is within 6 feet of the ground surface. All portions of a soil absorption system shall be located at a minimum horizontal distance of 10 feet from any lot line, 25 feet from any cistern or dwelling, 25 feet from a slope 12 percent or greater at the edge of a watercourse or along a lake shore, 50 feet from the high water shoreline of any lake or watercourse, and 50 feet from any water supply well.

Soils with limited soil absorption characteristics

85. Certain soils in the shoreland zoning area have severe limitations for successful operation of soil absorption sewage disposal systems because of slow permeability, shallow bedrock, high ground water or steep slopes. In any district where public sewerage service is not available, the width and area of all lots shall be sufficient to permit the use of an on-site soil absorption sewage disposal system constructed in accordance with Section H 62.20 of the Wisconsin Administrative Code. Where both a public water service and public sewerage service are not available, the lot width and area shall be increased in accordance with Chapter H-65 of the Wisconsin Administrative Code. The locations, descriptions, and characteristic limitations for various uses of soils found in the shoreland zoning area along Lake Michigan are given in the following publications with soil maps accompanying them:

Kenosha, Racine, Milwaukee, and Ozaukee Counties: Southeastern Wisconsin Regional Planning Commission's Planning Report No. 8, "Soils of Southeastern Wisconsin," June, 1966.

Sheboygan County: U. S. Department of Agriculture's "Soil Survey of Sheboygan County, Wisconsin," No. 18, Series 1924.

Manitowoc County: U. S. Department of Agriculture's "Soil Survey of Manitowoc County, Wisconsin," No. 34, Series 1926.

Kewaunee County: Wisconsin Geological and Natural History Survey in cooperation with the U. S. Department of Agriculture, "Soil Survey of Kewaunee County, Wisconsin," Bulletin No. XXXIX, Soil Series No. 9, 1914.

Door County: U. S. Department of Agriculture's "Soil Survey of Door County, Wisconsin, 1917.

The information on soil characteristics within the shoreland zoning area given in the last four reports noted is not presented in enough detail for effective regulation of the installation of soil absorption systems in the shorelands of these counties and percolation tests as noted in paragraph 84 will be required prior to approval of plans for such systems.

86. The following soils in Kenosha, Racine and Ozaukee Counties, as listed in S.E.W.R.P.C. Planning Report No. 8 noted above, have estimated percolation rates in part or all of the upper 3 feet of soil of more than 60 minutes for a drop of 1 inch. Areas having such soils shall not be used for on-site sewage disposal systems unless on-site percolation tests and other evidence of suitability of the soil at the site for such soil absorption sewage disposal facilities presented to the Sanitary Inspector are found acceptable and the plans of the proposed system are approved.

Table 6

Soils with Slow Persolation Rates
Kenosha, Racine and Ozaukee Counties

Soil Number	Soil Name	Soil Number	Soil Name
21, 332, 172Z	Hebran Loam	170Y, 22	Hebron sandy loam
54	Lawson silt loam	172Y, 357	Hochheim loam
370 250Z	Mosel sandy loam	297	Morley silt loam
371	Mosel loam	300	Ashkum-Beecher silt loam
70Y	Hochheim fine sandy loam	1	Rough broken land
11W	Alluvial land, wet	100	Kewaunee silt loam
42	Tichigan silt loam	99	Kewaunee silty clay loam
40	Saylesville loam	142	Manawa silt loam
218	Bono silty clay loam	165	Poygan silt loam
298	Ashkum silty clay loam	101	Kewaunee sandy loam
299	Blount silt loam	103	Kewaunee loam
172	Casco loam	162, 362	Theresa silt loam

87. Soils listed below located within the shoreland zoning area of Sheboygan, Manitowoc, Kewaunee and Door Counties have severe limitations for satisfactory operation of soil absorption sewage disposal systems because of slow permeability or high ground water and shall not be used for on-site sewage disposal unless evidence of suitability is furnished the Sanitary Inspector and the plans approved by him.

Table 7

Soils with Slow Absorption Characteristics
Sheboygan, Manitowoc, Kewaunee and Door Counties

Soil designation on soil map				Soil Name
Sheboygan County	Manitowoc County	Kewaunee County	Door County	
Ml	Ml			Maunee loam
Pc	Pc			Poygan silty clay loam
Sf	Sf			Saugatuck fine sand
Cm	Cm			Carlisle mich
	P	P	P	Peat
	Wm			Wabash silt loam
	Gr			Granby fine sand
			Mu	Muck

88. The following soils in Sheboygan, Manitowoc, Kewaunee and Door Counties in the shoreland area have various limitations for soil absorption type sewage disposal systems and evidence of on-site investigations of soil percolation, drainage, water table and other characteristics indicating suitability for the proposed use shall be furnished the Sanitary Inspector for review and approval prior to sewage disposal installations in such areas.

Table 8

Soil with Various Limitations for Soil Absorption
Sheboygan, Manitowoc, Kewaunee and Door Counties

Soil designation on soil map				Soil Name
Sheboygan County	Manitowoc County	Kewaunee County	Door County	
	Sl	Sl		Superior loam
Ss	Ss			Superior silt loam
Sc	Sc	Sc		Superior clay loam
	S	Sf		Superior find sandy loam
Ks	Ks			Kewaunee silty clay loam
	Kl			Kewaunee silt loam
	Bl			Berrien loamy find sand
Br	Br			Bridgeman find sand
Fl	Fl			Fox fine sandy loam
			(1)	Ledge rock

(1) Many areas of Door County north of Sturgeon Bay have exposed ledge rock or a cover of only a thin layer of soil.

No private sewerage system shall be approved for sites where there is less than 3 feet of soil between the bottom of the proposed tile field or seepage pit and high groundwater or bed rock.

Water Supply

89. Premises intended for human occupancy, within the shoreland zoning area, shall be provided with suitable plumbing fixtures served by a public water supply system where available. Where a connection with a public water system cannot be made within 500 feet of the structure a private water supply system may be used. Well construction and materials shall be as specified in Section RD 12 of the Wisconsin Administrative Code. Wells shall be located as specified in Section RD 12.04. Wells located in an area subject to periodic flooding shall be floodproofed. Wells shall not be located between private sewage disposal facilities and the lake shore, and shall be upslope from such disposal facilities.

Setbacks from the water

90. For lots that abut the shore of Lake Michigan, or the shore of navigable streams flowing into Lake Michigan, within the shoreland zoning area, all buildings and structures, except piers, wharves, boathouses, and shore protective structures, shall be set back at least 75 feet from all points along the normal high water line, and shall be located on a site having a surface elevation at least 2 feet above the experience highwater elevation unless otherwise specified by a flood plain zoning ordinance. Boathouses shall be located shoreward from the normal high water line except where construction lakeward of that line is approved by permit from the Zoning Administrator because of the existence of ledge rock or other conditions making construction shoreward impractical. Where the limit of the setback from the water specified would fall on a bank sloping 1 vertical to 2 horizontal ($26^{\circ}34'$) or more, or closer than 50 feet to the top of such slope, the required setback shall be at least 50 feet from the top of the slope having or exceeding that steepness.

91. The portions of the Lake Michigan shoreline designated by the following list have unique characteristics that require increased setbacks to avoid unsanitary conditions, or hazards to structures resulting from caving banks, with resultant dangers to public health and safety. These segments of the shoreline have a present lake bank generally 8 or more feet high near the normal high water shoreline, with a nearly level bench or terrace extending back a varying distance from the lakeward lake bank to a second steep (slope exceeding 1 on 2) bank formed by the lake at an earlier and higher lake stage, or by other natural processes. Where the second bank is within the shoreland zoning area and has a height in excess of 10 feet and an average slope in excess of 1 vertical to 2 horizontal, a minimum setback of 50 feet from the top of the steep bank shall be required; and no structure shall be built on the nearly level bench lakeward of the second bank within 25 feet of the base of the steep bank or within 50 feet of the top of the lakeward bank. The shorelines located in the following areas generally have these characteristics:

Ozaukee County:

Section 1, T 11 N, R 22 E
Sections 25 and 36, T 12 N, R 22 E
Section 30, T 12 N, R 23 E
Sections 6,7 and 18, T 12 N, R 23 E

Sheboygan County:

Sections 17, 19, 20, 30 and 31, T 13 N, R 23 E

Manitowoc County:

N.1/2 Sec. 27 and S.1/2 Sec. 22, T 17 N, R 23 E

Kewaunee County:

N.1/4 Sec. 36 and X.1/2 Sec. 25, T 22 N, R 24 E
N.1/4 Sec. 32, T 24 N, R 25 E
N.3/4 Sec. 10 and Sec. 3, T 24 N, R 25 E
Sec. 34, T 25 N, R 25 E, south of Algoma city limit
Sec. 24 and 13, T 25 N, R 25 E
Sections 5, 6, 7, and 18, T 25 N, R 26 E

Door County:

Sections 28 and 29, T 26 N, R 26 E
Sections 16 and 21, T 26 N, R 26 E

Additional small areas near the outlets from creeks and gulleys.

92. In shoreland zoning areas where there is definite evidence of recession of the lake bank over a period of 10 or more years due to erosion at the base caused by wave action or currents, all buildings and structures as noted in paragraph 91 shall be set back from the top of the receding bank a distance equal to at least 25 times the average annual bank recession rate during the last 25 years preceding the date of construction, as determined by the Zoning Administrator, where the setback distance so determined would be greater than the setbacks otherwise required by these regulations. When accurate data are not available to determine the average annual bank recession during the past 25 years at the desired construction site, data on recession of the lake shore bank in similar adjoining areas, or for a longer period of time, or for a 25 year earlier period during which contributing conditions were generally similar may be considered by the Zoning Administrator when making his determination of the average annual bank recession. The Corps of Engineers, U. S. Army, in investigations of the lake shore reported in 1952 (reference 3) found that nearly the entire lake shore from Sturgeon Bay south to the Illinois state line has been and continues to be subject to erosion and bank recession except where it has been protected by structures or stone armor or riprap, or where ledge rock exists in limited areas. North of Sturgeon Bay much of the shoreline is ledge rock or naturally protected by broken rock and the frontage subject to recession in limited to short reaches.

Shoreline Protective Measures

93. Existing developments in some areas may create conditions such that the setback from the water specified in the zoning regulations is not prectical or desirable. Such developments may include streets or highways, utility lines, adjacent structures, etc. Suitable shore protecting structures may be required by the Zoning Administrator or the Board of Adjustment as a condition for granting a variance from the setback requirement. Types of protective structures that would generally be considered satisfactory along the Lake Michigan shoreline are discussed in the following paragraphs. The following cautionary statement from the Corps of Engineers "Shore Protection Planning and Design" (reference 4) should be considered when deciding on the suitability of any proposed protection. "In selecting the shape, size, and

location of shore-protection works, the objective should be not only to design an engineering work which will accomplish the desired results most economically, but also to consider its effects on adjacent shorelines." Usuallly eroding shorelines are subject to some littoral drift predominately in one direction. In such cases the prevention of erosion along one property may increase the erosion of adjacent properties on the down-drift side by decreasing the supply of beach building materials available from eroding banks. For this reason careful consideration must be given to these related effects before granting a setback variance conditioned on shore protection work.

94. The following definitions of the types of structures are taken from the Corps of Engineers publication noted in the preceding paragraph (reference 4).

Bulkhead - A structure separating land and water areas, primarily designed to resist earth pressures. See also Seawall.

Revetment - A facing of stone, concrete, etc., built to protect a scarp, embankment, or shore structure against erosion by wave action or currents.

Riprap - A layer, facing, or protective mound of stones randomly placed to prevent erosion, scour, or sloughing of a structure or embankment; also the stone so used.

Seawall - A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action. See also Bulkhead.

Groin - A shore protective structure (built usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore. It is narrow in width, and its length may vary from less than one hundred to several hundred feet (extending from a point landward of the shoreline out into the water). Groins may be classified as permeable or impermeable; impermeable groins having a solid or nearly solid structure, permeable groins having openings through them of sufficient size to permit passage of appreciable quantities of littoral drift.

95. Protective measures to prevent recurring or continuing damage to shoreland properties include measures to prevent damage from erosion and wave action, and measures to prevent damage from flooding. In 1952 the Corps of Engineers, U. S. Army, with cooperation from the Beach Erosion Board, made a study of protective measures in connection with a report on "Property Damage on the Great Lakes Resulting from Changes in Lake Levels" (reference 3). A map showing damaged lake frontage and adjacent flooded areas along Lake Michigan shores was included in the report. This map showed general areas damaged by erosion and/or wave action along nearly the entire shoreline from the north end of Door County to the south state line, with the exception of the frontage between Racine and Kenosha. The map herewith as Exhibit 1, based on the Corps of Engineers investigation and recent inspections of the lake shore, shows the Wisconsin shoreline of Lake Michigan that is subject to serious erosion. Hydrographic charts showing general features of the shoreline of the lake are

published by the United States Lake Survey, Detroit. Descriptions of the coasts, harbors, etc., are contained in the Great Lakes Pilot issued annually by that organization. The U. S. Geological Survey topographic maps give information on the location and approximate height of the bluffs and low areas along the lake shore.

96. Much of the surface material along the lake shore is lacustrine clay and silt deposited on the bottom of the glacial lakes. In various local areas the surface material is sand, probably deposited as outwash from streams formed by the retreating glaciers. Since the present lake was formed waves and currents have cut into the earliest deposits, locally cutting bluffs into the surficial glacial or lake-laid deposits, or occasionally exposing the less deeply buried bedrock strata. Some of the material so eroded has been deposited along the shore of the present lake as beach deposits. As these deposits widened in some areas, material was swept inland from the shore and beaches by wind to form dunes.

97. The effects of erosion on the bluffs and shorelands increases or decreases as the lake level rises or falls. During periods of rising and high lake levels waves and currents generally tend to cause recession of the upland areas. During periods of falling or low lake levels the bluffs remain generally stable, but upland areas once lost remain lost. Increased developments along the lake shore increase the extent of damages experienced during high lake stages. To minimize the damage to shorelines and losses of lake front property during periods of high lake levels, large sums have been spent on largely uncoordinated attempts to protect and stabilize the shore line. Usually the urgency of such protective measures is not realized by the lake front property owner until a high lake stage is approached or reached, at a time when the difficulty and cost of adequate protective work is greatly increased. Normally it is quite difficult to protect the shoreline of a single property owner unless adjacent owners also undertake appropriate protective measures. Experience records covering more than a century indicate that high lake levels recur periodically at intervals of 5 to 22 years (see Table 3) and similar occurrences should be anticipated in the future. Best results in undertaking shore protective measures could be obtained most economically by anticipating low water periods and preparing a coordinated program of protective works along frontages needing protection that can be undertaken while the low stage prevails.

Acceptable Types of Shoreline Retention Structures

98. Types of shoreline retention or protection structures that would be suitable under a zoning regulation to allow building construction or other improvements closer to the shoreline than otherwise would be allowable depend to a large extent on the nature of the lake bank, the extent of the frontage involved and its relation to other adjacent frontages, the exposure of the frontage, the average rate of recession of the unprotected or inadequately protected shoreline, and the frequency, range, and duration of various lake levels. The various types of protective measures available, aside from strictly temporary measures, include the following principal types of protection, each of which has its own inherent advantages, disadvantages, and limitations. The suitability of any type for a particular application usually can be determined only after a careful study of the site and the exposure to erosive factors.

99. Seawalls or bulkheads built roughly parallel to the shoreline to be protected are perhaps the most generally applicable types of protection. The principal advantages of such structures are: (1) they provide positive protection and generally permit more intensive use of the adjacent upland; (2) they maintain a fixed alignment of the upland area frontage; and (3) they are adaptable to providing spot protection to small areas with a minimum of incidental damage to adjacent areas. Disadvantages of these protective structures are: (1) they are ineffective in maintaining a beach, in fact, any tendency toward loss of beach material in front of such a structure may well be intensified; (2) they provide no protection to adjacent frontage; and (3) because of the high cost their use is generally limited to high value areas. Structures of the seawall or bulkhead type are generally used where it is necessary to maintain the shore in an advanced position relative to that of adjacent shores, where there is little or no protective beach and a scant supply of littoral material, or where it is desired to maintain a depth of water along the shoreline as for a wharf. The shape of the structure should take into consideration any desired collateral use. The face may be vertical, sloping, curved or stepped. A seawall or bulkhead generally would be constructed along that line landward of which further recession of the shoreline is not to be permitted, or out to which land is to be reclaimed.

100. Various designs of seawalls or bulkheads generally would protect the lake shore adequately if properly constructed. The selection of the type to be used should be based on a study of foundation conditions, exposure to wave action, availability of materials, and costs. For example, a structure which depends on bottom penetration for stability could not be used on a rocky bottom, so a cellular steel sheet pile structure, stone mound or armor, crib structure, or mass concrete wall might be required. Generally some type of flexible structure involving a stone mat and random stone would be used on soft bottom, although cellular steel sheet pile structures, penetration type pile bulkheads, or concrete walls with pile cutoffs and possibly pile supports might be used depending on availability of materials and costs. Two types of erosion protective structures are shown on the sketches herewith as Exhibits 2 and 3. Designs for steel sheet pile cellular type and stepped type concrete seawalls are shown on Plate H-2 with the Corps of Engineers 1952

report previously noted (Reference 3). Many other designs differing in details but of similar structural adequacy and effectiveness could be used with satisfactory results (see Figures 5-1 to 5-13, inclusive, Reference 4).

101. Any of the shore protection structures can be built to such a height that no water would overtop them regardless of wave attack, though it is not ordinarily economically feasible to do so. Overtopping of a vertical faced structure located landward of the breaker zone should be reduced to a minimum if the top of the structure is set at least 1.5 times the breaking wave height above the highest anticipated water level under storm conditions at the site. If some overtopping is allowable, but it still is desired to minimize the effects of overtopping water which has damaging horizontal wave induced momentum, structure height may be set as low as 0.7 the breaking wave height above the anticipated storm water level. In such a case, under storm conditions, the overtopping water may still cause significant damage by being blown inland or by erosion of backfill or bank in running off.

102. Storm waves against which protection should be provided must be determined for various segments of the Lake Michigan frontage by the controlling factors involved, including fetch in the directions of exposures, storm frequencies and wind velocities and durations from these exposure directions, off-shore and near shore water depths, direction of shoreline alignment, causes of wave refraction, etc. A study of wave and lake-level statistics for Lake Michigan was completed by the Beach Erosion Board in March, 1953. In the study the characteristics of waves occurring at Milwaukee were determined from synoptic weather charts for the 3-year period 1948-'50. The highest wave computed was in the range of 15 to 16 feet and occurred in March, 1948. A study of frequency indicated that a wave of this height should occur on an average of about once in 2.5 years. The same study indicated that waves of about 12 feet in height would occur on an average of about twice a year (See Table 4). A wave of this height would break at a depth of about 15 feet and ordinarily would not reach structures built at the shoreline. Shoreline protective structures probably would be built approximately along the shoreline existing when the lake level is at mean lake level, elevation 578.69, or approximately two feet above datum. The maximum mean monthly lake level that can be expected to recur with reasonable frequency, or in about 5 percent of the years, is about 5 feet above datum as shown by study of the 1860 to 1950 record by the Beach Erosion Board (Reference 5). The same study shows that, at Milwaukee, a short period fluctuation of about 1.8 feet above the prevailing general lake level may be expected about once in 10 years; and a fluctuation of about 1.5 feet above the prevailing level might occur about once in 2.5 years. Study of a seven year record at Sturgeon Bay indicated slightly higher short period fluctuations in the same periods. Assuming that scour of at least 2.2 feet might occur at the base of the protective work, it appears that a maximum depth of about 7 feet might exist at the face of the lake-shore structure when the lake level is high. The protective structure should be adequate to absorb, withstand, or dissipate the energy of the maximum wave that could reach the structure without breaking. The largest wave that could reach the structure without breaking would be about 5.4 feet, since waves break at a depth approximately 1.3 times the wave height. Under these conditions the top of the protective structure should be about 10.6 feet

above low water datum to reduce the damaging effect of overtopping water, or as much as 15 feet above datum if it is desired to eliminate nearly all overtopping (See Para. 101). Usually the latter height cannot be economically justified unless the lake front property is of very high value. Protective structures of that height would be undesirable for residential use of the lake front as they would block the lake view unless the land shoreward of the structure is relatively high.

103. Eroding lake front also may be protected, in some cases, by artifically providing and maintaining an adequate beach. When conditions are suitable for artificial nourishment, long reaches of shore may be protected by this method at relatively low cost as compared with the adequate defensive structures. By correcting a deficiency in natural sand supply this treatment usually benefits rather than damages the shores beyond the immediate treatment area. The availability at reasonable cost of suitable material for the purpose is the most important limitation of this protective treatment. The method is more suitable for long reaches of shoreline than for relatively short segments of shore, as littoral drift normally tends to distribute the beach material, and continuing nourishment of one beach segment will ultimately benefit other down-drift frontage. The method is usually quite costly on a unit length basis when applied to shore segments of shore because of the usual need for a continuing program of beach nourishment to replace losses resulting from littoral drift.

104. A protective beach may be provided, under certain conditions, by properly designed groins (See plan for typical rubble mound groin system, Exhibit 4). This method should be used with caution for if the natural supply of littoral material is used to restore or widen a beach, a deficiency in supply is likely to be created in adjoining areas with resulting expansion of the problem area. Placing artificial fill in suitable quantity concurrently with groin construction may prevent detrimental effects of the groins and make it possible to build and hold an adequate beach for lake shore protection. Use of this method of protection requires careful study of the rate and direction of littoral transport, and of the character of material available to supply any needed artificial nourishment. Borrow material used may supply only a small proportion of material of proper beach building size. The sorting action of the waves in the area moves the finer particles seaward, leaving the coarser material shoreward of the plunge point until a relatively stable beach compatible with the wave spectrum of the eara is formed. The cyclic change in water level and wave pattern will ultimately establish the beach crest height. The foreshore and nearshore slopes will affect wave behavior and thus influence the natural beach crest height. If the beach fill is placed to an elevation lower than the natural crest height, a ridge will subsequently develop along the crest. Concurrent high water stage and high waves will overtop the crest and cause ponding and temporary flooding of the backshore. Such flooding, if undesirable, may be avoided by fixing the berm height slightly above the natural beach crest height. The berm height should be at an elevation above the high lake level that is approximately the vertical limit of uprush of average storm waves. Experience indicates that for Lake Michigan this places the vertical limit of protection at about 7 feet above the high lake level, excluding short period fluctuations, or about 12 feet above low water datum. If groins are used to protect a lakeshore the design

of the groins must be carefully studied with relation to conditions existing at the site. Such factors as spacing, direction, length, height, top slope, top elevation, permeability, character of bottom material and littoral drift material, all have important effects on the functioning of the groin system and must be adequately considered if the protection is to be satisfactory and reasonably permanent. Groins usually are built approximately perpendicular to the shore and extend from point landward of possible shoreline recession into the water a sufficient distance to stabilize the shoreline. A groin acts as a partial dam that intercepts a portion of the normal littoral drift. As material accumulates on the updrift side, supply to the downdrift shore is reduced and the downdrift shore recedes. If the groin system is properly built as to length, spacing, elevation, and permeability of the structures, and there is a well-established net littoral transport in one direction, groins may provide satisfactory beach stabilization. However, it should be noted that the beach protected would be subject to intermittent periods of advance and recession due to the relation of the prevailing water level to the top of the groins, and due to the changes in prevailing wave direction. Where there is a substantial variation in water levels over a period of years, satisfactory protection of a shoreline by groins may require excessively high and long structures.

105. The method of protection of the eroding bluffs along the Lake Michigan shore most applicable and acceptable for the greater part of the lake frontage is the revetting of the toe of the bluff with nonerodible material, such as stone, to prevent the waves from acting on the fine, erodible bluff materials. The general ready availability of crushed stone and riprap stone of suitable size and weight in eastern Wisconsin usually makes this type of protection the most economical. The revetment or rubble mound toe should be located at the maximum anticipated depth of scour and the top of the structure should normally extend above the design lake level to an elevation of approximately 0.7 to 1.5 times the height of the maximum wave that can break upon the structure, depending on whether a limited amount of overtopping or no erosion back of the protection can be accepted. The design lake level used should consider not only the periodic high general lake stages but also the temporary higher levels due to continuing strong winds or seiches caused by variations in barometric pressures. The height of the structure therefore depends upon the depth of the water on the lakeward side of the structure as well as the amount of overtopping allowable. This height will be influenced by the roughness and variation in slope of the face of the revetment, and by possible erosion along the lakeward side after construction of the revetment. To prevent leaching of the backfill or bluff material through the revetment the stone used in construction generally should be placed in two or three layers with a filter layer of finer crushed stone up to about 3 inches in diameter, a center layer of graded material from 3 inches up to a size sufficient to prevent displacement through voids in the outer layer, and a layer of cover stone of adequate size to withstand, without movement, the energy exerted by the maximum wave breaking upon it. In some cases the outer two layers may be placed as one operation by selective placement of the stone available. In some localities where floating ice fields are a major problem it may be desirable to increase the size of the cover stone to reducea tendency for the outer pieces to freeze in large ice blocks and be float-out of place. Usually if the cover stone are large enough to resist displacement

by wave action and are closely laid with a normal amount of interlocking the ice around them will not have sufficient flotation or strength to lift thestone out of place. When the revetment protection is placed at the base of a steeply sloping bluff it usually is desirable to grade at least the lower portion of the bluff to a stable slope of about 1 on 2. If the upper portion of bluff above the revetment is subject to erosion or caving due to groundwater or seepage it may be desirable to grade the entire bank to a flatter slope. Where there is a wide gradually sloping beach between the low water and high water shore lines it may be desirable to protect the beach, and indirectly the bluff, by construction of a rubble mound near the low water shore line instead of a stone revetment at the base of the bluff. This would allow continued use of the lakeshore area, possibly with backfill to above the required protection level. Where this method of protection is provided there must be adequate revetment protection at the ends of the frontage protected extending back to the base of the bluff so that erosion will not continue landward of the lakeshore protective structure. Typical sections of revetment and rubble mound are shown on exhibits 2 and 3.

106. Usually broken stone or concrete of unassorted sizes randomly dumped over the lake bank, as is frequently done in unplanned attempts to stop bank erosion that has reached a critical stage, does not form an acceptable shore protection that would permit a reduction in the setback requirements. Usually placed without an adequate filter bed of crushed stone, fills of such dumped material generally are too permeable to stop the pumping out of backfill material by wave action, thus allowing the bank protection materials to gradually become buried in the lake bottom and the erosion to continue.

107. In general, the criteria with respect to the use of shorelands, lot sizes, building restrictions, setbacks, sanitary provisions, etc., discussed in this report are the minimum requirements and are not to be considered a limitation on or repeal of any more restrictive requirements under any existing zoning, subdivision, or sanitary regulations; State Statutes, or Wisconsin Administrative Code provisions. No attempt has been made to include in this report all the provisions of a satisfactory shoreland zoning or flood plain zoning ordinance since the general provisions of such ordinances have been outlined in model ordinances prepared and distributed by the Department of Resource Development. Some minor modifications of the model ordinances considered desirable have been noted in the discussion of the various criteria herein.

A. R. Striegl
Civil Engineer

Feb. 26, 1968

Incls.:

List of References.
Appendix A "Shoreline Photographs
Exhibits 1,2,3,4

Shoreland and Flood Plain Zoning

Along the Wisconsin Shore of Lake Michigan

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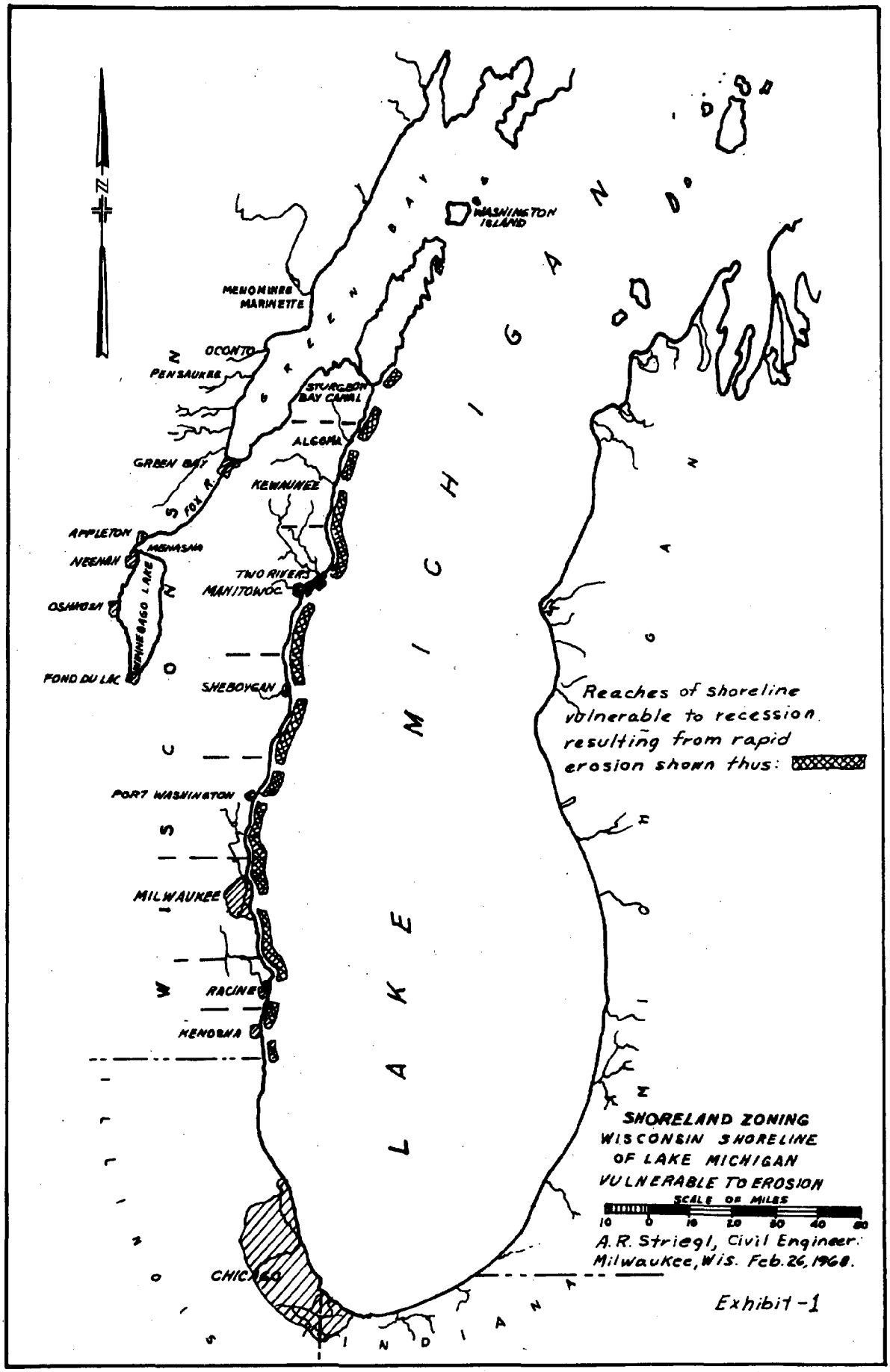
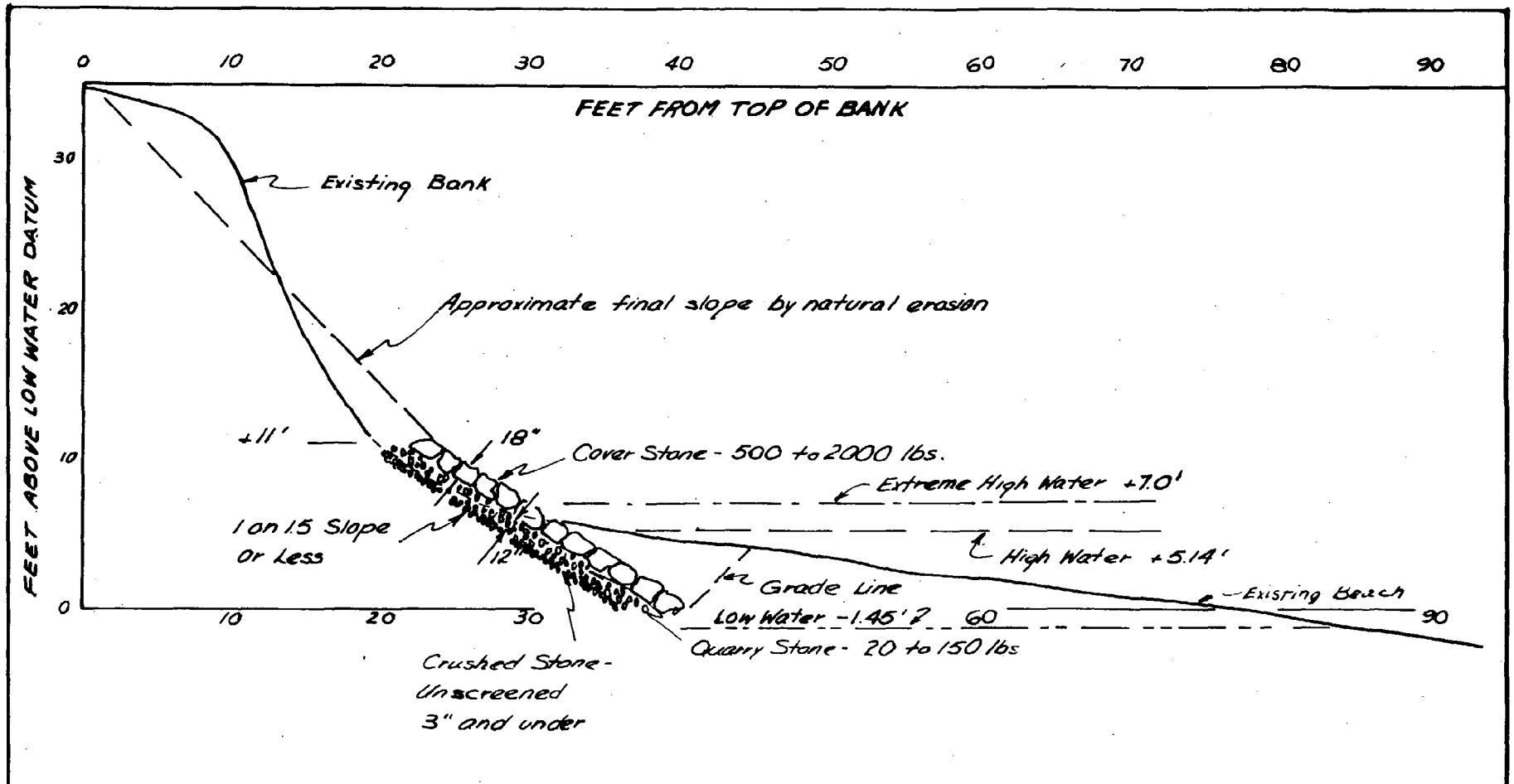
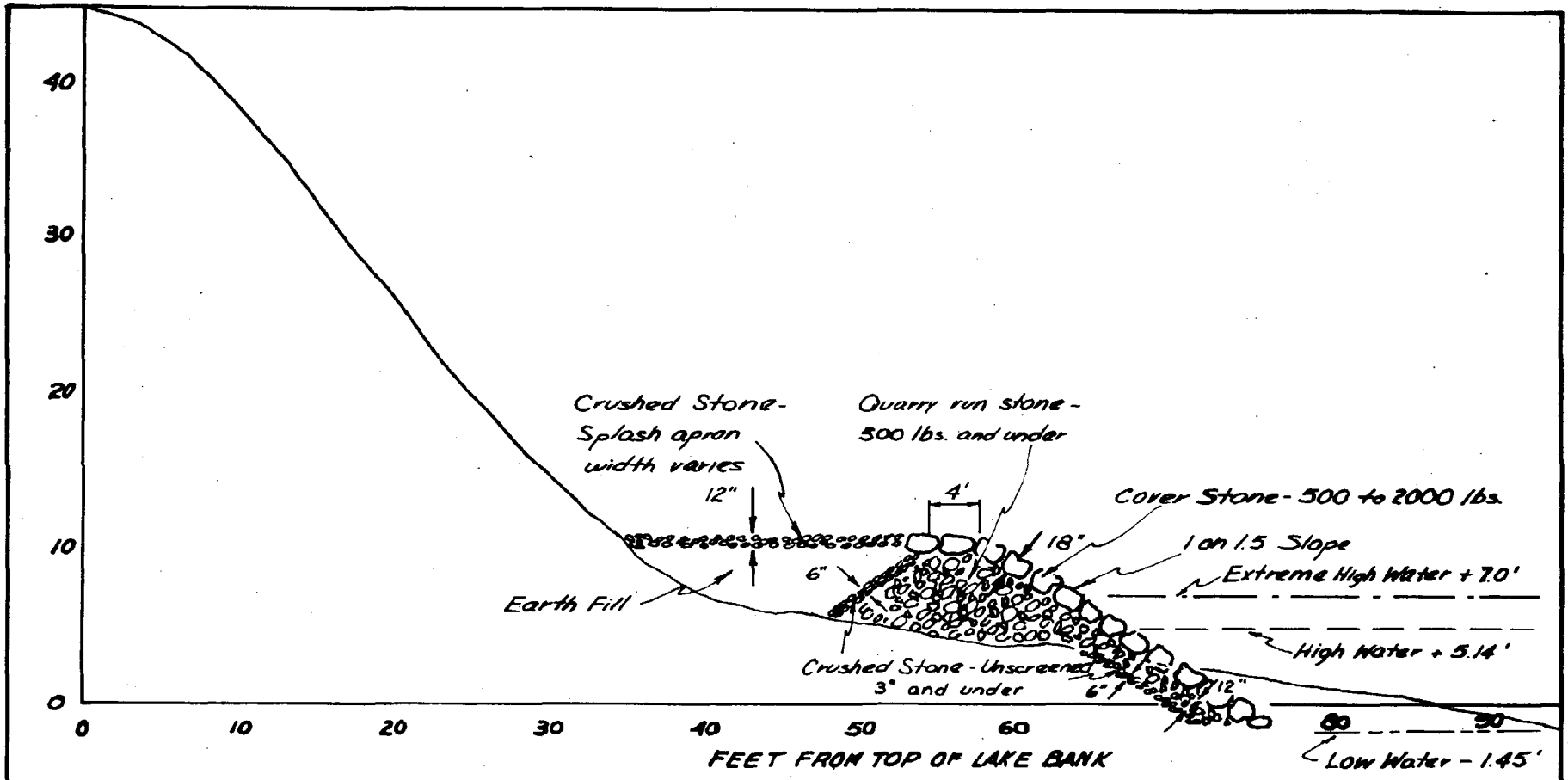
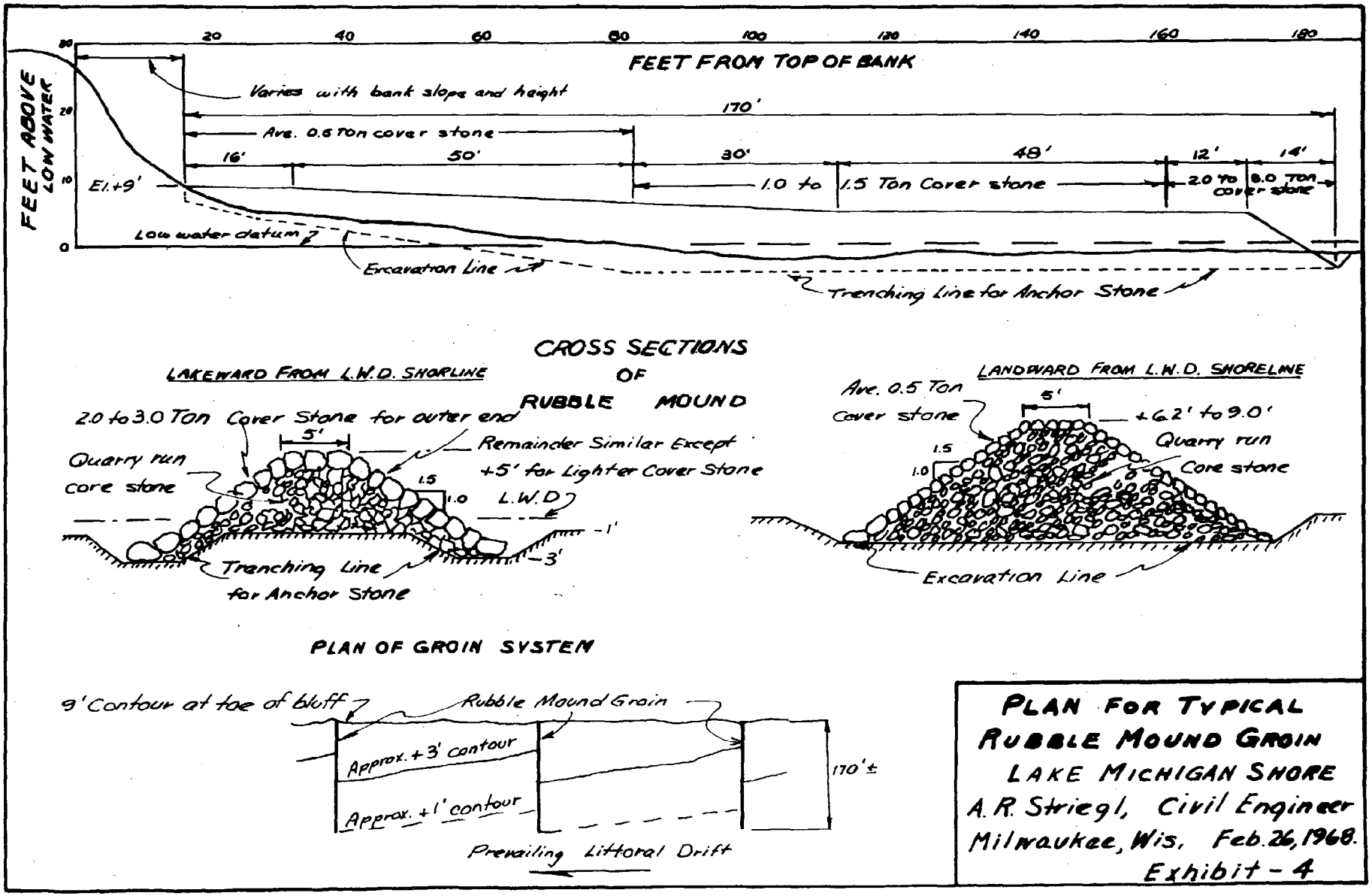

N
WASHINGTON ISLAND
MENOMINEE
MARINETTE
OCONTO
PENSAUKEE
STURGEON BAY CANAL
ALGOMA
GREEN BAY
KEWAUNEE
FOX R.
APPLETON
MENASHA
NEENAH
TWO RIVERS
MANITOWOC
OSHKOSH
WINNEBAGO LAKE
FOND DU LAC
SHEBOYGAN
PORT WASHINGTON
MILWAUKEE
RACINE
KENOSHA
CHICAGO
LAKE MICHIGAN
Reaches of shoreline vulnerable to recession resulting from rapid erosion shown thus:
SHORELAND ZONING
WISCONSIN SHORELINE
OF LAKE MICHIGAN
VULNERABLE TO EROSION
SCALE OF MILES
10 0 10 20 30 40 50
A.R. Striegl, Civil Engineer.
Milwaukee, Wis. Feb. 26, 1968.
Exhibit-1



TYPICAL RIPRAP REVETMENT
LAKE MICHIGAN SHORE
A. R. Striegl, Civil Engineer
Milwaukee, Wis. Feb. 26, 1968.
Exhibit - 2



PLAN FOR TYPICAL
RUBBLE MOUND SEA WALL
LAKE MICHIGAN SHORE
A.R. Strieql, Civil Engineer
Milwaukee, Wis. Feb. 26, 1968
Exhibit - 3



PLAN FOR TYPICAL RUBBLE MOUND GROIN
LAKE MICHIGAN SHORE
A.R. Striegl, Civil Engineer
Milwaukee, Wis. Feb. 26, 1968.
Exhibit - 4

COASTAL ZONE
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