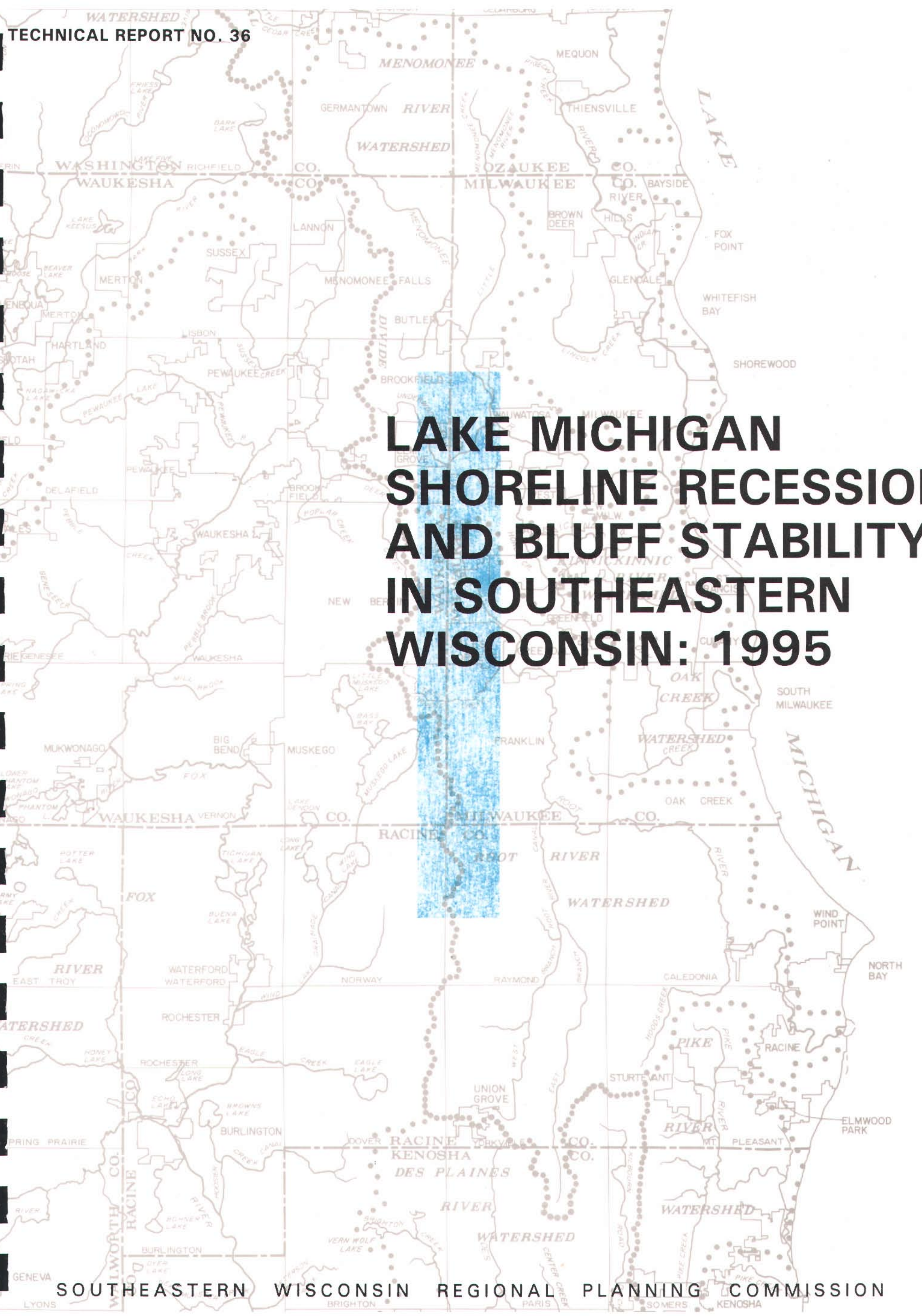
TECHNICAL REPORT NO. 36



LAKE MICHIGAN SHORELINE RECESSION AND BLUFF STABILITY IN SOUTHEASTERN WISCONSIN: 1995

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Special acknowledgment is due to Dr. Jeffrey A. Thornton, CLM, SEWRPC Principal Planner; Ms. Christine M. Hinz, SEWRPC Planner; and Mr. Edward J. Schmidt, SEWRPC Research Analyst, for their contributions to the conduct of this study and the preparation of this report.

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NUMBER 36

LAKE MICHIGAN SHORELINE RECESSION AND BLUFF STABILITY IN SOUTHEASTERN WISCONSIN: 1995

Prepared by the

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In Cooperation with the

WISCONSIN COASTAL
MANAGEMENT PROGRAM

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December 1997

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STATEMENT OF THE EXECUTIVE DIRECTOR

The Lake Michigan coastal area of Southeastern Wisconsin encompasses a relatively narrow strip of land along Lake Michigan in Kenosha, Racine, Milwaukee, and Ozaukee Counties, extending almost 77 miles from the Wisconsin-Illinois border to the Ozaukee-Sheboygan county line. This area is recognized as a unique setting for high-value urban development and open space, including outdoor recreational facilities with unique environmental assets which attract users from throughout the Region. For this reason, shoreline erosion and bluff stability conditions are important considerations in planning for the sound development and redevelopment of lands located in the Lake Michigan coastal area. Erosion and recession of shorelines and bluffs constitutes one of the more difficult and costly problems facing private property owners and local governments along the Lake Michigan coastline.

Shoreline erosion and bluff stability conditions in Southeastern Wisconsin were first surveyed in 1977 under the Wisconsin Coastal Management Program. Subsequently, additional studies were carried out for portions of the Southeastern Wisconsin shoreline between 1978 and 1989. While these studies provided information useful in managing the coastline, such studies must be reviewed and updated from time to time. Shoreline conditions may change as a result of changes in lake levels, in groundwater conditions, in stormwater management conditions, in the extent and condition of shore protection measures, in vegetative cover, and in the types of land uses in the shoreland areas.

Given the time that has elapsed since the last inventory of the entire shoreline was conducted, a reinventory of shoreline erosion and bluff stability conditions along the Southeastern Wisconsin Lake Michigan shoreline was deemed to be desirable. The reinventory would also provide an opportunity to evaluate the reliability of the methods used to forecast probable future shoreline erosion and bluff stability conditions. Therefore, in August 1994, the Regional Planning Commission responded to a request from the Wisconsin Department of Administration for the conduct of a study of current shoreline erosion and bluff stability conditions along the Lake Michigan shoreline. The study also compared the current conditions to the historical conditions documented in earlier studies. The study was conducted by the staff of the Regional Planning Commission and Geotechnical Consultants Tuncer B. Edil, David M. Mickelson, and John A. Chapman, and was partially funded by the Wisconsin Coastal Management Program. The study is intended to provide current technical data useful in the definition of, and in the development of solutions to, bluff stability and shoreline recession problems along the Lake Michigan shoreline of Southeastern Wisconsin.

The inventory of Lake Michigan shoreline conditions and bluff stability conducted during this recently completed Commission study has indicated that much of the Lake Michigan shoreline was in a more stable condition than found in the earlier studies. This may be attributed, in part, to the placement of shoreline protection structures in the southern portion of the Southeastern Wisconsin Region and the regrading of unstable bluff slopes. Notwithstanding this achievement, portions of the Lake Michigan shoreline, particularly in the northern portion of the Region, continue to be at risk, especially during future periods of higher lake levels. The study identified a need for continued monitoring of the shoreline, especially in those reaches with relatively high unprotected bluffs and where shoreline protection structures are in need of maintenance or are failing.

Respectfully submitted,

Philip C. Evenson

Philip C. Evenson
Executive Director

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Chapter I

INTRODUCTION

BACKGROUND

Shoreline erosion and bluff stability conditions are important considerations in planning for the protection and sound development and redevelopment of lands located along the Lake Michigan shoreline. Shoreline erosion and bluff stability conditions in Southeastern Wisconsin were surveyed in 1977,[1] and subsequently in Racine County in 1978[2] and 1982,[3] and in Milwaukee County, in 1989.[4] Such conditions can change over time since they are related, in part, to changes in, among other related factors, climate, water levels, the geometry of the onshore beach and nearshore areas, the extent and condition of shore protection measures, the type and extent of vegetation, and the type of land uses in shoreland areas.

In August 1994, the Southeastern Wisconsin Regional Planning Commission responded to a request from the Wisconsin Department of Administration for the conduct of a study of current shoreline erosion and bluff stability conditions along the Lake Michigan shoreline of Southeastern Wisconsin. The Commission obtained Federal funding through the Wisconsin Coastal Management Program in partial support of the conduct of the desired study. In addition to an inventory of current conditions, the study was to compare the current conditions to the historic conditions documented in the aforereferenced earlier studies.

The study was prepared over the period from November 1, 1994 through December 30, 1996, and the findings and recommendations are documented in this report for the four coastal counties in Southeastern Wisconsin—Kenosha, Racine, Milwaukee, and Ozaukee Counties. A similar study was undertaken and report prepared by the Bay-Lake Regional Planning Commission for the coastal counties lying north of Ozaukee County. Together these two reports provide valuable technical data intended to be used in defining and seeking solutions to severe and costly problems such as shore erosion, bluff recession and storm damage along the Lake Michigan shoreline.

STUDY AREA

The Lake Michigan coastal erosion and bluff stability study area in Southeastern Wisconsin consists of the lands along the Lake Michigan shoreline in Kenosha, Racine, Milwaukee, and Ozaukee Counties. The coastal area for Southeastern Wisconsin extends approximately 77 miles from the Wisconsin-Illinois border to the Ozaukee-Sheboygan county line.

For analytical purposes, the Lake Michigan shoreline was divided into 17 reaches, as shown on Map 1. These reaches were selected so as to have relatively uniform beach and bluff characteristics. These reaches generally correspond to those utilized in the aforereferenced 1977 shoreline erosion study, with some refinement to reflect current conditions.

The portions of Kenosha, Racine, Milwaukee, and Ozaukee Counties that directly affect, or are directly affected by shoreline erosion, bluff recession, and storm damage processes includes a relatively narrow strip of land along the Lake Michigan shoreline. This area is recognized as a unique setting for high-value urban development and for the provision of outdoor recreational facilities with unique environmental assets which attract users and interests from a much larger area.

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[1]*D.M. Mickelson, L. Acomb, N. Brouwer, T.B. Edil, C. Fricke, B. Haas, D. Hadley, C. Hess, R. Klauk, N. Lasca, and A.F. Schneider, Shore Erosion Study, Technical Report,* Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin, *Wisconsin Coastal Management Program, February 1977.*

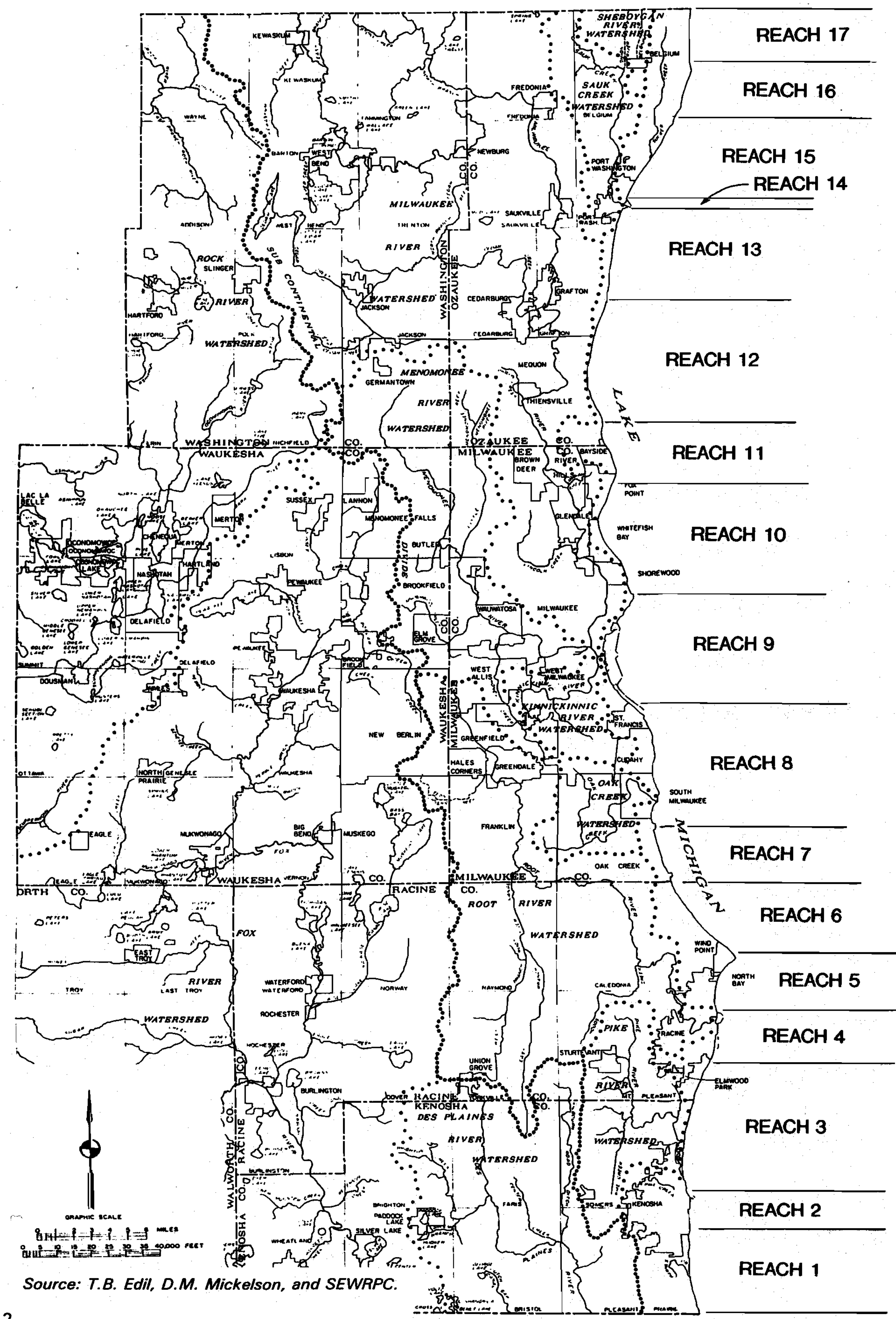
[2]*J.P. Keillor and R. DeGroot,* Recent Recession of Lake Michigan Shorelines in Racine County, Wisconsin, *University of Wisconsin Sea Grant Program, 1978.*

[3]*SEWRPC Community Assistance Planning Report No. 86,* A Lake Michigan Coastal Erosion Management Study for Racine County, Wisconsin, *October 1982.*

[4]*SEWRPC Community Assistance Planning Report No. 163,* A Lake Michigan Shoreline Erosion Management Plan for Milwaukee County, Wisconsin, *October 1989.*

Map 1

LAKE MICHIGAN SHORELINE REACHES IN THE SOUTHEASTERN WISCONSIN



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

NEED FOR A SHORELINE EROSION MANAGEMENT STUDY

The erosion and recession of shorelines and bluffs constitutes one of the more difficult and costly problems facing private property owners and local governments along the Lake Michigan coastline. From 1963 through 1995, average annual bluff recession rates ranged up to over 10.0 feet in Southeastern Wisconsin, with episodic rates as high as 100 feet during major storm events. It should be noted that since shoreline erosion tends to be episodic rather than continuous, erosion and recession rates will vary widely from year to year. Sound information on the existing and expected future shoreline recession and bluff stability conditions is needed to properly make land use and shoreline protection and development decisions.

In Southeastern Wisconsin, the most recent comprehensive study of shoreline erosion and bluff stability conditions and processes was conducted in 1977.[5] Subsequently, additional data were obtained for the Racine County coastline in 1982,[6] and for the Milwaukee County coastline in 1989.[7] Because of the dynamic nature of the shore erosion and bluff stability conditions and processes, it is important to have reliable information based upon sound inventories conducted over long periods of time. Given the time that has elapsed since the last comprehensive inventory was conducted, a reinventory of shoreline erosion and bluff stability was deemed to be desirable. The reinventory would also provide an opportunity to examine the reliability of the methods used to forecast probable future shoreline erosion and bluff stability conditions.

REVIEW OF PREVIOUS STUDIES

An important element of this study was the collation and analysis of the findings and recommendations of previous studies relating to Lake Michigan shoreline erosion and bluff recession in Southeastern Wisconsin. The following section identifies and briefly describes the four historic studies concerned. The findings of the current study are compared, as appropriate, to the findings of these earlier studies in Chapter IV, "Comparison of Study Findings to Previous Studies."

1. Shore Erosion Study, Technical Report, *Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin*; Appendix One, *Kenosha County*; Appendix Two, *Racine County*; Appendix Three, *Milwaukee County*; and Appendix Four, *Ozaukee County*; Wisconsin Coastal Management Program, 1977.

   An inventory of the shoreline conditions within the entire Southeastern Wisconsin Region was conducted in 1977 by a number of coastal technical consultants under the Wisconsin Coastal Management Program. The shoreline in Southeastern Wisconsin was divided into 17 reaches, each reach having similar physical- and erosion-related characteristics. Bluff slope stability analyses were conducted under the study for 168 sites within the Southeastern Wisconsin Region. The potential causes of severe shoreline erosion were identified. The study presented data on beach, bluff, and geologic characteristics, and analyzed shore damages and shore protection structures. The study included the preparation of estimates of short-term—10-year—and long-term—110-year—shoreline recession rates.

2. *Recent Recession of Lake Michigan Shorelines in Racine County, Wisconsin*, University of Wisconsin Sea Grant Program, 1978.

   Shoreline recession rates over the period 1968 through 1975 were reported. The largest bluff recession rates were recorded along the northern reaches of the Racine County coastline. In this area, bluff recession rates were found to average 5.8 feet per year along the unprotected reaches of shoreline over the period of observation, with one site averaging 14 feet per year. Recession rates measured south of the City of Racine average only 1.4 feet per year over the period of observation. The report noted that the most probable cause of the recession in the northern part of the County is a combination of high, unstable bluffs with a perched watertable, a lack of structural protection, and high exposure to storm wave action.

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[5]*D.M. Mickelson et al., op. cit.*

[6]*SEWRPC Community Assistance Planning Report No. 86, op. cit.*

[7]*SEWRPC Community Assistance Planning Report No. 163, op. cit.*

3. SEWRPC Community Assistance Planning Report No. 86, *A Lake Michigan Coastal Erosion Management Study for Racine County, Wisconsin*, 1982.

   Racine County shoreline recession rates reported in the two previous studies noted above were reported and compared to rates estimated under the study over the period 1963 through 1980. Bluff recession rates in Racine County were found to range up to 10 feet per year, averaging almost 1.5 feet per year along the unprotected reaches of the shoreline. The study presented data on beach, bluff, and shoreline geologic characteristics, and analyzed shore damages and existing shore protection structures. Recommendations were made regarding the use of structural and nonstructural measures to minimize the impacts of shoreline erosion.

4. SEWRPC Community Assistance Planning Report No. 163, *A Lake Michigan Shoreline Erosion Management Plan for Milwaukee County, Wisconsin*, 1989.

   Milwaukee County shoreline recession rates reported in the previous study noted above were reported and compared to rates estimated under the study for the period 1963 through 1985. Bluff recession rates in Milwaukee County were found to range up to 12.5 feet per year, averaging just under 1.0 feet per year along the unprotected reaches of the shoreline. The study presented data on beach, bluff, and shoreline geologic characteristics, and analyzed shore damages and existing shore protection structures. Bluff stability analysis were conducted under the study at 48 sites in Milwaukee County. Alternative and recommended shoreline protection plans were presented incorporating both structural and nonstructural measures to minimize the impacts of shoreline erosion.

PURPOSES AND SCOPE

The purposes of the Southeastern Wisconsin shoreline erosion and bluff recession study were to:

- Establish and document current shoreline erosion rates and bluff stability conditions.
- Compare the current shoreline erosion rates and bluff stability conditions with conditions which were documented and forecast in previous studies.
- Apply the latest bluff stability analytical techniques within each of the study reaches considered.
- Develop conclusions and recommendations as to the best means and procedures to be used for bluff stability analysis.

The work undertaken for this study consisted of six major elements:

1. Collection and mapping of information on shoreline erosion and bluff conditions in 1995;
2. Analyses of bluff stability;
3. Estimation of shoreline erosion rates;
4. Comparison of new bluff stability and erosion rate data to that found in previous studies;
5. Evaluation of the methodologies used in the previous studies and the current study and the provision of recommendations for improvements in the methodologies concerned; and
6. Documentation of the of findings and conclusions of the study.

Chapter II

COASTAL EROSION PROCESSES

Erosion and bluff recession along the Lake Michigan shoreline is an essentially natural process. However, human activities can influence this process, causing erosion to accelerate—such as by increasing the rate and volume of stormwater runoff—or decelerate—such as by the construction of shore protection measures. Thus, an understanding of both the natural and human influences on the dynamics and properties of shoreline erosion processes is important in any documentation of the current conditions regarding shoreline erosion and bluff recession along the Lake Michigan shoreline. This chapter describes the various factors which contribute to shoreline erosion and bluff recession, including climate, lake levels, wave action, groundwater seepage, stormwater runoff, freeze-thaw action, lake ice movement, the type of bluff and beach materials, and the types of vegetative cover. Because shoreline erosion and bluff recession processes often differ, they are considered separately in this chapter.

CLIMATE

Air temperature and the type, intensity, and duration of precipitation events affect the degree and extent of shoreline erosion. Climatic impacts on shoreline erosion include the effects of the annual freeze-thaw cycle acting on water contained within the bluff material; the effects of surface stormwater runoff over frozen soils in early spring; the effects on soil erosion of increased runoff during periods of heavy rainfall; and the effects of ice formation on wave action in the lake and on the shoreline. Wind can also contribute to shoreland erosion, both directly and indirectly through its effect on the Lake surface.

Air Temperature

Air temperature impacts primarily include the formation of ice on the lake, the initiation of freeze-thaw actions in soils, and a contribution to increased stormwater runoff rates over frozen soils. Table 1, presents average monthly air temperature variations at three stations located near the Lake Michigan shoreline for the 55-year period from 1940 through 1995. As shown in the table, winter temperatures, measured as the monthly means for December, January, and February, ranged from about 19°F to 27°F at the station located near Lake Michigan. Summer temperatures, measured as the monthly means for June, July, and August, ranged from about 62°F to 71°F.

The depth and duration of ground frost, or frozen ground, also influences hydrologic and soil erosion processes, particularly through freeze-thaw activity and the proportion of the total rainfall or snowmelt that runs off the land surface. The amount of snow cover is an important determinant of frost depth. Since the thermal conductivity of snow cover is less than one-fifth that of moist soil, heat loss from the soil to the colder atmosphere is greatly inhibited by the insulating snow cover. Snow cover is most likely during the months of December, January, and February, during which there is at least a 40 percent probability of having one inch or more of snow cover. Nevertheless, frozen ground is likely to exist throughout the study area for approximately four months each winter season, extending from late November through March, with more than six inches of frost occurring in January, February, and the first half of March.

Within the Lake, a similar freeze-thaw cycle is observed. Nearshore portions of Lake Michigan may begin to freeze in December, and ice breakup normally occurs in late March or early April. Shoreline ice cover affects shoreline erosion in several ways, as described later in this chapter.

The presence of Lake Michigan tends to moderate the climate of Southeastern Wisconsin. This is particularly true during those periods when the temperature differential between the lake water and the land air masses is the greatest. It is common, for example, for mid-day summer temperatures to be about 10°F lower in shoreline areas than in inland areas because of the cooling lake breezes.

Precipitation

Lake Michigan does not have as pronounced an effect on precipitation as it does on temperature. A minor Lake Michigan effect is apparent in the late spring and summer, when there is about 0.5 inch less rainfall per month in coastal areas than in areas farther inland. This difference may be attributed to the cool lake waters main-

Table 1

AIR TEMPERATURE CHARACTERISTICS AT SELECTED LOCATIONS IN THE REGION

Month	Observation Station Location								
	Kenosha (1948-1995)			Milwaukee (1940-1995)			Port Washington (1959-1995)		
	Average Daily Maximum	Average Daily Minimum	Mean	Average Daily Maximum	Average Daily Minimum	Mean	Average Daily Maximum	Average Daily Minimum	Mean
January	29.7	14.7	22.2	29.5	15.3	22.4	28.5	13.4	21.0
February	32.4	17.9	25.2	31.8	17.3	24.6	31.4	15.8	23.6
March	41.6	26.9	34.3	41.9	27.0	34.5	40.4	25.4	32.9
April	52.0	36.3	44.2	53.6	36.8	45.2	50.5	34.7	42.6
May	62.9	45.1	54.0	65.5	46.1	55.8	60.7	44.0	52.3
June	73.4	55.0	64.2	75.8	56.5	66.2	71.3	53.8	62.5
July	78.7	61.9	70.3	80.3	62.7	71.5	77.2	60.3	68.8
August	78.0	61.8	70.0	79.1	62.3	70.7	77.3	60.4	68.9
September . . .	70.4	53.4	62.0	71.0	53.9	62.5	69.3	52.6	61.0
October	60.2	42.7	51.4	60.5	43.0	51.8	58.2	41.5	49.8
November . . .	46.0	30.3	38.2	45.1	30.5	37.8	43.8	29.6	36.7
December . . .	34.1	19.5	26.9	32.8	19.4	26.1	32.8	18.3	25.6
Yearly Average	54.9	38.7	46.9	55.6	39.2	47.4	53.4	37.5	45.5

Source: National Oceanic Atmospheric Administration and SEWRPC.

taining a cooler lower atmosphere which inhibits convective precipitation. However, during the winter, Lake Michigan can serve as a source of moisture, resulting in slightly higher snowfalls near the Lake.

Precipitation within the study area takes the form of rain, sleet, hail, and snow, and ranges from gentle showers of trace quantities to brief, but intense, and potentially destructive, thunderstorms or major rainfall-snowmelt events. These latter may cause severe bluff and beach erosion. Average monthly precipitation ranged from about 29.5 to 32.3 inches for the three stations located near Lake Michigan, as shown in Table 2. Average total monthly precipitation typically ranged from about 1.1 to 1.4 inches in February, and from about 3.2 to 3.8 inches in July.

Extreme precipitation events may result in massive shoreland losses due to high levels of erosion, fluidization due to increased seepage, and slumping. A one-hour storm with an expected average recurrence interval of once every two years may be expected to have a total rainfall of about 1.2 inches. A one-hour, 10-year recurrence interval storm may be expected to have a total rainfall of about 1.8 inches, while a 24-hour, 10-year recurrence interval storm may be expected to have a total rainfall of about 3.7 inches.

Extended wet periods also may result in unusually high coastal losses. Such losses can be the result of higher lake levels resulting from regional precipitation patterns, or can be the result of stresses placed upon the bluffs due to saturated conditions and high groundwater levels resulting from extended and intense localized precipitation patterns. During the period from 1841 through 1995, the maximum annual amount of precipitation at Milwaukee was 50.36 inches, or 60 percent above the long-term annual average, which amount was recorded in 1876. The maximum monthly precipitation amount was 10.83 inches, which occurred in June 1917. In late 1986, a total of over 16 inches of precipitation fell at Milwaukee during August and September 1986. This period included a rainfall event far more severe than any recorded in the 85 years for which precipitation data have been recorded in the Milwaukee area. On August 6, 1986, about 6.84 inches of rain fell in the 24-hour period. The consequence of this unusually high level of precipitation in Southeastern Wisconsin and throughout the Lake Michigan drainage area was a rapid rise in the level of the Lake.

Table 2

PRECIPITATION CHARACTERISTICS AT SELECTED LOCATIONS IN THE REGION

Month	Observation Station Location					
	Kenosha		Milwaukee		Port Washington	
	1945-1995	1945-1995	1940-1995	1940-1995	1940-1995	1894-1995
	Average Total Precipitation	Average Snow and Sleet	Average Total Precipitation	Average Snow and Sleet	Average Total Precipitation	Average Snow and Sleet
January	1.83	11.58	1.74	12.99	1.39	10.64
February	1.13	10.99	1.35	11.96	0.95	10.59
March	2.41	5.75	2.57	8.29	1.63	7.16
April	3.44	1.25	3.24	1.94	2.79	1.48
May	3.08	0.05	2.94	0.27	3.01	0.05
June	3.49	0.00	3.41	0.00	3.02	0.00
July	3.51	0.00	3.70	0.00	3.77	0.00
August	3.77	0.00	3.80	0.00	4.04	0.00
September	2.90	0.00	3.00	0.00	3.03	0.00
October	2.59	0.16	2.50	0.64	2.24	0.24
November	2.96	1.60	2.81	3.93	2.81	1.71
December	1.77	7.01	1.77	9.90	1.46	6.23
Total	32.88	38.39	32.83	49.92	30.14	38.10
Yearly Average	2.70	3.20	2.70	4.20	2.50	3.20

Source: National Oceanic Atmospheric Administration and SEWRPC.

Wind

Wind can also contribute to shoreland losses, both directly and indirectly through its effect on the Lake surface. Prevailing winds in the Milwaukee area are from the west-northwest, as shown in Figure 1.[1] The wind speed has a velocity of about 11 miles per hour (mph) on a long-term average basis at Milwaukee. Winds are calm approximately 2 percent of the time, and peak gusts of up to 63 mph occur on an average annual basis. The highest recorded wind velocity at Milwaukee was 81 mph observed in July 1984.

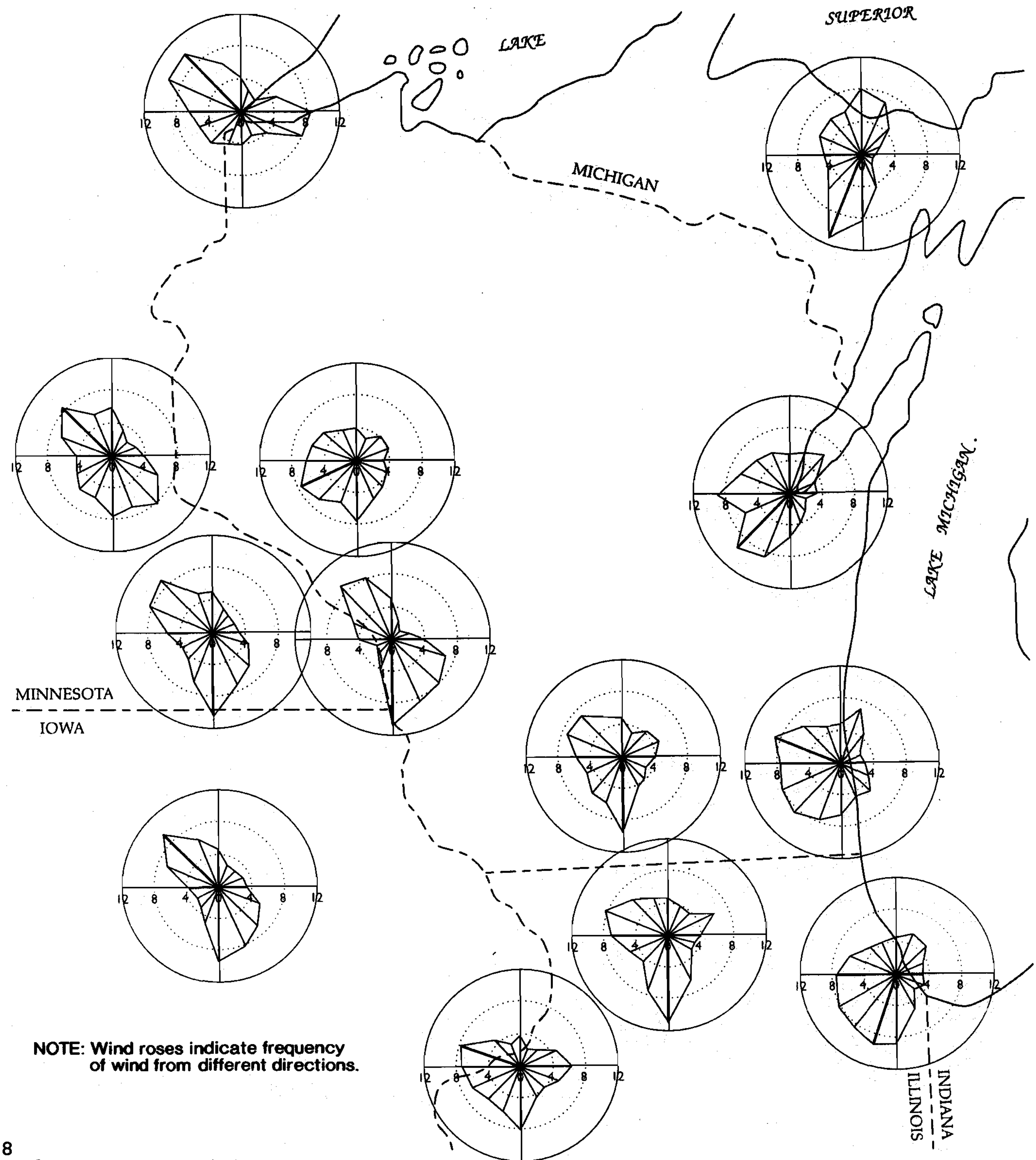
During the winter months—November through March, the prevailing winds generally blow from the west-northwest at an average velocity of about 13 mph. Conditions range from calm, experienced about 1 percent of the time, to peak gusts of about 45 mph on an average annual basis. During spring and early summer—April through June, the prevailing winds generally back to the north-northeast at velocities which range between 11 and 14 mph, decreasing in velocity as the season progresses. Peak gusts of about 50 mph occur on an average annual basis, with calm conditions prevailing about 2 percent of the time. During later summer and autumn—July through October, the prevailing winds have velocities of about 11 mph, and blow from the southwest during July and August, and from the south-southwest during September and October. Calm conditions occur about 3 percent of the time, and peak gusts of about 45 mph occur on an average annual basis. Record monthly gusts of about 80 mph have been recorded during each of the first six months of the year, while record gusts of about 60 mph have been observed in the latter six months. Lake winds influence coastal temperatures, resulting in a moderation of the coastal climate and air temperatures as noted above.

The direct effects of wind erosion on the Region's Lake Michigan coastline are considered to be minimal in comparison with the effects of wave-induced erosion. Wind driven waves can result in significant soil loss. Depending on the fetch, or distance over which the wind blows without interruption, wind effects also can include wind set-up, causing an actual tilt to be induced in the Lake surface, and the creation of seiches, or internal

[1] *Pamela Naber Knox,* Wind Atlas of Wisconsin, *Wisconsin Geological and Natural History Survey, Bulletin No. 94, 1996.*

Figure 1

ANNUAL WIND ROSES FOR SELECTED SITES



NOTE: Wind roses indicate frequency of wind from different directions.

Source: Wisconsin Geological and Natural History Survey.

waves, both of which can enhance the erosive action of wind-waves along the coast.

LAKE MICHIGAN WATER LEVELS

Lake water-level fluctuations affect rates of wave-induced shoreline erosion. High water levels result in more rapid recession of the shoreline. When the water level is low, wave energy is expended as waves break along the beach. However, when water levels rise, waves can break directly at the foot of the bluff—on the toe of the bluff—and erode the bluff material. The base of the slope is then undercut, creating unstable conditions in the slope above. This condition is eventually followed by slope failure and the movement of material down to the base of the bluff. As water levels decrease, the beach again widens and much of the wave energy is dissipated without directly impacting the bluff face.

There is often a time lag, however, between bluff recession rates and the decline in lake level because materials in the bluff take time to form a stable slope. Thus, even after water levels decline and wave erosion is decreased, bluff recession continues at a fairly high rate until the bluffs have reached a stable slope angle.

Figure 2, shows the annual mean water level for Lake Michigan, recorded at Milwaukee for the period from 1860 through 1997. The historic low annual mean lake level at Milwaukee—577.06 feet above National Geodetic Vertical Datum (NGVD), also referred to as Mean Sea Level Datum—occurred in 1964. The historic high annual mean lake level—582.48 feet NGVD—occurred in 1986. The 1986 annual mean surpassed the previous record high annual mean of 582.24 feet NGVD set in 1886. The historic record low and record high annual mean lake levels at Milwaukee differ by 5.42 feet around the long-term—1918 through 1995—average annual lake level elevation, 580.42 feet NGVD.

The level of Lake Michigan—and of Lake Huron to which it is hydraulically and hydrologically linked—is a function of the balance between inflows and outflows of water from the Lake. Differences between inflows and outflows result in changes in the storage—or volume of water—in the Lake which results, in turn, in Lake level fluctuations. Inflows to Lakes Michigan and Huron are from Lake Superior, the surface drainage system tributary to the Lakes, stormwater runoff from the land surface directly tributary to the Lakes, groundwater inflow, and precipitation falling directly onto the Lake surface. Outflows from Lakes Michigan and Huron are via surface drainage systems, both natural and artificial—primarily, and naturally, through the St. Claire River into Lake Erie but also through the artificial Lake Michigan Diversion at Chicago, groundwater outflow, and evaporation from the Lake surfaces.

The annual cycle in Lake Michigan water level elevations is shown in Figures 3 and 4. The highest water level elevations generally occur in June, July, and August; and the lowest water level elevations occur in January, February, and March. Generally, the lake levels rise from February through July and fall during the remainder of the year. The seasonal rise from February through July reflects the pattern of higher runoff and lower evaporation during that period, in comparison to the remainder of the year. In a typical one-year period, the range in average monthly Lake Michigan levels may be expected to be about one foot.

The historic range between maximum and minimum monthly mean water levels, as set forth above, is about five and one-half feet for all months of the year. The highest maximum monthly lake levels recorded at Milwaukee were measured in 1838—584.3 feet NGVD—and in 1886—583.3 feet NGVD. However, these 19th century water levels cannot be directly compared to recent water level measurements. Uncompensated channel improvements on the St. Claire River between 1933 and 1962 are reported to have reduced the levels of Lakes Michigan and Huron by about 1.2 feet.[2] Therefore, the maximum monthly Lake levels recorded in 1838 and 1886 are likely to be equivalent to water levels under existing channel conditions of about 583.1 feet NGVD and 582.1 feet NGVD, respectively. Therefore. These 19th century maximum monthly water levels are generally equivalent to the monthly mean water level of 583.2 feet NGVD measured in October 1986.

Lake Michigan water levels were considerably above average during the early 1970s, the period just prior to the period during which the 1977 shore erosion and bluff

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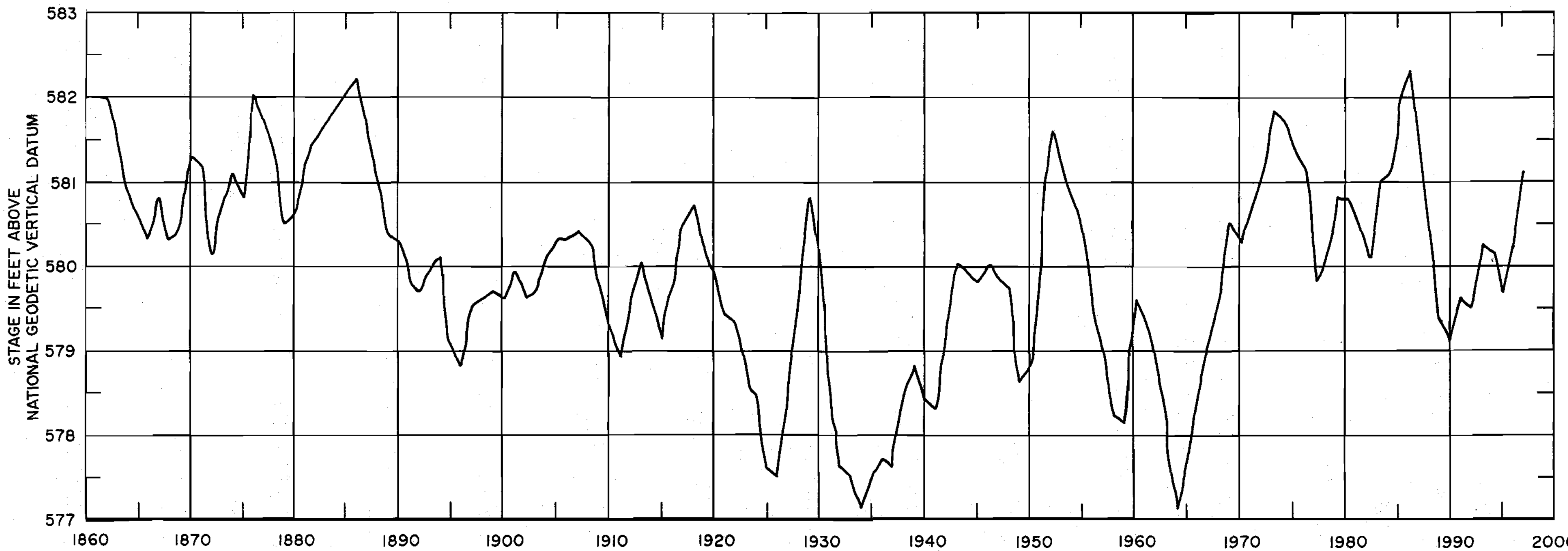
[2]*SEWRPC Planning Report No. 37,* A Water Resources Management Plan for the Milwaukee Harbor Estuary, *Volume One,* Inventory Findings; *Volume Two,* Alternative and Recommended Plans, *1987.*

Figure 2

LAKE MICHIGAN ANNUAL MEAN WATER LEVELS AT MILWAUKEE: 1860-1997

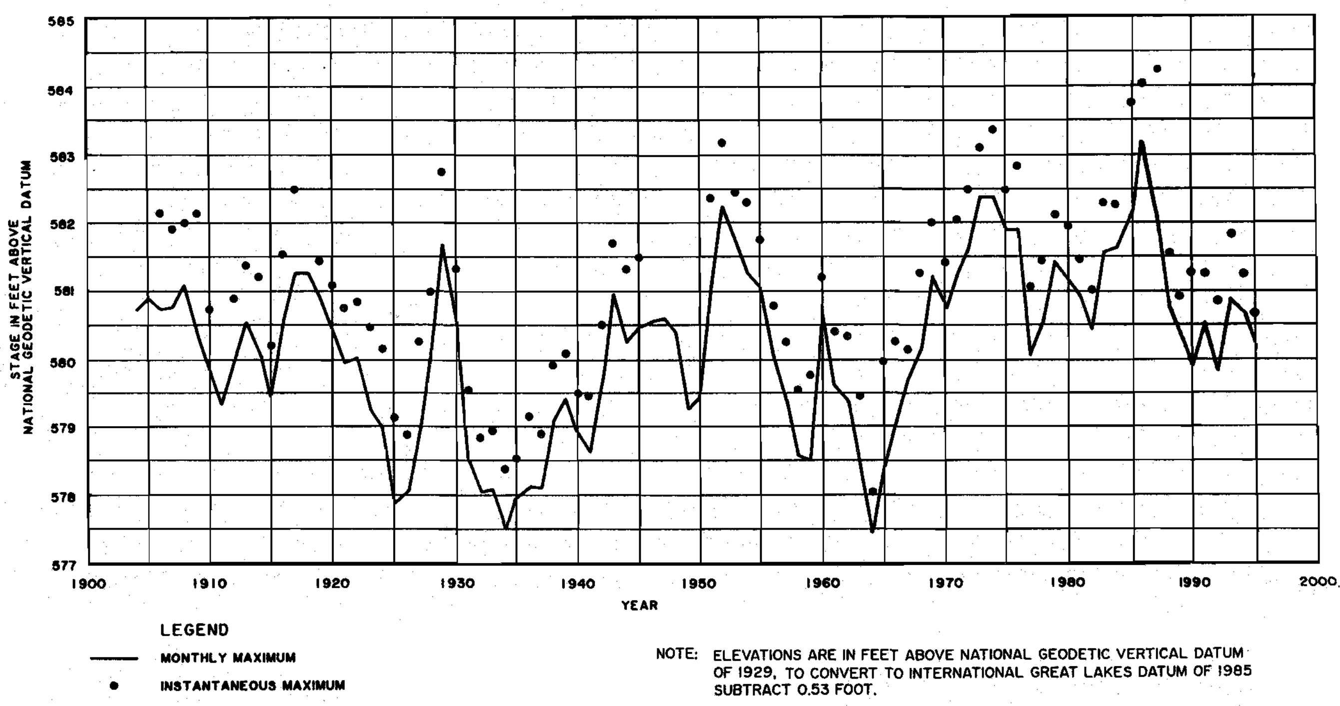


NOTE: ELEVATIONS ARE IN FEET ABOVE NATIONAL GEODETIC VERTICAL DATUM OF 1929, TO CONVERT TO INTERNATIONAL GREAT LAKES DATUM OF 1985 SUBTRACT 0.53 FOOT.

Source: National Ocean Survey, U.S. Army Corps of Engineers, and SEWRPC.

Figure 3

LAKE MICHIGAN ANNUAL MONTHLY MAXIMUM AND INSTANTANEOUS MAXIMUM STAGES AT MILWAUKEE: 1906-1995



Source: National Ocean Survey and SEWRPC.

stability study[3] was conducted. Lake Michigan levels between 1971 and 1976 were generally 0.09 to 1.21 feet higher than average.

As previously noted, record high lake levels at Milwaukee were experienced in 1986. These high lake levels were caused by unusually large amounts of precipitation. There was a significant decline in the level of Lake Michigan since the record high levels of October 1986. That decline continued through 1990, when the level of Lake Michigan dropped to 0.06 feet below the long-term average level of the Lake. Subsequently, the Lake level rose again, approaching the long-term average lake level in 1991, and, by 1992, began to rise above average, exceeding the long-term average level by about 0.43, 0.8, 0.7 and 0.1 feet during the period from 1992 through 1995.

It is important to note even during periods of lower water levels, severe storms can result in flooding. During a storm of March 9, 1987, the level of Lake Michigan at Milwaukee rose to 584.3 feet NGVD, the same elevation as the U.S. Army Corps of Engineers revised 100-year recurrence interval flood stage.[4] The lake level remained above 583.0 feet NGVD for most of that day, countering much of the previously observed lake level decline following October 1986.

There are a number of regulatory structures that have been constructed in the Great Lakes Basin. There five modest artificial diversions on the Great Lakes which change the natural supply of water to the lakes and/or which permit water to bypass a natural lake outlet, and

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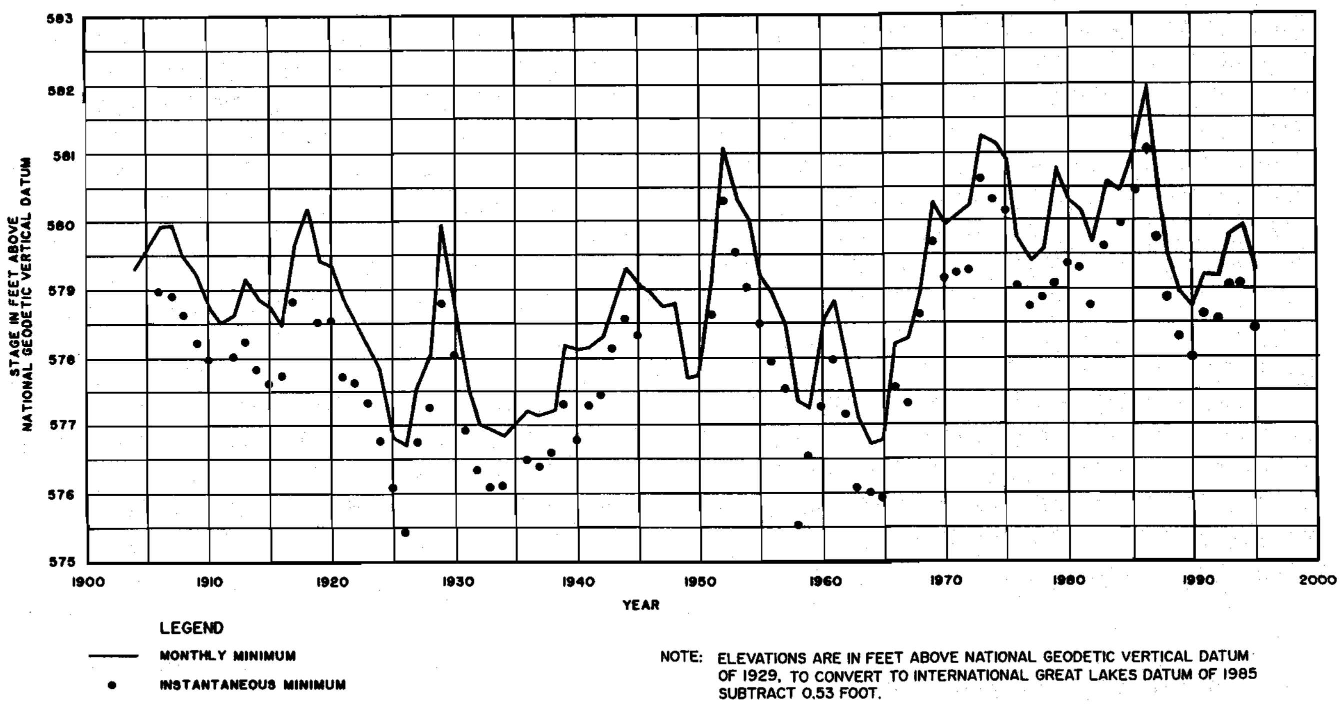
[3]*D.M. Mickelson, L. Acomb, N. Brouwer, T.B. Edil, C. Fricke, B. Haas, D. Hadley, C. Hess, R. Klauk, N. Lasca, and A.F. Schneider, Shore Erosion Study, Technical Report,* Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin, *Wisconsin Coastal Management Program, February 1977.*

[4]*U.S. Army Corps of Engineers,* Revised Report on Great Lakes Open Coast Flood Levels, *Detroit, Michigan, 1988.*

Figure 4

LAKE MICHIGAN ANNUAL MONTHLY MINIMUM AND INSTANTANEOUS MINIMUM STAGES AT MILWAUKEE: 1906-1995



Source: National Ocean Survey and SEWRPC.

two regulatory structures which regulate water levels and flows in the Great Lakes system, as shown on Map 2.

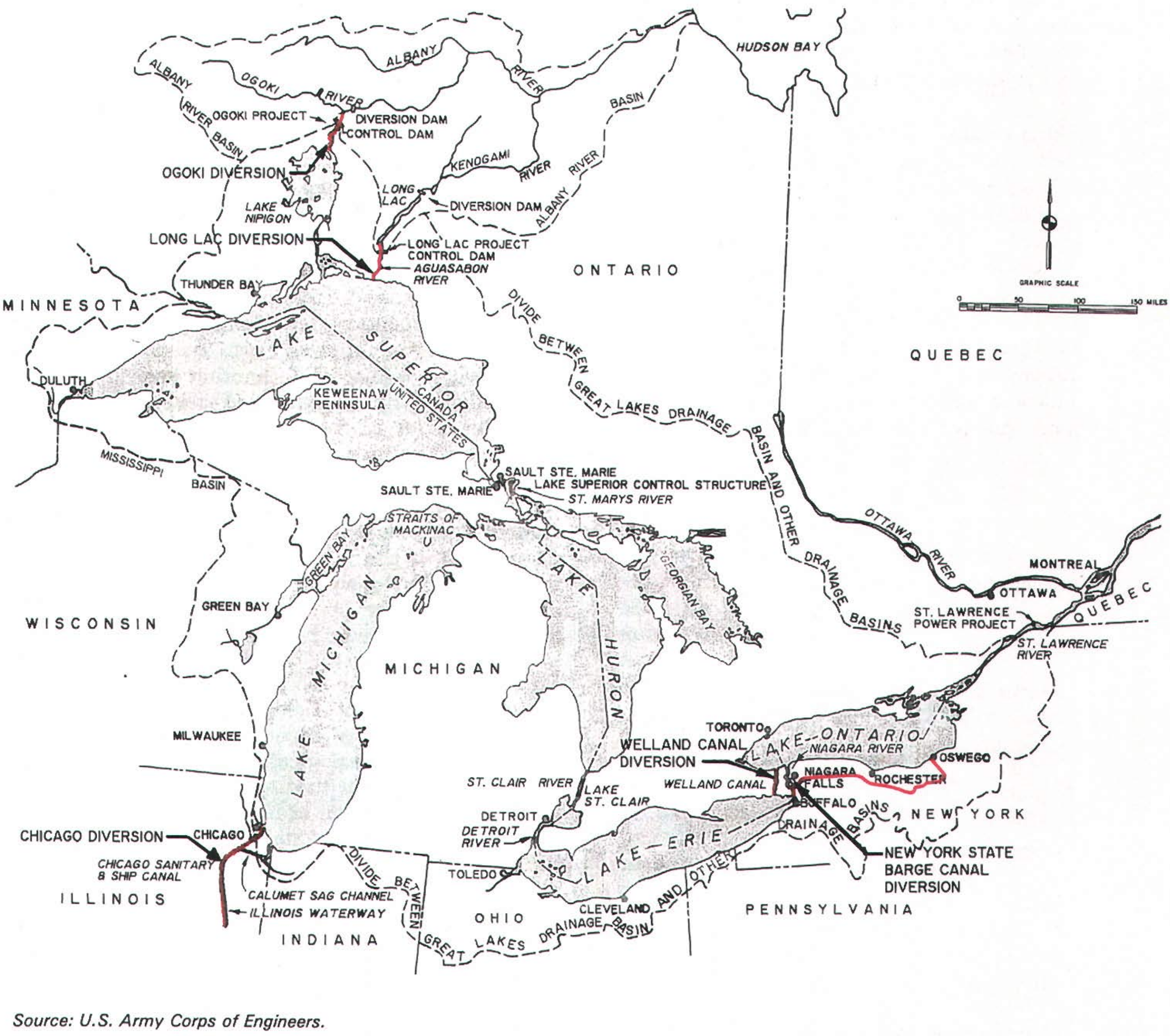
The five Diversions are the Long Lac, Ogoki, and Chicago diversions; the Welland Canal; and the New York State Barge Canal. Both the Ogoki and Long Lac diversions divert water from the Albany River Basin, which would otherwise drain to Hudson Bay, into Lake Superior. These two diversions were developed for the primary purpose of generating hydroelectric power. The Lake Michigan Diversion at Chicago diverts water from Lake Michigan to the Mississippi River Basin. This Diversion serves to dilute sewage effluent discharged from the Chicago Sanitary District and divert the effluent from the Lake. The Diversion also serves to facilitate navigation on the Chicago Sanitary and Ship Canal, and the generation of hydroelectric power in Illinois. The Welland Canal diverts water from Lake Erie across the Niagara Peninsula to Lake Ontario, bypassing the Niagara River and Niagara Falls, and was developed primarily for purposes of facilitating navigation and hydroelectric power generation. The New York State Barge Canal diverts water primarily for navigational purposes from Niagara River at Tonawanda, New York, ultimately discharging it to Lake Ontario and also to the Hudson River.

Water levels in the Great Lakes can be partially regulated by means of the artificial outlet control or regulatory structures. Currently, two of the Great Lakes—Lake Superior at Sault Ste. Marie and Lake Ontario through the St. Lawrence Seaway—are regulated under plans approved by the International Joint Commission (IJC). It should be noted that the regulation of Lake Superior affects the entire Great Lakes system, whereas the regulation of Lake Ontario does not affect the other lakes because of the sheer drop in the water level at Niagara Falls. Additional regulation of water levels on Lake Michigan, Huron, and Erie has been proposed as one method of alleviating shoreline erosion caused by fluctuating, but primarily high, water levels.

In August 1986, the governments of the United States and Canada requested that the International Joint Commission undertake a comprehensive study of potential means for alleviating the adverse impacts of changing water levels, including the very high levels as well as the very low levels, in the Great Lakes/St. Lawrence

Map 2

GREAT LAKES DRAINAGE BASIN AND ARTIFICIAL DIVERSIONS



Source: U.S. Army Corps of Engineers.

River Basin.[5] The study involved two phases. The first phase of the study included a characterization of water level fluctuations; their environmental, social and economic consequences; and the identification and description of potential lake level management measures.[6] The second phase included a comprehensive evaluation of potential solutions such as structural improvements, land use planning, and other management activities.[7] Increased regulation of the water levels of the Great Lakes by dredging to increase the hydraulic capacity of the lake outlet channels, by modifying existing diversions into and out of the lakes, and/or by constructing new diversions[8] was considered within the realm of structural improvements.

The governors of the Great Lakes States, as members of the Council of Great Lakes Governors, in 1986, voiced their support of the 1985 IJC findings that further large-scale diversions of water from the Great Lakes should be avoided.[9] This statement was consistent with the recommendations set forth in the final report of the IJC to the governments of Canada and the United States, which recommended an approach to lake level management in the Great Lakes based on nonstructural measures and a comprehensive shoreline management program, wherein structural interventions are used only in cases where other options are not found to be feasible.[10]

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[5]*International Joint Commission,* Plan of Study Concerning the Reference on Fluctuating Water Levels into the Great Lakes-St. Lawrence River Basin, *March 15, 1988.*

[6]*International Joint Commission,* Living With The Lakes: Challenges and Opportunities—A Progress Report to The International Joint Commission, *July 1989.*

[7]*International Joint Commission,* Final Phase. Levels Reference Study: Great Lake-St. Lawrence River Basin, *January 27, 1993.*

[8]*International Joint Commission,* Great Lakes Diversions & Consumptive Uses, *January 1985.*

[9]*Ibid.*

[10]*International Joint Commission,* Methods of Alleviating the Adverse Consequences of Fluctuating Water Levels in the Great Lakes-St. Lawrence River Basin: A Report to the Governments of Canada and the United States, *December 1993.*

BLUFF EROSION

While some Lake Michigan bluffs do incorporate bedrock formations within their structure—making them extremely resistant to the erosive forces of wind, waves and runoff—the Lake Michigan bluffs in Southeastern Wisconsin are composed of unconsolidated sediments, primarily sands and silts that tend to slough off in shallow layers. Bluff erosion occurs in the form of toe erosion, slumping, sliding, flow, surface erosion, and solifluction or fluidization, resulting in the intermittent, recession of the bluff, as illustrated in Figure 5.

On all slopes, gravity creates shear stresses which act to move material on the slope to a lower elevation. The shear stress forces acting on the materials in the bluffs are primarily determined by the weight of the soil and the water mass in the bluff, water pressures in the bluff, and external loads such as buildings and vibrations. Bluff materials have a shear strength which, in stable slopes, is greater than the stresses. The shear strength depends on the properties of the soil and the moisture content, which is, in part, determined by soil drainage. Bluffs fail when either the shear stress is increased or the shear strength decreased, altering the balance of forces until the stresses exceed the resisting soil strength; for example, undercutting at the toe of the slope by waves steepens the bluff and increases the shear stress.

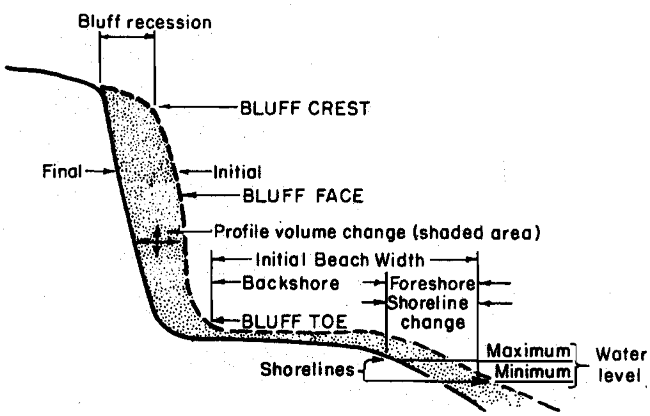
On most slopes which are undisturbed by man, and where waves are not eroding the base of the slope, an equilibrium between shear strength and shear stress, or between the forces acting to move material down the slope and the resistance of the materials in the slope to those forces, is established over a relatively long period of time.

Types of Slope Failure (Mass Wasting)

One major type of slope failure is sliding. In this type of failure, the material generally moves along a single slide plane. The two forms of slides common along the Southeastern Wisconsin shoreline are translational slides, and rotational slides or slumps. Translational slides involve a surface layer several inches to a few feet thick, sliding parallel to the face of the slope on a plane. Translational slides can occur either rapidly or slowly. Rotational slides, in contrast, often involve the slumping or sliding of a fairly large mass along a curved surface. The slide mass rotates, and often the top of the slump block is tilted back toward the slope face. Slumps usually take place suddenly and can cause extensive damage since they can result in a large recession of the bluff.

Figure 5

BLUFF AND BEACH ZONE CHARACTERISTICS



Source: U.S. Army Corps of Engineers, CRREL MONOGRAPH 85-1, May 1985.

The failure sequence typically occurs with toe erosion leading to the undercutting and destabilization of the bluff face, giving the bluff face a convex appearance. Gravitational forces then overcome the shear resistance of the soils leading to the slumping or sliding of a soil block giving the bluff face a concave appearance due to the composite slope created by the accumulation of soils at the base of the bluff. Further erosion of the bluff top leads to the creation of a less steep, uniform slope as the bluff top retreats.

A second major type of slope failure is flow, or fluidization. With this kind of slope failure, large amounts of water are present and the soil mass actually fluidizes and moves like a viscous fluid. Some flow commonly occurs at the toe of slump blocks during and relatively soon after a sliding failure. Since slump blocks rotate such that the top of the block is often tilted back toward the bluff, surface water can accumulate in these depressions and saturate the underlying soil. Flows also occur when intense rains saturate the surface layer of soil, or in the spring as ice melts near the soil surface. Flows can also occur where groundwater discharges along the bluff face through layers of silt or fine sand. If these more permeable soil layers are located between less permeable clay layers, removal of sediment by flow due to groundwater seepage—referred to as sapping—can occur, and cause undercutting which creates an unstable slope subject to slumping and sliding.

A third type of slope failure, related to flow, is solifluction. Solifluction is the slow, viscous downslope flow of water-saturated material over an impermeable base. Solifluction is often caused by freeze-thaw activity. During the thawing period, there is a buildup of excess moisture within the surficial soil mass. Because of underlying impermeable frozen ground, the pore pressures cannot be dissipated and, thus, shear resistance decreases. Also, the growth of ice crystals within the soil during winter months weakens the structure of the soil. The amount of moisture in a soil prior to thawing will affect the shear strength after it has thawed; the higher the moisture content before thawing, the greater the reduction in shear strength after thawing. The net result is a reduced shear resistance, or strength, which is less than the shear stress; therefore, even gentle slopes may fail. Solifluction can also occur in unconsolidated material which overlies impermeable bedrock.

A fourth type of slope failure is sheet wash, and rill and gully erosion. Both sheet wash and rill and gully erosion result from surface water runoff flowing over the top of the bluff, and over the slope face itself. Sheet wash is the unconfined flow of water over the soil surface during and following a rainfall. Depths of flow are generally less than one-tenth of an inch, and raindrop impact is the dominant factor in the detachment of soil particles. Once the particles are detached, they are transported downslope at a rate determined by the water runoff rate, slope steepness, vegetative cover, and roughness of the surface, and by the transportability of the detached soil particles, which is a function of particle size and density. In contrast to sheet wash, rills and gullies are formed by the channelized flow of water over the soil surface. Rill and gully formation tends to follow zones of weakness established by desiccation, cracking, and differences in soil expansion due to the cycles of freezing and thawing, and wetting and drying. On the lake bluffs, the rills are generally destroyed over the winter months by freeze-thaw activity and solifluction, whereas gullies may exist for years.

A fifth type of slope failure is rock or soil fall. This type of failure takes place when undercutting is extreme and near-vertical cliffs are produced. Even though some such segments of bluff are along the Lake Michigan shoreline, these are generally small, and rock or soil fall from vertical bluff faces plays only a small role in the overall shoreline erosion in the study area.

Wave Action

Several factors affect the type of slope failure that occurs and the severity of that failure. The physical characteristics of the beach and bluff have a major influence on the resistance of the slope to failure. Numerous other factors affect the external stresses that are placed upon the slope, resulting in various types of failure. Among these factors is wave action, particularly during storms.

Wind waves result from the transfer of energy from the moving air to the water through a combination of sheer stress and pressure fluctuations. The energy imparted to the water is internally dissipated during further interaction with the air and with the lake bottom, or through turbulence created by the wave breaking onto the shore or coastal structures. Waves on Lake Michigan have been observed to range in size from mere ripples to large waves of 15 feet in height or more.

When occurring concurrently with high lake levels, wave action can result in rapid and severe erosion of the toe of bluffs within the study area. This bluff toe erosion may cause instability of the entire bluff slope, and ultimately recession of the bluff. Wave action also affects the orientation, width, slope, and substrate of beaches and affect the depth and characteristics of the offshore areas. The characteristics of the offshore area also impact on the wave energy and heights. Figure 6 illustrates the pattern of breaking waves as they approach a beach.

Ice Formation

Ice formation tends to contribute to a seasonal cycle of bluff erosion. Ice formation has both positive and negative features. Stationary shore ice may serve to protect beach and bluff areas from wave action, while a nonstationary ice sheet, responding to wave motions, may scour these same areas and abrade shoreline structures. Ice, accumulating on shoreline structures as a result of freezing spray, can weigh down these structures or result in positive buoyancy during the periods of lake level rise, typically associated with spring runoff, which may contribute to the failure of such structures.

Seiches and surges combined with the positive buoyancy of an ice sheet, as noted above, also can be destructive to the shoreline. The motion associated with seiche- or surge-induced ice sheet movement is typically up and down—rising and sinking in time with the return period of these phenomena—but it also may be lateral as well given the Coriolis effects present in the Great Lakes. Floating ice fields, depending on wind conditions, may develop along the coast further contributing to the potential damage that may result from ice formation.

Finally, freeze-thaw activity may increase slope failure by causing solifluction.

Groundwater Seepage

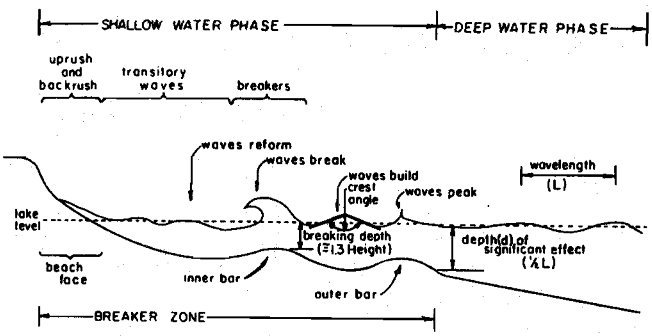
Groundwater seepage can affect bluff stability in several ways. In most areas along the Lake Michigan shoreline, groundwater moves toward the Lake and, in some places, discharges either at the toe of the bluff or from the bluff face. Saturated soil conditions decrease the grain-to-grain contact pressure in the soil and reduce the frictional resistance of the material to stress. Groundwater also adds weight to the bluff, further increasing stress on the slope. In addition, groundwater seepage creates a seepage pressure in the direction of water flow. This pressure is of particular importance in granular soils such as sands and silts, and is of lesser importance when the clay content of the soils is fairly high. If groundwater actually discharges from the bluff face, some undercutting of materials may also occur. Removal of bluff materials by groundwater is especially important when sand layers either are interbedded with fine-grained materials or are present at the bluff top. When a layer of permeable sand is present on the top of the bluff, large amounts of water percolate through the sand until a less permeable material is reached. Water then travels laterally along this less permeable layer toward the bluff face. If the water flow is sufficiently large, this seepage can erode the fine materials from the less permeable layer, washing out fine materials from within the bluff. This process, known as sapping, can induce the sudden failure of the bluff face.

Vegetative Cover

Vegetation can have both a positive and negative effect on bluff stability and erosion, although vegetative cover generally results in positive benefit. The above ground portion of the vegetation physically intercepts raindrops, thereby reducing their potential to loosen particles on the bluff face; reduces the impact of wind; and serves to trap windblown and washed off sediment. Likewise, the underground portion of vegetation serves to bind unconsolidated material in place; prevent slippage between soil layers parallel to the bluff face; and retard surface wash off, filtering out sediment carried by the wash. However, the fact that the roots of the vegetation slow runoff and contribute to enhanced infiltration of the runoff also provides infiltration passages into the bluff face may contribute to a decrease in bluff stability as a result of increased groundwater content and levels. Thus, while vegetative cover may effectively reduce sheet and rill erosion and shallow translational sliding, it is best

Figure 6

TYPICAL PATTERN OF
WAVES APPROACHING A BEACH



Note: ≅ denotes approximately

Source: S.N. Hanson, J.S. Perry, and W. Wallace, Great Lakes Shore Erosion Protection—A General Review with Case Studies, Wisconsin Coastal Management Program, 1977.

accomplished by plants with relatively shallow root systems to avoid excessive infiltration.

Vegetation can also contribute to slope stability through the removal of groundwater from the bluff by transpiration of groundwater through the plant. In addition, vegetation on the top of the bluff may serve to intercept and divert some surface runoff; thus, preventing it from moving down the bluff face.

Probably one of the most significant aspects of the lack of vegetation on a bluff face is that it serves as an effective indicator of recent erosion.

BEACH EROSION

Beaches in the Region are composed primarily of mixtures of sand and gravel, with scattered deposits of pure sand and gravel in places. The clays and silts that form part of the terrestrial soils tend to be washed out and carried in the littoral drift into the nearshore zone, where it is deposited offshore. The typical beach profile, shown in Figure 7, is similar to those observed in the marine coastal zone, including the gently sloping backshore area consisting of one or more horizontal berms and the more active, slightly more steeply sloped foreshore area exposed to wind and wave action. Given the soil and erosion characteristics associated with the Lake Michigan coastal zone, the steeper slopes are usually comprised of coarse gravels, while the more gently sloping areas are comprised of sand and fine gravels.

Beach materials, and hence the appearance of the beach, are in a constant state of flux, especially in the foreshore zone where wave action and return flows are constantly moving materials shoreward and lakeward. Storm events, which produce high steep waves along the Southeastern Wisconsin coast, tend to be erosive in nature, while the small waves occurring between storms tend to build beaches. Figure 7, shows the process of beach erosion in response to the impact of high, steep waves.

Wave Action

Of the erosive processes affecting beaches, the most significant is wave action. Wave action affects the orientation, width, slope, and substrate of beaches. As breaking waves approach a beach, shoreland material is eroded and carried lakeward by the turbulence and backwash generated by steep waves impacting beaches and coastal structures. While these transported materials can be replaced through the net landward transport of sediments that occurs under nonstorm conditions, the fact that most waves rarely impact coastlines in the perpendicular—usually striking the coast in an oblique manner—means that rarely do eroded sediments get replaced on the coast at their place of origin. Rather, they are transported along the coastline and deposited elsewhere.

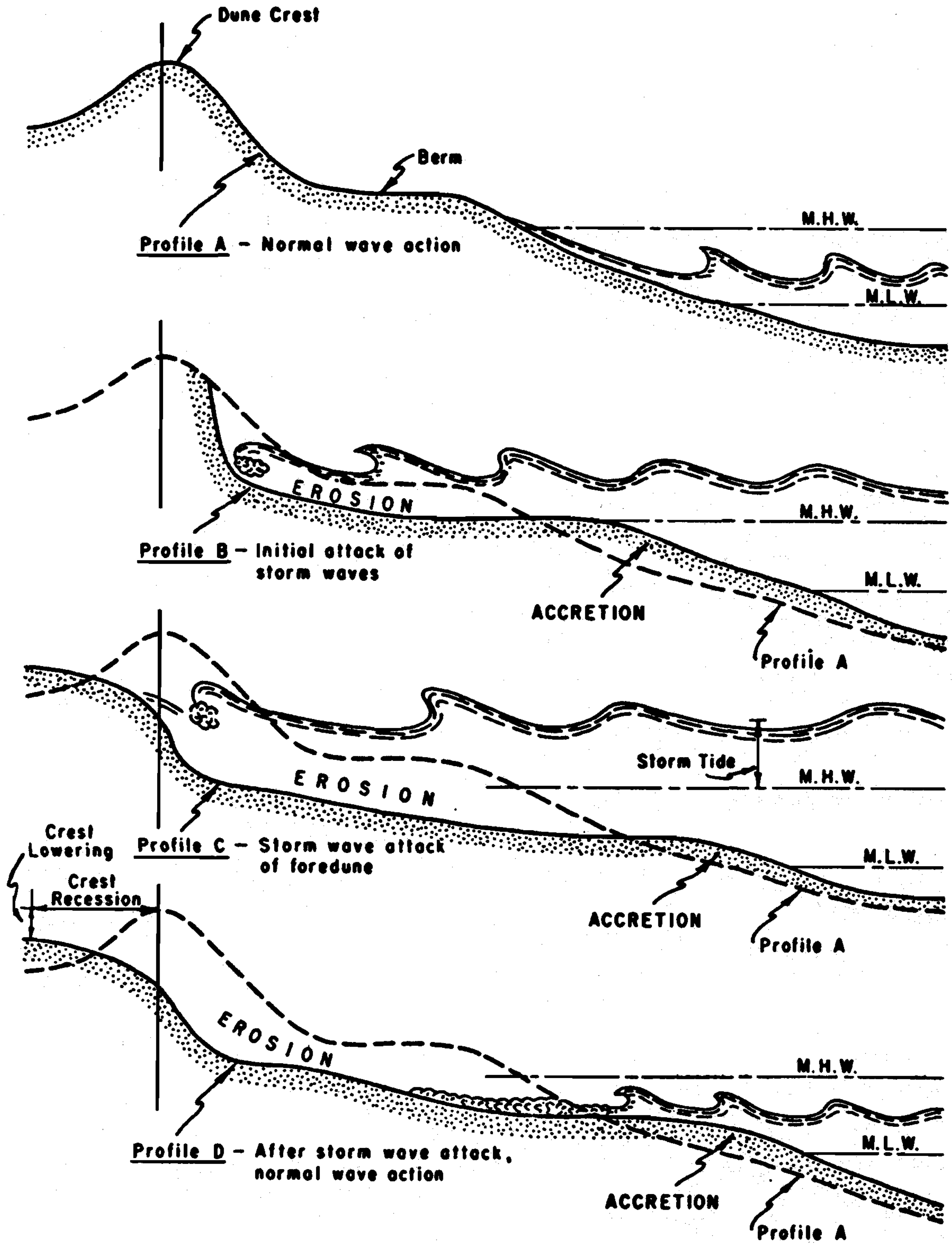
Wave action is also important because of its potential for damaging shore protection structures such as revetments, bulkheads, breakwaters, and groins. Not only is wave damage that damage associated with the direct impact of the waves upon the coast, but also, for example, that damage associated with undesirable deposition of sediments—accretion—at other points along the coast.

The effects of wave action-related erosion include a steepening of the beach face accompanied by a retreat of the lakeward edge of the backshore area and a reduction in slope of the lake bottom immediately adjacent to the beach face. One or more offshore sandbars may also develop parallel to the coastline as a result of deposition of eroded materials at the lower energy lakeward edge of the surf zone; similarly, some deposition can also occur in the backshore berm area as the result of wave action. Beach erosion generally occurs during spring and period of northeasterly winds which are enhanced by the long fetch afforded by the orientation of the lake.

The deposition of suspended sediments in offshore sandbars can moderate the erosivity of subsequent wave action by causing waves to break prior to directly impacting the beach face. Their generally steep lake

Figure 7

TYPICAL BEACH PROFILE AND EROSION PROCESSES



M.H.W. denotes Mean High Water
M.L.W denotes Mean Low Water

Source: U.S. Army Corps of Engineers.

faces also act to quickly dissipate wave energy, further reducing their impact on the beach face.

Currents

As noted above, sediment eroded from the beach is rarely redeposited on the same beach. Generally, eroded sediments are transported parallel to the shoreline along the beach by longshore currents. Longshore currents are currents in the breaker zone running generally parallel to the shoreline and usually caused by waves breaking at an angle to the shoreline. Longshore currents transport sediment, which is suspended in the current or bounced and rolled along the lake bottom, parallel to the shore. While the longshore currents within the coastal zone of Southeastern Wisconsin may move in either a northerly or southerly direction in response to the direction of the incident waves, the net sediment transport is to the south. Evidence of this fact is the tendency for beaches to exhibit accretion on the north side of groins, piers, and other structures while erosion occurs on the southerly side of such structures.

Because of the dynamic nature of the coastal area, the topography of beaches can be severely affected by even a single storm event. Beaches are not stable features. Nevertheless, many beaches do develop a dynamic equilibrium over time when long-term, multi-year rates of erosion and accretion achieve some degree of balance.

A beach is said to be stable, even though subject to storm and seasonal changes, when the long-term—several years or more—rates of supply and loss of material are approximately equal.

CONCLUSION

Because bluff slope and beach stability are influenced by a number of dynamic factors, slope failure and beach erosion are processes that occur in an abrupt, unpredictable, fashion as opposed to a uniform, relatively stable continuous fashion. After each incremental slope failure, the soil masses tend to temporarily assume a stable configuration until the net effect of the many influencing factors decreases slope stability, thus precipitating another incremental failure. Beach materials and, to a lesser degree, the beach shape are being changed constantly by materials being moved shoreward and lakeward. High steep waves tend to be erosive to beaches while small waves tend to build beaches. Because of the dynamic nature of the coastal erosion processes, it is important to periodically document bluff stability and shoreline erosion conditions and to evaluate methods for predicting future conditions. The determination of the natural rates of coastline recession, and the stability of the bluffs as of 1995 as well as an evaluation of the methodology for predicting such conditions forms the content of the subsequent chapters of this report.

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Chapter III

INVENTORY FINDINGS AND ANALYSIS

INTRODUCTION

Shoreline erosion and bluff stability conditions are important considerations in preservation, development, and land use regulation decisions for lands located along the Lake Michigan shoreline. Such conditions may change over time since they are related, in part, to changes in other conditions such as water levels, the geometry of the onshore beach and nearshore areas, the extent and condition of shore protection measures, the type and extent of vegetation existing, and, to some extent, the type of land uses and structures in place. As noted in Chapter I, shoreline erosion and bluff stability conditions in Southeastern Wisconsin were documented in a 1977 study,[1] and, subsequently, for Racine County in 1982,[2] and Milwaukee County in 1989.[3] This chapter provides updated data on bluff stability and rates of shoreline recession for the Lake Michigan coastal areas of Southeastern Wisconsin.

The updated data on bluff stability and shoreline erosion are presented by shoreline "reach." Seventeen such reaches were considered, as shown on Map 1. These reaches vary in length from one to more than seven miles and generally have been selected based upon bluff, beach, and other shoreline characteristics. The shoreline reaches used are similar to those used in the aforementioned 1977 shore erosion study, but were refined to reflect certain changes in shoreline conditions which have occurred since that time.

Within each shoreline reach, the inventory and analysis data are organized by analysis sections corresponding to U.S. Public Land Survey sections. Within certain sections, "erosion analysis zones" are also delineated to describe the current conditions. These smaller subdivisions have certain bluff and beach characteristics that differentiate them from other parts of the shoreline within the analysis section. Within each section or erosion analysis zone, the location of data points is given by reference to the nearest public streets, or, in the absence of public streets, by the distance north of the south line of the section or erosion zone within a section as a decimal. In other words, location 6.4 is 0.4 mile north of the south line of Section 6 within the erosion reach section concerned.

Because of the comparisons being made with the findings of previous studies, it is important to document the important inventory dates of the studies being compared. The 1977 Shoreline Erosion Study inventory data are based on field work conducted in the summer of 1976, oblique photographs taken in May 1976, and vertical aerial photographs taken in May 1975. The 1989 Milwaukee County data are based on field work conducted in the summers of 1986 through 1988, oblique aerial photographs taken in April 1987, and vertical aerial photographs taken in March 1985. The 1982 Racine County Study data are based upon vertical aerial photographs taken in April 1980. The current inventory data are based on field work conducted in the summer of 1995, oblique aerial photographs taken May 2nd, 1994, and vertical aerial photographs taken in March 1995.

The data and analyses reported herein were conducted to evaluate the conditions in each of the designated analysis reaches. The evaluation of individual lakeshore properties and the detailed design of shore protection measures will require further site-specific analyses by a professional geotechnical or coastal engineer.

INVENTORY AND ANALYSIS PROCEDURES

The bluff stability and shoreline erosion characteristics of each shoreline reach were determined under this study

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[1]*D.M. Mickelson, L. Acomb, N. Brouwer, T.B. Edil, C. Fricke, B. Haas, D. Hadley, C. Hess, R. Klauk, N. Lasca, and A.F. Schneider, Shore Erosion Study, Technical Report,* Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin, *Wisconsin Coastal Management Program, February 1977.*

[2]*SEWRPC Community Assistance Planning Report No. 86,* A Lake Michigan Coastal Erosion Management Study for Racine County, Wisconsin, *October 1982.*

[3]*SEWRPC Community Assistance Planning Report No. 163,* A Lake Michigan Shoreline Erosion Management Plan for Milwaukee County, Wisconsin, *October 1989.*

utilizing inventory data collected on bluff characteristics, beach characteristics, and current and historic bluff and shoreline locations. These data were collected utilizing the following methods: 1) aerial photograph interpretation utilizing the Southeastern Wisconsin Regional Planning Commission's ratioed and rectified 1963, 1975, and 1995 aerial photographs which are available at a scale of one inch equals 400 feet; 2) map interpretation using large-scale topographic maps prepared to Commission specifications, at scales of one inch equals 100 or 200 feet, with two-foot contour intervals, over the period 1976 through 1993 for all of the shoreline, except Ozaukee County, north of the City of Mequon; 3) interpretation of oblique aerial photographs taken by Dr. Tuncer B. Edil, P.E., during 1994 of the entire Lake Michigan shoreline in Southeastern Wisconsin, excepting the southerly portion of Kenosha County which does not have sizable bluffs; and 4) field surveys conducted during 1995. The following section describes the methods used to identify and evaluate the various factors relating to bluff stability and shoreline erosion.

Bluff and Beach Characteristics

The bluffs along the shoreline of Lake Michigan within the Southeastern Wisconsin Region exhibit a variety of height, slope, composition, vegetative cover, and groundwater conditions. These conditions affect the degree and rate of bluff recession in the study area. During 1995, field surveys were conducted to measure the geometry of the bluff slope and beach. Measurements of the geometry of the bluff slope, were conducted at 192 sites, the general location of which are set forth in Table 3. These measurements provided a basis for site-specific assessments of the bluff conditions at the selected locations. The 1995 field observations were conducted by a field survey party which reoccupied the 1976 and selected 1987 bluff profile sites wherever possible. However, the field party did not visually survey the beach or bluff in between the profiles, as was done in the 1977 study. This procedure was used in order to facilitate the reassessment of erosion and bluff conditions and to assess changes which had taken place between 1976 and 1995. Bluff profiles were measured using a 100-foot steel tape and inclinometer. Slope segments were documented in a manner suitable for entering into a computer program used for analyzing the bluff stability. At each profile site, observations were also made on the extent of vegetative cover on the bluff face and the type of bluff materials on face of the bluff where the bluff face was exposed. In shoreline areas where the bluff face was covered with fill, debris, or vegetation, the underlying stratigraphy was determined using historical geologic records or soil boring data where available. In addition, general observations were made, noting the types of failure and the amount of horizontal recession of the bluff top, based upon bluff top features observed and identified on vertical and oblique photographs.

Beach width was measured at each profile. In addition, for 33 selected sites the field party also measured the distance from the shore lakeward to a water depth of five feet for comparison with the 1977 study findings. Observations were also made on the predominant type of existing offshore bottom materials.

Beach width and nearshore conditions are highly variable, both seasonally and from year to year with changes in water levels. As noted in Chapter II, Lake Michigan water levels were higher in 1976 by about 0.6 foot on an annual average and by over one foot during the summer months than in 1995, and, any comparisons of beach and nearshore conditions between those periods must consider this fact.

Bluff Stability

Using the field survey data described above, slope stability data were prepared for each profile site. Slope stability analyses were performed for the bluffs using modified versions of the computer program STABL.[4] The program is based upon the Modified Bishop Method for estimating slope stability and the potential for failures and can generate circular failure surfaces, sliding block surfaces, and irregularly shaped surfaces. It is capable of evaluating the effects of different soil and groundwater conditions, earthquakes, and surcharge loadings. Bluff slope data used as inputs to the program include the geometry of the slope, bluff stratigraphy interfaces, soil properties, and estimated groundwater elevations. The program has been modified by Associate Professor Peter J. Bosscher of the University of Wisconsin-Madison for personal computer use, and for data enhancement purposes.

Using shear strengths and stresses, factors of safety were calculated for potential failure surfaces within the bluffs. A safety factor is defined as the ratio of the forces resisting shear to the forces promoting shear along the failure surface. Thus, a safety factor less than or equal to 1.0 indicates that the forces promoting failure are greater than or equal to the forces resisting failure.

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[4] *R.A. Siegel,* STABL User Manual, *Joint Highway Research Project, Purdue University and the Indiana State Highway Commission, JHRP-75-9, June 1975.*

Table 3

SUMMARY OF LAKE MICHIGAN SHORE BLUFF PROFILE LOCATIONS IN SOUTHEASTERN WISCONSIN: 1995

County	Analysis Reach by U.S. Public Land Survey Township, Range, and Section	1995 Profile Number	Corresponding Profile Number from Previous Studies[a]
Kenosha	Reach 1		
	T1, R23E, Section 32	1-1	76-3
	T1, R23E, Section 29	1-2	76-2
	T1, R23E, Section 20	1-3	76-2
	T1, R23E, Section 17	1-4	76-2
	Reach 3		
	T2N, R23E, Section 30	3-1	76-2
	T2N, R23E, Section 19	3-2	76-4
	T2N, R23E, Section 19	3-3	76-3
	T2N, R23E, Section 19	3-4	76-2
	T2N, R23E, Section 19	3-5	76-1
	T2N, R23E, Section 18	3-6	76-4
	T2N, R23E, Section 18	3-7	76-2
	T2N, R23E, Section 18	3-8	76-2
	T2N, R23E, Section 8	3-9	76-3
	T2N, R23E, Section 8	3-10	76-2
	T2N, R23E, Section. 8	3-11	76-1
	T2N, R23E, Section 5	3-12	76-3
	T2N, R23E, Section 5	3-13	76-2
	T2N, R23E, Section 5	3-14	76-1
Racine	Reach 3		
	T3N, R23E, Section 32	3-15	76-3
	T3N, R23E, Section 32	3-16	76-2
	T3N, R23E, Section 29	3-17	76-4
	T3N, R23E, Section 28	3-18	76-3
	T3N, R23E, Section 28	3-19	76-1
	T3N, R23E, Section 28	3-20	76-2
	Reach 4		
	T4N, R23E, Section 21	4-1	76-1
	T4N, R23E, Section 21	4-2	76-2
	Reach 5		
	T4N, R23E, Section 4	5-1	76-2
	T4N, R23E ,Section 4	5-2	76-1
	T4N, R23E, Section 33	5-3	76-1
	T4N, R23E, Section 33	5-4	76-2
	T4N, R23E, Section 27	5-5	76-3
	T4N, R23E, Section 27	5-6	76-2
	T4N, R23E, Section 27	5-7	76-1
	Reach 6		
	T4N, R23E, Section 22	6-1	76-2
	T4N, R23E, Section 21	6-2	76-1
	T4N, R23E, Section 16	6-3	76-4
	T4N, R23E, Section 16	6-4	76-3
	T4N, R23E, Section 16	6-5	82-3
	T4N, R23E, Section 16	6-6	82-4
	T4N, R23E, Section 16	6-7	76-2
	T4N, R23E, Section 17	6-8	82-5
	T4N, R23E, Section 17	6-9	82-6
	T4N, R23E, Section 17	6-10	82-7
	T4N, R23E, Section 17	6-11	76-1
	T4N, R23E, Section 8	6-12	76-1
	T4N, R23E, Section 8	6-13	82-8

Table 3 (continued)

County	Analysis Reach by U.S. Public Land Survey Township, Range, and Section	1995 Profile Number	Corresponding Profile Number from Previous Studies[a]
Racine (continued)	Reach 6 (continued)		
	T4N, R23E, Section 8	6-14	76-2
	T4N, R23E, Section 8	6-15	82-9
	T4N, R23E, Section 8	6-16	76-3
	T4N, R23E, Section 7	6-17	76-4
	T4N, R23E, Section 6	6-18	76-2
	T4N, R23E, Section 6	6-19	76-1
Milwaukee	Reach 7		
	T5N, R23E, Section 31	7-1	87-1
	T5N, R23E, Section 31	7-2	95-1
	T5N, R23E, Section 31	7-3	76-3
	T5N, R23E, Section 31	7-4	76-2
	T5N, R23E, Section 31	7-5	87-2
	T5N, R22E, Section 36	7-6	76-1
	T5N, R22E, Section 36	7-7	87-3
	T5N, R22E, Section 24	7-8	76-1
	T5N, R22E, Section 24	7-9	87-10
	T5N, R22E, Section 24	7-10	87-11
	T5N, R22E, Section 24	7-11	87-13
	T5N, R22E, Section 24	7-12	76-2
	T5N, R22E, Section 24	7-13	87-14
	T5N, R22E, Section 24	7-14	76-3
	Reach 8		
	T5N, R22E, Section 13	8-1	87-15
	T5N, R22E, Section 13	8-2	87-17
	T5N, R22E, Section 13	8-3	76-1
	T5N, R22E, Section 13	8-4	87-18
	T5N, R22E, Section 13	8-5	87-19
	T5N, R22E, Section 13	8-6	76-2
	T5N, R22E, Section 13	8-7	87-20
	T5N, R22E, Section 12	8-8	87-21
	T5N, R22E, Section 12	8-9	87-22
	T5N, R22E, Section 12	8-10	76-1
	T5N, R22E, Section 12	8-11	76-2
	T5N, R22E, Section 12	8-12	87-24
	T5N, R22E, Section 1	8-13	87-25
	T5N, R22E, Section 1	8-14	76-1
	T5N, R22E, Section 1	8-15	76-2
	T5N, R22E, Section 1	8-16	87-27
	T5N, R22E, Section 1	8-17	87-28
	T5N, R22E, Section 1	8-18	76-3
	T6N, R22E, Section 36	8-19	76-1
	T6N, R22E, Section 36	8-20	87-30
	T6N, R22E, Section 36	8-21	87-31
	T6N, R22E, Section 36	8-22	76-3
	T6N, R22E, Section 36	8-23	87-32
	T6N, R22E, Section 36	8-24	76-2
	T6N, R22E, Section 36	8-25	87-33
	T6N, R22E, Section 25	8-26	76-1
	T6N, R22E, Section 25	8-27	76-2
	T6N, R22E, Section 25	8-28	87-35
	T6N, R22E, Section 25	8-29	76-3
	T6N, R22E, Section 25	8-30	76-4
	T6N, R22E, Section 25	8-31	87-37
	T6N, R22E, Section 24	8-32	87-38

Table 3 (continued)

County	Analysis Reach by U.S. Public Land Survey Township, Range, and Section	1995 Profile Number	Corresponding Profile Number from Previous Studies[a]
Milwaukee (continued)	Reach 8 (continued)		
	T6N, R22E, Section 24	8-33	87-39
	T6N, R22E, Section 24	8-34	76-1
	T6N, R22E, Section 24	8-35	87-40
	T6N, R22E, Section 14	8-36	87-46
	T6N, R22E, Section 14	8-37	87-47
	T6N, R22E, Section 14	8-38	87-48
	T6N, R22E, Section 14	8-39	87-50
	T6N, R22E, Section 14	8-40	87-52
	T6N, R22E, Section 14	8-41	87-54
	Reach 9		
	T6N, R22E, Section 10	9-1	87-56
	Reach 10		
	T7N, R22E, Section 10	10-1	87-58
	T7N, R22E, Section 3	10-2	76-1
	T7N, R22E, Section 3	10-3	76-2
	T7N, R22E, Section 3	10-4	76-3
	T7N, R22E, Section 3	10-5	76-4
	T8N, R22E, Section 34	10-6	76-1
	T8N, R22E, Section 33	10-7	76-2
	T8N, R22E, Section 33	10-8	76-3
	T8N, R22E, Section 28	10-9	76-1
	T8N, R22E, Section 28	10-10	76-3
	T8N, R22E, Section 28	10-11	76-5
	T8N, R22E, Section 21	10-12	76-3
	T8N, R22E, Section 21	10-13	76-4
	T8N, R22E, Section 16	10-14	76-1
	Reach 11		
	T8N, R22E, Section 10	11-1	82-10
	T8N, R22E, Section 10	11-2	76-1
	T8N, R22E, Section.4	11-3	87-101
	T8N, R22E, Section 4	11-4	87-103
Ozaukee	Reach 11		
	T9N, R22E, Section 33	11-5	82-1
	T9N, R22E, Section 33	11-6	76-2
	T9N, R22E, Section 33	11-7	76-3
	T9N, R22E, Section 28	11-8	76-3
	T9N, R22E, Section 28	11-9	76-2
	Reach 12		
	T9N, R22E, Section 28	12-1	82-3
	T9N, R22E, Section 28	12-2	76-1
	T9N, R22E, Section 21	12-3	76-1
	T9N, R22E, Section 21	12-4	82-4
	T9N, R22E, Section 21	12-5	76-2
	T9N, R22E, Section 17	12-6	76-1
	T9N, R22E, Section 17	12-7	82-5
	T9N, R22E, Section 17	12-8	76-2
	T9N, R22E, Section 17	12-9	76-3
	T9N, R22E, Section 8	12-10	76-1
	T9N, R23E, Section 8	12-11	95-1
	T9N, R23E, Section 8	12-12	76-2
	T9N, R23E, Section 8	12-13	82-6
	T9N, R23E, Section 8	12-14	76-3
	T9N, R23E, Section 8	12-15	76-1

Table 3 (continued)

County	Analysis Reach by U.S. Public Land Survey Township, Range, and Section	1995 Profile Number	Corresponding Profile Number from Previous Studies[a]
Ozaukee (continued)	Reach 12 (continued)		
	T9N, R23E, Section 8	12-16	76-2
	T9N, R23E, Section 8	12-17	76-3
	T10N, R22E, Section 33	12-18	76-1
	T10N, R22E, Section 33	12-19	76-2
	T10N, R22E, Section 33	12-20	82-20
	T10N, R22E, Section 33	12-21	76-3
	T10N, R22E, Section 28	12-22	76-1
	T10N, R22E, Section 28	12-23	76-2
	T10N, R22E, Section 28	12-24	76-3
	T10N, R22E, Section 28	12-25	82-9
	Reach 13		
	T10N, R22E, Section 21	13-1	76-1
	T10N, R22E, Section 21	13-2	76-2
	T10N, R22E, Section 21	13-3	76-3
	T10N, R22E, Section 16	13-4	76-1
	T10N, R22E, Section 16	13-5	76-2
	T10N, R22E, Section 16	13-6	82-15
	T10N, R22E, Section 10	13-7	76-1
	T10N, R22E, Section 10	13-8	76-2
	T10N, R22E, Section 10	13-9	76-3
	T10N, R22E, Section 3	13-10	76-1
	T10N, R22E, Section 3	13-11	76-2
	T10N, R22E, Section 3	13-12	82-14
	T10N, R22E, Section 3	13-13	76-3
	T10N, R22E, Section 3	13-14	82-13
	T11N, R22E, Section 33	13-15	76-1
	T11N, R22E, Section 33	13-16	82-12
	T11N, R22E, Section 33	13-17	76-2
	T11N, R22E, Section 33	13-18	82-11
	Reach 15		
	T11N, R22E, Section 33	15-1	80-1
	T11N, R23E, Section 28	15-2	80-2
	T11N, R23E, Section 28	15-3	80-3
	T11N, R23E, Section 28	15-4	76-1
	T11N, R23E, Section 21	15-5	82-17
	T11N, R23E, Section 21	15-6	76-1
	T11N, R23E, Section 22	15-7	76-2
	T11N, R23E, Section 15	15-8	76-1
	T11N, R23E, Section 14	15-9	76-3
	T11N, R23E, Section 11	15-10	76-1
	T11N, R23E, Section 11	15-11	76-2
	T11N, R23E, Section 11	15-12	76-3
	T11N, R23E, Section 11	15-13	76-4
	T11N, R23E, Section 2	15-14	76-2

[a]1976 conditions are set forth in Mickelson et al., Shore Erosion Study, Technical Report, op. cit., 1982 conditions for Racine County are set forth in SEWRPC Community Assistance Report No. 86, op. cit., and 1987 conditions for Milwaukee County are set forth in SEWRPC Community Assistance Report No. 163, op cit..

Source: J.A. Chapman, T.B. Edil, D.M. Mickelson, and SEWRPC.

The particular method of analysis for calculating safety factors used in this study, the Modified Bishop Method, is applicable to circular-shaped failure surfaces. For each potential failure surface, the resisting forces, such as soil cohesion and friction, and the driving forces, such as the soil mass along the potential failure surface, were determined and a corresponding safety factor calculated. The program generates and evaluates several potential failure surfaces in order to identify the most critical, and the most likely, failure surface.

Two separate versions of the STABL program were used in the slope stability analysis for the analyses shoreline.[5] The first version utilized a deterministic approach in which site-specific data collected at the profile sites were used to compute 100 potential failure surfaces at the given location. The 10 potential failure surfaces with the lowest safety factors are identified and plotted. This analysis technique is the same as used in the 1977 and 1989 studies.

For purposes of this study, the ranges of values adopted in the aforementioned previous studies of 1977 and 1989 were used, which indicated the bluff to be unstable, with respect to rotational failures, when the safety factor was less than 1.0; marginally stable, with respect to rotational failures, when the safety factor was between 1.0 through 1.1; and, stable, with respect to rotational failures, when the safety factor was greater than 1.1. However, safety factors of between 1.1 and 1.19 were also considered marginally stable with respect to rotational failures, if the 1995 field observations indicated that bluff failure was occurring. In such situations, the bluff was considered to be stable with respect to rotational failures when the safety factor was greater than 1.2.[6]

[5]*P.J. Bosscher, T.B. Edil, and D. M. Mickelson, "Evaluation of Risks of Slope Instability along a Coastal Reach,"* Proceedings of the Vth International Symposium on Landslides, *1988, Lausanne, Switzerland, 1988. See also Chapter IV: J.A. Chapman, T.B. Edil, and D.M. Mickelson,* Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline, *University of Wisconsin-Madison, December 1996.*

[6]*J.A. Chapman, Tuncer B. Edil, and D.M. Mickelson,* Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline, *University of Wisconsin-Madison, December 1996.*

The second version utilized a probabilistic approach which allowed the input data to vary randomly within specified dispersions.[7] The probabilistic analysis was used in selected locations only to provide a general assessment of the stability of the bluff slopes within an entire bluff erosion zone, where the bluff characteristics vary, rather than only at the specific profile sites. Using this technique, several stability analyses were made by varying bluff conditions with a reasonable range for a given reach.

As with the deterministic analysis, 100 potential failure surfaces were examined for a given set of conditions with the failure surfaces with the lowest 10 safety factors then identified. However, under the probabilistic analysis method, 25 different sets of conditions were analyzed using a range of input parameters, such as soil strength values, rather than a single deterministic set of values. Each condition was used to generate 100 potential failure surfaces and safety factors, with the lowest 10 safety factors for each condition forming a set of 250 safety factors to be considered. The evaluation considers the range of the values and the proportion of the safety factors within this set which falls into the ranges previously noted to be associated with the three conditions of unstable, marginally stable, and stable slopes.

In addition, the probabilistic analyses also considered the range and distribution of the values within a set of 25 safety factors, based upon the lowest safety factor in each of the 25 conditions analyzed. The probabilistic analysis was used to improve the evaluation of those profile sites where some of the bluff characteristics were not well defined and where the results of the deterministic analyses were unclear, that is, the resulting safety factor was near 1.0. Further, the probabilistic analysis quantified the risk of slope failure where some of the analysis factors could not be accurately determined by measurement. This analysis technique is the same as used in the 1989 study.

In terms of the probabilistic bluff stability analysis, for purposes of this study, the ranges of values adopted in the aforementioned previous study of 1989 were used, with the bluff indicated to be unstable when more than 75 percent of the set of most critical conditions determined in each of the 25 analyses considered were less than 1.0, and more than 50 percent of the 250 conditions analyzed were less than 1.0; marginally stable when

[7]*The term "dispersion" refers to the variability of data from a mean value.*

between 25 and 75 percent of the set of most critical conditions determined in each of the 25 analyses considered was less than 1.0, and between 10 and 50 percent of the 250 conditions analyzed was less than 1.0; and stable when less than 25 percent of the set of most critical conditions determined in each of the 25 analyses considered was less than 1.0, and less than 10 percent of the 250 conditions analyzed was less than 1.0.

Shoreline Recession Rates

The rate of shoreline recession may be estimated by measuring the change in location of a bluff edge, or the landward edge of the beach where no bluff is present, over a specified time period. Shoreline recession distances were measured using Regional Planning Commission ratioed and rectified, one inch equals 400 feet scale aerial photographs taken in 1963, 1970, 1975, and 1995, with measurements being made for the periods of 1963, 1970, and 1975 through 1995. All measurements on the aerial photographs were made parallel to the east-west U.S. Public Land Survey section lines. The measurements were then corrected for variations in the angle of the shoreline in order to represent recession perpendicular to the shoreline. Shoreline recession was measured at intervals of about 0.25 mile along the entire study area shoreline. Appendix A presents the measured shoreline recession rates for three periods for each shoreline recession reach.

SHORELINE REACH 1: CITY OF KENOSHA AND VILLAGE OF PLEASANT PRAIRIE, KENOSHA COUNTY

Shoreline Reach 1 is a 4.7-mile-long reach of shoreline extending from the Wisconsin-Illinois state line on the south line of U.S. Public Land Survey Section 32, Township 1 North, Range 23 East, Village of Pleasant Prairie, at about 128th Street extended, north to the southern end of the shore protection revetment at the Kenosha Water Utility sewage treatment plant at about 80th Street just south of the east-west centerline of U.S. Public Land Survey Section 8, Township 1 North, Range 23 East, City of Kenosha, as shown on Map 3. Land uses along this reach were comprised almost entirely of partially developed residential subdivisions with the existing residences mixed intermittently with undeveloped lots. The only significant nonresidential lands in this shoreline reach included approximately 800 feet of shoreline which was part of the Trident Marina development facilities located at the southern limit of the reach, and 0.5 mile of shoreline which was part of a 145-acre open space tract located at the northern end of the reach.

As of 1995, nearly the entire shoreline in Reach 1 was protected by structural shoreline protection measures, consisting of numerous structures of various types protecting either individual properties or short reaches incorporating more than one property. The most common shore protection measures in this reach area were revetments and groins. The 1977 study designated this reach as the most critical reach of the entire Lake Michigan shoreline in Wisconsin in terms of shoreline damage and recession rates.

As shown on Map 3, Reach 1 was further segmented into five analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the five analysis sections in Reach 1.

U.S. Public Land Survey Section 32, Township 1 North, Range 23 East, Village of Pleasant Prairie, Kenosha County

This shoreline analysis section extends from the Wisconsin-Illinois state line at about 128th Street extended in the Trident Marina development north to about 116th Street (Tobin Road) in the Village of Pleasant Prairie, as shown on Map 4. Except for about 800 feet of shoreline in the Trident Marina development at the south end of the section, the entire shoreline area was occupied by residential subdivision lands with a mix of residential land use and undeveloped lots.

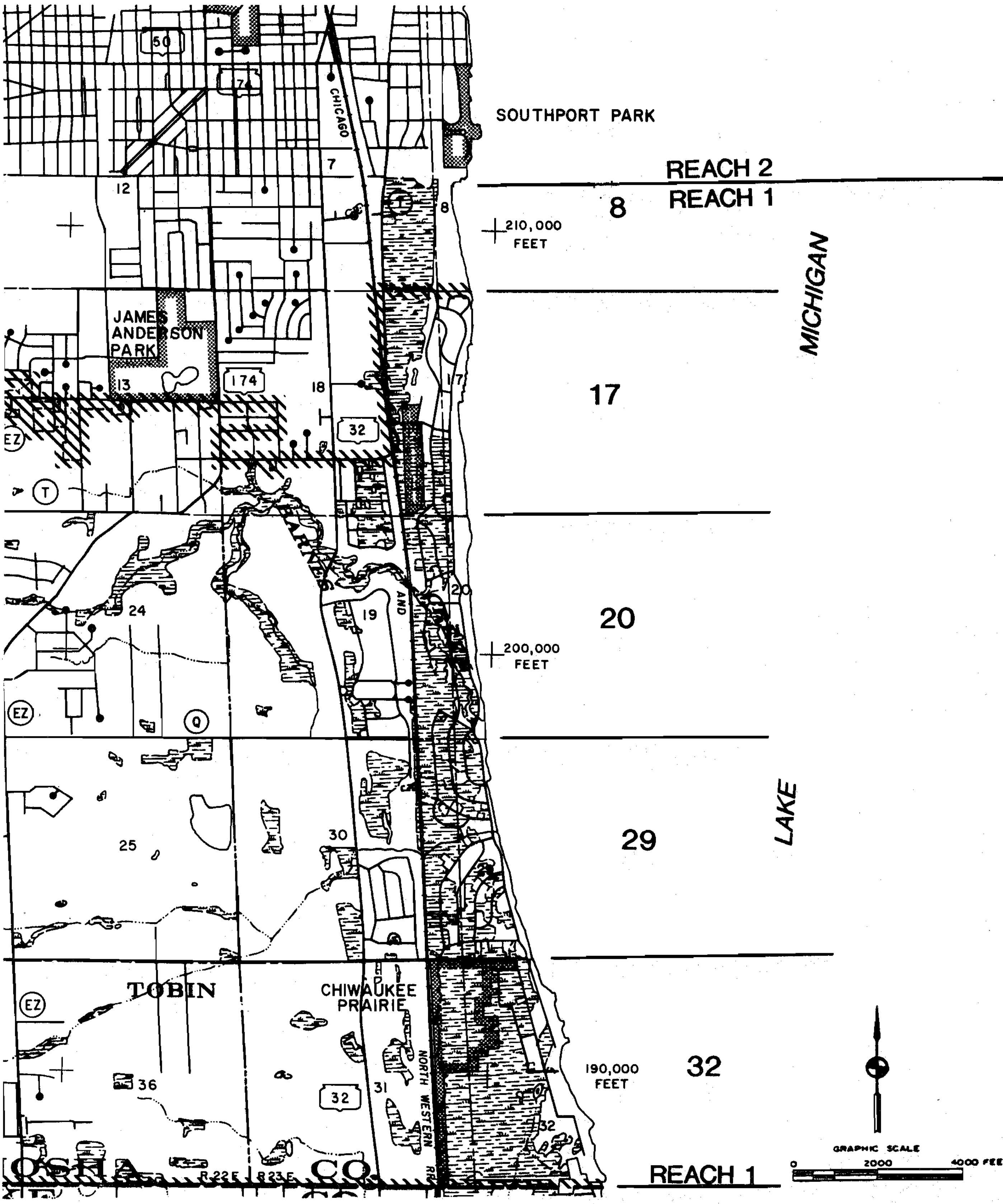
In 1995, the beach width in Section 32 ranged from almost being nonexistent to about 80 feet. Variations in beach width over short distances were common throughout the section, with the changes being controlled largely by shore protection structures. Nearly all of the shoreline in this section was covered by shoreline protection structures of various types protecting individual properties, short reaches incorporating more than one property, or the segment of 1st Avenue which traversed a portion of the section along the lakeshore.

In this section no significant bluff existed, with the rise from lake level to the upland surface being a gentle beach slope with a low sand dune ridge and swale complex. No bluff stability analyses were conducted within Section 32 in this study or in the 1977 study.

In 1995, the beach material in this section was noted to be sand. In the 1977 study, the beach width was reported to be between zero and 100 feet, with the wider

Map 3

BLUFF ANALYSIS SECTIONS WITHIN REACH 1

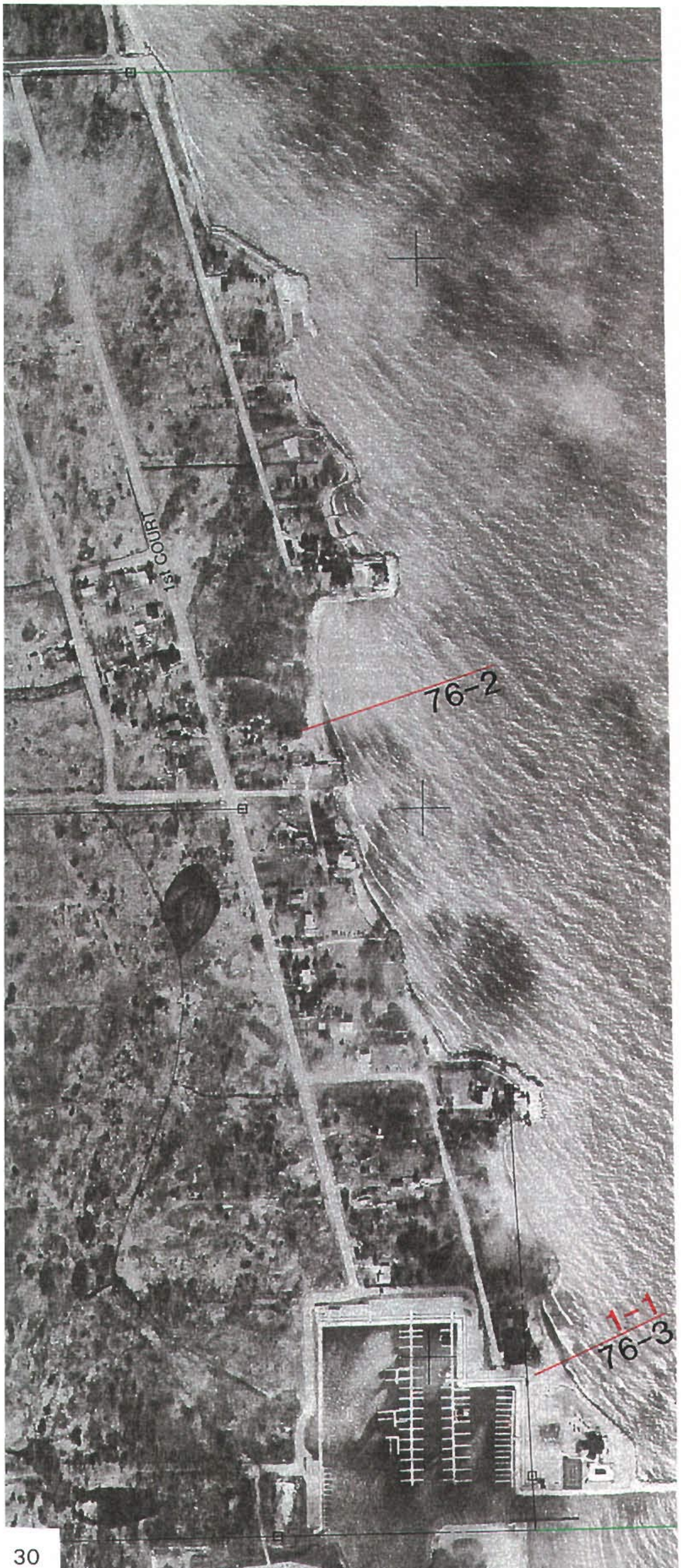


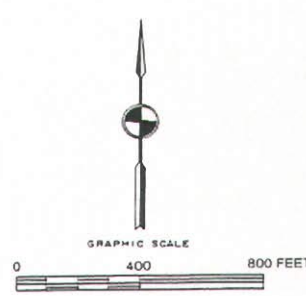
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 4

SHORELINE EROSION REACH 1: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 32, Township 1 North, Range 23 East
Village of Pleasant Prairie, Kenosha County





LEGEND

PROFILE SITE LOCATION

1-1 PROFILE NUMBER: 1995 FIELD INVENTORY

76-3 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

portions of the beach being located in the northern portion of the section, and the beach materials were reported to be sand with small amounts of gravelly material. At Profile No. 1-1, the nearshore material was noted to be sand and a nearshore lakebed depth of five feet was reached at 147 feet offshore in 1995. At the same site, the nearshore materials were noted to be sand and a nearshore depth of five feet was reached at 120 feet offshore in 1976.

Shoreline recession data for Section 32 were estimated at three locations. These data indicated a recession of between 20 and 60 feet, or between 0.6 and 1.9 feet per year, occurred between 1963 and 1995. About 20 feet of that recession, or about one foot per year, appeared to have occurred after 1975. The 1977 study reported recession rates of nine to 12 feet per year for this section. The highest erosion rate estimates in this section were made from near the center of the section south to the Trident Marina development.

U.S. Public Land Survey Section 29, Township 1 North, Range 23 East, Village of Pleasant Prairie, Kenosha County

This shoreline analysis section extends from about 116th Street (Tobin Road) north to about 104th Street extended, in the Village of Pleasant Prairie, as shown on Map 5. The entire shoreline area was occupied by residential subdivision lands with a mix of residential land use and undeveloped lots.

In 1995, the beach width in Section 29 ranged from almost being nonexistent to about 100 feet. Variations in beach width over short distances were common throughout the reach, with the changes being controlled largely by shoreline protection structures with the widest beach areas within reaches where groin systems were in place. Nearly all of the shoreline in this section was covered by shoreline protection structures of various types protecting individual properties, short reaches incorporating more than one property, or the segment of 1st Avenue which traversed a portion of the section along the lakeshore.

In this section no significant bluff existed, with the rise from lake level to the upland surface being a gentle beach slope with a low sand dune ridge and swale complex. No bluff stability analyses were conducted within Section 29 in this study or in the 1977 study.

In the 1977 study, the beach width was reported to be between zero and 100 feet, with the widest portion of the beach being located in the central portion of the section, and the beach materials in the section were reported to be sand with small amounts of gravelly material. At Profile No. 1-2, the nearshore material was noted to be sand and a nearshore lakebed depth of five feet was reached at 236 feet offshore in 1995. At the same site, the nearshore material was also noted to be sand and a nearshore depth of five feet was reached at 70 feet offshore in 1976.

Shoreline recession data for Section 29 were estimated at five locations. These data indicated a recession of between 20 and 160 feet, or between 0.6 and five feet per year, occurred between 1963 and 1995. Nearly all of that recession appeared to have occurred prior to 1975. The 1977 study reported recession rates of seven to 12 feet per year for this section. The highest erosion rate estimates in this section were made in the northern half of the section.

U.S. Public Land Survey Section 20, Township 1 North, Range 23 East, Village of Pleasant Prairie, Kenosha County

This shoreline analysis section extends from about 104th Street extended north to about 93rd Street extended in the Village of Pleasant Prairie, as shown on Map 6. The entire shoreline area was occupied by residential subdivision lands with a mix of residential land use and undeveloped lots.

In 1995, the beach width in Section 20 ranged from almost being nonexistent to about 70 feet. Variations in beach width over short distances were common throughout the reach, with the changes being controlled largely by shoreline protection structures. Nearly all of the shoreline in this section was covered by shoreline protection structures of various types protecting individual properties, short reaches incorporating more than one property, or the segments of 1st Avenue which traversed a portion of the section along the lakeshore.

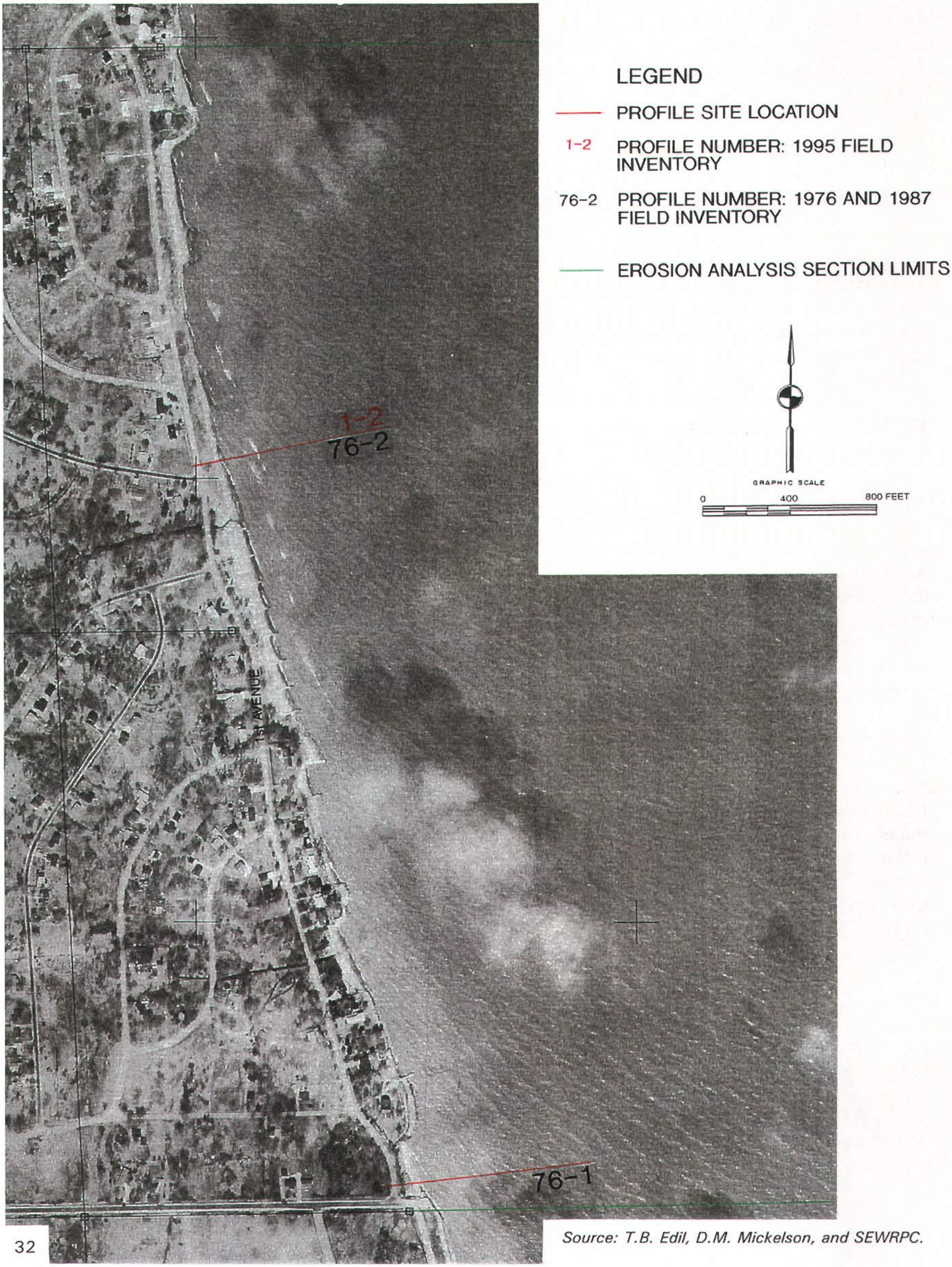
In this section no significant bluff existed, with the rise from lake level to the upland surface being a gentle beach slope with a low sand dune ridge and swale complex. No bluff stability analyses were conducted within Section 20 in this study or in the 1977 study.

In 1995, the beach materials in the section were noted to be medium-to-fine sand with some gravel near the bluff toe. In the 1977 study, the beach width was reported to be between zero and 75 feet, with the widest portion of the beach being located in the north-central portion of the section within a groin system, and beach materials were reported to be sand with small amounts of gravelly

Map 5

SHORELINE EROSION REACH 1: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 29, Township 1 North, Range 23 East
Village of Pleasant Prairie, Kenosha County

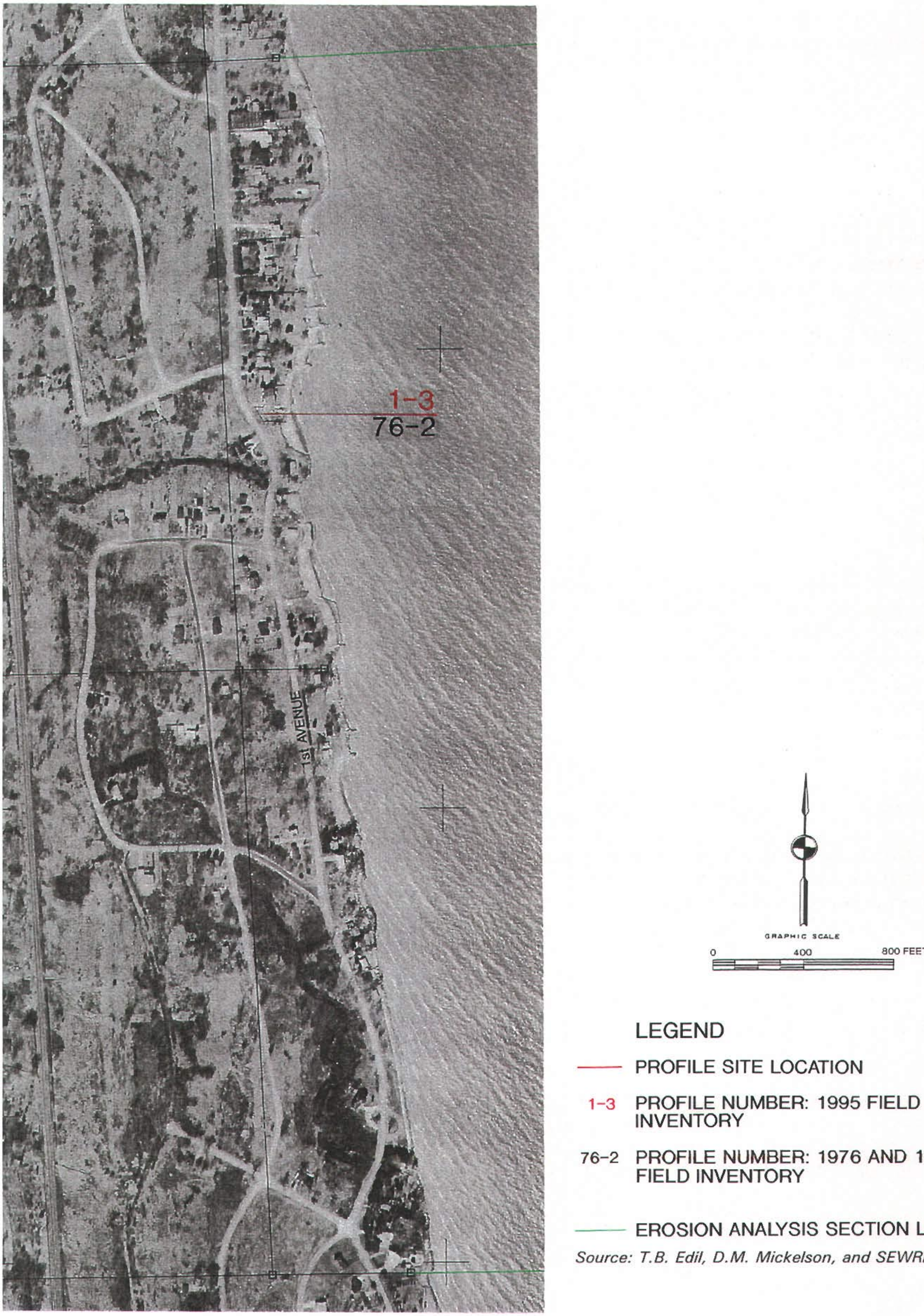


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 6

SHORELINE EROSION REACH 1: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 20, Township 1 North, Range 23 East
Village of Pleasant Prairie, Kenosha County



LEGEND

PROFILE SITE LOCATION

1-3 PROFILE NUMBER: 1995 FIELD INVENTORY

76-2 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

material. At Profile No. 1-3, the nearshore material was noted to be sand and a nearshore lakebed depth of five feet was reached at 106 feet offshore in 1995. At the same site, the nearshore materials were noted to be cobbles and a nearshore depth of five feet was reached at 200 feet offshore in 1976.

Shoreline recession data for Section 20 were estimated at five locations. These data indicated a recession of between 40 and 130 feet, or between 1.2 and 4.1 feet per year, occurred between 1963 and 1995. About 10 feet of that recession, or about 0.5 foot per year, appeared to have occurred after 1975. The 1977 study reported recession rates of three to seven feet per year for this section. The highest erosion rate estimates in this section were made near the northern end of this section.

U.S. Public Land Survey Section 17, Township 1 North, Range 23 East, Village of Pleasant Prairie, Kenosha County

This shoreline analysis section extends from about 93rd Street extended north to about 85th Street in the Village of Pleasant Prairie, as shown on Map 7. The entire shoreline area was occupied by residential subdivision lands with a mix of residential land use and undeveloped lots.

In 1995, the beach width in Section 17 ranged from almost being nonexistent to about 150 feet. Variations in beach width over short distances were common throughout the reach, with the changes being controlled largely by shoreline protection structures. Nearly all of the shoreline in this section was covered by shoreline protection structures of various types protecting individual properties or reached incorporating multiple properties. A groin and beach system extended across about 0.75 mile, or about 75 percent of the shoreline in the section.

In this section, no significant bluff existed in the southern half of the section, with the rise from lake level to the upland surface being a gentle beach slope and a sand dune ridge and swale complex. In the northern half of the section, a bluff with a height of 10 to 20 feet was present. The 1977 report indicated the bluff to be composed of dune sand with organic layers. No bluff stability analyses were conducted within Section 17 in this study or the 1977 study.

In 1995, the beach materials in the section were noted to be sand with a gravel bluff toe. In the 1977 study, the beach width was reported to be between zero and 50 feet, with the widest portions of the beach being contained within groin systems, and the beach materials were reported to be sand with small amounts of gravelly material. At Profile No. 1-4, the nearshore materials were noted to be sand and a nearshore lakebed depth of five feet was reached at 70 feet offshore in 1995. At this same site, the nearshore materials were noted to be sand and gravel and a nearshore depth of five feet was reached at 65 feet offshore in 1976.

Shoreline recession data for Section 17 were estimated at five locations. These data indicated a recession of between 40 and 130 feet, or between 1.2 and 4.1 feet per year, occurred between 1963 and 1995. About 10 to 30 feet of that recession, or about 0.5 to 1.5 feet per year, appeared to have occurred after 1975 in the southern half of the section, while in the northern half, all of the recession appeared to have occurred before 1975. The 1977 study reported recession rates of two to nine feet per year for this section. The highest erosion rate estimates in this section, were made in the southern portion and at the very northern end.

Southern One-Half of U.S. Public Land Survey Section 8, Township 1 North, Range 23 East, City of Kenosha, Kenosha County

This shoreline analysis section extends from about 85th Street extended, north about 0.5 mile to the southern end of the revetment at the Kenosha Water Utility sewage treatment plant at about 80th Street in the City of Kenosha, as shown on Map 8. The entire shoreline area was in open space use.

In 1995, the shoreline in this portion of Section 8 was protected by a uniform riprap revetment with no significant beach. A low bluff with a height of up to about 20 feet did exist at the north and south ends of the reach and was located 100 to 200 feet landward of the revetment. No bluff stability analyses were conducted within this portion of Section 8 in this study or in the 1977 study.

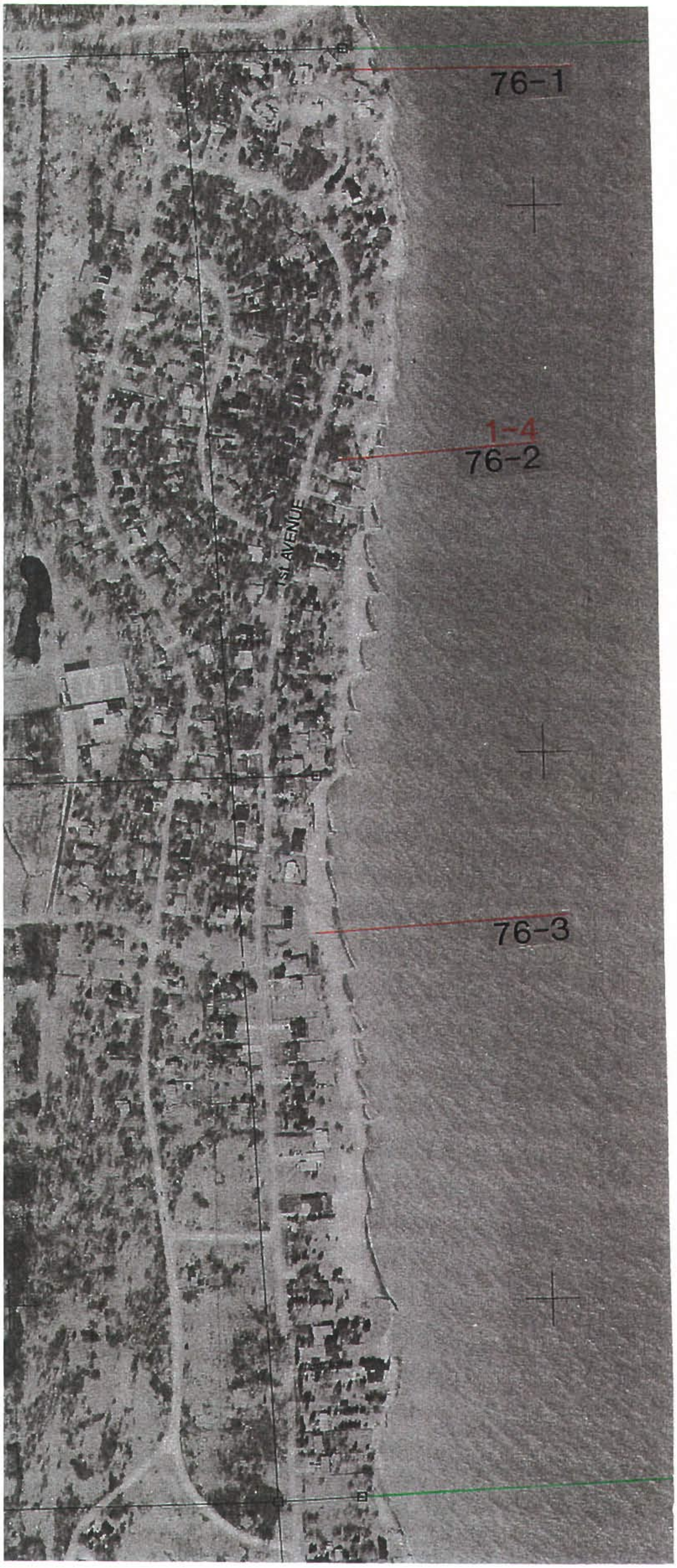
In the 1977 study, the beach width was reported to be narrow to nonexistent, and the beach materials in the southern half of this section were reported to be newly accreting sand and gravel within a groin system.

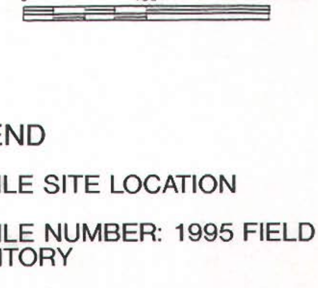
Shoreline recession data for this portion of Section 8 were estimated at two locations. These data indicated a recession of between 110 and 190 feet, or between 3.4 and 5.9 feet per year, occurred between 1963 and 1995. All of that recession appeared to have occurred before 1975, indicating that the revetment constructed between

Map 7

SHORELINE EROSION REACH 1: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 17, Township 1 North, Range 23 East
Village of Pleasant Prairie, Kenosha County





LEGEND

PROFILE SITE LOCATION

1-4 PROFILE NUMBER: 1995 FIELD INVENTORY

76-2 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

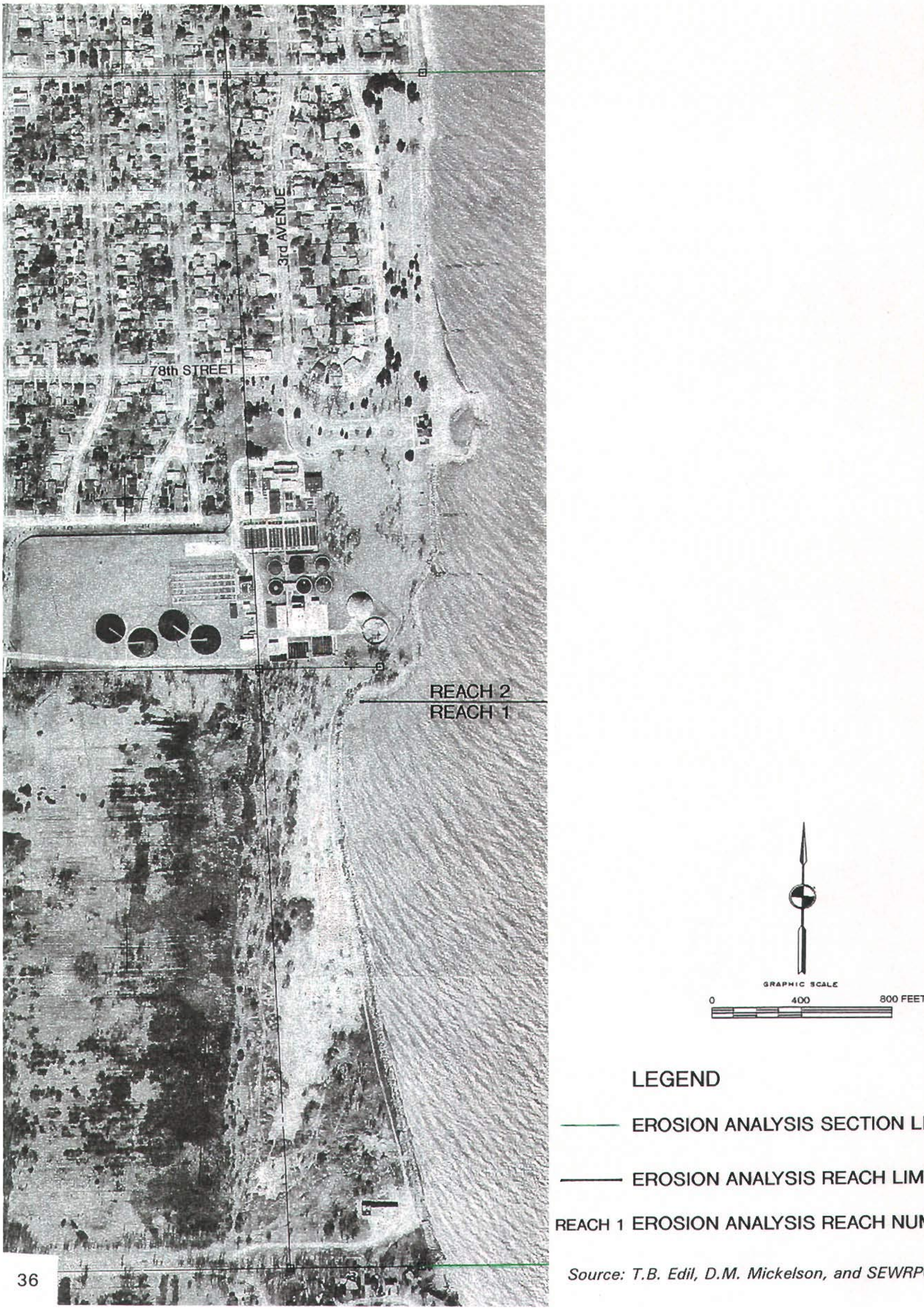
EROSION ANALYSIS SECTION LIMITS

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 8

SHORELINE EROSION REACHES 1 AND 2: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 8, Township 1 North, Range 23 East
City of Kenosha, Kenosha County



LEGEND

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS REACH LIMITS

REACH 1 EROSION ANALYSIS REACH NUMBER

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

1970 and 1975 has stabilized the shoreline in this section. The 1977 study reported a recession rate of two feet per year for this section.

SHORELINE REACH 2: CITY OF KENOSHA, KENOSHA COUNTY

Shoreline Reach 2 is a 2.4-mile-long reach of shoreline extending from the southern end of the shore protection revetment at the Kenosha Water Utility sewage treatment plant at about 80th Street just south of the east-west center line of U.S. Public Land Survey Section 8, Township 1 North, Range 23 East, City of Kenosha, north to the south line of U.S. Public Land Survey Sections 29 and 30, Township 2 North, Range 23 East, City of Kenosha at about 45th Street extended just south of the southern boundary of J.F. Kennedy Park, as shown on Map 9. Land uses along this reach comprised open space and recreational uses in Southport Park, the Kemper Center, Eichelman Park, Wofenbuttal Park, Lakefront Stadium Park, and Simmons Island Park; residential lands between the parklands south of the Kenosha Harbor; the Kenosha Water Utility sewage treatment plant; and the Kenosha Harbor facilities, including the Southport Marina, the dredged material confined disposal facility, and the Kenosha water treatment plant.

As of 1995, the entire shoreline in Reach 2, except for the bathing beach at Simmons Island Park, was protected by structural shoreline protection measures of various types, including riprap revetments, groin-beach systems, bulkheads, and breakwater systems. In addition, a narrow beach has formed along the groin system in Southport Park. The reach had no significant bluff, except in Simmons Island Park where the bluff height reached about 20 feet.

As shown on Map 9, Reach 2 was further segmented into three shoreline analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three shoreline analysis sections in Reach 2.

Northern One-Half of U.S. Public Land Survey Section 8, Township 1 North, Range 23 East, City of Kenosha, Kenosha County

This shoreline analysis section extends from about the southern end of the revetment protecting the Kenosha Water Utility sewage treatment plant at about 80th Street north to the north end of Southport Park at 75th Street in the City of Kenosha, as shown on Map 8. The entire shoreline area was occupied by the Kenosha Water Utility sewage treatment plant and open space in Southport Park.

In 1995, within this portion of Section 8, there was a narrow beach along the groin system within Southport Park with a width which varied from almost nothing to about 80 feet at the southern end, and an armored pocket swimming beach which had a width of about 70 feet. The entire shoreline of the section was covered by shoreline protection structures, including a riprap revetment and a groin-beach system. Data on beach and nearshore conditions were not collected in either study for this section.

In this section, no significant bluff existed. No bluff stability analyses were conducted within this portion of Section 8 in this study or in the 1977 study.

In the 1977 study, the beach width was reported to be zero to 100 feet, with the widest portion of the beach located in the central portion of the section, and the beach material in the northern half of this section was reported to be sand.

Shoreline recession data for this portion of Section 8 were estimated at two locations. These data indicated a recession of between 40 and 50 feet, or between 1.2 and 1.5 feet per year, occurred between 1963 and 1995. All of that recession appeared to have occurred prior to 1975, or was caused by the regrading of the shoreline associated with construction of the shore protection structures. The 1977 study reported a recession rate of four feet per year for this section.

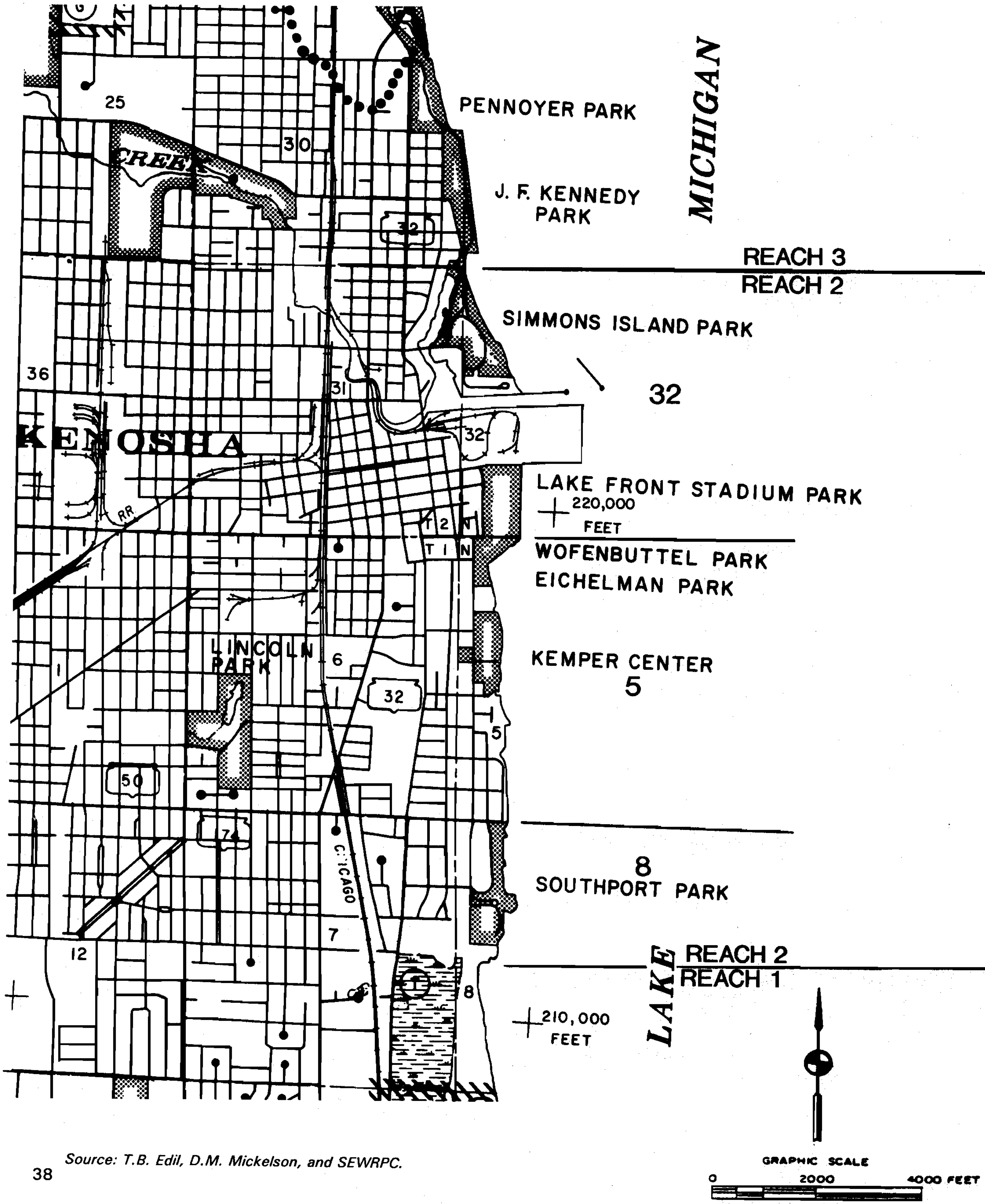
U.S. Public Land Survey Section 5, Township 1 North, Range 23 East, City of Kenosha, Kenosha County

This shoreline analysis section extends from the north end of Southport Park at 75th Street north to the north end of Eichelman Park at 60th Street in the City of Kenosha, as shown on Map 10. The shoreline area was occupied by residential lands, except for Eichelman Park, the Kemper Center grounds, and a 0.2-mile reach where 1st Avenue traversed a portion of the section along the lakeshore.

The only significant beach in Section 5 was the sand beach at Eichelman Park which was oriented in a northeast-southwest direction and was up to 200 feet wide in the northeast in 1995. That beach was protected by a north-south breakwater. The remainder of the

Map 9

BLUFF ANALYSIS SECTIONS WITHIN REACH 2

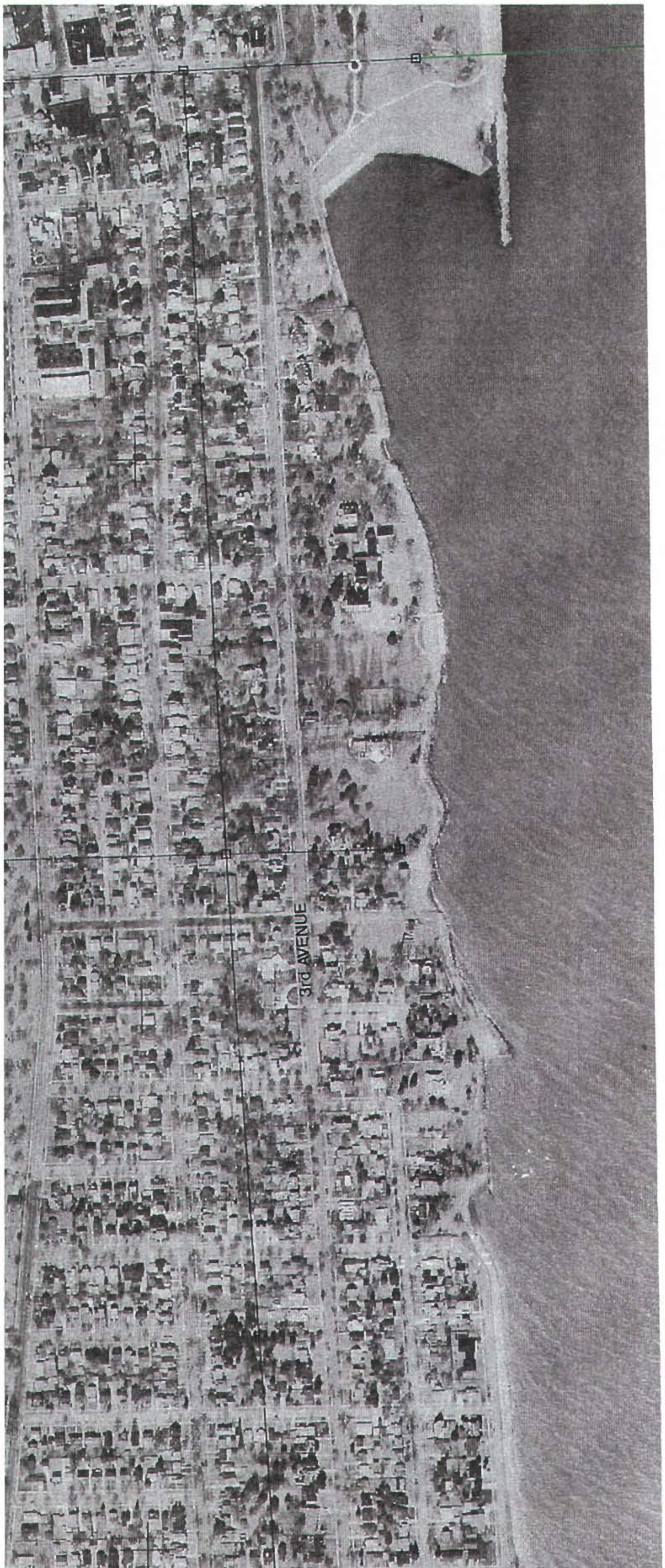


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 10

SHORELINE EROSION REACH 2: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 5, Township 1 North, Range 23 East
City of Kenosha, Kenosha County



GRAPHIC SCALE
0 400 800 FEET

LEGEND

EROSION ANALYSIS SECTION LIMITS

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

shoreline was oriented north-south and was covered by shoreline protection structures, including revetments, bulkheads, and the breakwater at the north end. Data on nearshore conditions were not collected in either study for this section.

In this section no significant bluff existed. No bluff stability analyses were conducted within Section 5 in this study or in the 1977 study.

In the 1977 study, the beach width was reported to be between 60 and 85 feet in the northernmost portion of the section, and the beach material in this section was reported to be sand.

Shoreline recession data for Section 5 were estimated at four locations. These data indicated a recession of between 10 and 50 feet, or between 0.3 and 1.5 feet per year, occurred between 1963 and 1995. All of that recession appeared to have occurred prior to 1975, or was caused by the regrading of the shoreline associated with the construction of the shore protection structures. The 1977 study reported a recession rate of six feet per year for this section.

U.S. Public Land Survey Section 32, Township 2 North, Range 23 East, City of Kenosha, Kenosha County

This shoreline analysis section extends from the north end of Eichelman Park at 60th Street north to about 45th Street extended just south of the southern boundary of J.F. Kennedy Park, in the City of Kenosha, as shown on Map 11. The shoreline area was occupied by recreational lands in Wofenbuttal Park, Lakefront Stadium Park, and Simmons Island Park; the Kenosha Water Utility water treatment plant; and the Kenosha Harbor facilities, including the Southport Marina and the harbor dredged material confined disposal facility.

The only significant beach in Section 32 was the sand beach at Simmons Island Park. That beach had a width of up to 200 feet on the south end in 1995. The shoreline south of Simmons Island Park was protected by the harbor entrance and protection structures comprising bulkheads, revetments, and a breakwater. Data on nearshore conditions were not collected in either study for this section.

In this section, no significant bluff existed, except at Simmons Island Park. No bluff stability analyses were conducted within Section 32 in this study or in the 1977 study.

The shoreline in Section 32 was stabilized by the extensive structural protection measures and no shoreline recession data were estimated in either this study or the 1977 study.

SHORELINE REACH 3: CITY OF KENOSHA AND TOWN OF SOMERS, KENOSHA COUNTY; TOWN OF MT. PLEASANT, RACINE COUNTY

Shoreline Reach 3 is a 7.3-mile-long reach of shoreline extending from the south line of U.S. Public Land Survey Sections 29 and 30, Township 2 North, Range 23 East, City of Kenosha, at about 45th Street extended just south of the southern boundary of J.F. Kennedy Park, north to Durand Avenue extended on the north line of U.S. Public Land Survey Section 28, Township 3 North, Range 23 East, Town of Mt. Pleasant, as shown on Map 12. Land uses along this reach include open spaces in J.F. Kennedy, Pennoyer, and Alford Parks; and the Carthage College campus, with the remaining shore lands primarily in residential use, except for short sections of open land in Kenosha County and industrial lands at the very north end of the reach in Racine County. As of 1995, about 2.4 linear miles, or about 80 percent, of the shoreline in Reach 3 were protected by structural shoreline protection measures, consisting of revetments and groins.

As shown on Map 12, Reach 3 was further segmented into seven shoreline analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the seven shoreline analysis sections in Reach 3.

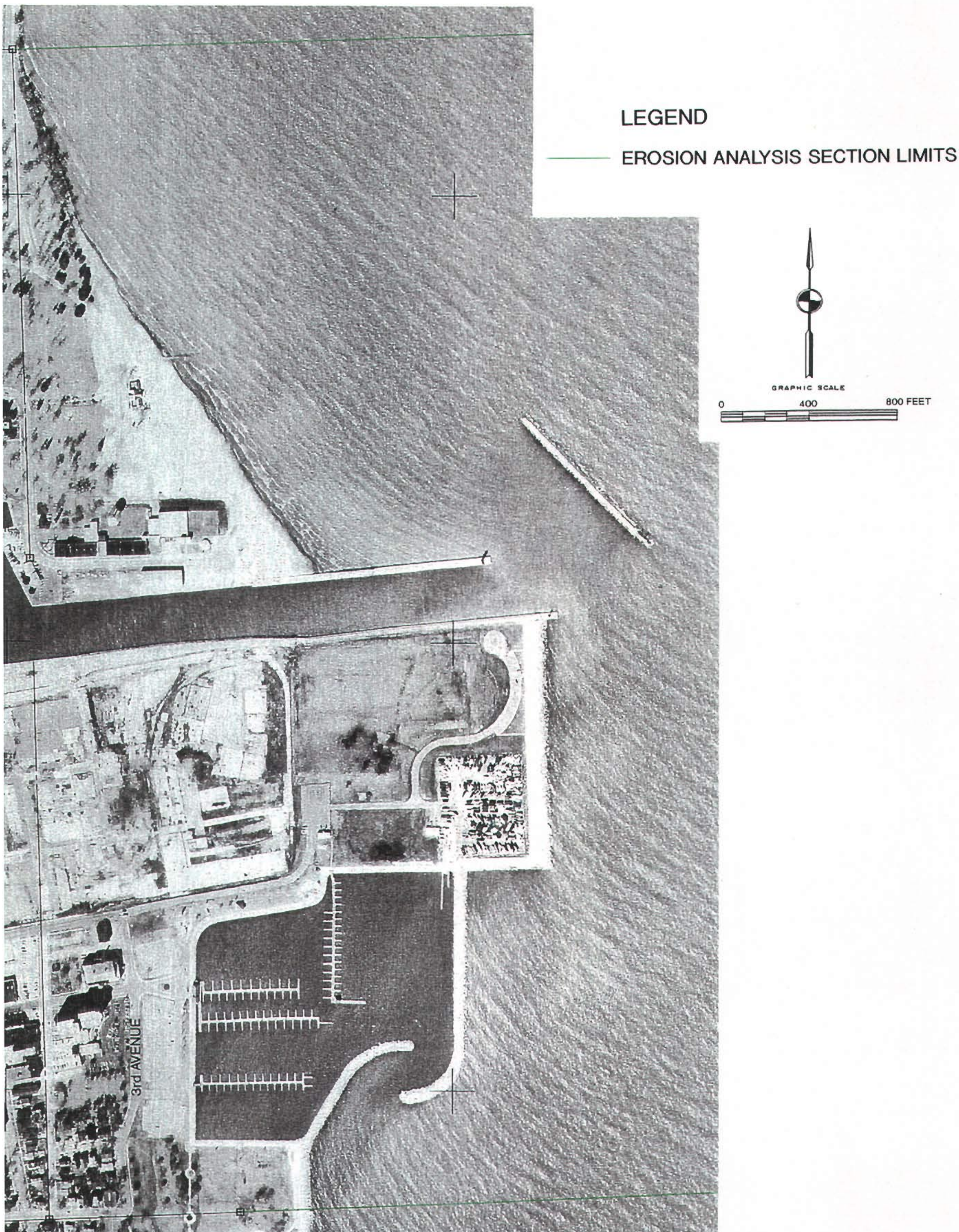
U.S. Public Land Survey Section 30, Township 2 North, Range 23 East, City of Kenosha, Kenosha County

This shoreline analysis section extends from about 45th Street extended just south of the southern boundary of J.F. Kennedy Park north through J.F. Kennedy Park and Pennoyer Park and into Alford Park at 31st Street extended, in the City of Kenosha, as shown on Map 13. In 1995, the entire lakeshore area was occupied by parkland which was largely in open space use. J.F. Kennedy Memorial Drive traversed the section and in the southern half of the section was located immediately adjacent to a revetment constructed along the lakeshore. The outlet of the Pike River and its estuary was located

Map 11

SHORELINE EROSION REACH 2: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

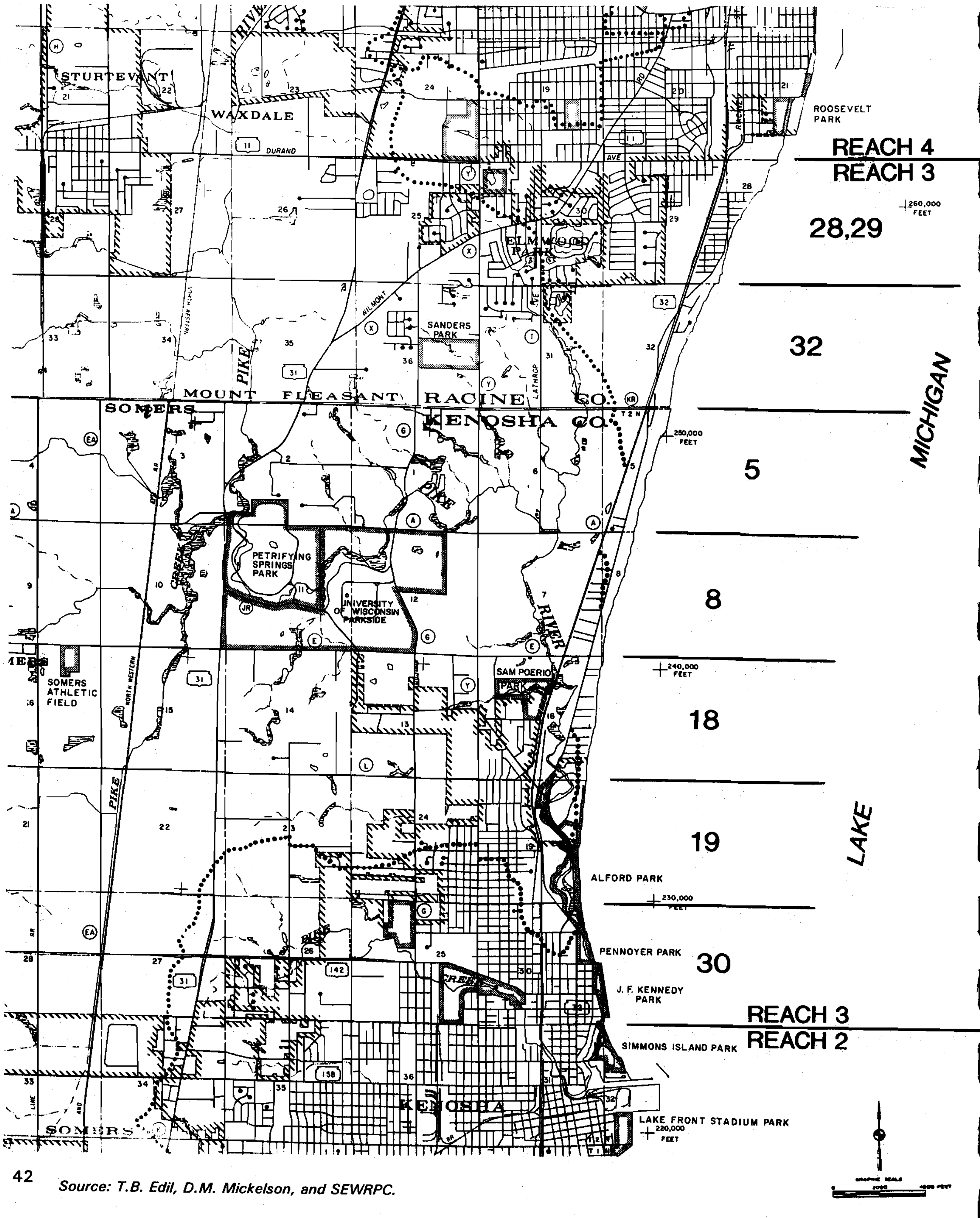
U.S. Public Land Survey Section 32, Township 2 North, Range 23 East
City of Kenosha, Kenosha County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 12

BLUFF ANALYSIS SECTIONS WITHIN REACH 3

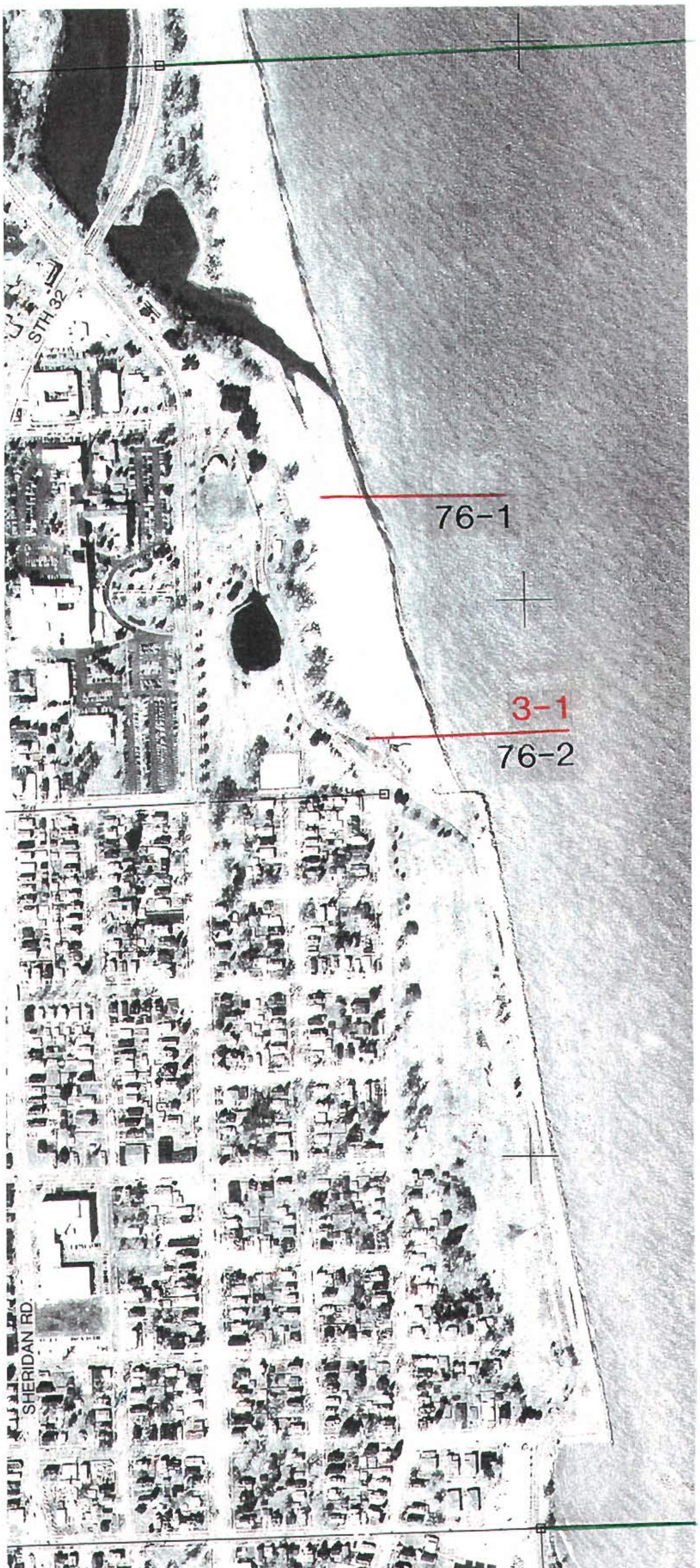


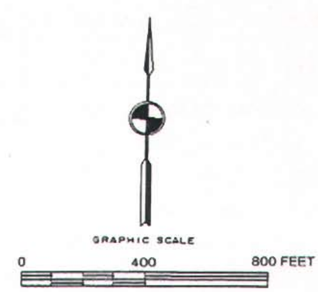
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 13

SHORELINE EROSION REACH 3: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 30, Township 2 North, Range 23 East
City of Kenosha, Kenosha County





LEGEND

PROFILE SITE LOCATION

3-1 PROFILE NUMBER: 1995 FIELD INVENTORY

76-2 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

about 1,000 feet south of the northern limits of the section.

In 1995, the southern half of the section was protected by a revetment and a wide beach extended from the north end of that revetment through the northern end of the section. A low bluff with a height of up to 15 feet existed at the southern end of the section and in part of the northern half of this section. The bluff was located from 200 to 300 feet west of the lakeshore in most locations, but extended to within 10 feet of the shore in the center of the section. In 1995, the bluff appeared stable and fully vegetated.

In 1995, two bluff profile field surveys were made within Section 30, both by reoccupying sites of field surveys conducted in 1976. Both sites had similar geometry in 1995 to that documented in 1976. However, bare sand appeared to have migrated landward at the top of the beach. The stability of the bluff in Section 30 of Reach 3 was characterized by Profile No. 3-1. No erosion of the bluff was observed at this site during the 1995 survey and the bluff appeared to be stable. The bluff material at the profile site was estimated to be predominantly medium-fine sand. Results of the slope stability analysis, shown in Figure 8, indicated the bluff was stable, with a safety factor of greater than 5.0. One further site occupied during the 1977 study was not reoccupied during the current study since there were no signs of failure, and since the profile was similar to Profile No. 3-1. The 1977 study reported the bluff had a safety factor of greater than 1.25 at both of these profile sites.

In 1995, the beach in the northern portion of the section was noted to be sandy, with gravel at the water line, and was up to 250 feet wide in the northern half of the section, except immediately north of the revetment, where it tapered to less than 10 feet. Offshore bathymetry appeared to be gently sloping north of the revetment. The beach had buried groins below the sand that stabilized the beach. In the 1977 study, the beach width was reported to be zero and 275 feet, with the widest portion of the beach located in the northern portion of the section, and the beach materials were reported to be sand and gravel. At Profile No. 3-1, the near offshore surface materials consisted primarily of gravel. The nearshore lakebed depth of five feet was reached at only about 22 feet offshore. However, this profile section was located at a point just down drift of the Pike River mouth and was not considered typical of the analysis section which has a more gentle offshore slope. The primary nearshore material was gravel. No information was reported on offshore depth in the 1977 study for comparison purposes.

Shoreline recession data for Section 30 were estimated at two locations, with both estimates indicating that no significant recession had occurred between 1963 and 1995. The 1977 study reported a recession rate of two to three feet per year for the northern half of this section. These data indicated that the currently existing shore protection revetment on the south and the presence of the sand beach and buried groin system on the north were effective in mitigating shoreline recession. As long as the revetment in the southern half of the section is maintained, it appears that the shoreline will remain stable, except, perhaps, under extreme high water levels.

Another phenomenon associated with Lake Michigan which impacted the shoreline in analysis Section 30 in the vicinity of the Pike River estuary was the damming of the mouth of the Pike River by littoral drift in Lake Michigan. During storms on Lake Michigan, when onshore winds prevail, littoral drift rates increase landward of the surf zone and the mouth of the River can be dammed by the formation of a foreshore berm. Berms as high as six feet above the normal water level of the Pike River have been observed following severe northeasterly storms on the Lake. Subsequent to berm formation, the water level in the Pike River estuary begins to rise and continues to do so until the berm is breached. The River starts to flow over the crest of the berm, at which time rapid scouring of the sand and gravel deposits occurs with attendant rapid declines in water levels in the estuary. Photographs of such a breached berm about six feet tall are presented in Figure 9.

Sudden breaching of the berm by the River had, on several occasions, caused deaths by drowning of people who were swept into Lake Michigan from the beach at the mouth of the Pike River. Recommendations set forth in the Pike River watershed plan[8] provide for the construction of a jetty system with periodic dredging to mitigate the identified problems caused by the sand bar formation across the mouth of the Pike River.

U.S. Public Land Survey Section 19, Township 2 North, Range 23 East, City of Kenosha, Kenosha County

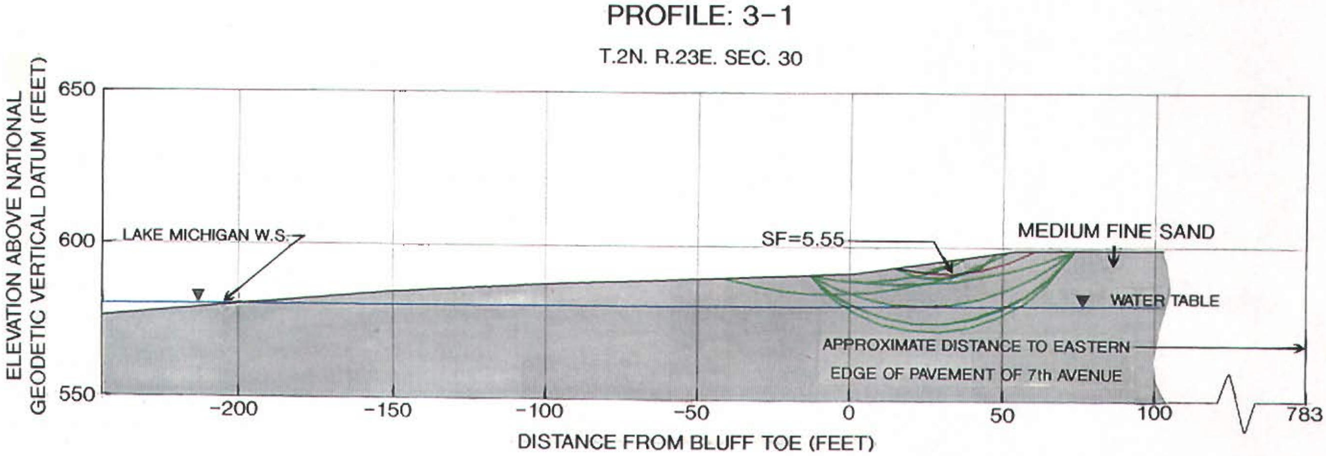
This shoreline analysis section extends from 31st Street extended at Alford Park at to the north line of Section 19 on the Carthage College campus in the City of Kenosha, as shown on Map 14. The entire lakeshore area in the southern half of the section was occupied by

[8]*SEWRPC Planning Report No. 35,* A Comprehensive Plan for the Pike River Watershed, *June 1983.*

Figure 8

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSIS

U.S. Public Land Survey Section 30, Township 2 North, Range 23 East
City of Kenosha, Kenosha County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 9

PHOTOGRAPHS OF A BREACHED BERM AT THE MOUTH OF THE PIKE RIVER IN JANUARY 1982

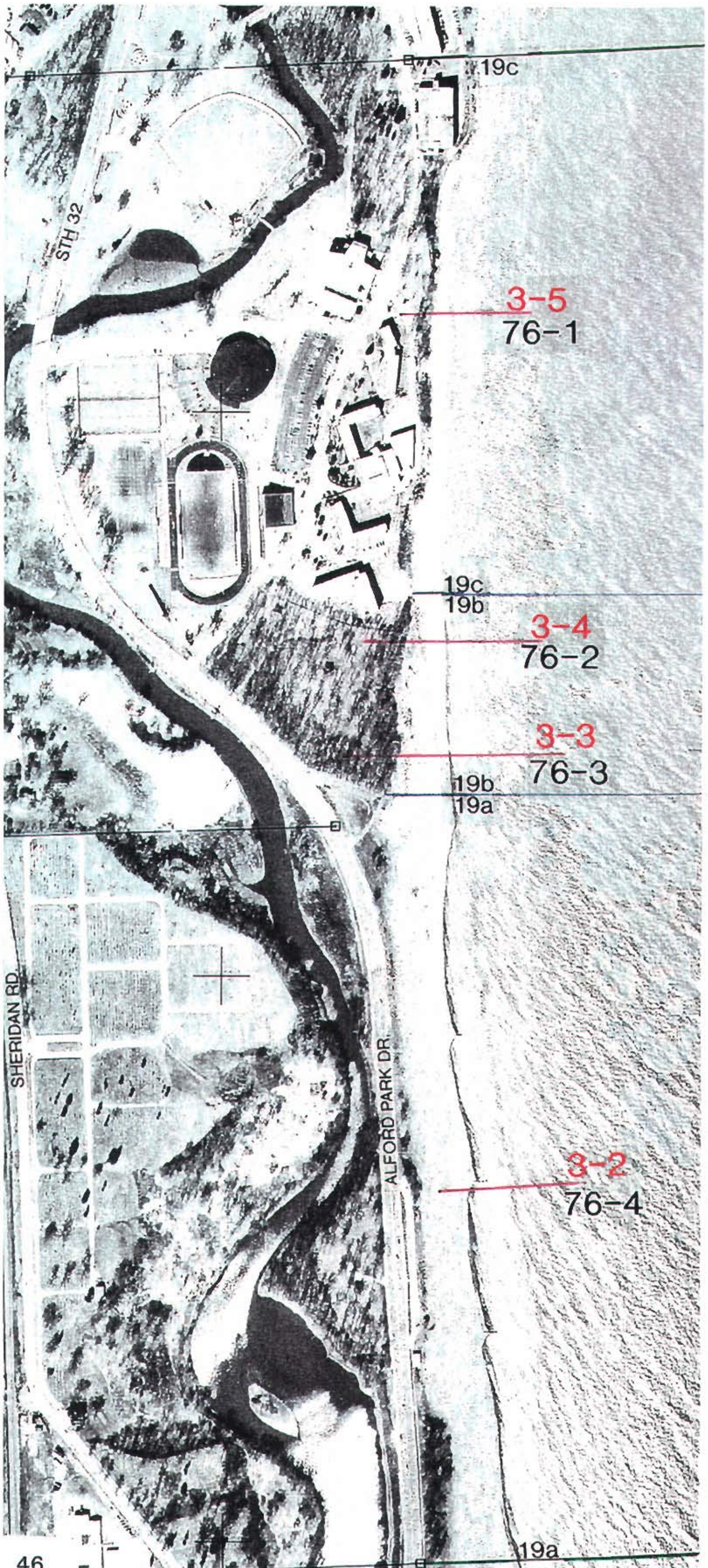
Source: SEWRPC.

parkland, while the northern half of the section was occupied by the Carthage College campus. Overall, the shoreline of this section was relatively stable with a wide beach or protected low bluff throughout. Areas where shoreline problems were identified in the 1977 study have been modified with shore protection structures. The

Map 14

SHORELINE EROSION REACH 3: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 19, Township 2 North, Range 23 East
City of Kenosha, Kenosha County



GRAPHIC SCALE
0 400 800 FEET

LEGEND

PROFILE SITE LOCATION

3-3 PROFILE NUMBER: 1995 FIELD INVENTORY

76-3 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

19a EROSION ANALYSIS ZONE NUMBER

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

bluff materials in this section were estimated to be primarily sand and silts with some intermixed clays. For analysis purposes, Section 19 was further subdivided into three erosion zones, as shown on Map 14. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are described below for each of the three erosion zones in Section 19.

Erosion Zone 19a

Erosion Zone 19a extends from 31st Street extended in Alford Park north about 0.5 mile to the point where Alford Park Drive curves westerly away from the Lake, as shown on Map 14. This zone had a 200- to 300-foot-wide beach with a narrow strip of vegetation separating Alford Park Drive from the lakeshore. A low bluff with a height of about 10 feet existed at the southern end of the zone. In 1995, the bluff appeared stable and was vegetated.

In 1995, one bluff profile field survey was made within Zone 19a by occupying a site in the general vicinity of a site for which a field survey was conducted in 1976, as shown on Map 14. The precise location of the 1976 site could not be ascertained. The site had similar geometry in 1995 to that documented in 1976. No erosion of the bluff was observed during the 1995 survey and the bluff appeared to be stable. The stability of the bluff in Zone 19a of Reach 3 was characterized by Profile No. 3-2. The bluff material at the profile site was estimated to be predominantly silt and clay. Results of the slope stability analysis, shown in Figure 10, indicated the bluff was stable, with a safety factor of greater than 3.0. The 1977 study reported that the bluff had a safety factor of 0.21 at this profile site.

In 1995, the beach materials within Zone 19a were noted to be sand and gravel, and the beach was from 200 to 300 feet wide. The beach had buried groins below the sand that stabilized the beach. In the 1977 study, the beach width was reported to be between 180 and 275 feet, and the beach materials were reported to be sand and gravel. At Profile No. 3-2, the nearshore surface materials consisted primarily of cobbles, and a nearshore lakebed depth of five feet was reached at 136 feet offshore in 1995. No specific information was reported on offshore depth in the 1977 study for comparison purposes.

Shoreline recession rates for Erosion Zone 19a were estimated at three locations. These data indicated a recession of between 10 and 20 feet, or between 0.3 and 0.6 foot per year, occurred between 1963 and 1995. All of that recession appeared to have occurred prior to 1975, with no further recession of shoreline occurring between 1975 and 1995. Thus, it appeared that the existing groin system and the presence of the sand beach have effectively stabilized the shoreline in this reach, with the groin system along the beach apparently effectively holding sand in position. The 1977 study reported recession rates of four feet per year for this erosion zone.

Erosion Zone 19b

Erosion Zone 19b extends from the northerly limit of Erosion Zone 19a north about 0.1 mile to the point immediately east of the Carthage College most southerly building, as shown on Map 14. This zone had a wide beach fronting a low bluff. The bluff had a height of about 18 to 25 feet and was heavily vegetating. In 1995, the bluff appeared stable.

In 1995, two bluff profile field surveys were made within Zone 19b by occupying two sites for which field surveys were conducted in 1976, as shown on Map 14. Both sites had similar geometry in 1995 to that documented in 1976. No erosion of the bluff was observed during the 1995 survey at either profile site and the bluff appeared to be stable. The stability of the bluff in Erosion Zone 19b of Reach 3 was characterized by Profile Nos. 3-3 and 3-4. The bluff material at the profile sites was noted at small exposures to be medium and fine sand with interbedded silt. Results of the slope stability analysis, shown in Figure 10, indicated the bluff was stable, with safety factors of more than 3.0 at Profile No. 3-3 and 1.84 at Profile No. 3-4.

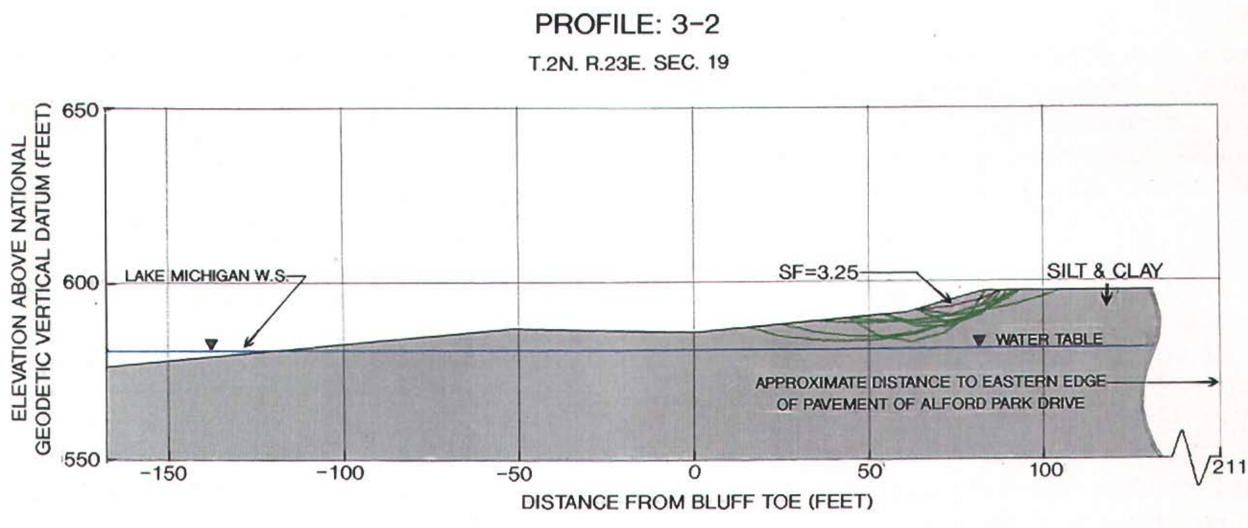
In 1995, the beach within Zone 19b was from 100 to 220 feet wide. In the 1977 study, the beach width was reported to be between 140 and 200 feet, and the beach materials were reported to be sand and gravel. At Profile No. 3-3 the nearshore lakebed depth of five feet was reached at 155 feet offshore, and the primary offshore materials were cobbles and sand in 1995. No specific information was reported on offshore depth in the 1977 study.

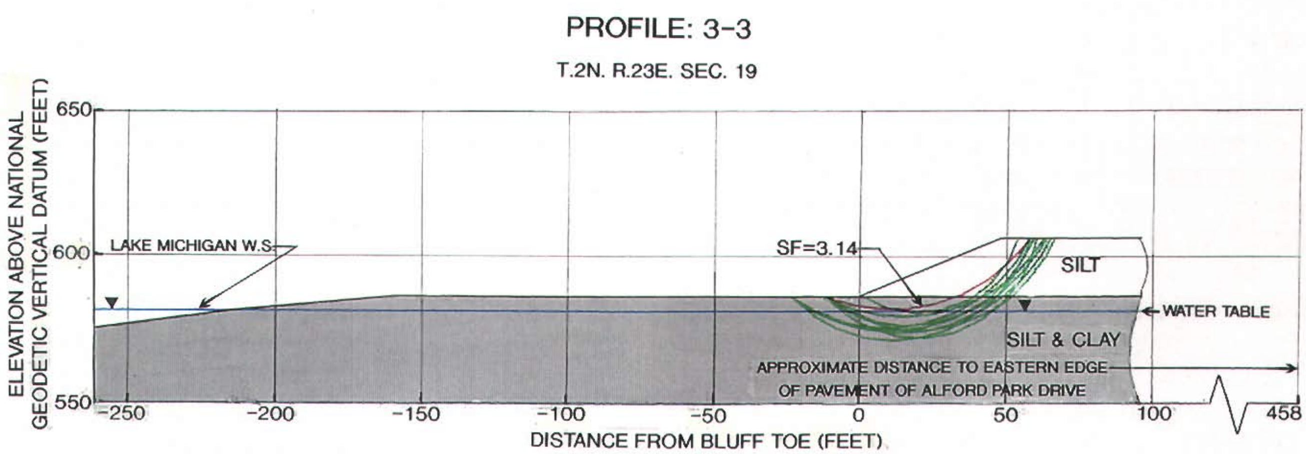
Shoreline recession data for Erosion Zone 19b were estimated at one location. The data indicated that no significant recession had occurred between 1963 and 1995. Thus, it appeared that the relatively wide beach and the bluff were stable in this zone. The 1977 study reported a recession rate of two feet per year for this zone.

Figure 10

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 19, Township 2 North, Range 23 East
City of Kenosha, Kenosha County



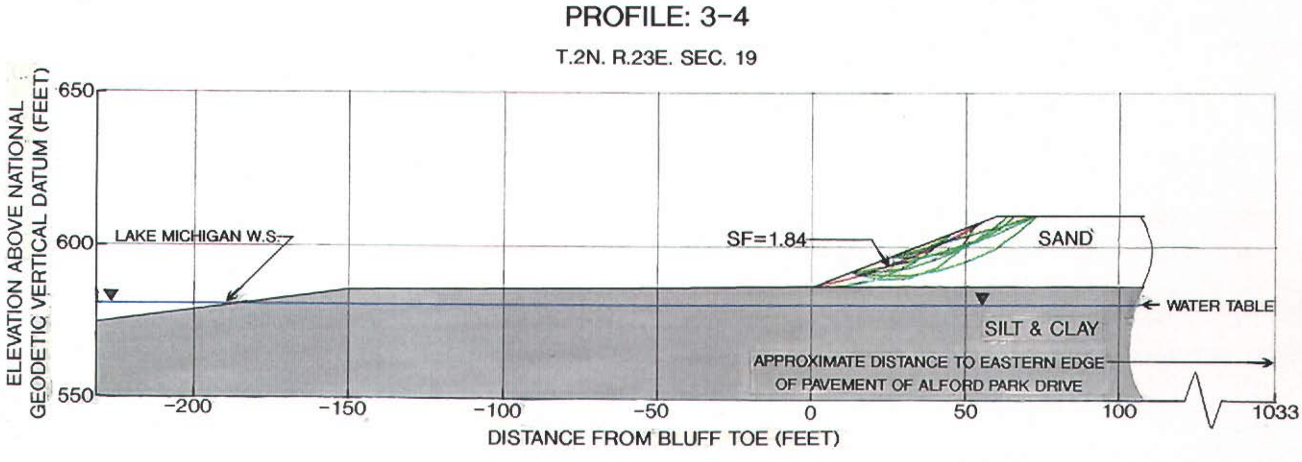


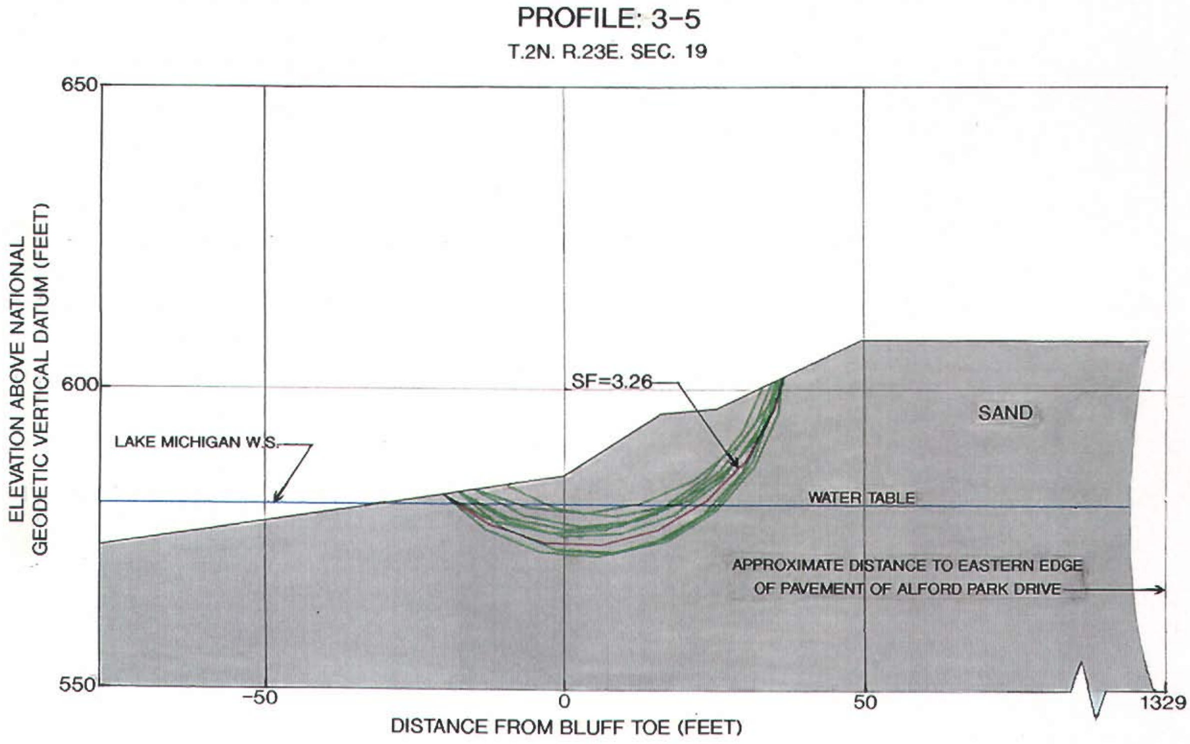
Erosion Zone 19c

Erosion Zone 19c extends from a point east of the southernmost Carthage College facilities building north about 0.4 mile along the Carthage College facilities to the north line of Section 19, as shown on Map 14. This zone had a narrower beach than the zone immediately to the south, ranging from 25 to 50 feet wide. The bluff in this zone had a height of from 15 to 25 feet. Most of the bluff was protected by a revetment. In 1995, the bluff appeared well-vegetated.

In 1995, one bluff profile field survey was made within Zone 19c by occupying a site for which a field survey was conducted in 1976. The site had different geometry than was documented in 1976, as a result of some regrading and the revetment construction. The stability

Figure 10 (continued)





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

of the bluff in Zone 19c of Reach 3 was characterized by Profile No. 3-5. No erosion of the bluff was observed during the 1995 survey and the bluff appeared to be stable by rotational failures, but translational failures are possible. Few exposures were present to determine the bluff stratigraphy at the profile site. However, the bluff material at the profile site was assumed to be primarily fine sand and silt. Results of the slope stability analysis, shown in Figure 10, indicated that the bluff was stable with respect to rotational failures, with a safety factor of greater than 3.0. The 1977 study reported that the bluff was unstable, having a safety factor of 0.46. However, since that time the site has been regraded and a revetment was constructed.

In 1995, the beach within Zone 19c was about 25 to 50 feet wide, and, in most locations, fronted a revetment and the bluff. In the 1977 study, the beach width was reported to be between zero and 110 feet, with the widest portion of the beach located in the southern portion of the zone, and the beach materials were reported to be sand and some gravel in the southern portion of the zone. No beach materials were reported in the 1977 study for the northern portion of the zone due to the construction of a new revetment. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 19c were estimated at two locations, indicating a recession of between 40 and 70 feet, or between 1.2 and 2.2 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of between 10 and 20 feet, or between 0.5 and one foot per year, occurring between 1975 and 1995. It appeared that the revetment which was installed after 1975 had largely stabilized the shoreline. The 1977 study reported a recession rate of three feet per year for this zone.

As long as the revetment in the zone is maintained, it appears that the shoreline will remain stable at moderate water levels.

U.S. Public Land Survey Section 18, Township 2 North, Range 23 East, Town of Somers, Kenosha County

This shoreline analysis section extends from the south line of Section 18 on the Carthage College campus in the City of Kenosha north to 12th Street (CTH E) extended in the Town of Somers, as shown on Map 15. The southern 0.15 mile of Section 18 was occupied by the Carthage College campus. The remaining shoreline was occupied entirely by residential land, including limited areas with multi-family residential uses. Much of the shoreline was protected by a variety of different types of shore protection structures. The bluff materials in this section were estimated to be between 10 and 20 feet of predominantly silt and clay overlain by about 10 feet of clay, which was overlain with silty-clay and some sand and gravel. The 1977 study reported significant erosion problems in this section. For analysis purposes, Section 18 was further subdivided into six erosion zones, as shown on Map 15. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the six erosion zones in Section 18.

Erosion Zone 18a

Erosion Zone 18a extends from the south line of Section 18 north about 0.25 mile to 16th Place, as shown on Map 15. This zone had a 50-foot-wide beach fronting a low bluff with a height of about 25 feet. Some of the dwellings in the residential areas north of the Carthage College campus were situated within 20 feet of the bluff edge. In 1995, the bluff was approximately 80 percent vegetated with the cover consisting of locust, grasses, and shrubs. The 1995 field observations indicated about five feet of retreat in the bluff top since 1975. However, the bluff was more vegetated in 1995 than in 1976, which suggested that most of the bluff in this zone had been stabilized.

No bluff stability analyses were conducted within Erosion Zone 18a during this study or the 1977 study.

The beach within Zone 18a was about 50 feet wide. In the 1977 study, the beach width was reported to be less than five feet, and the beach material was reported to be cobbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 18a were estimated at one location. These data indicated a recession of about 40 feet, or about 1.2 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. The vegetation which increased in coverage after 1975 indicated a largely stabilized bluff. The 1977 study reported a recession rate of three feet per year for this erosion zone.

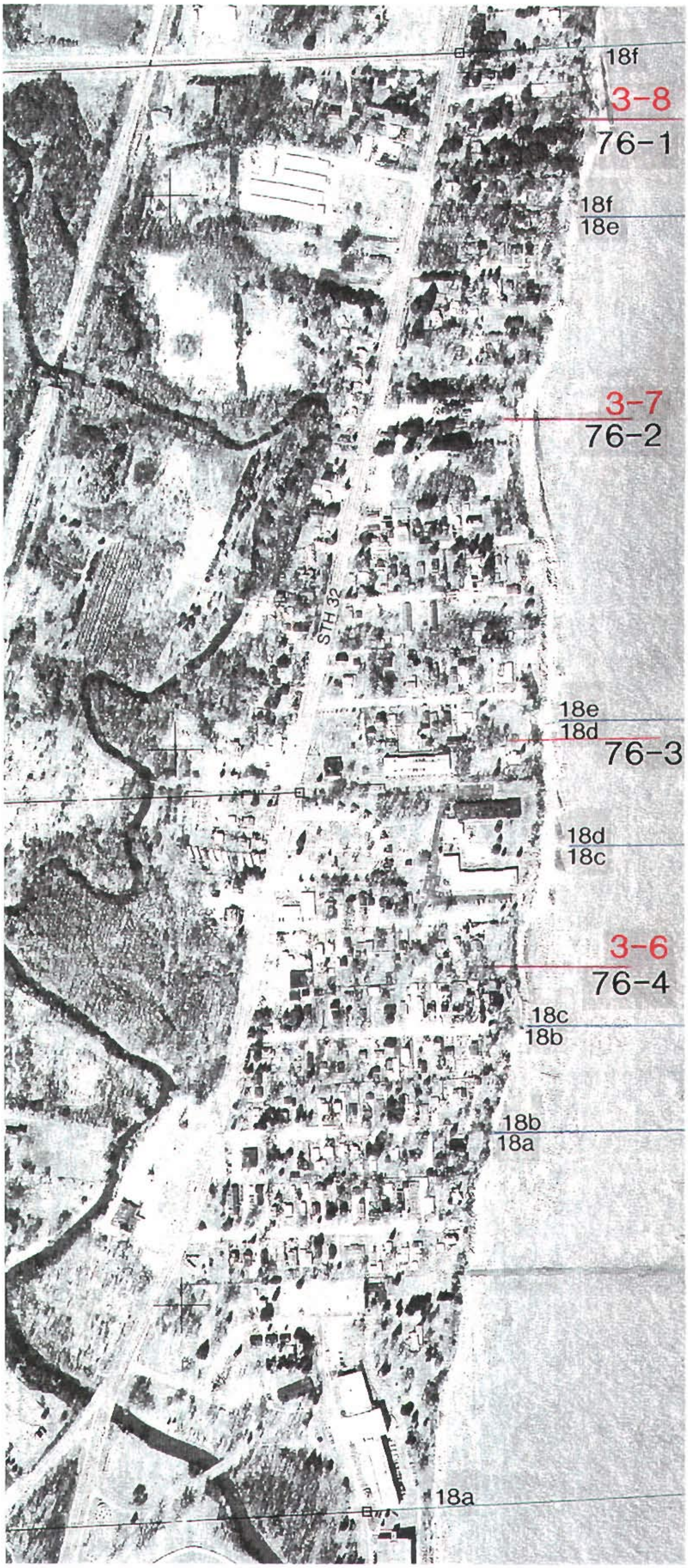
Erosion Zone 18b

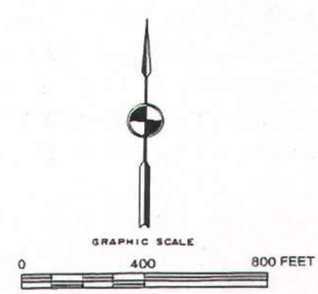
Erosion Zone 18b extends from the northerly limit of Erosion Zone 18a at 16th Place north about 0.1 mile to 16th Street, as shown on Map 15. This zone had a 50-foot-wide beach fronting a low bluff which was protected by a large fill put in place just prior to 1975. The bluff had a height of about 25 feet. In 1995, the bluff material within this zone remained concealed by fill

Map 15

SHORELINE EROSION REACH 3: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 18, Township 2 North, Range 23 East
Town of Somers, Kenosha County





LEGEND

PROFILE SITE LOCATION

3-6 PROFILE NUMBER: 1995 FIELD INVENTORY

76-4 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

18c EROSION ANALYSIS ZONE NUMBER

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

material deposited at the site. The 1995 field observations identified minor recent slope movement on the bluff.

No bluff stability analyses were conducted within Erosion Zone 18b during this study or the 1977 study.

The beach within Zone 18b was about 50 feet wide, and, in most locations, fronted by fill. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 18b were not estimated.

Erosion Zone 18c

Erosion Zone 18c extends from the northerly limit of Erosion Zone 18b at 16th Street north about 0.12 mile to 15th Street, as shown on Map 15. The southern portion of this zone had a similar beach to Erosion Zone 18b immediately to the south, ranging from 25 to 50 feet wide. In 1995, the beach in the northern portion of this zone broadened to between 50 and 100 feet in width at places due to the presence of a series of groins east of the multi-family residential area located between 14th Place and 15th Place. Small fills and placement of riprap to protect the base of the bluff were observed. The bluff in this zone had a height of from 25 to 30 feet. In 1995, the bluff was about 80 percent vegetated with the cover consisting of locust and shrubs. The vegetation suggested that most of the bluff in this zone had been stabilized. The 1995 field observations indicated about five feet of retreat in the bluff top since 1975.

In 1995, one bluff profile field survey was made within Zone 18c by occupying a site for which a field survey was conducted in 1976. The shape of the bluff at this site had changed slightly, remaining concave in shape, but with less accumulated material at the foot of the bluff. The stability of the bluff in Zone 18c of Reach 3 was characterized by Profile No. 3-6. The bluff material at the profile site was estimated to be primarily lacustrine silt with some clay and fine sand. Results of the slope stability analysis, shown in Figure 11, indicated that the bluff was stable, with a safety factor of 1.88. Profile 3-6, however, has some potential to fail by shallow translational sliding. The 1977 study did not report a bluff safety factor at this profile site.

The beach within Zone 18c was 25 to 50 feet wide. In the 1977 study, no significant beach area was reported. At Profile No. 3-6, the primary nearshore surface materials consisted primarily of sand and the nearshore lakebed depth of five feet was reached at 40 feet offshore in 1995. This was similar to the reported offshore depth profile in the 1977, although that study reported the nearshore surface materials as cobbles.

Shoreline recession data for Erosion Zone 18c were estimated at one location. These data indicated a recession of about 130 feet, or about 4.1 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of about 30 feet, or about 1.5 feet per year, occurring between 1975 and 1995. The placement of fill and riprap, and the vegetation which increased in coverage on the bluff slope, after 1975 suggested that the bluff was partially stabilized. The 1977 study reported a recession rate of three feet per year for this erosion zone.

Erosion Zone 18d

Erosion Zone 18d extends from the northerly limit of Erosion Zone 18c at 15th Street north about 0.1 mile to the point about 50 feet south of 14th Place, as shown on Map 15. This zone had a similar beach to the northern portion of Erosion Zone 18c immediately to the south, ranging from 50 to 100 feet in width, fronting a low bluff of 25 to 30 feet in height. The beach was contained within a series of groins, and the bluff was protected by a revetment. In 1995, the bluff was vegetated, with the cover consisting of grasses. The 1995 field observations indicated about 10 feet of retreat in the bluff top since 1975.

In 1995, no bluff stability analyses were conducted within Zone 18d. However, bluff stability analyses were conducted during the 1977 study. At that time, the site was poorly vegetated, with an evident slump scarp. The base of the bluff was protected by groins in the south and by a revetment in the northern portion of the zone. The bluff was more vegetated in 1995 than in 1976, and the vegetation suggested that the bluff had been stabilized. The 1977 study did not report a bluff safety factor at this profile site.

The beach within Zone 18d was about 50 to 100 feet wide and fronted the revetment and the bluff. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 18d were not estimated.

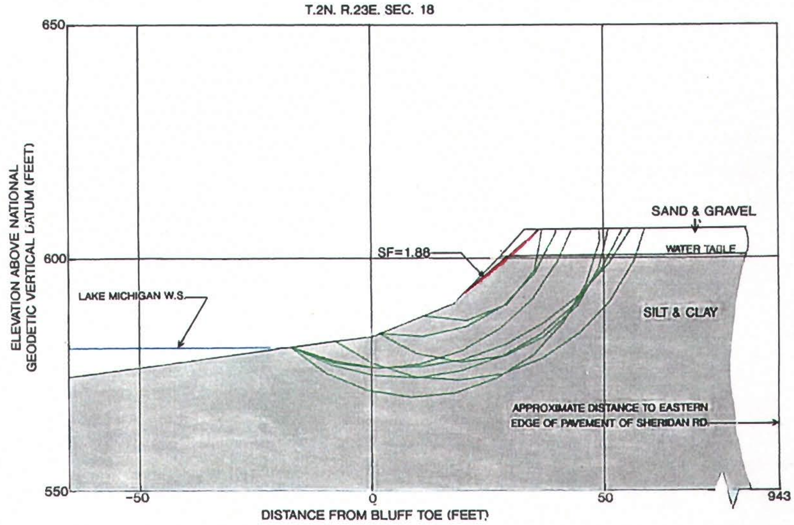
The shoreline revetment in this zone must be maintained to ensure future bluff stability.

Figure 11

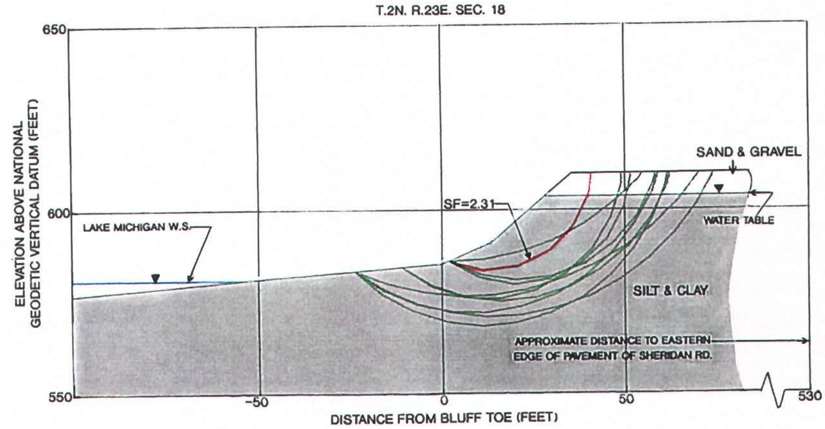
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 18, Township 2 North, Range 23 East
Town of Somers, Kenosha County

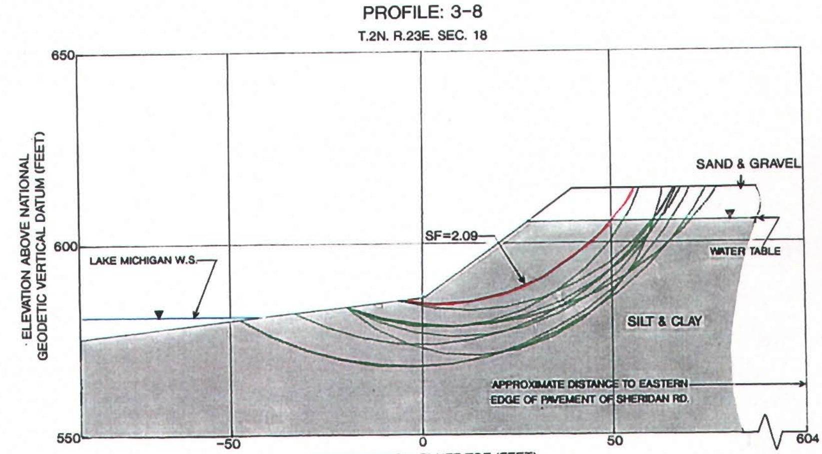
PROFILE: 3-6
T.2N. R.23E. SEC. 18



PROFILE: 3-7
T.2N. R.23E. SEC. 18



PROFILE: 3-8
T.2N. R.23E. SEC. 18



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Erosion Zone 18e
Erosion Zone 18e extends from the northerly limit of Erosion Zone 18d at 14th Place north about 0.3 mile to about 13th Street, as shown on Map 15. This zone had a 50-foot-wide beach fronting a bluff with a height of about 30 feet. This zone appeared to have experienced considerable erosion during the high water periods in the 1970s and 1980s. However, there has been a significant increase in the amount of vegetation between 1976 and 1995. In 1995, the bluff was approximately 90 percent vegetated with the cover consisting of horsetails, grasses, and aspen. The 1995 field observations indicated about 10 feet of retreat in the bluff top since 1975.

In 1995, one bluff profile field survey was made within Zone 18e by occupying a site for which a field survey was conducted in 1976. The site appeared to have experienced considerable erosion since 1976. However, no significant, ongoing erosion of the bluff was observed during the 1995 survey and the bluff appeared to be relatively stable. The stability of the bluff in Zone 18e of Reach 3 was characterized by Profile No. 3-7. The bluff material at the profile site was primarily silt and clay. Results of the slope stability analysis, shown in Figure 11, indicated that the bluff was stable with respect to rotational failures, with a safety factor of 2.31. However, signs of translational failures were noted during the 1995 field survey and shallow failures may occur. The 1977 study did not report a bluff safety factor at this profile site.

The beach within Zone 18e was about 50 feet wide. In the 1977 study, the beach width was reported to be less than 20 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 18e were estimated at one location. These data indicated a recession of about 50 feet, or about 1.6 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. The vegetation which increased in coverage on the bluff slope after 1975 indicated a largely stabilized bluff. The 1977 study did not report a recession rate for this erosion zone.

Erosion Zone 18f
Erosion Zone 18f extends from the northerly limit of Erosion Zone 18e at 13th Street north about 0.1 mile to the north section line of Section 18, near the point where 12th Street (CTH E) extended intersects the lakeshore, as shown on Map 15. This zone had a 50-foot-wide beach, and was littered with riprap, and, at the northern edge, small groins fronted a bluff which had a height of about 30 feet. In 1995, the bluff was about 80 percent vegetated, with the cover consisting of grasses and locust trees. There was a considerable increase in the amount of vegetation between 1976 and 1995. In 1995, the bluff appeared stable. However, the 1995 field observations indicated about 15 feet of retreat in the bluff top since 1975.

In 1995, one bluff profile field survey was made within Zone 18f by occupying a site for which a field survey was conducted in 1976. The site experienced some erosion since 1976, with the bluff slope becoming less steep. The stability of the bluff in Zone 18f of Reach 3 was characterized by Profile No. 3-8. Results of the slope stability analysis, shown in Figure 11, indicated that the bluff was stable, with a safety factor of 2.09 with respect to rotational failures, however, shallow translational failures are possible in this zone. The 1977 study did not report a bluff safety factor at this profile site.

The beach within Zone 18f was about 50 feet wide. In the 1977 study, the beach width was reported to be zero to five feet, and the beach materials were reported to be sand and gravel with some cobbles toward the southern edge of the zone. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 18f were estimated at one location. These data indicated a recession of about 90 feet, or about 2.8 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 50 feet, or 2.5 feet per year, occurred between 1975 and 1995. However, the current bluff profile and beach conditions, and the vegetation which increased in coverage on the bluff slope, after 1975 indicated that the bluff was largely stabilized in 1995. The 1977 study reported a recession rate of three feet per year for this erosion zone.

Although this zone was considered stable in 1995, it could experience marked erosion during future periods of higher lake levels, with the possibility of translational failure.

U.S. Public Land Survey Section 8, Township 2 North, Range 23 East, Town of Somers, Kenosha County
This shoreline analysis section extends from the south line of Section 8 at 12th Street (CTH E) extended in the

Town of Somers north to south line of Section 5 at 7th Street (CTH A) extended, as shown on Map 16. The shoreline was occupied by residential land, including limited areas with multi-family residential uses, with scattered commercial facilities. Much of the shoreline was protected by a variety of different types of shore protection structures. The bluff materials in this section were generally covered, but were estimated to be approximately 20 feet of primarily silt, overlain by clay, overlain by sand. The 1977 study reported the bluff to be unstable in areas where shoreline protection was absent. The 1995 field observations indicated that this situation remained unchanged. For analysis purposes, Section 8 was further subdivided into four erosion zones, as shown on Map 16. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the four erosion zones in Section 8.

Erosion Zone 8a

Erosion Zone 8a extends from the south line of Section 8 north about 0.2 mile to about 11th Street extended, as shown on Map 16. This zone had a beach width ranging from nonexistent to 40 feet with several old groins, many of which have been covered by riprap and rubble, and appeared to be ineffective. The bluff had a height of about 35 feet in this zone. A sea wall protected the toe of the bluff in short sections of this zone, and riprap fill was placed in sections. Vegetation covered approximately 60 percent of the bluff slope. The 1995 field observations indicated zero to 15 feet of retreat in the bluff top since 1975.

In 1995, one bluff profile field survey was made within Zone 8a by occupying a site for which a field survey was conducted in 1976. The site had a significantly different geometry to that documented in 1976. The shape of the bluff had been changed by regrading of slump blocks, and placement of fill and a seawall at the bluff toe. Vegetation covered approximately 40 percent of the upper bluff slope at this site. The underlying geology of the lower bluff was mostly concealed by this material, but was estimated to be silt and clay overlain by silt and sand. The stability of the bluff in Zone 8a of Reach 3 was characterized by Profile No. 3-9. Results of the slope stability analysis, shown in Figure 12, indicated that the bluff was stable with respect to rotational failures, with a safety factor of 2.19. However, signs of transitional failures were noted in the 1995 field survey. The 1977 study reported a bluff safety factor of 0.82.

The beach within Zone 8a was up to 40 feet wide, and, in most locations, formed among old groins. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 8a were estimated at two locations. These data indicated a recession of between 90 and 100 feet, or between about 2.8 and 3.1 feet per year, occurred between 1963 and 1995. The data indicated that a recession of between 40 and 50 feet, or between two and 2.5 feet per year, occurred between 1975 and 1995. Thus, it appeared that the groin system and the riprap and rubble fill was not fully effective in stabilizing the bluff in this zone, the exception being in the vicinity of Profile No. 3-9 where fill and a seawall protected the bluff toe. The 1977 study reported a recession rate of three feet per year for this erosion zone.

Erosion Zone 8b

Erosion Zone 8b extends from the northerly limit of Erosion Zone 8a at 11th Street north about 0.2 mile to the point about 50 feet north of the intersection of STH 32 and 10th Street extended, as shown on Map 16. This zone had a beach width ranging from nonexistent to 50 feet. The bluff had a height of about 35 feet in this zone, and was completely protected by rubble and riprap fill, some of which had been added subsequent to 1976. In 1995, the bluff material in this zone was concealed by fill material deposited at the site. The 1995 field observations indicated that there had been less than five feet of retreat in the bluff top in this zone since 1975.

No bluff stability analyses were conducted within Erosion Zone 18a during this study or the 1977 study. The zone was considered stable as long as the shoreline protection structures are maintained.

The beach within Zone 8b varied from nonexistent to about 50 feet in width. In the 1977 study, the beach width was reported to be zero to 20 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 8b were not estimated.

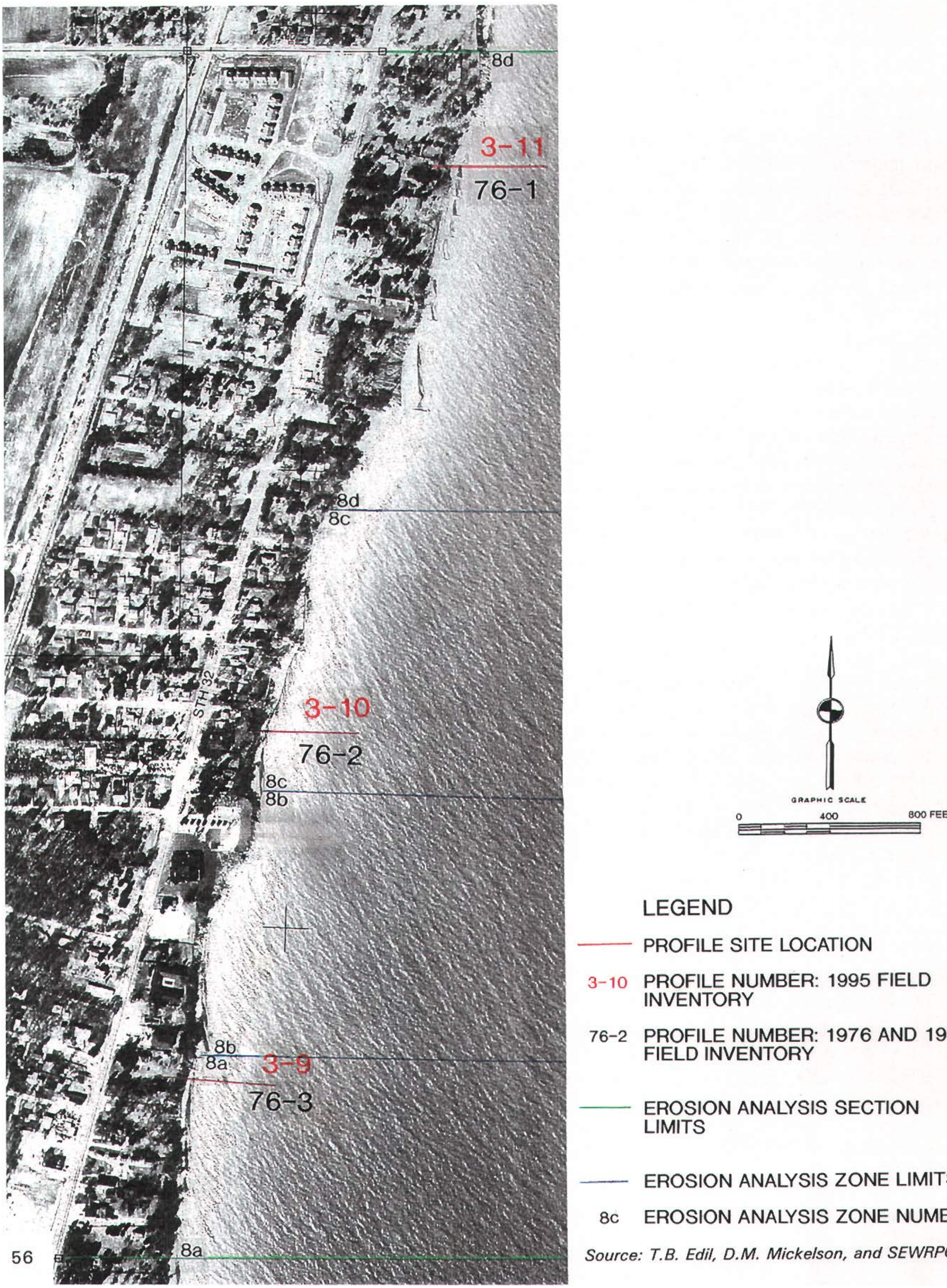
Erosion Zone 8c

Erosion Zone 8c extends from the northerly limit of Erosion Zone 8b at 10th Street extended north about

Map 16

SHORELINE EROSION REACH 3: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 8, Township 2 North, Range 23 East
Town of Somers, Kenosha County



LEGEND

PROFILE SITE LOCATION

3-10 PROFILE NUMBER: 1995 FIELD INVENTORY

76-2 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

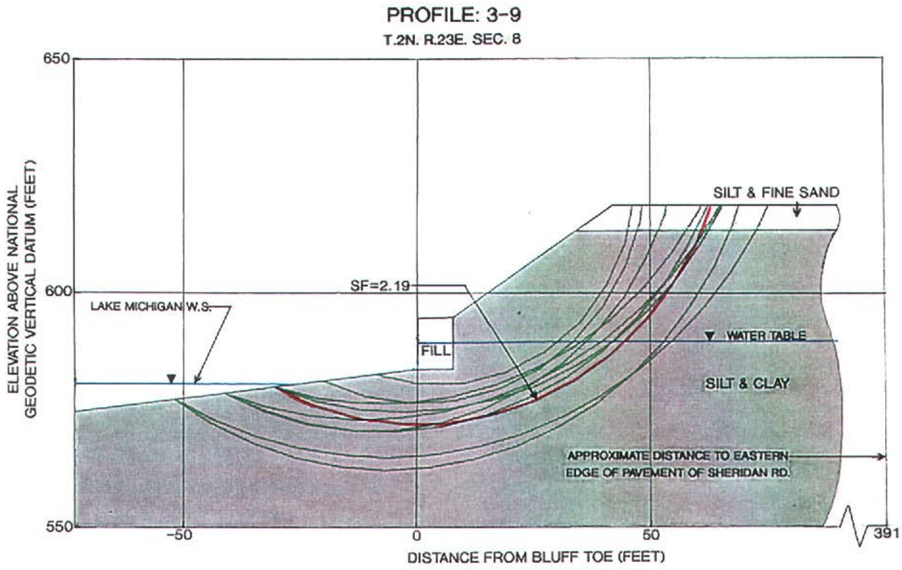
8c EROSION ANALYSIS ZONE NUMBER

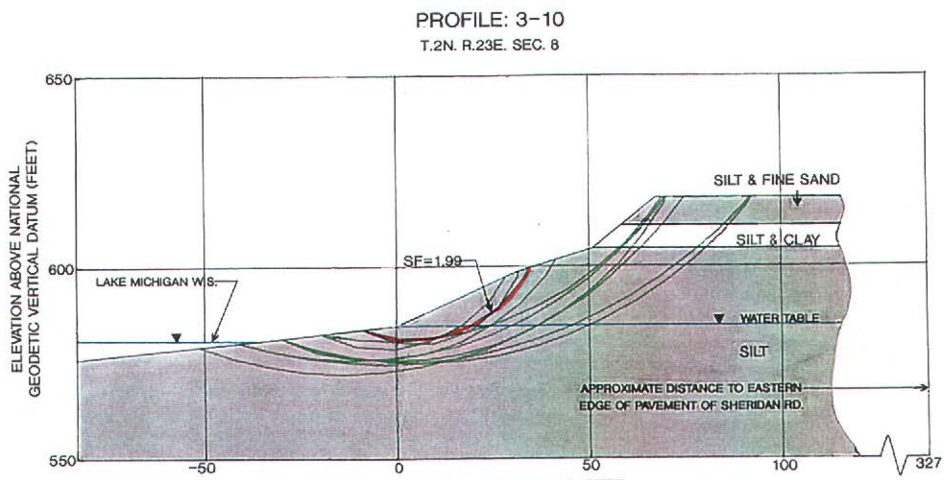
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

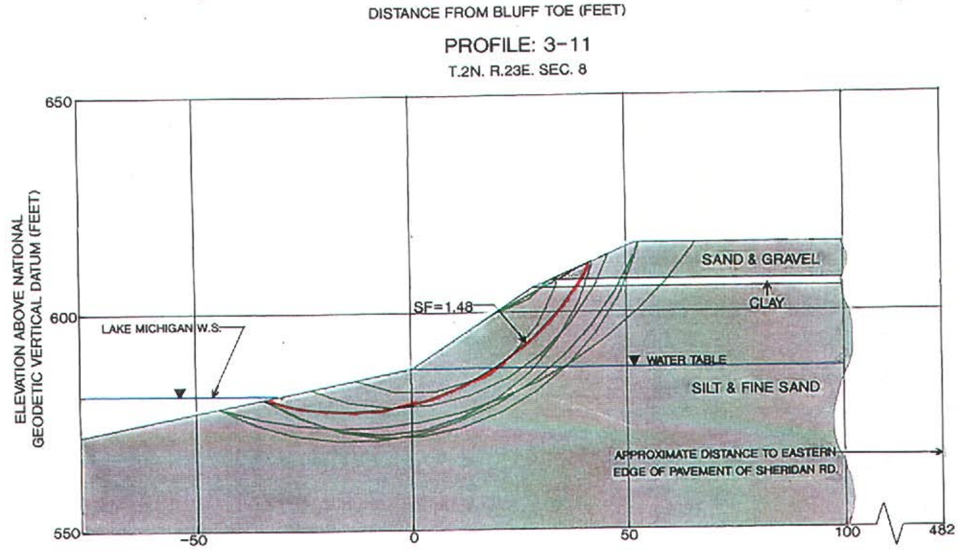
Figure 12

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 8, Township 2 North, Range 23 East
Town of Somers, Kenosha County







Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

0.2 mile to a point about 150 feet north of the intersection of STH 32 and the southernmost portion of 8th Street extended, as shown on Map 16. This zone had a beach width of less than 30 feet. The bluff had a height of 25 to 30 feet in this zone and was generally unprotected except for riprap fill which had been placed in selected areas by riparian property owners. The bluff was approximately 50 percent vegetated, which was an increase in the amount of vegetation since 1976. The 1995 field observations indicated a retreat of the bluff top of between five and 20 feet since 1976, with small-scale slumps and translational slides present.

In 1995, one bluff profile field survey was made within Zone 8c by occupying a site for which a field survey was conducted in 1976. The bluff profile had been changed by some small fills and placement of riprap to protect the base of the bluff. The stability of the bluff in Zone 8c of Reach 3 was characterized by Profile No. 3-10. The bluff material at this site was assumed to be silt, overlain by silt and clay, overlain by silt and sand. Results of the slope stability analysis, shown in Figure 12, indicated that the bluff was stable with respect to rotational failures, with a safety factor of 1.99. Translational failures should be considered possible. The 1977 study reported a bluff safety factor of 0.94.

The beach was less than 30 feet wide within Zone 8c. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 8c were estimated at one location. These data indicated a recession of about 120 feet, or about 3.8 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of about 30 feet, or about 1.5 feet per year, occurring between 1975 and 1995. The placement of riprap within this zone after 1975 appeared to have partially stabilized portions of the shoreline. However, the bluff remained unstable in places. The 1977 study reported a recession rate of three feet per year for this erosion zone.

Erosion Zone 8d

Erosion Zone 8d extends from the northerly limit of Erosion Zone 8c at 8th Street extended north about 0.4 mile to 7th Street extended, as shown on Map 16. In the southern portion of the zone, a massive fill, placed since 1975, created a beach behind an existing groin situated north of the beach site. North of this feature, the zone had a wide and stable beach, north of which riprap protected the toe of the bluff and small gravel beaches occurred between groins. The bluff in this zone had a height of 25 to 30 feet. In 1995, the bluff was vegetated, with a considerable increase in the amount of vegetation between 1976 and 1995, and the bluff appeared stable as the result of extensive regrading of the bluff slope throughout the zone. The 1995 field observations indicated zero to 10 feet of retreat in the bluff top since 1976.

In 1995, one bluff profile field survey was made within Zone 8d by occupying a site for which a field survey was conducted in 1976. No significant erosion of the bluff was observed at this site during the 1995 survey and the bluff appeared to be stable. The stability of the bluff in Zone 8c of Reach 3 was characterized by Profile No. 3-11. Results of the slope stability analysis, shown in Figure 12, indicated that the bluff was stable, with a safety factor of 1.48. The 1977 study reported a bluff safety factor of 0.94. However, since that time, the site has been regraded, and riprap and rubble placed at the toe of the bluff.

The beach within Zone 8d was up to 150 feet wide, and, in most locations, was part of a groin system and backed by riprap fill. In 1995, the beach material in the northern portion of this zone was noted to be gravel between short groins. In the 1977 study, the beach width was reported to be between zero and 20 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 8d were estimated at two locations. These data indicated a recession of between 70 and 170 feet, or between 2.2 and 5.3 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of between 30 and 50 feet, or between 1.5 and 2.5 feet per year, occurring between 1975 and 1995. The placement of riprap fill within this zone, and the regrading of the bluff slopes, the wide beach, and the vegetation which increased in coverage on the bluff slope, after 1975, all indicated that the bluff was largely stabilized. The 1977 study reported a recession rate of two feet per year for this erosion zone.

U.S. Public Land Survey Section 5, Township 2 North, Range 23 East, Town of Somers, Kenosha County

This shoreline analysis section extends from the south line of Section 5 at 7th Street extended north to County

Line Road (CTH KR) extended in the Town of Somers, as shown on Map 17. The shoreline was occupied entirely by residential land, including limited areas with multi-family residential uses. Much of the shoreline was protected by a variety of different types of shore protection structures. The bluff materials in this section were estimated to be primarily silt and fine sand, with some areas of silt and clay in the southern portion of the section grading to till overlain by silt and sand in the central and northern portions of the section. For analysis purposes, Section 5 was further subdivided into eight erosion zones, as shown on Map 17. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the eight erosion zones in Section 5.

Erosion Zone 5a

Erosion Zone 5a extends from the northerly limit of Section 8 north about 0.2 mile, as shown on Map 17. This zone had little or no beach, and was protected by riprap and rubble. Many of the old groins observed during the 1976 survey had been covered by the rubble. The bluff had a height of about 30 feet in this zone. In 1995, the bluff appeared marginally stable as the result of the placement of the thin layer of rubble on the bluff face. This material obscured the site geology. The 1995 field observations indicated zero to 10 feet of retreat of the bluff top since 1976. A number of structures that could be endangered by the future erosion of the bluff were observed to be located in close proximity to the bluff top within this zone.

In 1995, one bluff profile field survey was made within Zone 5a by occupying a site for which a field survey was conducted in 1976. The profile had been significantly modified by the placement of rubble, and the present bluff slope was not considered natural. The stability of the bluff in Zone 5a of Reach 3 was characterized by Profile No. 3-12. Results of the slope stability analysis, shown in Figure 13, indicated that the bluff was stable, with a safety factor of 1.18, based on the deterministic rotational bluff stability analysis method. Profile No. 3-12 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.87 to 1.5 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for five, or 20 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 11, or 4.4 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered stable. The 1977 study reported a bluff safety factor of 0.57.

There was little or no beach within Zone 5a. In the 1977 study, the beach width was reported to be about five feet, and the beach materials were reported to be sand and gravel. The bluff was fronted by riprap and rubble. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 5a were estimated at one location. These data indicated a recession of about 70 feet, or about 2.2 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of about 30 feet, or about 1.5 feet per year, occurring between 1975 and 1995. The placement of riprap and rubble fill within this zone after 1975 appeared to have largely stabilized the bluff. The 1977 study reported a recession rate of two feet per year for this erosion zone.

Erosion Zone 5b

Erosion Zone 5b extends from the northerly limit of Erosion Zone 5a north about 0.1 mile, as shown on Map 17. This zone had a 50-foot-wide beach within a well-maintained groin system fronting a bluff with a height of about 25 feet. The bluff top had been regraded and lawned by riparian residents. In 1995, the bluff and beach appeared to be stable as long as the groin system is maintained. The 1995 field observations indicated no noticeable change in the bluff top since 1976.

No bluff stability analyses were conducted within Erosion Zone 5b in this study or the 1977 study.

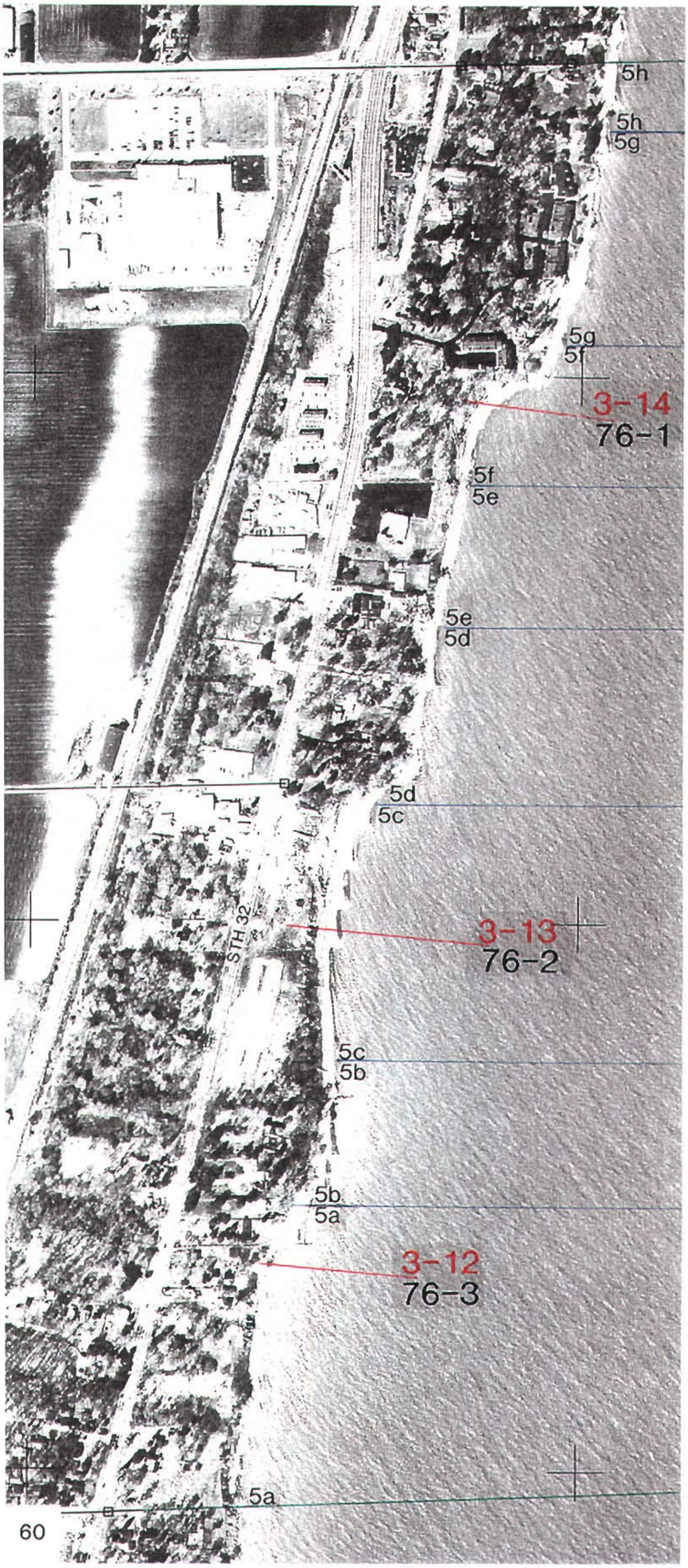
The beach was up to 50 feet wide within Zone 5b and fronted by groins. In the 1977 study, the beach width was reported to be between zero and 40 feet, and the beach material was reported to be gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

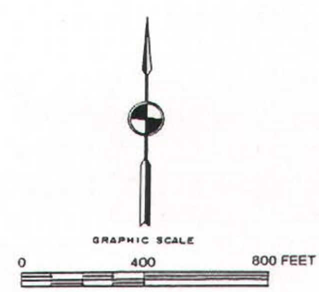
Shoreline recession data for Erosion Zone 5b were estimated at one location. These data indicated a recession of about 60 feet, or about 1.9 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with no further recession of the bluff between 1975 and 1995. The placement of groins within this zone and regrading of

Map 17

SHORELINE EROSION REACH 3: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 5, Township 2 North, Range 23 East
Town of Somers, Kenosha County





LEGEND

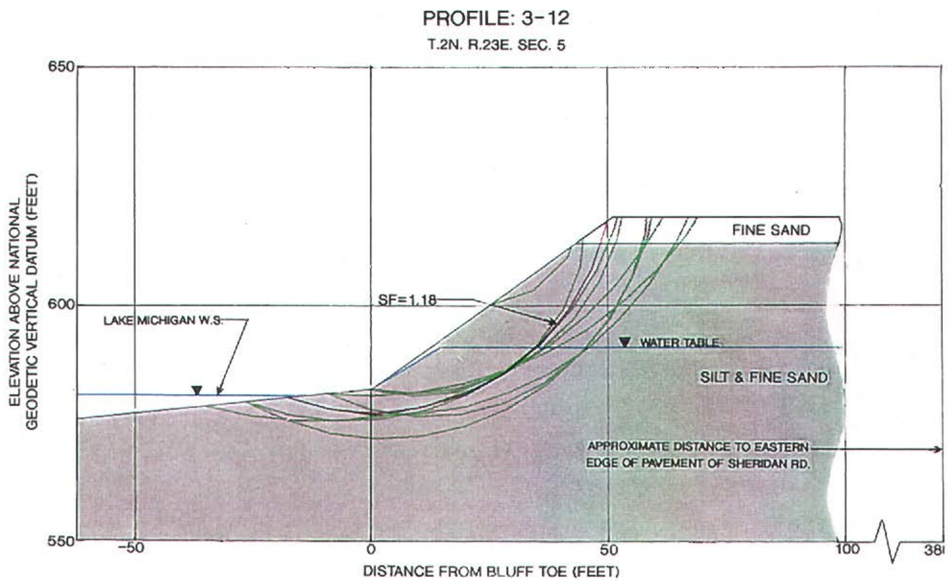
- PROFILE SITE LOCATION
- 3-13 PROFILE NUMBER: 1995 FIELD INVENTORY
- 76-2 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY
- EROSION ANALYSIS SECTION LIMITS
- EROSION ANALYSIS ZONE LIMITS
- 5c EROSION ANALYSIS ZONE NUMBER

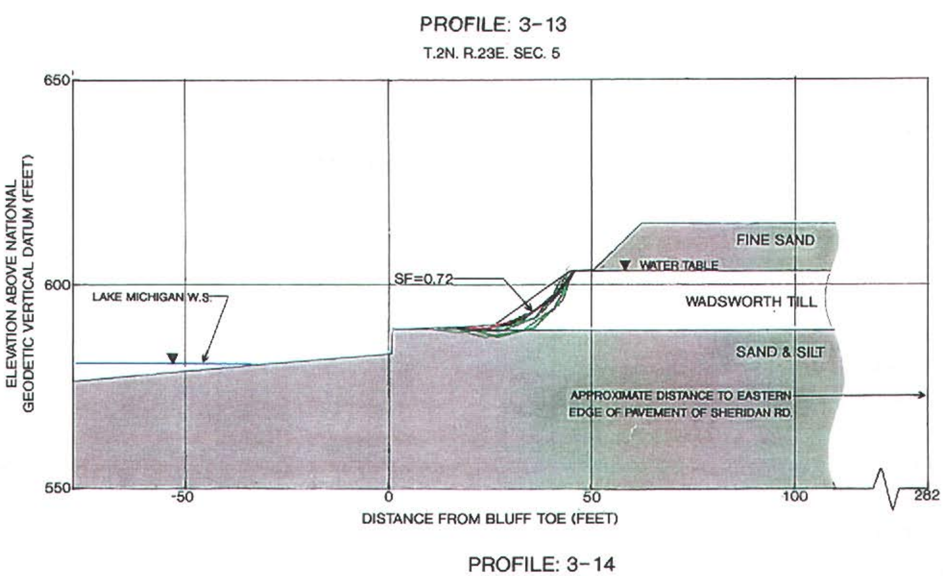
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

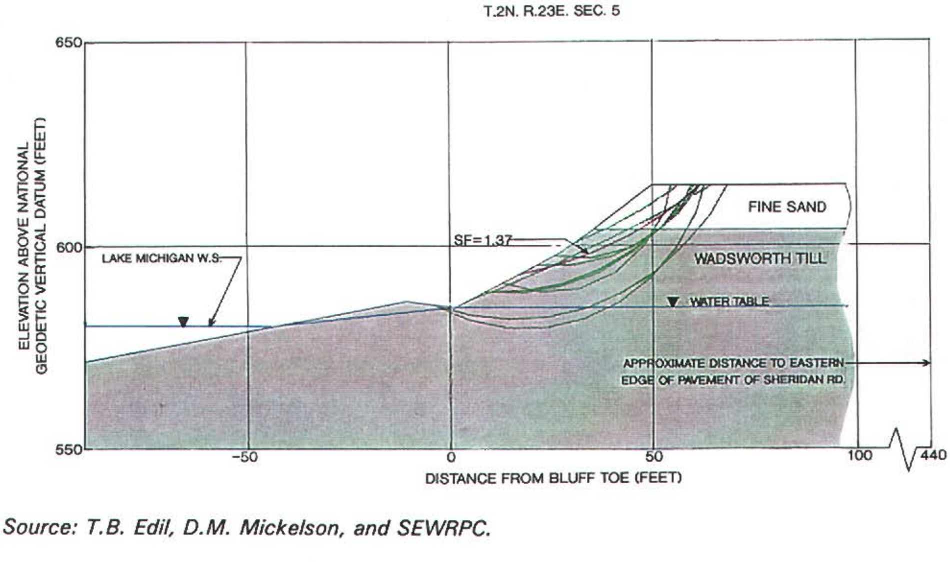
Figure 13

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 5, Township 2 North, Range 23 East
Town of Somers, Kenosha County







Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

the bluff slopes after 1975 appeared to have largely stabilized the bluff. The 1977 study did not report a recession rate for this erosion zone.

Erosion Zone 5c

Erosion Zone 5c extends from the northerly limit of Erosion Zone 5b north about 0.2 mile, as shown on Map 17. In 1995, there were no structures on the bluff between STH 32 and the bluff top. The southern portion of this zone had a 50-foot-wide beach, contained with a groin system, fronting bluffs with a height of 25 to 30 feet. The bluff toe was protected by debris. Although this zone was unstable and eroding in 1976, the bluff was vegetated with grasses and small bushes in 1995, with an increase in the amount of vegetation between 1976 and 1995. The 1995 field observations indicated zero to 15 feet of retreat of the bluff top since 1976.

In 1995, one bluff profile field survey was made within Zone 5c by occupying a site for which a field survey was conducted in 1976. The site had been significantly modified by the placement of debris, and the present bluff slope was not considered natural. The stability of the bluff in Zone 5c of Reach 3 was characterized by Profile No. 3-13. Results of the slope stability analysis, shown in Figure 13, indicated that the bluff was unstable, with a safety factor of 0.72, which was the same as that reported in the 1977 study. Translational failures may also occur in Zone 5c.

The beach was up to 50 feet wide within Zone 5c contained within a groin system. In the 1977 study, the beach width was reported to be between 20 and 40 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 5c were estimated at one location. These data indicated a recession of about 140 feet, or about 4.4 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of about 30 feet, or about 1.5 feet per year, occurring between 1975 and 1995. The placement of rubble on the bluff slopes within this zone after 1975 appeared to have partially stabilized the bluff. The 1977 study reported a recession rate of three feet per year for this erosion zone.

No significant erosion of the bluff was observed during the 1995 survey and the bluff appeared to be marginally stable as a result of the added debris. However, the bluff will require further protection during future periods of higher lake levels.

Erosion Zone 5d

Erosion Zone 5d extends from the northerly limit of Erosion Zone 5c north about 0.1 mile, as shown on Map 17. This zone was protected by old groins and rubble-covered slopes. The groins appeared to be marginally effective in building the beach which was up to 75 feet in width in this zone. The bluff in this zone had a height of 25 to 30 feet. The 1995 field observations indicated that there had been no noticeable change in the bluff slope since 1976. A number of structures were within 50 feet of the bluff top.

No bluff stability analyses were conducted within Erosion Zone 5d in this study or the 1977 study.

The beach was up to 75 feet wide within Zone 5d contained within a groin system. In the 1977 study, the beach width was reported to be between 15 and 20 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 5d were not estimated. The 1977 study reported a recession rate of three feet per year for this erosion zone.

In 1995, the bluff appeared stable. However, this zone will need to be protected with riprap during future periods of higher lake levels.

Erosion Zone 5e

Erosion Zone 5e extends from the northerly limit of Erosion Zone 5d north about 0.1 mile, as shown on Map 17. This zone had a 50-foot-wide beach fronting a bluff with a height of about 30 feet. In 1995, the whole zone was protected by a large riprap revetment, which had been extended southward to the southern edge of the zone subsequent to 1976. An outbuilding, situated on a portion of the bluff top that was being undercut in 1976, had been removed. In 1995, the bluff appeared stable as the result of being regraded, and most of the bluff slope was not considered natural. A limited amount of natural bluff slope remained only at the southern edge of this zone. The 1995 field observations indicated that there had been no noticeable change in the bluff slope since 1976.

No bluff stability analyses were conducted within Erosion Zone 5e in this study or the 1977 study.

The beach was up to 50 feet wide within Zone 5e and backed by riprap and the bluff. In the 1977 study, the beach width was reported to be between five and 15 feet, and the beach materials were reported to be cobbles and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 5e were estimated at one location. These data indicated a recession of about 100 feet, or about 3.1 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of about 20 feet, or about one foot per year, occurring between 1975 and 1995. The placement of riprap on the bluff slopes within this zone after 1975 appeared to have partially stabilized the bluff. The 1977 study did not report a recession rate for this erosion zone.

Erosion Zone 5f

Erosion Zone 5f extends from the northerly limit of Erosion Zone 5e north about 0.1 mile, as shown on Map 17. This zone had a 50-foot-wide beach, within a groin system, fronting a bluff, protected by riprap fill, with a height of about 30 feet. In 1995, the southern portions of the bluff in this zone had been regraded and small groins installed. However, these groins did not appear to be very effective in building the beach. In 1995, the bluff appeared to be in a similar condition to that observed in 1976, at which time it was reported as eroding. The 1995 field observations indicated zero to 20 feet of retreat in portions of the bluff top since 1976.

In 1995, one bluff profile field survey was made within Zone 5f by occupying a site for which a field survey was conducted in 1976. The site had been significantly modified by regrading, and the present bluff slope was not considered natural. The stability of the bluff in Zone 5f of Reach 3 was characterized by Profile No. 3-14. Results of the slope stability analysis, shown in Figure 13, indicated that the bluff was stable with respect to rotational failure, with a safety factor of 1.37. The 1977 study reported a bluff safety factor of 0.47. Field observations indicated that translational failures may occur in this zone.

The beach was up to 50 feet wide within Zone 5f and contained within a groin system. In the 1977 study, the beach width was reported to be about five feet, and the beach materials where present were reported to be cobbles and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 5f were not estimated. The 1977 study did not report a recession rate for this erosion zone.

Erosion Zone 5g

Erosion Zone 5g extends from the northerly limit of Erosion Zone 5f north about 0.15 mile, as shown on Map 17. This zone had been extensively regraded and protected by riprap and fill. This material appeared to have been placed on and within the groins that existed in 1976. In 1995, a low bluff with a height of about 30 feet existed in this zone. The bluff appeared stable, with riprap extending upslope to a graded lawn at the bluff top. The 1995 field observations indicated that there had been no visible changes in the bluff slope.

No bluff stability analyses were conducted within Erosion Zone 5g in this study or the 1977 study.

The beach was up to 50 feet wide within Zone 5g. In the 1977 study, the beach width was reported to be between 10 and 15 feet, and the beach materials were reported to be pebbles and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 5g were estimated at one location. These data indicated a recession of about 60 feet, or about 1.9 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. The placement of rubble on the bluff slopes within this zone after 1975 appeared to have partially stabilized the bluff. The 1977 study did not report a recession rate for this erosion zone.

Erosion Zone 5h

Erosion Zone 5h extends from the northerly limit of Erosion Zone 5g north about 0.05 mile to County Line Road (CTH KR) extended, as shown on Map 17. This zone had a 50- to 75-foot-wide beach, within a groin system, fronting a low bluff. The bluff had a height of about 25 feet. In 1995, the bluff appeared stable behind the beach. The 1995 field observations indicated zero to 10 feet of retreat in the bluff top since 1975.

No bluff stability analyses were conducted within Erosion Zone 5h in this study or the 1977 study. The bluff appeared to be unchanged from its 1976 condition.

The beach was up to 75 feet wide within Zone 5h and contained within a groin system. In the 1977 study, no beach was reported within this zone. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 5h were not estimated. The 1977 study did not report a recession rate for this erosion zone.

The groins present in this zone will require maintenance in the future to ensure their continued effectiveness.

U.S. Public Land Survey Section 32, Township 3 North, Range 23 East, Town of Mt. Pleasant, Racine County

This shoreline analysis section extends from the south line of Section 32 at County Line Road (CTH KR) extended north to Chicory Road extended in the Town of Mt. Pleasant in Racine County, as shown on Map 18. The shoreline was occupied entirely by residential land. Much of the shoreline was protected by a variety of different types of shore protection structures. The bluffs in this section ranged from 30 to 40 feet in height. The bluff materials were intermixed fine sand and silt overlying till in the southern portions of the section, grading to sand and gravelly sand overlying till in the northern portions of the section. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for Section 32.

In 1995, this zone had little or no beach, and was protected along approximately 95 percent of the shoreline length by riprap and rubble at the bluff toe. The bluff had a height of about 30 feet in this zone, rising to about 40 feet in height at the northern end of the section. Portions of the bluff had been regraded. In 1995, the bluff appeared stable, with the exception of two areas located approximately 0.3 mile north of County Line Road (CTH KR) and extending for approximately 0.05 mile north, and 0.4 mile north of County Line Road (CTH KR) and extending for approximately 0.1 mile north. Both areas were essentially unprotected and subject to translational sliding or slumping. The southern area of erosion had an unprotected bluff toe and a nonexistent beach. The northern area of erosion lacked vegetation cover. The 1995 field observations indicated five to 15 feet of retreat in the bluff top in these areas since 1975. Both areas should be protected by revetments to prevent indentation of the shoreline due to differential erosion in these areas.

In 1995, two bluff profile field surveys were made within Section 32 by occupying the southern two of three sites for which field surveys were conducted in 1976. The sites had been significantly modified by regrading and placement of rubble and riprap. The present bluff slope was not considered natural. The stability of the bluff in Section 32 of Reach 3 was characterized by Profile Nos. 3-15 and 3-16. Results of the slope stability analysis, shown in Figure 14, indicated that the bluff was stable with respect to rotational failure, with safety factors of 1.69 at Profile No. 3-15 and 1.37 at Profile No. 3-16. The 1977 study reported bluff safety factors at these sites of 0.41 and 0.49, at Profile Nos. 3-15 and 3-16, respectively. Field observations indicated that translational failures may occur in this zone.

The beach within Section 32 was less than 20 feet wide. In 1995, most of the beach in this section was covered by rubble. In the 1977 study, the beach width was reported to be between zero and 20 feet, and the beach materials were reported to be predominantly sand and gravel in those portions of the section where a beach was present. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

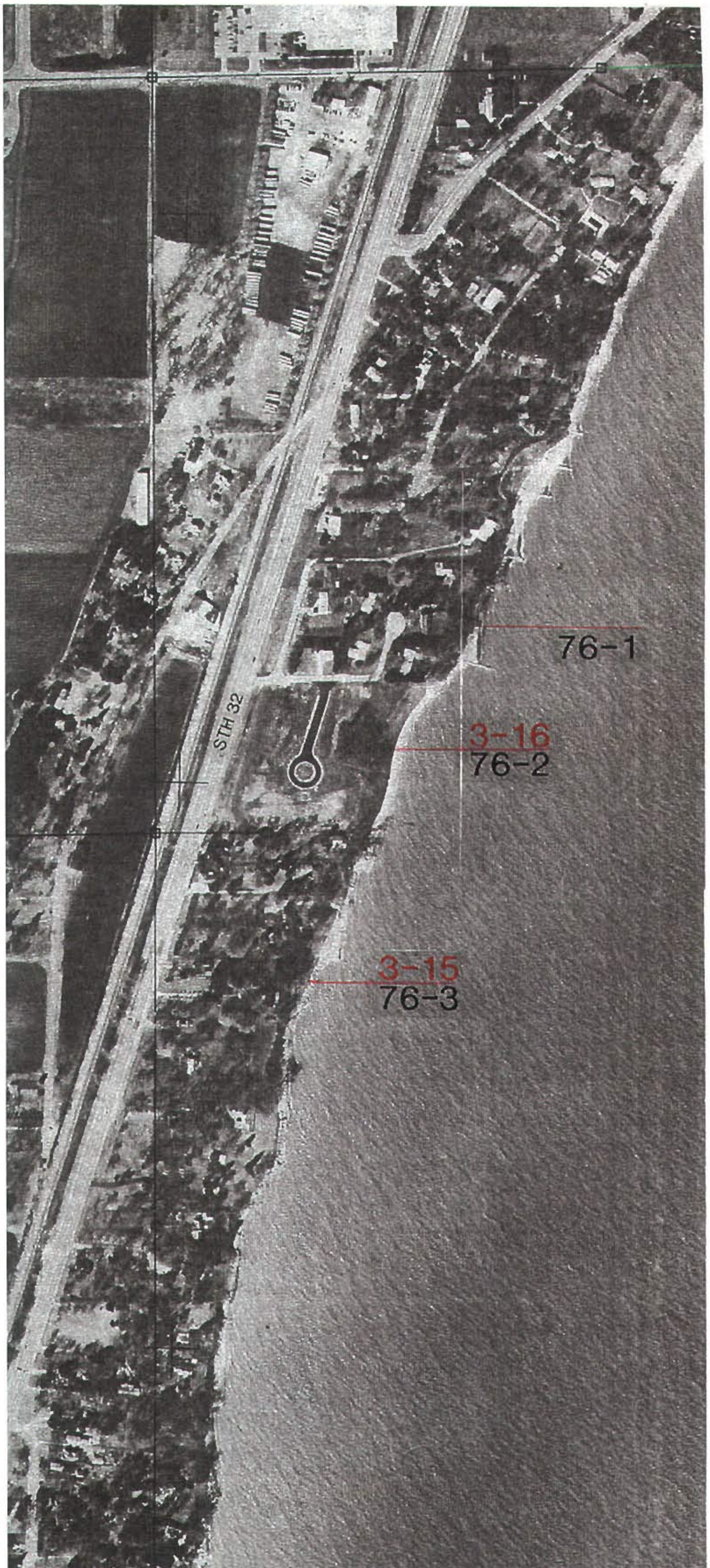
Shoreline recession data for Section 32 were estimated at five locations. These data indicated a recession of between 30 and 80 feet, or between 0.9 and 2.5 feet per year, occurred between 1963 and 1995. The lowest recessions were observed in the southern portions of the section, south of Profile No. 3-16. Recessions increased in severity to the north of this profile site, with the greatest recessions being observed in the vicinity of the north section line of Section 32. This observation most likely reflected the change in shoreline protection structures. Nevertheless, the data indicated that most of that recession occurred prior to 1975, with a recession of between zero and 10 feet, or between zero and 0.5 foot per year, occurring between 1975 and 1995. The placement of riprap and rubble on the bluff slopes within this zone after 1975 appeared to have largely stabilized the bluff, especially in the northern portions of the section where erosion was reduced to near zero. The 1977 study reported a recession rate for this erosion zone of between two and three feet per year.

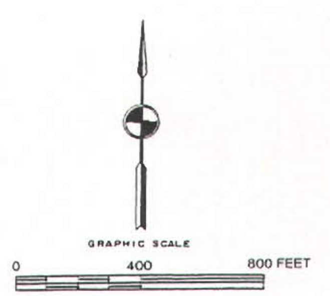
The shoreline in this section may experience renewed erosion in the event of a future lake level rise.

Map 18

SHORELINE EROSION REACH 3: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 32, Township 3 North, Range 23 East
Town of Mt. Pleasant, Racine County





LEGEND

PROFILE SITE LOCATION

3-15 PROFILE NUMBER: 1995 FIELD INVENTORY

76-3 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

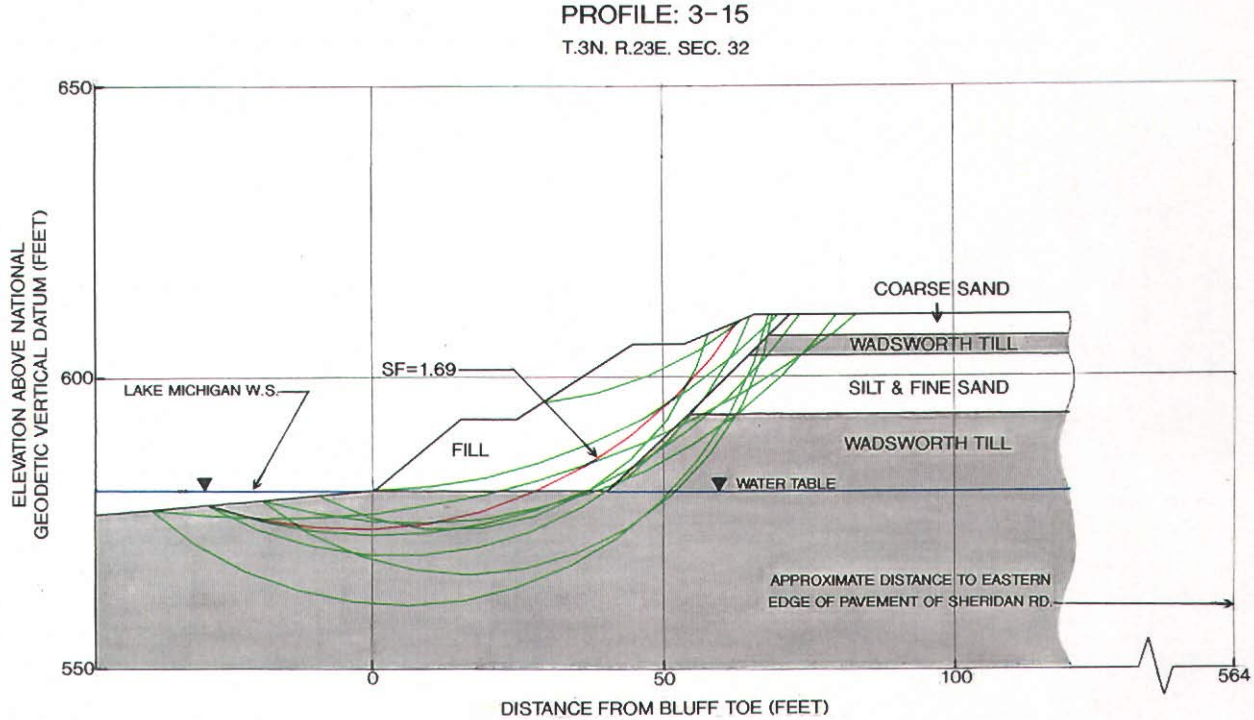
EROSION ANALYSIS SECTION LIMITS

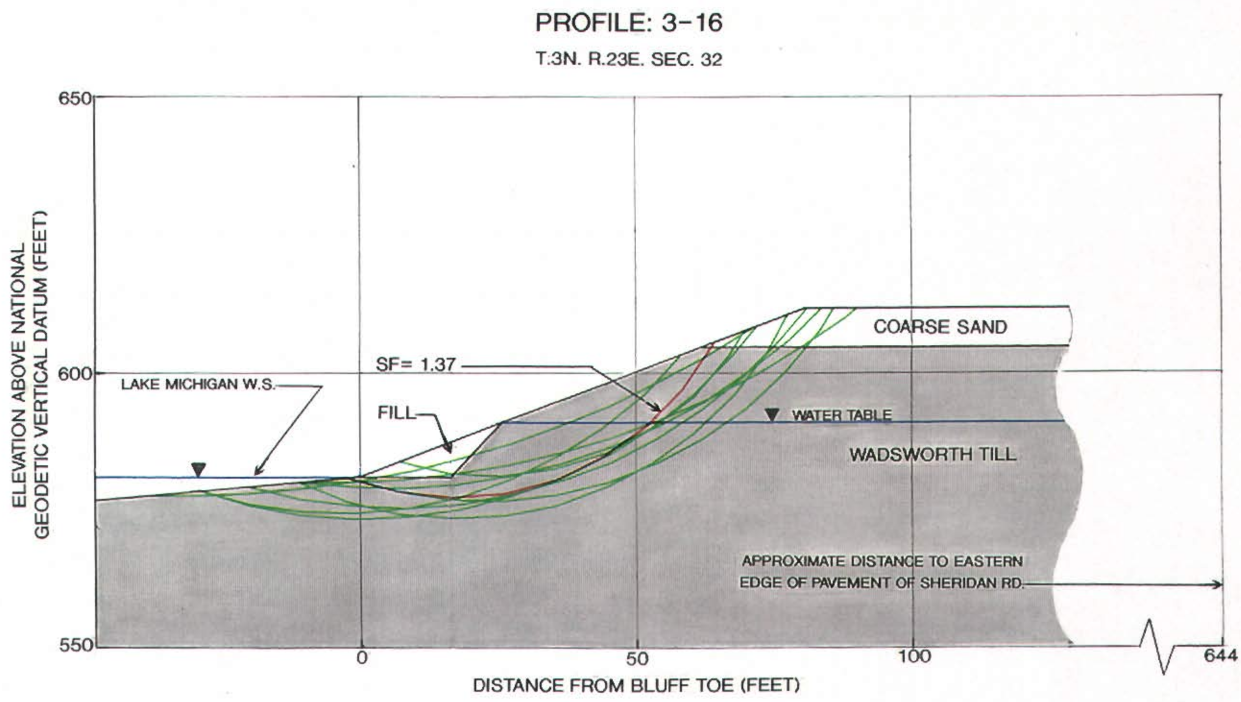
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 14

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 32, Township 3 North, Range 23 East
Town of Mt. Pleasant, Racine County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

U.S. Public Land Survey Sections 28 and 29, Township 3 North, Range 23 East, Town of Mt. Pleasant, Racine County

This shoreline analysis section extends from the south line of Section 28 at Chicory Road extended in the Town of Mt. Pleasant in Racine County north to Durand Avenue (STH 11) extended, as shown on Map 19. The shoreline was occupied by residential land in the southern portions of the section and industrial land in the north. The geology of the bluffs in this section was characterized by interbedded silt and fine sand overlying till throughout its length. In the northern portion of the section, a layer of silt and silty clay of up to 10 feet in thickness occurred at the interface between the till and the silt and fine sand strata. Much of the shoreline was protected by a variety of different types of shore protection structures. The placement of debris at the toe of the bluff in this section obscured the till stratum, which was observed during the 1977 study in this portion of the bluff. For analysis purposes, Section 28 was further subdivided into four erosion zones, as shown on Map 19. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the four erosion zones in Section 28.

Erosion Zone 28a

Erosion Zone 28a extends from the northerly limit of Section 32 at Chicory Road extended north about 0.12 mile to a point approximately 50 feet south of the intersection of STH 32 and Athaleen Avenue, as shown on Map 19. This zone had a beach width ranging up to 50 feet, protected by several groins, fronting a low bluff with a height of about 40 feet. In 1995, the lower part of the bluff was protected by a groin and, where it had been regraded, appeared stable. The upper part of the bluff, where it had not been regraded or covered with rubble fill, was observed to be subject to shallow translational slides. The 1995 field observations indicated no noticeable changes in this zone since 1976.

No slope stability analyses were conducted within Erosion Zone 28a in this study or the 1977 study.

The beach was up to 50 feet wide within Erosion Zone 28a and contained within a groin system. In 1995, most of the beach in this zone was covered by rubble. In the 1977 study, the beach width was reported to be between zero and five feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 28a were estimated at one location. These data indicated a recession of about 80 feet, or about 2.5 feet per year, occurred between 1963 and 1995. The recession data indicated no further recession between 1975 and 1995. The zone appeared to be subject to shallow translational failures where it had not been regraded and protected by the placement of rubble on the bluff slopes. The 1977 study reported a recession rate for this erosion zone of two feet per year.

Erosion Zone 28b

Erosion Zone 28b extends from the northerly limit of Erosion Zone 28a at Athaleen Avenue north about 0.14 mile to a point approximately 150 feet south of the intersection of STH 32 and Richard Avenue, as shown on Map 19. This zone was completely protected by a massive fill, which appeared stable. No beach was present. The bluff had a height of about 40 feet. The bluff material at the profile sites was concealed by fill material deposited at the site. The 1995 field observations indicated no apparent retreat in the bluff top since 1975.

No slope stability analyses were conducted within Erosion Zone 28b in this study or the 1977 study.

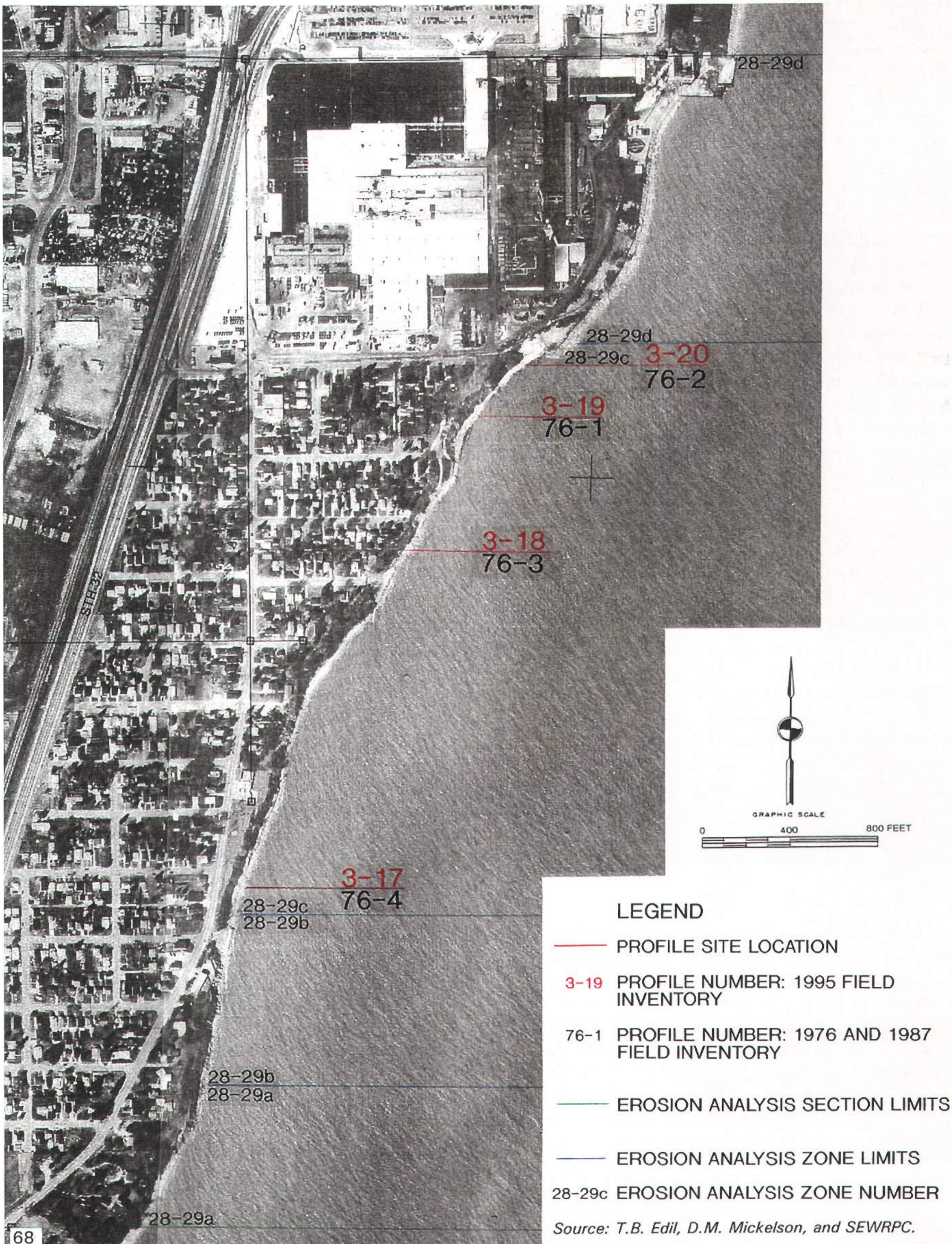
There was little or no beach within Erosion Zone 28b. In the 1977 study, the beach width was reported to be between five and 10 feet, and the beach materials were reported to be pebbles and cobbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 28b were estimated at one location. These data indicated a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. The placement of rubble on the bluff slopes within this zone after

Map 19

SHORELINE EROSION REACH 3: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 28 and 29, Township 3 North, Range 23 East
Town of Mt. Pleasant, Racine County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

1975 appeared to have largely stabilized the bluff. The 1977 study reported a recession rate for this erosion zone of four feet per year.

Erosion Zone 28c

Erosion Zone 28c extends from the northerly limit of Erosion Zone 28b at Richard Avenue north about 0.49 mile to the point where the southern property line of the J.I. Case property intersects the lakeshore in the vicinity of Larson Street, as shown on Map 19. Riprap had been added along the bluff toe, especially in the southern half of the zone, and no beach was present. The bluff in this zone had a height of 40 feet. The northern quarter of the zone was lightly protected by a small amount of riprap and approximately 60 percent vegetated, in contrast to the well-protected, 80 percent vegetated condition of the southern half of the zone. The bluff was more vegetated in 1995 than in 1976. The 1995 field observations indicated no apparent recession of the bluff top within this zone.

In 1995, four bluff profile field surveys were made within Zone 28c by occupying four sites in the southern portion of the zone for which field surveys were conducted in 1976. These sites had been significantly modified from the eroding conditions documented in 1976 due to the placement of riprap in the form of limestone blocks to protect the base of the bluff. The stability of the bluff in Zone 28c of Reach 3 was characterized by Profile Nos. 3-17 through 3-20. Results of the slope stability analysis, shown in Figures 15 and 16, indicated that the bluff was stable with respect to rotational failures in the southern half of the zone, with safety factors ranging from 1.23 at Profile No. 3-18 to 1.25 at Profile No. 3-17. In the northern quarter of the zone, the bluff was considered to be unstable with respect to rotational failure, with safety factors ranging from 0.79 at Profile No. 3-20 to 0.98 at Profile No. 3-19. Profile 3-19 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors of 0.64 to 1.39 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 76 percent of the most critical 25 conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 29 percent of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered marginally unstable. The northern portion of this zone which was indicated as unstable with respect to both rotational and translational failures and should be monitored carefully during future periods of higher lake levels. The 1977 study reported bluff safety factors of 0.54 to 0.7 for these profile sites.

There was no beach within Erosion Zone 28c in this study or the 1977 study. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 28c were estimated at two locations. These data indicated a recession of about 40 feet, or about 1.2 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of between 10 and 20 feet, or between 0.5 and one foot per year, occurring between 1975 and 1995. The placement of riprap on the bluff slopes within this zone after 1975 appeared to have largely stabilized the bluff in the southern half of the zone. The northern half of the zone remained unstable. The 1977 study did not report a recession rate for this erosion zone.

Erosion Zone 28d

Erosion Zone 28d extends from the northerly limit of Erosion Zone 28c at the southern property line of the J.I. Case property at about Larson Street north about 0.25 mile to Durand Avenue (STH 11) extended, as shown on Map 19. The beach in this zone was nonexistent. The bluff in this zone had a height of about 40 feet and was protected with riprap. The bluff slope had been regraded, and was considered stable. The 1995 field observations indicated no apparent retreat in the bluff top since 1976.

No bluff stability analyses were conducted within Erosion Zone 28d in this study or the 1977 study.

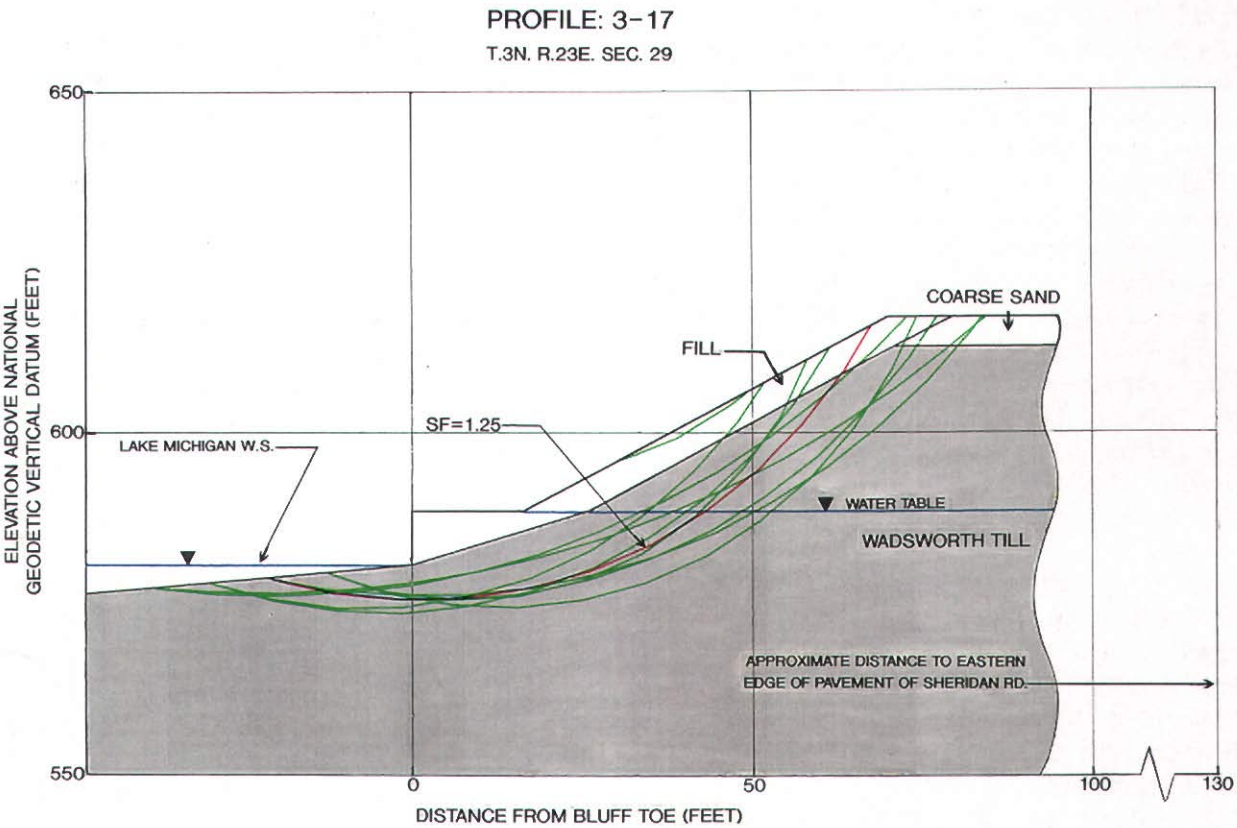
There was no beach within Erosion Zone 28d. In the 1977 study, the beach width was reported to be between zero and 10 feet, and the beach materials were reported to be gravel, pebbles, stone, slag, wood, iron, and junk in those portions of the zone where a beach was present. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

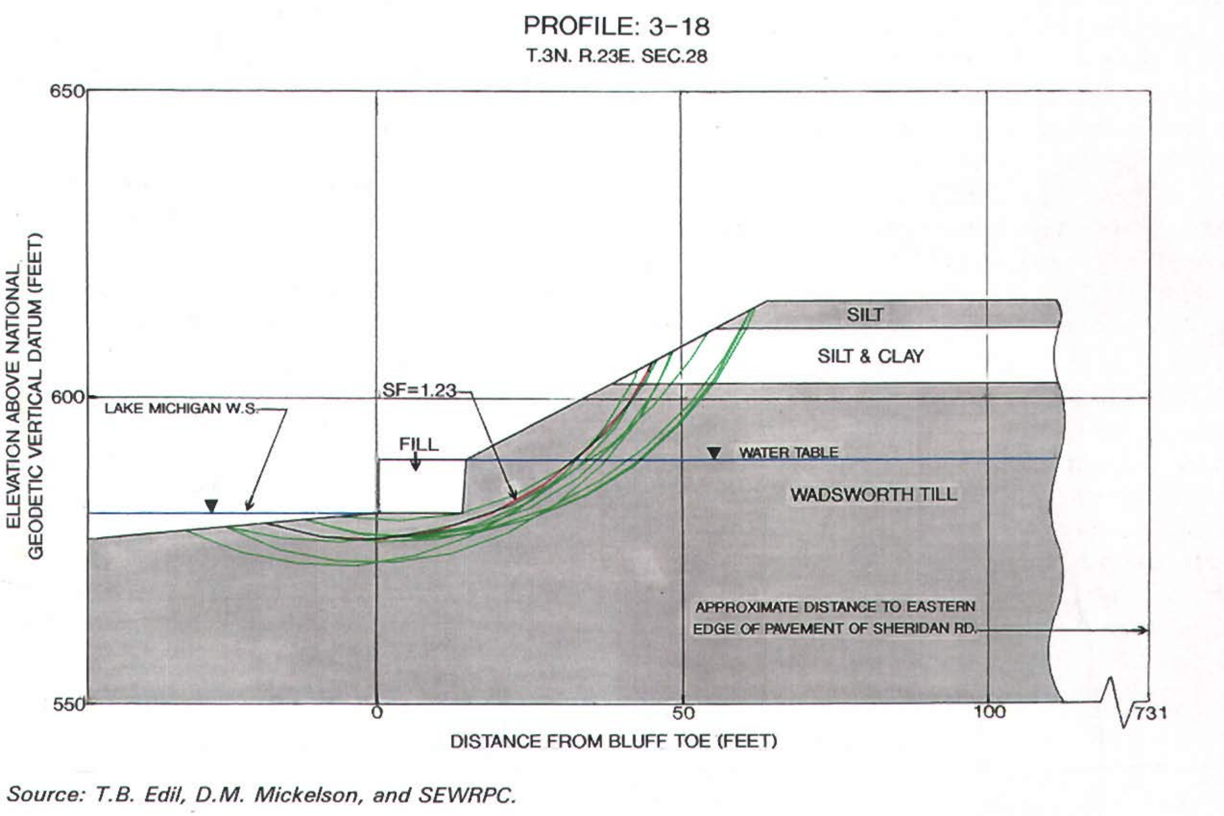
Shoreline recession data for Erosion Zone 28d were not estimated. The 1977 study also did not report a recession rate for this erosion zone.

Figure 15

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Sections 28 and 29, Township 3 North, Range 23 East
Town of Mt. Pleasant, Racine County



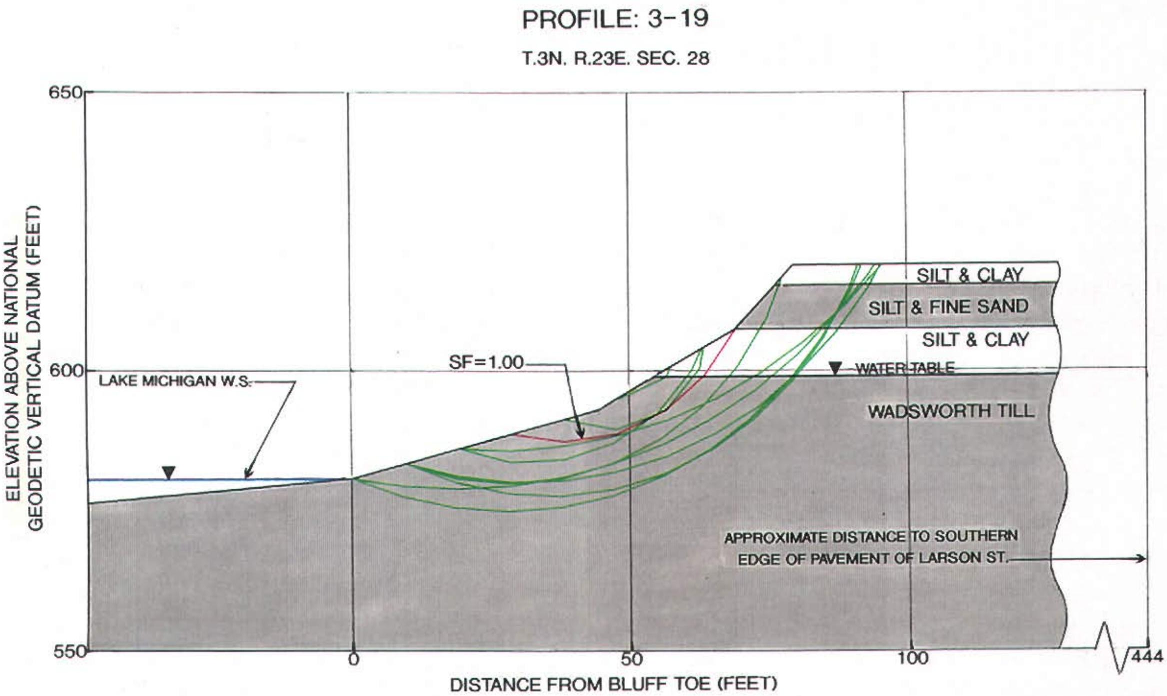


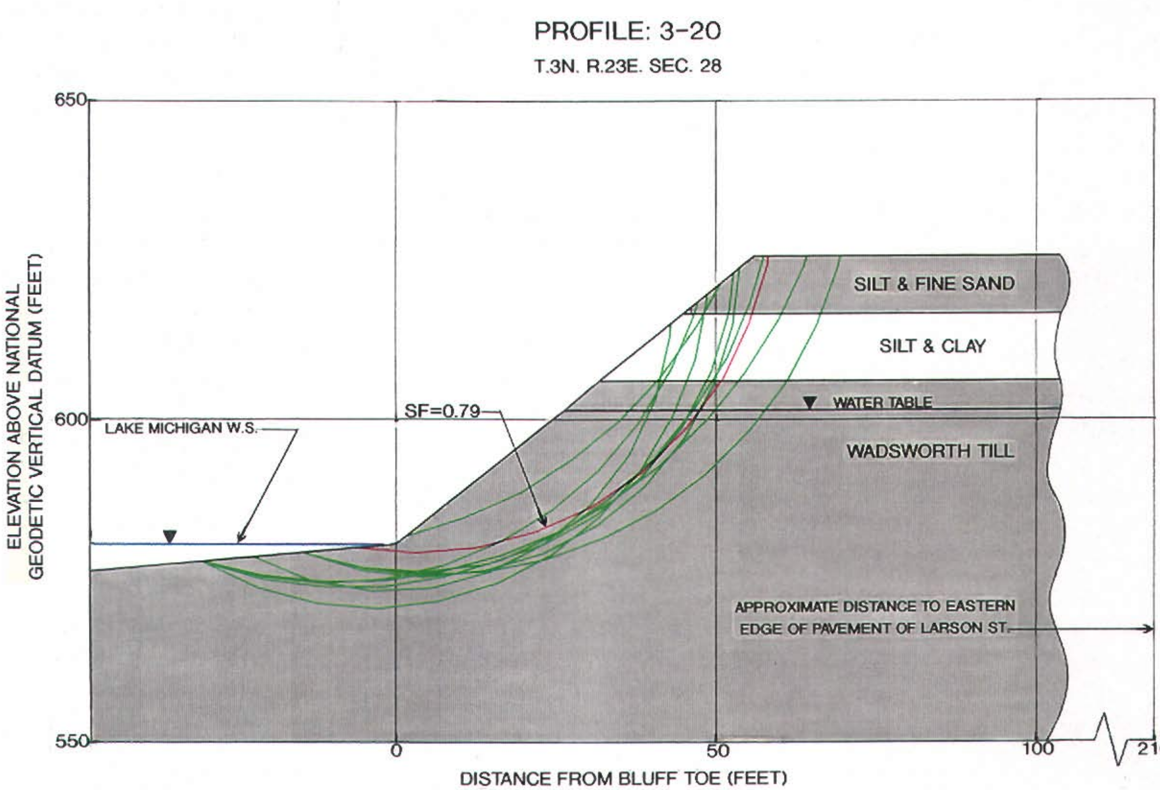
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 16

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 28, Township 3 North, Range 23 East
Town of Mt. Pleasant, Racine County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

The bluff within Erosion Zone 28d is considered to be stable provided the riprap is maintained.

SHORELINE REACH 4: CITY OF RACINE AND TOWN OF MT. PLEASANT, RACINE COUNTY

Shoreline Reach 4 is a three-mile-long reach of shoreline extending through the southern and central portions of the City of Racine from about Durand Avenue extended, on the south line of U.S. Public Land Survey Section 21, Township 3 North, Range 23 East, City of Racine, north to St. Patrick Street extended at the southern end of North Beach Park, Town of Mt. Pleasant, on the north line of U.S. Public Land Survey Section 9, Township 3 North, Range 23 East, as shown on Map 20. Land uses along this reach included open spaces in Lakefront Festival, Pershing, and Roosevelt Parks, with the remaining shore lands primarily in residential use in the north-central portion of the reach and institutional, recreational, and industrial uses at the northern and southern ends of the reach, including the Gateway Technical Institute in the south and Racine Harbor Marina in the north. As of 1995, the entire shoreline in Reach 4 was protected by structural shoreline protection measures, consisting of revetments and groins, and the bulkheads, revetments, and breakwater systems of the Racine Harbor Marina.

As shown on Map 20, Reach 4 was further segmented into three shoreline analysis sections corresponding to U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three shoreline analysis sections in Reach 4.

U.S. Public Land Survey Section 21, Township 3 North, Range 23 East, City of Racine, Racine County

This shoreline analysis section extends from Durand Avenue extended north through Roosevelt Park to just north of 17th Street extended in the City of Racine, as shown on Map 21. In 1995, the lakeshore area was occupied by industrial land uses, parkland, and residential land uses. The entire section was protected by a revetment at the toe of the bluff which had a height of up to 40 feet. The bluff materials in this section were generally obscured, but were estimated to be primarily till in the lower two-thirds of the bluff overlain by intermixed silt, clay, and sand. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for Section 21.

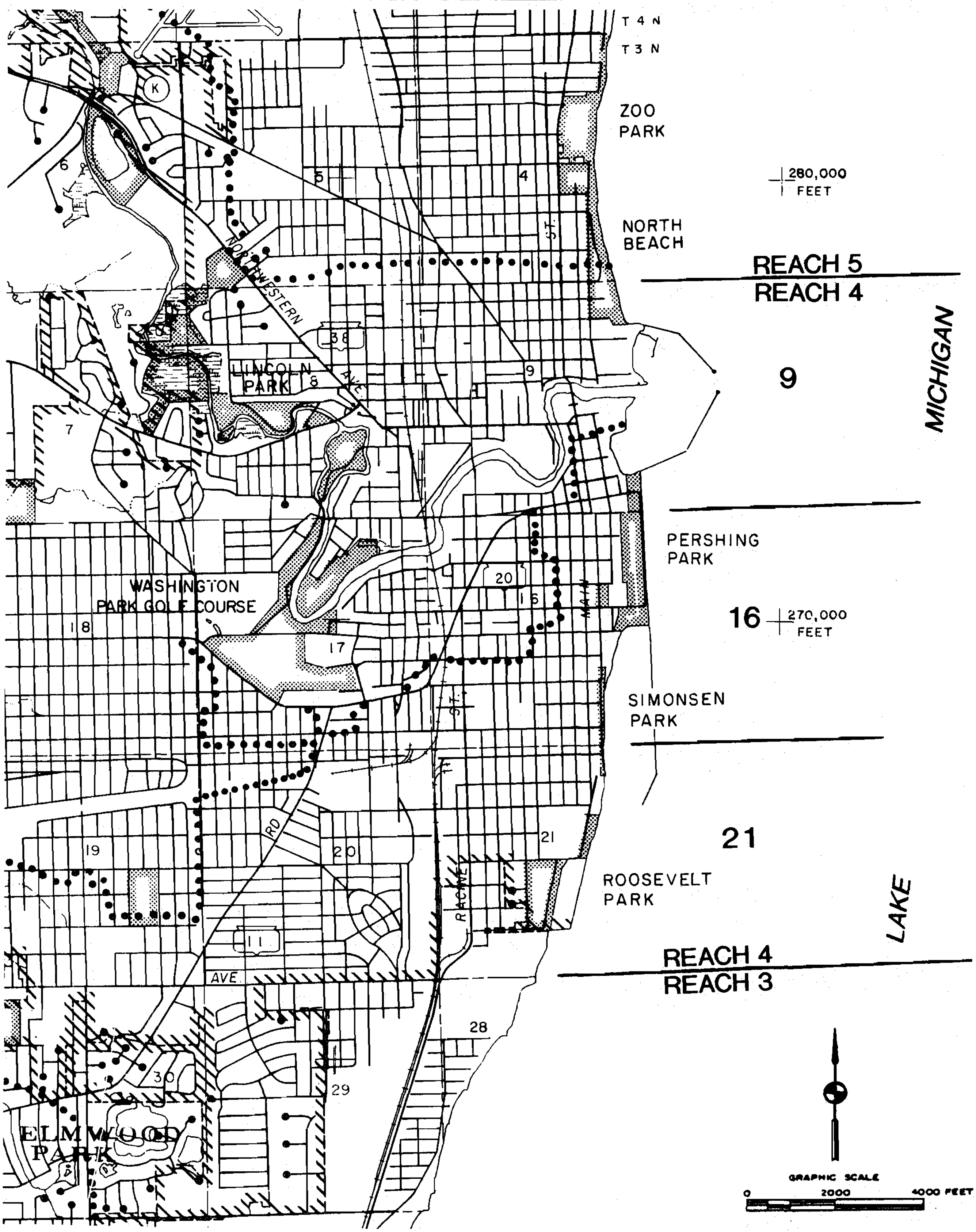
In 1995, this section had little or no beach, and was protected along the entire shoreline length by revetments. The bluff had a height of about 50 feet, and the bluff slope had been regraded since 1976. In 1995, the bluff appeared stable. The 1995 field observations indicated no apparent retreat in the bluff top in this section since 1976.

In 1995, two bluff profile field surveys were made within Section 21, both by reoccupying sites of field surveys conducted in 1976. Both sites had markedly different site geometry in 1995 to that documented in 1976. Profile No. 4-1 at the southern end of the reach was less changed than Profile No. 4-2 at the northern extreme of the reach. Profile No. 4-1 appeared to have had fill added at the toe of the bluff slope. Both slopes had been regraded, with the bluff at Profile No. 4-2 being extensively regraded to reduce the steepness of the bluff slope. The stability of the bluff in Section 21 of Reach 4 was characterized by Profile Nos. 4-1 and 4-2. Results of the slope stability analysis, shown in Figure 17, indicated the bluff had a safety factor of 0.87 at Profile No. 4-1 and stable, with a safety factor of 1.55 at Profile No. 4-2, based upon the deterministic bluff stability analysis method. Profile 4-1 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.87 to 2.14 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for six, or 24 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 45, or 18 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable. The 1977 study reported the bluffs had a safety factor of 0.88 at Profile No. 4-1 and reported a safety factor of 0.57 on the bluff face, with a safety factor of 0.91 overall, at Profile No. 4-2.

There was no beach in this section. The bluff was fronted by revetment or rubble throughout. Offshore bathymetry appeared to be steeply sloping. At the Profile No. 4-1 site, the near offshore surface materials consisted primarily of sand, and the nearshore lakebed depth

Map 20

BLUFF ANALYSIS SECTIONS WITHIN REACH 4



Source: T. B. Edil, D. M. Mickelson, and SEWRPC.

Map 21

SHORELINE EROSION REACH 4: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 21, Township 3 North, Range 23 East
City of Racine, Racine County

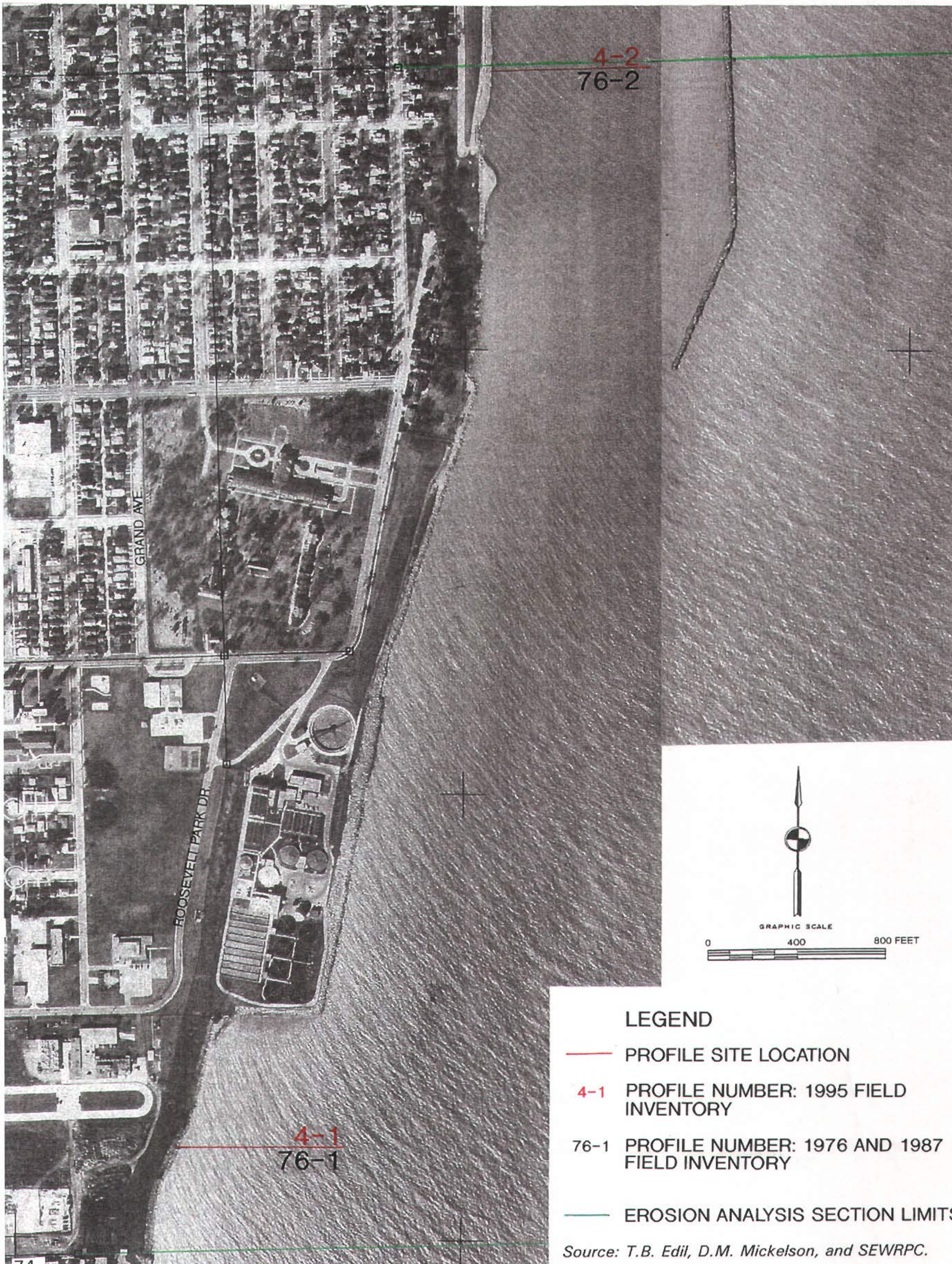
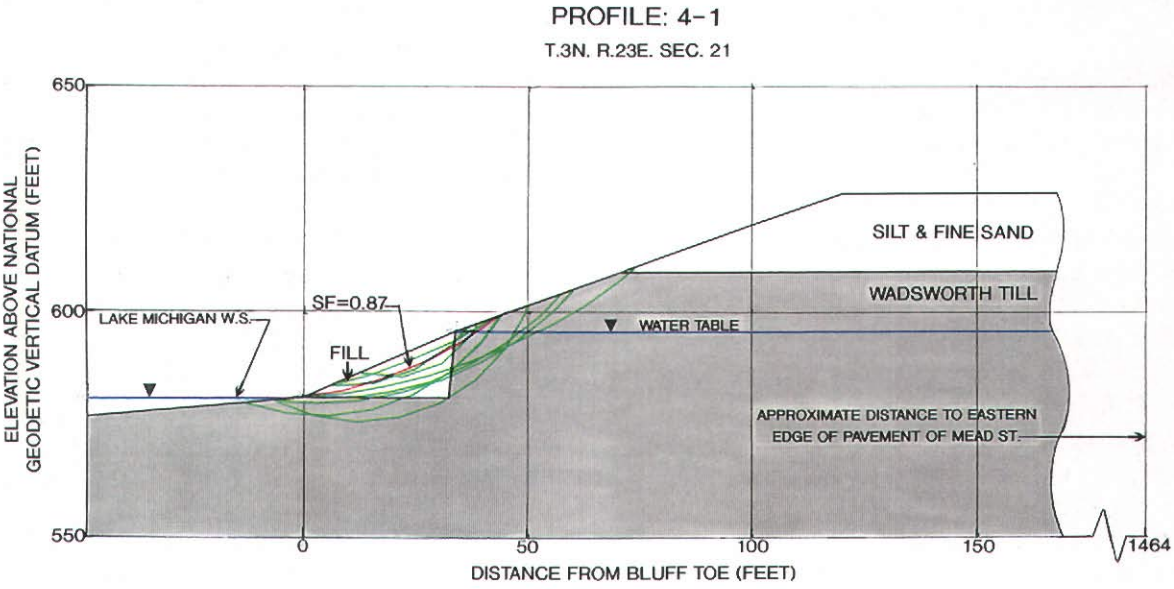
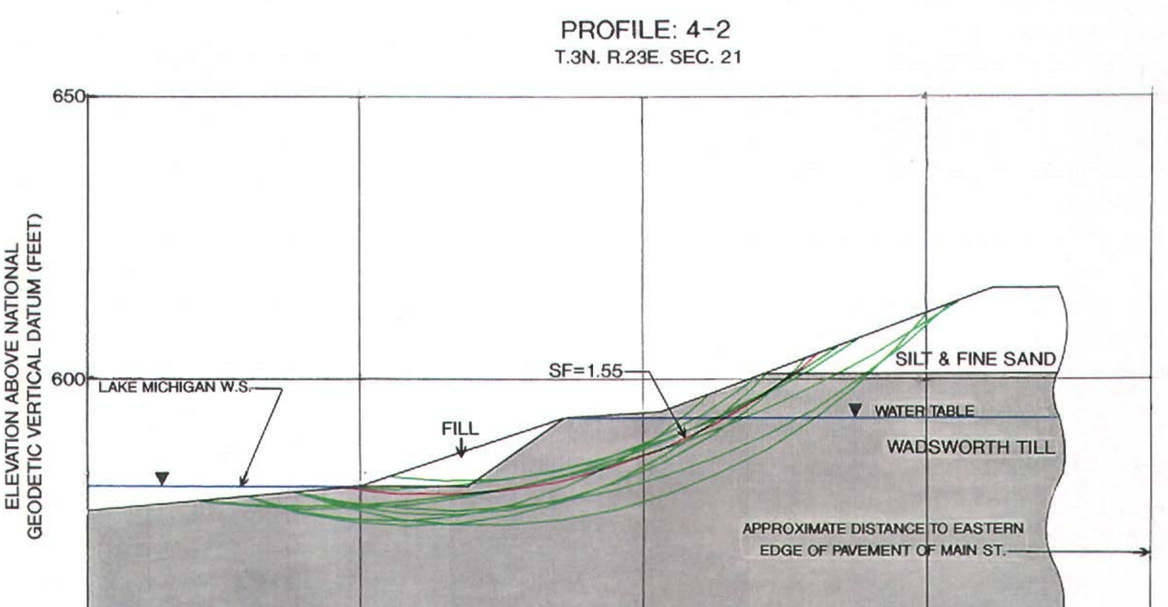


Figure 17

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 21, Township 3 North, Range 23 East
City of Racine, Racine County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

of five feet was reached at about 17 feet offshore in 1995. In 1976, the nearshore lake bed depth of five feet was reached at about 20 feet offshore at Profile No. 4-1 and at about 25 feet offshore at Profile No. 4-2. The offshore surface materials observed during 1976 were gravel in the northern portion of the section, and gravel and rocks in the southern portion.

Shoreline recession data for Section 21 of Reach 4 were estimated at four locations. These data indicated a recession of between 10 and 70 feet, or between 0.3 and 2.2 feet per year, occurred between 1963 and 1995. Recession decreased from south to north, decreasing from 70 feet in the vicinity of the southern profile site, to about 40 to 50 feet in the middle portions of the reach, to about 10 feet in the vicinity of the north section line of Section 21. The maximum observed recession occurred in the vicinity of the southern profile site, Profile No. 4-1. The data indicated that most of that recession occurred prior to 1975, with a recession of between zero and 20 feet, or up to about one foot per year, occurring between 1975 and 1995. These data conformed to a similar distribution pattern as the 1963 to 1995 data, with the severity of erosion decreasing from south to north within the section. The maximum observed recession occurred both north and south of the Racine Water and Wastewater Utilities sewage treatment plant, located on the coastline between 24th Street and 21st Street. The placement of riprap and rubble throughout this zone after 1975 appeared to have partially stabilized the bluff. No further recession was observed in the northern portion of the section, immediately south of the north section line. The 1977 study reported a recession rate of two feet per year for this erosion zone.

In 1995, the bluff appeared to be partially stable within Section 21, although more substantial shoreline protection may be necessary during future periods of higher lake levels.

U.S. Public Land Survey Section 16, Township 3 North, Range 23 East, City of Racine, Racine County

This shoreline analysis section extends from about 17th Street extended north to about 7th Street, in the City of Racine, as shown on Map 22. In 1995, the lakeshore area was occupied by commercial and industrial land uses, including Gateway Technical Institute; and residential lands, including limited areas of multi-family residential development. In 1995, the section was protected by a variety of shoreline protection structures, including revetments and breakwaters. The beach was nonexistent, and there was no natural bluff, within this section.

No bluff stability analyses were conducted within Section 16 during this study or in 1976 or 1982.

No measurements or observations were made of the nearshore lakebed depth or material within Section 16 in 1995 or in 1976 or 1982.

Shoreline recession data for Section 16 were not estimated.

U.S. Public Land Survey Section 9, Township 3 North, Range 23 East, City of Racine, Racine County

This shoreline analysis section extends from about 7th Street extended north to St. Patrick Street extended, at the southern end of North Beach Park, in the City of Racine, as shown on Map 23. In 1995, the lakeshore area was occupied by commercial and industrial land uses, including Racine Harbor Marina; parklands, including Pershing and Lakefront Festival Parks; and residential lands, including limited areas of multi-family residential development. The Racine Harbor infrastructure occupied the lakeshore in this section. In 1995, the section was protected by a variety of shoreline protection structures, including revetments and breakwaters. The beach was generally nonexistent, except for within groin systems in isolated areas immediately adjacent to shoreline protection structures in the northern portion of the section, and there was no natural bluff within this section.

No bluff stability analyses were conducted within Section 9 during this study or in 1976 or 1982.

No measurements or observations were made of the nearshore lakebed depth or material within Section 9 in 1995 or in 1976 or 1982.

Shoreline recession data for Section 9 were not estimated.

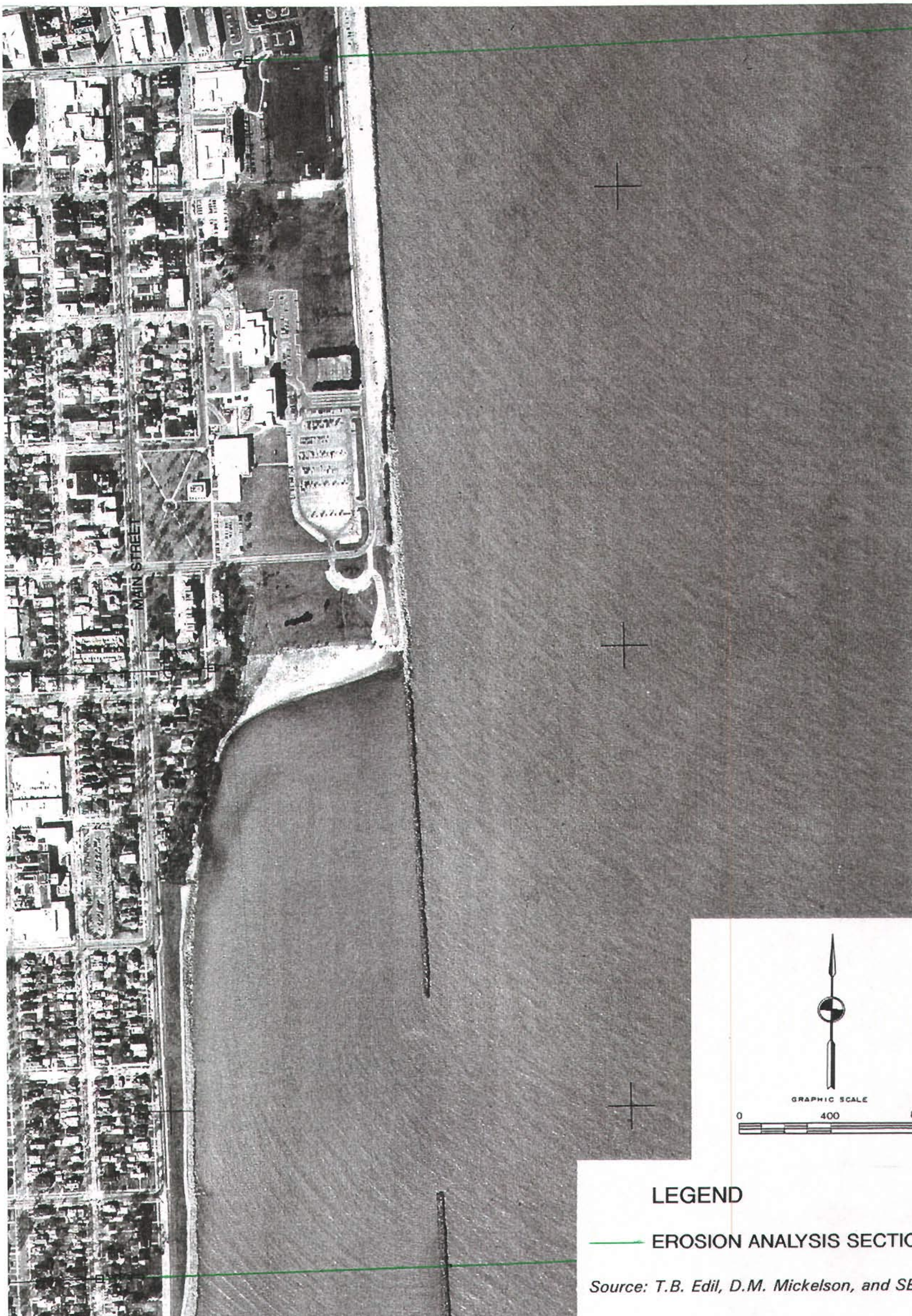
SHORELINE REACH 5: CITY OF RACINE AND VILLAGE OF WIND POINT, RACINE COUNTY

Shoreline Reach 5 is a three-mile-long reach of shoreline extending through the northern portion of the City of Racine from about North Beach Park at St. Patrick Street, on the south line of U.S. Public Land Survey

Map 22

SHORELINE EROSION REACH 4: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 16, Township 3 North, Range 23 East
City of Racine, Racine County

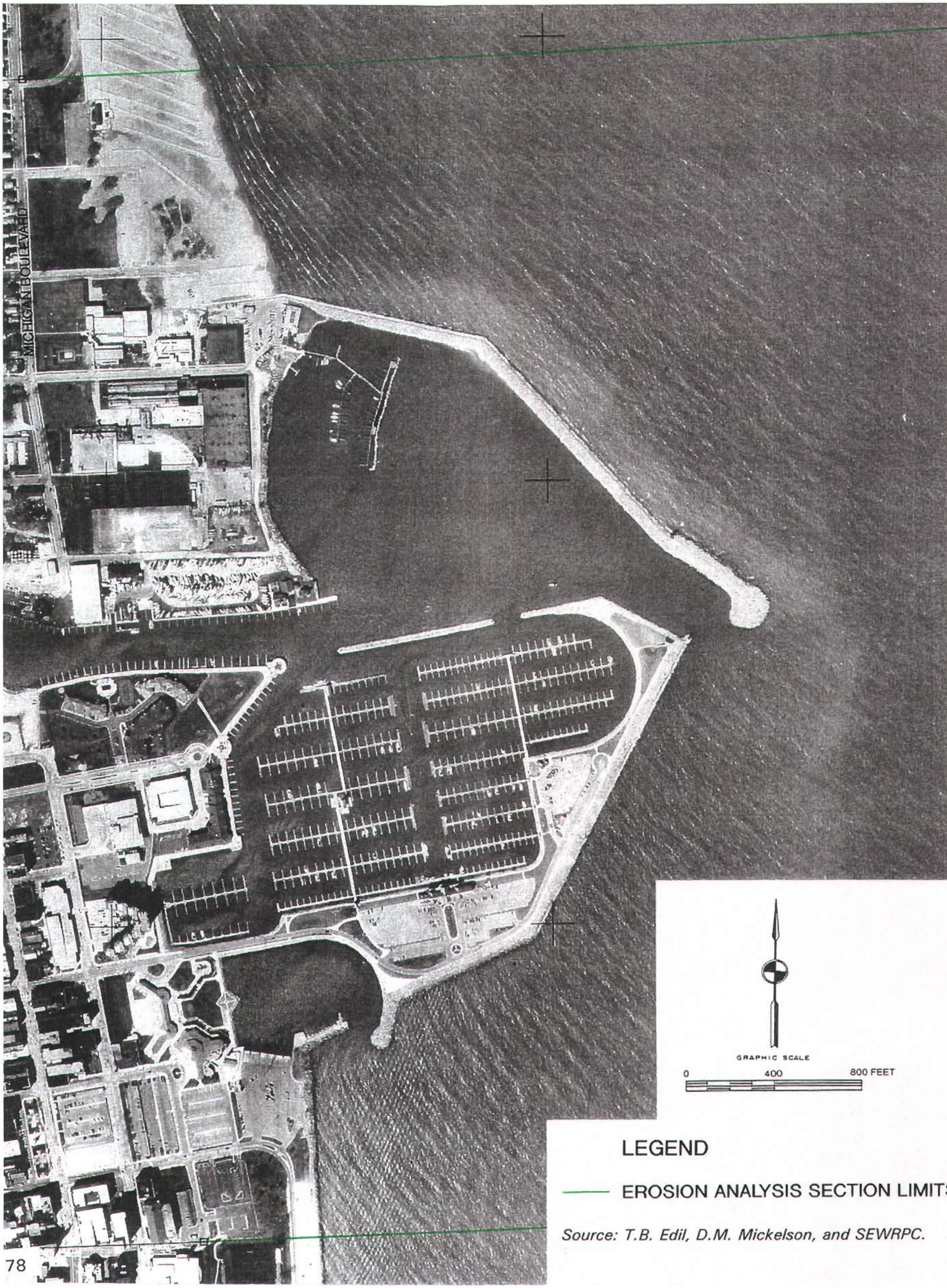


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 23

SHORELINE EROSION REACH 4: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 9, Township 3 North, Range 23 East
City of Racine, Racine County



Source: *T.B. Edil, D.M. Mickelson, and SEWRPC.*

Section 4, Township 3 North, Range 23 East, City of Racine, north to a point just north of Shoop Park at Four Mile Road on the north line of U.S. Public Land Survey Section 27, Township 4 North, Range 23 East, Village of Wind Point, as shown on Map 24. Land uses along this reach included open spaces in North Beach Park, the Zoological Gardens, and Shoop Park, with the remaining shore lands primarily in residential use. In 1976, this reach was ranked 10th in the list of the 10 most critical portions of the Lake Michigan shoreline in Wisconsin. As of 1995, the entire shoreline in Reach 5 was protected by structural shore protection measures, consisting of revetments and groins.

As shown on Map 24 Reach 5 was further segmented into three analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three analysis sections in Reach 5.

U.S. Public Land Survey Section 4, Township 3 North, Range 23 East, City of Racine, Racine County

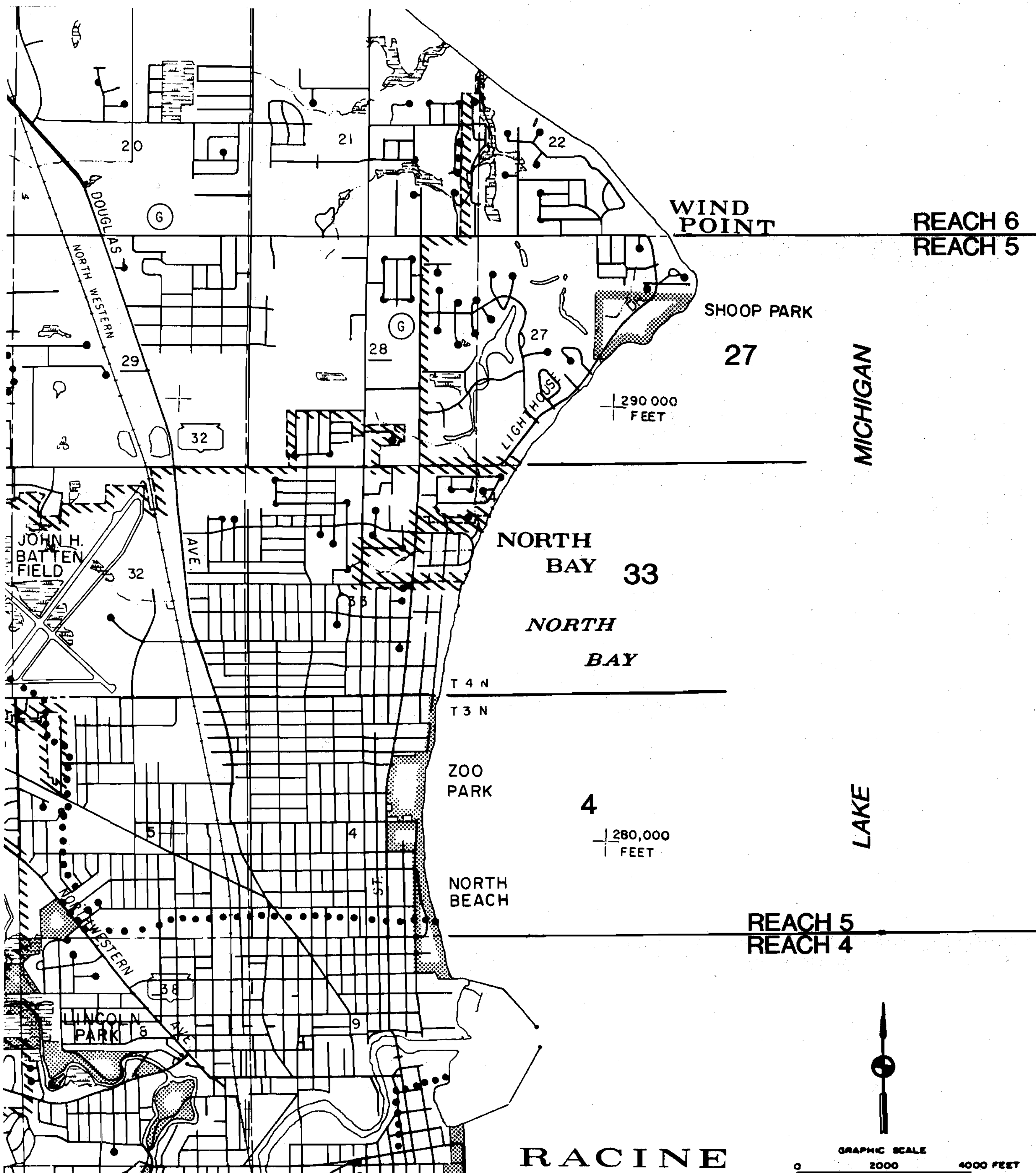
This shoreline analysis section extends from St. Patrick Street north through North Beach Park and the Zoological Gardens to Melvin Avenue in the City of Racine, as shown on Map 25. In 1995, the lakeshore area was occupied by parkland and residential land uses. The parkland was located along the central portion of the section, with residential land use located both north and south of the parks. The entire section was protected by groins at the toe of the bluff which had a height of 35 to 40 feet. The bluff materials in this section were concealed as a result of the extensive shoreline protection works and fill, but were estimated to be medium-fine sand overlain by silt and fine sand. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for Section 4.

In 1995, this section had a broad beach of up to 250 feet in width at the southern extreme of the section diminishing to nonexistent at the northern extreme. Portions of the shoreline within this section were protected by a variety of different types of structures, including groins and riprap in the south and a seawall in the north. The bluff had a height of 35 to 45 feet. In 1995, the bluff appeared stable and vegetated, although signs of translational slumping were present in the northern portions of the section. The 1995 field observations indicated no visible retreat in the bluff top in this section since 1976.

In 1995, two bluff profile field surveys were made within Section 4, both by reoccupying sites of field surveys conducted in 1976. Both sites had a similar site geometry in 1995, to that documented in 1976. Profile No. 5-1 was located in the southern portion of the section where Chatham Street makes a left-hand turn along the southern boundary of the Zoological Gardens, adjacent to the southern boundary of the Zoological Gardens. Profile No. 5-2 was centrally located within the reach at the point where Goold Street intersected the shoreline. The sites had significantly different geometries to those documented in 1976. Profile No. 5-1 was least different, with minor changes in the shape of the beach dunes fronting the bluff. One dune was observed at this site in 1995 in contrast to the two or three dunes reported in the 1977 study. Profile No. 5-2 was most different, with a low beach dune at the bluff toe and a vertical slope immediately below the bluff crest being observed in 1995. These features were not reported at this site in the 1977 study. The stability of the bluff in Section 4 of Reach 5 was characterized by Profile Nos. 5-1 and 5-2. Results of the slope stability analysis, shown in Figure 18, indicated the bluff was marginally stable, with safety factors of 1.0 at Profile No. 5-1 and 1.09 at Profile No. 5-2, based upon the deterministic bluff stability analysis method. Profile Nos. 5-1 and 5-2 were also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.88 to 1.56 for both sites. Profile No. 5-1 had a range in safety factors from 0.88 to 1.46 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 13, or 52 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 26, or 10.4 percent, of the 250 conditions analyzed. Profile No. 5-2 had a range in safety factors from 0.95 to 1.56 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for four, or 16 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for four, or 1.6 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff at Profile No. 5-1 was

Map 24

BLUFF ANALYSIS SECTIONS WITHIN REACH 5

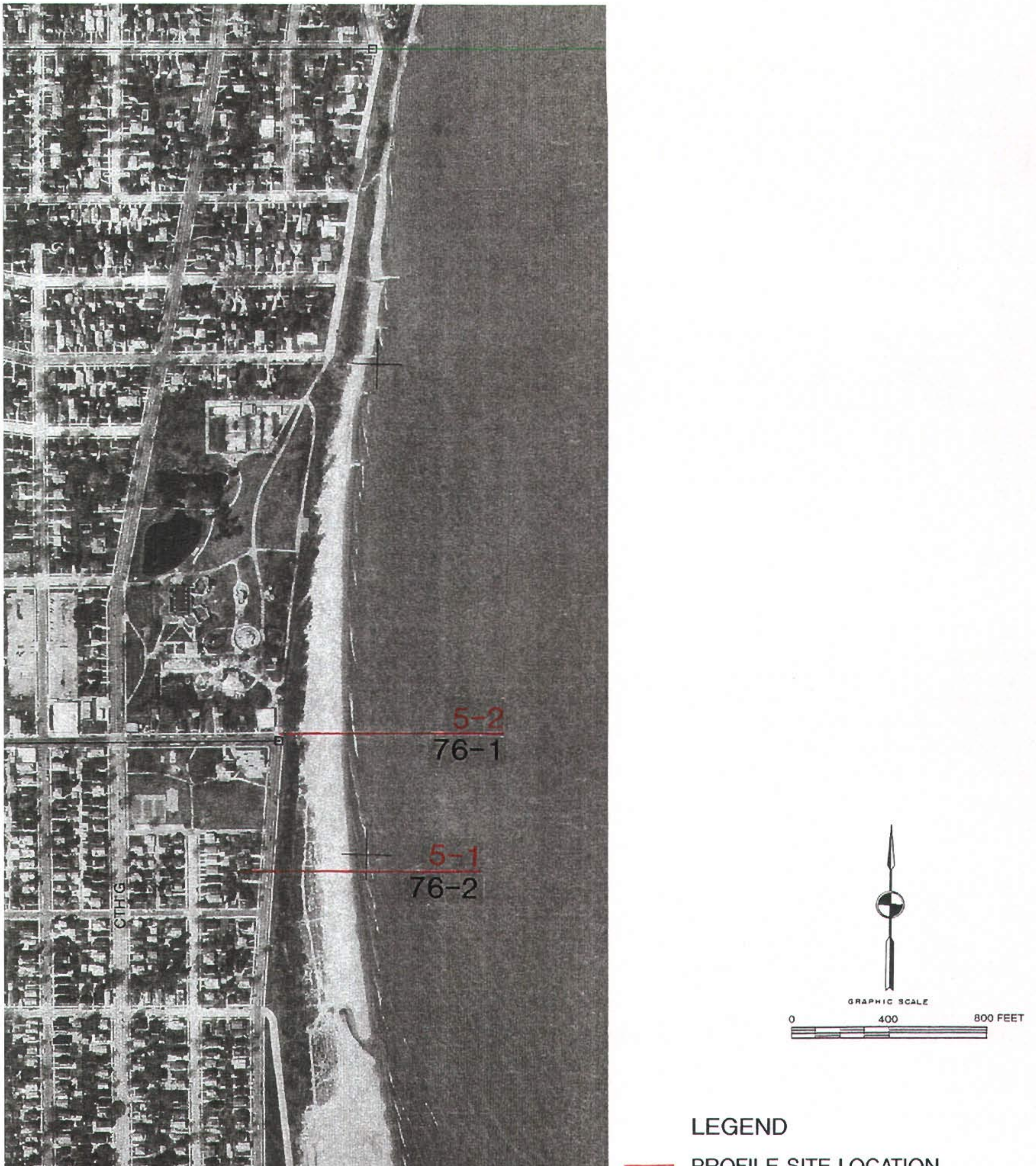


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 25

SHORELINE EROSION REACH 5: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 4, Township 3 North, Range 23 East
City of Racine, Racine County



LEGEND

PROFILE SITE LOCATION

5-2 PROFILE NUMBER: 1995 FIELD INVENTORY

76-1 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

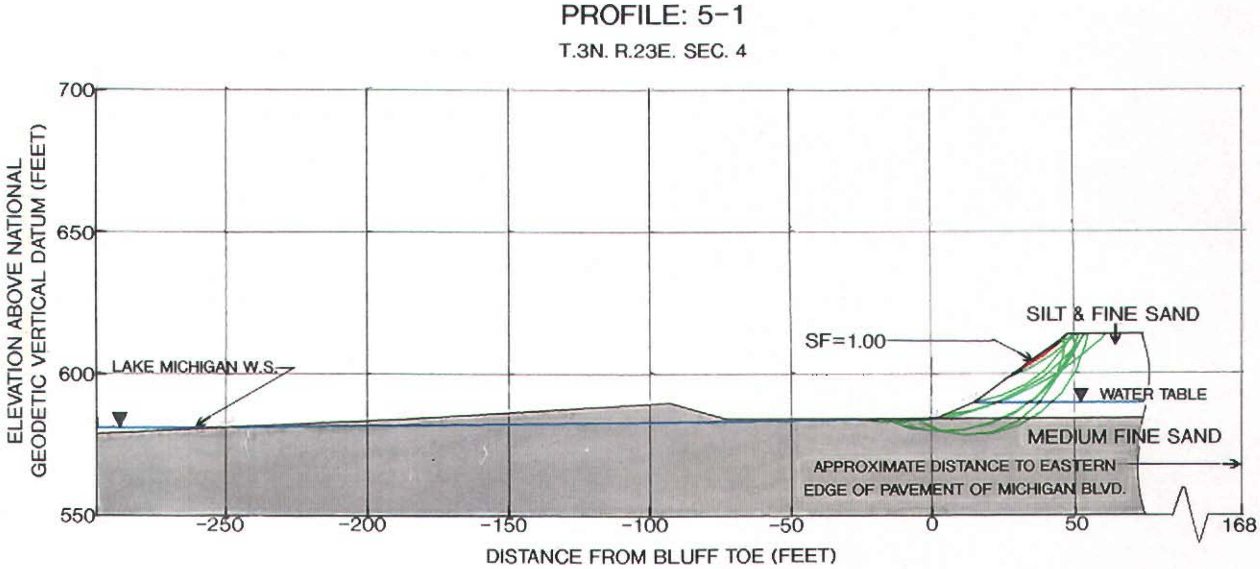
EROSION ANALYSIS SECTION LIMITS

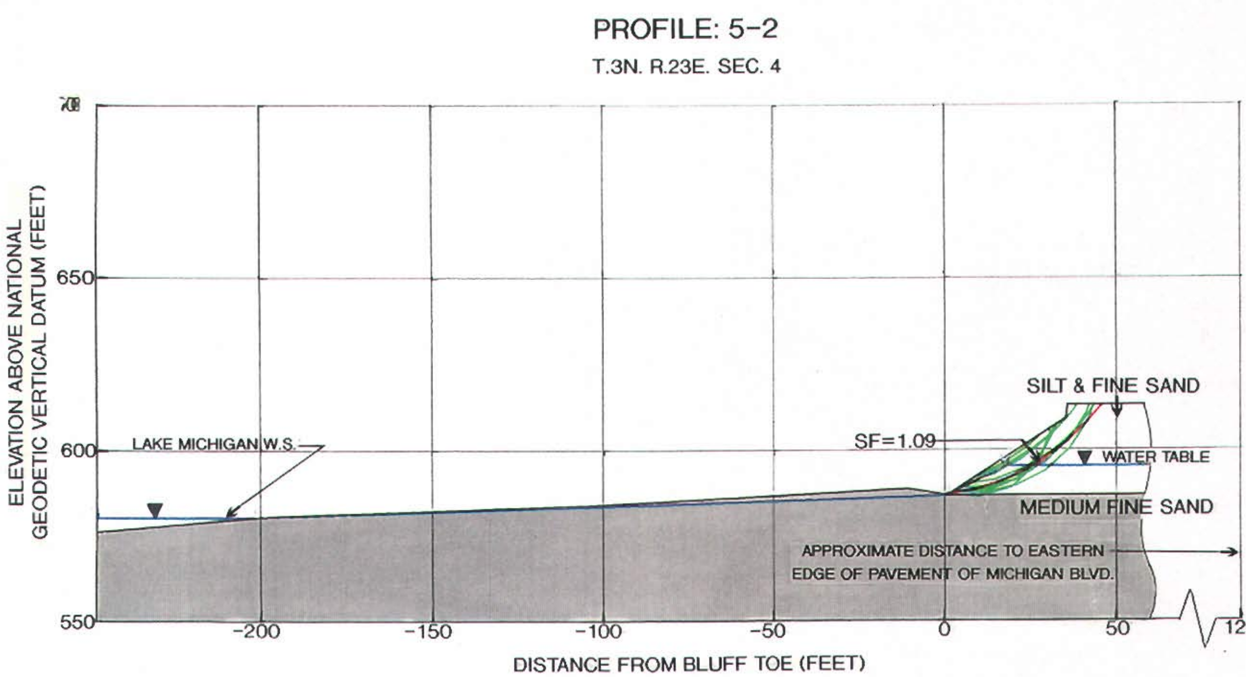
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 18

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 4, Township 3 North, Range 23 East
City of Racine, Racine County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

considered unstable, and the bluff at Profile No. 5-2 was considered marginally stable with the possibility of both rotational and translational failures. The 1977 study reported a bluff safety factor of 1.0 at both sites.

The beach in the southern portion of Section 4 was found to be sandy, and was up to 250 feet wide in the southern half of the section, tapering to less than 25 feet in the north of Section 4. In the 1977 study, the beach width was reported to be between zero and 250 feet, with the widest portion of the beach located in the southern portion of the section, and the beach materials were reported to be sand in the southern portion of the section, grading to gravel in the northern portion. At the Profile No. 5-2 site, the near offshore surface materials consisted primarily of sand. The nearshore lakebed depth of five feet was reached at about 143 feet offshore. No information was reported on offshore depth in the 1977 study for comparison purposes.

Shoreline recession data for Section 4 of Reach 5 were estimated at five locations. These data indicated a recession of between zero and 20 feet, or between zero and 0.6 foot per year, occurred between 1963 and 1995. The data indicated that most of that recession in the extreme southern portion, at about St. Patrick Street, and the northern portions of the section, north of Goold Street, occurred prior to 1975, with no further recession occurring between 1975 and 1995. The data further indicated that shoreline recession increased in the south-central portions of the section, adjacent to Hoffert Drive at North Beach Park, subsequent to 1975, with a recession of between 10 and 20 feet, or between 0.5 and one foot per year, occurring between 1975 and 1995. The placement of riprap and rubble within this zone after 1975 appeared to have partially stabilized the bluff. The 1977 study reported a recession rate of between one and five feet per year for this erosion zone.

U.S. Public Land Survey Sections 33 and 34, Township 4 North, Range 23 East, City of Racine, Racine County

This shoreline analysis section extends from Melvin Avenue extended to the north lines of Sections 33 and 34 at Three Mile Road extended, as shown on Map 26. The entire lakeshore area in this section was occupied by residential land uses. The shoreline has been modified by shore protection structures, primarily riprap and rubble, and old groins, many of which appear to be in need of repair. The bluff materials in this section were generally covered, but were estimated to be till in the lower half of the bluff overlain by sand. For analysis purposes, Sections 33 and 34 were further subdivided into three erosion zones, as shown on Map 26. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are described below for each of the three erosion zones in Sections 33 and 34.

Erosion Zone 33a

Erosion Zone 33a extends from the southerly limit of Section 33 north about 0.45 mile to Flower Lane extended, as shown on Map 26. This zone had a 50- to 100-foot-wide beach protected by groins. A low bluff with a height of about 25 to 35 feet existed in this zone. The bluff toe was protected by riprap or revetment over about 90 percent of the shoreline length. In 1995, the bluff appeared stable and was vegetated. The 1995 field observations indicated that no assessment of retreat in the bluff top could be made due to regrading and vegetation cover.

No bluff stability analyses were conducted within Erosion Zone 33a in this study or the 1997 study.

The beach was up to 100 feet in width within Zone 33a, contained with a groin system. In the 1977 study, the beach width was reported to be between zero and 20 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 33a were estimated at two locations. These data indicated a recession of between zero and 20 feet, or between zero and 0.6 foot per year, occurred between 1963 and 1995. The greatest shoreline loss occurred in the southern portion of the zone in the vicinity of Melvin Avenue and decreased to the north, with no recession being estimated in the vicinity of Lombard Avenue extended. The 1977 study reported a recession rate of one foot per year in the southern portion of this erosion zone.

Erosion Zone 33b

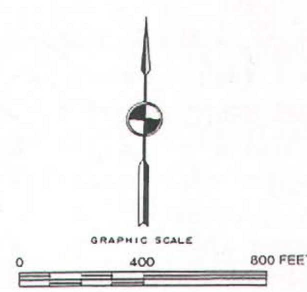
Erosion Zone 33b extends from the northerly limit of Erosion Zone 33a north about 0.1 mile to a point where Lansdale Lane and northern portion Shore Acres Drive extended intersect the lakeshore, as shown on Map 26. This zone had a narrow beach fronting a low bluff. The bluff had a height of about 18 to 25 feet and was reported as very unstable in 1976. In 1995, the bluff was heavily vegetated with aspen and goldenrod covering approximately the entire bluff slope. In 1995, the bluff appeared stable with respect to rotational failures, but exhibits translational sliding and creep on the bluff face and some slight erosion of the bluff toe. The 1995 field observations indicated that no assessment of retreat in the bluff top could be made due to the vegetation cover.

In 1995, one bluff profile field survey was made within Zone 33b by occupying a site for which a field survey was conducted in 1976, as shown on Map 26. The site had a markedly different geometry in 1995, to that documented in 1976 due to extensive regrading. The

Map 26

SHORELINE EROSION REACH 5: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 33 and 34, Township 4 North, Range 23 East
City of Racine, Racine County



LEGEND

PROFILE SITE LOCATION

5-3 PROFILE NUMBER: 1995 FIELD INVENTORY

76-1 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

33-34c EROSION ANALYSIS ZONE NUMBER

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

stability of the bluff in Erosion Zone 33b of Reach 5 was characterized by Profile No. 5-3. Results of the slope stability analysis, shown in Figure 19, indicated the bluff was stable with respect to rotational failures, with a safety factor of 1.65. Field observations indicated that translational failures are also possible. The 1977 study reported a bluff safety factor of 0.89.

The beach was less than 50 feet wide within Zone 33b. In 1995, the beach materials were noted to be primarily sand and cobbles. In the 1977 study, the beach width was reported to be between 20 and 40 feet, and the beach material was reported to be sand. At Profile No. 5-3, the nearshore lakebed depth of five feet was reached at 54 feet offshore. The primary offshore material was sand. There appeared to have been a shallowing of the beach profile at this site, where the nearshore lakebed depth of five feet was reached at approximately 80 feet, with a bottom consisting of sand and gravel, in the 1977 study.

Shoreline recession data for Erosion Zone 33b were estimated at one location. These data indicated a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. The data indicated that most of the recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. The increased vegetation coverage of the bluff slope after 1975 appeared to have largely stabilized the bluff. The 1977 study did not report a recession rate for this erosion zone.

Shoreline protection structures will be required within Erosion Zone 33b to prevent severe erosion of the bluff during future periods of higher lake levels.

Erosion Zone 33c

Erosion Zone 33c extends from the northerly limit of Erosion Zone 33b in the vicinity of Lansdale Lane and the northern portion Shore Acres Drive extended north approximately 0.45 mile to the north section line of Section 33 at Three Mile Road, as shown on Map 26. This zone had a similar beach to the zone immediately to the south, ranging from zero to 50 feet in width. The bluff in this zone had a height of from 15 to 25 feet. Most of the bluff was protected by revetments and groins. In 1995, the bluff appeared stable and was well-vegetated. The 1995 field observations indicated that no assessment of retreat in the bluff top could be made due to the vegetation cover.

In 1995, one bluff profile field survey was made within Zone 33c by occupying a site for which a field survey was conducted in 1976. The site had a similar geometry to that which was documented in 1976, although the bluff slope appeared to be less steep. The stability of the bluff in Zone 33c of Reach 5 was characterized by Profile No. 5-4. Results of the slope stability analysis, shown in Figure 19, indicated that the bluff was stable with respect to rotational failures, with a safety factor of 1.74. Field observations indicated that shallow translational failures are possible in this zone. The 1977 study reported a bluff safety factor of 0.85.

The beach was up to 50 feet wide within Zone 33c. In 1995, the beach materials were noted to be primarily sand and cobbles. In the 1977 study, the beach width was reported to be between zero and 20 feet, and the beach material was reported to be sand. No measurements or observations were made of the nearshore lakebed depth of material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 33c were estimated at two locations. These data indicated a recession of between zero and 30 feet, or between zero and 0.9 foot per year, occurred between 1963 and 1995. The data indicated that most of the recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. The placement of additional shoreline protection structures after 1975 appeared to have largely stabilized the bluff. The 1977 study reported a recession rate of between one and three feet per year for this erosion zone.

Regular maintenance of the shoreline protection structures will be required to prevent future erosion within Erosion Zone 33c.

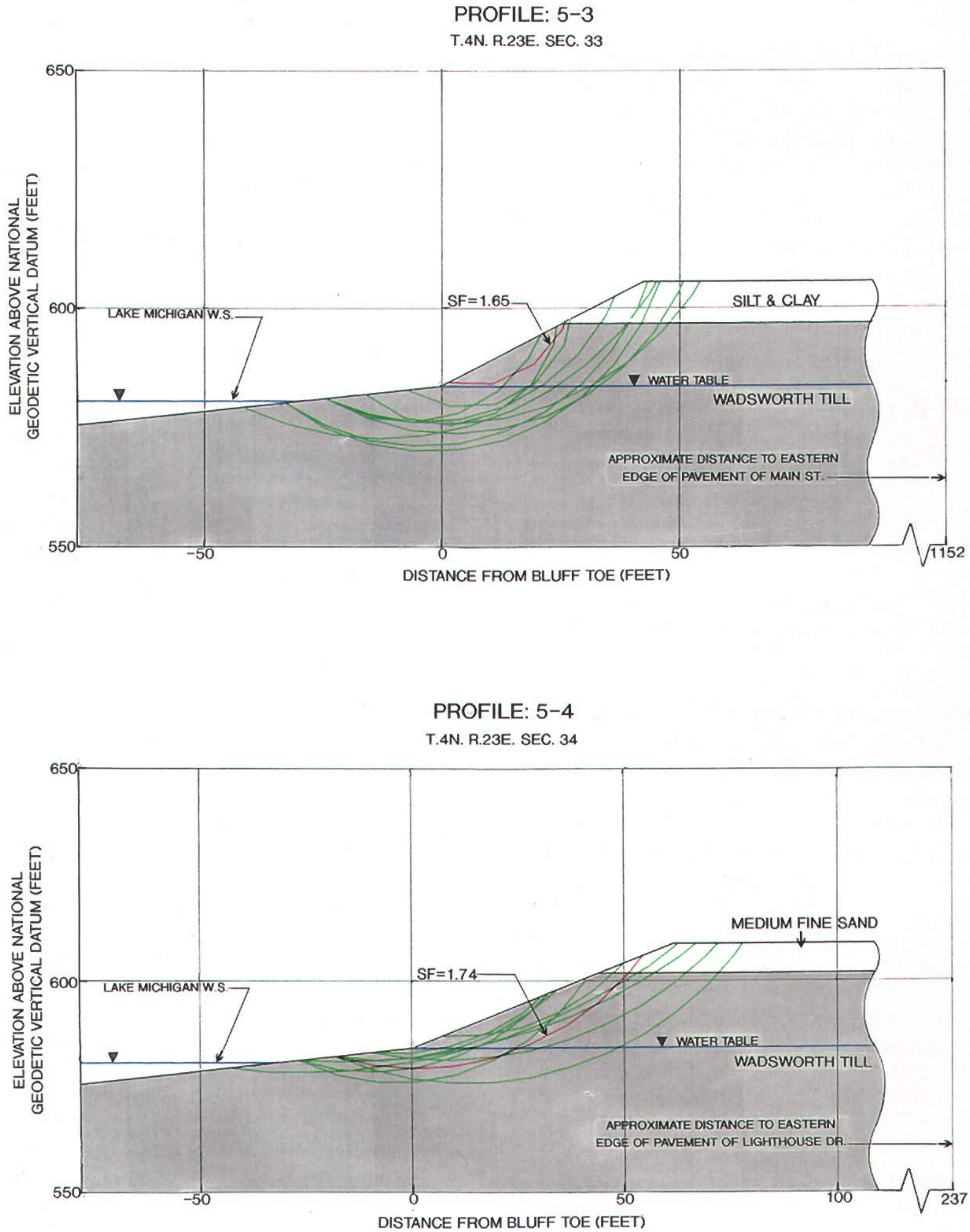
U.S. Public Land Survey Section 27, Township 4 North, Range 23 East, Village of Wind Point, Racine County

This shoreline analysis section extends from the north line of Section 27 at Three Mile Road extended in the City of Racine north to south line of Section 22 at Four Mile Road (CTH G) extended in the Village of Wind Point, as shown on Map 27. The shoreline was occupied by residential land, and by park and open spaces uses at Shoop Park. Much of the shoreline was protected by a variety of different types of shore protection structures. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by intermixed silt and clay, with some sand in specific locations. Large sections of fill in the southern portion of this zone, placed subsequent to 1970, appeared to have stabilized the shoreline erosion problems previously observed in this section. For analysis purposes, Sec-

Figure 19

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Sections 33 and 34, Township 4 North, Range 23 East
City of Racine, Racine County

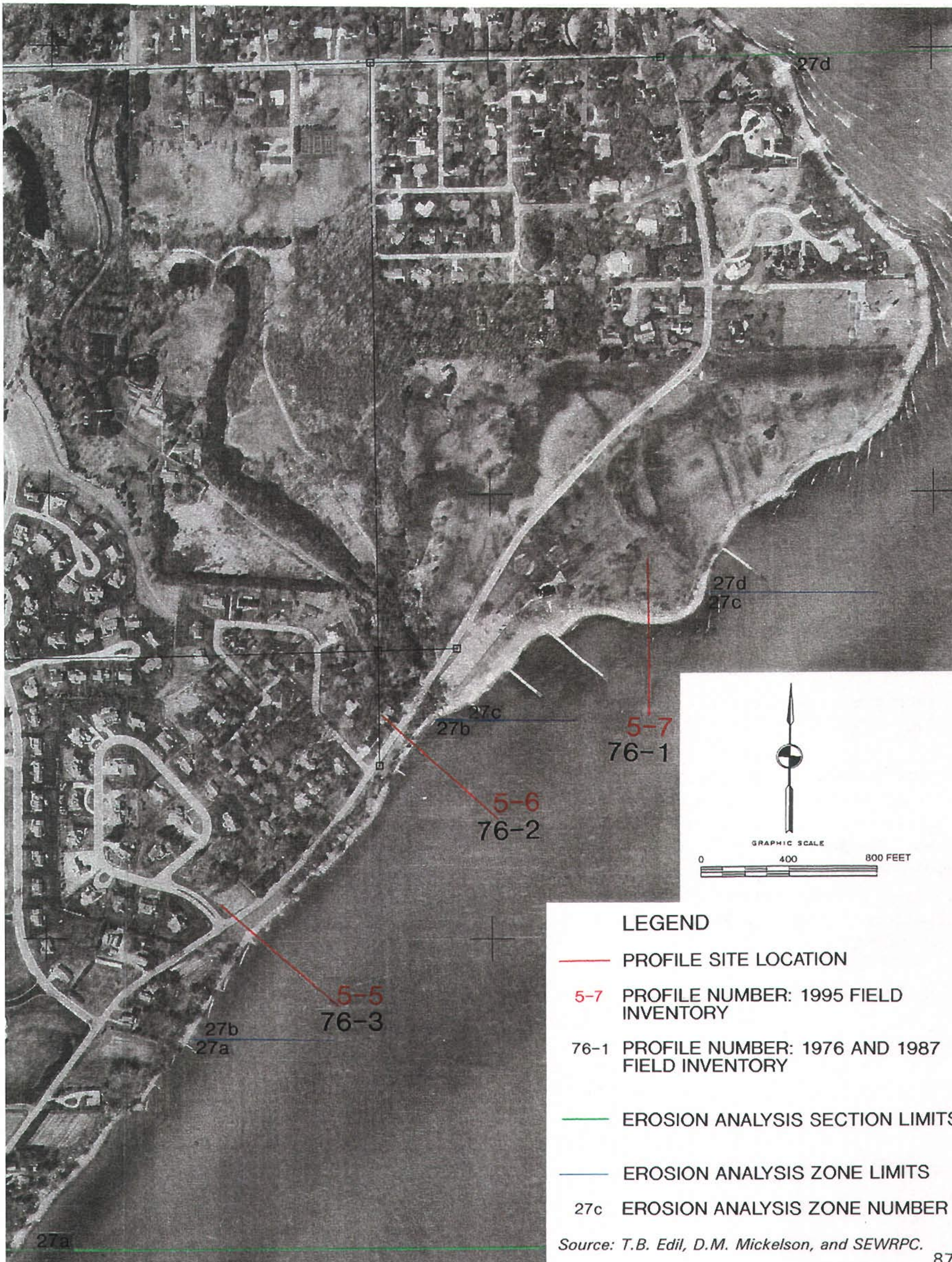


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 27

SHORELINE EROSION REACH 5: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 27, Township 4 North, Range 23 East
Village of Wind Point, Racine County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

tion 27 has been further subdivided into four erosion zones, as shown on Map 27. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the four erosion zones in Section 27.

Erosion Zone 27a

Erosion Zone 27a extends from the northerly limit of Section 33 north about 0.2 mile to W. Lake Meadow Drive East extended, as shown on Map 27. This zone had a beach with a width of about 25 feet contained within two small groins located in the northern portion of the zone. A low bluff with a height of about 20 feet existed in this zone. In 1995, the bluff was protected by a debris field extending out onto the beach. The upper part of the bluff was partially vegetated, with grasses and brush covering approximately 50 percent of the bluff slope. The bluff appeared to be moderately stable with some evidence of shallow slides and soil creep, evidenced by numerous trees leaning toward the water, being observed. The 1995 field observations indicated between zero and two feet of retreat in the bluff top since 1976 and that rotational and shallow translational failures are both possible in this zone.

No bluff stability analyses were conducted within Erosion Zone 27a in this study or the 1977 study.

The beach was up to 25 feet wide within Zone 27a, contained within two small groins. In the 1977 study, the beach width was reported to be between zero and five feet, and the beach materials were reported to be generally absent with the shorelands covered by dumped debris. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 27a were estimated at one location. These data indicated a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. The 1977 study reported a recession rate of one foot per year for this erosion zone.

Erosion Zone 27b

Erosion Zone 27b extends from the northerly limit of Erosion Zone 27a at W. Lake Meadow Drive East north about 0.26 mile, as shown on Map 27. This zone had a narrow to nonexistent beach, being completely protected by a revetment of large limestone blocks and small groins. The bluff had a height of about 25 feet in this zone. The bluff material at the profile sites was concealed by fill material deposited at the site. The 1995 field observations indicated that there had been no visible retreat in the bluff top since 1975. However, the bluff top was close to Lighthouse Road throughout much of this zone, with several structures present between Lighthouse Road and the bluff top in the northern portion of the zone.

In 1995, two bluff profile field surveys were made within Zone 27b by occupying sites for which field surveys were conducted in 1976. The southernmost site had a markedly different site geometry to that documented in 1976 due to extensive regrading. Some small fills to protect the base of the bluff were also observed at Profile No. 5-5, which was located in the southern portion of the zone in the vicinity of Lamplighter Lane extended. Profile No. 5-6, located in the northern portion of the zone in the vicinity of Merriburr Lane extended, was similar in geometry to that documented in 1976. The stability of the bluff in Zone 27b of Reach 5 was characterized by Profile Nos. 5-5 and 5-6. Results of the slope stability analysis, shown in Figure 20, indicated that the bluff was stable with respect to rotational failures, having safety factors of 1.7 at the southern Profile No. 5-5 site, and 1.49 at the northern Profile No. 5-6 site. However, shallow translational failures were observed in 1995 and may occur at the Profile No. 5-6 site in the future. The 1977 study reported bluff safety factors of 1.1 overall, with a safety factor of 0.83 on the bluff face, respectively, at these sites.

The beach was very narrow within Erosion Zone 27b. In the 1977 study, the beach width was reported to be between zero and 65 feet, and the beach materials were reported to be sand, pebbles, and cobbles. At Profile No. 5-5, the primary nearshore surface materials consisted primarily of sand and gravel, and the nearshore lakebed depth of five feet was reached at 72 feet offshore in 1976. At Profile No. 5-6, the primary nearshore surface materials consisted primarily of sand and gravel, and the nearshore lakebed depth of five feet was reached at 46 feet offshore in 1976. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995.

Shoreline recession data for Erosion Zone 27b were estimated at one location. These data indicated a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with no further

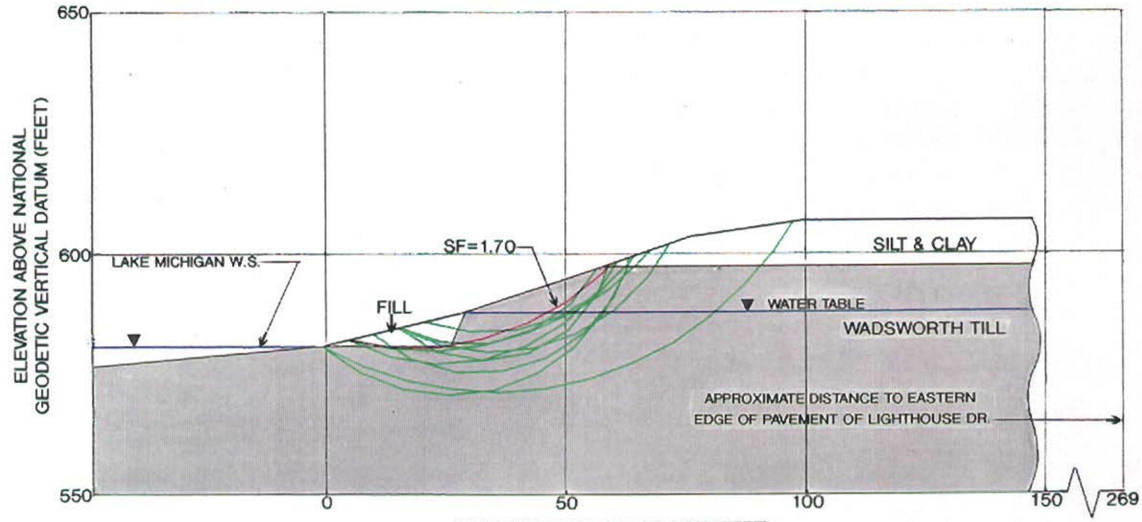
Figure 20

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 27, Township 4 North, Range 23 East
Village of Wind Point, Racine County

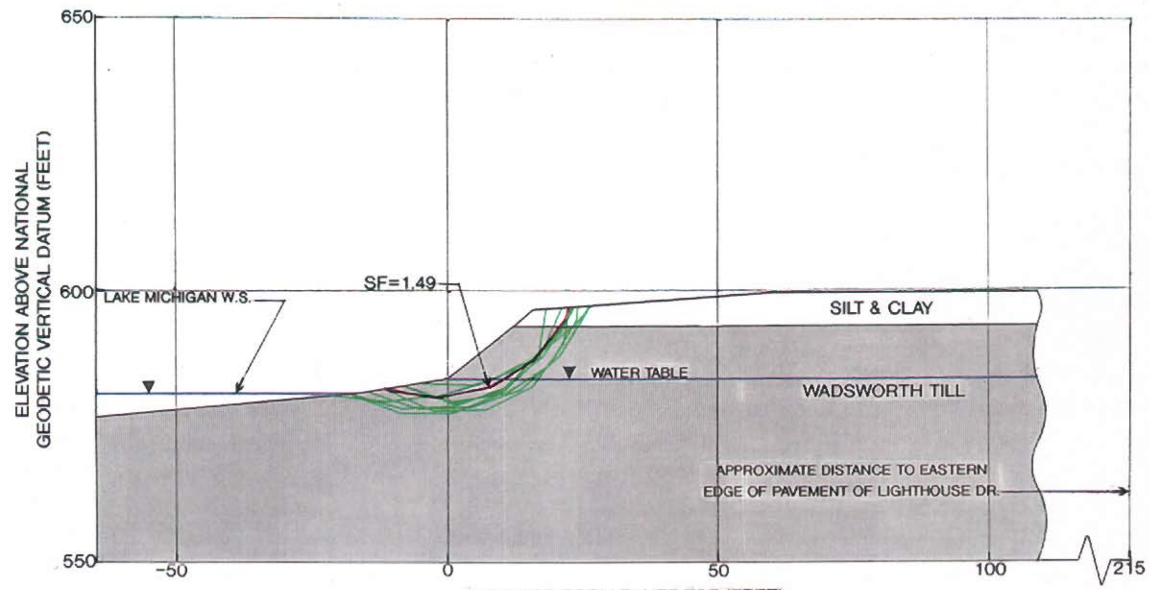
PROFILE: 5-5

T.4N. R.23E. SEC. 27



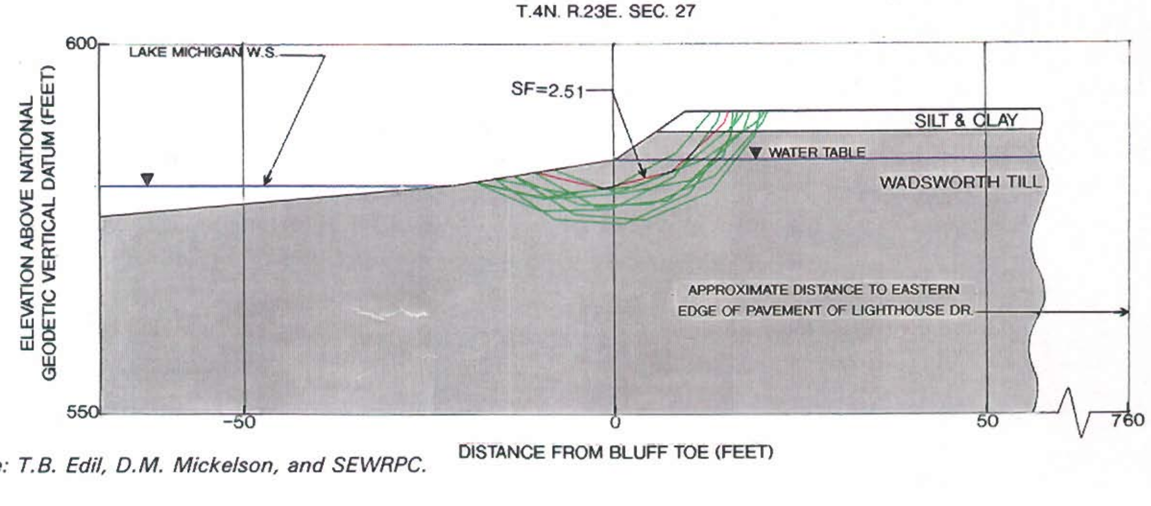
PROFILE: 5-6

T.4N. R.23E. SEC. 27



PROFILE: 5-7

T.4N. R.23E. SEC. 27



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

recession occurring between 1975 and 1995. The 1977 study did not report a recession rate for this erosion zone.

Erosion Zone 27c

Erosion Zone 27c extends from the northerly limit of Erosion Zone 27b north about 0.1 mile, as shown on Map 27. The zone had a beach of about 25 feet in width, maintained by long groins. The bluff in this zone had a height of about 10 feet, and was well-vegetated. In 1995, the bluff appeared stable, despite being unprotected. The 1995 field observations indicated that there had been no visible retreat in the bluff top since 1975.

In 1995, one bluff profile field survey was made within Zone 27c by occupying a site for which a field survey was conducted in 1976. The site had a similar geometry to that documented in 1976. The stability of the bluff in Zone 27c of Reach 5 was characterized by Profile No. 5-7. Results of the slope stability analysis, shown in Figure 20, indicated that the bluff was stable with respect to rotational failures, with a safety factor of 2.51. However, evidence of some shallow translational failures was present. Profile No. 5-7 was also analyzed using the probabilistic bluff stability analysis method which indicated that the bluff was stable with respect to rotational failures, with a safety factor of greater than 1.0 for all 250 conditions analyzed. The 1977 study reported a bluff safety factor of 0.70.

The beach was about 25 feet in width within Zone 27c, contained within a groin system. In 1995, the beach material was noted to be cobbles. In the 1977 study, the beach width was reported to be between five and 100 feet, and the beach materials were reported to be mostly gravel with some sand accretion due to the presence of the groin system. At Profile No. 5-7, the nearshore lakebed depth of five feet was reached at about 330 feet offshore—the depth of the lakebed at 200 feet offshore was noted to be about three feet—and the primary offshore material was cobbles in 1995. At Profile No. 5-7, the primary nearshore surface materials consisted primarily of pebbles and cobbles, and the nearshore lakebed depth of five feet was reached at 170 feet offshore in 1977. These data indicated a shallowing of the offshore bathymetric profile since 1976.

Shoreline recession data for Erosion Zone 27c were estimated at one location. These data indicated a recession of about 40 feet, or about 1.2 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. The 1977 study did not report a recession rate for this erosion zone.

Erosion Zone 27d

Erosion Zone 27d extends from the northerly limit of Erosion Zone 27c north about 0.45 mile to Four Mile Road extended, as shown on Map 27. This zone had a beach with a width of about 50 feet. The bluff in this zone had a height of about 10 feet. Riprap protected the toe of the bluff, and most of the bluff was vegetated, with about 40 percent of the bluff slope being covered by horsetails and grasses. In 1995, slump blocks and bluff toe erosion were noted in this zone. The 1995 field observations indicated from five to 10 feet of retreat in the bluff top since 1975.

No bluff stability analyses were conducted within Erosion Zone 27d in this study or the 1977 study.

The beach was about 50 feet in width within Zone 27d fronting a low bluff. In the 1977 study, the beach width was reported to be between 10 and 30 feet, and the beach materials were reported to be mostly pebbles, cobble, and a little sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

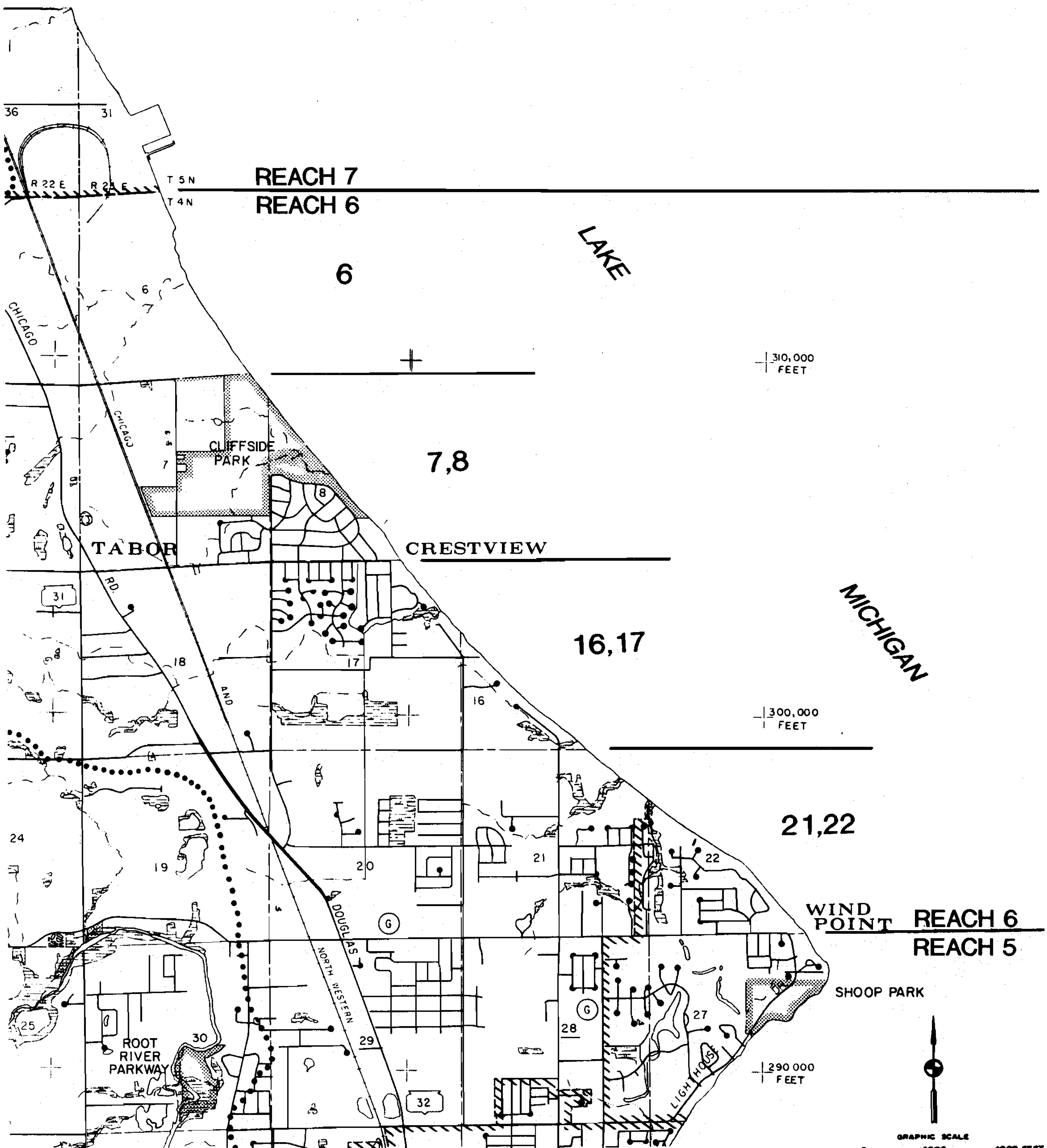
Shoreline recession data for Erosion Zone 27d were estimated at two locations. These data indicated a recession of between 20 and 40 feet, or between 0.6 and 1.2 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of between zero and 10 feet, or between zero and 0.5 foot per year, occurring between 1975 and 1995. The 1977 study reported a recession rate of 0.9 foot per year for this erosion zone.

SHORELINE REACH 6: VILLAGE OF WIND POINT AND TOWN OF CALEDONIA, RACINE COUNTY

Shoreline Reach 6 is a 12-mile-long reach of shoreline extending from the north line of U.S. Public Land Survey Section 28, Township 4 North, Range 23 East, Village of Wind Point, at Four Mile Road north to County Line Road extended on the north line of U.S. Public Land Survey Section 6, Township 4 North, Range 23 East, Town of Caledonia, as shown on Map 28. Land uses along this reach include open spaces

Map 28

BLUFF ANALYSIS SECTIONS WITHIN REACH 6



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

in Cliffside and Lake Michigan Parks, residential lands, and remnant agricultural lands, with the Oak Creek Power Plant, an industrial land use, being located at the northern extreme of the reach in Milwaukee County. In 1976, this reach ranked third in the list of critical portions of the Lake Michigan shoreline in Wisconsin. As of 1995, about three linear miles, or about 50 percent, of the shoreline in Reach 6 were protected by structural shore protection measures, consisting of revetments and groins.

As shown on Map 28, Reach 6 was further segmented into four shoreline analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the four shoreline analysis sections in Reach 6.

U.S. Public Land Survey Sections 21 and 22, Township 4 North, Range 23 East, Village of Wind Point and Town of Caledonia, Racine County

This shoreline analysis section extends from Four Mile Road extended in the Village of Wind Point north to E. Five Mile Road extended, in the Town of Caledonia, as shown on Maps 29 and 30. In 1995, the entire lakeshore area was occupied by residential lands. The Dominican College occupied part of the upland at the northern end of the section. In 1995, the southern half of the section was protected by seawalls and revetments. The northern half of the section was protected by revetments and a groin system, which appeared to be effective in accreting sand, fronting a 20- to 30-foot-wide beach. The bluff materials in this section were estimated to be primarily silty clay or fine sand and silt. For analysis purposes, Sections 21 and 22 were further subdivided into four erosion zones, as shown on Maps 29 and 30. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the four erosion zones in Sections 21 and 22.

Erosion Zone 21a

Erosion Zone 21a extends from the south line of Section 21 at Four Mile Road extended north about 0.55 mile to about a point on the lakeshore adjacent to the northern end of Hunt Club Road, as shown on Map 29. This zone had a beach width of up to 40 feet contained within a groin system along portions of the shoreline. The low bluff had a height of up to 20 feet in this zone. Seawalls and revetments protected the toe of the bluff. Much of the bluff had been regraded. Vegetation, primarily grasses and horsetails, covered approximately 20 percent of the bluff slope. The 1995 field observations indicated that no assessment of retreat in the bluff top could be made due to the vegetation cover.

No bluff stability analyses were conducted within Erosion Zone 21a in this study or the 1977 study.

The beach was between 20 and 50 feet in width within Erosion Zone 21a and contained within a groin system. In the 1977 study, the beach width was reported to be between zero and 60 feet, with the widest portion of the beach located in the central portion of the zone, and the beach materials were reported to be sand and pebbles, with occasional cobbles in specific locations. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 21a were estimated at three locations. These data indicated a recession of between 20 and 90 feet, or between 0.6 and 2.8 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with a recession of between zero and 10 feet, or between zero and 0.5 foot per year, occurring between 1975 and 1995. These data indicated that the currently existing shore protection revetments and seawalls, and the regrading of the bluff slope, appeared to have partially stabilized the bluff, especially in the southern and northern portions of the zone where recession was reduced to zero. The 1977 study reported a recession rate of nine feet per year for this zone.

Erosion Zone 21b

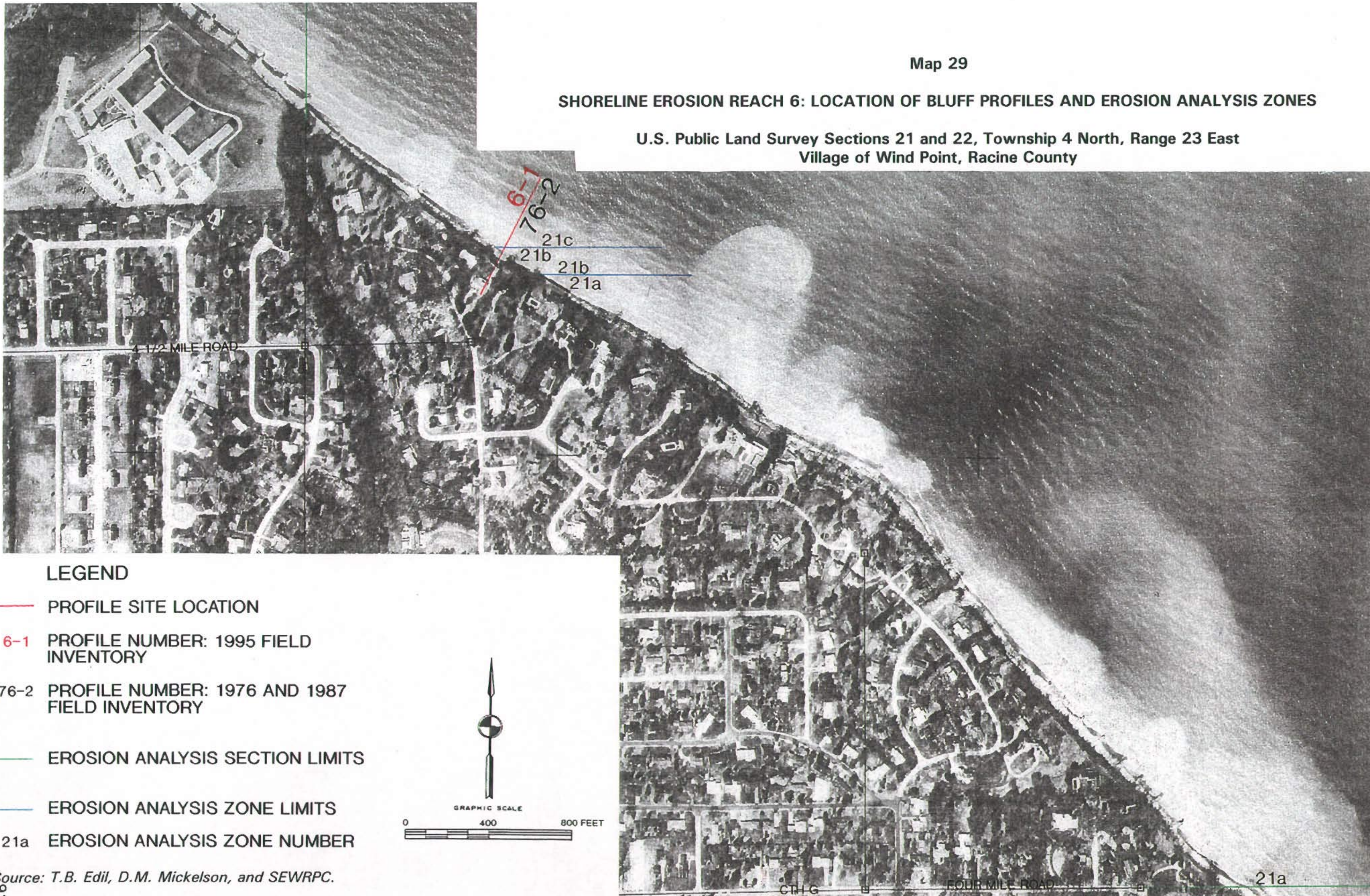
Erosion Zone 21b extends from the northerly limit of Erosion Zone 21a north about 0.02 mile to N. Wood Drive extended, as shown on Map 29. This zone had little or no beach. The low bluff had a height of up to 20 feet in this zone. In 1995, there were no shoreline protection structures in this zone. Vegetation covered approximately 10 percent of the bluff slope. The 1995 field observations indicated about 10 feet of retreat in the bluff top since 1976. Signs of recent shallow slides and flows were present.

In 1995, one bluff profile field survey was made within Zone 21b by occupying a site for which a field survey was conducted in 1976. The site had a significantly different geometry to that documented in 1976. The

Map 29

SHORELINE EROSION REACH 6: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 21 and 22, Township 4 North, Range 23 East
Village of Wind Point, Racine County



LEGEND

PROFILE SITE LOCATION

6-1 PROFILE NUMBER: 1995 FIELD INVENTORY

76-2 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

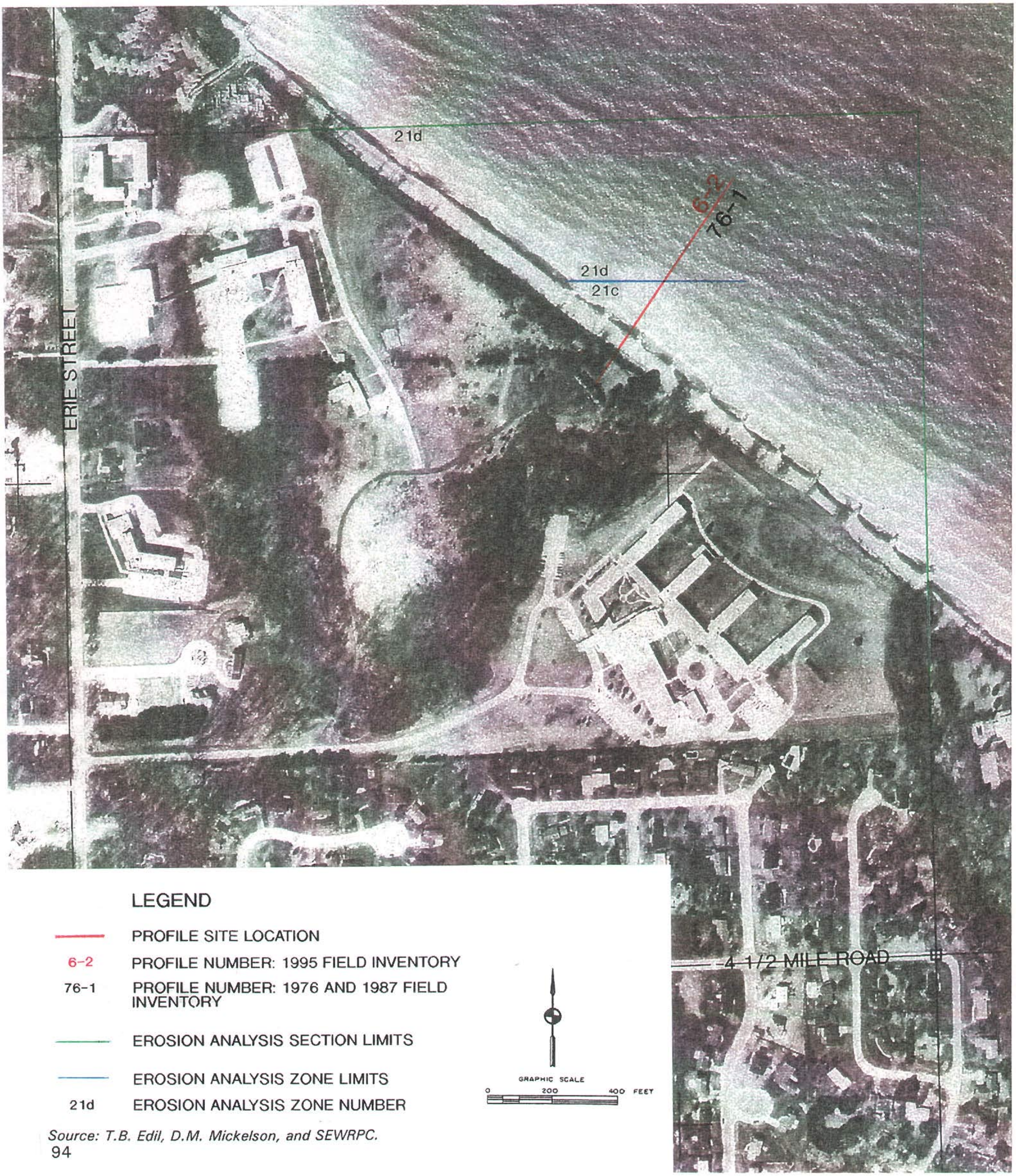
21a EROSION ANALYSIS ZONE NUMBER

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 30

SHORELINE EROSION REACH 6: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 21 and 22, Township 4 North, Range 23 East
Town of Caledonia, Racine County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

shape of the bluff had steepened with a vertical face developing at the bluff toe. The stability of the bluff in Zone 21b of Reach 6 was characterized by Profile No. 6-1. Results of the slope stability analysis, shown in Figure 21, indicated that the bluff was unstable, with a safety factor of 0.91, based upon the deterministic bluff stability analysis method. Profile No. 6-1 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.58 to 1.99 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for nine, or 36 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 31, or 12.4 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable. Field observations in 1995 indicated that translational failures may occur in unprotected areas. The 1977 study reported a bluff safety factor of 3.1.

The beach was nonexistent within Zone 21b. In the 1977 study, the beach width was reported to be between 25 and 55 feet, and the beach materials were reported to be sand and pebbles. At Profile No. 6-1, the primary nearshore surface materials were not noted in 1995. However, the nearshore lakebed depth of five feet was reached at 250 feet offshore. This represented a significant shallowing of the nearshore bathymetry. In 1977, the nearshore lakebed depth of five feet was reached at 38 feet offshore. The primary nearshore surface materials at this site in 1976 were sand and gravel.

Shoreline recession data for Erosion Zone 21b were not estimated. The 1977 study did not report a recession rate for this erosion zone.

Erosion Zone 21c

Erosion Zone 21c extends from the northerly limit of Erosion Zone 21b at N. Wood Drive extended north about 0.3 mile, as shown on Maps 29 and 30. This zone had little or no beach in the southern portion of the zone. However, a beach with a width of 50 to 75 feet contained within a groin system existed in the northern two-thirds of the zone. The low bluff had a height of up to 20 feet in this zone. In 1995, the bluff was protected by a revetment. Vegetation covered approximately 90 percent of the bluff slope. The 1995 field observations indicated that no assessment of retreat in the bluff top could be made due to the vegetation cover. However, signs of recent translational slumping and bluff toe erosion were present at the bluff toe.

In 1995, one bluff profile field survey was made within Zone 21c by occupying a site for which a field survey was conducted in 1976. The site had a significantly different geometry to that documented in 1976 due to the regarding of the bluff slope. The stability of the bluff in Zone 21c of Reach 6 was characterized by Profile No. 6-2. Results of the slope stability analysis, shown in Figure 21, indicated that the bluff was stable with respect to rotational failures, with a safety factor of 3.3. Field observations in 1995 indicated that translational failures may occur in this zone. The 1977 study reported a bluff safety factor of 2.8.

The beach was nonexistent in the southern one-third of the zone, broadening to about 75 feet in width in the northern two-thirds of Zone 21c where a groin system retarded the movement of sand. In the 1977 study, the beach width was reported to be between 25 and 55 feet, and the beach materials were reported to be sand and cobbles. At Profile No. 6-2, the primary nearshore surface materials were not noted in 1995. However, the nearshore lakebed depth of five feet was reached at 350 feet offshore. This represented a significant shallowing of the nearshore bathymetry. In 1977, the nearshore lakebed depth of five feet was reached at 30 feet offshore. The primary nearshore surface material at this site in 1976 was gravel.

Shoreline recession data for Erosion Zone 21c were estimated at one location. These data indicated a recession of about 60 feet, or about 1.9 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 40 feet, or about two feet per year, occurred between 1975 and 1995. Thus, it appeared that the revetment and groin system were not fully effective in stabilizing the bluff within this zone, especially in the northern portion where the revetment appeared to be missing or buried in sand and overtopped. The 1977 study reported a recession rate of two feet per year for this erosion zone.

In 1995, the revetment in the northern portion of Zone 21c showed signs of overtopping, resulting in bluff toe erosion. In the extreme northern end of the zone, the revetment appeared to be buried in sand or missing, resulting in bluff failure by shallow slides.

Erosion Zone 21d

Erosion Zone 21d extends from the northerly limit of Erosion Zone 21c north about 0.1 mile to the north sec-

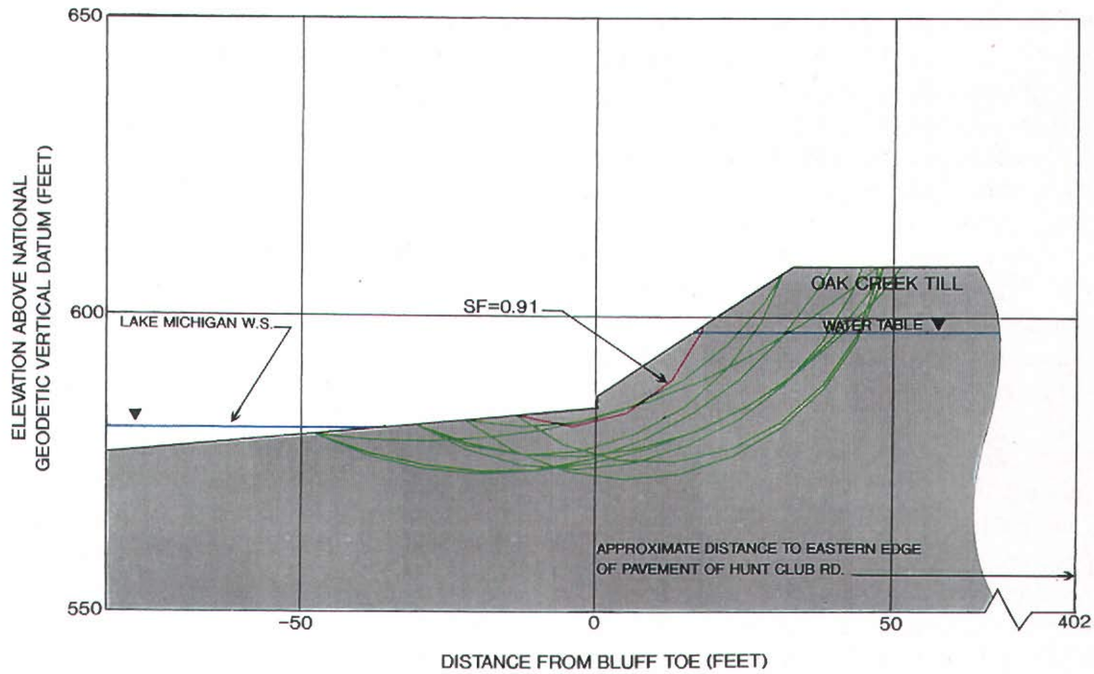
Figure 21

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Sections 21 and 22, Township 4 North, Range 23 East
Village of Wind Point and Town of Caledonia, Racine County

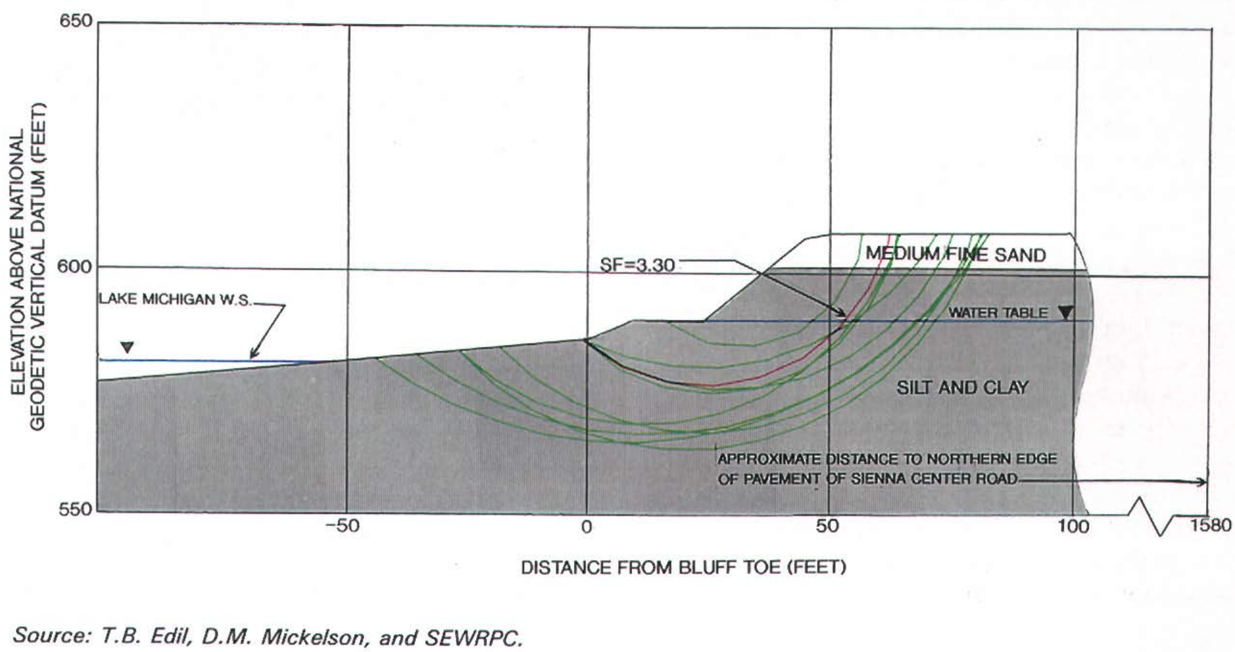
PROFILE 6-1

T.4N. R.23E. SEC.22



PROFILE 6-2

T.4N. R.23E. SEC.21



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

tion line of Section 22 at E. Five Mile Road extended, as shown on Map 30. This zone had a beach width of up to 150 feet. The low bluff had a height of up to 20 feet in this zone. In 1995, there were no shoreline protection structures in this zone. Vegetation covered approximately 50 percent of the bluff slope. The 1995 field observations indicated zero to 10 feet of retreat in the bluff top since 1976. Signs of recent shallow slides and flows were present.

No bluff stability analyses were conducted within Erosion Zone 21d in this study or the 1977 study.

The beach was up to 150 feet wide within Zone 21d. In the 1977 study, the beach width was reported to be between 25 and 55 feet, and the beach materials were reported to be sand and pebbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 21d were estimated at one location. These data indicated a recession of about 20 feet, or about 0.6 foot per year, occurred between 1963 and 1995. The data indicated that a recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995. Thus, it appeared that the increase in vegetation between 1976 and 1995 was largely ineffective in stabilizing the bluff in this zone. The 1977 study reported a recession rate of two feet per year for this erosion zone.

U.S. Public Land Survey Sections 16 and 17, Township 4 North, Range 23 East, Town of Caledonia, Racine County

This shoreline analysis section extends from E. Five Mile Road extended north to about Six Mile Road (CTH G) extended, in the Town of Caledonia, as shown on Maps 31 and 32. In 1995, the entire lakeshore area was occupied by residential lands, including areas with multi-family residential uses, especially in the southern portion of the section. The Dominican College and agricultural lands occupied parts of the upland within the section. In 1995, most of the shoreline within the section was protected by a variety of shoreline protection structures, some of which, particularly those located in the northern portion of the section, were in need of maintenance. Shoreline protection structures present within this section included revetments and groins in the southern portion of the section and debris and seawalls in the northern portion of the section. The bluff materials in this section were estimated to be primarily till in the lower half of the bluff face overlain by fine sand and silt. For analysis purposes, Sections 16 and 17 were further subdivided into two erosion zones, as shown on Maps 31 and 32. In the 1977 study, these sections had been subdivided into four erosion zones, which have been consolidated into two zones due to the subsequent installation of shoreline protection structures within the section. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the two erosion zones in Sections 16 and 17.

Erosion Zone 16a

Erosion Zone 16a extends from the south line of Section 16 at E. Five Mile Road extended north about 0.35 mile to about Robin Lane extended, as shown on Map 31. This zone had a beach width of up to 50 feet contained within a groin system along portions of the shoreline. The bluff had a height of about 20 feet in the southern portion of this zone, rising to about 60 feet in the central and northern portions. In 1995, revetments and groins protected the shoreline within this zone, many of which had been added since 1976. In contrast, vegetation cover, primarily bushes and weeds, had decreased by 80 percent from the vegetation cover in 1976, to approximately 50 percent coverage of the bluff slope. The 1995 field observations indicated that no assessment of retreat in the bluff top could be made due to the vegetation cover. However, zero to five feet of retreat in the bluff top since 1975 were estimated.

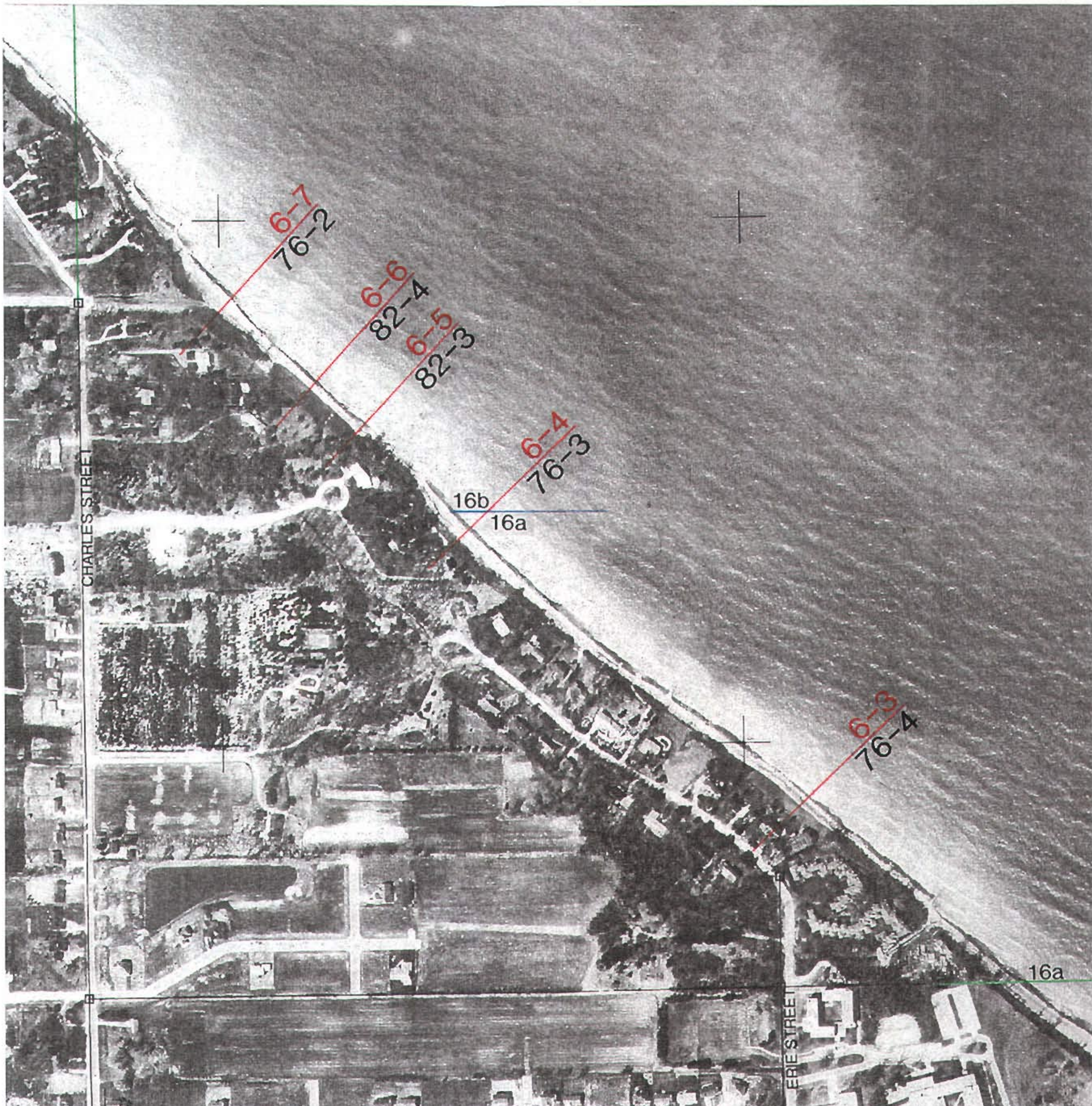
In 1995, two bluff profile field surveys were made within Zone 16a by occupying sites for which field surveys were conducted in 1976. The sites had significantly different geometries to those documented in 1976. The shape of the bluffs had been changed by regrading of slump blocks and slump scarps, and, at Profile No. 6-3, by the placement of fill at the bluff toe. The stability of the bluffs in Zone 16a of Reach 6 was characterized by Profile Nos. 6-3 and 6-4. Results of the slope stability analysis, shown in Figure 22, indicated that the bluffs were stable with respect to rotational failures, with safety factors of 1.7 at Profile No. 6-3 in the central portion of the zone and 1.45 at Profile No. 6-4 in the northern portion of the zone. Field observations indicated that translational failures are possible in this zone. The 1977 study reported bluff safety factors of 0.49 and 0.66 at Profile Nos. 6-3 and 6-4, respectively.

The beach was up to 50 feet in width within Erosion Zone 16a. In the 1977 study, the beach width was reported to be between zero and 40 feet, and the beach materials were reported to be sand, pebbles, and cobbles. At Profile No. 6-3, the primary nearshore surface materials were not noted in 1995. However, the

Map 31

SHORELINE EROSION REACH 6: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 16 and 17, Township 4 North, Range 23 East
Town of Caledonia, Racine County



LEGEND

PROFILE SITE LOCATION

6-4 PROFILE NUMBER: 1995 FIELD INVENTORY

76-3 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

16a EROSION ANALYSIS ZONE NUMBER

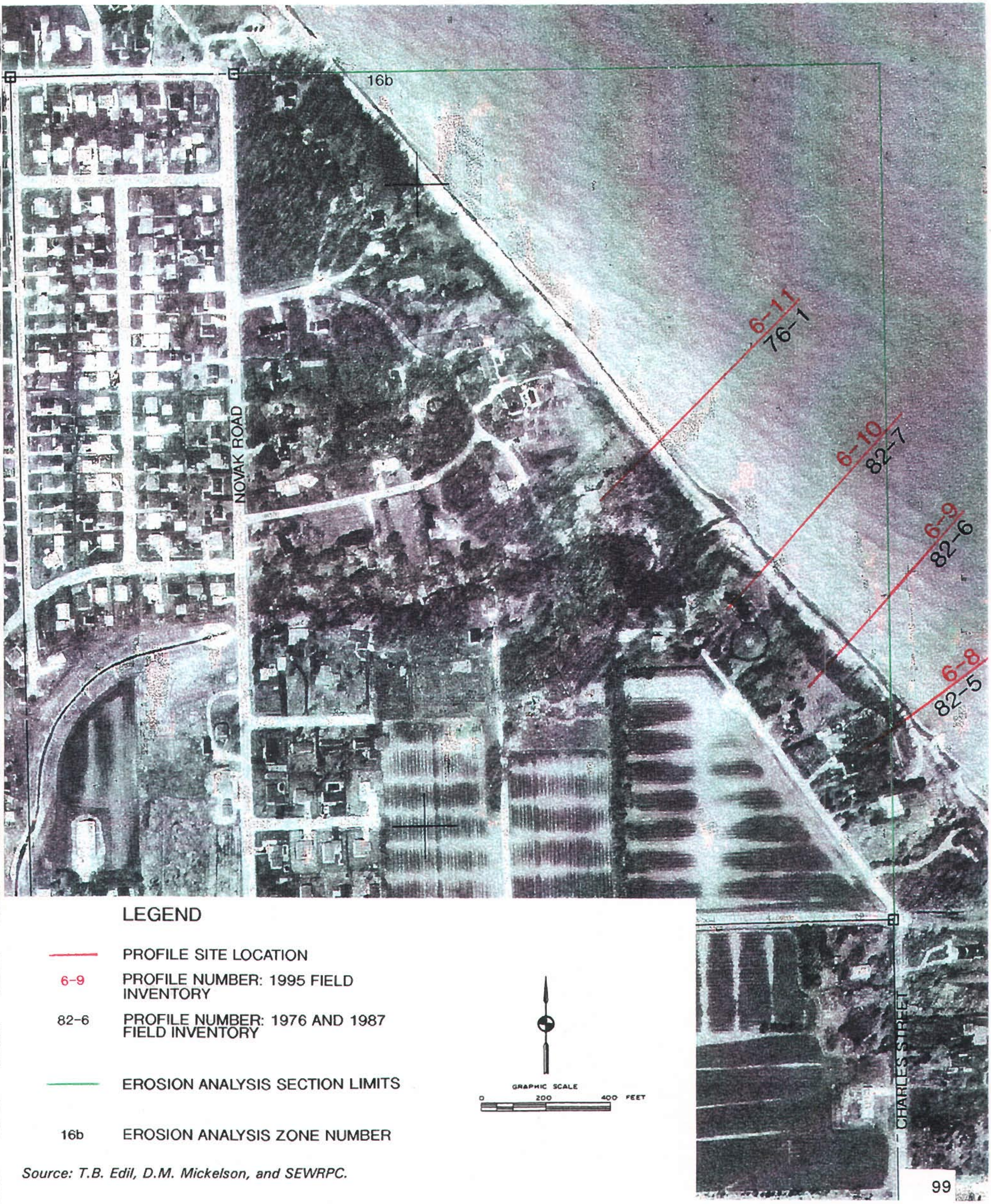
GRAPHIC SCALE
0 400 800 FEET

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 32

SHORELINE EROSION REACH 6: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 16 and 17, Township 4 North, Range 23 East
Town of Caledonia, Racine County



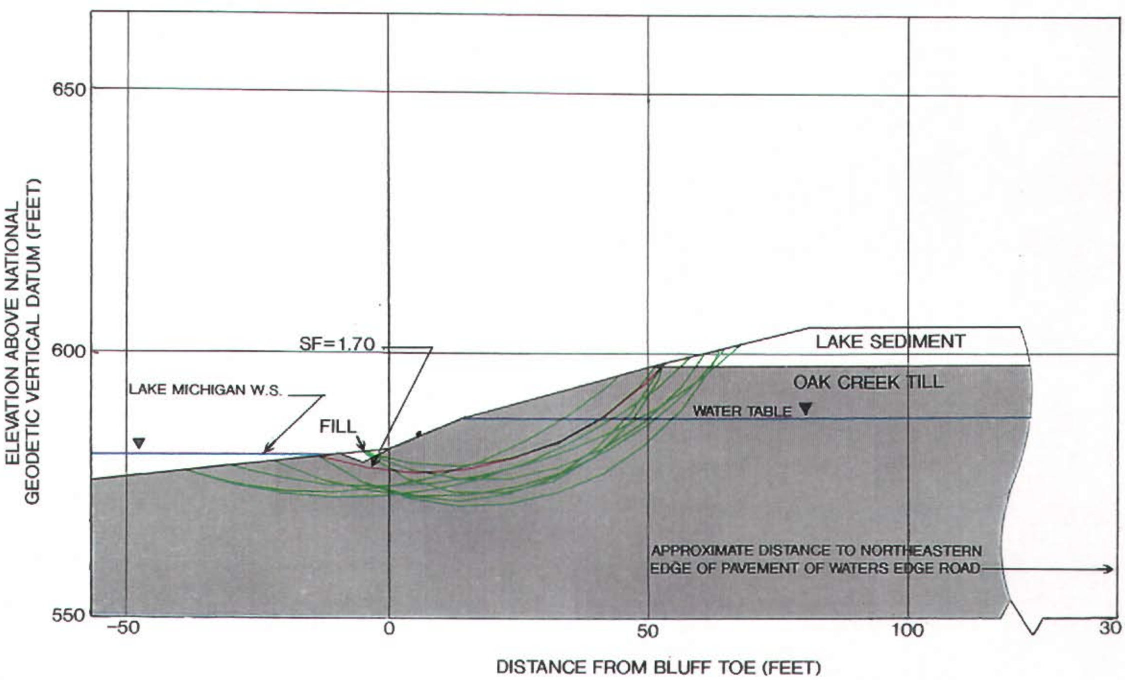
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 22

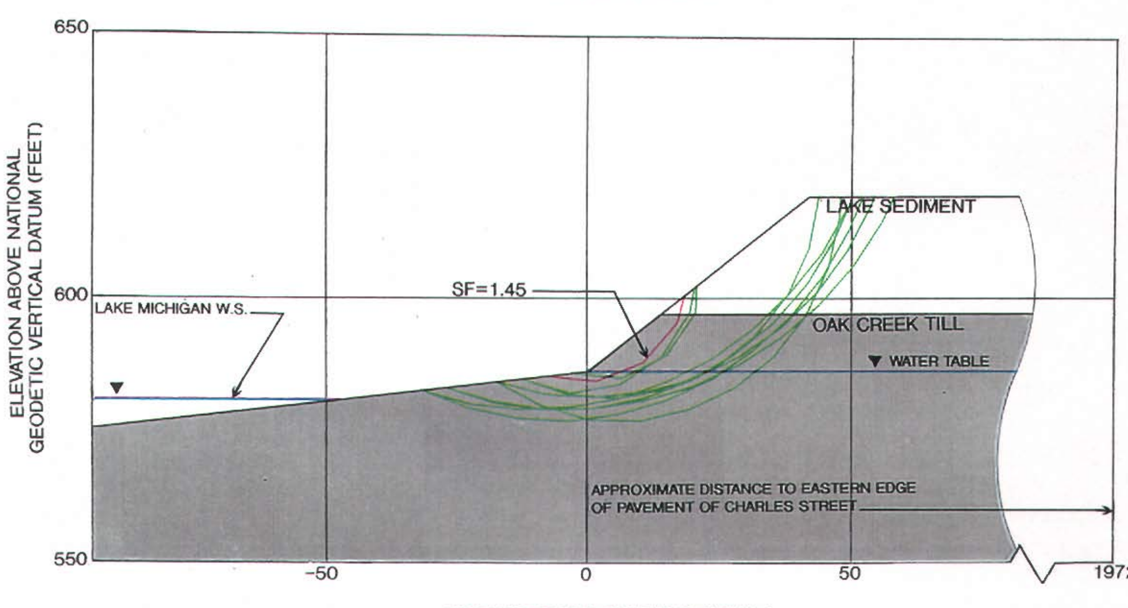
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 16, Township 4 North, Range 23 East
Town of Caledonia, Racine County

PROFILE 6-3
T.4N. R.23E. SEC.16



PROFILE 6-4
T.4N. R.23E. SEC.16



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

nearshore lakebed depth of five feet was reached at about 500 feet offshore. This represented a significant shallowing of the nearshore bathymetry. In 1977, the nearshore lakebed depth of five feet was reached at 44 feet offshore. The primary nearshore surface materials at this site in 1976 were sand and gravel.

Shoreline recession data for Erosion Zone 16a were estimated at three locations. These data indicated a recession of between 20 and 50 feet, or between 0.6 and 1.6 feet per year, occurred between 1963 and 1995. In the northern portion of the zone, from about the southern end of Waters Edge Street to Robin Lane, the data indicated that most of that recession occurred prior to 1975, with a recession of between zero and 10 feet, or between zero and 0.5 foot per year, occurring between 1975 and 1995. These data indicated that the regrading of the bluff slope, appeared to have largely stabilized the bluff, especially in the northernmost portion of the zone where recession was reduced to zero. In the southern portion of the zone, from E. Five Mile Road extended to about the northern extent of Erie Street, the data indicated a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. Thus, the placement of fill and regrading of the bluff slope were not fully effective in stabilizing the bluff in this portion of the zone. The 1977 study reported a recession rate of two feet per year for this zone.

Erosion Zone 16b

Erosion Zone 16b extends from the northerly limit of Erosion Zone 16a north about 0.65 mile to Six Mile Road extended, as shown on Maps 31 and 32. This zone had a similar beach to the zone immediately to the south, ranging up to about 50 feet in width. The bluff had a height of about 60 feet in this zone. In 1995, there were a variety of shoreline protection structures in this zone, including low seawalls and debris fields. Vegetation covered between 50 and 100 percent of the bluff slope. The 1995 field observations indicated that no assessment of retreat in the bluff top could be made due to the vegetation cover and the placement of debris which covered the bluff slope. However, zero to five feet of retreat in the bluff top since 1975 was estimated.

In 1995, two bluff profile field surveys were made within Zone 16b by occupying sites for which a field surveys were conducted in 1976. These sites had significantly different geometries to those documented in 1976. The shape of the bluffs had been changed by the regrading of slump blocks, and, at Profile No. 6-11, the removal of the slump scarp. The bluff profile at Profile No. 6-11 had been changed into a convex shape by regrading. Also in 1995, five bluff profile field surveys were made within Zone 16b by occupying sites for which field surveys were conducted in 1982. The stability of the bluffs in Zone 16b of Reach 6 was characterized by Profile Nos. 6-5 through 6-11. Results of the slope stability analysis, shown in Figures 23 through 25, indicated that the bluffs were marginally unstable, with safety factors ranging from 0.93 to 0.98 in the southern half of the zone, to stable, with safety factors ranging from 1.25 to 1.53 in the northern half of the zone, based upon the deterministic bluff stability analysis method. Profile Nos. 6-5 through 6-8 were also analyzed using the probabilistic bluff stability analysis method. At Profile No. 6-5, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.79 to 1.78 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 21, or 84 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 23, or 9.2 percent, of the 250 conditions analyzed. At Profile No. 6-6, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.83 to 1.39 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 11, or 44 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 29, or 11.6 percent, of the 250 conditions analyzed. At Profile No. 6-7, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.74 to 1.32 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 21, or 84 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 119, or 47.6 percent, of the 250 conditions analyzed. At Profile No. 6-8, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.94 to 1.44 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 11, or 44 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 11.6 percent of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally unstable at Profile Nos. 6-5, 6-6, and 6-8, and unstable at Profile No. 6-7. Shallow slides occurred intermittently throughout this zone in 1995. The 1977 study reported

Figure 23

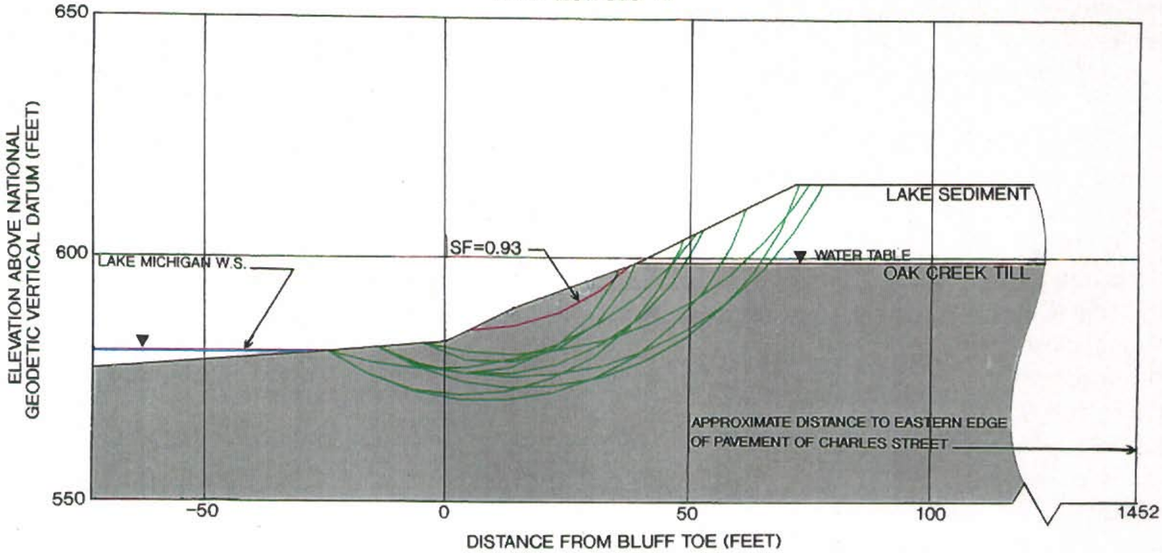
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 16, Township 4 North, Range 23 East

Town of Caledonia, Racine County

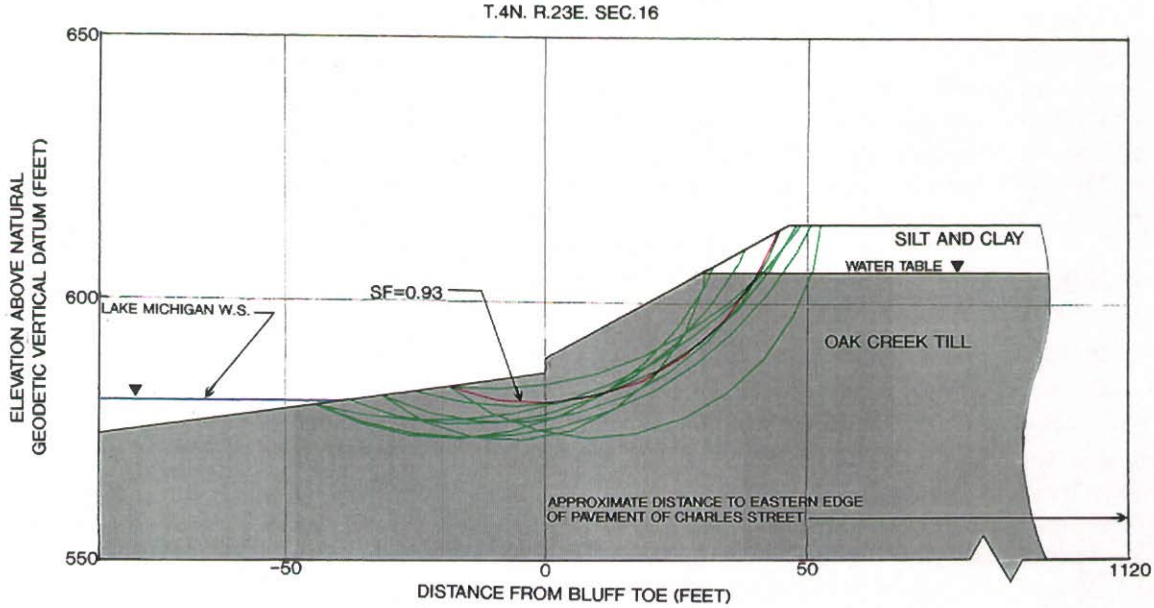
PROFILE 6-5

T.4N. R.23E. SEC. 16



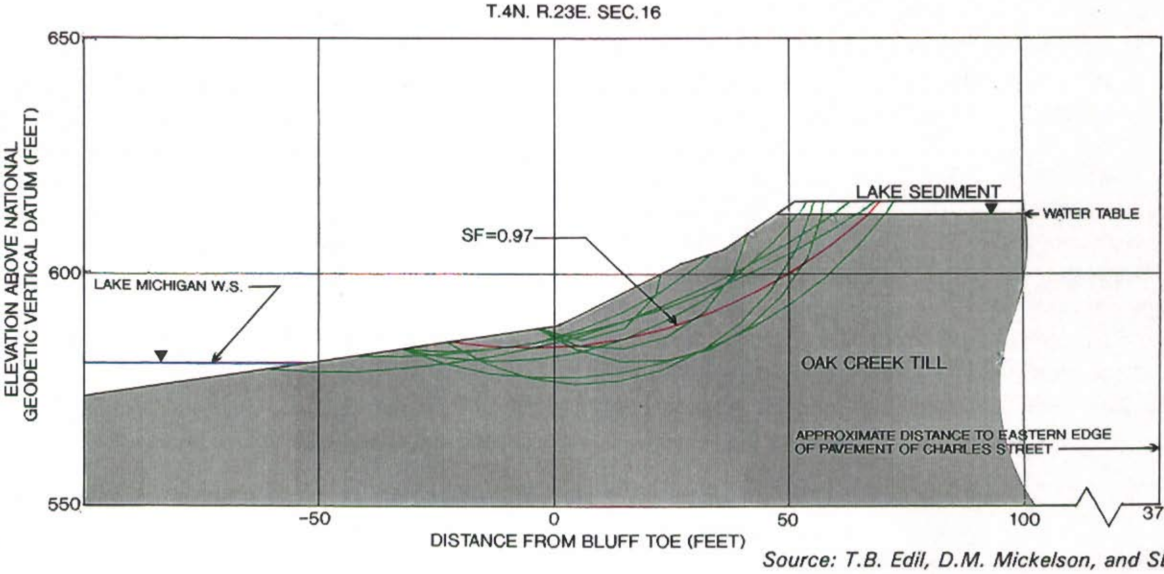
PROFILE 6-6

T.4N. R.23E. SEC.16



PROFILE 6-7

T.4N. R.23E. SEC.16

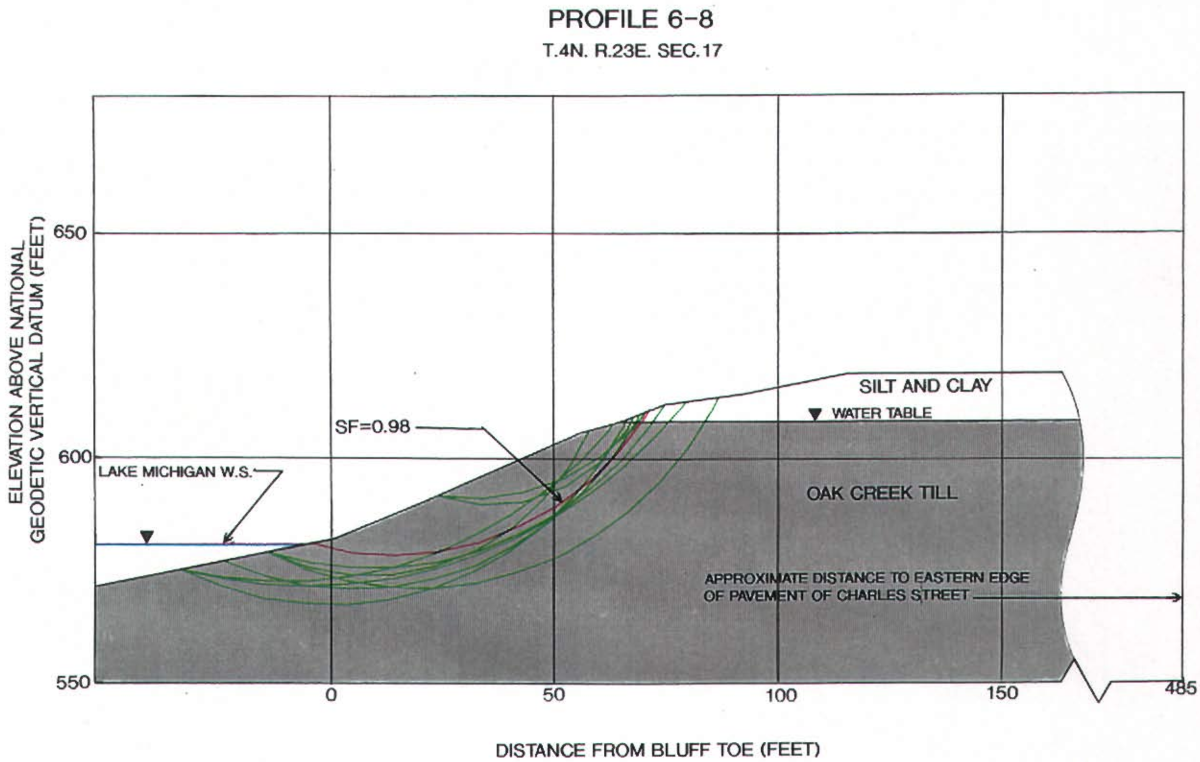


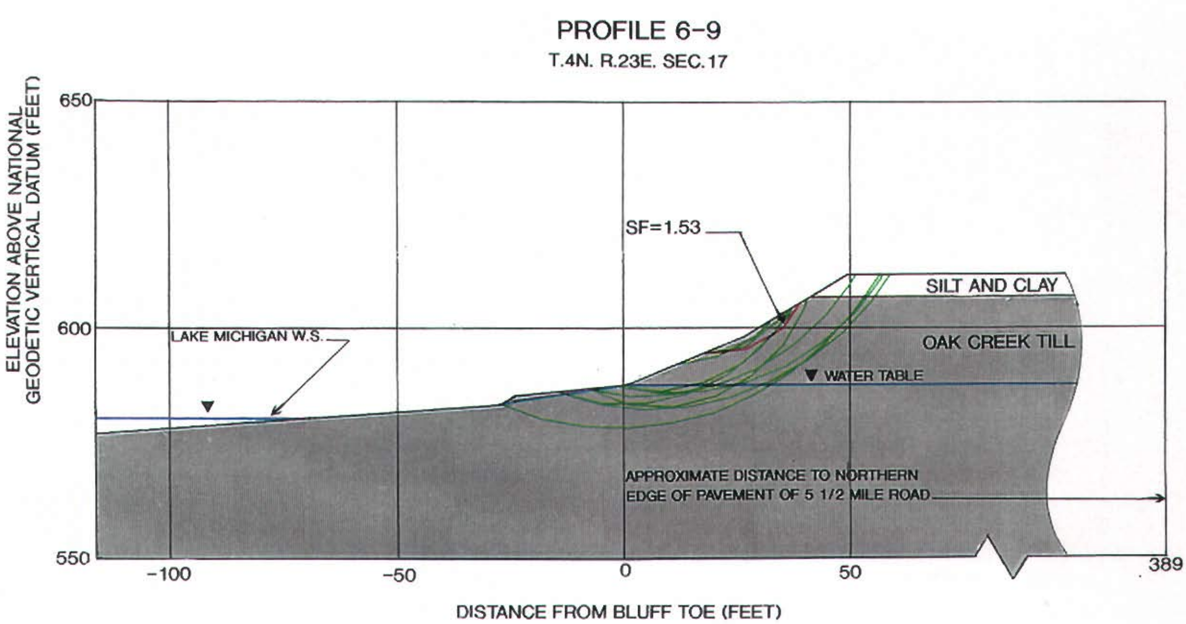
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 24

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 17, Township 4 North, Range 23 East
Town of Caledonia, Racine County



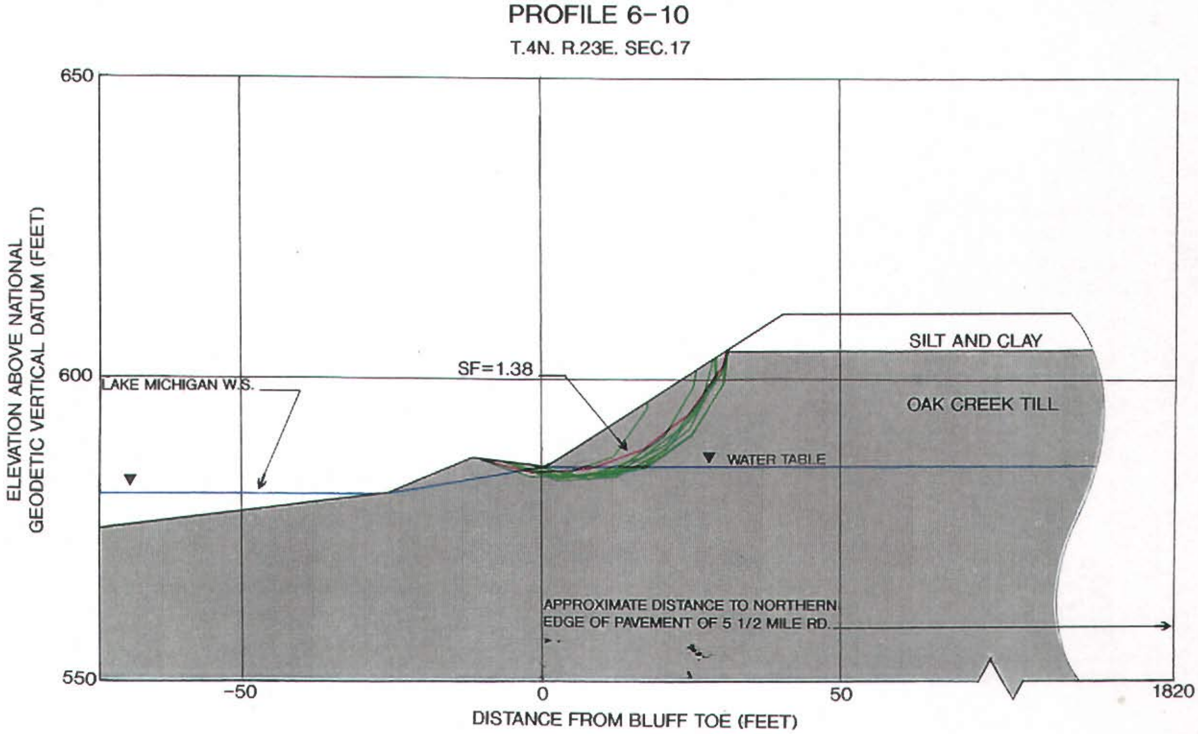


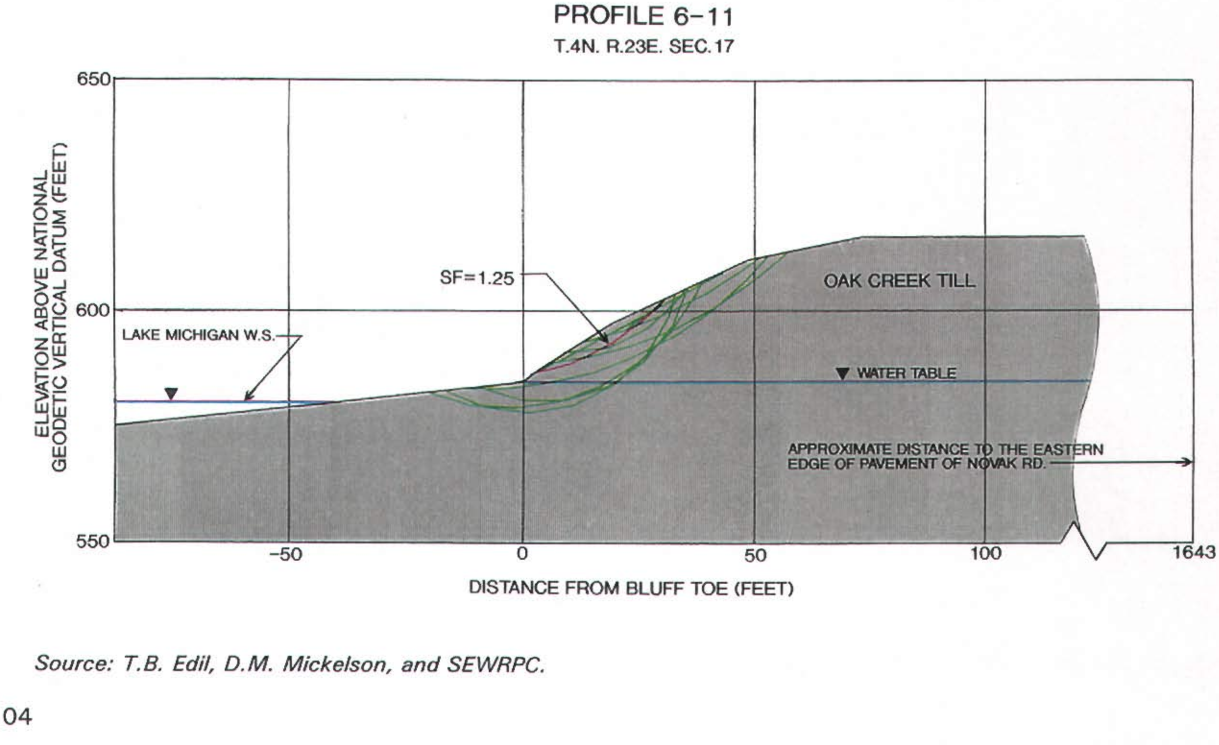
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 25

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 17, Township 4 North, Range 23 East
Town of Caledonia, Racine County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

bluff safety factors of 0.41 in the southern portion of the zone and 0.94 in the northern portion of the zone.

The beach was up to 50 feet in width within Zone 16b. In the 1977 study, the beach width was reported to be between 30 and 75 feet, and the beach materials were reported to be primarily sand and gravel in the southern portion of the zone, grading to sand, pebbles, and cobbles in the northern portion of the zone. In 1977, the nearshore lakebed depth of five feet was reached at 42 feet offshore at Profile No. 6-7 and 30 feet offshore at Profile No. 6-11. The primary nearshore surface materials at these sites in 1976 were sand at Profile No. 6-7, and sand and gravel at Profile No. 6-11.

Shoreline recession data for Erosion Zone 16b were estimated at two locations. These data indicated a recession of between 30 and 40 feet, or between 0.9 and 1.2 feet per year, occurred between 1963 and 1995, with the higher rate of recession occurring in the southern portion of the zone. The data indicated a recession of between 10 and 30 feet, or between 0.5 and 1.5 feet per year, occurred between 1975 and 1995, also with the higher rate of recession occurring in the southern portion of the zone. Thus, it appeared that the regrading of the bluff slope was not fully effective in stabilizing the bluff in this zone. The 1977 study reported recession rates of between one and two feet per year for this erosion zone.

In 1995, a few low seawalls within Zone 16b had been overtopped and were in need of maintenance. Other areas within this zone had no shoreline protection structures installed. In both cases, the bluff could be subject to bluff toe erosion, leading to bluff top retreat, during future periods of higher lake levels.

U.S. Public Land Survey Sections 7 and 8, Township 4 North, Range 23 East, Town of Caledonia, Racine County

This shoreline analysis section extends from Six Mile Road (CTH G) extended north to Seven Mile Road extended, in the Town of Caledonia, as shown on Maps 33 and 34. In 1995, the southern half of the section was occupied by residential lands and park lands, including Lake Michigan and Cliffside Parks; and the northern half of the section by agricultural lands. In 1995, the southern half of the section was protected by revetments and groins. The northern half of the section was unprotected by shoreline protection structures. The bluff materials in this section were generally covered, but were estimated to be primarily till in the lower quarter of the bluff, overlain by fine sand and silt, overlain by till with intermixed fine sand and silt. For analysis purposes, Sections 7 and 8 were further subdivided into four erosion zones, as shown on Maps 33 and 34. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the four erosion zones in Sections 7 and 8.

Erosion Zone 7a

Erosion Zone 7a extends from the south line of Section 8 at Six Mile Road extended north about 0.2 mile to a point on the lakeshore adjacent to the intersection of Indian Trail and Lake Shore Drive, as shown on Map 33. This zone had little or no beach fronting a bluff which had a height of about 50 feet. In 1995, the bluff was unprotected in this zone. The 1995 field observations indicated zero to 10 feet of retreat in the bluff top since 1976.

No bluff stability analyses were conducted within Erosion Zone 7a in this study or the 1977 study.

The beach was narrow to nonexistent within Erosion Zone 7a. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 7a were estimated at one location. These data indicated a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. In 1995, the bluff was observed to be actively eroding by shallow slides and flows within this zone. The 1977 study reported a recession rate of two feet per year for this zone.

In 1995, two structures were located within close proximity to the bluff edge, but were not considered to be in immediate danger. Roadways and other structures were located well back from the edge of the bluff. Notwithstanding, the recent construction of a groin system within Erosion Zone 7b located immediately north of this zone could accelerate the erosion of the bluff within this zone if a considerable amount of sand is retained within the groin system. Without shoreline protection structures being installed, the bluff within this zone will remain unstable and continue to retreat at a moderate rate.

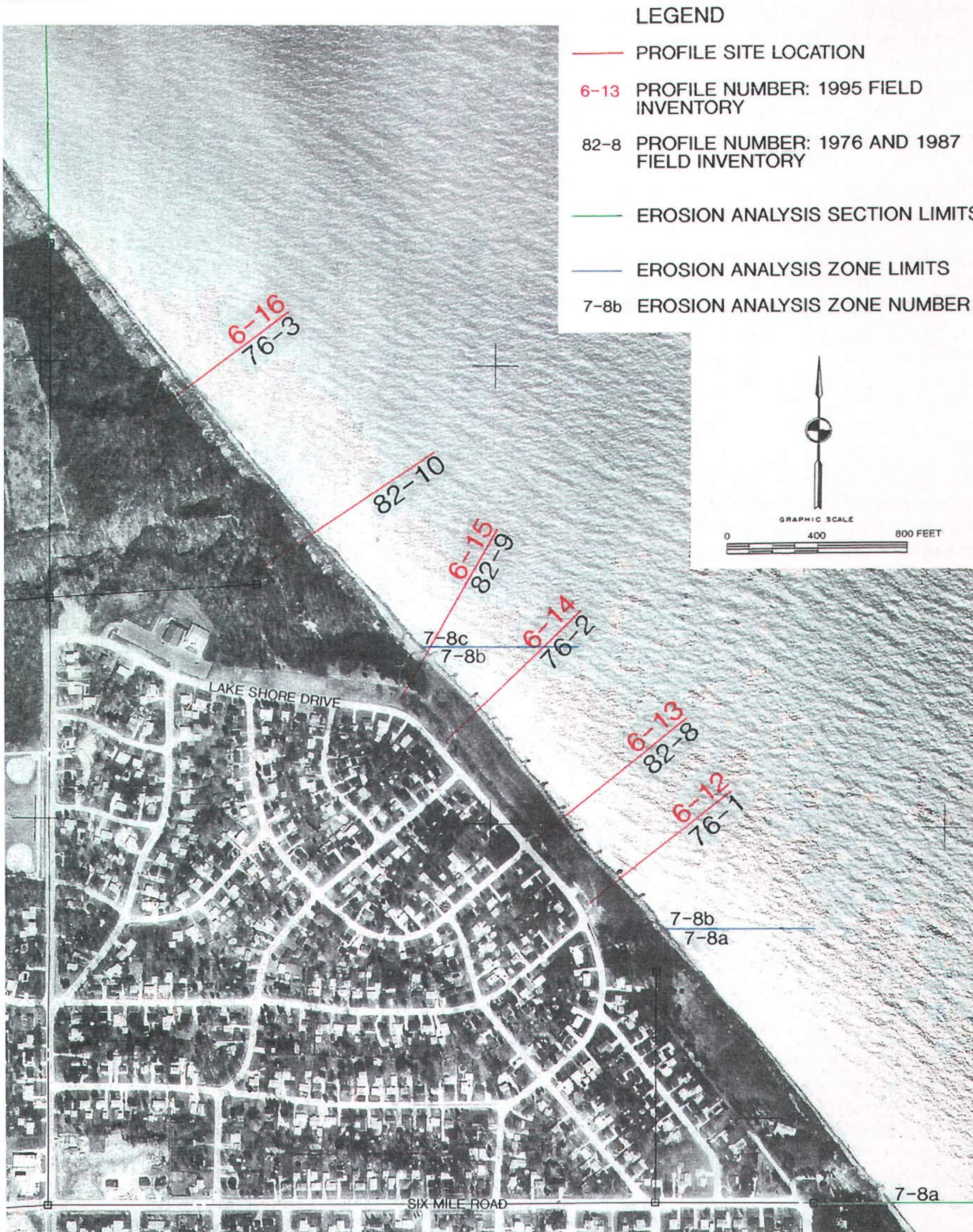
Erosion Zone 7b

Erosion Zone 7b extends from the northerly limit of Erosion Zone 7a at Indian Trail extended north about 0.2 mile to a point on the lakeshore adjacent to the

Map 33

SHORELINE EROSION REACH 6: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 7 and 8, Township 4 North, Range 23 East
Town of Caledonia, Racine County

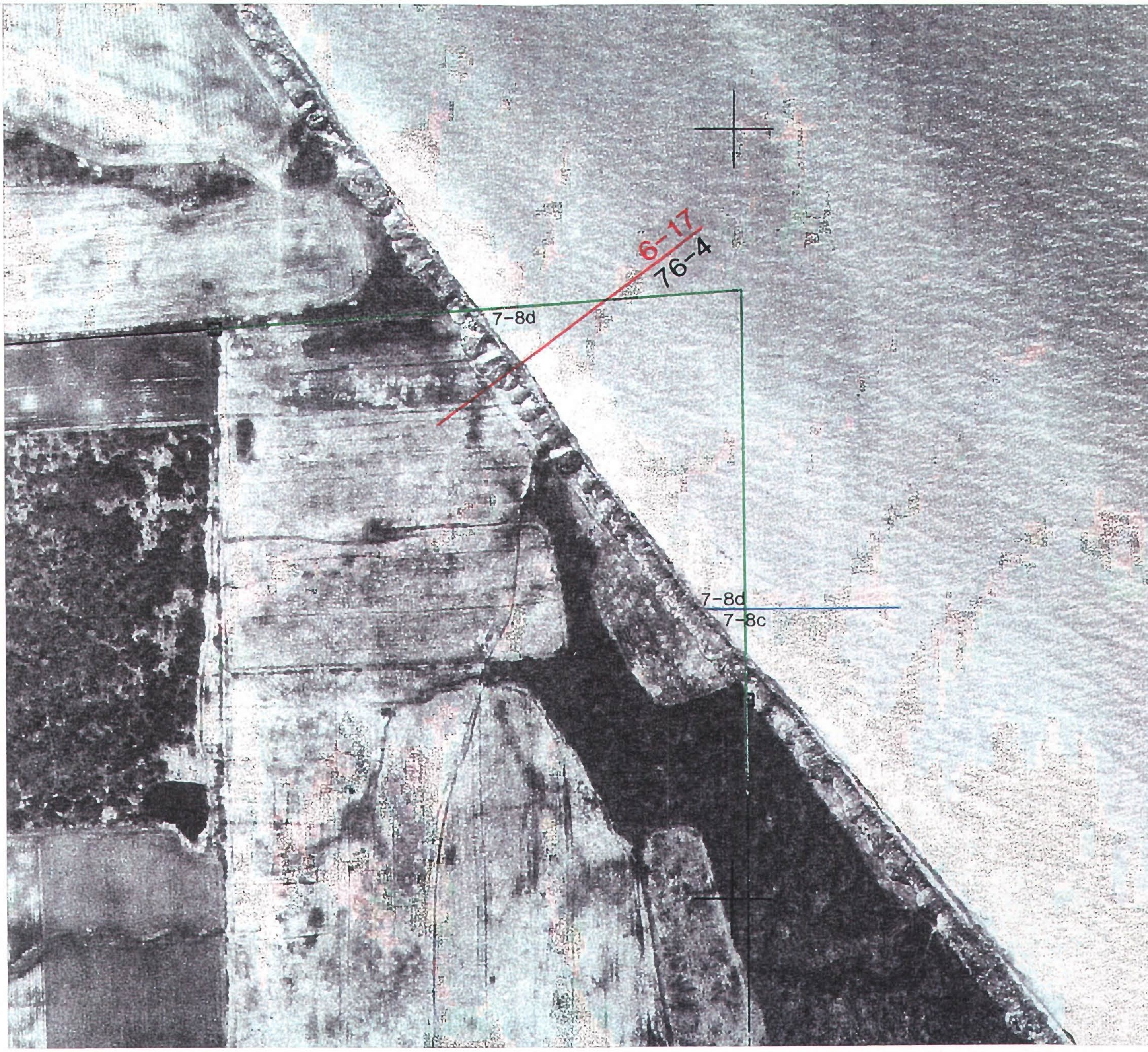


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 34

SHORELINE EROSION REACH 6: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 7 and 8, Township 4 North, Range 23 East
Town of Caledonia, Racine County



LEGEND

PROFILE SITE LOCATION

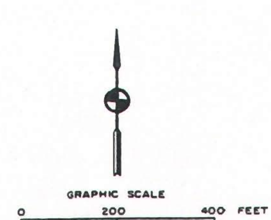
6-17 PROFILE NUMBER: 1995 FIELD INVENTORY

76-4 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

7-8c EROSION ANALYSIS ZONE NUMBER



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

intersection of Lake Shore Drive and Lamberton Road (Middle Road extended), as shown on Map 33. This zone had a narrow beach contained within a recently constructed groin system. The bluff, protected by a large revetment which was under construction during the 1995 field survey, had a height of between 50 and 60 feet in this zone. The 1995 field observations did not indicate any retreat in the bluff top as the bluff top had been regraded since 1976. Signs of small translational slides were present.

In 1995, two bluff profile field surveys were made within Zone 7b by occupying sites for which field surveys were conducted in 1976. The sites had significantly different geometries to those documented in 1976. The shape of the bluffs had been changed by the regrading of slump blocks, and, at Profile No. 6-12, the placement of fill at the bluff toe. Also in 1995, two bluff profile field surveys were made within Zone 7b by occupying sites for which field surveys were conducted in 1982. The stability of the bluff in Zone 7b of Reach 6 was characterized by Profile Nos. 6-12 through 6-15. Results of the slope stability analysis, shown in Figures 26 and 27, indicated that the bluff was stable with respect to rotational failures, with safety factors ranging from 1.46 to 2.38. Field observations indicated that translational failures may occur in this zone. The 1977 study reported bluff safety factors of 1.62 and 1.68 at Profile Nos. 6-12 and 6-14, respectively.

The beach was 20 to 50 feet within Zone 7b. In the 1977 study, the beach width was reported to be between zero and 30 feet, and the beach materials were reported to be covered by slump block material which had accumulated at the toe of the bluff. At Profile No. 6-14, the primary nearshore surface materials were noted to be cobbles and sand, with the nearshore lakebed depth of five feet reached at 93 feet offshore in 1995. This represented a shallowing of the nearshore bathymetry. In 1977, the nearshore lakebed depth of five feet was reached at 82 feet offshore. The primary nearshore surface materials at this site in 1976 were sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at Profile No. 6-12 in 1995. However, in 1977, the nearshore lakebed depth of five feet was reached at 100 feet offshore, with the primary nearshore surface materials at this site being sand and gravel.

Shoreline recession data for Erosion Zone 7b were estimated at one location. These data indicated a recession of about 100 feet, or about 3.1 feet per year, occurred between 1963 and 1995. The data indicated that a recession of about 80 feet, or about 4.0 feet per year, occurred between 1975 and 1995. However, the recent construction of a large revetment and groin system, and the regrading of the bluff slope, is likely to largely stabilize the bluff in this zone in the future. The 1977 study did not report a recession rate for this erosion zone.

Several structures which were located near the bluff top in 1976 had been removed by 1995, and the placement of the revetment and groin system, and regrading of the bluff slope, was likely to solve erosion problems in this zone. However, the presence of the groin system may increase shoreline loss in Erosion Zone 7a located immediately south of this zone.

Erosion Zone 7c

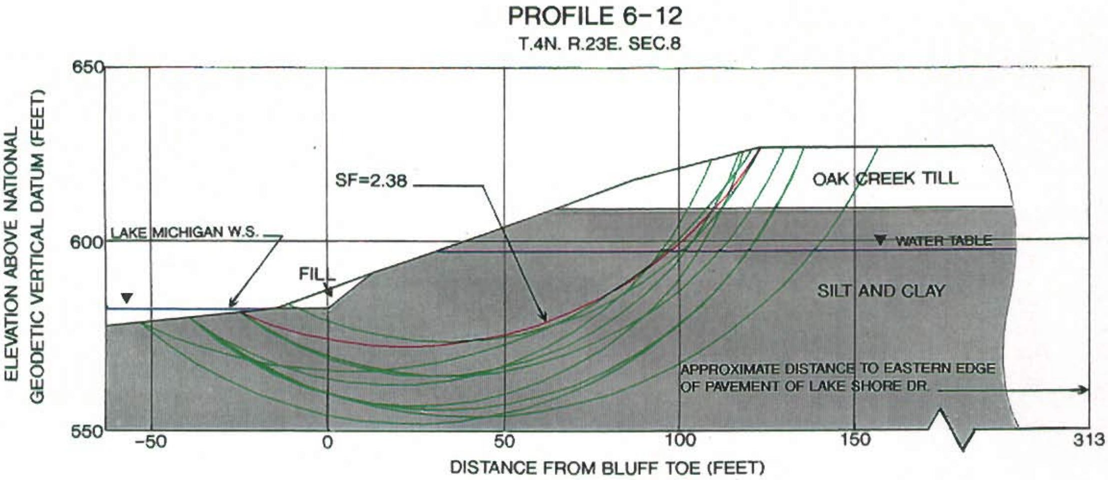
Erosion Zone 7c extends from the northerly limit of Erosion Zone 7b north, adjacent to Lake Michigan and Cliffside Parks, about 0.4 mile, as shown on Maps 33 and 34. This zone had little or no beach. However, a beach with a width of about 50 feet had formed at the northern extreme of the groin system located within Erosion Zone 7b immediately south of this zone. The bluff had a height of up to 60 feet in this zone. In 1995, the bluff was unprotected. Vegetation, consisting of grasses, weeds, and small shrubs, covered approximately 50 percent of the bluff slope. The 1995 field observations indicated from 20 to 30 feet of retreat in the bluff top since 1976. Signs of slumping and shallow translational slides and flows were present, with the material produced by mass wasting of the bluff face being removed from the top of the beach, maintaining a steeply sloping bluff face. In 1995, the bluff top had a distinctly scalloped appearance consistent with the occurrence of slumps, which were estimated to result from groundwater focussing at these locations.

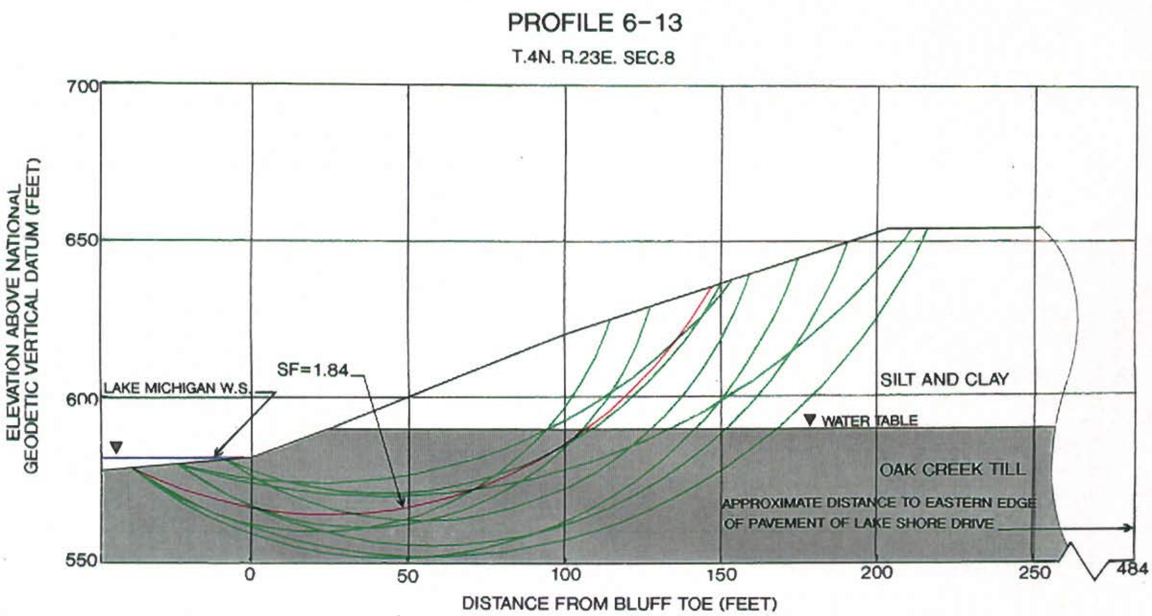
In 1995, one bluff profile field survey was made within Zone 7c by occupying a site for which a field survey was conducted in 1976. The site had a significantly different geometry to that documented in 1976 due to the regrading of the bluff slope. One further bluff profile field survey site occupied during a field survey which was conducted in 1982 was not reoccupied in 1995. The stability of the bluff in Zone 7c of Reach 6 was characterized by Profile No. 6-16. Results of the slope stability analysis, shown in Figure 27, indicated that the bluff was unstable, with a safety factor of 0.89, based upon the deterministic bluff stability analysis method. Profile No. 6-16 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.84 to 1.31 for the 250 conditions

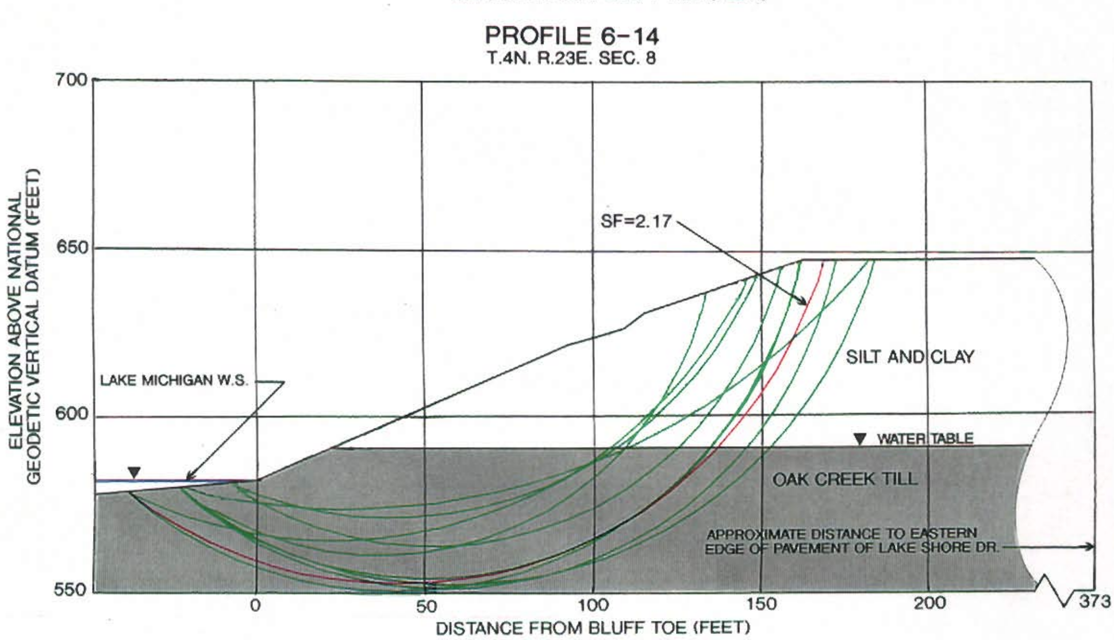
Figure 26

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 8, Township 4 North, Range 23 East
Town of Caledonia, Racine County







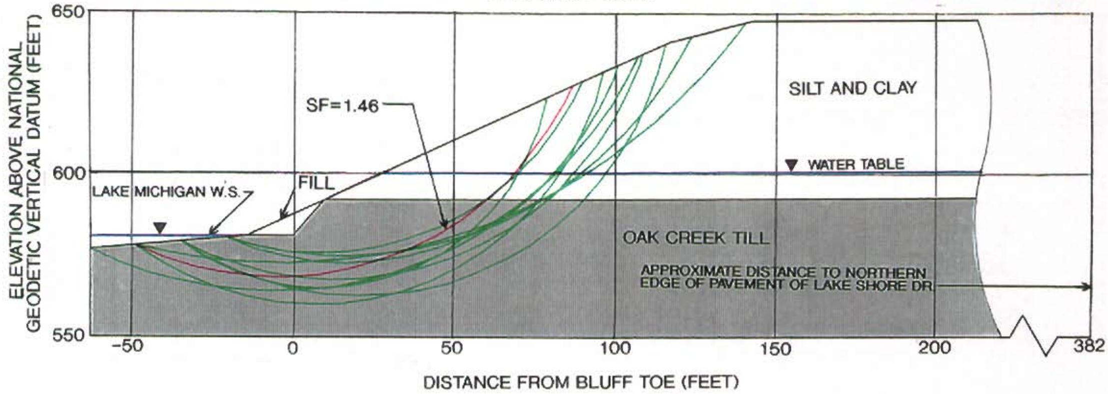
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 27

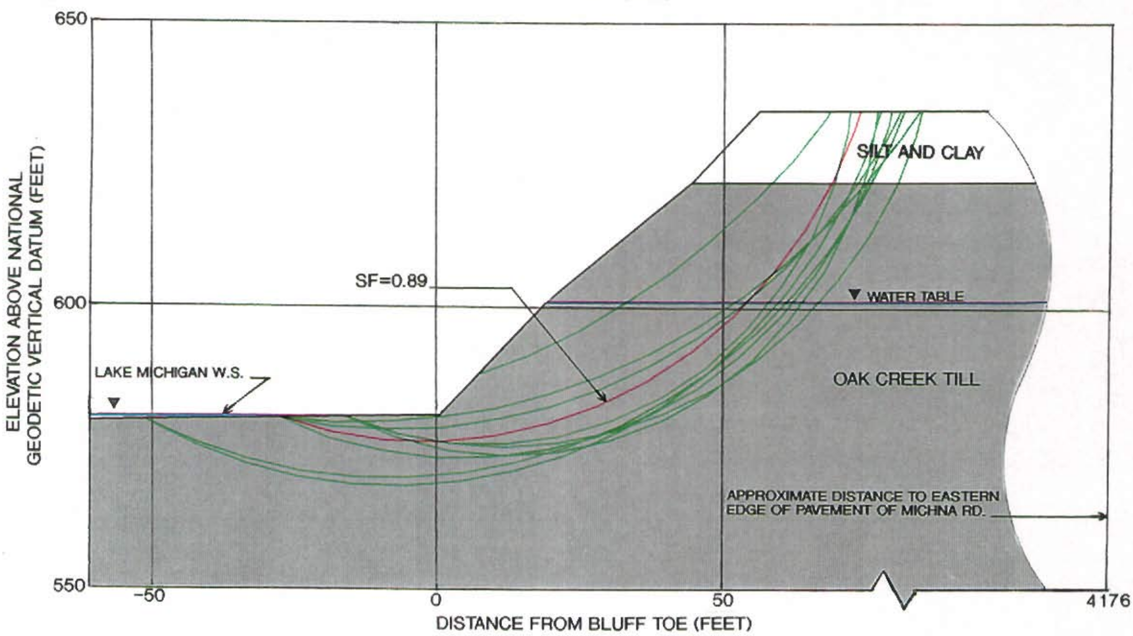
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 8, Township 4 North, Range 23 East
Town of Caledonia, Racine County

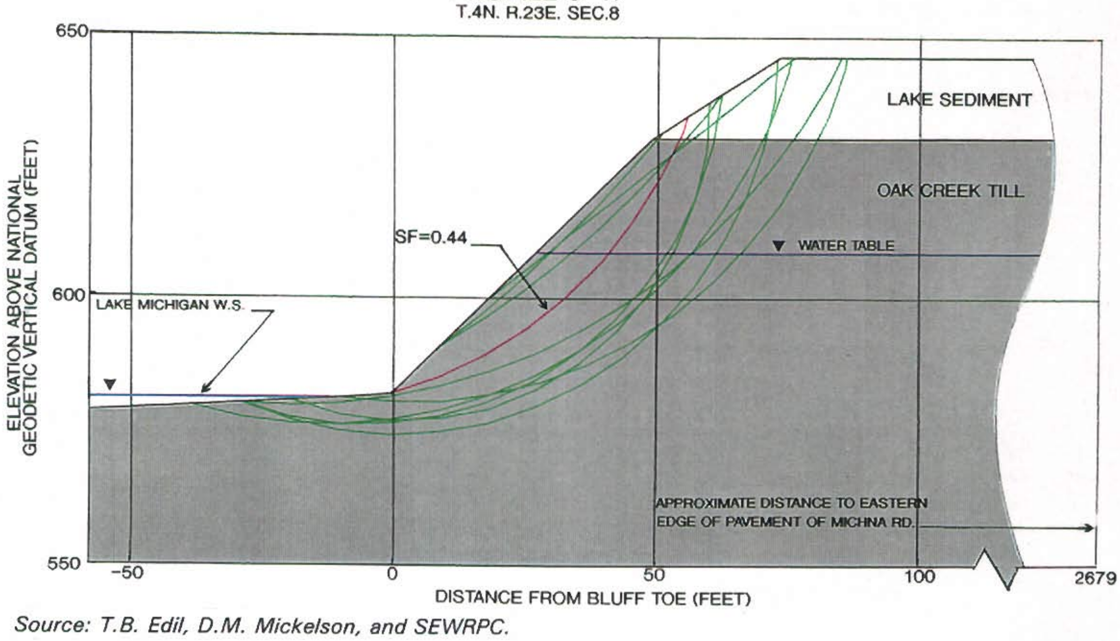
PROFILE 6-15
T.4N. R.23E. SEC.8



PROFILE 6-16
T.4N. R.23E. SEC.8



PROFILE 6-17
T.4N. R.23E. SEC.8



 Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

considered. The analytical results indicated a safety factor of less than 1.0 for 17, or 68 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 89, or 35.6 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally unstable with respect to rotational failure. The 1995 field observations indicated that shallow translational failures may occur. The 1977 study reported a bluff safety factor of 0.55.

The beach width was narrow extending up to 50 feet within Zone 7c. In the 1977 study, the beach width was reported to be between zero and 15 feet, and the beach materials were reported to be slump block and debris flow materials overlying the beach materials which were estimated to be sand and gravel. In 1977, at Profile No. 6-16, the nearshore lakebed depth of five feet was reached at 70 feet offshore, with the primary nearshore surface materials at this site consisting of sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995.

Shoreline recession data for Erosion Zone 7c were estimated at two locations. These data indicated a recession of between 150 and 190 feet, or between 4.7 and 5.9 feet per year, occurred between 1963 and 1995. The data indicated a recession of between 70 and 100 feet, or between 3.5 and 5.0 feet per year, occurred between 1975 and 1995. Thus, it appeared that the bluff was not stabilized within this zone, and was continuing to recess. The 1977 study did not report a recession rate for this erosion zone.

Erosion Zone 7d

Erosion Zone 7d extends from the northerly limit of Erosion Zone 7c north about 0.15 mile to the north section line of Section 7 at Seven Mile Road extended, as shown on Map 34. This zone had little or no beach. The bluff had a height of up to 70 feet in this zone. In 1995, there were no shoreline protection structures in this zone. Vegetation, consisting of low shrubs and weeds, covered approximately 70 percent of the bluff slope. The 1995 field observations indicated 20 to 30 feet of retreat in the bluff top since 1976. Signs of shallow translational slides and flows were present. While this zone was similar in many ways to Erosion Zone 7c, located immediately to the south of this zone, the bluff top was not scalloped within this zone.

In 1995, one bluff profile field survey was made within Zone 7d by occupying a site for which a field survey was conducted in 1976. The site had a slightly different geometry to that documented in 1976. The stability of the bluff in Zone 7d of Reach 6 was characterized by Profile No. 6-17. Results of the slope stability analysis, shown in Figure 27, indicated that the bluff was unstable with respect to rotational failure, with a safety factor of 0.44. The 1977 study reported a bluff safety factor of 0.49.

The beach was narrow to nonexistent within Zone 7d. In the 1977 study, the beach width was reported to be between 10 and 20 feet, and the beach materials were reported to be sand and gravel. In 1977, at Profile No. 6-17, the nearshore depth lakebed depth of five feet was reached at 60 feet offshore, with the primary nearshore surface material at this site consisting of gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995.

Shoreline recession data for Erosion Zone 7d were estimated at one location. These data indicated a recession of about 220 feet, or about 6.9 feet per year, occurred between 1963 and 1995. The data indicated that a recession of about 120 feet, or about 6.0 feet per year, occurred between 1975 and 1995. Thus, it appeared that this zone remained in an actively eroding state. The 1977 study reported a recession rate of three feet per year for this erosion zone.

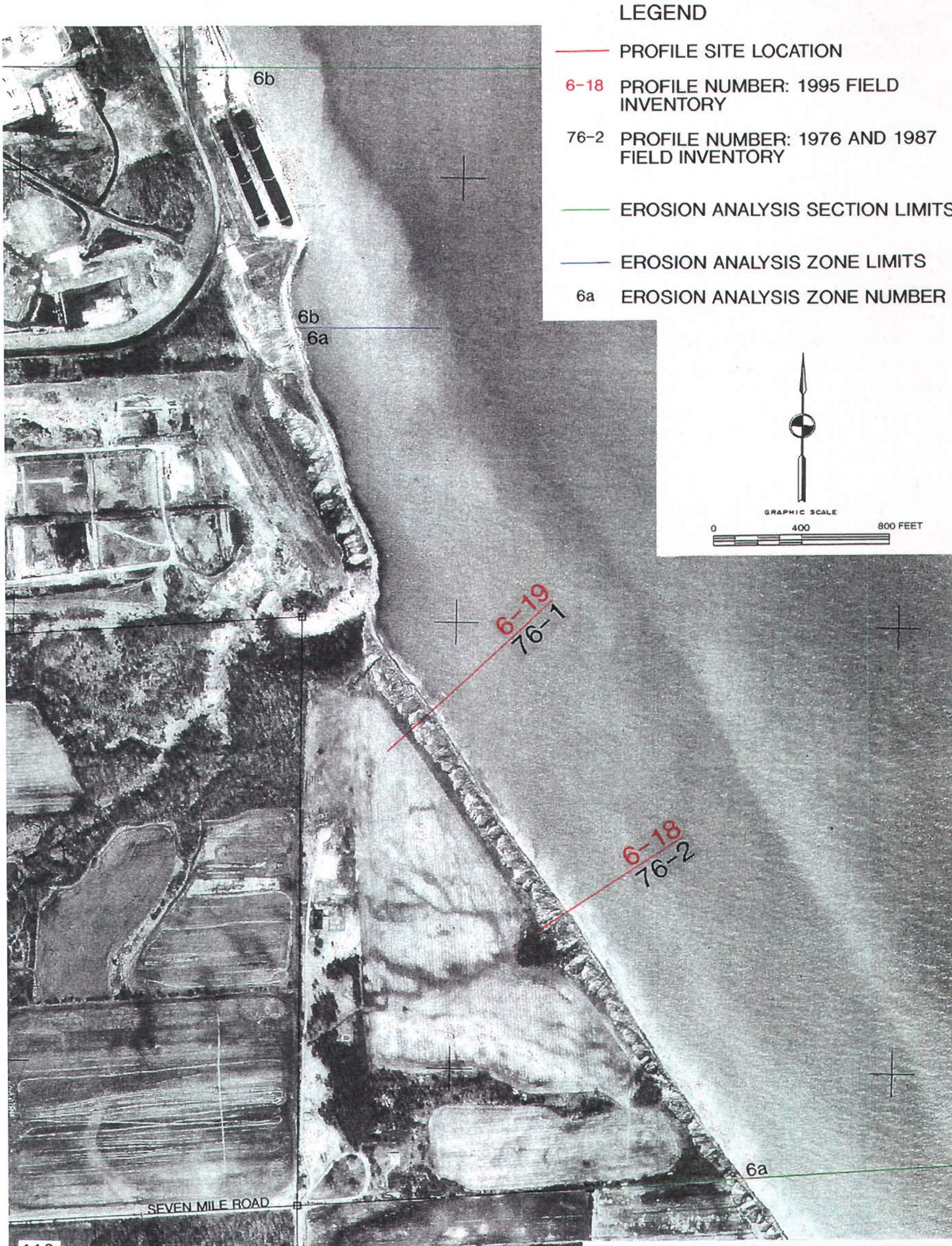
U.S. Public Land Survey Section 6, Township 4 North, Range 23 East, Town of Caledonia, Racine County

This shoreline analysis section extends from Seven Mile Road extended north to about County Line Road extended at the north section line of Section 6, in the Town of Caledonia, as shown on Map 35. In 1995, the lakeshore area was occupied by agricultural and industrial lands, with the Wisconsin Electric Power Company's Oak Creek Power Plant situated at the northern extreme of the section. In 1995, most of the shoreline within this section was unprotected, although a revetment and other shoreline protection structures have been placed on the power plant property. The bluff materials in this section were estimated to be primarily till overlain by a thin cap of sand, fine sand, and silt. For analysis purposes, Section 6 was further subdivided into two erosion zones, as shown on Map 35. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the two erosion zones in Section 6.

Map 35

SHORELINE EROSION REACH 6: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 6, Township 4 North, Range 23 East
Town of Caledonia, Racine County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Erosion Zone 6a

Erosion Zone 6a extends from the south line of Section 6 at Seven Mile Road extended north about 0.75 mile to about the southern boundary of the Wisconsin Electric Power Company site, as shown on Map 35. This zone had little or no beach. The bluff had a height of between 60 and 100 feet in this zone. In 1995, the bluff was unprotected within this zone, with vegetation cover, primarily shrubs, grasses, and weeds, extending over about 20 percent of the bluff slope. The 1995 field observations indicated 30 to 50 feet of retreat in the bluff top since 1975. Signs of recent shallow slides and flows, and localized slumps, were present.

In 1995, two bluff profile field surveys were made within Zone 6a by occupying sites for which field surveys were conducted in 1976. The sites had significantly different geometries to those documented in 1976. The stability of the bluffs in Zone 6a of Reach 6 was characterized by Profile Nos. 6-18 and 6-19. Results of the slope stability analysis, shown in Figure 28, indicated that the bluffs were marginally stable, with safety factors of 0.99 at Profile No. 6-18 in the southern portion of the zone and 1.05 at Profile No. 6-19 in the central portion of the zone, based upon the deterministic bluff stability analysis method. Profile Nos. 6-18 and 6-19 were also analyzed using the probabilistic bluff stability analysis method. At Profile No. 6-18, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.82 to 1.29 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 13, or 52 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 41, or 16.4 percent, of the 250 conditions analyzed. At Profile No. 6-19, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.88 to 1.19 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for five, or 20 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 29, or 11.6 percent, of the 250 conditions analyzed. Given the analytical results the bluffs were considered marginally stable. Field observations indicated that shallow translational failures are possible. The 1977 study reported bluff safety factors of 1.23 and 1.2 at Profile Nos. 6-18 and 6-19, respectively.

The beach was narrow to nonexistent within Erosion Zone 6a. In the 1977 study, the beach width was reported to be between zero and 15 feet, and the beach materials were reported to be sand and gravel, with some boulders at the northern end of the zone. At Profile No. 6-18, the nearshore lakebed depth of five feet was reached at 70 feet offshore in 1977. The primary nearshore surface material at this site in 1976 was cobbles. At Profile No. 6-19, the nearshore lakebed depth of five feet was reached at 75 feet offshore in 1977. The primary nearshore surface materials at this site in 1976 were sand and gravel.

Shoreline recession data for Erosion Zone 6a were estimated at three locations. These data indicated a recession of between 210 and 290 feet, or between 6.6 and 9.1 feet per year, occurred between 1963 and 1995, with the highest rate of shoreline recession occurring in the central portions of the zone. The data indicated a recession of between 120 and 160 feet, or between six and eight feet per year, occurring between 1975 and 1995, with the greatest rate of recession occurring in the central portion of the zone. Thus, the bluff appeared to continue to be actively eroding within this zone. The 1977 study reported a recession rate of three feet per year for this zone.

Erosion Zone 6b

Erosion Zone 6b extends from the northerly limit of Erosion Zone 6a north adjacent to the Wisconsin Electric Power Company's Oak Creek Power Plant about 0.25 mile to County Line Road extended, as shown on Map 35. This zone had a nonexistent beach. The bluff had a height of about 100 feet in this zone. In 1995, there were a variety of shoreline protection structures in this zone, including revetments. Vegetation covered between 50 and 100 percent of the bluff slope. The 1995 field observations indicated no apparent retreat in the bluff top since 1976.

No bluff stability analyses were conducted within Erosion Zone 6b in this study or the 1977 study.

The beach was nonexistent within Zone 6b. No measurements or observations of nearshore lakebed depth or materials were made at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 16b were not estimated. The 1977 study did not report recession rates for this erosion zone.

In 1995, minor erosion observed behind the revetment within Zone 6b suggested that the revetment may have been overtopped. However, it appeared that the revetment was successful in controlling erosion within this

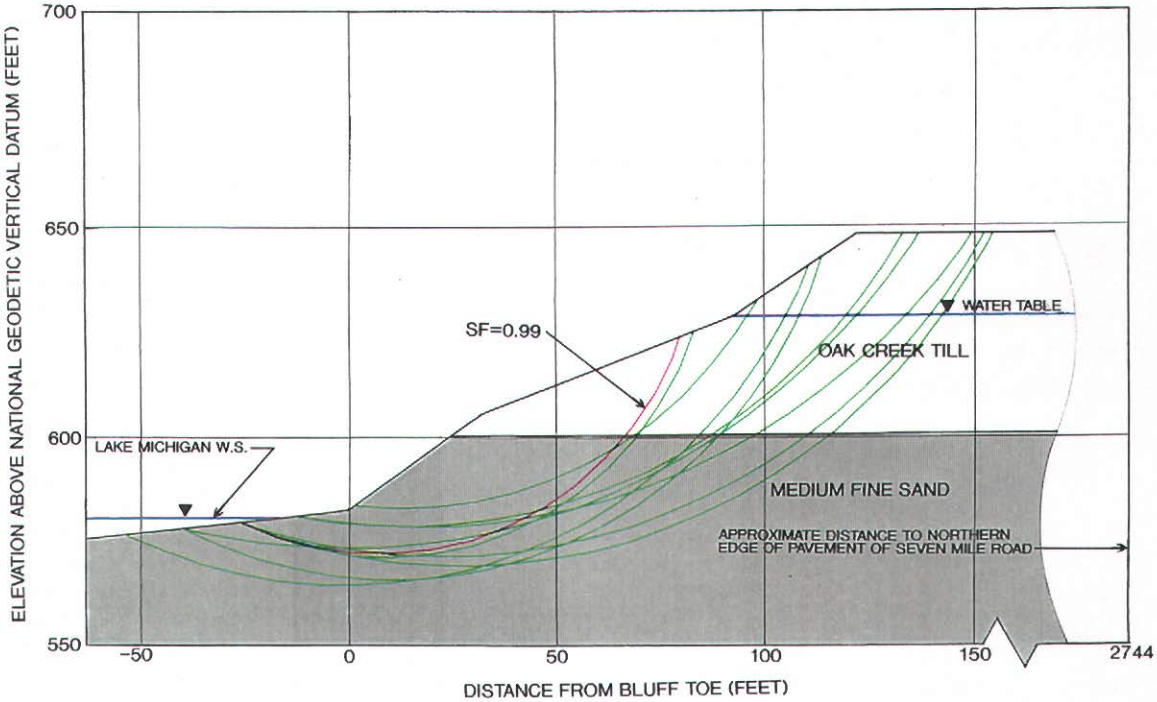
Figure 28

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 6, Township 4 North, Range 23 East
Town of Caledonia, Racine County

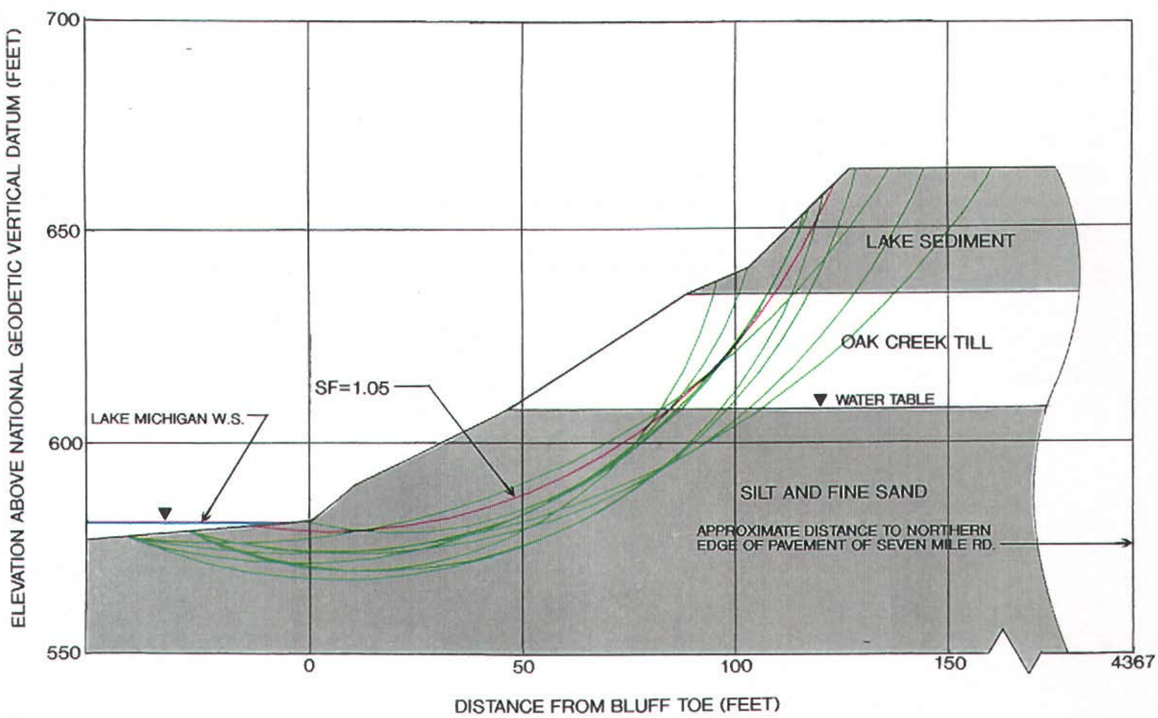
PROFILE 6-18

T.4N. R.23E. SEC.6



PROFILE 6-19

T.4N. R.23E. SEC.6



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

zone. Continued maintenance of the shoreline protection structures within Erosion Zone 6b is required to prevent shoreline loss during future periods of higher lake levels. In contrast, Erosion Zone 6a is likely to continue to erode unless shoreline protection structures are installed. No structures are endangered by shoreline recession within this zone.

SHORELINE REACH 7: CITY OF OAK CREEK, MILWAUKEE COUNTY

Shoreline Reach 7 is a five-mile-long reach of shoreline extending from the south line of U.S. Public Land Survey Section 36, Township 5 North, Range 23 East, City of Oak Creek, at County Line Road north to Addison Lane extended near the north line of U.S. Public Land Survey Section 24, Township 5 North, Range 22 East, City of Oak Creek, as shown on Map 36. Land uses along this reach include open spaces in Bender Park situated in the central portion of the reach, residential lands in the north, remnant agricultural lands in the south, and industrial and commercial land uses at intervals throughout the reach. The Oak Creek Power Plant of the Wisconsin Electric Power Company was located at the southern extreme of the reach and the South Shore Sewage Treatment Plant of the Milwaukee Metropolitan Sewerage District at the northern extreme of the reach. In 1976, this reach ranked fourth in the list of critical portions of the Lake Michigan shoreline in Wisconsin. As of 1995, about one linear mile, or about 35 percent, of the shoreline in Reach 7 were protected by structural shore protection measures, consisting of revetments, rubble fills, and groins.

As shown on Map 36, Reach 7 was further segmented into four shoreline analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the four shoreline analysis sections in Reach 7.

U.S. Public Land Survey Section 31, Township 5 North, Range 23 East and Section 36, Township 5 North, Range 22 East, City of Oak Creek, Milwaukee County

This shoreline analysis section extends from County Line Road extended north to E. Oakwood Road extended, in the City of Oak Creek, as shown on Map 37. In 1995, the lakeshore area was occupied by park and industrial lands. The Wisconsin Electric Power Company Oak Creek Power Plant occupied part of the lakeshore at the southern end of the section. In 1995, the southern half of the section was protected by revetments. The northern half of the section was protected by a broad beach of about 150 feet in width in the central portion of the section tapering to about 62.5 feet in width at the north end of the section, which appeared to be accreting sand north of the Wisconsin Electric Power Company's revetment, fronting a 60- to 125-foot-high bluff. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by intermixed fine sand and silt, overlain by till. For analysis purposes, Sections 31 and 36 were further subdivided into three erosion zones, as shown on Map 37. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three erosion zones in Sections 31 and 36.

Erosion Zone 31a

Erosion Zone 31a extends from the south line of Section 36 at County Line Road extended north about 0.45 mile to about a point on the lakeshore adjacent to the landward end of the northernmost revetment protecting the Oak Creek Power Plant site in the vicinity of Elm Road extended, as shown on Map 37. This zone had little or no beach. The bluff had a height of up to 60 feet in this zone. Seawalls and revetments protected the toe of the bluff. Much of the bluff had been modified. Vegetation covered approximately 40 percent of the bluff slope and approximately 70 percent of the terrace at the bluff toe. The 1995 field observations indicated between three and 20 feet of retreat in the bluff top since 1977. Signs of soil flows and translational slides were observed.

No bluff stability analyses were conducted within Erosion Zone 31a in this study or the 1977 study.

The beach was narrow or nonexistent within Erosion Zone 31a. In the 1977 study, the beach width was reported to be less than 20 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

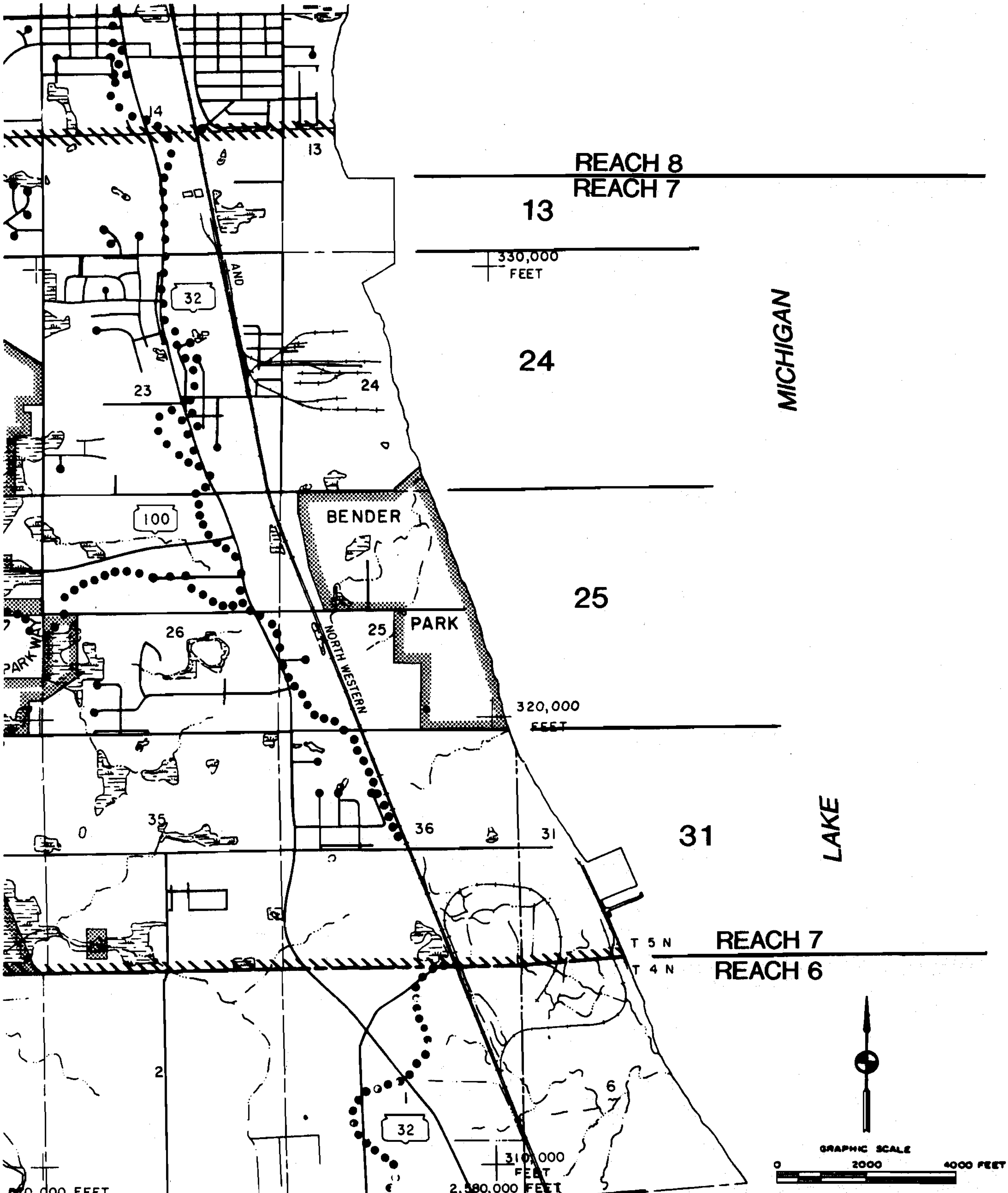
Shoreline recession data for Erosion Zone 31a were not estimated.

Erosion Zone 31b

Erosion Zone 31b extends from the northerly limit of Erosion Zone 31a adjacent to the Wisconsin Electric Power Company's Oak Creek Power Plant at about Elm Road north about 0.4 mile, as shown on Map 37. This

Map 36

BLUFF ANALYSIS SECTIONS WITHIN REACH 7

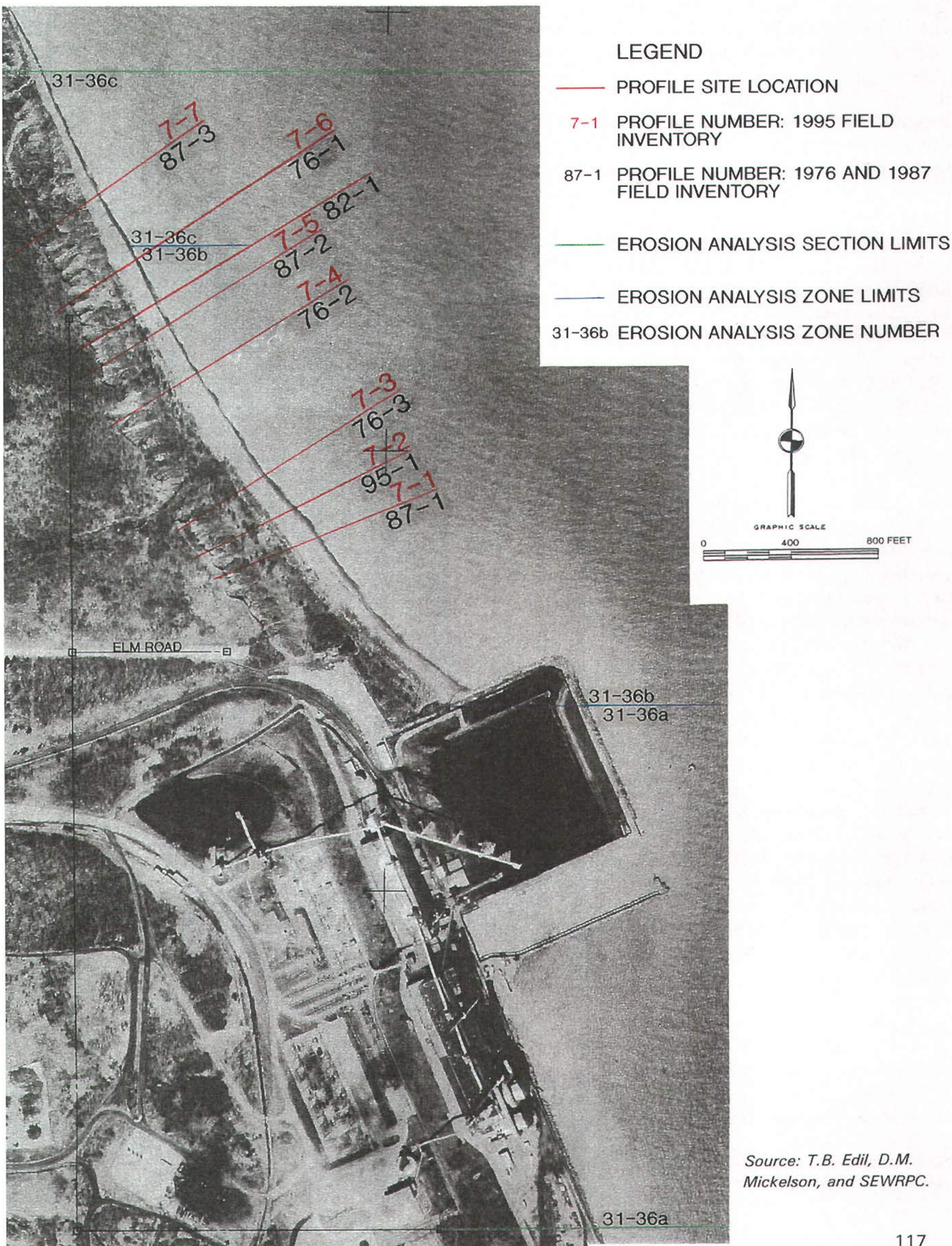


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 37

SHORELINE EROSION REACH 7: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 31, Township 5 North, Range 23 East, and
U.S. Public Land Survey Section 36, Township 5 North, Range 22 East
City of Oak Creek, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

zone had a broad beach ranging from about 150 feet in width in the southern portion of the zone to about 100 feet in width in the northern portion of the zone. The bluff had a height of about 100 feet in this zone. Vegetation covered between 50 and 60 percent of the bluff slope. The 1995 field observations indicated two to 15 feet of retreat in the bluff top since 1976. Signs of soil flows and surface rills were observed.

In 1995, three bluff profile field surveys were made within Zone 31b by occupying sites for which field surveys were conducted in 1976. The reoccupied sites had significantly different geometries to those documented in 1976. In the northern portion of the zone, Profile Nos. 7-4 and 7-6 appeared to have become less steeply sloped, while in the central portion of the zone, Profile No. 7-3 appeared to have become steeper. Also in 1995, three bluff profile surveys were made within Zone 31b by occupying sites for which field surveys were conducted in 1987. The reoccupied sites had significantly different geometries to those documents in 1987. All three sites appeared to have become less steeply sloped. One additional bluff profile field survey was made within Zone 31b at a site not previously occupied. The stability of the bluff in Zone 31b of Reach 7 was characterized by Profile Nos. 7-1 through 7-6. Results of the slope stability analysis, shown in Figures 29 through 31, indicated that the bluff ranged from unstable, with a safety factor of 0.92 at Profile No. 7-6 in the northern extreme of the zone, to stable, with a safety factor of 1.59 in the south, based upon the deterministic bluff stability analysis method. Profile No. 7-6 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.58 to 1.25 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 22, or 88 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 148, or 59.2 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered unstable with both rotational and translational failures possible. The 1977 study reported bluff safety factors of 0.81 to 1.38, and the 1987 study reported bluff safety factors of 1.0 to 1.43.

The beach was between 100 and 150 feet in width within Zone 31b. In the 1977 study, the beach width was reported to be less than 20 feet, and the beach materials were reported to be sand and gravel. At Profile No. 7-3, the nearshore lakebed depth of five feet was reached at 30 feet offshore in 1977. The primary nearshore surface material at this site in 1976 was gravel. At Profile No. 7-4, the nearshore lakebed depth of five feet was reached at 35 feet offshore in 1977. The primary nearshore surface material at this site in 1976 was gravel. At Profile No. 7-6, the nearshore lakebed depth of five feet was reached at 41 feet offshore in 1977. The primary nearshore surface materials at this site in 1976 were sand and gravel. No measurements or observations of nearshore lakebed depth or materials were made at this site in 1995.

Shoreline recession data for Erosion Zone 31b were estimated at one location. These data indicated a recession of about 90 feet, or about 2.8 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 40 feet, or about two feet per year, occurred between 1975 and 1995. Thus, it appeared that the central portion of the bluff within this zone had not been stabilized and was continuing to recess. The 1977 study did not report recession rates for this erosion zone.

Erosion Zone 31c

Erosion Zone 31c extends from the northerly limit of Erosion Zone 31b north about 0.15 mile to E. Oakwood Road extended, as shown on Map 37. This zone had a beach width of between 50 and 75 feet. The bluff had a height of up to 100 feet in this zone. In 1995, the bluff was unprotected. Vegetation covered approximately 70 percent of the bluff slope. The 1995 field observations indicated that no assessment of retreat in the bluff top could be made. Signs of rotational and translational failures and soil flows near the bluff toe were present.

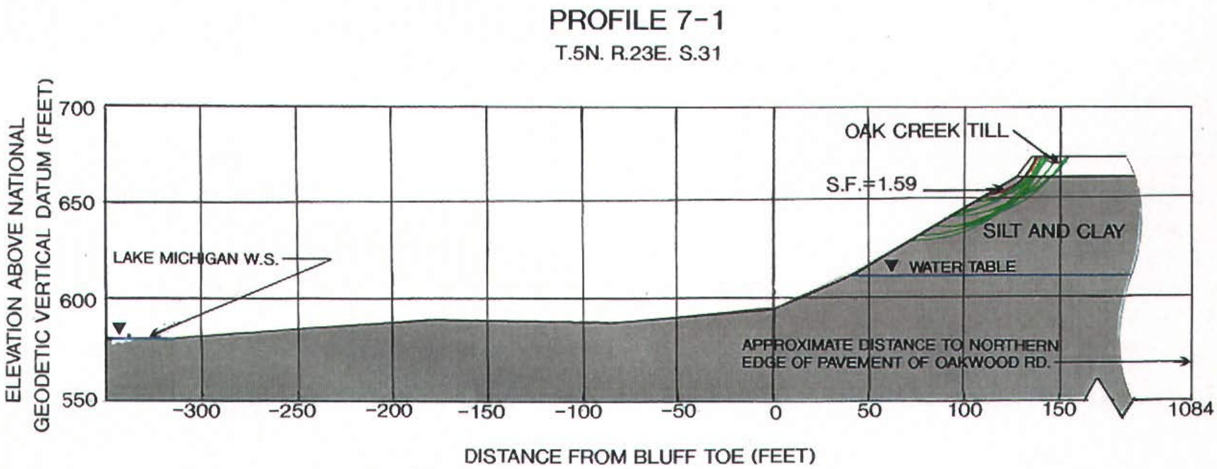
In 1995, one bluff profile field survey was made within Zone 31c by occupying a site for which a field survey was conducted in 1987. The site had a significantly different geometry to that documented in 1987. The site appeared to have become less steeply sloped as the result of the removal of slumped bluff material. The stability of the bluff in Zone 31c of Reach 7 was characterized by Profile No. 7-7. Results of the slope stability analysis, shown in Figure 31, indicated that the bluff was stable with respect to rotational failures, with a safety factor of 1.50. However, 1995 field observations indicated that translational failures may occur. The 1987 study reported a bluff safety factor of 1.18.

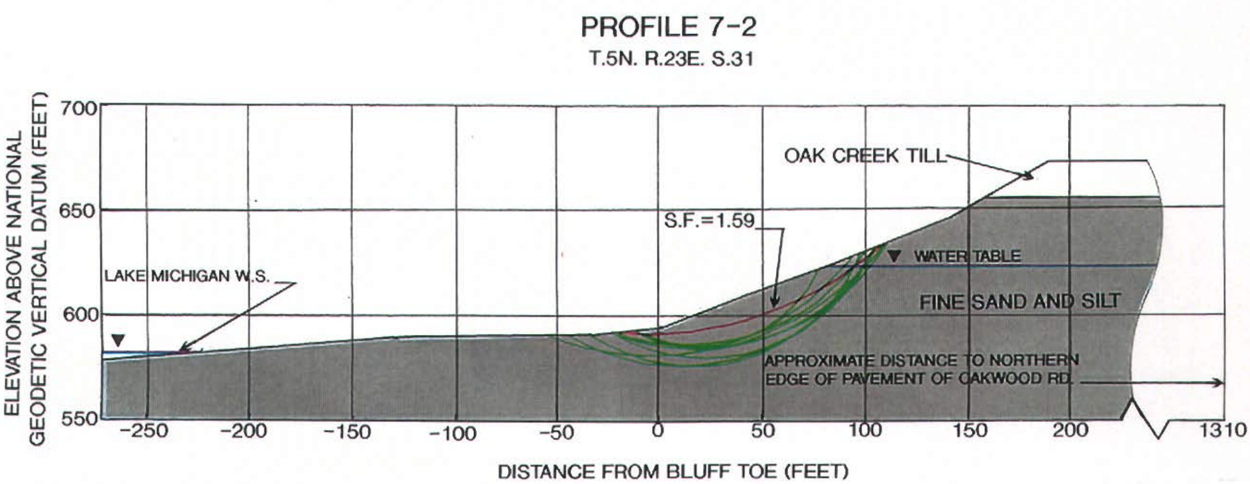
The beach was 50 to 100 feet in width within Zone 31c. In the 1977 study, the beach width was reported to be between 10 and 20 feet, and the beach materials were reported to be sand and gravel. No measurements or

Figure 29

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 31, Township 5 North, Range 23 East
City of Oak Creek, Milwaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1977.

Shoreline recession data for Erosion Zone 31c were estimated at two locations. These data indicated a recession of between 10 and 40 feet, or between 0.3 and 1.2 feet per year, occurred between 1963 and 1995. The data indicated a recession of up to 20 feet, or one foot per year, occurred between 1975 and 1995. The northern portion of the bluff had been stabilized and was accreting within this zone, while the southern portion of the bluff within this zone had not been stabilized and was continuing to recess. The 1977 study reported a recession rate of three feet per year for this erosion zone.

U.S. Public Land Survey Section 25, Township 5 North, Range 22 East, City of Oak Creek, Milwaukee County

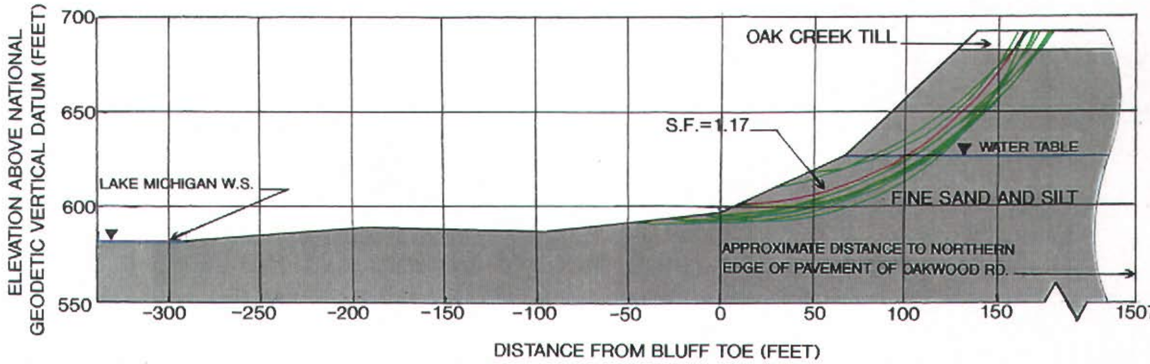
This shoreline analysis section extends from E. Oakwood Road extended north to E. Ryan Road extended, in the City of Oak Creek, as shown on Map 38. In 1995, the entire section was occupied by Bender Park. In 1995, the northern portion of the section was being regraded and the southern portion of the section was

Figure 30

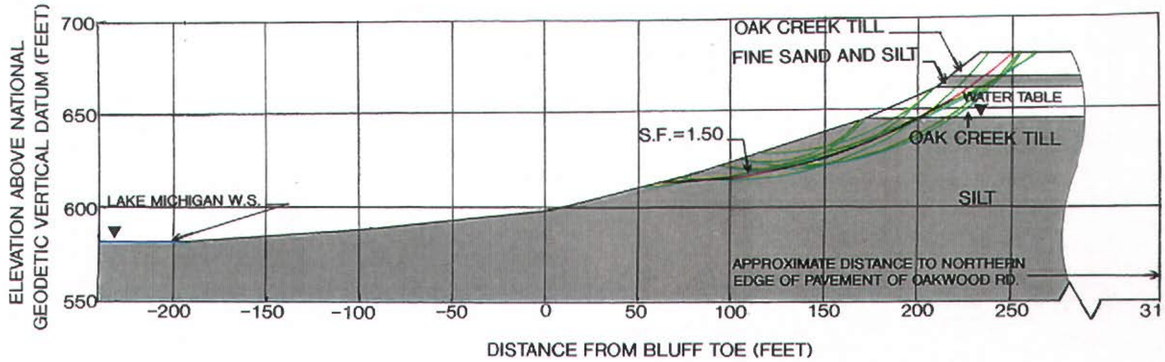
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 31, Township 5 North, Range 23 East
City of Oak Creek, Milwaukee County

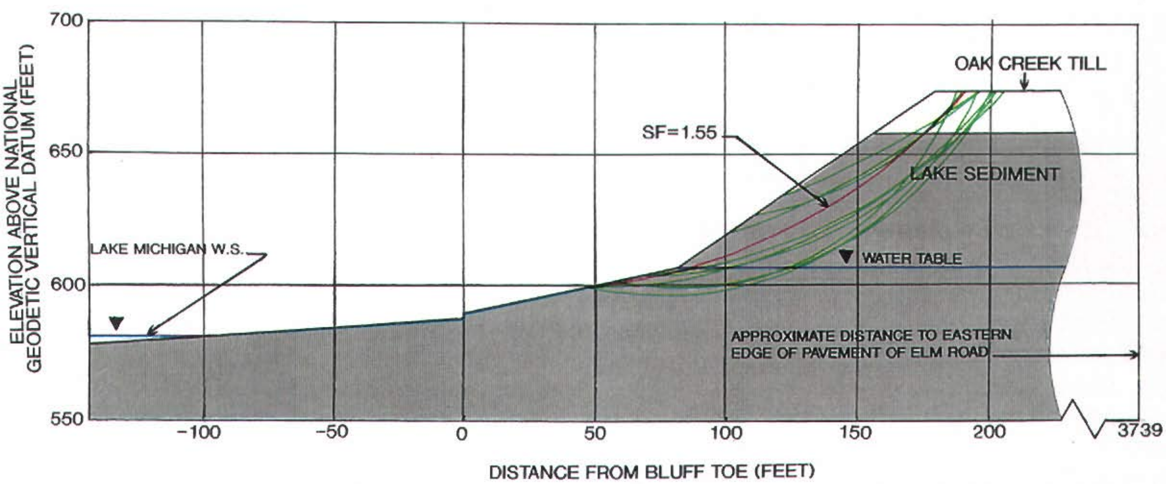
PROFILE 7-3
T.5N. R.23E. S.31



PROFILE 7-4
T.5N. R.23E. S.31



PROFILE 7-5
T.5N. R.23E. SEC. 31

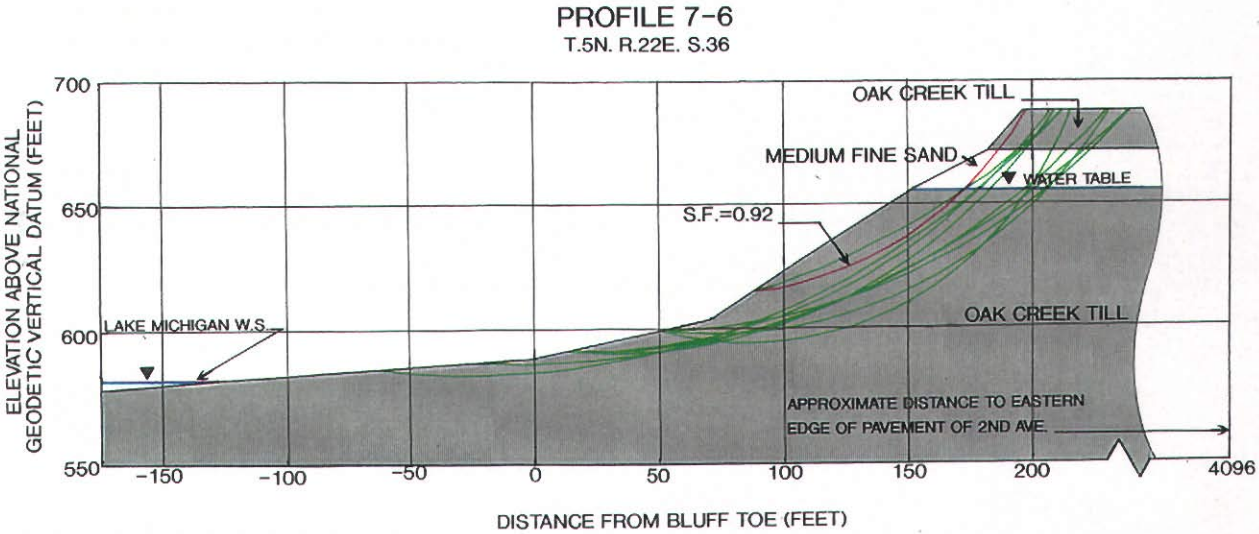


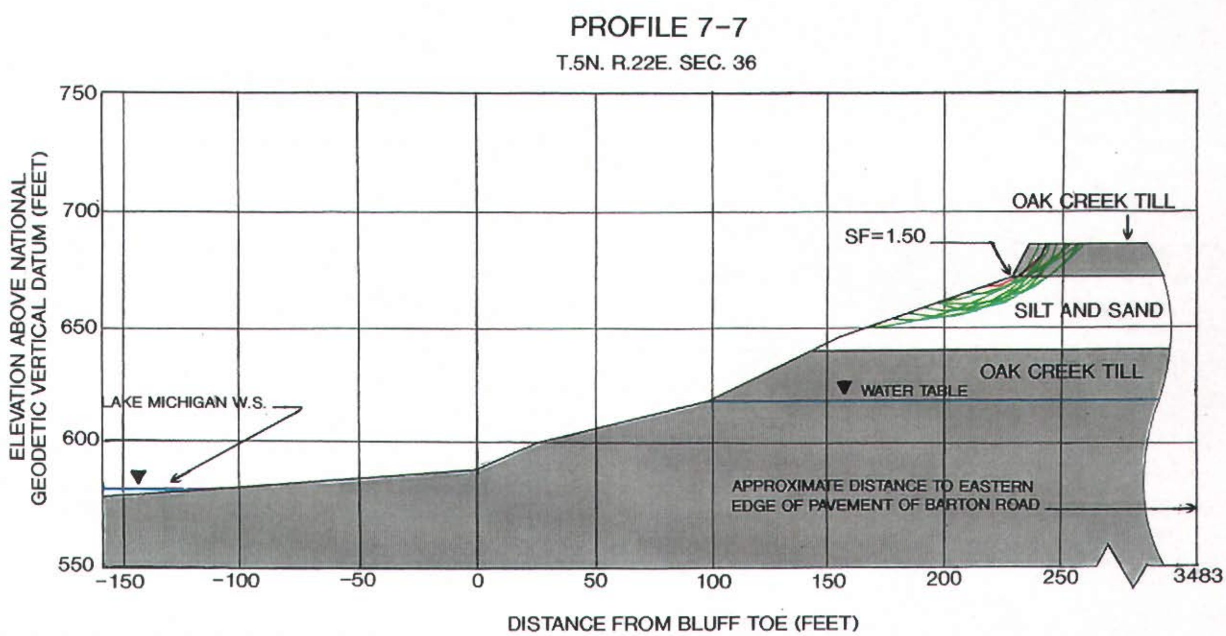
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 31

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 36, Township 5 North, Range 22 East
City of Oak Creek, Milwaukee County





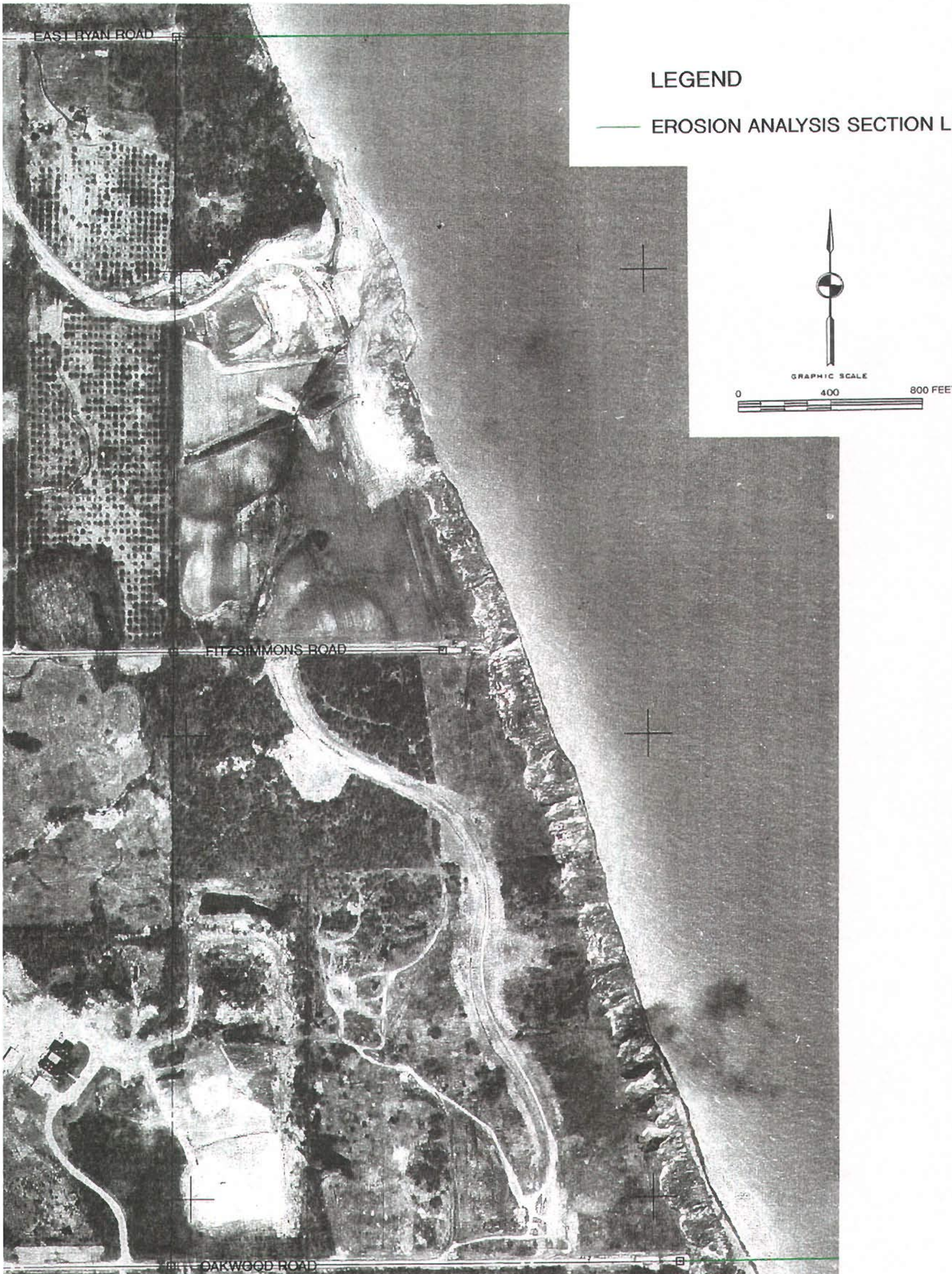
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

scheduled for regrading following completion of the regrading project in the northern portion of the section. The bluff materials in this section were generally obscured by construction activities associated with the regrading of the bluff slopes, but were estimated to be primarily till in the lower quarter of the bluff, overlain by fine sand and silt, overlain by till with intermixed fine sand and silt. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for Section 25.

Map 38

SHORELINE EROSION REACH 7: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 25, Township 5 North, Range 22 East
City of Oak Creek, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

In 1995, this zone had little or no beach fronting a bluff which had a height of between 100 and 110 feet. The bluff was unprotected in this zone, but was undergoing stabilization by regrading of the bluff slope. The 1995 field observations indicated that no assessment of retreat of the bluff top could be made due to the construction activities.

No bluff stability analyses were conducted within Section 25 in this study. In 1987, four bluff profile field surveys were made within Section 25, by reoccupying the sites for which field surveys were conducted in 1976. Results of the slope stability analyses indicated that the bluff ranged from unstable to stable in 1976, with safety factors of between 0.69 and 1.24. In 1976, bluff stability decreased from the southern portion of the section, where the greatest bluff stability was measured, to the northern portion of the section. The least bluff stability occurred in the central portion of the section. Results of the slope stability analyses indicated that the bluff was unstable to marginally stable in 1987, with safety factors of between 0.7 and 1.13, with the greater bluff stability occurring in the south-central portion of the section and the least bluff stabilities occurring in the extreme south and central portions of the section.

The beach was narrow to nonexistent within Section 25. In the 1977 study, the beach width was reported to be between five and 20 feet in the southern portion of the section and less than five feet in the northern portion of the section, and the beach materials were reported to be pebbles and cobbles in the southern portion of the section grading to cobbles in the northern portion of the section. No measurements or observations of nearshore lakebed depth or materials were made at this site in 1995.

Shoreline recession data for Section 25 were estimated at five locations. These data indicated a recession of between 10 and 400 feet, or between 0.3 and 12.5 feet per year, occurred between 1963 and 1995. The data indicated a recession of between -10 and 160 feet, or between -0.5 and 8.0 feet per year, occurring between 1975 and 1995. The bluff at the southern extreme of the section appeared to be accreting. However, throughout the major portion of the section, the bluff appeared to be unstable, with shoreline loss increasing from south to north. The greatest loss of shoreline occurred at the northern extreme of the section. The 1977 study reported a recession rate of between two and three feet per year for this section.

U.S. Public Land Survey Section 24, Township 5 North, Range 22 East, City of Oak Creek, Milwaukee County

This shoreline analysis section extends from E. Ryan Road extended north to about Addison Lane extended, in the City of Oak Creek, as shown on Map 39. The shoreline was occupied by Bender Park in the southern portion of the section and by commercial and industrial lands in the central and northern portions of the section, with the Milwaukee Metropolitan Sewerage District South Shore Sewage Treatment Plant being located at the northern extreme of the section. The bluff materials in this section were generally covered, but were estimated to be primarily till in the lower quarter of the bluff, overlain by fine sand and silt, overlain by till with intermixed fine sand and silt. For analysis purposes, Section 24 was further subdivided into four erosion zones, as shown on Map 39. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the four erosion zones in Section 24.

Erosion Zone 24a

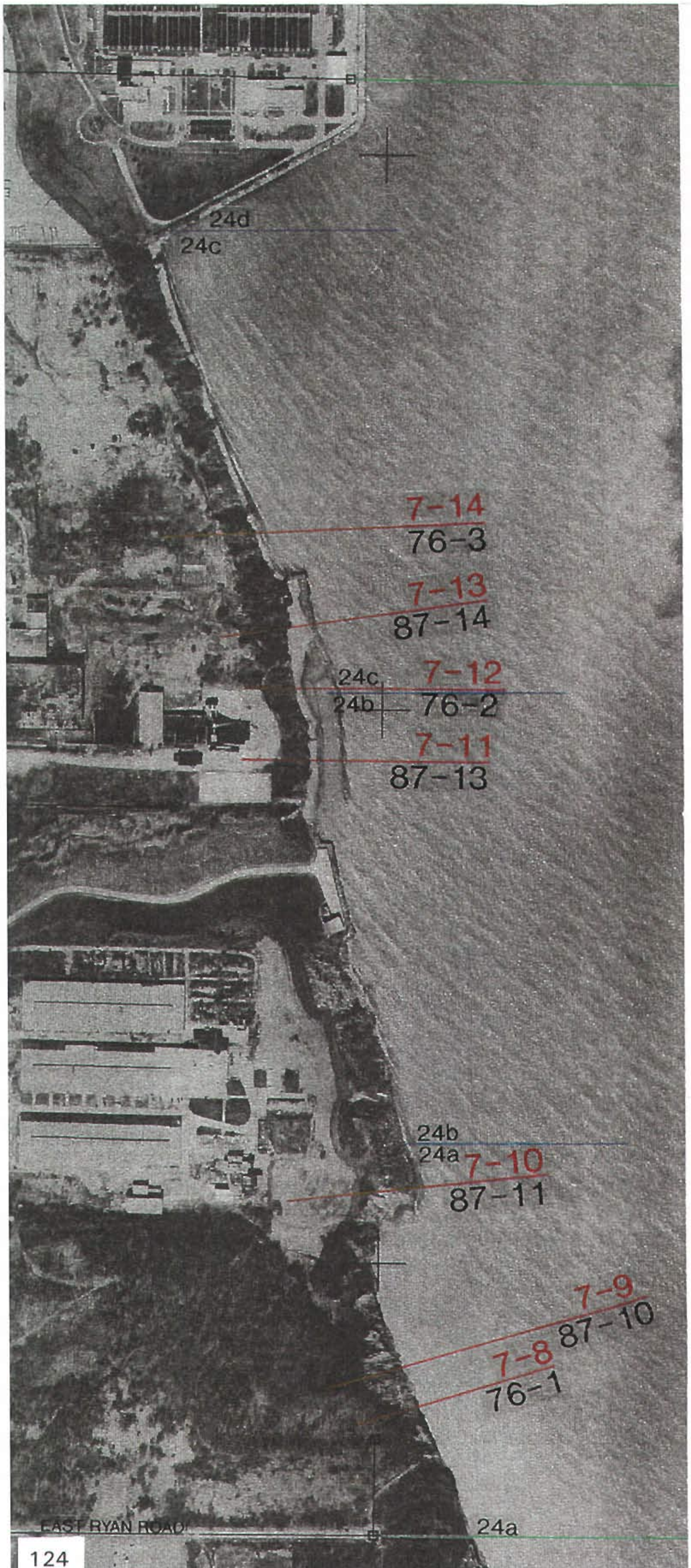
Erosion Zone 24a extends from the south line of Section 24 at E. Ryan Road extended north about 0.2 mile, as shown on Map 39. This zone little or no beach fronting a bluff which had a height of about 80 feet. In 1995, the bluff was unprotected in this zone. The 1995 field observations indicated that no assessment of retreat of the bluff top could be made. Vegetation covered between zero and 30 percent of the bluff slope. Signs of rotational slumping were observed.

In 1995, one bluff profile field survey was made within Zone 24a by occupying a site for which a field survey was conducted in 1976. The site had a significantly different geometry to that documented in 1976. The shape of the bluff had become less steep. Also in 1995, two bluff profile field surveys were made within Zone 24a by occupying sites for which field surveys were conducted in 1987. At Profile No. 7-9 in the central portion of the zone, the bluff had a significantly different geometry to that documented in 1987. The shape of the bluff had become less steep. At Profile No. 7-10 in the northern portion of the zone, the bluff retained a similar shape to that documented in 1987. The stability of the bluff in Zone 24a of Reach 7 was characterized by Profile Nos. 7-8 through 7-10. Results of the slope stability analysis, shown in Figures 32 and 33, indicated that the bluff was unstable in the northern and southern portions of the zone, with safety factors ranging from 0.8 to 0.99, but stable in the central portion of the zone which

Map 39

SHORELINE EROSION REACH 7: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 24, Township 5 North, Range 22 East
City of Oak Creek, Milwaukee County



GRAPHIC SCALE
0 400 800 FEET

LEGEND

PROFILE SITE LOCATION

7-10 PROFILE NUMBER: 1995 FIELD INVENTORY

87-11 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

24b EROSION ANALYSIS ZONE NUMBER

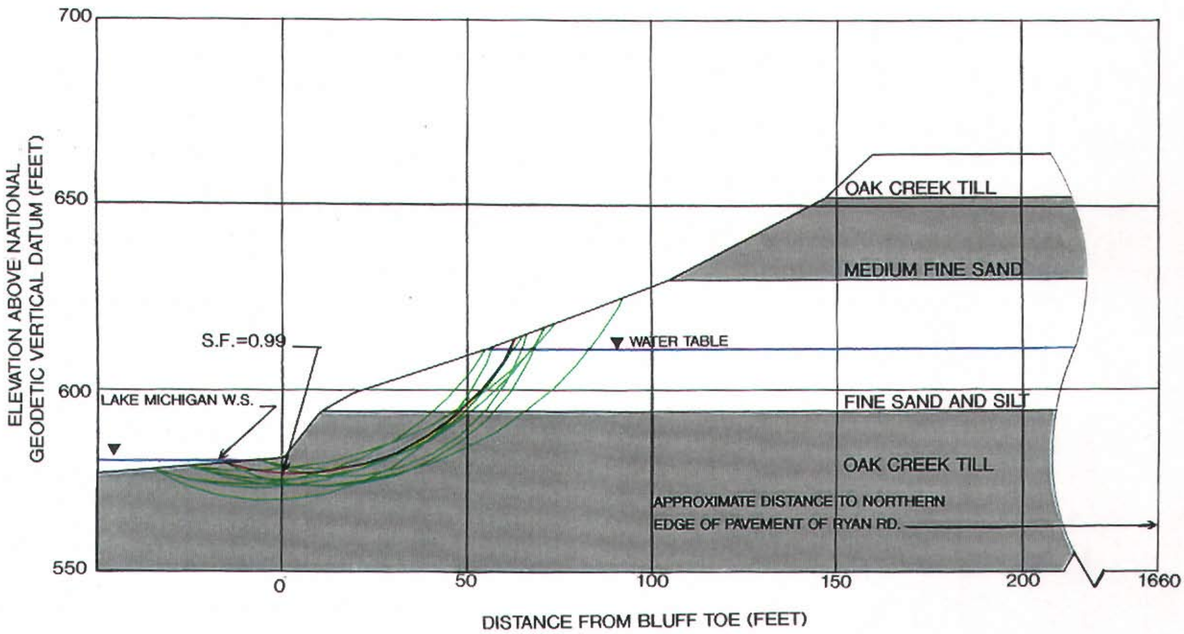
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 32

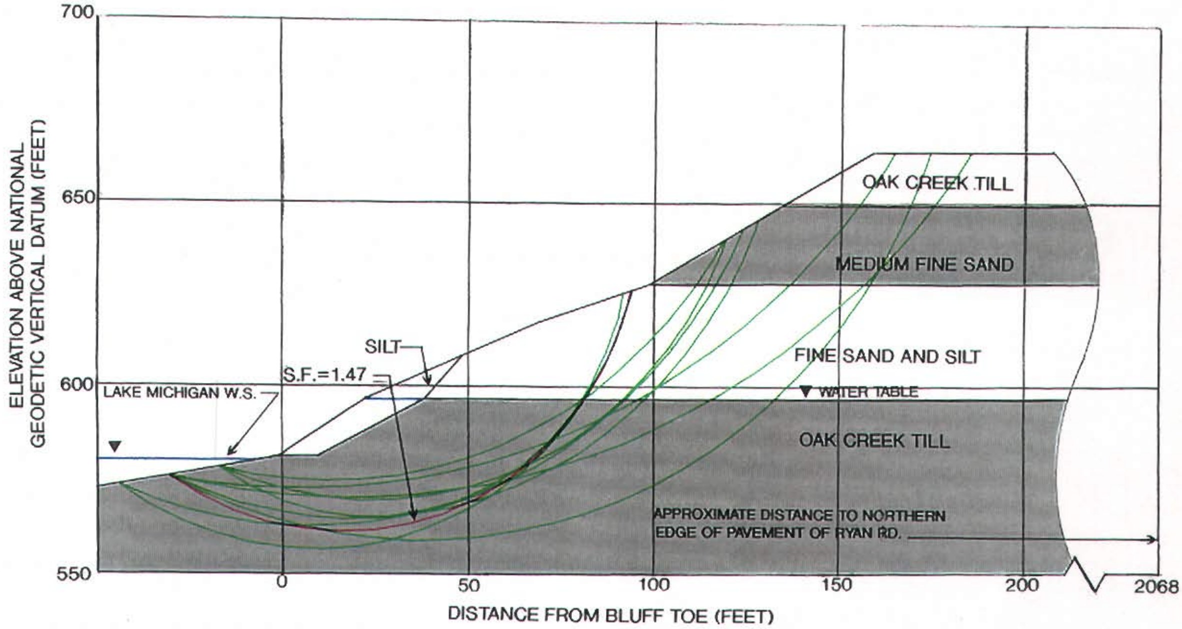
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 24, Township 5 North, Range 22 East
City of Oak Creek, Milwaukee County

PROFILE 7-8
T.5N. R.22E. S.24



PROFILE 7-9
T.5N. R.22E. S.24



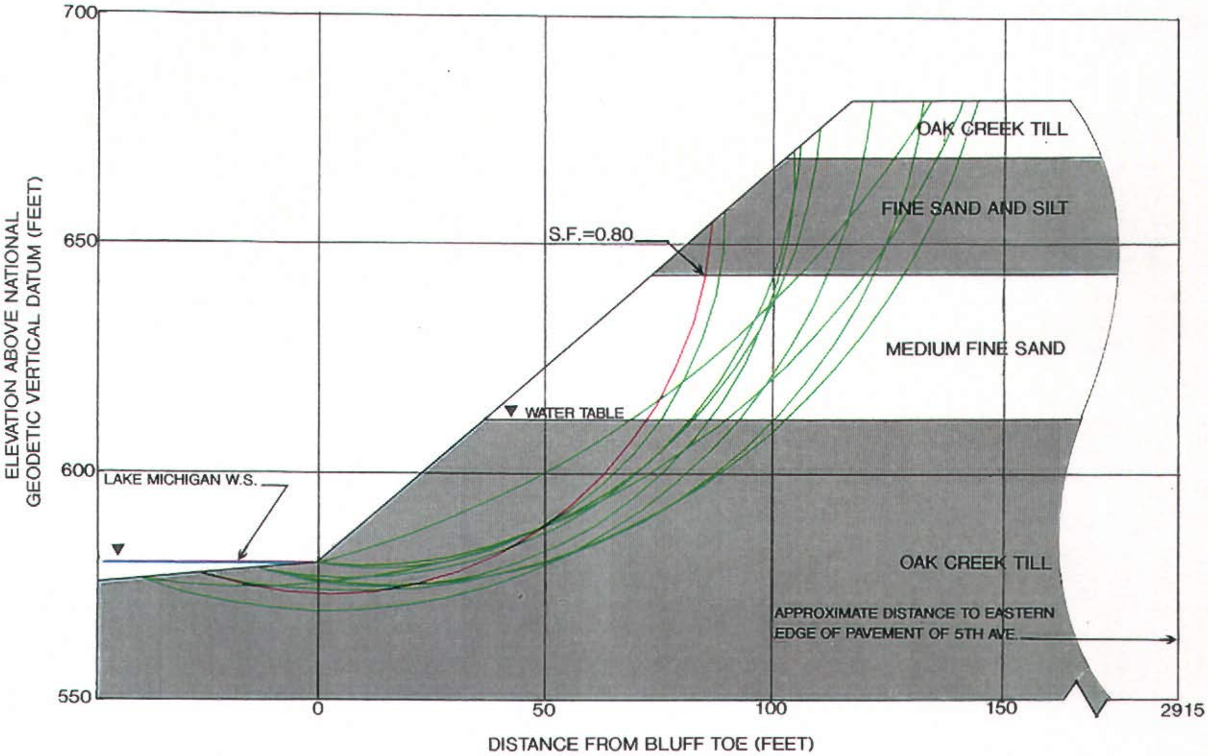
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 33

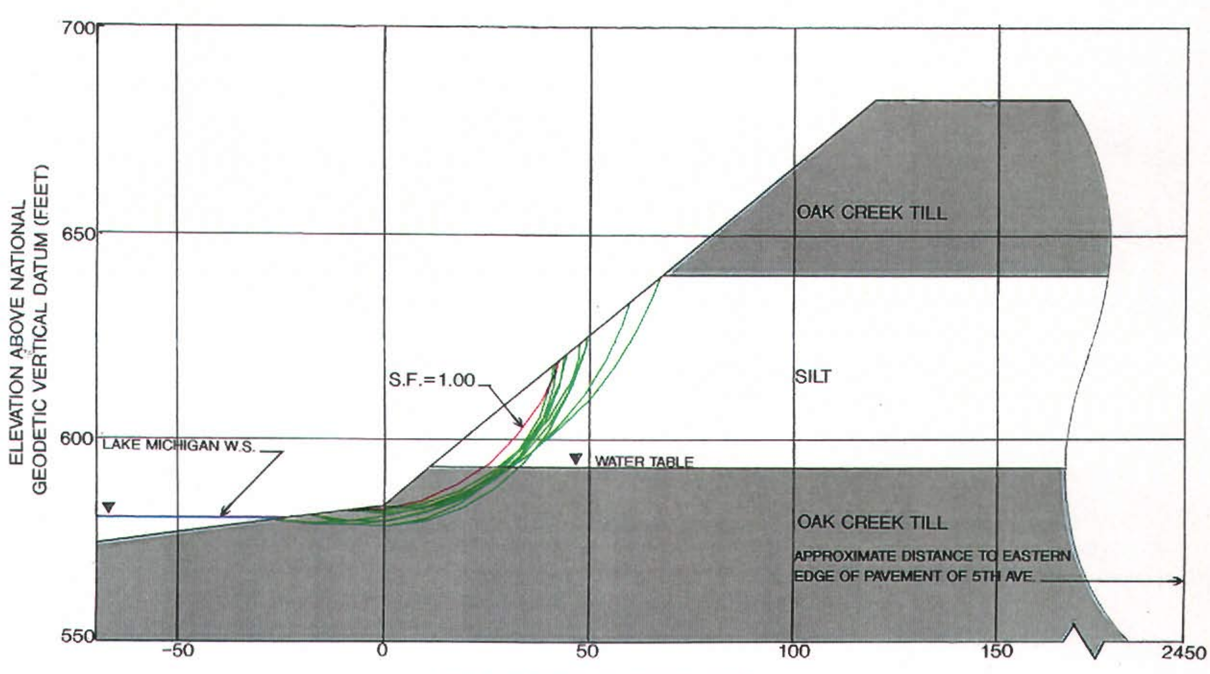
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

**U.S. Public Land Survey Section 24, Township 5 North, Range 22 East
City of Oak Creek, Milwaukee County**

PROFILE 7-10
T.5N. R.22E. S.24



PROFILE 7-11
T.5N. R.22E. S.24



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

had a safety factor of 1.47, based upon the deterministic bluff stability analysis method. Profile No. 7-8 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.87 to 1.42 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for five, or 20 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 29, or 11.6 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a bluff safety factor of 0.54. The 1987 study reported bluff safety factors of between 0.86 and 0.87.

The beach was nonexistent within Erosion Zone 24a. Also, in the 1977 study, no beach was reported. In 1977, the nearshore lakebed depth of five feet was reached at 90 feet offshore. The primary nearshore surface materials at this site in 1976 were not reported. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995.

Shoreline recession data for Erosion Zone 24a were estimated at one location. These data indicated a recession of about 400 feet, or about 12.5 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 160 feet, or about eight feet per year, occurring between 1975 and 1995. In 1995, the bluff was observed to be subject to rotational slumping within this zone. The 1977 study reported a recession rate of two feet per year for this zone.

Erosion Zone 24b

Erosion Zone 24b extends from the northerly limit of Erosion Zone 24a north about 0.3 mile to a point on the lakeshore about 400 feet north of the intersection of Lakeside Avenue and Chicago Road (STH 32), as shown on Map 39. This zone had a narrow beach of less than 25 feet in width. The bluff, protected by a riprap seawall and debris field, had a height of about 80 feet in this zone. The 1995 field observations that no assessment of retreat of the bluff top could be made. Vegetation covered approximately 80 percent of the bluff slope.

In 1995, one bluff profile field survey was made within Zone 24b by occupying a site for which a field survey was conducted in 1987. The site had a significantly different geometry to that documented in 1987. The shape of the bluff had become steeper. The stability of the bluff in Zone 24b of Reach 7 was characterized by Profile No. 7-11. Results of the slope stability analysis, shown in Figure 33, indicated that the bluff was unstable, with a safety factor of 0.99, based upon the deterministic bluff stability analysis method. Profile No. 7-11 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.76 to 1.12 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 23, or 92 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 179, or 71.6 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered unstable with respect to both rotational and translational failures. The 1987 study reported a bluff safety factor of 0.92.

The beach was narrow within Zone 24b. In the 1977 study, the beach width was reported to be less than five feet, and the beach material was reported to be boulders. No measurements or observations were made of the nearshore lakebed depth or material in 1995 or in 1977.

Shoreline recession data for Erosion Zone 24b were not estimated. The 1977 study did not report a recession rate for this erosion zone.

The placement of concrete slabs at the bluff toe within Erosion Zone 24b appeared to have protected the bluff toe from erosion, and resulted in the 1995 field observations indicating that the bluff slope in this zone was marginally stable. This observation was supported by the greater extent of shoreline loss in Erosion Zone 24a immediately to the south, which appears to have eroded about 50 feet more than in Erosion Zone 24b. Slumps or washouts were observed immediately to the north of this zone at one location. Also, the northern portion of this zone in the vicinity of Depot Street had been modified since 1976 by the construction of the water intake facility serving the City of Oak Creek Water Utility. The bluff slope around this site had been regraded and a revetment placed. No further shoreline loss was observed at this location.

Erosion Zone 24c

Erosion Zone 24c extends from the northerly limit of Erosion Zone 24b north about 0.3 mile to the southern boundary of the Milwaukee Metropolitan Sewerage District South Shore Sewage Treatment Plant property, as shown on Map 39. The southern portion of this zone had little or no beach. However, a beach with a width of about 25 feet existed in the northern portion of Erosion Zone 24c. The bluff had a height of up to 70 feet in this zone. In 1995, the bluff was protected in places along the southern portions of the zone. An offshore breakwater and the remains of an old revetment existed in the southernmost portion of the zone, a small breakwater existed in the central portion of the zone, and the remnants of a revetment existed in scattered locations in the northern portion of the zone, which was largely unprotected. Vegetation covered between 10 and 50 percent of the bluff slope. The 1995 field observations indicated that no assessment of retreat of the bluff top could be made. Signs of translational slides and soil flows were present. In 1995, the bluff appeared to have undergone several large slumps.

In 1995, two bluff profile field surveys were made within Zone 24c by occupying sites for which field surveys were conducted in 1976. The sites had slightly different geometries to those documented in 1976. At Profile No. 7-12, the bluff slope appeared to be more convex than in 1976. At Profile No. 7-14, the bluff slope appeared to be less steep. Also in 1995, one further bluff profile field survey site was occupied within Zone 24c, by reoccupying a site for which a field survey was conducted in 1987. This site had a slightly different geometry to that documented in 1987. At Profile No. 7-13, the bluff appeared to have developed an incipient scarp at the bluff top. The stability of the bluff in Zone 24c of Reach 7 was characterized by Profile Nos. 7-12 through 7-14. Results of the slope stability analysis, shown in Figure 34, indicated that the bluff was stable in the southern portion of the zone, but unstable in the central and northern portions of the zone with respect to rotational failures, with safety factors ranging from 0.8 to 1.29, based upon the deterministic bluff stability analysis method. Profile No. 7-14 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.85 to 1.38 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 13, or 52 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 27, or 10.8 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered marginally stable with respect to both rotational and translational failures. The 1977 study reported bluff safety factors of between 0.54 and 0.57, the latter being applicable only to the lower bluff slope at Profile No. 7-12 as the result of the stabilizing effect of massive muds flows and slumping. The 1987 study reported a bluff safety factor of 0.92.

The beach width was 20 to 70 feet within Zone 24c. In the 1977 study, the beach width was reported to be up to 20 feet, and the beach materials were reported to be pebbles and sand. At Profile No. 7-12, the nearshore lakebed depth of five feet was reached at 100 feet offshore in 1977. Primary nearshore surface materials were not reported. In 1977, at Profile No. 7-14, the nearshore lakebed depth of five feet was reached at 60 feet offshore, with the primary nearshore surface material at this site consisting of sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 24c were estimated at one location. These data indicated a recession of about 60 feet, or about 1.9 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 20 feet, or about one foot per year, occurred between 1975 and 1995. Thus, it appeared that the bluff was not fully stabilized within this zone, and was continuing to recess. The 1977 study did not report a recession rate for this erosion zone.

Of the shoreline protection structures present within Erosion Zone 24c, only the small breakwater in the central portion of the zone appeared to be functioning with a modicum of effectiveness, although signs of shallow slides were observed in places. In the other portions of this zone, the remnant revetments appeared to be ineffective at stabilizing the bluff, with the structure in the southern portion of the zone appearing to be somewhat more effective at stabilizing the bluff than the structure in the northern portion of the zone. In 1995, bluff toe erosion was observed in the southern portion of the reach suggesting that the offshore breakwater had been submerged during periods of higher lake levels. Signs of shallow translational failures were present in this portion of the zone. Several industrial buildings were observed to be in relatively close proximity to the bluff edge. In the northern portion of the zone, signs of shallow slides and slumps were present. Thus, shoreline erosion is likely to continue within Erosion Zone 24c unless steps are taken to prevent further shoreline recession.

Erosion Zone 24d

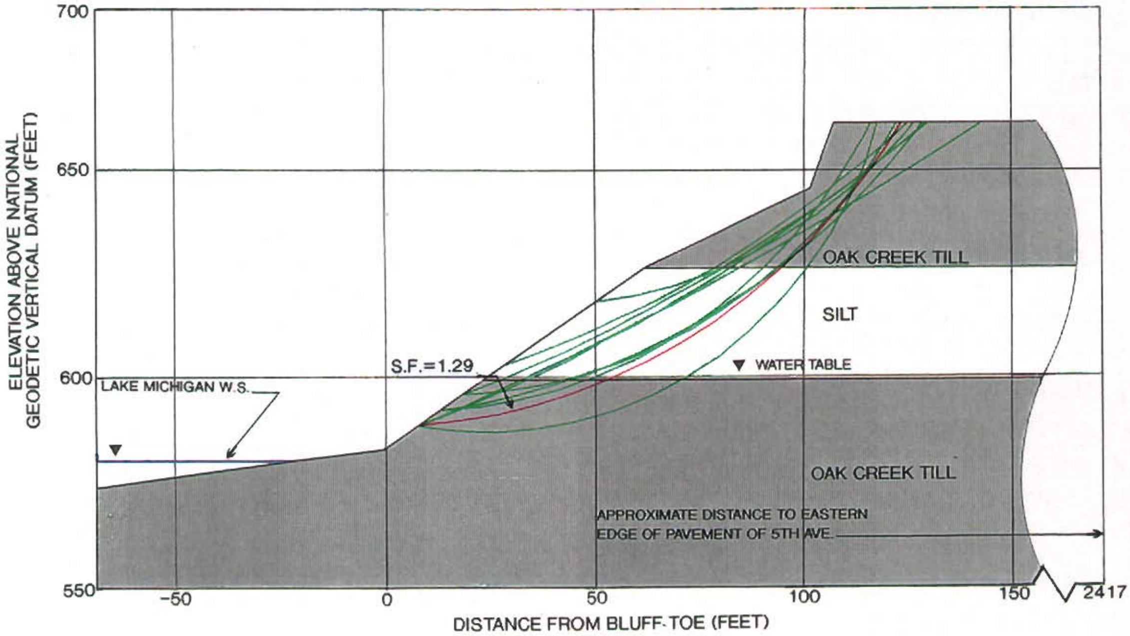
Erosion Zone 24d extends from the northerly limit of Erosion Zone 24c north, adjacent to the Milwaukee Metropolitan Sewerage District South Shore Sewage

Figure 34

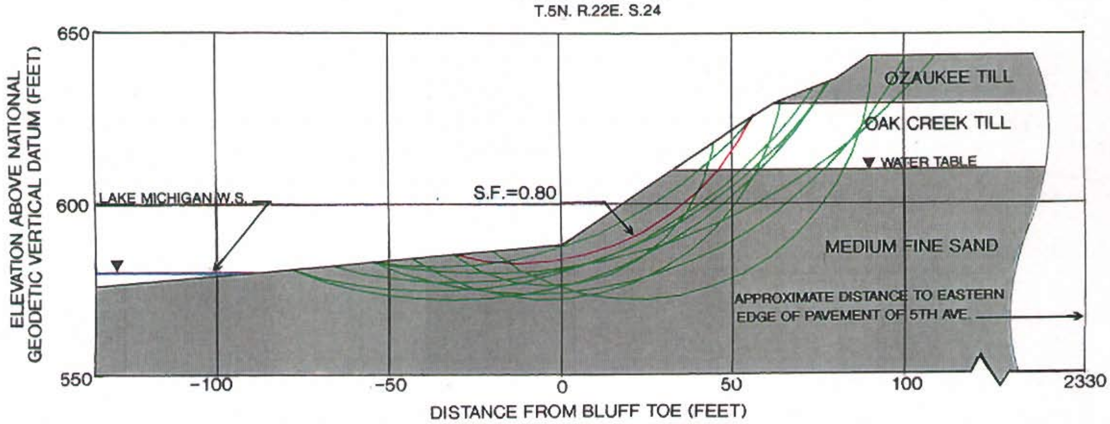
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 24, Township 5 North, Range 22 East
City of Oak Creek, Milwaukee County

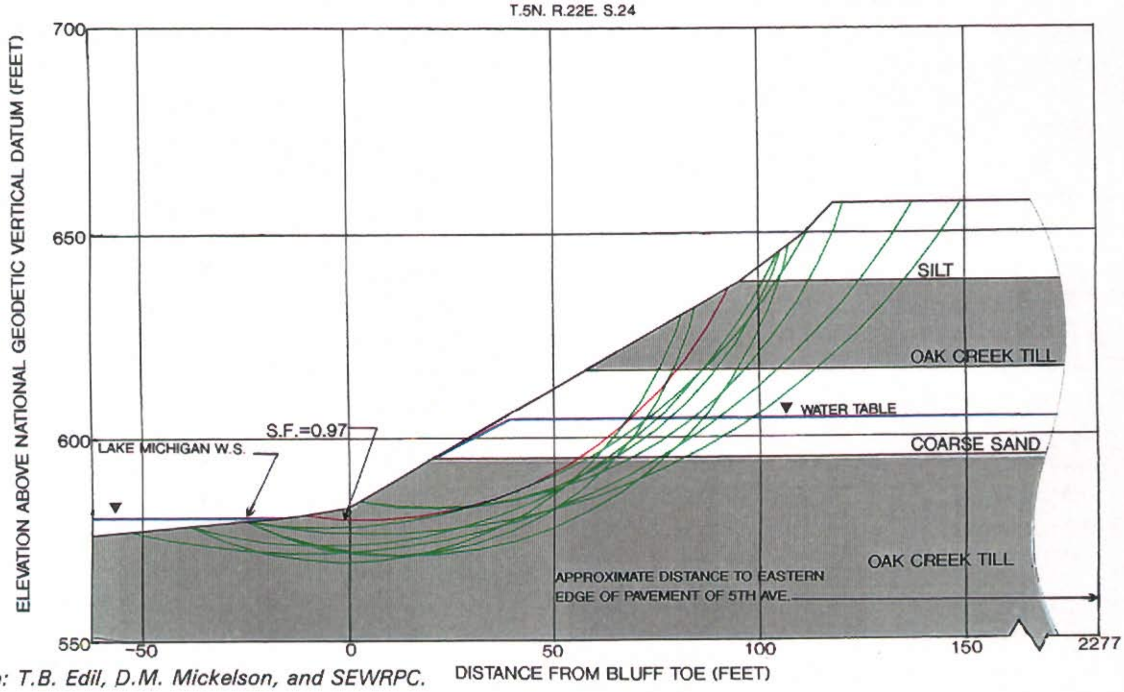
PROFILE 7-12
T.5N. R.22E. S.24



PROFILE 7-13
T.5N. R.22E. S.24



PROFILE 7-14
T.5N. R.22E. S.24



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Treatment Plant, about 0.1 mile to the north section line of Section 24 at Puetz Road extended, as shown on Map 39, and about 0.3 mile to the north boundary line of the Milwaukee Metropolitan Sewerage District South Shore Sewage Treatment Plant, as also shown on Map 39. This zone had a nonexistent beach. The bluff had a height of up to 70 feet in this zone. In 1995, the entire shoreline was protected by shoreline protection structures, including fill and a revetment. The 1995 field observations indicated no noticeable retreat in the bluff top since 1976.

No bluff stability analyses were conducted within Erosion Zone 24d in this study or in 1976 or 1987.

The beach was nonexistent within Zone 24d. In the 1977 study, the beach width was reported to be between zero and 20 feet, and the beach materials were reported to be pebbles and sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 24d were not estimated. The 1977 study did not report a recession rate for this erosion zone.

SHORELINE REACH 8: CITIES OF CUDAHY, OAK CREEK, ST. FRANCIS, AND SOUTH MILWAUKEE, MILWAUKEE COUNTY

Shoreline Reach 8 is a 5.7-mile-long reach of shoreline extending from about Addison Lane extended, at the northern property line of the Milwaukee Metropolitan Sewerage District South Shore Sewage Treatment Plant, about 0.3 mile north of the south line of U.S. Public Land Survey Section 13, Township 5 North, Range 22 East, City of Oak Creek, north to E. Oklahoma Avenue extended on the north line of U.S. Public Land Survey Section 14, Township 6 North, Range 22 East, City of St. Francis, as shown on Map 40. Land uses along this reach include open spaces, including Grant, Warnimont, Sheridan, and Bayview Parks situated in the central and northern portions of the reach; residential lands in the southern and northern portions of the reach, including limited areas with multi-family residential uses; and industrial and commercial land uses in the southern portion of the reach. The Milwaukee Metropolitan Sewerage District South Shore Sewage Treatment Plant was located at the southern extreme of the reach and the abandoned Wisconsin Electric Power Company Lakeside Power Plant at the northern extreme of the reach. The South Milwaukee Yacht Club harbor facilities were also located in the southern portion of this reach. In 1976, this reach ranked 11th in the list of critical portions of the Lake Michigan shoreline in Wisconsin. As of 1995, about three linear miles, or about one-half, of the shoreline in Reach 8 were protected by structural shore protection measures, consisting of revetments, rubble fills, and groins, and, in the northern extreme of the reach, the southern portions of the breakwater system of the Port of Milwaukee.

As shown on Map 40, Reach 8 was further segmented into seven shoreline analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the seven shoreline analysis sections in Reach 8.

U.S. Public Land Survey Section 13, Township 5 North, Range 22 East, Cities of Oak Creek and South Milwaukee, Milwaukee County

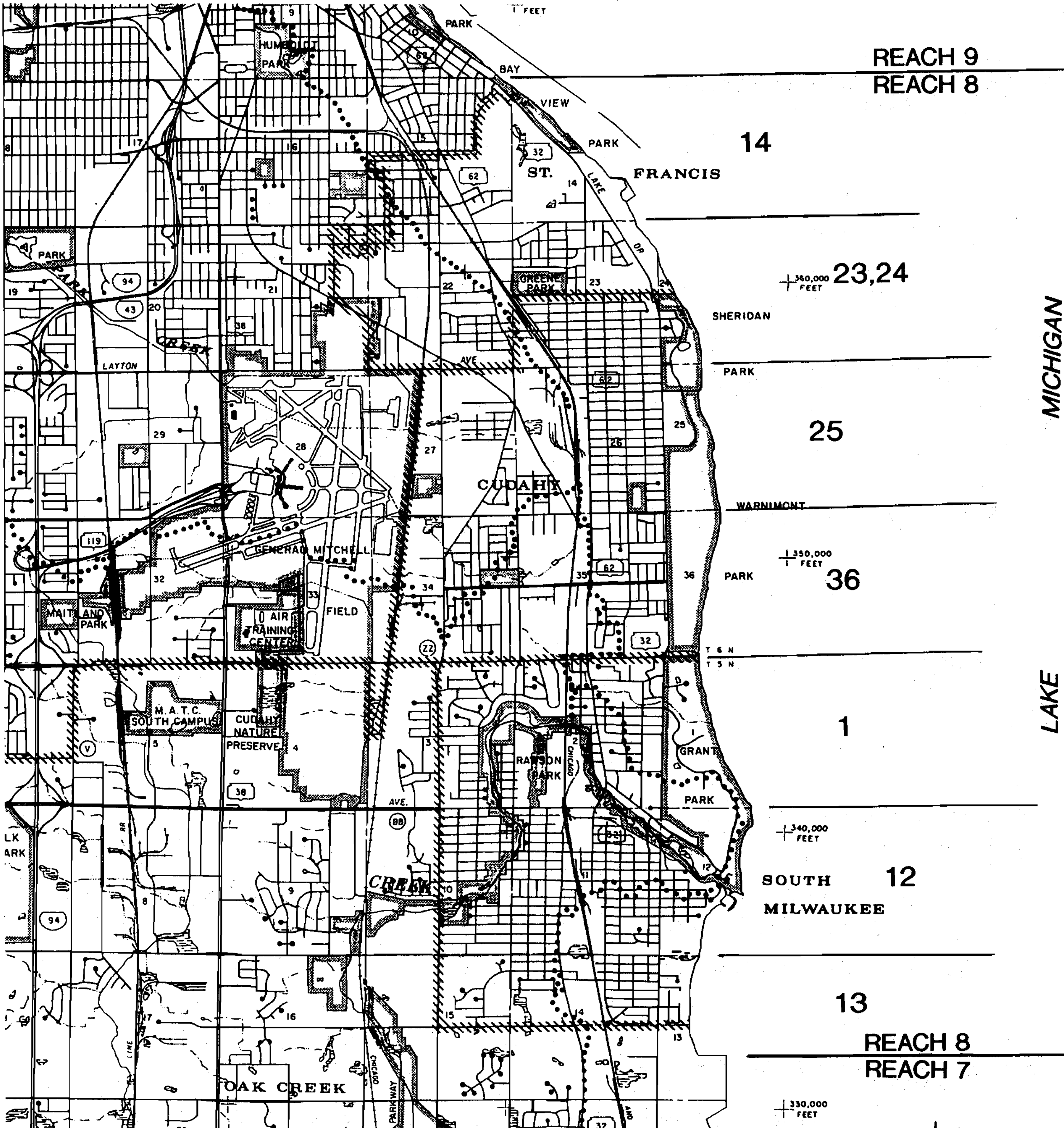
This shoreline analysis section extends from Addison Lane extended, in the City of Oak Creek, north to Drexel Avenue extended, in the City of South Milwaukee, as shown on Map 41. In 1995, the lakeshore area was occupied by residential and industrial lands. The Milwaukee Metropolitan Sewerage District South Shore Sewage Treatment Plant occupied part of the lakeshore at the southern end of the section. In 1995, the section, north of the sewage treatment plant revetment, was largely unprotected except for rubble fills. The section was fronted by a broad beach of about 600 feet in width which appeared to have accreted behind the sewage treatment plant revetment in the southern portion of the section tapering to about 50 feet in width at the northern end of the section. The bluff in this section ranged from 70 feet in height in the southern portion of the section, to 110 feet in height in the central portion of the section, to 80 feet in height in the northern portion of the section. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by sand and clay, grading to sand and silt in the north. For analysis purposes, Section 13 was further subdivided into three erosion zones, as shown on Map 41. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three erosion zones in Section 13.

Erosion Zone 13a

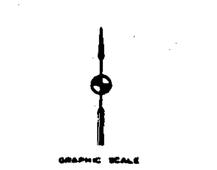
Erosion Zone 13a extends from about 0.3 mile north of Puetz Road, at about Addison Lane extended, in the City of Oak Creek, north about 0.2 mile to about Hillcrest

Map 40

BLUFF ANALYSIS SECTIONS WITHIN REACH 8



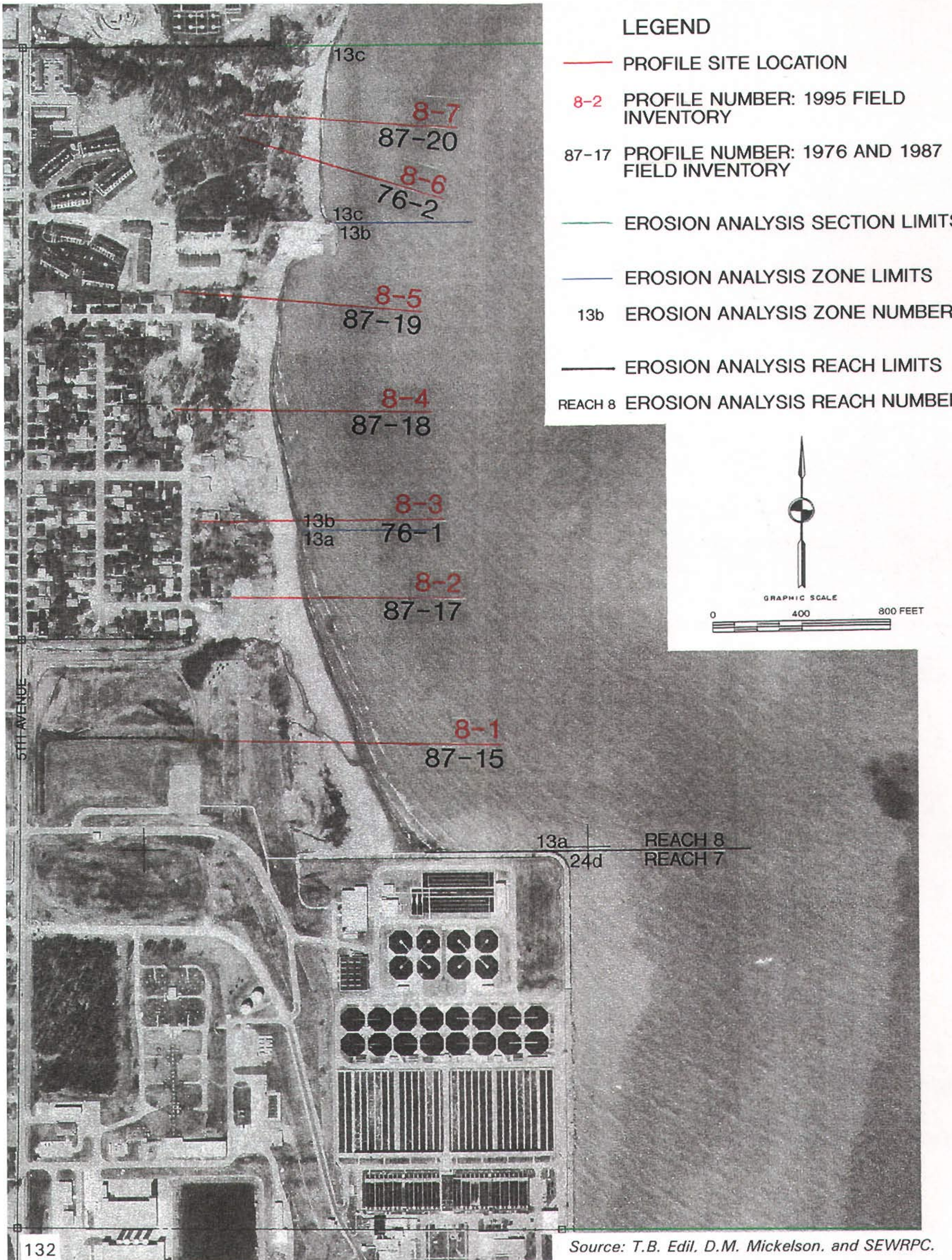
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.



Map 41

SHORELINE EROSION REACH 7: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 13, Township 5 North, Range 22 East
Cities of Oak Creek and South Milwaukee, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Avenue extended, in the City of South Milwaukee, as shown on Map 41. This zone had a broad beach of up to 600 feet in width in the southern portion of the zone tapering to about 100 feet in width in the northern portion, fronting the bluff which had a height of up to 110 feet. The bluff was largely unprotected except for rubble fill. Much of the bluff had been modified. Vegetation, primarily consisting of horsetails and thistles, covered between 10 and 40 percent of the bluff slope. The 1995 field observations indicated that no assessment of retreat of the bluff top could be made. Signs of shallow translational slides were observed in the northern portion of the zone.

In 1995, two bluff profile field surveys were made within Zone 13a by occupying sites for which field surveys were conducted in 1987. The reoccupied sites had significantly different geometries to those documents in 1987. The two sites appeared to have become less steeply sloped. The stability of the bluff in Zone 13a of Reach 8 was characterized by Profile Nos. 8-1 and 8-2. Results of the slope stability analysis, shown in Figure 35, indicated that the bluff was stable in the southern portion of the zone, with a safety factor of 1.84 at Profile No. 8-1, and unstable with respect to both rotational and translational failures in the northern portion of the zone, with a safety factor of 0.86 at Profile No. 8-2. The 1987 study reported bluff safety factors of 1.48 and 0.74 at Profile Nos. 8-1 and 8-2, respectively.

The beach was broad, ranging in width from about 600 feet adjacent to the Milwaukee Metropolitan Sewerage District South Shore Sewage Treatment Plant revetment in the south to about 100 feet in the north, within Erosion Zone 13a. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be sand and pebbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 13a were not estimated.

Erosion Zone 13b

Erosion Zone 13b extends from the northerly limit of Erosion Zone 13a at about Hillcrest Avenue north about 0.3 mile to Marina Road, as shown on Map 41. This zone had a broad beach ranging from about 150 feet in width in the southern portion of the zone to about 100 feet in width in the northern portion of the zone. The bluff had a height of about 100 feet in this zone. Vegetation, primarily consisting of horsetails, grasses, and shrubs, covered about 40 percent of the bluff slope. The 1995 field observations indicated that no assessment of retreat of the bluff top could be made.

In 1995, one bluff profile field survey was made within Zone 13b by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a significantly different geometry that documented in 1976. In the southern portion of the zone, Profile No. 8-3 appeared to have become less steeply sloped. Also in 1995, two bluff profile surveys were made within Zone 13b by occupying sites for which field surveys were conducted in 1987. The reoccupied sites had significantly different geometries to those documented in 1987. The two sites appeared to have become less steeply sloped, with the northernmost site at Profile No. 8-5 having been significantly modified by the placement of fill. The stability of the bluff in Zone 13b of Reach 8 was characterized by Profile Nos. 8-3 through 8-5. Results of the slope stability analysis, shown in Figures 35 and 36, indicated that the bluff was unstable with respect to both rotational and translational failures in the southern portion of the zone, with safety factors ranging from 0.74 at Profile No. 8-3 to 0.89 at Profile No. 8-4. At Profile No. 8-5 in the northern portion of the zone, the results of the slope stability analysis, shown in Figure 36, indicated that the bluff was marginally stable, with a safety factor of 1.07. The 1977 study reported bluff safety factors of 0.97 for the entire bluff face and 0.34 for the scarp slope at the top of the bluff. The 1987 study reported bluff safety factors of 0.74 to 1.13, with the more stable slope being located at Profile No. 8-5. The 1995 field observations indicated that translational failures may occur throughout this zone.

The beach was between 100 and 150 feet in width within Zone 13b. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be sand and pebbles, with boulders and broken concrete in places. At Profile No. 8-3, the primary nearshore surface materials consisted primarily of sand and the nearshore lakebed depth of five feet was reached at 200 feet offshore in 1995. At Profile No. 8-3, the nearshore lakebed depth of five feet was reached at 105 feet offshore in 1977. The primary nearshore surface materials at this site in 1976 were reported to be sand.

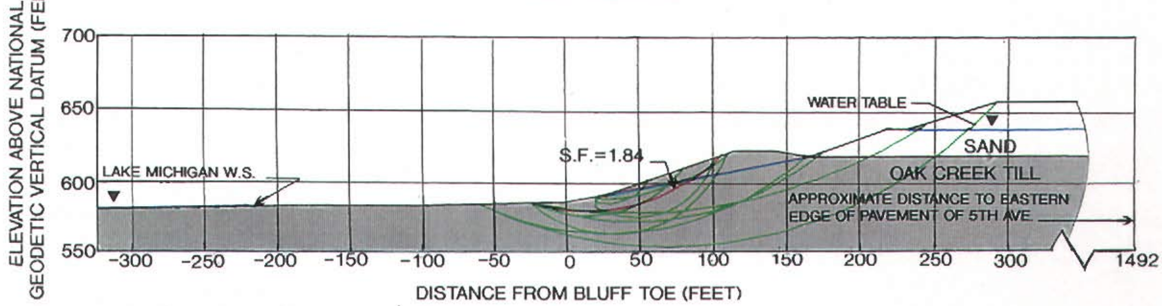
Shoreline recession data for Erosion Zone 13b were estimated at one location. These data indicated a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. The data indicated that most of

Figure 35

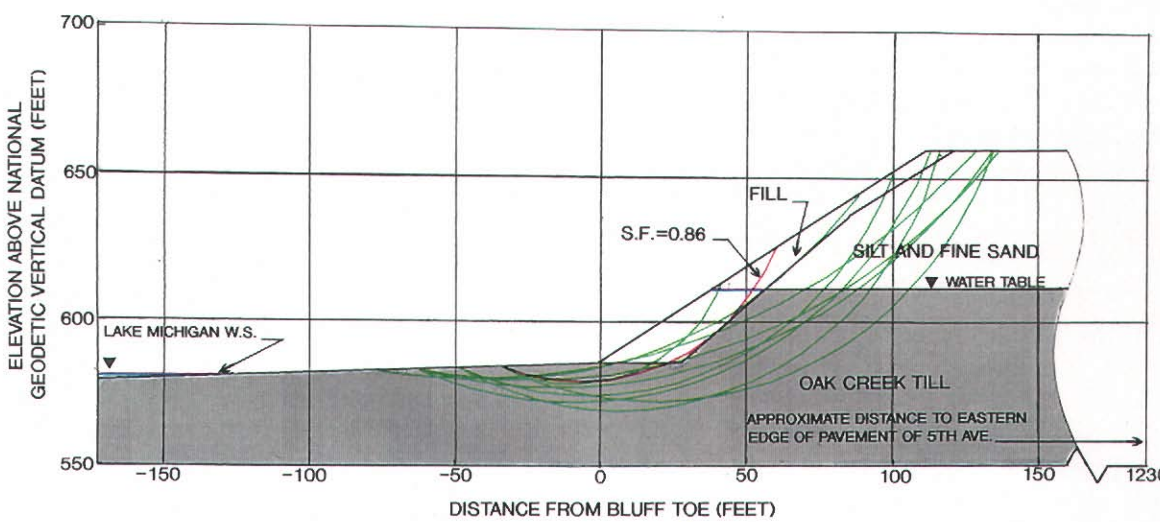
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 13, Township 5 North, Range 22 East
City of South Milwaukee, Milwaukee County

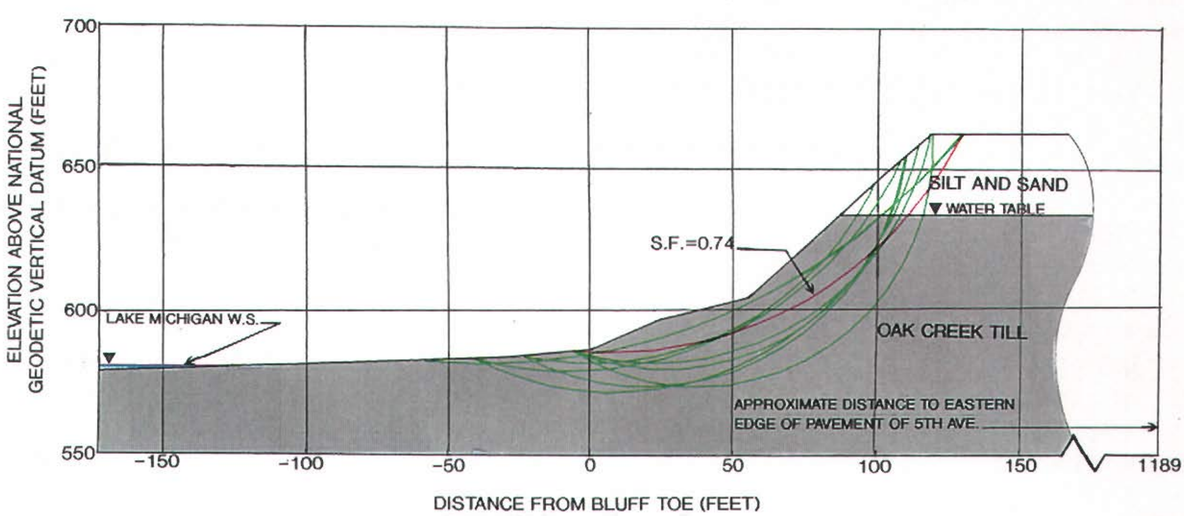
PROFILE 8-1
T.5N. R.22E. S.13



PROFILE 8-2
T.5N. R.22E. S.13



PROFILE 8-3
T.5N. R.22E. S.13

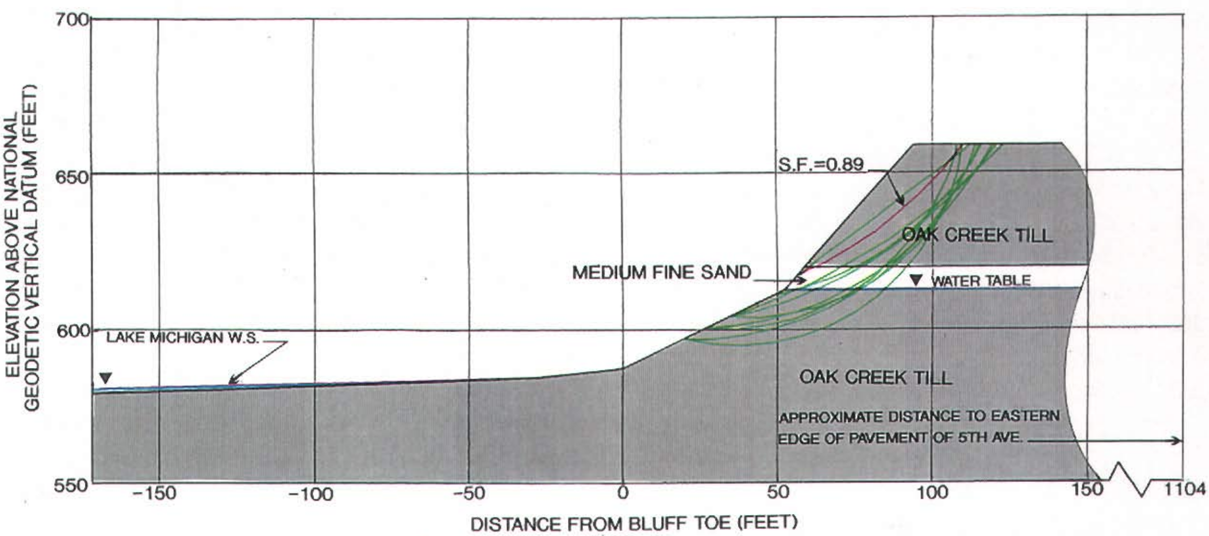


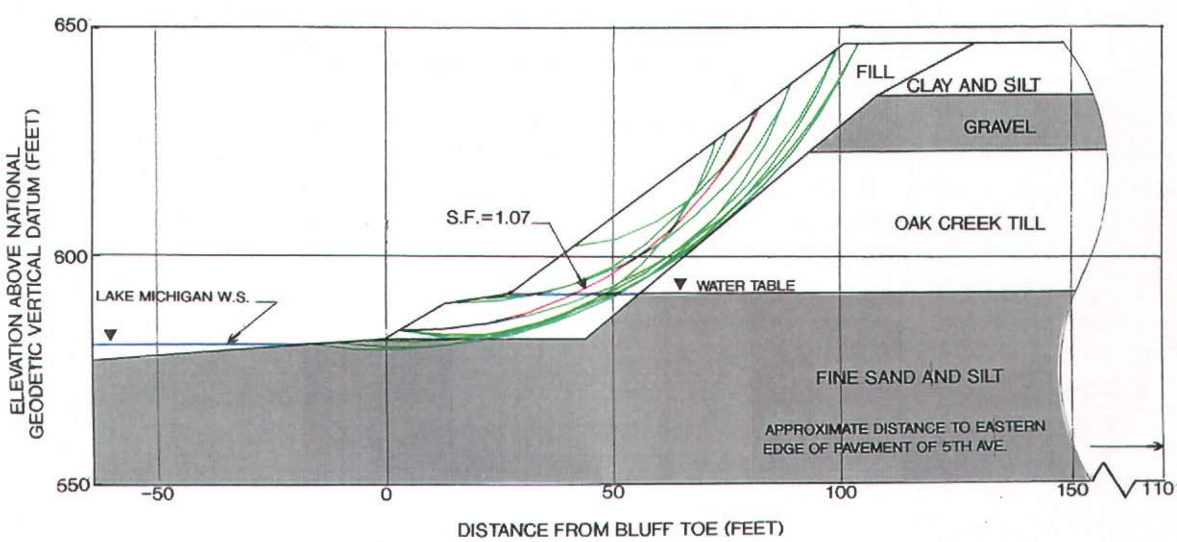
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 36

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 13, Township 5 North, Range 22 East
City of South Milwaukee, Milwaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

that recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. Thus, it appeared that portions of the bluff within this zone had been largely stabilized. The 1977 study reported a recession rate of 0.7 foot per year for this erosion zone.

In 1995, it appeared that several houses within this zone had been removed from the bluff top since 1975. It also appeared that shoreline recession would be likely to continue within Erosion Zone 13b unless measures are implemented to protect the bluff toe. The private marina at the northern extreme of this zone was observed to protect the base of the bluff slope to a degree.

Erosion Zone 13c

Erosion Zone 13c extends from the northerly limit of Erosion Zone 13b at the northern revetment of the private marina north about 0.15 mile to E. Drexel Avenue extended, as shown on Map 41. This zone had a beach width of between 25 and 100 feet. The widest portion of the beach was located in the southern portion of the zone where sand appeared to be accreting behind the marina's revetment. The bluff had a height of about 80 feet in this zone. In 1995, the bluff face was interrupted by a gully system, and was unprotected. Vegetation covered approximately 90 percent of the bluff slope. The 1995 field observations indicated that no assessment of retreat in the bluff top could be made. Signs of shallow translational slides were present.

In 1995, one bluff profile field survey was made within Zone 13c by occupying a site for which a field survey was conducted in 1976. The site had a significantly different geometry to that documented in 1976. The site appeared to have become less steeply sloped. Also in 1995, one bluff profile field survey was made within Zone 13c by occupying a site for which a field survey was conducted in 1987. The site had a significantly different geometry to that documented in 1976. The site appeared to have become less steeply sloped. The vertical bluff face reported in 1987 had become a sloping bluff face. The stability of the bluff in Zone 13c of Reach 8 was characterized by Profile Nos. 8-6 and 8-7. Results of the slope stability analysis, shown in Figure 37, indicated that the bluff was unstable, with safety factors of 0.87 and 0.81, based upon the deterministic bluff stability analysis method. Profile No. 8-6 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.63 to 1.44 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 25, or 100 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 106, or 42.4 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered unstable with respect to both rotational and translational failures. The 1977 study did not report a bluff safety factor, and the 1987 study reported a bluff safety factor of 0.78.

The beach was 25 to 100 feet in width within Zone 13c. In the 1977 study, the beach width was reported to be about 20 feet, and the beach materials were reported to be sand and pebbles. At Profile No. 8-6, the primary nearshore surface materials consisted primarily of sand and the nearshore lakebed depth of five feet was reached at 185 feet offshore in 1995. At Profile No. 8-3, the nearshore lakebed depth of five feet was reached at 100 feet offshore in 1977. The primary nearshore surface materials at this site in 1976 were reported to be sand.

Shoreline recession data for Erosion Zone 13c were estimated at one location. These data indicated a recession of about 40 feet, or about 1.2 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 20 feet, or about one foot per year, occurred between 1975 and 1995. Thus, it appeared that this zone had not been stabilized and was continuing to recess. The 1977 study did not report a recession rate for this erosion zone.

The gully system which was observed in the northern portion of Erosion Zone 13c in 1995 is likely to continue to erode. The gully walls are particularly susceptible to erosion within this zone.

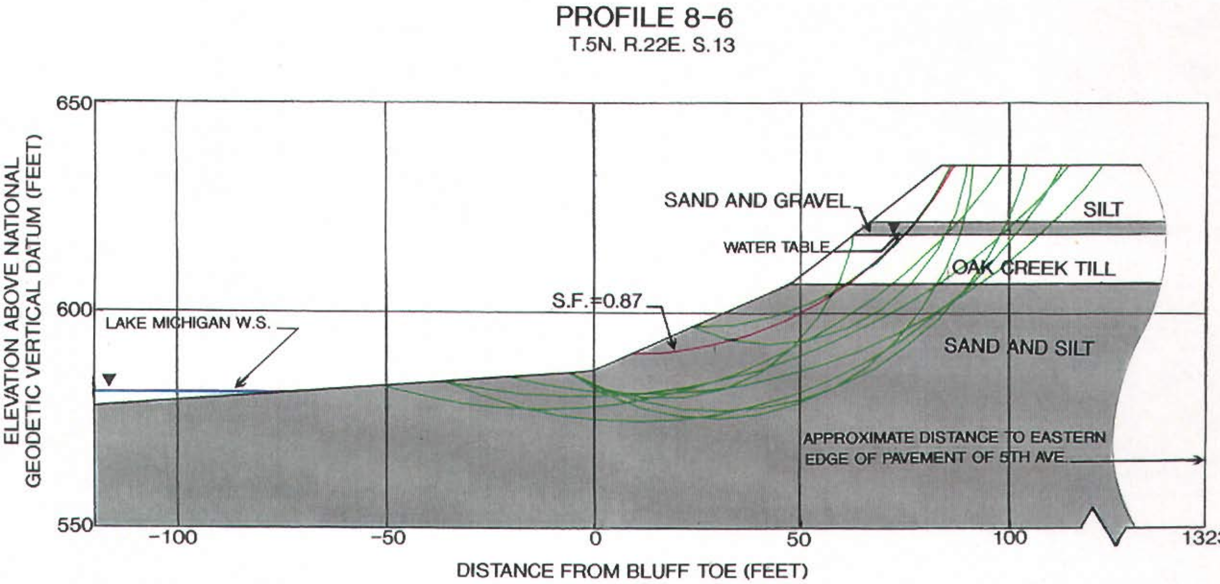
U.S. Public Land Survey Section 12, Township 5 North, Range 22 East, City of South Milwaukee, Milwaukee County

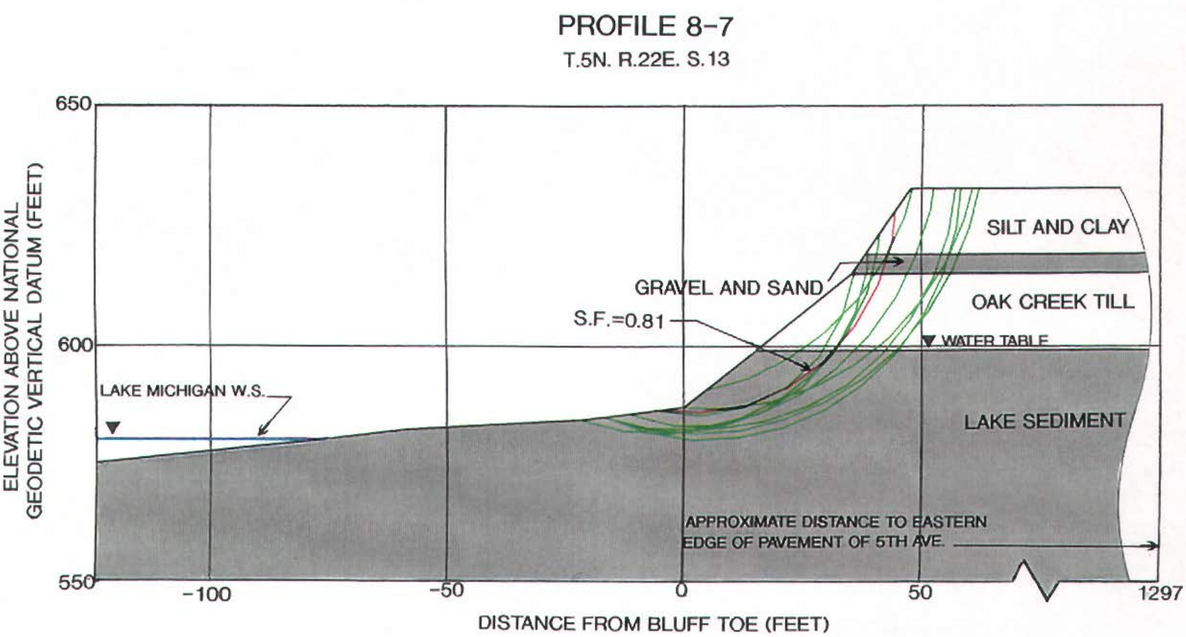
This shoreline analysis section extends from E. Drexel Avenue extended north to Rawson Avenue extended, in the City of South Milwaukee. In 1995, the shoreline was occupied by industrial land uses, including the City of South Milwaukee Sewage Treatment Plant, residential land uses, and the South Milwaukee Yacht Club in the southern portion of the section; and park lands, including the Grant Park Golf Course, in the central and northern portions of the section. The bluff materials in this section were generally covered, but were estimated to be primarily silt and clay in the lower quarter of the bluff, overlain by till, overlain by sand, silt, and clay. For analysis purposes, Section 12 was further subdivided into four erosion zones, as shown on Map 42. The inventory and analysis findings relating to bluff, beach,

Figure 37

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 13, Township 5 North, Range 22 East
City of South Milwaukee, Milwaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

and nearshore area conditions and shoreline recession are discussed below for each of the four erosion zones in Section 12.

Erosion Zone 12a

Erosion Zone 12a extends from the north line of Section 13 at E. Drexel Avenue extended north, adjacent to the City of South Milwaukee Sewage Treatment Plant, about 0.1 mile to about Manistique Avenue extended, as shown on Map 42. This zone had a 25 to 50 feet wide beach fronting the bluff which had a height of between 60 and 70 feet. In 1995, the bluff was largely protected by a debris field in this zone. Vegetation covered about 40 percent of the bluff slope. The 1995 field observa-

Map 42

SHORELINE EROSION REACH 8: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 12, Township 5 North, Range 22 East
City of South Milwaukee, Milwaukee County

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

tions indicated that no assessment of retreat of the bluff top could be made. Signs of shallow rotational slides were present.

In the current study, two bluff profile surveys were made within Erosion Zone 12a, by reoccupying the sites for which field surveys were conducted in 1987. The southern site at Profile No. 8-8 had a significantly different geometry to that documented in 1987 due to the placement of fill. The northern site at Profile No. 8-9 appeared unchanged. The stability of the bluffs in Erosion Zone 12a of Reach 8 was characterized by Profile Nos. 8-8 and 8-9. Results of the slope stability analyses, shown in Figure 38, indicated that the bluff was unstable to stable, with safety factors of between 0.84 and 1.17, with the greater bluff stability occurring in the central portion of the zone and the least bluff stability occurring in the northern portion of the zone. The 1977 study did not report a bluff safety factor. The 1995 field observations indicted that translational failures may occur.

The beach was between 25 and 50 feet in width within Erosion Zone 12a, and consisting of concrete debris. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be sand. No measurements or observations of nearshore lakebed depth or materials were made at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 12a were estimated at two locations. These data indicated a recession of between 10 and 40 feet, or between 0.3 and 1.2 feet per year, occurred between 1963 and 1995. The data indicated a recession of between zero and 20 feet, or between zero and one foot per year, occurring between 1975 and 1995. The greatest loss of shoreline occurred at the southern extreme of the section, but placement of fill within this zone appeared to have largely stabilized the bluff in the central portion of the zone. The 1977 study reported a recession rate of 0.7 foot per year for this zone.

Erosion Zone 12b

Erosion Zone 12b extends from the northerly limit of Erosion Zone 12a at about Manistique Avenue extended north about 0.15 mile to Marion Avenue, as shown on Map 42. This zone had a 25 to 100 feet wide beach fronting the bluff which had a height of between 60 and 70 feet. In 1995, the bluff was protected in this zone by a debris field and rubble. Vegetation covered about 80 percent of the bluff slope. The 1995 field observations indicated that no assessment of retreat of the bluff top could be made.

In the current study, one bluff profile survey was made within Erosion Zone 12b, by reoccupying the site for which a field survey was conducted in 1976. The site at Profile No. 8-10 had a significantly different geometry to that documented in 1976. The bluff slope appeared to have become steeper. The stability of the bluff in Erosion Zone 12b of Reach 8 was characterized by Profile No. 8-10. Results of the slope stability analyses, shown in Figure 39, indicated that the bluff was unstable, with a safety factor of 0.93, based upon the deterministic bluff stability analysis method. Profile No. 8-10 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.82 to 1.47 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 11, or 44 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 46, or 18.4 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a bluff safety factor of 0.78.

The beach was between 25 and 100 feet in width within Erosion Zone 12b, and consisting of cobbles and sand. In the 1977 study, the beach was reported to be nonexistent, and the beach materials were covered by a concrete revetment. No measurements or observations of nearshore lakebed depth or materials were made at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 12b were not estimated. The 1977 study did not report a recession rate for this zone.

Erosion Zone 12c

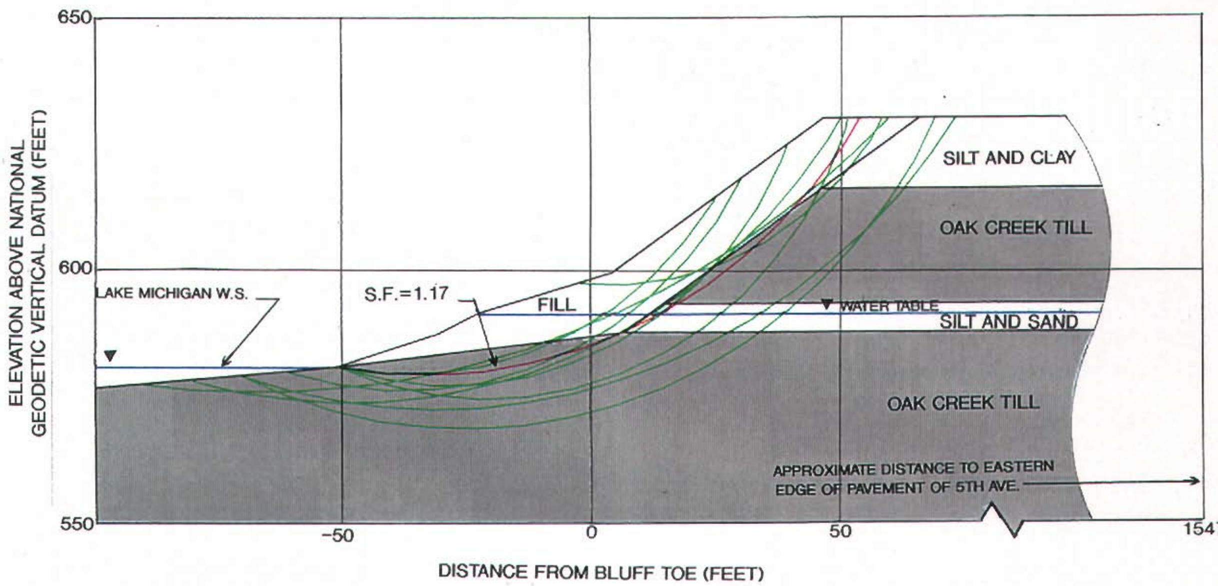
Erosion Zone 12c extends from the northerly limit of Erosion Zone 12b at about Marion Avenue extended north about 0.1 mile the southernmost revetment of the South Milwaukee Yacht Club harbor in the vicinity of Marshall Avenue, as shown on Map 42. This zone had a beach of up to 150 feet in width fronting the bluff with a height of between 60 and 70 feet. In 1995, the bluff was protected in this zone by a debris field. Vegetation covered about 80 percent of the bluff slope. The 1995 field observations indicated that no assessment of retreat of the bluff top could be made.

Figure 38

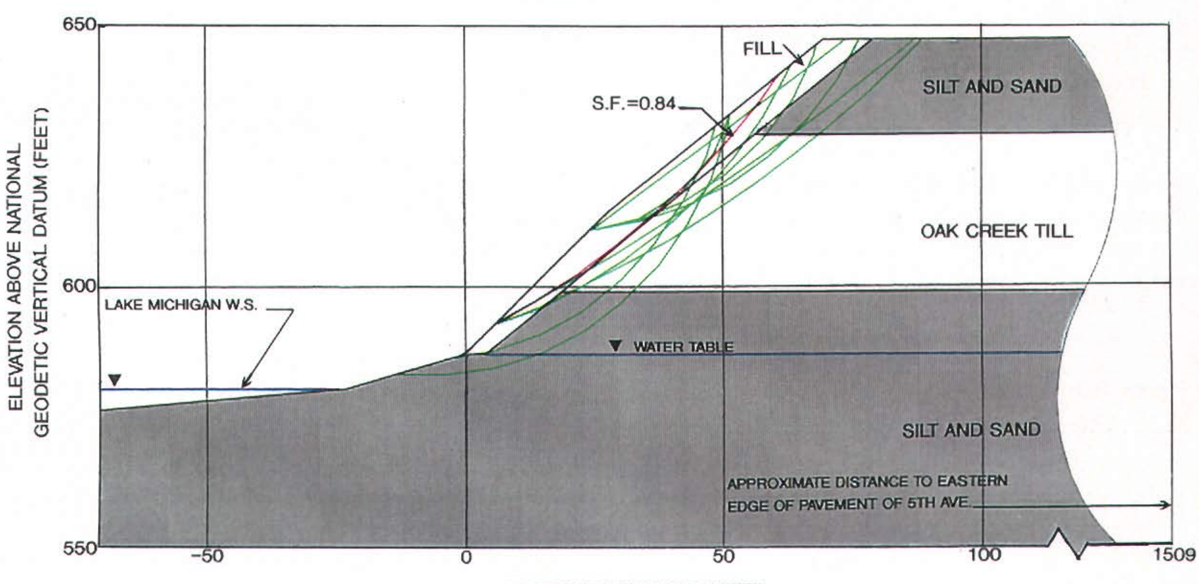
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 12, Township 5 North, Range 22 East
City of South Milwaukee, Milwaukee County

PROFILE 8-8
T.5N. R.22E. S.12



PROFILE 8-9
T.5N. R.22E. S.12

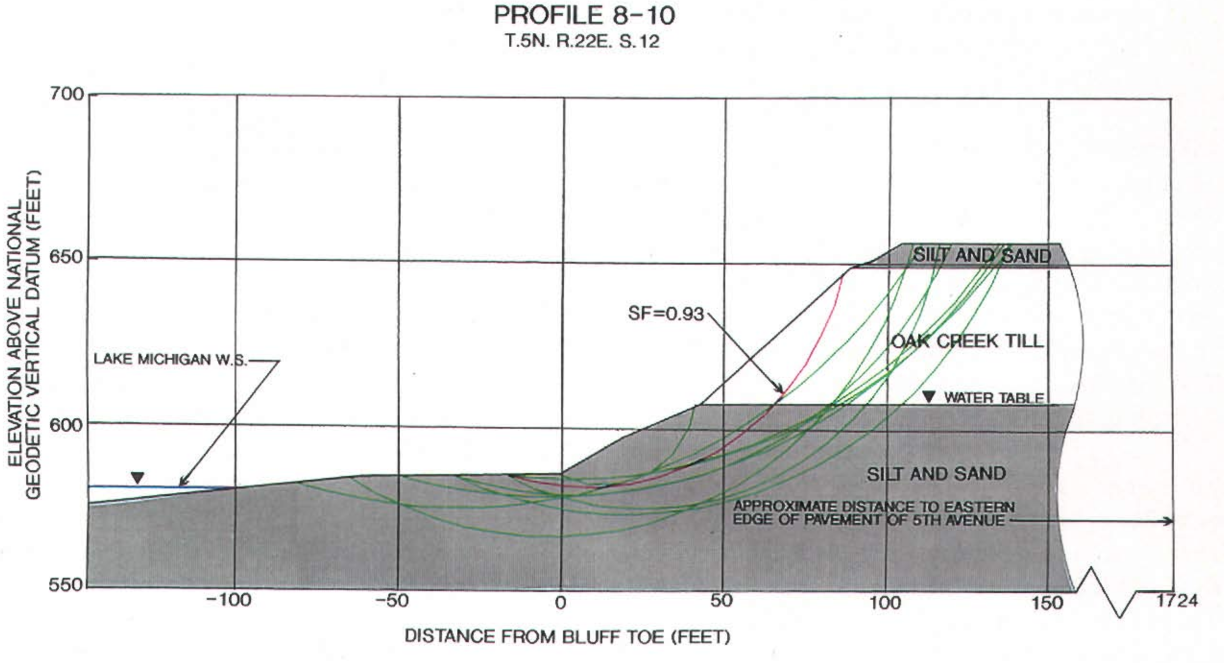


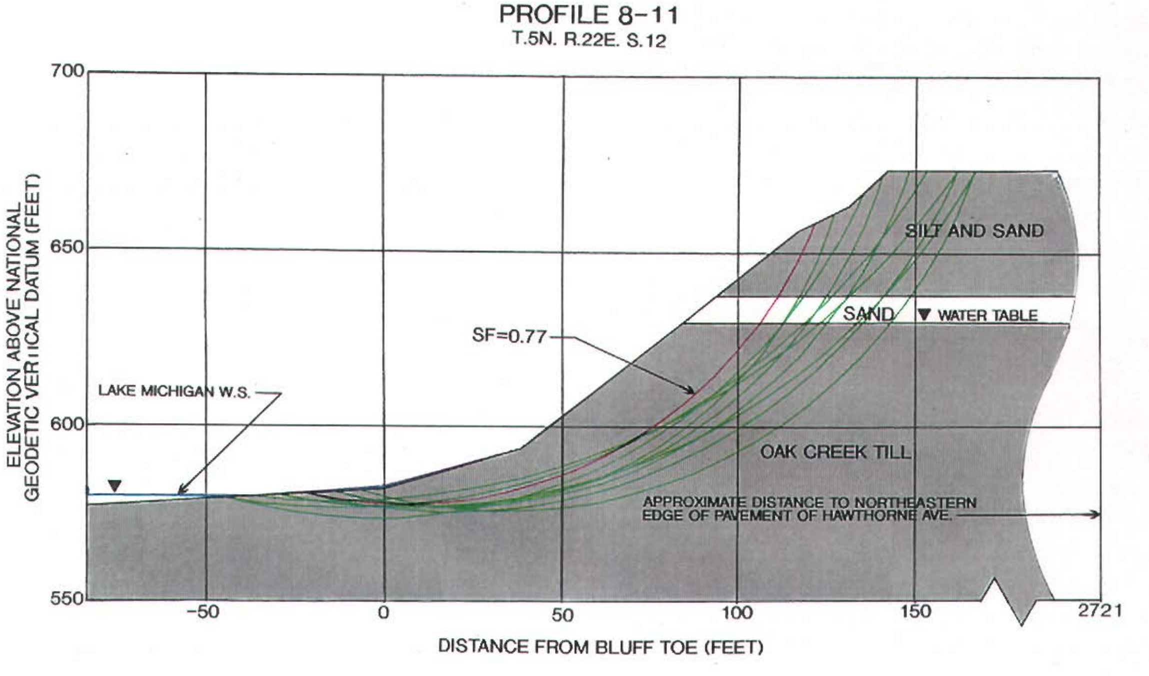
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 39

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 12, Township 5 North, Range 22 East
City of South Milwaukee, Milwaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

No bluff stability analyses were conducted within Erosion Zone 12c in this study or in 1976 or 1987 studies.

The beach was up to 150 feet in width within Erosion Zone 12c. In the 1977 study, the beach width was reported to be about 20 feet, and the beach materials were not reported. No measurements or observations of nearshore lakebed depth or materials were made at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 12c were estimated at one location. These data indicated a recession of about 40 feet, or about 1.2 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. Thus, the placement of debris within this zone appeared to have partially stabilized the bluff within this zone. The 1977 study did not report a recession rate for this zone.

Erosion Zone 12d

Erosion Zone 12d extends from the northerly limit of Erosion Zone 12c in the vicinity of Marshall Avenue north about 0.7 mile to Rawson Avenue extended, as shown on Map 42. This zone had a broad beach ranging from about 600 feet in width in the southern portion of the zone adjacent to and north of the South Milwaukee Yacht Club revetment to about 25 feet in width in the northern portion of the zone. The bluff had a height of about 100 feet in this zone. Vegetation covered about 100 percent of the bluff slope in the southern and central portions of the zone to about 70 percent of the bluff slope in the northern portion of the zone. Vegetation in the northern portion of the zone consisted of juniper and trees. The 1995 field observations indicated that no assessment of retreat of the bluff top could be made. Signs of shallow translational or rotational slides were present in the northern portion of the zone.

In 1995, one bluff profile field survey was made within Zone 12d by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a significantly different geometry to that documented in 1976. Profile No. 8-11 appeared to have developed a slight bluff scarp at the bluff top, and the material previously accumulated at the bluff toe had been lost. The stability of the bluff in Zone 12d of Reach 8 was characterized by Profile No. 8-11. Results of the slope stability analysis, shown in Figure 39, indicated that the bluff was unstable with respect to both rotational and translational failures, with a safety factor of 0.77. The 1977 study reported a bluff safety factor of 0.82.

The beach was up to 600 feet in width within Zone 12d, decreasing in width from the south, where sand appeared to be retained behind the South Milwaukee Yacht Club revetment, to the north, where the beach width decreased to about 25 feet. In the 1977 study, the beach width was reported to be about 20 feet, and the beach material was reported to be sand. At Profile No. 8-11, the primary nearshore surface materials consisted primarily of sand and the nearshore lakebed depth of five feet was reached at 140 feet offshore in 1995. At Profile No. 8-11, the nearshore lakebed depth of five feet was reached at 65 feet offshore in 1977. The primary nearshore surface materials at this site in 1976 were reported to be sand.

Shoreline recession data for Erosion Zone 12d were estimated at two locations. These data indicated a recession of between 40 and 130 feet, or between 1.2 and 4.1 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession at the northern extreme of the zone occurred prior to 1975, with a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. Little change was observed in the central and northern portion of the reach where a recession of about 20 feet, or about one foot per year, occurred between 1975 and 1995. Thus, it appeared that groin system placed on the point between Manitoba Avenue extended and Rawson Avenue extended had partially stabilized the bluff within this extreme northern portion of the zone. The 1977 study reported a recession rate of one foot per year for this erosion zone.

In 1995, it appeared that shoreline recession would be likely to continue within Erosion Zone 12d unless measures are implemented to protect the bluff toe. The groin system at the northern extreme of this zone was observed to protect the base of the bluff slope to the north of the groin to a degree, but immediately south of the southern groin the beach was narrow enough in 1995 that the bluff toe was being cut by waves. At this location, the bluff slope was steep and lacked vegetative cover. Hence, it was anticipated that the steeper part of the bluff would move upslope and eventually produce bluff top retreat.

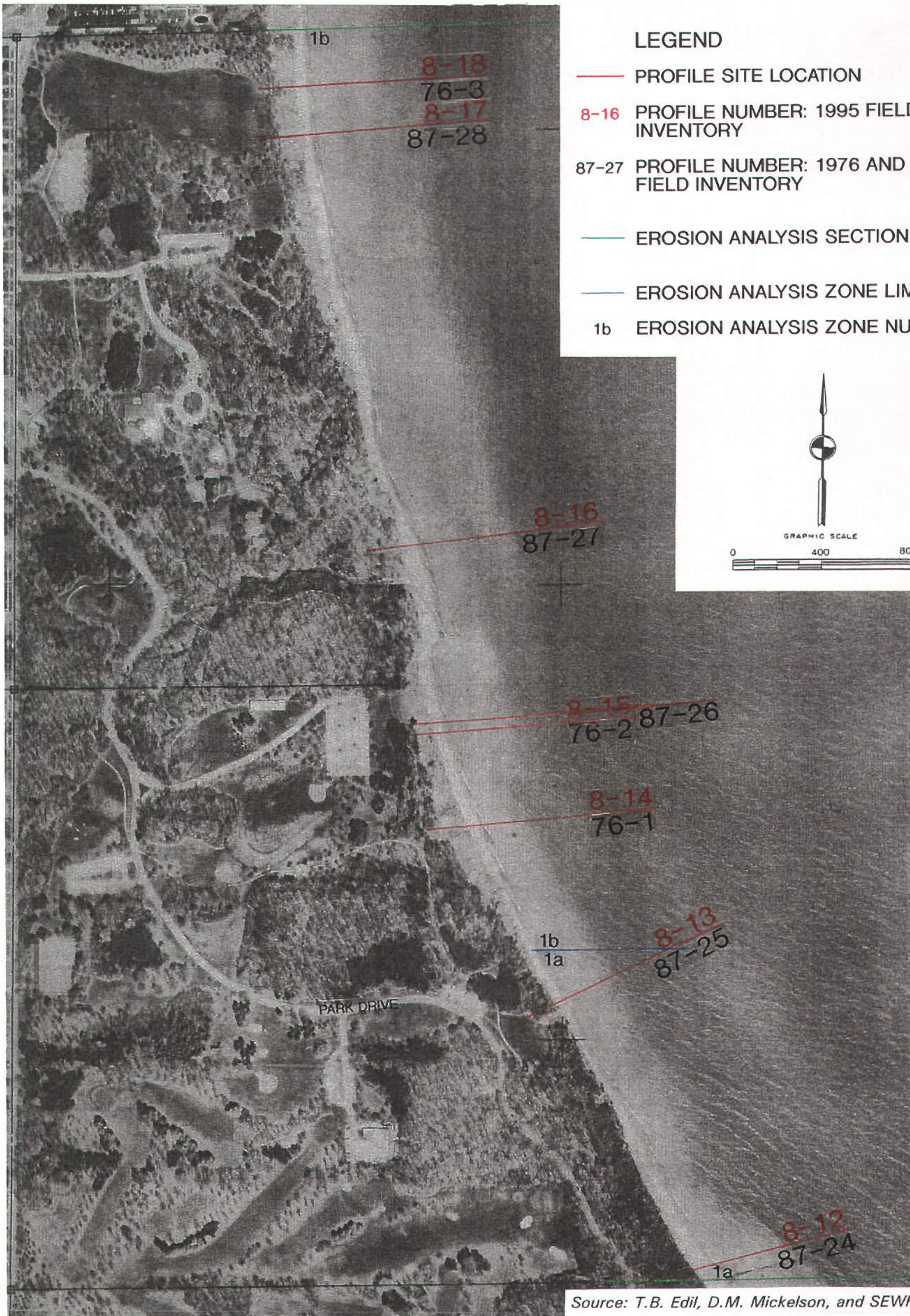
U.S. Public Land Survey Section 1, Township 5 North, Range 22 East, City of South Milwaukee, Milwaukee County

This shoreline analysis section extends from Rawson Avenue extended north to College Avenue extended, in the City of South Milwaukee, as shown on Map 43. The

Map 43

SHORELINE EROSION REACH 8: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 1, Township 5 North, Range 22 East
City of South Milwaukee, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

entire shoreline was occupied by Grant Park. The bluff materials in this section were estimated to be primarily till in the lower quarter of the bluff, overlain by intermixed silt and sand. In the northern portion of the section, the bluff was further overlain by 10 to 20 feet of till. For analysis purposes, Section 1 was further subdivided into two erosion zones, as shown on Map 43. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the two erosion zones in Section 1.

Erosion Zone 1a

Erosion Zone 1a extends from the south line of Section 1 at Rawson Avenue extended north about 0.3 mile to about Cherry Street extended in the City of South Milwaukee, as shown on Map 43. This zone had a beach of between 20 and 100 feet in width fronting a bluff which had a height of between 90 and 100 feet. In 1995, the bluff was protected by a groin system within this zone. Signs of minor soil creep were observed on the bluff slope.

In 1995, two bluff profile field surveys were made within Zone 1a by occupying sites for which field surveys were conducted in 1987. At Profile No. 8-12 in the southern portion of the zone and at Profile No. 8-13 in the northern portion of the zone, the bluff had a significantly different geometry to that documented in 1987. The shape of the bluff had become less steep. The stability of the bluff in Zone 1a of Reach 8 was characterized by Profile Nos. 8-12 and 8-13. Results of the slope stability analysis, shown in Figure 40, indicated that the bluff was unstable to marginally stable in the zone, with safety factors ranging from 0.98 to 1.09, based upon the deterministic bluff stability analysis method. Profile Nos. 8-12 and 8-13 were also analyzed using the probabilistic bluff stability analysis method. At Profile No. 8-12, the probabilistic bluff stability analysis method resulted in a range of safety factors from 0.69 to 1.36 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for nine, or 36 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 52, or 20.8 percent, of the 250 conditions analyzed. At Profile No. 8-13, the probabilistic bluff stability analysis method resulted in a range of safety factors from 0.92 to 1.49 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for six, or 24 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 14, or 5.6 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff at Profile No. 8-12 was considered marginally stable with respect to both rotational and translational failures and the bluff at Profile No. 8-13 was considered stable. The 1987 study reported bluff safety factors of between 0.83 and 0.92. The bluff safety factor of about 1.0 at Profile No. 8-12 indicated that the bluff may be stable with respect to shallow slides, but could remain unstable with respect to slumps.

The beach ranged between 20 feet and 100 feet in width within Erosion Zone 1a, with the widest portions of the beach located in the southern portion of the zone behind the groin system at the southern extreme of the zone. In the 1977 study, the beach width was reported to be about 20 feet, and the beach materials were reported to be cobbles and pebbles grading to sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 1a were estimated at two locations. These data indicated a recession of between 130 and 330 feet, or between 4.1 and 10.3 feet per year, occurred between 1963 and 1995, with the greatest rate of bluff recession being reported from the northern portion of the zone. The data indicated a recession of between 10 and 310 feet, or between 0.5 and 15.5 feet per year, occurring between 1975 and 1995. Thus, it appeared that the bluff had been partially stabilized in the southern portion of the zone, in the vicinity of the groin system, but remained unstable and actively recessing in the northern portion of the zone. The 1977 study reported a recession rate of one foot per year for this zone.

Erosion Zone 1b

Erosion Zone 1b extends from the northerly limit of Erosion Zone 1a north about 0.7 mile to College Avenue, as shown on Map 43. This zone had a beach of about 50 feet in width. The bluff was unprotected with a height of between 90 and 100 feet in this zone. In 1995, vegetation covered 20 to 60 percent of the bluff slope. Signs of shallow slides were common.

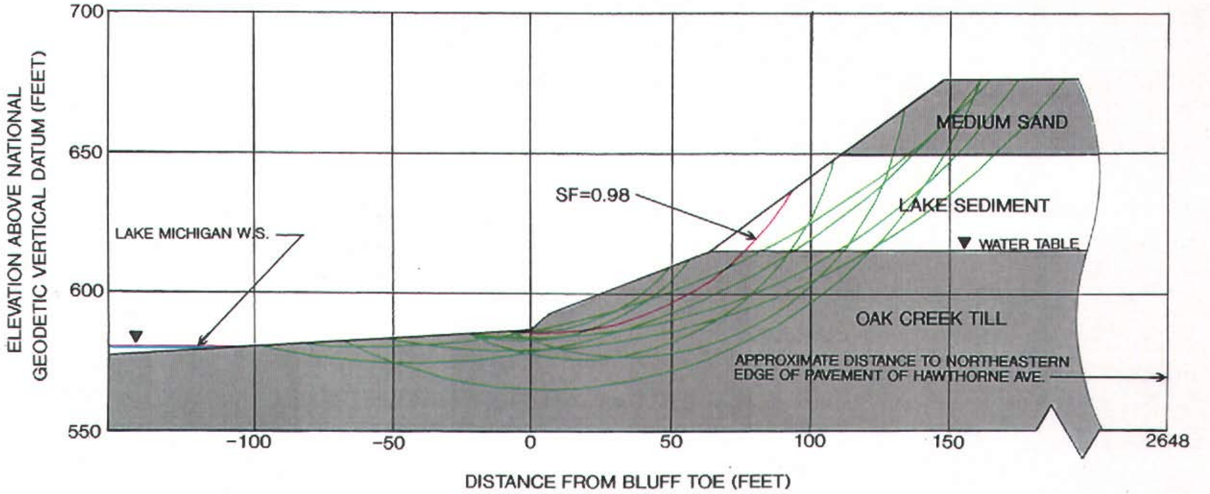
In 1995, three bluff profile field surveys were made within Zone 1b by occupying sites for which field surveys were conducted in 1976. The sites had signifi-

Figure 40

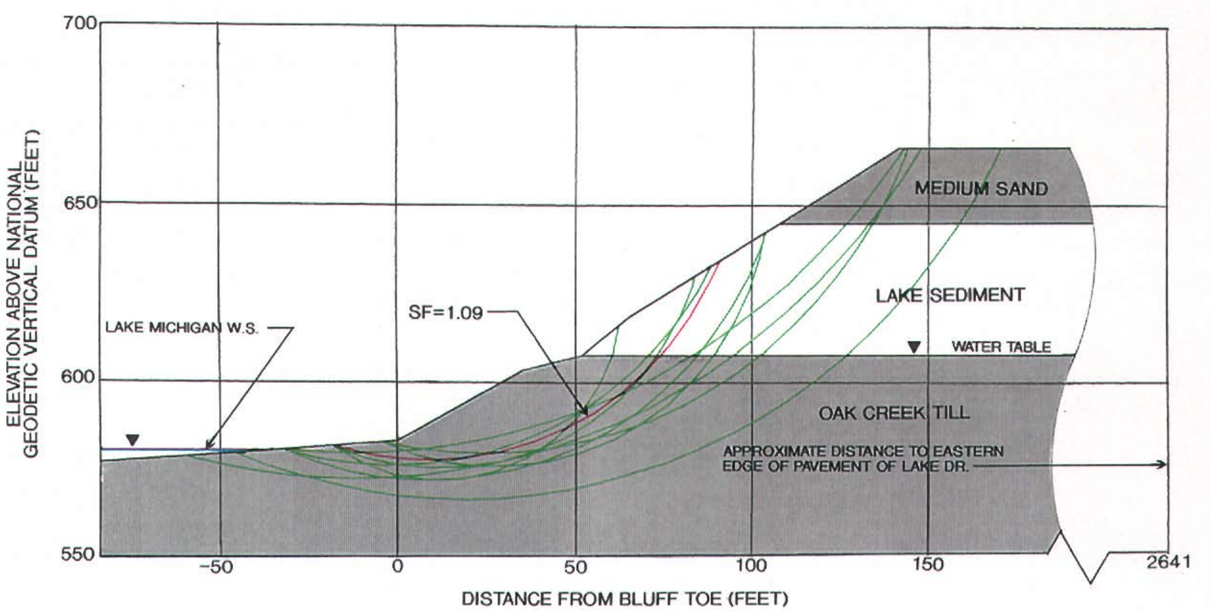
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 1, Township 5 North, Range 22 East
City of South Milwaukee, Milwaukee County

PROFILE 8-12
T.5N. R.22E. S.1



PROFILE 8-13
T.5N. R.22E. S.1



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

cantly different geometries to those documented in 1976. The shapes of the bluff had become less steep, with a scarp having developed at Profile No. 8-15. Also in 1995, two bluff profile field surveys were made within Zone 1b by occupying sites for which field surveys were conducted in 1987. The sites had significantly different geometries to those documented in 1987. The shape of the bluffs had become less steep. The proximity of Profile No. 8-15, which coincided with a 1976 bluff profile field survey site, to that of a third 1987 bluff profile field survey site, would suggest that little further change in the geometry of that site occurred subsequent to 1987. The stability of the bluffs in Zone 1b of Reach 8 was characterized by Profile Nos. 8-14 through 8-18. Results of the slope stability analyses, shown in Figures 41 and 42, indicated that the bluff was marginally stable to stable in the extreme south of the zone and in the central portions of the zone at Profile Nos. 8-14, 8-16, and 8-17, with bluff safety factors ranging from 1.07 to 1.21; unstable in the southern portion of the zone, with a bluff safety factor of 0.81; and, marginally unstable in the extreme northern portion of the zone, with a bluff safety factor of 0.98, based upon the deterministic bluff stability analysis method. Profile No. 8-18 was also analyzed using the probabilistic bluff stability analysis method. At Profile No. 8-18, the probabilistic bluff stability analysis method resulted in a range of safety factors from 0.59 to 1.28 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 16, or 64 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 108, or 43.2 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study reported bluff safety factors of between 0.4 and 0.51. The 1987 study reported bluff safety factors of between 0.86 and 1.23, with the least stable portions of the bluff located in the southern and central portions of the zone.

The beach was about 50 feet in width within Zone 1b. In the 1977 study, the beach width was reported to be about 20 feet, and the beach materials were reported to be cobbles and pebbles grading to sand. At Profile No. 8-15, the primary nearshore surface material was sand and the nearshore lakebed depth of five feet was reached at 65 feet offshore in 1995. At Profile No. 8-18, the primary nearshore surface materials consisted primarily of gravel and the nearshore lakebed depth of five feet was reached at 72 feet offshore. In 1977, at Profile Nos. 8-15 and 8-18, the nearshore lakebed depth was reached at 67 and 27 feet offshore, respectively, and the primary nearshore surface materials at Profile Nos. 8-15 and 8-18 in 1976 were reported to be sand and coarse gravel, respectively. The primary nearshore surface material at Profile No. 8-14 in 1976 was reported to be sand and the nearshore lakebed depth of five feet was reached at 65 feet offshore. It appeared that the lakebed had become shallower at Profile No. 8-18 in the northern portion of the zone since 1976, while the lakebed in the southern portion of the zone was largely unchanged. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1987.

Shoreline recession data for Erosion Zone 1b were estimated at three locations. These data indicated a recession of between 40 and 70 feet, or between 1.2 and 2.2 feet per year, occurred between 1963 and 1995, with the greatest rate of bluff recession being reported from the central and southern portions of the zone. The data indicated a recession of about 20 feet, or about one foot per year, occurring between 1975 and 1995. Thus, it appeared that the bluff had been partially stabilized in the central and southern portions of the zone, but remained unstable and actively recessing in the northern portion of the zone. The 1977 study reported a recession rate of one foot per year for this zone.

In 1995, it appeared that this zone was unstable with respect to slumps and shallow slides. Unless the bluff toe is protected within this zone, the shallow slides are likely to remain active. Bluff top recession is likely to occur during future periods of higher lake levels.

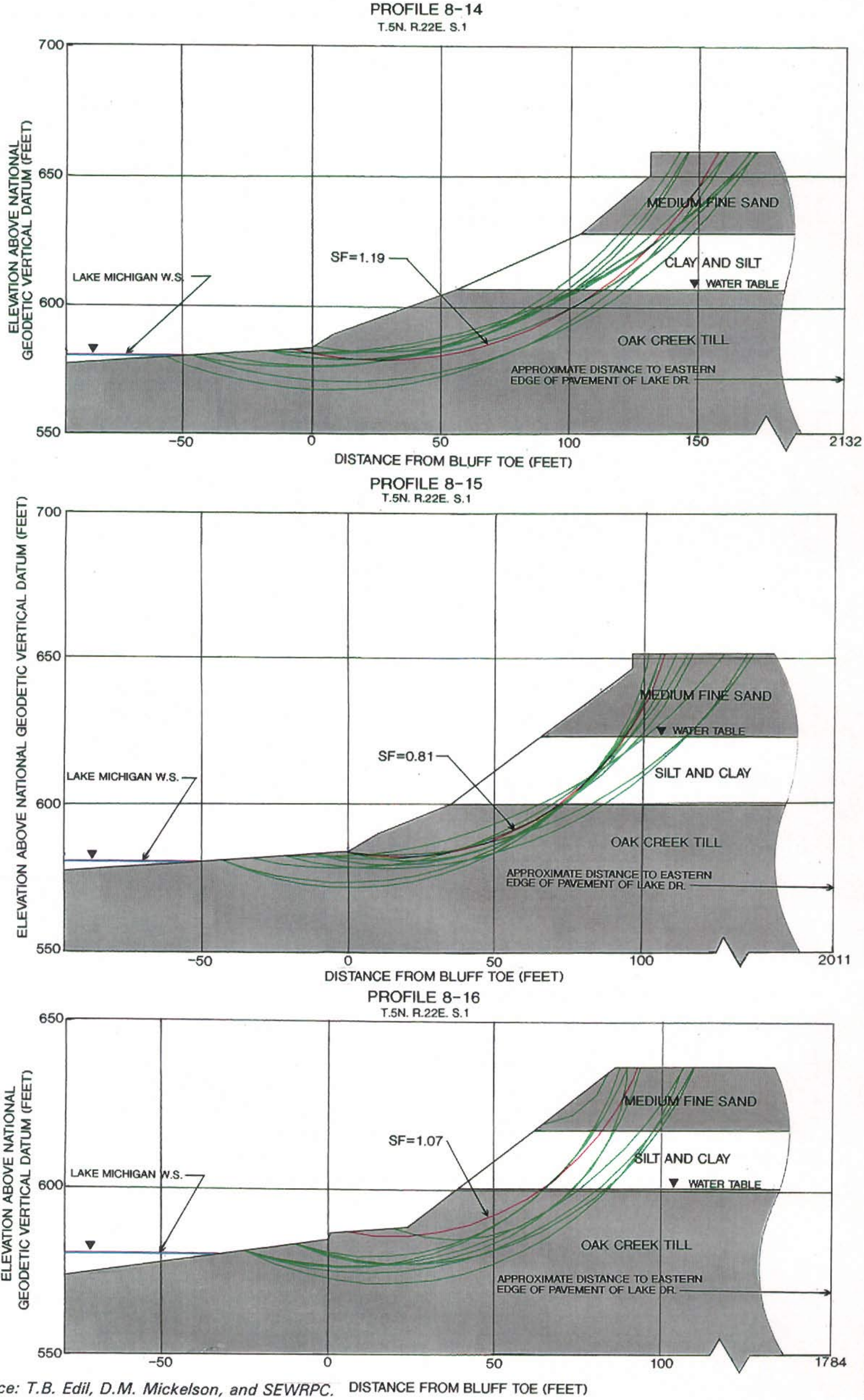
U.S. Public Land Survey Section 36, Township 6 North, Range 22 East, City of Cudahy, Milwaukee County

This shoreline analysis section extends from College Avenue extended, in the City of South Milwaukee, north to E. Grange Avenue extended, in the City of Cudahy, as shown on Map 44. The entire shoreline was occupied by Warnimont Park. The bluff materials in this section were estimated to be primarily till in the lower one-third of the bluff, overlain by sand and silt, overlain by 10 to 20 feet of till. The entire section was unpro-

Figure 41

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 1, Township 5 North, Range 22 East
City of South Milwaukee, Milwaukee County

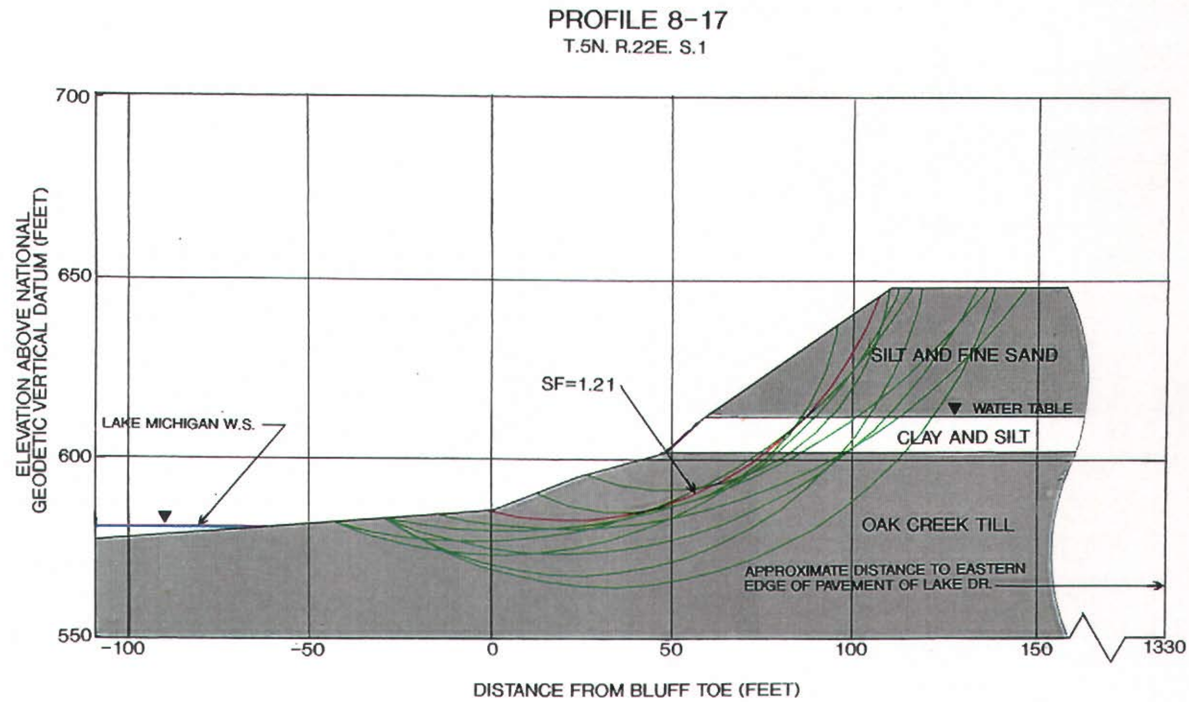


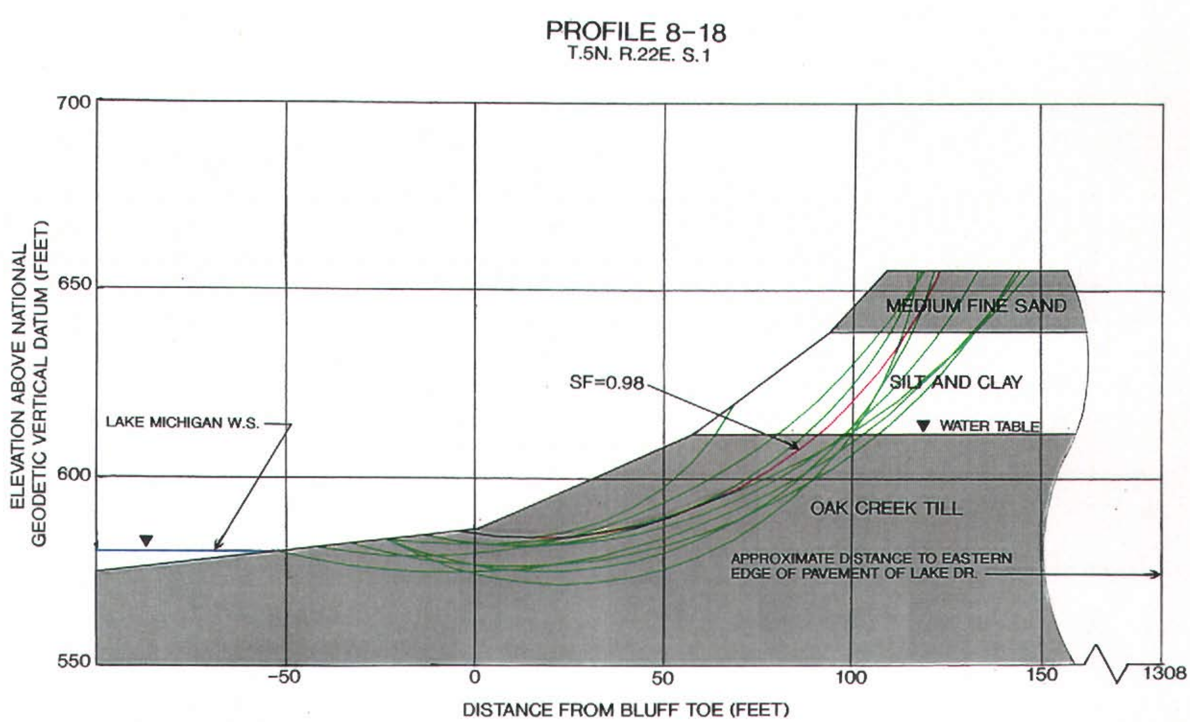
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 42

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 1, Township 5 North, Range 22 East
City of South Milwaukee, Milwaukee County



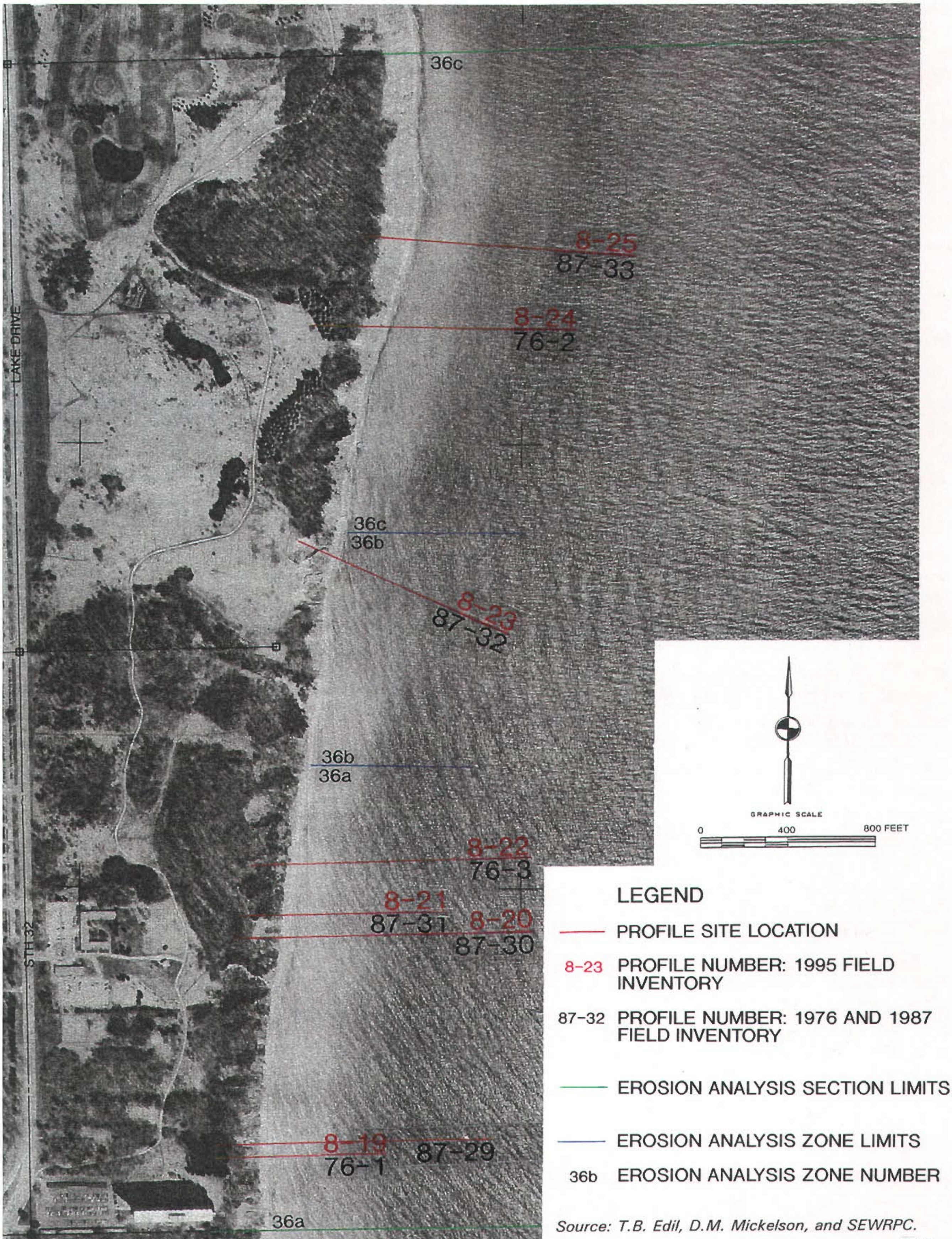


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 44

SHORELINE EROSION REACH 8: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 36, Township 6 North, Range 22 East
City of Cudahy, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

tected by shoreline protection structures. For analysis purposes, Section 36 was further subdivided into three erosion zones, as shown on Map 44. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three erosion zones in Section 36.

Erosion Zone 36a

Erosion Zone 36a extends from the south line of Section 36 at College Avenue extended north about 0.4 mile to about E. Henry Avenue extended in the City of Cudahy, as shown on Map 44. This zone had a beach of about 100 feet in width fronting a bluff which had a height of between 90 and 100 feet. In 1995, vegetation, comprising shrubs and some trees, covered approximately 60 percent of the bluff slope. The bluff within this zone was characterized by seeps of water coming from the sand and silt stratum. Signs of shallow slides were observed on the bluff slope.

In 1995, two bluff profile field surveys were made within Zone 36a by occupying sites for which field surveys were conducted in 1976. At Profile No. 8-19 in the southern portion of the zone and at Profile No. 8-22 in the northern portion of the zone, the bluff had slightly different geometries to those documented in 1976. The shape of the bluff had become generally less steep. The steeply sloping scarps at the bluff toe, most pronounced at Profile No. 8-22 in 1976, was not observed in 1995. Also in 1995, two bluff profile field surveys were made within Zone 36a by occupying sites for which field surveys were conducted in 1987. A third site, occupied in 1987, but not reoccupied in 1995, was located in close proximity to Profile No. 8-19. At Profile Nos. 8-20 and 8-21 in the central portion of the zone, the bluff had a slightly different geometry to that documented in 1987. The shape of the bluff had become less steep. At Profile No. 8-19, assuming this site to be representative of the adjacent 1987 site shown on Map 44, the slope had a significantly different geometry to that documented in 1987, being considerably less steeply sloping. The stability of the bluff in Zone 36a of Reach 8 was characterized by Profile Nos. 8-19 through 8-22. Results of the slope stability analysis, shown in Figures 43 and 44, indicated that the bluff was unstable to marginally stable in the zone, with safety factors ranging from 0.76 to 1.04, based upon the deterministic bluff stability analysis method. Profile Nos. 8-19 and 8-22 were also analyzed using the probabilistic bluff stability analysis method. At Profile No. 8-19, the probabilistic bluff stability analysis method resulted in a range of safety factors from 0.82 to 1.2 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 12, or 48 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 86, or 34.4 percent, of the 250 conditions analyzed. At Profile No. 8-22, the probabilistic bluff stability analysis method resulted in a range of safety factors from 0.71 to 1.17 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 18, or 72 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 145, or 58 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff at Profile No. 8-19 was considered to be marginally stable, and the bluff at Profile No. 8-22 was considered unstable with respect to both rotational and translational failures. The least stable portions of the shoreline were located in the central portion of the zone. The 1977 study reported bluff safety factors of 0.5 in the southern portion of the zone and 1.19 in the northern portion of the zone. The 1987 study reported bluff safety factors of between 0.71 and 1.69, with the stable portion of the bluff slope being located at Profile No. 8-20 in the central portion of the zone.

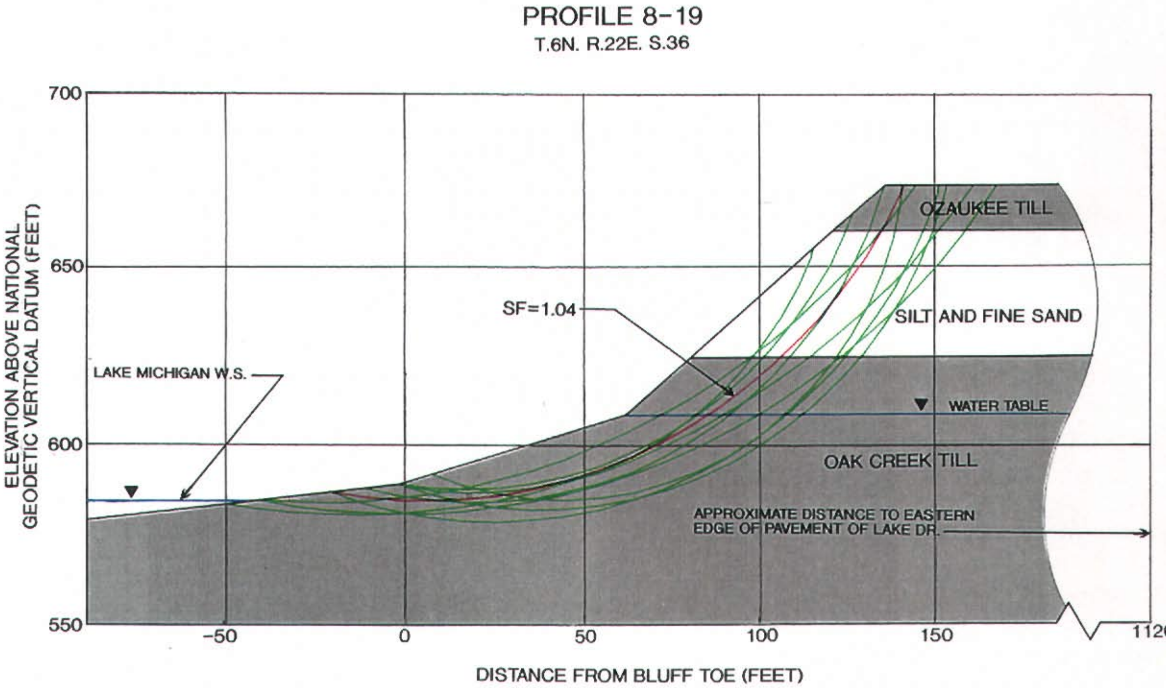
The beach was about 100 feet in width within Erosion Zone 36a. In the 1977 study, the beach width was reported to be greater than 20 feet, and the beach materials were reported to be slumped silt, soil, and till. At Profile No. 8-19, the primary nearshore surface material was gravel and the nearshore lakebed depth of five feet was reached at 40 feet offshore in 1976. At Profile No. 8-22, the primary nearshore surface materials consisted primarily of sand and the nearshore lakebed depth of five feet was reached at 110 feet offshore. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

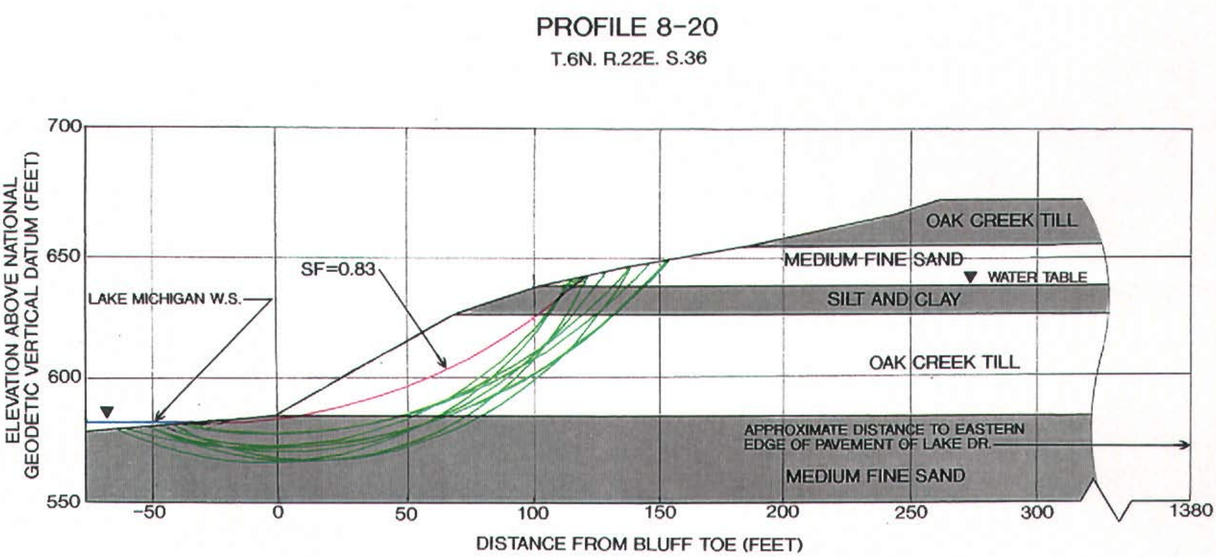
Shoreline recession data for Erosion Zone 36a were estimated at two locations. These data indicated a recession of between 40 and 60 feet, or between 1.2 and 1.9 feet per year, occurred between 1963 and 1995, with the greater rate of bluff recession being reported from the northern portion of the zone. The data indicated a recession of between 10 and 20 feet, or between 0.5 and one foot per year, occurring between 1975 and 1995.

Figure 43

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 36, Township 6 North, Range 22 East
City of Cudahy, Milwaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

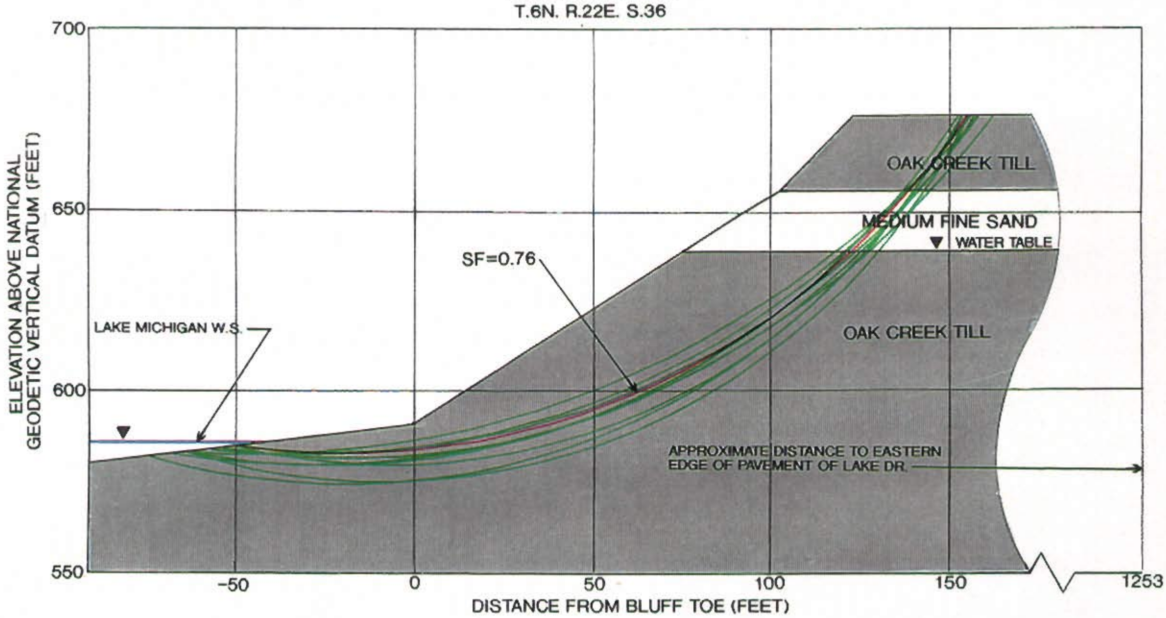
Figure 44

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 36, Township 6 North, Range 22 East
City of Cudahy, Milwaukee County

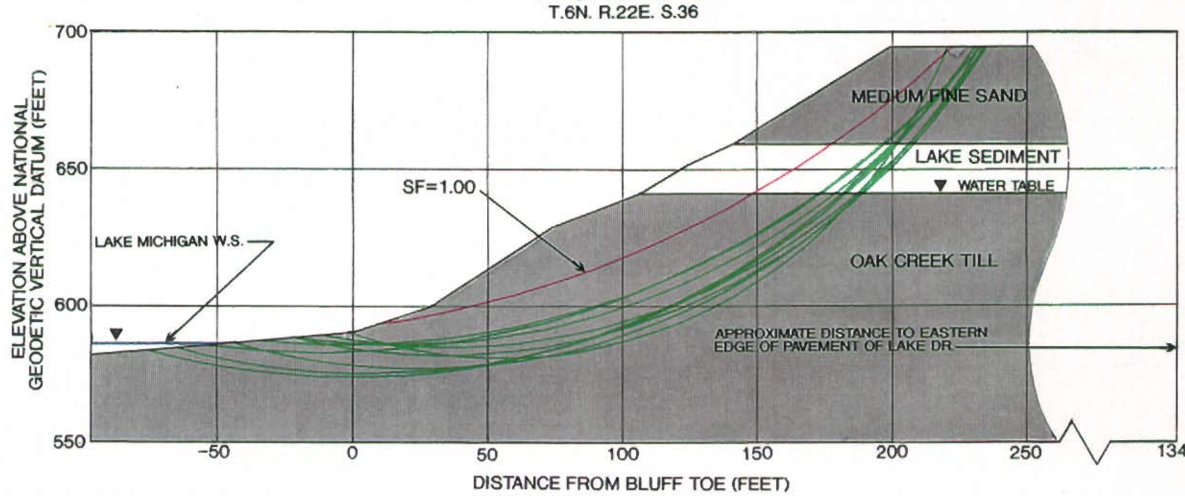
PROFILE 8-21

T.6N. R.22E. S.36



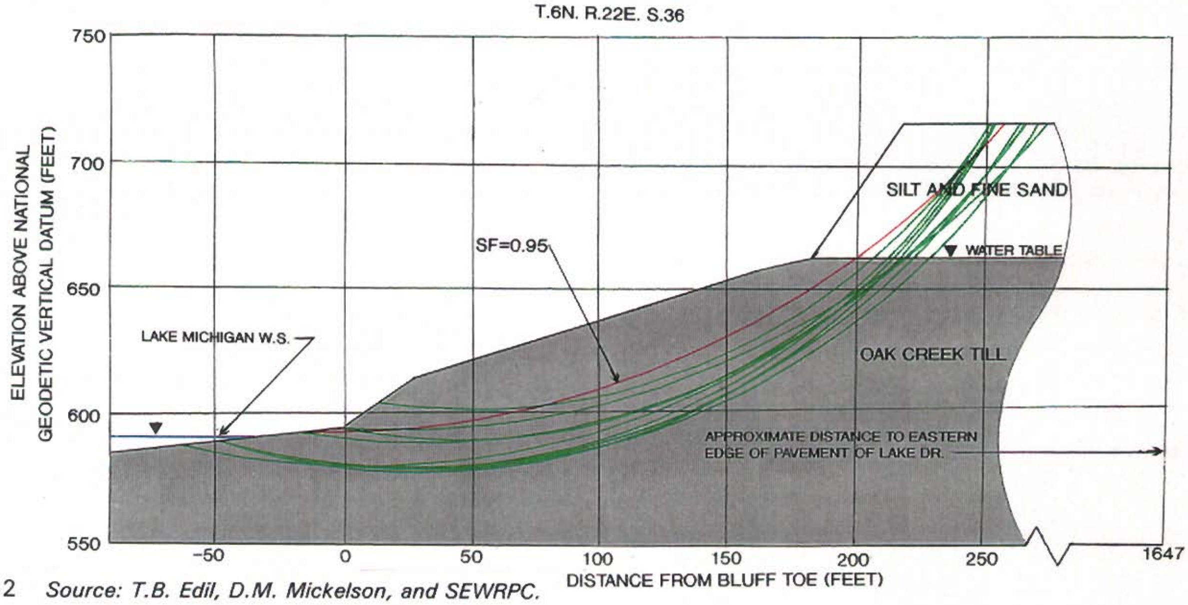
PROFILE 8-22

T.6N. R.22E. S.36



PROFILE 8-23

T.6N. R.22E. S.36



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Thus, it appeared that the bluff had been partially stabilized in the northern portion of the zone, but remained unstable in the southern portion of the zone. The 1977 study reported a recession rate of one foot per year for this zone.

In 1995, a large apartment complex was located in the southern portion of this zone, adjacent to Warnimont Park, between College Avenue and Eaton Lane extended. The shoreline adjacent to this complex was unprotected by shoreline protection structures. The bluff safety factors within Erosion Zone 36a and the presence of shallow slides indicate that the bluff should be considered as unstable over time.

Erosion Zone 36b

Erosion Zone 36b extends from the northerly limit of Erosion Zone 36a at about E. Henry Avenue extended north about 0.2 mile to E. Iona Terrace extended, as shown on Map 44. This zone had a beach of about 50 feet in width. The bluff was unprotected with a height of between 90 and 100 feet in this zone. In 1995, vegetation covered approximately 70 percent of the bluff slope. The vegetated slopes were interrupted by deep scallops in the bluff top within this zone that indicated areas of groundwater focussing and sapping of the silt and sand stratum of the bluff slope. Active springs were observed in 1995 at the base of the sand and silt stratum and the top of the till stratum. Signs of shallow translational slides were present on the upper bluff slope, and signs of an old rotational failure or terrace were observed.

In 1995, one bluff profile field survey was made within Zone 36b by occupying a site for which a field survey was conducted in 1987. The site had a significantly different geometry to that documented in 1987. The shape of the bluff had become considerably less steep, with a scarp developing at the bluff toe at Profile No. 8-23. The stability of the bluff in Erosion Zone 36b of Reach 8 was characterized by Profile No. 8-23. Results of the slope stability analyses, shown in Figure 44, indicated that the bluff was unstable, with a bluff safety factor of 0.95 based upon the deterministic bluff stability analysis method. Profile No. 8-23 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.86 to 1.27 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for eight, or 32 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 66, or 26.4 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered marginally stable with respect to both rotational and translational failures. The 1987 study reported a bluff safety factor of 0.72.

The beach was about 50 feet in width within Zone 36b. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be sand and pebbles with cobbles present at the high-wave line. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 36b were estimated at one location. These data indicated a recession of about 50 feet, or about 1.6 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. Thus, it appeared that the bluff had been partially stabilized within the zone. The 1977 study did not report a recession rate for this zone.

Erosion Zone 36c

Erosion Zone 36c extends from the northerly limit of Erosion Zone 36b at about E. Iona Terrace extended north about 0.4 mile to the north section line of Section 36 at E. Grange Avenue, as shown on Map 44. This zone had a beach of between 50 and 100 feet in width. The bluff was unprotected with a height of between 90 and 100 feet in this zone. In 1995, vegetation covered approximately 10 percent of the bluff slope, which was scalloped by deep ravines vegetated with cedar, birch, and poplar. The deep scallops in the bluff top within this zone indicated areas of groundwater focussing and sapping of the silt and sand stratum of the bluff slope. Springs were observed in 1995 at the base of the sand and silt stratum and the top of the till stratum.

In 1995, one bluff profile field survey was made within Zone 36c by occupying a site for which a field survey was conducted in 1976. The site had a slightly different geometry to that documented in 1976. The shape of the bluff had become smoother and somewhat less steep. Also in 1995, one bluff profile field survey was made within Zone 36c by occupying a site for which a field survey was conducted in 1987. The site had a significantly different geometry to that documented in 1987. The shape of the bluff had become considerably smoother and less steep, while maintaining a slightly convex shape. The stability of the bluff in Zone 36c of Reach 8 was characterized by Profile Nos. 8-24 and

8-25. Results of the slope stability analyses, shown in Figure 45, indicated that the bluff was unstable with respect to both rotational and translational failures, with a bluff safety factor of between 0.79 and 0.90. The 1977 study reported a bluff safety factor of 0.54 at Profile No. 8-24. The 1987 study reported a bluff safety factor of 0.65 at Profile No. 8-25.

The beach was between 50 and 100 feet in width within Zone 36c. In the 1977 study, the beach width was reported to be greater than 20 feet, and the beach materials were reported to be sand and pebbles with cobbles present at the high-wave line. In 1995, the primary nearshore surface material at Profile No. 8-24 was sand and the nearshore lakebed depth of five feet was reached at 120 feet offshore. At Profile No. 8-24, the primary nearshore surface material was sand and the nearshore lakebed depth of five feet was reached at 80 feet offshore in 1976. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1987.

Shoreline recession data for Erosion Zone 36c were estimated at two locations. These data indicated a recession of between 70 and 130 feet, or between 2.2 and 4.1 feet per year, occurred between 1963 and 1995. The data indicated a recession of between 20 and 40 feet, or between one and two feet per year, occurring between 1975 and 1995. Thus, it appeared that the bluff had been partially stabilized within the zone. The 1977 study did not report a recession rate for this zone.

Substantial shoreline protection structures would be required to prevent wave erosion of the shoreline and to stabilize the bluffs within this section. Groundwater seepage at the lower sand and silt-till interface, particularly in the central portions of the section, is likely to remain a problem unless some means of draining the groundwater is identified.

U.S. Public Land Survey Section 25, Township 6 North, Range 22 East, City of Cudahy, Milwaukee County

This shoreline analysis section extends from E. Grange Avenue extended north to Layton Avenue extended, in the City of Cudahy, as shown on Map 45. The entire shoreline was occupied by Warnimont and Sheridan Parks. The bluff materials in this section were estimated to be primarily sand and fine gravel overlain by till intermixed with sand and fine silt in the southern portion of the section, and sand and fine gravel overlain by 10 to 20 feet of till in the central and northern portions of the section. The section was largely unprotected by shoreline protection structures, except in the central portion of the section where a revetment protects the shoreline at the City of Cudahy water intake structure and in the northern portion of the section where a groin system fronted a narrow beach and a bluff with a height of about 100 feet. For analysis purposes, Section 25 was further subdivided into three erosion zones, as shown on Map 45, by combining the southernmost two erosion zones described in the 1977 study into one zone in 1995. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three erosion zones in Section 25.

Erosion Zone 25a

Erosion Zone 25a extends from the south line of Section 25 at E. Grange Avenue extended north about 0.5 mile to about E. Edgerton Avenue extended, at the southern side of the City of Cudahy City Hall property, in the City of Cudahy, as shown on Map 45. This zone had a beach of about 50 feet in width fronting a bluff which had a height of about 100 feet. In 1995, vegetation covered approximately 10 percent of the bluff slope. The bluff within this zone was characterized by seeps of water coming from the upper portion of the till stratum. Signs of shallow slides were observed on the bluff slope, and sheetwash erosion of the bluff face during the summer months was inferred from the lack of vegetation cover on the bluff slope. A few ravines, similar to those observed in 1995 in the central and northern portions of Section 36 immediately to the south of Erosion Zone 25a, were present in this zone.

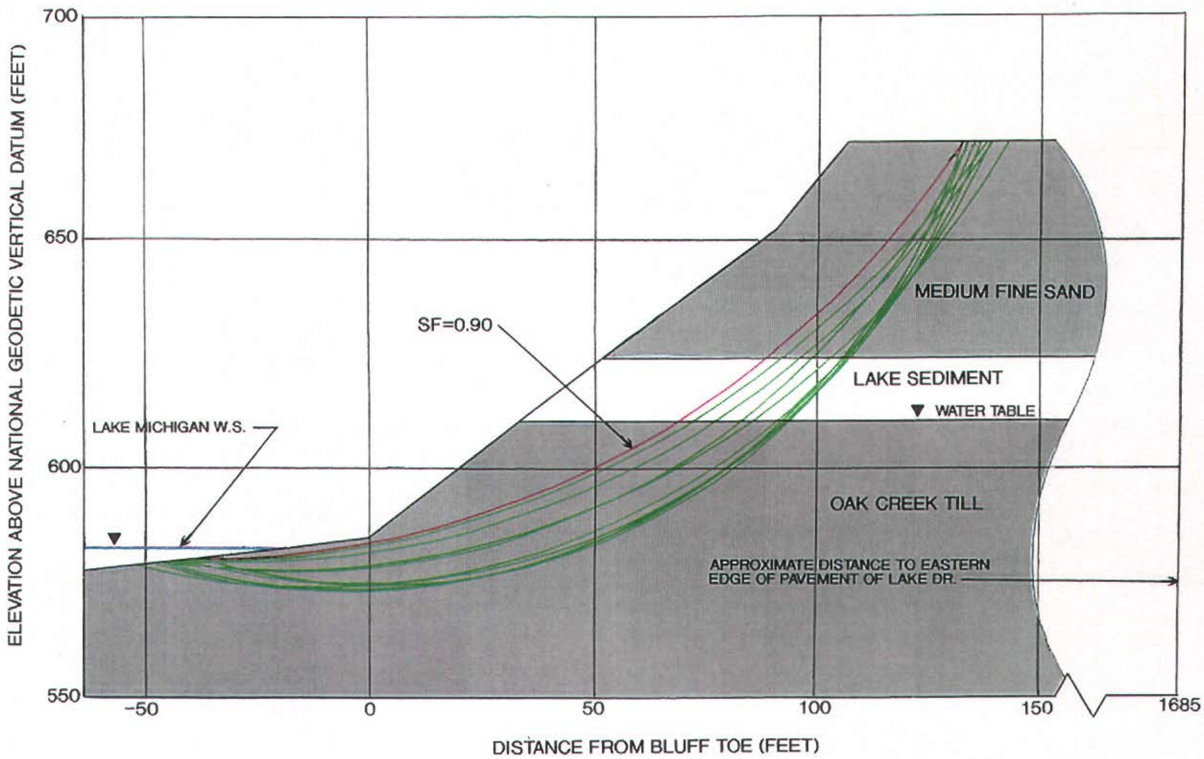
In 1995, two bluff profile field surveys were made within Zone 25a by occupying sites for which field surveys were conducted in 1976. The bluffs had slightly different geometries to those documented in 1976. The shape of the bluff had become less steep at Profile No. 8-26. At Profile No. 8-27, the shape of the bluff had become somewhat steeper. Also in 1995, one bluff profile field survey was made within Zone 25a by occupying a site for which a field survey was conducted in 1987. At Profile No. 8-28, in the northern portion of the zone, the bluff had a significantly different geometry to that documented in 1987. The shape of the bluff had become less steep. The stability of the bluff in Zone 25a of Reach 8 was characterized by Profile Nos. 8-26 through 8-28. Results of the slope stability analysis, shown in Figures 46 and 47, indicated that the bluff was unstable in the zone, with safety factors ranging from 0.83 to 0.95, based upon the deterministic bluff stability analysis method. Profile Nos. 8-26 and 8-28 were also analyzed using the probabilistic bluff stability analysis

Figure 45

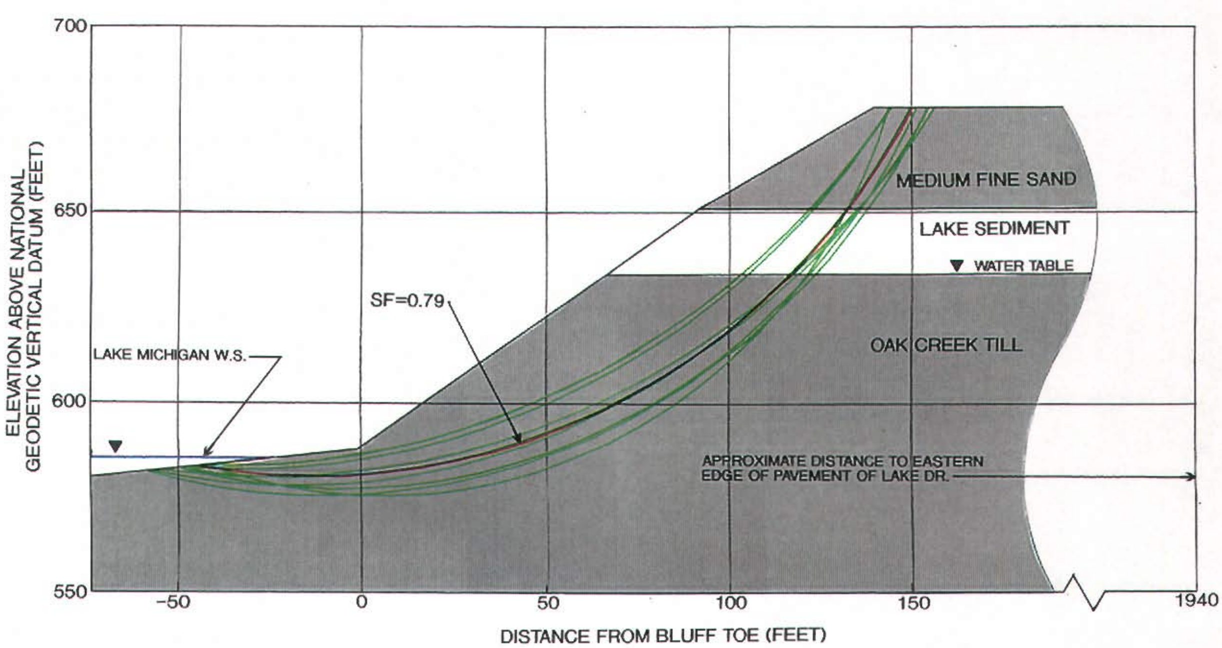
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 36, Township 6 North, Range 22 East
City of Cudahy, Milwaukee County

PROFILE 8-24
T.6N. R.22E. S.36



PROFILE 8-25
T.6N. R.22E. S.36

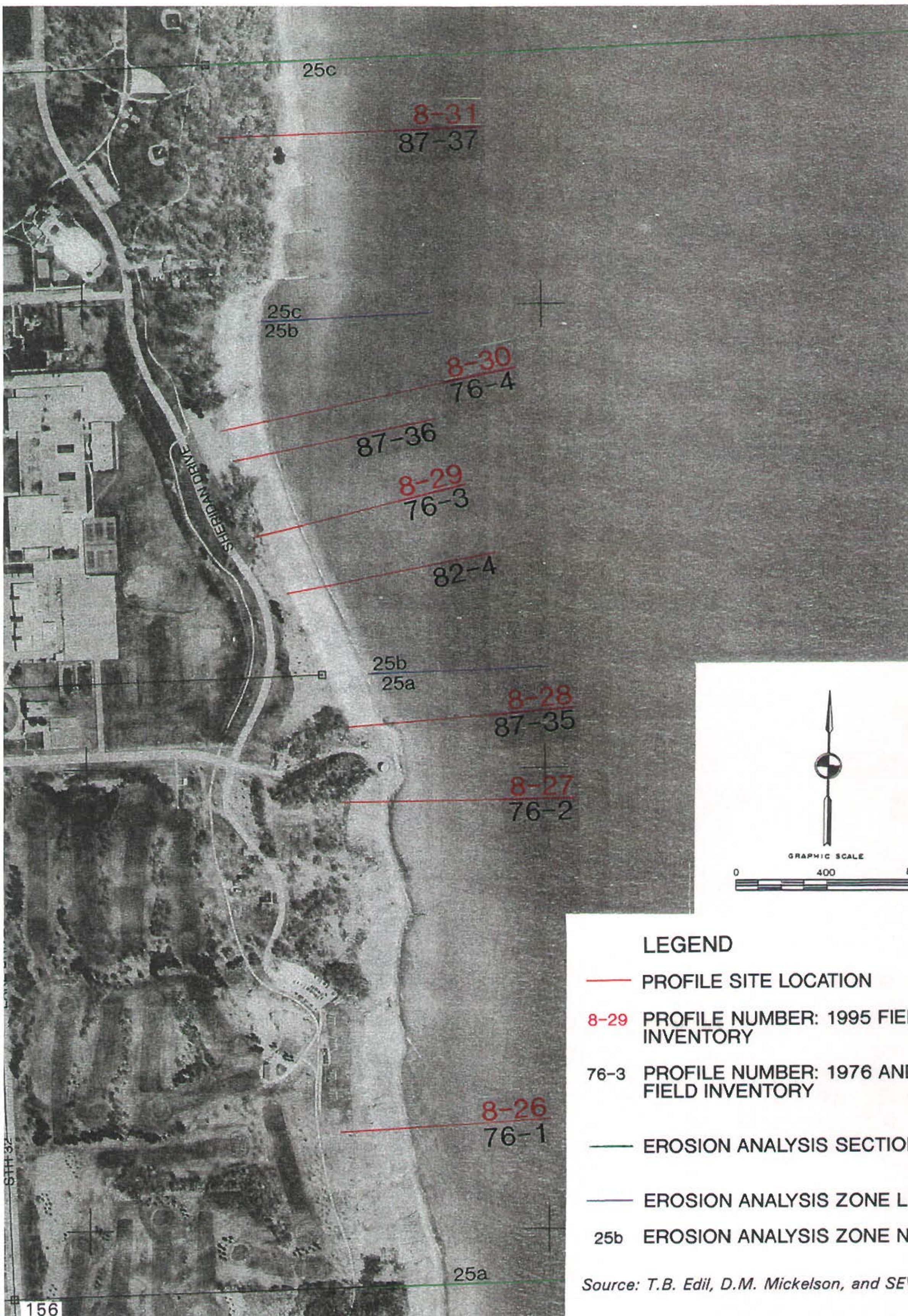


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 45

SHORELINE EROSION REACH 8: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 25, Township 6 North, Range 22 East
City of Cudahy, Milwaukee County



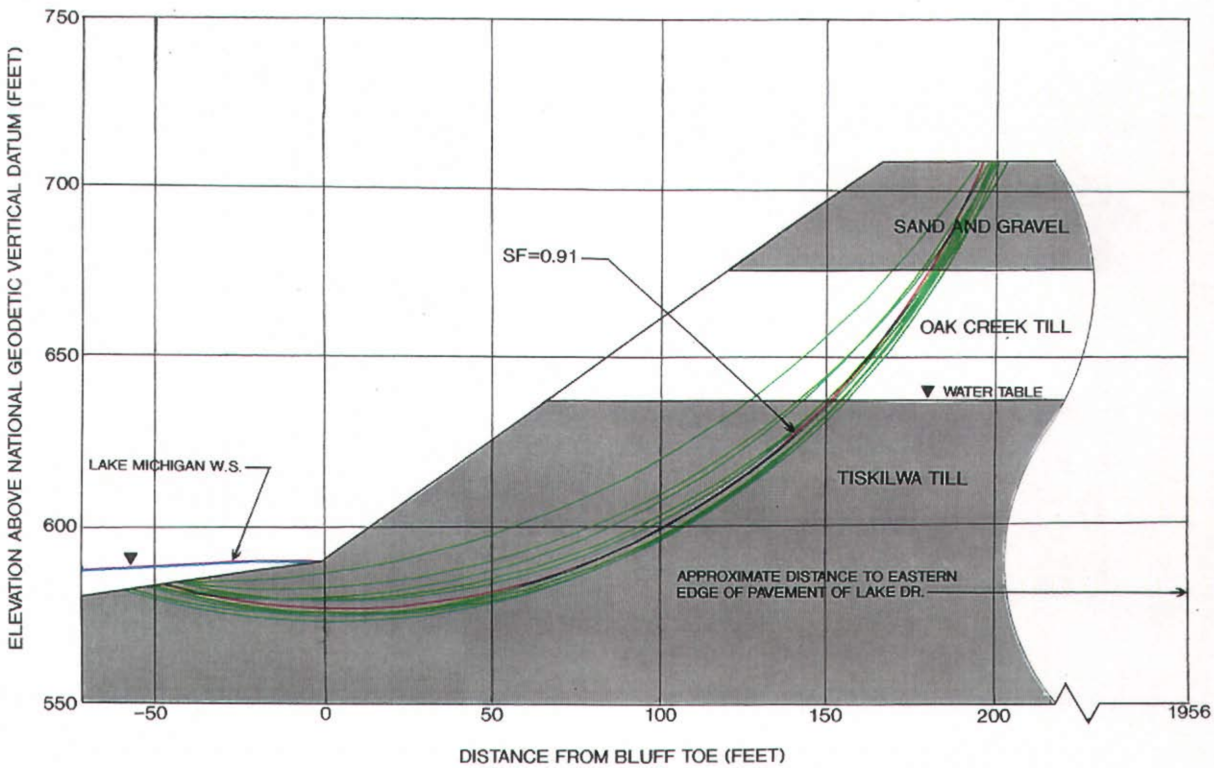
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 46

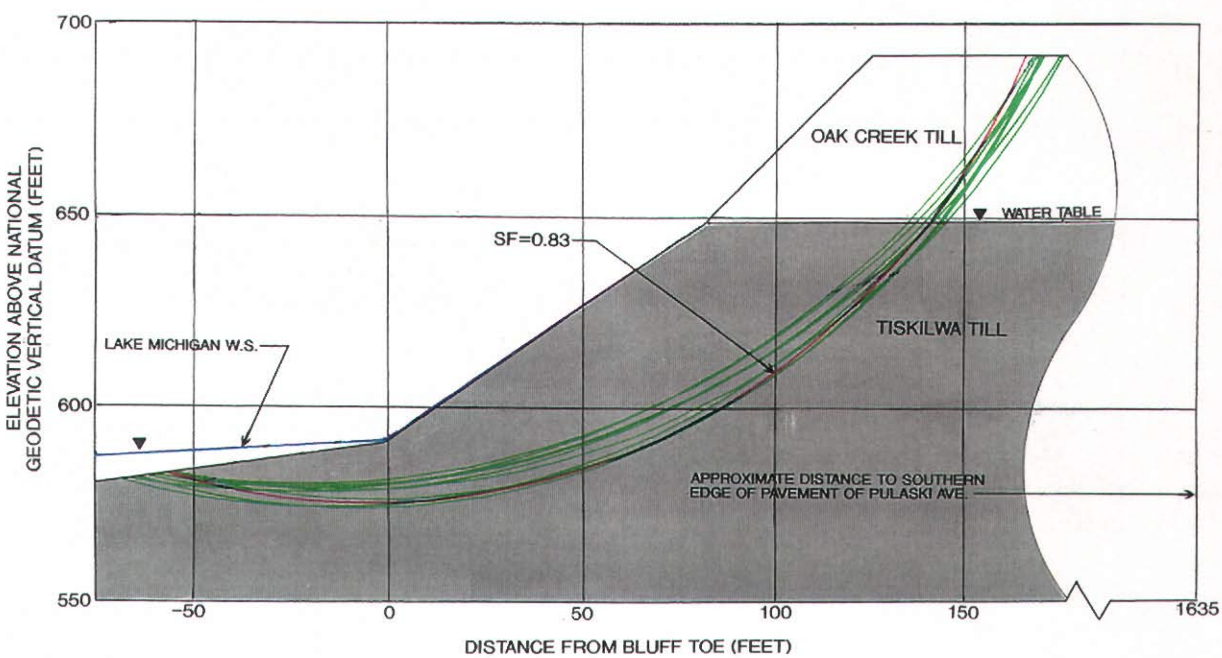
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 25, Township 6 North, Range 22 East
City of Cudahy, Milwaukee County

PROFILE 8-26
T.6N. R.22E. S.25



PROFILE 8-27
T.6N. R.22E. S.25



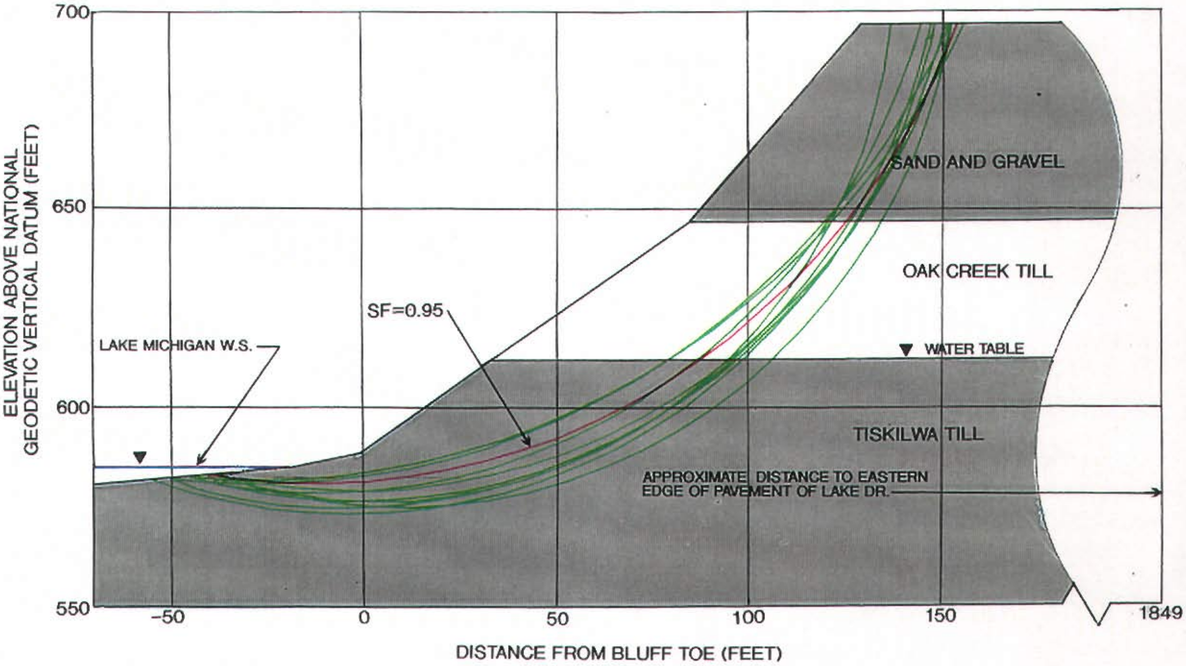
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 47

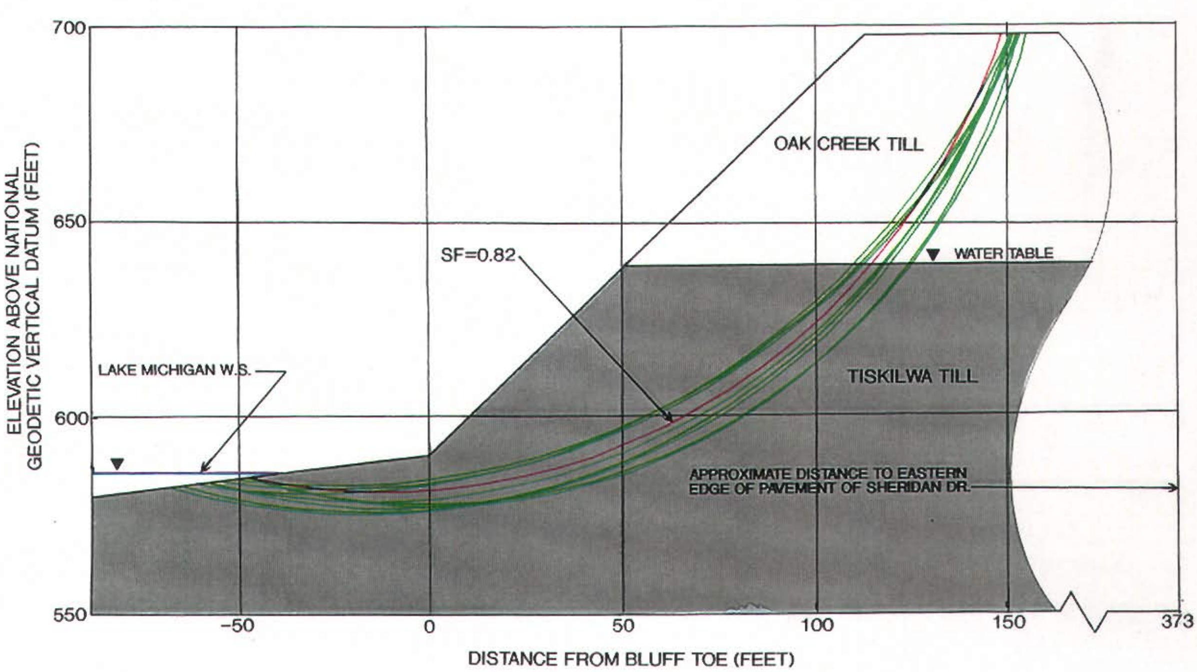
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

**U.S. Public Land Survey Section 25, Township 6 North, Range 22 East
City of Cudahy, Milwaukee County**

PROFILE 8-28
T.6N. R.22E. S.25



PROFILE 8-29
T.6N. R.22E. S.25



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

method. At Profile No. 8-26, the probabilistic bluff stability method resulted in a range of safety factors from 0.55 to 0.92 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 25, or 100 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 250, or 100 percent, of the 250 conditions analyzed. At Profile No. 8-28, the probabilistic bluff stability method resulted in a range of safety factors from 0.76 to 1.29 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 12, or 48 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 52, or 20.8 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff at Profile No. 8-26 was considered unstable, and the bluff at Profile No. 8-28 was considered marginally stable, with respect to both rotational and translational failures. The 1977 study reported bluff safety factors of 0.33 and 0.68 at Profile Nos. 8-26 and 8-27, respectively. The 1987 study reported a bluff safety factor of 0.82 at Profile No. 8-28.

The beach was about 50 feet in width within Erosion Zone 25a, and was accreting sand north of the northernmost revetment of the City of Cudahy water intake in the northern portion of the zone. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be pebbles at the water's edge and sand to the base of the bluff. In 1995, at Profile No. 8-27, the primary nearshore surface material was cobbles and the nearshore lakebed depth of five feet was reached at 72 feet offshore. The primary nearshore surface materials consisted primarily of cobbles and the nearshore lakebed depth of five feet was reached at 60 feet offshore in 1976. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1987.

Shoreline recession data for Erosion Zone 25a were estimated at two locations. These data indicated a recession of between 10 and 130 feet, or between 0.3 and 4.1 feet per year, occurred between 1963 and 1995, with the greater rate of bluff recession being reported from the northern portion of the zone. The data indicated that most of the recession occurred prior to 1975, with a recession of between zero and 40 feet, or between zero and two feet per year, occurring between 1975 and 1995. Thus, it appeared that the bluff had been partially stabilized in this zone, with no further recession of the shoreline observed in the northern portion of the zone. The 1977 study did not report a recession rate for this zone.

In 1995, several small shoreline protection structures were observed within this zone. However, these structures appeared to be ineffective in stabilizing the bluff, except in the area around the City of Cudahy water intake where the bluff slope was stabilized by a revetment.

Erosion Zone 25b

Erosion Zone 25b extends from the northerly limit of Erosion Zone 25a at about E. Edgerton Avenue extended north about 0.4 mile to Munkwitz Avenue extended at about the northern property line of Cudahy High School, as shown on Map 45. This zone had a beach of about 50 feet in width. The bluff was generally unprotected with a height of about 100 feet in this zone. In 1995, vegetation covered approximately 10 percent of the bluff slope. Signs of shallow slides were present.

In 1995, two bluff profile field surveys were made within Zone 25b by occupying sites for which field surveys were conducted in 1976. The site at Profile No. 8-30 had a significantly different geometry to that documented in 1976. The shape of the bluff had become less steep. At Profile No. 8-29, the shape of the bluff appeared to be unchanged. The stability of the bluff in Zone 25b of Reach 8 was characterized by Profile Nos. 8-29 and 8-30. Results of the slope stability analyses, shown in Figures 47 and 48, indicated that the bluff was unstable with respect to both rotational and translational failures, with bluff safety factors of 0.74 at Profile No. 8-30 and 0.82 at Profile No. 8-29. The 1977 study reported bluff safety factors of 0.49 and 0.88 at Profile Nos. 8-29 and 8-30, respectively.

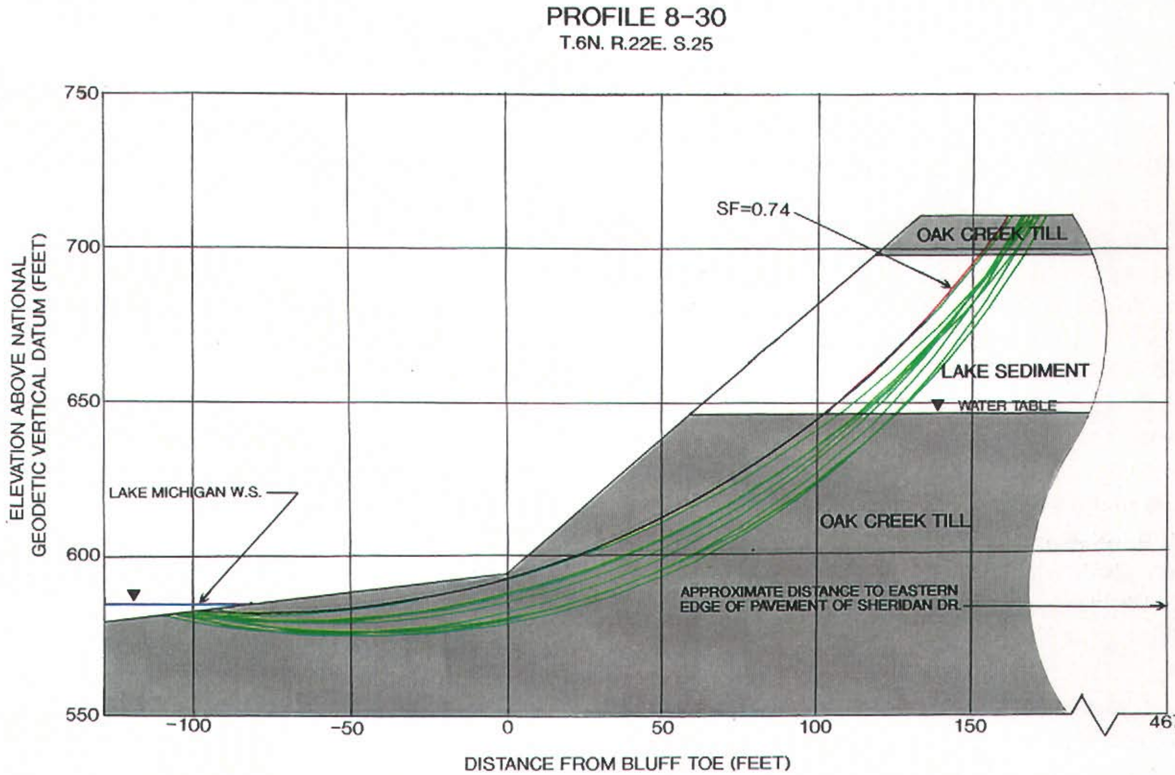
The beach was about 50 feet in width within Zone 25b. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be pebbles at the water's edge, with sand to the base of the bluff. In 1995, at Profile No. 8-29, the primary nearshore surface material was silt and the nearshore lakebed depth of five feet was reached at 75 feet offshore. The nearshore lakebed depth of five feet was reached at 50 feet offshore in 1976. The primary nearshore surface materials were not reported.

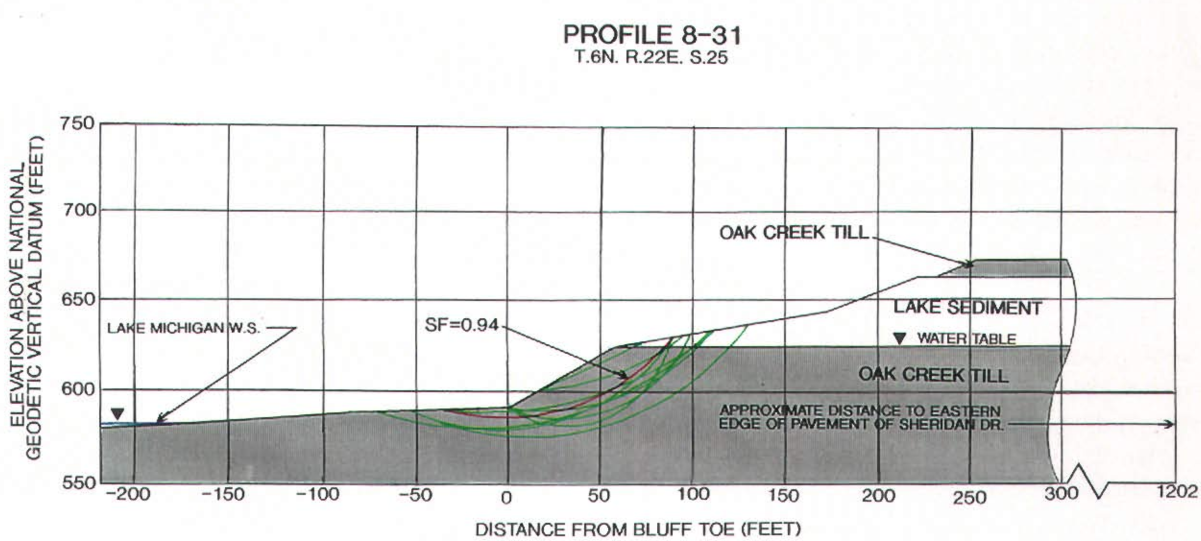
Shoreline recession data for Erosion Zone 25b were estimated at one location. These data indicated a recession of about 90 feet, or about 2.8 feet per year, occurred

Figure 48

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 25, Township 6 North, Range 22 East
City of Cudahy, Milwaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. Thus, it appeared that the bluff had been partially stabilized within the zone. The 1977 study reported a recession rate of 0.3 foot per year for this zone.

In 1995, it appeared that the presence of a groin system in Erosion Zone 25c immediately to the north of this zone was retaining sand that had previously been deposited within Zone 25b. Therefore, shoreline loss appeared to be taking place within this zone, as evidenced by the indented shoreline that had been produced through this process over time. Based on the degree of indentation that had occurred, it appeared that there had been 10 to 50 feet of retreat of the bluff top since 1976.

Erosion Zone 25c

Erosion Zone 25c extends from the northerly limit of Erosion Zone 25b at about Munkwitz Avenue extended north about 0.2 mile to the north section line of Section 25 at Layton Avenue, as shown on Map 45. This zone had a beach of between 50 and 125 feet in width contained within a groin system. The bluff was had a height of about 100 feet in this zone. In 1995, vegetation, comprising mature trees, covered approximately 100 percent of the bluff slope. Signs of some tension cracks and indications of soil creep were present.

In 1995, one bluff profile field survey was made within Zone 25c by occupying a site for which a field survey was conducted in 1987. The site had a significantly different geometry to that documented in 1987. The shape of the bluff had become much less steep over its entire length, although the toe of the bluff had become steeper at the shoreline. The stability of the bluff in Zone 35c of Reach 8 was characterized by Profile No. 8-31. Results of the slope stability analyses, shown in Figure 48, indicated that the bluff was unstable, with a bluff safety factor of 0.94 based upon the deterministic bluff stability analysis method. Profile No. 8-31 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.78 to 1.9 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 11, or 44 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 26, or 10.4 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1987 study reported a bluff safety factor of 1.21.

The beach was between 50 and 125 feet in width within Zone 25c. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be pebbles at the water's edge, with sand present to the base of the bluff. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 25c were estimated at two locations. These data indicated a recession of between 20 and 50 feet, or between 0.6 and 1.6 feet per year, occurred between 1963 and 1995. The data indicated a recession of between zero and 20 feet, or between zero and one foot per year, occurring between 1975 and 1995. Thus, it appeared that the bluff had been partially stabilized within the zone, with little or no further erosion occurring within all but the northernmost portion of this zone. The 1977 study reported a recession rate of one foot per year for this zone.

In 1995, the bluff within Erosion Zone 25c appeared to be more stable than the zones to the south.

U.S. Public Land Survey Sections 23 and 24, Township 6 North, Range 22 East, Cities of Cudahy and St. Francis, Milwaukee County

This shoreline analysis section extends from Layton Avenue extended, in the City of Cudahy, north to about Howard Avenue, in the City of St. Francis, as shown on Map 46. The southern portion of the shoreline was occupied by Sheridan Park, and the northern portion of the shoreline by residential lands, including limited areas of multi-family and institutional land uses. The bluff materials in this section were covered, but were estimated to be primarily sand and fine gravel overlain by till. The section was protected by a variety of shoreline protection structures, including a groin system and rubble fill. A narrow beach of up to 50 feet in width fronted the bluff with a height of between 60 and 100 feet. The higher portions of the bluff abutted Section 25 to the south. For analysis purposes, Section 24 was further subdivided into two erosion zones, as shown on Map 46. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the two erosion zones in Section 24.

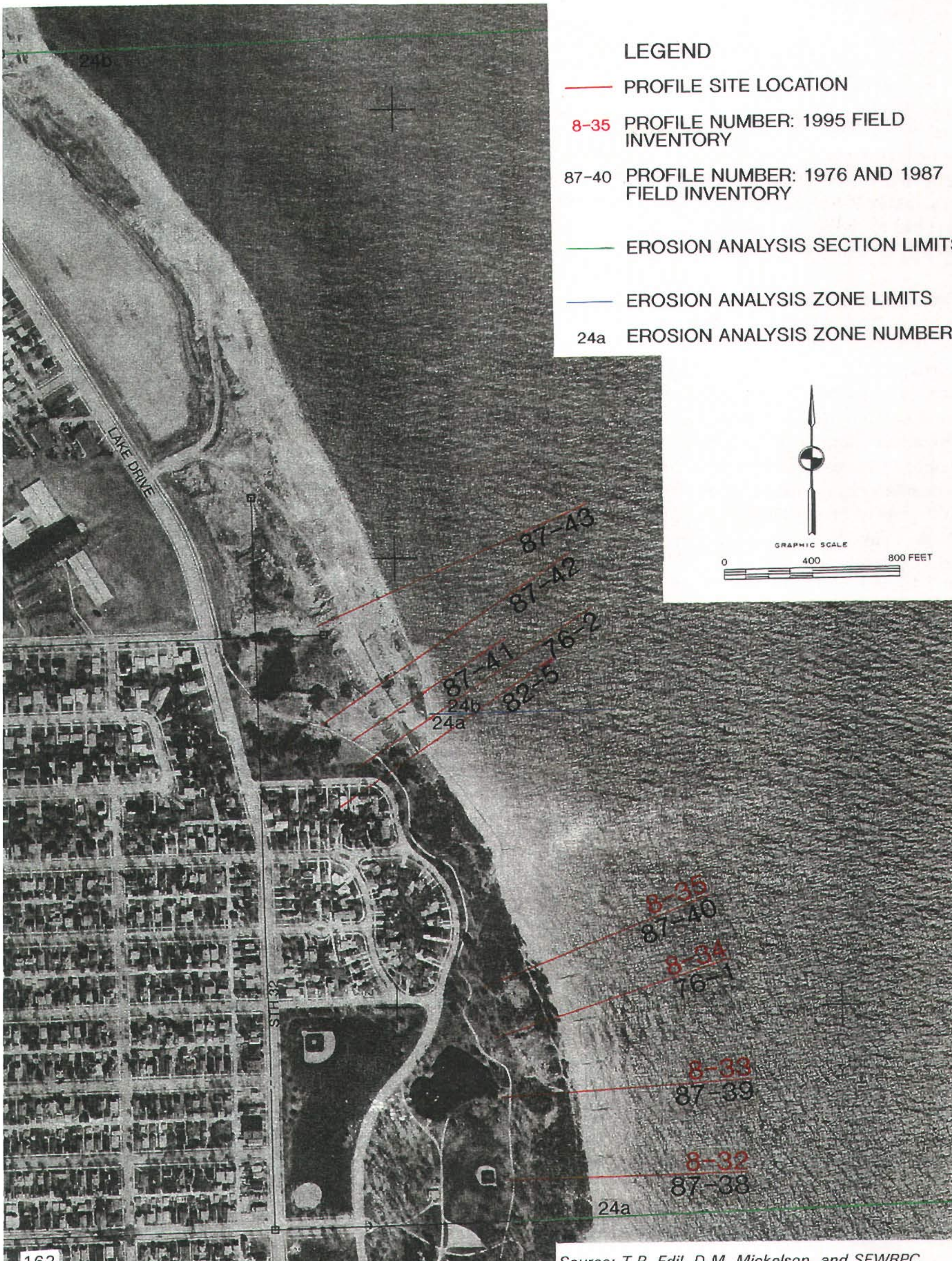
Erosion Zone 24a

Erosion Zone 24a extends from the south line of Section 24 at Layton Avenue extended north about 0.4 mile to about Whitaker Avenue extended, in the City of Cudahy, as shown on Map 46. This portion of the shoreline in Section 24 was occupied by Sheridan Park. The

Map 46

SHORELINE EROSION REACH 8: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 23 and 24, Township 6 North, Range 22 East
Cities of Cudahy and St. Francis, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

zone had a beach of about 50 feet in width, contained within a groin system, fronting a bluff which had a height of about 100 feet. In 1995, vegetation, comprising grasses, covered approximately 100 percent of the bluff slope within this zone. In 1995, signs of soil creep were present.

In 1995, one bluff profile field survey was made within Zone 24a by occupying a site for which a field survey was conducted in 1976. The bluff had a significantly different geometry to that documented in 1976. The shape of the bluff had become steeper at Profile No. 8-34, and a beach fronted the bluff. Also in 1995, three bluff profile field surveys were made within Erosion Zone 24a by occupying sites for which field surveys were conducted in 1987. At all three sites, the bluff had a significantly different geometry to that documented in 1987. The shape of the bluff had become less steep. The stability of the bluff in Zone 24a of Reach 8 was characterized by Profile Nos. 8-32 through 8-35. Results of the slope stability analysis, shown in Figures 49 and 50, indicated that the bluff was unstable to marginally stable with respect to deep-seated slumps and shallow slides at Profile Nos. 8-32, 8-34, and 8-35, with safety factors ranging from 0.8 to 1.04, based upon the deterministic bluff stability analysis method. At Profile No. 8-33, the bluff appeared to be stable with respect to rotational failures, with a safety factor of 1.12. Profile Nos. 8-34 and 8-35 were also analyzed using the probabilistic bluff stability analysis method. At Profile No. 8-34, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.72 to 1.18 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 25, or 100 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 200, or 80 percent, of the 250 conditions analyzed. At Profile No. 8-35, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.89 to 1.58 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for eight, or 32 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 13, or 5.2 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered unstable at Profile No. 8-34, and marginally stable at Profile No. 8-35 with respect to both rotational and translational failures. The 1977 study reported a bluff safety factor of 0.6 at Profile No. 8-34. The 1987 study reported bluff safety factors of 1.02, 0.74, and 0.93 at Profile Nos. 8-32, 8-33, and 8-35, respectively.

The beach was about 50 feet in width within Erosion Zone 24a, and was accreting sand within the groin system. In the 1977 study, the beach width was reported to be greater than 20 feet, and the beach material was reported to be sand. In 1995, at Profile No. 8-34, the primary nearshore surface material was cobbles and the nearshore lakebed depth of five feet was reached at 87 feet offshore. The primary nearshore surface materials were not reported and the nearshore lakebed depth of five feet was reached at 53 feet offshore in 1976. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1987.

Shoreline recession data for Erosion Zone 24a were estimated at one location. These data indicated a recession of about 50 feet, or about 1.6 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 20 feet, or about one foot per year, occurring between 1975 and 1995. Thus, it appeared that the groin system had partially stabilized the bluff within this zone. The 1977 study reported a recession rate of one foot per year for this zone.

Erosion Zone 24b

Erosion Zone 24b extends from the northerly limit of Erosion Zone 24a at about Whitaker Avenue extended, in the City of Cudahy, north about 0.6 mile to Howard Avenue extended, in the City of St. Francis, as shown on Map 46. This zone had little or no beach fronting the bluff which decreased in height from about 100 feet in the southern portion of the zone to about 60 feet in the northern portion of the zone. In 1995, this zone was being regraded and shoreline protection structures, in the form of a large fill, were being placed.

No bluff stability analyses were conducted within Erosion Zone 24b, in this study or in 1976.

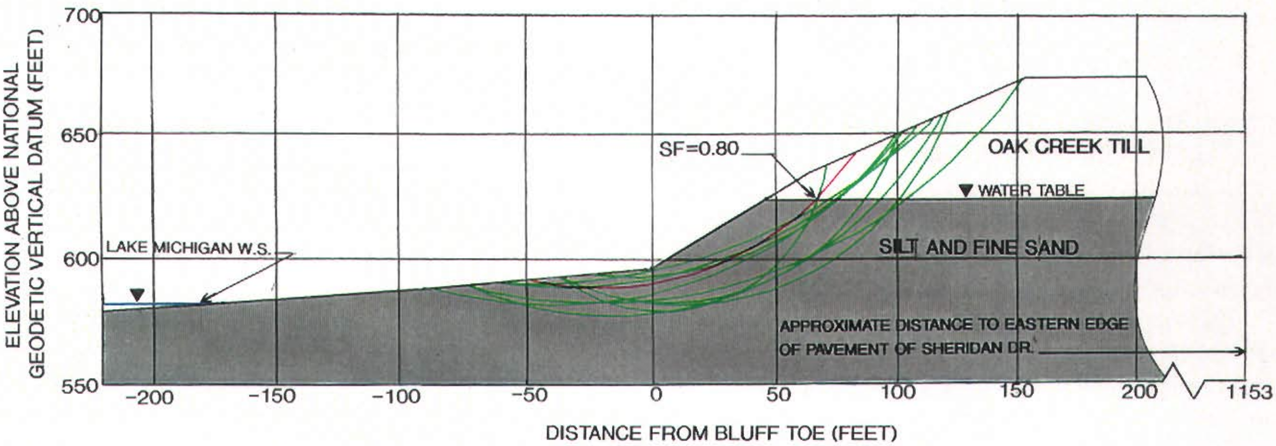
The beach was nonexistent within Zone 25b. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be sand and gravel with cobbles and boulders. No observations or measurements were made of the nearshore lakebed depth or materials during in this study or in 1976 or 1987.

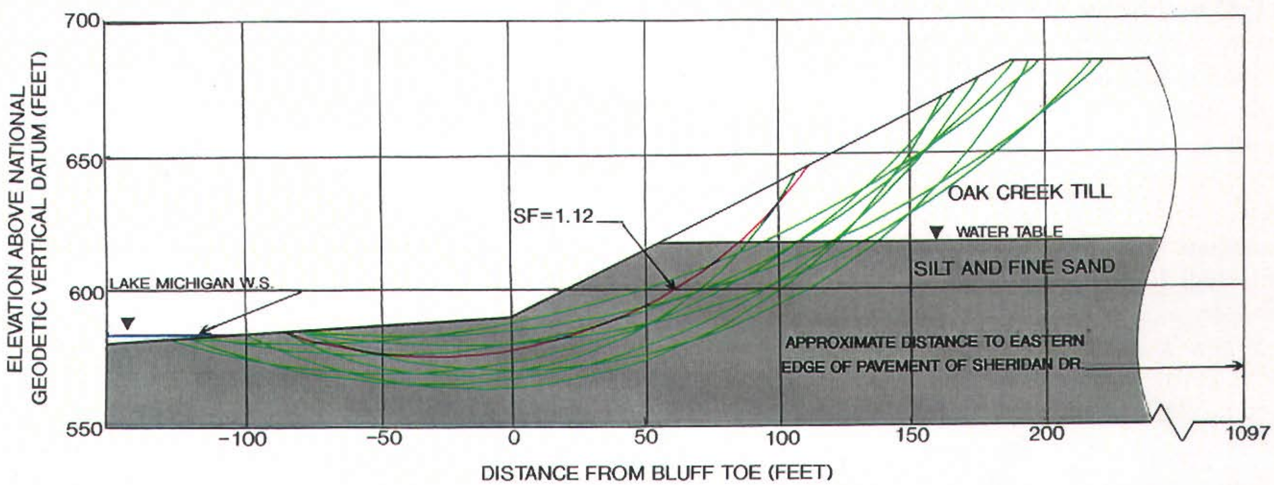
Shoreline recession data for Erosion Zone 24b were estimated at three locations. These data indicated a recession of between 30 and 160 feet, or between 0.9 and five feet per year, occurred between 1963 and 1995, with the

Figure 49

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 24, Township 6 North, Range 22 East
City of Cudahy, Milwaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

greatest recession occurring in the central and northern portions of the zone. The data indicated a recession of between 20 and 40 feet, or between one and two feet per year, occurring between 1975 and 1995. Thus, it appeared that the bluff had been partially stabilized within the zone. The 1977 study did not report a recession rate for this zone.

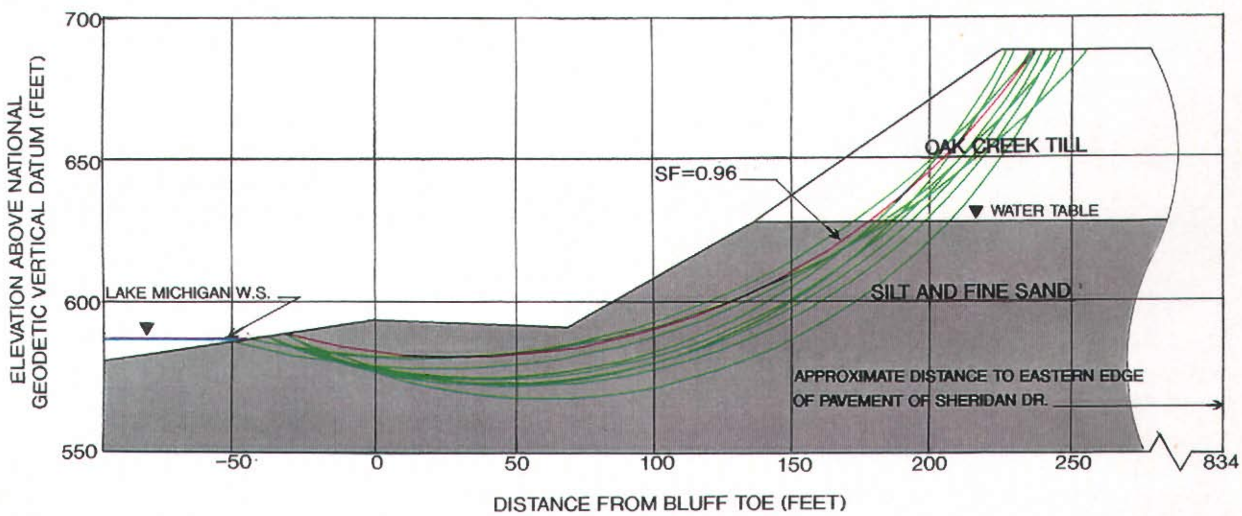
In 1995, the regrading of the bluff and placement of a massive fill were in progress.

Figure 50

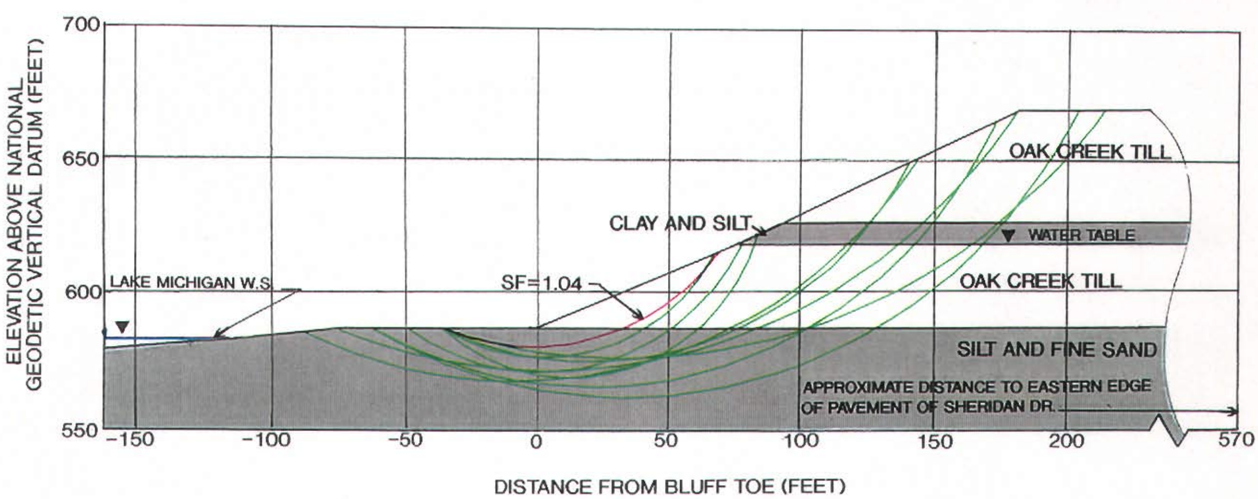
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 24, Township 6 North, Range 22 East
City of Cudahy, Milwaukee County

PROFILE 8-34
T.6N. R.22E. S.24



PROFILE 8-35
T.6N. R.22E. S.24



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

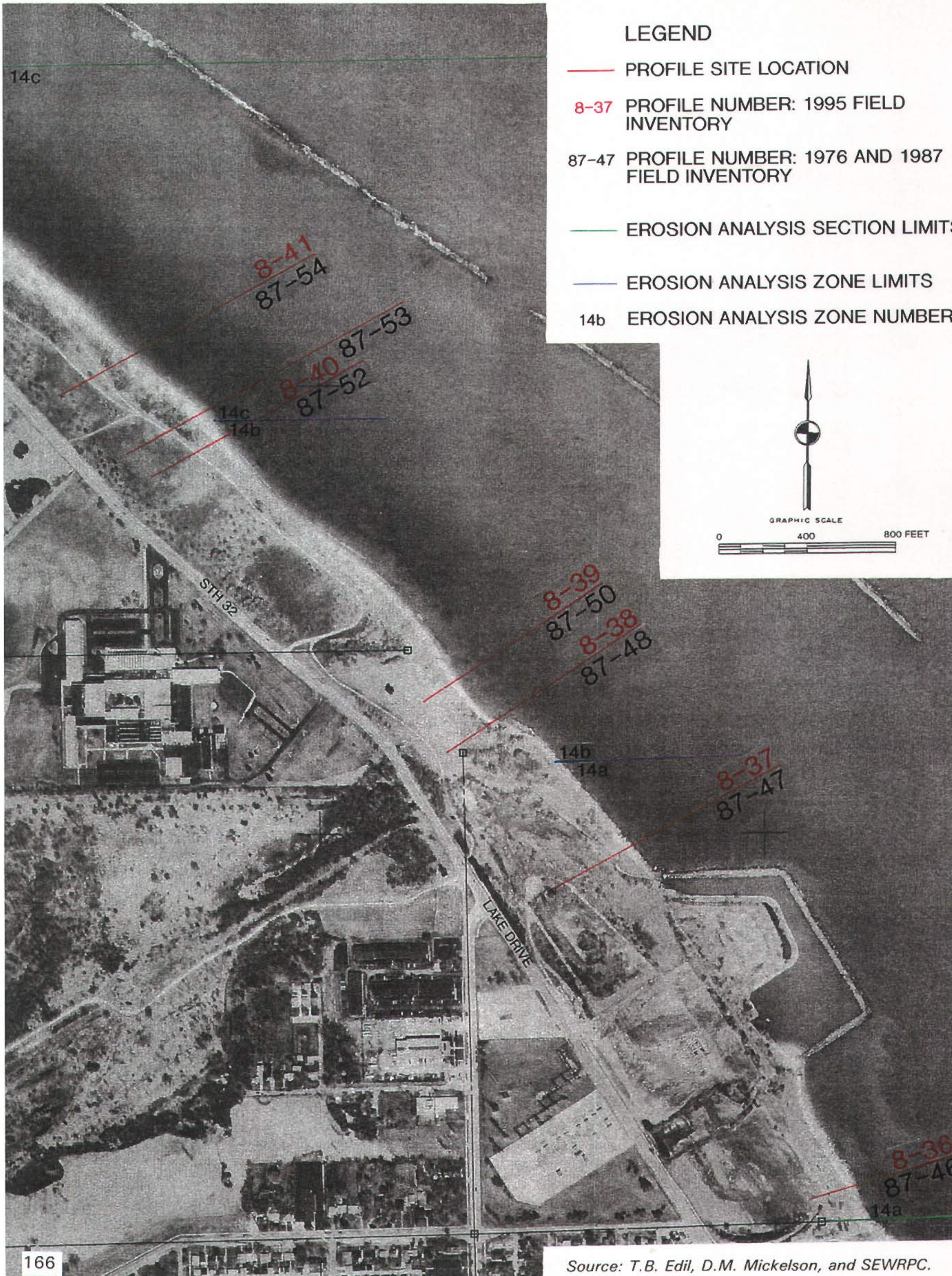
U.S. Public Land Survey Section 14, Township 6 North, Range 22 East, Cities of Milwaukee and St. Francis, Milwaukee County

This shoreline analysis section extends from Howard Avenue extended, in the City of St. Francis, north to E. Oklahoma Avenue extended, in the City of Milwaukee, as shown on Map 47. The shoreline was occupied by industrial land uses, including the abandoned Wisconsin Electric Power Company Lakeside Power Plant site, in the southern half of the section, and by open space land uses, including Bayview Park, in the northern half of the section. The bluff materials in this section were esti-

Map 47

SHORELINE EROSION REACH 8: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 14, Township 6 North, Range 22 East
City of St. Francis, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

mated to be primarily till underlain by sand and silt. The section was protected by a variety of shoreline protection structures in the southern and northern portions and unprotected by shoreline protection structures in the central portion. For analysis purposes, Section 14 was further subdivided into three erosion zones, as shown on Map 47. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three erosion zones in Section 14.

Erosion Zone 14a

Erosion Zone 14a extends from the south line of Section 14 at Howard Avenue extended north about 0.4 mile, adjacent to the Wisconsin Electric Power Company Lakeshore Power Plant site, to about Morgan Avenue extended in the City of St. Francis, as shown on Map 47. This zone had little or no beach fronting a bluff which had a height of about 60 feet. In 1995, vegetation covered approximately 100 percent of the bluff slope. The bluff within this zone had been regraded and was protected by a revetment, and, in the extreme northern portion of the zone, by concrete rubble fill. Signs of some soil creep and very localized shallow slides were present.

In 1995, two bluff profile field surveys were made within Zone 14a by occupying sites for which field surveys were conducted in 1987. At Profile No. 8-36 in the southern portion of the zone and at Profile No. 8-37 in the northern portion of the zone, the bluffs had slightly different geometries to those documented in 1976. The shape of the bluffs had become generally less steep as a result of being regraded. The stability of the bluff in Erosion Zone 14a of Reach 8 was characterized by Profile Nos. 8-36 and 8-37. Results of the slope stability analysis, shown in Figure 51, indicated that the bluff was stable in the zone, with safety factors ranging from 1.8 in the south at Profile No. 8-36 to 1.95 in the north at Profile No. 8-37. The 1987 study reported bluff safety factors of between 1.17 and 1.33 at Profile Nos. 8-36 and 8-37, respectively.

The beach was narrow to nonexistent within Erosion Zone 14a. In the 1977 study, no beach was reported. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 14a were not estimated. The 1977 study did not report a recession rate for this zone.

Erosion Zone 14b

Erosion Zone 14b extends from the northerly limit of Erosion Zone 14a at about Morgan Avenue extended north about 0.3 mile to Ohio Avenue extended, as shown on Map 47. This zone had a beach of up to 50 feet in width. The bluff was unprotected, except for the southernmost extreme of the zone which had some rubble fill placed at the toe of the bluff. The bluff had a height of between 30 and 35 feet in this zone. In 1995, vegetation covered approximately 20 percent of the bluff slope. Signs of shallow slides and small slumps were present.

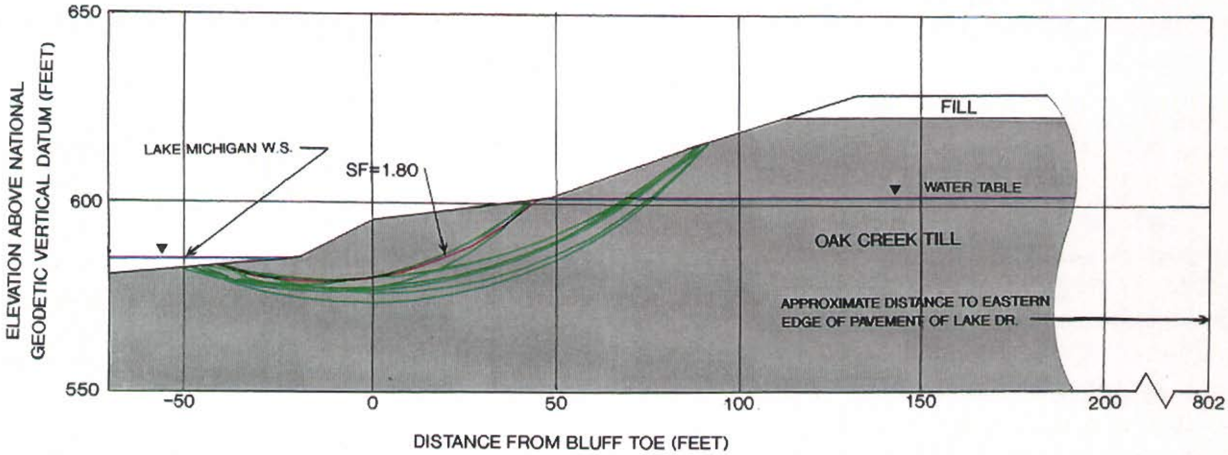
In 1995, three bluff profile field surveys were made within Zone 14b by occupying sites for which field surveys were conducted in 1987. The sites had significantly different geometries to those documented in 1987. The shapes of the bluffs had become considerably less steep. The stability of the bluff in Zone 36b of Reach 8 was characterized by Profile Nos. 8-38 through 8-40. Results of the slope stability analyses, shown in Figures 51 and 52, indicated that the bluff was unstable to marginally stable with respect to slumps at Profile Nos. 8-38 and 8-39, with bluff safety factors ranging from 0.9 to 1.01, and stable with respect to rotational failures at Profile No. 8-40, with a safety factor of 1.13, from south to north within the zone, based upon the deterministic bluff stability analysis method. Profile Nos. 8-38 and 8-39 were also analyzed using the probabilistic bluff stability analysis method. At Profile No. 8-38, the probabilistic bluff stability analysis method resulted in a range of safety factors from 0.78 to 1.49 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 16, or 64 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 44, or 17.6 percent, of the 250 conditions analyzed. At Profile No. 8-39, the probabilistic bluff stability analysis method resulted in a range of safety factors from 0.81 to 1.38 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 15, or 60 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 64, or 25.6 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures at Profile Nos. 8-38 and 8-39. The 1987 study reported bluff safety factors of between 0.81 to 0.99.

Figure 51

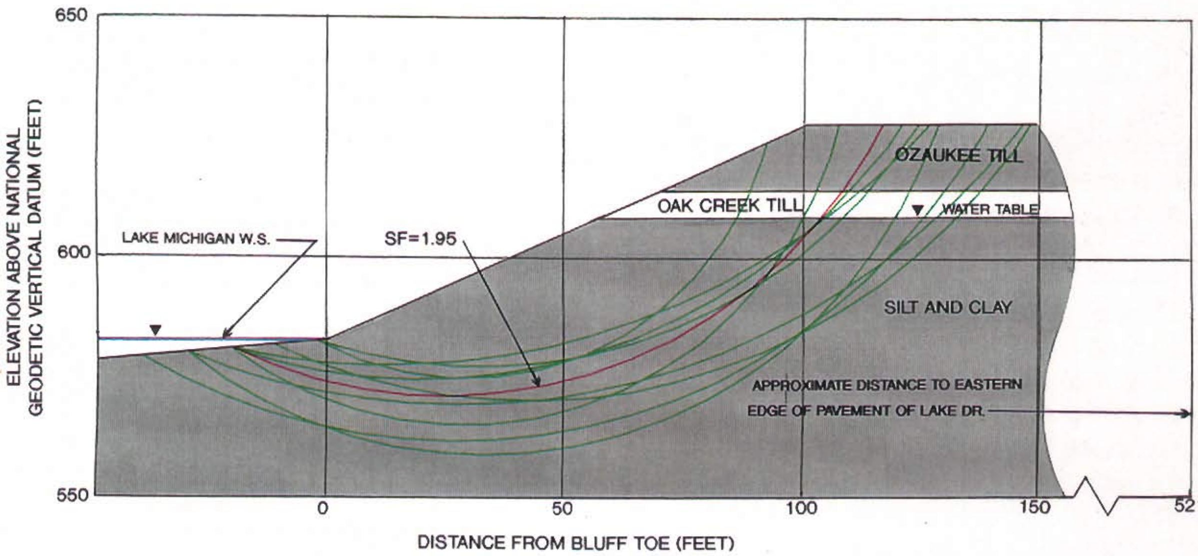
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 14, Township 6 North, Range 22 East
City of St. Francis, Milwaukee County

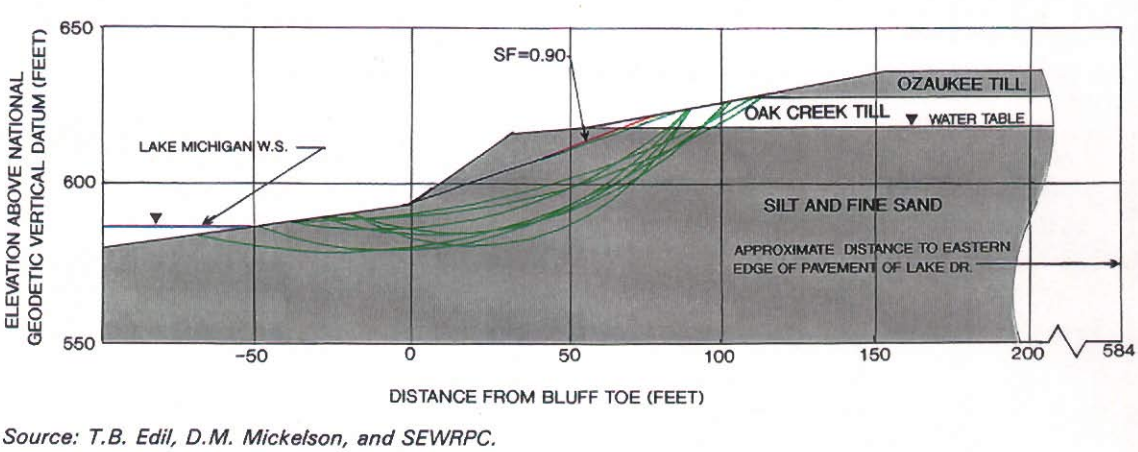
PROFILE 8-36
T.6N. R.22E. S.14



PROFILE 8-37
T.6N. R.22E. S.14



PROFILE 8-38
T.6N. R.22E. S.14



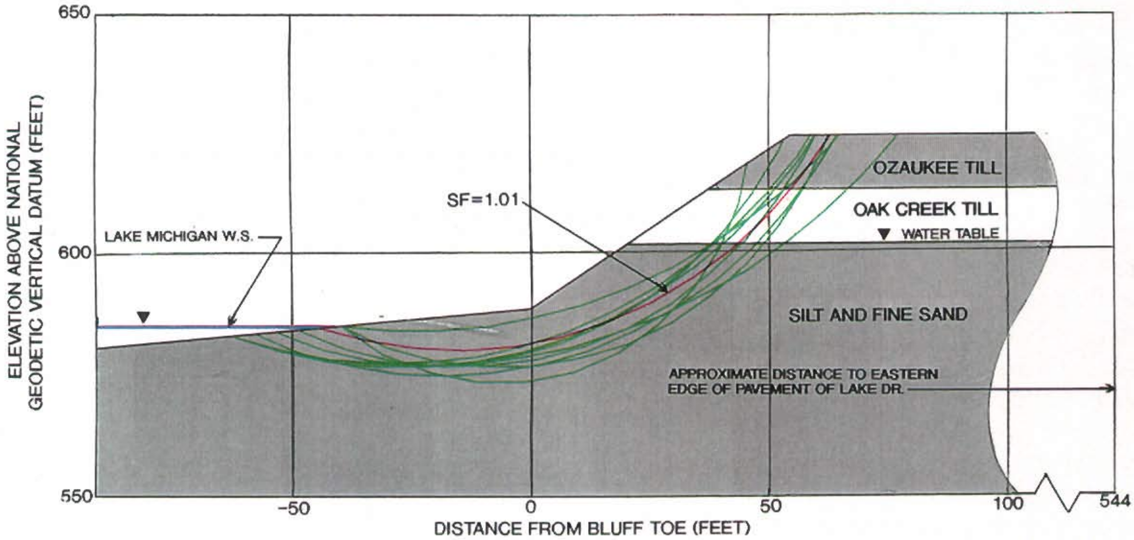
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 52

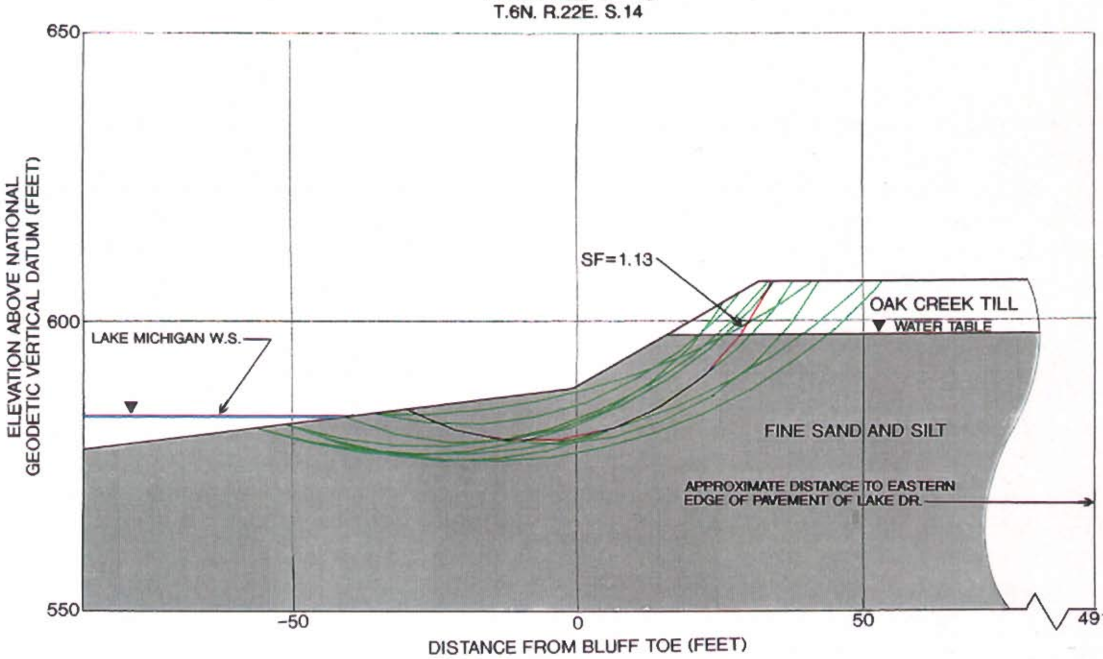
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 14, Township 6 North, Range 22 East
City of St. Francis, Milwaukee County

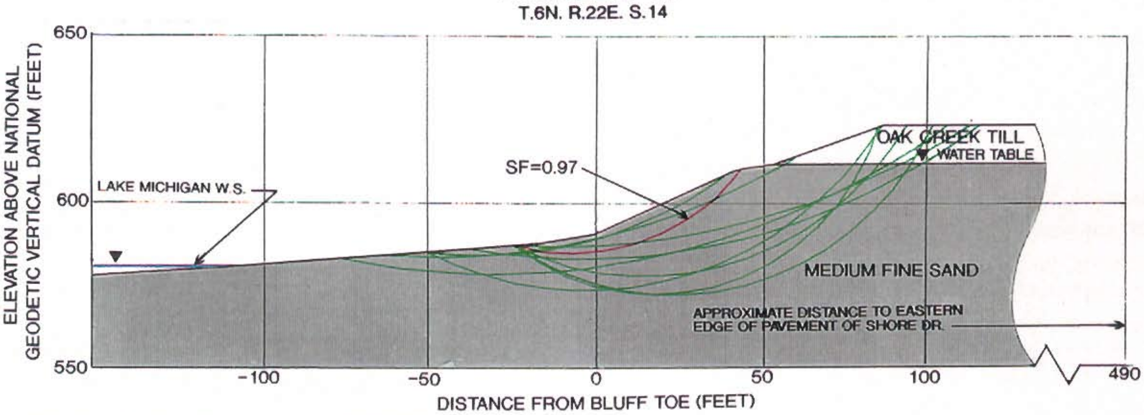
PROFILE 8-39
T.6N. R.22E. S.14



PROFILE 8-40
T.6N. R.22E. S.14



PROFILE 8-41
T.6N. R.22E. S.14



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

The beach was up to 50 feet in width within Zone 14b. In the 1977 study, the beach width was reported to be about five feet. No data on beach materials were reported in the 1977 study. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 14b were not estimated. The 1977 study did not report a recession rate for this zone.

Erosion Zone 14c

Erosion Zone 14c extends from the northerly limit of Erosion Zone 14b at about Ohio Avenue extended north about 0.3 mile to the north section line of Section 14 at E. Oklahoma Avenue, as shown on Map 47. This zone had a beach increasing in width from about 50 feet in the south to about 100 feet in the north of the zone. The beach and bluff were protected by the Southshore Breakwater. The bluff had a height of between 25 and 30 feet in this zone. In 1995, vegetation, comprising mature trees, covered approximately 80 percent of the bluff slope. Signs of some creep and localized shallow slides were present.

In 1995, one bluff profile field survey was made within Zone 14c by occupying a site for which a field survey was conducted in 1987. The site had a significantly different geometry to that documented in 1987. The shape of the bluff had become less steep. One bluff profile field survey within Zone 14c occupied in 1987 was not reoccupied in 1995. The site, which was in close proximity to Profile No. 8-40, was estimated to have a slightly different geometry to that documented in 1987. The shape of the bluff had become less steep. The stability of the bluff in Zone 14c of Reach 8 was characterized by Profile No. 8-41. Results of the slope stability analyses, shown in Figure 52, indicated that the bluff was marginally stable with respect to failure by slumping, with a bluff safety factor of 0.97, based upon the deterministic bluff stability analysis method. Profile No. 8-41 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.93 to 1.71 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for six, or 24 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for six, or 2.4 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered stable. The 1987 study reported a bluff safety factor of 1.17.

The beach was between 50 and 100 feet in width within Zone 14c. In the 1977 study, the beach width was reported to be about five feet, and the beach materials were not reported. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 14c were not estimated. The 1977 study did not report a recession rate for this zone.

As long as the Southshore Breakwater continues to protect the shoreline within Erosion Zone 14c, the bluffs within this section should remain stable.

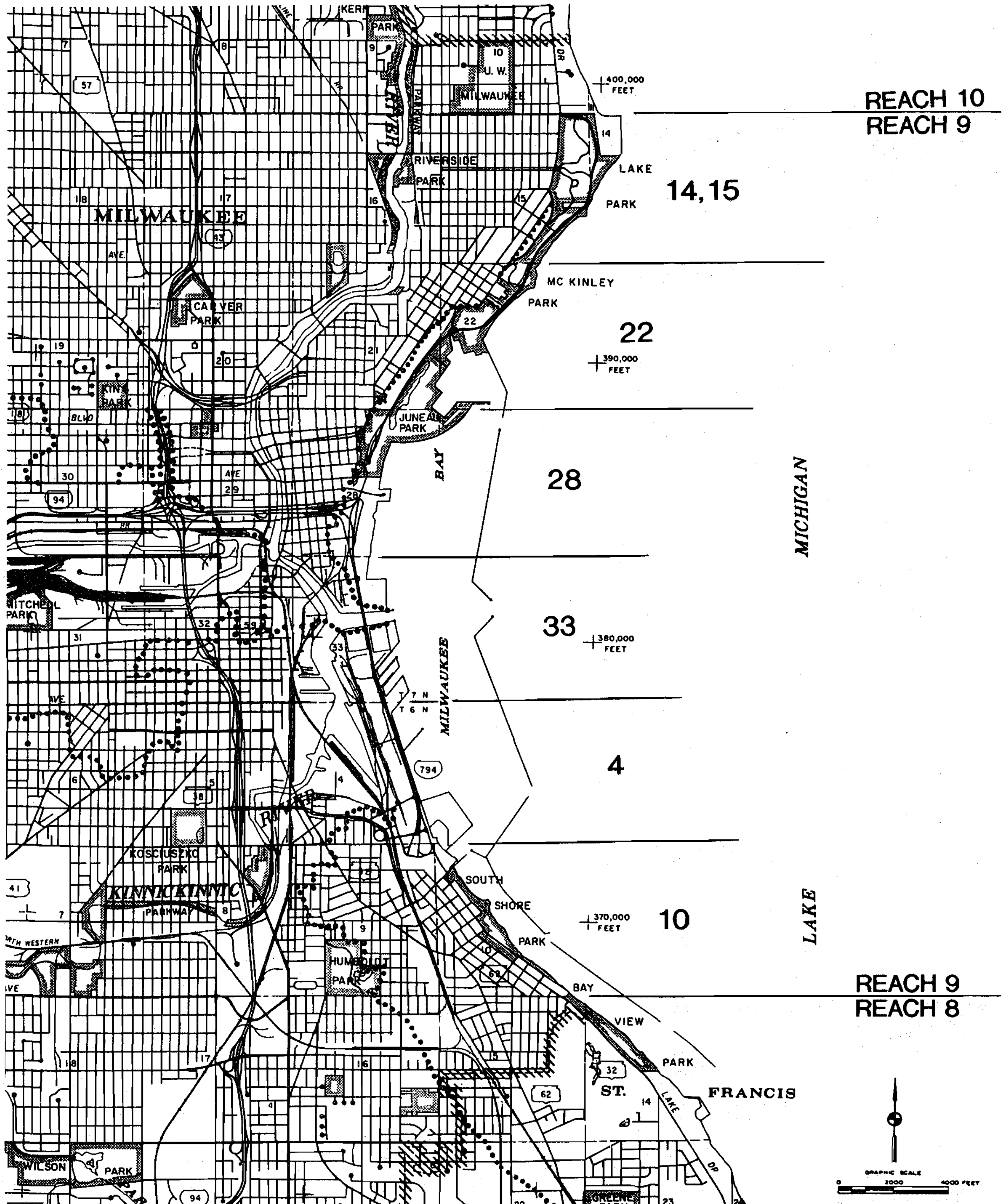
SHORELINE REACH 9: CITY OF MILWAUKEE, MILWAUKEE COUNTY

Shoreline Reach 9 is a six-mile-long reach of shoreline extending from about E. Oklahoma Avenue extended at the south line of U.S. Public Land Survey Section 10, Township 6 North, Range 22 East, City of Milwaukee, north to Kenwood Boulevard extended on the north line of U.S. Public Land Survey Section 14, Township 7 North, Range 22 East, City of Milwaukee, as shown on Map 48. Land uses along this reach include open spaces, including Bayview, Henry Meier Festival, Veterans, Juneau, McKinley, and Lake Parks; residential lands in the southern and northern portions of the reach, including areas with multi-family residential uses; and industrial and commercial land uses in the central portion of the reach. The Milwaukee Metropolitan Sewerage District Jones Island Sewage Treatment Plant and Port of Milwaukee were located in the central portion of the reach. The South Shore Yacht Club harbor facilities were located in the southern portion of this reach, and the Milwaukee Yacht Club and McKinley Marina harbor facilities were located in the northern portion of this reach. As of 1995, about six linear miles, or about 100 percent, of the shoreline in Reach 9 were protected by structural shore protection measures, consisting of bulkheads, revetments, rubble fills, and groins, and the offshore breakwater system approximately centered on the Milwaukee Harbor.

As shown on Map 48, Reach 9 was further segmented into six shoreline analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the six shoreline analysis sections in Reach 9.

Map 48

BLUFF ANALYSIS SECTIONS WITHIN REACH 9



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

U.S. Public Land Survey Section 10, Township 6 North, Range 22 East, City of Milwaukee, Milwaukee County

This shoreline analysis section extends from E. Oklahoma Avenue extended north to Lincoln Avenue extended, in the City of Milwaukee, as shown on Map 49. In 1995, the lakeshore area was occupied by parkland in the southern and central portions of the section, and by residential and industrial lands in the northernmost portion of the section. The South Shore Yacht Club occupied part of the lakeshore in the northern portion of the section. In 1995, the section was protected by the Southshore Breakwater, and by a variety of shoreline protection structures, including revetments and groins. The section was fronted by a beach ranging in width from about 25 feet at the southern extreme of the section to about 200 feet in the central portion of the section immediately south of the South Shore Yacht Club piers. At the northern end of the section, north of the South Shore Yacht Club piers, the shoreline was fully protected by revetments and the beach was nonexistent. The bluff in this section was about 25 feet in height. The bluff materials in this section were generally covered, but were estimated to be primarily sand overlain by till, overlain by sand. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for Section 10.

In 1995, this zone had a beach of up to 200 feet in width in the southern portion of the section fronting the bluff which had a height of about 25 feet. No beach was present in the northern portions of this section. The bluff was largely protected. In the southern portion of the section, there was a groin system extending from E. Oklahoma Avenue north to the revetment around the South Shore Water Treatment Plant intake structure at Texas Drive. In the northern portion of the section, a revetment extended from the South Shore Yacht Club pier at about Nock Street north to Lincoln Avenue. The entire section was located behind the Southshore Breakwater. Vegetation covered between 80 and 100 percent of the bluff slope. In 1995, signs of minor creep and shallow slides were present.

In 1995, one bluff profile field survey was made within Section 10 by occupying a site for which field survey was conducted in 1987. The reoccupied site had a significantly different geometry to that documented in 1987. The site appeared to have become less steeply sloped. The stability of the bluff in Section 10 of Reach 9 was characterized by Profile No. 9-1. Results of the slope stability analysis, shown in Figure 53, indicated that the bluff was stable in the southern portion of the section with a safety factor of 2.40. The 1987 study reported a bluff safety factor of 1.21.

The beach was broad, ranging in width from about 25 feet to about 200 feet adjacent to the South Shore Yacht Club revetment, within Section 10. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be sand and cobbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Section 10 were not estimated.

U.S. Public Land Survey Section 4, Township 6 North, Range 22 East, City of Milwaukee, Milwaukee County

This shoreline analysis section extends from Lincoln Avenue extended north to Greenfield Avenue extended, in the City of Milwaukee, as shown on Map 50. In 1995, the entire lakeshore area was occupied by industrial land uses. The Port of Milwaukee and the Milwaukee Metropolitan Sewerage District Jones Island Sewage Treatment Plant occupied the lakeshore in this section. In 1995, the section was protected by the Southshore Breakwater, and by a variety of revetments. The beach was nonexistent, and there was no natural bluff, within this section.

No bluff stability analyses were conducted within Section 4 during this study or in 1976 or 1987.

No measurements or observations were made of the nearshore lakebed depth or material within Section 4 in 1995 or in 1976 or 1987.

Shoreline recession data for Section 4 were not estimated.

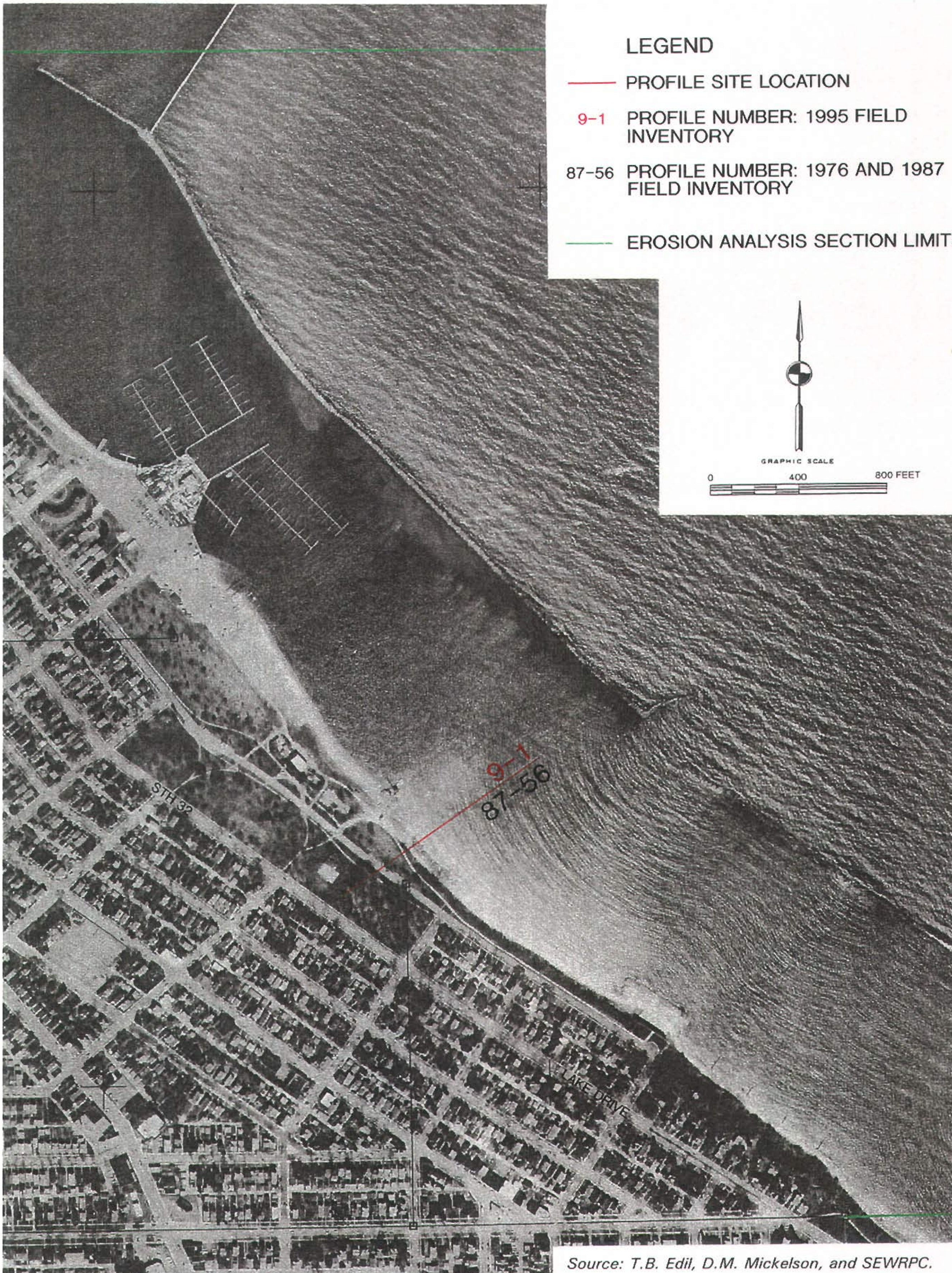
U.S. Public Land Survey Section 33, Township 7 North, Range 22 East, City of Milwaukee, Milwaukee County

This shoreline analysis section extends from Greenfield Avenue extended north to about E. Menomonee Street extended, in the City of Milwaukee, as shown on Map 51. In 1995, the lakeshore area was occupied by industrial land uses in the southern half of the section and by parkland, including the Henry Meier Festival

Map 49

SHORELINE EROSION REACH 9: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 10, Township 6 North, Range 22 East
City of Milwaukee, Milwaukee County

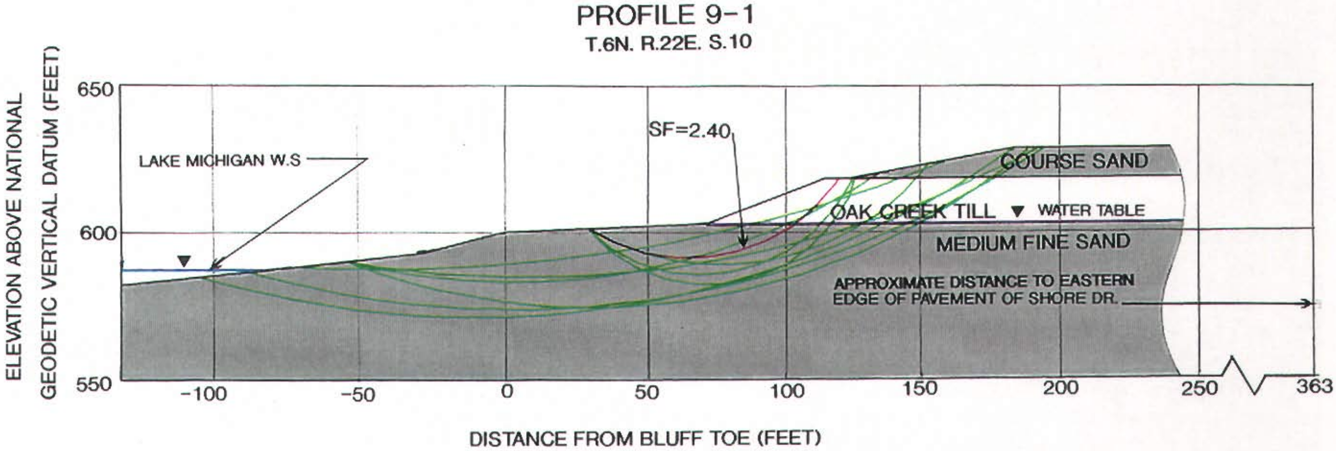


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 53

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSIS

U.S. Public Land Survey Section 10, Township 6 North, Range 22 East
City of Milwaukee, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Park, in the northern half of the section. The Port of Milwaukee and the Milwaukee Metropolitan Sewerage District Jones Island Sewage Treatment Plant occupied the southern portion of the lakeshore in this section. In 1995, the section was protected by the Northshore and Southshore Breakwaters, and by a variety of revetments. The beach was nonexistent, and there was no natural bluff, within this section.

No bluff stability analyses were conducted within Section 33 during this study or in 1976 or 1987.

No measurements or observations were made of the nearshore lakebed depth or material within Section 33 in 1995 or in 1976 or 1987.

Shoreline recession data for Section 33 were not estimated.

U.S. Public Land Survey Section 28,
Township 7 North, Range 22 East,
City of Milwaukee, Milwaukee County

This shoreline analysis section extends from about E. Menomonee Street extended north to Juneau Avenue extended, in the City of Milwaukee, as shown on Map 52. In 1995, the lakeshore area was occupied by industrial land uses in the southern half of the section and by parkland, including the Henry Meier Festival Park, in the northern half of the section. The Port of Milwaukee and the Milwaukee Metropolitan Sewerage District Jones Island Sewage Treatment Plant occupied the southern portion of the lakeshore in this section. In 1995, the section was protected by the Northshore and Southshore Breakwaters, and by a variety of revetments. The beach was nonexistent, and there was no natural bluff, within this section.

No bluff stability analyses were conducted within Section 33 during this study or in 1976 or 1987.

No measurements or observations were made of the nearshore lakebed depth or material within Section 33 in 1995 or in 1976 or 1987.

Shoreline recession data for Section 33 were not estimated.

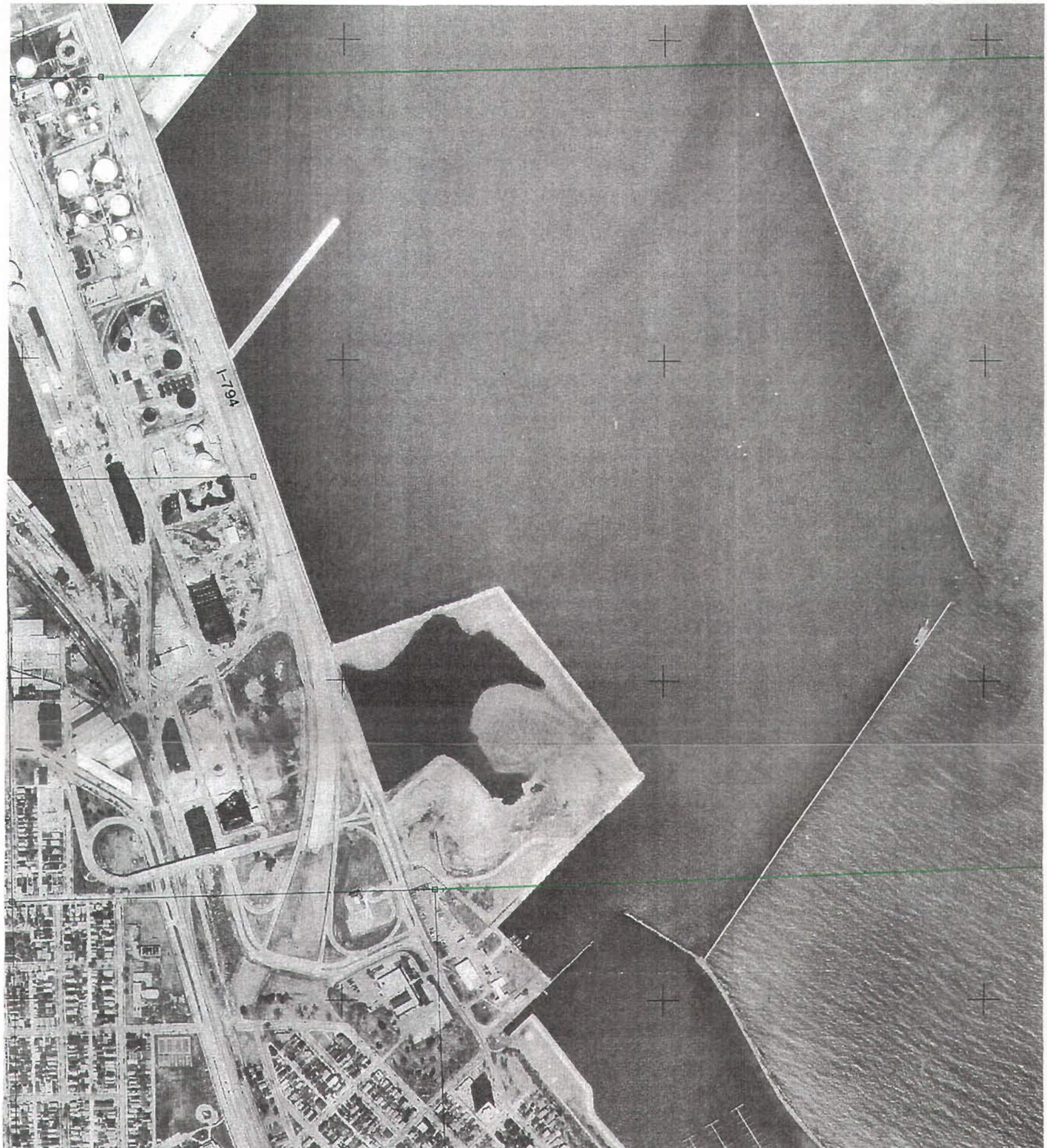
U.S. Public Land Survey Section 22,
Township 7 North, Range 22 East,
City of Milwaukee, Milwaukee County

This shoreline analysis section extends from Juneau Avenue extended north to North Avenue extended, in

Map 50

SHORELINE EROSION REACH 9: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

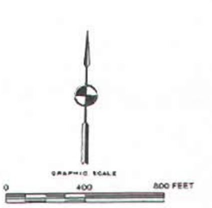
U.S. Public Land Survey Section 4, Township 6 North, Range 22 East
City of Milwaukee, Milwaukee County



LEGEND

EROSION SECTION LIMITS

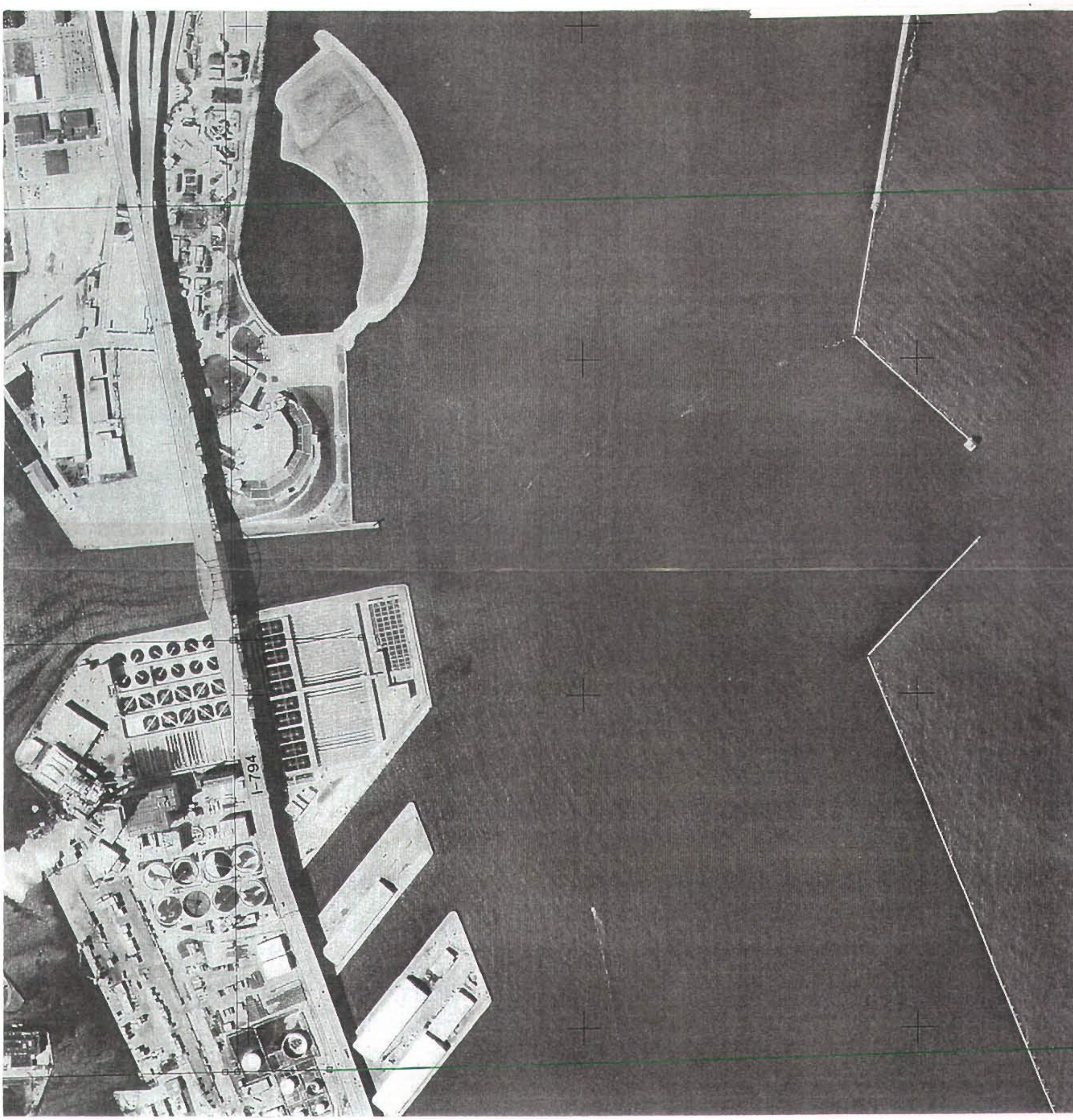
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.



Map 51

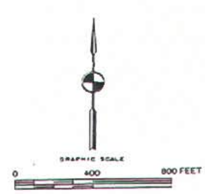
SHORELINE EROSION REACH 9: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 33, Township 7 North, Range 22 East
City of Milwaukee, Milwaukee County



LEGEND

EROSION SECTION LIMITS

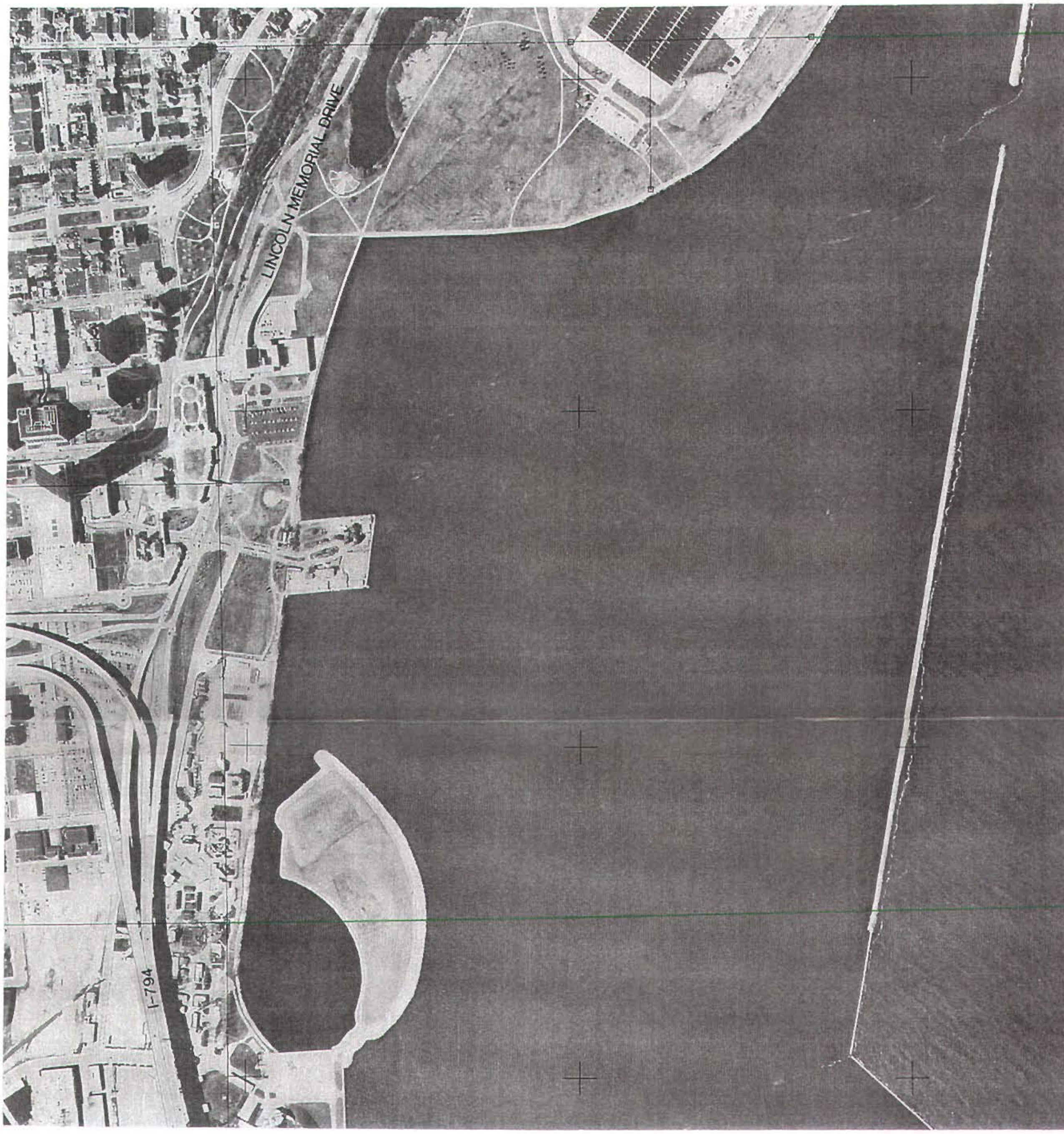


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 52

SHORELINE EROSION REACH 9: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 28, Township 7 North, Range 22 East
City of Milwaukee, Milwaukee County



LEGEND

—— EROSION SECTION LIMITS

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

the City of Milwaukee, as shown on Map 53. In 1995, the lakeshore area was occupied by industrial land uses in the southern half of the section and by parkland, including Juneau and McKinley Parks and the Milwaukee Yacht Club and McKinley Marina, in the northern half of the section. In 1995, the southern half of the section was protected by the Northshore Breakwater, and by a variety of revetments. The beach was nonexistent within the southern half of this section. In the northern half of the section, several small beaches of up to 200 feet in width, including McKinley Beach and the southern portion of Bradford Beach, existed in portions of the shoreline in the vicinity of LaFayette Hill Drive and North Avenue. There was no natural bluff within Section 22.

No bluff stability analyses were conducted within Section 22 during this study or in 1976 or 1987.

No measurements or observations were made of the nearshore lakebed depth or material within Section 22 in 1995 or in 1976 or 1987.

Shoreline recession data for Section 22 were not estimated.

U.S. Public Land Survey Sections 14 and 15, Township 7 North, Range 22 East, City of Milwaukee, Milwaukee County

This shoreline analysis section extends from North Avenue extended north to Kenwood Boulevard extended, in the City of Milwaukee, as shown on Map 54. In 1995, the lakeshore area was occupied by parkland, including McKinley and Lake Parks, in the southern and central portions of the section, and by industrial land uses, including the Linnwood Avenue Water Treatment Plant, in the northernmost portion of the section. In 1995, the southern half of the section was unprotected. A broad beach, Bradford Beach, of up to 300 feet in width existed in the southern portion of this section. In the northern portion of the section, the beach was nonexistent. The shoreline was protected by a variety of shoreline protection structures, including riprap and revetments. There was no natural bluff within Sections 14 and 15.

No bluff stability analyses were conducted within Sections 14 and 15 during this study or in 1976 or 1987.

No measurements or observations were made of the nearshore lakebed depth or material within Sections 14 and 15 in 1995 or in 1976 or 1987.

Shoreline recession data for Section 14 were estimated at one location. These data indicated a recession of about 20 feet, or about 0.6 foot per year, occurred between 1963 and 1995. The data indicated that most of the recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. Thus, it appeared that the revetment had largely stabilized the bluff within this section. In addition, shoreline recession data for Section 15 were estimated at three locations. These data indicated a recession of between 20 and 70 feet, or between 0.6 and 2.2 feet per year, occurred between 1963 and 1995, with the greatest rate of recession occurring in the central portion of the section. The data indicated that most of the recession in the northern portion of the section occurred prior to 1975, with a recession of about -20 feet, or about -1.0 foot per year, occurring between 1975 and 1995. Thus, it appeared that the revetment had largely stabilized the bluff within the northern portion of this section, while Bradford Beach in the central and southern portions of the section was only partially stabilized. The 1977 study reported a recession rate of two feet per year for Section 15, but did not report a recession rate for Section 14.

SHORELINE REACH 10: CITY OF MILWAUKEE AND VILLAGES OF FOX POINT, SHOREWOOD, AND WHITEFISH BAY, MILWAUKEE COUNTY

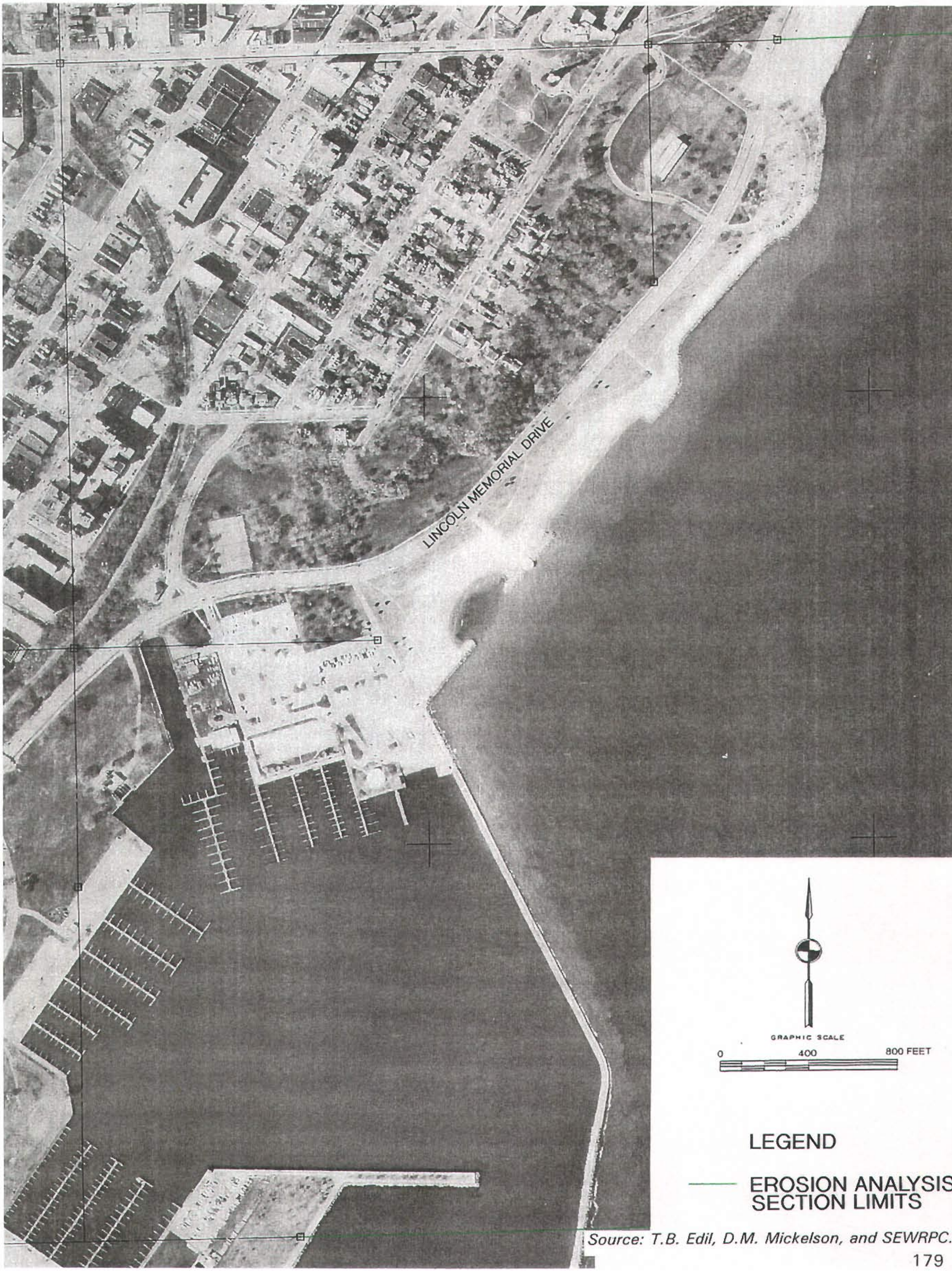
Shoreline Reach 10 is a 6.5-mile-long reach of shoreline extending from about E. Burleigh Street extended at the south line of U.S. Public Land Survey Section 10, Township 7 North, Range 22 East, City of Milwaukee, north to Bradley Road extended on the north line of U.S. Public Land Survey Section 16, Township 8 North, Range 22 East, Village of Fox Point, as shown on Map 55. Land uses along this reach include open spaces, including Shorewood (Atwater), Buckley, Big Bay, Silver Spring, and Klode Parks and Shorewood Nature Preserve, and residential lands, including limited areas with multi-family residential uses. As of 1995, about six linear miles, or about 90 percent, of the shoreline in Reach 10 were protected by structural shore protection measures, consisting of revetments, rubble fills, and groins.

As shown on Map 55, Reach 10 was further segmented into six shoreline analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline

Map 53

SHORELINE EROSION REACH 9: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 22, Township 7 North, Range 22 East
City of Milwaukee, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 54

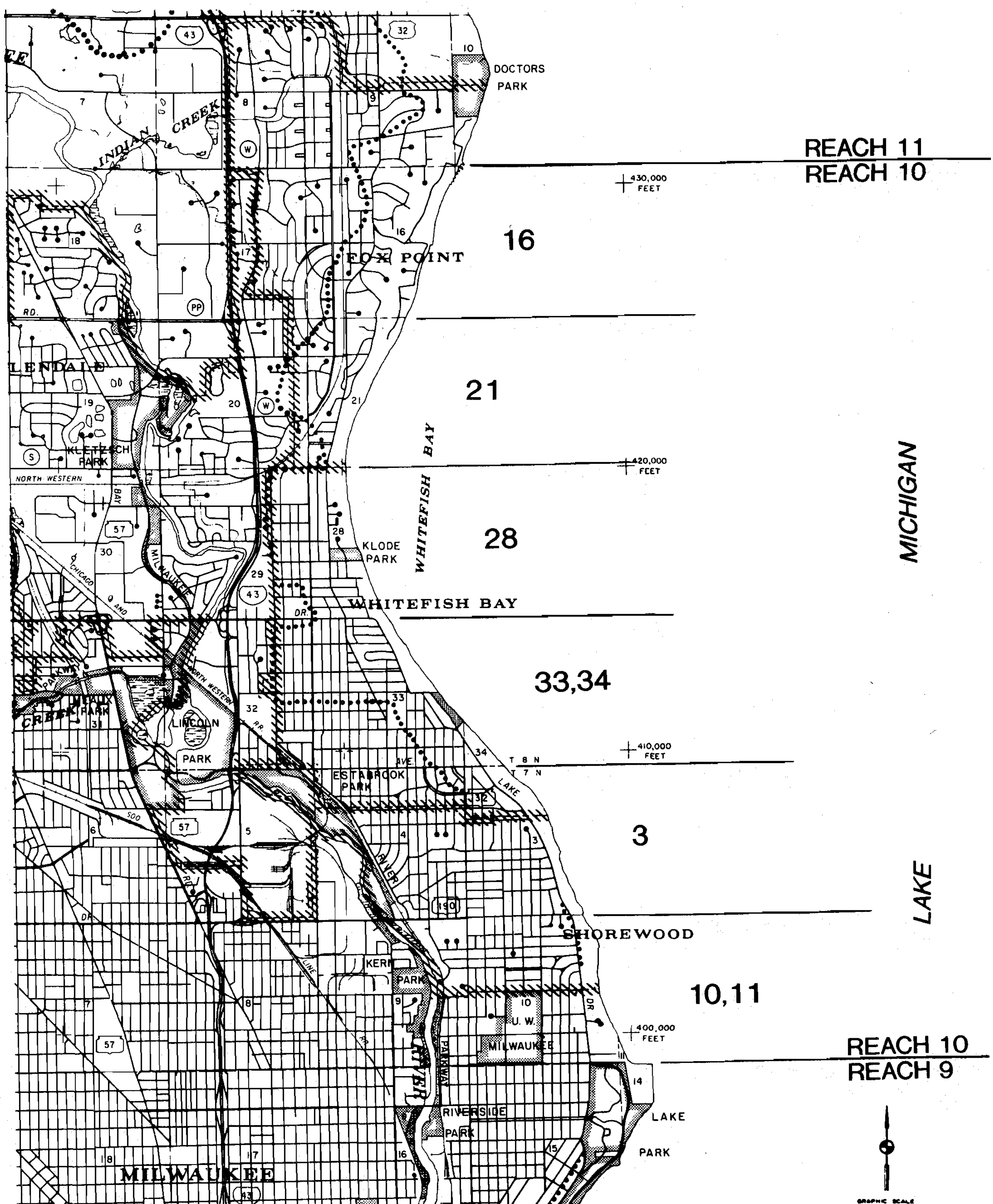
SHORELINE EROSION REACH 9: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 14 and 15, Township 7 North, Range 22 East
City of Milwaukee, Milwaukee County

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 55

BLUFF ANALYSIS SECTIONS WITHIN REACH 10



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

recession are discussed below for each of the six shoreline analysis sections in Reach 10.

U.S. Public Land Survey Section 10, Township 7 North, Range 22 East, City of Milwaukee and Village of Shorewood, Milwaukee County

This shoreline analysis section extends from E. Burleigh Street extended, in the City of Milwaukee, north to E. Capitol Drive extended, in the Village of Shorewood, as shown on Map 56. In 1995, the lakeshore area was occupied by parklands, including Shorewood Nature Preserve, and residential lands. In 1995, the section was protected by a variety of shoreline protection structures, including revetments, riprap fills, and groins, and a short, approximately 250-foot breakwater in the central portion of the section Stratford Court extended, in the Village of Shorewood. The section was fronted by a beach up to about 25 feet in width. A natural terrace of about 15 feet in height fronted the bluff in the northern quarter of the section. The bluff in this section was about 80 feet in height in the northern and southern portions of the section, and about 120 feet in height in the central portions of the section. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by sand and gravel, overlain by till. For analysis purposes, Section 10 was further subdivided into four erosion zones, as shown on Map 56. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the four erosion zones in Section 10.

Erosion Zone 10a

Erosion Zone 10a extends from E. Burleigh Street, in the City of Milwaukee, north about 0.6 mile to about Stratford Court extended, in the Village of Shorewood, as shown on Map 56. This zone had a beach of up to 50 feet in width fronting the bluff which had a height of about 80 feet. The bluff was protected by a number of small shoreline protection structures on the beach, and, in the northern portion of the zone, a breakwater of about 250 feet in length extending into Erosion Zone 10b to the north. Vegetation, comprising mature trees, covered about 100 percent of the bluff slope. In 1995, signs of creep and evidence of tension cracks were present.

In 1995, one bluff profile field survey was made within Erosion Zone 10a by occupying a site for which field survey was conducted in 1987. The reoccupied site had a significantly different geometry to that documented in 1987. The site appeared to have become less steeply sloped, with the sill at the bluff toe greatly diminished in size. The stability of the bluff in Zone 10a of Reach 10 was characterized by Profile No. 10-1. Results of the slope stability analysis, shown in Figure 54, indicated that the bluff was stable in the southern portion of the zone, with a safety factor of 1.27. The 1987 study reported a bluff safety factor of 2.97.

The beach ranged up to about 50 feet in width within Erosion Zone 10a. In 1995, the beach was composed of sand and fine gravel. In the 1977 study, the beach width was reported to be about 20 feet, and the beach material was reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 10a were estimated at three locations. These data indicated a recession of between 20 and 30 feet, or between 0.6 and 0.9 foot per year, occurred between 1963 and 1995. Bluff recession increased from south to north within the zone. The data indicated that, in the southernmost portion of the zone, most of the recession occurred prior to 1975, with no further recession occurring in the vicinity of E. Burleigh Street between 1975 and 1995. The data also indicated that, throughout most of the zone, a recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995. Thus, it appeared that the revetment at the Linnwood Avenue Water Treatment Plant located in the northern extreme of Reach 9 had largely stabilized the bluff within the southernmost portion of this zone. However, the bluff had been only partially stabilized the bluff top throughout the larger part of the zone, north of E. Burleigh Street. The 1977 study did not report a recession rate for this zone.

In 1995, there was evidence of shoreline accretion in the southernmost portion of Erosion Zone 10a as a result of sediment trapping by the shoreline protection structures and land forms immediately to the south in the City of Milwaukee. The bluff in this portion of the zone was considered fairly stable as a result, although there was considered to be a potential for large slumps. However due to the lack of cutting at the base of the bluff, the risk of slumping is considered small.

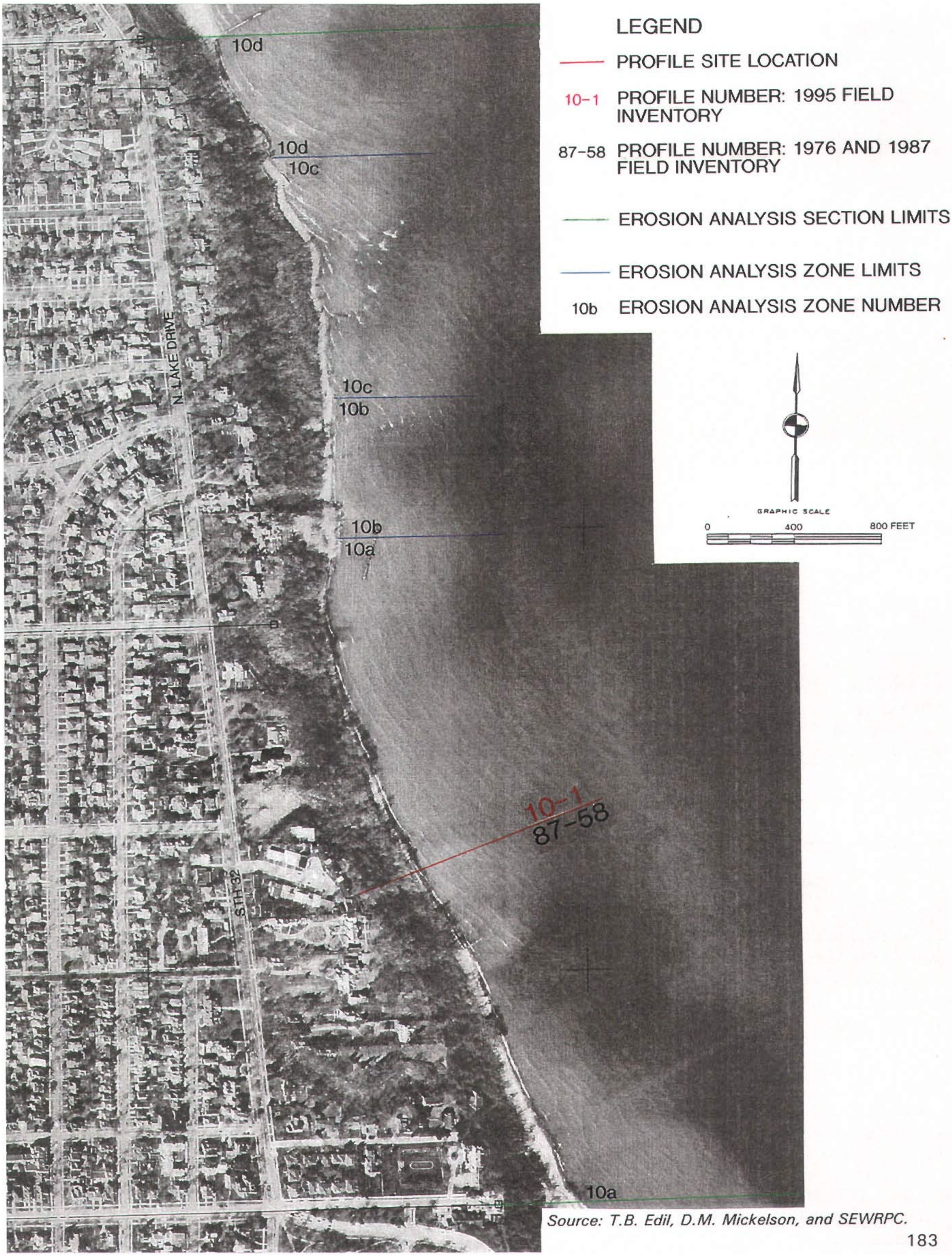
Erosion Zone 10b

Erosion Zone 10b extends from about Stratford Court extended north about 0.1 mile to about Newton Avenue extended, in the Village of Shorewood, as shown on Map 56. This zone had a beach of up to 50 feet in width fronting the bluff which had a height of about 120 feet. The bluff was protected by a massive rubble fill, and, in

Map 56

SHORELINE EROSION REACH 10: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 10, Township 7 North, Range 22 East
City of Milwaukee and Village of Shorewood, Milwaukee County

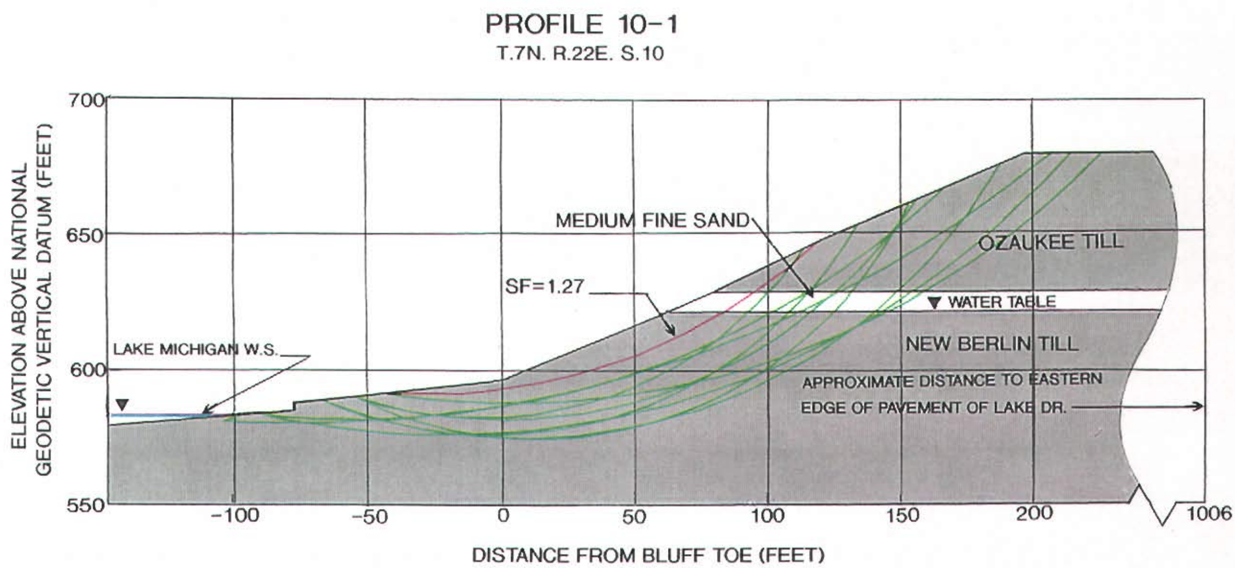


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 54

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSIS

U.S. Public Land Survey Section 10, Township 7 North, Range 22 East
City of Milwaukee, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

the southern portion of the zone, a breakwater of about 250 feet in length extending into Erosion Zone 10a to the south. In 1995, signs of creep and evidence of tension cracks were present on the wooded bluff top within the Shorewood Nature Preserve, and large slump blocks were present in the northern portion of the zone. Mature trees covered the bluff slope except in those areas where slides had occurred and on the scarps of the slump blocks.

No bluff stability analyses were conducted within Erosion Zone 10b in this study. However, one bluff profile field survey was made within Erosion Zone 10b in 1976 and in 1987. The 1977 study reported a bluff stability factor of 1.26. The 1987 study reported a bluff safety factor of 2.13.

The beach ranged up to about 50 feet in width within Erosion Zone 10b. In the 1977 study, the beach width was reported to be about 20 feet, and the beach material was reported to be sand. The nearshore lakebed depth of five feet was reached at 90 feet offshore in 1976. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 10b were not estimated. The 1977 study did not report a recession rate for this zone.

Erosion Zone 10c

Erosion Zone 10c extends from about Newton Avenue north about 0.2 mile to a point on the lakeshore adjacent to the southernmost extent of Hartcourt Place, in the Village of Shorewood, as shown on Map 56. This zone had a beach of between 25 and 50 feet in width fronting the bluff which had a height of about 120 feet. A terrace of about 15 feet in height and up to 300 feet in width fronted the bluff within this zone. The bluff was protected by a number of small shoreline protection structures. The 1995 field observations indicated that evidence of deep-seated slump blocks and bluff toe erosion was present in portions of this zone.

No bluff stability analyses were conducted within Erosion Zone 10c in this study or in 1976. However, two bluff profile field surveys were made within Erosion Zone 10c in 1987. The 1987 study reported bluff safety factors of 1.12 to 1.54.

The beach ranged up to about 50 feet in width within Erosion Zone 10c, with the wider portion of the beach occurring in the northern portion of the zone. In the 1977 study, the beach width was reported to be about 50 feet, and the beach materials were reported to be sand and cobbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 10c were estimated at one location. These data indicated a recession of about 40 feet, or about 1.2 feet per year, occurred between 1963 and 1995. The data indicated that a recession of about 20 feet, or about one foot per year, occurred between 1975 and 1995. Thus, it appeared that the bluff had been only partially stabilized by the shoreline protection structures within this zone. The 1977 study did not report a recession rate for this zone.

In 1995, there was evidence of wave erosion among the shoreline protection structures located within Erosion Zone 10c. This erosion of the shoreline can be expected to continue during future periods of higher lake levels without continuous shoreline protection in this zone.

Erosion Zone 10d

Erosion Zone 10d extends from the northern extent of Erosion Zone 10c north about 0.1 mile to Capitol Drive extended, in the Village of Shorewood, as shown on Map 56. This zone had little or no beach fronting the bluff which had a height of about 80 feet. The bluff was protected by a number of small shoreline protection structures, including a revetment and small groins.

No bluff stability analyses were conducted within Erosion Zone 10d in this study or in 1976. However, one bluff profile field survey was made within Erosion Zone 10d in 1987. The 1987 study reported a bluff safety factor of 0.81.

The beach was narrow to nonexistent within Erosion Zone 10d. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 10d were estimated at one location. These data indicated a recession of about 40 feet, or about 1.2 feet per year, occurred between 1963 and 1995. The data indicated that most of the recession occurred prior to 1975, with a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. Thus, it appeared that the revetment and groin system had partially stabilized by the bluff within this zone. The 1977 study reported a recession rate of two feet per year for this zone.

In 1995, there was evidence of wave overtopping of the shoreline protection structures located within Erosion Zone 10d, leading to bluff toe erosion. This erosion of the shoreline can be expected to continue during future periods of higher lake levels unless maintenance of the shoreline protection structures within this zone is completed during the present low water level period.

U.S. Public Land Survey Section 3, Township 7 North, Range 22, Villages of Shorewood and Whitefish Bay, Milwaukee County

This shoreline analysis section extends from Capitol Drive extended, in the Village of Shorewood, north to Hampton Avenue extended, in the Village of Whitefish Bay, as shown on Map 57. In 1995, the lakeshore area was occupied by parkland, including Shorewood (Atwater) Park, and residential lands. In 1995, the section was protected by a variety of shoreline protection structures, including revetments, rubble fills, and groins. The section was fronted by a beach up to about 125 feet in width. The bluff in this section was about 80 feet in height in the southern portion of the section, about 110 feet in height in the central portion of the section, and about 75 feet in height in the northern portion of the section. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by intermixed sand and silt, overlain by till. For analysis purposes, Section 3 was further subdivided into three erosion zones, as shown on Map 57. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three erosion zones in Section 3.

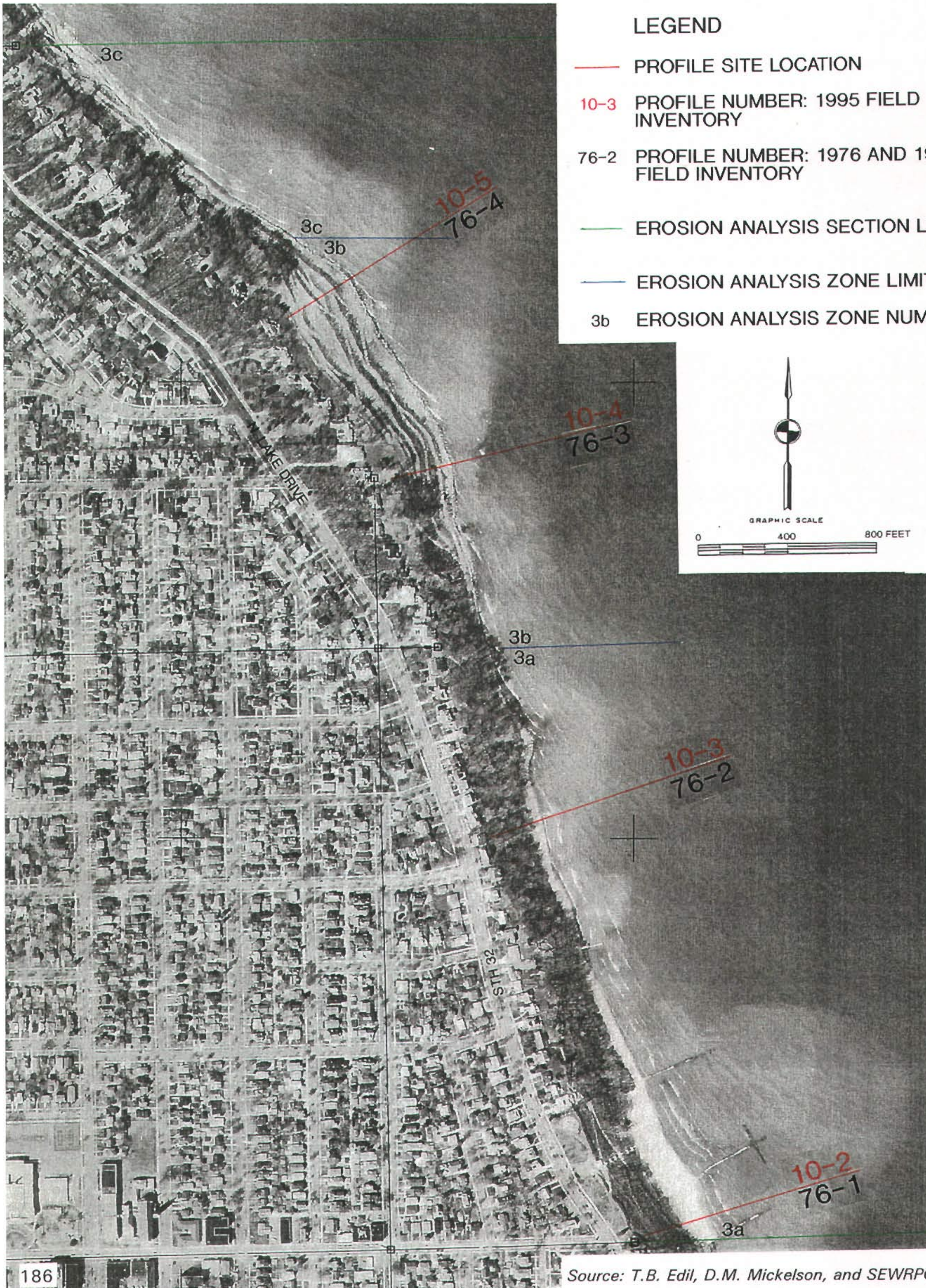
Erosion Zone 3a

Erosion Zone 3a extends from the southern section line of Section 3 at Capitol Drive north about 0.5 mile to about Congress Street extended, in the Village of Shorewood, as shown on Map 57. This zone had a beach of between 50 and 150 feet in width fronting the bluff which had a height of about 80 feet. The bluff was pro-

Map 57

SHORELINE EROSION REACH 10: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 3, Township 7 North, Range 22 East
Villages of Shorewood and Whitefish Bay, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

tected by a number of small shoreline protection structures, including seawalls and revetments. Vegetation, comprising mature trees, covered between 80 and 100 percent of the bluff slope.

In 1995, two bluff profile field surveys were made within Erosion Zone 3a by occupying sites for which field surveys were conducted in 1976. The reoccupied sites had similar geometries to those documented in 1976, although the site at Profile No. 10-3 appeared to have become more steeply sloped. The stability of the bluff in Zone 3a of Reach 10 was characterized by Profile Nos. 10-2 and 10-3. Results of the slope stability analysis, shown in Figure 55, indicated that the bluff was stable in the zone, with safety factors of 1.13 at Profile No. 10-2 and 1.39 at Profile No. 10-3. The 1977 study reported bluff safety factors of 0.76 and 1.2 at Profile Nos. 10-2 and 10-3, respectively.

The beach ranged up to about 150 feet in width within Erosion Zone 3a, with the widest portion of the beach being contained within a groin system at Shorewood (Atwater) Park. In the 1977 study, the beach width was reported to be about 20 feet, and the beach material was reported to be sand. At Profile No. 10-2, the nearshore lakebed depth of five feet was reached at 188 feet offshore in 1995, with the nearshore lakebed materials noted to be sand. The nearshore lakebed depth of five feet was reached at 80 feet offshore in 1976, with the nearshore lakebed materials reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1987. At Profile No. 10-3, no measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 3a were estimated at three locations. These data indicated a recession of between zero and 40 feet, or between zero and 1.2 feet per year, occurred between 1963 and 1995. Bluff recession decreased from south to north within the zone. The data indicated that, in the southern and northern portions of the zone, most of the recession occurred prior to 1975, with recessions of about 10 feet, or about 0.5 foot per year, occurring in the vicinity of Capitol Drive between 1975 and 1995, and of about -10 feet, or about -0.5 foot per year, occurring in the vicinity of Congress Street between 1975 and 1995. The data also indicated that, in the central portion of the zone, a recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995. Thus, it appeared that the seawalls and revetments in the northern and southern portions of Zone 3a had largely stabilized the bluff. However, the bluff had been only partially stabilized in the central portion of the zone, in the vicinity of Wood Place in the Village of Shorewood. The 1977 study reported a recession rate of two feet for this zone.

In 1995, the shoreline in Erosion Zone 3a was considered fairly stable as long as the wide beach remained and the shoreline protection structures are maintained to minimize wave erosion at the base of the bluff.

Erosion Zone 3b

Erosion Zone 3b extends from about Congress Street extended, in the Village of Shorewood, north about 0.3 mile to about Cumberland Boulevard extended, in the Village of Whitefish Bay, as shown on Map 57. This zone had a beach of up to 100 feet in width, increasing in width northward from a narrow to nonexistent beach in the southern portion of the reach. The bluff had a height of about 110 feet. The bluff was protected by a massive rubble fill, placed after 1976, but prior to 1987. The fill was partially vegetated with weeds and bushes covering approximately 30 percent of the bluff slope. In 1995, signs of small tension cracks were present, which suggested a potential for deep-seated slumps to occur.

In 1995, two bluff profile field surveys were made within Erosion Zone 3b by occupying sites for which field surveys were conducted in 1976. The reoccupied sites had slightly different geometries to those documented in 1976, with a number of slope breaks being present during 1995 which were absent in 1976. The stability of the bluff in Zone 3b of Reach 10 was characterized by Profile Nos. 10-4 and 10-5. Results of the slope stability analysis, shown in Figure 56, indicated that the bluff was stable in the zone, with safety factors of 1.27 at Profile No. 10-4 and 1.62 at Profile No. 10-5. The 1977 study reported bluff safety factors of 0.69 and 0.46 at Profile Nos. 10-4 and 10-5, respectively.

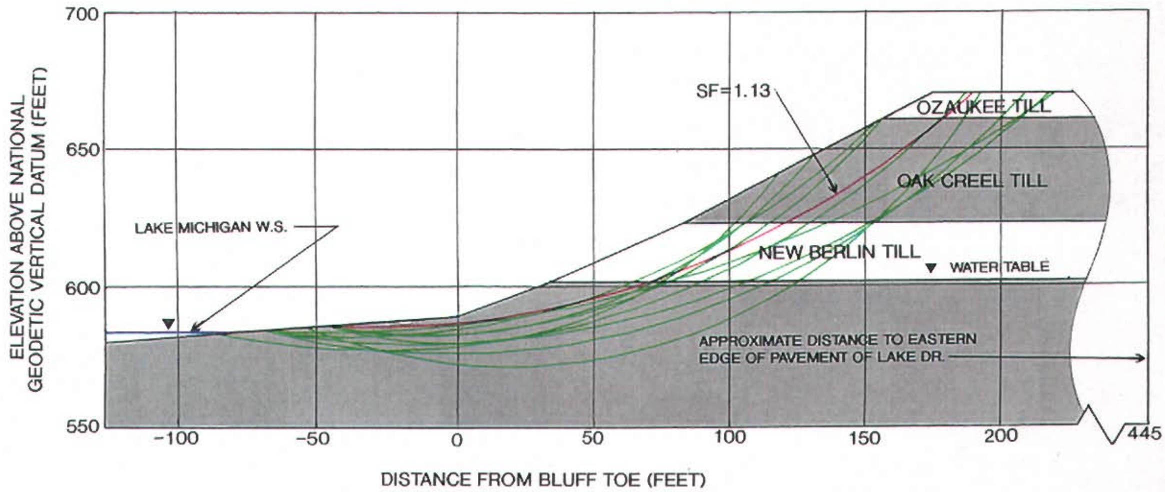
The beach ranged up to about 100 feet in width within Erosion Zone 3b. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be sand and gravel. At Profile No. 10-4, the nearshore lakebed depth of five feet was reached at 75 feet offshore in 1976, with the nearshore surface materials reported to be sand. At Profile No. 10-5, the nearshore lakebed depth of five feet was reached at 45 feet offshore in 1976, with the nearshore surface materials reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Figure 55

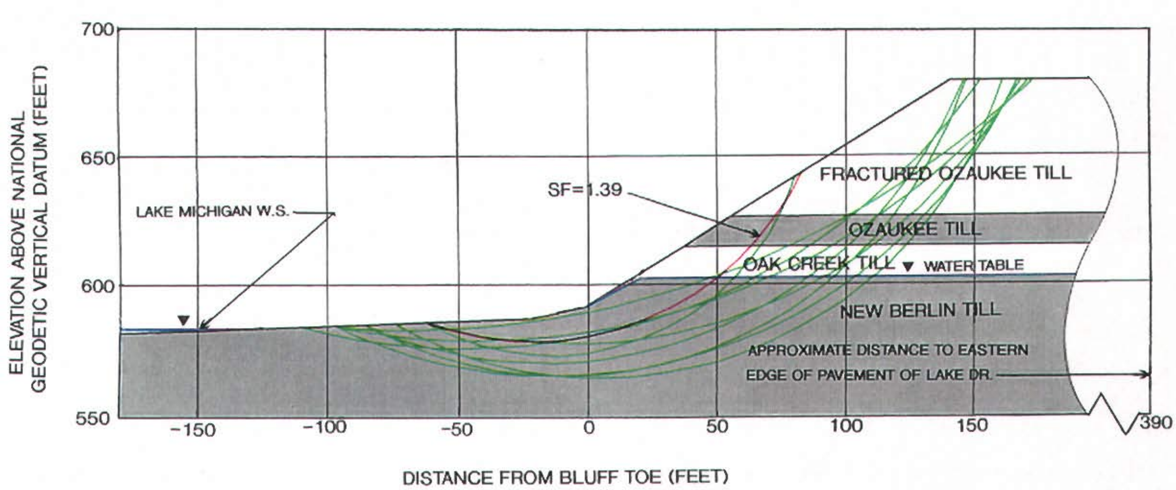
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 3, Township 7 North, Range 22 East
Village of Shorewood, Milwaukee County

PROFILE 10-2
T.7N. R.22E. S.3



PROFILE 10-3
T.7N. R.22E. S.3



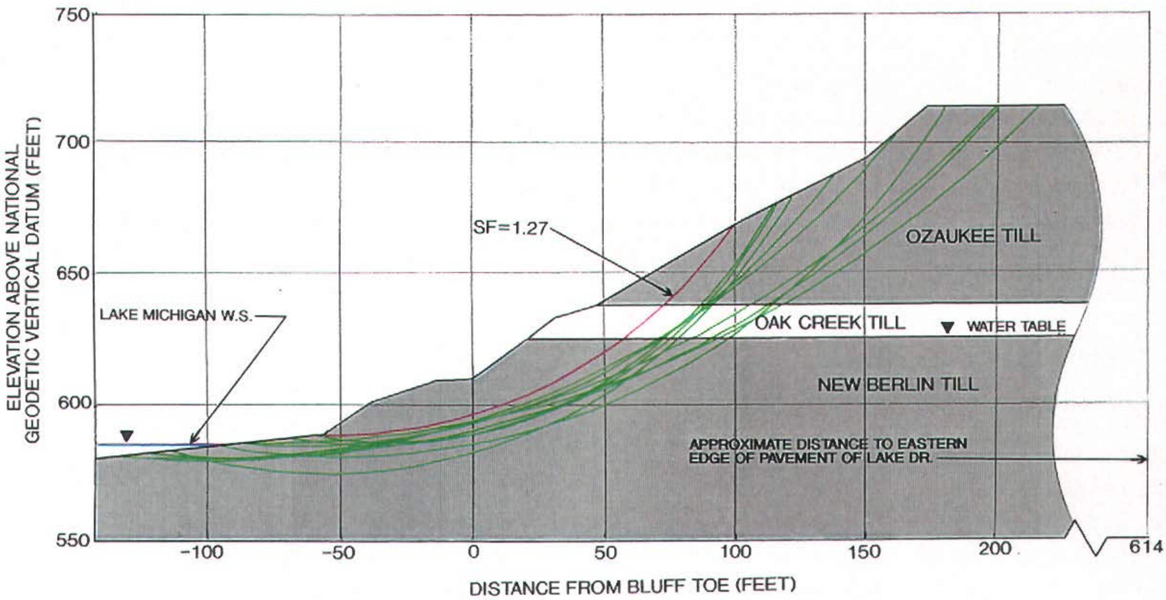
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 56

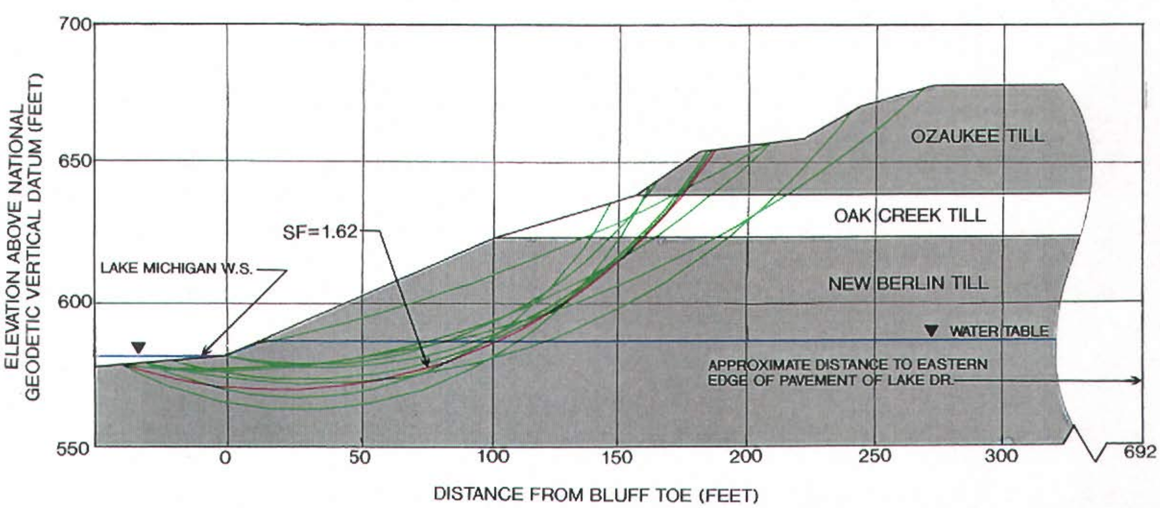
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 3, Township 7 North, Range 22 East
Village of Shorewood, Milwaukee County

PROFILE 10-4
T.7N. R.22E. S.3



PROFILE 10-5
T.7N. R.22E. S.3



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Shoreline recession data for Erosion Zone 3b were estimated at two locations. These data indicated a recession of between zero and 50 feet, or between zero and 1.6 feet per year, occurred between 1963 and 1995. Bluff recession increased from south to north within the zone. The data indicated that, in the southern portion of the zone, most of the recession occurred prior to 1975, with recessions of about -10 feet, or about -0.5 foot per year, occurring in the vicinity of Congress Street, in the Village of Shorewood, between 1975 and 1995. The data also indicated that, in the central portion of the zone, a recession of about 40 feet, or about two feet per year, occurred between 1975 and 1995. Thus, it appeared that the seawalls and revetments in the southern portion of Zone 3b had largely stabilized the bluff. However, the bluff appeared not to have been stabilized in the central portion of the zone, in the vicinity of Glendale Avenue, in the Village of Whitefish Bay. The 1977 study did not report a recession rate for this zone.

Erosion Zone 3c

Erosion Zone 3c extends from about Cumberland Boulevard extended north about 0.2 mile to the north section line of Section 3 at Hampton Avenue, in the Village of Whitefish Bay, as shown on Map 57. This zone had a beach of between 25 and 50 feet in width fronting the bluff which had a height of about 75 feet. The bluff was largely unprotected in this zone, although a rubble fill was being placed in 1994 and appeared to be complete in 1995. The 1995 field observations indicated that evidence of shallow translational slides and soil flows were present in this zone.

No bluff stability analyses were conducted within Erosion Zone 3c in this study or in 1976.

The beach was nonexistent to narrow within Erosion Zone 3c. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 3c were estimated at one location. These data indicated a recession of about -30 feet, or about -0.9 foot per year, occurred between 1963 and 1995. The data indicated no further accretion occurring between 1975 and 1995. Thus, it appeared that the bluff had been largely stabilized by the rubble fills placed within this zone. The 1977 study reported a recession rate of three feet per year for this zone.

U.S. Public Land Survey Sections 33 and 34, Township 8 North, Range 22 East, Village of Whitefish Bay, Milwaukee County

This shoreline analysis section extends from the south line of Section 34 at Hampton Avenue extended north to Silver Spring Drive extended in the Village of Whitefish Bay in Milwaukee County, as shown on Map 58. The shoreline was occupied by residential lands and open spaces, including Buckley and Big Bay Parks. Much of the shoreline was protected by a variety of different types of shoreline protection structures, including seawalls, rubble fills, and riprap. The bluffs in this section ranged from 70 to 80 feet in height. The bluff materials were covered, but were estimated to be till underlain by intermixed silt and sand, overlying till. Prior to the placement of the shoreline protection structures, the 1977 study had defined eight erosion zones within this section. In 1995, the extent of the shoreline protection structures within this section did not support the subdivision of this portion of Reach 10 into erosion zones. Thus, the inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for Sections 33 and 34.

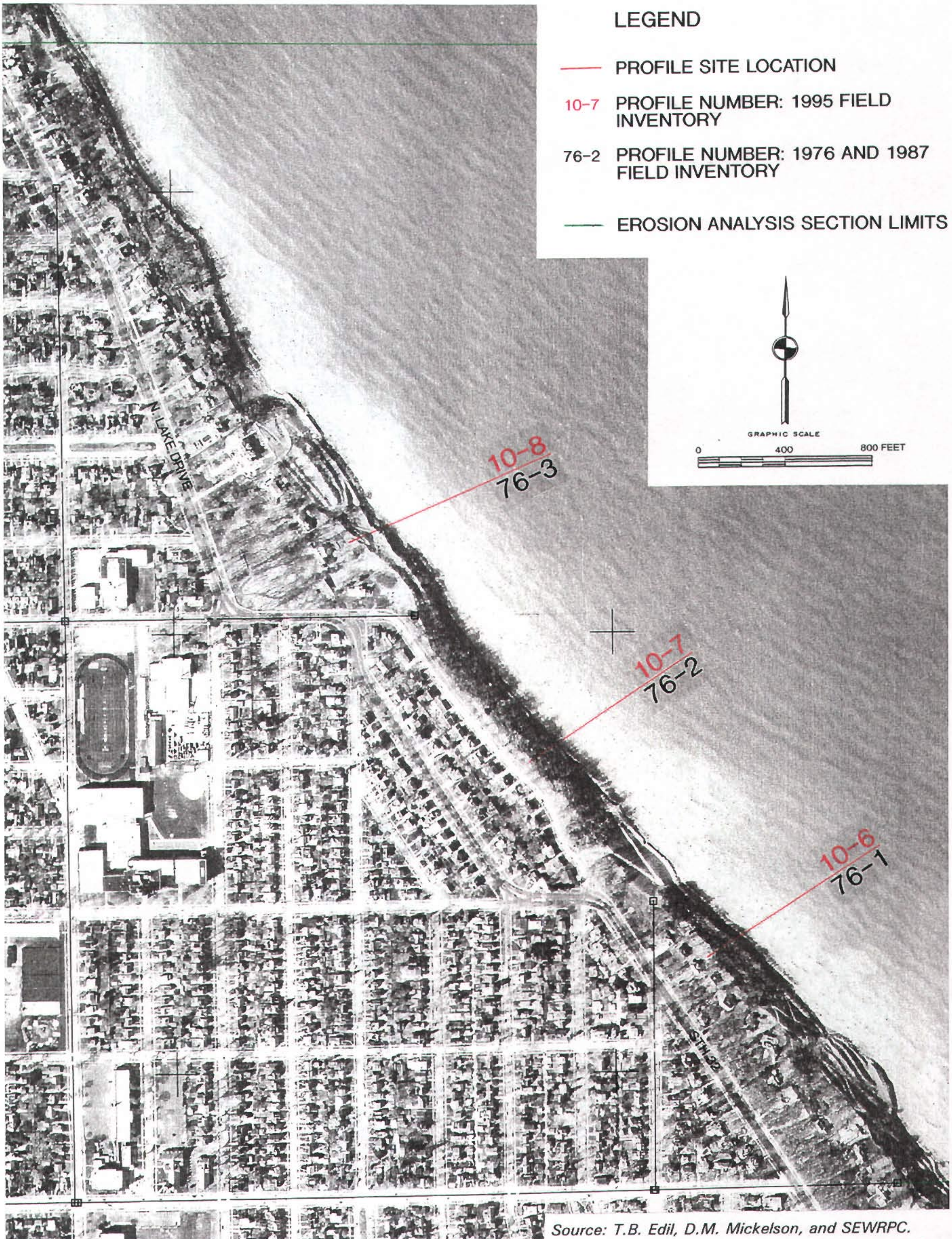
In 1995, this section had little or no beach, and was protected by seawalls, riprap, and rubble at the bluff toe. The bluff had a height of about 70 feet, rising to about 80 feet in height in the central portion of the section. Portions of the bluff had been regraded. In 1995, the bluff appeared stable, except for some minor translational sliding. The northern area had evidence of some erosion at the bluff toe. The bluff slopes were approximately 100 percent vegetated.

In 1995, three bluff profile field surveys were made within Sections 33 and 34 by occupying sites for which field surveys were conducted in 1976. At Profile Nos. 10-6 and 10-8, the sites had been significantly modified by regrading, and, at Profile No. 10-6, by the placement of rubble fill. At Profile No. 10-7, the site appeared to be slightly modified by regrading. The stability of the bluff in Sections 33 and 34 of Reach 10 was characterized by Profile Nos. 10-6 through 10-8. Results of the slope stability analyses, shown in Figures 57 and 58, indicated that the bluff was stable with respect to rotational failures, with safety factors of 1.26

Map 58

SHORELINE EROSION REACH 10: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 33 and 34, Township 8 North, Range 22 East
Village of Whitefish Bay, Milwaukee County

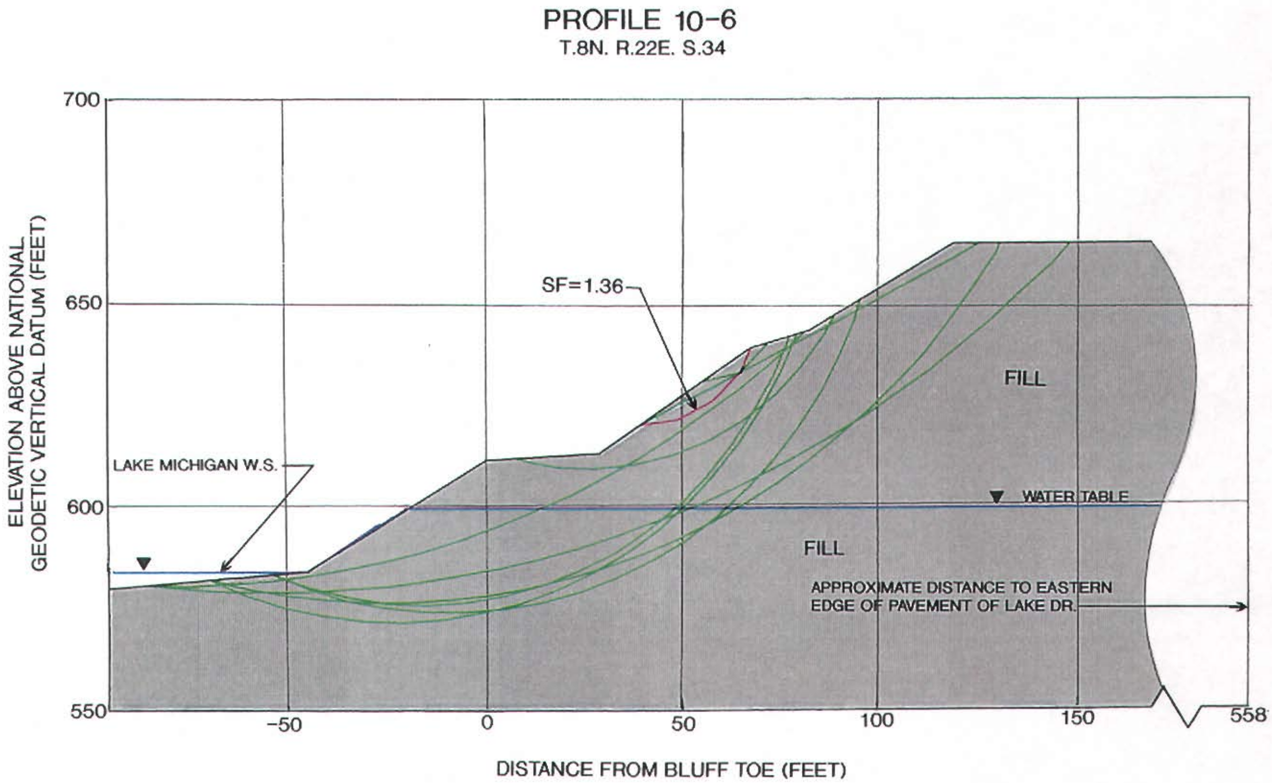


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 57

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSIS

U.S. Public Land Survey Section 34, Township 8 North, Range 22 East
Village of Whitefish Bay, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

at Profile Nos. 10-7 and 10-8, and, with a safety factor of 1.36 at Profile No. 10-6. However, 1995 field observations indicated that translational failures may occur. The 1977 study reported bluff safety factors at these sites of 0.46 to 1.0.

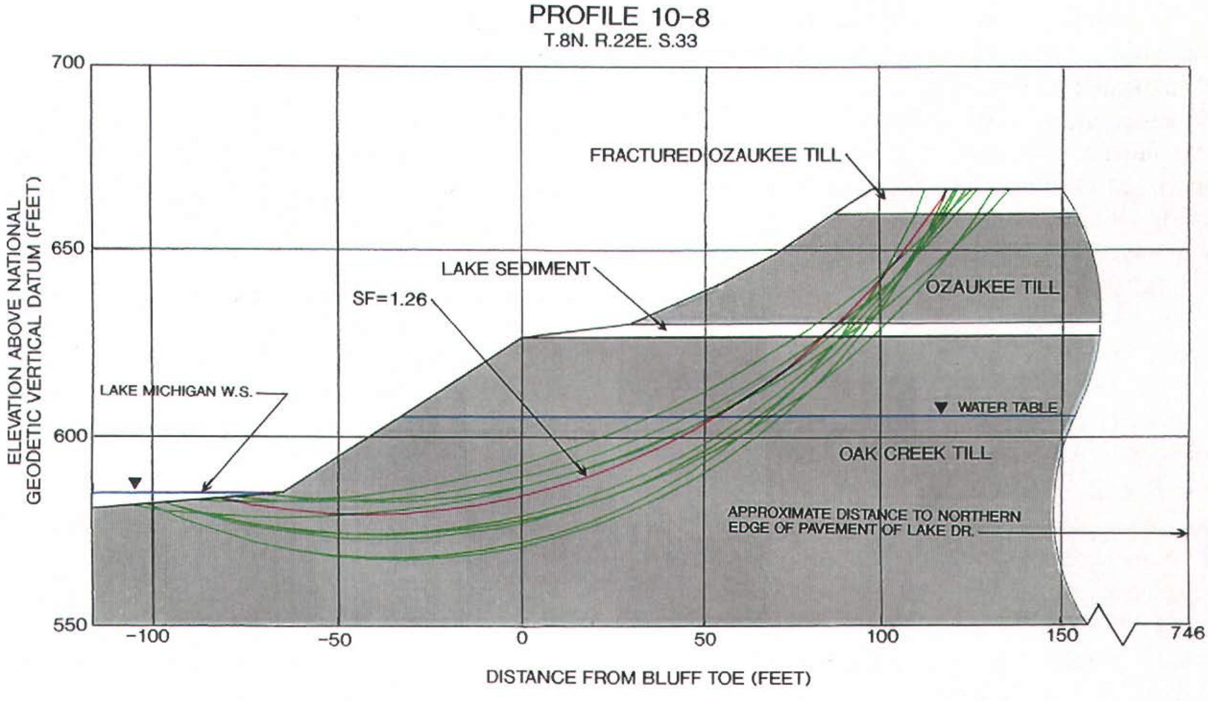
The beach within Sections 33 and 34 was less than 20 feet wide and fronted by riprap and the bluff. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be predominantly sand in the central portions of the section, with sand and cobbles in the southern portion of the section, and cobbles in the northern portion of the section. In 1995, at Profile No. 10-7, the nearshore lakebed depth of five feet was reached at 125 feet offshore, with the nearshore surface materials reported to be sand. The nearshore lakebed depth of five feet was reached at 110 feet offshore in 1976, with the nearshore surface material reported to be sand. At Profile No. 10-6, the nearshore lakebed depth of five feet was reached at 115 feet offshore in 1976. At Profile No. 10-8, the nearshore lakebed depth of five feet was reached at 120 feet offshore in 1976. The nearshore surface materials at both sites were estimated to be sand. No measurements or observations were made of the nearshore lakebed depth or material at these sites in 1995.

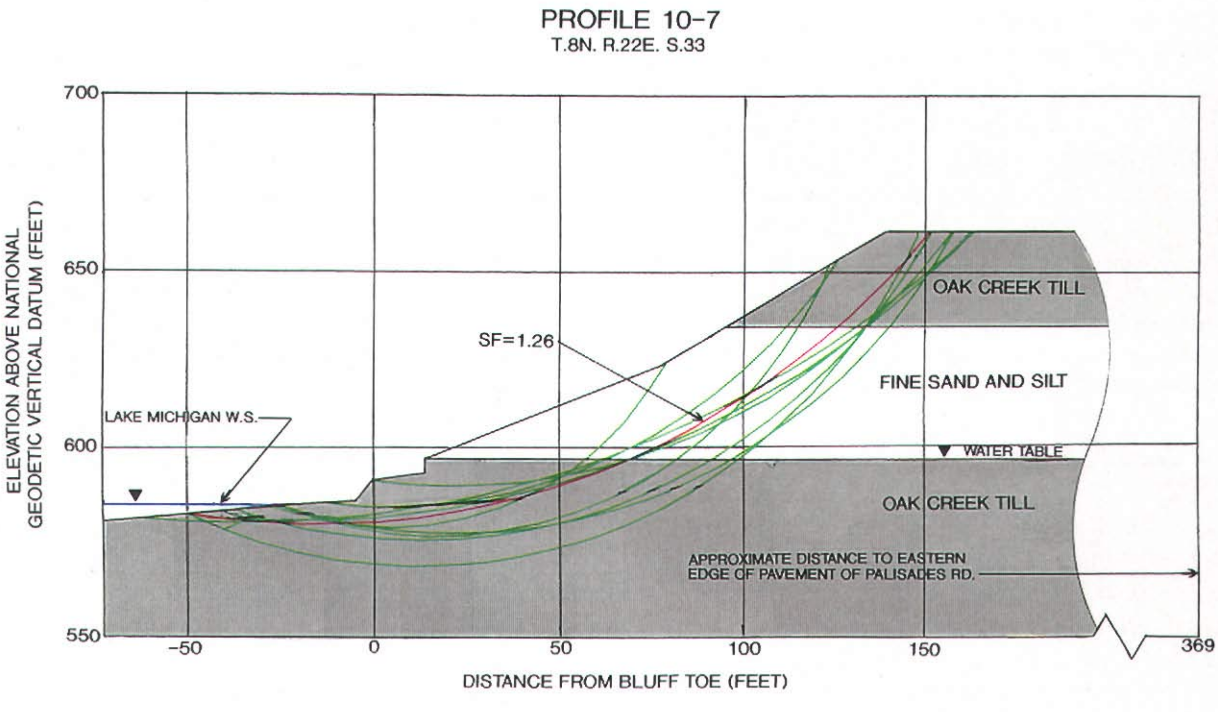
Shoreline recession data for Sections 33 and 34 were estimated at five locations. These data indicated a recession of up to 10 feet, or 0.3 foot per year, occurred between 1963 and 1995. Shoreline accretions, probably

Figure 58

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 33, Township 8 North, Range 22 East
Village of Whitefish Bay, Milwaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

due to the placement of fill, occurred in the southernmost and northernmost portions of the section, and in the central portion of the section. In the north-central portion of the section, the data indicated that little or no recession occurred between 1963 and 1995. At about Hampton Avenue and north of about Henry Clay Street, the data indicated an accretion of up to 70 feet occurred between 1975 and 1995. In contrast, at about Fairmount Avenue in the vicinity of Buckley and Big Bay Parks, the data indicated about 10 feet, or about 0.5 foot per year of recession occurring between 1975 and 1995. In 1995, it appeared that the seawall within this portion of the section had been overtopped and that the bluff slope was failing by shallow slides. Generally, the placement of riprap and rubble on the bluff slopes within this section after 1975 appeared to have largely stabilized the bluff. The 1977 study reported recession rates for this section of between two and three feet per year.

U.S. Public Land Survey Section 28, Township 8 North, Range 22, Village of Whitefish Bay, Milwaukee County

This shoreline analysis section extends from Silver Spring Drive extended north to School Road or Mill Road extended, in the Village of Whitefish Bay, as shown on Map 59. In 1995, the lakeshore area was occupied by parkland, including Klode Park, and residential lands. In 1995, the section was protected by a variety of shoreline protection structures, including rubble fills. The section was fronted by a beach up to about 125 feet in width. The bluff in this section was about 70 feet in height in the southern portion of the section, rising to about 100 feet in height in the northern portion of the section. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by intermixed sand and silt and silt and clay, overlain by till. For analysis purposes, Section 28 was further subdivided into three erosion zones, as shown on Map 59. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three erosion zones in Section 28.

Erosion Zone 28a

Erosion Zone 28a extends from the southern section line of Section 28 at Silver Spring Drive north about 0.5 mile to about Montclair Avenue extended in the vicinity of the northern property line of Klode Park, in the Village of Whitefish Bay, as shown on Map 59. This zone had a beach of up to 50 feet in width fronting the bluff which had a height of about 70 feet. The bluff was protected by a number of shoreline protection structures, including rubble fills, and the bluff slope had been largely regraded. Vegetation, comprising grasses and trees, covered approximately 100 percent of the bluff slope. Although portions of the southern shoreline within this zone were being modified in 1995, signs of some movement of the slide mass under and around the fill, in the form of fresh scarps on the bluff slope, were present, and evidence of shallow slides and small scarps was observed.

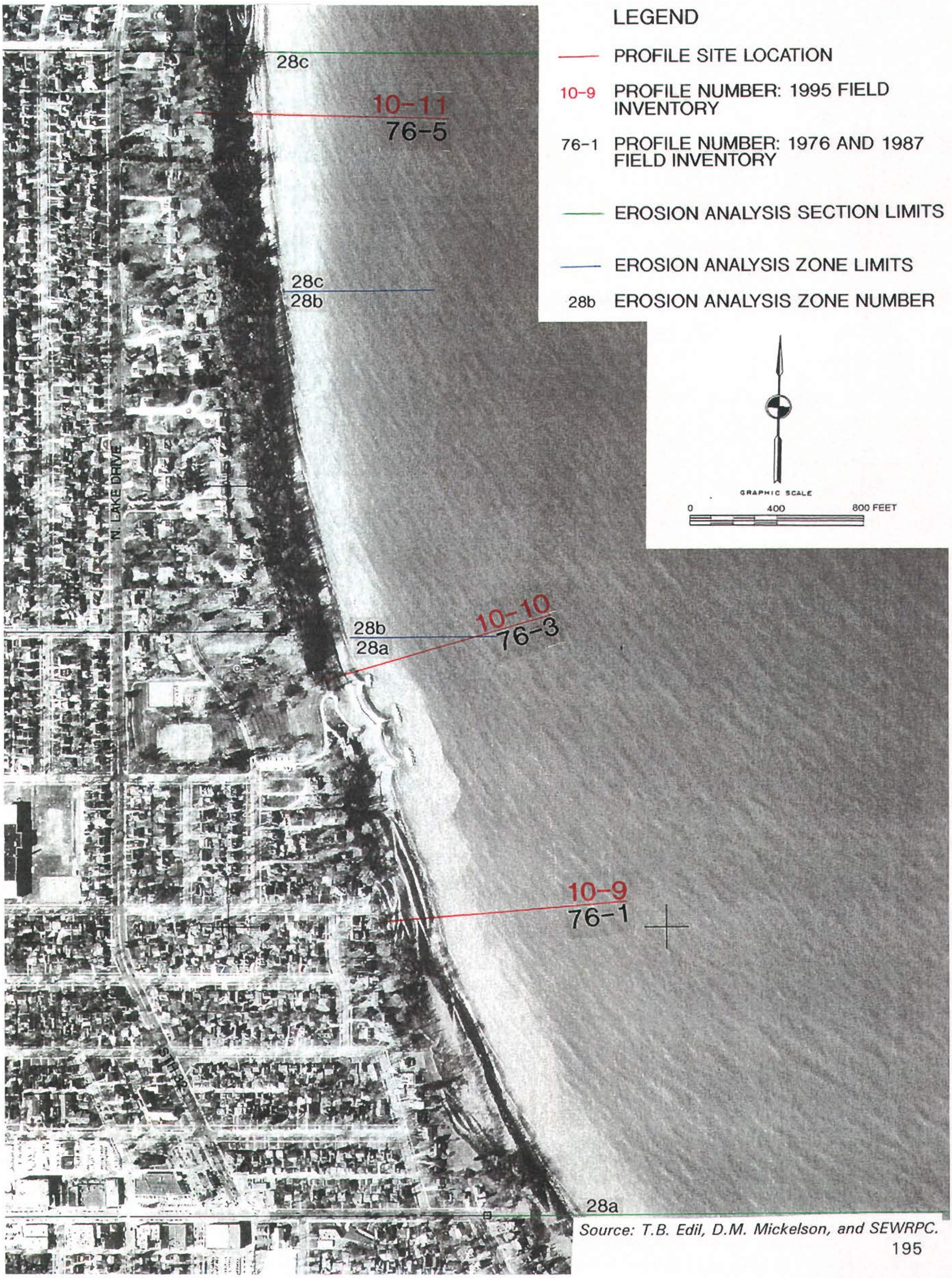
In 1995, two bluff profile field surveys were made within Erosion Zone 28a by occupying sites for which field surveys were conducted in 1976. The reoccupied sites had significantly different geometries to those documented in 1976. The site at Profile No. 10-9 appeared to have been terraced, eliminating the escarpment and slumped till at the bluff toe, and the site at Profile No. 10-10 appeared to have been regraded to a concave shape. The stability of the bluff in Zone 28a of Reach 10 was characterized by Profile Nos. 10-9 and 10-10. Results of the slope stability analysis, shown in Figure 59, indicated that the bluff was unstable to marginally stable in the zone, with safety factors of 0.95 at Profile No. 10-10 and 1.0 at Profile No. 10-9, based upon the deterministic bluff stability analysis method. At Profile No. 10-9, the probabilistic bluff stability analysis method resulted in a range of safety factors from 0.82 to 1.37 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 16, or 64 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 90, or 36 percent, of the 250 conditions analyzed. At Profile No. 10-10, the probabilistic bluff stability analysis method resulted in a range of safety factors from 0.77 to 1.27 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 14, or 56 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 99, or 39.6 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study reported bluff safety factors of 0.79 and 0.93 at Profile Nos. 10-9 and 10-10, respectively.

The beach ranged up to about 50 feet in width within Erosion Zone 28a, with the widest portion of the beach being contained within the shoreline protection structures

Map 59

SHORELINE EROSION REACH 10: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 28, Township 8 North, Range 22 East
Village of Whitefish Bay, Milwaukee County

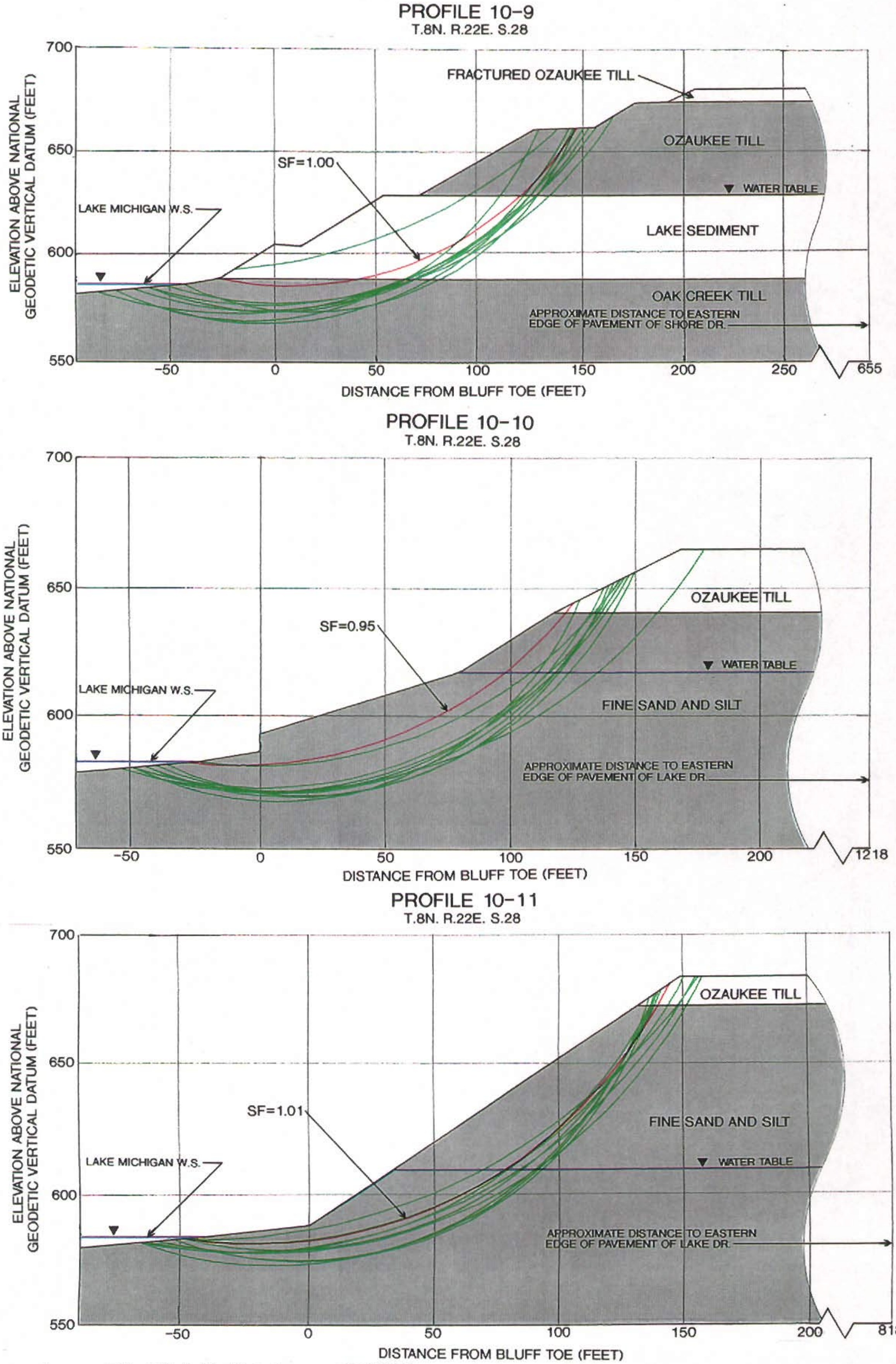


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 59

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 28, Township 8 North, Range 22 East
Village of Whitefish Bay, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Klode Park. In the 1977 study, the beach width was reported to be greater than 25 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, with sand at the bluff toe. At Profile No. 10-9, the nearshore lakebed depth of five feet was reached at 120 feet offshore in 1976, with the nearshore lakebed materials noted to be sand. At Profile No. 10-10, the nearshore lakebed depth of five feet was reached at 126 feet offshore in 1976, with the nearshore lakebed materials reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or 1987.

Shoreline recession data for Erosion Zone 28a were estimated at three locations. These data indicated a recession of between -90 and 10 feet, or between -2.8 and 0.3 foot per year, occurred between 1963 and 1995. Bluff recession increased from south to north within the zone. The data indicated recessions of between -70 and 10 feet, or between -3.5 and 0.5 foot per year, occurring between 1975 and 1995, with bluff recession increasing from south to north. Thus, it appeared that the placement of fill in the southern portion of Zone 28a in the vicinity of Silver Spring Drive had largely stabilized the bluff. However, the bluff appeared not to have been stabilized in the central and northern portions of the zone, north of about Day Avenue in the Village of Whitefish Bay. The 1977 study reported a recession rate of two feet per year for this zone.

Erosion Zone 28b

Erosion Zone 28b extends from about Montclair Avenue extended north about 0.3 mile to about Devon Street extended, in the Village of Whitefish Bay, as shown on Map 59. This zone had a beach of between 50 and 75 feet in width fronting the bluff with a height of between 70 and 100 feet. The bluff was unprotected by shoreline protection structures. The bluff was approximately 100 percent vegetated. In 1995, signs of creep and a few small scarps were present, which suggested a potential for minor movement on the bluff. However, a boathouse and culvert close to the top of the beach were observed to have been in the same position since 1976.

No bluff stability analyses were conducted within Erosion Zone 28b in this study or in 1976.

The beach ranged up to about 75 feet in width within Erosion Zone 28b. In the 1977 study, the beach width was reported to be greater than 25 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, with sand to the bluff toe. The nearshore lakebed depth of five feet was reached at 126 feet offshore in 1976. The nearshore surface materials were not reported. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 28b were estimated at one location. These data indicated a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. The data indicated that most of the recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. Thus, it appeared that the bluff was stable in this zone. The 1977 study did not report a recession rate for this zone.

Erosion Zone 28c

Erosion Zone 28c extends from about Montclair Avenue extended north about 0.2 mile to the north section line of Section 28 at Mill Road, in the Village of Whitefish Bay, as shown on Map 59. This zone had a beach of between 25 and 50 feet in width fronting the bluff which had a height of about 100 feet. The bluff was largely unprotected in this zone. Two large bluff failures have occurred within this zone between 1987 and 1995 as a result of shallow slides of several feet in thickness. The 1995 field observations indicated that several old, large slump blocks were present in this zone, but there appeared to be no evidence of recent movement of these larger blocks. However, evidence of shallow slides was present.

In 1995, one bluff profile field survey was made within Erosion Zone 28c by occupying a site for which a field survey was conducted in 1976. The reoccupied site had significantly different geometry to that documented in 1976. The profile appeared to be steeper, but lacking a number of slope breaks present during 1976. The stability of the bluff in Zone 28c of Reach 10 was characterized by Profile No. 10-11. Results of the slope stability analysis, shown in Figure 59, indicated that the bluff was marginally stable with respect to large slumps in the zone, with a safety factor of 1.01, based upon the deterministic bluff stability analysis method. Profile No. 10-11 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.55 to 1.17 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 20, or 80 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 171, or 68.4 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered unstable with respect to both rotational and translational failures. The 1977 study reported a bluff safety factor of 0.83.

The beach ranged up to about 50 feet in width within Erosion Zone 28c. In the 1977 study, the beach width was reported to be greater than 25 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, with sand to the bluff toe. At Profile No. 10-11, the nearshore lakebed depth of five feet was reached at 161 feet offshore in 1995, with the nearshore lakebed materials noted to be sand. The nearshore lakebed depth of five feet was reached at 150 feet offshore in 1976, with the nearshore lakebed materials reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1987.

Shoreline recession data for Erosion Zone 28c were estimated at one location. These data indicated a recession of about 20 feet, or about 0.6 foot per year, occurred between 1963 and 1995. The data indicated that no further recession occurred between 1975 and 1995. Thus, it appeared that the bluff had been largely stabilized within this zone. The 1977 study did not report a recession rate for this zone.

In 1995, the lack of vegetation on the lower 30 to 50 percent of the bluff slope, which suggested active bluff slope failure within this zone, indicated that these areas of shallow slides were likely to continue to move up slope and produce bluff top erosion in the future. The apparent increasing instability of the bluff in this zone indicated a high potential for considerable bluff top retreat, even without a lake level change. Bluff top retreat was considered to be very likely during future periods of higher lake levels within this zone. Several houses located within 50 to 75 feet of the bluff top are likely to be affected by such a recession.

U.S. Public Land Survey Section 21, Township 8 North, Range 22, Village of Fox Point, Milwaukee County

This shoreline analysis section extends from Mill Road extended north to Good Hope Road extended, in the Village of Fox Point, as shown on Map 60. In 1995, the entire lakeshore area was occupied by residential lands. In 1995, the section was protected by a variety of shoreline protection structures, including rubble fills, revetments, and groins. The section was fronted by a narrow to nonexistent beach. The bluff in this section was about 120 feet in height in the southern and central portions of the section, dropping to a natural terrace of about 15 feet in height in the northern portion of the section. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by silt, intermixed sand and silt and silt and clay, overlain by till. For analysis purposes, Section 21 was further subdivided into four erosion zones, as shown on Map 60. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the four erosion zones in Section 21.

Erosion Zone 21a

Erosion Zone 21a extends from the southern section line of Section 21 at Mill Road extended north about 0.2 mile to about Acacia Road extended, in the Village of Fox Point, as shown on Map 60. This zone had little or no beach fronting the bluff which had a height of about 120 feet. The bluff was protected by a number of shoreline protection structures, including rubble fills. Vegetation, comprising grasses and trees, covered between 60 and 100 percent of the bluff slope. In 1995, signs of bluff toe erosion and translational slides were present.

No bluff stability analyses were conducted within Erosion Zone 21a in this study or in 1976.

The beach was less than 25 feet in width within Erosion Zone 21a. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 21a were estimated at one location. These data indicated a recession of about 20 feet, or about 0.6 foot per year, occurred between 1963 and 1995. The data indicated no further recession occurring between 1975 and 1995. Thus, it appeared that the placement of fill within Zone 21a had largely stabilized the bluff. The 1977 study did not report a recession rate for this zone.

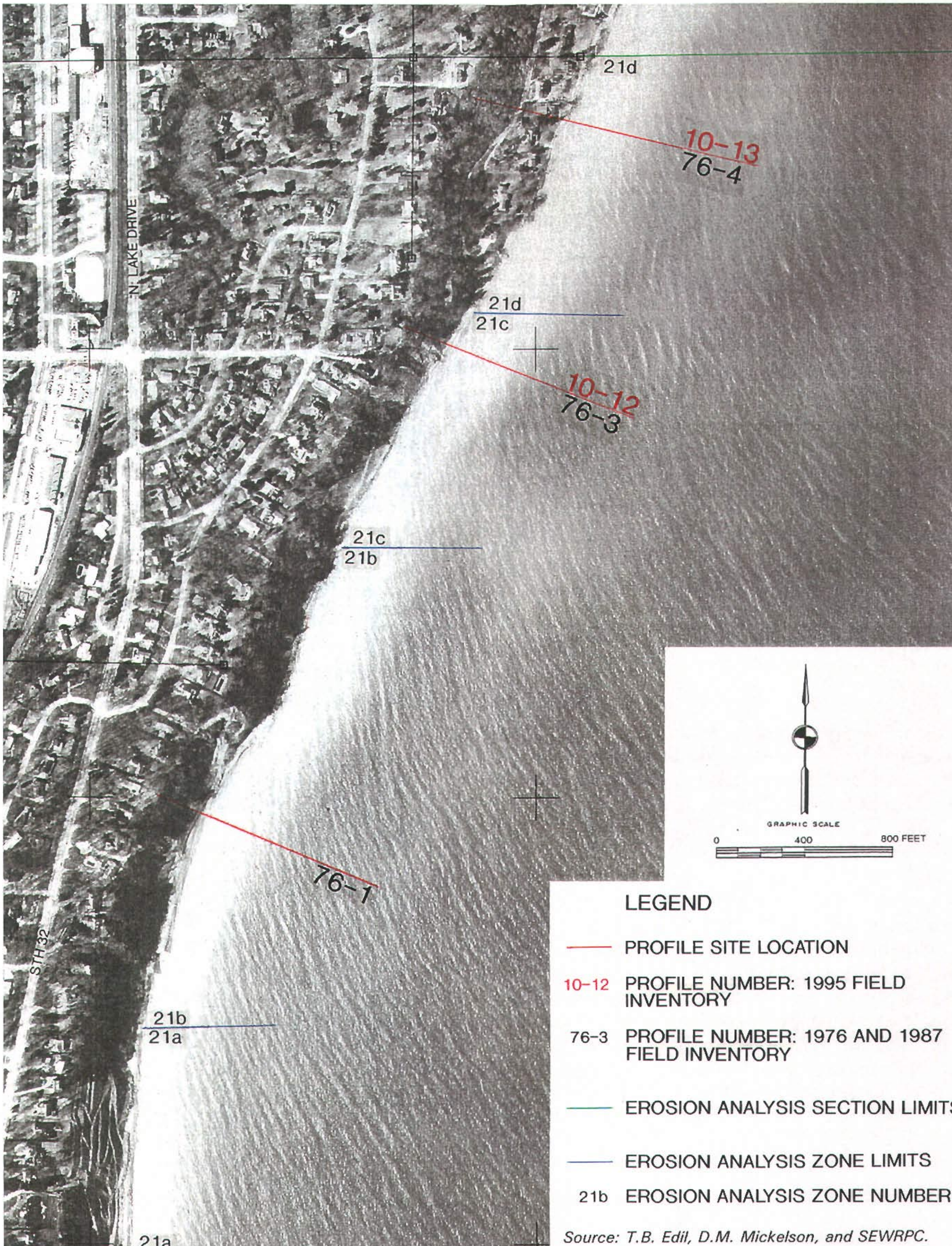
Erosion Zone 21b

Erosion Zone 21b extends from about Acacia Road extended north about 0.4 mile to about View Place extended (or Foxdale Road extended), in the Village of Fox Point, as shown on Map 60. This zone had a beach of up to 25 feet in width, contained within a system of groins in the southern portion of the zone, fronting the bluff with a height of about 120 feet. The bluff was largely protected by a variety of shoreline protection structures, including revetments and a small groin system. However, the bluff was unprotected in portions

Map 60

SHORELINE EROSION REACH 10: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 21, Township 8 North, Range 22 East
Village of Fox Point, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

of the zone. Vegetation, comprising grasses and trees, covered between 60 and 100 percent of the bluff slope in the southern and central portions of the zone, but less than 50 percent of the bluff slope in the northern portion of the zone. In 1995, signs of shallow slides were present.

No bluff stability analyses were conducted within Erosion Zone 21b in this study. However, in 1976, one bluff profile field survey was made within Erosion Zone 21b. The 1977 study reported a bluff safety factor of 1.0.

The beach ranged up to about 25 feet in width within Erosion Zone 21b, with the widest portions of the beach contained within a small groin system in the southern portion of the zone. In the 1977 study, the beach width was reported to be less than 20 feet, and the beach materials were reported to be sand and cobbles. The nearshore lakebed depth of five feet was reached at 150 feet offshore in 1976. The nearshore surface materials were not reported. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 21b were estimated at two locations. These data indicated a recession of between 40 and 60 feet, or between 1.2 and 1.9 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 20 feet, or about one foot per year, occurring between 1975 and 1995. Thus, it appeared that the bluff had been partially stabilized in this zone due to the placement of fill. The 1977 study reported a recession rate of two feet per year for this zone.

In 1995, it appeared that the revetment in the southern portion of Erosion Zone 21b had been overtopped and had become ineffective in reducing wave erosion of the base of the bluff. Throughout the zone evidence of shallow slides was present, increasing in frequency from south to north within the zone. Several houses were located within close proximity to the edge of the bluff and appeared to be at risk, even at the relatively modest recession rate determined within this zone. In the northern portion of the zone, the bluff was steeply sloped near the bluff toe, suggesting that shallow slides within this portion of the zone will result in bluff top recession in the future. Although portions of this area of the zone were protected by a revetment, it appeared that the revetment had not been maintained and that it was being regularly overtopped, contributing the occurrence of shallow slides in this area and placing the houses located on the bluff top at risk.

Erosion Zone 21c

Erosion Zone 21c extends from about Foxdale Road extended north about 0.2 mile to about the southernmost extreme of Beach Drive, in the Village of Fox Point, as shown on Map 60. This zone had little or no beach fronting the bluff which had a height of about 120 feet. The bluff was protected in this zone by a massive fill placed within this zone during 1987. In 1995, evidence of translational slides and erosion of the bluff toe was present.

In 1995, one bluff profile field survey was made within Erosion Zone 21c by occupying a site for which a field survey was conducted in 1976. The reoccupied site had slightly different geometry to that documented in 1976. The profile appeared to be somewhat more convex and lacking the scarp present at the bluff top during 1976. The stability of the bluff in Zone 21c of Reach 10 was characterized by Profile No. 10-12. Results of the slope stability analysis, shown in Figure 60, indicated that the bluff was unstable in the zone, with a safety factor of 0.98, based upon the deterministic bluff stability analysis method. Profile No. 10-12 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.54 to 1.23 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 23, or 92 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 208, or 83.2 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered unstable with respect to both rotational and translational failures. The 1977 study reported a bluff safety factor of 0.45.

The beach was narrow to nonexistent within Erosion Zone 21c. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be sand. At Profile No. 10-12, the nearshore lakebed depth of five feet was reached at 155 feet offshore in 1976, with the nearshore lakebed materials noted to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 21c were estimated at one location. These data indicated a recession of about 20 feet, or about 0.6 foot per year, occurred between 1963 and 1995. The data indicated that no further recession occurred between 1975 and 1995. Thus, it appeared that the bluff had been largely stabi-

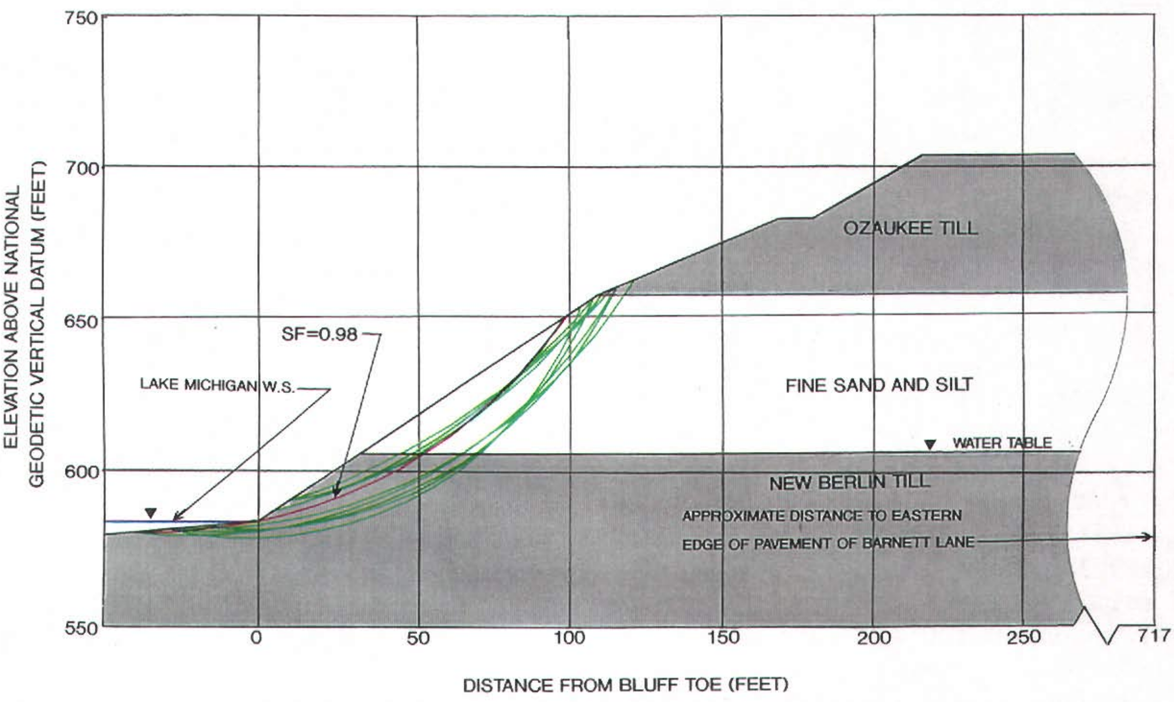
Figure 60

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 21, Township 8 North, Range 22 East
Village of Fox Point, Milwaukee County

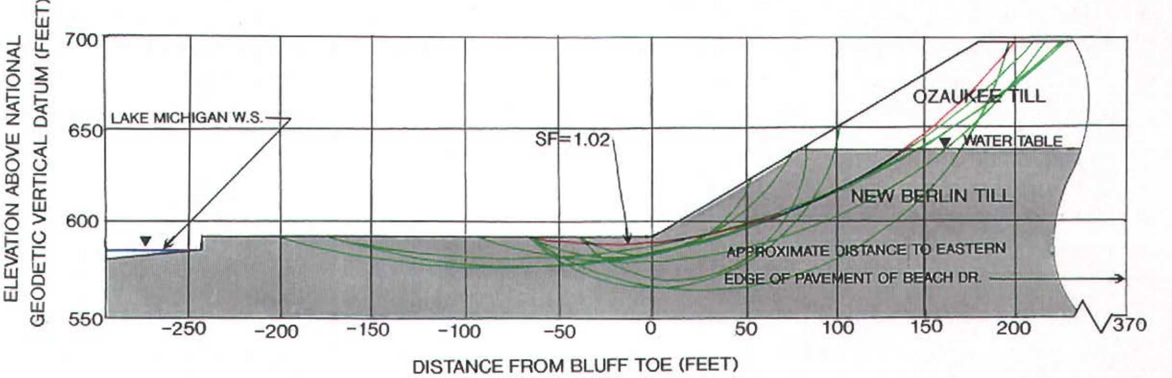
PROFILE 10-12

T.8N. R.22E. S.21



PROFILE 10-13

T.8N. R.22E. S.21



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

lized within this zone. The 1977 study did not report a recession rate for this zone.

Erosion Zone 21d

Erosion Zone 21d extends from about the southernmost extreme of Beach Drive north about 0.2 mile to the northern section line of Section 21 at Good Hope Road extended, in the Village of Fox Point, as shown on Map 60. This zone had little or no beach fronting a natural terrace which had a height of about 15 feet. The bluff terrace was protected in this zone by rubble fill.

In 1995, one bluff profile field survey was made within Erosion Zone 21d by occupying a site for which a field survey was conducted in 1976. No profile of the bluff terrace was presented in the 1977 study. The stability of the bluff in Zone 21d of Reach 10 was characterized by Profile No. 10-13. Results of the slope stability analysis, shown in Figure 60, indicated that the bluff was marginally stable in the zone, with a safety factor of 1.02, based upon the deterministic bluff stability analysis method. Profile No. 10-13 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.79 to 1.69 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 11, or 44 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 23, or 9.2 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a bluff safety factor of 1.1.

The beach was narrow to nonexistent within Erosion Zone 21d. In the 1977 study, the beach width was reported to be less than five feet, and the beach materials were reported to be sand and cobbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 21d were estimated at one location. These data indicated a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 20 feet, or about one foot per year, occurred between 1975 and 1995. Thus, it appeared that the bluff terrace had not been effectively stabilized within this zone. The 1977 study reported a recession rate of six feet per year for this zone.

U.S. Public Land Survey Section 16, Township 8 North, Range 22 East, Village of Fox Point, Milwaukee County

This shoreline analysis section extends from the south line of Section 16 at Good Hope Road extended north to Bradley Road extended in the Village of Fox Point in Milwaukee County, as shown on Map 61. The shoreline was occupied by residential lands. Much of the shoreline was protected by a variety of different types of shoreline protection structures, including groins and riprap. The bluff in this section was fronted by a natural terrace which was about 15 feet in height. The bluff materials were covered, but were estimated to be till. For analysis purposes, Section 16 was not further subdivided. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for Section 16.

Section 16 extend from the northerly limit of Section 21 at Good Hope Road extended north about one mile to Bradley Road extended at the northerly limit of Section 16, Village of Fox Point, Milwaukee County, as shown on Map 61. In 1995, this section had a beach which ranged in width from narrow to nonexistent in the southern portion of the section up to 75 feet in width within the groin systems in the central portion of the section. The bluff was fronted by a natural terrace of about 15 feet in height. In 1995, the bluff appeared stable and the bluff slopes were approximately 100 percent vegetated.

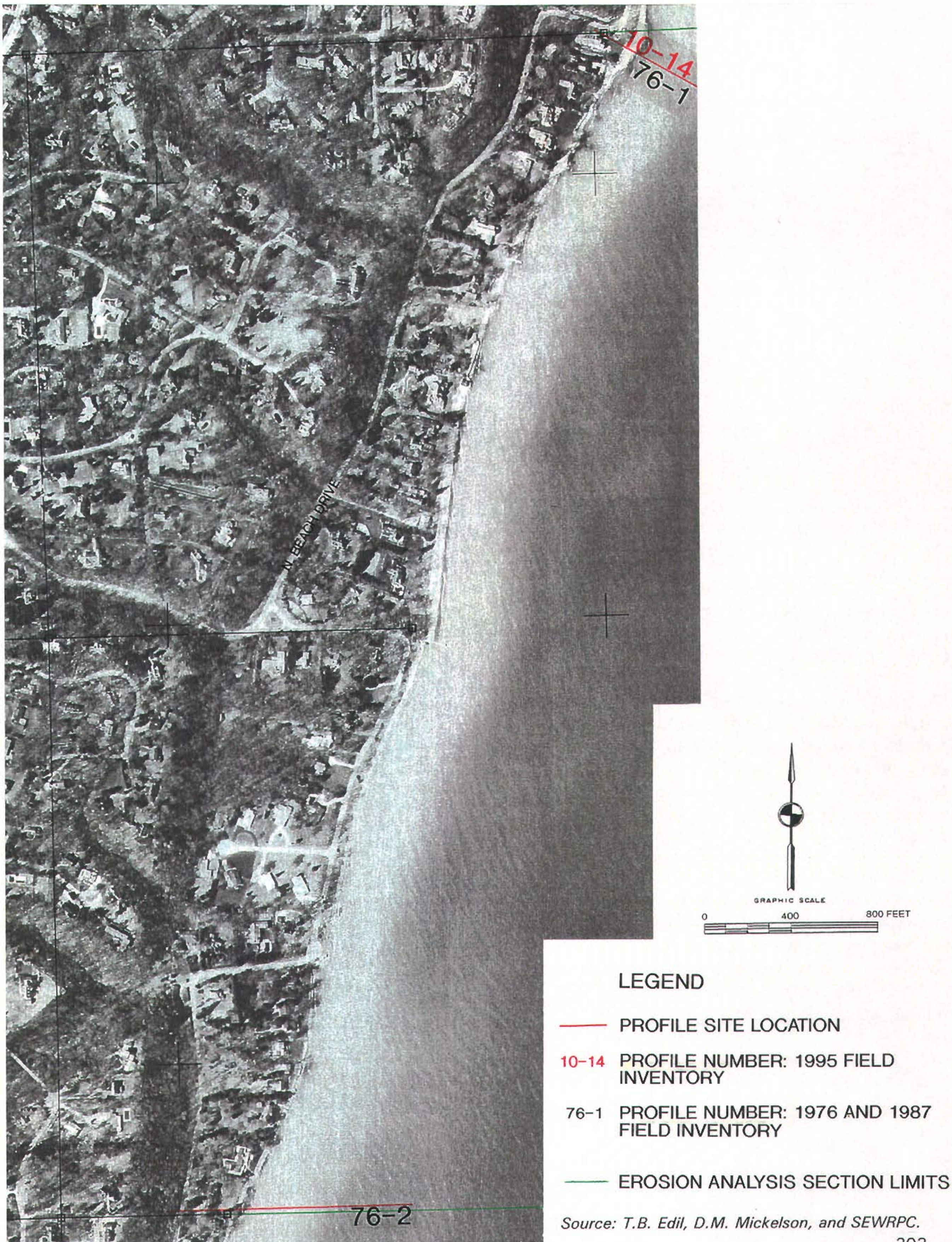
In 1995, one bluff profile field survey was made within Section 16 by occupying a site for which a field survey was conducted in 1976. One other bluff profile field survey for which a field survey was conducted in 1976 was not reoccupied. At Profile No. 10-14, the site had been significantly modified with a broad beach fronting a steeper bluff slope. The stability of the bluff in Section 16 of Reach 10 was characterized by Profile No. 10-14. Results of the slope stability analyses, shown in Figure 61, indicated that the bluff was stable, with a safety factor of 1.52. The 1977 study reported bluff safety factors of 1.1 to 1.4, the former being determined at Profile No. 10-14.

The beach within Section 16 was up to 75 feet in width. In the 1977 study, the beach width was reported to be less than 20 feet, and the beach material was reported to be sand. In 1995, at Profile No. 10-14, the nearshore lakebed depth of five feet was reached at 119 feet offshore, with the nearshore surface materials reported to be sand. The nearshore lakebed depth of five feet was reached at 150 feet offshore in 1976, with the nearshore

Map 61

SHORELINE EROSION REACH 10: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 16, Township 8 North, Range 22 East
Village of Fox Point, Milwaukee County

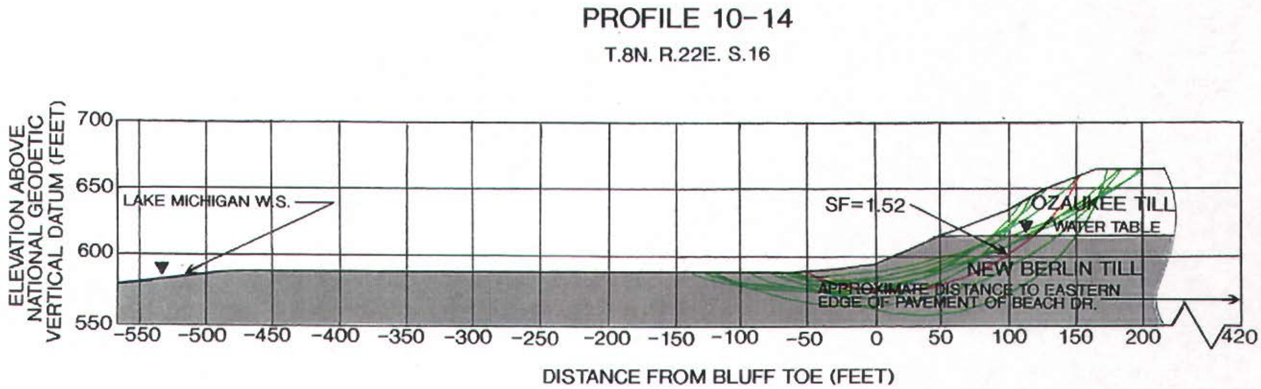


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 61

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSIS

U.S. Public Land Survey Section 16, Township 8 North, Range 22 East
Village of Fox Point, Milwaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

surface material reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1987.

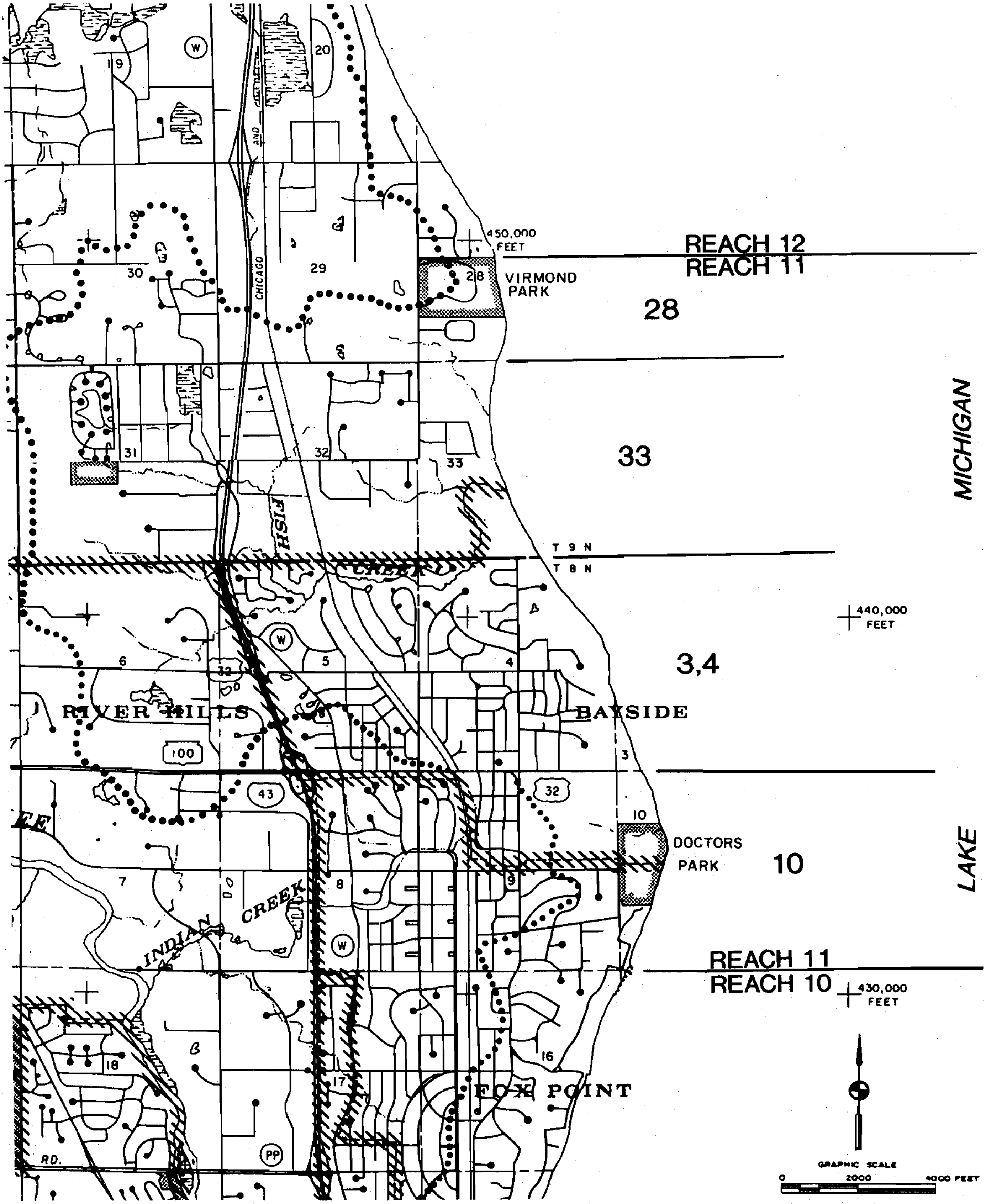
Shoreline recession data for Section 16 were estimated at five locations. These data indicated a recession of between 10 and 80 feet, or between 0.3 and 2.5 feet per year, occurred between 1963 and 1995. In the north-central portion of the section, the data indicated that the greatest amount of recession of about 80 feet, or about 2.5 feet per year, occurred between 1963 and 1995. The data indicated that most of that recession occurred prior to 1975, with no further recession occurring in the central portions of the section between 1975 and 1995. In the north-central and southern portions of the section, the data indicated between 20 and 30 feet, or between one and 1.5 feet per year of recession occurring between 1975 and 1995. In 1995, with the exception of the north-central and southernmost portions of the section, it appeared that the shoreline protection structures have largely stabilized the bluff, while in the north-central and southernmost portions of the section—in the vicinities of the portion of the shoreline adjacent to the intersection of Goodrich Circle and Lilac Lane, and Good Hope Road—it appeared that the shoreline protection structures have partially stabilized the bluff. Continued recession of the shoreline during 1995 in the southernmost portion of the section in the vicinity of Good Hope Road appeared to have occurred south of the groin system which was accreting sand on its northern side. The 1977 study reported recession rates for this section of between two and six feet per year.

SHORELINE REACH 11: VILLAGES OF BAYSIDE AND FOX POINT, MILWAUKEE COUNTY, AND CITY OF MEQUON, OZAUKEE COUNTY

Shoreline Reach 11 is a 3.5-mile-long reach of shoreline extending from about Bradley Road extended at the south line of U.S. Public Land Survey Section 10, Township 8 North, Range 22 East, Village of Fox Point in Milwaukee County, north to Ravine Drive extended at the mid-section line of U.S. Public Land Survey Section 28, Township 9 North, Range 22 East, City of Mequon in Ozaukee County, as shown on Map 62. Land uses along this reach include open spaces, including Doctors and Virmond Parks and the Schlitz Audubon Center, and residential lands. As of 1995, about one linear mile, or about 30 percent, of the shoreline in Reach 11 were protected by structural shore protection measures, consisting of seawalls, revetments, rubble fills, and groins.

Map 62

BLUFF ANALYSIS SECTIONS WITHIN REACH 11



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

As shown on Map 62, Reach 11 was further segmented into four shoreline analysis sections corresponding to the U.S. Public Land Survey sections, or portions thereof, for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the four shoreline analysis sections in Reach 11.

U.S. Public Land Survey Section 10, Township 8 North, Range 22 East, Villages of Bayside and Fox Point, Milwaukee County

This shoreline analysis section extends from Bradley Road extended, in the Village of Fox Point, north to Brown Deer Road extended in the vicinity of the northern boundary of the Schlitz Audubon Center, in the Village of Bayside, as shown on Map 63. In 1995, the lakeshore area was occupied by parklands, including Doctors Park and the Schlitz Audubon Center, and residential lands. In 1995, the section was protected by a variety of shoreline protection structures, including revetments, riprap fills, and groins. The section was fronted by a beach up to about 125 feet in width. A natural terrace of about 15 feet in height fronted the bluff. The bluff in this section was about 100 feet in height. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by sand and gravel, overlain by till. For analysis purposes, Section 10 was further subdivided into three erosion zones, as shown on Map 63. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three erosion zones in Section 10.

Erosion Zone 10a

Erosion Zone 10a extends from Bradley Road extended north about 0.35 mile to a point on the lakeshore adjacent to the southernmost extent of Allen Lane, in the Village of Fox Point, as shown on Map 63. This zone had a beach of up to 37.5 feet in width fronting the bluff terrace which had a height of about 15 feet. The bluff terrace was protected by a number of shoreline protection structures, including seawalls and revetments. Vegetation covered about 100 percent of the bluff slope.

No bluff stability analyses were conducted within Erosion Zone 10a in this study or in 1976.

The beach ranged up to about 37.5 feet in width within Erosion Zone 10a. In the 1977 study, the beach width was reported to be about 30 feet, and the beach material was reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 10a were estimated at two locations. These data indicated a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated that most of the recession occurred prior to 1975, with a recession of about -10 feet, or about -0.5 foot per year, occurring between 1975 and 1995. Thus, it appeared that the sea wall and revetment located within this zone had largely stabilized the bluff terrace. The 1977 study reported a recession rate of one foot per year for this zone.

Erosion Zone 10b

Erosion Zone 10b extends from the northernmost point of Erosion Zone 10a, in the Village of Fox Point, north about 0.3 mile to about the northern boundary of Doctors Park, in the Village of Bayside, as shown on Map 63. This zone had a beach of up to 125 feet in width, contained within a groin system, fronting the bluff which had a height of about 100 feet. The bluff was protected by a natural concentration of boulders along the water's edge. In the southern portion of the zone, a poorly maintained seawall and revetment was located at the base of the bluff. In the central portion of the zone, adjacent to Doctors Park, the bluff was protected by a groin system. In 1995, signs of small shallow slides in localized areas of the zone and evidence of creep were present. The bluff slope was approximately 100 percent vegetated within this zone.

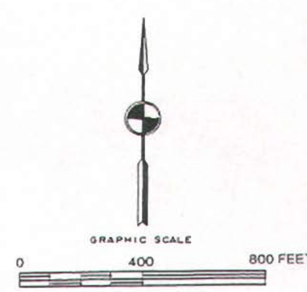
In 1995, one bluff profile field survey was made within Erosion Zone 10b by occupying a site for which a field survey was conducted in 1987. The reoccupied site had a significantly different geometry to that documented in 1987. The bluff slope appeared to have become less steeply sloped, and the beach appeared to have become significantly wider. The stability of the bluff in Erosion Zone 10b of Reach 11 was characterized by Profile No. 11-1. Results of the slope stability analysis, shown in Figure 62, indicated that the bluff was stable in the zone, with a safety factor of 1.86. The 1987 study reported a bluff safety factor of 1.22.

The beach ranged up to about 125 feet in width within Erosion Zone 10b, with the widest portions of the beach contained within the groin system in the central portion of the zone. In the 1977 study, the beach width was reported to be about 15 feet, and the beach material was reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Map 63

SHORELINE EROSION REACH 11: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 10, Township 8 North, Range 22 East
Villages of Bayside and Fox Point, Milwaukee County



LEGEND

PROFILE SITE LOCATION

11-1 PROFILE NUMBER: 1995 FIELD INVENTORY

82-10 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

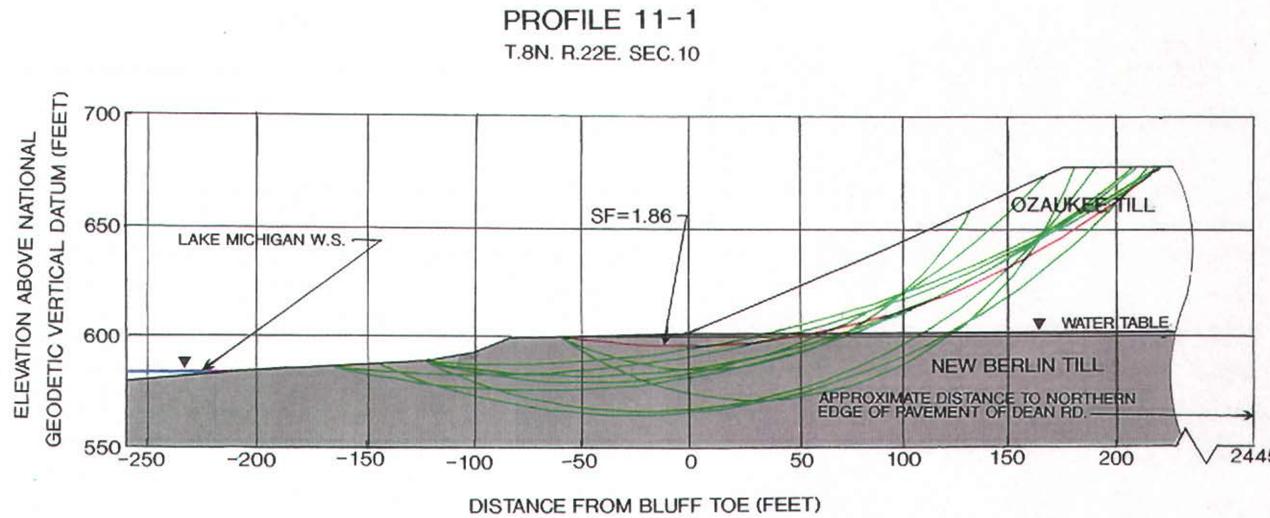
10b EROSION ANALYSIS ZONE NUMBER

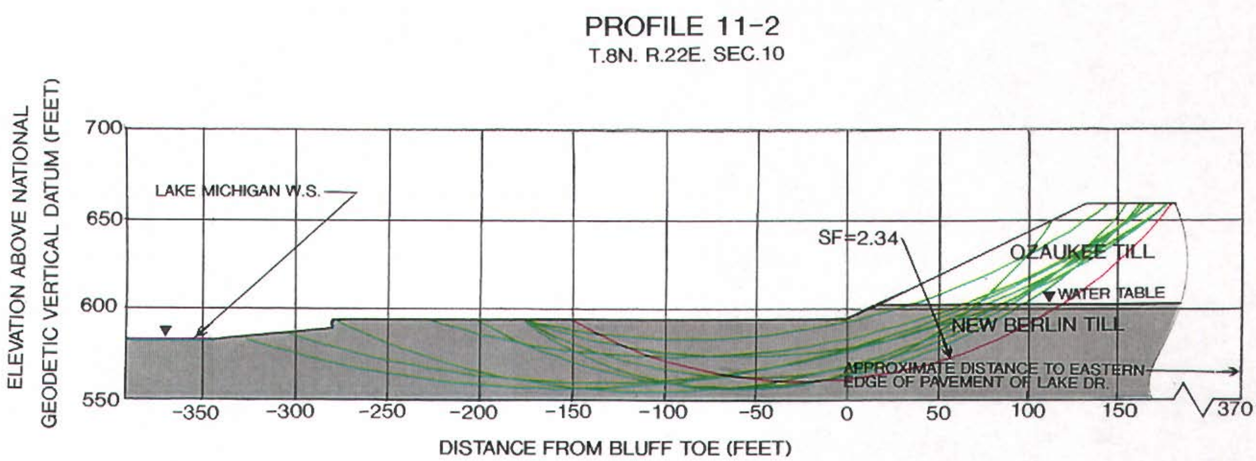
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 62

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 10, Township 8 North, Range 22 East
Village of Bayside, Milwaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Shoreline recession data for Erosion Zone 10b were estimated at one location. These data indicated a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. Thus, it appeared that the sea wall and revetment located within the southern portion of this zone was ineffective in stabilizing the bluff. The 1977 study did not report a recession rate for this zone.

In 1995, the sea wall and revetment in the southern portion of this zone appeared to be poorly maintained. In places, waves broke directly against the shoreline protection structures and appeared to overtop the structures.

Erosion Zone 10c

Erosion Zone 10c extends from about the northern boundary of Doctors Park north about 0.35 mile to the north section line of Section 10 at about Brown Deer Road extended, in the Village of Bayside, as shown on Map 63. This zone had a beach of between 50 and 170 feet in width, with the widest portion of the beach located in the southern portion of the zone north of the groin system contained within Erosion Zone 10b located immediately south of Zone 10c. The bluff had a height of about 100 feet within this zone. A terrace of about 15 feet in height and up to 275 feet in width fronted the bluff within this zone. The bluff was unprotected by shoreline protection structures.

In 1995, one bluff profile field survey was made within Erosion Zone 10c by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a similar geometry to that documented in 1987. The stability of the bluff in Zone 10c of Reach 11 was characterized by Profile No. 11-2. Results of the slope stability analysis, shown in Figure 62, indicated that the bluff was stable in the zone, with a safety factor of 2.34. The 1977 study reported a bluff safety factor of 1.39.

The beach ranged up to about 170 feet in width within Erosion Zone 10c, with the wider portion of the beach occurring in the southern portion of the zone adjacent to the groin system within Doctors Park. In the 1977 study, the beach width was reported to be about 25 feet, and the beach material was reported to be sand. In 1995, at Profile No. 11-2, the nearshore lakebed depth of five feet was reached at 102 feet offshore, with the nearshore surface materials reported to be sand. The nearshore lakebed depth of five feet was reached at 100 feet offshore in 1976, with the nearshore surface material reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1987.

Shoreline recession data for Erosion Zone 10c were estimated at two locations. These data indicated a recession of between 10 and 20 feet, or between 0.3 and 0.6 foot per year, occurred between 1963 and 1995. Recession increased from south to north within the zone. The data indicated that most of this recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. Thus, it appeared that the bluff had been only partially stabilized by the shoreline protection structures within this zone. The 1977 study reported a recession rate of one foot per year for this zone.

U.S. Public Land Survey Sections 3 and 4, Township 8 North, Range 22 East, Village of Bayside, Milwaukee County

This shoreline analysis section extends from Brown Deer Road extended north to County Line Road extended, in the Village of Bayside, as shown on Map 64. In 1995, the lakeshore area was occupied by residential lands. In 1995, the section was largely unprotected by shoreline protection structures, except for limited areas in the northern portion of the section. The section was fronted by a beach of between 25 and 50 feet in width. A natural terrace of about 15 feet in height fronted the bluff in the southern portion of the section. The bluff in this section was between 80 and 100 feet in height. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by intermixed sand and silt, overlain by till. For analysis purposes, Sections 3 and 4 were further subdivided into two erosion zones, as shown on Map 64. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the two erosion zones in Sections 3 and 4.

Erosion Zone 3a

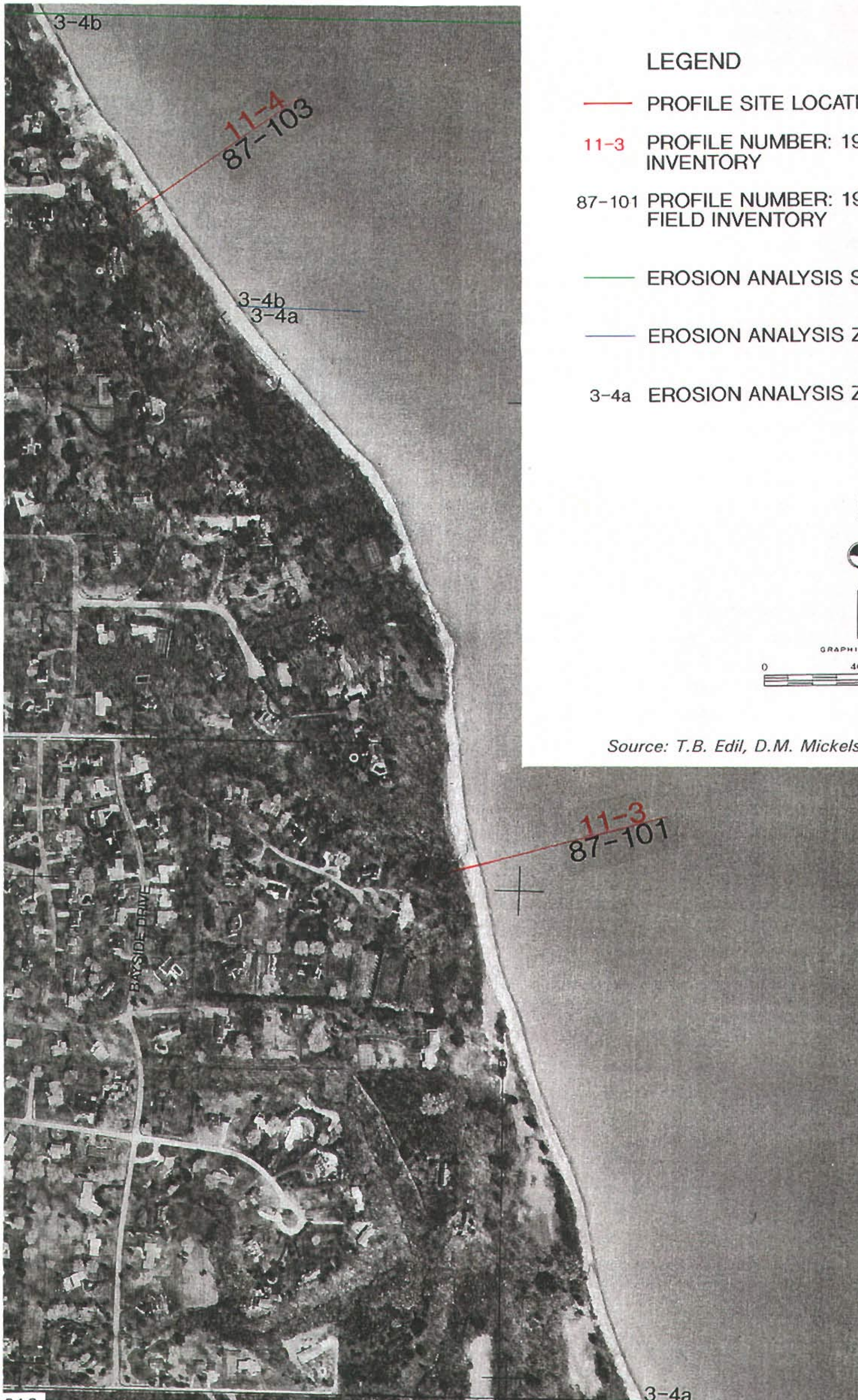
Erosion Zone 3a extends from Brown Deer Road extended north about 0.85 mile to a point on the lakeshore approximately midway between Crocker Place extended and Ravine Lane (Donges Court) extended, in the Village of Bayside, as shown on Map 64. This zone had a beach of up to 50 feet in width fronting the bluff terrace which had a height of about 15 feet. The bluff terrace was unprotected by shoreline protection structures. The bluff was about 100 feet in height within this zone. Vegetation covered about 100 percent of the bluff slope.

In 1995, one bluff profile field survey was made within Erosion Zone 3a by occupying a site for which a field survey was conducted in 1987. The reoccupied site had a slightly different geometry to that documented in 1987. Both the slope of the bluff terrace and the bluff slope appeared to have become less steeply sloped, and the bluff terrace more pronounced in the 1995 survey. The stability of the bluff in Zone 3a of Reach 11 was characterized by Profile No. 11-3. Results of the slope

Map 64

SHORELINE EROSION REACH 11: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 3 and 4, Township 8 North, Range 22 East
Village of Bayside, Milwaukee County



LEGEND

PROFILE SITE LOCATION

11-3 PROFILE NUMBER: 1995 FIELD INVENTORY

87-101 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

3-4a EROSION ANALYSIS ZONE NUMBER

GRAPHIC SCALE

0 400 800 FEET

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

stability analysis, shown in Figure 63, indicated that the bluff was stable in the zone, with a safety factor of 1.39. The 1987 study reported a bluff safety factor of 1.71.

The beach ranged up to about 50 feet in width within Erosion Zone 3a. In the 1977 study, the beach width was reported to be up to 25 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, with sand to the base of the bluff terrace. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 3a were estimated at four locations. These data indicated a recession of between 10 and 50 feet, or between 0.3 and 1.6 feet per year, occurred between 1963 and 1995. Bluff recession generally increased from south to north within the zone. The data indicated that, in the southernmost portion of the zone, most of the recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. The data also indicated a recession of between 10 and 20 feet, or between 0.5 and one foot per year, occurring in the central and northern portions of the zone between 1975 and 1995. Thus, it appeared that the bluff terrace had been largely stabilized in the southern portion of the zone, and partially stabilized in the central and northern portions of the zone. The 1977 study reported a recession rate of one foot per year for this zone.

Erosion Zone 3b

Erosion Zone 3b extends from the northernmost point of Erosion Zone 3a north about 0.2 mile to about the north section line of Section 4 at County Line Road extended, in the Village of Bayside, as shown on Map 64. This zone had a beach of between 25 and 50 feet in width fronting the bluff which had a height of between 80 and 100 feet. The bluff was protected in limited areas by fill and a revetment. In 1995, signs of translational slides and rotational failures, and bluff toe erosion, were present. The bluff slope was approximately 40 percent vegetated within this zone, with masses of vegetation having slid to the bluff toe.

In 1995, one bluff profile field survey was made within Erosion Zone 3b by occupying a site for which a field survey was conducted in 1987. The reoccupied site had a significantly different geometry to that documented in 1987. The bluff slope appeared to have become less steeply sloped, with a more convex shape, above a distinct step of about 30 feet in height. The stability of the bluff in Zone 3b of Reach 11 was characterized by Profile No. 11-4. Results of the slope stability analysis, shown in Figure 63, indicated that the bluff was marginally stable in the zone with respect to rotational failures, with a safety factor of 1.07, based upon the deterministic bluff stability analysis method. Profile No. 11-4 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.71 to 1.5 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 16, or 64 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 149, or 59.6 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered unstable with respect to both rotational and translational failures. The 1987 study reported a bluff safety factor of 0.85.

The beach ranged up to about 50 feet in width within Erosion Zone 3b. In the 1977 study, the beach width was reported to be between 15 and 25 feet, and the beach material was reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 3b were estimated at two locations. These data indicated a recession of between 50 and 70 feet, or between 1.6 and 2.1 feet per year, occurred between 1963 and 1995. The data indicated that most of this recession occurred prior to 1975, with a recession of about 20 feet, or about one foot per year, occurring between 1975 and 1995. Thus, it appeared that the placement of limited fill and revetments had partially stabilized the bluff. The 1977 study reported a recession rate of 0.2 foot per year for this zone.

In 1995, one residence was located on the edge of the bluff, with several other houses in close proximity to the bluff top. It appeared that placement of a revetment and fill had occurred in order to stabilize the bluff at the point where the residence was at the bluff edge. However, it also appeared that the revetment had been overtopped, suggesting that the entire shoreline protection structure at this point was under designed and not wholly effective in stabilizing the bluff. Placement of rubble fill and shoreline protection structures to protect the bluff toe from wave erosion would be required to stabilize the bluff within this zone.

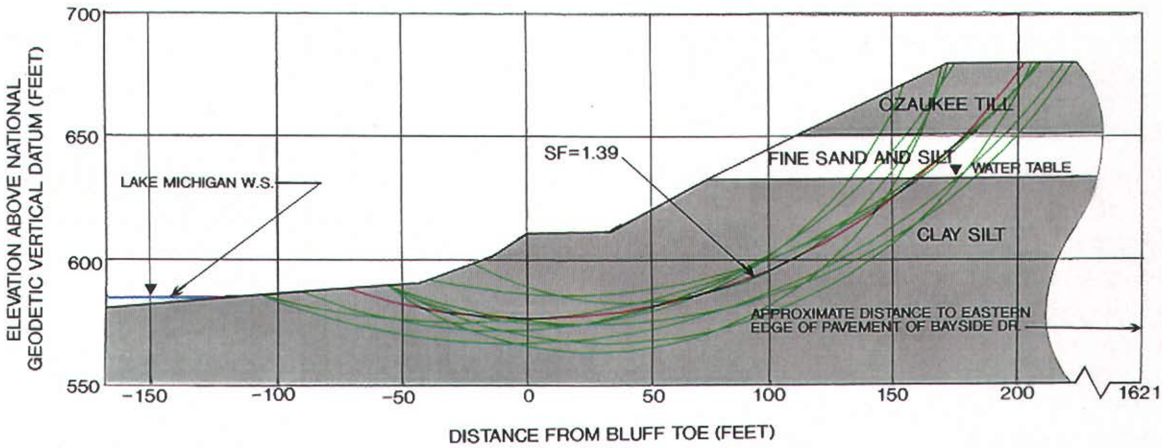
Figure 63

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 10, Township 8 North, Range 22 East
Village of Bayside, Milwaukee County

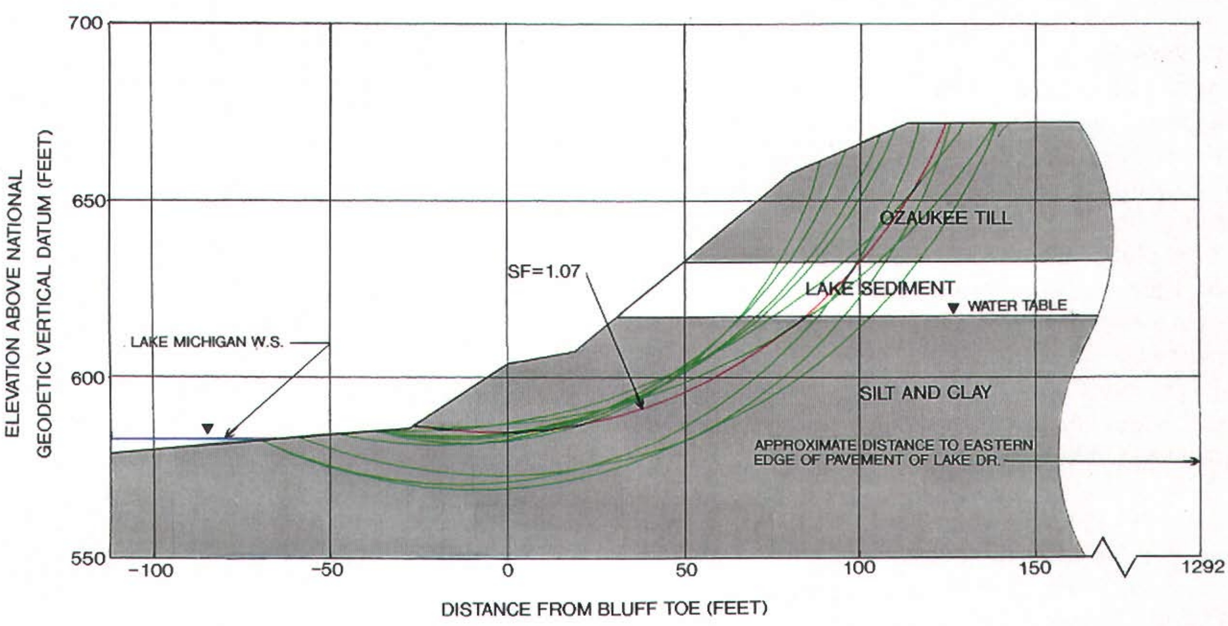
PROFILE 11-3

T.8N. R.22E. SEC.4



PROFILE 11-4

T.8N. R.22E. SEC.4



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

U.S. Public Land Survey Section 33, Township 9 North, Range 22 East, City of Mequon and Village of Bayside, Ozaukee County

This shoreline analysis section extends from County Line Road extended, in the Village of Bayside, north to Donges Bay Road extended, in the City of Mequon, as shown on Map 65. In 1995, the lakeshore area was occupied by residential lands. In 1995, the section was protected by a variety of shoreline protection structures, including revetments, rubble fills, and groins. The section was fronted by a beach up to about 50 feet in width. The bluff in this section was about 80 feet in height. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by silt, overlain by till. For analysis purposes, Section 33 was further subdivided into three erosion zones, as shown on Map 65. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three erosion zones in Section 33.

Erosion Zone 33a

Erosion Zone 33a extends from County Line Road extended, in the Village of Bayside, north to a point of the lakeshore adjacent to the northernmost extent of Pine Lane, in the Village of Bayside, in the vicinity of the boundary between the Village of Bayside and the City of Mequon, as shown on Map 65. This zone had a beach of between 25 and 50 feet in width and fronted a bluff with a height of about 80 feet. In 1995, the bluff was protected by a number of shoreline protection structures, including seawalls, revetments, and rubble fills. Vegetation covered between 30 and 50 percent of the bluff slope.

No bluff stability analyses were conducted within Erosion Zone 33a in this study or in 1976.

The beach ranged up to about 50 feet in width within Erosion Zone 33a. In the 1977 study, the beach width was reported to be between 15 and 25 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, with sand to the bluff toe. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 33a were estimated at two locations. These data indicated a recession of between 40 and 70 feet, or between 1.2 and 2.1 feet per year, occurred between 1963 and 1995. Bluff recession decreased from south to north within the zone. The data indicated that, in the northernmost portion of the zone, most of the recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. The data also indicated, in the southern portion of the zone, a recession of about 20 feet, or about one foot per year, occurring between 1975 and 1995. Thus, it appeared that the fills and revetments placed within this zone during the 1980s had partially stabilized the bluff. The 1977 study reported a recession rate of 0.2 foot per year for this zone.

In 1995, several large residences were observed to be in close proximity to the bluff top within Erosion Zone 33a. The fill and revetments placed within this zone appear to have stabilized the bluff slope at this time.

Erosion Zone 33b

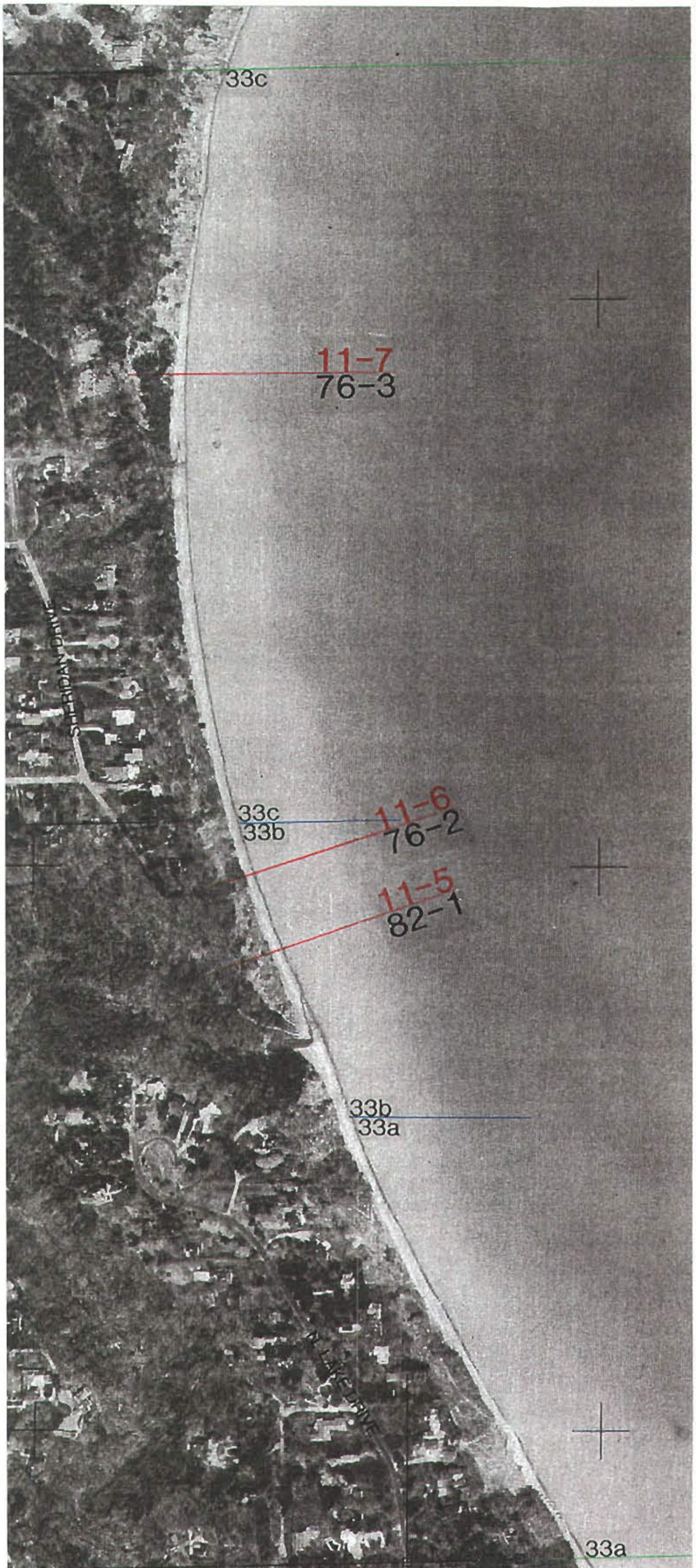
Erosion Zone 33b extends from the northernmost point of Erosion Zone 33a, in the Village of Bayside, north about 0.3 mile to about Zedler Lane extended, in the City of Mequon, as shown on Map 65. This zone had a beach of up to 100 feet in width at the mouth of a large gully located in the central portion of this zone. The bluff had a height of about 100 feet. The bluff was unprotected, except for a small revetment in the southern portion of the zone. In 1995, signs of shallow translational slides and soil creep were present, and in many places, trees appeared to be tilted downslope or were overturned, and the bluff top was scalloped in places. The bluff slope was approximately 50 percent vegetated with trees and shrubs.

In 1995, one bluff profile field survey was made within Erosion Zone 33b by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a significantly different geometry to that documented in 1987. The bluff slope appeared to have become more steeply sloped, with a more distinct scarp at the bluff top. Also in 1995, one bluff profile field survey was made within Erosion Zone 33b by occupying a site for which a field survey was conducted in 1982. The stability of the bluff in Zone 33b of Reach 11 was characterized by Profile Nos. 11-5 and 11-6. Results of the slope stability analysis, shown in Figure 64, indicated that the bluff was unstable in the central portion of the zone, with a safety factor of 0.72, but stable with respect to rotational failures in the northern portion of the zone, with a safety factor of 1.12. The 1995 field observations indicated that translational failures may occur throughout the zone. The 1977 study

Map 65

SHORELINE EROSION REACH 11: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 33, Township 9 North, Range 22 East
City of Mequon and Village of Bayside, Ozaukee County



GRAPHIC SCALE
0 400 800 FEET

LEGEND

PROFILE SITE LOCATION

11-5 PROFILE NUMBER: 1995 FIELD INVENTORY

82-1 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

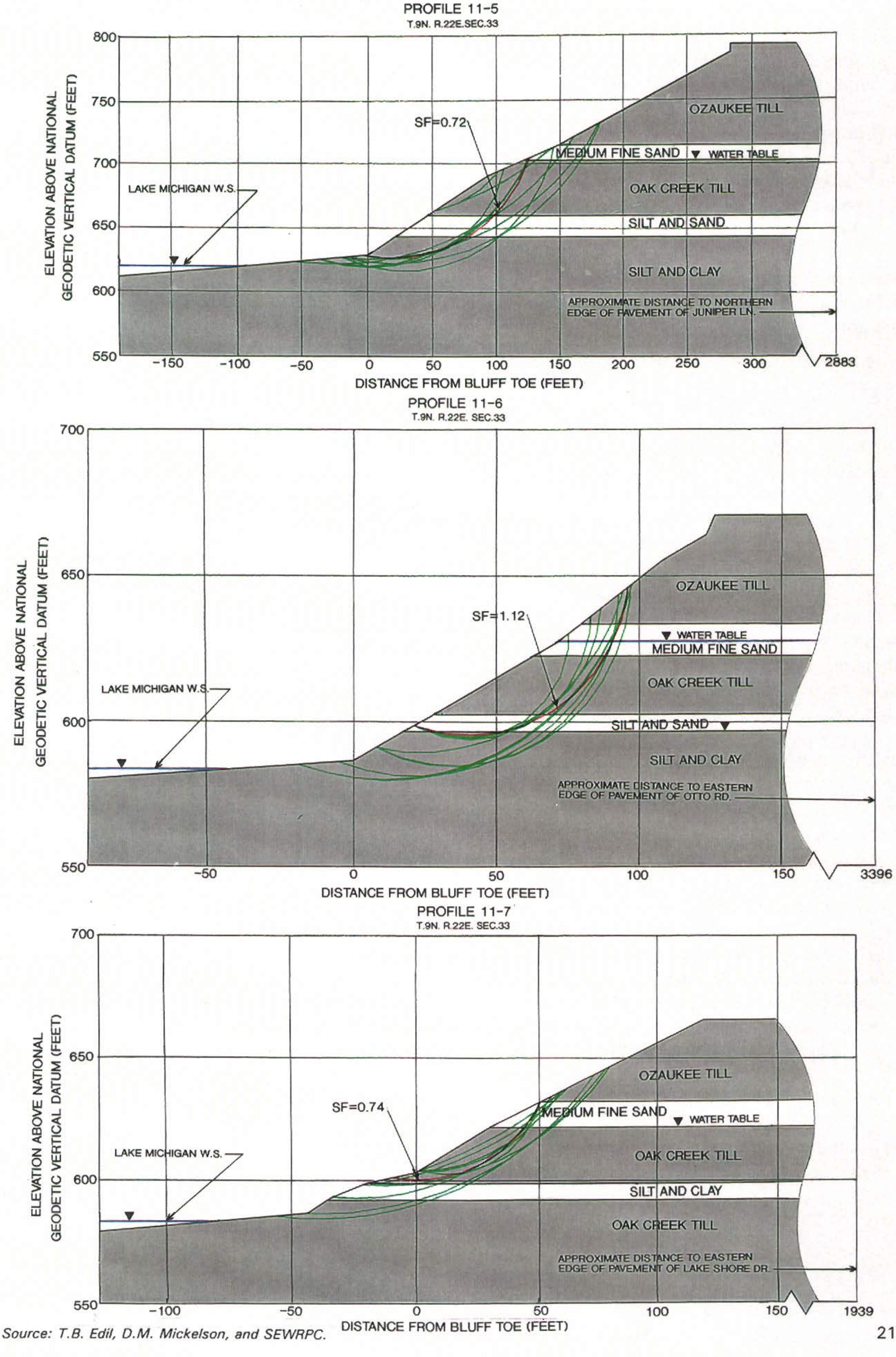
33a EROSION ANALYSIS ZONE NUMBER

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 64

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 33, Township 9 North, Range 22 East
City of Mequon, Ozaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

reported a bluff safety factor of 1.03 at Profile No. 11-6.

The beach ranged up to about 100 feet in width within Erosion Zone 33b. The widest portion of the beach was in the central portion of the zone. In the 1977 study, the beach width was reported to be about 25 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, with sand to the bluff toe. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 33b were not estimated. The 1977 study did not report a recession rate for this zone.

In 1995, erosion was expected to continue within Erosion Zone 33b unless shoreline protection measures are taken in the future.

Erosion Zone 33c

Erosion Zone 33c extends from about Zedler Lane extended north about 0.5 mile to the north line of Section 33 at about Donges Bay Road extended, in the City of Mequon, as shown on Map 65. This zone had a beach of up to 50 feet in width, diminishing in width from south to north. The bluff had a height of about 100 feet within this zone. In 1995, the bluff was unprotected by shoreline protection structures. Signs of shallow slides, in the form of trees that were tipping or rotated, were present.

In 1995, one bluff profile field survey was made within Erosion Zone 33c by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a similar geometry to that documented in 1976. However, the scarp at the bluff top appeared to have been removed, and a slight step was present on the lower bluff slope in the 1995 survey. The stability of the bluff in Zone 33c of Reach 11 was characterized by Profile No. 11-7. Results of the slope stability analysis, shown in Figure 64, indicated that the bluff was unstable with respect to both rotational and translational failures in the zone, with a safety factor of 0.74. The 1977 study reported a bluff safety factor of 1.13.

The beach ranged up to about 50 feet in width within Erosion Zone 33c, but diminished in size to less than 25 feet in width in the northern portion of the zone. In the 1977 study, the beach width was reported to be between 10 and 25 feet, and the beach material was reported to be sand. At Profile No. 11-7, the nearshore lakebed depth of five feet was reached at 45 feet offshore in 1976, with the nearshore surface materials reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 33c were estimated at three locations. These data indicated a recession of about 40 feet, or about 1.2 feet per year, occurred between 1963 and 1995. The data indicated that most of this recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. Thus, it appeared that the bluff was only partially stabilized within this zone. The 1977 study did not report a recession rate for this zone.

In 1995, two boat houses reported to be located at the top of the bluff in the southern portion of this zone during the 1977 study appeared to be in the same position, suggesting that the shoreline within this portion of the zone had been relatively stable. Nevertheless, it also appeared that this zone could be subject to increased recessions of the bluff top during a future higher lake level period.

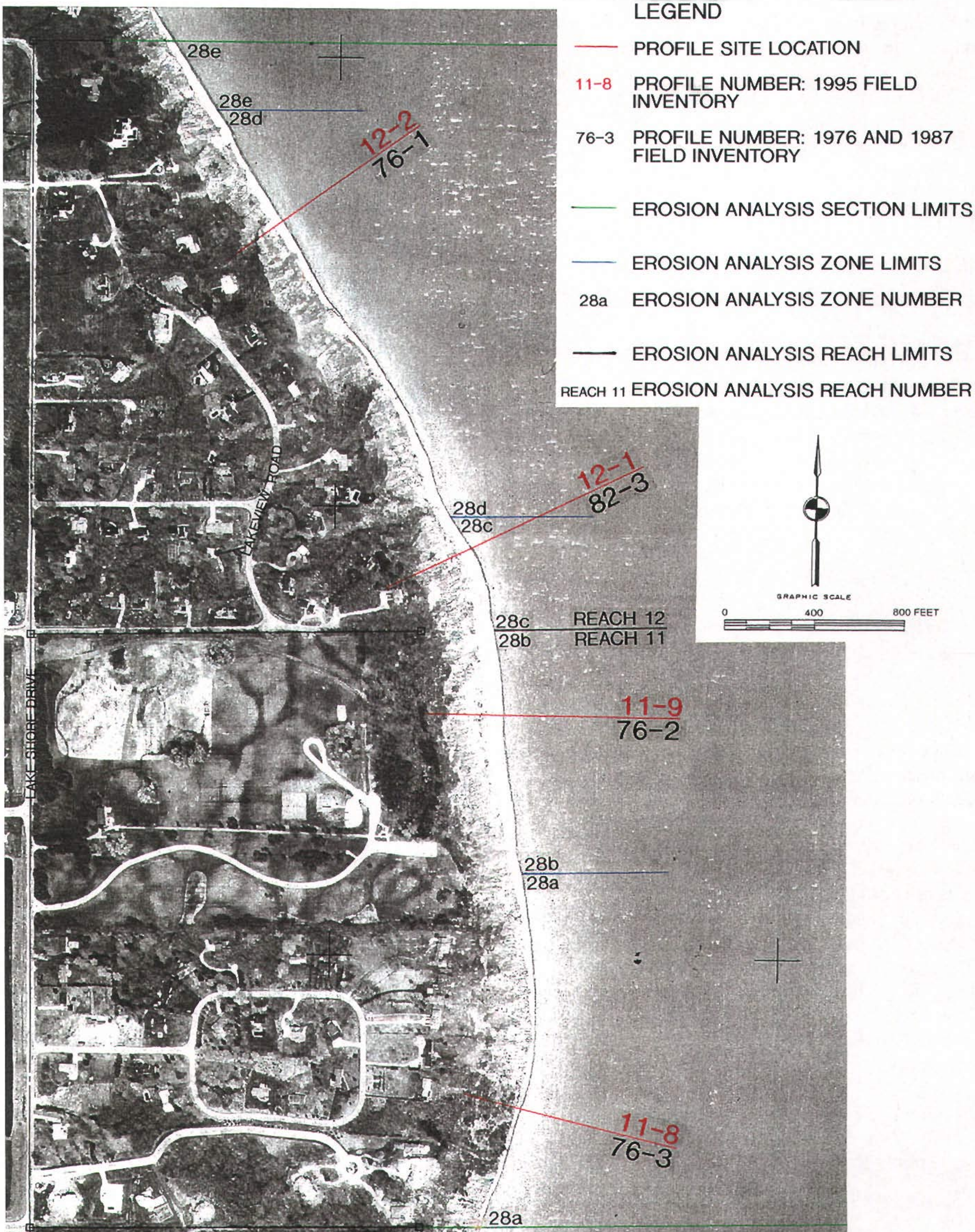
Southern One-Half of U.S. Public Land Survey Section 28, Township 9 North, Range 22 East, City of Mequon, Ozaukee County

This shoreline analysis section extends from Donges Bay Road extended, at the south line of Section 28, north to Ravine Drive extended, at about the mid-section line of Section 28, on the north boundary of Virmond Park, in the City of Mequon, as shown on Map 66. In 1995, the lakeshore area was occupied by parklands, including Virmond Park, and residential lands. In 1995, the section was largely unprotected by shoreline protection structures. The section was fronted by a beach which ranged from about 12.5 feet in width in the southern portion of the section, up to about 100 feet in width at the northern extreme of the reach. The bluff in this section was about 140 feet in height. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by intermixed silt, sand, and till, overlain by till. The composition of the middle portion of the bluff grades from the intermixed stratum in the southern portion of the section, to sand in the central portion of the section, to till in the northern portion of the section. For analysis purposes, Section 28 within Reach 11 was further subdivided into two erosion zones, as shown on Map 66. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the two erosion zones in Section 28, located

Map 66

SHORELINE EROSION REACHES 11 AND 12: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 28, Township 9 North, Range 22 East
City of Mequon, Ozaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

within Reach 11. The inventory and analysis findings for the three further erosion zones, located within Reach 12, are discussed in the following section of this report.

Erosion Zone 28a
Erosion Zone 28a extends from Donges Bay Road extended north about 0.3 mile to a point of the lakeshore adjacent to the southern boundary of Virmond Park, in the City of Mequon, as shown on Map 66. This zone had a beach of between 12.5 and 25 feet in width fronting a bluff with a height of about 140 feet. In 1995, the bluff was unprotected. Vegetation, comprising aspen, juniper, and grasses, covered about 80 percent of the bluff slope. Signs of shallow translational slides were present.

In 1995, one bluff profile field survey was made within Erosion Zone 28a by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a similar geometry to that documented in 1976, although the bluff slope appeared to have become less steeply sloped. The stability of the bluff in Zone 28a of Reach 11 was characterized by Profile No. 11-8. Results of the slope stability analysis, shown in Figure 65, indicated that the bluff was unstable with respect to both rotational and translational failures in the central portion of the zone, with a safety factor of 0.77. The 1977 study reported a bluff safety factor of 0.8.

The beach ranged up to about 50 feet in width within Erosion Zone 28a. In the 1977 study, the beach width was reported to be between 15 and 25 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, with sand to the bluff toe. At Profile No. 11-8, the nearshore lakebed depth of five feet was reached at 50 feet offshore in 1976, with the nearshore surface materials reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 33a were estimated at two locations. These data indicated a recession of between 40 and 100 feet, or between 1.2 and 3.1 feet per year, occurred between 1963 and 1995. Bluff recession increased from south to north within the zone. The data indicated that most of the recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. Thus, the bluff appeared to be partially stabilized within this zone. The 1977 study did not report a recession rate for this zone.

Erosion Zone 28b
Erosion Zone 28b extends from the northernmost point of Erosion Zone 28a north about 0.1 mile through Virmond Park to about Ravine Drive extended, in the City of Mequon, as shown on Map 66. This zone had a beach of up to 100 feet in width. The bluff had a height of about 140 feet. The bluff was unprotected. In 1995, signs of shallow translational slides were present throughout the zone, and evidence of relatively large mudflows was observed in the gullies within this zone. The bluff slope was approximately 50 percent vegetated with trees and shrubs, with the lower one-half to two-thirds of the bluff slope being vegetated with only shrubs.

In 1995, one bluff profile field survey was made within Erosion Zone 28b by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a significantly different geometry to that documented in 1976. The bluff slope appeared to have become less steeply sloped. The stability of the bluff in Zone 28b of Reach 11 was characterized by Profile No. 11-9. Results of the slope stability analysis, shown in Figure 65, indicated that the bluff was unstable with respect to both rotational and translational failures, with a safety factor of 0.69. The 1977 study reported a bluff safety factor of 0.69.

The beach ranged up to about 100 feet in width within Erosion Zone 28b. The widest portion of the beach was in the northern portion of the zone. In the 1977 study, the beach width was reported to be between 15 and 25 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, with sand to the bluff toe. In 1995, at Profile No. 11-9, the nearshore lakebed depth of five feet was reached at 65 feet offshore, with the nearshore surface materials reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1976 or in 1987.

Shoreline recession data for Erosion Zone 28b were not estimated. The 1977 study did not report a recession rate for this zone.

In 1995, erosion was expected to continue within Erosion Zone 28b unless shoreline protection measures are taken in the future.

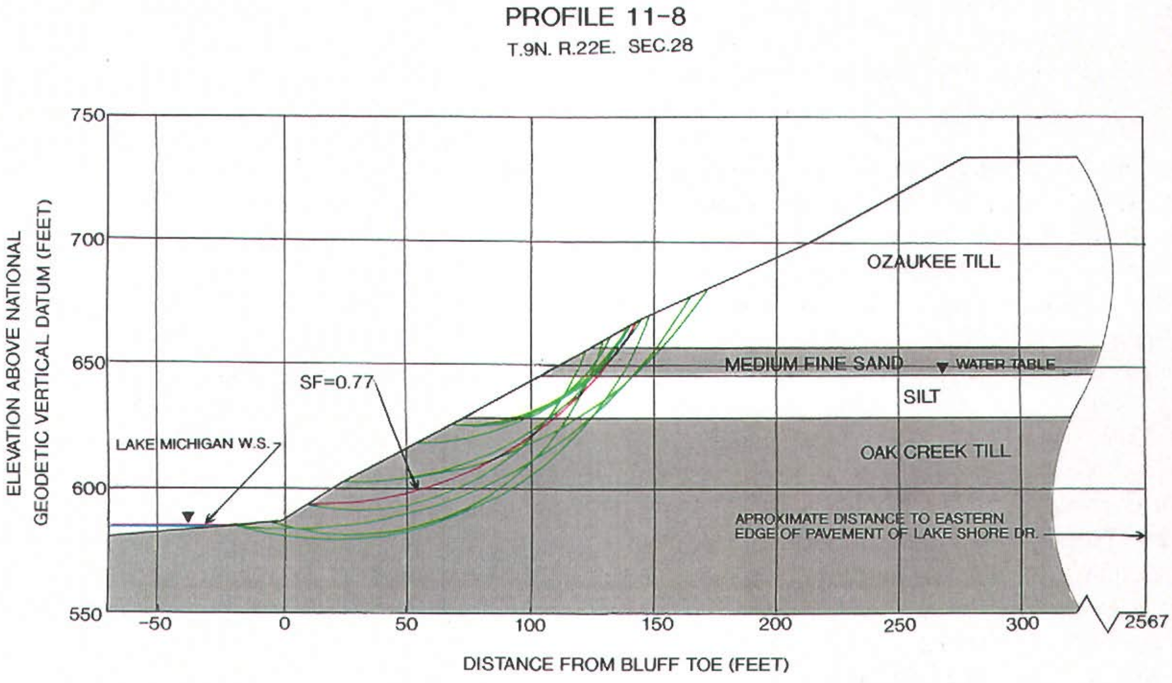
SHORELINE REACH 12: CITY OF MEQUON AND TOWN OF GRAFTON, OZAUKEE COUNTY

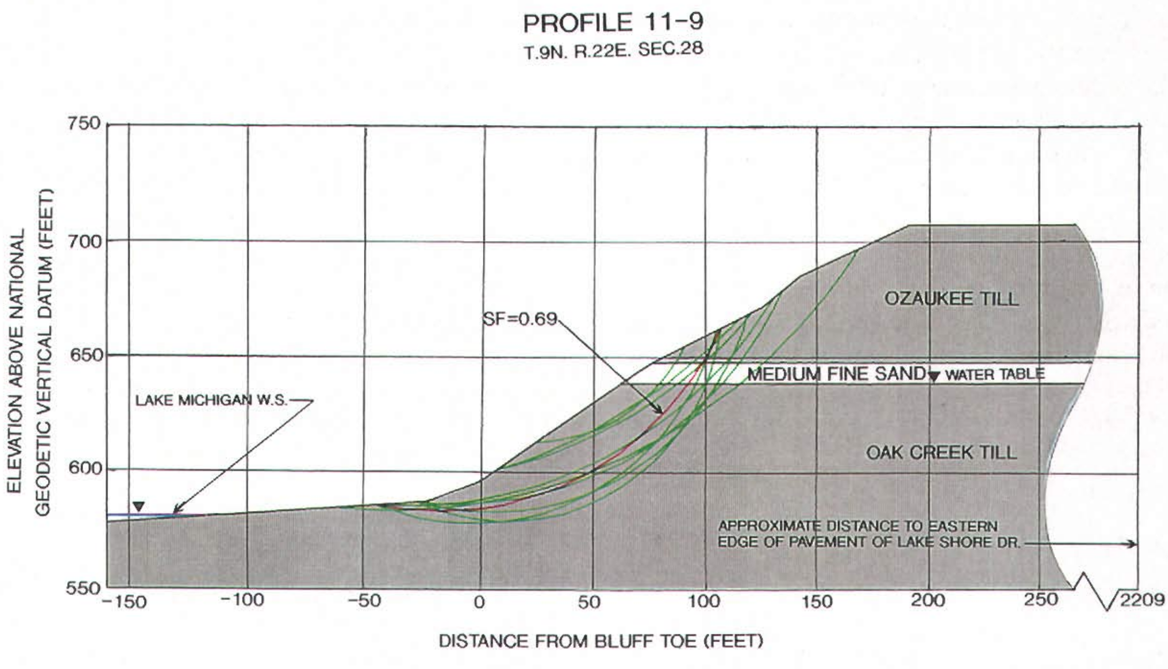
Shoreline Reach 12 is a 6.5-mile-long reach of shoreline extending from about Ravine Drive on the northern boundary of Virmond Park at the mid-section line of U.S. Public Land Survey Section 28, Township 9 North,

Figure 65

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 28, Township 9 North, Range 22 East
City of Mequon, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Range 22 East, City of Mequon, north to Falls Road extended at the north section line of U.S. Public Land Survey Section 28, Township 10 North, Range 22 East, Town of Grafton in Ozaukee County, as shown on Map 67. Land uses along this reach include residential and open space lands. As of 1995, about one linear mile, or about 10 percent, of the shoreline in Reach 12 was protected by structural shore protection measures, consisting of seawalls, revetments, rubble fills, and groins.

As shown on Map 67, Reach 12 was further segmented into seven shoreline analysis sections corresponding to the U.S. Public Land Survey sections, or portions thereof, for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the seven shoreline analysis sections in Reach 12.

Northern One-Half of U.S. Public Land Survey Section 28, Township 9 North, Range 22 East, City of Mequon, Ozaukee County

This shoreline analysis section extends from Ravine Drive at the northern boundary of Virmond Park north to Mequon Road extended, at the north line of Section 28, in the City of Mequon, as shown on Map 66. In 1995, the lakeshore area was occupied by parklands, including Virmond Park, and residential lands. In 1995, the section was unprotected by shoreline protection structures. The section was fronted by a beach which ranged from narrow to nonexistent to about 100 feet in width at the southern extreme of the reach. The bluff in this section was about 140 feet in height. The bluff materials in this section were generally covered, but were estimated to be primarily till overlain by sand, overlain by till. The composition of the middle portion of the bluff grades from sand in the southern portion of the section to till in the northern portion of the section. For analysis purposes, Section 28 within Reach 12 was further subdivided into three erosion zones, as shown on Map 66. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three remaining erosion zones in Section 28, located within Reach 12. The inventory and analysis findings for Erosion Zones 28a and 28b, located within Reach 11, are discussed above.

Erosion Zone 28c

Erosion Zone 28c extends from about Ravine Drive extended north about 0.1 mile to about N. Point Road extended, in the City of Mequon, as shown on Map 66. This zone had a beach of about 50 to 100 feet in width, diminishing in width from south to north. The bluff had a height of about 140 feet within this zone. In 1995, the bluff was unprotected by shoreline protection structures. In 1995, signs of shallow translational slides were present throughout the zone, and evidence of relatively large mudflows was observed in the gullies within this zone. The bluff slope was approximately 50 percent vegetated with trees and shrubs, with the lower one-half to two-thirds of the bluff slope being vegetated with only shrubs.

In 1995, one bluff profile field survey was made within Erosion Zone 28c by occupying a site for which a field survey was conducted in 1982. The stability of the bluff in Zone 28c of Reach 12 was characterized by Profile No. 12-1. Results of the slope stability analysis, shown in Figure 66, indicated that the bluff was unstable with respect to both rotational and translational failures, with a safety factor of 0.57. The 1977 study did not report a bluff safety factor.

The beach ranged up to about 100 feet in width within Erosion Zone 28c. The widest portion of the beach was in the southern portion of the zone. In the 1977 study, the beach width was reported to be between 15 and 25 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, with sand to the bluff toe. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 28c were estimated at one location. These data indicated a recession of about 20 feet, or about 0.6 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. Thus, the bluff appeared not to be stabilized within this zone. The 1977 study did not report a recession rate for this zone.

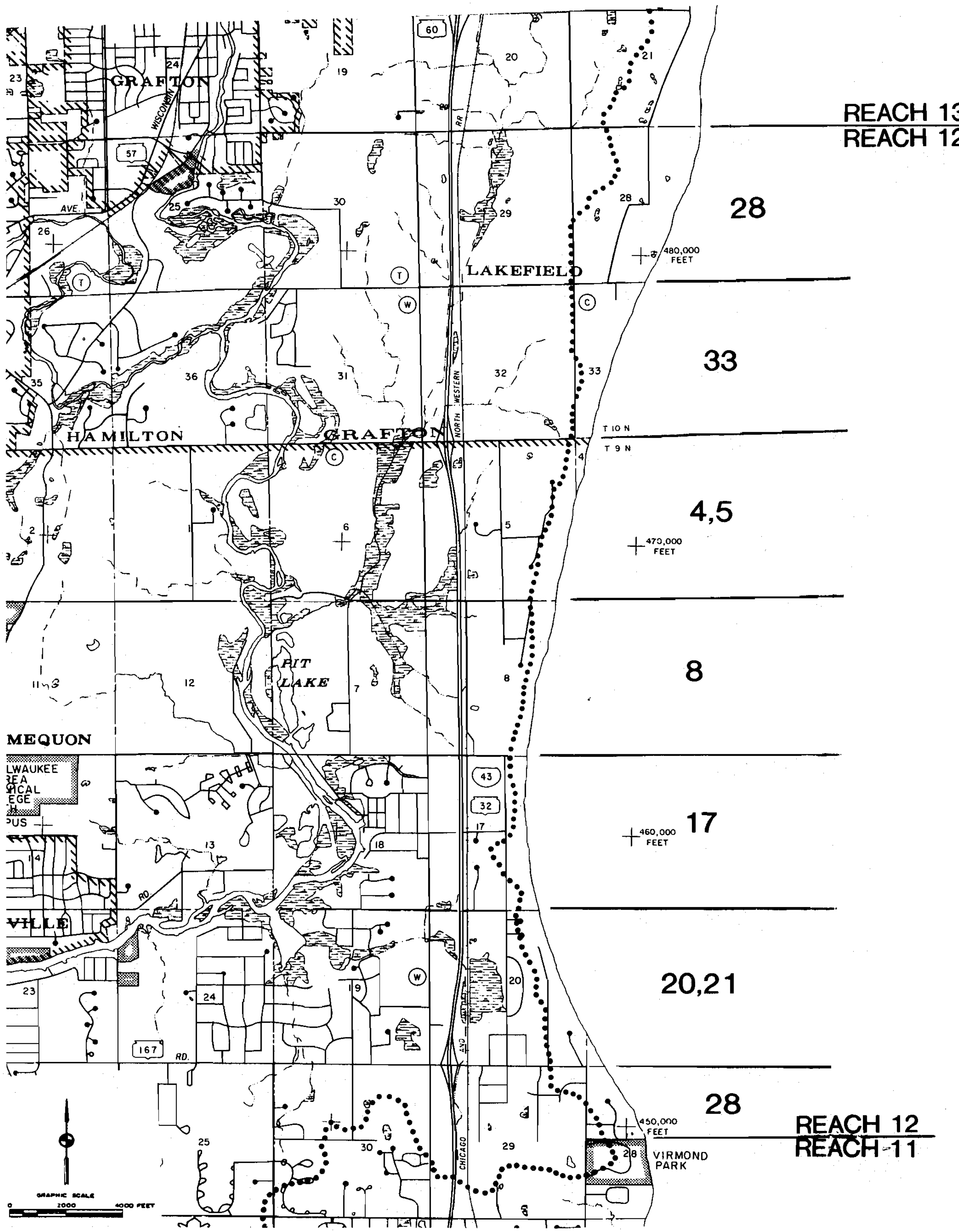
In 1995, erosion was expected to continue within Erosion Zone 28c unless shoreline protection measures are taken in the future.

Erosion Zone 28d

Erosion Zone 28d extends from about N. Point Road extended north about 0.4 mile to a point on the lakeshore approximately midway between Highview Drive extended and Mequon Road extended, in the City of Mequon, as shown on Map 66. This zone had a beach of up to 25 feet in width. The bluff had a height of about

Map 67

BLUFF ANALYSIS SECTIONS WITHIN REACH 12

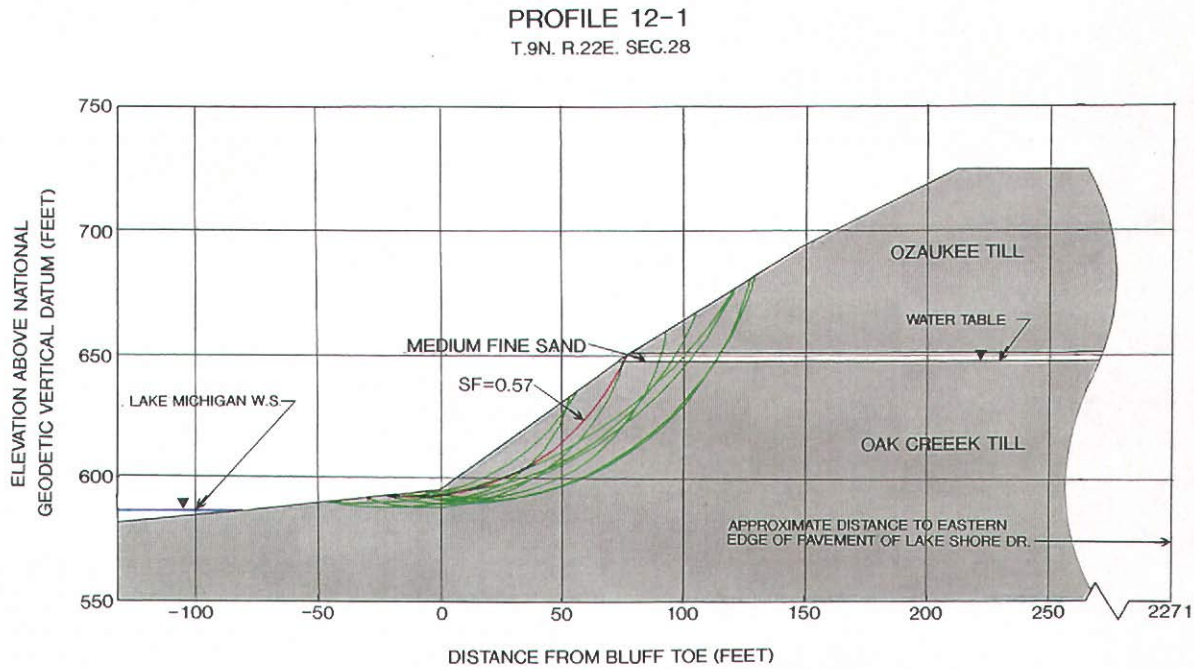


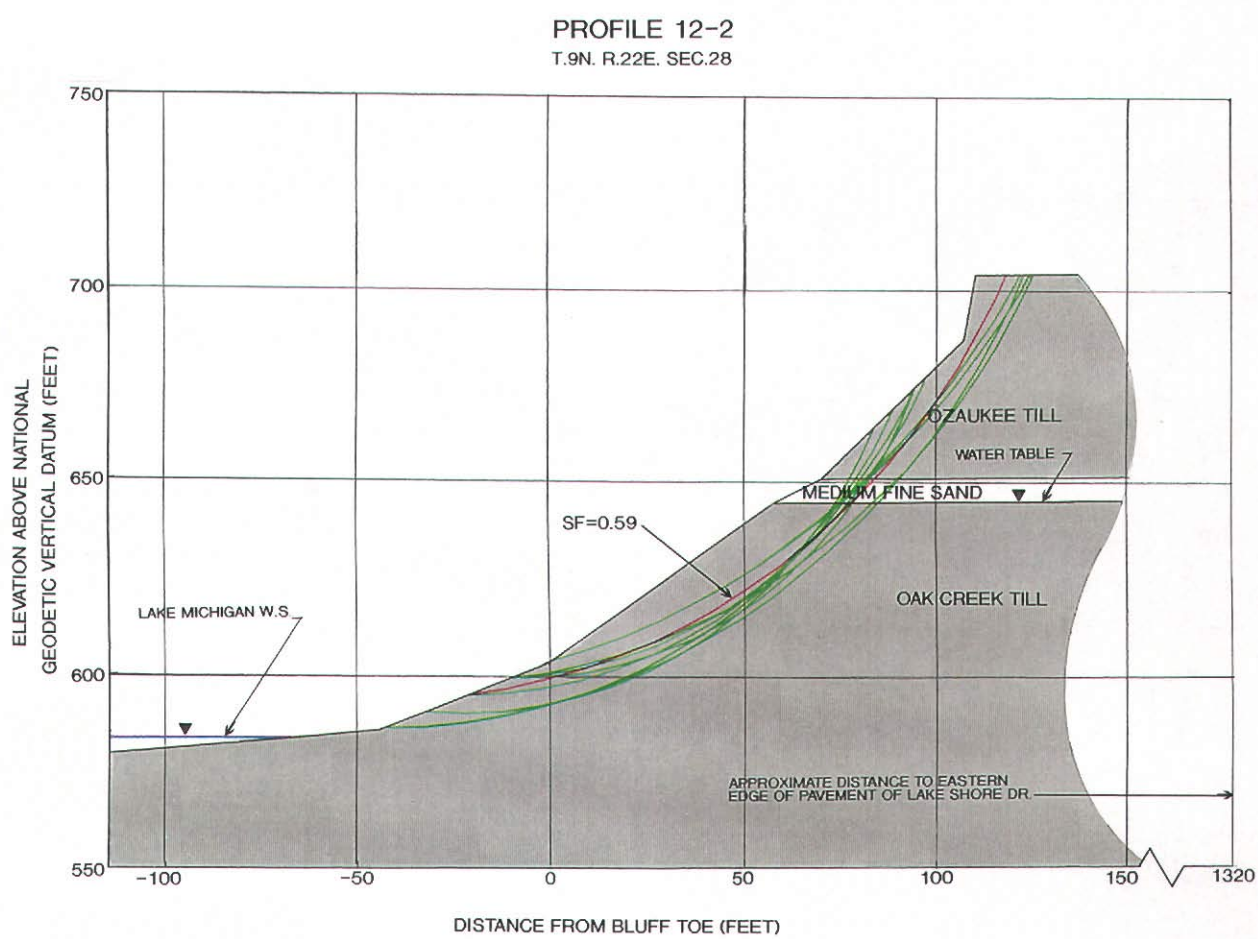
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 66

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 28, Township 9 North, Range 22 East
City of Mequon, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

140 feet within this zone. In 1995, the bluff was unprotected by shoreline protection structures. In 1995, signs of shallow translational slides were present throughout the zone, and evidence of relatively large mudflows was observed in the gullies within this zone. The bluff slope was approximately 50 percent vegetated. Numerous trees, formerly on the bluff slope, were observed at the top of the beach amongst slide debris. This material was being eroded by wave action.

In 1995, one bluff profile field survey was made within Erosion Zone 28d by occupying a site for which a field survey was conducted in 1976. The site had a similar geometry to that documented in 1976, but the downward movement of material on the bluff face had slightly flattened the bluff slope and accentuated the scarp at the bluff top. The stability of the bluff in Zone 28d of Reach 12 was characterized by Profile No. 12-2. Results of the slope stability analysis, shown in Figure 66, indicated that the bluff was unstable with respect to both rotational and translational failures, with a safety factor of 0.59. The 1977 study reported a bluff safety factor of 0.68.

The beach ranged up to about 50 feet in width within Erosion Zone 28d. The widest portion of the beach was in the southern and northern portions of the zone. A mudslide in the central portion of the zone significantly reduced the beach width. In the 1977 study, the beach width was reported to be between 15 and 25 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, with sand to the bluff toe. In 1995, at Profile No. 12-2, the nearshore lakebed depth of five feet was reached at 176 feet offshore, with the nearshore surface materials reported to be sand. At Profile No. 12-2, the nearshore lakebed depth of five feet was reached at 100 feet offshore in 1976, with the nearshore surface materials reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1987.

Shoreline recession data for Erosion Zone 28d were estimated at one location. These data indicated a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 30 feet, or about 1.5 feet per year, occurring between 1975 and 1995. The 1977 study did not report a recession rate for this zone.

In 1995, the bluff top in Erosion Zone 28d was observed to be actively retreating through mudflows and slides, with the material accumulating at the bluff toe being removed by wave erosion. It may be anticipated that such toe erosion will increase during future periods of higher lake levels, again causing an over-steepening of the bluff slope leading to further slides and bluff top retreat, unless shoreline protection measures are taken in the future.

Erosion Zone 28e

Erosion Zone 28e extends from a point on the lakeshore approximately midway between Highview Drive extended and Mequon Road extended north about 0.1 mile to Mequon Road extended, in the City of Mequon, as shown on Map 66. This zone had a beach of about 25 feet in width. The bluff had a height of about 140 feet within this zone. In 1995, the bluff was unprotected by shoreline protection structures. In 1995, signs of shallow translational slides were present throughout the zone, and evidence of soil creep was observed in the lower portions of the bluff slope within this zone. The bluff slope was approximately 50 percent vegetated with aspen and birch, with maple and basswood present in protected gullies.

No bluff stability analyses were conducted within Erosion Zone 28e in this study or in 1976.

The beach ranged up to about 25 feet in width within Erosion Zone 28e. In the 1977 study, the beach width was reported to be between 15 and 25 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, with sand to the bluff toe. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 28e were estimated at one location. These data indicated a recession of about 70 feet, or about 2.2 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 30 feet, or about 1.5 feet per year, occurring between 1975 and 1995. The 1977 study did not report a recession rate for this zone.

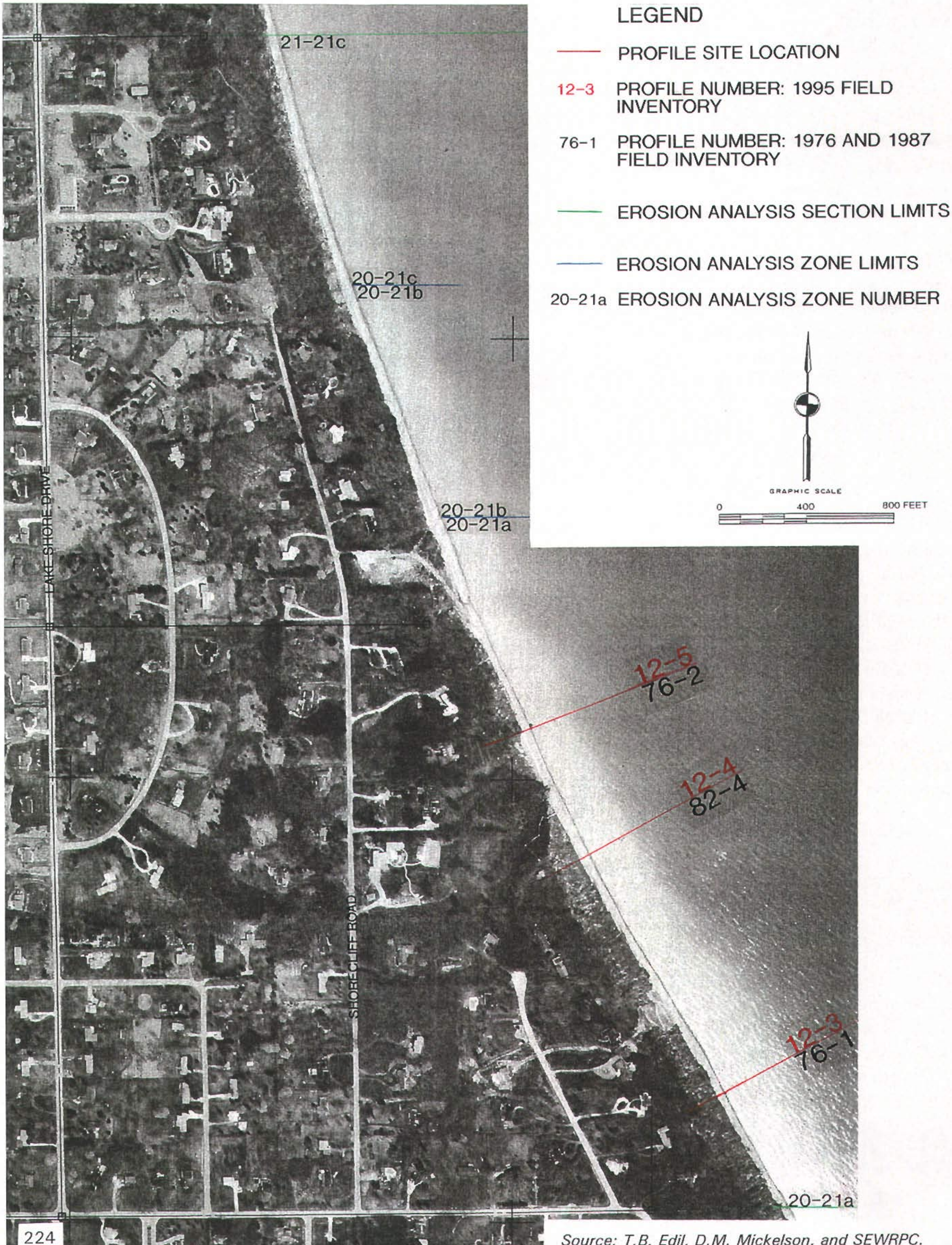
U.S. Public Land Survey Sections 20 and 21, Township 9 North, Range 22 East, City of Mequon, Ozaukee County

This shoreline analysis section extends from Mequon Road north to Oaks Lane, as shown on Map 68. The shoreline area of this section was occupied by residential lands, consisting mainly of single-family residences. The bluff in this section ranged in height from 80 to 110 feet. The beach in this section ranged in width from 30 to 50 feet. The 1995 field observations indicated that most of the bluff was failing, with the exception of the

Map 68

SHORELINE EROSION REACH 12: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 20 and 21, Township 9 North, Range 22 East
City of Mequon, Ozaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

areas being protected by revetments, and even these areas appear to be experiencing minor failure and soil creep behind them. For further analysis, Section 21 was further subdivided into three erosion zones, as shown on Map 68. The inventory and analysis findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the three zones.

Erosion Zone 21a

This shoreline analysis section extends from the south line of the section north about 0.6 mile, as shown on Map 68. The beach in this zone ranged between 10 and 30 feet fronting a bluff of about 80 feet in height. The bluff slope in Zone 21a was about 50 percent vegetated. No shoreline protection structures existed, with the exception of one seawall, which, according to the photographs, was built sometime between 1988 and 1994. The 1995 field observations indicated that erosion was occurring by shallow translational slides and some small slumps on the upper part of the bluff. Mudflows were reported as active in the existing gullies.

In 1995, three profile field surveys were made within Zone 21a by occupying sites for which field surveys were conducted in 1976 and 1982. The stability of the bluff in Erosion Zone 21a was characterized by Profile Nos. 12-3 through 12-5. Results of the slope stability analysis, shown in Figure 67, indicated that the bluff was unstable to marginally stable with respect to rotational failures, with safety factors of 1.0 at Profile No. 12-3, 0.95 at Profile No. 12-4, and 1.03 at Profile No. 12-5, based upon the deterministic bluff stability analysis method. Profile Nos. 12-3 through 12-5 were also analyzed using the probabilistic bluff stability analysis method. At Profile No. 12-3, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.88 to 1.4 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for five, or 20 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 20, or 8 percent, of the 250 conditions analyzed. At Profile No. 12-4, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.93 to 1.38 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for six, or 24 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 34, or 13.6 percent, of the 250 conditions analyzed. At Profile No. 12-5, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.82 to 1.5 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for five, or 20 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 32, or 12.8 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable to stable with respect to rotational failures. The 1995 field observations indicated that translational failures may occur. The 1977 study reported safety factors of 1.05 and 0.86 at Profile Nos. 12-3 and 12-5 from south to north within this zone. The 1982 study did not report a safety factor for Profile No. 12-4.

In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be sand with gravel. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 21a were estimated at two locations. The data indicated that a recession of between 20 and 40 feet, or between 0.6 and 1.2 feet per year, occurred between 1963 and 1995. Most that recession appeared to have occurred prior to 1975, with a recession of between zero and 10 feet, or between zero and 0.5 foot per year, occurring between 1975 and 1995. The 1977 study reported a recession rate of two feet per year for this zone.

Erosion Zone 21b

Erosion Zone 21b extends from the northerly limits of Erosion Zone 21a north about 0.02 mile, as shown on Map 68. The beach in this zone was about 50 feet in width. The entire shoreline was protected revetment and seawall. The seawalls were present in the 1977 study, but the revetment has been extended one property northward and southward since that time. In addition, a revetment has been placed in front of the seawall, providing more protection. The bluff slope was reported as 100 percent vegetated with spruce, cedar, maple, basswood, and birch and was stable, with the exception of the north end, where there appeared to be some wave overtopping of the revetment and bluff toe erosion occurring.

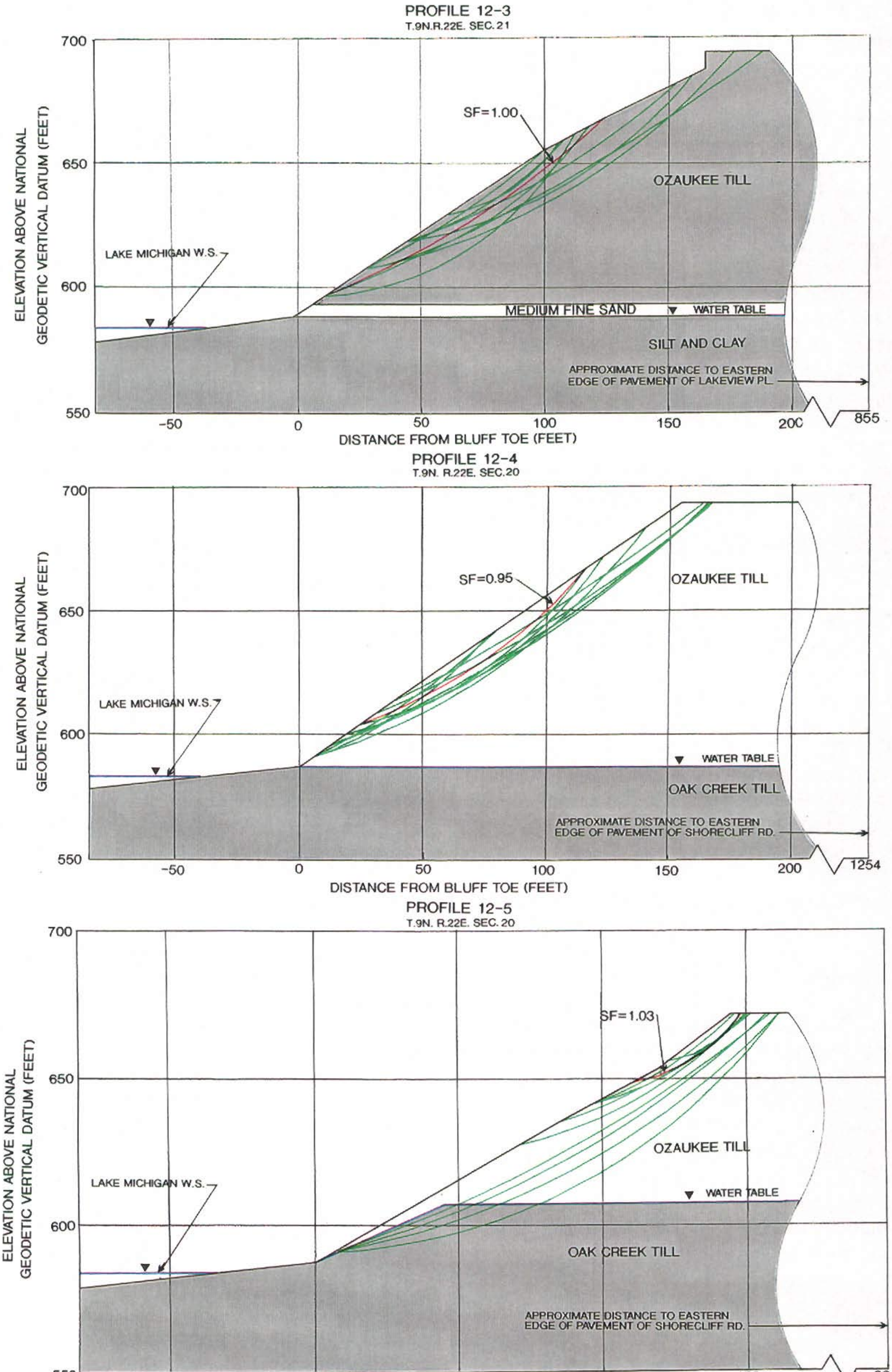
No bluff stability analyses were conducted within Erosion Zone 21b during this study or the 1977 study.

In 1995, the beach within Zone 21b was about 50 feet in width. In the 1977 study, the beach width was reported

Figure 67

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Sections 20 and 21, Township 9 North, Range 22 East
City of Mequon, Ozaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

to be about 20 feet, and the beach material was reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 21b were estimated at one location. The data indicated that no significant recession had occurred between 1963 and 1995.

Erosion Zone 21c

Erosion Zone 21c extends from the northerly limits of Erosion Zone 21b north to the north line of the section, as shown on Map 68. The beach in this zone was about 50 feet in width. The shoreline in this zone is unprotected. The upper one-third of the bluff slope was reported as being vegetated with mature trees. The lower portion of the bluff shows evidence of translational sliding that is similar to what was taking place at this site in 1976.

During the 1977 study, one bluff stability analyses was conducted within Zone 21c which had a safety factor of 0.65. It was not remeasured in 1995 because of difficulty of access.

In 1995, the beach within Zone 21b was about 50 feet in width. In the 1977 study, the beach width was reported to be about 20 feet, and the beach material was reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

No shoreline recession data for Erosion Zone 21b was estimated.

U.S. Public Land Survey Section 17, Township 9 North, Range 22, City of Mequon, Ozaukee County

This shoreline analysis section extends from Glen Oaks Lane extended north to Highland Road extended, in the City of Mequon, as shown on Map 69. In 1995, the lakeshore area was occupied by residential lands. In 1995, the section was protected by a variety of shoreline protection structures, including rubble fills, revetments, and groins. The section was fronted by a beach of between 25 and 75 feet in width, with the widest area of beach located in the central portion of the section. The bluff in this section was about 100 feet in height. The bluff materials in this section were generally covered, but were estimated to be primarily intermixed silt and clay and sand and till, overlain by till. For analysis purposes, Section 17 was further subdivided into five erosion zones, as shown on Map 69. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the five erosion zones in Section 17.

Erosion Zone 17a

Erosion Zone 17a extends from the south line of Section 17 at Glen Oaks Road extended, in the City of Mequon, north about 0.2 mile, as shown on Map 69. This zone had a beach of up to 50 feet in width fronting the bluff which had a height of about 100 feet. The bluff was protected by a number of shoreline protection structures, including a revetment and small groins. Vegetation, comprising grasses, horsetails, sumac, and juniper, covered approximately 75 percent of the bluff slope. In 1995, signs of shallow translational slides and earthflows in the ravines were present, and small scarps were observed. The 1995 field observations indicated that there have been no visible changes in the bluff slope.

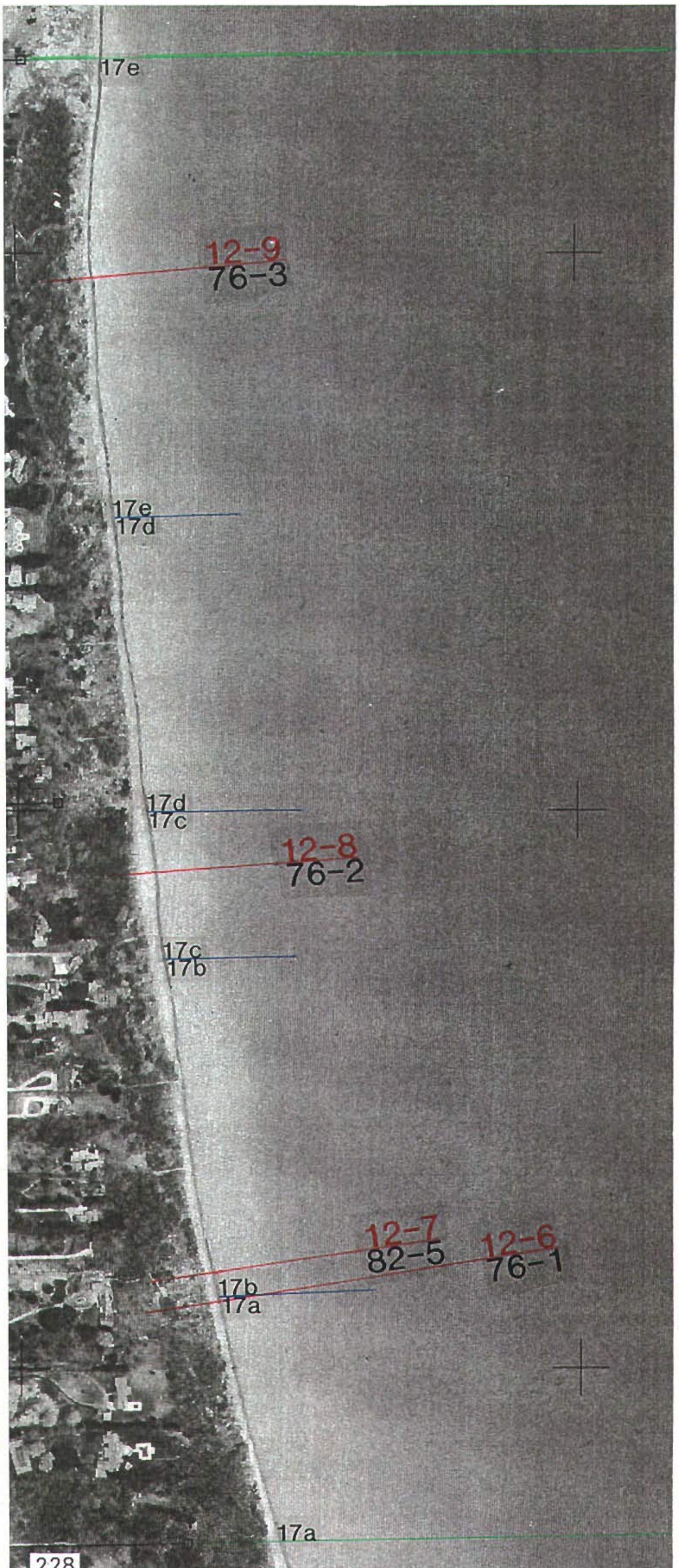
In 1995, one bluff profile field survey was made within Erosion Zone 17a by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a similar geometry to that documented in 1976, although the bluff slope had more of a convex character at the bluff toe during 1995 than during 1976. The stability of the bluff in Zone 17a of Reach 12 was characterized by Profile No. 12-6. Results of the slope stability analysis, shown in Figure 68, indicated that the bluff was marginally stable in the zone with respect to rotational failures, with a safety factor of 1.08, based upon the deterministic bluff stability analysis method. Profile 12-6 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.94 to 1.39 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for two, or 8 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for six, or 2.4 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a bluff safety factor of 1.0.

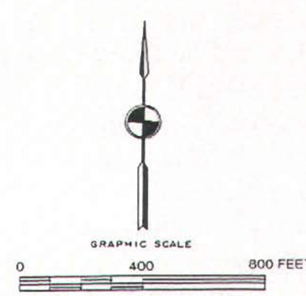
The beach ranged up to about 50 feet in width within Erosion Zone 17a. In the 1977 study, the beach width was reported to be about 20 feet, and the beach materials were reported to be gravel at the water's edge, grading to sand at the bluff toe. At Profile No. 12-6, the nearshore lakebed depth of five feet was reached at 100

Map 69

SHORELINE EROSION REACH 12: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 17, Township 9 North, Range 22 East
City of Mequon, Ozaukee County





LEGEND

PROFILE SITE LOCATION

12-6 PROFILE NUMBER: 1995 FIELD INVENTORY

76-1 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

17a EROSION ANALYSIS ZONE NUMBER

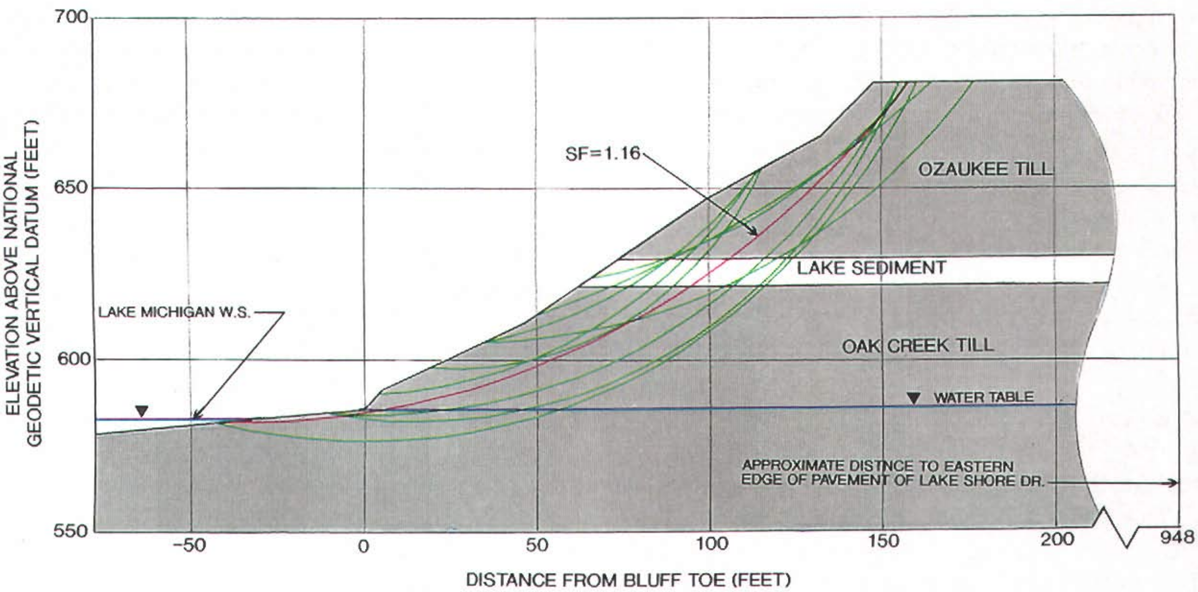
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 68

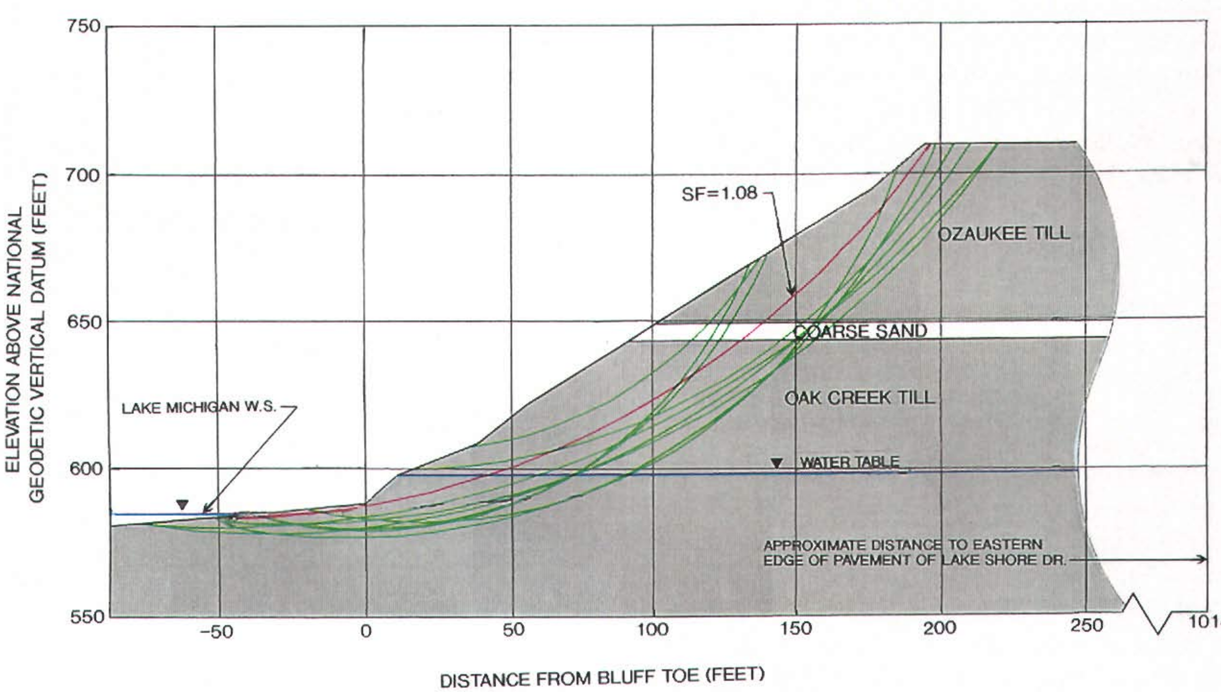
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 28, Township 9 North, Range 22 East
City of Mequon, Ozaukee County

PROFILE 12-7
T.9N. R.22E. SEC. 17



PROFILE 12-6
T.9N. R.22E. SEC. 17



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

feet offshore in 1976. The nearshore lakebed materials were not noted. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or 1987.

Shoreline recession data for Erosion Zone 17a were estimated at one location. These data indicated a recession of about 20 feet, or about 0.6 foot per year, occurred between 1963 and 1995. The data indicated that most of the recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. Thus, the bluff appeared to be partially stabilized within this zone. The 1977 study did not report a recession rate for this zone.

In 1995, small slumps and localized flows were observed on the lower portions of the bluff slopes within Erosion Zone 17a which appeared to be due, in part, to the revetment and groin system which partially protected the bluff toe being overtopped.

Erosion Zone 17b

Erosion Zone 17b extends from the northern limit of Erosion Zone 17a north about 0.2 mile, as shown on Map 69. This zone had a beach of up to 50 feet in width fronting the bluff which had a height of about 100 feet. The bluff was partially protected by a revetment. Vegetation, comprising sumac and shrubs on the upper bluff slopes and horsetails and juniper on the lower bluff slopes, covered approximately 50 percent of the bluff slope, largely the upper bluff slope. In 1995, the lower bluff slope was largely exposed, and signs of a fresh scarp and bluff toe erosion were present. Evidence of a large slump block was observed in the northern portion of the zone where the boundary between the vegetated surfaces of the bluff slope and the failing surface of the bluff slope decreased in elevation. The 1995 field observations indicated between zero and 10 feet of retreat in the bluff top since 1976.

In 1995, one bluff profile field survey was made within Erosion Zone 17b by occupying a site for which a field survey was conducted in 1987. The stability of the bluff in Zone 17b of Reach 12 was characterized by Profile No. 12-7. Results of the slope stability analysis, shown in Figure 68, indicated that the bluff was marginally stable in the zone, with a safety factor of 1.16, based upon the deterministic bluff stability analysis method. Profile No. 12-7 was also analyzed using the probabilistic bluff stability analysis method. The analytical results indicated a safety factor of greater than 1.0 for 250, or 100 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered stable with respect to rotational failures. The 1995 field observations indicted that translational failures may occur. The 1977 study did not report a bluff safety factor.

The beach ranged up to about 50 feet in width within Erosion Zone 17b, with the widest portion of the beach located in the northern portion of the zone. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be gravel at the water's edge, grading to sand at the bluff toe. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 17b were estimated at one location. These data indicated a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated that most of the recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. Thus, the bluff appeared to be partially stabilized within this zone. The 1977 study did not report a recession rate for this zone.

In 1995, fresh scarps were observed on the bluff slopes within Erosion Zone 17b, which indicated deep-seated slumping in portions of this zone. A staircase, constructed on the bluff face between 1989 and 1994, was observed to be broken in places, further indicating slope failure. A revetment located at the base of the stairway appeared to be being overtopped and largely ineffective in protecting the bluff toe at this site. Notwithstanding, the 1995 field observations indicated little change in the appearance of the bluff within this zone.

Erosion Zone 17c

Erosion Zone 17c extends from the northern limit of Erosion Zone 17b north about 0.1 mile to about Dandelion Lane extended, in the City of Mequon, as shown on Map 69. This zone had a beach of up to 75 feet in width fronting the bluff which had a height of about 100 feet. The bluff was unprotected in this zone. Vegetation, consisting of shrubs, covered approximately 50 percent of the bluff slope, which was a decrease in the amount of vegetation coverage since 1976. In 1995, signs of a large, deep-seated slump were observed throughout the zone, extending from the beach to the scarp at the bluff top. The 1995 field observations indicated between zero to 10 feet of retreat in the bluff top since 1976.

In 1995, one bluff profile field survey was made within Erosion Zone 17c by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a significantly different geometry to that documented in 1976. A scarp appeared to be developing at the bluff top in 1995, and the elevated portion of the lower bluff slope, immediately above the bluff toe, observed in 1976 appeared to be absent in 1995, although a step was observed in the bluff slope at this location. The stability of the bluff in Zone 17c of Reach 12 was characterized by Profile No. 12-8. Results of the slope stability analysis, shown in Figure 69, indicated that the bluff was stable in the zone with respect to rotational failures, with a safety factor of 1.48. The 1977 study reported a bluff safety factor of 0.89 on the lower bluff slope and 1.43 on the upper bluff slope.

The beach ranged up to about 75 feet in width within Erosion Zone 17c. In the 1977 study, the beach width was reported to be about 20 feet, and the beach materials were reported to be gravel at the water's edge, grading to sand at the bluff toe. At Profile No. 12-8, the nearshore lakebed depth of five feet was reached at 110 feet offshore in 1976. The nearshore lakebed materials were noted to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 17c were estimated at one location. These data indicated a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated a recession of 10 feet, or 0.5 foot per year, occurring between 1975 and 1995. Thus, the bluff top appeared not to be stabilized within this zone. The 1977 study did not report a recession rate for this zone.

Erosion Zone 17d

Erosion Zone 17d extends from the northern limit of Erosion Zone 17c at Dandelion Lane, in the City of Mequon, north about 0.2 mile, as shown on Map 69. This zone had a beach of up to 50 feet in width fronting the bluff which had a height of about 100 feet. The bluff was unprotected in this zone. Vegetation, comprising mature trees such as cedar, dogwood, and aspen, covered approximately 90 percent of the upper bluff slope. Vegetation, comprising horsetails and weeds, covered approximately 60 percent of the lower bluff slope, which appeared to be an increase in the amount of vegetation coverage since 1975. In 1995, signs of earth flows and shallow translational slides were present. Evidence of the slow movement of a large rotational block was observed on the upper bluff scarp in portions of the zone where the upper bluff slope was considerably steeper than the lower bluff slope. The 1995 field observations indicated between zero and five feet of retreat in the bluff top since 1976.

No bluff stability analyses were conducted within Erosion Zone 17d in this study or in 1976.

The beach ranged up to about 75 feet in width within Erosion Zone 17d. In the 1977 study, the beach width was reported to be about 20 feet, and the beach materials were reported to be gravel at the water's edge, grading to sand at the bluff toe. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 17d were not estimated. The 1977 study did not report a recession rate for this zone.

In 1995, evidence of active shoreline erosion was observed on the bluff slopes within Erosion Zone 17d. It appeared that slope failure was likely to continue, with the resultant loss of woodland vegetation on the bluff top and increased bluff top retreat.

Erosion Zone 17e

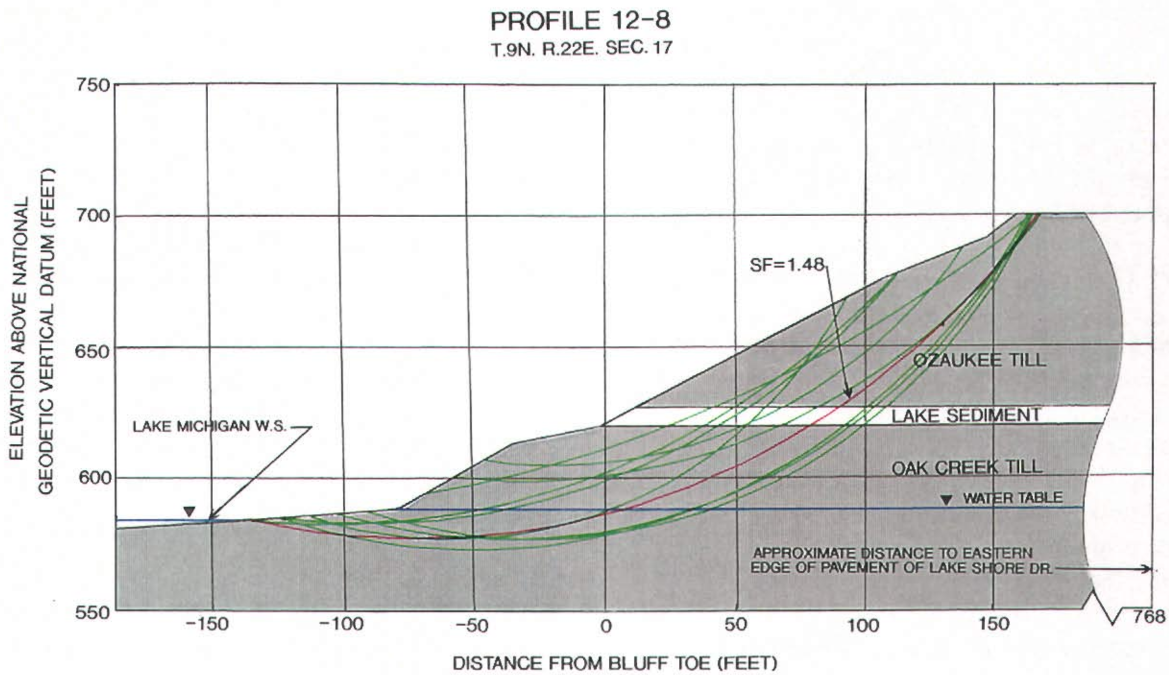
Erosion Zone 17e extends from the northern limit of Erosion Zone 17d north about 0.3 mile, as shown on Map 69. This zone had a beach of up to 25 feet in width fronting the bluff which had a height of about 100 feet. The bluff was unprotected in this zone. Vegetation, comprising mature trees such as cedar, dogwood, and aspen, covered approximately 60 percent of the upper bluff slope. In 1995, signs of earth flows and shallow translational slides were present. Evidence of the slow movement of a large rotational block was observed on the upper bluff scarp in portions of the zone where the upper bluff slope was considerably steeper than the lower bluff slope. The 1995 field observations indicated no visible retreat of the bluff top since 1976.

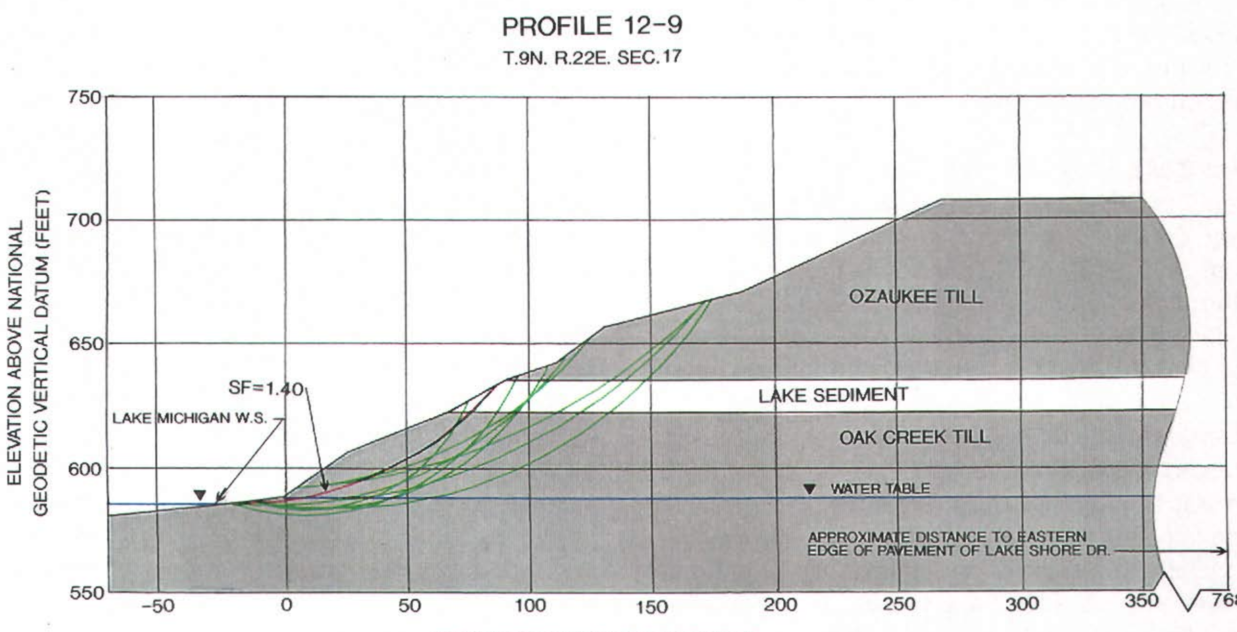
In 1995, one bluff profile field survey was made within Erosion Zone 17e by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a slightly different geometry to that documented in 1976. The step in the bluff slope observed in 1976 appeared as three distinct steps in 1995, with each step having a less steep slope than in 1976. Further, the slope at the bluff toe appeared to have become less steeply sloped in 1995 than in 1976. The stability of the bluff in Zone 17e of Reach 12 was characterized by Profile No. 12-9. Results of the slope stability analysis, shown in Figure 69, indicated that the bluff was stable in the zone with respect to rotational failures, with a safety factor of 1.40. How-

Figure 69

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 17, Township 9 North, Range 22 East
City of Mequon, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

ever, 1995 field observations indicated that translational failures may occur. The 1977 study reported a bluff safety factor of 0.94 for the lower bluff slope and of 0.94 for the upper bluff slope.

The beach ranged up to about 25 feet in width within Erosion Zone 17e. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be gravel at the water's edge, grading to sand at the bluff toe. At Profile No. 12-9, the nearshore lakebed depth of five feet was reached at 130 feet offshore in 1976. The nearshore lakebed materials were noted to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 17e were estimated at two locations. These data indicated a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated that most of the recession occurred prior to 1975 in the southernmost portion of the zone, with no further recession occurring between 1975 and 1995. In the northern portion of the zone, the data indicated about 10 feet, or 0.5 foot per year of recession occurring between 1975 and 1995. Thus, the bluff appeared to be partially stabilized within this zone. The 1977 study reported a recession rate of three feet per year for this zone.

In 1995, evidence of active shoreline erosion was observed on the bluff slopes within Erosion Zone 17e. It appeared that slope failure was likely to continue, with the resultant loss of woodland vegetation on the bluff top and increased bluff top retreat.

U.S. Public Land Survey Section 8, Township 9 North, Range 22 East, City of Mequon, Ozaukee County

This shoreline analysis section extends from Highland Road north to Lakeshore Drive, as shown on Map 70. The shoreline area of this section was occupied by Concordia College in the southern half and residential lands in the northern half. The beach ranged from being nonexistent to being 30 feet wide throughout much of the section. With the exception of the northern end of the section, no structures were present on the beach or offshore. In 1995, the bluffs were reported as unstable throughout this section and had a height of up to 120 feet. The slopes of the bluff were up to 50 percent vegetated. Signs of slumping and associated earthflows were present. For further analysis, Section 8 was further subdivided into four erosion zones, as shown on Map 70. The inventory and analysis findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the four zones.

Erosion Zone 8a

This shoreline analysis section extends from the south line of the section line north about 0.1 mile, as shown on Map 70. The entire shoreline of this zone was occupied by Concordia College. The beach in this zone ranged between 10 and 30 feet. The bluff slope in Zone 8a was reported as having no vegetation. The 1995 field observations indicated that the bluff top was scalloped and shallow slumps were responsible for the removal of much of the material which become earthflows further down the slope. Active failure was taking place in this zone and significant erosion was reported.

In 1995, two bluff profile field surveys were made within Zone 8a. One of these profiles reoccupied a site for which a field survey was conducted in 1976 and the other was a new profile site first measured in 1995. The stability of the bluff in Zone 8a was characterized by Profile Nos. 12-10 and 12-11. Results of the slope stability analysis, shown in Figure 70, indicated that the bluff was unstable at Profile No. 12-10, with a safety factor of 0.67, and marginally stable at Profile No. 12-11, with a safety factor of 1.11, with respect to both rotational and translational failures. The 1977 study reported a safety factor of 0.96 at Profile No. 12-10.

In 1995, beach materials within Zone 8a were noted to be sand and gravel. In the 1977 study, the beach width was reported to be between zero and 10 feet, and the beach materials were reported to be pebbles and cobbles mixed with some sand at the toe. No measurements or observations were made of the nearshore lakebed depth or materials within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 8a were not estimated.

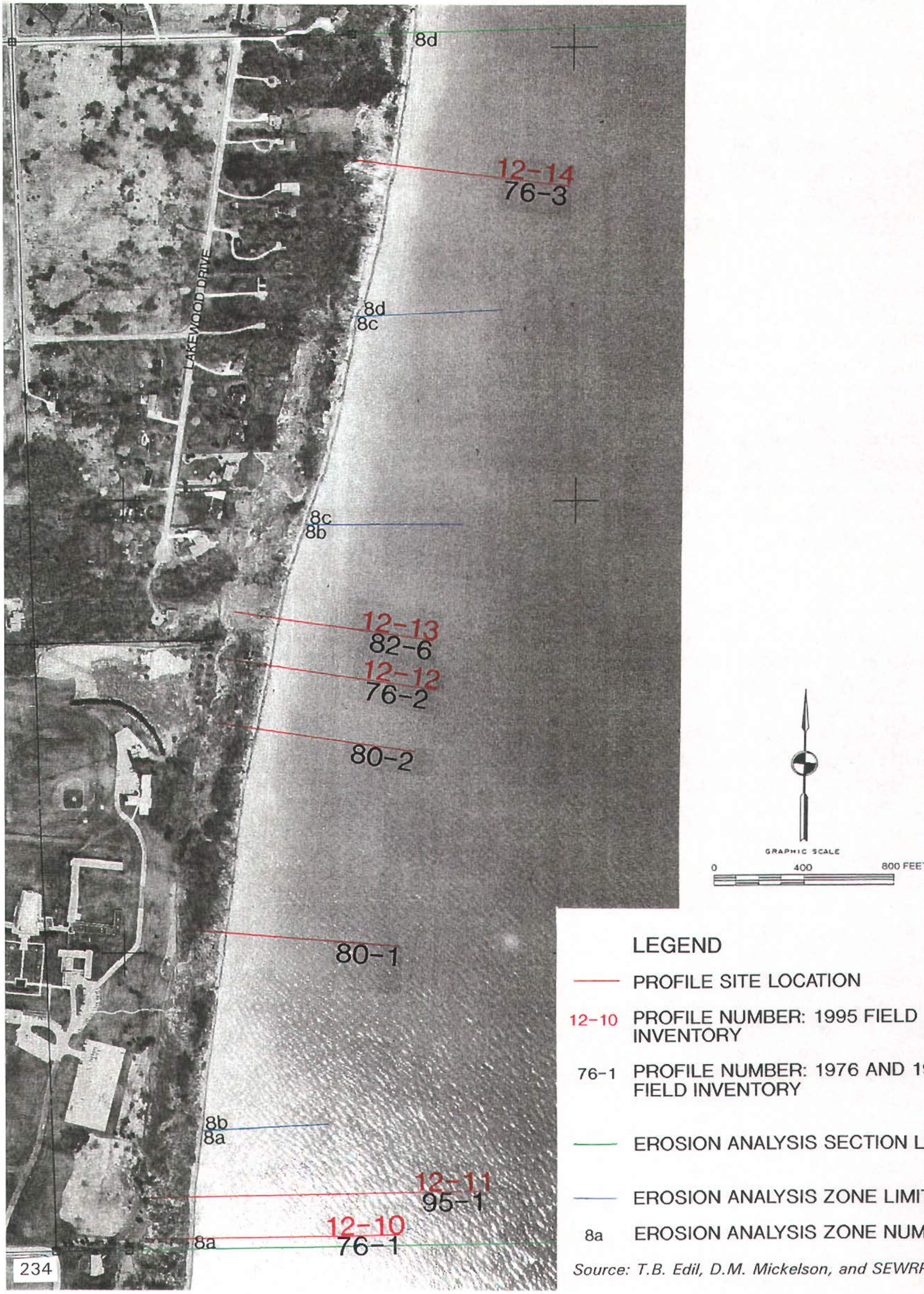
Erosion Zone 8b

This shoreline analysis section extends from the northerly limits of Erosion Zone 8a north about 0.5 mile, as shown on Map 70. The beach in this zone ranged between 10 and 20 feet in width and numerous flows overlaying the upper beach sand. There were no protection structures on the beach and wave erosion at the base of the bluff was significant even at times of relatively low water. The upper portion of the slope was well-vegetated with shrubs and mature trees, but the lower

Map 70

SHORELINE EROSION REACH 12: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 8 Township 9 North, Range 22 East
City of Mequon, Ozaukee County



LEGEND

PROFILE SITE LOCATION

12-10 PROFILE NUMBER: 1995 FIELD INVENTORY

76-1 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

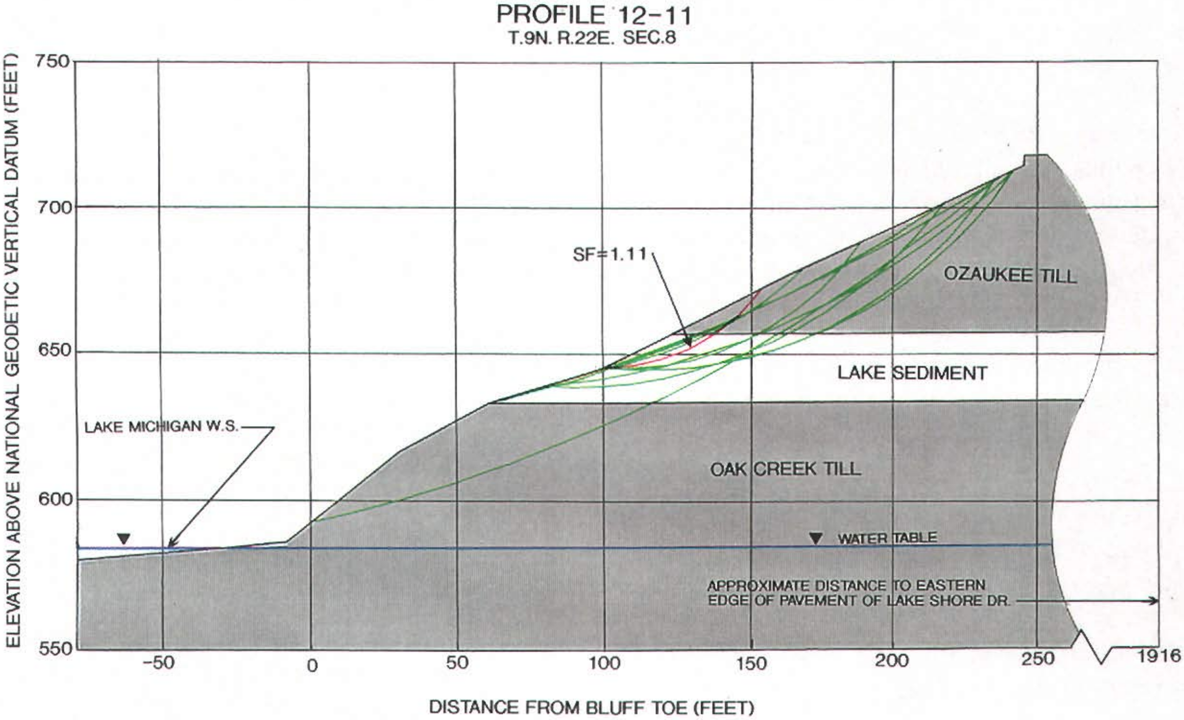
8a EROSION ANALYSIS ZONE NUMBER

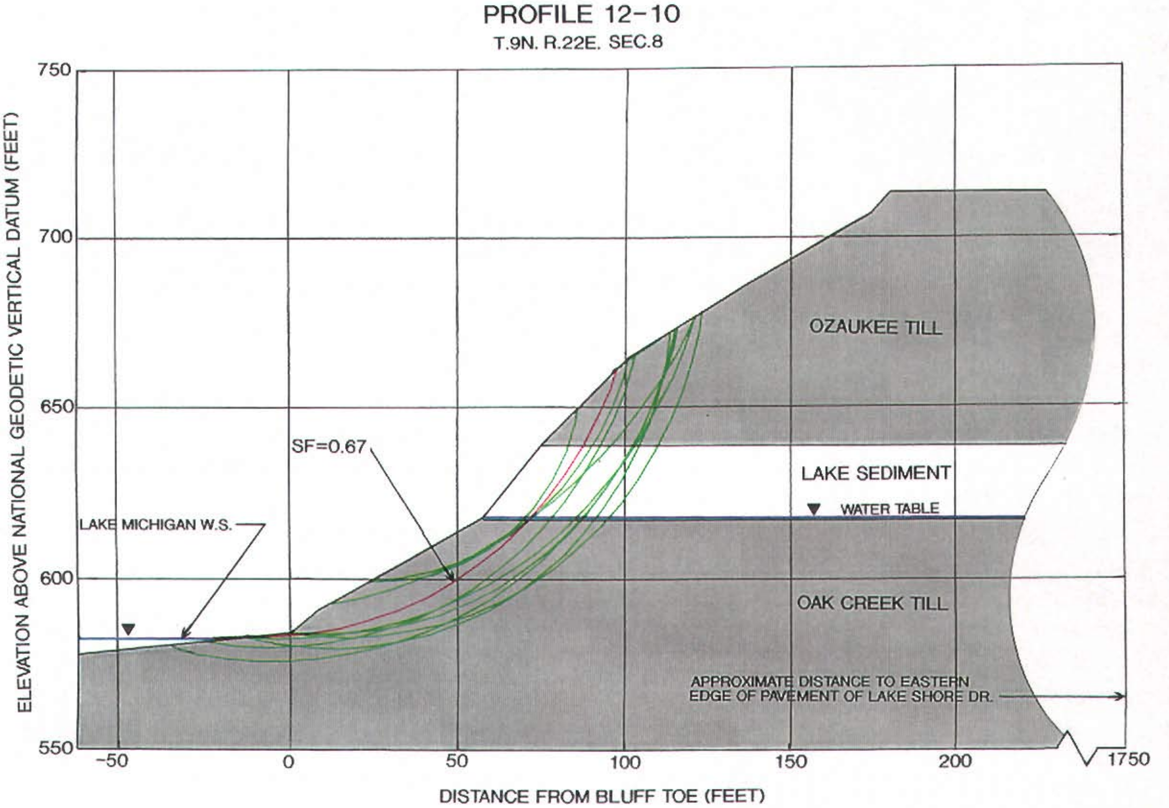
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 70

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 8, Township 9 North, Range 22 East
City of Mequon, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

portion of the slope was less than 50 percent vegetated. The 1995 field observations indicated that the upper part of the slope shows a fresh scarp which was evidently the top of a large deep-seated slump lump.

In 1995, two bluff profile field surveys were made within zone 8b. One of these profiles reoccupied a site for which a field survey was conducted in 1976 and the other reoccupied a site for which a field survey conducted in 1982. The stability of the bluff in Zone 8b was characterized by Profile Nos. 12-12 and 12-13. Results of the slope stability analysis, shown in Figure 71, indicated that the bluff was unstable at Profile No. 12-12, with a safety factor of 0.78, and marginally stable at Profile No. 12-13, with a safety factor of 1.11, with respect to both rotational and translational failures. The 1977 study reported a safety factor of 0.71 at Profile No. 12-12. The 1982 study did not report a safety factor for Profile No. 12-13.

In 1995, beach materials within Zone 8b were noted to be sand and gravel. In the 1977 study, the beach width was reported to be between zero and 10 feet, and the beach materials were reported to be pebbles and cobbles mixed with some sand at the toe. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 8b were estimated at two locations. These data indicated that a recession of between 20 and 40 feet, or between 0.6 and 1.2 feet per year, occurred between 1963 and 1995. The data indicated a recession of between 10 and 30 feet, or between 0.5 and 1.5 feet per year, occurred between 1975 and 1995. Thus, the bluff top appeared to continue to be retreating.

Erosion Zone 8c

This shoreline analysis section extends from the northerly limits of erosion Zone 8b north about 0.2 mile, as shown on Map 70. The beach in this zone ranged between 10 and 20 feet in width and was littered with mature trees that have come down the bluff. The lower bluff appears to be part of slump block that moved sometime prior to the mid-1970s. The 1995 field observations indicated that all of the bluff was now failing by shallow translational slides. Thick sand in the middle part of the bluff was considered to probably contribute to instability in the northern part of Section 8 because of groundwater sapping.

No bluff stability analyses were conducted within Erosion Zone 8c during this study or the 1977 study.

In 1995, beach materials within Zone 8c were noted to be sand and gravel. In the 1977 study, the beach width was reported to be between zero and 10 feet, and the beach materials were reported to be pebbles and cobbles mixed with some sand at the toe. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 8c were not estimated.

Erosion Zone 8d

This shoreline analysis section extends from the northerly limits of Erosion Zone 8c north to the end of the section, as shown on Map 70. The beach in this zone ranged between 10 and 20 feet in width. The upper portion of the bluff top was mostly vegetated with mature trees and the lower portion was basically unvegetated and failing. The field observations in 1995 indicated that at one small section the mature vegetation was missing at the bluff top and the bluff was actively eroding from the bluff top to the beach.

In 1995, one bluff profile field survey was made within Zone 8d, by reoccupying a site for which a field survey was conducted in 1976. The stability of the bluff in Zone 8d was characterized by Profile No. 12-14. Results of the slope stability analysis, shown in Figure 71, indicated that the bluff was unstable with respect to both rotational and translational failures at Profile No. 12-14, with a safety factor of 0.59. The 1977 study reported a safety factor of 0.78.

In 1995, beach materials within Zone 8d were noted to be sand and gravel. In the 1977 study, the beach width was reported to be between 15 and 25 feet, and the beach materials were reported to be pebbles and cobbles mixed with some sand at the toe. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

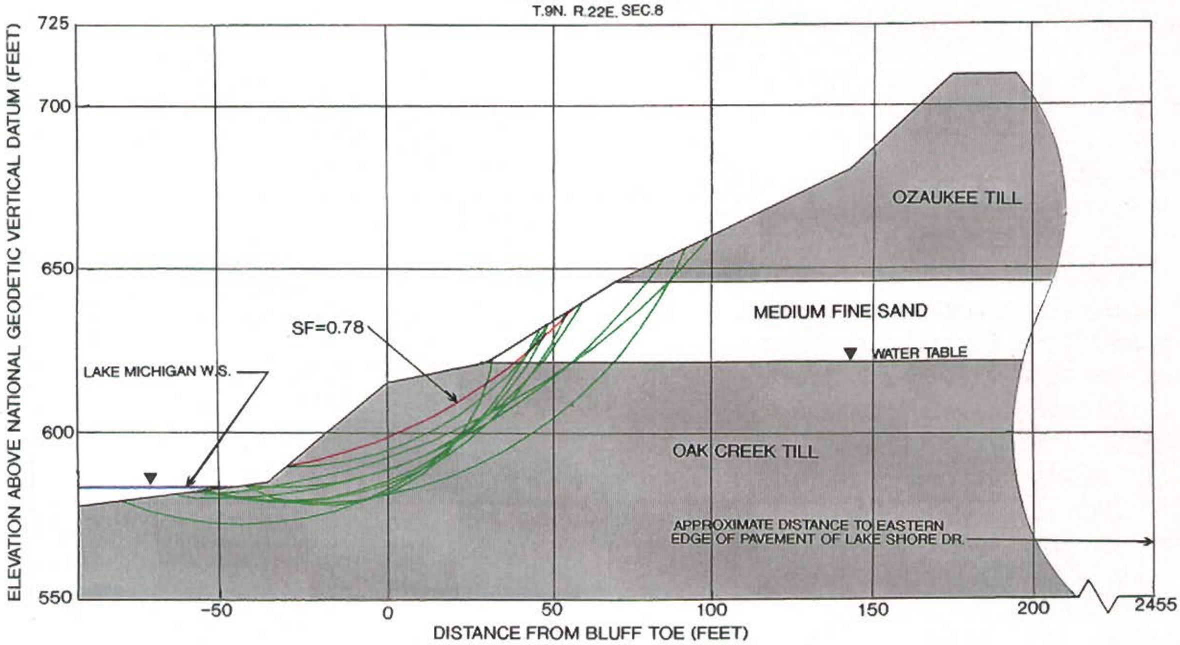
Shoreline recession data for Erosion Zone 8d were estimated at two locations. The data indicated that a recession of between zero and 10 feet, or between zero and 0.3 foot per year, occurred between 1963 and 1995. The data indicated that most of that recession in the northern portion of the zone occurred prior to 1975, with no further recession occurring between 1975 and 1995. In

Figure 71

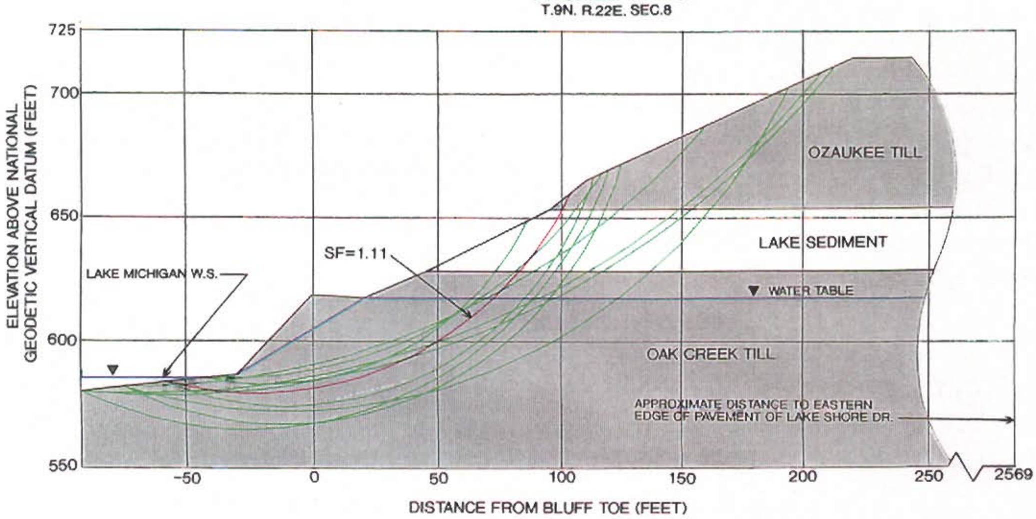
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 8, Township 9 North, Range 22 East
City of Mequon, Ozaukee County

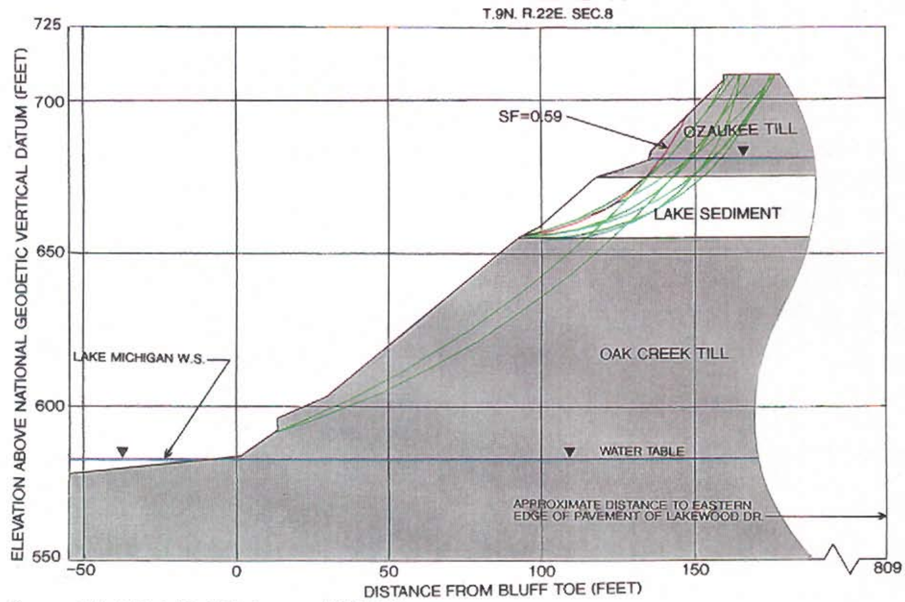
PROFILE 12-12
T.9N. R.22E. SEC.8



PROFILE 12-13
T.9N. R.22E. SEC.8



PROFILE 12-14
T.9N. R.22E. SEC.8



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

the southern portion of the zone, the data indicated a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. The 1977 study reported a recession rate of three feet per year in this zone.

U.S. Public Land Survey Sections 4 and 5, Township 9 North, Range 22 East, City of Mequon, Ozaukee County

This shoreline analysis section extends from Bonniwell Road extended on the south line of Section 5 north to Pioneer Road (CTH C) extended on the north line of Section 4, in the City of Mequon, as shown on Map 71. In 1995, the lakeshore area was occupied by residential and open space lands. In 1995, the section was largely unprotected. The section was fronted by a beach which ranged from narrow to nonexistent up to about 50 feet in width, with the widest area of beach located in the central portion of the section. The bluff in this section was between 120 and 130 feet in height. The bluff materials in this section was generally covered, but were estimated to be primarily till underlain by sand and gravel, underlain by silt and clay. The lower silt and clay layer was underlain by till in the northern portion of the section. For analysis purposes, Sections 4 and 5 were further subdivided into three erosion zones, as shown on Map 71. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three erosion zones in Sections 4 and 5.

Erosion Zone 4a

Erosion Zone 4a extends from the south line of Section 4 at Bonniwell Road extended north about 0.2 mile to a point on the lakeshore adjacent to the southernmost extent of Birchwood Lane, in the City of Mequon, as shown on Map 71. This zone had a narrow beach of up to 25 feet in width fronting the bluff which had a height of about 120 feet. The bluff was unprotected within this zone. Vegetation, comprising trees such as cedar, spruce, birch, maple, and aspen, covered approximately 70 percent of the upper bluff slope. Vegetation, comprising horsetails and thistles, covered approximately 30 percent of the lower bluff slope. In 1995, signs of shallow translational slides were present, and large scarps were observed. The 1995 field observations indicated between zero and 10 feet of retreat in the bluff top since 1976.

No bluff stability analyses were conducted within Erosion Zone 4a in this study or in 1976.

The beach ranged up to about 50 feet in width within Erosion Zone 4a. In the 1977 study the beach width was reported to be between 15 and 25 feet, and the beach materials were reported to be gravel and pebbles at the water's edge, grading to sand at the bluff toe. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 4a were estimated at two locations. These data indicated a recession of between zero and 40 feet, or between zero and 1.2 feet per year, occurred between 1963 and 1995. The data indicated that most of the recession in the southern portion of the zone occurred prior to 1975, with no further recession occurring between 1975 and 1995. In the northern portion of the zone, the data indicated a recession of about 10 feet, or 0.5 foot per year, occurring between 1975 and 1995. Thus, the bluff appeared to be partially stabilized within this zone. The 1977 study reported a recession rate of three feet per year for this zone.

In 1995, shallow translational slides were observed on the lower portions of the bluff slopes within Erosion Zone 4a, possibly as a result of the presence of the thick sand unit that drained the slope in the middle portion of the bluff and which produced an instability in that portion of the bluff.

Erosion Zone 4b

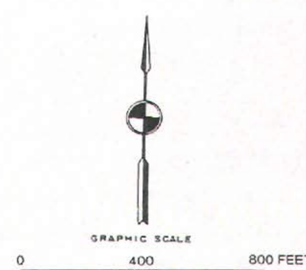
Erosion Zone 4b extends from the northern limit of Erosion Zone 4a at the southernmost extent of Birchwood Lane north about 0.55 mile to a point on the lakeshore adjacent to the northernmost extent of Birchwood Lane, as shown on Map 71. This zone had a beach of up to 50 feet in width fronting the bluff which had a height of about 130 feet. The bluff was unprotected in this zone, except for a single structure in the central portion of the zone built as a revetment. Vegetation, consisting of horsetails, thistles, and small locust trees, covered approximately 35 percent of the lower bluff slope. Vegetation, consisting of aspen and pine trees, covered between 60 and 100 percent of the upper bluff slope. In 1995, signs of translational slumping were present in the northern portions of the zone, while evidence of rotational slumping and soil flows at the bluff toe was observed in the southern portion of the zone. The 1995 field observations indicated zero to 10 feet or retreat in the bluff top since 1976.

In 1995, two bluff profile field surveys were made within Erosion Zone 4b by occupying sites for which

Map 71

SHORELINE EROSION REACH 12: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 4 and 5, Township 9 North, Range 22 East
City of Mequon, Ozaukee County



LEGEND

PROFILE SITE LOCATION

12-15 PROFILE NUMBER: 1995 FIELD INVENTORY

76-1 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

4-5a EROSION ANALYSIS ZONE NUMBER

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

field surveys were conducted in 1976. The reoccupied sites had slightly different geometries to those documented in 1976. At Profile No. 12-15, the concave portion of the lower bluff slope observed in 1976 appeared to have been replaced by a convex portion of lower bluff slope, and the steeply sloped bluff toe appeared to have been lost. At Profile No. 12-16, the lower portion of the bluff slope appeared to have a slight convex shape that was absent in 1976. The stability of the bluff in Zone 4b of Reach 12 was characterized by Profile Nos. 12-15 and 12-16, as shown on Map 71. Results of the slope stability analysis, shown in Figure 72, indicated that the bluff was unstable in the zone, with safety factors of 0.96 and 0.63, at Profile Nos. 12-15 and 12-16, respectively, based upon the deterministic bluff stability analysis method. Profile No. 12-15 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.71 to 1.37 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 12, or 48 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 35, or 14 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered marginally unstable with respect to both rotational and translational failures. The 1977 study reported bluff safety factors of 0.85 and 0.66, at Profile Nos. 12-15 and 12-16, respectively.

The beach ranged up to about 50 feet in width within Erosion Zone 4b. In the 1977 study, the beach width was reported to be between 15 and 25 feet, and the beach materials were reported to be gravel and pebbles at the water's edge, grading to sand at the bluff toe. At Profile No. 12-15, the nearshore lakebed depth of five feet was reached at 150 feet offshore in 1976. The nearshore lakebed materials were not noted. At Profile No. 12-16, the nearshore lakebed depth of five feet was reached at 120 feet offshore in 1976. The nearshore lakebed materials were noted to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 4b were estimated at one location. These data indicated a recession of about 50 feet, or about 1.6 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 40 feet, or about two feet per year, occurring between 1975 and 1995. Thus, the bluff did not appear to be effectively stabilized within this zone. The 1977 study did not report a recession rate for this zone.

In 1995, the bluff top within Erosion Zone 4b appeared to be scalloped, with the lower portions of the bluff actively eroding in this zone. The single structure, which appeared to have been built as a revetment in the central portion of this zone, appeared to be overtopped and of insufficient size to hold back failed materials falling from higher up on the bluff slope. In the northern portion of the zone, the bluff top appeared to be relatively stable, but the bluff safety factor of 0.63 suggested that the bluff was unstable and has the potential to fail.

Erosion Zone 4c

Erosion Zone 4c extends from the northern limit of Erosion Zone 4b at the northern extreme of Birchwood Lane north about 0.3 mile to Pioneer Road extended at the north line of Section 4, in the City of Mequon, as shown on Map 71. This zone had a beach of up to 25 feet in width fronting the bluff which had a height of about 120 feet. The bluff was unprotected in this zone. Vegetation, consisting of trees such as maple, basswood, and pine, covered approximately 100 percent of the bluff slope. In 1995, signs of several rotational slump blocks were observed throughout the zone. Evidence of older scarps at the bluff top was present. The 1995 field observations indicated that no assessment of retreat in the bluff top could be made in this zone due to the heavy vegetation growth.

In 1995, one bluff profile field survey was made within Erosion Zone 4c by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a significantly different geometry to that documented in 1976. A second step in the bluff slope was observed during 1995 in addition to that reported in 1976. The stability of the bluff in Zone 4c of Reach 12 was characterized by Profile No. 12-17. Results of the slope stability analysis, shown in Figure 72, indicated that the bluff was unstable with respect to both rotational and translational failures in the zone, with a safety factor of 0.76. The 1977 study reported a bluff safety factor of 0.68.

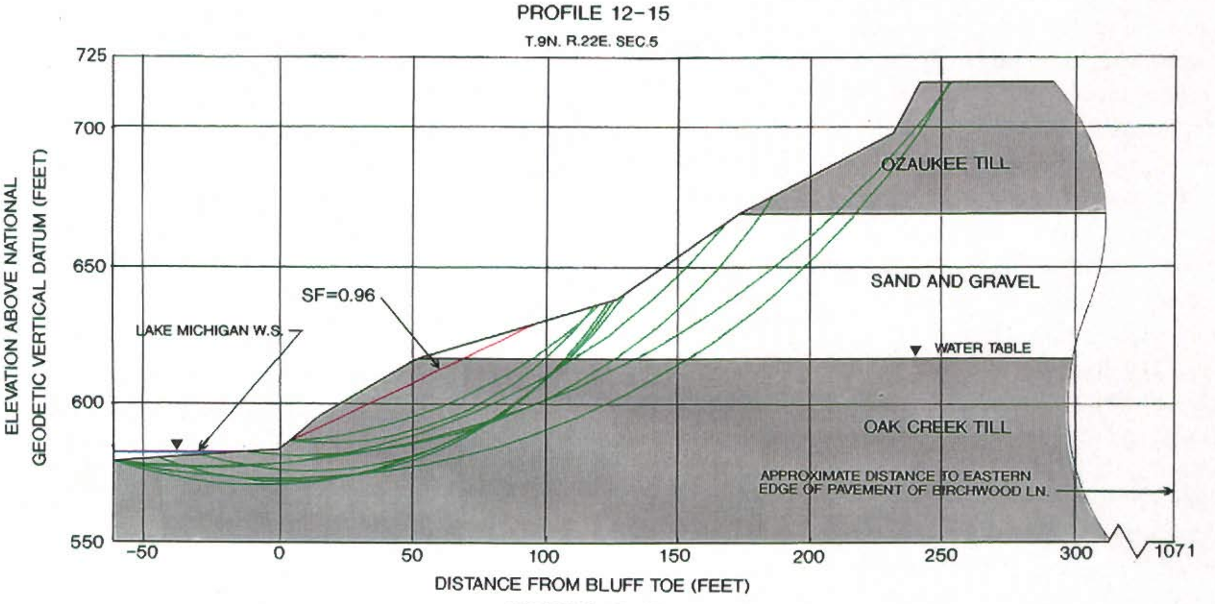
The beach ranged up to about 25 feet in width within Erosion Zone 4c. In the 1977 study, the beach width was reported to be between zero and 15 feet, and the beach materials were reported to be pebbles and cobbles at the water's edge, grading to sand at the bluff toe. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

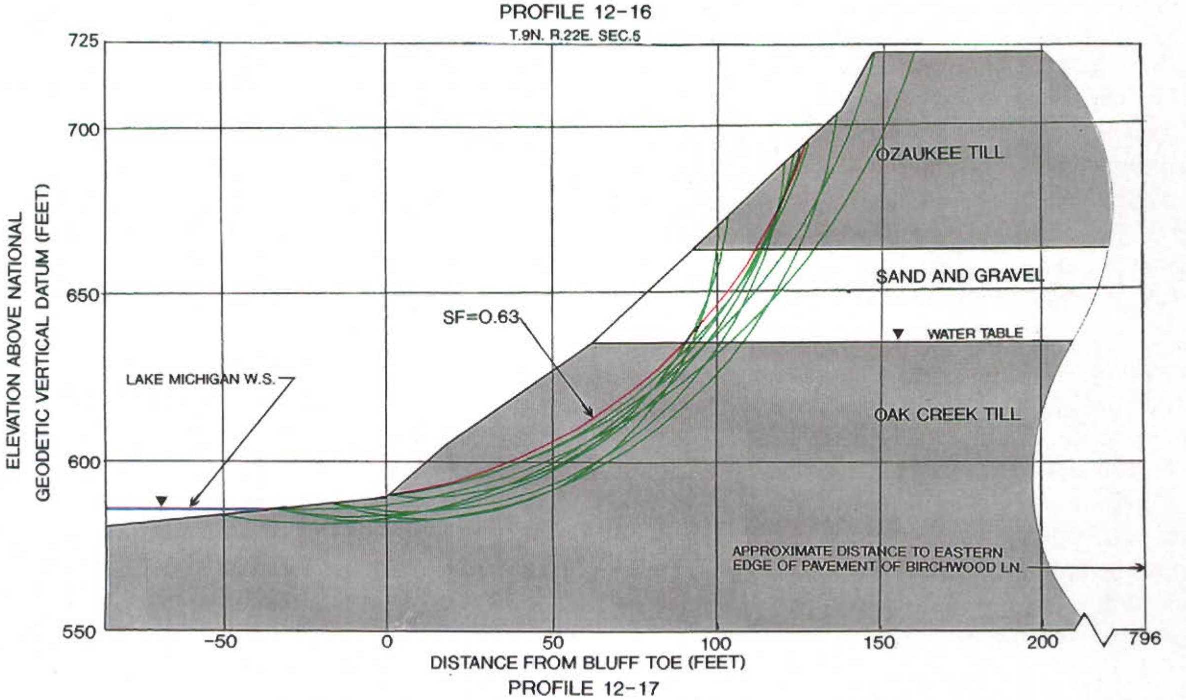
Shoreline recession data for Erosion Zone 4c were estimated at two locations. These data indicated a recession

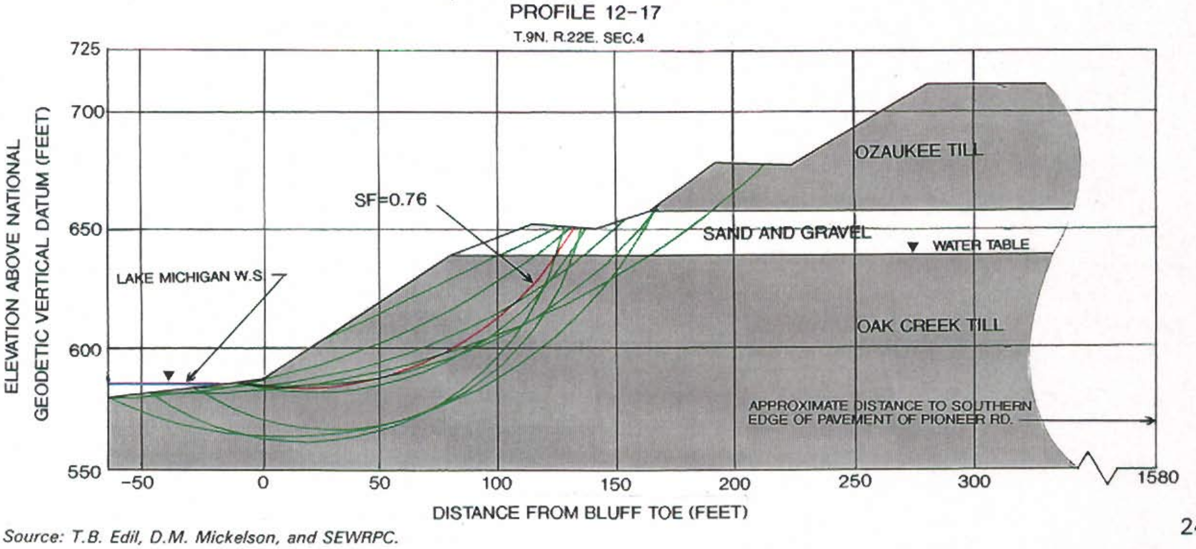
Figure 72

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Sections 4 and 5, Township 9 North, Range 22 East
City of Mequon, Ozaukee County







Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

of between 20 and 70 feet, or between 0.6 and 2.2 feet per year, occurred between 1963 and 1995. The data indicated a recession of between 20 and 30 feet, or between one and 1.5 feet per year, occurring between 1975 and 1995. The bluff appeared not to be stabilized within this zone. The 1977 study did not report a recession rate for this zone.

U.S. Public Land Survey Section 33, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County

This shoreline analysis section extends from Pioneer Road north to the projection of CTH T, as shown on Map 71. The shoreline area of this section was occupied by residential lands, mainly consisting of single-family residences on large lots. The beach in this section ranged from being nonexistent to up to 50 feet in width. Shoreline protection structures, constructed by individual property owners, existed near the south end of the section which consist of a revetment of limestone blocks at the top of the beach. The bluff in this section had a height of up to 130 feet at the south end, dropping to about 120 feet at the north end. The 1995 field observations indicated that nearly all of the bluff was failing or had the potential to fail in the future. For further analysis, Section 33 was further subdivided into four erosion zones, as shown on Map 72. The inventory and analysis findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the four zones.

Erosion Zone 33a

This shoreline analysis section extends from the south line of the section north about 0.25 mile, as shown on Map 72. The beach in this zone was about 40 feet in width. The bluff slope in Zone 33a was about 120 feet in height and about 80 percent vegetated. In 1995, there appeared to be little change in this area since 1976, with the exception of the southern end which had been regraded and a massive fill installed.

In 1995, one bluff profile field survey was made within Zone 33a, by reoccupying a site for which a field survey was conducted in 1976. The stability of the bluff in Zone 33a was characterized by Profile No. 12-18. Results of the slope stability analysis, shown in Figure 73, indicated that the bluff was stable at Profile No. 12-18, with a safety factor of 1.88. The 1977 study reported a safety factor of 0.98.

In the 1977 study, the beach width was reported to be about 20 feet, and the beach material was reported to be sand mixed with pebbles and cobbles. No measurements or observations were made of the nearshore lakebed depth or materials within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 33a were estimated at one location. These data indicated a recession of about 20 feet, or about 0.6 foot per year. The data indicated a recession of about 20 feet, or about one foot per year, occurred between 1975 and 1995. Thus, the bluff top appeared not to have been stabilized within this zone.

Slope stability continues to be a problem on the property immediately north of where the fill was installed. By 1995, the third property to the north had been regraded, terraced, and protected with revetments. This regraded slope was fairly stable, except there seemed to be rotational movement on a large slump block in the lower one-third of the bluff.

Erosion Zone 33b

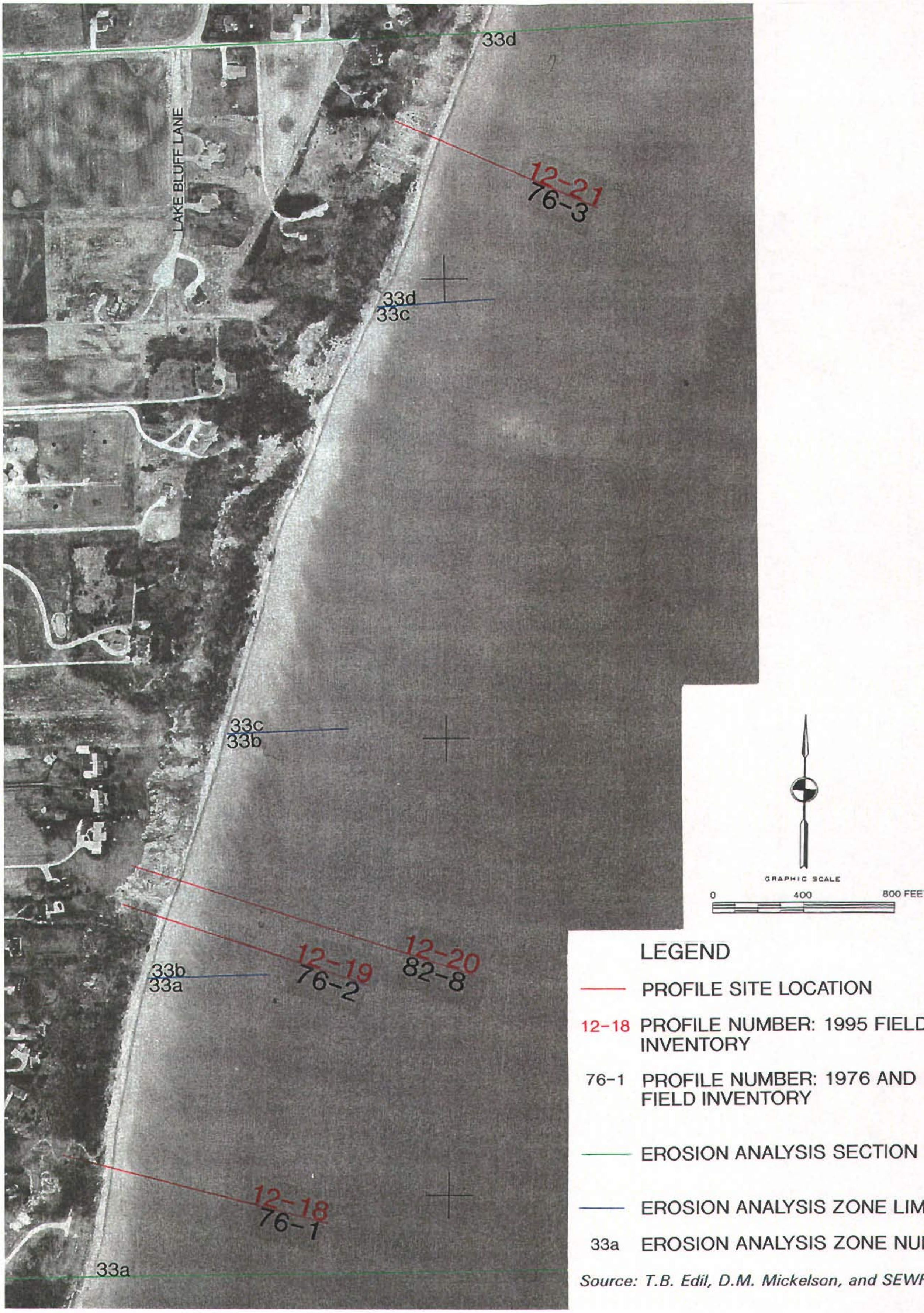
This shoreline analysis section extends from the northerly limits of Erosion Zone 33a north about 0.2 mile, as shown on Map 72. The beach in this zone varied from being nonexistent to about 40 feet in width. The bluff slope was less than 20 percent vegetated. The 1995 field observations indicated that most of the failures in this zone were occurring by shallow translational slides, flows, and surface wash.

In 1995, two bluff profile field surveys were made within Zone 33b. One of these sites reoccupied a site for which a field survey was conducted in 1976 and the other reoccupied a site for which a field survey was conducted in 1982. The stability of the bluff in Zone 33a was characterized by Profile Nos. 12-19 and 12-20. Results of the slope stability analysis, shown in Figures 73 and 74, indicated that the bluff was marginally stable, with safety factors of 1.01 and 1.11, based upon the deterministic bluff stability analysis method. Profile No. 12-20 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.43 to 0.81 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 25, or 100 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 250, or 100 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered unstable with respect to both rotational and translational failures. The 1977 study reported a safety factor of 0.65

Map 72

SHORELINE EROSION REACH 12: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 33, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County



LEGEND

PROFILE SITE LOCATION

12-18 PROFILE NUMBER: 1995 FIELD INVENTORY

76-1 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

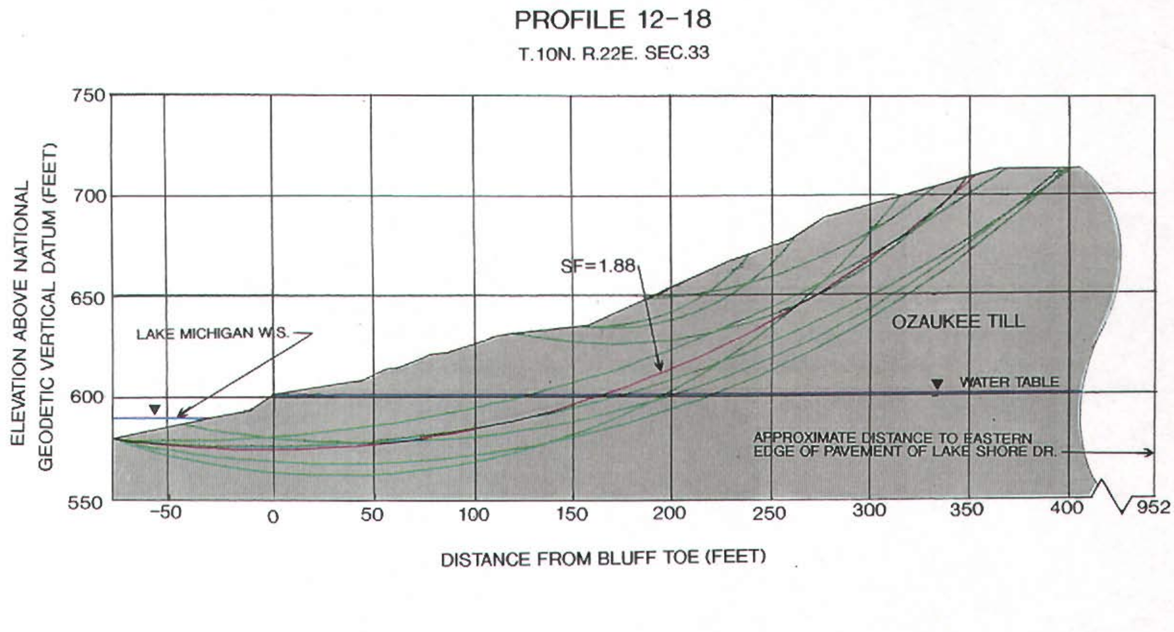
33a EROSION ANALYSIS ZONE NUMBER

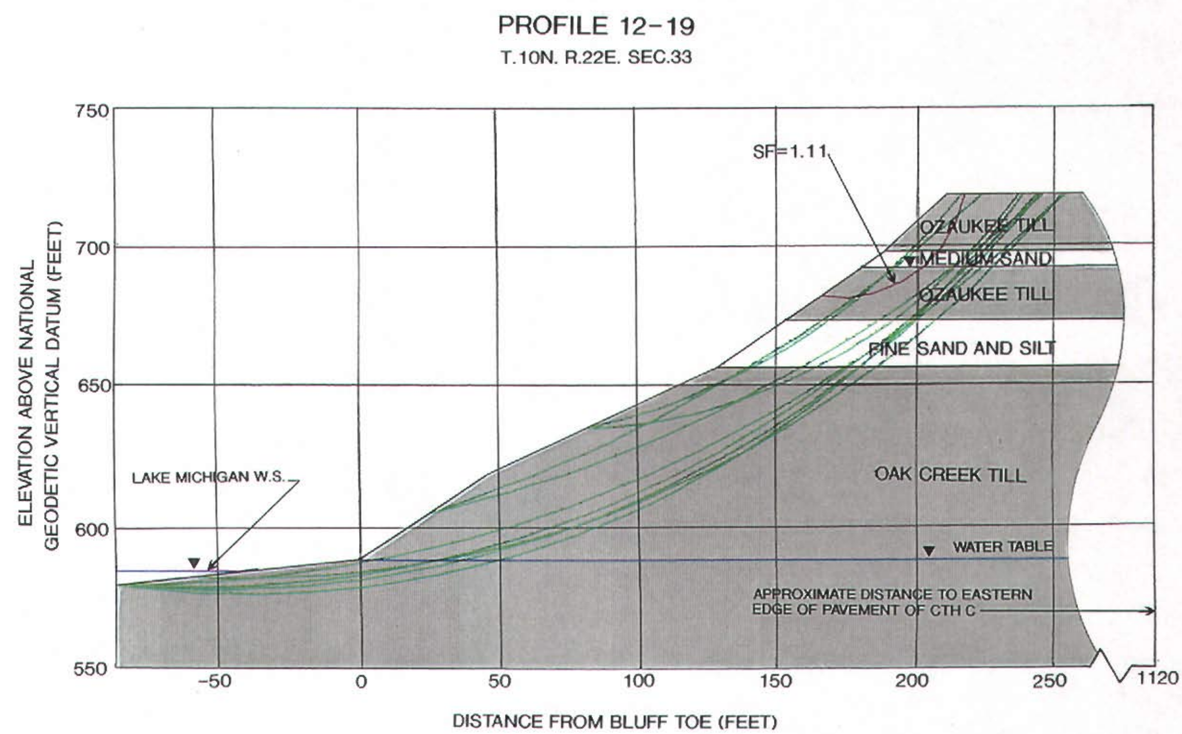
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 73

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 33, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County





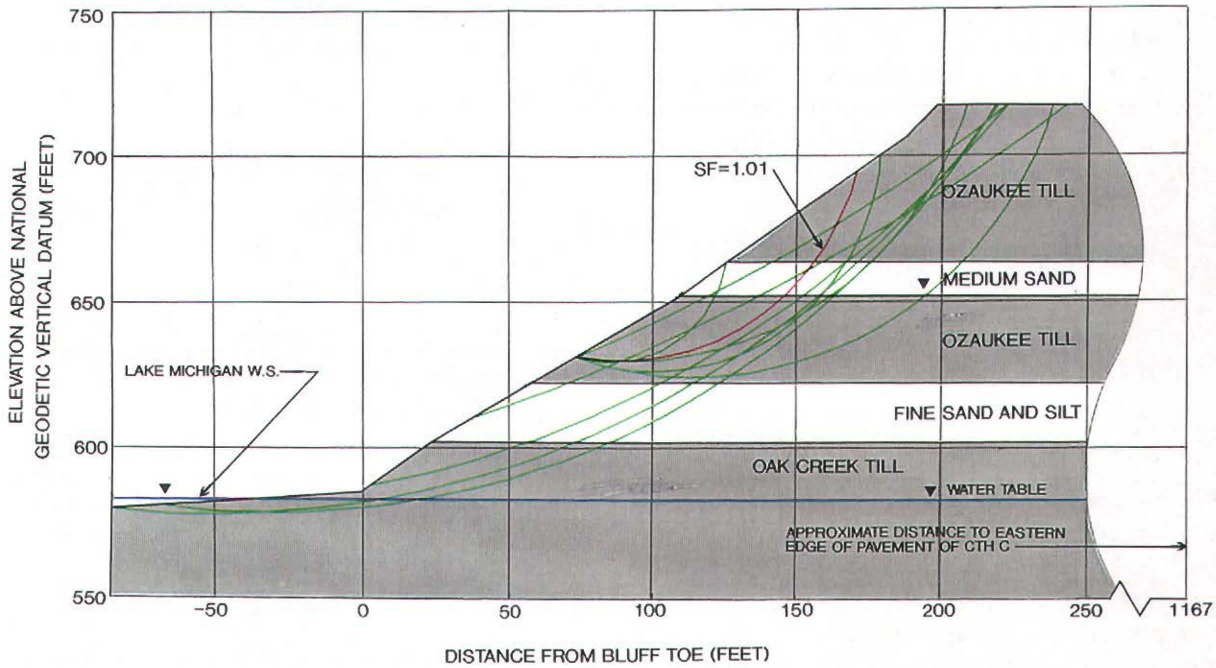
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 74

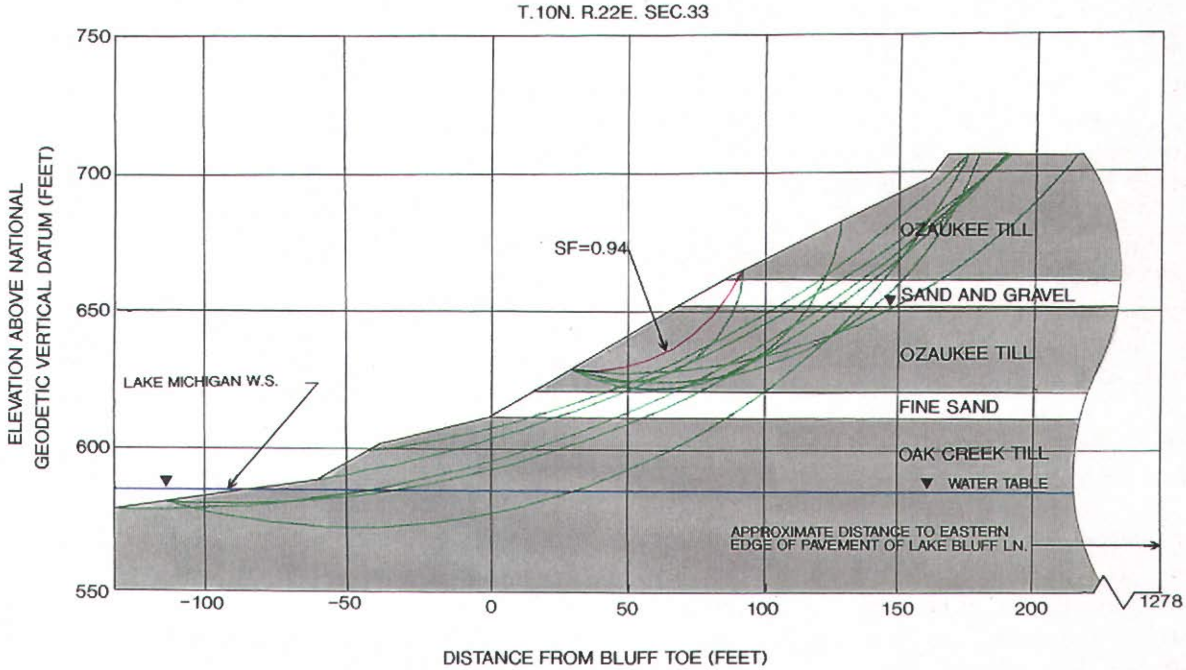
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 33, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County

PROFILE 12-20
T.10N. R.22E. SEC.33



PROFILE 12-21
T.10N. R.22E. SEC.33



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

at Profile No. 12-19. The 1982 study did not report a safety factor at Profile No. 12-20.

The change from a safety factor at Profile No. 12-19 of 0.65 in 1976 to 1.11 in 1995 was considered to be a result of a buildup of failed material near the bottom of the slope. However, during future periods of higher lake levels this material will be likely to erode, resulting in a much lower safety factor.

In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or materials within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 33b were estimated at one location. These data indicated a recession of about 30 feet, or about 0.9 foot per year. The data indicated a recession of about 20 feet, or one foot per year, occurred between 1975 and 1995.

Erosion Zone 33c

This shoreline analysis section extends from the northerly limits of Erosion Zone 33b north about 0.35 mile, as shown on Map 72. The beach in this zone varied between 20 and 40 feet in width. The bluff slope was 70 percent vegetated. The 1995 field observations indicated that lower part of the bluff appeared to be an old slump block that was slowly being eroded away by waves. In 1995, the lower slope had abundant northern white cedar which suggested that there were major seeps along the top of the lower clay unit that could not be seen as they were covered by slump material. Signs of fresh failures on the scarp of the upper bluff were present in 1995 that further suggested the shifting of this large slump block. Signs of another fresh failure just south of where a large gully penetrated the bluff face were present.

No bluff stability analyses were conducted within Erosion Zone 33c in this study or the 1977 study.

In the 1977 study, the beach width was reported to be about 20 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 33c were estimated at two locations. These data indicated a recession of between 20 and 40 feet, or between about 0.6 and 1.2 feet per year. The data indicated a recession of between 10 and 20 feet, or between 0.5 to one foot per year, occurred between 1975 and 1995.

Erosion Zone 33d

This shoreline analysis section extends from the northerly limits of Erosion Zone 33c north to the north line of the section, as shown on Map 72. The beach in this zone varied between 20 and 40 feet in width. The bluff slope was 90 percent vegetated with horsetails, junipers, and grasses and was relatively straight. The 1995 field observations indicated that there were substantial areas of shallow sliding and flows and there was no evidence of the large slump block at the base of the bluff reported in the 1977 study.

In 1995, one bluff profile field survey was made within Zone 33d, by reoccupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 33d was characterized by Profile No.12-21. Results of the slope stability analysis, shown in Figure 74, indicated that the bluff was unstable at Profile No. 12-21, with a safety factor of 0.94, based upon the deterministic bluff stability analysis. Profile No. 12-21 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.48 to 1.03 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 25, or 100 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 247, or 98.8 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered unstable with respect to both rotational and translational failures. The 1977 study reported a safety factor of 0.92.

In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 33d was estimated at one location. These data indicated a recession of 30 feet, or about 0.9 foot per year. The data indicated a recession of about 20 feet, or about one foot per year, occurred between 1975 and 1995.

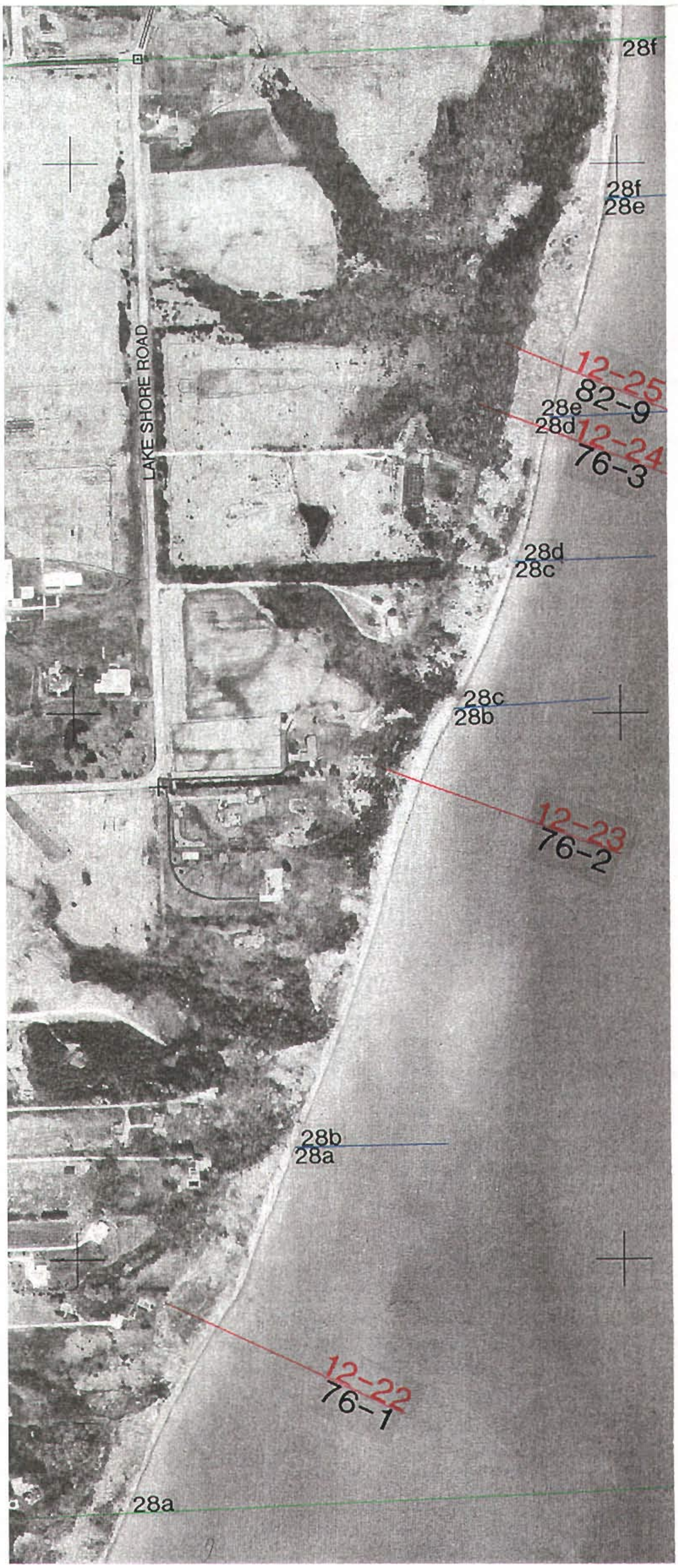
U.S. Public Land Survey Section 28, Township 10 North, Range 22, Town of Grafton, Ozaukee County

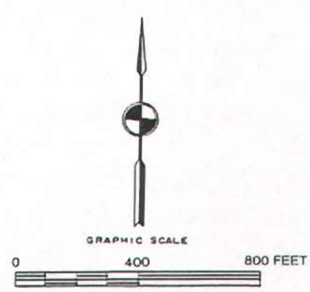
This shoreline analysis section extends from Lakefield Road (CTH T) extended north to Falls Road extended, in the Town of Grafton, as shown on Map 73. In 1995, the lakeshore area was occupied by agricultural and

Map 73

SHORELINE EROSION REACH 12: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 28, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County





LEGEND

PROFILE SITE LOCATION

12-22 PROFILE NUMBER: 1995 FIELD INVENTORY

76-1 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

28a EROSION ANALYSIS ZONE NUMBER

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

residential lands. In 1995, the section was unprotected by shoreline protection structures. The section was fronted by a beach of up to 25 feet in width. The bluff in this section was between 120 and 130 feet in height. The bluff materials in this section were generally covered by slumped materials, but were estimated to be primarily till overlain by sand and gravel and sand and silt, overlain by till. Locally, along the bluff top, the uppermost stratum of till was overlain by a stratum of sand, sand and gravel, and silty clay. For analysis purposes, Section 28 was further subdivided into seven erosion zones, as shown on Map 73. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the seven erosion zones in Section 28.

Erosion Zone 28a

Erosion Zone 28a extends from the south line of Section 28 at Lakefield Road extended, in the Town of Grafton, north about 0.25 mile, as shown on Map 73. This zone had a beach of up to 25 feet in width fronting the bluff which had a height of about 120 feet. The bluff was unprotected within this zone. Vegetation covered approximately 90 percent of the bluff slope. In 1995, signs of translational slides and erosion of the bluff toe were present. The 1995 field observations indicated between zero and 10 feet of retreat in the bluff top since 1976.

In 1995, one bluff profile field survey was made within Erosion Zone 28a by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a similar geometry to that documented in 1976, although the bluff toe slope had a steeper slope during 1995 than during 1976. The stability of the bluff in Zone 28a of Reach 12 was characterized by Profile No. 12-22. Results of the slope stability analysis, shown in Figure 75, indicated that the bluff was marginally stable in the zone with respect to rotational failures, with a safety factor of 1.02, based upon the deterministic bluff stability analysis method. Profile No. 12-22 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.8 to 1.36 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for seven, or 30 percent, of the 23 critical conditions, as represented by the set of most critical conditions determined in each of the 23 analyses considered. In addition, a safety factor of less than 1.0 was determined for 43, or 19 percent, of the 230 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a bluff safety factor of 0.85.

The beach ranged up to about 25 feet in width within Erosion Zone 28a. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be gravel in the southern portion of the zone grading to sand in the central and northern portions of the zone. The 1977 study also reported broken trees on the beach in the southern portion of the zone. At Profile No. 12-22, the nearshore lakebed depth of five feet was reached at 135 feet offshore in 1976. The nearshore lakebed materials were noted to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or 1987.

Shoreline recession data for Erosion Zone 28a were estimated at two locations. These data indicated a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 20 feet, or about one foot per year, occurring between 1975 and 1995. Thus, the bluff did not appear to be stabilized within this zone. The 1977 study reported a recession rate of three feet per year for this zone.

In 1995, active shallow slides and slopewash were observed on the lower portions of the bluff slopes within Erosion Zone 28a at Profile No. 12-22. As a result, bluff top recession can be anticipated in the future within this zone.

Erosion Zone 28b

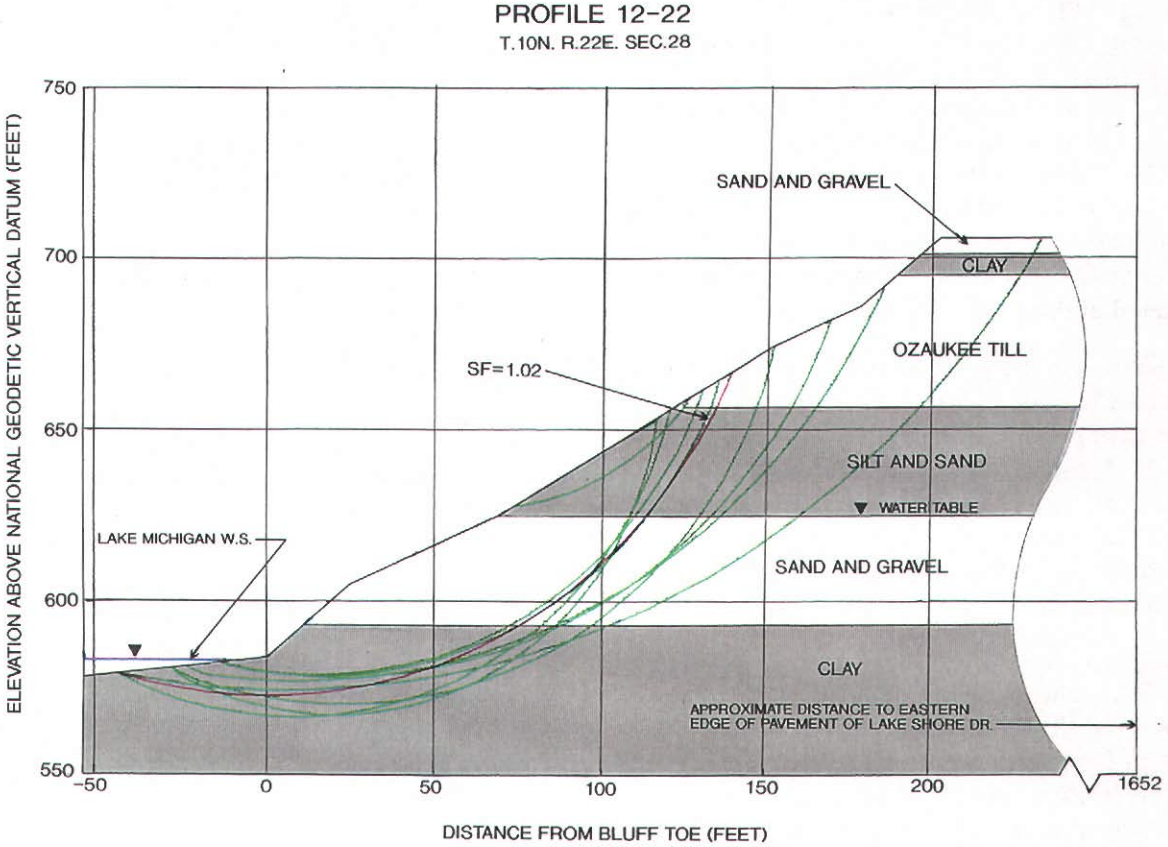
Erosion Zone 28b extends from the northern limit of Erosion Zone 28a north about 0.3 mile to the mid-section line of Section 28 at a point about 250 feet north of the location at which Lake Shore Road turns northward after making an easterly turn within the Town of Grafton, as shown on Map 73. This zone had a beach of up to 75 feet in width fronting the bluff which had a height of about 120 feet. The bluff was unprotected within this zone. Vegetation, comprising horsetails, juniper, locust, and shrubs, covered approximately 90 percent of the bluff slope. In 1995, the lower bluff slope was largely exposed, although an old slump block appeared to protect the bluff slope from failures, resulting in bluff top recession. The 1995 field observations indicated between zero and 15 feet of retreat in the bluff top since 1976.

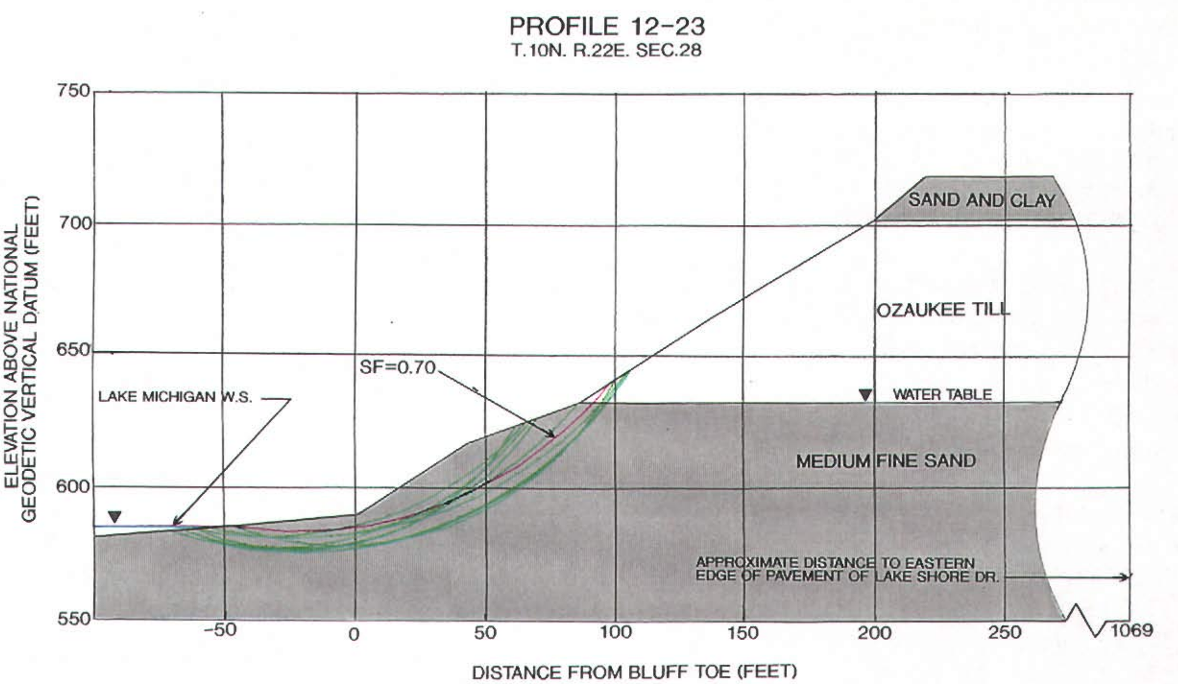
In 1995, one bluff profile field survey was made within Erosion Zone 28b by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a similar geometry to that documented in 1976, although the bluff toe slope had a steeper slope during 1976 than during 1995. The stability of the bluff in Zone 28b of

Figure 75

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 28, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Reach 12 was characterized by Profile No. 12-23. Results of the slope stability analysis, shown in Figure 75, indicated that the bluff was unstable with respect to both rotational and translational failures in the zone, with a safety factor of 0.7. The 1977 study reported a bluff safety factor 0.96.

The beach ranged up to about 75 feet in width within Erosion Zone 28b. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be gravel at the water's edge, grading to sand at the bluff toe. At Profile No. 12-22, the nearshore lakebed depth of five feet was reached at 110 feet offshore in 1976. The nearshore lakebed materials were not noted. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

Shoreline recession data for Erosion Zone 28b were estimated at one location. These data indicated a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 40 feet, or about two feet per year, occurring between 1975 and 1995. Thus, the bluff did not appear to be stabilized within this zone. The 1977 study did not report a recession rate for this zone.

Erosion Zone 28c

Erosion Zone 28c extends from the northern limit of Erosion Zone 28b north about 0.1 mile, as shown on Map 73. This zone had a beach of up to 25 feet in width fronting the bluff which had a height of about 130 feet. The bluff was unprotected in this zone. Vegetation, consisting of scattered juniper and shrubs, covered approximately 90 percent of the bluff slope. In 1995, signs of shallow slides and sheet wash were observed throughout the zone. The 1995 field observations indicated between zero and five feet of retreat in the bluff top since 1976.

No bluff stability analyses were conducted within Erosion Zone 28c in this study or in 1976.

The beach ranged up to about 25 feet in width within Erosion Zone 28c. In the 1977 study, the beach width was reported to be about 20 feet, and the beach material was reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 28c were estimated at one location. These data indicated a recession of about 50 feet, or about 1.6 feet per year, occurred between 1963 and 1995. The data indicated that most of the recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. The bluff appeared to be largely stabilized within this zone. The 1977 study did not report a recession rate for this zone.

Erosion Zone 28d

Erosion Zone 28d extends from the northern limit of Erosion Zone 28c north about 0.1 mile, as shown on Map 73. This zone had a beach of up to 50 feet in width fronting the bluff which had a height of about 130 feet. The bluff was unprotected in this zone, except for an old slump block which was being actively eroded in 1995. Vegetation covered approximately 5 percent of the bluff slope. In 1995, signs of translational slides were present. Evidence of larger-scale slumping in the past was also observed in portions the zone. The 1995 field observations indicated between zero and five feet of retreat in the bluff top since 1976.

In 1995, one bluff profile field survey was made within Erosion Zone 28d by occupying a site for which a field survey was conducted in 1976. The reoccupied site had a similar geometry to that documented in 1976, although the bluff toe slope had a steeper slope during 1976 than during 1995, and the central portion of the bluff slope appeared to have taken on a more concave aspect in 1995. The stability of the bluff in Zone 28d of Reach 12 was characterized by Profile No. 12-24. Results of the slope stability analysis, shown in Figure 76, indicated that the bluff was unstable with respect to both rotational and translational failures in the zone, with a safety factor of 0.84. The 1977 study reported a bluff safety factor of 0.83.

The beach ranged up to about 50 feet in width within Erosion Zone 28d. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be sand. At Profile No. 12-24, the nearshore lakebed depth of five feet was reached at 115 feet offshore in 1976. The nearshore lakebed materials were noted to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1987.

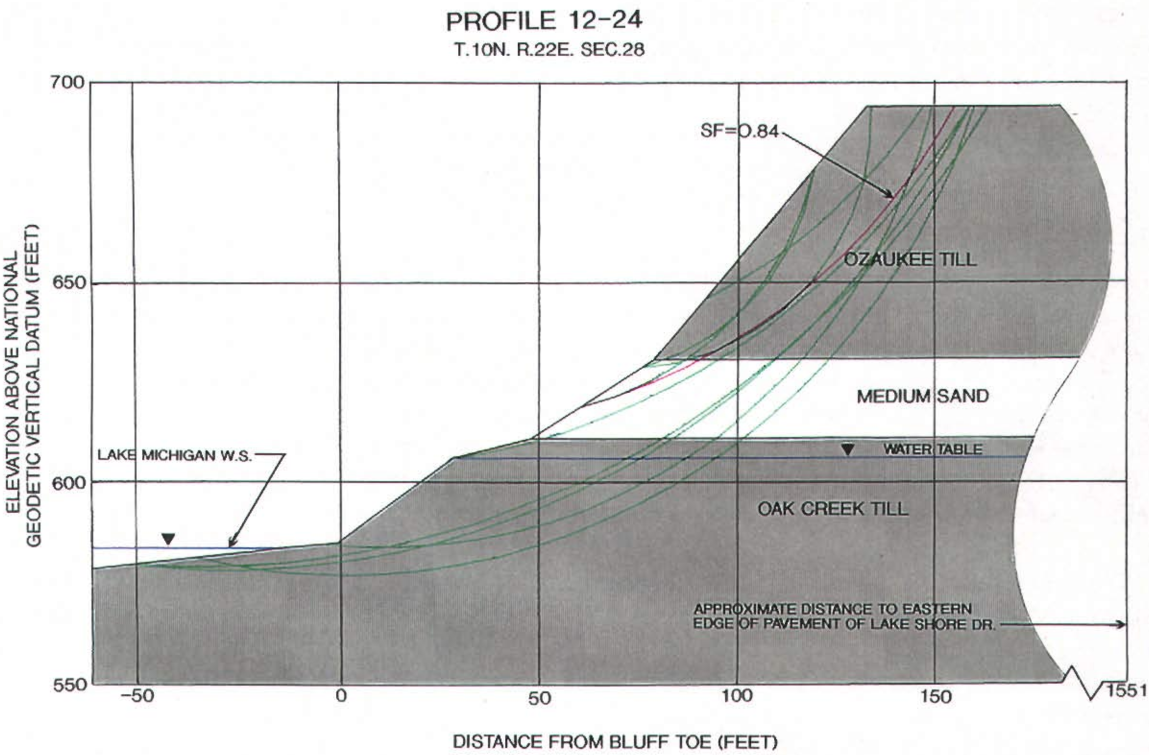
Shoreline recession data for Erosion Zone 28d were not estimated. The 1977 study did not report a recession rate for this zone.

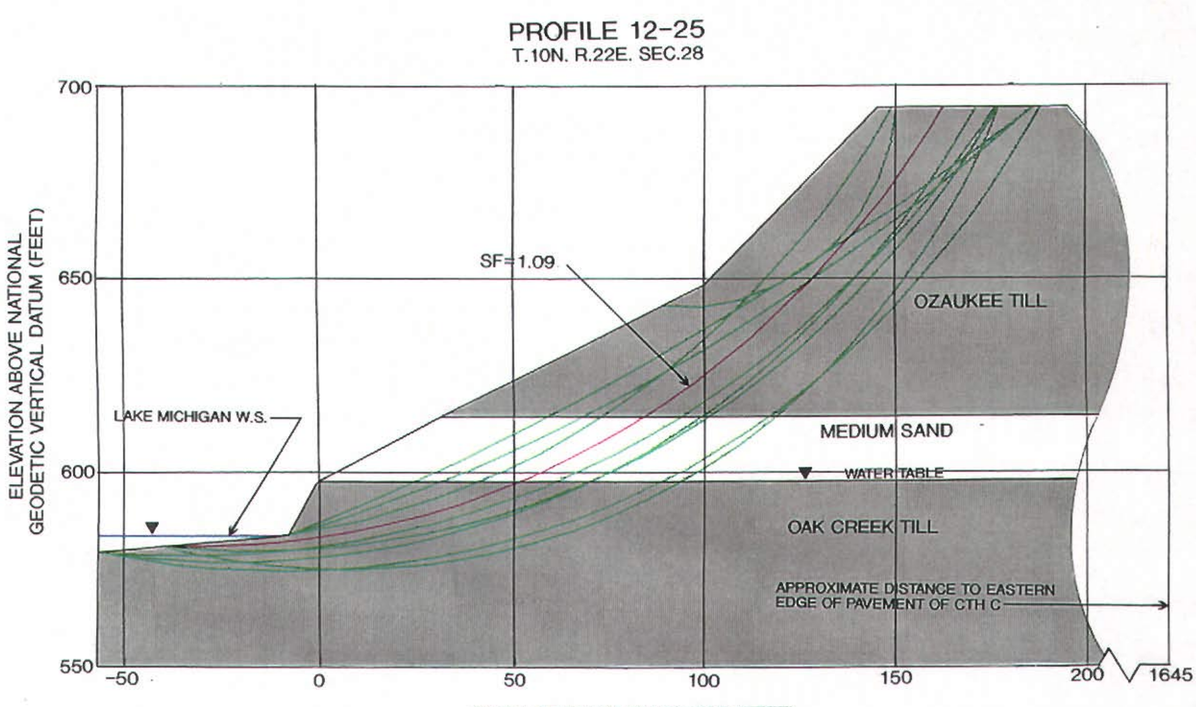
In 1995, evidence of active shoreline erosion was observed on the slump block located on the bluff slopes within Erosion Zone 28d. It appeared that sliding and larger-scale slumping may resume when the slump block is eroded away, resulting in increased bluff top retreat in the future.

Figure 76

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 28, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Erosion Zone 28e

Erosion Zone 28e extends from the northern limit of Erosion Zone 28d north about 0.15 mile, as shown on Map 73. This zone had a beach of up to 25 feet in width fronting the bluff which had a height of about 120 feet. The bluff was unprotected in this zone. Vegetation covered approximately 5 percent of the bluff slope. In 1995, signs of translational slides, sheetwash, and bluff toe erosion were present, and a gully occurred at the northern end of this zone. The 1995 field observations indicated zero to five feet of retreat in the bluff top since 1976.

In 1995, one bluff profile field survey was made within Erosion Zone 28e by occupying a site for which a field survey was conducted in 1982. The stability of the bluff in Zone 28e of Reach 12 was characterized by Profile No. 12-25. Results of the slope stability analysis, shown in Figure 76, indicated that the bluff was marginally stable in the zone with respect to rotational failures, with a safety factor of 1.09, based upon the deterministic bluff stability analysis method. Profile No. 12-25 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.88 to 1.26 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for seven, or 28 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 55, or 22 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study did not report a bluff safety factor for this zone.

The beach ranged up to about 25 feet in width within Erosion Zone 28e. In the 1977 study, the beach width was reported to be about five feet, and the beach material was reported to be gravel. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 28e were not estimated. The 1977 study did not report a recession rate for this zone.

In 1995, evidence of active shoreline erosion was observed on the bluff slopes within Erosion Zone 28e. It appeared that major slumps could occur during future periods of higher lake levels.

Erosion Zone 28f

Erosion Zone 28f extends from the northern limit of Erosion Zone 28e north about 0.1 mile, as shown on Map 73. This zone had a beach of up to 25 feet in width fronting the bluff which had a height of about 120 feet. The bluff was unprotected by shoreline protection structures in this zone, although its situation as the northern wall of a gully and its wider beachfront due to the delivery of materials onto the beach from the gully mouth, did appear to offer a degree of protection to the bluff slope. Vegetation, comprising white cedar on the lower bluff slopes and of maple, birch, and basswood on the upper bluff slopes, covered between 85 and 90 percent of the bluff slope. In 1995, signs of translational slides, sheetwash, and bluff toe erosion were present, and a gully occurred at the northern end of this zone. The 1995 field observations indicated no visible retreat in the bluff top since 1976.

No bluff stability analyses were conducted within Erosion Zone 28f in this study or in 1976.

The beach ranged up to about 25 feet in width within Erosion Zone 28f. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be gravel in the southern portion of the zone grading to sand in the northern portion of the zone. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976 or 1987.

Shoreline recession data for Erosion Zone 28f were not estimated. The 1977 study did not report a recession rate for this zone.

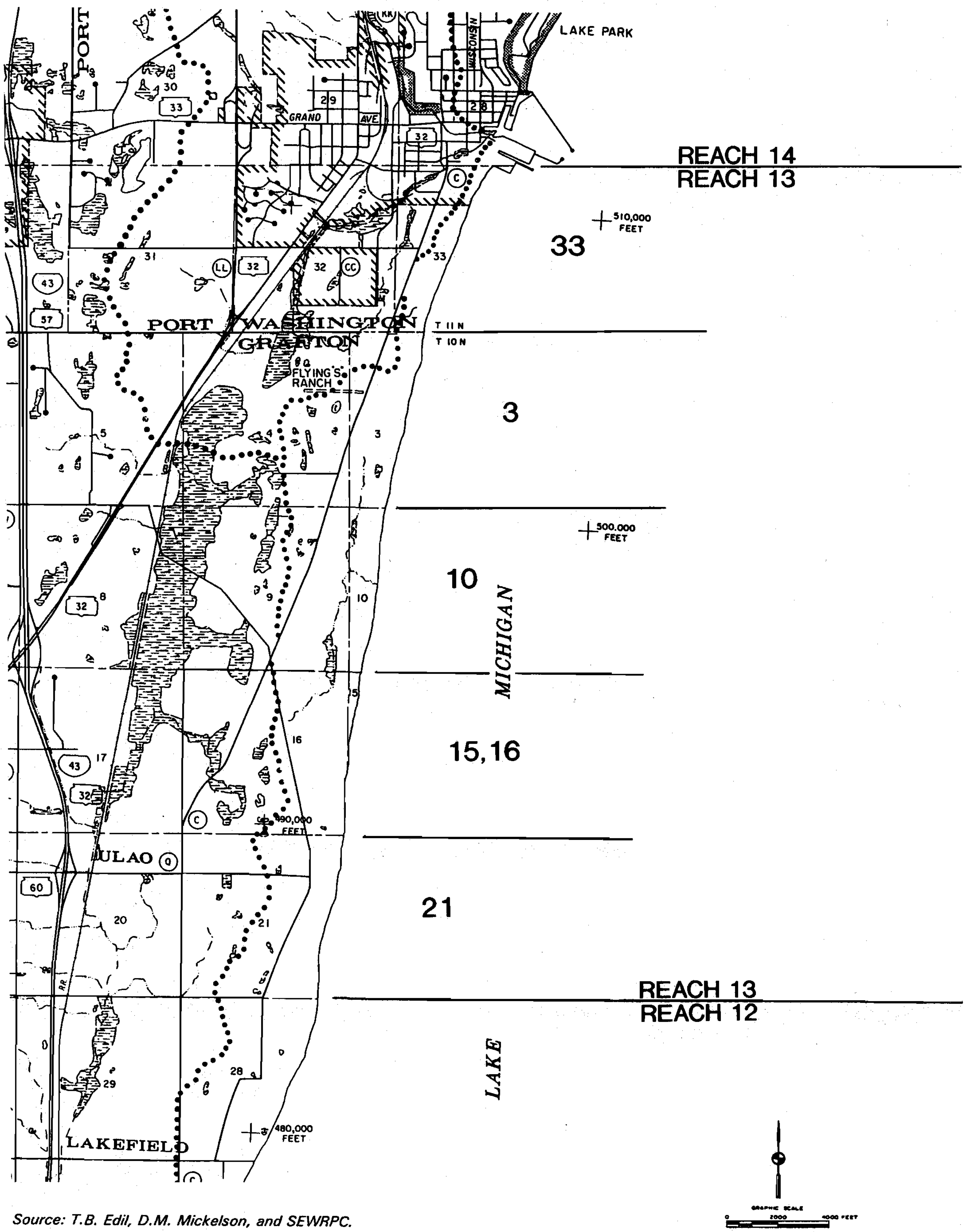
SHORELINE REACH 13: CITY OF PORT WASHINGTON AND TOWN OF GRAFTON, OZAUKEE COUNTY

Shoreline Reach 13 is a five-mile-long reach of shoreline extending from the south line of U.S. Public Land Survey Section 21, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County, at about Falls Road, north to the north line of U.S. Public Land Survey Section 33, Township 11 North, Range 22 East, City of Port Washington, Ozaukee County, as shown on Map 74. Land uses in this reach included agricultural and other open space uses, residential lands, and woodlands.

Beach widths in Reach 13 varied between five and 15 feet. The bluff height throughout Reach 13 was about 120 feet. The southern part of the reach was dominated

Map 74

BLUFF ANALYSIS SECTIONS WITHIN REACH 13



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

by large slump blocks and shallow slides which occurred throughout the reach where the bluff had not been stabilized by shoreline protection structures. In many areas of Reach 13, the lower parts of the slump blocks were being cut by wave action.

As shown on Map 74, Reach 13 was further segmented into five shoreline analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the five shoreline analysis sections in Reach 13.

U.S. Public Land Survey Section 21, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County

This shoreline analysis section extends from Falls Road north to the south line of U.S. Public Land Survey Section 16, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County, as shown on Map 75. The shoreline area was occupied by agricultural and other open space uses and residential lands. The bluffs in this section ranged from 110 to 130 feet. The beach was narrow, ranging from 10 to 15 feet in width, and there were no erosion control structures on the beach or the bluff. The 1995 field observations indicated that all of Section 21 was actively eroding and much of it showed signs of large, active slumps. For further analysis, Section 21 was further subdivided into five erosion zones, as shown on Map 75. The inventory and analysis findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the five zones.

Erosion Zone 21a

This shoreline analysis section extends from Falls Road north about 0.05 mile, as shown on Map 75. The beach in this zone was narrow to nonexistent. The bluff in Zone 21a was completely vegetated with northern white cedar in the lower portion of the bluff, and mixed hardwoods on the upper portion of the bluff.

No bluff stability analyses were conducted within Erosion Zone 21a during this study or the 1977 study.

In the 1977 study, the beach width was reported to be between 10 and 20 feet, and the beach materials were reported to be cobbles and pebbles with some sand. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 21a were not estimated.

Erosion Zone 21b

Erosion Zone 21b extends from the northerly limits of Erosion Zone 21a north about 0.08 mile, as shown on Map 75. This zone had a very narrow to nonexistent beach. In 1995, an existing slump block, reported in the 1977 study as being about halfway up the slope of the bluff, appeared to have moved further down the bluff slope to the lower part of the slope. The 1995 field observations indicated that it was probable that this block would continue to move in the future, and that small en-echelon failures would form at the bluff top. In 1995, the bluff was noted to be about 30 percent vegetated.

In 1995, one bluff profile field survey was made within Zone 21b by occupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 21b was characterized by Profile No. 13-1. Results of the slope stability analysis, shown in Figure 77, indicated that the bluff was stable with respect to rotational failures within this zone, with a safety factor of 1.32, based upon the deterministic bluff stability analysis. However, 1995 field observations indicated that translational failures may occur. The 1977 study reported a safety factor 0.59 at the toe of the bluff.

In 1995, the beach within Zone 21b was narrow to nonexistent. In the 1977 study, the beach width was reported to be between 10 and 20 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 21b were estimated at one location. The data indicated that a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. Most that recession appeared to have occurred prior to 1975, with a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. The 1977 study did not report a recession rate for this zone.

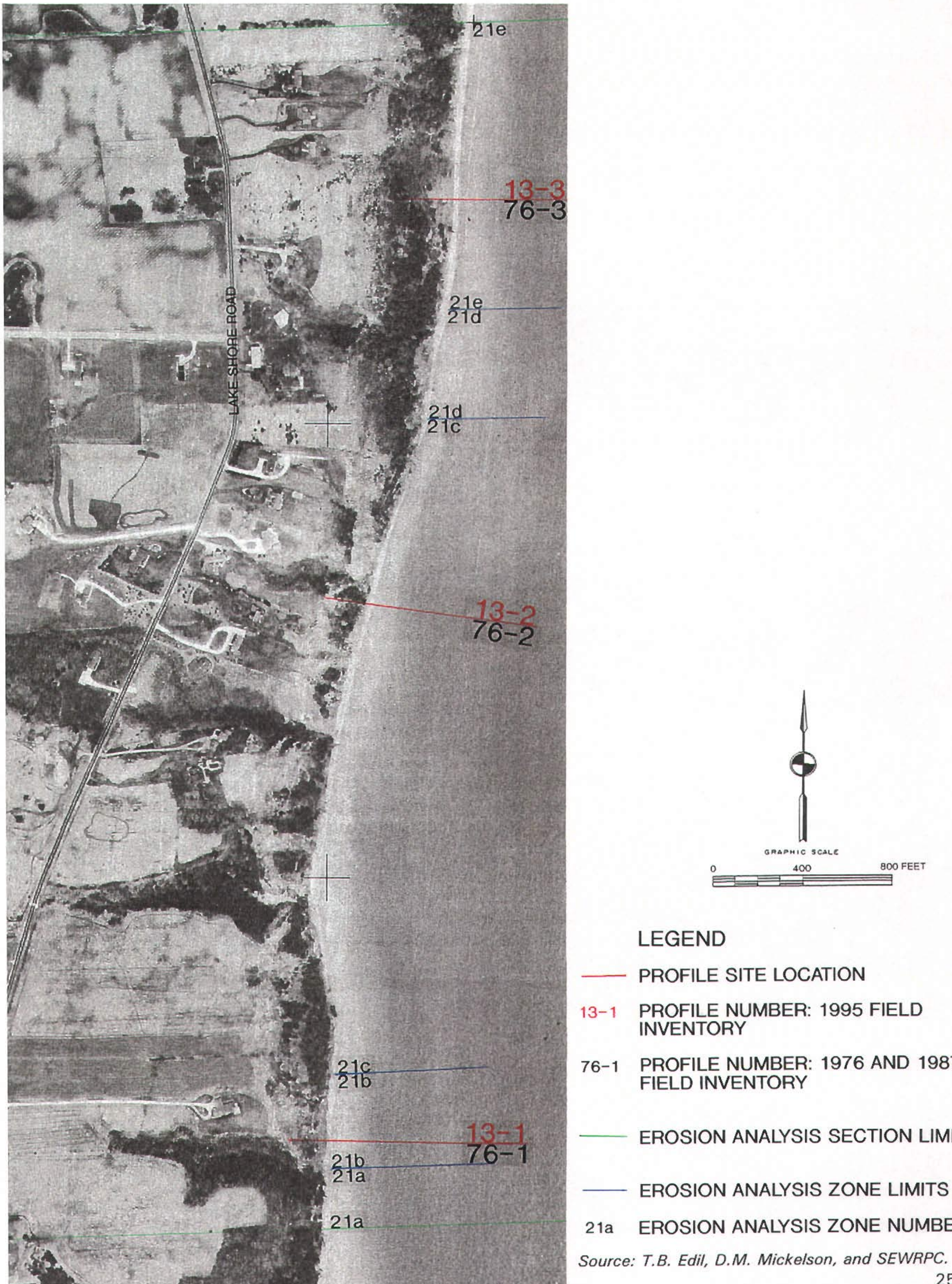
Erosion Zone 21c

Erosion Zone 21c extends from the northerly limits of Erosion Zone 21b north about 0.55 mile, as shown on Map 75. This zone had a very narrow beach and a bluff height of about 120 feet. A large slump block or several large slump blocks existed near the top of the bluff in 1976. The 1995 field observations indicated that there had been little or no change in this slump block since

Map 75

SHORELINE EROSION REACH 13: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 21, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County



LEGEND

PROFILE SITE LOCATION

13-1 PROFILE NUMBER: 1995 FIELD INVENTORY

76-1 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

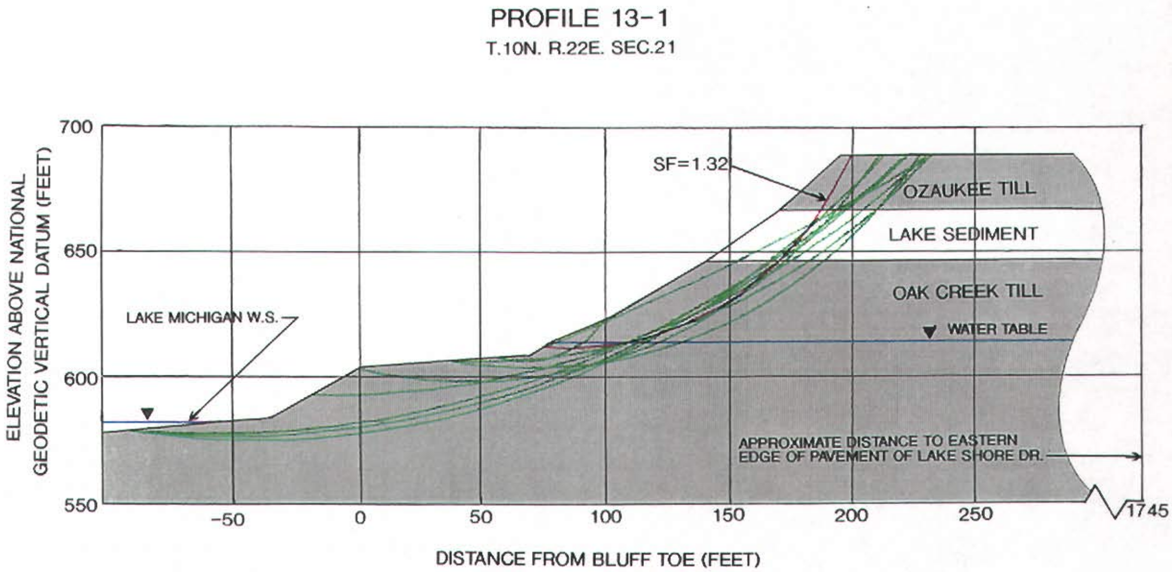
21a EROSION ANALYSIS ZONE NUMBER

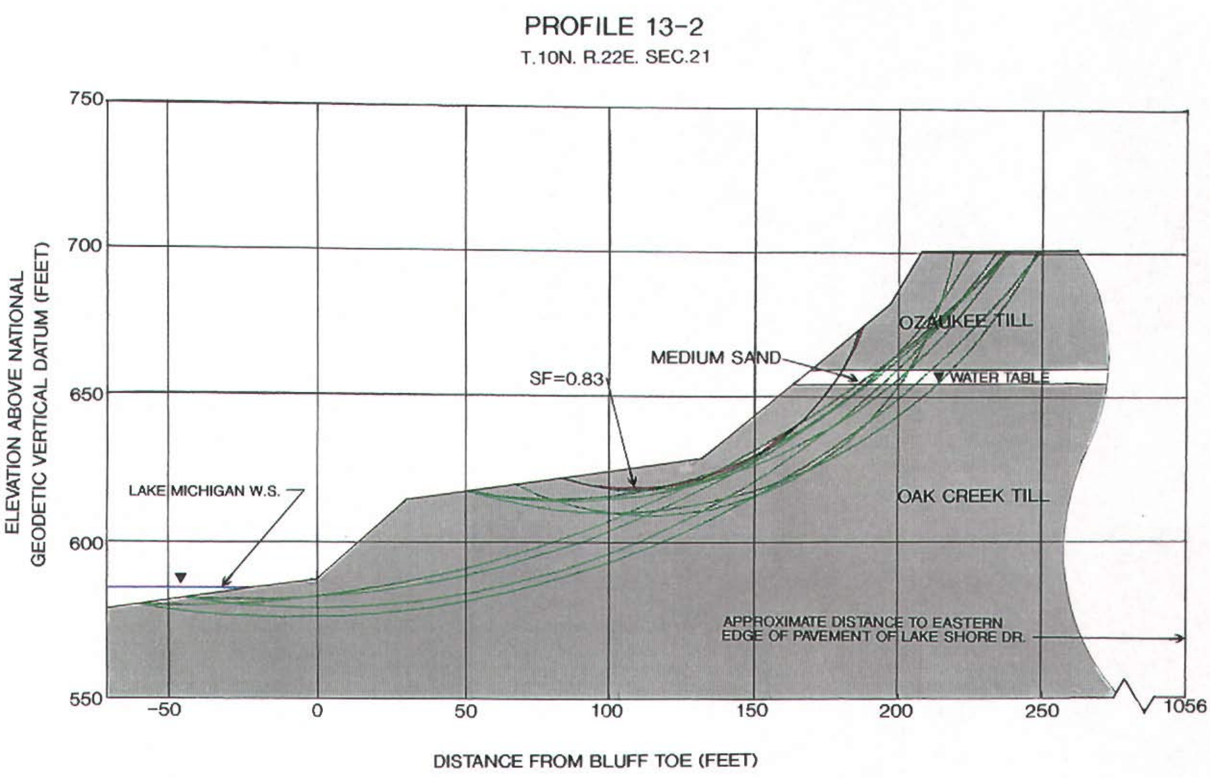
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 77

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 21, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

1976, with the exception of several masses dropping about halfway down the bluff. About 0.3 mile into Zone 21c, a deep-seated failure was noted to have taken place, with at least 20 feet of the bluff top observed to have been lost in 1995. In addition, en-echelon failures were noted to be occurring near the bluff top.

In 1995, one bluff profile field survey was made within Zone 21c by occupying a site for which a field survey was conducted in 1976. The bluff material at this site was estimated to be till interbedded with sand. The stability of the bluff in Erosion Zone 21c was characterized by Profile No. 13-2. Results of the slope stability analysis, shown in Figure 77, indicated that the bluff was unstable with respect to both rotational and translational failures, with a safety factor of 0.83, based upon the deterministic bluff stability analysis. The 1977 study reported a safety factor of 0.82 for the top of the bluff.

In the 1977 study, the beach width was reported to be between 10 and 25 feet, and the beach materials were reported to be medium-grained sand with some cobbles, pebbles, and gravel. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 21c were estimated at one location. The data indicated that a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995.

Erosion Zone 21d

Erosion Zone 21d extends from the northerly limits of Erosion Zone 21c north about 0.09 mile, as shown on Map 75. This zone had a 20- to 30-foot-wide beach and a bluff height of up to about 130 feet. The lower slope of the bluff in this zone was occupied by a large slump block which was vegetated with northern white cedar and some hardwoods. The upper part of the slope was vegetated with shrubs and grass-like vegetation. The 1995 field observations noted that, although this zone appeared little changed since 1976, small en-echelon failures had formed at the bluff top.

No bluff stability analyses were conducted within Erosion Zone 21d during this study or the 1977 study.

In 1995, the beach within Zone 21d was between 20 and 30 feet wide. In the 1977 study, the beach width was reported to be between 10 and 20 feet, and the beach materials were reported to be intermixed pebbles, cobbles, and gravel. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 21d were estimated at one location. These data indicated that a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995.

Erosion Zone 21e

Erosion Zone 21c extends from the northerly limits of Erosion Zone 21d north to the north line of the section, as shown on Map 75. This zone had a beach of between five and 15 feet in width and a bluff height of about 120 feet. In 1995, this zone consisted of several large slump blocks which produced a low, gentle slope in this bluff profile. In this zone, the lower part of the bluff was vegetated with northern white cedar and mixed hardwoods. The middle and upper parts of the bluff were vegetated with shrubs and grass-like vegetation. The 1995 field observations indicated that erosion of the bluff top was occurring by shallow en-echelon slides, rather than by movement of the large slump block itself. Observations of the lower part of the bluff also indicated that erosion was occurring during storms at the front of the slump block at the top of the beach.

In 1995, one bluff profile field survey was made within Zone 21e by occupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 21e was characterized by Profile No. 13-3. Results of the slope stability analysis, shown in Figure 78, indicated that the bluff was stable with respect to rotational failures, with a safety factor of 1.81, based upon the deterministic bluff stability analysis. The 1977 study reported a safety factor of 0.75 for the toe of the bluff.

In the 1977 study, the beach width was reported to be between 10 and 20 feet, and the beach materials were reported to be intermixed cobbles, pebbles, and gravel. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 21e were estimated at one location. The data indicated that no measurable recession occurred between 1963 and 1995.

U.S. Public Land Survey Sections 15 and 16, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County

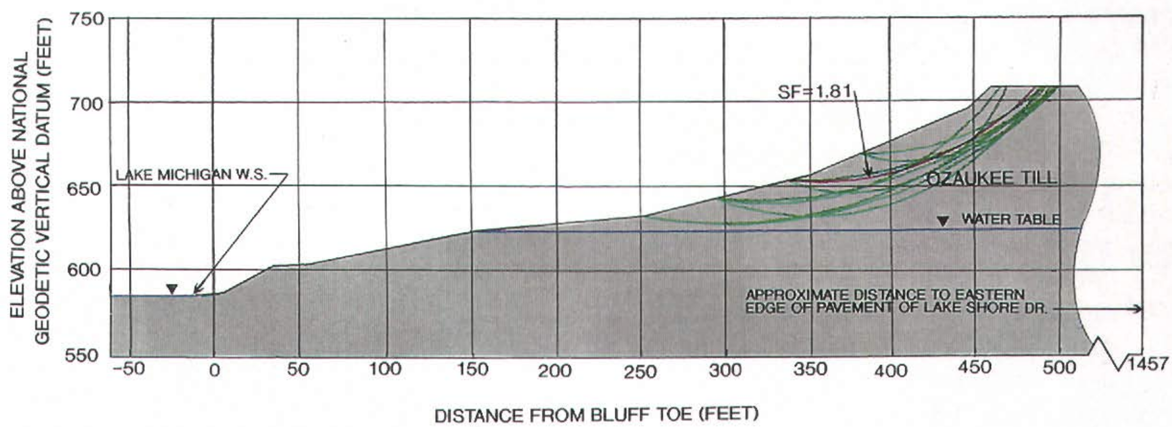
This shoreline analysis section extends from the south line of U.S. Public Land Survey Section 16, Town-

Figure 78

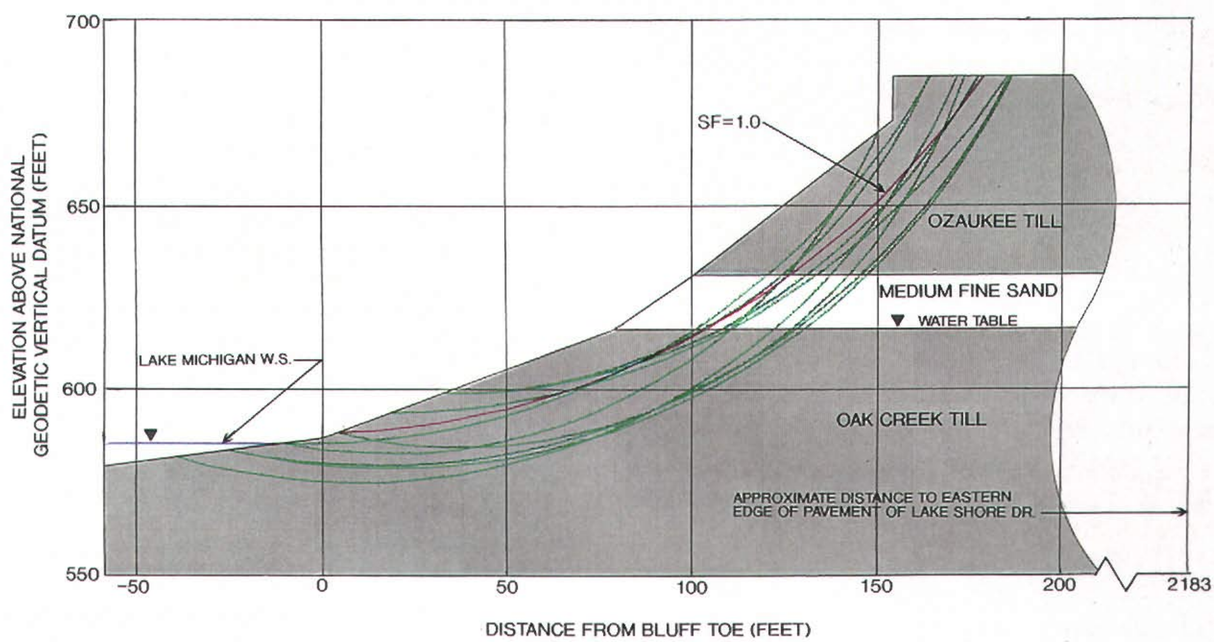
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Sections 16 and 21, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County

PROFILE 13-3
T.10N. R.22E. SEC.21



PROFILE 13-4
T.10N. R.22E. SEC.16



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

ship 10 North, Range 22 East, Town of Grafton, Ozaukee County, north the south line of U.S. Public Land Survey Section 10, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County, at about Ulao Parkway Road extended, as shown on Map 76. The shoreline area was occupied by agricultural and residential lands and woodlands. The bluffs in this section ranged from 110 to 130 feet. The beach width ranged from being nonexistent to about 20 feet. Few erosion control structures existed in this zone. For further analysis, Section 16 was further subdivided into two erosion zones, as shown on Map 76. The inventory and analysis findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the two zones.

Erosion Zone 16a

Erosion Zone 16a extends from the south line of Section 16 north 0.7 mile, as shown on Map 76. The beach in this zone ranged from being nonexistent to 20 feet in width. In 1995, the bluff in this had height of about 100 feet. The bluff was noted to be 80 to 90 percent vegetated. The southern part of the bluff was vegetated mostly by northern white cedar and the northern part by shrubs and grass-like vegetation. The 1995 field observations indicated that the lower part of the bluff was protected by old slump blocks which were eroding along much of the beach.

In 1995, one bluff profile field survey was made within Zone 16a by occupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 16a was characterized by Profile No. 13-4. Results of the slope stability analysis, shown in Figure 78, indicated that the bluff was marginally stable, with a safety factor of 1.0, based upon the deterministic bluff stability analysis. Profile No. 13-4 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.79 to 1.44 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for seven, or 28 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 39, or 15.6 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a safety factor of 0.59 for the upper slope of the bluff.

In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be pebbles with some sand. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 16a were estimated at two locations. These data indicated that a recession of between 10 and 50 feet, or between 0.3 and 1.6 feet per year, occurred between 1963 and 1995. The data indicated that, in the northern part of the zone, most of that recession occurred prior to 1975, with a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995, while, in the southern portion of the zone, a recession of about 10 feet, or about 0.5 foot per year between 1975 and 1995 was indicated. Thus, although portions of the bluff within this zone appeared to have been stabilized, it appeared that the bluff slope was not fully stabilized in the southern portion of the zone.

In 1995, riprap and debris had been placed on the higher part of the bluff on at least two properties in the northern end of Zone 16a.

Erosion Zone 16b

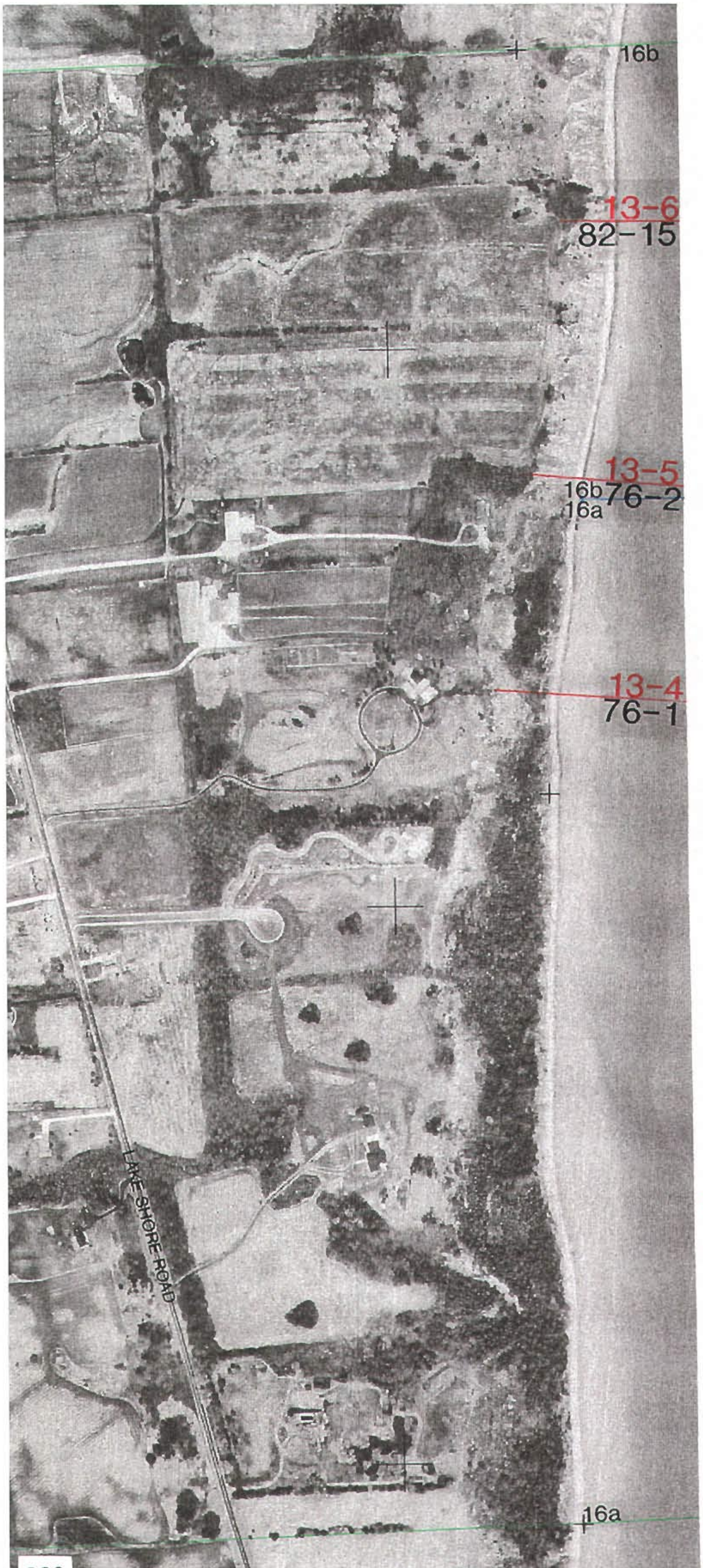
Erosion Zone 16b extends from the northerly limits of Erosion Zone 16a north to the north line of the section, as shown on Map 76. This zone had a beach of between five and 15 feet in width and a bluff height of up to about 120 feet. The bluff in this zone was poorly vegetated, to about 20 percent of the bluff slope, with horsetails, sumac, and grassy vegetation.

In 1995, two bluff profile field surveys were made within Zone 16b by occupying sites for which field surveys were conducted in 1976 and in 1982. The stability of the bluff in Erosion Zone 16b was characterized by Profile Nos. 13-5 and 13-6. Results of the slope stability analyses, shown in Figure 79, indicated that the bluff was unstable with respect to both rotational and translational failures, with a safety factor of 0.73 at Profile No. 13-5 and a safety factor of 0.81 at Profile No. 13-6, based upon the deterministic bluff stability analysis. The 1977 study reported a safety factor of 0.65 at Profile No. 13-5. The 1982 study did not report a bluff safety factor at Profile No. 13-6.

Map 76

SHORELINE EROSION REACH 13: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Sections 15 and 16, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County



LEGEND

PROFILE SITE LOCATION

13-4 PROFILE NUMBER: 1995 FIELD INVENTORY

76-1 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

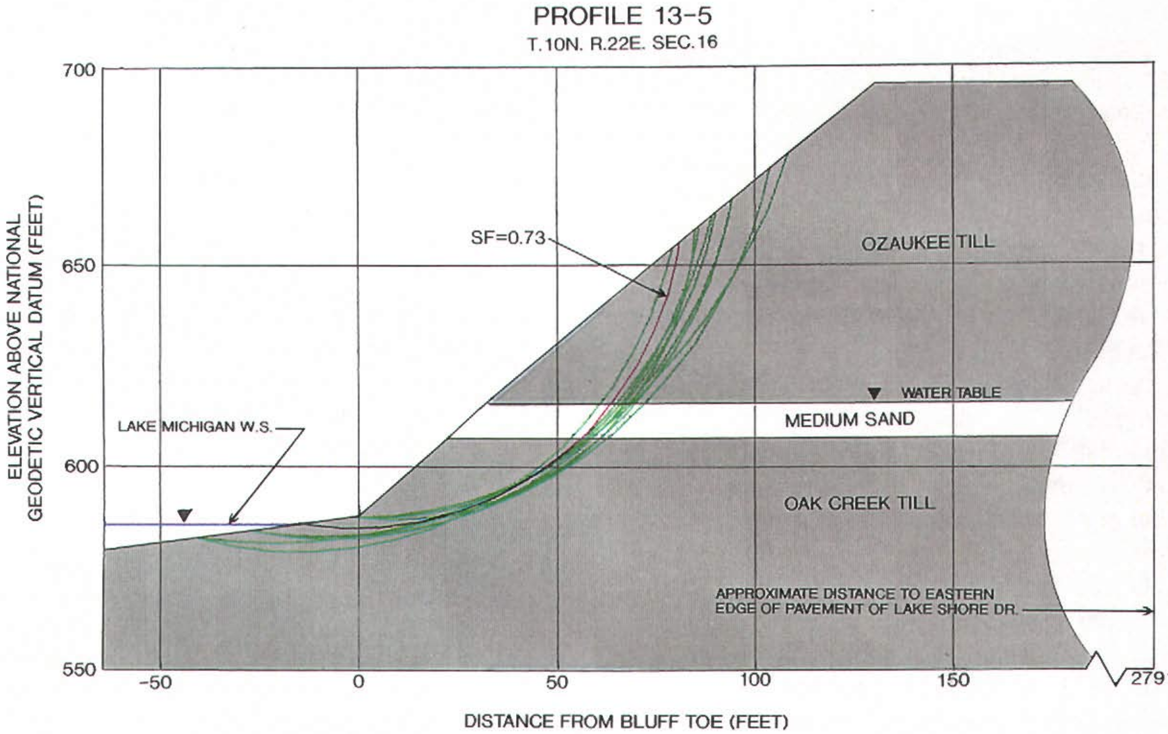
16a EROSION ANALYSIS ZONE NUMBER

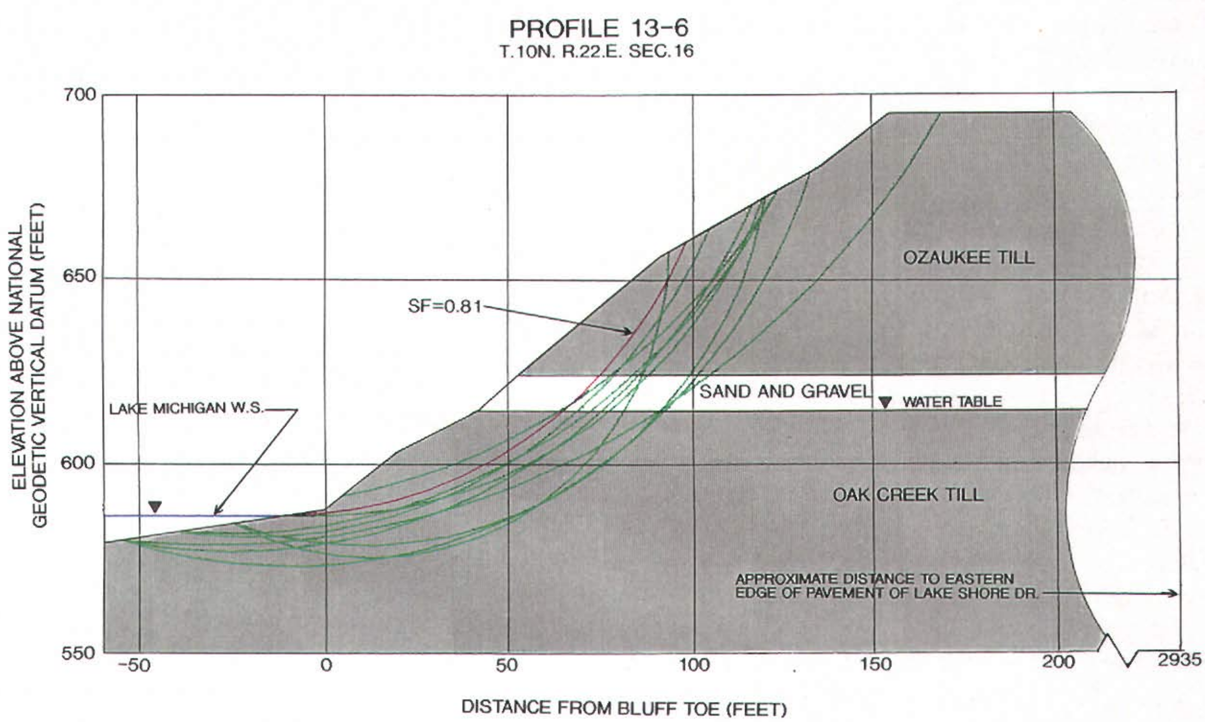
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 79

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 16, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be sand with some pebbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 16b were estimated at one location. The data indicated that no measurable recession occurred between 1963 and 1995.

U.S. Public Land Survey Section 10, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County

This shoreline analysis section extends the south line of U.S. Public Land Survey Section 10, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County, north to the south line of U.S. Public Land Survey Section 3, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County, as shown on Map 77. The shoreline area of this section was occupied by undeveloped lots, woodlands and other open lands, and residential land use. The bluffs in this section ranged from about 100 to 110 feet in height. The beach was narrow, ranging from 10 to 30 feet in width, and there were no erosion control structures on the beach or the bluff. The 1995 field observations indicated that the existing slopes were straight and vegetation free, suggesting that significant numbers of shallow slides and slopewash were occurring. For further analysis, Section 10 was further subdivided into three erosion zones, as shown on Map 77. The inventory and analysis findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the three zones.

Erosion Zone 10a

Erosion Zone 10a extends from the south line of the section, north about 0.5 mile, as shown on Map 77. This zone had a beach of between 10 and 30 feet in width. The bluff in this zone was poorly vegetated, with shrubs and grasses covering about 10 percent of the bluff slope. The 1995 field observations indicated that the bluff was eroding by shallow slides, mud flows, and sheetwash. The top of the bluff appeared to be more scalloped than in the 1977 study, suggesting a concentration of mud flows and gully erosion in places where surface drainage or groundwater seepage was occurring.

In 1995, two bluff profile field surveys were made within Zone 10a by occupying a site for which a field survey was conducted in 1976, and by occupying an additional new site in 1995. The stability of the bluff in Erosion Zone 10a was characterized by Profile Nos. 13-7 and 13-8. Results of the slope stability analyses, shown in Figure 80, indicated that the bluff was unstable, with a safety factor of 0.99 at Profile No. 13-7 and a safety factor of 0.59 at Profile No. 13-8, based upon the deterministic bluff stability analysis. Profile No. 13-7 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.78 to 1.17 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 13, or 52 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 116, or 46.4 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a safety factor of 0.59 at Profile No. 13-7.

In the 1977 study, the beach width was reported to be greater than 20 feet, and the beach material was reported to be sand with some pebbles. No measurements or observations were made of the nearshore lakebed depth or materials within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 10a were estimated at three locations. These data indicated a recession of between 10 and 60 feet, or between 0.3 and 1.9 feet per year, occurring between 1963 and 1995. The highest recessions occurred in the southern portions of the zone. The data indicated a recession of about 40 feet, or two feet per year, occurred in both of the two southern locations between 1975 and 1995. In the northern portion of the zone, the data indicated no further recession occurring between 1975 and 1995. The 1977 study reported a recession rate for this erosion zone of about two feet per year.

Erosion Zone 10b

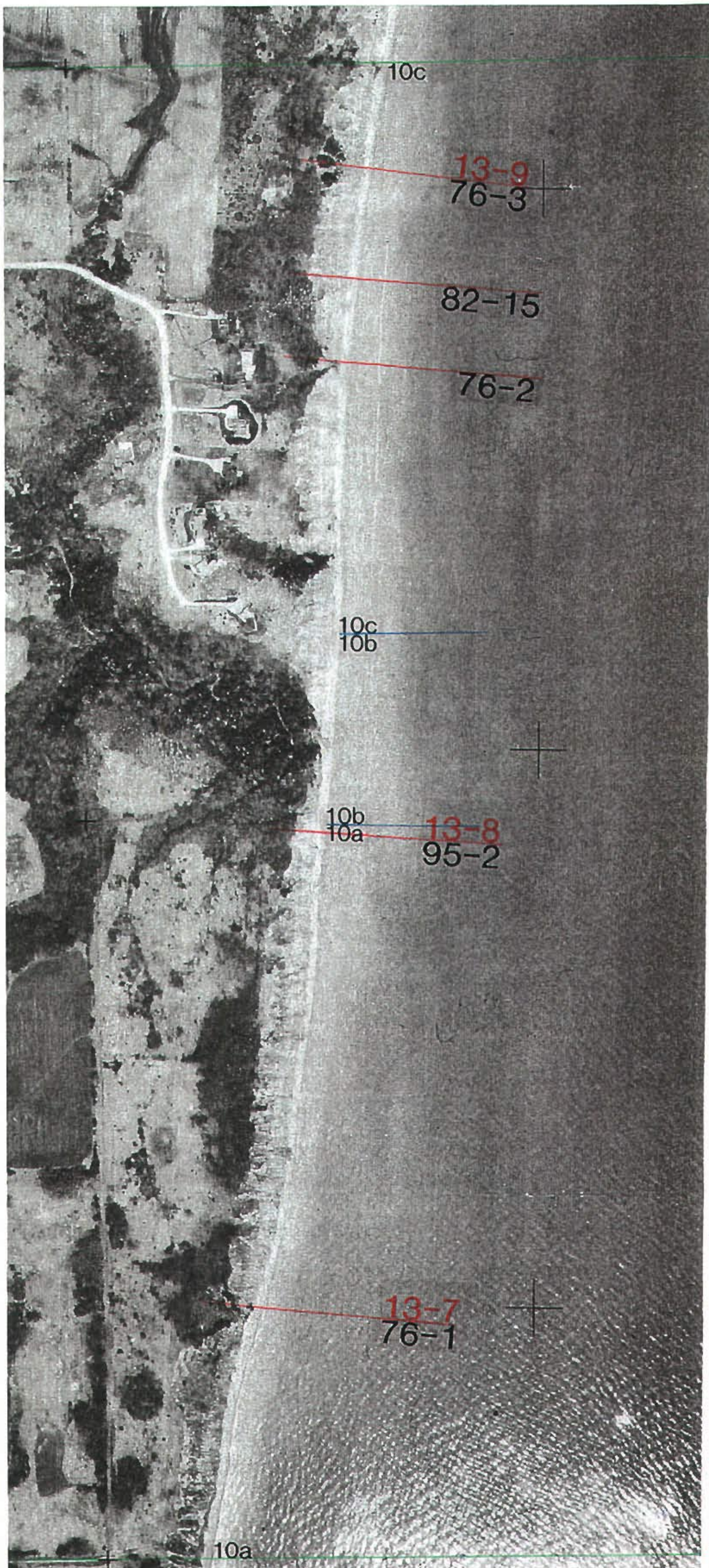
Erosion Zone 10b extends from the northerly limits of Erosion Zone 10a north about 0.13 mile, as shown on Map 77. The bluffs in this zone were up to 110 feet in height. The height of the bluff decreased where a large gully system cut through the middle of this zone and then increased to the north. The beach in this zone was about 20 to 30 feet in width and was fed by sediment carried out of the gully mouth.

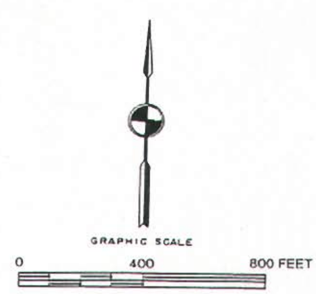
No bluff stability analyses were conducted within Erosion Zone 10b during this study or the 1977 study.

Map 77

SHORELINE EROSION REACH 13: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 10, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County





LEGEND

PROFILE SITE LOCATION

13-9 PROFILE NUMBER: 1995 FIELD INVENTORY

76-3 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

13a EROSION ANALYSIS ZONE NUMBER

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

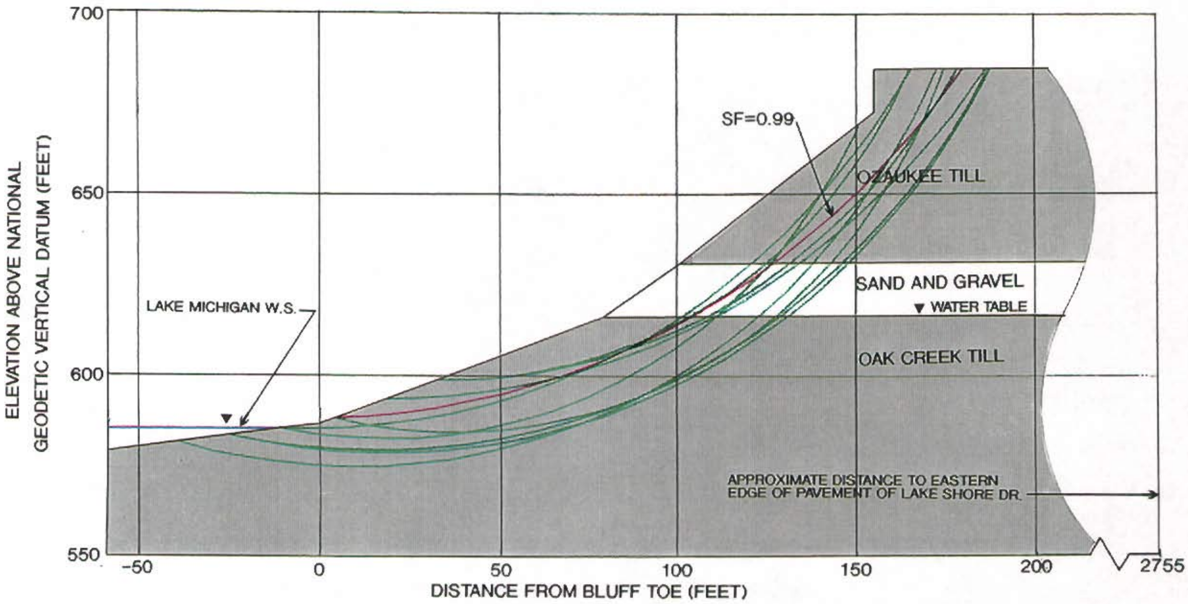
Figure 80

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 10, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County

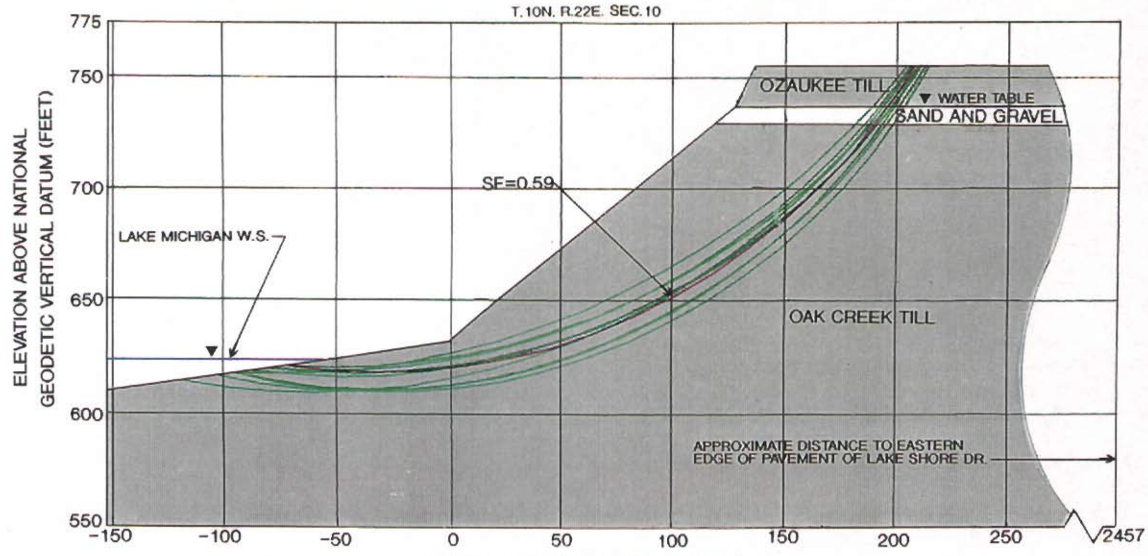
PROFILE 13-7

T.10N. R.22E. SEC.10



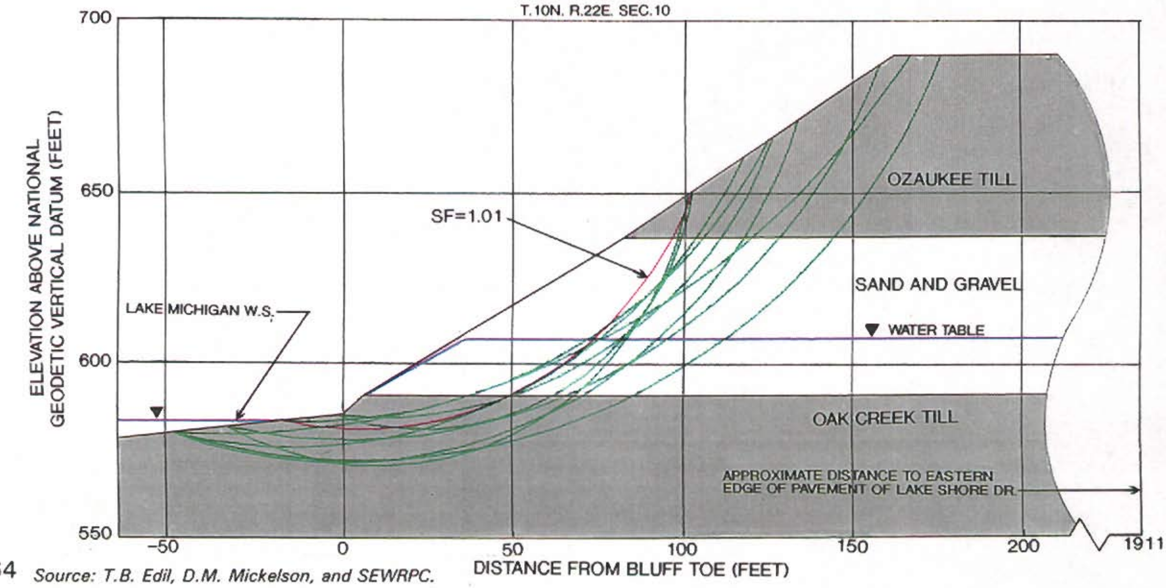
PROFILE 13-8

T.10N. R.22E. SEC.10



PROFILE 13-9

T.10N. R.22E. SEC.10



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

In 1995, the beach within Zone 10b was between 20 and 30 feet wide. In the 1977 study, the beach width was reported to be greater than 20 feet, and the beach materials were reported to be sand and pebbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 10b were not estimated.

Erosion Zone 10c

Erosion Zone 10c extends from the northerly limits of Erosion Zone 10b north to the north line of the section, as shown on Map 77. This zone had a beach of between 10 and 20 feet in width. No shoreline protection structures existed within this zone in 1995. The bluff in this zone had a height of up to about 110 feet. The bluff was poorly vegetated, with horsetails, shrubs, and grassy vegetation covering about 20 percent of the bluff slope. The 1995 field observations indicated that shallow slides and flows were occurring and that the bluff top in this zone had a scalloped appearance.

In 1995, one bluff profile field survey was made within Zone 10c by occupying one of the two sites for which field surveys were conducted in 1976. The stability of the bluff in Erosion Zone 10c was characterized by Profile No. 13-9. Results of the slope stability analyses, shown in Figure 80, indicated that the bluff was marginally stable, with a safety factor of 1.01, based upon the deterministic bluff stability analysis. Profile No. 13-9 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.83 to 1.22 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 17, or 68 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 90, or 36 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a safety factor of 0.69 for the toe of the bluff.

In the 1977 study, the beach width was reported to be greater than 20 feet, and the beach material was reported to be sand with some cobbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 10c were not estimated.

U.S. Public Land Survey Section 3, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County

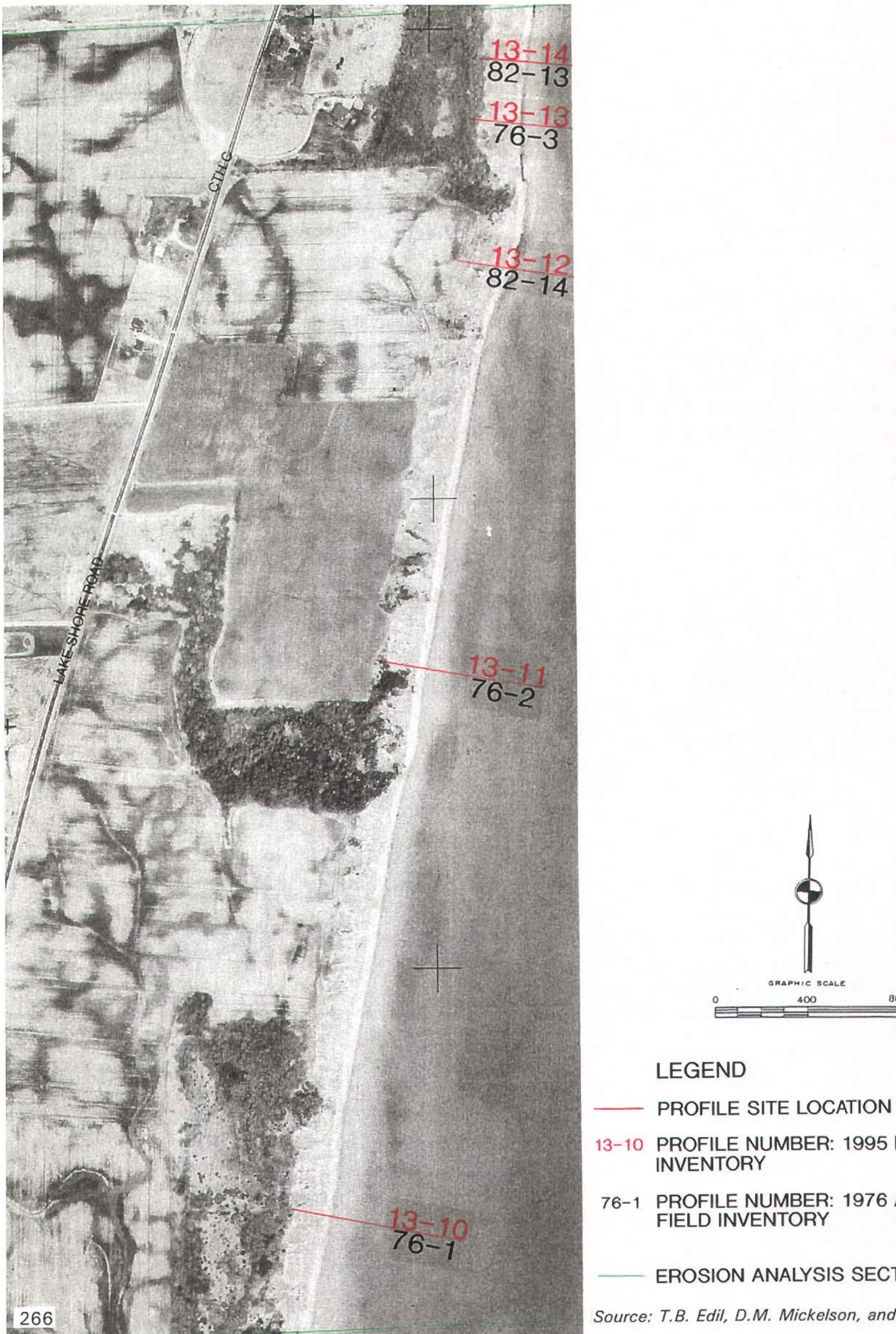
This shoreline analysis section extends the south line of U.S. Public Land Survey Section 3, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County, at about Ulao Parkway extended, north to the south line of U.S. Public Land Survey Section 33, Township 11 North, Range 22 East, Town of Port Washington, Ozaukee County, as shown on Map 78. The shoreline area of this section was occupied mainly by agricultural lands, with some residential land uses and woodland areas intermixed. The bluffs in this section ranged from about 100 to 110 feet in height, with the exception of the middle of the section where a large gully intersected the shoreline. The beach in this zone was narrow, ranging between 10 and 30 feet in width. The 1995 field observations indicated that the entire bluff in this section was eroding, mostly by shallow slides and slumps. In the northern portion of the section, there was a marked scalloping at the top of the bluff indicating focusing of groundwater or surface water. In some of these locations, mudflow sediments were reported as crossing the beach area to the present water line.

In 1995, five bluff profile field surveys were made within Section 3. Three of these profiles occupied sites for which field surveys were conducted in 1976 and the other two profiles occupied sites for which field surveys were conducted in 1982. The stability of the bluff in Section 3 was characterized by Profile Nos. 13-10 through 13-14. Results of the slope stability analyses, shown in Figures 81 and 82, indicated that the bluff was unstable to marginally stable with respect to rotational failures throughout the southern and northern portions of the section, with safety factors ranging between 0.75 and 1.03, based upon the deterministic bluff stability analysis. The bluff at Profile No. 13-11 in the south-central portion of the section was stable, with a safety factor of 1.19, based upon the deterministic bluff stability analysis. Profile Nos. 13-12 and 13-13 were also analyzed using the probabilistic bluff stability analysis method. At Profile No. 13-12, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.87 to 1.24 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 14, or 56 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined

Map 78

SHORELINE EROSION REACH 13: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 3, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County



LEGEND

PROFILE SITE LOCATION

13-10 PROFILE NUMBER: 1995 FIELD INVENTORY

76-1 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

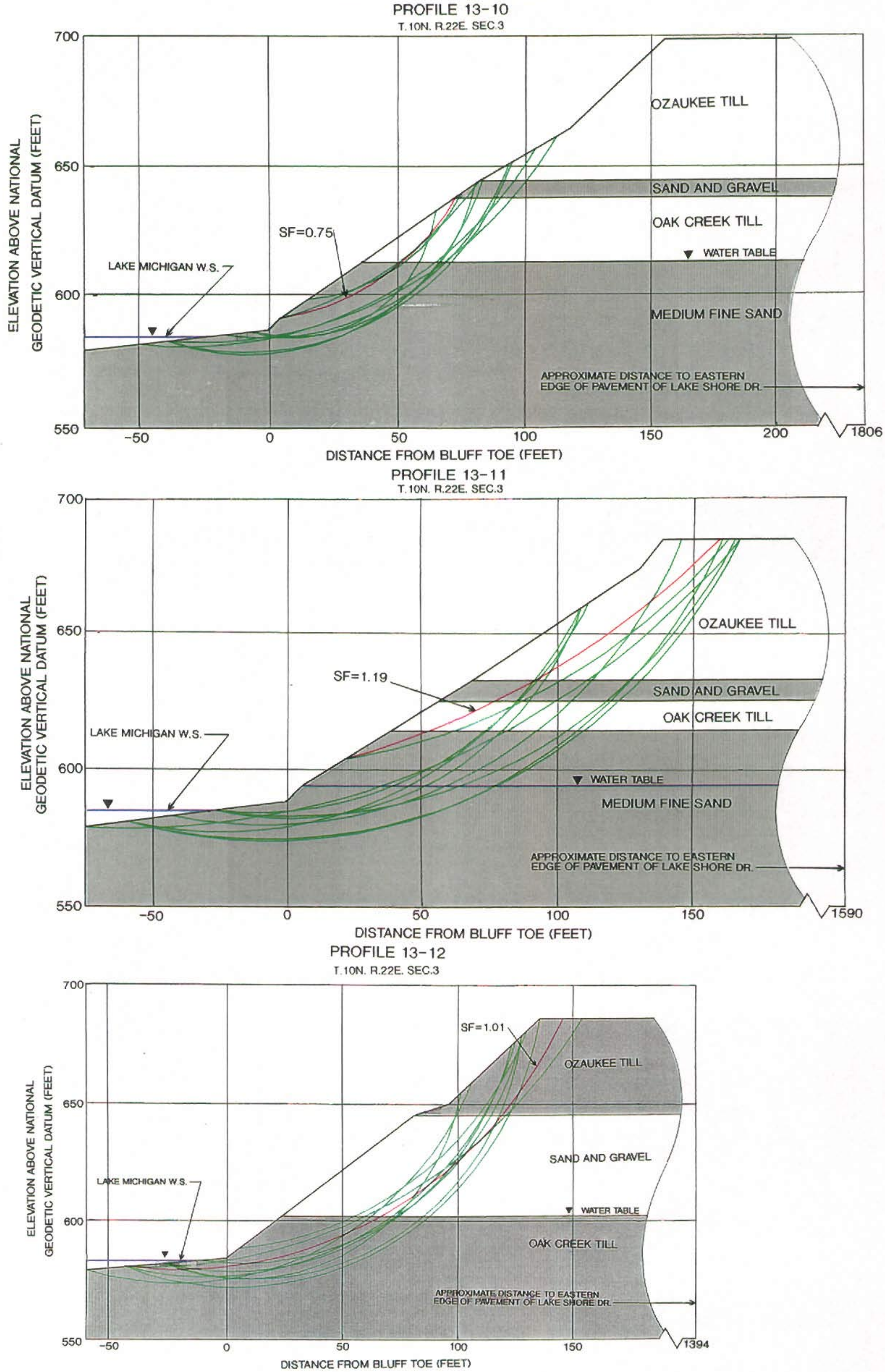
EROSION ANALYSIS SECTION LIMITS

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 81

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 3, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County

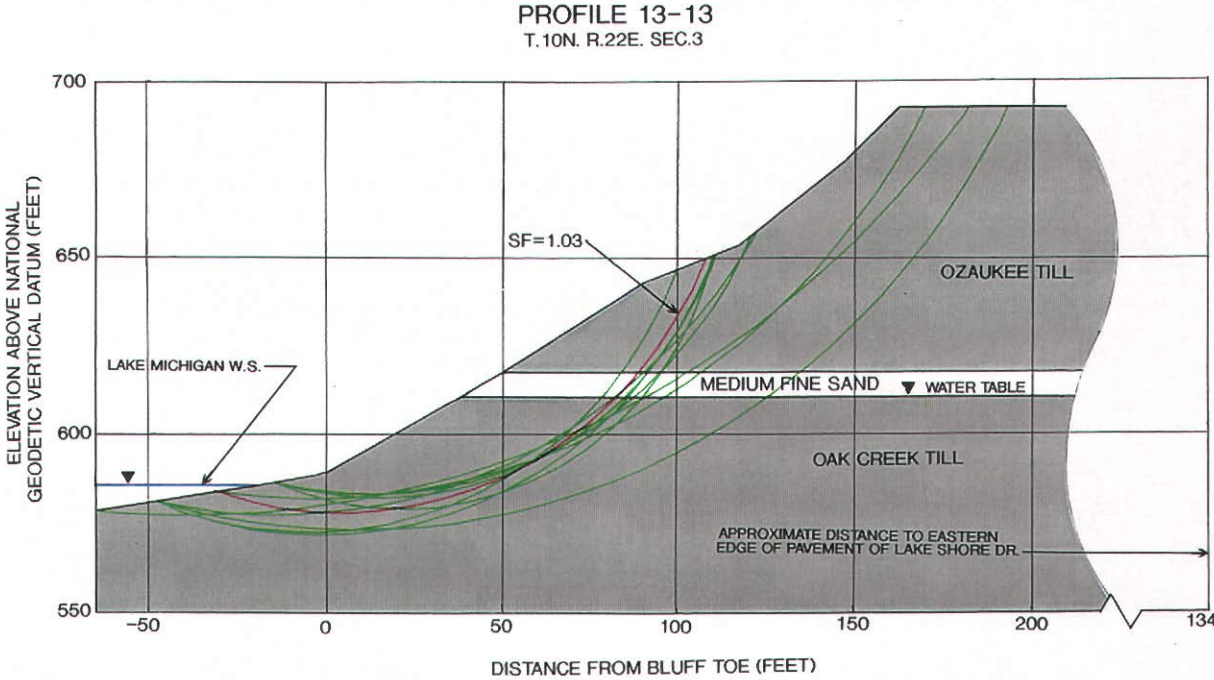


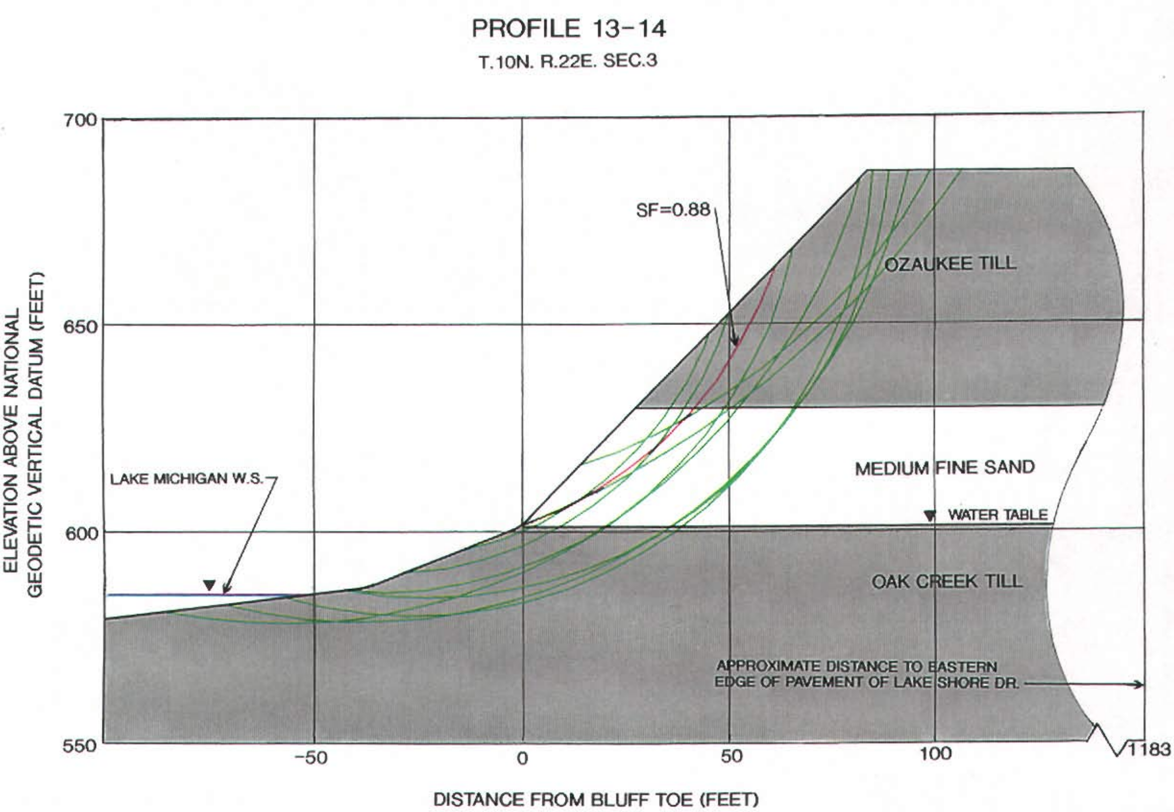
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 82

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 3, Township 10 North, Range 22 East
Town of Grafton, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 97, or 38.8 percent, of the 250 conditions analyzed. At Profile No. 13-13, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.84 to 1.2 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 13, or 52 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 62, or 24.8 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study reported safety factors ranging between 0.49 and 0.51. The 1982 study did not report bluff safety factors at these sites.

In the 1977 study, the beach width was reported to be between 10 and 25 feet, and the beach materials were reported to be pebbles and cobbles with some gravel at the water's edge. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Section 3 was estimated at four locations. These data indicated a recession of between 10 and 20 feet, or between 0.3 and 0.6 foot per year, occurred between 1963 and 1995. The data indicated a recession of between zero and 10 feet, or between zero and 0.5 foot per year, occurred between 1975 and 1995. The 1977 study reported a recession rate for this erosion zone of two feet per year.

U.S. Public Land Survey Section 33, Township 11 North, Range 22 East, Town of Port Washington, Ozaukee County

This shoreline analysis section extends the south line of U.S. Public Land Survey Section 33, Township 11 North, Range 22 East, Town of Grafton, Ozaukee County, at about Sauk Road extended, north to the south line of U.S. Public Land Survey Section 28, Township 11 North, Range 22 East, Town of Port Washington, Ozaukee County, as shown on Map 79. The shoreline area of this section was occupied mainly by agricultural lands, with some residential land use. The bluffs in this section ranged from about 110 to 120 feet in height. The beach in this section ranged from 10 to 50 feet in width. The 1995 field observations indicated that most of the bluff in this section was failing by shallow slides and mudflows, and that the upper part of the bluff was scalloped as it was in the section immediately to the south. For analysis purposes, Section 33 was further subdivided into two erosion zones, as shown on Map 79. The inventory and analysis findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the two zones.

Erosion Zone 33a

Erosion Zone 33a extends from the south line of the section line, north about 0.47 mile, as shown on Map 79. This zone had a beach of between 10 and 30 feet in width. The bluff was about 30 to 40 percent vegetated in this zone with grasses and weeds. The field observations in 1995 indicated that large mudflows and slides were taking place in the scallops located at the top of the bluff. Some documented areas of vegetation on the slope in 1976 appeared to have been removed as the actively eroding part of the slope worked its way to the top of the bluff between 1975 and 1995.

In 1995, one bluff profile field survey was made within Zone 33a by occupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 33a was characterized by Profile No. 13-15. Results of the slope stability analyses, shown in Figure 83, indicated that the bluff was unstable with respect to both rotational and translational failures, with a safety factor of 0.88, based upon the deterministic bluff stability analysis. The 1977 study reported a safety factor of 0.62.

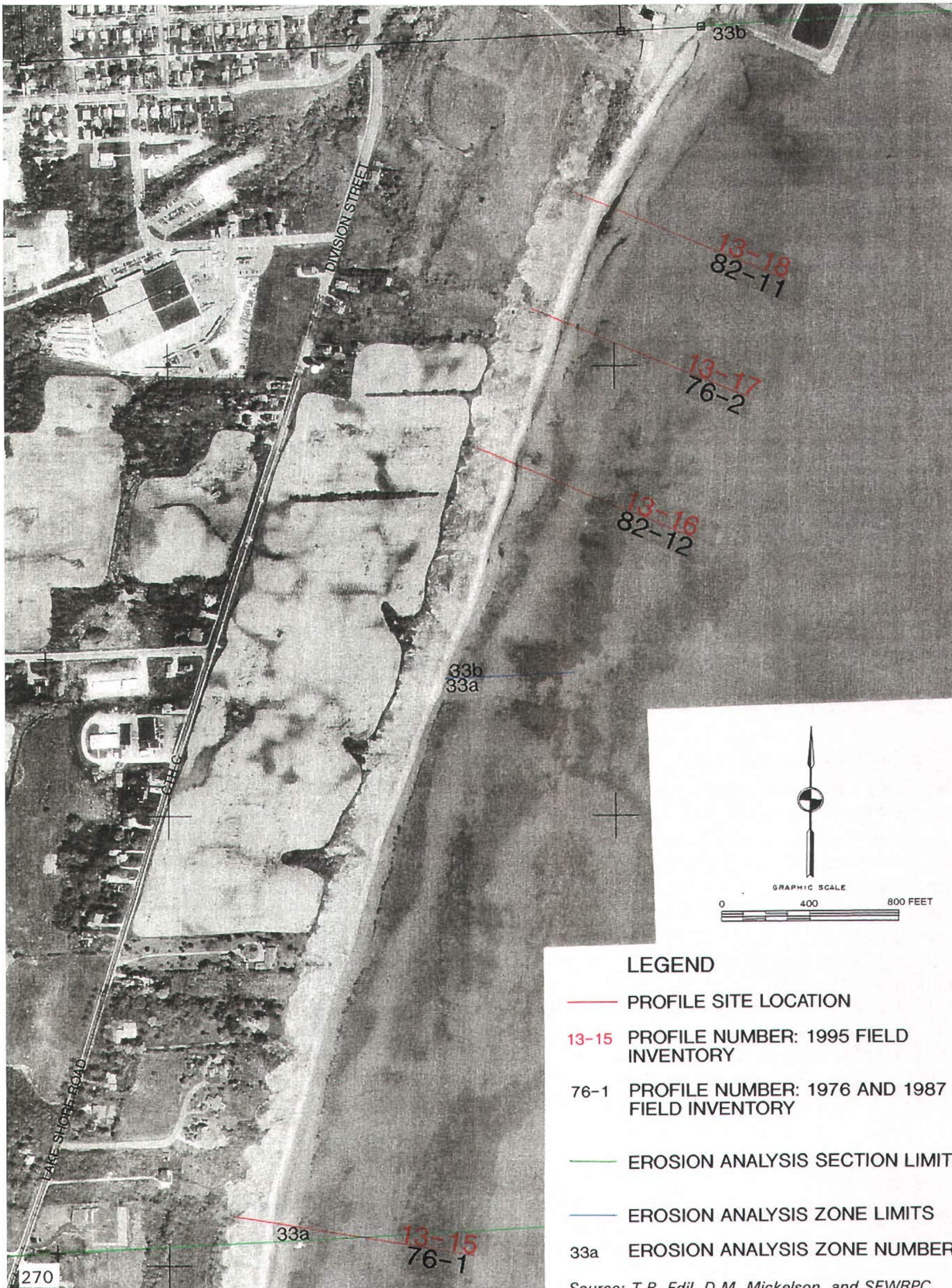
In the 1977 study, the beach width was reported to be between 20 and 30 feet, and the beach materials were reported to be sand and pebbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 33a were estimated at two locations. These data indicated a recession of about 20 feet, or about 0.6 foot per year, occurred between 1963 and 1995 in the northern portion of the zone. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. In the southern portion of the zone, the data indicated that no recession had occurred between 1963 and 1995. Thus, the bluff appeared to be partially stabilized within this zone.

Map 79

SHORELINE EROSION REACH 13: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 33, Township 11 North, Range 22 East
Town of Port Washington, Ozaukee County

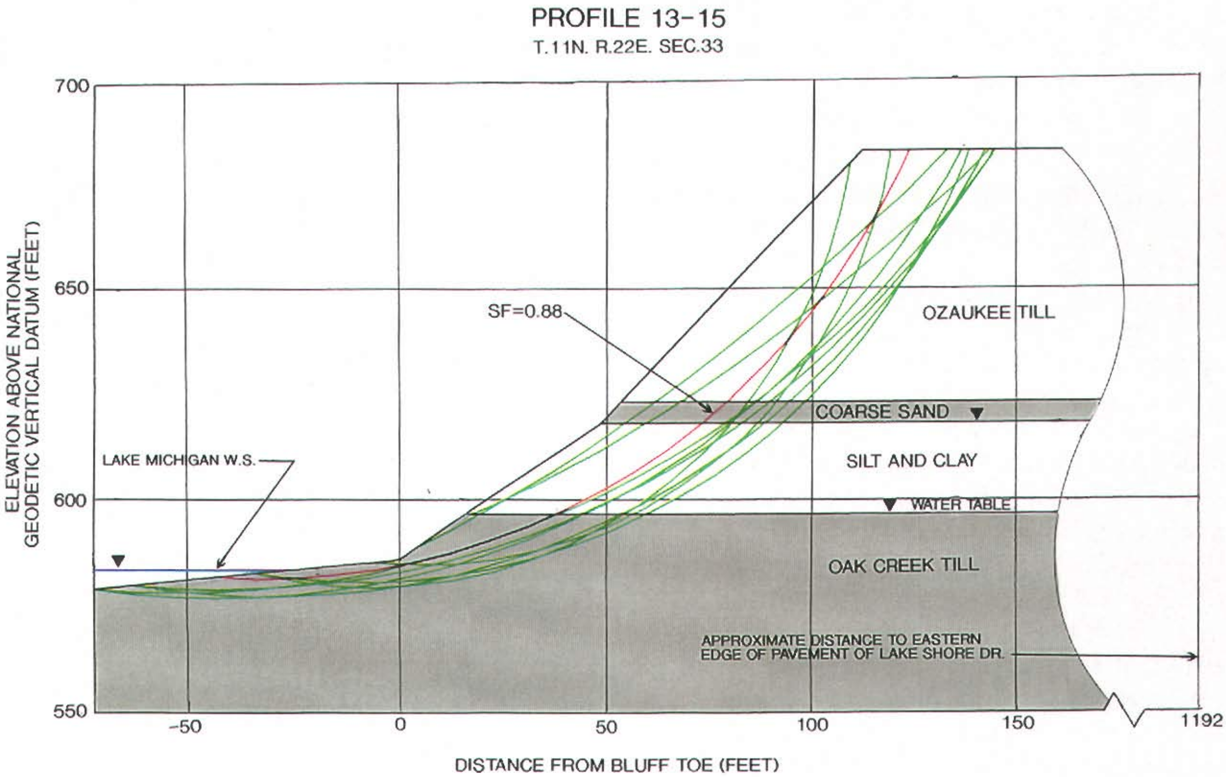


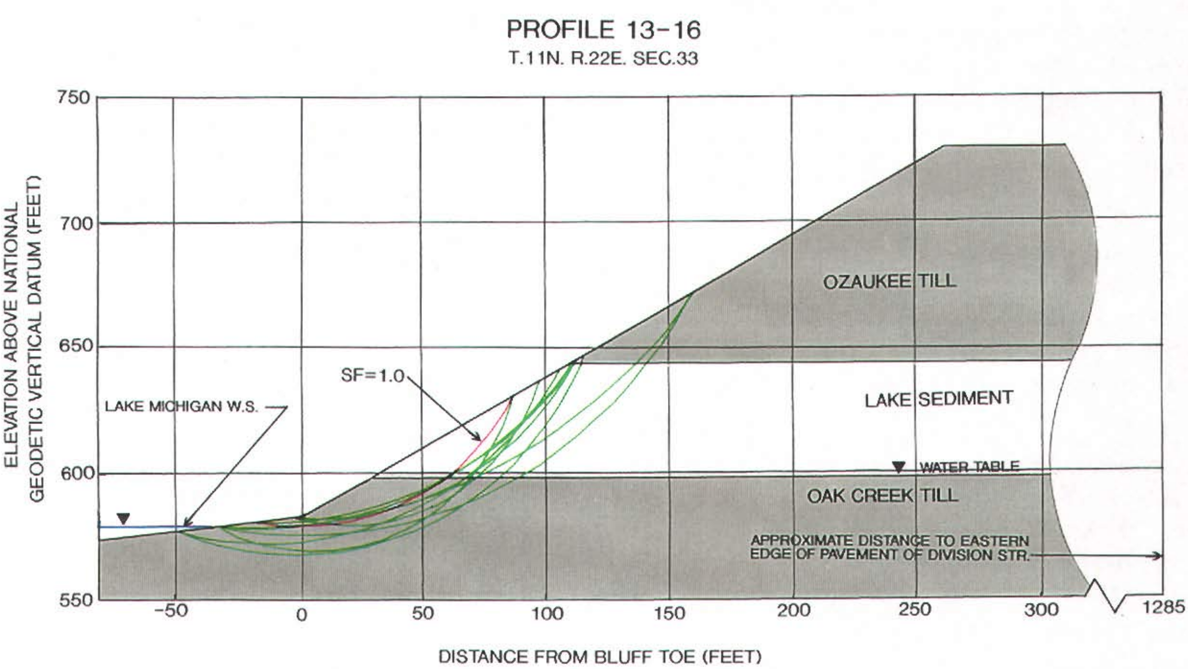
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 83

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 33, Township 11 North, Range 22 East
Town of Port Washington, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Erosion Zone 33b

Erosion Zone 33b extends from the northerly limit of Erosion Zone 33a north to the north line of Section 33, as shown on Map 79. The entire shoreline of this zone was occupied by the City of Port Washington Power Plant. This zone had a beach of between 10 and 50 feet in width. The bluff in this zone was noted to be about 60 percent vegetated in 1995. The 1995 field observations indicated that some recent failures had taken place, and signs of small, shallow slides were present.

In 1995, three bluff profile field surveys were made within Zone 33b by occupying sites for which field surveys were conducted in 1976 and 1982. The stability of the bluff in Erosion Zone 33b was characterized by Profile Nos. 13-16 through 13-18. Results of the slope stability analyses, shown in Figures 83 and 84, indicated that the bluff was marginally stable, with a safety factor of 1.0 at Profile No. 13-16; stable, with a safety factor of 1.16 at Profile No. 13-17; and unstable, with a safety factor of 0.88 at Profile No. 13-18, based upon the deterministic bluff stability analysis. Profile No. 13-16 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.88 to 1.38 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for eight, or 32 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 13, or 5.2 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a safety factor of 0.81 at Profile No. 13-17. The 1982 study did not report a bluff safety factor.

In the 1977 study, the beach width was reported to be between 20 and 30 feet, and the beach materials were reported to be sand and pebbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 33b were estimated at three locations. These data indicated a recession of between 20 and 50 feet, or between 0.6 and 1.6 feet per year, occurred between 1963 and 1995. The highest recessions of Zone 33b occurred in the northern part of the zone prior to 1975. The data indicated no further recession in this portion of the zone between 1975 and 1995. In the southern and central portions of the zone, the data indicated a recession of about 10 feet, or about 0.5 foot per year, occurring between 1975 and 1995. Thus, the bluff appeared to be partially stabilized within this zone.

SHORELINE REACH 14: CITY OF PORT WASHINGTON, OZAUKEE COUNTY

Shoreline Reach 14 is a 0.5-mile-long reach of shoreline extending from the south line of U.S. Public Land Survey Section 28, Township 11 North, Range 22 East, City of Port Washington, 0.5 mile north to the mid-section line about 200 feet north of the Port Washington Harbor, as shown on Map 80. The entire southern portion of the shoreline in Reach 14 was occupied by the City of Port Washington Power Plant, while the northern portion was occupied by the Port Washington Harbor. The shoreline within this reach was completely protected by a variety of shoreline protection structures, including revetments, bulkheads, and a breakwater system centered on Port Washington Harbor.

As shown on Map 80, Reach 14 was not further segmented for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for Reach 14.

Southern One-Half of U.S. Public Land Survey Section 28, Township 11 North, Range 22 East, Town of Port Washington, Ozaukee County

This shoreline analysis section extends from the south line of Section 28 north to a point about 200 feet north of the northern edge of the Port Washington Harbor, as shown on Map 81. In 1995, the southern portion of the section was occupied by the City of Port Washington Power Plant, while the northern portion was occupied by Port Washington Harbor. In 1995, the harbor was protected by a groin on the south side and a large breakwater attached to the shore on the north side. In this section, no significant bluff existed, with the rise from the lake level to the upland surface being a gentle slope, and no natural exposures existed within this reach.

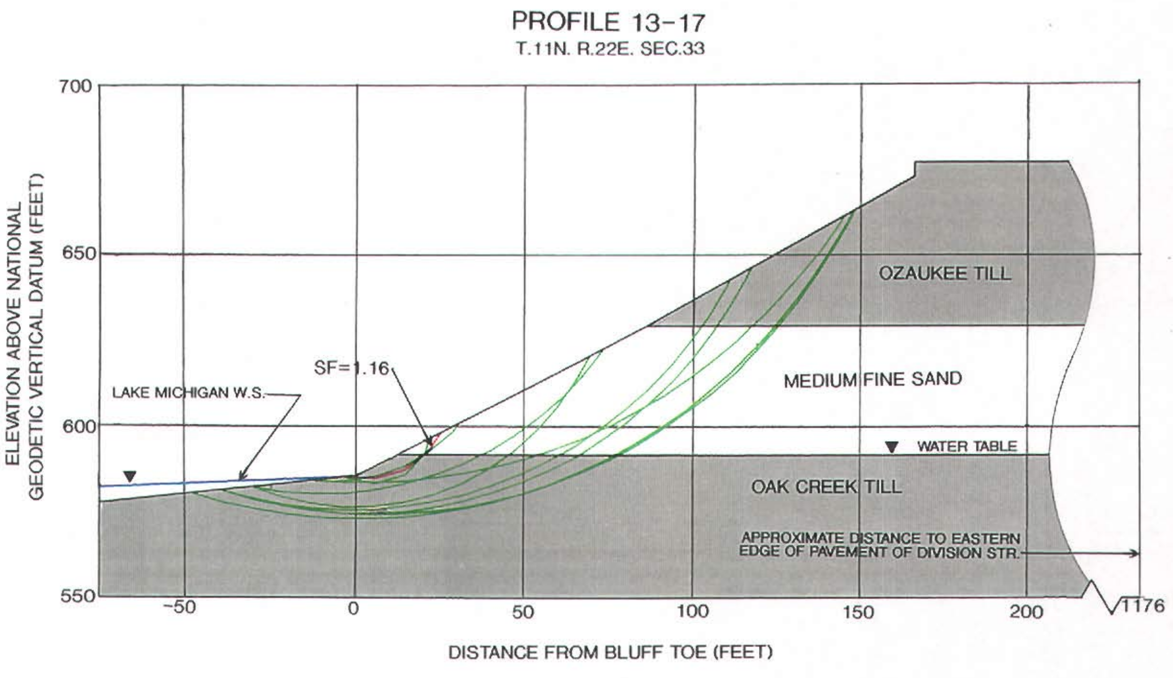
No bluff stability analyses were conducted within Reach 14 in this study or in the 1977 study.

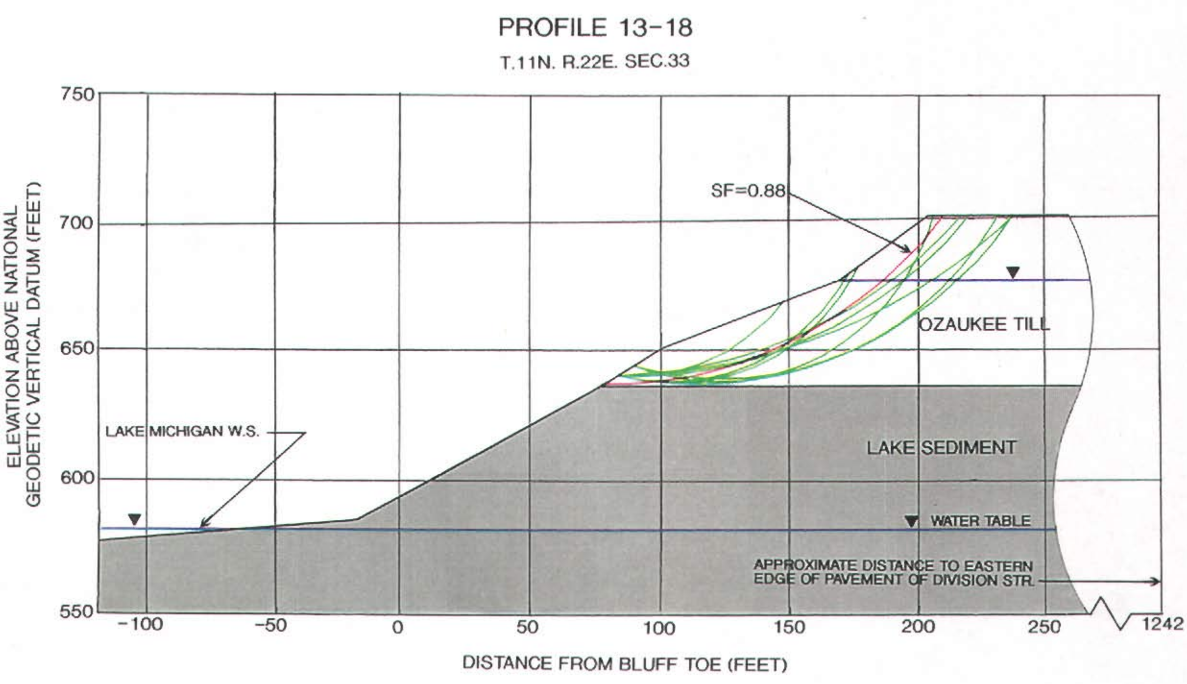
No measurements or observations were made of the nearshore lakebed depth or materials within this zone in 1995 or in 1976.

Figure 84

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 33, Township 11 North, Range 22 East
Town of Port Washington, Ozaukee County

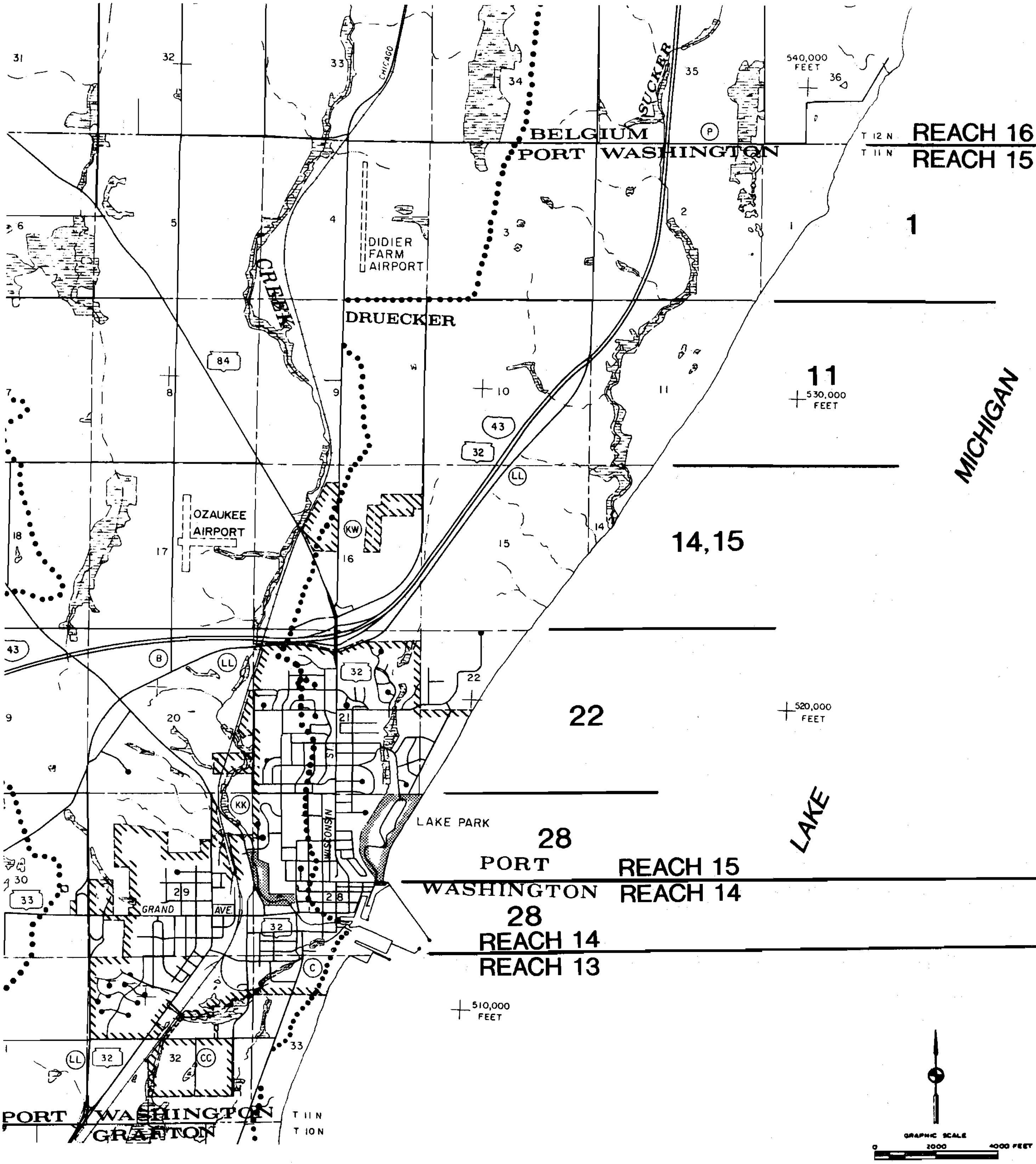




Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 80

BLUFF ANALYSIS SECTIONS WITHIN REACHES 14 AND 15

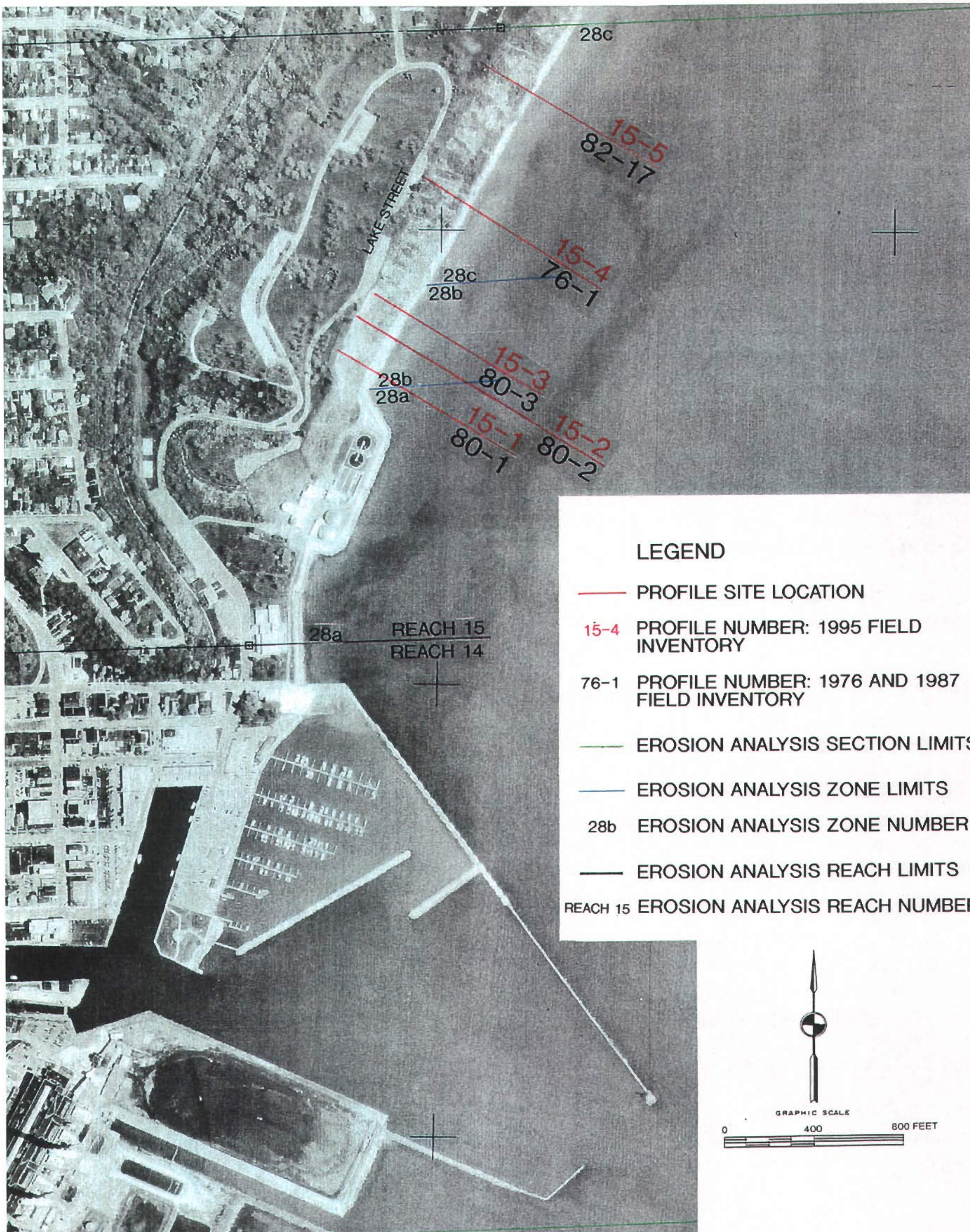


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 81

SHORELINE EROSION REACHES 14 AND 15: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 28, Township 11 North, Range 22 East
City of Port Washington, Ozaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Shoreline recession data for Reach 14 were not estimated.

SHORELINE REACH 15: TOWN OF PORT WASHINGTON, OZAUKEE COUNTY

Shoreline Reach 15 is a five-mile-long reach of shoreline extending from about 200 feet north of the Port Washington Harbor, north to about CTH P at the south line of U.S. Public Land Survey Section 36, Township 12 North, Range 23 East, Village of Belgium, as shown on Map 80. Land uses along this reach included open spaces in Lake Park and residential lands mixed with undeveloped lots and agricultural lands. Beach widths in Reach 15 varied between 25 and 50 feet. Bluff height ranged from about 85 to 120 feet. The entire shoreline in Reach 15 was fronted by a lake terrace which protected the bluff from erosion. In 1995, bluff failures were characterized by shallow slides, with only localized slumps. As shown on Map 80, Reach 15 was further segmented into six shoreline analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the six shoreline analysis sections in Reach 15.

Northern One-Half of U.S. Public Land Survey Section 28, Township 11 North, Range 22 East, Town of Port Washington, Ozaukee County

This shoreline analysis section extends from the mid-section line about 200 feet north of the northern edge of the Port Washington Harbor north to the southern end of the City of Port Washington Sewage Treatment Plant, as shown on Map 81. In 1995, the entire southern portion of the section was occupied by the City of Port Washington Sewage Treatment Plant, while the northern portion was occupied by open space and recreational land uses, including Lake Park. Much of the shoreline was protected by a variety of different types of shore protection structures. The bluff in this section ranged from 50 to 100 feet in height. For further analysis, the northern half of Section 28 was further subdivided into three erosion zones, as shown on Map 81. The inventory and analysis findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the three zones.

Erosion Zone 28a

Erosion Zone 28a extends from about 200 feet north of the Port Washington Harbor to the northern edge of the City of Port Washington Sewage Treatment Plant, as shown on Map 81. This zone had a 30- to 50-foot-wide beach fronting a low terrace which was entirely protected by shoreline structures. In this zone, the bluff was located well behind the terrace and well back from the shoreline. The bluff was completely vegetated and stable. The 1995 field observations indicated no retreat of the bluff top between 1975 and 1995.

No bluff stability analyses were conducted within Erosion Zone 28a during this study or the 1977 study.

In 1995, the beach within Zone 28a was between 30 and 50 feet wide and fronted a low lake terrace. In the 1977 study, the beach width was reported to be about 15 feet, and the beach material was reported to be sand. No measurements or observations were made of the nearshore lakebed depth or materials within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 28a were not estimated.

Erosion Zone 28b

Erosion Zone 28b extends from the northern edge of the City of Port Washington Wastewater Treatment Plant north about 0.08 mile, as shown on Map 81. This zone had about a 50-foot-wide beach fronting a low lake terrace and a bluff with a height of up to 100 feet. In this zone, the bluff was located well behind the terrace and was set well back from the shoreline. The 1995 field observations indicated that the bluff, which was less than 50 percent vegetated, was actively eroding and appeared to have undergone several large failures in the last 20 years. The bluff slope was reported as vegetation-free with the exception of slide masses near the bottom of the bluff slope.

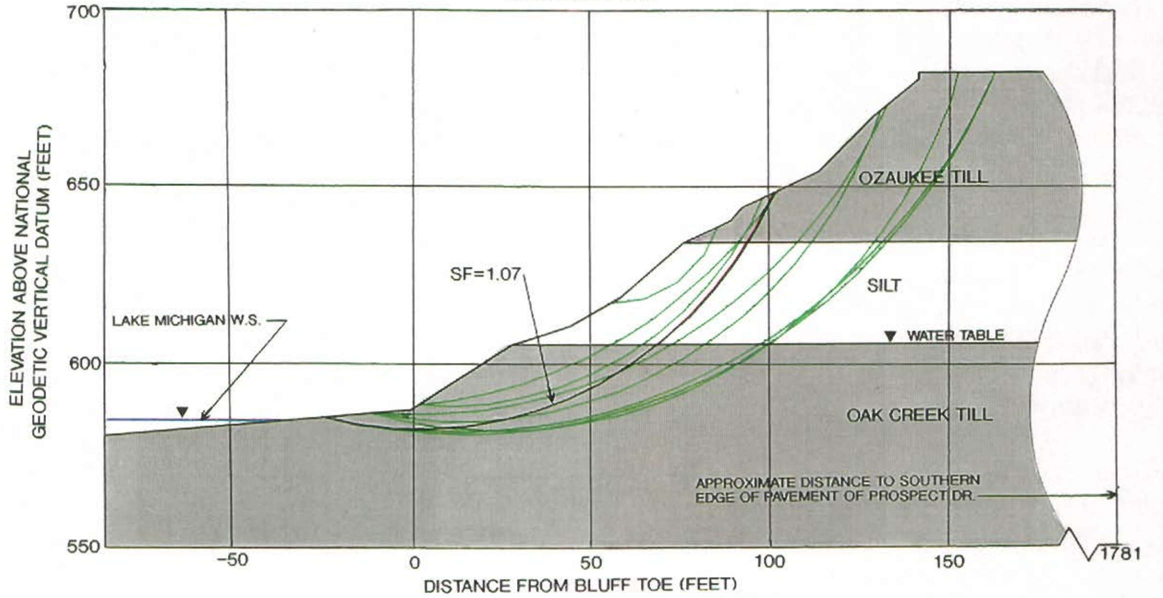
In 1995, three bluff profile field surveys were made within Zone 28b by occupying sites for which field surveys were conducted in 1980. The stability of the bluff in Erosion Zone 28b was characterized by Profile Nos. 15-1 through 15-3. Results of the slope stability analysis, shown in Figure 85, indicated that the bluff was marginally stable, with a safety factor of 1.07 at Profile No. 15-1, and stable, with safety factors of 1.17 at Profile No. 15-2 and 1.18 at Profile No. 15-3 with respect to rotational failures, based upon the deterministic bluff stability analysis. However, 1995 field observations indicated that translational failures may occur. The 1980 study did not report a specific safety factor for these three profile sites.

Figure 85

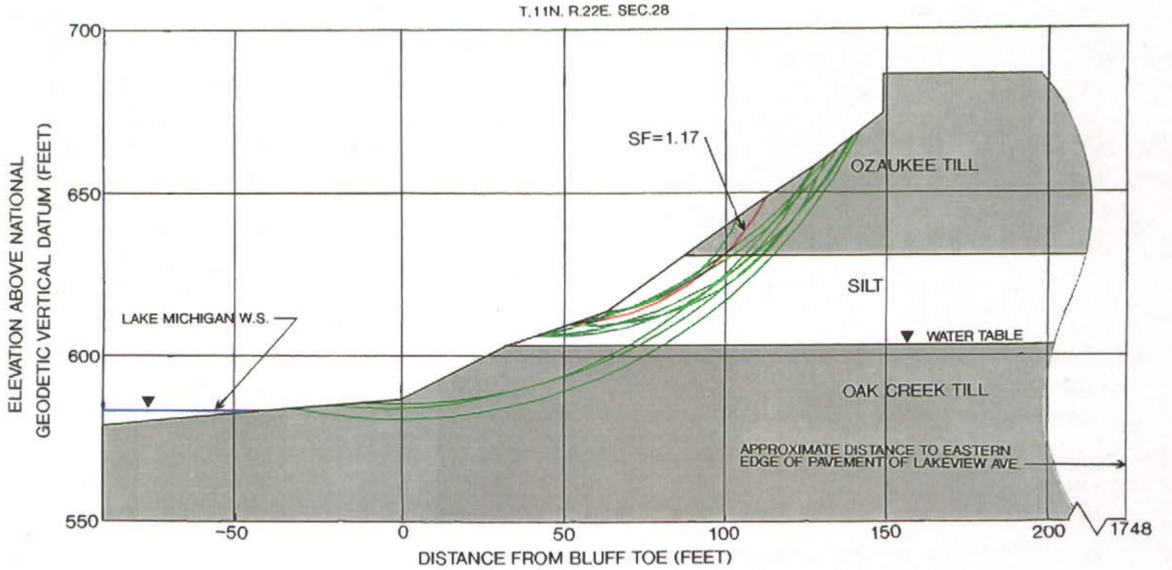
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 28, Township 11 North, Range 22 East
City of Port Washington, Ozaukee County

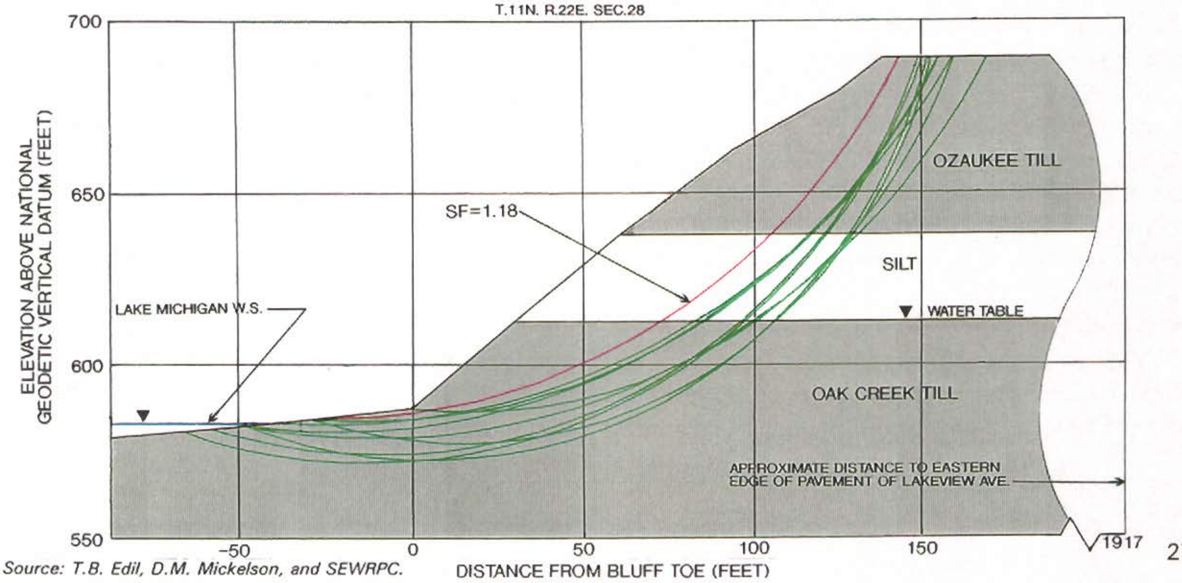
PROFILE 15-1
T.11N. R.22E. SEC.28



PROFILE 15-2
T.11N. R.22E. SEC.28



PROFILE 15-3
T.11N. R.22E. SEC.28



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

In 1995, the beach within Zone 28b was about 50 feet wide and beach materials were noted to be sand and gravel. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be sand. At Profile No. 15-2 the nearshore lakebed depth of five feet was reached at 65 feet offshore. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 28b were estimated at one location. The data indicated that a recession of about 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995.

Although Zone 28b was considered stable in 1995, the bluff in this zone has undergone several large failures and remains a threat to the park roads and parking areas on the bluff top. Unless some type of shore protection is provided, Erosion Zone 28b will continue to erode at a moderately high rate. Continued erosion may eventually require rerouting of some of the streets.

Erosion Zone 28c

Erosion Zone 28c extends from the northerly limit of Erosion Zone 28b, north to the south line of U.S. Public Land Survey Section 22, Township 11 North, Range 22 East, City of Port Washington, as shown on Map 81. This zone had about a 20- to 40-foot-wide beach fronting a low lake terrace. The bluff in this zone had a height of between 125 and 150 feet. In 1995, the bluff was reported as about 60 percent vegetated. The 1995 field observations indicated about five to 10 feet of retreat in the bluff top since 1975.

In 1995, two bluff profile field surveys were made within Zone 28c, by reoccupying a site for which a field survey was conducted in 1976 and by reoccupying a site for which a field survey was conducted in 1982. The stability of the bluff in Erosion Zone 28c of Reach 15 was characterized by Profile Nos. 15-4 and 15-5. Results of the slope stability analysis, shown in Figure 86, indicated that the bluff was unstable, with safety factors of 0.97 at Profile No. 15-4 and 0.92 at Profile No. 15-5, based upon the deterministic bluff stability analysis method. Profile Nos. 15-4 and 15-5 were also analyzed using the probabilistic bluff stability analysis method. At Profile No. 15-4, the probabilistic bluff stability analysis method resulted in a range of safety factors from 0.7 to 1.2 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 18, or 72 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 101, or 40.4 percent, of the 250 conditions analyzed. At Profile No. 15-5, the probabilistic bluff stability analysis resulted in a range of safety factors from 0.73 to 1.33 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 12, or 48 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 87, or 34.8 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a bluff safety factor of 1.21 at Profile No. 15-4. The 1977 study did not report a bluff safety factor at Profile No. 15-5.

The beach within Zone 28c was 25 to 40 feet wide and fronted a low terrace. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach material was reported to be cobbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or 1976.

Shoreline recession data for Erosion Zone 28c were estimated at one location. These data indicated that a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995.

Unless some type of shore protection is provided in Erosion Zone 28c, the shoreline will continue to erode at a moderately high rate.

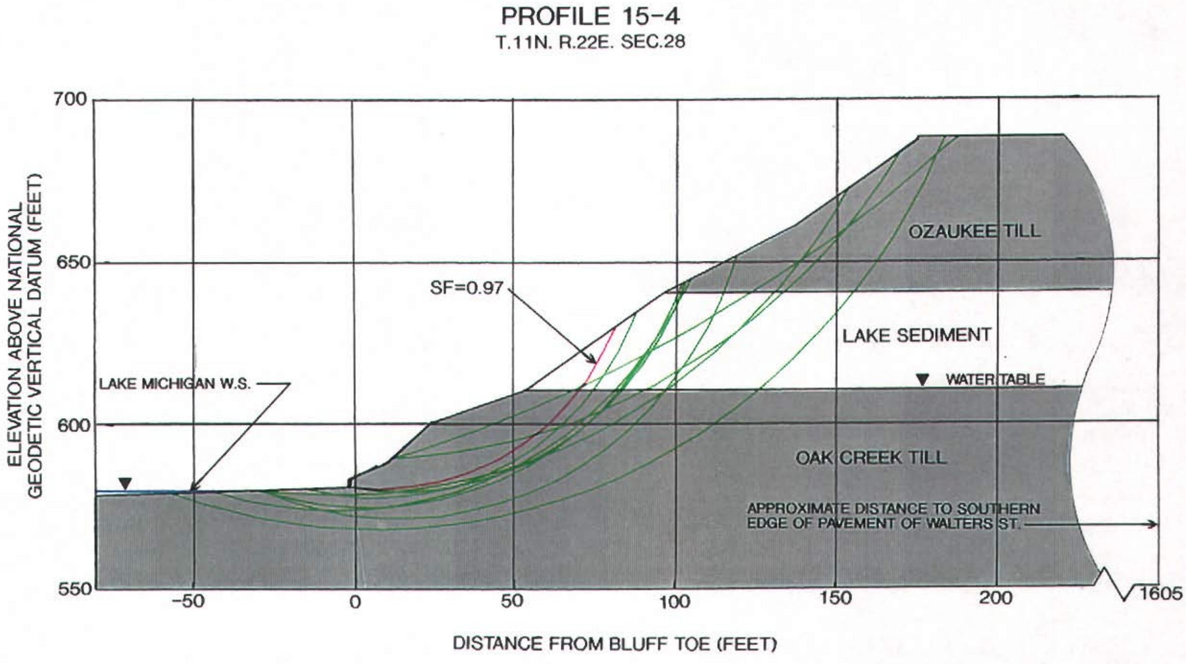
U.S. Public Land Survey Section 22, Township 11 North, Range 22 East, City of Port Washington, Ozaukee County

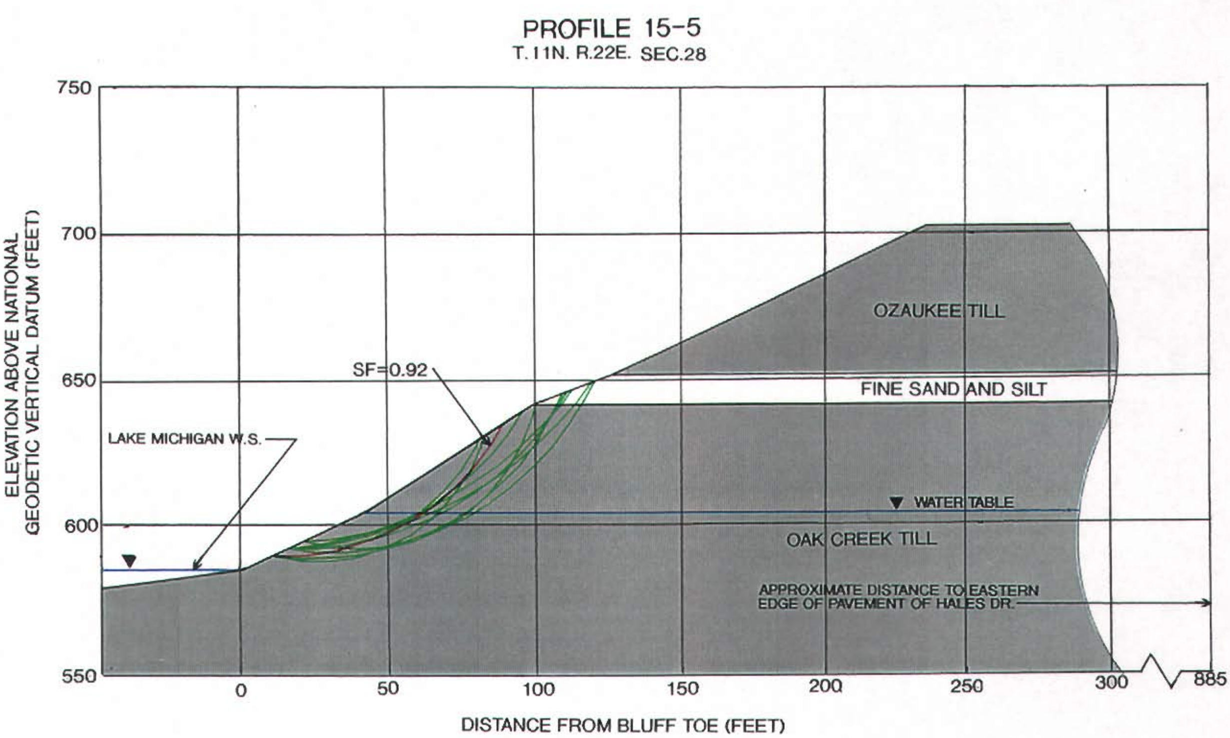
This shoreline analysis section extends from about Walters Street extended at the south line of U.S. Public Land Survey Section 22, Township 11 North, Range 22 East, City of Port Washington, north to about Ranch Road extended at the south line of U.S. Public Land Survey 15, Township 11 North, Range 22 East, City of Port Washington, as shown on Map 82. The entire shoreline was occupied by residential land uses with a mix of residential land use and undeveloped lots. A number of new homes appeared to have been built in

Figure 86

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 28, Township 11 North, Range 22 East
City of Port Washington, Ozaukee County



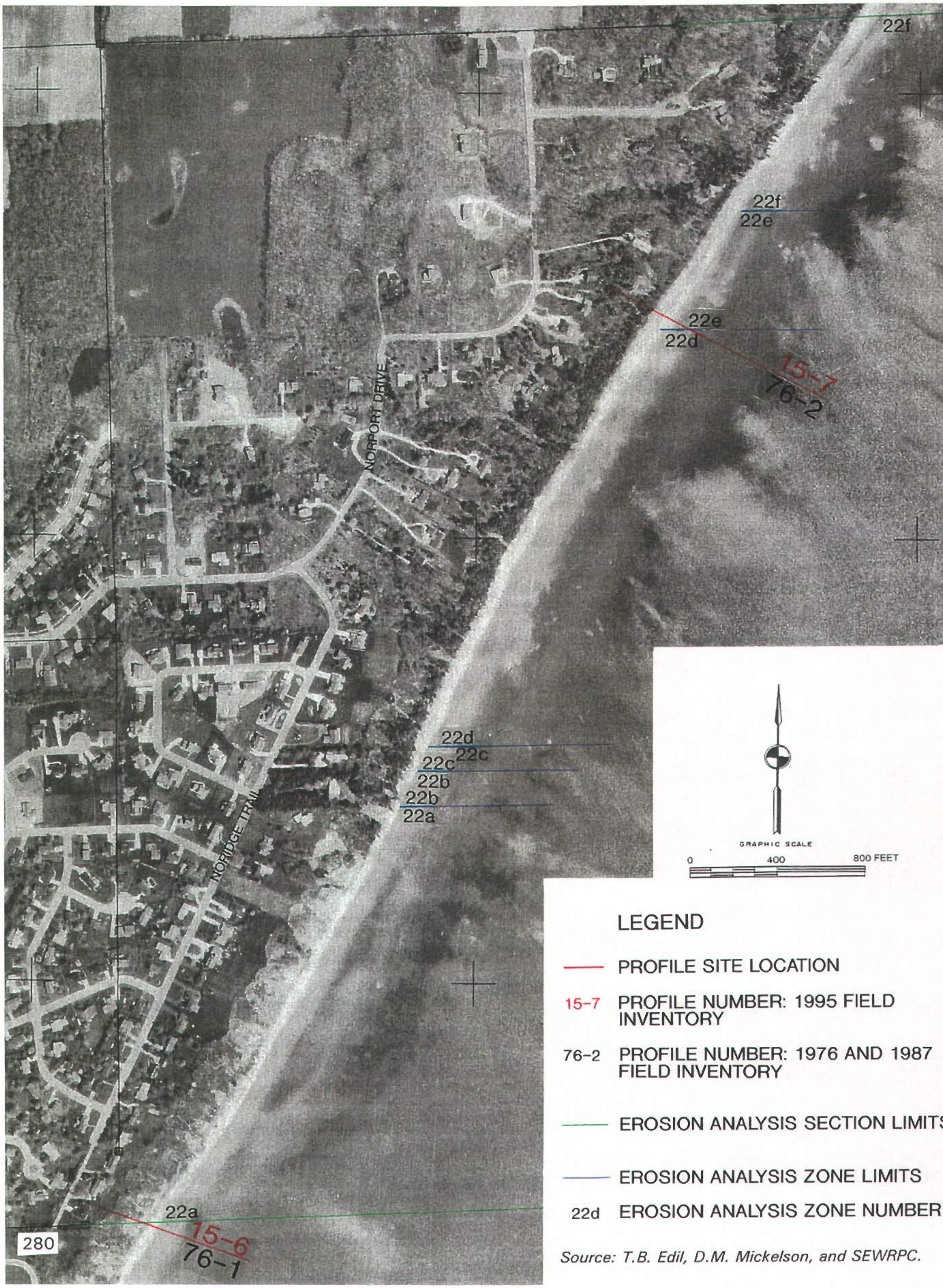


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 82

SHORELINE EROSION REACH 15: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 22, Township 11 North, Range 22 East
City of Port Washington, Ozaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

this zone since 1976. Some of these homes were built within 75 to 100 feet of the bluff top in the southern portion of the section which was previously reported as having low to moderate rates of erosion, mostly from shallow slides. The bluffs in this section ranged from 80 to 100 feet in height. The beach width in this section varied between 30 and 100 feet and in places was littered with boulders from the lower part of the bluff. For further analysis, Section 22 was further subdivided into six erosion zones, as shown on Map 82. The inventory and analysis and findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the six zones.

Erosion Zone 22a

Erosion Zone 22a extends from where Noridge Trail ends north about 0.35 mile, as shown on Map 82. This zone had a 50-foot-wide beach fronting a low terrace. The bluff in this zone had a height of about 100 feet. The 1995 field observations indicated that signs of translational failures were present and noted that the bluff was 50 to 80 percent vegetated with shrubs and trees. Bluff failure in this zone seemed to be a result of shallow slides.

In 1995, one bluff profile field survey was made within Zone 22b by occupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 28a was characterized by Profile No. 15-6. Results of the slope stability analysis, shown in Figure 87, indicated that the bluff was unstable with respect to both rotational and translational failures, with a safety factor of 0.72, based upon the deterministic bluff stability analysis. The 1977 study reported a safety factor of 0.61 for this site.

In the 1977 study, the beach width was reported to be between five and 25 feet, and the beach materials were reported to be cobbles and sand. At Profile No. 15-6, the nearshore lakebed depth of five feet was reached at 192 feet offshore. The nearshore lakebed materials were not reported. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995.

Shoreline recession data for Erosion Zone 22a were estimated at one location. These data indicated that a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995.

Erosion Zone 22b

Erosion Zone 22b extends from the northern limit of Erosion Zone 22a north about 0.03 mile, as shown on Map 82. This zone had a 30- to 50-foot-wide beach fronting a low terrace. The 1995 field observations indicated the central portion of this zone to be 100 percent vegetated with junipers, sumac, and aspens. The lower one-third of the slope was noted to be less well-vegetated, but stable, except for small translational slides on the lower portions of the slope. The vegetated portion of the slope was lined with riprap, although it was not considered a maintained structure.

No bluff stability analyses were conducted within Erosion Zone 22b during this study or the 1977 study.

In 1995, the beach within Zone 22b was between 30 and 50 feet wide and fronting a low lake terrace. In the 1977 study, the beach width was reported to be between five and 25 feet, and the beach materials were reported to be sand and cobbles. No measurements or observations were made of the nearshore lakebed depth or materials within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 22b were not estimated.

Erosion Zone 22c

Erosion Zone 22c extends from the northern limit of Erosion Zone 22b north about 0.02 mile, as shown on Map 82. This zone had about a 50-foot-wide beach. The 1995 field observations noted the upper quarter of the bluff to be almost fully vegetated and the lower portion to be about 20 percent vegetated. In 1977, this zone was reported as unstable and the 1995 field observations indicated the same, with shallow slides being the primary mechanism of bluff failure.

No bluff stability analyses were conducted within Erosion Zone 22c during this study or the 1977 study.

In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be sand and cobbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 22c were not estimated.

Erosion Zone 22d

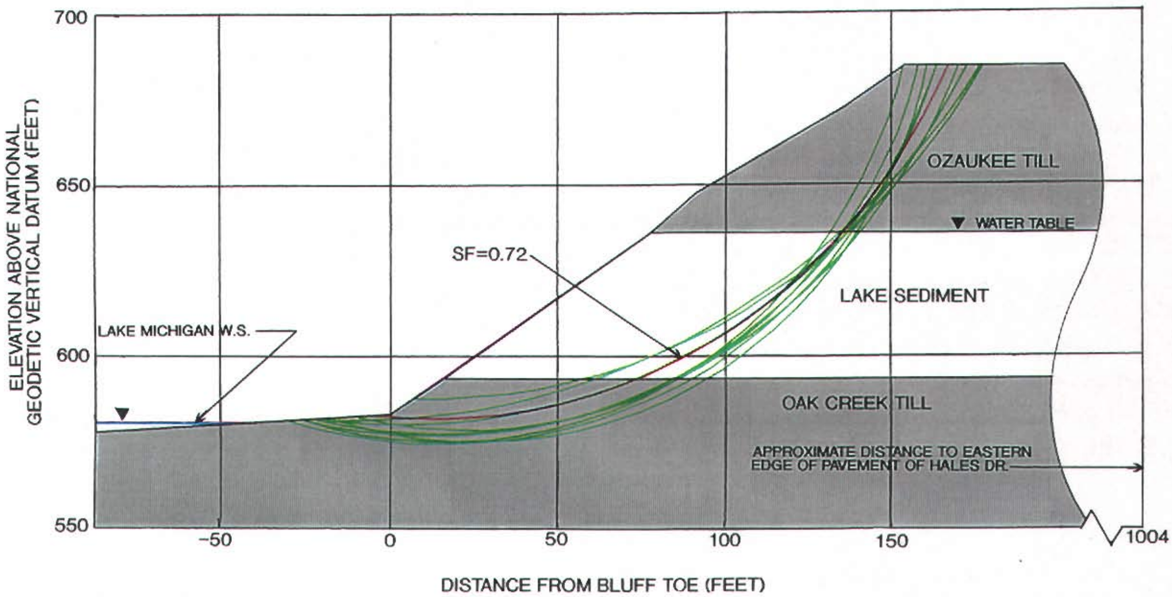
Erosion Zone 22d extends from the northern boundary of Erosion Zone 22c north about 0.35 mile, as shown on Map 82. This zone had a 50- to 80-foot-wide beach. The 1995 field observations noted the bluff to be 100 percent vegetated with junipers, sumac, and aspen in the north-

Figure 87

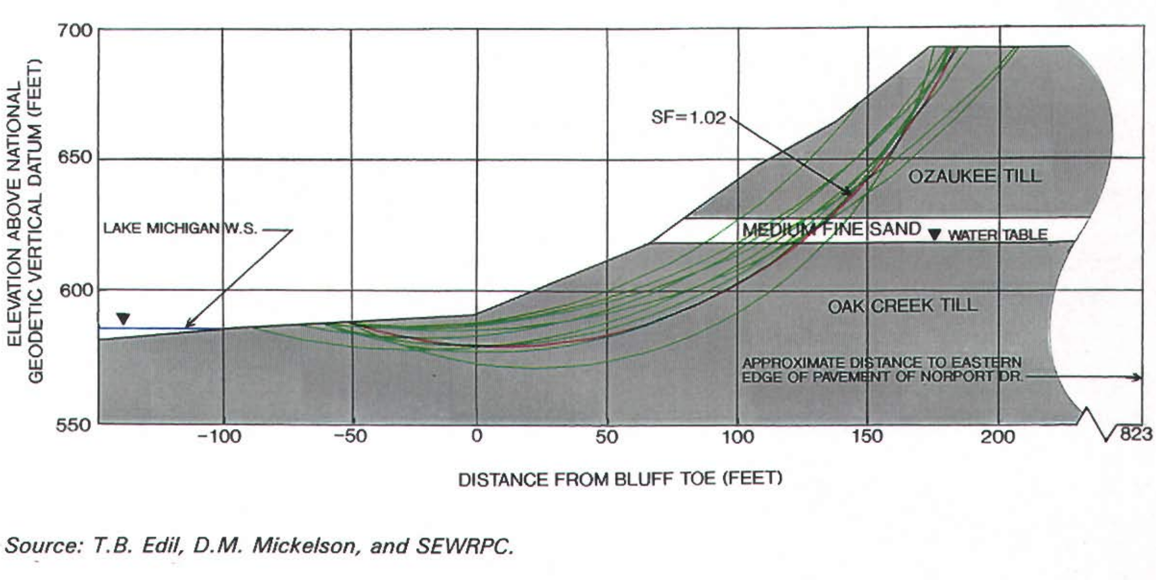
DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 22, Township 11 North, Range 22 East
City of Port Washington, Ozaukee County

PROFILE 15-6
T.11N. R.22E. SEC.22



PROFILE 15-7
T.11N. R.22E. SEC.22



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

ern portion of the zone and about 70 percent vegetated in the southern portion of the zone. In 1995, the bluff slope was noted as marginally stable to stable, having narrow zones where translational slides had occurred.

No bluff stability analyses were conducted within Erosion Zone 22d during this study or the 1977 study.

In the 1977 study, the beach width was reported to be between five and 30 feet, and the beach materials were reported to be sand and gravel. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 22d were estimated at one location. The data indicated that no significant recession had occurred between 1963 and 1995.

Erosion Zone 22e
Erosion Zone 22e extends from the northern edge of the Erosion Zone 22d north about 0.1 mile, as shown on Map 82. This zone had a 70- to 100-foot-wide beach fronting a low lake terrace. The bluff had a height of up to 100 feet. In 1995, the upper portion of the bluff was noted to be 60 to 70 percent vegetated with shrubs and grasses, with some mature trees on the lower bluff. One house in this zone was less than 20 feet from the edge of the bluff, although it appeared not to be immediately threatened by bluff top retreat. The 1995 field observations indicated that there appeared to have been little bluff top recession since 1976.

In 1995, one bluff profile field survey was made within Zone 22e by reoccupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 28a was characterized by Profile No. 15-7. Results of the slope stability analysis, shown in Figure 87, indicated that the bluff was marginally stable, with a safety factor of 1.02, based upon the deterministic bluff stability analysis. Profile No. 15-7 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.87 to 1.42 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for nine, or 36 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 50, or 20 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluff was considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a safety factor of 1.7.

In the 1977 study, the beach width was reported to be between five and 15 feet, and the beach materials were reported to be sand with some gravel. No measurements or observations on the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 22e were estimated at one location. These data indicated that a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995.

Erosion Zone 22f
Erosion Zone 22f extends from the northerly limit of Erosion Zone 22e north about 0.15 mile the northern section line, as shown on Map 82. This zone had a 30- to 70-foot-wide beach fronting a low terrace. In 1995, the bluff was completely vegetated with mature trees and was stable, except for some small areas of shallow slides.

No bluff stability analyses were conducted within Erosion Zone 22f during this study or the 1977 study.

In the 1977 study, the beach width was reported to be between 30 and 70 feet, and the beach material was reported to be sand with some gravel. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

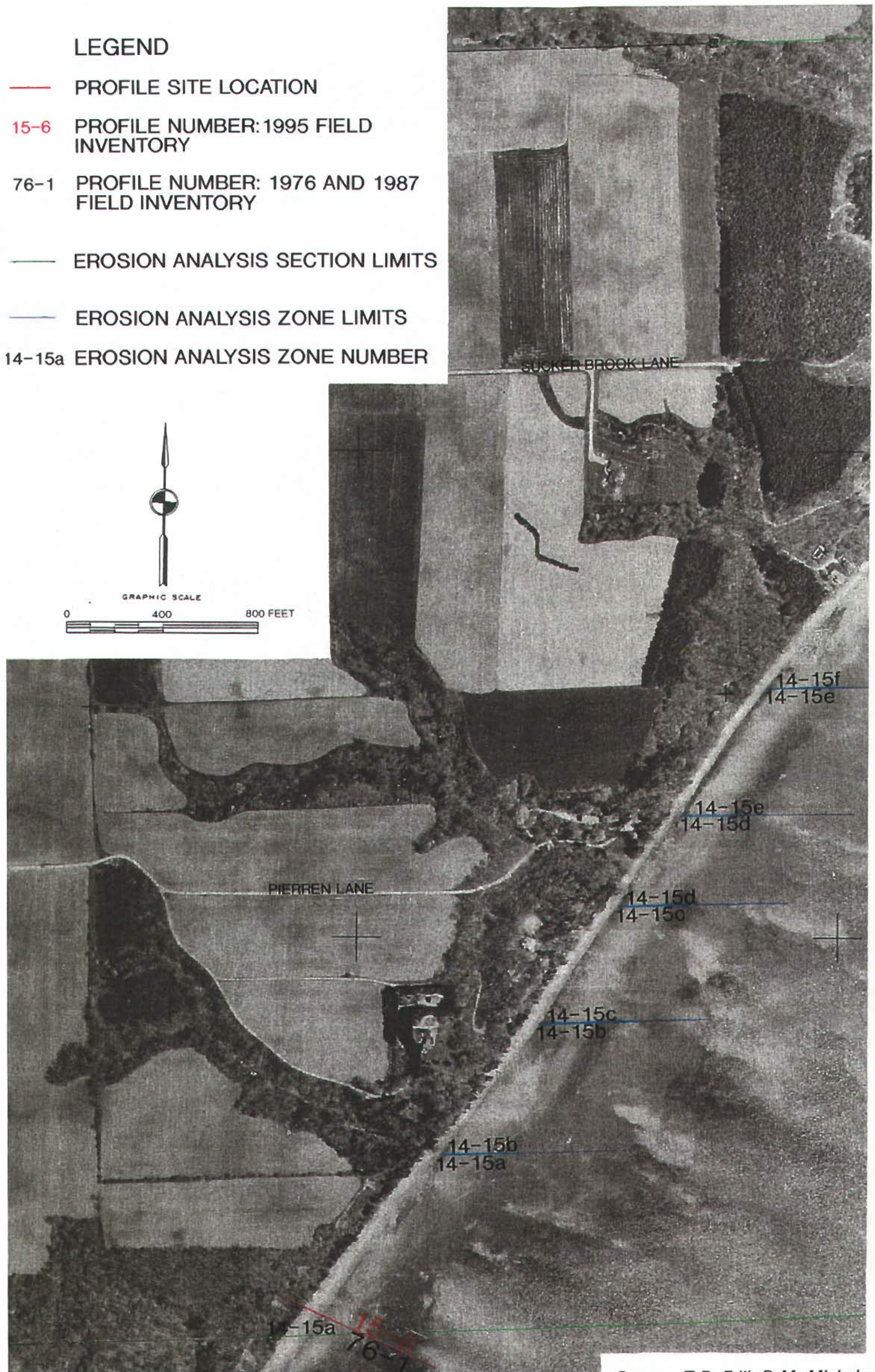
Shoreline recession data for Erosion Zone 22f were estimated at one location. These data indicated that a recession of about 20 feet, or about 0.6 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995.

U.S. Public Land Survey Sections 14 and 15, Township 11 North, Range 22 East, Town of Port Washington, Ozaukee County
This shoreline analysis section extends from the south line of U.S. Public Land Survey Section 15, Township 11 North, Range 22 East, Town of Port Washington, north to the north line of U.S. Public Land Survey 14, Township 11 North, Range 22 East, Town of Port Washington, as shown on Maps 83 and 84. The shoreline was occupied by agricultural lands and woodlands intermixed with residential land uses, several of which were built between 1976 and 1995. Portions of the shoreline were protected by a variety of different types of shore protection structures, with revetments being the most common. The beach width in this

Map 83

SHORELINE EROSION REACH 15: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 15, Township 11 North, Range 22 East
Town of Port Washington, Ozaukee County

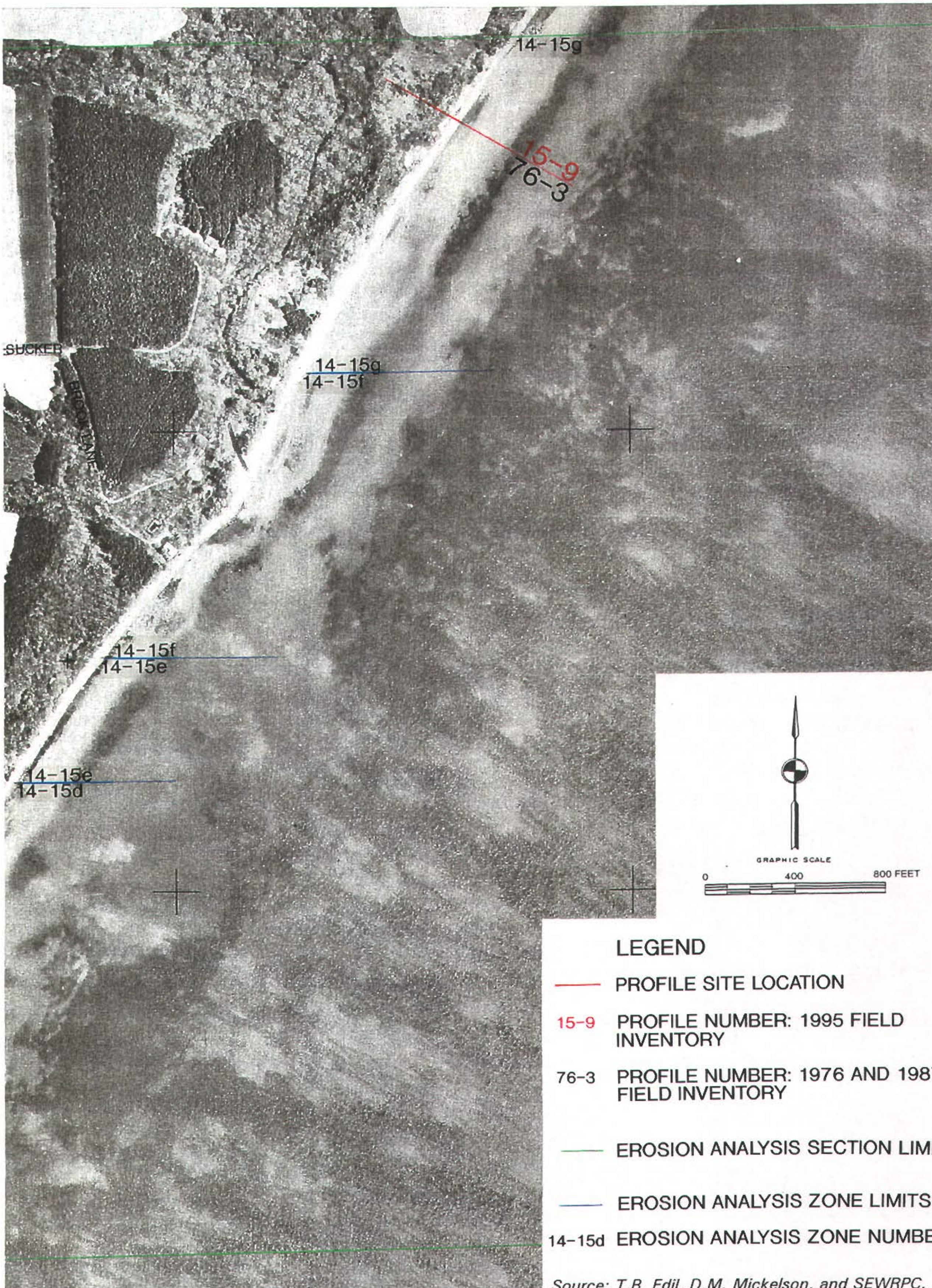


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 84

SHORELINE EROSION REACH 15: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 14, Township 11 North, Range 22 East
Town of Port Washington, Ozaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

section varied between 25 and 50 feet, with the central portion being fronted by a low lake terrace. The bluff in this section was up to 60 feet in height. For further analysis, Sections 14 and 15 were further subdivided into seven erosion zones, as shown on Maps 83 and 84. The inventory and analysis and findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the seven zones.

Erosion Zone 14a

Erosion Zone 14a extends from the south line north about 0.14 mile, as shown on Map 83. This zone had a 20- to 50-foot-wide beach fronting a low bluff. The bluff in this zone was about 60 feet high and was eroding by small slumps and translational slides. The lakeshore area in this zone was occupied entirely by woodlands.

In 1995, one bluff profile field survey was made within Zone 14a by reoccupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 14a was characterized by Profile No. 15-8. Results of the slope stability analysis, shown in Figure 88, indicated that the bluff was stable with respect to rotational failures, with a safety factor of 1.32, based upon the deterministic bluff stability analysis. However, 1995 field observations indicated that translational failures may occur. The 1977 study reported a safety factor of 1.04 for Profile No. 15-8.

In 1995, the beach material in this section was noted to be sand and cobbles. In the 1977 study, the beach width was reported to be up to 25 feet, and the beach materials were reported to be sand with cobbles and pebbles. At Profile No. 15-8 the nearshore lakebed depth of five feet was reached at 65 feet offshore in 1976. Nearshore lakebed materials were not reported. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 14a were not estimated.

Erosion Zone 14b

Erosion Zone 14b extends from the northerly limit of Erosion Zone 14a north about 0.1 mile, as shown on Map 83. This zone had a 30- to 50-foot-wide beach fronting a low bluff. In 1995, the bluff was completely vegetated with mature trees and stable.

No bluff stability analyses were conducted within Erosion Zone 14b during this study or the 1977 study.

In 1995, the beach material in this zone was noted to be mostly cobbles. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 14b were not estimated.

Erosion Zone 14c

Erosion Zone 14c extends from the northerly limit of Erosion Zone 14b north about 0.1 mile, as shown on Map 83. This zone had a 40-foot-wide beach fronting a low bluff. In 1995, the upper portion of the bluff was completely vegetated with mature trees and stable. The 1995 field observations indicated that the lower portion of the bluff appeared to be affected by toe erosion, evidenced by displaced trees and shallow slides which had brought small masses of material down onto the beach.

No bluff stability analyses were conducted in Erosion Zone 14c in the current study. However, a bluff stability analysis was conducted during the 1977 study. At that time, the bluff was reported having no recent failures and was marginally stable, with a safety factor of 1.0.

In 1995, the beach material in this zone was noted to be cobbles. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 14c were estimated at one location. These data indicated that a recession of about 40 feet, or about 1.2 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995.

In 1995, two buildings were in close proximity to the edge of the bluff.

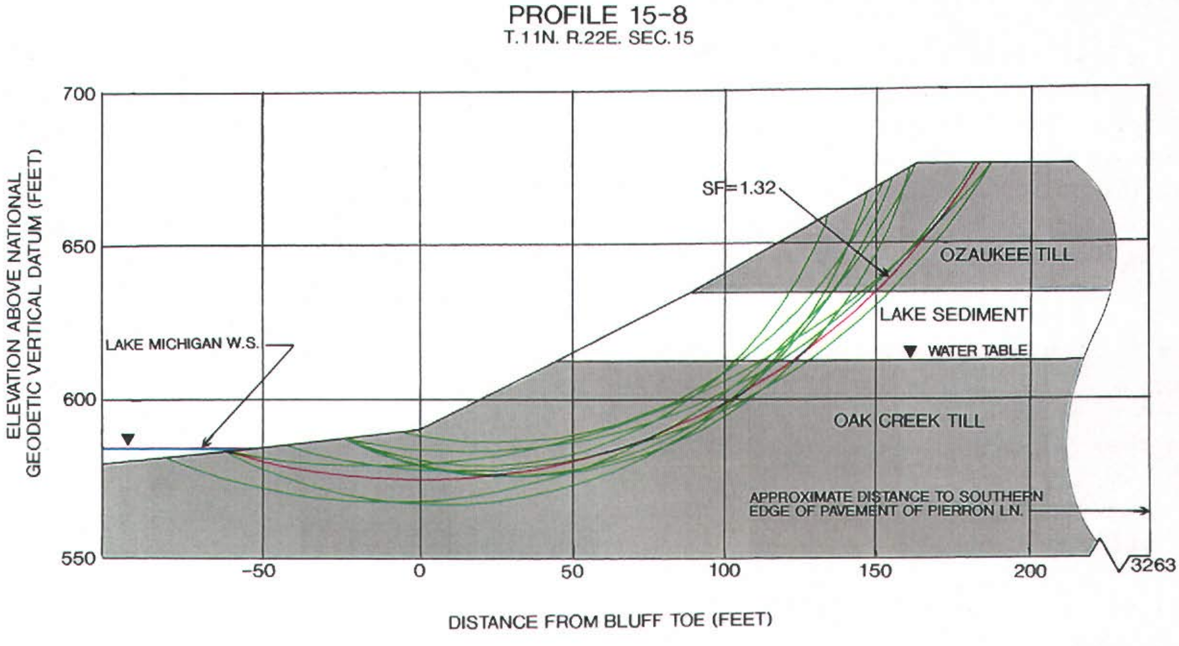
Erosion Zone 14d

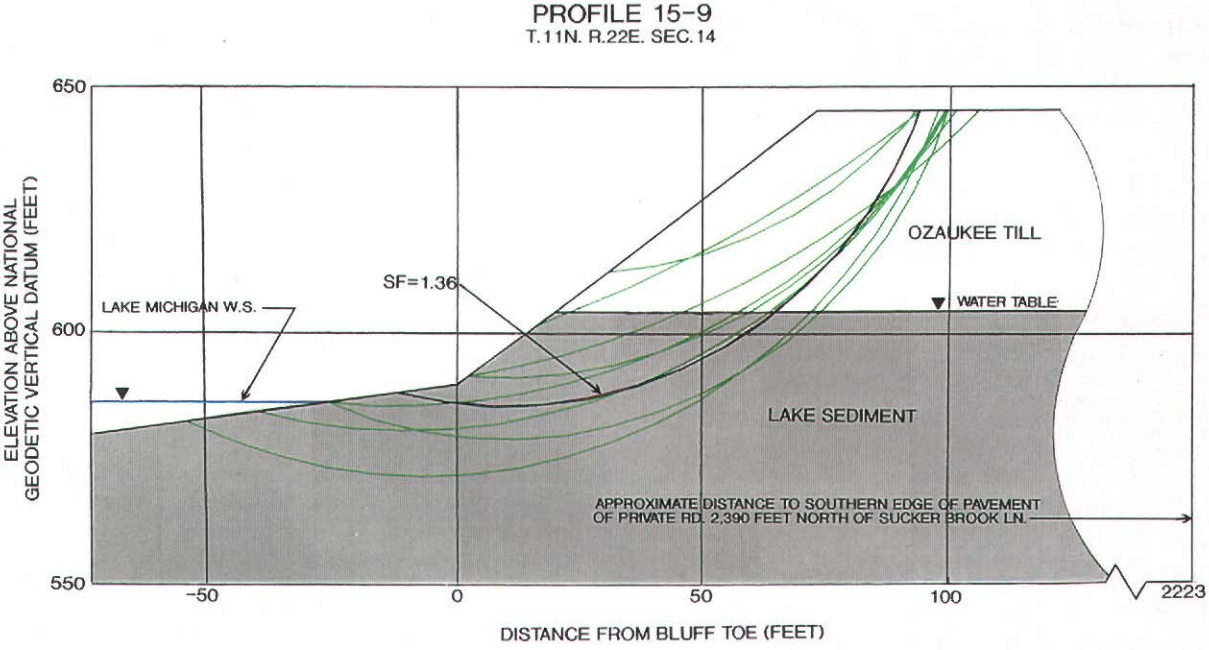
Erosion Zone 14d extends from the northerly limit of Erosion Zone 14c north about 0.1 mile, as shown on

Figure 88

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Sections 14 and 15, Township 11 North, Range 22 East
Town of Port Washington, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Maps 83 and 84. This zone had a 40-foot-wide beach fronting a low terrace that was partly vegetated. The 1995 field observations indicated that little erosion was taking place.

No bluff stability analyses were conducted within Erosion Zone 14d in this study or during the 1977 study.

In 1995, the beach within Zone 14d was about 30 feet in width and fronted a low terrace which was protected by two revetments. In the 1977 study, the beach width was reported to be about 30 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 14d were not estimated.

Erosion Zone 14e

Erosion Zone 14e extends from the northerly limit of Erosion Zone 14d north about 0.23 mile, as shown on Map 84. This zone had a 40-foot-wide beach fronting a low bluff which appeared to be eroding from top to bottom in 1995. It was reported that shallow slides were slowly taking place in this zone in 1976, but, because the bluff was barely higher than the existing terrace to the north and the south, the erosion was considered manageable.

No bluff stability analyses were conducted within Erosion Zone 14e in this study or in the 1977 study.

In the 1977 study, the beach width was reported to be between five and 15 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made in the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data were not estimated for Zone 14e.

Erosion Zone 14f

Erosion Zone 14f extends from the northerly limit of Erosion Zone 14e north about 0.23 mile, as shown on Map 84. This zone had a 25- to 30-foot-wide beach fronting a low, wooded terrace. The shoreline area was occupied mainly by woodlands, with some residential land use in the northern portion of the zone. A tributary stream entered Lake Michigan near the northern extreme of this zone.

No bluff stability analyses were conducted within Erosion Zone 14f in this study or during the 1977 study.

In 1995, the beach material in this section was noted to be mostly cobbles. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made in the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 14f were estimated at one location. The data indicated that no significant recession occurred between 1963 and 1995.

Erosion Zone 14g

Erosion Zone 14g extends from the northerly limits of Erosion Zone 14f to the north line of Section 14, as shown on Map 84. This zone had a 20- to 30-foot-wide beach with no shoreline protection structures. A low bluff of about 20 feet in height existed at the south end of the zone, increasing to about 50 feet in height near the northern end of the zone. The bluff in this zone was about 50 to 60 percent vegetated. The 1995 field observations indicated that wave erosion was occurring at the bluff during periods of high water, resulting in shallow slides along all of the bluff within this zone.

In 1995, one bluff profile field survey was made within Zone 14g by reoccupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 14g was characterized by Profile No. 15-9. Results of the slope stability analysis, shown in Figure 88, indicated that the bluff was stable with respect to rotational failures, with a safety factor of 1.36, based upon the deterministic bluff stability analysis. However, 1995 field observations indicated that translational failures may occur. The 1977 study reported a safety factor of 0.9 at this profile site.

In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material within this zone in 1995 or in 1976.

Shoreline recession data for Erosion Zone 14g were estimated at one location. The data indicated that no significant recession occurred between 1963 and 1995.

U.S. Public Land Survey Section 11, Township 11 North, Range 22 East, Town of Port Washington, Ozaukee County

This shoreline analysis section extends from the south line of Section 11 north to about Lake Drive at the south line of U.S. Public Land Survey Section 1, Township 11 North, Range 22 East, Town of Port Washington, Ozaukee County, as shown on Map 85. In 1995, the entire section was occupied by agricultural and residential uses and woodlands. Bluffs existing in the northern and southern portions of this section were up to 80 feet in height. The central portion of this section was terraced with a low bluff located well back from the shoreline. For further analysis, Section 11 was further subdivided into five erosion zones, as shown on Map 85. The inventory and analysis findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the five zones.

Erosion Zone 11a

Erosion Zone 11a extends from the south line of Section 11 north about 0.1 mile, as shown on Map 85. This zone had a 10- to 30-foot-wide beach fronting a bluff which had a height of up to 80 feet. The 1995 field observations indicated that the upper portion of the bluff was vegetated with mature trees and was stable. The lower 15 feet of the bluff appeared to have been affected by shallow translational slides, pushing trees and soil onto the beach in places.

In 1995, one bluff profile field survey was made within Zone 11a by reoccupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 11a was characterized by Profile No. 15-10. Results of the slope stability analysis, shown in Figure 89, indicated that the bluff was marginally stable with respect to rotational failures, with a safety factor of 1.10, based upon the deterministic bluff stability analysis method. Profile No. 15-10 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.58 to 1.45 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 17, or 68 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 135, or 54 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered unstable with respect to both rotational and translational failures. The 1977 study reported a bluff safety factor of 1.09.

In 1995, the beach within Zone 11a was about 30 feet wide and was noted to be composed of cobbles. In the 1977 study, the beach width was reported to be between five and 15 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 11a were estimated at one location. These data indicated that a recession of about 50 feet, or about 1.6 feet per year, occurred between 1963 and 1995. The data indicated a recession of about 50 feet, or about 2.5 feet per year, occurring between 1975 and 1995.

Erosion Zone 11b

Erosion Zone 11b extends from the northerly limit of Erosion Zone 11a north about 0.25 mile, as shown on Map 85. This zone had a 10- to 30-foot-wide beach fronting a bluff which had a height of up to 60 feet. In 1995, the bluff was about 50 percent vegetated with mostly shrubs. The 1995 field observations reported that bluff failure was occurring by translational slides. The formation of scalloped shapes on the bluff top suggested that slumping was also occurring in this zone.

In 1995, one bluff profile field survey was made within Zone 11b by occupying a site for which a field surveys was conducted in 1976. The stability of the bluff in Erosion Zone 11b was characterized by Profile No. 15-11. Results of the slope stability analysis, shown in Figure 89, indicated that the bluff was unstable, with a safety factor of 0.95, based upon the deterministic bluff stability analysis method. Profile No. 15-11 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.74 to 1.32 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 11, or 44 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 72, or 28.8 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered marginally stable with respect to both rotational and translational failures. The 1977 study reported a bluff safety factor of 0.99.

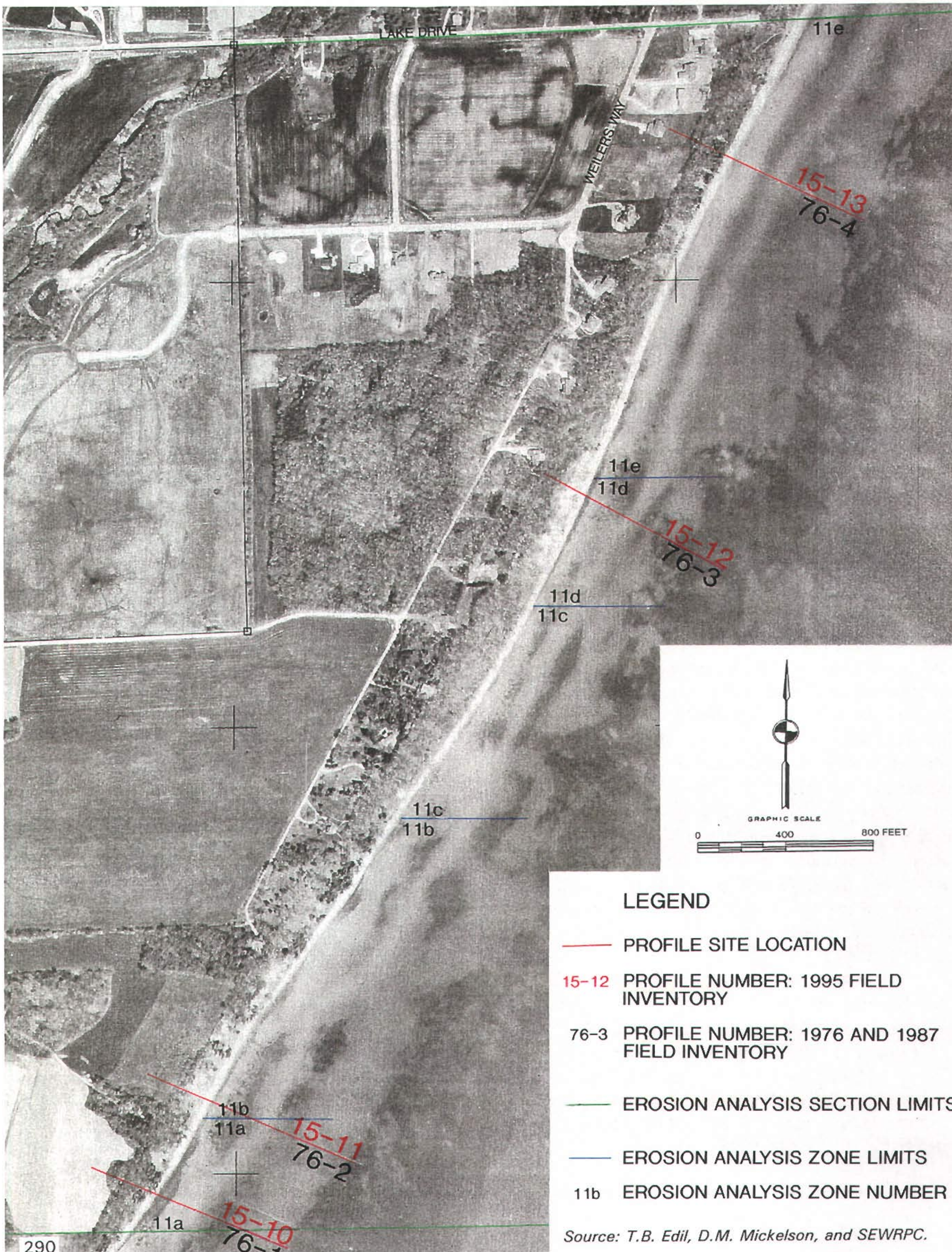
In 1995, the beach within Zone 11b varied between 10 and 30 feet wide and was noted to be composed of coarse cobbles. In the 1977 study, the beach width was reported to be between five and 15 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or materials at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 11b were estimated at one location. The data indicated that a recession of about 10 feet, or about 0.3 foot per year, occurred between 1963 and 1995. The data indicated a

Map 85

SHORELINE EROSION REACH 15: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 11, Township 11 North, Range 22 East
Town of Port Washington, Ozaukee County

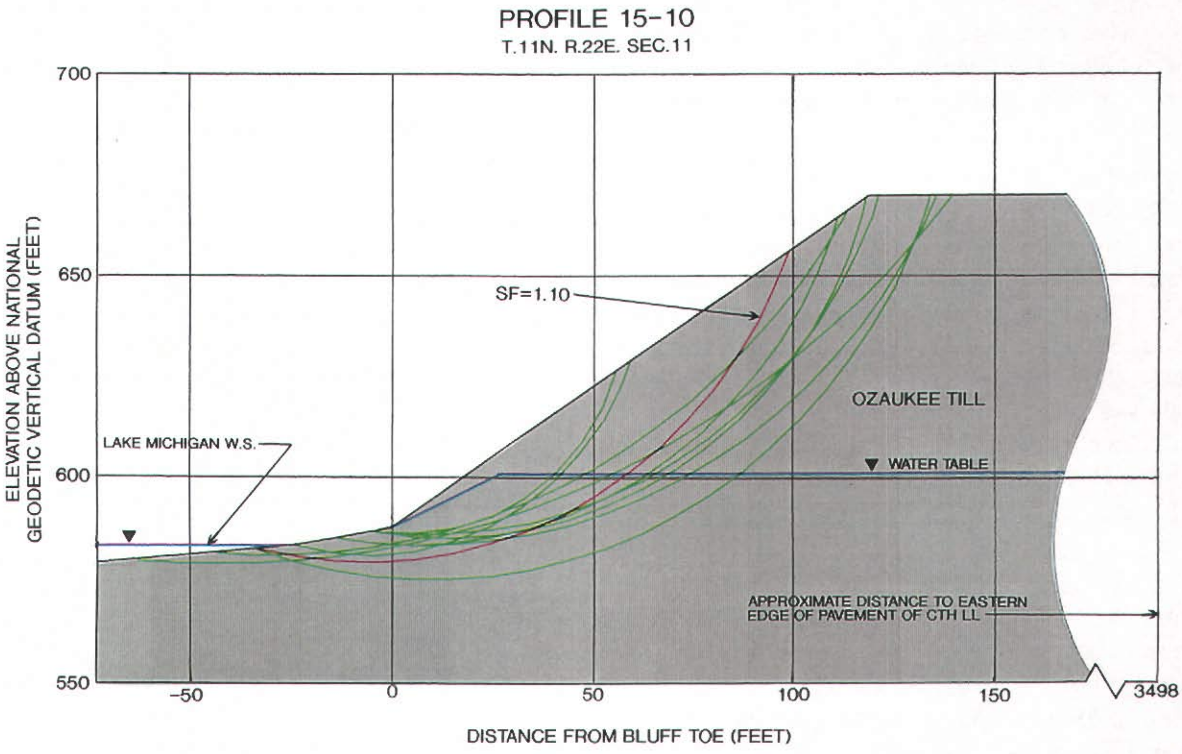


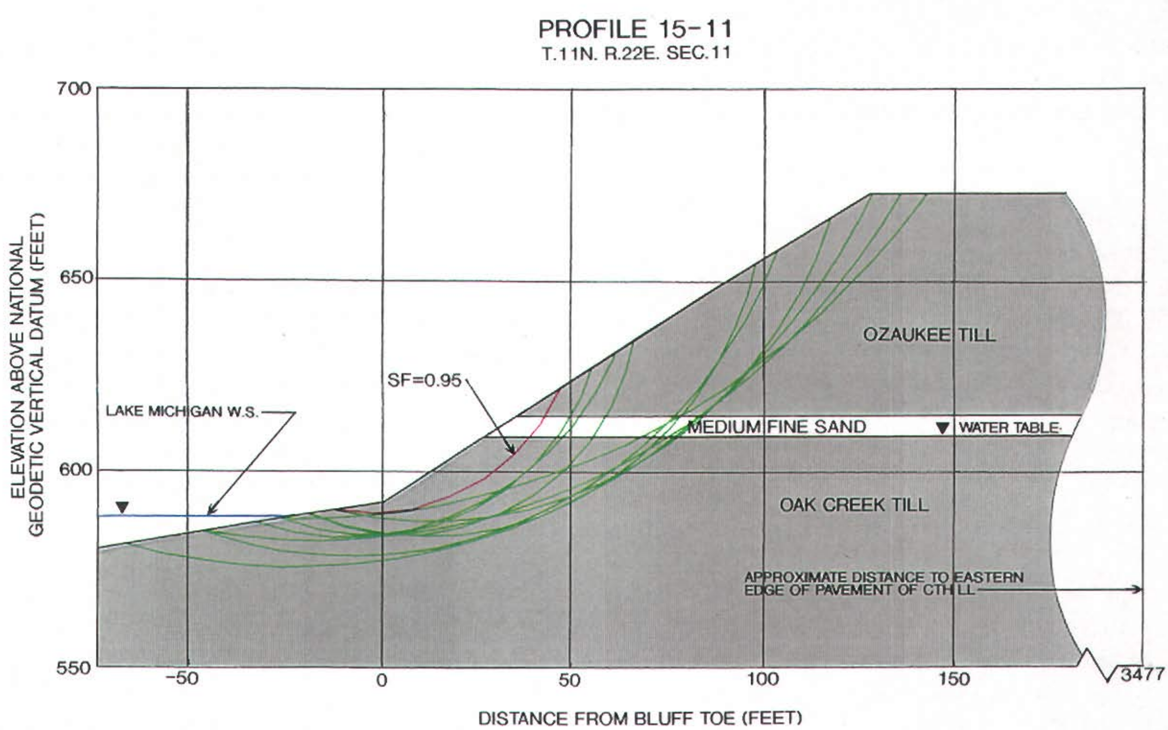
Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Figure 89

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Section 11, Township 11 North, Range 22 East
Town of Port Washington, Ozaukee County





Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995.

Erosion Zone 11c

Erosion Zone 11c extends from the northerly limit of Erosion Zone 11b north about 0.18 mile, as shown on Map 85. This zone had about a 10- to 30-foot-wide beach fronting a bluff which had a height of up to 60 feet. The bluff was 100 percent vegetated and stable.

No bluff stability analyses were conducted within Erosion Zone 18a during this study or the 1977 study.

The beach within Zone 11c varied between 10 and 30 feet wide and was noted to be composed of coarse cobbles in 1995. In the 1977 study, the beach width was reported to be between five and 20 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 11c were estimated at one location. The data indicated that a recession of about 20 feet, or about 0.6 foot per year, occurred between 1963 and 1995. The data indicated a recession of about 10 feet, or about 0.5 foot per year, occurred between 1975 and 1995.

In 1995, it was not clear why the bluff slopes in this zone had stable vegetated slopes, while the zones to the north and the south of Erosion Zone 11c had failing bluffs, since the geology remained the same between these zones.

Erosion Zone 11d

Erosion Zone 11d extends from the northerly limit of Erosion Zone 11c north about 0.11 mile, as shown on Map 85. This zone had a 10- to 30-foot-wide beach fronting a bluff which had a height of up to 60 feet. In 1995, vegetation in this zone existed mainly on the upper portions of the bluff. The 1995 field observations indicated that severe erosion was taking place, mostly by shallow slides. The lower portion of the bluff had become almost completely mobilized.

In 1995, one bluff profile field survey was made within Zone 11d by occupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 11d was characterized by Profile No. 15-12. Results of the slope stability analysis, shown in Figure 90, indicated that the bluff was unstable, with a safety factor of 0.92, based upon the deterministic bluff stability analysis method. Profile No. 15-12 was also analyzed using the probabilistic bluff stability analysis method which resulted in a range of safety factors from 0.67 to 1.22 for the 250 conditions considered. The analytical results indicated a safety factor of less than 1.0 for 19, or 76 percent, of the 25 critical conditions, as represented by the set of most critical conditions determined in each of the 25 analyses considered. In addition, a safety factor of less than 1.0 was determined for 172, or 68.8 percent, of the 250 conditions analyzed. Given the analytical results and the 1995 field observations, the bluffs were considered unstable with respect to both rotational and translational failures. The 1977 study reported a similar bluff safety factor of 0.91.

The beach within Zone 11d varied between 10 and 30 feet wide and was noted to be composed of coarse cobbles in 1995. In the 1977 study, the beach width was reported to be about 20 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 11d were not estimated.

Erosion Zone 11e

Erosion Zone 11e extends from the northerly limit of Erosion Zone 11d north to the north line of the section, as shown on Map 85. This zone had a 30- to 50-foot-wide beach fronting a bluff which had a height of up to 60 feet. In 1995, this zone was mostly vegetated with the exception of a few scar areas produced as a result of shallow slides.

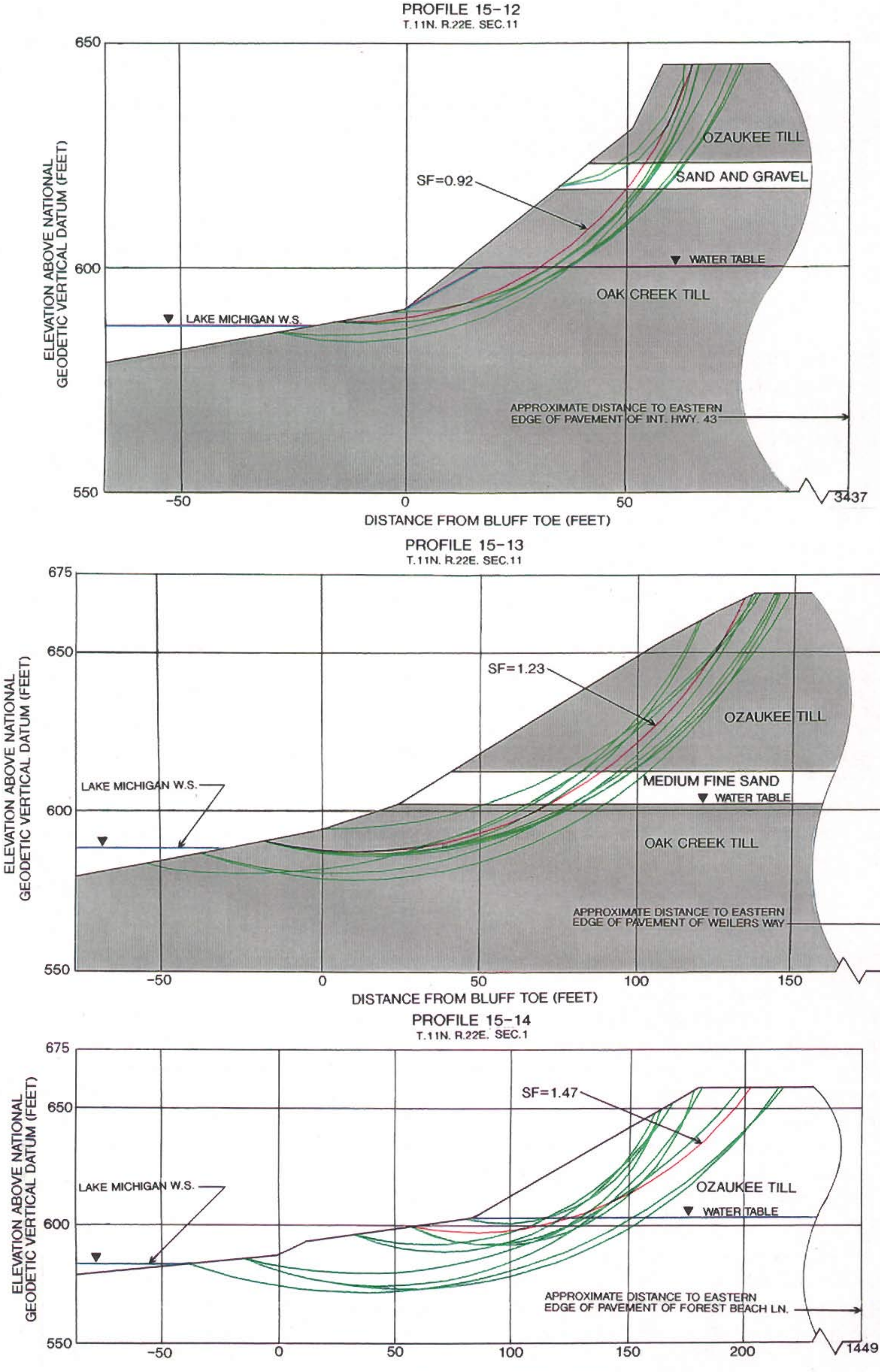
In 1995, one bluff profile field survey was made within Zone 11e by reoccupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 11e was characterized by Profile No. 15-13. Results of the slope stability analysis, shown in Figure 90, indicated that the bluff was stable, with a safety factor of 1.23. The 1977 study reported a bluff safety factor of 1.0.

The beach within Zone 11e varied between 30 and 50 feet wide and was noted to be composed of coarse cobbles in 1995. In the 1977 study, the beach width was reported to be five and 30 feet, with the widest portion of the beach located at the northern extreme of the zone,

Figure 90

DETERMINISTIC BLUFF SLOPE STABILITY ANALYSES

U.S. Public Land Survey Sections 1 and 11, Township 11 North, Range 22 East
Town of Port Washington, Ozaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 11e were estimated at two locations. These data indicated that a recession of between zero and 30 feet, or about 0.9 foot per year, occurred between 1963 and 1995, with the greatest recession occurring in the southern portion of the zone. The data indicated that most of this recession occurred prior to 1975, with no further recession occurring between 1975 and 1995. The 1977 study reported a recession rate of one foot per year in this zone.

U.S. Public Land Survey Section 1, Township 11 North, Range 22 East, Town of Port Washington, Ozaukee County

This shoreline analysis section extends from about Lake Drive at the south line of Section 1, north to about CTH P at the south line of U.S. Public Land Survey Section 36, Township 12 North, Range 22 East, Town of Belgium, Ozaukee County, as shown on Map 86. In 1995, the northern and southern portions of the section were occupied by residential land uses and the central portion was occupied by woodlands. In 1995, the central portion of the section formed a point which consisted of an exposure of dolomite bedrock. Bluffs in this section were up to 60 feet in height. The northern two-thirds of the bluff was fronted by a terrace protecting the bluff from erosion. For further analysis, Section 1 was further subdivided into three erosion zones, as shown on Map 86. The inventory and analysis findings relating to bluff, beach, and nearshore conditions and shoreline recession are discussed below for each of the three zones.

Erosion Zone 1a

Erosion Zone 1a extends from about Lake Drive at the south line of the section, north about 0.15 mile, as shown on Map 86. This zone had a 30- to 50-foot-wide beach fronting a bluff which had a height of about 50 feet. In 1995, this zone was mostly vegetated with shrubs and trees and was stable, except for a small amount of toe erosion that was very localized. A gently sloping lower bluff existed. This lower bluff slope may have been the inside edge of a terrace which has been largely eroded away.

One bluff profile field survey site for which a bluff profile survey was conducted in 1976 was not reoccupied during the current study. The 1977 study reported a bluff safety factor of 1.0 at Profile No. 76-1.

The beach within Zone 1a varied between 30 and 50 feet wide and was noted to be composed of pebbles and small cobbles in 1995. In the 1977 study, the beach width was reported to be less than 20 feet, and the beach materials were also reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 1a were estimated at one location. The data indicated that no measurable recession occurred between 1963 and 1995 in this zone. The 1977 study reported a recession rate of about one foot per year in this zone.

Erosion Zone 1b

Erosion Zone 1b extends from the northerly limit of Erosion Zone 1a north about 0.15 mile, as shown on Map 86. This zone had a 30- to 50-foot-wide beach. In 1995, this zone was completely vegetated and appeared stable, except for a small amount of toe erosion at the base of the bluff.

No bluff stability analyses were conducted within Erosion Zone 1b during this study or the 1977 study.

In the 1977 study, the beach width was reported to be less than 20 feet, and the beach materials were reported to be cobbles and pebbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 1b were estimated at one location. These data indicated a recession of about 40 feet, or about 1.2 feet per year, occurring between 1963 and 1995. The data indicated a recession of about 20 feet, or about one foot per year, occurring between 1975 and 1995.

Erosion Zone 1c

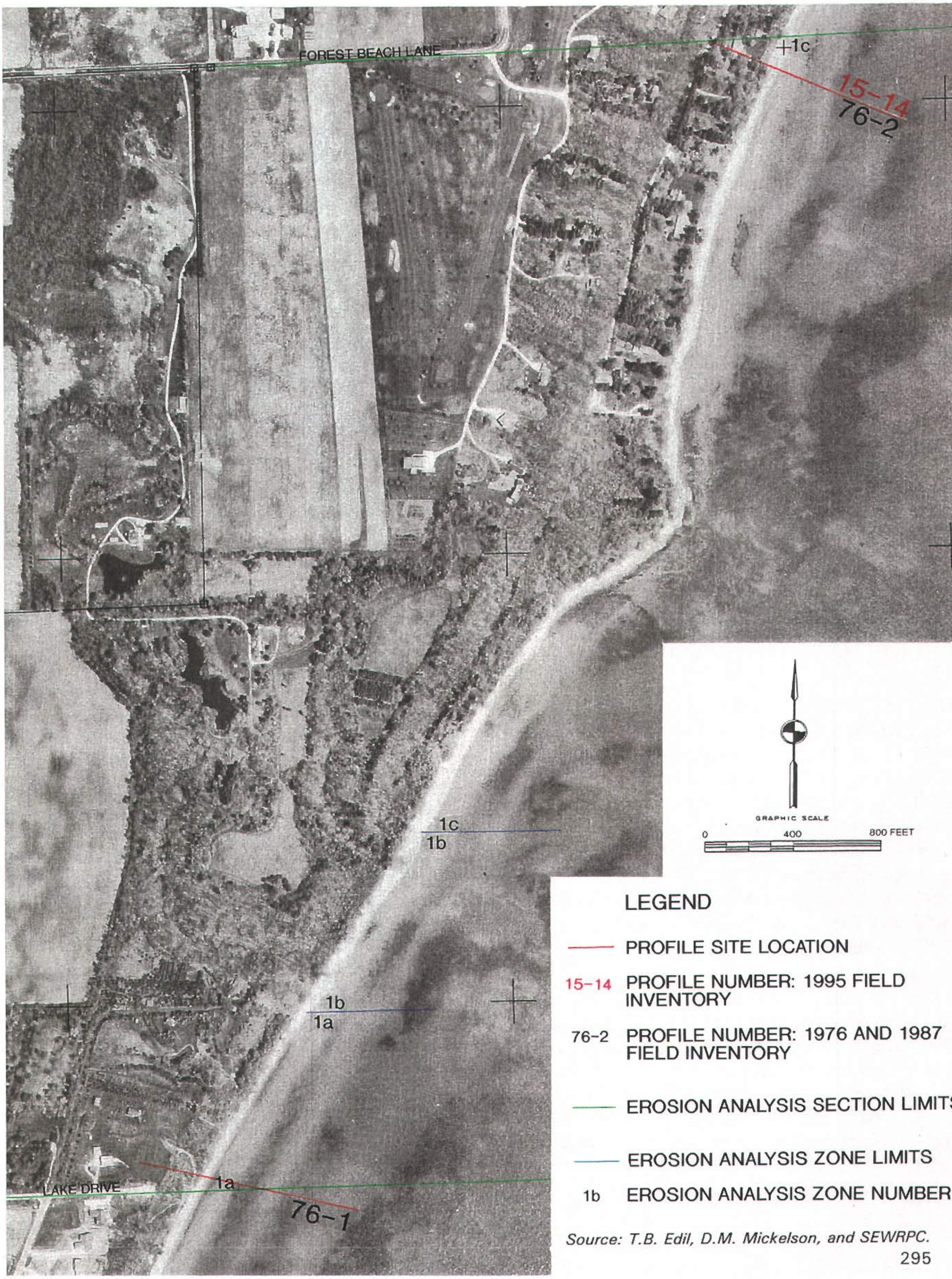
Erosion Zone 1c extends from the northerly limit of Erosion Zone 1b north to the north line of the section, as shown on Map 86. In 1995, the entire bluff was vegetated and stable. The entire bluff was fronted by a terrace, except in the central portion of the zone where the shore formed a point. In 1995, there was a bedrock exposure at beach level at this point.

In 1995, one bluff profile field survey was made within Zone 1c by occupying a site for which a field survey was conducted in 1976. The stability of the bluff in Erosion Zone 1c was characterized by Profile No. 15-14. Results of the slope stability analysis, shown in Fig-

Map 86

SHORELINE EROSION REACH 15: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 1, Township 11 North, Range 22 East
Town of Port Washington, Ozaukee County



LEGEND

PROFILE SITE LOCATION

15-14 PROFILE NUMBER: 1995 FIELD INVENTORY

76-2 PROFILE NUMBER: 1976 AND 1987 FIELD INVENTORY

EROSION ANALYSIS SECTION LIMITS

EROSION ANALYSIS ZONE LIMITS

1b EROSION ANALYSIS ZONE NUMBER

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

ure 90, indicated that the bluff was stable, with a safety factor of 1.47. The 1977 study did not report a bluff safety factor.

The beach within Zone 1c varied between 30 and 50 feet wide. In the 1977 study, the beach width was reported to be less than 20 feet, and the beach material in the southern portion of Zone 1c was reported to be composed of pebbles and cobbles. In the central portion of the zone, no beach materials were observed as the bedrock shelf was exposed. In the northern portion of the zone, beach materials were composed of cobbles and pebbles, with sand in some areas. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Erosion Zone 1c were estimated at three locations. The data indicated a recession of between zero and 30 feet, or between zero and 0.9 foot per year, occurred between 1963 and 1995. The data indicated a recession of between zero and 30 feet, or between zero and 1.5 feet per year, occurred between 1975 and 1995. Recession rates were greatest in the southern and central portion of the zone. No measurable recession occurred in the northern portion of the zone between 1963 and 1975.

The 1995 field observations indicated that a minor amount of erosion was taking place within Zone 1c.

SHORELINE REACH 16: TOWN OF BELGIUM, OZAUKEE COUNTY

Shoreline Reach 16 is a three-mile-long reach of shoreline extending from about CTH P at the south line of U.S. Public Land Survey Section 36, Township 12 North, Range 23 East, Town of Belgium north to about CTH D at the northern boundary of Harrington Beach State Park at the south line of U.S. Public Land Survey Section 19, Township 12 North, Range 23 East, Village of Belgium, as shown in Map 87. Land uses along this reach comprised open space and recreational uses at Harrington Beach State Park and residential lands mixed with undeveloped tracts.

As of 1995, nearly the entire shoreline in Reach 16, except for the central and southern portions of the parkland and the southern edge and northern end of the reach which contained exposures of resistant dolomite bedrock, was protected by shoreline protection structures. Existing structures generally consisted of various types protecting either individual properties or short reaches incorporating more than one property. The most common shore protection measures in this reach were riprap and revetments.

As shown on Map 87, Reach 16 was further segmented into three analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three analysis sections in Reach 16.

U.S. Public Land Survey Section 36, Township 12 North, Range 22 East, Town of Belgium, Ozaukee County

This shoreline analysis section extends from CTH P to CTH A, in the Town of Belgium, as shown on Map 88. The entire shoreline area was occupied by residential land uses and undeveloped lots. In 1995, the beach width in Section 36 ranged from 30 to 80 feet. The entire beach within this section fronted a low terrace. Variations in beach width over short distances were common throughout the section, with the changes being controlled largely by the presence of shoreline protection structures. Nearly all of the shoreline in this section was covered by shoreline protection structures of various types protecting individual properties or reaches incorporating multiple properties. In this section, the bluff was located well behind the terrace and well back from the shoreline. In 1995, the bluff was completely vegetated and stable.

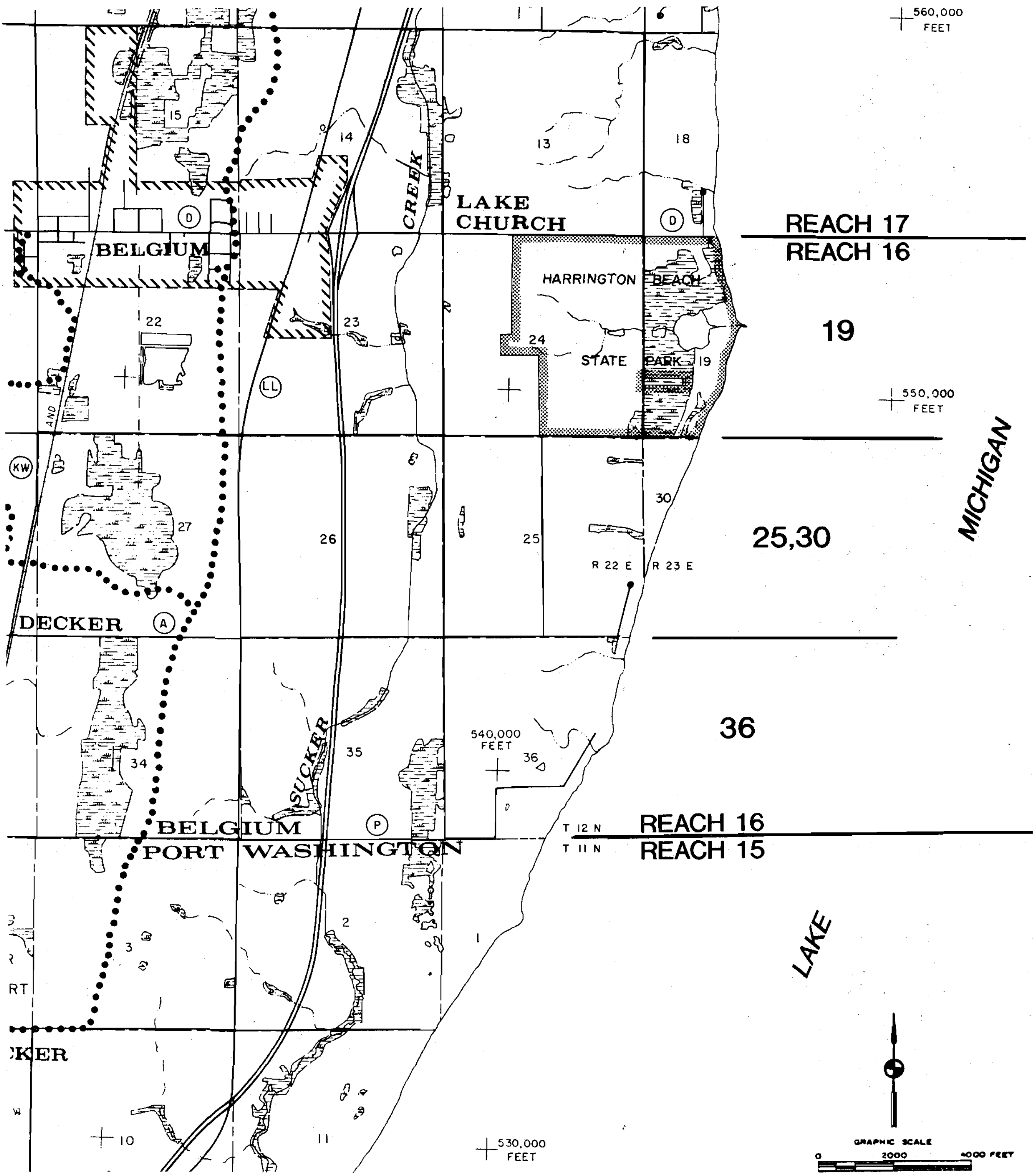
No bluff stability analyses were conducted within Section 36 in this study or in the 1977 study.

In the 1977 study, the beach width was reported to be less than 20 feet, and the beach materials in this section were reported to be cobbles and pebbles with some areas of sand. In the central portion of the section, no beach materials were observed, as the bedrock shelf was exposed. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Section 36 were estimated at five locations. These data indicated a recession of between zero and 50 feet, or between zero and 1.6 feet per year, occurred between 1963 and 1995. The data indicated a recession of between zero and 20 feet, or between zero and one foot per year, occurred between 1975 and 1995. The highest erosion rates were noted in the central portions of the section and at the very north-

Map 87

BLUFF ANALYSIS SECTIONS WITHIN REACH 16

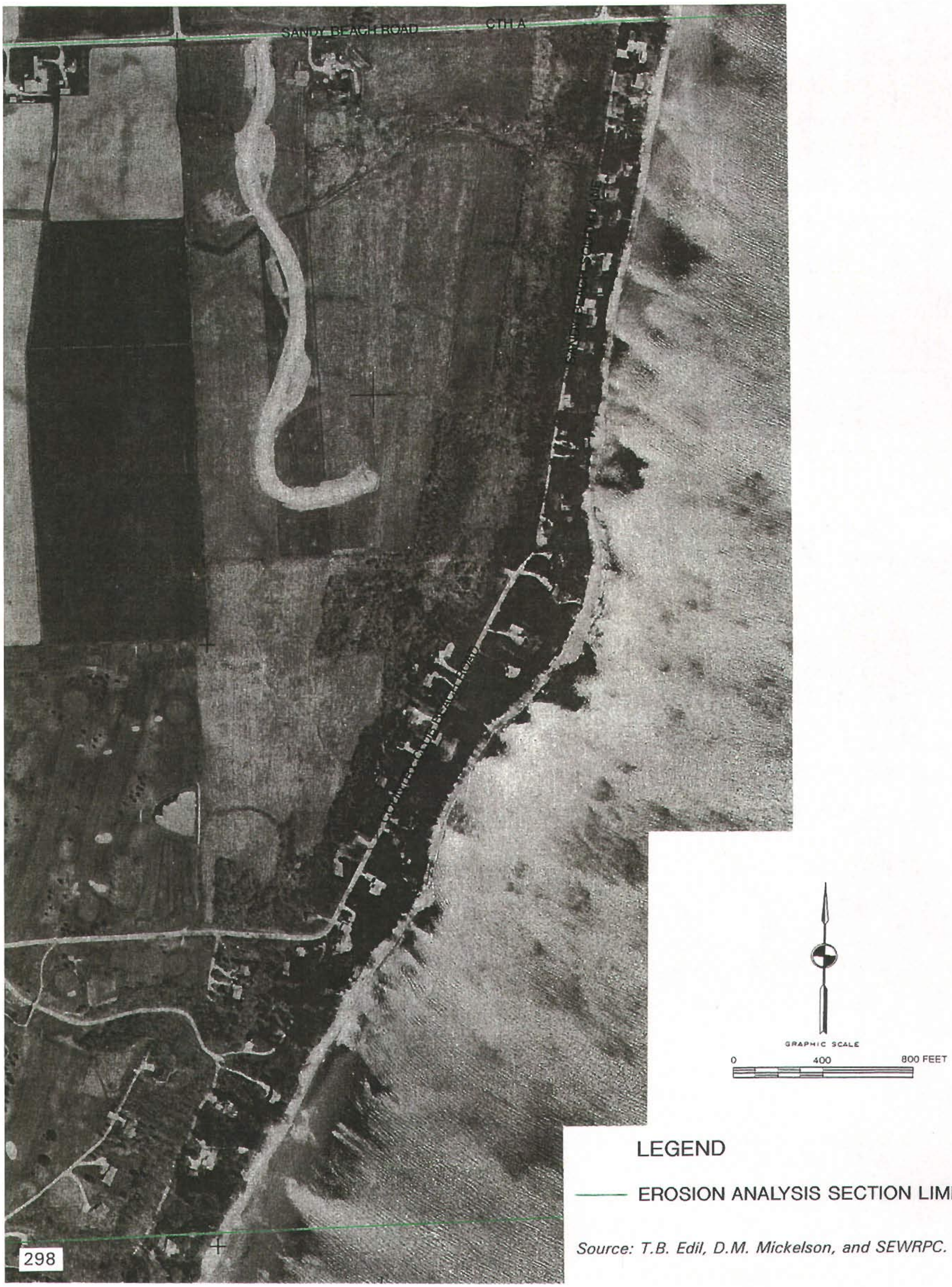


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 88

SHORELINE EROSION REACH 16: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 36, Township 12 North, Range 22 East
Town of Belgium, Ozaukee County



LEGEND

—— EROSION ANALYSIS SECTION LIMITS

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

ern end of the section. No measurable recession was observed in the southernmost and north-central portions of the section between 1963 and 1995. The 1977 study reported a recession rate of 0.1 foot per year within this section.

U.S. Public Land Survey Sections 25 and 30, Township 12 North, Range 22 and 23 East, Town of Belgium, Ozaukee County

This shoreline analysis section extends from about CTH A north to about Cedar Beach Road, in the Town of Belgium, as shown on Map 89. The entire shoreline area was occupied by residential land uses and undeveloped lots. In 1995, the beach width in Sections 25 and 30 ranged from 30 to about 80 feet. The entire beach in this section fronted a low terrace. Variations in beach width over short distances were common throughout the section, with the changes being controlled largely by the presence of shoreline protection structures. Nearly all of the low terrace in this section was covered by shoreline protection structures of various types protecting individual properties or short reaches incorporating more than one property. Some seawalls present in 1976 were noted to have been replaced with revetments in 1995. In this section, the bluff was located well behind the terrace and well back from the shoreline. In 1995, the bluff was considered to be completely stable.

No bluff stability analyses were conducted within Sections 25 and 30 in this study or in the 1977 study.

In 1995, the beach materials were noted to be sand and cobbles. In the 1977 study, the beach width was reported to be less than 20 feet narrowing to less than 10 feet in the northern portion of the section, and the beach materials in this section was reported also to be sand to cobbles. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Sections 25 and 30 were estimated at five locations. These data indicated a recession of between 10 and 50 feet, or between 0.3 and 1.6 feet per year, occurred between 1963 and 1995. The data indicated a recession of between 10 and 20 feet, or between 0.5 and one foot per year, occurred between 1975 and 1995. The highest erosion rates were estimated in the very northern portion of the section and in the very southern portion of the section. However, in the south-central portion of the section, the data indicated no further recession between 1975 and 1995.

U.S. Public Land Survey Section 19, Township 12 North, Range 23 East, Town of Belgium, Ozaukee County

This shoreline analysis section extends from about Cedar Beach Road north to CTH D, in the Town of Belgium, as shown on Map 90. The entire shoreline area was occupied by open space and recreational uses at Harrington Beach State Park. In 1995, the beach width in Section 19 ranged from being almost nonexistent to about 150 feet. The southern half of this section was fronted by a low terrace. In this portion of the section, the bluff was located well behind the terrace and well back from the shoreline. Most of the shoreline remained unprotected, with the exception of the very northern end of the section where a small groin system, partly covered with sand, was present. In 1995, the bluff was vegetated and was considered to be stable.

No bluff stability analyses were conducted within Section 19 in this study or in the 1977 study.

In 1995, the beach material in the southern portion of the section was noted as sand and cobbles. In the 1977 study, the beach width was reported to be less than 20 feet, and the beach materials in the southern portion of the section were reported to be cobbles and pebbles. The beach materials in the central portion of the section were reported to be sand in 1977. In the northern portion of the section, the bedrock shelf was reported to be exposed in places, and intermixed with a beach consisting of angular cobbles and sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Section 19 were estimated at five locations. These data indicated a recession of between 30 and 80 feet, or between 0.9 and 2.5 feet per year, occurred between 1963 and 1995. In the southern, central and extreme northern portions of the section, the data indicated a recession of between 10 and 40 feet, or between 0.5 and two feet per year, occurred between 1975 and 1995. In the north-central portion of the section, however, the data indicated no further recession between 1975 and 1995. The 1977 study did not report a recession rate for this section.

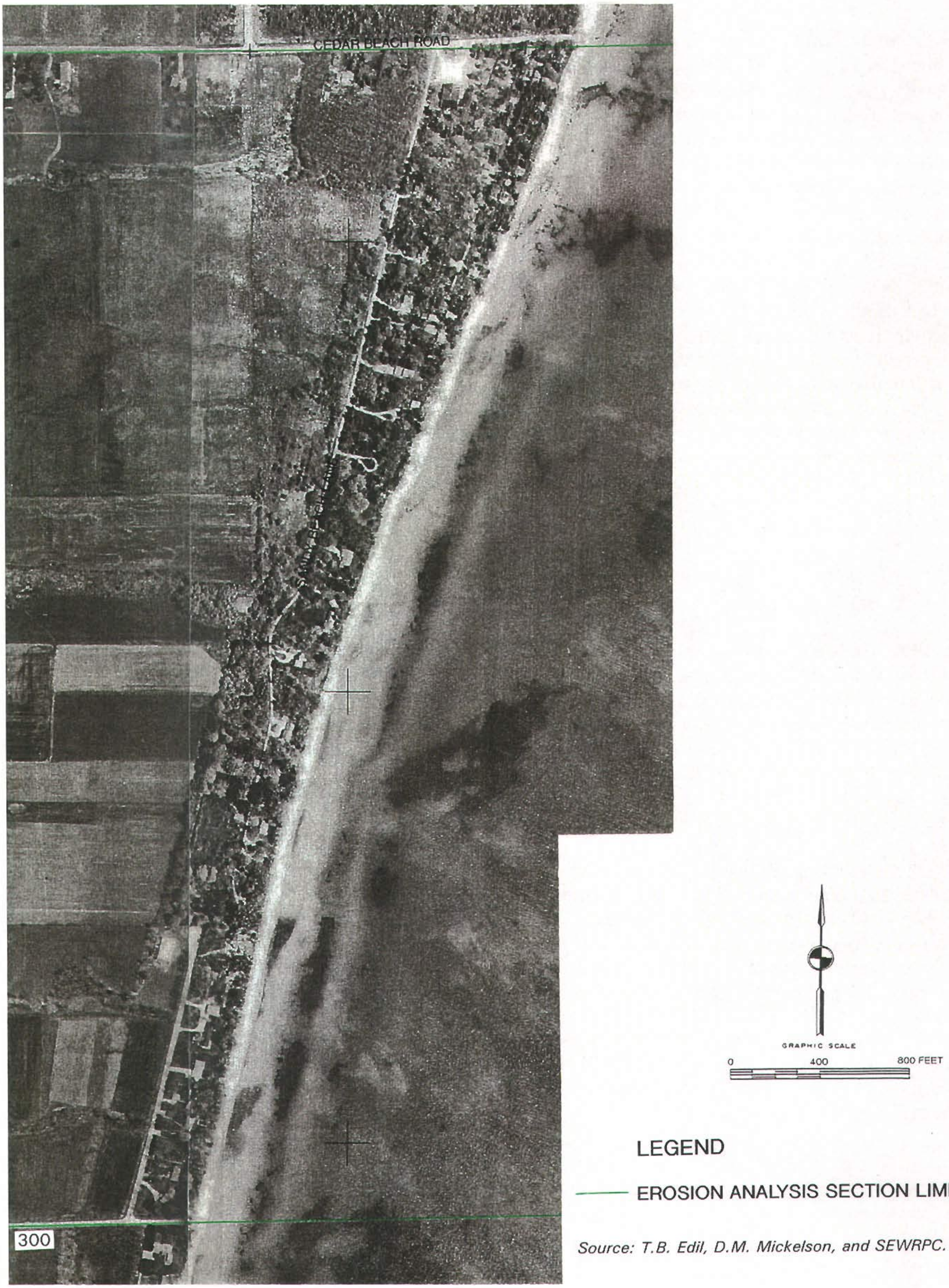
SHORELINE REACH 17: TOWN OF BELGIUM, OZAUKEE COUNTY

Shoreline Reach 17 is a 3.5-mile-long reach of shoreline extending from about CTH D at the northern edge of

Map 89

SHORELINE EROSION REACH 16: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 30, Township 12 North, Range 22 East
and Section 25, Township 12 North, Range 22 East
Town of Belgium, Ozaukee County



LEGEND

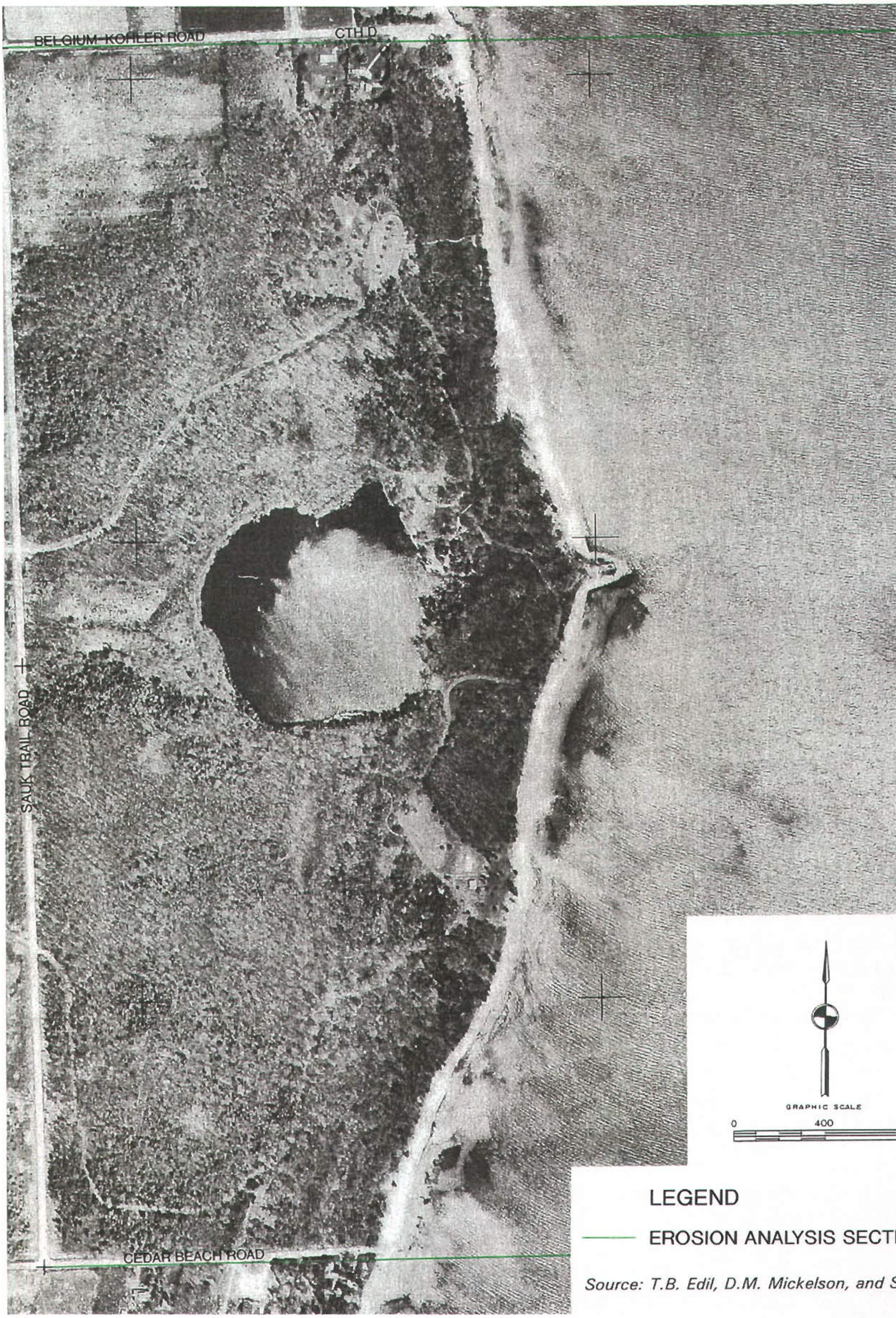
EROSION ANALYSIS SECTION LIMITS

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 90

SHORELINE EROSION REACH 16: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 19, Township 12 North, Range 23 East
Town of Belgium, Ozaukee County



LEGEND

EROSION ANALYSIS SECTION LIMITS

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Harrington Beach at the south line of U.S. Public Land Survey Section 18, Township 12 North, Range 23 East, Town of Belgium, north to about CTH K at the Ozaukee-Sheboygan county line on the south line of U.S. Public Land Survey Section 31, Township 13 North, Range 23 East, Town of Belgium, as shown on Map 91. Land uses along this reach were comprised almost entirely of existing residences mixed intermittently with undeveloped lots and agricultural uses. As of 1995, about two linear miles, or about 70 percent, of the shoreline in Reach 17 were protected by structural shore protection measures, consisting of mainly revetments and riprap.

As shown on Map 91, Reach 17 was further segmented into three analysis sections corresponding to the U.S. Public Land Survey sections for the purpose of describing the bluff-related and shoreline erosion characteristics. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for each of the three analysis sections in Reach 17.

U.S. Public Land Survey Section 18, Township 12 North, Range 23 East, Town of Belgium, Ozaukee County

This shoreline analysis section extends from CTH D at the northern edge of Harrington Beach State Park to Silver Beach Road, in the Town of Belgium, as shown on Map 92. The entire shoreline area was occupied by residential land use, with a mix of undeveloped lots and rural land. In 1995, the beach width in Section 18 ranged from 30 to 100 feet. The beach within this section entirely fronted a low terrace of which about half was lined with revetments. Variations in beach width over short distances were common throughout the reach, with the changes being controlled largely by the presence of shoreline protection structures. Nearly all of the shoreline in the northern half of this section was covered by shoreline protection structures of various types protecting individual properties or reached incorporating multiple properties. The southern half of this section was largely unprotected. In this section, the bluff was located well behind the terrace and well back from the shoreline. In 1995, the bluff was vegetated or in agricultural uses and was considered to be stable.

No bluff stability analyses were conducted within Section 18 in this study or in the 1977 study.

In 1995, the beach material in this section was noted to be sand. In the 1977 study, the beach width was reported to be less than 20 feet, and the beach material was also reported to be sand. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Section 18 were estimated at five locations. These data indicated a recession of between zero and 40 feet, or between zero and 1.2 feet per year, occurred between 1963 and 1995. The data indicated no further recession occurred in the south-central, central, and north-central portions of the section between 1975 and 1995. The data indicated a recession of between 10 and 15 feet, or between 0.5 and 0.8 foot per year, occurred in the southern and northern portions of Section 18 between 1975 and 1995. The 1977 study reported a recession rate of 0.1 foot per year in this section.

U.S. Public Land Survey Section 7, Township 12 North, Range 23 East, Town of Belgium, Ozaukee County

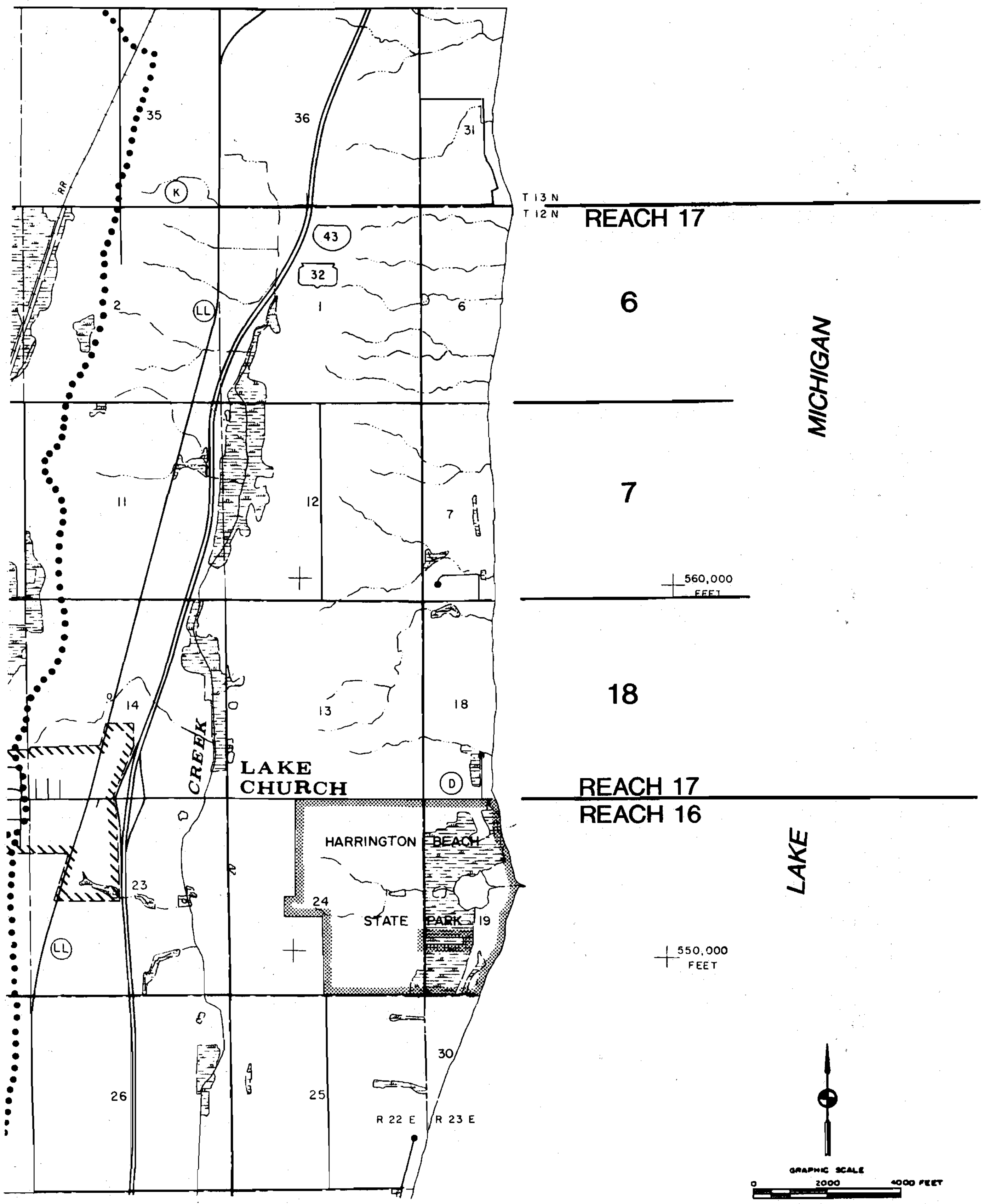
This shoreline analysis section extends from about Silver Beach Road north to about Jay Road, in the Town of Belgium, as shown on Map 93. The entire shoreline area was occupied by residential subdivision lands, with a mix of residential land use and undeveloped lots. In 1995, the beach width in Section 7 ranged from 30 to about 100 feet. The entire shoreline in this section was fronted by a low terrace. Variations in beach width over short distances were common throughout the section, with the changes being controlled largely by the presence of shoreline protection structures. Nearly all of the terrace face in this section was covered by shoreline protection structures of various types protecting individual properties or short reaches incorporating more than one property. The most common shoreline protection measure in this section was riprap. In this section, the bluff was located well behind the terrace and well back from the shoreline. In 1995, the bluff was completely vegetated and was considered to be stable.

No bluff stability analyses were conducted within Section 7 in this study or in the 1977 study.

In the 1977 study, the beach width was reported to be less than 20 feet, and the beach materials in the section were reported to be sand. No measurements or obser-

Map 91

BLUFF ANALYSIS SECTIONS WITHIN REACH 17

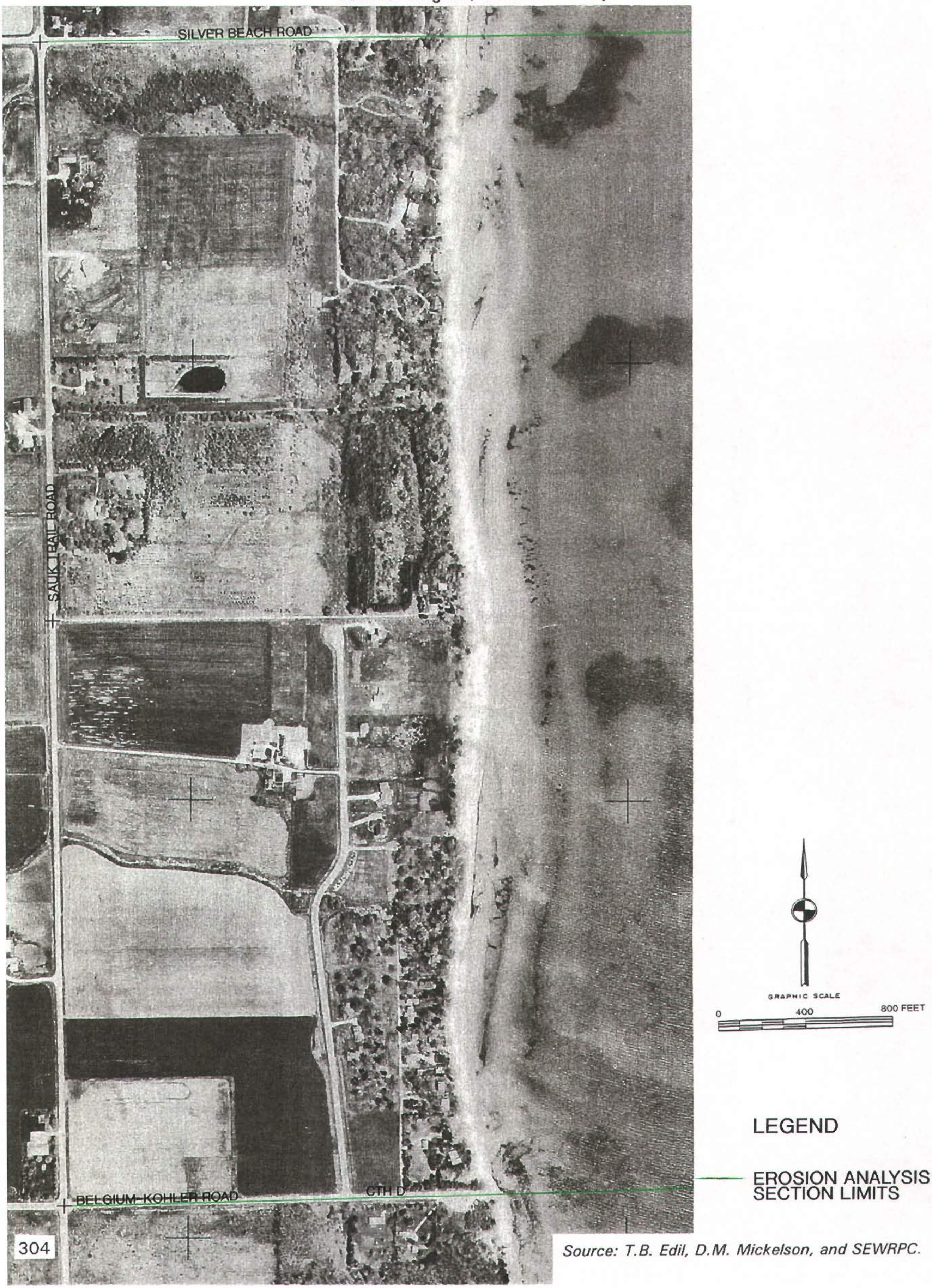


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 92

SHORELINE EROSION REACH 17: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 18, Township 12 North, Range 23 East
Town of Belgium, Ozaukee County

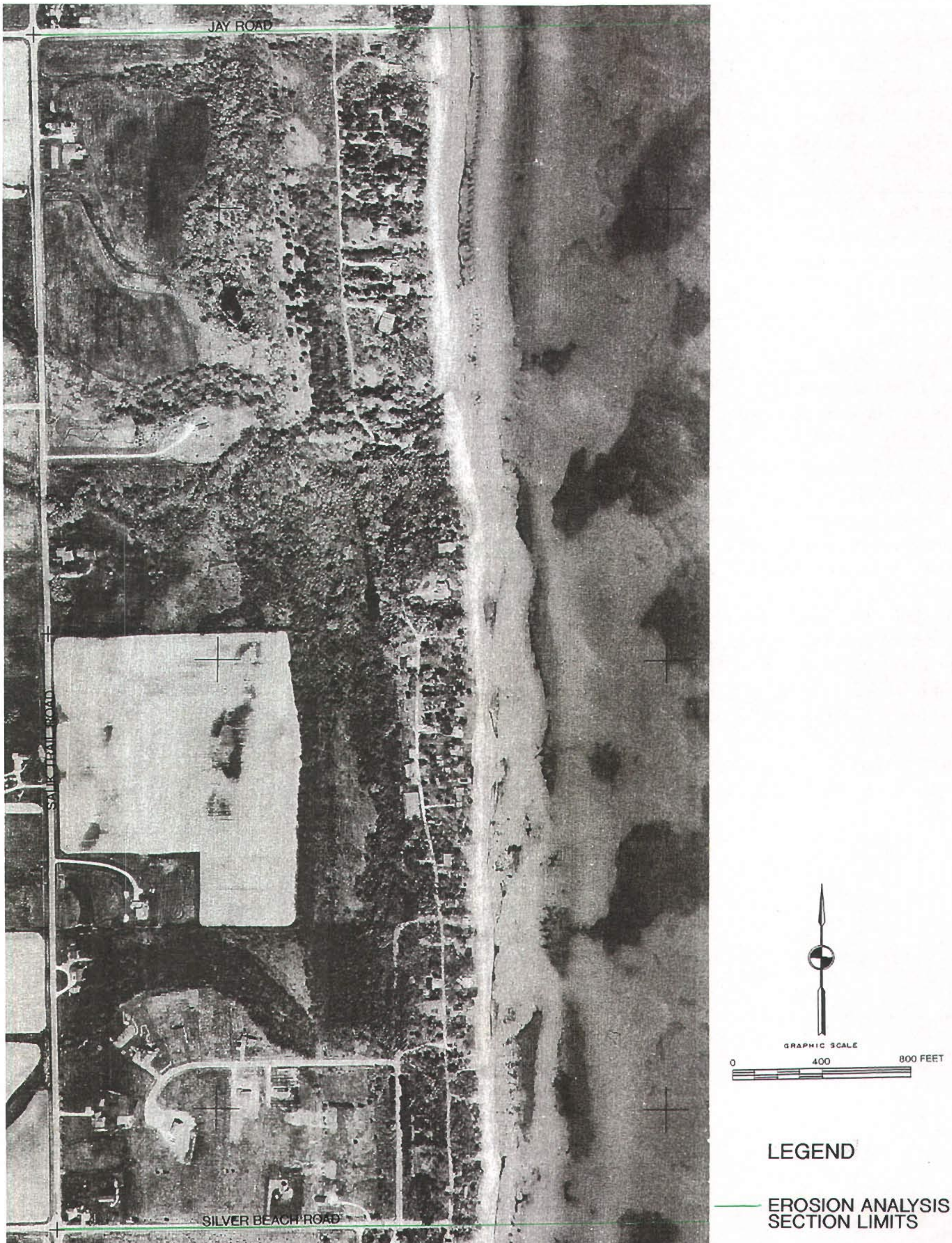


Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

Map 93

SHORELINE EROSION REACH 17: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 7, Township 12 North, Range 23 East
Town of Belgium, Ozaukee County



Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

vations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Section 7 were estimated at five locations. These data indicated a recession of between zero and 90 feet, or between zero and 2.8 feet per year, occurred between 1963 and 1995. Nearly all of that recession appeared to have occurred prior to 1975, with a recession of between five and 20 feet, or between 0.2 and one foot per year, occurring between 1975 and 1995. The highest erosion rate estimates were made in the central portion of the section, while shoreline recession data in the north-central and south-central portions of the section indicated no further recession in these portions of the section between 1975 and 1995.

Although this section was considered stable in 1995, it could experience marked erosion during future periods of higher lake levels. In particular, it should be monitored for flanking of the existing revetments caused by increased erosion of unprotected shoreline areas.

U.S. Public Land Survey Section 6, Township 12 North, Range 23 East, Town of Belgium, Ozaukee County

This shoreline analysis section extends from about Jay Road north to about CTH K at the Ozaukee-Sheboygan county line in the Town of Belgium, as shown on Map 94. The entire shoreline area was occupied by residential land uses, with some undeveloped rural land in the northern portion of the section. In 1995, the beach width in Section 20 ranged from 30 to about 100 feet. The beach in this section entirely fronted a low terrace. Variations in beach width over short distances were common throughout the section, with the changes being controlled largely by the presence of shoreline protection structures. Approximately 50 percent of the terrace fronting this section was covered by shoreline protection structures of various types protecting individual properties. The most common shoreline protection structure in this section was riprap. In this section, the bluff was located well behind the terrace and well back from the shoreline. In 1995, the bluff was completely vegetated and considered to be stable.

No bluff stability analyses were conducted within Section 6 in this study or in the 1977 study.

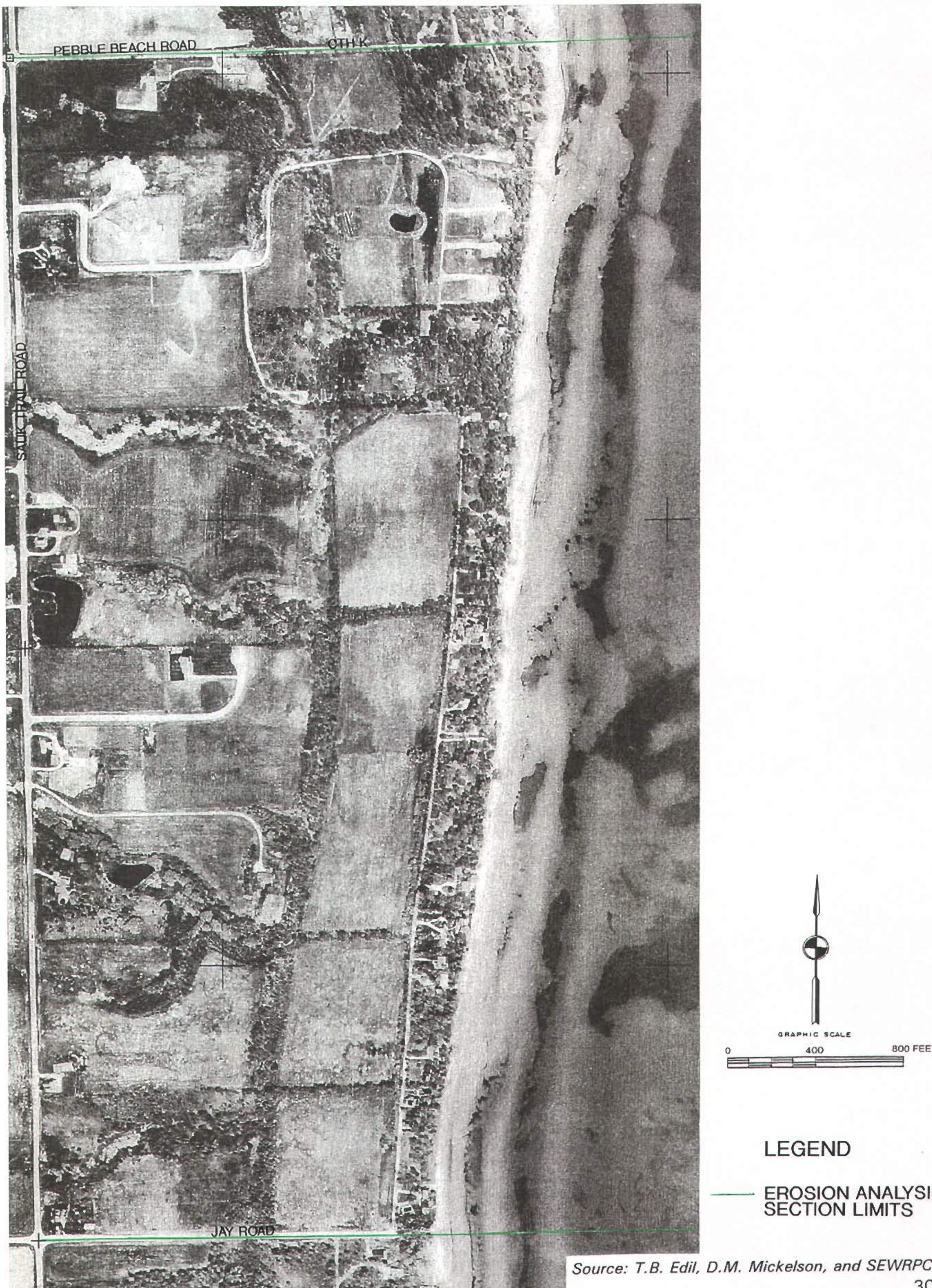
In 1995, the beach materials in the section were noted to be sand and gravel. In the 1977 study, the beach width was reported to be less than 20 feet, and the beach materials were reported to be sand with small amounts of gravelly material. No measurements or observations were made of the nearshore lakebed depth or material at this site in 1995 or in 1976.

Shoreline recession data for Section 6 were estimated at five locations. These data indicated a recession of between 40 and 130 feet, or between 1.2 and 4.1 feet per year, occurred between 1963 and 1995. The data indicated a recession of between zero and 60 feet, or between zero and three feet per year, occurring between 1975 and 1995. In all but the northernmost portion of the section, the data indicated that shoreline recession had been reduced to between zero and 10 feet, or to between zero and 0.5 foot per year between 1975 and 1995. In the northernmost portion of the section, shoreline recession continued, with about 60 feet, or about three feet per year of recession occurring between 1975 and 1995. The highest erosion rate estimates were noted in the northern portion of Section 6. The 1977 study reported a recession rate of 0.2 foot per year for this section.

Map 94

SHORELINE EROSION REACH 17: LOCATION OF BLUFF PROFILES AND EROSION ANALYSIS ZONES

U.S. Public Land Survey Section 6, Township 12 North, Range 23 East
Town of Belgium, Ozaukee County



LEGEND

EROSION ANALYSIS SECTION LIMITS

Source: T.B. Edil, D.M. Mickelson, and SEWRPC.

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Chapter IV

EVALUATION OF ANALYTICAL METHODS FOR PREDICTING LONG-TERM SLOPE STABILITY

INTRODUCTION

As part of this shoreline recession and bluff stability study, historic data on bluff characteristics were collated and new data were collected and analyzed to evaluate the predictive capabilities of four methods for estimating Lake Michigan bluff slope stability. The four methods concerned, together with the findings of the comparative evaluation, are described in a report entitled, *Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline*, dated December 1996, and prepared by Geotechnical Consultants John A. Chapman, Tuncer B. Edil, and David M. Mickelson. Based upon the findings of the evaluation, the aforereferenced report sets forth a recommended methodology to be used for future bluff stability analyses. This chapter briefly summarizes the findings and recommendations of the comparative evaluation as set forth in the aforereferenced December 1996 report.

METHODS OF BLUFF SLOPE STABILITY ANALYSIS

As indicated in Chapter II of this report, bluff slope failure is the result of gravitational forces acting on bluff slope materials to move the materials to a lower elevation along the bluff slope. The ability of the bluff slope to resist failure is the result of a combination of factors including groundwater levels and flows, the shear strength of the bluff slope materials, and the shape of the slope. A mathematical assessment of bluff stability, that is of the forces acting on the bluff and the ability of the bluff to resist failure, is commonly known as a bluff slope stability analyses.

As indicated in Chapter III of this report, bluff slope stability analyses are made using two different types of input data. Under the deterministic approach, a specific set of conditions prevailing at an individual site along the shoreline are used as input data. Under the probabilistic approach, a range of conditions expected to be encountered within a specified portion of the shoreline are used as input data. Both approaches were used in the analyses described in Chapter III, and were comparatively evaluated in the aforereferenced December 1996 report. The four methods evaluated were the Deterministic Bishop's Method; the probabilistic Bishop's Method, termed the Monte Carlo Simulation of Bishop's Method; the Deterministic Infinite Slope Analysis Method; and the probabilistic Infinite Slope Analysis Method, termed the First Order Second Moment Simulation of Infinite Slope Method. The Bishop's Methods were specifically developed for forecasting rotational slides,[1] while the Infinite Slope Methods were deemed to be more appropriate for forecasting shallow failures and translational slides.[2]

All four methods were adapted for computer-based model application. The Bishop's Method calculations were performed using the programs STABL,[3] for the deterministic methodology; and STABLMC,[4] for the probabilistic methodology. The Infinite Slope Method calculations were performed using the programs INSLOPE,[5] based upon the deterministic methodology,

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[1]*Bishop (1956) cited in J.A. Chapman, T.B. Edil, and D.M. Mickelson,* Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline, *University of Wisconsin-Madison, December 1996.*

[2]*A.K. Turner, and R.L. Schuster, "Landslides: Investigation and Mitigation,"* Transportation Research Board Special Report No. 247, *1996.*

[3]*R.A. Siegel,* STABL User Manual, *Joint Highway Research Project Report No. JHRP-75-9, Purdue University and Indiana State Highway Commission, June 1975.*

[4]*P.J. Bosscher, T.B. Edil, and D.M. Mickelson, "Evaluation of Risks of Slope Instability Along a Coastal Reach,"* Proceedings of the Vth International Symposium on Landslides, *A.A. Balkema Publishers, Rotterdam, 1988.*

[5]*A.K. Turner, and R.L. Schuster, op. cit.*

and INSLOPE-FOSM,[6] based upon the first order second moment analytical methodology. All four models were applied using input data collected by the Southeastern Wisconsin Regional Planning Commission for the Lake Michigan shoreline within the Southeastern Wisconsin Region under the current study; in a similar study being conducted by the Bay-Lake Regional Planning Commission of the rest of the Lake Michigan shoreline in Wisconsin; and data collated from studies conducted in 1977[7] and 1988[8] under the State Coastal Management Program and by the Southeastern Wisconsin Regional Planning Commission.

EVALUATION OF BLUFF SLOPE ANALYSIS METHODS

Deterministic Application of Bishop's Method

The Bishop's method of evaluating bluff slope stability is described in detail in the aforereferenced December 1996 report. This particular method of analysis is most applicable to circular-shaped, or rotational, failure surfaces. For each potential failure surface, the resisting forces or strength parameters, such as soil cohesion and friction, and the driving forces, such as the soil mass along the failure surface and pore water pressures, are determined and a corresponding safety factor calculated. The analysis procedure generates and evaluates a number of potential failure surfaces in order to identify the most critical, and the most likely, failure surface. The Bishop method is a "method of slices" procedure, in that the analysis divides a potential sliding mass into a number of vertical sections. The forces exerted in a vertical direction are taken into account, while the difference between the horizontal forces across a section, or between sections, are ignored.

Using shear strengths and stresses, factors of safety are calculated for potential failure surfaces within the bluff. A safety factor is defined as the ratio of the forces resisting shear to the forces promoting shear along the failure surface. Thus, a safety factor less than or equal to 1.0 indicates that the forces promoting failure are greater than or equal to the forces resisting failure. Typically, computer-based applications of this method are used to generate randomly 100 potential failure surfaces and corresponding safety factors for a given bluff site. The 10 failure surfaces with the lowest safety factors are identified and used to derive estimates of bluff stability. In the application of this model to the Lake Michigan shoreline data set, the division between failing and nonfailing bluffs was set at a safety factor of 1.1, as opposed to the theoretical division value of 1.0, in order to include marginally stable bluffs.

Four criteria were used to determine the utility of the Bishop's bluff stability method as a means of determining bluff slope stability along the Lake Michigan shoreline. These criteria were the ability of the model to predict failure, or nonfailure, correctly; the ability of the model to predict the magnitude of failure correctly; the ability of the model to predict the location of a failure on the bluff slope correctly; and the ability of the model to predict the extent of bluff top recession correctly.

Data to evaluate the ability of Bishop's Method to predict bluff slope stability were available for 115 sites. The data needed to evaluate each of the four criteria varies and complete data were not available for all sites. Thus the number of data sets available to assess the models utility for determining bluff slope stability using the deterministic application of Bishop's Method varied for each of the four criteria considered, as set forth in Table 4.

The results of the analyses, set forth in Table 4, indicated that a deterministic application of Bishop's Method correctly predicted the occurrence of failures, failure magnitude, and failure location within a specific profile site in about 70 percent of the cases. The model correctly predicted the extent of the bluff top recession in about 55 percent of the cases.

Probabilistic Application of Bishop's Method

As already noted, the probabilistic application of Bishop's Method of estimating bluff slope stability is referred to as the Monte Carlo Simulation of Bishop's Method. This method calculates a bluff safety factor for a set of conditions which are selected to reflect observed variability in the field data. These sets of conditions include a range of soil strength parameters, soil group interface elevations, soil strata slopes, and groundwater levels.

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[6] *J.T. Christian, "Reliability Methods for Stability of Existing Slopes,"* Proceedings of Uncertainty '96, *Volume 1, American Society of Civil Engineers, 1996.*

[7] *D.M. Mickelson, R. Klauk, L. Acomb, T. Edil, and B. Haas, Wisconsin Coastal Erosion Management Program,* Shore Erosion Study, Technical Report, *1977.*

[8] *SEWRPC Community Assistance Planning Report No. 163,* A Lake Michigan Shoreline Erosion Management Plan for Milwaukee County, Wisconsin, *October 1989.*

Table 4

PREDICTIVE CAPABILITY OF THE DETERMINISTIC BISHOP'S METHOD

Criteria	Percent of Profiles Matching Predictions	Number of Profiles with Available Data
Predict Failure or Nonfailure	68	115
Predict Failure Magnitude	70	94
Predict Failure Location in Slope	79	96
Predict Extent of Bluff Recession	55	91

Source: John A. Chapman, Tuncer B. Edil, and David M. Mickelson, Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline, December 1996.

Under this approach, typically, 25 applications are made of the analytical procedure, each with a different set of input data. The lowest 10 safety factors are identified for each application, resulting in a set of 250 safety factor values per bluff profile. This set of 250 safety factor values and the lowest 25 safety factors values contained within the set of 250 safety factors are then used to characterize the bluff stability condition. The data sets are used to calculate a stability index value, Beta, which is used as a measure of both the bluff stability condition and the bluff critical condition. The Beta index value is defined as the mean value of the respective set of safety factors, minus one, divided by the standard deviation of the respective set of safety factors. Theoretically, values of Beta of less than zero indicate a 50 percent or higher probability of bluff slope failure. However, for the application of this model to the Lake Michigan shoreline data set, the division between failing and nonfailing bluffs was modified by increasing the Beta value to 1.1 for critical conditions, and to 1.8 for unstable conditions. These values were selected based upon a review of recorded observations for bluffs along the Lake Michigan shoreline and the values were found to correlate well with other values used to interpret the results of this model as reported in the literature.

Data to evaluate the ability of the Monte Carlo Simulation of Bishop's Method to predict bluff slope stability were available for 64 sites. The results of the analyses, set forth in Table 5, indicated that a modified probabilistic Bishop's Method correctly predicted the occurrence of failures in about 80 percent of cases. The model was able to predict some translational failures by approximating such failures as shallow rotational slides. When the probabilistic Bishop's Method is used in conjunction with the deterministic Bishop's Method, a more reliable evaluation of bluff slope failure potential is possible, as shown by the data set forth in Table 6. This finding suggests the use of a methodology providing for the application of the deterministic version of Bishop's Method to all applicable sites supplemented by the use of the probabilistic version of Bishop's Method for sites where the findings of the deterministic stability analysis are on the margins of the defined safety factor definitions—that is, where the safety factors are in or near the range of 1.0 to 1.1.

Deterministic Application of Infinite Slope Analysis Method

The Infinite Slope Analysis Method of evaluating bluff slope stability is described in detail in the aforereferenced December 1996 report. This method calculates the bluff safety factor for a failure surface under translational slide phenomenon, based upon soil type, bluff slope angle, and groundwater seepage on or behind the bluff face. The Infinite Slope Analysis Method assumes that the bluff failure occurs in a thin layer with the failure surface parallel to the bluff slope surface. The application of this method results in the calculation of a safety factor similar to that calculated for Bishop's Method. In the application of this model to the Lake Michigan shoreline data set, it was found that the use of average value data acquired from analyses of the major soil groupings present did not properly account for weathering effects when these soils are exposed at the bluff surface. Thus, the model parameters were refined to account for the reduced cohesion typical of weathered soils.

Data to evaluate the ability of the deterministic application of the Infinite Slope Analysis Method to forecast bluff slope stability were available for 115 sites. The

Table 5

PREDICTIVE CAPABILITY OF THE PROBABILISTIC BISHOP'S METHOD

Bluff Condition Present	Percent of Analyses with Correct Predictions		
	Critical Condition Beta = 1.1	Unstable Condition Beta = 1.8	Number of Profiles with Available Data
All Bluffs	81	80	64
Rotationally Failing Bluffs	80	80	15
Translationally Failing Bluffs	78	83	41
Nonfailing Bluffs	100	63	8

Source John A. Chapman, Tuncer B. Edil, and David M. Mickelson, Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline, December 1996.

Table 6

PREDICTIVE CAPABILITY OF THE COMBINED DETERMINISTIC AND PROBABILISTIC BISHOP'S METHOD

Bluff Condition Present	Percent of Analyses with Correct Predictions		
	Critical Condition	Unstable Condition	Number of Profiles with Available Data
All Bluffs	89	88	64
Rotationally Failing Bluffs	87	87	15
Translationally Failing Bluffs	90	93	41
Nonfailing Bluffs	88	63	8

Source: John A. Chapman, Tuncer B. Edil, and David M. Mickelson, Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline, December 1996.

results of the analyses, set forth in Table 7, indicated that the deterministic Infinite Slope Analysis Method correctly predicted the occurrence of failures in about 85 percent of cases.

Probabilistic Application of Infinite Slope Analysis Method

The probabilistic application of the Infinite Slope Analysis Method is referred to as the First Order Second Moment Infinite Slope Analysis Method. This method calculates a probabilistic bluff safety factor for a number of failure surfaces, an array of bluff soils and soil properties, and a range of bluff slopes. The First Order Second Moment Infinite Slope Analysis Method calculated the bluff safety factor for a set of conditions which were selected to reflect potential variability in the field data within a section of the shoreline in a manner similar to that employed in the Monte Carlo Simulation of Bishop's Method. The range of results generated using the First Order Second Moment Infinite Slope Analysis Method are expressed in terms of a statistical variation of the stability index value of Beta, as that index is defined in the Monte Carlo Simulation of Bishop's Method.

Data to evaluate the ability of First Order Second Moment Infinite Slope Analysis Method to forecast bluff slope failure were available for 115 sites. The results of the analyses, set forth in Table 8, indicated that the First Order Second Moment Infinite Slope Analysis Method, like the deterministic Infinite Slope Analysis Method, was sensitive to the affects of weathering on the soil

Table 7

PREDICTIVE CAPABILITY OF THE DETERMINISTIC INFINITE SLOPE ANALYSIS METHOD

Bluff Condition Present	Percent of Analyses with Correct Predictions	Number of Profiles with Available Data
All Bluffs	85	115
Translationally Failing Bluffs	85	74
Shallow Rotationally Failing Bluffs	100	11
Rotationally Failing Bluffs	91	11
Nonfailing Bluffs	56	9

Source: John A. Chapman, Tuncer B. Edil, and David M. Mickelson, Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline, December 1996.

Table 8

PREDICTIVE CAPABILITY OF THE FIRST ORDER SECOND MOMENT INFINITE SLOPE ANALYSIS METHOD

Bluff Condition Present	Percent of Analyses with Correct Predictions		Number of Profiles with Available Data
	Unrefined Soil Cohesion Factor Beta = 0.25	Refined Soil Cohesion Factor Beta = 0.0	
All Bluffs	51	85	115
Translationally Failing Bluffs	49	85	74
Shallow Rotationally Failing Bluffs	45	100	11
Rotationally Failing Bluffs	69	91	11
Nonfailing Bluffs	54	56	9

Source: John A. Chapman, Tuncer B. Edil, and David M. Mickelson, Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline, December 1996.

cohesion characteristics. In the application of this model to the Lake Michigan shoreline data set, using the unrefined soil cohesion properties, the division between failing and nonfailing bluffs was set at a Beta value of 0.25, rather than at the theoretical Beta value of zero. Use of the refined value of Beta of 0.25 and the unrefined soil cohesion properties was found to effectively differentiate between failing and nonfailing conditions in about 50 percent of cases, as shown in Table 8. Using the refined soil cohesion characteristics with a slope stability index value, Beta, of zero increased the ability of the model to correctly predict failure or nonfailure to about 85 percent of cases, as shown in Table 8. Unlike the use of the probabilistic Bishop's Method in conjunction with the deterministic Bishop's Method, use of the First Order Second Moment Infinite Slope Analysis Method with the deterministic Infinite Slope Analysis Method did not result in a more thorough evaluation of bluff slope failure potential.

CONCLUSIONS

Each of the aforedescribed four models were determined to provide reasonably accurate predictions of bluff failure. The Bishop's Method-based models were successful in predicting bluff stability in about 70 percent of cases when used as a deterministic model, and in about 80 percent of cases when used as a probabilistic model. The

Infinite Slope Analysis Method-based models were successful in predicting bluff stability in about 85 percent of cases whether used as a deterministic or as a probabilistic model. When all four models were used to describe the bluff conditions for the specific site or shoreline section, the combined result was successful in predicting the stability of the bluff slope in about 90 percent of cases. It may be further concluded that the Bishop's Method should be used where rotational failures are expected, and the Infinite Slope Analysis Method should be used when shallow failures, or translational failures, are expected. In the case of the Bishop's Method, the best results can be expected when the probabilistic method is used to supplement the deterministic analyses in cases where the calculated safety factor values are within the margins of the defined stability criteria. In contrast, the use of the probabilistic application of the Infinite Slope Analysis Method does not appear to result in more accurate predictions if used to supplement the deterministic application of that model.

Chapter V

SUMMARY AND CONCLUSIONS

INTRODUCTION

Shoreline erosion and bluff stability conditions are important considerations in planning for the protection and sound development and redevelopment of lands located along the Lake Michigan shoreline. Shoreline erosion and bluff stability conditions in Southeastern Wisconsin were surveyed in 1977,[1] and subsequently in Racine County in 1978[2] and 1982,[3] and in Milwaukee County in 1989.[4] Because such conditions can change over time, the Wisconsin Department of Administration, the Southeastern Wisconsin Regional Planning Commission, and the Bay-Lake Regional Planning Commission in August 1994 proposed the conduct of a study of current shoreline erosion and bluff stability conditions along the Lake Michigan shoreline. The planning effort, prepared in part with funding from Wisconsin Coastal Management Program and conducted between November 1994 through December 1996, included an inventory of the current bluff stability and shoreline erosion conditions, and a comparison of those conditions to the historic conditions found in the earlier studies. This report documents the findings and recommendations of the inventories and analyses undertaken within the four coastal counties of Southeastern Wisconsin—Kenosha, Racine, Milwaukee, and Ozaukee Counties—and complements a similar study undertaken by the Bay-Lake Regional Planning Commission for the Lake Michigan coastal counties of Wisconsin lying north of Ozaukee County. Together these two reports provide valuable technical data intended to be used in the definition of, and in the development of solutions to, costly problems associated with shoreline erosion, bluff recession, and storm damage along the Lake Michigan shoreline.

The Lake Michigan coastal erosion and bluff stability study area in Southeastern Wisconsin consisted of the lands along the Lake Michigan shoreline in Kenosha, Racine, Milwaukee, and Ozaukee Counties that directly affect, or are directly affected by shoreline erosion, bluff recession, and storm damage processes. This relatively narrow strip of land along the Lake Michigan shoreline extends approximately 77 miles from the Wisconsin-Illinois state line to the Ozaukee-Sheboygan county line. For analytical purposes, the Lake Michigan shoreline was divided into 17 reaches, as shown on Map 95. These reaches were selected so as to have relatively uniform beach and bluff characteristics. These reaches generally correspond to those utilized in the aforereferenced 1977 shoreline erosion study, with some refinement to reflect current conditions.

Erosion of the Lake Michigan shoreline is an essentially natural process. However, human activities can influence this process, causing erosion to accelerate or decelerate. Various factors contribute to bluff and beach erosion, including broader indirect factors such as climate and lake levels, as well as the direct factors, such as wave action, groundwater seepage, stormwater runoff rates and volumes of flow, freeze-thaw action, lake ice movement, the type of bluff and beach material, and the type of vegetative cover. Because bluff zone erosion, beach zone erosion, and shoreline recession processes often differ, they are considered separately herein.

Bluff Erosion

While some Lake Michigan bluffs do incorporate bedrock formations within their structure, making them extremely resistant to the erosive forces of wind, waves and runoff, the Lake Michigan bluffs in Southeastern

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[1] *D.M. Mickelson, L. Acomb, N. Brouwer, T. Edil, C. Fricke, B. Haas, D. Hadley, C. Hess, R. Klauk, N. Lasca, and A.F. Schneider, Shore Erosion Study, Technical Report,* Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin, *Wisconsin Coastal Management Program, February 1977.*

[2] *J.P. Keillor and R. DeGroot,* Recent Recession of Lake Michigan Shorelines in Racine County, Wisconsin, *University of Wisconsin Sea Grant Program, 1978.*

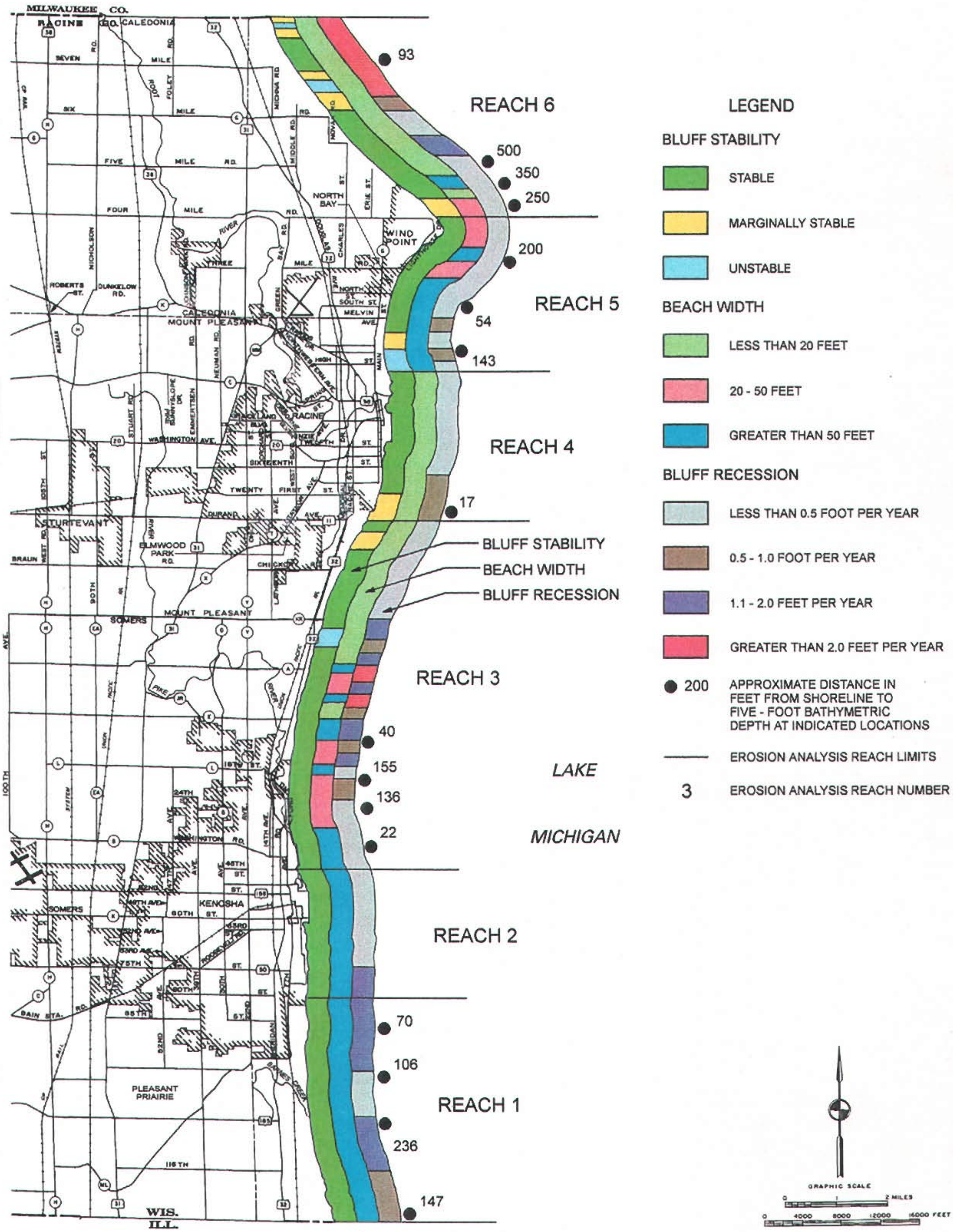
[3] *SEWRPC Community Assistance Planning Report No. 86,* A Lake Michigan Coastal Erosion Management Study for Racine County, Wisconsin, *October 1982.*

[4] *SEWRPC Community Assistance Planning Report No. 163,* A Lake Michigan Shoreline Erosion Management Plan for Milwaukee County, Wisconsin, *October 1989.*

Map 95

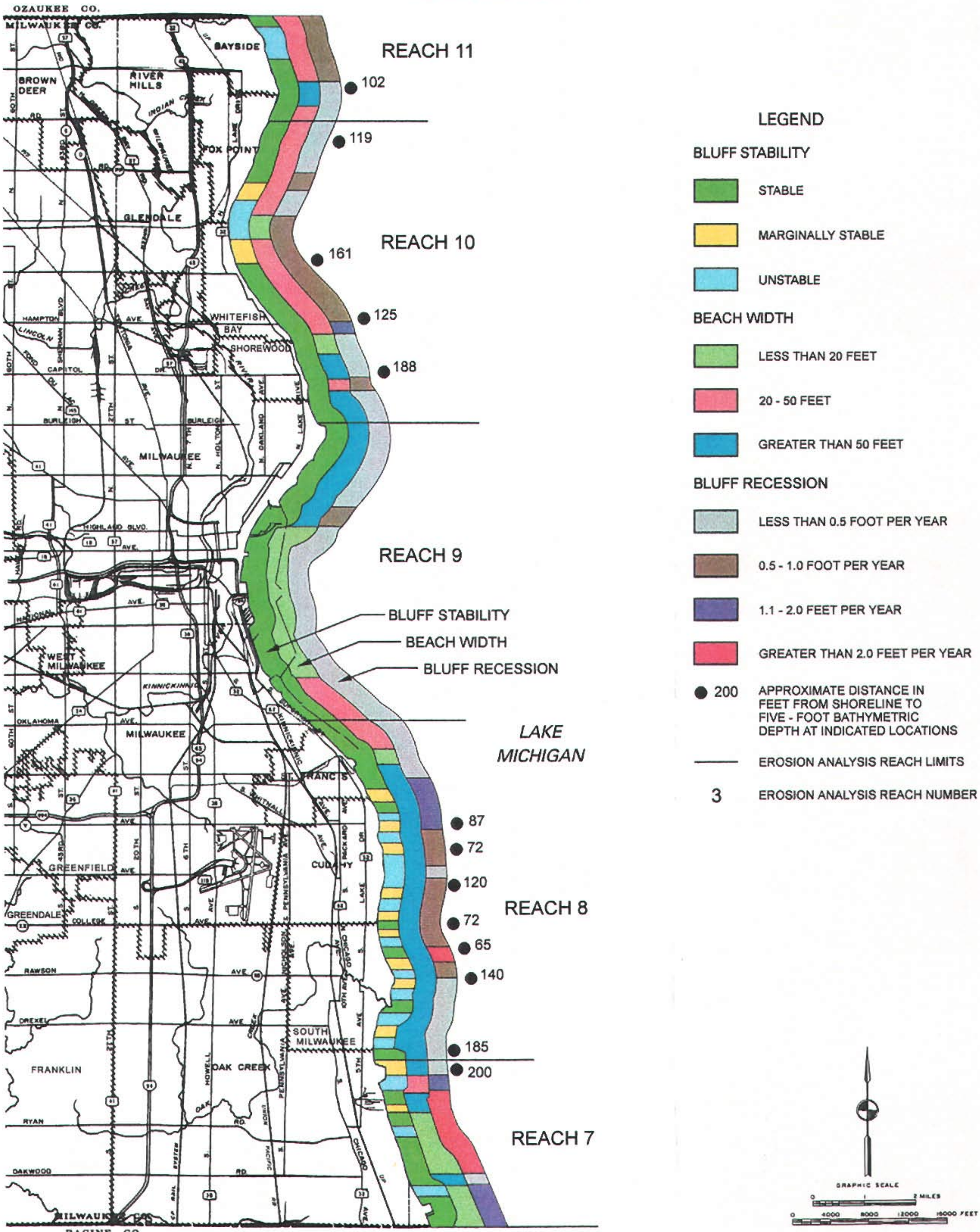
SUMMARY OF LAKE MICHIGAN SHORELINE EROSION AND BLUFF STABILITY ANALYSES IN SOUTHEASTERN WISCONSIN: 1995

KENOSHA AND RACINE COUNTIES



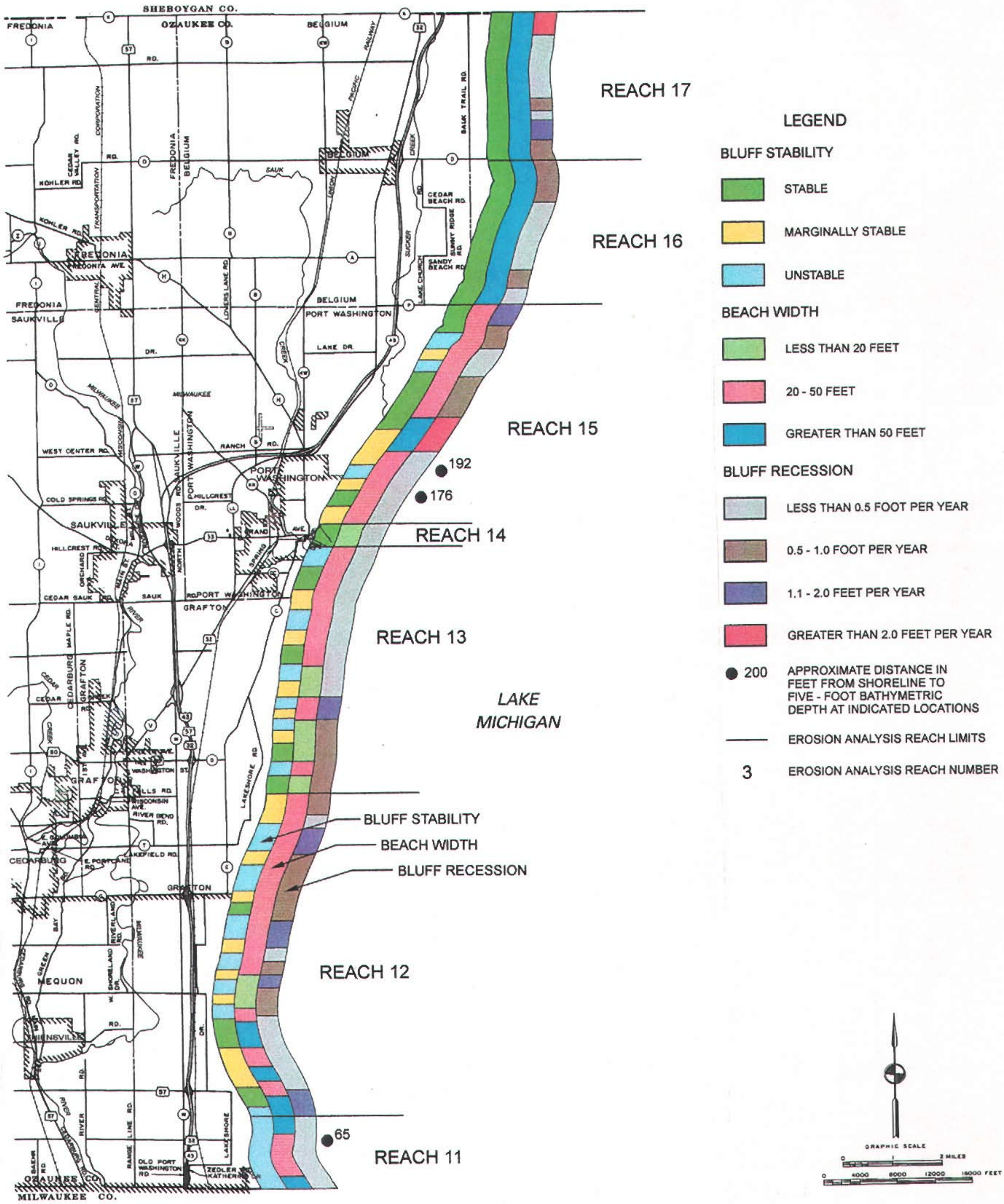
Map 95 (continued)

MILWAUKEE COUNTY



Map 95 (continued)

OZAUKEE COUNTY



Source: T.B. Edil, D.M. Mickelson, J.A. Chapman, and SEWRPC.

Wisconsin are composed of unconsolidated sediments, primarily sands, silts, and clays that tend to slough off in shallow layers and also in deep slips. Bluff erosion occurs in the form of toe erosion, slumping, sliding, flow, surface erosion, and solifluction, resulting in the intermittent recession of the bluff, as illustrated in Figure 5.

Two forms of slides are common along the Southeastern Wisconsin shoreline: translational slides, and rotational slides or slumps. Translational slides involve a surface layer several inches to a few feet thick, sliding parallel to the face of the slope. Translational slides can occur either rapidly or slowly. Rotational slides, in contrast, often involve the slumping, or sliding, of a fairly large mass along a curved surface. The slide mass rotates, and often the top of the slump block is tilted back toward the slope face. Slumps usually take place suddenly and can cause extensive damage since they can result in a large recession of the bluff.

Flows occur when large amounts of water are present and the soil mass actually moves like a viscous fluid. Flows also occur when intense rains saturate the surface layer of soil, in the spring as intergranular ice melts near the soil surface, or where groundwater discharges along the bluff face through layers of silt or fine sand. If these more permeable soil layers are located between less permeable clay layers, removal of sediment by flow due to groundwater seepage, referred to as sapping, can occur. Solifluction, related to flow, is caused by freeze-thaw activity.

Sheet wash and rill and gully erosion result from surface water runoff flowing over the top of the bluff, and over the slope face itself. Sheet wash is the unconfined flow of water over the soil surface during and following a rainfall. Rills and gullies are formed by the channelized flow of water over the soil surface. Rill and gully formation tends to follow zones of weakness established by desiccation, cracking, and differences in soil expansion due to the cycles of freezing and thawing and wetting and drying. These activities remove soil from bluffs.

On most slopes which are undisturbed by human activities, and where waves are not eroding the base of the slope, an equilibrium between the forces acting to move material down the slope and the resistance of the materials in the slope to those forces is established over a relatively long period of time.

Beach Erosion

Beaches in the Region are composed primarily of mixtures of sand and gravel, with scattered deposits of pure sand and gravel in places. The clays and silts that form part of the terrestrial soils tend to be washed out and carried in the littoral drift into the nearshore zone, where they are deposited offshore. Figure 7 illustrates a typical beach profile in the Lake Michigan coastal zone, including the gently sloping back shore area consisting of one or more horizontal berms and the more active, slightly more steeply sloped foreshore area exposed to wind and wave action. Given the soil and erosion characteristics associated with the Lake Michigan coastal zone, the steeper slopes are usually comprised of coarse gravels, while the more gently sloping areas are comprised of sand and fine gravels.

Beach materials, and hence the appearance of the beach, are in a constant state of flux, especially in the foreshore zone where wave action and return flows are constantly moving materials shoreward and lakeward. Storm events, which produce high, steep waves along the Southeastern Wisconsin coast, tend to be erosive in nature, while the small waves occurring between storms tend to build beaches.

Shoreline Recession

Shore land loss is the result of beach and bluff erosion processes, wherein wave and wind action gradually remove shoreline materials lakeward where they may be transported offshore or longshore by lake currents. As already noted above, shoreline recession is related to a number of factors affecting the bluff and beach stability, particularly including lake levels, with higher lake levels exposing unprotected portions of the shoreline to erosive processes. Offshore conditions, including depth, materials, and the presence of offshore structures, such as sandbars, is also an important factor with the lack of sandbars and beaches, and steeper offshore conditions resulting in increased wave forces and associated erosion.

INVENTORY AND ANALYSIS PROCEDURES

The bluff stability and shoreline erosion characteristics of each shoreline reach were determined under this study through analysis of inventory data collected on bluff and beach characteristics. These data were collected at carefully selected shoreline locations which had previously been surveyed under the aforereferenced earlier shoreline erosion and bluff stability studies. These data were collected by aerial photographic interpretation using comparable Commission one inch equals 400 feet scale vertical ratioed and rectified aerial photographs taken in 1963, 1970, 1975, and 1995. All of the photographs were prepared to Regional Planning Commission specifications, utilizing the Commission horizontal survey control network. The vertical aerial photographs were supplemented by oblique aerial photographs taken by Dr. Tuncer B. Edil, P.E., during May of 1994 of the entire Lake Michigan shoreline in Southeastern Wisconsin, excepting the most southerly portion of Kenosha County which does not have sizable bluffs; and large-scale topographic maps, with two-foot contour intervals, compiled between 1976 and 1993, for all of the shoreline except Ozaukee County, north of the City of Mequon. In addition, substantial field survey data was gathered under the study during 1995.

As previously noted, the results of the current 1995 study are compared to the data presented in the aforereferenced 1977[5] and 1989[6] studies. For purposes of this summary chapter, the data and results of the analyses reported in the 1977 study are uniformly referenced as the "1977" data even though the field work and aerial photography used in that study had base years of 1975 and 1976. Furthermore, the data and results of the analyses reported in the 1989 study are uniformly referenced as "1989" data even though the field work and aerial photography used in that study were undertaken in 1982, 1985, 1986, and 1987. Likewise, the data and results of the analyses reported in the current 1995 study are uniformly referenced as "1995" data.

Bluff Characteristics

During 1995, field surveys were conducted to measure the geometry of the bluff slope at 192 sites, the general locations of which are set forth in Table 9. These measurements provided a basis for site-specific assessments of the bluff conditions at the selected locations. The 1995 field observations were conducted by a field survey party which reoccupied the 1977 and selected 1982 and 1987 bluff profile sites wherever possible. Bluff profiles were measured using a 100-foot steel tape and inclinometer. Slope segments were documented as to the nature and extent of vegetative cover on the bluff face, the type of bluff materials on the face of the bluff where the bluff face was exposed, the types of failures, and the amount of horizontal recession of the bluff top, if any were evident.

Calculations of bluff stability factors were made for specific sets of conditions prevailing at individual sites within the shoreline—the deterministic approach—or for more general sets of conditions prevailing within a specified portion of the shoreline—the probabilistic approach. The methods used were the Deterministic Bishop's Method and the Monte Carlo Simulation of Bishop's Method. The Bishop's Method calculations were performed by the computer programs STABL,[7] based upon the deterministic methodology, and STABLMC,[8] based upon the probabilistic methodology. Bishop's Method was specifically developed for forecasting rotational slides. However, it does, in some cases, provide information relating to translational slides when such slides are similar to shallow rotational movements.[9]

For purposes of this study, the ranges of values adopted in the aforereferenced 1977 and 1989 studies for interpreting the results of the deterministic bluff safety analyses were used. The bluff was considered to be unstable when the safety factor was less than 1.0; marginally stable when the safety factor was between 1.0 through 1.1; and, stable when the safety factor was greater than 1.1.

Likewise, in terms of the probabilistic bluff stability analysis, for purposes of this study, the ranges of values adopted in the aforereferenced 1989 study were used. The bluff was considered to be unstable when more than 75 percent of the set of 25 most critical conditions, including the lowest safety factors was less than 1.0, and more than 50 percent of the 250 conditions, including the 10 lowest safety factors, was less than 1.0; marginally stable when between 25 and 75 percent of the set of 25 most critical conditions considered was less than 1.0, and between 10 and 50 percent of the 250 conditions considered was less than 1.0; and stable when less than

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[5] *D.M. Mickelson et al., 1977, op. cit.*

[6] *SEWRPC Community Assistance Planning Report No. 163, op. cit.*

[7] *R.A. Siegel,* STABL User Manual, *Joint Highway Research Project, Purdue University and the Indiana State Highway Commission, JHRP-75-9, June 1975.*

[8] *P.J. Bosscher, T.B. Edil, and D.M. Mickelson, "Evaluation of Risks of Slope Instability Along a Coastal Reach,"* Proceedings of the Vth International Symposium on Landslides, *A.A. Balkema Publishers, Rotterdam, 1988.*

[9] *J.A. Chapman, T.B. Edil, and D.M. Mickelson,* Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline, *University of Wisconsin-Madison, December 1996.*

Table 9

SUMMARY OF LAKE MICHIGAN SHORE BLUFF STABILITY FACTORS IN SOUTHEASTERN WISCONSIN: 1995

County	Shoreline Analysis Reach by U.S. Public Land Survey Town, Range, and Section	1995 Profile Site	Corresponding Profile Number from Previous Studies	Deterministic Bluff Stability Safety Factor	
				1995 Conditions	1977 Study[a] Conditions Unless Noted
Kenosha	Reach 3				
	T2N, R23E, Section 30	3-1	76-2	5.55	>1.25
	T2N, R23E, Section 19	3-2	76-4	3.25	0.21
	T2N, R23E, Section 19	3-3	76-3	3.14	0.51
	T2N, R23E, Section 19	3-4	76-2	1.84	0.54
	T2N, R23E, Section 19	3-5	76-1	3.26	0.46
	T2N, R23E, Section 18	3-6	76-4	1.88	- -
	T2N, R23E, Section 18	3-7	76-2	2.31	- -
	T2N, R23E, Section 18	3-8	76-2	2.09	- -
	T2N, R23E, Section 8	3-9	76-3	2.19	0.82
	T2N, R23E, Section 8	3-10	76-2	1.99	0.94
	T2N, R23E, Section. 8	3-11	76-1	1.48	0.94
	T2N, R23E, Section 5	3-12	76-3	1.18	0.57
	T2N, R23E, Section 5	3-13	76-2	0.72	0.72
	T2N, R23E, Section 5	3-14	76-1	1.37	0.47
Racine	Reach 3				
	T3N, R23E, Section 32	3-15	76-3	1.68	0.41
	T3N, R23E, Section 32	3-16	76-2	1.37	0.49
	T3N, R23E, Section 29	3-17	76-4	1.25	0.63
	T3N, R23E, Section 28	3-18	76-3	1.23	0.56
	T3N, R23E, Section 28	3-19	76-1	1.00	0.70
	T3N, R23E, Section 28	3-20	76-2	0.79	0.54
	Reach 4				
	T4N, R23E, Section 21	4-1	76-1	0.87	0.88
	T4N, R23E, Section 21	4-2	76-2	1.55	0.57
	Reach5				
	T4N, R23E, Section 4	5-1	76-2	1.00	1.00
	T4N, R23E ,Section 4	5-2	76-1	1.09	1.00
	T4N, R23E, Section 33	5-3	76-1	1.65	0.89
	T4N, R23E, Section 33	5-4	76-2	1.74	0.85
	T4N, R23E, Section 27	5-5	76-3	1.70	0.83
	T4N, R23E, Section 27	5-6	76-2	1.49	0.57
	T4N, R23E, Section 27	5-7	76-1	2.51	0.70
	Reach 6				
	T4N, R23E, Section 22	6-1	76-2	0.91	3.10
	T4N, R23E, Section 21	6-2	76-1	3.30	2.80
	T4N, R23E, Section 16	6-3	76-4	1.70	0.49
	T4N, R23E, Section 16	6-4	76-3	1.45	0.66
	T4N, R23E, Section 16	6-5	82-3	0.93	- -
	T4N, R23E, Section 16	6-6	82-4	0.93	- -
	T4N, R23E, Section 16	6-7	76-2	0.97	0.41
	T4N, R23E, Section 17	6-8	82-5	0.98	- -
	T4N, R23E, Section 17	6-9	82-6	1.53	- -
	T4N, R23E, Section 17	6-10	82-7	1.38	- -
	T4N, R23E, Section 17	6-11	76-1	1.25	0.94
	T4N, R23E, Section 8	6-12	76-1	2.38	1.62
	T4N, R23E, Section 8	6-13	82-8	1.84	- -
	T4N, R23E, Section 8	6-14	76-2	2.17	1.68[b]
	T4N, R23E, Section 8	6-15	82-9	1.46	- -
	T4N, R23E, Section 8	6-16	76-3	0.89	0.55
	T4N, R23E, Section 7	6-17	76-4	0.44	0.49
	T4N, R23E, Section 6	6-18	76-2	0.99	1.23
	T4N, R23E, Section 6	6-19	76-1	1.05	1.20

Table 9 (continued)

County	Shoreline Analysis Reach by U.S. Public Land Survey Town, Range, and Section	1995 Profile Site	Corresponding Profile Number from Previous Studies	Deterministic Bluff Stability Safety Factor	
				1995 Conditions	1977 Study[a] Conditions Unless Noted
Milwaukee	Reach 7				
	T5N, R23E, Section 31	7-1	87-1	1.59	1.00[c]
	T5N, R23E, Section 31	7-2	95-1	1.59	- -
	T5N, R23E, Section 31	7-3	76-3	1.17	1.38
	T5N, R23E, Section 31	7-4	76-2	1.50	0.81
	T5N, R23E, Section 31	7-5	87-2	1.55	1.43[c]
	T5N, R22E, Section 36	7-6	76-1	0.92	0.96
	T5N, R22E, Section 36	7-7	87-3	1.50	1.18[c]
	T5N, R22E, Section 24	7-8	76-1	0.99	0.54
	T5N, R22E, Section 24	7-9	87-10	1.47	0.86[c]
	T5N, R22E, Section 24	7-10	87-11	0.80	0.87[c]
	T5N, R22E, Section 24	7-11	87-13	1.00	0.92[c]
	T5N, R22E, Section 24	7-12	76-2	1.29	0.57
	T5N, R22E, Section 24	7-13	87-14	0.80	0.92[c]
	T5N, R22E, Section 24	7-14	76-3	0.97	0.54
	Reach 8				
	T5N, R22E, Section 13	8-1	87-15	1.84	1.48[c]
	T5N, R22E, Section 13	8-2	87-17	0.86	0.74[c]
	T5N, R22E, Section 13	8-3	76-1	0.74	0.38
	T5N, R22E, Section 13	8-4	87-18	0.89	0.74[c]
	T5N, R22E, Section 13	8-5	87-19	1.07	1.13[c]
	T5N, R22E, Section 13	8-6	76-2	0.87	0.34
	T5N, R22E, Section 13	8-7	87-20	0.81	0.78[c]
	T5N, R22E, Section 12	8-8	87-21	1.17	1.25[c]
	T5N, R22E, Section 12	8-9	87-22	0.84	0.91[c]
	T5N, R22E, Section 12	8-10	76-1	0.93	0.78
	T5N, R22E, Section 12	8-11	76-2	0.77	0.82
	T5N, R22E, Section 12	8-12	87-24	0.98	0.83[c]
	T5N, R22E, Section 1	8-13	87-25	1.09	0.92[c]
	T5N, R22E, Section 1	8-14	76-1	1.19	0.40
	T5N, R22E, Section 1	8-15	76-2	0.81	0.51
	T5N, R22E, Section 1	8-16	87-27	1.07	1.23[c]
	T5N, R22E, Section 1	8-17	87-28	1.21	0.86[c]
	T5N, R22E, Section 1	8-18	76-3	0.98	0.40
	T6N, R22E, Section 36	8-19	76-1	1.04	0.50
	T6N, R22E, Section 36	8-20	87-30	0.83	1.69[c]
	T6N, R22E, Section 36	8-21	87-31	0.76	0.71[c]
	T6N, R22E, Section 36	8-22	76-3	1.00	1.19
	T6N, R22E, Section 36	8-23	87-32	0.95	0.72[c]
	T6N, R22E, Section 36	8-24	76-2	0.90	0.54
	T6N, R22E, Section 36	8-25	87-33	0.79	0.65[c]
	T6N, R22E, Section 25	8-26	76-1	0.91	0.33
	T6N, R22E, Section 25	8-27	76-2	0.83	0.68
	T6N, R22E, Section 25	8-28	87-35	0.95	0.82[c]
	T6N, R22E, Section 25	8-29	76-3	0.82	0.49
	T6N, R22E, Section 25	8-30	76-4	0.74	0.88
	T6N, R22E, Section 25	8-31	87-37	0.94	1.21[c]
	T6N, R22E, Section 24	8-32	87-38	0.80	1.02[c]
	T6N, R22E, Section 24	8-33	87-39	1.12	0.74[c]
	T6N, R22E, Section 24	8-34	76-1	0.96	0.60
	T6N, R22E, Section 24	8-35	87-40	1.04	0.93[c]
	T6N, R22E, Section 14	8-36	87-46	1.80	1.17[c]
	T6N, R22E, Section 14	8-37	87-47	1.95	1.33[c]
	T6N, R22E, Section 14	8-38	87-48	0.90	0.85[c]
	T6N, R22E, Section 14	8-39	87-50	1.01	0.81[c]
	T6N, R22E, Section 14	8-40	87-52	1.13	0.99[c]
	T6N, R22E, Section 14	8-41	87-54	0.97	1.17[c]
	Reach 9				
	T6N, R22E, Section 10	9-1	87-56	2.40	1.21[c]

Table 9 (continued)

County	Shoreline Analysis Reach by U.S. Public Land Survey Town, Range, and Section	1995 Profile Site	Corresponding Profile Number from Previous Studies	Deterministic Bluff Stability Safety Factor	
				1995 Conditions	1977 Study[a] Conditions Unless Noted
Milwaukee (continued)	Reach 10				
	T7N, R22E, Section 10	10-1	87-58	1.27	2.97[c]
	T7N, R22E, Section 3	10-2	76-1	1.13	0.76
	T7N, R22E, Section 3	10-3	76-2	1.39	1.20
	T7N, R22E, Section 3	10-4	76-3	1.27	0.69
	T7N, R22E, Section 3	10-5	76-4	1.62	0.46
	T8N, R22E, Section 34	10-6	76-1	1.36	0.46
	T8N, R22E, Section 33	10-7	76-2	1.26	1.00
	T8N, R22E, Section 33	10-8	76-3	1.26	0.78
	T8N, R22E, Section 28	10-9	76-1	1.00	0.79
	T8N, R22E, Section 28	10-10	76-3	0.95	0.93
	T8N, R22E, Section 28	10-11	76-5	1.01	0.83
	T8N, R22E, Section 21	10-12	76-3	0.98	0.45
	T8N, R22E, Section 21	10-13	76-4	1.02	1.10
	T8N, R22E, Section 16	10-14	76-1	1.52	- -
	Reach 11				
	T8N, R22E, Section 10	11-1	82-10	1.86	1.22[b]
	T8N, R22E, Section 10	11-2	76-1	2.34	1.39
	T8N, R22E, Section 4	11-3	87-101	1.39	1.71[c]
	T8N, R22E, Section 4	11-4	87-103	1.07	0.85[c]
Ozaukee	Reach 11				
	T9N, R22E, Section 33	11-5	82-1	0.72	- -
	T9N, R22E, Section 33	11-6	76-2	1.12	1.03
	T9N, R22E, Section 33	11-7	76-3	0.74	1.13
	T9N, R22E, Section 28	11-8	76-3	0.77	0.80
	T9N, R22E, Section 28	11-9	76-2	0.69	0.69
	Reach 12				
	T9N, R22E, Section 28	12-1	82-3	0.57	- -
	T9N, R22E, Section 28	12-2	76-1	0.59	0.68
	T9N, R22E, Section 21	12-3	76-1	1.00	1.05
	T9N, R22E, Section 21	12-4	82-4	0.95	- -
	T9N, R22E, Section 21	12-5	76-2	1.03	0.86
	T9N, R22E, Section 17	12-6	76-1	1.08	1.00
	T9N, R22E, Section 17	12-7	82-5	1.16	- -
	T9N, R22E, Section 17	12-8	76-2	1.48	0.89
	T9N, R22E, Section 17	12-9	76-3	1.40	0.94
	T9N, R22E, Section 8	12-10	76-1	0.67	0.96
	T9N, R23E, Section 8	12-11	95-1	1.11	- -
	T9N, R23E, Section 8	12-12	76-2	0.78	0.71
	T9N, R23E, Section 8	12-13	82-6	1.11	- -
	T9N, R23E, Section 8	12-14	76-3	0.59	0.78
	T9N, R23E, Section 8	12-15	76-1	0.96	0.85
	T9N, R23E, Section 8	12-16	76-2	0.63	0.66
	T9N, R23E, Section 8	12-17	76-3	0.76	0.68
	T10N, R22E, Section 33	12-18	76-1	1.88	0.98
	T10N, R22E, Section 33	12-19	76-2	1.11	0.65
	T10N, R22E, Section 33	12-20	82-20	1.01	- -
	T10N, R22E, Section 33	12-21	76-3	0.94	0.92
	T10N, R22E, Section 28	12-22	76-1	1.02	0.85
	T10N, R22E, Section 28	12-23	76-2	0.70	0.96
	T10N, R22E, Section 28	12-24	76-3	0.84	0.83
	T10N, R22E, Section 28	12-25	82-9	1.09	- -
	Reach 13				
	T10N, R22E, Section 21	13-1	76-1	1.32	0.59
	T10N, R22E, Section 21	13-2	76-2	0.83	0.82
	T10N, R22E, Section 21	13-3	76-3	1.81	0.75
	T10N, R22E, Section 16	13-4	76-1	1.00	0.59
	T10N, R22E, Section 16	13-5	76-2	0.73	0.65
	T10N, R22E, Section 16	13-6	82-15	0.81	- -

Table 9 (continued)

County	Shoreline Analysis Reach by U.S. Public Land Survey Town, Range, and Section	1995 Profile Site	Corresponding Profile Number from Previous Studies	Deterministic Bluff Stability Safety Factor	
				1995 Conditions	1977 Study[a] Conditions Unless Noted
Ozaukee (continued)	Reach 13 (continued)				
	T10N, R22E, Section 10	13-7	76-1	0.99	0.59
	T10N, R22E, Section 10	13-8	76-2	0.59	0.79
	T10N, R22E, Section 10	13-9	76-3	1.01	0.69
	T10N, R22E, Section 3	13-10	76-1	0.75	0.52
	T10N, R22E, Section 3	13-11	76-2	1.19	0.49
	T10N, R22E, Section 3	13-12	82-14	1.01	- -
	T10N, R22E, Section 3	13-13	76-3	1.03	0.51
	T10N, R22E, Section 3	13-14	82-13	0.88	- -
	T11N, R22E, Section 33	13-15	76-1	0.88	0.62
	T11N, R22E, Section 33	13-16	82-12	1.00	- -
	T11N, R22E, Section 33	13-17	76-2	1.16	0.81
	T11N, R22E, Section 33	13-18	82-11	0.88	- -
	Reach 15				
	T11N, R22E, Section 33	15-1	80-1	1.07	- -
	T11N, R23E, Section 28	15-2	80-2	1.17	- -
	T11N, R23E, Section 28	15-3	80-3	1.18	- -
	T11N, R23E, Section 28	15-4	76-1	0.97	1.21
	T11N, R23E, Section 21	15-5	82-17	0.92	- -
	T11N, R23E, Section 21	15-6	76-1	0.72	0.61
	T11N, R23E, Section 22	15-7	76-2	1.02	1.70
	T11N, R23E, Section 15	15-8	76-1	1.32	1.04
	T11N, R23E, Section 14	15-9	76-3	1.36	0.90
	T11N, R23E, Section 11	15-10	76-1	1.10	1.09
	T11N, R23E, Section 11	15-11	76-2	0.95	0.99
	T11N, R23E, Section 11	15-12	76-3	0.92	0.91
	T11N, R23E, Section 11	15-13	76-4	1.23	1.00
	T11N, R23E, Section 2	15-14	76-2	1.47	- -

[a] *1977 conditions are set forth in Mickelson et al., Shore Erosion Study, Technical Report, Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin.*

[b] *Indicates 1982 conditions of profile site reported in SEWRPC Community Assistance Planning Report No. 86, A Lake Michigan Coastal Erosion Management Study for Racine County, Wisconsin.*

[c] *Indicates 1987 conditions of profile site reported in SEWRPC Community Assistance Planning Report No. 163, A Lake Michigan Shoreline Erosion Management Plan for Milwaukee County, Wisconsin.*

Source: J.A. Chapman, T.B. Edil, D.M. Mickelson, and SEWRPC.

25 percent of the set of 25 most critical conditions considered was less than 1.0, and less than 10 percent of the 250 conditions considered was less than 1.0.

The results of the bluff stability calculations are set forth in Table 9, together with the corresponding value of the bluff safety factor determined in the previous studies. The probabilistic calculations were only performed to elucidate marginally stable conditions as identified by the deterministic analyses. The results of these calculations are set forth in Table 10.

Beach and Nearshore Lakebed Characteristics

Beach width was measured at each profile site. In addition, for 33 selected sites, the distance from the shore lakeward to a water depth of five feet was also measured for comparison with the 1977 study findings. Observations were also made on the predominant type of existing offshore bottom materials.

The results of the beach width and nearshore lakebed observations are set forth in Tables 11 and 12, together with the corresponding values of the beach widths and nearshore bathymetry determined in the previous study.

Beach width and nearshore conditions are highly variable, both seasonally and from year to year with changes in water levels. As noted in Chapter II, in 1976, the year in which the field surveys reported in the 1977 study were made, the average annual Lake Michigan

Table 10

SUMMARY OF DETERMINISTIC AND PROBABILISTIC SLOPE STABILITY ANALYSIS RESULTS FOR ROTATIONAL SLIDING

			Deterministic Analysis[a]	Probabilistic Analysis[a]			
County	Shoreline Analysis Reach by U.S. Public Land Survey Town, Range, and Section	1995 Profile Site	Safety Factor	Range of Safety Factors	Percent of 250 Safety Factors Conducted <1.0	Percent of 25 Lowest Safety Factors Conducted <1.0	Model-Indicated Stability Classification of Section[b]
Kenosha	Reach 3						
	T2N, R23E, Section 30	3-1	5.55	- -	- -	- -	S
	T2N, R23E, Section 19	3-2	3.25	- -	- -	- -	S
	T2N, R23E, Section 19	3-3	3.14	- -	- -	- -	S
	T2N, R23E, Section 19	3-4	1.84	- -	- -	- -	S
	T2N, R23E, Section 19	3-5	3.26	- -	- -	- -	S
	T2N, R23E, Section 18	3-6	1.88	- -	- -	- -	S
	T2N, R23E, Section 18	3-7	2.31	- -	- -	- -	S
	T2N, R23E, Section 18	3-8	2.09	- -	- -	- -	S
	T2N, R23E, Section 8	3-9	2.19	- -	- -	- -	S
	T2N, R23E, Section 8	3-10	1.99	- -	- -	- -	S
	T2N, R23E, Section. 8	3-11	1.48	- -	- -	- -	S
	T2N, R23E, Section 5	3-12	1.18	0.87-1.5	4.4	20	S
	T2N, R23E, Section 5	3-13	0.72	- -	- -	- -	U
	T2N, R23E, Section 5	3-14	1.37	- -	- -	- -	S
Racine	Reach 3						
	T3N, R23E, Section 32	3-15	1.69		- -	- -	S
	T3N, R23E, Section 32	3-16	1.37	- -	- -	- -	S
	T3N, R23E, Section 29	3-17	1.25	- -	- -	- -	S
	T3N, R23E, Section 28	3-18	1.23	- -	- -	- -	S
	T3N, R23E, Section 28	3-19	1.00	0.64-1.39	29.2	76	M
	T3N, R23E, Section 28	3-20	0.79	- -	- -	- -	U
	Reach 4						
	T4N, R23E, Section 21	4-1	0.87	0.87-2.10	18	24	M
	T4N, R23E, Section 21	4-2	1.55	- -	- -	- -	S
	Reach 5						
	T4N, R23E, Section 4	5-1	1.00	0.88-1.46	10.4	52	U
	T4N, R23E ,Section 4	5-2	1.09	0.95-1.56	1.6	16	M
	T4N, R23E, Section 33	5-3	1.65	- -	- -	- -	S
	T4N, R23E, Section 33	5-4	1.74	- -	- -	- -	S
	T4N, R23E, Section 27	5-5	1.70	- -	- -	- -	S
	T4N, R23E, Section 27	5-6	1.49	- -	- -	- -	S
	T4N, R23E, Section 27	5-7	2.51	- -	- -	- -	S
	Reach 6						
	T4N, R23E, Section 22	6-1	0.91	0.58-1.99	12.4	36	M
	T4N, R23E, Section 21	6-2	3.3	- -	- -	- -	S
	T4N, R23E, Section 16	6-3	1.7	- -	- -	- -	S
	T4N, R23E, Section 16	6-4	1.45	- -	- -	- -	S
	T4N, R23E, Section 16	6-5	0.93	0.79-1.78	9.2	84	M
	T4N, R23E, Section 16	6-6	0.93	0.83-1.39	11	44	M
	T4N, R23E, Section 16	6-7	0.97	0.74-1.32	47.6	84	U
	T4N, R23E, Section 17	6-8	0.98	0.94-1.44	11.6	44	M
	T4N, R23E, Section 17	6-9	1.53	- -	- -	- -	S
	T4N, R23E, Section 17	6-10	1.38	- -	- -	- -	S
	T4N, R23E, Section 17	6-11	1.25	- -	- -	- -	S
	T4N, R23E, Section 8	6-12	2.38	- -	- -	- -	S
	T4N, R23E, Section 8	6-13	1.84	- -	- -	- -	S
	T4N, R23E, Section 8	6-14	2.17	- -	- -	- -	S
	T4N, R23E, Section 8	6-15	1.46	- -	- -	- -	S
	T4N, R23E, Section 8	6-16	0.89	0.84-1.31	35.6	68	M
	T4N, R23E, Section 7	6-17	0.44	- -	- -	- -	U
	T4N, R23E, Section 6	6-18	0.99	0.82-1.29	16.4	52	M
	T4N, R23E, Section 6	6-19	1.05	0.88-1.19	11.6	20	M

Table 10 (continued)

County	Shoreline Analysis Reach by U.S. Public Land Survey Town, Range, and Section	1995 Profile Site	Deterministic Analysis[a] Safety Factor	Probabilistic Analysis[a] Range of Safety Factors	Probabilistic Analysis[a] Percent of 250 Safety Factors Conducted <1.0	Probabilistic Analysis[a] Percent of 25 Lowest Safety Factors Conducted <1.0	Model-Indicated Stability Classification of Section[b]
Milwaukee	Reach 7						
	T5N, R23E, Section 31	7-1	1.59	0.58-1.25	59.2	88	S
	T5N, R23E, Section 31	7-2	1.59	- -	- -	- -	S
	T5N, R23E, Section 31	7-3	1.17	- -	- -	- -	S
	T5N, R23E, Section 31	7-4	1.50	- -	- -	- -	S
	T5N, R23E, Section 31	7-5	1.55	- -	- -	- -	S
	T5N, R22E, Section 36	7-6	0.92	0.58-1.25	59.2	88	U
	T5N, R22E, Section 36	7-7	1.50	- -	- -	- -	S
	T5N, R22E, Section 24	7-8	0.99	0.87-1.42	11.6	20	M
	T5N, R22E, Section 24	7-9	1.47	- -	- -	- -	S
	T5N, R22E, Section 24	7-10	0.80	- -	- -	- -	U
	T5N, R22E, Section 24	7-11	1.00	0.76-1.12	71.6	92	U
	T5N, R22E, Section 24	7-12	1.29	- -	- -	- -	S
	T5N, R22E, Section 24	7-13	0.80	- -	- -	- -	U
	T5N, R22E, Section 24	7-14	0.97	0.85-1.38	10.8	52	M
	Reach 8						
	T5N, R22E, Section 13	8-1	1.84	- -	- -	- -	S
	T5N, R22E, Section 13	8-2	0.86	- -	- -	- -	U
	T5N, R22E, Section 13	8-3	0.74	- -	- -	- -	U
	T5N, R22E, Section 13	8-4	0.89	- -	- -	- -	U
	T5N, R22E, Section 13	8-5	1.07	- -	- -	- -	M
	T5N, R22E, Section 13	8-6	0.87	0.63-1.44	42.4	100	U
	T5N, R22E, Section 13	8-7	0.81	- -	- -	- -	U
	T5N, R22E, Section 12	8-8	1.17	- -	- -	- -	S
	T5N, R22E, Section 12	8-9	0.84	- -	- -	- -	U
	T5N, R22E, Section 12	8-10	0.93	0.82-1.47	18.4	44	M
	T5N, R22E, Section 12	8-11	0.77	- -	- -	- -	U
	T5N, R22E, Section 12	8-12	0.98	0.69-1.36	20.8	36	M
	T5N, R22E, Section 1	8-13	1.09	0.92-1.49	5.6	24	S
	T5N, R22E, Section 1	8-14	1.19	- -	- -	- -	S
	T5N, R22E, Section 1	8-15	0.81	- -	- -	- -	U
	T5N, R22E, Section 1	8-16	1.07	- -	- -	- -	M
	T5N, R22E, Section 1	8-17	1.21	- -	- -	- -	S
	T5N, R22E, Section 1	8-18	0.98	0.59-1.28	43.2	64	M
	T6N, R22E, Section 36	8-19	1.04	0.82-1.2	34.4	48	M
	T6N, R22E, Section 36	8-20	0.83	- -	- -	- -	U
	T6N, R22E, Section 36	8-21	0.76	- -	- -	- -	U
	T6N, R22E, Section 36	8-22	1.00	0.71-1.17	58	72	U
	T6N, R22E, Section 36	8-23	0.95	0.86-1.27	26.4	32	M
	T6N, R22E, Section 36	8-24	0.90	- -	- -	- -	U
	T6N, R22E, Section 36	8-25	0.79	- -	- -	- -	U
	T6N, R22E, Section 25	8-26	0.91	0.55-0.92	100	100	U
	T6N, R22E, Section 25	8-27	0.83	- -	- -	- -	U
	T6N, R22E, Section 25	8-28	0.95	0.76-1.29	20.8	48	M
	T6N, R22E, Section 25	8-29	0.82	- -	- -	- -	U
	T6N, R22E, Section 25	8-30	0.74	- -	- -	- -	U
	T6N, R22E, Section 25	8-31	0.94	0.78-1.9	10.4	44	M
	T6N, R22E, Section 24	8-32	0.80	- -	- -	- -	U
	T6N, R22E, Section 24	8-33	1.12	- -	- -	- -	S
	T6N, R22E, Section 24	8-34	0.96	0.72-1.18	80	100	U
	T6N, R22E, Section 24	8-35	1.04	0.89-1.58	5.2	32	M
	T6N, R22E, Section 14	8-36	1.80	- -	- -	- -	S
	T6N, R22E, Section 14	8-37	1.95	- -	- -	- -	S
	T6N, R22E, Section 14	8-38	0.90	0.78-1.49	17.6	64	M
	T6N, R22E, Section 14	8-39	1.01	0.81-1.38	25.6	60	M
	T6N, R22E, Section 14	8-40	1.13	- -	- -	- -	S
	T6N, R22E, Section 14	8-41	0.97	0.93-1.71	2.4	24	S
	Reach 9						
	T6N, R22E, Section 10	9-1	2.40	- -	- -	- -	S

Table 10 (continued)

County	Shoreline Analysis Reach by U.S. Public Land Survey Town, Range, and Section	1995 Profile Site	Deterministic Analysis[a] Safety Factor	Probabilistic Analysis[a] Range of Safety Factors	Percent of 250 Safety Factors Conducted <1.0	Percent of 25 Lowest Safety Factors Conducted <1.0	Model-Indicated Stability Classification of Section[b]
Milwaukee (continued)	Reach 10						
	T7N, R22E, Section 10	10-1	1.27	- -	- -	- -	S
	T7N, R22E, Section 3	10-2	1.13	- -	- -	- -	S
	T7N, R22E, Section 3	10-3	1.39	- -	- -	- -	S
	T7N, R22E, Section 3	10-4	1.27	- -	- -	- -	S
	T7N, R22E, Section 3	10-5	1.62	- -	- -	- -	S
	T8N, R22E, Section 34	10-6	1.36	- -	- -	- -	S
	T8N, R22E, Section 33	10-7	1.26	- -	- -	- -	S
	T8N, R22E, Section 33	10-8	1.26	- -	- -	- -	S
	T8N, R22E, Section 28	10-9	1.00	0.82-1.37	36	64	M
	T8N, R22E, Section 28	10-10	0.95	0.77-1.27	39.6	56	M
	T8N, R22E, Section 28	10-11	1.01	0.55-1.17	68.4	80	U
	T8N, R22E, Section 21	10-12	0.98	0.54-1.23	83.2	92	U
	T8N, R22E, Section 21	10-13	1.02	0.79-1.69	9.2	44	M
	T8N, R22E, Section 16	10-14	1.52	- -	- -	- -	S
	Reach 11						
	T8N, R22E, Section 10	11-1	1.86	- -	- -	- -	S
	T8N, R22E, Section 10	11-2	2.34	- -	- -	- -	S
	T8N, R22E, Section 4	11-3	1.39	- -	- -	- -	S
	T8N, R22E, Section 4	11-4	1.07	0.71-1.50	59.6	64	U
Ozaukee	Reach 11						
	T9N, R22E, Section 33	11-5	0.72	- -	- -	- -	U
	T9N, R22E, Section 33	11-6	1.12	- -	- -	- -	S
	T9N, R22E, Section 33	11-7	0.74	- -	- -	- -	U
	T9N, R22E, Section 28	11-8	0.77	- -	- -	- -	U
	T9N, R22E, Section 28	11-9	0.69	- -	- -	- -	U
	Reach 12						
	T9N, R22E, Section 28	12-1	0.57	- -	- -	- -	U
	T9N, R22E, Section 28	12-2	0.59	- -	- -	- -	U
	T9N, R22E, Section 21	12-3	1.00	0.88-1.40	8	20	S
	T9N, R22E, Section 21	12-4	0.95	0.93-1.38	13.6	24	M
	T9N, R22E, Section 21	12-5	1.03	0.82-1.50	12.8	20	M
	T9N, R22E, Section 17	12-6	1.08	0.94-1.39	2.4	8	M
	T9N, R22E, Section 17	12-7	1.16	- -	- -	- -	S
	T9N, R22E, Section 17	12-8	1.48	- -	- -	- -	S
	T9N, R22E, Section 17	12-9	1.40	- -	- -	- -	S
	T9N, R22E, Section 8	12-10	0.67	- -	- -	- -	U
	T9N, R23E, Section 8	12-11	1.11	- -	- -	- -	M
	T9N, R23E, Section 8	12-12	0.78	- -	- -	- -	U
	T9N, R23E, Section 8	12-13	1.11	- -	- -	- -	M
	T9N, R23E, Section 8	12-14	0.59	- -	- -	- -	U
	T9N, R23E, Section 4	12-15	0.96	0.71-1.37	14	48	M
	T9N, R23E, Section 4	12-16	0.63	- -	- -	- -	U
	T9N, R23E, Section 4	12-17	0.76	- -	- -	- -	U
	T10N, R22E, Section 33	12-18	1.88	- -	- -	- -	S
	T10N, R22E, Section 33	12-19	1.11	- -	- -	- -	M
	T10N, R22E, Section 33	12-20	1.01	0.43-0.81	100	100	U
	T10N, R22E, Section 33	12-21	0.94	0.48-1.03	98.8	100	U
	T10N, R22E, Section 28	12-22	1.02	0.8-1.36	18.7	30.4	M
	T10N, R22E, Section 28	12-23	0.70	- -	- -	- -	U
	T10N, R22E, Section 28	12-24	0.84	- -	- -	- -	U
	T10N, R22E, Section 28	12-25	1.09	0.88-1.26	22	28	M
	Reach 13						
	T10N, R22E, Section 21	13-1	1.32	- -	- -	- -	S
	T10N, R22E, Section 21	13-2	0.83	- -	- -	- -	U
	T10N, R22E, Section 21	13-3	1.81	- -	- -	- -	S
	T10N, R22E, Section 16	13-4	1.00	0.79-1.44	15.6	28	M
	T10N, R22E, Section 16	13-5	0.73	- -	- -	- -	U
	T10N, R22E, Section 16	13-6	0.81	- -	- -	- -	U
	T10N, R22E, Section 10	13-7	0.99	0.78-1.17	46.4	52	M
	T10N, R22E, Section 10	13-8	0.59	- -	- -	- -	U

Table 10 (continued)

County	Shoreline Analysis Reach by U.S. Public Land Survey Town, Range, and Section	1995 Profile Site	Deterministic Analysis[a] Safety Factor	Probabilistic Analysis[a] Range of Safety Factors	Probabilistic Analysis[a] Percent of 250 Safety Factors Conducted <1.0	Probabilistic Analysis[a] Percent of 25 Lowest Safety Factors Conducted <1.0	Model-Indicated Stability Classification of Section[b]
Ozaukee (continued)	Reach 13 (continued)						
	T10N, R22E, Section 10	13-9	1.01	0.83-1.22	36	68	M
	T10N, R22E, Section 3	13-10	0.75	- -	- -	- -	U
	T10N, R22E, Section 3	13-11	1.19	- -	- -	- -	S
	T10N, R22E, Section 3	13-12	1.01	0.87-1.24	38.8	56	M
	T10N, R22E, Section 3	13-13	1.03	0.84-1.20	24.8	52	M
	T10N, R22E, Section 3	13-14	0.88	- -	- -	- -	U
	T11N, R22E, Section 33	13-15	0.88	- -	- -	- -	U
	T11N, R22E, Section 33	13-16	1.0	0.88-1.38	5.2	32	M
	T11N, R22E, Section 33	13-17	1.16	- -	- -	- -	S
	T11N, R22E, Section 33	13-18	0.88	- -	- -	- -	U
	Reach 15						
	T11N, R22E, Section 33	15-1	1.07	- -	- -	- -	M
	T11N, R23E, Section 28	15-2	1.17	- -	- -	- -	S
	T11N, R23E, Section 28	15-3	1.18	- -	- -	- -	S
	T11N, R23E, Section 28	15-4	0.97	0.7-1.2	40.4	72	M
	T11N, R23E, Section 21	15-5	0.92	0.73-1.33	34.8	48	M
	T11N, R23E, Section 21	15-6	0.72	- -	- -	- -	U
	T11N, R23E, Section 22	15-7	1.02	0.87-1.42	20	36	M
	T11N, R23E, Section 15	15-8	1.32	- -	- -	- -	S
	T11N, R23E, Section 14	15-9	1.36	- -	- -	- -	S
	T11N, R23E, Section 11	15-10	1.10	0.58-1.45	54	68	U
	T11N, R23E, Section 11	15-11	0.95	0.74-1.32	28.8	44	M
	T11N, R23E, Section 11	15-12	0.92	0.67-1.22	68.8	76	U
	T11N, R23E, Section 11	15-13	1.23	- -	- -	- -	S
	T11N, R23E, Section 2	15-14	1.47	- -	- -	- -	S

[a] *The deterministic slope stability analysis utilizes site-specific data collected at individual profile sites to compute potential slope failure surfaces. The probabilistic slope stability analysis evaluates slope stability as soil properties, stratigraphy, and groundwater conditions vary randomly within specified ranges. The intent of the probabilistic analysis is to provide a general assessment of the stability of bluff slopes within entire bluff analysis sections, rather than at specific profile sites. The probabilistic analysis helps improve the evaluation of those profile sites where some bluff characteristics are not well-defined.*

[b] *The following abbreviations were used:*
M — Marginal
U — Unstable
S — Stable

Source: J.A. Chapman, T.B. Edil, D.M. Mickelson, and SEWRPC.

water level was about 0.6 foot higher than the 1995 level, and over one foot higher during the summer months. These differences must be considered in any comparisons of beach and nearshore conditions in these two years. Given the beach slopes in Southeastern Wisconsin, the difference in water levels between 1976, the period of the field survey for the 1977 study, and 1995 can account for between five and 20 feet of beach width. In view of this, and the inherent potential differences in observations due to wave and seiche effects, beach widths with a difference of less than 20 feet were reported to be unchanged.

Shoreline Recession Characteristics

Shoreline recession rates were based upon measurements made using one inch equals 400 feet scale, ratioed and rectified, Regional Planning Commission aerial photographs taken in 1963, 1970, 1975, and 1995. All measurements on the aerial photographs were made parallel to the east-west U.S. Public Land Survey section or quarter section lines. The measurements were then corrected for the differences in the bearing of the shoreline and the bearing of the section or quarter section lines concerned in order to represent recession perpendicular to the shoreline. Shoreline recession was measured at intervals of about one-quarter mile along the entire 77-mile study area shoreline.

The results of the shoreline recession analysis are set forth in Appendix A, for the periods 1963 through 1995, 1970 through 1995, and 1975 through 1995. For comparison purposes, Appendix A also sets forth recession

Table 11

SUMMARY OF LAKE MICHIGAN ESTIMATED BEACH WIDTHS IN SOUTHEASTERN WISCONSIN: 1995

County	Shoreline Analysis Reach by U.S. Public Land Survey Township, Range, Section	Erosion Zone	Estimated Beach Width	
			1995 Conditions	1977 Conditions
Kenosha	Reach 1			
	T1N, R23E, Section 32	Section 32	0 to 80 feet	0 to 100 feet
	T1N, R23E, Section 29	Section 29	0 to 100 feet	0 to 100 feet
	T1N, R23E, Section 20	Section 20	0 to 70 feet	0 to 75 feet
	T1N, R23E, Section 17	Section 17	0 to 150 feet	0 to 50 feet
	T1N, R23E, Section 8	Section 8, southern half	No significant beach	No significant beach
	Reach 2			
	T1N, R23E, Section 8	Section 8, northern half	0 to 80 feet	0 to 100 feet
	T1N, R23E, Section 5	Section 5	0 to 200 feet	60 to 85 feet
	T2N, R23E, Section 32	Section 32	0 to 200 feet	- -
	Reach 3			
	T2N, R23E, Section 30	Section 30	0 to 250 feet	0 to 275 feet
	T2N, R23E, Section 19	Zone 19a	200 to 300 feet	180 to 275 feet
		Zone 19b	100 to 220 feet	140 to 200 feet
		Zone 19c	25 to 50 feet	0 to 110 feet
	T2N, R23E, Section 18	Zone 18a	About 50 feet	0 to 5 feet
		Zone 18b	About 50 feet	No significant beach
		Zone 18c	25 to 50 feet	No significant beach
		Zone 18d	50 to 100 feet	No significant beach
		Zone 18e	About 50 feet	Less than 20 feet
		Zone 18f	About 50 feet	0 to 5 feet
	T2N, R23E, Section 8	Zone 8a	0 to 40 feet	5 to 20 feet
		Zone 8b	0 to 50 feet	0 to 20 feet
		Zone 8c	0 to 30 feet	5 to 20 feet
		Zone 8d	0 to 150 feet	0 to 20 feet
	T2N, R23E, Section 5	Zone 5a	No significant beach	About 5 feet
		Zone 5b	About 50 feet	0 to 40 feet
		Zone 5c	50 to 100 feet	20 to 40 feet
		Zone 5d	40 to 75 feet	15 to 20 feet
		Zone 5e	About 50 feet	5 to 15 feet
		Zone 5f	About 50 feet	About 5 feet
		Zone 5g	30 to 50 feet	10 to 15 feet
		Zone 5h	50 to 75 feet	No significant beach
Racine	Reach 3			
	T3N, R23E, Section 32	Section 32	0 to 20 feet	0 to 20 feet
	T3N, R23E, Section 28-29	Zone 28-29a	0 to 50 feet	0 to 5 feet
		Zone 28-29b	0 to 10 feet	5 to 10 feet
		Zone 28-29c	No significant beach	No significant beach
		Zone 28-29d	No significant beach	0 to 10 feet
	Reach 4			
	T3N, R23E, Section 21	Section 21	No significant beach	No significant beach
		Sections 9 and 16	No significant beach	No significant beach
	Reach 5			
	T3N, R23E, Section 4	Section 4	10 to 250 feet	0 to 250 feet
	T4N, R23E, Section 33-34	Zone 33-34a	50 to 100 feet	0 to 20 feet
		Zone 33-34b	20 to 50 feet	20 to 40 feet
		Zone 33-34c	0 to 50 feet	0 to 20 feet
	T4N, R23E, Section 27	Zone 27a	About 25 feet	0 to 5 feet
		Zone 27b	No significant beach	0 to 65 feet
		Zone 27c	About 25 feet	5 to 100 feet
		Zone 27d	About 50 feet	10 to 30 feet
	Reach 6			
	T4N, R23E, Section 21	Zone 21a	20 to 50 feet	0 to 60 feet
		Zone 21b	No significant beach	25 to 55 feet
		Zone 21c	0 to 75 feet	25 to 55 feet
		Zone 21d	About 150 feet	25 to 55 feet

Table 11 (continued)

County	Shoreline Analysis Reach by U.S. Public Land Survey Township, Range, Section	Erosion Zone	Estimated Beach Width	
			1995 Conditions	1977 Conditions
Racine (continued)	Reach 6 (continued)			
	T4N, R23E, Section 16	Zone 16a	20 to 50 feet	0 to 40 feet
		Zone 16b	10 to 50 feet	30 to 75 feet
	T4N, R23E, Section 7-8	Zone 7-8a	No significant beach	15 to 20 feet
		Zone 7-8b	20 to 50 feet	0 to 30 feet
		Zone 7-8c	10 to 50 feet	0 to 15 feet
		Zone 7-8d	No significant beach	10 to 20 feet
	T4N, R23E, Section 6	Zone 6a	No significant beach	0 to 15 feet
		Zone 6b	No significant beach	No significant beach
Milwaukee	Reach 7			
	T5N, R22E, Section 31-36	Zone 31-36a	No significant beach	Less than 20 feet
		Zone 31-36b	100 to 150 feet	Less than 20 feet
		Zone 31-36c	50 to 100 feet	10 to 20 feet
	T5N, R22E, Section 25	Section 25	No significant beach	5 to 20 feet
	T5N, R22E, Section 24	Zone 24a	No significant beach	No significant beach
		Zone 24b	0 to 40 feet	Less than 5 feet
		Zone 24c	20 to 70 feet	up to 20 feet
		Zone 24d	0 to 25 feet	0 to 20 feet
	Reach 8			
	T5N, R22E, Section13	Zone 13a	100 to 600 feet	5 to 20 feet
		Zone 13b	50 to 200 feet	5 to 20 feet
		Zone 13c	50 to 100 feet	About 20 feet
	T5N, R22E, Section 12	Zone 12a	25 to 50 feet	5 to 20 feet
		Zone 12b	25 to 100 feet	No significant beach
		Zone 12c	100 to 150 feet	About 20 feet
		Zone 12d	25 to 600 feet	About 20 feet
	T5N, R22E, Section 1	Zone 1a	20 to 100 feet	About 20 feet
		Zone 1b	30 to 100 feet	About 20 feet
	T6N, R22E, Section 36	Zone 36a	50 to 100 feet	Greater than 20 feet
		Zone 36b	20 to 50 feet	5 to 20 feet
		Zone 36c	20 to 100 feet	Greater than 20 feet
	T6N, r22E, Section 25	Zone 25a	About 50 feet	5 to 20 feet
		Zone 25b	About 50 feet	5 to 20 feet
		Zone 25c	50 to 100 feet	5 to 20 feet
	T6N, R22E, Section 24	Zone 24a	0 to 50 feet	Greater than 20 feet
		Zone 24b	No significant beach	5 to 20 feet
	T6N, R22E, Section 14	Zone 14a	No significant beach	No significant beach
		Zone 14b	20 to 50 feet	About 5 feet
		Zone 14c	About 50 feet	About 5 feet
	Reach 9			
	T6N, R22E, Section 10	Section 10	20 to 200 feet	5 to 20 feet
	T6N, R22E, Section 4	Section 4	No significant beach	No significant beach
	T7N, R22E, Section 33	Section 33	No significant beach	No significant beach
	T7N, R22E, Section 28	Section 28	No significant beach	No significant beach
	T7N, R22E, Section 22	Section 22	0 to 150 feet	5 to 20 feet
	T7N, R22E, Sections 14-15	Sections 14-15	0 to 170 feet	No significant beach
	Reach 10			
	T7N, R22E, Section 10	Zone 10a	0 to 70 feet	About 20 feet
		Zone 10b	5 to 40 feet	About 50 feet
		Zone 10c	30 to 50 feet	About 50 feet
		Zone 10d	About 5 feet	5 to 20 feet
	T7N, R22E, Section 3	Zone 3a	0 to 150 feet	About 20 feet
		Zone 3b	5 to 50 feet	5 to 20 feet
		Zone 3c	0 to 5 feet	5 to 20 feet
	T7N, R22E, Sections 33-34	Sections 33 and 34	0 to 50 feet	5 to 20 feet
	T7N, R22E, Section 28	Zone 28a	0 to 20 feet	Greater than 25 feet
		Zone 28b	20 to 50 feet	Greater than 25 feet
		Zone 28c	20 to 50 feet	Greater than 25 feet

Table 11 (continued)

County	Shoreline Analysis Reach by U.S. Public Land Survey Township, Range, Section	Erosion Zone	Estimated Beach Width	
			1995 Conditions	1977 Conditions
Milwaukee (continued)	Reach 10 (continued)			
	T8N, R22E, Section 21	Zone 21a	About 5 feet	Less than 25 feet
		Zone 21b	0 to 30 feet	About 25 feet
		Zone 21c	No significant beach	5 to 20 feet
		Zone 21d	No significant beach	Less than 5 feet
	T8N, R22E, Section 16	Section 16	0 to 75 feet	Less than 20 feet
	Reach 11			
	T8N, R22E, Section 10	Zone 10a	20 to 40 feet	About 30 feet
		Zone 10b	5 to 125 feet	About 15 feet
		Zone 10c	50 to 170 feet	About 25 feet
	T8N, R22E, Section 3-4	Zone 3-4a	10 to 50 feet	up to 25 feet
		Zone 3-4b	20 to 40 feet	15 to 25 feet
Ozaukee	Reach 11			
	T9N, R22E, Section 33	Zone 33a	20 to 40 feet	15 to 25 feet
		Zone 33b	30 to 100 feet	About 25 feet
		Zone 33c	5 to 50 feet	10 to 25 feet
	T9N, R22E, Section 28	Zone 28a	0 to 50 feet	15 to 25 feet
		Zone 28b	30 to 100 feet	15 to 25 feet
	Reach 12			
	T9N, R22E, Section 28	Zone 28c	40 to 100 feet	15 to 25 feet
		Zone 28d	0 to 50 feet	15 to 25 feet
		Zone 28e	About 30 feet	15 to 25 feet
	T9N, R22E, Sections 20-21	Zone 20-21a	30 to 60 feet	5 to 20 feet
		Zone 20-21b	30 to 50 feet	About 20 feet
		Zone 20-21c	About 40 feet	5 to 20 feet
	T9N, R22E, Section 17	Zone 17a	10 to 50 feet	About 20 feet
		Zone 17b	5 to 50 feet	5 to 20 feet
		Zone 17c	40 to 70 feet	About 20 feet
		Zone 17d	20 to 75 feet	About 20 feet
		Zone 17e	5 to 25 feet	5 to 20 feet
	T9N, R22E, Section 8	Zone 8a	0 to 20 feet	0 to 10 feet
		Zone 8b	0 to 20 feet	0 to 10 feet
		Zone 8c	0 to 20 feet	0 to 10 feet
		Zone 8d	20 to 40 feet	15 to 25 feet
	T9N, R22E, Sections 4-5	Zone 4-5a	5 to 50 feet	15 to 25 feet
		Zone 4-5b	5 to 50 feet	15 to 25 feet
		Zone 4-5c	5 to 30 feet	0 to 15 feet
	T10N, R22E, Section 33	Zone 33a	About 50 feet	About 20 feet
		Zone 33b	5 to 40 feet	5 to 20 feet
		Zone 33c	20 to 50 feet	About 20 feet
		Zone 33d	5 to 30 feet	5 to 20 feet
	T10N, R22E, Section 28	Zone 28a	10 to 30 feet	5 to 20 feet
		Zone 28b	20 to 75 feet	5 to 20 feet
		Zone 28c	About 30 feet	About 20 feet
		Zone 28d	20 to 50 feet	5 to 20 feet
		Zone 28e	0 to 20 feet	About 5 feet
		Zone 28f	20 to 30 feet	5 to 20 feet
	Reach 13			
	T10N, R22E, Section 21	Zone 21a	0 to 5 feet	10 to 20 feet
		Zone 21b	0 to 5 feet	10 to 20 feet
		Zone 21c	0 to 5 feet	10 to 25 feet
		Zone 21d	20 to 30 feet	10 to 20 feet
		Zone 21e	5 to 15 feet	10 to 20 feet
	T10N, R22E, Sections 15-16	Zone 15-16a	0 to 20 feet	5 to 20 feet
		Zone 15-16b	5 to 15 feet	5 to 20 feet
	T10N, R22E, Section 10	Zone 10a	10 to 30 feet	Greater than 20 feet
		Zone 10b	20 to 30 feet	Greater than 20 feet
		Zone 10c	10 to 20 feet	Greater than 20 feet
	T10N, R22E, Section 3	Section 3	10 to 30 feet	10 to 25 feet
	T11N, R22E, Section 33	Zone 33a	10 to 30 feet	20 to 30 feet
		Zone 33b	10 to 50 feet	20 to 30 feet

Table 11 (continued)

County	Shoreline Analysis Reach by U.S. Public Land Survey Township, Range, Section	Erosion Zone	Estimated Beach Width	
			1995 Conditions	1977 Conditions
Ozaukee (continued)	Reach 14 T11N, R22E, Section 28	Section 28, southern half	No significant beach	No significant beach
	Reach 15			
	T11N, R22E, Section 28	Zone 28a	30 to 50 feet	About 15 feet
		Zone 28b	About 50 feet	5 to 20 feet
		Zone 28c	20 to 40 feet	5 to 20 feet
	T11N, R22E, Section 22	Zone 22a	About 50 feet	5 to 25 feet
		Zone 22b	30 to 50 feet	5 to 25 feet
		Zone 22c	About 50 feet	5 to 20 feet
		Zone 22d	50 to 80 feet	5 to 30 feet
		Zone 22e	70 to 100 feet	5 to 15 feet
		Zone 22f	30 to 70 feet	30 to 70 feet
	T11N, R22E, Sections 14-15	Zone 14-15a	20 to 50 feet	up to 25 feet
		Zone 14-15b	30 to 50 feet	5 to 20 feet
		Zone 14-15c	About 40 feet	5 to 20 feet
		Zone 14-15d	About 40 feet	About 30 feet
		Zone 14-15e	About 40 feet	5 to 15 feet
		Zone 14-15f	25 to 30 feet	5 to 20 feet
		Zone 14-15g	20 to 30 feet	5 to 20 feet
	T11N, R22E, Section 11	Zone 11a	10 to 30 feet	5 to 15 feet
		Zone 11b	10 to 30 feet	5 to 15 feet
		Zone 11c	10 to 30 feet	5 to 20 feet
		Zone11d	10 to 30 feet	About 20 feet
		Zone 11e	30 to 50 feet	5 to 30 feet
	T11N, R22E, Section 1	Zone 1a	30 to 50 feet	Less than 20 feet
		Zone 1b	30 to 50 feet	Less than 20 feet
		Zone 1c	30 to 50 feet	Less than 20 feet
	Reach 16			
	T12N, R22E, Section 36	Section 36	30 to 80 feet	Less than 20 feet
	T12N, R22E, Sections 25-30	Sections 25-30	30 to 80 feet	5 to 20 feet
	T12N, R22E, Section 19	Section 19	0 to 150 feet	Less than 20 feet
	Reach 17			
	T12N, R22E, Section 18	Section 18	30 to 100 feet	Less than 20 feet
	T12N, R22E, Section 7	Section 7	30 to 100 feet	Less than 20 feet
	T12N, R22E, Section 6	Section 6	30 to 100 feet	Less than 20 feet

Source: J.A. Chapman, T.B. Edil, D.M. Mickelson, and SEWRPC.

rate data developed under the 1977 study for those sites at which such recession rates were determined in the 1977 study.

The recession rates data developed in the 1995 study were based upon measurements made on large-scale vertical aerial photographs taken in 1963, 1970, 1975, and 1995. Importantly, all of the photographs, for all of the years concerned, were ratioed and rectified to Regional Planning Commission specifications, utilizing the Commission horizontal survey control network, and were therefore comparable. The data presented in the 1977 report for recession rates were developed from a variety of sources. The data reported were intended to represent "long-term recession rates" approximating an average rate over a 100-year period,[10] and were developed from measurements made on vertical aerial photographs, older small-scale topographic maps, and from the original U.S. Public Land Survey plats. The sources for data collected in the 1977 study clearly were not of the uniform scale and quality of the photographs used in the 1995 study.

INVENTORY AND ANALYSIS FINDINGS

The results of the current inventory and analysis are summarized in Tables 9 through 12 and Appendix A,

[10]*D.M. Mickelson et al., 1977, op. cit.*

Table 12

BATHYMETRY DATA SUMMARY

County	Shoreline Reach Analysis by U.S. Public Land Survey Township, Range, Section	1995 Profile Site	1995 Data—Distance from Shore in Feet to Five Foot Depth, Unless Otherwise Noted (bottom material)	1977 Profile Site	1977 Data—Distance from Shore in Feet to Five Foot Depth, Unless Otherwise Noted (bottom material)
Kenosha	Reach 1				
	T1N, R23E, Section 32	1-1	147 feet (sand)	75-3	120 feet (sand)
	T1N, R23E, Section 29	1-2	236 feet (sand)	75-1	70 feet (sand)
	T1N, R23E, Section 20	1-3	106 feet (sand)	75-2	200 feet (cobbles)
	T1N, R23E, Section 17	1-4	70 feet (sand)	75-2	65 feet (sand/gravel)
	Reach 3				
	T2N, R23E, Section 30	3-1	22 feet (gravel)	75-1	N/A
	T2N, R23E, Section 19	3-2	136 feet (cobbles)	75-4	N/A
	T2N, R23E, Section 19	3-3	155 feet (cobbles/sand)	75-3	N/A
	T2N, R23E, Section 18	3-6	40 feet (sand)	75-4	40 feet (cobbles)
Racine	Reach 4				
	T3N, R23E, Section 21	4-4	17 feet (sand)	75-1	20 feet (gravel/rocks)
	Reach 5				
	T3N, R23E, Section 4	5-2	143 feet (sand)	75-1	N/A
	T4N, R23E, Section 33	5-3	54 feet (sand)	75-1	80 feet (sand/gravel)
	T4N, R23E, Sections 27	5-7	200 feet to 3 foot depth (cobbles)	75-1	170 feet (pebbles/cobbles)
	Reach 6				
	T4N, R23E, Section 21	6-1	250 feet[a]	75-2	38 feet (sand/gravel)
	T4N, R23E, Section 21	6-2	350 feet[a]	75-1	30 feet (gravel)
	T4N, R23E, Section 16	6-3	500 feet[a]	75-4	44 feet (sand/gravel)
	T4N, R23E, Sections 7/8	6-14	93 feet (cobbles/sand)	75-2	85 feet (sand/gravel)
Milwaukee	Reach 8				
	T5N, R22E, Section 13	8-3	200 feet (sand)	75-1	100 feet (sand)
	T5N, R22E, Section 13	8-6	185 feet (sand)	75-2	105 feet (sand)
	T5N, R22E, Section 12	8-11	140 feet (sand)	75-2	65 feet (sand)
	T5N, R22E, Section 1	8-15	65 feet (sand/gravel)	75-2	67 feet (sand)
	T5N, R22E, Section 1	8-18	72 feet (gravel)	75-3	27 feet (gravel)
	T6N, R22E, Section 36	8-24	120 feet (sand)	75-2	80 feet (sand)
	T6N, R22E, Section 25	8-27	72 feet (cobbles)	75-2	60 feet (cobbles)
	T6N, R22E, Section 25	8-29	75 feet (silty)	75-3	50 feet (silty)
	T6N, R22E, Section 24	8-34	87 feet (rocky/cobbles)	75-1	53 feet (rocky)
	Reach 10				
	T7N, R22E, Section 3	10-2	188 feet (sand)	75-1	80 feet (sand)
	T8N, R22E, Section 33	10-7	125 feet (sand)	75-2	110 feet (sand)
	T8N, R22E, Section 28	10-11	161 feet (sand)	75-4	150 feet (sand)
	T8N, R22E, Section 16	10-14	119 feet (sand)	75-1	150 feet (sand)
Ozaukee	Reach 11				
	T8N R22E, Section 10	11-2	102 feet (sand)	75-2	100 feet (sand)
	T9N, R22E, Section 28	11-9	65 feet (sand)	75-1	N/A
	Reach 15				
	T11N, R22E, Section 28	15-4	176 feet (sand)	75-1	100 feet (sand)
	T11N, R22E, Section 22	15-6	192 feet (sand/cobbles)	75-1	110 feet (sand)

NOTE: N/A indicates not available.

[a]*Measured from boat.*

Source: J.A. Chapman, T.B. Edil, D.M. Mickelson, and SEWRPC.

and are shown on Map 95. The findings of the inventory and analysis relating to bluff, beach and nearshore conditions are summarized below by shoreline reach.

Shoreline Reach 1: City of Kenosha and Village of Pleasant Prairie, Kenosha County

Shoreline Reach 1 is a 4.7-mile-long reach of shoreline extending from the Wisconsin-Illinois state line on the south line of U.S. Public Land Survey Section 32, Township 1 North, Range 23 East, Village of Pleasant Prairie, at about 128th Street extended, north to the southern end of the shore protection revetment at the Kenosha Water Utility sewage treatment plant at about 80th Street just south of the east-west centerline of U.S.

Public Land Survey Section 8, Township 1 North, Range 23 East, City of Kenosha. In 1995, land uses along this reach were comprised almost entirely of partially developed residential subdivisions with the existing residences mixed intermittently with undeveloped lots. The only significant nonresidential lands in this shoreline reach included approximately 800 feet of shoreline which was part of the Trident Marina development facilities located at the southern limit of the reach, and 0.5 mile of shoreline which was part of an open space tract located at the northern end of the reach and owned by the Kenosha Water Utility and the Wisconsin Electric Power Company.

As of 1995, nearly the entire shoreline in Reach 1 was protected by structural shoreline protection measures, consisting of numerous structures of various types protecting either individual properties or short reaches incorporating more than one property. The most common shore protection measures in this reach area were revetments and groins.

This shoreline reach contained no significant segments of bluffs, with the majority of the shoreline consisting of a gently sloping beach and a low sand dune ridge and swale complex. Since no significant segments of bluffs existed, bluff slope stability analyses were not conducted within this reach.

In 1995, beach widths within Reach 1 varied from nonexistent to 150 feet throughout the reach, as shown in Table 11. Variations in beach width were common throughout the reach with changes being controlled by shoreline protection structures. No significant beach was present in the northern 0.5 mile of shoreline of the reach, which is entirely protected by a revetment. The beach widths within Reach 1 appeared to be similar to the beach widths reported in the 1977 study, except for an increase in beach width in the northern portion of the section just south of the revetment noted above.

The nearshore bathymetry documented in 1995 indicated a general shallowing of the bathymetric profile at the two southernmost of the four profile sites as compared to findings reported in the 1977 study, as shown in Table 12. One of these sites was just north of the Trident Marina, and one was in the midst of a groin system. One of the northern sites located just downstream of a groin system indicated an offshore deepening, and one site located within a groin system indicated no significant change. In 1995, the nearshore lakebed material was noted to be sand throughout the reach. The 1977 study also reported sand as the predominant offshore material, but also noted the presence of cobbles and gravel in the offshore material in the central and north-central portions of the reach. The lakebed material and water depth data generally are consistent with the deposition in the nearshore zone of sand carried along the shoreline by the longshore currents that exist in southern Lake Michigan.[11] It appears that sand is continuing to be trapped by the headland-type land extensions at, and just north of, the Trident Marina facilities.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally lower than those estimated during the 1977 study. Recession rates were measured at 18 sites within Reach 1 in 1995, and were found to range from zero to 5.9 feet per year for the period of 1963 through 1995; and from zero to 1.5 feet per year for the period from 1975 through 1995. Long-term recession rates reported in the 1977 study within Reach 1 ranged from two to 12 feet per year. All recession rates greater than seven feet per year found in the 1977 study were located in the southern half of the reach. The apparent decrease in the rate of shoreline recession within this reach may be attributed to the maintenance and expansion of the extensive shoreline protection structures covering the shoreline within this reach; and, in the southern portion of the reach, the apparent accretion of sand in the nearshore area.

Shoreline Reach 2: City of Kenosha, Kenosha County

Shoreline Reach 2 is a 2.4-mile-long reach of shoreline extending from the southern end of the shore protection revetment at the Kenosha Water Utility sewage treatment plant at about 80th Street just south of the east-west center line of U.S. Public Land Survey Section 8, Township 1 North, Range 23 East, City of Kenosha, north to the south line of U.S. Public Land Survey Sections 29 and 30, Township 2 North, Range 23 East, City of Kenosha at about 45th Street extended just south of the southern boundary of J.F. Kennedy Park. In 1995, land uses along this reach comprised open space and recreational uses in Southport Park, the Kemper Center, Eichelman Park, Wofenbuttal Park, Lakefront Stadium Park, and Simmons Island Park; residential lands between the parklands south of the Kenosha Harbor; the Kenosha Water Utility sewage treatment plant; and the Kenosha Harbor facilities, including the Southport

[11]*See SEWRPC,* Lake Michigan Estuary and Direct Drainage Area Subwatersheds Planning Program Prospectus, *September 1978, Chapter III, "Processes and Phenomena," and Figure 16.*

Marina, the dredged material confined disposal facility, and the Kenosha water treatment plant.

As of 1995, the entire shoreline in Reach 2, except for the bathing beach at Simmons Island Park, was protected by structural shoreline protection measures of various types, including riprap revetments, groin-beach systems, bulkheads, and breakwater systems. In addition, a narrow beach has formed along the groin system in Southport Park.

This shoreline reach contained no significant segments of bluff, except in Simmons Island Park where the bluff height reached about 20 feet. Since no significant segments of bluff existed, bluff slope stability analyses were not conducted within this reach.

In 1995, the only significant beaches which existed were the narrow beach formed along the groin system along Southport Park and a small armored pocket beach in that park; the sand beach at Eichelman Park; and the bathing beach at Simmons Island Park. Beach widths within Reach 2 varied from nonexistent to 200 feet throughout the reach, as shown in Table 11. Beach characteristics within this reach were generally similar to, but somewhat wider than, the widths reported in the 1977 study.

The nearshore bathymetry was not documented in the 1995 study at any sites within Reach 2.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally lower than those reported in the 1977 study. Recession rates were measured at five sites within Reach 2 in 1995, and were found to range from 0.6 to 1.5 feet per year for the period from 1963 through 1995; and from zero to 0.5 foot per year for the period from 1975 through 1995. Long-term recession rates reported in the 1977 study within Reach 2 were six feet per year. The apparent decrease in the rate of shoreline recession in this reach may be attributed to the maintenance and expansion of shoreline protection structures covering the shoreline within this reach.

Shoreline Reach 3: City of Kenosha and Town of Somers, Kenosha County; Town of Mt. Pleasant, Racine County

Shoreline Reach 3 is a 7.3-mile-long reach of shoreline extending from the south line of U.S. Public Land Survey Sections 29 and 30, Township 2 North, Range 23 East, City of Kenosha, at about 45th Street extended just south of the southern boundary of J.F. Kennedy Park, north to Durand Avenue extended on the north line of U.S. Public Land Survey Section 28, Township 3 North, Range 23 East, Town of Mt. Pleasant. In 1995, land uses along this reach include open spaces in J.F. Kennedy, Pennoyer, and Alford Parks; and the Carthage College campus, with the remaining shore lands primarily in residential use, except for short sections of open land in Kenosha County and industrial lands at the very north end of the reach in Racine County. As of 1995, about 2.4 linear miles, or about 80 percent, of the shoreline in Reach 3 were protected by structural shoreline protection measures, consisting of revetments and groins.

Bluff heights ranged up to 40 feet within Reach 3, increasing from less than 20 feet in the southern portion of the reach to about 40 feet at the northern extremity of the reach. Twenty bluff profile sections were surveyed in this reach during the 1995 field survey period. Bluff safety factors determined during the 1995 study ranged from 0.79 at the northern end of the reach to over 5.0 at the southern end of the reach. The stability analyses, as summarized in Tables 9 and 10, indicated a general trend of decreasing bluff stability within the reach from south to north. Bluff safety factors reported in the 1977 study, also set forth in Table 9, ranged from 0.54 at the northern extremity of the reach to greater than 1.25 at the southern extremity of the reach. The bluff safety factors determined based upon the 1995 study were generally equal to or greater than those reported in the 1977 study, indicating that the bluffs within Reach 3 had become generally more stable during the intervening period. There appeared to be a shift from the largely unstable bluff slope conditions reported in the 1977 study to largely stable conditions observed during 1995. This shift may be attributed to the construction of shoreline protection structures and the regrading of the bluff slopes within this reach. Of the 20 bluff safety factors determined based upon 1995 conditions, 17, or 85 percent, indicated stable conditions with respect to rotational failures; one, or 5 percent, indicated marginally stable conditions with respect to rotational failures; and two, or 10 percent, indicated unstable conditions with respect to rotational failures.

In 1995, beach widths within Reach 3 varied from nonexistent to 300 feet, as shown in Table 11. In the central and southern portions of the reach, the beach widths appeared to have increased from the widths reported in the 1977 study. These changes in beach width may be attributed to the accretion of sand at and near shoreline protection structures. At four locations, or at about 18 percent of the locations surveyed, beach widths decreased within the reach. The general trend of decreasing beach width from south to north within the reach, reported in the 1977 study, was also observed during the 1995 field survey.

The nearshore bathymetry documented in 1995 indicated no change in the bathymetric profile, compared to findings reported in the 1977 study at the one site evaluated, as shown in Table 12. In 1995, the nearshore lakebed material was noted to range from gravel, to cobbles and sand, to sand from south to north within the reach.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally lower than those reported in the 1977 study. Recession rates were measured at 25 sites within Reach 3 in 1995, and were found to range from 0.3 to 5.3 feet per year for the period from 1963 through 1995, and from zero to 2.5 feet per year for the period from 1975 through 1995. Long-term recession rates reported in the 1977 study within Reach 3 ranged from two to four feet per year. The apparent decrease in the rate of shoreline recession in all but the south-central portion of this reach may be attributed to the maintenance and expansion of shoreline protection structures within this reach.

Another phenomenon which has impacted the shoreline within Reach 3 in the vicinity of the Pike River estuary was the damming of the mouth of the Pike River by littoral drift. During storms on Lake Michigan, when onshore winds prevail, littoral drift rates increase landward of the surf zone and the mouth of the Pike River can be dammed by the formation of a foreshore berm. Berms as high as six feet above the normal stage of the Pike River have been observed following severe northeasterly storms on the Lake. Subsequent to berm formation, the water level in the Pike River estuary begins to rise and continues to do so until the berm is breached. The River starts to flow over the crest of the berm, at which time rapid scouring of the sand and gravel deposits occurs with attendant rapid declines in water levels in the estuary. The sudden breaching of the berm by the River has, on several occasions, caused deaths by drowning of people who were swept into Lake Michigan from the beach at the mouth of the Pike River. Recommendations set forth in the Pike River watershed plan[12] provide for the mitigation of the identified problems caused by the sand bar formation across the mouth of the Pike River.

[12]*SEWRPC Planning Report No. 35,* A Comprehensive Plan for the Pike River Watershed, *June 1983.*

Shoreline Reach 4: City of Racine and Town of Mt. Pleasant, Racine County

Shoreline Reach 4 is a three-mile-long reach of shoreline extending through the southern and central portions of the City of Racine from about Durand Avenue extended at the J.I. Case property, on the south line of U.S. Public Land Survey Section 21, Township 3 North, Range 23 East, Town of Mt. Pleasant, north to St. Patrick Street extended at the southern end of North Beach Park, City of Racine, on the north line of U.S. Public Land Survey Section 9, Township 3 North, Range 23 East. In 1995, land uses along this reach included open spaces in Lakefront Festival, Pershing, and Roosevelt Parks, with the remaining shore lands primarily in residential use in the north-central portion of the reach and institutional, recreational, and industrial uses at the northern and southern ends of the reach, including the Gateway Technical Institute and the City of Racine sewage treatment plant in the south and Racine Harbor Marina in the north. As of 1995, the entire shoreline in Reach 4 was protected by structural shoreline protection measures, consisting of revetments and groins, and the bulkheads, revetments, and breakwater systems of the Racine Harbor Marina.

Bluff heights were about 50 feet in the southern portion of Reach 4. No significant natural bluff was present in the northern portion of the reach within the City of Racine. Two bluff profile sections were surveyed during the 1995 field survey period, both sites being in the southern one mile of the reach. Bluff safety factors determined during the 1995 study were 0.87 at the southern end of the reach and 1.55 at a location about one mile north of the southern boundary of the reach. Bluff safety factors reported in the 1977 study, also set forth in Table 9, were 0.88 at the southern site and 0.57 at the northern site. The increase in stability at the northern site is attributed to the modification of shoreline protection structures within this reach.

In 1995, beach widths within Reach 4 generally were insignificant, as shown in Table 11, except for the wide beach within groin systems in the City of Racine's North Beach immediately north of shoreline protection structures at the northern limit of the reach. The same beach conditions were noted for this reach compared to the conditions reported in the 1977 study.

The nearshore bathymetry documented in 1995 indicated little change in the bathymetric profile at the one site evaluated as compared to findings reported in the 1977 study, as shown in Table 12. However, in 1995, the nearshore lakebed material was noted to be sand at this site, in contrast to the gravel and rock substrate reported during the 1977 study. This change in offshore lakebed material may be attributed to the deposition of sand, transported in the longshore currents, within the interstices of the gravel and rock substrate reported in the 1977 study. However, such deposition was not accompanied by a shallowing of the nearshore bathymetry at this site.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally lower than those estimated during the 1977 study. Recession rates were measured within Reach 4 in 1995, and were found to range from 0.3 to 2.2 feet per year for the period from 1963 through 1995, and from zero to one foot per year for the period from 1975 through 1995. Long-term recession rate estimates reported in the 1977 study within Reach 4 indicated a recession rate of two feet per year.

Shoreline Reach 5: City of Racine and Village of Wind Point, Racine County

Shoreline Reach 5 is a three-mile-long reach of shoreline extending through the northern portion of the City of Racine from about North Beach Park at St. Patrick Street, on the south line of U.S. Public Land Survey Section 4, Township 3 North, Range 23 East, City of Racine, north to a point just north of Shoop Park at Four Mile Road on the north line of U.S. Public Land Survey Section 27, Township 4 North, Range 23 East, Village of Wind Point. In 1995, land uses along this reach included open spaces in North Beach Park, the Zoological Gardens, and Shoop Park, with the remaining shore lands primarily in residential use. As of 1995, the entire shoreline in Reach 5 was protected by structural shore protection measures, consisting of revetments and groins.

Bluff heights ranged from 10 to 45 feet within Reach 5, diminishing from south to north within the reach. Seven bluff profile sections were surveyed during the 1995 field survey period. Bluff safety factors determined during the 1995 study ranged from 1.0 at the southern end of the reach to 2.51 at the northern end of the reach. The stability analysis data, as summarized in Tables 9 and 10, indicate a general trend of increasing bluff stability within this reach from south to north. Bluff safety factors reported in the 1977 study, also set forth in Table 9, ranged from 1.0 at the southern end of the reach to 0.7 at the northern end of the reach. The bluff safety factors determined based upon the 1995 study were generally equal to or greater than those reported in the 1977 study, indicating that the bluffs within Reach 5 had become generally more stable during the intervening period. Generally, there appeared to have been a shift from the largely unstable bluff slope conditions reported in the 1977 study to largely stable conditions observed during 1995. This increase in stability may be attributed to the construction of shoreline protection structures and to regrading of the bluff slopes within this reach. Of the seven bluff safety factors determined based upon 1995 conditions, five indicated stable conditions with respect to rotational failures; one indicated marginally stable conditions with respect to rotational failures; and one indicated unstable conditions with respect to rotational failures.

In 1995, beach widths within Reach 5 varied from nonexistent to 250 feet, as shown in Table 11. With the exception of the north-central portion of the reach, the beach widths within Reach 5 appeared to have remained stable or increased somewhat from the beach widths reported in the 1977 study or remained the same. In the north-central portion of the reach, however, the beach width decreased at two sites with no significant beach being present at one location where a beach of up to 65 feet in width was reported in the 1977 study. In general, the trend of decreasing beach width from south to north within the reach, reported in the 1977 study, was also observed during the 1995 field survey period.

The nearshore bathymetry documented in 1995 indicated a slight deepening of the nearshore lakebed profile in the central portion of the reach and a slight shallowing of the nearshore lakebed profile in the northern portion of the reach at the sites as compared to findings reported in the 1977 study, as shown in Table 12. In 1995, the nearshore lakebed material was noted to be sand at the two southern sites, grading to cobbles in the north within the reach. These materials are similar to those reported in the 1977 study.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally lower than those estimated during the 1977 study. Recession rates were measured at 13 sites within Reach 5 in 1995, and were found to range from zero to 1.2 feet per year for the period from 1963 through 1995, and from zero to one foot per year for the period from 1975 through 1995, with the lowest recession rates being found in the north-central portion of the reach. Long-term recession rate estimates reported in the 1977 study within Reach 5 ranged from one to five feet per year. The apparent decrease in the rate of shoreline recession within all but the south-central portion of this reach may be attributed to the maintenance and expansion of shoreline protection structures within portions of this reach since 1977.

Shoreline Reach 6: Village of Wind Point and Town of Caledonia, Racine County

Shoreline Reach 6 is a 12-mile-long reach of shoreline extending from the north line of U.S. Public Land Survey Section 28, Township 4 North, Range 23 East, Village of Wind Point, at Four Mile Road north to County Line Road extended on the north line of U.S. Public Land Survey Section 6, Township 4 North, Range 23 East, Town of Caledonia. In 1995, land uses along this reach include open spaces in Cliffside and Lake Michigan Parks, residential lands, and remnant agricultural lands, with the Oak Creek Power Plant, an industrial land use, being located at the northern extreme of the reach in Milwaukee County. As of 1995, about three linear miles, or about 50 percent, of the shoreline in Reach 6 were protected by structural shore protection measures, consisting of revetments and groins.

Bluff heights ranged from 20 to 100 feet, with the highest segments of bluff located in the central portions of Reach 6. Nineteen bluff profile sections were surveyed during the 1995 field survey period. Bluff safety factors determined during the 1995 study ranged from less than 1.0 at the southern and northern sections of the reach to over 2.0 at locations where structural bluff stabilization measures are in place in the central portion of the reach. No trends in bluff stability were apparent within this reach, although the central portions of the reach were somewhat more stable than the extremes. This is due, in part, to the placement of structural bluff stabilization measures at the Town of Caledonia's Lake Michigan Park and on the U.S. Army property in the north-central portion of the reach since 1977. Bluff safety factors reported in the 1977 study, also set forth in Table 9, ranged from 3.1 at the southern end of the reach to less than 1.0 in the northern section of the reach. The bluff safety factors determined based upon the 1995 study were generally equal to or greater than those reported in the 1977 study. Four, or 21 percent, of the factors were less than those reported in the 1977 study, while eight, or 42 percent, were greater than those reported in the 1977 study. Of the 19 bluff safety factors determined during 1995, 10, or 52 percent, indicated stable conditions with respect to rotational failures; seven, or 37 percent, indicated marginally stable conditions with respect to rotational failures; and two, or 11 percent, indicated unstable conditions with respect to rotational failures. The central portion of the reach remained the most stable portion.

In 1995, beach widths within Reach 6 varied from nonexistent to 150 feet, as shown in Table 11. In about half of this reach, the beach widths appeared to have decreased from the widths reported in the 1977 study. The general trend of decreasing beach width from south to north within the reach, reported in the 1977 study, was also observed during the 1995 field survey period, with the exception of the southern portion of the reach.

The nearshore bathymetry documented in 1995 indicated a significant shallowing in the bathymetric profile at the three profile sites, and some shallowing at the fourth site, as compared to findings reported in the 1977 study, as shown in Table 12. The three sites where the nearshore was found to be significantly more shallow are immediately north of Wind Point, the easterly most land form along the Southeastern Wisconsin shoreline which could be responsible for sand could having been deposited by the longshore drift.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally lower than those estimated during the 1977 study, especially in the southern portion of the reach. Recession rates were measured at 16 sites within Reach 6 in 1995, and were found to range from 0.6 to 9.1 feet per year for the period from 1963 through 1995, and from zero to eight feet per year for the period from 1975 through 1995. In the northern portions of the reach, the shoreline was estimated to be receding at a rate of between 3.5 and eight feet per year during these periods. Long-term recession rate estimates reported in the 1977 study within Reach 6 ranged from 0.8 to nine feet per year, with the greatest rate of shoreline recession occurring in the southernmost portion of the reach.

Shoreline Reach 7: City of Oak Creek, Milwaukee County

Shoreline Reach 7 is a five-mile-long reach of shoreline extending from the south line of U.S. Public Land Survey Section 36, Township 5 North, Range 23 East, City of Oak Creek, at County Line Road north to Addison Lane extended near the north line of U.S. Public Land Survey Section 24, Township 5 North, Range 22 East, City of Oak Creek. In 1995, land uses along this reach include open spaces in Bender Park situated in the central portion of the reach, residential lands in the north, remnant agricultural lands in the south, and industrial and commercial land uses at intervals throughout the reach. The Oak Creek Power Plant of the Wisconsin Electric Power Company was located at the southern extreme of the reach and the South Shore Sewage Treatment Plant of the Milwaukee Metropolitan Sewerage District at the northern extreme of the reach. As of 1995, about one linear mile, or about 35 percent, of the shoreline in Reach 7 were protected by structural shore protection measures, consisting of revetments, rubble fills, and groins.

Bluff heights ranged from 60 to 110 feet within Reach 7. Fourteen bluff profile sections were surveyed during the 1995 field survey period. Bluff safety factors determined during the 1995 study ranged from 1.59 at the southern end of the reach to 0.97 at the northern end of the reach, with a general decline in bluff safety factors through the reach since 1977. Bluff safety factors reported in the 1977 study, also set forth in Table 9, followed a similar pattern and ranged from 1.0 at the southern end of the reach to 0.54 at the northern end of the reach. The bluff safety factors determined based upon the 1995 study were generally equal to or greater than those reported in the 1977 study, although three, or 21 percent, of the factors were less than those reported in the 1977 study. Of the 14 bluff safety factors determined based upon 1995 conditions, eight, or 57 percent, indicated stable conditions with respect to rotational failures; two, or 14 percent, indicated marginally stable conditions with respect to rotational failures; and four, or 29 percent, indicated unstable conditions with respect to rotational failures. The southern portion of the reach remained the most stable portion.

In 1995, beach widths within Reach 7 varied from being nonexistent to 150 feet, as shown in Table 11. In about one-third of this reach, the beach widths appeared to have decreased from the widths reported in the 1977 study. The general trend of a relatively constant beach width from south to north within the reach, reported in the 1977 study, was not observed during the 1995 field survey period, with an increase in beach width being noted in the northern and south-central portions of the reach.

The nearshore bathymetry was not documented within Reach 7 in 1995.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were measured at nine sites within Reach 7 in 1995, and were found to range from 0.3 to 12.5 feet per year for the period from 1963 through 1995, and from one to eight feet per year for the period from 1975 through 1995. In the north-central portion of the reach, the shoreline was estimated in the 1995 study to be receding at a rate of between six and eight feet per year. Long-term recession rate estimates reported in the 1977 study within Reach 7 ranged from two to three feet per year, with the greatest rate of shoreline recession, in contrast to the 1995 observations, occurring in the southern portion of the reach.

Shoreline Reach 8: Cities of Cudahy, Oak Creek, St. Francis, and South Milwaukee, Milwaukee County

Shoreline Reach 8 is a 5.7-mile-long reach of shoreline extending from about Addison Lane extended, at the northern property line of the Milwaukee Metropolitan Sewerage District South Shore Sewage Treatment Plant, about 0.3 mile north of the south line of U.S. Public Land Survey Section 13, Township 5 North, Range 22 East, City of Oak Creek, north to E. Oklahoma Avenue extended on the north line of U.S. Public Land Survey Section 14, Township 6 North, Range 22 East, City of St. Francis. In 1995, land uses along this reach include open spaces, including Grant, Warnimont, Sheridan, and Bayview Parks situated in the central and northern portions of the reach; residential lands in the southern and northern portions of the reach, including limited areas with multi-family residential uses; and industrial and commercial land uses in the southern portion of the reach. The Milwaukee Metropolitan Sewerage District South Shore Sewage Treatment Plant was located at the southern extreme of the reach and the abandoned Wisconsin Electric Power Company Lakeside Power Plant at the northern extreme of the reach. The South Milwaukee Yacht Club harbor facilities were also located in the southern portion of this reach. As of 1995, about three linear miles, or about one-half, of the shoreline in Reach 8 were protected by structural shore protection measures, consisting of revetments, rubble fills, and groins, and, in the northern extreme of the reach, the southern portions of the breakwater system of the Port of Milwaukee.

Bluff heights ranged from 25 to 110 feet within Reach 8, diminishing from south to north within this reach. Forty-one bluff profile sections were surveyed during the 1995 field survey period. Bluff safety factors determined during the 1995 study ranged from 0.97 at the northern end of the reach to 1.84 at the southern end of the reach. The stability analysis data, as summarized in Tables 9 and 10, indicates a general trend of decreasing bluff stability within the reach from south to north. These values, set forth in Table 9, followed a similar pattern of distribution as that reported in the 1977 study, with the majority of bluff safety factors indicating less than stable conditions. Bluff safety factors determined during the 1977 study, also set forth in Table 9, ranged from 1.17 at the northern end of the reach to 1.48 at the southern end of the reach. The bluff safety factors determined based upon the 1995 study were equal to or greater than those reported in the 1977 study for much of the reach, although 30 percent of the bluff safety factors determined during the 1995 study were lower than those reported in the 1977 study. With the exception of short segments of the north-central portion of the reach, the bluff safety factors were generally less than 1.1. Of the 41 bluff safety factors determined during 1995, 10, or 24 percent, indicated stable conditions with respect to rotational failures; 12, or 29 percent, indicated marginally stable conditions with respect to rotational failures; and 19, or 47 percent, indicated unstable conditions with respect to rotational failures.

In 1995, beach widths within Reach 8 varied from nonexistent to 600 feet, as shown in Table 11. The beach widths within Reach 8 appeared to have increased from the widths reported in the 1977 study. The general trend of a relatively constant beach width from south to north within the reach, reported in the 1977 study, was not observed during the 1995 field survey period. These changes may be attributed to the changes in the extent of the shoreline protection structures which took place within the reach since 1977.

The nearshore bathymetry documented in 1995 indicated a general shallowing of the bathymetric profile at six of the nine sites, with the other three sites remaining the same, as compared to findings reported in the 1977 study, as shown in Table 12. In 1995, the nearshore lakebed material was noted to be sand in the southern portion of the reach, grading to sand and gravel through gravel to rocks and cobbles from south to north within the reach, except at one site in the north-central portion of the reach where the substrate was indicated to be silt. These substrates were similar to those reported during the 1977 study at most sites within this reach.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally the same or slightly lower than those estimated during the 1977 study. Recession rates were measured at 21 sites within Reach 8 during the 1995 study, and generally ranged from 0.3 to five feet per year, with one site in Grant Park estimated to have a recession rate of 10.3 feet per year, for the period from 1963 through 1995, and from zero to two feet per year during the period from 1975 through 1995. The same site in Grant Park was estimated to be receding at a rate of 15.5 feet per year during this period. Long-term recession rate estimates reported in the 1977 study within Reach 8 ranged from 0.3 to one foot per year.

Shoreline Reach 9: City of Milwaukee, Milwaukee County

Shoreline Reach 9 is a six-mile-long reach of shoreline extending from about E. Oklahoma Avenue extended at the south line of U.S. Public Land Survey Section 10, Township 6 North, Range 22 East, City of Milwaukee, north to Kenwood Boulevard extended on the north line of U.S. Public Land Survey Section 14, Township 7 North, Range 22 East, City of Milwaukee. In 1995, land uses along this reach include open spaces, including Bayview, Henry Meier Festival, Veterans, Juneau, McKinley, and Lake Parks; residential lands in the southern and northern portions of the reach, including areas with multi-family residential uses; and industrial and commercial land uses in the central portion of the reach. The Milwaukee Metropolitan Sewerage District Jones Island Sewage Treatment Plant and Port of Milwaukee were located in the central portion of the reach. The South Shore Yacht Club harbor facilities were located in the southern portion of this reach, and the Milwaukee Yacht Club and McKinley Marina harbor facilities were located in the northern portion of this reach. As of 1995, about six linear miles, or about 100 percent, of the shoreline in Reach 9 were protected by structural shore protection measures, consisting of bulkheads, revetments, rubble fills, and groins, and the offshore breakwater system approximately centered on the Milwaukee Harbor.

Bluff heights were about 25 feet in the southern portion of Reach 9. No natural segments of bluff existed in the northern portions of the reach, which were occupied by the Port of Milwaukee and related facilities. One bluff profile section was surveyed during the 1995 field survey period. The bluff safety factor determined during the 1995 study was 2.4. This value, set forth in Table 9, was higher than the bluff safety factor of 1.21 reported in the 1977 study and also set forth in Table 9. Both values indicated the bluff to be stable with respect to rotational failures within this reach.

In 1995, beach widths within Reach 9 varied from nonexistent to 170 feet, as shown in Table 11. The beach widths in the northern portion of Reach 9 appeared to have increased from the widths reported in the 1977 study. These changes may be attributed to the construction of shoreline protection structures within this reach since the 1977 study. The beach widths in the southern portion for Reach 9 appeared to be largely unchanged.

The nearshore bathymetry was not documented at any sites within Reach 9 in 1995.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally somewhat lower than those estimated during the 1977 study. Recession rates were measured at three sites within Reach 9 during the 1995 study, and were about one foot per year for the period from 1975 through 1995 in the southern portion of Section 15 of Town 7 North, Range 22 East. Long-term recession rate estimates reported in the 1977 study within Reach 9 were two feet per year.

Shoreline Reach 10: City of Milwaukee and Villages of Fox Point, Shorewood, and Whitefish Bay, Milwaukee County

Shoreline Reach 10 is a 6.5-mile-long reach of shoreline extending from about Kenwood Boulevard extended at the south line of U.S. Public Land Survey Section 10, Township 7 North, Range 22 East, City of Milwaukee, north to Bradley Road extended on the north line of U.S. Public Land Survey Section 16, Township 8 North, Range 22 East, Village of Fox Point. In 1995, land uses along this reach include open spaces, including Shorewood (Atwater), Buckley, Big Bay, Silver Spring, and Klode Parks and Shorewood Nature Preserve, and residential lands, including limited areas with multifamily residential uses. As of 1995, about six linear miles, or about 90 percent, of the shoreline in Reach 10 were protected by structural shore protection measures, consisting of revetments, rubble fills, and groins.

Bluff heights ranged from 70 to 120 feet within Reach 10. In the northern portions of this reach, the bluff was fronted by a natural bluff terrace which had a height of about 15 feet. Fourteen bluff profile sections were surveyed during the 1995 field survey period. Bluff safety factors determined during the 1995 study ranged from 1.27 at the southern end of the reach to 1.52 at the northern end of the reach. The stability analysis data, as summarized in Tables 9 and 10, indicates fairly uniform bluff safety factors within the reach, with the exception of the northern extremity of the reach which was found to have bluff safety factors of about 1.0. Bluff safety factors determined during the 1977 study, also set forth in Table 9, ranged from 1.1 at the northern end of the reach to 2.97 at the southern end of the reach. These data indicated a decreasing bluff stability between these extremes throughout the reach. Notwithstanding, the bluff safety factors determined based upon the 1995 study were equal to or greater than those reported in the 1977 study for much of the reach. Only two, or 14 percent, of the bluff safety factors determined in the 1995 study were lower than those reported in the 1977 study. With the exception of short portions at the extremes of the reach, the bluff safety factors were reported in the 1977 study were less than 1.1. In contrast, of the 14 bluff safety factors determined based upon 1995 conditions, nine, or 64 percent, indicated stable conditions with respect to rotational failures; three, or 21 percent, indicated marginally stable conditions with respect to rotational failures; and two, or 15 percent, indicated unstable conditions with respect to rotational failures. This change is due, in part, to the construction of shoreline protection structures and filling which has occurred at several properties within this reach.

In 1995, beach widths within Reach 10 varied from nonexistent to 150 feet, as shown in Table 11. Changes in the beach widths within the reach were variable at six of the 16 sections evaluated, a decrease in beach width was noted. Seven sections were indicated to have increased beach widths and five were found to be unchanged.

The nearshore bathymetry documented in 1995 indicated a general shallowing of the bathymetric profile at all but one of the four profile sites as compared to findings reported in the 1977 study, as shown in Table 12. In 1995, the nearshore lakebed material was noted to be sand throughout the reach, which was the same as that reported during the 1977 study.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally slightly lower than those estimated during the 1977 study. Recession rates were measured at 25 sites within Reach 10 during the 1995 study, and generally ranged from zero to 1.6 feet per year for the period from 1963 through 1995, and from zero to two feet per year during the period from 1975 through 1995. Long-term recession rate estimates reported in the 1977 study within the reach ranged from one to six feet per year. The apparent decrease in the rate of shoreline recession at selected locations within this reach may be attributed to the extent of shoreline protection structures measures within the reach.

Shoreline Reach 11: Villages of Bayside and Fox Point, Milwaukee County, and City of Mequon, Ozaukee County

Shoreline Reach 11 is a 3.5-mile-long reach of shoreline extending from about Bradley Road extended at the south line of U.S. Public Land Survey Section 10, Township 8 North, Range 22 East, Village of Fox Point in Milwaukee County, north to Ravine Drive extended at the mid-section line of U.S. Public Land Survey Section 28, Township 9 North, Range 22 East, City of Mequon in Ozaukee County. In 1995, land uses along this reach include open spaces, including Doctors and Virmond Parks and the Schlitz Audubon Center, and residential lands. As of 1995, about one linear mile, or about 30 percent, of the shoreline in Reach 11 was protected by structural shore protection measures, consisting of seawalls, revetments, rubble fills, and groins.

Bluff heights ranged from 80 to 140 feet within Reach 11, increasing from south to north within the reach. In the southern portions of this reach, the bluff was fronted by a natural bluff terrace with a height of about 15 feet. Nine bluff profile sections were surveyed during the 1995 field survey period. Bluff safety factors determined during the 1995 study ranged from 0.69 at the northern end of the reach to 1.86 at the southern end of the reach. The stability analysis data, as summarized in Tables 9 and 10, indicate a general trend of decreasing bluff stability within the reach from south to north. Bluff safety factors reported in the 1977 study, also set forth in Table 9, ranged from 0.69 at the northern end of the reach to 1.22 at the southern end of the reach. The bluff safety factors determined based upon the 1995 study were equal to or greater than those reported in the 1977 study for 67 percent of the sites evaluated, while 33 percent of the bluff safety factors determined in the 1995 study were lower than those reported in the 1977 study. With the exception of the southern portion of the reach, the bluff safety factors were generally less than 1.1. Of the nine bluff safety factors determined based upon 1995 conditions, four, or 44 percent, indicated stable conditions with respect to rotational failures; none indicated marginally stable conditions with respect to rotational failures; and five, or 56 percent, indicated unstable conditions with respect to rotational failures.

In 1995, beach widths within Reach 11 varied from nonexistent to 100 feet, as shown in Table 11. The beach widths within the reach appeared to be increased from the widths reported in the 1977 study. These changes may be attributed to the changes in the shoreline protection structures within the reach.

The nearshore bathymetry documented in 1995 indicated little change in the bathymetric profile at two profile sites as compared to findings reported in the 1977 study, as shown in Table 12. In 1995, the nearshore lakebed material was noted to be sand, which was the same as that reported in the 1977 study.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally lower than those estimated during the 1977 study, except in the southern portion of the reach where rates were higher. Recession rates were measured at 14 sites within Reach 11 during the 1995 study, and generally ranged from 0.3 to 2.5 feet per year for the period from 1963 through 1995, and from zero to one foot per year during the period from 1975 through 1995. Long-term recession rate estimates reported in the 1977 study within the reach ranged from 0.2 to one foot per year.

Shoreline Reach 12: City of Mequon and Town of Grafton, Ozaukee County

Shoreline Reach 12 is a 6.5-mile-long reach of shoreline extending from about Ravine Drive on the northern boundary of Virmond Park at the mid-section line of U.S. Public Land Survey Section 28, Township 9 North, Range 22 East, City of Mequon, north to Falls Road extended at the north section line of U.S. Public Land Survey Section 28, Township 10 North, Range 22 East, Town of Grafton in Ozaukee County. In 1995, land uses along this reach include residential and open space lands. As of 1995, about one linear mile, or about 10 percent, of the shoreline in Reach 12 was protected by structural shore protection measures, consisting of seawalls, revetments, rubble fills, and groins.

Bluff heights ranged from 80 to 140 feet within Reach 12. Twenty-five bluff profile sections were surveyed during the 1995 field survey period. Bluff safety factors determined during the 1995 study ranged from 0.57 at the southern end of the reach to 1.09 at the northern end of the reach. No trends were evident within these data, although bluff safety factors increased slightly in the central portion of the reach. These values, set forth in Table 9, followed a pattern of distribution similar to that reported in the 1977 study, with the majority of bluff safety factors indicating less than stable conditions. Bluff safety factors reported in the 1977 study, also set forth in Table 9, ranged from 0.68 at the southern end of the reach to 0.83 at the northern end of the reach. The bluff safety factors determined based upon the 1995 study were similar to those reported in the 1977 study for much of the reach, although about one-quarter of the bluff safety factors determined in the 1995 study were lower than those reported in the 1977 study. The bluff safety factors within the reach were generally less than 1.1. Of the 25 bluff safety factors determined based upon 1995 conditions, five, or 20 percent, indicated stable conditions with respect to rotational failures; nine, or 36 percent, indicated marginally stable conditions with respect to rotational failures; and 11, or 44 percent, indicated unstable conditions with respect to rotational failures.

In 1995, beach widths within Reach 12 varied from nonexistent to 100 feet, as shown in Table 11. The beach widths within Reach 12, with the exception of a single segment in the central portion of the reach, appeared to have remained unchanged or increased from the widths reported in the 1977 study.

The nearshore bathymetry was not documented within Reach 12 in 1995.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally lower than those estimated during the 1977 study. Recession rates were measured at 25 sites within Reach 12 during the 1995 study, and generally ranged from zero to 2.2 feet per year during the period from 1963 through 1995, and from zero to two feet per year during the period from 1975 through 1995. Long-term recession rate estimates reported in the 1977 study within Reach 12 ranged from two to three feet per year.

Shoreline Reach 13: City of Port Washington and Town of Grafton, Ozaukee County

Shoreline Reach 13 is a five-mile-long reach of shoreline extending from about Falls Road at the southern edge of U.S. Public Land Survey Section 21, Township 10 North, Range 22 East, Town of Grafton, Ozaukee County, north to the south edge of the Port Washington Harbor structure at the northern edge of U.S. Public Land Survey Section 33, Township 11 North, Range 22 East, City of Port Washington, Ozaukee County. In 1995, land uses in this reach included agricultural and residential lands and woodlands.

Bluff heights ranged from 100 to 130 feet within Reach 13. Eighteen bluff profile sections were surveyed during the 1995 field survey period. Bluff safety factors determined during the 1995 study ranged from 1.32 at the southern end of the reach to 0.88 at the northern end of the reach. No trends were evident within these data, which are set forth in Table 9. A majority of bluff safety factors indicated less than stable conditions. Bluff safety factors determined during 1977, also set forth in Table 9, ranged from 0.59 at the southern end of the reach to 0.81 at the northern end of the reach. The bluff safety factors determined based upon the 1995 study were generally equal to or greater than those reported in the 1977 study for much of the reach, with one exception where the bluff safety factor determined in the 1995 study was less than that reported in the 1977 study. The bluff safety factors within Reach 13 were generally less than 1.1. Of the 18 bluff safety factors determined based upon 1995 conditions, four, or 22 percent, indicated stable conditions with respect to rotational failures; six, or 33 percent, indicated marginally stable conditions with respect to rotational failures; and eight, or 45 percent, indicated unstable conditions with respect to rotational failures.

In 1995, beach widths within Reach 13 varied from nonexistent to 30 feet, as shown in Table 11. The beach widths within the reach were generally the same or, in the southern portion of the reach, narrower than the widths reported in the 1977 study. In the 1995 study, the beach width appeared to generally increase from south to north through the reach.

The nearshore bathymetry was not documented within Reach 14 in 1995.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally the same or lower than those estimated during the 1977 study. Recession rates were measured at 18 sites within Reach 13 during the 1995 study, and generally ranged from zero to 1.9 feet per year during the period from 1963 through 1995, and from zero to two feet per year during the period from 1975 through 1995, with the greatest rate of recession being noted in the central portion of the reach. Long-term recession rate estimates reported in the 1977 study within Reach 13 were two feet per year.

Shoreline Reach 14: City of Port Washington, Ozaukee County

Shoreline Reach 14 is a 0.5-mile-long reach of shoreline extending from the southern boundary of U.S. Public Land Survey Section 28, Township 11 North, Range 22 East, City of Port Washington, 0.5 mile north to the mid-section line about 200 feet north of the Port Washington Harbor. The entire southern portion of the shoreline in Reach 14 was occupied by the City of Port Washington Power Plant, while the northern portion was occupied by the Port Washington Harbor. The shoreline within this reach was completely protected by a variety of shoreline protection structures, including revetments, bulkheads, and a breakwater system centered on Port Washington Harbor.

This shoreline reach contained no significant segments of bluff with the majority of the shoreline consisting of a gently sloping beach and a low sand dune ridge and swale complex. Since no significant segments of bluff existed, bluff slope stability analyses were not conducted within this reach.

There were no significant beaches found within Reach 14 in 1995 or in the 1977 study.

The nearshore bathymetry was not documented within Reach 14 in 1995.

Shoreline recession rates were not estimated during the 1995 study or the 1977 study for Reach 14.

Shoreline Reach 15: Town of Port Washington, Ozaukee County

Shoreline Reach 15 is a five-mile-long reach of shoreline extending from about 200 feet north of the Port Washington Harbor, north to about CTH P at the southern line of U.S. Public Land Survey Section 36, Township 12 North, Range 23 East, Village of Belgium. In 1995, land uses along this reach included open spaces in Lake Park and residential lands mixed with undeveloped lots and agricultural lands. The entire shoreline in Reach 15 was fronted by a lake terrace which protected the bluff from erosion.

Bluff height ranged from about 85 to 120 feet within Reach 15. Fourteen bluff profile sections were surveyed during the 1995 field survey period. Bluff safety factors determined during the 1995 study ranged from 1.07 at the southern end of the reach to 1.47 at the northern end of the reach. No trends were evident within these data, which are set forth in Table 9, although the north-central and south-central portions of the reach tended to have lower bluff safety factors in comparison to the northern, southern, and central portions of the reach. About half of bluff safety factors indicated less than stable conditions. Bluff safety factors reported in the 1977 study, also set forth in Table 9, ranged from 1.0 at the northern end of the reach to 1.21 at the southern end of the reach. The bluff safety factors determined based upon the 1995 study were generally equal to or greater than those reported in the 1977 study for much of the reach, with the exception of three of the sites where the bluff safety factors determined in the 1995 study were lower than those reported in the 1977 study. Of the 14 bluff safety factors determined based upon 1995 conditions, six, or 43 percent, indicated stable conditions with respect to rotational failures; five, or 36 percent, indicated marginally stable conditions with respect to rotational failures; and three, or 21 percent, indicated unstable conditions with respect to rotational failures.

In 1995, beach widths within Reach 15 varied from 10 to 100 feet, as shown in Table 11, with the widest beaches located in the south-central portion of the reach. The beach widths found within the reach were generally the same or greater than the beach widths reported in the 1977 study. During the 1995 field survey period, the beach widths appeared to generally increase from the southern to south-central portion of the reach, then decrease to north, increasing again in the northernmost portion of the reach.

The nearshore bathymetry documented in 1995 indicated a shallowing of the bathymetric profile at two profile sites where data were gathered during the 1995 study, as shown in Table 12. In 1995, the nearshore lakebed material was noted to be sand in the southern portion of the reach and sand and cobbles in the northern portion of the reach. These data indicate a possible coarsening of the nearshore lakebed materials in the northern portion of the reach when compared to the 1977 study, which reported sand throughout the reach.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally lower than those estimated during the 1977 study. Recession rates were measured at 18 sites within Reach 15 during the 1995 study, and generally ranged from zero to 1.6 feet per year during the period from 1963 through 1995, and from zero to 2.5 feet per year during the period from 1975 through 1995, with the greatest rate of recession rates being noted in the central portion of the reach. Long-term recession rate estimates reported in the 1977 study within Reach 15 were one foot per year.

Shoreline Reach 16: Town of Belgium, Ozaukee County

Shoreline Reach 16 is a three-mile-long reach of shoreline extending from about CTH P at the south line of U.S. Public Land Survey Section 36, Township 12 North, Range 23 East, Town of Belgium, north to about CTH D at the northern boundary of Harrington Beach State Park at the southern line of U.S. Public Land Survey Section 19, Township 12 North, Range 23 East, Village of Belgium. In 1995, land uses along this reach comprised open space and recreational uses at Harrington Beach State Park and residential lands mixed with undeveloped tracts. As of 1995, nearly the entire shoreline in Reach 16, except for the central and southern portions of the parkland and the southern edge and northern end of the reach which contained exposures of resistant dolomite bedrock, was protected by shoreline protection structures. Existing structures generally consisted of various types protecting either individual properties or short reaches incorporating more than one property. The most common shore protection measures in this reach were riprap and revetments.

This shoreline reach contained no significant segments of bluff, with the majority of the shoreline consisting of a gently sloping beach, and a low sand dune ridge and swale complex. Since the existing natural bluffs in the reach were set well back from the lake shore and separated from the shoreline by an extensive bluff terrace, bluff slope stability analyses were not conducted within this reach.

In 1995, beach widths within Reach 16 varied from nonexistent to 150 feet, as shown in Table 11, with the widest beaches located in the northern portion of the reach. The beach widths found within Reach 16 in the 1995 study were generally greater than the beach widths reported in the 1977 study. During the 1995 study, the beach width appeared to increase from the southern to the northern portions of the reach.

The nearshore bathymetry was not documented within Reach 16 in 1995.

Shoreline recession rates as estimated in 1995, and set forth in Appendix A, were generally greater than that estimated during the 1977 study. Recession rates were measured at eight sites within Reach 16 during the 1995 study, and generally ranged from zero to 2.5 feet per year during the period from 1963 through 1995, and from zero to one foot per year during the period from 1975 through 1995. Long-term recession rate estimates reported in the 1977 study within Reach 16 were 0.1 foot per year.

Shoreline Reach 17: Town of Belgium, Ozaukee County

Shoreline Reach 17 is a 3.5-mile-long reach of shoreline extending from about CTH D at the northern edge of Harrington Beach at the south line of U.S. Public Land Survey Section 18, Township 12 North, Range 23 East, Town of Belgium, north to about CTH K at the Ozaukee-Sheboygan county line on the south line of U.S. Public Land Survey Section 31, Township 13 North, Range 23 East, Town of Belgium. In 1995, land uses along this reach were comprised almost entirely of existing residences mixed intermittently with undeveloped lots and agricultural uses. As of 1995, about two linear miles, or about 70 percent, of the shoreline in Reach 17 were protected by structural shore protection measures, consisting of mainly revetments and riprap.

This shoreline reach contained no significant segments of bluff with the majority of the shoreline consisting of a gently sloping beach, and a low sand dune ridge and swale complex. Since the existing natural bluffs within the reach were set well back from the lake shore and separated from the shoreline by an extensive bluff terrace, bluff slope stability analyses were not conducted within this reach.

In 1995, beach widths within Reach 17 varied from 30 to 100 feet, as shown in Table 11. The beach widths found in the 1995 study within Reach 17 were generally greater than the beach widths reported in the 1977 study.

The nearshore bathymetry was not documented within Reach 17 in 1995.

Shoreline recession rates estimated in 1995, set forth in Appendix A, were generally greater than those estimated during the 1977 study. Recession rates were measured at 17 sites within Reach 17 during the 1995 study, and generally ranged from zero to 4.1 feet per year during the period from 1963 through 1995, and from zero to three feet per year during the period from 1975 through 1995, with the greatest rates of recession being noted in the northern and southernmost extremities of the reach. Long-term recession rate estimates reported in the 1977 study within Reach 17 were 0.1 to 0.2 foot per year.

SUMMARY

Inventory and Analysis Procedures

The analyses of Lake Michigan shoreline conditions and bluff stability conducted under this planning program were based upon measurements made on comparable large-scale, ratioed and rectified, aerial photographs taken in 1963, 1970, 1975, and 1995, to Regional Planning Commission specifications utilizing the Commission horizontal survey control network. In addition, the inventory and analysis was based upon oblique aerial photographs obtained over the period of 1963 through 1995; large-scale topographic mapping of the Lake Michigan shoreline also prepared to Commission standards between 1976 through 1993; and extensive field surveys conducted in 1995. For analytical purposes the data obtained in the inventories was organized and analyzed on the basis of 17 shoreline analysis reaches which were established to divide the approximately 77 miles of shoreline within Southeastern Wisconsin into reaches each having relatively uniform bluff, beach and shoreline structure characteristics. The inventory data were used to analyze and describe the following shoreland conditions as of 1995:

- Bluff stability at 184 bluff profile field survey sites.
- Beach widths for 189 shoreland segments.
- Nearshore bathymetry and nearshore lakebed materials composition at 33 sites.
- Shoreline recession rates at 239 sites located at approximately one-quarter mile intervals.

The 1995 conditions data and analysis were also compared to the historic conditions data developed in a 1977 study[13] of the Lake Michigan shoreline conditions.

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[13]*D.M. Mickelson et al., 1977, op. cit.*

A similar study was conducted by the Bay-Lake Regional Planning Commission for the portions of the Lake Michigan shoreline north of Ozaukee County. The findings and recommendations of this study, and of the Bay-Lake Commission study are intended to provide current technical data useful in the definition of, and the development of solutions to, bluff stability and shoreline recession problems along the Lake Michigan shoreline.

Bluff Stability

Bluff stability based upon calculated factors of safety is summarized in Tables 9 and 10, and is shown graphically on Map 95. In general, the data obtained during the 1995 study indicate that much of the Lake Michigan shoreline was in a more stable condition in 1995 than reported in the 1977 study. A summary of the results of the 1995 conditions bluff stability analysis indicates the following:

- At 80 sites, or 43 percent of the sites, the bluffs were found to be stable.
- At 47 sites, or 26 percent of the sites, the bluffs were found to be marginally stable.
- At 57 sites, or 31 percent of the sites, the bluffs were found to be unstable.

A comparison of the 1995 stability analyses to the analyses results reported in the 1977 study indicates the following for the sites where comparable data were reported in the 1977 study:

- At 72 sites, or 47 percent of the sites, the bluff stability was found to be more stable.
- At 69 sites, or 45 percent of sites, the bluff stability was found to be unchanged.
- At 13 sites, or 8 percent of sites, the bluff stability was found to be less stable.

In many cases the apparent increase in bluff stability may be attributed to the construction of shoreline protection structures and/or bluff regrading. This is most apparent in the shorelines through Kenosha and Racine Counties. Significant portions of the Lake Michigan shoreline, however, particularly in the northern shoreline in the Southeastern Wisconsin Region, continue to be at risk, especially during periods of high lake levels. In this regard, 26 sites, or 46 percent of all of the unstable sites, were located within Ozaukee County and the same number were located in the areas which were not protected by the breakwater system within Milwaukee County. Of the sites where the bluffs were indicated to be less stable in 1995 based upon comparison with the data reported in the 1977 study, six sites, or 46 percent of the sites, were located in Milwaukee County; and four sites, or 31 percent of the sites, were located in Ozaukee County.

Beach Widths

Beach widths are summarized in Table 11, and are shown graphically on Map 95. One of the factors to be considered in comparing data on beach widths is the differences in Lake Michigan lake levels between the 1977 study and the 1995 study. As noted in Chapter III, lake levels in the summer of 1976, the period of field survey for the 1977 study, were about one foot higher than the lake levels in the summer of 1995, the period of field survey for this 1995 study. Given the beach slopes in Southeastern Wisconsin, this difference in water levels can account for between five to 20 feet of beach width. Given this difference and the potential variation in observation due to wave and seiche effects, beach widths with a difference of less than 20 feet between those reported in the 1977 study and those observed in 1995 were reported as unchanged. A summary of the beach widths determined based upon 1995 conditions compared to those reported in the 1977 study is presented below:

- The 1995 beach widths were found to be greater than the reported 1977 conditions at 91 sites, or 48 percent of the sites at which comparable data were available based upon the 1977 study.
- The 1995 beach widths were found to be the same or similar to the reported 1977 conditions at 69 sites, or 37 percent of sites at which comparable data were available based upon the 1977 study.
- The 1995 beach widths were found to be narrower than the 1977 conditions at 28 sites, or 15 percent of sites at which comparable data were available based upon the 1977 study.

Thus, the data indicate that in a little less than half of the sites evaluated, the beach widths were indicated to be increasing.

These changes may also be attributed, in part, to the long-term buildup of material behind structures which extend lakeward, such as groin systems, major harbor area protection structures, or lakeward extending land forms. Such structures are more prevalent on the Kenosha, Racine, and southern Milwaukee County shorelines than in northern Milwaukee County and Ozaukee County. The largest beach width increases were more prevalent in the former or southern portion of the shoreline. The largest beach width increases were noted to be located within groin systems, or north of major structures. The changes in beach widths may be attributed to the presence of major shoreline protection structures which extend some distance lakeward of the natural shoreline of Lake Michigan and which may be expected to trap material in the littoral drift. As an example, the reconstruction of the Racine Harbor Marina breakwater in 1983 to 1984 appears to have increased sand deposition along the shoreline immediately north of the harbor.

While the installation of structural shoreline protection measures has increased beach widths, such measures may be expected over time to reduce the amount of beach-building material available in the littoral drift. The trapping of the material by such structural measures can cause a lack of material down drift of the structures. These conditions appear to exist, to some extent, based upon the following observations regarding the data presented in Table 11:

- Only two of the seven sites within the two southernmost reaches, located south of the Kenosha Harbor, were found to have increased beach widths, with both sites being located within groin systems. Two sites in those reaches were found to have decreased beach widths.

- Within Racine County, only five, or 18 percent of the sites evaluated, showed increased beach widths. Those sites were located north of the Racine Harbor breakwater and the Wind Point land form.

- For Kenosha, Racine, and Ozaukee Counties, 78, or 59 percent of the sites evaluated, were found to have the same or narrower beach widths in 1995 than those reported in the 1977 study.

Nearshore Bathymetric Characteristics

The nearshore lakebed observations are summarized in Table 12, and are shown graphically on Map 95. In general, the data obtained during the 1995 study indicated no clear trend in the nearshore bathymetry in comparison with the data reported in the 1977 study. In the case of this data set, it should be noted that comparable data for both the 1995 and 1977 studies were available at only 28 sites. Moreover, as already noted, the lake levels during the 1977 field survey were about one foot higher than during the 1995 field survey. Because of this, and because of the inherent differences in the data sets due to lake seiche and wave effects, only differences in offshore distances of greater than 10 percent and greater than 20 feet were considered to be indicative of physical changes. These changes include:

- At 15 sites, or 54 percent of the sites at which comparable data were available, a general decrease in depth of the nearshore waters was found.

- At nine sites, or 32 percent of sites at which comparable data were available, no change in the nearshore depth was found.

- At four sites, or 14 percent of sites at which comparable data were available, a general deepening of the nearshore depth was found.

The sites which showed the greatest decrease in offshore water depths were located just north of Wind Point in Racine County, where such a trend would be expected due to littoral drift deposition.

Nearshore lakebed materials were generally found to be the same in 1995 as were reported in the 1977 study. However, changes in lakebed materials were noted at eight, or about one-third of sites where comparable data was available. The 1995 data indicate a trend toward the presence of sand in those areas where the distance offshore to the five feet lakebed depth increased in the southernmost reaches. Change in nearshore materials were noted at three locations in Milwaukee and Ozaukee Counties, indicating the lakebed materials to be more coarse.

Although based upon relatively few data, these observations are consistent with the potential deposition of sands being carried south within Lake Michigan by the longshore drift. However, the deposition of sands within the Region may not be representative of natural shoreline building processes within Lake Michigan. Rather, the deposition pattern may be attributed to the presence of shoreline protection structures, especially in the southern portions of the shoreline in Southeastern Wisconsin. These data on nearshore conditions, combined with the beach width data discussed above, support observations made during the 1995 field surveys where sand was observed to be accreting to the north, and, often, eroding to the south, of structures, such as groins and breakwaters, and land forms, such as Wind Point.

Bluff Recession

Bluff recession rates are summarized in Appendix A, and are shown graphically for the period between 1975 through 1995 on Map 95. In general, the data obtained during the 1995 study indicated a decrease in the rate of shoreline recession in comparison with the long-term recession rate data reported in the 1977 study. Findings with respect to a comparison of recession rates determined for the period 1963 through 1995 with the long-term recession rates reported in the 1977 study include:

- For 39 analysis sections, or 62 percent of the sections within which comparable data were available, a decrease in the rate of shoreline recession was indicated.

- For eight analysis sections, or 13 percent of the sections within which comparable data were available, no significant change in the rate of shoreline recession was indicated.

- For 16 analysis sections, or 25 percent of the sections within which comparable data were available, an increase in the rate of shoreline recession was indicated.

Findings with respect to a comparison of recession rates determined for the period 1975 through 1995 with long-term recession rate estimates reported in the 1977 study include:

- For 49 analysis sections, or 78 percent of the sections within which comparable data were available, or at 10 more sites than reported for the period from 1963 through 1995, a decrease in the rate of shoreline recession was indicated.

- For eight analysis sections, or 13 percent of the sections within which comparable data were available, or at the same number of sites as reported for the period from 1963 through 1995, no change in shoreline recession was indicated.

- For six analysis sections, or 9 percent of the sections within which comparable data were available, or 10 fewer sites than reported for the period from 1963 through 1995, an increase in the rate of shoreline recession was indicated.

These data indicated that the long-term shoreline recession rates determined during the 1977 study generally were greater than the more current rates of recession found during the 1995 study and, consequently, may be assumed to represent a conservative estimate of the rate of recession based upon a partial period of analysis where none, or limited shoreline protection measures were in place. This is particularly the case in the southern portions of the Region where shoreline protection measures have been constructed. The earlier data are more consistent with the current data on the rate of shoreline loss in the northern portions of the Region where shoreline protection structures have not been constructed, especially in Ozaukee County. In some cases, the current data indicate an increase in the recession rates in this northern portion of the shoreline. These data are consistent with the observations, set forth above, of a general decline in bluff slope stability from south to north within the Region that, through the process of shoreland loss, contributes to the general southward movement of particles within Lake Michigan.

The greatest number of changes in shoreline recession rates was observed south of the Port of Milwaukee and in northern Ozaukee County, with the rates of recession during the period from 1963 through 1995 generally being higher than the long-term recession rates reported in the 1977 study. In many cases, the elevated rates of shoreline recession reported for the period from 1963 through 1995 indicated that most of the recession took place prior to 1975, especially in the southern portions of the Region, where the rates of recession determined during the 1995 study for the period between 1975 and 1995 were generally less than those reported in the 1977 study and for the period from 1963 through 1995. Such a finding is inexplicable, in that water levels which occurred from 1970 through 1987 were at all time highs. However, in some cases, the findings reflect a period of no or reduced recession following placement of structural protection measures and bluff regrading. Typically, the average recession rate for the shorter, and latest, period of from 1975 to 1995 would be most impacted in such cases, resulting in lower estimates than made for longer and earlier periods.

Review of the data indicates that the Commission-estimated rates of shoreline recession in the Southeastern Wisconsin Region for the period between 1963 through 1995 represent the most appropriate basis upon which to plan for the coastal areas within the Region. In the case of areas where changes in shoreline protection structures have occurred between 1963 and 1965, the use of the shoreline recession rates estimated for the period between 1975 through 1995 should be considered.

Analytic Methods for Predicting Long-Term Bluff Stability

As part of this shoreline recession and bluff stability study, historic data on bluff characteristics were collated and new data were collected and analyzed to evaluate the predictive capabilities of four methods for estimating Lake Michigan bluff slope stability. The four methods concerned, together with the findings of the comparative evaluation, are described in a report entitled, *Effectiveness of Analysis Methods for Predicting Long Term Slope Stability on the Lake Michigan Shoreline*, dated December 1996, and prepared by Geotechnical Consultants John A. Chapman, Tuncer B. Edil, and David M. Mickelson. The four methods evaluated were the Deterministic Bishop's Method; the probabilistic Bishop's Method, termed the Monte Carlo Simulation of Bishop's Method; the Deterministic Infinite Slope Analysis Method; and the probabilistic Infinite Slope Analysis Method, termed the First Order Second Moment Simulation of Infinite Slope Method.

Each of the aforedescribed four models were determined to provide reasonably accurate predictions of bluff failure. The Bishop's Method-based models were successful in predicting bluff stability in about 70 percent of cases when used as a deterministic model, and in about 80 percent of cases when used as a probabilistic model. The Infinite Slope Analysis Method-based models were successful in predicting bluff stability in about 85 percent of cases whether used as a deterministic or as a probabilistic model. When all four models were used to describe the bluff conditions for the specific site or shoreline section, the combined result was found to be successful in predicting the stability of the bluff slope in about 90 percent of cases. It may be further concluded that the Bishop's Method should be used where rotational failures are expected, and the Infinite Slope Analysis Method should be used when shallow failures, or translational failures, are expected. In the case of the Bishop's Method, the best results can be expected when the probabilistic method is used to supplement the deterministic analyses in cases where the calculated safety factor values are within the margins of the defined stability criteria. In contrast, the use of the probabilistic application of the Infinite Slope Analysis Method does not appear to result in more accurate predictions if used to supplement the deterministic application of that model.

CONCLUSION

The inventory of Lake Michigan shoreline conditions and bluff stability conducted during this planning program and summarized graphically in Map 95 has indicated that much of the Lake Michigan shoreline was in a more stable condition during the 1995 field surveys than during the 1977 study and other previous studies. This may be attributed to the placement of shoreline protection structures in the southern portion of the Southeastern Wisconsin Region and the regrading of unstable bluff slopes. Notwithstanding this achievement, portions of the Lake Michigan shoreline, particularly in the northern portion of the Southeastern Wisconsin Region, continue to be at risk, especially during future periods of higher lake levels. The study identified a need for continued monitoring of the shoreline, especially in those reaches with relatively high unprotected bluffs and where shoreline protection structures are in need of maintenance, failing or failed, and where shoreline protection structures have been placed in isolated situations and are likely cause differential erosion processes acting on unprotected portions of the shoreline in the vicinity of those structures.

The data and analyses presented herein will serve as a data base for system-level shoreland development and preservation planning programs. The data and shoreline recession for the periods 1963 through 1995 and 1975 through 1995, as summarized in Appendix A, and the bluff stability data set forth in Tables 9 and 10, are intended to be useful in defining the risk of shoreline erosion in the future and for developing system-level land use and preservation plans for the Lake Michigan shoreline reaches. However, it should be noted that shoreline erosion evaluations and project designs for properties or analysis sections will require the collection and analysis of more detailed site-specific geotechnical and coastal engineering data.

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APPENDICES

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Appendix A

LAKE MICHIGAN SHORELINE RECESSION DATA

Table A-1

LAKE MICHIGAN SHORELINE RECESSION DATA: 1963-1995

County	Shoreline Analysis Reach and U.S. Public Land Survey Township, Range, and Section	Shoreline Recession Data						
		1963-1995		1970-1995		1975-1995		1977 Erosion Study (feet per year)
		Total (feet)	Average Annual (feet per year)	Total (feet)	Average Annual (feet per year)	Total (feet)	Average Annual (feet per year)	
Kenosha	Reach 1							
	T1N, R23E, Section 32	0	0.0	0	0	0	0	10
	T1N, R23E, Section 32	60	1.9	40	1.6	20	1	- -
	T1N, R23E, Section 32	50	1.6	20	0.8	20	1	12
	T1N, R23E, Sections 29 and 32	20	0.6	0	0	30	1.5	9
	T1N, R23E, Section 30	50	1.6	-10	-0.4	10	0.5	- -
	T1N, R23E, Section 29	130	4.1	40	1.6	0	0	12
	T1N, R23E, Section 30	160	5.0	0	0	10	0.5	- -
	T1N, R23E, Sections 20 and 29	30	0.9	20	0.8	0	0	7
	T1N, R23E, Section 19	40	1.2	20	0.8	10	0.5	- -
	T1N, R23E, Section 20	40	1.2	20	0.8	10	0.5	3
	T1N, R23E, Section 20	130	4.1	60	2.4	0	0	- -
	T1N, R23E, Sections 17 and 20	80	2.5	20	0.8	10	0.5	5
	T1N, R23E, Section 17	130	4.1	120	4.8	10	0.5	- -
	T1N, R23E, Section 17	40	1.2	30	1.2	30	1.5	5
	T1N, R23E, Section 17	40	1.2	10	0.4	0	0	- -
	T1N, R23E, Sections 7 and 18	110	3.4	40	1.6	0	0	2
	T1N, R23E, Section 7	190	5.9	90	3.6	0	0	- -
	T1N, R23E, Section 7	60	1.9	30	1.2	30	1.5	4
	T1N, R23E, Section 8	40	1.2	20	0.8	0	0	- -
	Reach 2							
	T1N, R23E, Section 5	40	1.2	10	0.4	10	0.5	- -
	T1N, R23E, Section 5	50	1.5	20	0.8	0	0	6
	T1N, R23E, Section 5	30	0.9	10	0.4	0	0	- -
	T1N, R23E, Section 5	20	0.6	10	0.4	10	0.5	- -
	Reach 3							
	T2N, R23E, Section 30	40	1.2	20	0.8	-10	-0.5	- -
	T2N, R23E, Sections 19 and 30	10	0.3	0	0.0	0	0.0	4
	T2N, R23E, Section 19	20	0.6	10	0.4	10	0.5	- -
	T2N, R23E, Section 19	30	0.9	10	0.4	0	0.0	2
	T2N, R23E, Section 19	70	2.2	40	1.6	20	1.0	- -
	T2N, R23E, Sections 18 and 19	40	1.2	10	0.4	10	0.5	3
	T2N, R23E, Section 18	130	4.1	40	1.6	30	1.5	3
	T2N, R23E, Section 18	50	1.6	20	0.8	10	0.5	- -
	T2N, R23E, Sections 7 and 18	90	2.8	60	2.4	50	2.5	3
	T2N, R23E, Section 7	100	3.1	40	1.6	40	2.0	- -
	T2N, R23E, Section 7	120	3.8	50	2.0	30	1.5	3
	T2N, R23E, Section 8	170	5.3	90	3.6	50	2.5	- -
	T2N, R23E, Sections 5 and 8	70	2.2	40	1.6	30	1.5	2
	T2N, R23E, Section 5	60	1.9	20	0.8	0	0.0	- -
	T2N, R23E, Section 5	140	4.4	70	2.8	30	1.5	3
	T2N, R23E, Section 5	100	3.1	40	1.6	20	1.0	- -
	T2N, R23E, Section 5	60	1.9	50	2.0	10	0.5	- -
	T3N, R23E, Section 32 and T2N, R23E, Section 5	30	0.9	20	0.8	10	0.5	3
Racine	Reach 3							
	T3N, R23E, Section 32	60	1.9	10	0.4	10	0.5	- -
	T3N, R23E, Section 32	50	1.6	10	0.4	0	0.0	- -
	T3N, R23E, Section 32	40	1.2	20	0.8	10	0.5	- -
	T3N, R23E, Sections 29 and 32	80	2.5	50	2.0	0	0.0	2
	T3N, R23E, Section 29	30	0.9	0	0.0	0	0.0	4
	T3N, R23E, Section 29	30	0.9	30	1.2	10	0.5	- -
	T3N, R23E, Section 28	30	0.9	30	1.2	20	1.0	- -

Table A-1 (continued)

County	Shoreline Analysis Reach and U.S. Public Land Survey Township, Range, and Section	Shoreline Recession Data						
		1963-1995		1970-1995		1975-1995		1977 Erosion Study (feet per year)
		Total (feet)	Average Annual (feet per year)	Total (feet)	Average Annual (feet per year)	Total (feet)	Average Annual (feet per year)	
Racine (continued)	Reach 4							
	T3N, R23E, Section 21	70	2.2	70	2.8	20	1.0	2
	T3N, R23E, Section 21	40	1.2	40	1.6	10	0.5	- -
	T3N, R23E, Section 21	50	1.6	30	1.2	20	1.0	
	T3N, R23E, Sections 16 and 21	10	0.3	0	0.0	0	0.0	2
	T3N, R23E, Section 16	20	0.6	20	0.8	0	0.0	- -
	T3N, R23E, Section 16	10	0.3	10	0.4	0	0.0	- -
	Reach 5							
	T3N, R23E, Sections 4 and 9	0	0.0	0	0.0	0	0.0	5
	T3N, R23E, Section 4	10	0.3	20	0.8	20	1.0	- -
	T3N, R23E, Section 4	10	0.3	10	0.4	10	0.5	- -
	T3N, R23E, Section 4	10	0.3	0	0.0	0	0.0	- -
	T3N, R23E, Section 4	20	0.6	20	0.8	0	0.0	1
	T4N, R23E, Section 33 and T3N, R23E, Section 3	20	0.6	20	0.8	20	1.0	1
	T4N, R23E, Section 33	0	0.0	0	0.0	0	0.0	- -
	T4N, R23E, Section 33	30	0.9	30	1.2	0	0.0	- -
	T4N, R23E, Section 33	0	0.0	0	0.0	0	0.0	3
	T4N, R23E, Sections 27 and 34	30	0.9	10	0.4	0	0.0	1
	T4N, R23E, Section 27	10	0.3	0	0.0	0	0.0	- -
	T4N, R23E, Section 27	40	1.2	30	1.2	10	0.5	- -
	T4N, R23E, Section 27	40	1.2	40	1.6	0	0.0	- -
	Reach 6							
	T4N, R23E, Sections 22 and 27	20	0.6	0	0.0	10	0.5	9
	T4N, R23E, Section 22	50	1.6	20	0.8	0	0.0	- -
	T4N, R23E, Section 21	90	2.8	10	0.4	10	0.5	- -
	T4N, R23E, Section 21	60	1.9	50	2.0	40	2.0	2
	T4N, R23E, Sections 16 and 21	20	0.6	20	0.8	10	0.5	2
	T4N, R23E, Section 16	50	1.6	30	1.2	10	0.5	- -
	T4N, R23E, Section 16	50	1.6	50	2.0	0	0.0	- -
	T4N, R23E, Section 17	40	1.2	30	1.2	30	1.5	1
	T4N, R23E, Sections 8 and 17	30	0.9	20	0.8	10	0.5	2
	T4N, R23E, Section 8	100	3.1	100	4.0	80	4.0	- -
	T4N, R23E, Section 7	150	4.7	130	5.2	100	5.0	- -
	T4N, R23E, Section 7	190	5.9	150	6.0	70	3.5	- -
	T4N, R23E, Sections 6 and 7	220	6.9	140	5.6	120	6.0	3/0.8
	T4N, R23E, Section 6	290	9.1	280	11.2	160	8.0	- -
	T4N, R23E, Section 6	210	6.6	200	8.0	120	6.0	- -
	T4N, R23E, Section 6			Not Measured				
Milwaukee	Reach 7							
	T5N, R23E, Sections 30 and 31			Not Measured				- -
	T5N, R22E, Section 36	90	2.8	60	2.4	40	2.0	- -
	T5N, R22E, Section 36	40	1.2	20	0.8	20	1.0	- -
	T5N, R22E, Sections 25 and 36	10	0.3	-10	-0.4	-10	-0.5	3.0
	T5N, R22E, Section 25	200	6.2	190	7.6	120	6.0	- -
	T5N, R22E, Section 25	140	4.4	130	5.2	120	6.0	- -
	T5N, R22E, Section 25	190	5.9	180	7.2	130	6.5	- -
	T5N, R22E, Sections 23 and 26	400	12.5	310	12.4	160	8.0	2.0
	T5N, R22E, Sections 23 and 24			Not Measured				- -
	T5N, R22E, Sections 23 and 24			Not Measured				- -
	T5N, R22E, Section 24	60	1.9	30	1.2	20	1.0	- -
	Reach 8							
	T5N, R22E, Sections 13 and 14			Not Measured				- -
	T5N, R22E, Section 13	30	0.9	10	0.4	0	0.0	0.7
	T5N, R22E, Section 14	40	1.2	40	1.6	20	1.0	- -
	T5N, R22E, Sections 11 and 14	10	0.3	10	0.4	0	0.0	0.7
	T5N, R22E, Section 12	40	1.2	10	0.4	10	0.5	- -
	T5N, R22E, Section 12			Not Measured				- -
	T5N, R22E, Section 12	40	1.2	30	1.2	20	1.0	- -
	T5N, R22E, Sections 2 and 11	130	4.1	10	0.4	10	0.5	1.0

Table A-1 (continued)

County	Shoreline Analysis Reach and U.S. Public Land Survey Township, Range, and Section	Shoreline Recession Data						
		1963-1995		1970-1995		1975-1995		1977 Erosion Study (feet per year)
		Total (feet)	Average Annual (feet per year)	Total (feet)	Average Annual (feet per year)	Total (feet)	Average Annual (feet per year)	
Milwaukee (continued)	Reach 8 (continued)							
	T5N, R22E, Section 2	330	10.3	310	12.4	310	15.5	- -
	T5N, R22E, Section 2	70	2.2	30	1.2	20	1.0	- -
	T5N, R22E, Section 2	70	2.2	30	1.2	20	1.0	1.0
	T6N, R22E, Section 35 and T5N, R22E, Section 2	40	1.2	20	0.8	20	1.0	1.0
	T6N, R22E, Section 35	60	1.9	20	0.8	10	0.5	- -
	T6N, R22E, Section 35	50	1.6	20	0.8	10	0.5	- -
	T6N, R22E, Section 35	70	2.2	30	1.2	20	1.0	- -
	T6N, R22E, Sections 26 and 35	130	4.1	80	3.2	40	2.0	- -
	T6N, R22E, Section 26	10	0.3	10	0.4	0	0.0	- -
	T6N, R22E, Section 26	90	2.8	20	0.8	10	0.5	0.3
	T6N, R22E, Section 26	20	0.6	10	0.4	0	0.0	- -
	T6N, R22E, Section 24	50	1.6	50	2.0	20	1.0	1.0
	T6N, R22E, Section 23	30	0.9	30	1.2	20	1.0	- -
	T6N, R22E, Section 23	110	3.4	80	3.2	40	2.0	- -
	T6N, R22E, Section 23	160	5.0	120	4.8	40	2.0	- -
	T6N, R22E, Section 14	Not Measured						
	Reach 9							
	T6N, R22E, Sections 3, 4, and 10	Not Measured						
	T7N, R22E, Sections 28 and 33	Not Measured						
	T7N, R22E, Section 22	Not Measured						
	T7N, R22E, Sections 15 and 22	30	0.9	30	1.2	20	1.0	2
	T7N, R22E, Section 15	70	2.2	40	1.6	20	1.0	- -
	T7N, R22E, Section 15	20	0.6	0	0.0	-20	-1.0	- -
	T7N, R22E, Section 15	Not Measured						
	T7N, R22E, Sections 13 and 14	Not Measured						
	Reach 10							
	T7N, R22E, Sections 10 and 14	20	0.6	0	0.0	0	0.0	- -
	T7N, R22E, Section 10	20	0.6	20	0.8	10	0.5	- -
	T7N, R22E, Section 10	30	0.9	10	0.4	10	0.5	- -
	T7N, R22E, Section 10	40	1.2	20	0.8	20	1.0	- -
	T7N, R22E, Sections 3 and 10	40	1.2	10	0.4	10	0.5	2
	T7N, R22E, Section 3	20	0.6	20	0.8	10	0.5	- -
	T7N, R22E, Section 3	0	0.0	-10	-0.4	-10	-0.5	- -
	T7N, R22E, Section 3	50	1.6	40	1.6	40	2.0	- -
	T7N, R22E, Section 3	-30	-0.9	-30	-1.2	-30	-1.5	3
	T8N, R22E, Section 33	10	0.3	10	0.40	10	0.5	- -
	T8N, R22E, Section 33	-50	-1.6	-50	-2.0	-50	-2.5	- -
	T8N, R22E, Section 33	0	0.0	0	0.0	0	0.0	- -
	T8N, R22E, Sections 28 and 33	-90	-2.8	-90	-3.6	-70	-3.5	2
	Reach 12							
	T8N, R22E, Section 28	10	0.3	0	0.0	0	0.0	- -
	T8N, R22E, Section 28	10	0.3	10	0.4	10	0.5	- -
	T8N, R22E, Section 28	30	0.9	0	0.0	0	0.0	- -
	T8N, R22E, Sections 21 and 28	20	0.6	0	0.0	0	0.0	- -
	T8N, R22E, Section 21	60	1.9	10	0.4	20	1.0	- -
	T8N, R22E, Section 21	40	1.2	30	1.2	20	1.0	2
	T8N, R22E, Section 21	20	0.6	10	0.4	0	0.0	- -
	T8N, R22E, Sections 16 and 21	30	0.9	20	0.8	20	1.0	6
	T8N, R22E, Section 16	10	0.3	0	0.0	0	0.0	- -
	T8N, R22E, Section 16	10	0.3	0	0.0	0	0.0	- -
	T8N, R22E, Section 16	80	2.5	50	2.0	30	1.5	- -
	Reach 11							
	T8N, R22E, Sections 9 and 16	10	0.3	10	0.4	0	0.0	1
	T8N, R22E, Section 9	10	0.3	10	0.4	-10	-0.5	- -
	T8N, R22E, Section 9	10	0.3	10	0.4	10	0.5	- -
	T8N, R22E, Section 9	20	0.6	20	0.8	0	0.0	- -
	T8N, R22E, Sections 4 and 9	10	0.3	10	0.4	0	0.0	1

Table A-1 (continued)

County	Shoreline Analysis Reach and U.S. Public Land Survey Township, Range, and Section	Shoreline Recession Data: 1963-1995 Total (feet)	1963-1995 Average Annual (feet per year)	1970-1995 Total (feet)	1970-1995 Average Annual (feet per year)	1975-1995 Total (feet)	1975-1995 Average Annual (feet per year)	1977 Erosion Study (feet per year)
Milwaukee (continued)	Reach 11 (continued)							
	T8N, R22E, Section 4	50	1.6	50	2.4	20	1.0	- -
	T8N, R22E, Section 4	40	1.2	40	1.6	10	0.5	- -
	T8N, R22E, Section 4	50	1.6	40	1.6	20	1.0	- -
Ozaukee	Reach 11							
	T9N, R22E, Section 33 and T8N, R22E, Section 4	70	2.1	50	2.0	20	1.0	0.2
	T9N, R22E, Section 33	40	1.2	10	0.4	0	0.0	- -
	T9N, R22E, Section 33	40	1.2	0	0.0	0	0.0	- -
	T9N, R22E, Section 33	40	1.2	0	0.0	0	0.0	- -
	T9N, R22E, Sections 28 and 33	40	1.2	0	0.0	0	0.0	- -
	T9N, R22E, Section 28	100	3.1	20	0.8	0	0.0	- -
	T9N, R22E, Section 28	20	0.6	10	0.4	10	0.5	- -
	T9N, R22E, Section 28	30	0.9	30	1.2	30	1.5	- -
	Reach 12							
	T9N, R22E, Sections 21 and 28	70	2.2	60	2.4	30	1.5	- -
	T9N, R22E, Section 20	20	0.6	10	0.4	10	0.5	2.0
	T9N, R22E, Section 20	40	1.2	20	0.8	0	0.0	- -
	T9N, R22E, Section 20	0	0.0	0	0.0	0	0.0	- -
	T9N, R22E, Sections 17 and 20	20	0.6	0	0.0	0	0.0	- -
	T9N, R22E, Section 17	10	0.3	10	0.4	0	0.0	- -
	T9N, R22E, Section 17	10	0.3	10	0.4	10	0.5	- -
	T9N, R22E, Section 17	10	0.3	0	0.0	0	0.0	- -
	T9N, R22E, Sections 8 and 17	10	0.3	10	0.4	10	0.5	3.0
	T9N, R22E, Section 8	20	0.6	20	0.8	10	0.5	- -
	T9N, R22E, Section 8	40	1.2	40	1.6	30	1.5	- -
	T9N, R22E, Section 8	10	0.3	0	0.0	10	0.5	- -
	T9N, R22E, Sections 5 and 8	0	0.0	0	0.0	0	0.0	3.0
	T9N, R22E, Section 5	40	1.2	40	1.6	10	0.5	- -
	T9N, R22E, Section 5	50	1.6	50	2.0	40	2.0	- -
	T9N, R22E, Section 5	70	2.2	60	2.4	30	1.5	- -
	T9N, R22E, Section 5	20	0.6	20	0.8	20	1.0	- -
	T10N, R22E, Section 33	30	0.9	20	0.8	20	1.0	- -
	T10N, R22E, Section 33	40	1.2	20	0.8	20	1.0	- -
	T10N, R22E, Section 33	20	0.6	10	0.4	10	0.5	- -
	Reach 13							
	T10N, R22E, Sections 28 and 33	30	0.9	20	0.8	20	1.0	3
	T10N, R22E, Section 28	30	0.9	20	0.8	20	1.0	
	T10N, R22E, Section 28	10	0.3	20	0.8	40	2.0	
	T10N, R22E, Section 28	50	1.6	10	0.4	0	0.0	- -
	T10N, R22E, Sections 21 and 28			Not Measured				
	T10N, R22E, Section 21	30	0.9	20	0.8	10	0.5	
	T10N, R22E, Section 21	10	0.3	10	0.4	10	0.5	- -
	T10N, R22E, Section 21	30	0.9	20	0.8	10	0.5	- -
	T10N, R22E, Sections 16 and 21	0	0.0	0	0.0	0	0.0	
	T10N, R22E, Section 16	10	0.3	10	0.4	10	0.5	- -
	T10N, R22E, Section 16	50	1.6	20	0.8	10	0.5	- -
	T10N, R22E, Section 16	0	0.0	0	0.0	0	0.0	- -
	T10N, R22E, Sections 10 and 15	60	1.9	40	1.6	40	2.0	2
	T10N, R22E, Section 10	50	1.6	40	1.6	40	2.0	- -
	T10N, R22E, Section 10	10	0.3	0	0.0	0	0.0	- -
	T10N, R22E, Section 10			Not Measured				
	T10N, R22E, Sections 3 and 10	10	0.3	10	0.4	10	0.5	2
	T10N, R22E, Section 3	20	0.6	10	0.4	10	0.5	- -
	T10N, R22E, Section 3	10	0.3	0	0.0	0	0.0	
	T10N, R22E, Section 3	20	0.6	10	0.4	10	0.5	- -
	T10N, R22E, Section 4	0	0.0	0	0.0	0	0.0	
	T11N, R22E, Section 33	20	0.6	20	0.8	10	0.5	
	T11N, R22E, Section 33	20	0.6	20	0.8	10	0.5	- -
	T11N, R22E, Section 33	20	0.6	10	0.4	10	0.5	

Table A-1 (continued)

County	Shoreline Analysis Reach and U.S. Public Land Survey Township, Range, and Section	Shoreline Recession Data						
		1963-1995		1970-1995		1975-1995		1977 Erosion Study (feet per year)
		Total (feet)	Average Annual (feet per year)	Total (feet)	Average Annual (feet per year)	Total (feet)	Average Annual (feet per year)	
Ozaukee (continued)	Reach 14							
	T11N, R22E, Sections 28 and 33	50	1.6	10	0.4	0	0.0	- -
	Reach 15							
	T11N, R22E, Section 28	30	0.9	10	0.4	10	0.5	- -
	T11N, R22E, Sections 21 and 28	10	0.3	10	0.4	10	0.5	- -
	T11N, R22E, Section 22	10	0.3	10	0.4	10	0.5	- -
	T11N, R22E, Section 22	0	0.0	0	0.0	0	0.0	
	T11N, R22E, Section 22	10	0.3	10	0.4	10	0.5	- -
	T11N, R22E, Section 15 and 22	20	0.6	10	0.4	10	0.5	- -
	T11N, R22E, Section 15	40	1.2	20	0.8	10	0.5	- -
	T11N, R22E, Section 14	0	0.0	0	0.0	0	0.0	- -
	T11N, R22E, Section 14	50	1.6	50	2.0	50	2.5	- -
	T11N, R22E, Sections 11 and 14	50	1.6	50	2.0	50	2.5	- -
	T11N, R22E, Section 11	10	0.3	10	0.4	10	0.5	- -
	T11N, R22E, Section 11	20	0.6	10	0.4	10	0.5	- -
	T11N, R22E, Section 11	30	0.9	0	0.0	0	0.0	- -
	T11N, R22E, Sections 2 and 11	0	0.0	0	0.0	0	0.0	1
	T11N, R22E, Section 1	40	1.2	40	1.6	20	1.0	- -
	T11N, R22E, Section 1	20	0.6	20	0.8	10	0.5	
	T11N, R22E, Section 1	30	0.9	60	2.4	30	1.5	- -
	Reach 16							
	T12N, R22E, Section 36	0	0.0	0	0.4	0	0	- -
	T12N, R22E, Section 36	10	0.3	10	0.4	10	0.5	- -
	T12N, R22E, Section 36	30	0.9	30	1.2	20	1.0	- -
	T12N, R22E, Section 36	0	0.0	0	0	0	0.0	- -
	T12N, R22E, Sections 25 and 36	50	1.6	30	1.2	10	0.5	0.1
	T12N, R23E, Section 30	10	0.3	10	0.4	0	0.0	- -
	T12N, R23E, Section 30	30	0.9	0	0.0	20	1.0	- -
	T12N, R23E, Section 30	10	0.3	10	0.4	10	0.5	- -
	T12N, R23E, Sections 19 and 30	40	1.2	20	0.8	10	0.5	
	T12N, R23E, Section 19	30	0.9	30	1.2	10	0.5	- -
	T12N, R23E, Section 19	80	2.5	80	3.2	40	2.0	- -
	T12N, R23E, Section 19	50	1.6	30	1.2	0	0.0	- -
	Reach 17							
	T12N, R23E, Sections 18 and 19	35	1.1	35	1.4	15	0.8	- -
	T12N, R23E, Section 18	20	0.6	10	0.4	0	0.0	- -
	T12N, R23E, Section 18	10	0.3	60	2.4	0	0.0	
	T12N, R23E, Section 18	0	0.0	0	0	0	0	- -
	T12N, R23E, Sections 7 and 18	40	1.2	10	0.4	10	0.5	0.1
	T12N, R23E, Section 7	20	0.6	10	0.4	0	0.0	- -
	T12N, R23E, Section 7	90	2.8	80	3.2	20	1.0	- -
	T12N, R23E, Section 7	0	0.0	40	1.6	0	0.0	- -
	T12N, R23E, Sections 6 and 7	45	1.4	15	0.6	5	0.2	
	T12N, R23E, Section 6	40	1.2	10	0.4	0	0.0	- -
	T12N, R23E, Section 6	40	1.2	30	1.2	10	0.5	
	T12N, R23E, Section 6	70	2.2	20	0.8	10	0.5	- -
	T12N, R23E, Section 6	130	4.1	100	4.0	60	3.0	0.2

Source: J.A. Chapman, T.B. Edil, D.M. Mickelson, and SEWRPC.