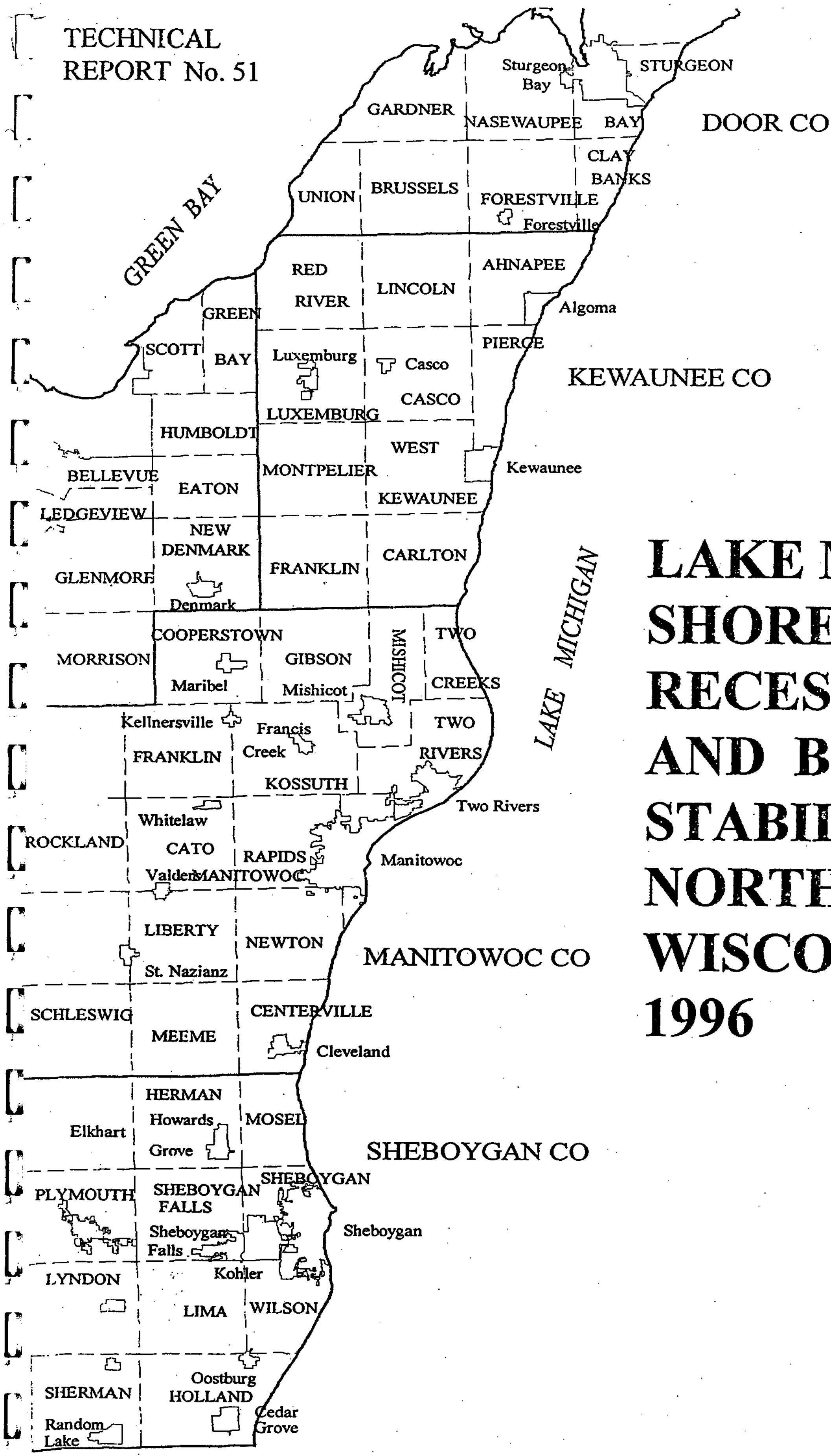
TECHNICAL REPORT No. 51



LAKE MICHIGAN SHORELINE RECESSION AND BLUFF STABILITY IN NORTHEASTERN WISCONSIN: 1996

BAY-LAKE REGIONAL PLANNING COMMISSION

PRELIMINARY DRAFT

TECHNICAL REPORT

LAKE MICHIGAN SHORELINE RECESSION AND BLUFF STABILITY IN NORTHEASTERN WISCONSIN: 1996

Prepared by the:

Bay-Lake Regional Planning Commission
211 North Broadway
Old Fort Square Suite 211
Green Bay, Wisconsin 54303
Project Manager - Dale W. Mohr
Research Assistant - Alex M. Jerabek
and
Geotechnical Consultants:
John A. Chapman
Tuncer B. Edil
David M. Mickelson

In Cooperation with the

WISCONSIN COASTAL
MANAGEMENT PROGRAM

The preparation of this report was financed in part by the Wisconsin Coastal Management Program under the Coastal Zone Management Act of 1972, administered by the Federal Office of Coastal Zone Management, National Oceanic and Atmospheric Administration.

March 1997

TABLE OF CONTENTS

LAKE MICHIGAN SHORELINE RECESSION AND BLUFF STABILITY IN NORTHEASTERN WISCONSIN: 1996

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 Northeastern Wisconsin were surveyed in a number of studies conducted in 1977[1] , 1980[2] , and 1988.[3] 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 Seashore 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 (SEWRPC) 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. The Bay-Lake Regional Planning Commission (BLRPC) was a joint applicant in receiving Federal funding to conduct a somewhat similar study for the shoreline of Lake Michigan in Northeastern Wisconsin. Bay-Lake's study, though less detailed, would be used to compare existing bluff conditions along the shoreline of Lake Michigan with those reported conditions in earlier studies.

The information gained from this study would be published in similar forms by both Commissions. Three separate documents will be produced under this study. The Southeastern Wisconsin Regional Planning Commission's document details the findings and recommendations for the four coastal counties in Southeastern Wisconsin--Kenosha, Racine, Milwaukee, and Ozaukee. This document details the findings and recommendations for the four coastal counties in Northeastern Wisconsin--Sheboygan, Manitowoc, Kewaunee, and Door. The third document

---

[1] D. M. Mickelson, L. Acomb, N. Brouwer, T. Edil, C. Fricke, B. Haas, D. Hadlev, C. Hess, R. Klauk, N. Lasca, and A.F. Schneider, Shore Erosion Study, Technical Report Appendix 5, 6, Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin, Wisconsin Coastal Management Program, February 1977.

[2] D. M. Mickelson, L. Acomb, N. Brouwer, T. Edil, C. Fricke, B. Haas, D. Hadlev, C. Hess, R. Klauk, N. Lasca, and A.F. Schneider, Shore Erosion Study, Technical Report 7, Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin, Wisconsin Coastal Management Program, July 1980.

[3] Bay-Lake Regional Planning Commission, Kewaunee County Coastal Hazard Management Plan , August 1988.

details the results of two methods used to project erosion of the bluffs and determine their stability for the coastlines in both Southeastern and Northeastern Wisconsin.

Together these three 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 Northeastern Wisconsin consists of the lands along the Lake Michigan shoreline in Sheboygan, Manitowoc, Kewaunee, and Door Counties. The coastal area for Northeastern Wisconsin extends approximately 77 miles from the Sheboygan-Ozaukee county line to the Kewaunee-Door county line.

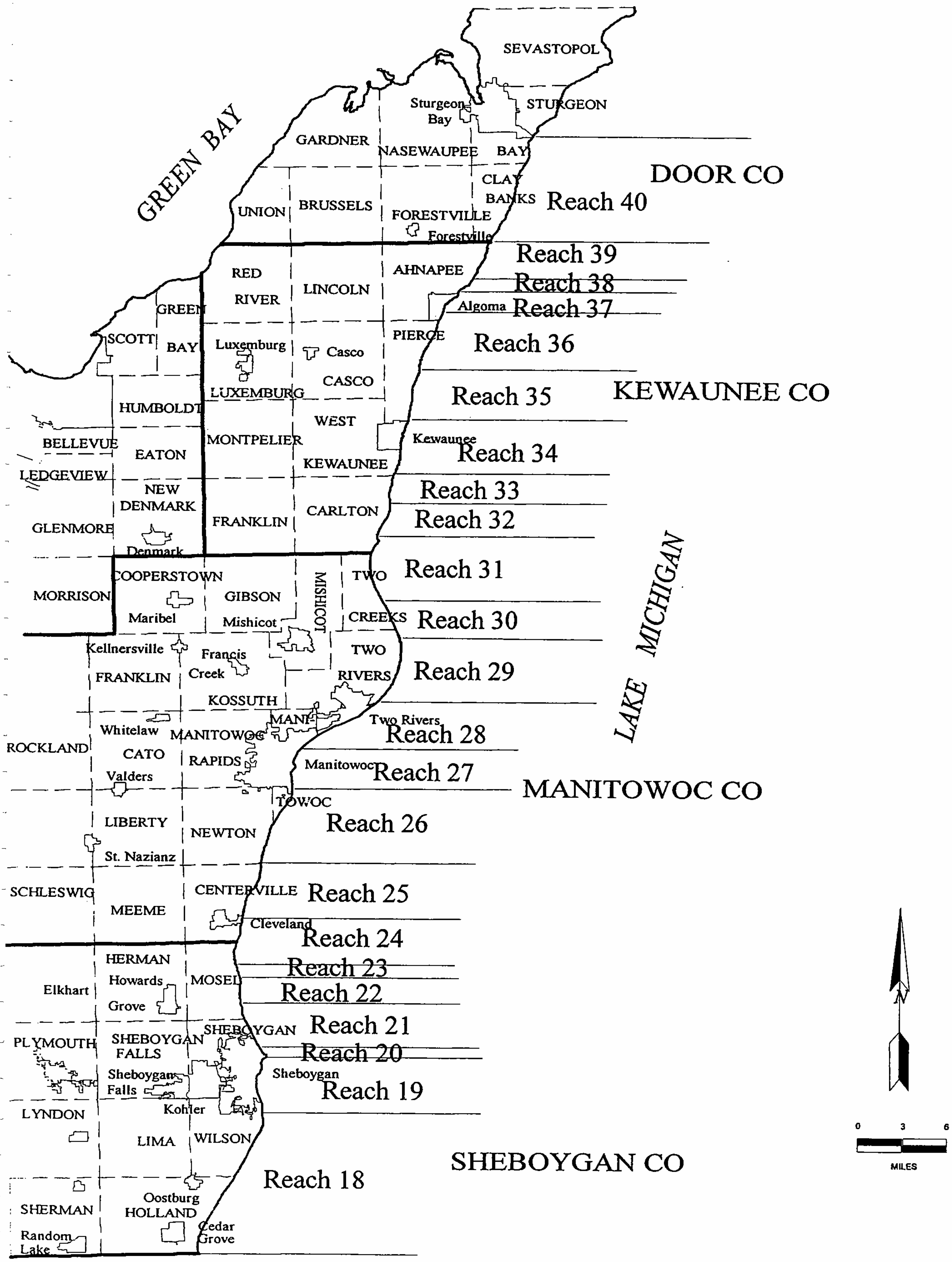
For analytical purposes, the Lake Michigan shoreline was divided into 23 reaches, as shown on Map I-1. These reaches were selected so as to have relatively uniform beach and bluff characteristics. These reaches generally correspond to those utilized in the aforereferenced 1977 shoreline erosion study, with some refinement to reflect current conditions.

The portions of Sheboygan, Manitowoc, Kewaunee, and Door 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.

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 1976 through 1996, average annual bluff recession rates ranged up to over 8.0 feet in Northeastern Wisconsin. 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.

Map I-1
Lake Michigan Shoreline Reaches in the Northeastern Wisconsin Region



Source: Bay-Lake Regional Planning Commission, 1997.

In Northeastern Wisconsin, the most recent comprehensive study of shoreline erosion and bluff stability conditions and processes was conducted in 1977 and 1980.[4] Subsequently, additional data were obtained for the Kewaunee County coastline in 1988.[5]

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 re-inventory of shoreline erosion and bluff stability was deemed to be desirable. The re-inventory 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 Northeastern Wisconsin. The following section identifies and briefly describes the 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 Five, Sheboygan County; Appendix Seven, Northern Manitowoc, Kewaunee, and Door County; and Appendix Six, Southern and Central Manitowoc County; Wisconsin Coastal Management Program, 1977.

   An inventory of the shoreline conditions within the entire Northeastern Wisconsin Region was conducted in 1976 by a number of coastal technical consultants under the Wisconsin Coastal Management Program. The shoreline in Northeastern Wisconsin was divided into 23 reaches, each reach having similar physical and erosion-related characteristics. Bluff slope stability analyses were conducted under the study for 124 sites within the Northeastern 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-- shoreline recession rates.

[4] D. M. Mickelson et al., op. cit.

[5] Bay-Lake Regional Planning Commission, Kewaunee County Coastal Hazard Management Plan, August 1988.

2. BLRPC, Kewaunee County Coastal Hazard Management Plan , August 1988.

   In an attempt to document the existing and probable future coastal concerns of shoreline property owners, the Commission staff developed and transmitted a Shoreline Property Owners Questionnaire to all Kewaunee County shoreline property owners. The results of the Shoreline Property Owners Questionnaire clearly indicate that a coastal erosion problem exists in Kewaunee County, as 73 percent of the respondents stated that shoreline erosion was a problem on their property. Further, nearly 60 percent of the shoreline property owners reported losing more than 11 feet of coastal property in recent years. Nearly 55 percent of the respondents reported bluff slumping on their property.

PURPOSES AND SCOPE

The purposes of the Northeastern 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 1996;
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 findings and conclusions of the study.

LAKE MICHIGAN SHORELINE RECESSION AND BLUFF STABILITY IN NORTHEASTERN WISCONSIN: 1996

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

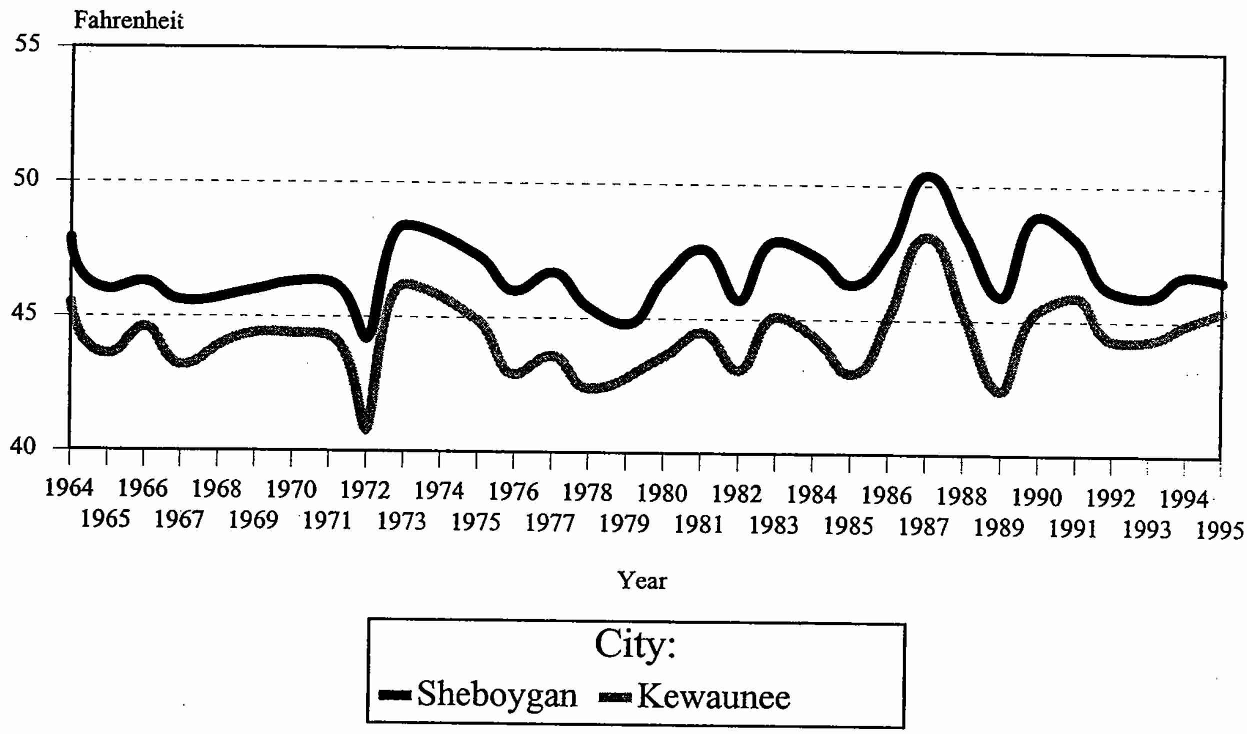
Air temperature impacts primarily include the formation of ice on the lake, the initiation of freeze-thaw actions in soils, and a contribution to increased stormwater runoff rates over frozen soils. Fig. II-1, presents average monthly air temperature variations at two stations located near the Lake Michigan shoreline for the 32-year period from 1964 through 1995. As shown in the figure, temperatures reported at the two stations varied from one another by two to five degrees The coldest years were 1972 and 1989.

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.

Fig. II-1

Mean Annual Temperature Record

Western Shore, Lake Michigan (1964-1995)



Source: National Oceanic Atmosperic Administration; Bay-Lake Regional Planning Commission, 1997

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 Lake Michigan, 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 Northeastern 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^{o} 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 maintaining 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 events may latter cause severe bluff and beach erosion. Mean annual precipitation ranged from about 19.5 to 38.3 for the two stations located near Lake Michigan, as shown in Fig. II-2.

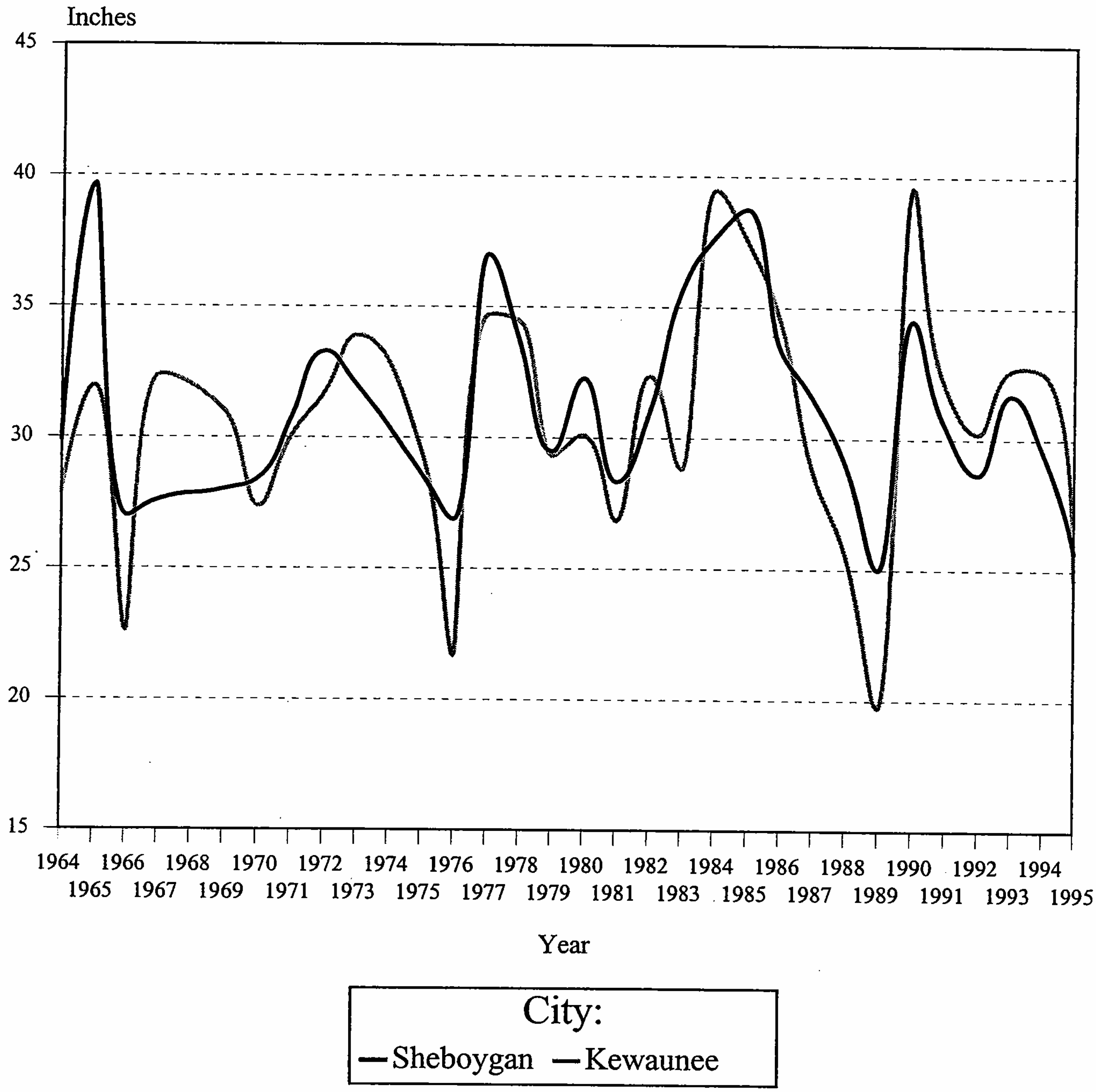
Extreme precipitation events may result in massive shoreland losses due to high levels of erosion, fluidization due to increased seepage, and slumping. A one-hour storm with an expected average recurrence interval of once every two years may be expected to have a total rainfall of about 1.2 inches. A 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 1964 through

Fig II-2

Precipitation Record

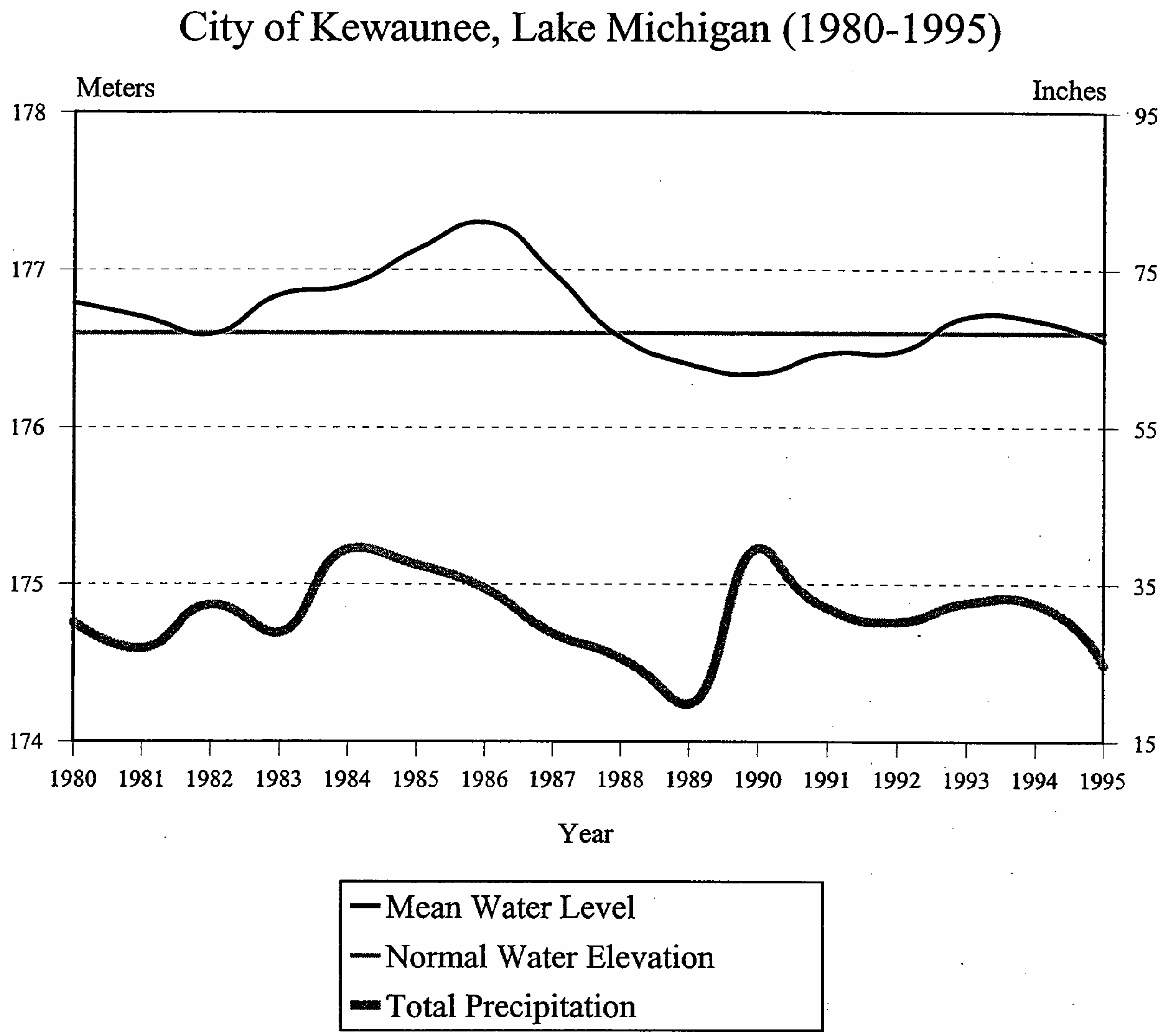
Western Shore, Lake Michigan (1964-1995)



Source: National Oceanic Atmospheric Administration; Bay-Lake Regional Planning Commission, 1997

Fig II-3

Precipitation, Water Levels



Source: U.S. Army Corps of Engineers; National Oceanic Atmospheric Administration; Bay-Lake Regional Planning Commission, 1997

1995, the maximum annual amount of precipitation at Sheboygan was 39.3 inches (1965) and . at Kewaunee was 38.7 inches (1990). The lowest precipitation recordings at Sheboygan and Kewaunee took place in 1989. In late 1986, a total of over 16 inches of precipitation fell during August and September 1986. This period included a rainfall event far more severe than any recorded in the coastal region. 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 Northeastern Wisconsin and throughout the Lake Michigan drainage area was a rapid rise in the level of the Lake. A comparrison of the normal water elevation, mean water levels, and precipitation total is detailed in Fig. II-3.

Wind

Wind can also contribute to shoreland losses, both directly and indirectly through its effect on the Lake surface. Prevailing winds in the Green Bay area are from the southwest, as shown in Fig. II-4.[1] The wind speed has a velocity of about 12 miles per hour (mph) on a long-term average basis at Green Bay. At Milwaukee, the wind speed velosity is about 11 miles per hour (mph) and the prevailing winds are from the north-northwest. At Green Bay the winds are calm approximately four percent of the time, and peak gusts of up to 56 mph occur on an average annual basis. The highest recorded wind velocity at Green Bay was 81 mph observed in May 1989. At Milwaukee the winds are calm approximately two 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.

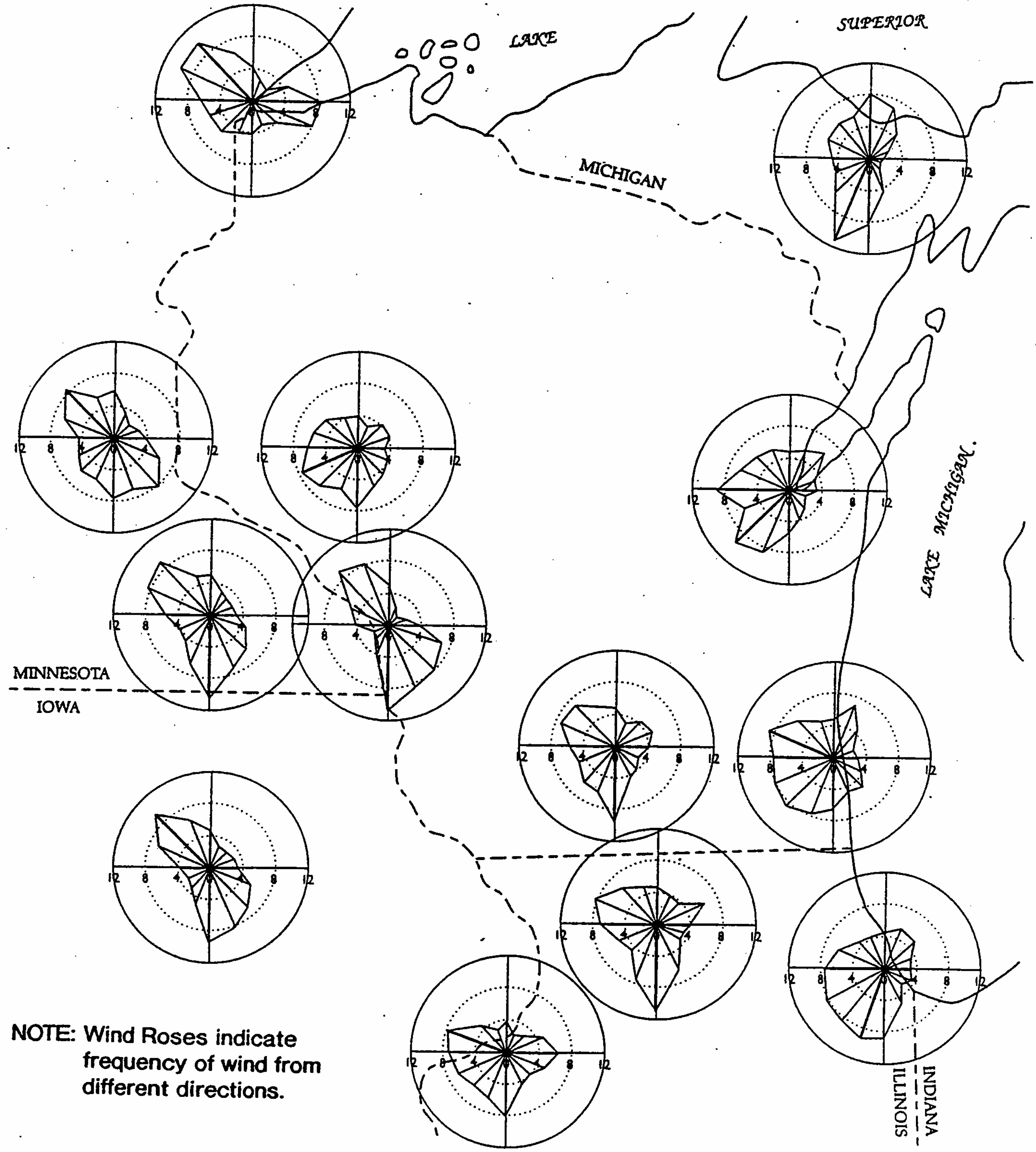
At the Milwaukee station, during the winter months--November through March, the prevailing winds generally blow from the west-northwest at an average velocity of about 13 mph. Conditions range from calm, experienced about one percent of the time, to peak gusts of about 45 mph on an average annual basis. 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 two 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 three 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.

At the Green Bay station, during the winter months--November through February, the prevailing winds generally blow from the west at an average velocity of about 11 mph. In March the prevailing winds come from the northeast at an average velocity of about 12 mph. Conditions range from calm, experienced about three percent of the time, to peak gusts of about 57 mph on an average annual basis. During spring and early summer--April through June, the prevailing winds remain from the northeast until June when they return to south-southwest which range between 10

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

Fig II-4

ANNUAL WIND ROSES FOR SELETED SITES



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

Source: Wisconsin Geological and Natural History Survey

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 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 II-5 details the annual mean water level for Lake Michigan, recorded at Sturgeon Bay and at Kewaunee for the period from 1980 through 1995. The historic low annual mean lake level at Sturgeon Bay--176.35 feet occurred in 1990. The historic high annual mean lake level--177.79 feet occurred in 1986. The historic record low and record high annual mean lake levels at Sturgeon Bay differ by 1.44 feet. The average annual lake level elevation was 176.75 feet.

The historic low annual mean lake level at Kewaunee--176.34 feet occurred in 1990. The historic high annual mean lake level--177.30 feet occurred in 1986. The historic record low and record high annual mean lake levels at Sturgeon Bay differ by 0.96 feet. The average annual lake level elevation was 176.71 feet.

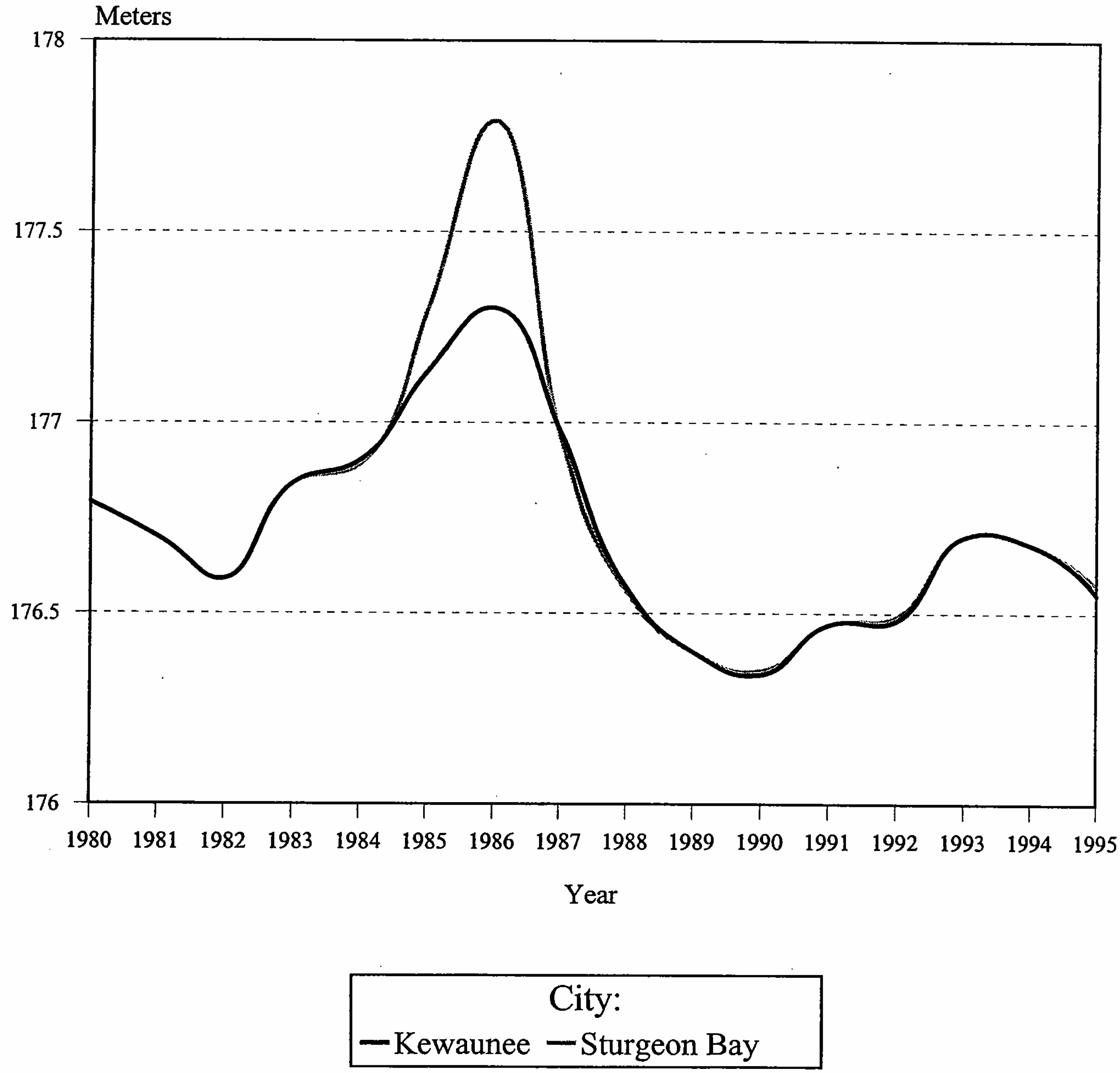
Additionally, Lake Michigan water levels were considerably above average during the early 1970s, the period just prior to the period during which the 1977 shore erosion and bluff stability study[2] was conducted. Lake Michigan levels between 1971 and 1976 were generally 0.09 to 1.21 feet higher than average. Between 1984 and 1986, lake levels were generally 0.14 to 1.04 feet higher than average.

[2] 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.

Fig II-5

Mean Annual Water Levels

Western Shore, Lake Michigan (1980-1995)



Source: U.S. Army Corps of Engineers; National Oceanic Atmospheric Administration; Bay-Lake Regional Planning Commission, 1997

As previously noted, record-high lake levels at Sturgeon Bay and Kewaunee 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 0.04 feet below the long term average level of the Lake. Subsequently, the Lake level rose again, approaching the long term average lake level in 1982.

It is important to note even during periods of lower water levels, severe storms can result in flooding.

There are a number of regulatory structures that have been constructed in the Great Lakes Basin. There are 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 two regulatory structures which regulate water levels and flows in the Great Lakes system, as shown on Map II-1.

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.

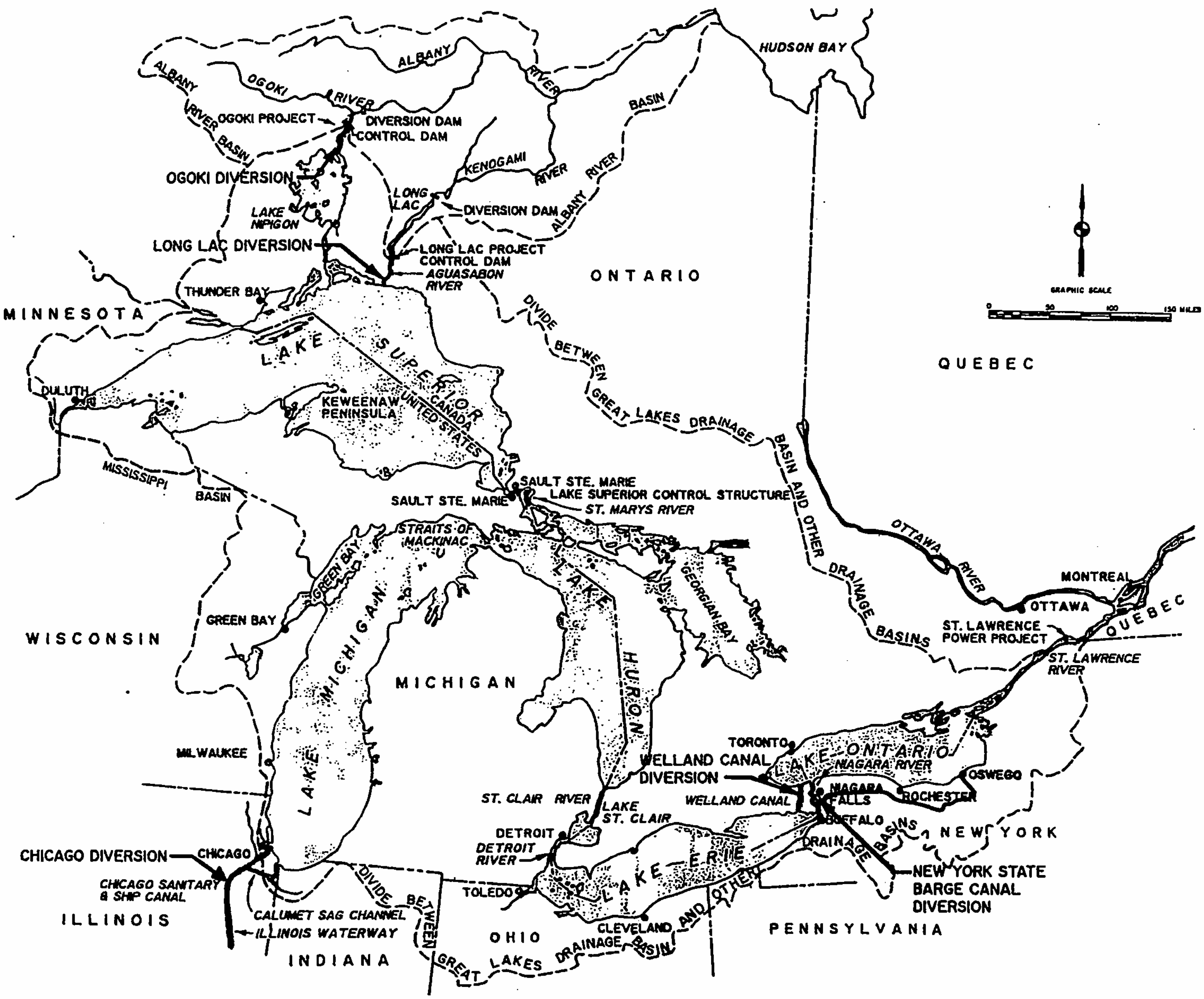
Water levels in the Great Lakes can be partially regulated by means of the artificial outlet control or regulatory structures. Currently, two of the Great Lakes--Lake Superior at Sault Ste. Marie and Lake Ontario through the St. Lawrence Seaway--are regulated under plans approved by the International 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 River Basin.[3] The study involved two phases. The first phase of the study included a characterization of water level fluctuations; their environmental, social and

---

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

Map II-1
GREAT LAKES DRAINAGE BASIN AND ARTIFICAL DIVERSIONS



Source: U. S. Army Corps of Engineers.

economic consequences; and the identification and description of potential lake level management measures.[4] The second phase included a comprehensive evaluation of potential solutions such as structural improvements, land use planning, and other management activities.[5] 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[6] 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.[7] 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.[8]

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 Northeastern 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 Fig. II-6.

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.

---

[4] International Joint Commission, Living With The Lakes: Challenges and Opportunities-A Progress Report to The International Joint Commission, July 17, 1989.

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

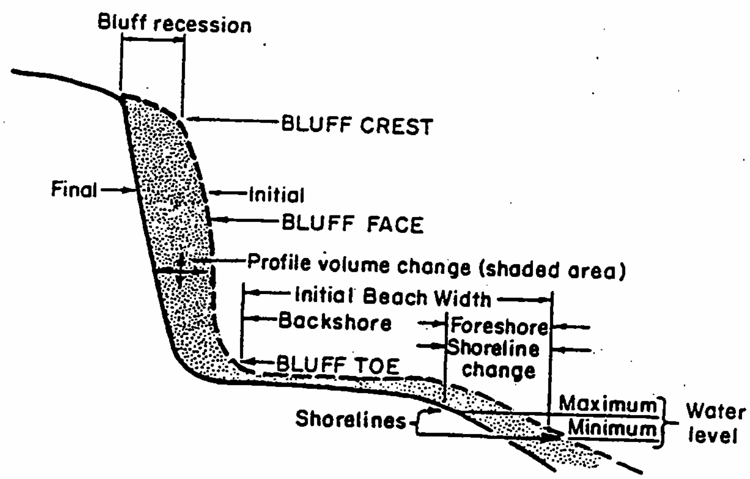
[6] International Joint Commission, Great Lakes Diversions & Consumptive Uses, January 1985.

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

[8] 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.

Fig II-6

BLUFF AND BEACH ZONE CHARACTERISTICS



Source: U.S. Army Corps of Engineers

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

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 Northeastern 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. 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.

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 liquefies and moves like a 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 intergranular 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 pore pressure within the 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 freezing will affect the shear strength after it has thawed; the higher the moisture content before freezing, the greater the reduction in shear strength after thawing. The net result is a 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 II-7 illustrates the pattern of breaking waves as they approach a beach.

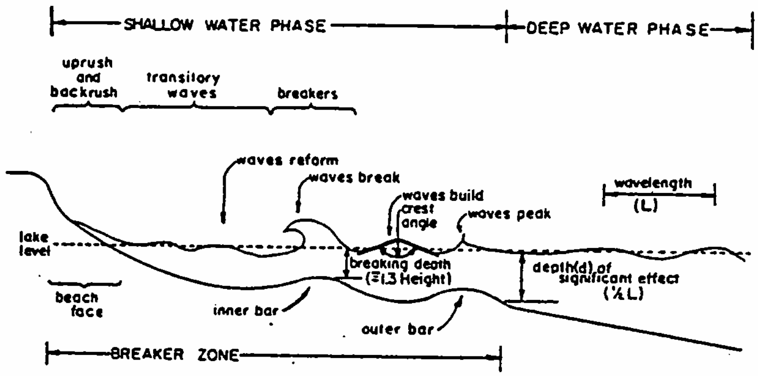
Ice Formation

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.

Fig II-7

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.*

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 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 Fig. II-8, 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 Wisconsin coastline, tend to be erosive in nature, while the small waves occurring between storms tend to build beaches. Figure II-8, 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.

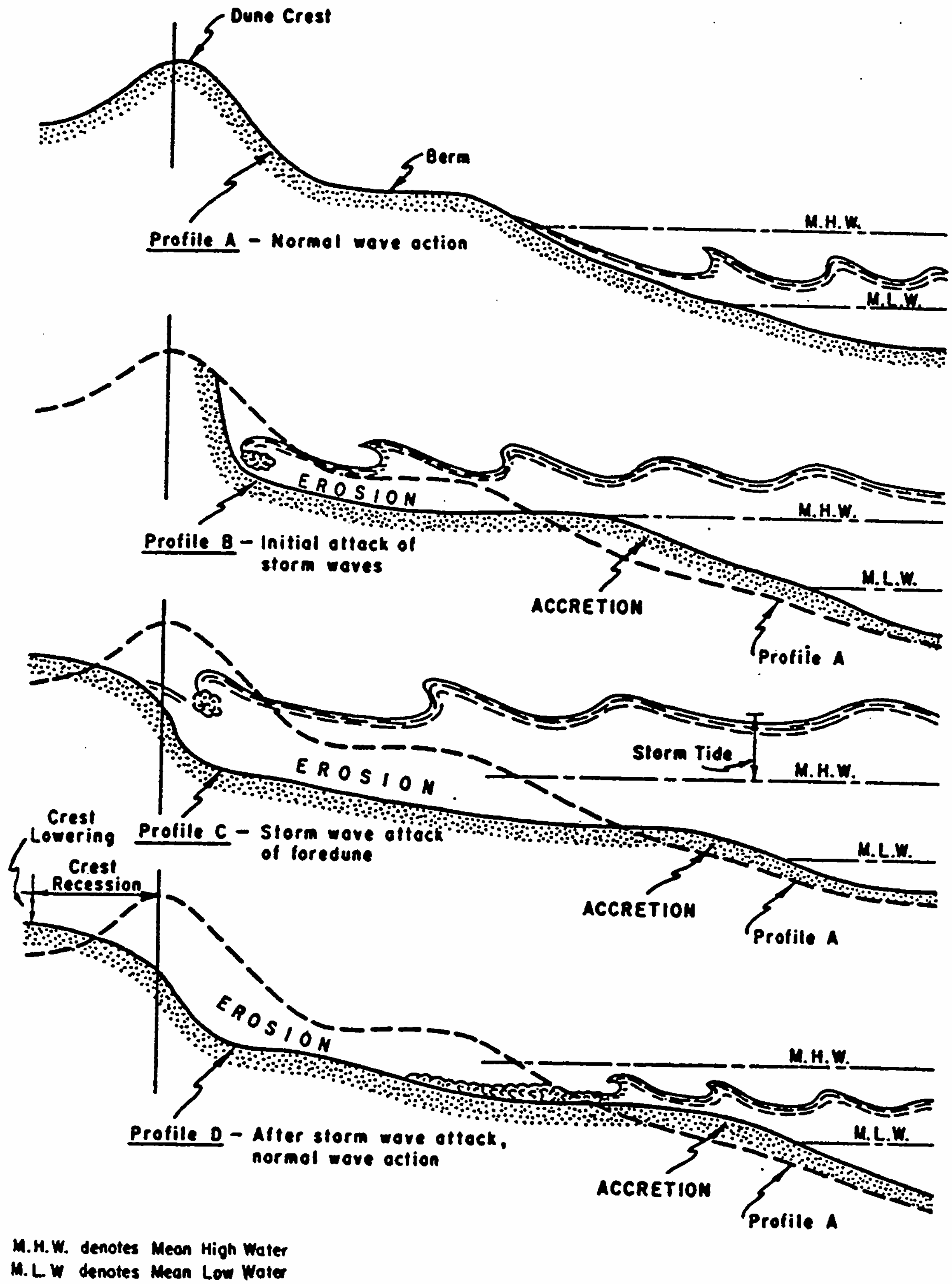
The deposition of suspended sediments in offshore sandbars can moderate the erosivity of subsequent wave action by causing waves to break prior to directly impacting the beach face. Their generally steep lake faces also act to quickly dissipate wave energy, further reducing their impact on the beach 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

Fig II-8

TYPICAL BEACH PROFILE AND EROSION PROCESSES



Source: U.S. Army Corps of Engineers

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 1996 as well as an evaluation of the methodology for predicting such conditions forms the content of the subsequent chapters of this report.

LAKE MICHIGAN SHORELINE RECESSION AND BLUFF STABILITY IN NORTHEASTERN WISCONSIN: 1996

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 Northeastern Wisconsin were documented in a 1977,[1] 1980[2] and for Kewaunee County, in 1988.[3] This chapter provides updated data on bluff stability and rates of shoreline recession for the Lake Michigan coastal areas of Northeastern Wisconsin.

The updated data on bluff stability and shoreline erosion are presented by shoreline "reach." Twenty-two such reaches were considered, as shown on Map I-1. These reaches vary in length from one to more than twelve 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.

Note: In the earlier 1977 study, a number of sections were mis-identified. These errors have been corrected in the 1996 report. The sections numbers used in the report to identify geographical locations are not in error and will stay the same. However, the township and range for selected sections were mis-identified. These previous errors do not adversely affect the data in this report.

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

---

[1] D. M. Mickelson, L. Acomb, N. Brouwer, T. Edil, C. Fricke, B. Haas, D. Hadlev, C. Hess, R. Klauk, N. Lasca, and A.F. Schneider, Shore Erosion Study, Technical Report Appendix 5, 6, Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin, Wisconsin Coastal Management Program, February 1977.

[2] D. M. Mickelson, L. Acomb, N. Brouwer, T. Edil, C. Fricke, B. Haas, D. Hadlev, C. Hess, R. Klauk, N. Lasca, and A.F. Schneider, Shore Erosion Study, Technical Report 7, Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin, Wisconsin Coastal Management Program, July 1980.

[3] Bay-Lake Regional Planning Commission, Kewaunee County Coastal Hazard Management Plan , August 1988.

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 miles 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 current inventory data are based on field work conducted in the summer of 1996, oblique aerial photographs taken in the Spring of 1996, and enlargements of unrectified vertical aerial photographs.

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. The stability of the bluff has been labeled with subjective classes of likely, possible, or unlikely for both the deeper rotational slides and shallow translational slides. These subjective classes are for general understanding only, and cannot be used as site specific engineering analyses.

INVENTORY AND ANALYSIS PROCEDURES

The bluff stability and shoreline erosion characteristics of each shoreline reach were determined under this study 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 Bay-Lake Regional Planning Commission's unrectified 1978, and 1992 aerial photographs which are available at a scale of one inch equal to 2,400 feet; 2) map interpretation using large-scale topographic maps; 3) interpretation of oblique aerial photographs taken by Bay-Lake Regional Planning Commission during 1996 of the entire Lake Michigan shoreline in Northeastern Wisconsin, and 4) field surveys conducted during 1996. 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 Northeastern 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 1996, 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 124 sites, the general location of which are set forth in Appendix A. These measurements provided a basis for site-specific assessments of the bluff conditions at the selected locations. The 1996 field observations were conducted by a field survey party which reoccupied the 1976 and selected 1980 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 1996. 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 the 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, in 1977, selected sites were measured for the distance from the shore lakeward to a water depth of five feet. The 1996 field party took a number or measurements to the five foot water depth. However, this field party was unsuccessful in duplicating measurements of the five foot water depth as done in the 1977 study. Because of the inaccuracies experienced in the data gathered, it was decided not to include the data. Therefore, the data gathered for comparison with the 1977 study data were discarded. Though this information is preferable to have, it does not negatively affect the overall study's findings on bluff stability. It is recommended that future measurements be taken of the water depth at the five foot level under more controlled conditions.

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 during the summer months than in 1996, and, any comparisons of beach and nearshore conditions between those periods must consider this fact.

Note: Appendix A contains the table detailing the information gathered in 1996 and lists the 1977 and 1996 "Factors of Safety" (FS). Appendix B contains a detailed look at each of the profiles field visited in 1996.

<u>Bluff Stability</u>

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

---

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

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.

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 analyses 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 1980 studies.

For purposes of this study, the ranges of values adopted in the aforementioned previous studies of 1977 and 1980 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 1.10 and 1.19 were also considered marginally stable, with respect to rotational failures, if the 1996 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]

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

---

[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.

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

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.

In terms of the probabilistic bluff stability analysis, for purposes of this study, the ranges of values adopted in the aforementioned previous study of 1977 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 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.

Subjective Stability Categories

The analyses of the models, measurements of oblique photos, and field observations were used to establish the subjective stability categories of likely, possible, or unlikely to have failure bluffs likely to have failures have low safety factors, below 0.9, as determined by the computer analyses, and site conditions seen to previously result in failures. Bluffs having possible failures have intermediate safety factors of 0.9 to 1.1, and site conditions previously resulting in some failures. The bluffs unlikely to have failures have safety factors greater than 1.1 and site conditions which have not exhibited failures recently. These subjective classes are given for both deep rotational failures, which occur less frequently, and shallow translational failures, which occur often.

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.

Upon completion of the field work, a rate of bluff top recession was calculated for various profiles using aerial photography acquired from the U. S. Army Corps. of Engineers. Enlargements of unrectified vertical aerial photographs from 1978 and 1992 at a scale of one inch equaling 2,400 feet were used. The distance from the bluff's edge was measured from a know point common in both the 1978 and 1992 photos. The measurement was converted into ground feet and subtracted to determine the approximate amount of recession. This was not done for all profiles. In some cases measurements of this type were not possible due to lack of a common feature in which to measure from. A recession rate in feet per year was calculated for the profile by dividing the total recession by the number of years between photograph dates. Appendix A presents the measured shoreline recession rates for two periods --1978--1992-- for designated shoreline recession reaches as well as the table detailing the percent deviation from U.S.G.S. Topographic Quadrangles.

SHORELINE REACH 18: SHEBOYGAN COUNTY

Shoreline Reach 18 extends from the Ozaukee-Sheboygan County line north to the north edge of T.14N., R.23E., Section 14, at the north edge of Kohler-Andre State Park (Map III-1). Residential development continues to makeup most of the land use today. In 1977 housing density ranged from 18 houses per square mile in the southern portion of the reach to over 45 houses per square mile to the north. Numerous protective barriers were installed along this reach. In 1977, beach widths within Reach 18 varied from nonexistant to 100 feet. All of the reach is low sandy shore with no bluffs. This part of the shoreline was not studied by the field party in 1996.

SHORELINE REACH 19: SHEBOYGAN COUNTY

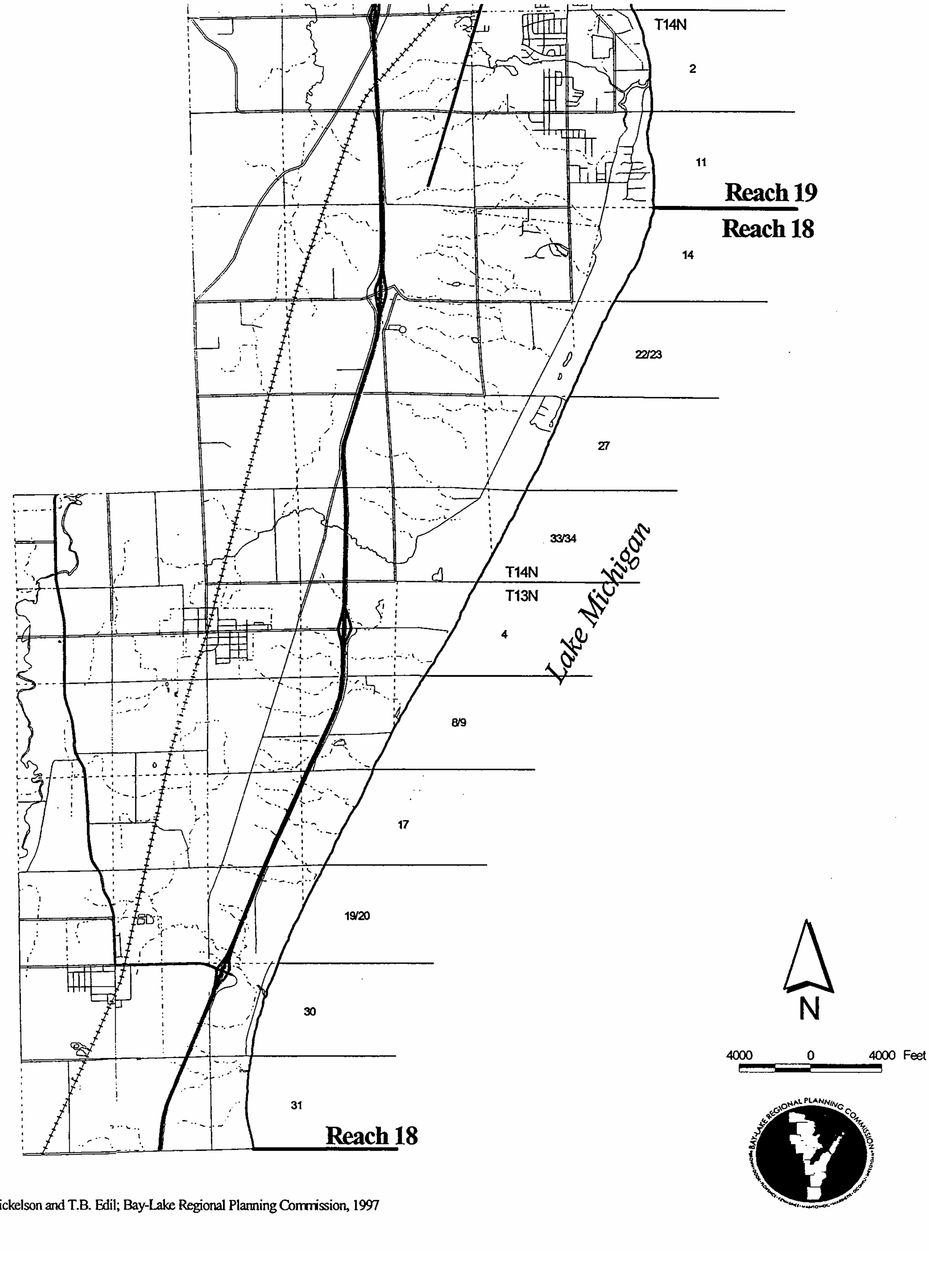
Shoreline Reach 19 is about four miles long, extending from the north edge of Kohler-Andre State Park into downtown Sheboygan (Map III-2). The shoreline in Reach 19 Sections 11 and 2 of T.15N., R.23E. is low and sandy with beaches ranging from nonexistant to 37 feet. These sections were not studied by the field party in 1996. The bluff does develop in Section 35 and continues through Section 26. The inventory and analysis findings relating to bluff, beach, and nearshore area conditions and shoreline recession are discussed below for Sections 35 and 26 in Reach 19.

T15N R23E SEC.35: SHEBOYGAN COUNTY

Section 35 extends from the south edge of the Sheboygan Sewage Treatment Plant north to Union Ave. The bluffs in Section 35 range from 30 to 50 feet in height. The majority of these bluffs are covered by fill. Two geotechnical bore holes in 1976 reveal 10 feet of sand at the toe overlain by 10 feet of till and lake clay. The sand above the till ranges from two to 20 feet in depth. Land use within this section is primarily residential and recreational, as this section lies within the urban area of the city of Sheboygan. Eighty to 100 percent vegetation cover consisting of grasses and shrubs cover this reach. Riprap emplacements protect almost the entire mile of shoreline within this section.

Profile 77-1 was determined to have a factor of safety of 1.5 in 1977 and predicted to have a circular failure in the upper slope, (Appendix B). This profile is now well vegetated with seeps occurring near the toe. This profile is protected by riprap and has had no bluff top recession since 1975. It now appears stable and unlikely to fail, having a factor of safety of 3.4 with respect to

Map III-1
Bluff Analysis Sections Within Reach 18



Source: D.M. Mickelson and T.B. Edil; Bay-Lake Regional Planning Commission, 1997

rotational failures. Profile 77-2 (Appendix B) had a factor of safety of 1.53 in 1977 and was predicted to have a large, circular failure throughout the slope. This profile has now been regraded and is protected by riprap. This profile currently has a factor of safety of 0.96 with respect to rotational failures based on our assumptions.

In 1977 the beach width varied from 35 feet in the southern end, no beach in the middle, and a beach ranging from 15 to 75 feet in the northern end of the section. In 1996 the beach width is recorded as being nonexistant to 16 feet.

No shoreline recession or water depth data were estimated in 1996. In 1977 the recession rate was one foot per year and water depth at the five foot level was recorded as being between 50 and 72 feet.

T15N R23E SEC. 26: SHEBOYGAN COUNTY

Section 26 extends from Union Ave. north to the Sheboygan River. The bluff disappears in the southern part of the section and the shoreline is low, mostly underlain by lake and river sediments. All of the shoreline is protected within this section. No measurements or observations were made here by the field party in 1996.

SHORELINE REACH 20: SHEBOYGAN COUNTY

Shoreline Reach 20 includes all of section 23 in R.15N., R.23E. in downtown Sheboygan (Map III-2). It is mostly protected by the harbor breakwater and is made up of a combination of beach and riprap. Land use within this reach is made up of mostly commercial and residential structures to include the Sheboygan Yacht Club, Marina and Coast Guard Station.

No measurements or observations were made here by the field party in 1977 or 1996.

SHORELINE REACH 21: SHEBOYGAN COUNTY

Shoreline Reach 21 extends from the south edge of Section 14 north of Superior Ave. to about two thirds of the way through Section 34 in T.16N., R.23E. (Map III-2). In 1996, the land use in the southern part of the reach was urban with mixed uses of residential, commercial, and public open spaces. The northern end of this reach was suburban and agricultural. This land use is similar to that which existed in 1977.

T15N R23E SEC.14: Sheboygan County

Section 14 extends from about Superior Ave. north to two blocks north of North Ave. in Sheboygan. The bluffs in this section range from 40 to 50 feet in height. The bluff is composed of 20 feet of silty clay near the toe overlain by 10 feet of silt overlain by sand. Dolomite of Devonian age crops out at the shoreline at Sheboygan Point. The bluffs are 80 to 100 percent vegetated with grasses and mature trees. The bluffs show evidence of old rotational failures but currently appear stable.

Profile 77-1 currently appears stable and well vegetated, having a factor of safety of 2.11 (Appendix B) with respect to rotational failures. Profile 77-2 (Appendix B) had a factor of safety of 1.5 in 1977. This profile exhibits old, rotational failures that are currently well vegetated. Overall, there have been few changes since 1975. Profile 77-2 currently has a factor of safety of 2.36 with respect to rotational failures. The shoreline is protected by riprap and groins creating wide, sandy beaches. This bluff is unlikely to fail by rotational or shallow translational failures. The land use within this section continues to be primarily made-up of residential developments with some recreational sites. This section lies within the urban area of the city of Sheboygan.

In 1996 the beach width was reported to be 58 feet at 77-1, and 29 feet at 77-2. In 1977 the beach width was reported as being between 10 and 30 feet.

No shoreline recession rate data were available for this section in 1977. This was due to the fact that almost the entire shoreline was protected by heavy structures and because the shoreline was further protected by the presence of bedrock at or near the lake surface. Erosion was estimated to be very slight in 1977. Recession rate was calculated in 1996 for 77-2. The rate was calculated to be 0.35 feet per year.

T15N P.23E SEC.11: Sheboygan County

Section 11 extends from two blocks north of North Ave. to the Pigeon River (Map III-2). The bluffs in the section range from 30 to 40 feet in height. The bluffs consist of Valders till low in the bluff overlain by lacustrine silt and clay. Discontinuous seeps occur at the mid bluff throughout the section. Translational failures appear to be the most common mode of failure. The bluffs are 80 percent vegetated with grasses and some shrubs. Riprap is present along most of this section. Twenty foot wide beaches of sand and cobbles are common. Land use in this section is primarily residential.

This section is divided into two erosion zones. Zone 11a extends from 11.0 to 11.6. The bluff in this zone is well vegetated with trees. The bluffs are commonly steep. Profile 77-1 had a factor safety of 2.2 in 1977 (Appendix B). This profile is currently protected by riprap and has very active seeps but appears stable. Profile 77-1 has a current factor of safety of 2.82 with respect to rotational failures. Profile 77-2 had a factor of safety of 1.5 in 1977. There was no access to this profile in 1996. Profile 80-18 shows translational failures and is protected by riprap. This profile appears stable and the translational failures have apparently ceased. Profile 80-18 has a current factor of safety of 1.77 with respect to rotational failures. This zone is unlikely to have deep rotational failures, but translational failures are possible.

The second zone, zone 11b extends from 11.6 to the north end of the section. This zone shows 20 to 30 percent vegetation of grasses. Profile 80-21 shows soil flows and translational failures. This profile has a deterministic factor of safety of 1.11 with respect to rotational failures. A probabilistic analysis of profile 80-21 resulted in factors of safety ranging from 0.49 to 1.65. Forty-eight percent of the 25 most critical trials resulted in unstable conditions, while 43.6 percent of all of the trials resulted in unstable conditions (Appendix B). There has been about 10 to 15 feet of bluff top recession since 1975. Profile 80-22 is currently protected by riprap. This bluff exhibits translational failures. Profile 80-22 has a factor of safety of 1.82 with respect to rotational failures. There has been more than 20 feet of bluff top recession since 1975 at this location. Shallow translational failures are likely, possibly resulting in significant bluff top erosion in the future.

In 1996 the beach width was reported to be 33 feet at 77-1, and 25 feet at 80-21. In 1977 the beach width was reported to be between 10 to 40 feet wide near the center of Section 11.

Recession rate was calculated in 1996 for 77-1 and 77-2. to be five feet per year and 4.5 feet per year respectively. In 1977, the recession rate for the center of the section was three feet per year.

T15N R23E SEC.2/3: Sheboygan County

This section extends from the Pigeon River to the extension of Playbird Rd. to Lake Michigan (Map III-2). The bluffs in this section range from 45 to 50 feet in height. They are composed of 10 to 20 feet of silt at the toe overlain by 20 to 30 feet of sand, silt and clay. The bluff is capped by a thin sand layer. Some till is present in the bluff near the center of the section. There is a 30 to 60 percent vegetation cover of horse tails and grasses. Seeps occur in the upper bluff at the northern end of the section while the southern end of the section exhibits drier bluffs. The beach width ranges from 25 to 35 feet. The beaches are sand and cobbles. Riprap is present near the south end of the section, where the beach is less than five feet wide. Land use within this section is primarily residential with some agricultural uses throughout. There are six erosion zones within this section.

Erosion zone 2a extends from 2.0 to 2.15. This zone has low sandy terraces. Zone 2b extends from 2.15 to 2.55. The bluffs are partly vegetated and have translational and shallow rotational failures. Profile 77-1 had a factor of safety of 1.02 in 1977 (Appendix B). Profile 77-1 currently has a factor of safety of 1.41 with respect to rotational failures. The bluff at this profile currently is protected by riprap, and has about a 50 percent vegetation cover. There are no seeps and the bluff appears to be failing by soil falls and flows. Profile 77-2 (Appendix B) had a factor of safety of 0.79 in 1977. This profile currently shows translational failures and soil flows. Profile 77-2 currently has a factor of safety of 1.56 with respect to rotational failures. It has a 30 percent vegetation cover and shows some bluff top recession since 1975. Profile 80-33 shows translational failures and soil flows, 20 percent vegetation cover, no seeps and five to 10 feet of bluff top recession since 1975. Profile 80-33 has a current factor of safety of 1.60 with respect to rotational failures. Nearly all of this erosion zone is actively eroding and several houses are close to the bluff. In this zone, deep rotational failures are unlikely, while shallow translational failures are likely.

Erosion zone 2c extends from 2.55 to 2.65. This zone is heavily vegetated with trees with low bluff formed by a river gully. Erosion zone 2d extends from 2.65 to 2.7. This zone is poorly vegetated and exhibits shallow rotational and translational failures. In both of the above erosion zones there are houses close to the bluff edge.

Erosion zone 2e extends from 2.7 to 2.8. This zone has low sandy terraces in the mouth of the Pigeon River. Zone 2f extends from 2.8 to the north end of the section. Profile 80-30 (Appendix B) shows translational failures, 60 percent vegetation and seeps in the upper bluff. This profile has a current factor of safety of 1.44 with respect to rotational failures. These seeps are very active. There was little residential development in this zone as of 1996.

In 1996 the beach width was reported to be 25 to 37 feet. The beach materials within this section are made of cobbles, sand, and pebbles.

Shoreline recession data for Section 2/3 were estimated at two locations. These data indicated a recession of between 10 and 50 feet or between 0.7 and 3.6 feet per year occurred between 1978 and 1992.

T16N R23E SEC.34: Sheboygan County

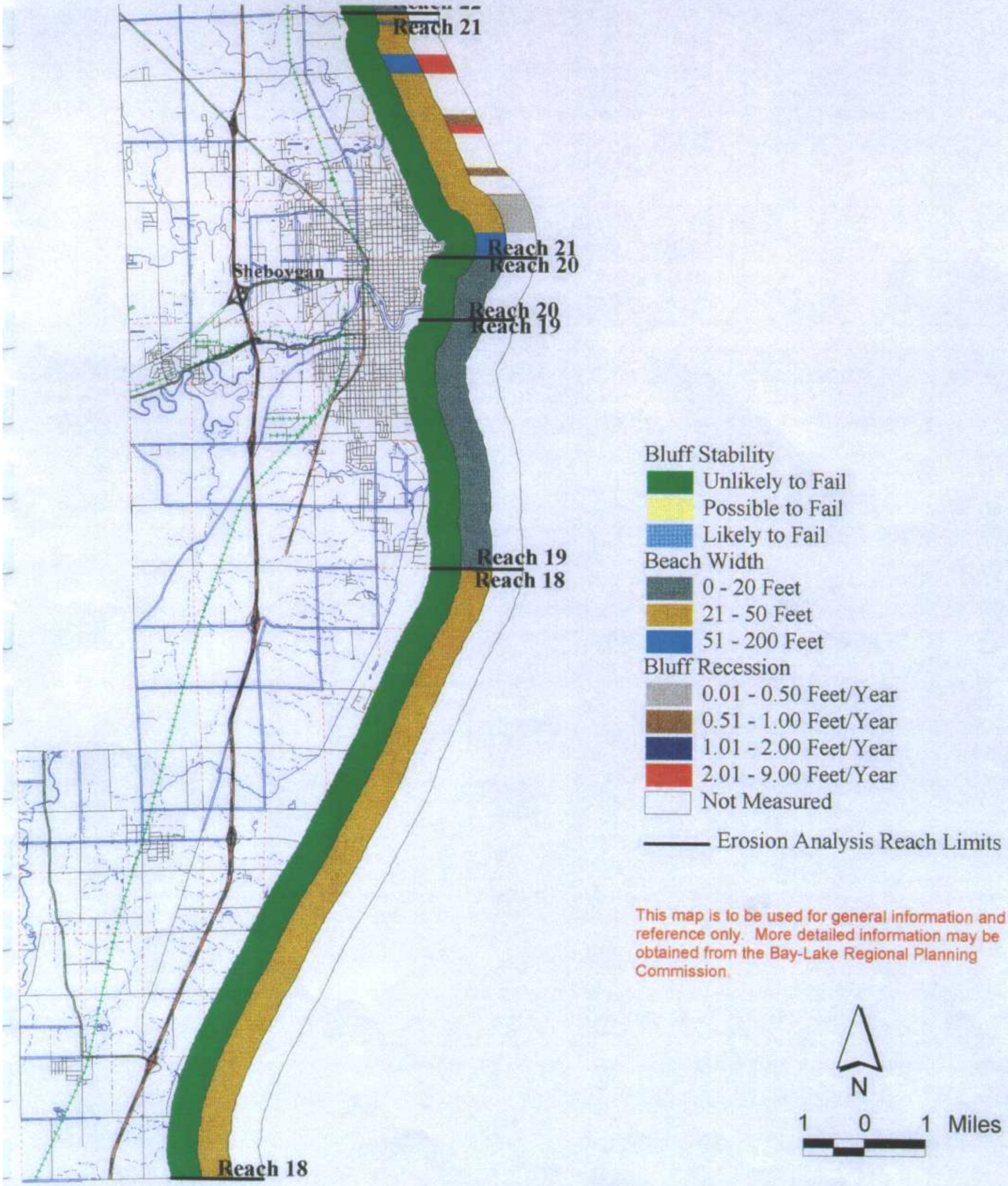
Section 34 extends from the extension of Playbird Rd. to the lake northward to the extension of Garton Rd. to the Lakeshore (Map III-2). The break between Reach 21 and Reach 22 occurs at about 34.6, at the change in shoreline orientation. The bluffs in Section 34 range from 30 to 50 feet in height. The bluff materials consist at the toe of reddish brown Haven till in the middle and northern parts of the section, overlain by Lacustrine silt and clay. Fine sand and silt is present at the top of the bluff. Discontinuous Valders till is also exposed at various places throughout the bluff in the northern half of the section. The bluff is 20 to 30 percent vegetated with grasses and horse tails. Seeps are seen in the mid to upper bluff. The bluff exhibits translational and shallow rotational failures with some soil flows. There are a few large rotational failures. Beach width ranges from 15 to 50 feet and the beach is made of sand and pebbles. The land use within this section is primarily residential in the northern half and primarily agricultural in the south with woodlots throughout.

The section is divided into three erosion zones. Zone 34a extends from 34.0 to 34.25. This zone shows translational failures and vegetation of grasses. Profile 77-1 (Appendix B) had a factor safety of 1.42 in 1977. This profile currently shows shallow rotational failures and soil flows, and about a 90 percent vegetation coverage of grasses. The profile has a current factor of safety of 1.27 with respect to rotational failures. Erosion on the face has been significant, while little bluff top recession has occurred since 1975. Rotational failures are possible, with the risk of a rotational failure increasing in the near future. Shallow translational failures are likely to occur.

Zone 34b extends from 34.25 to 34.6. This zone shows toe erosion, translational failures and soil flows. The bluffs are well vegetated with mature trees. Zone 34c extends from 34.6 to the north end of the section. This zone is poorly vegetated with some grasses. The bluffs exhibit translational slides and soil flows. Profile 80-26 is about 20 percent vegetated, and has translational failures and seeps. This profile has a current factor of safety of 1.72 (Appendix A) with respect to rotational failures. There has been about 10 feet of bluff top recession since 1975. Profile 80-25 has about 30 percent vegetation with mostly grasses, shallow translational failures, and five to 10 feet of bluff top recession since 1975. Profile 80-25 has a current factor of safety of 1.84 with respect to rotational failures. Profile 77-2 was determined to have a factor of safety of 0.82 in 1977. This profile now exhibits soil flows and translational failures. Profile 77-2 has a current factor of safety of 1.94 with respect to rotational failures. There has been five to 10 feet of bluff top recession since 1975 at this site. Profile 77-3 had a factor of safety of 1.0 in 1977. This profile currently shows shallow circular failures, five percent vegetation and seeps. Profile 77-3

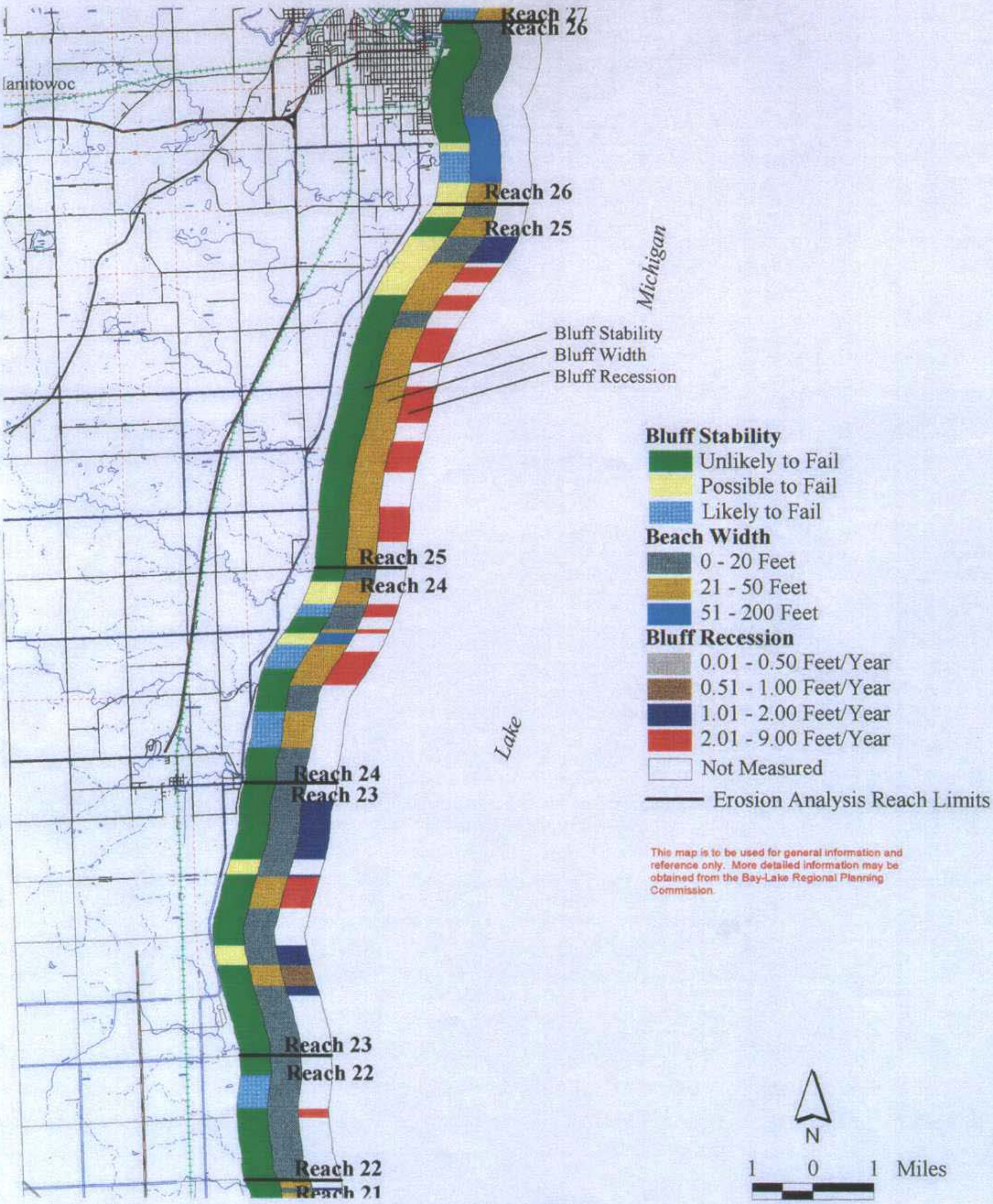
10a

Map V-1
Summary of Lake Michigan Erosion and Bluff Stability Analyses in Northeastern Wisconsin: 1996



Source: T.B. Edil, D.M. Mickelson, J.A. Chapman, A. Jerabek, and BLRPC, 1996.

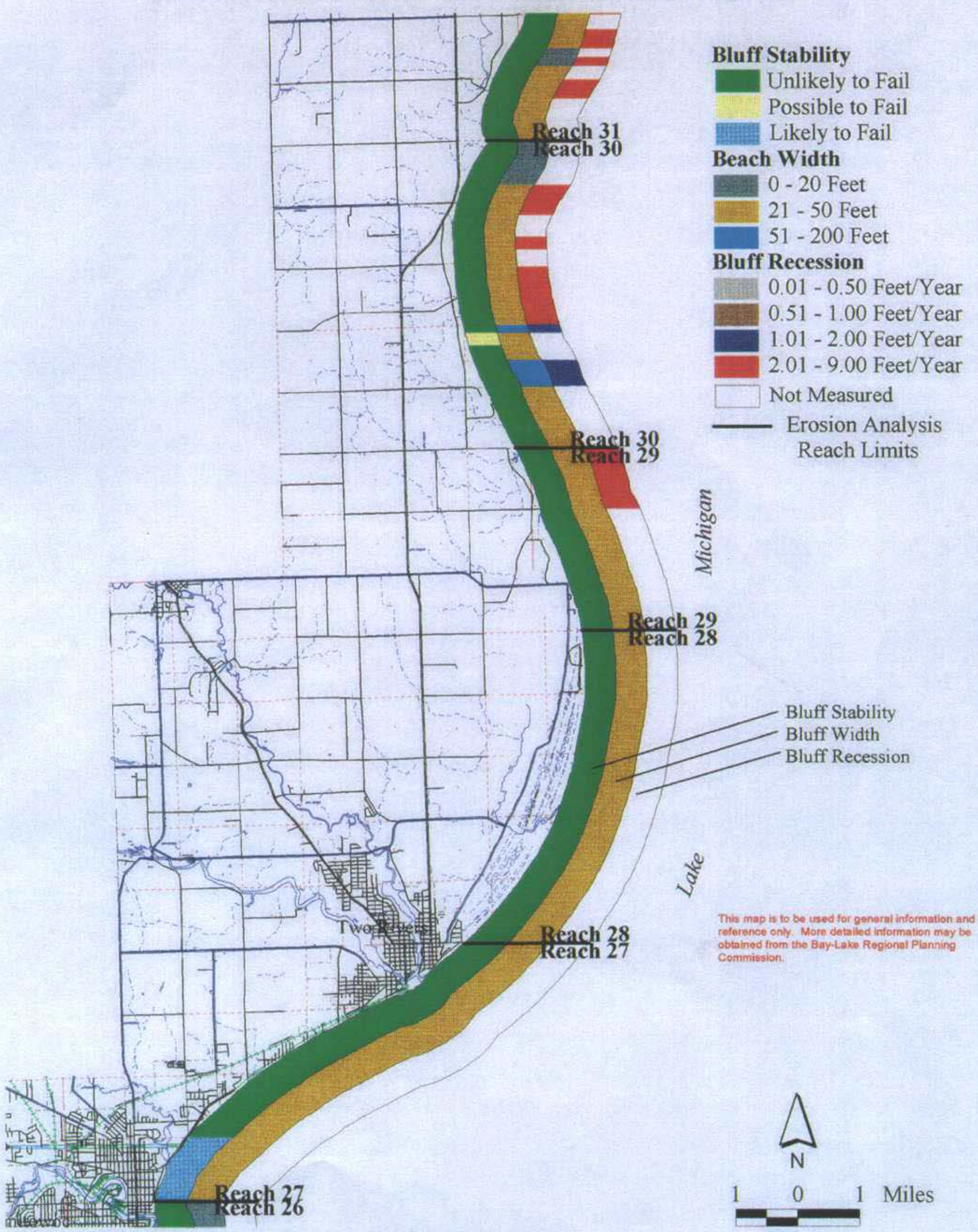
Map V-2
Summary of Lake Michigan Erosion and Bluff Stability Analyses in Northeastern Wisconsin: 1996



Source: T.B. Edil, D.M. Mickelson, J.A. Chapman, A. Jerabek, and BLRPC, 1996.

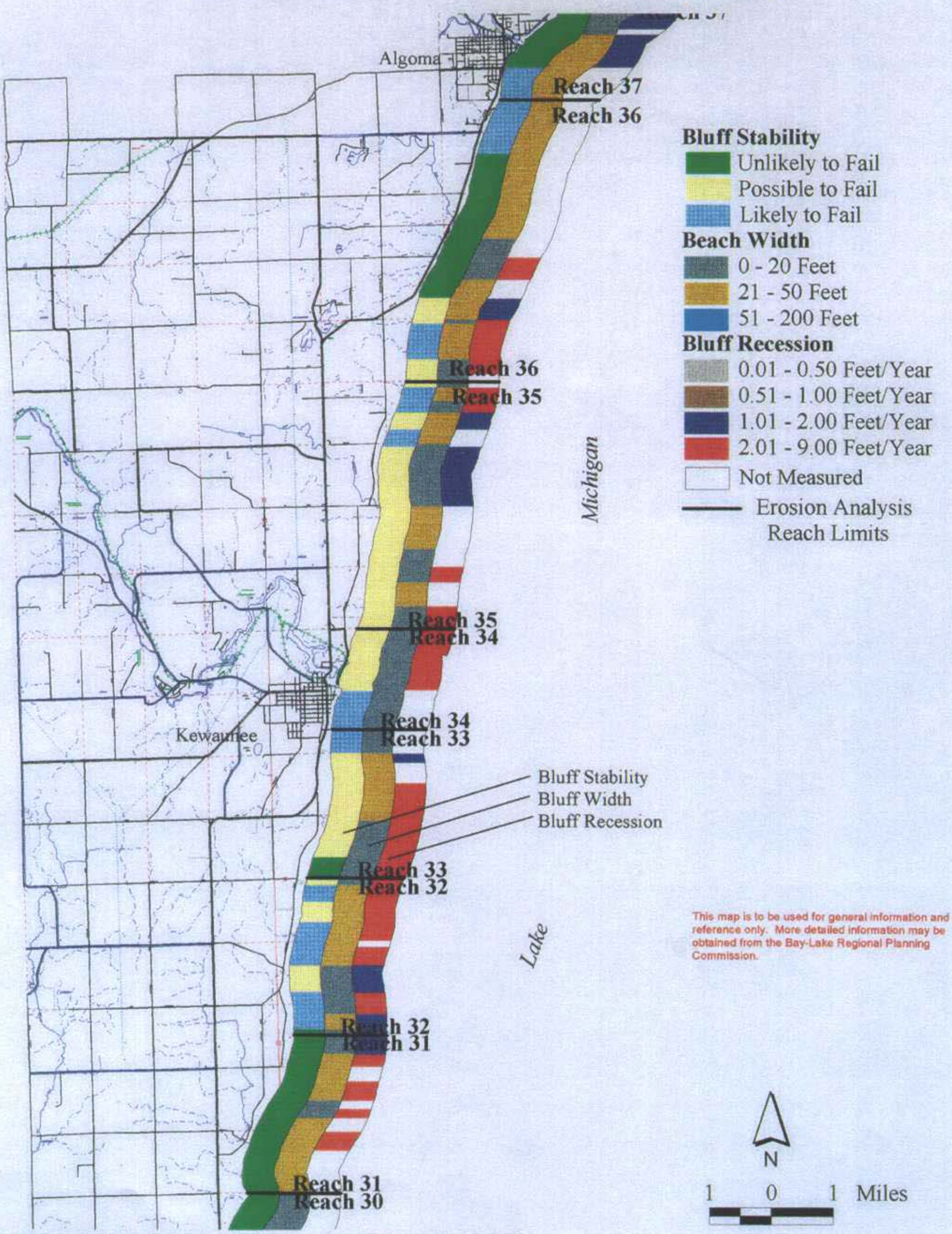
10 c

Map V-3
Summary of Lake Michigan Erosion and Bluff Stability Analyses in Northeastern Wisconsin:1996



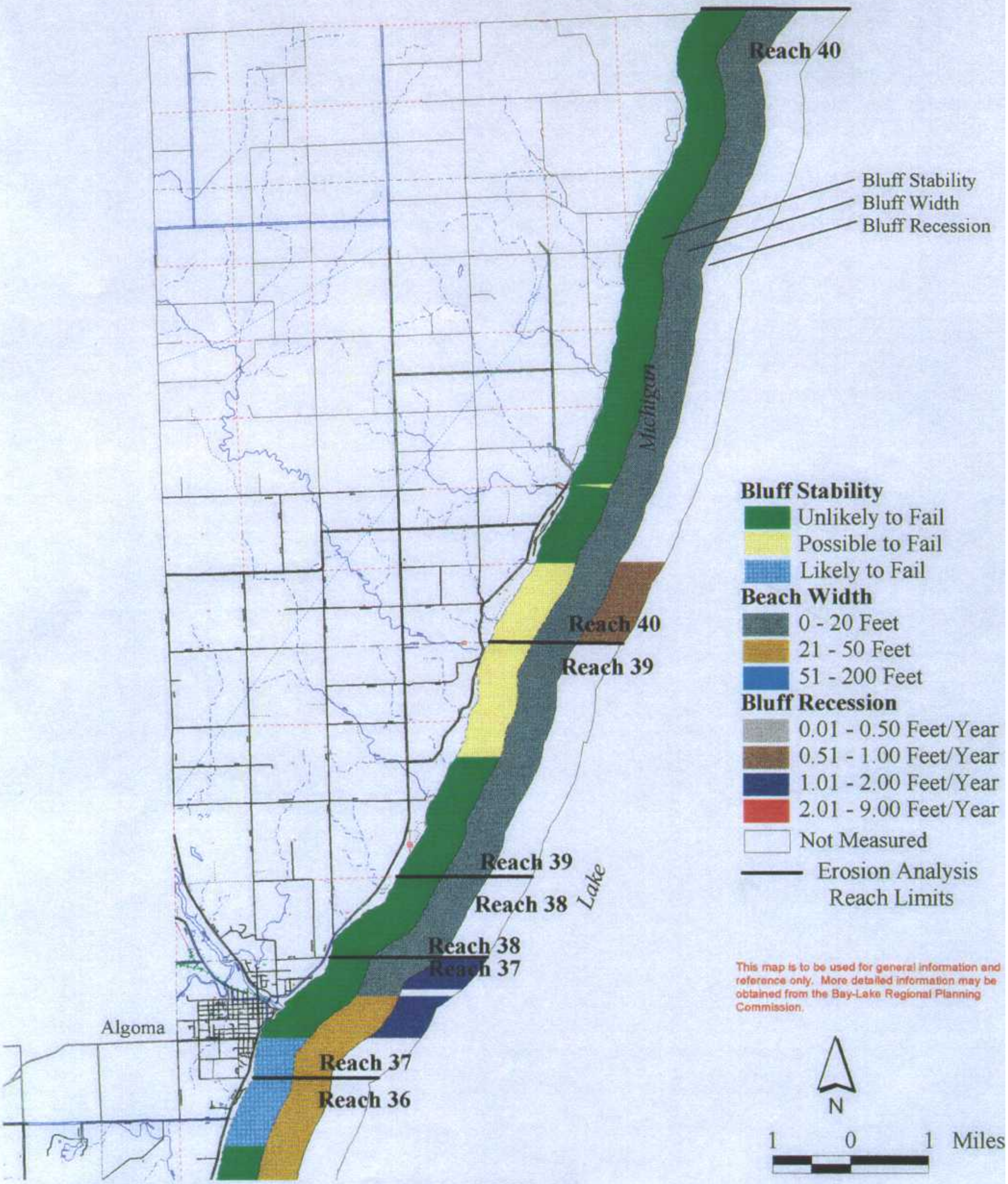
Source: T.B. Edil, D.M. Mickelson, J.A. Chapman, A. Jerabek, and BLRPC, 1996.

Map V-4
Summary of Lake Michigan Erosion and Bluff Stability Analyses in Northeastern Wisconsin: 1996



Source: T.B. Edil, D.M. Mickelson, J.A. Chapman, A. Jerabek, and BLRPC, 1996.

Map V-5
Summary of Lake Michigan Erosion and Bluff Stability Analyses in Northeastern Wisconsin:1996



Source: T.B. Edil, D.M. Mickelson, J.A. Chapman, A. Jerabek, and BLRPC, 1996.

has a current factor of safety of 1.31 with respect to rotational failures. This zone is likely to have shallow translational failures in the future, while deep rotational failures are unlikely.

In 1996 the beach width was reported to be 14 to 53 feet and made of sand and pebbles. In 1977 the beach width was reported as being between 20 and 60 feet.

Shoreline recession data for Section 34 were estimated at four locations. These data indicated a recession of between 15 and 30 feet or between 1.1 and 2.1 feet per year occurred between 1978 and 1992.

Shoreline Reach 22: Sheboygan County

Shoreline Reach 22 begins at the break in shoreline orientation at about 34.6, part way through the section just described (Map III-2). The northern boundary is the north edge of Section 22 at Haven. The major reason for this reach designation is the orientation of the shoreline. Bluff characteristics and conditions continue much as they are in Reach 21. Land use in the area is predominantly agricultural as in 1977.

T16N R23E SEC.27: Sheboygan County

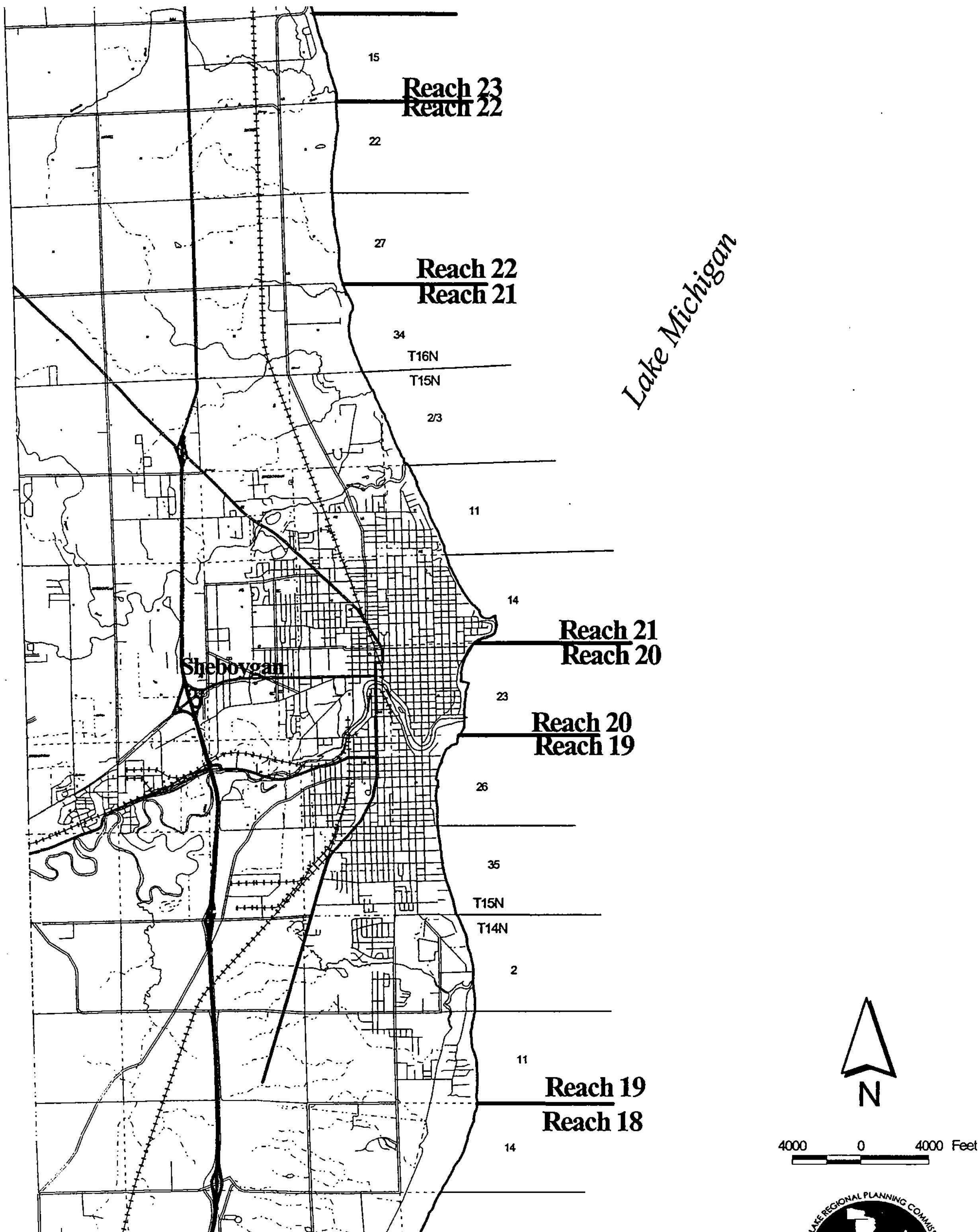
Section 27 covers the area from the extension of Garton Rd. to the lake north to the extension of Rowe Rd. to the lake (Map III-2). The bluffs within this section range from 30 to 50 feet high. The bluff materials consist of Haven till at the toe overlain by 20 feet of silt. A thin, discontinuous layer of Valders till overlies the silt, which is overlain by 10 feet of thinly bedded sand, silt and clay. Seeps occur throughout the section in the mid to upper bluff. There is a 20 to 90 percent vegetation cover of grasses. The beaches range from about 10 to 20 feet wide and are composed of sand and pebbles. Land use within this section is primarily agricultural. All bluffs in the section are currently failing. The land use is agricultural with some woodlots.

Three erosion zones are recognized. Erosion zone 27a extends from 27.0 to 27.6. The bluff in this zone has a steep face with little vegetation and exhibits translational failures. Profile 80-35 shows translational failures, and has a current factor of safety of 1.24 with respect to rotational failures (Appendix A). Profile 80-36 exhibits soil flows, soil falls, and toe erosion. This profile has a factor of safety of 2.13 with respect to rotational failures. Five to 10 feet of bluff top recession has occurred since 1975 at this site. Profile 80-37 shows translational failures and 25 feet of bluff top recession since 1975. Profile 80-37 currently has a factor of safety of 1.20 with respect to rotational failures. Shallow translational failures are likely, while rotational failures are unlikely.

Erosion zone 27b extends from 27.6 to 27.9. This zone has large rotational failures and more vegetation cover than the other zones in this section. Profile 80-38 shows little bluff top recession since 1975. Profile 80-38 has a current factor of safety of 1.80 with respect to rotational failures (Appendix A). Shallow translational failures are likely, while rotational failures are possible within zone 27b. Zone 27c extends from 27.9 to the north end of the section. This zone has translational failures and 50 percent vegetation coverage of grasses.

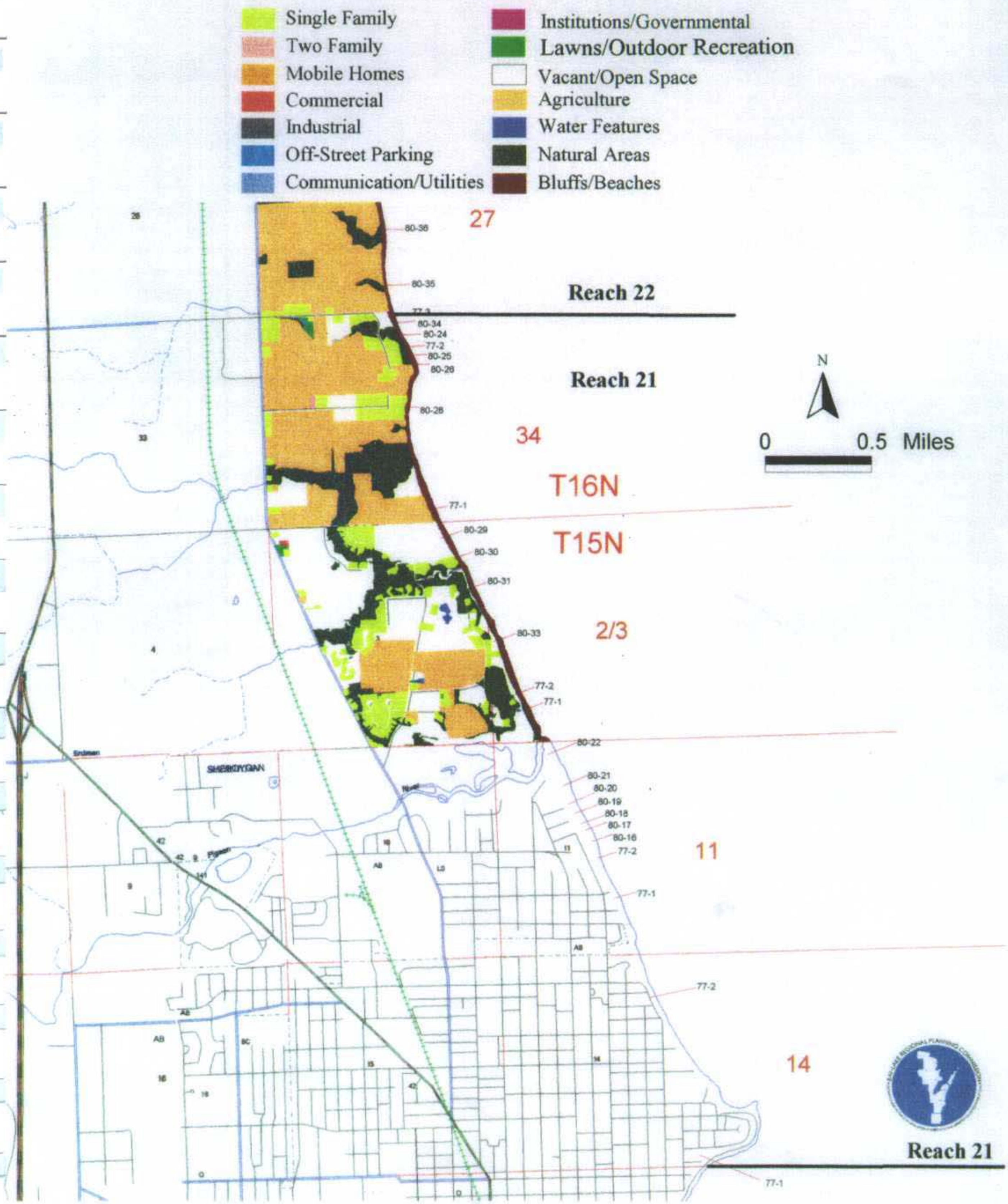
Map III-2

Bluff Analysis Sections Within Reach 19, 20, 21, & 22



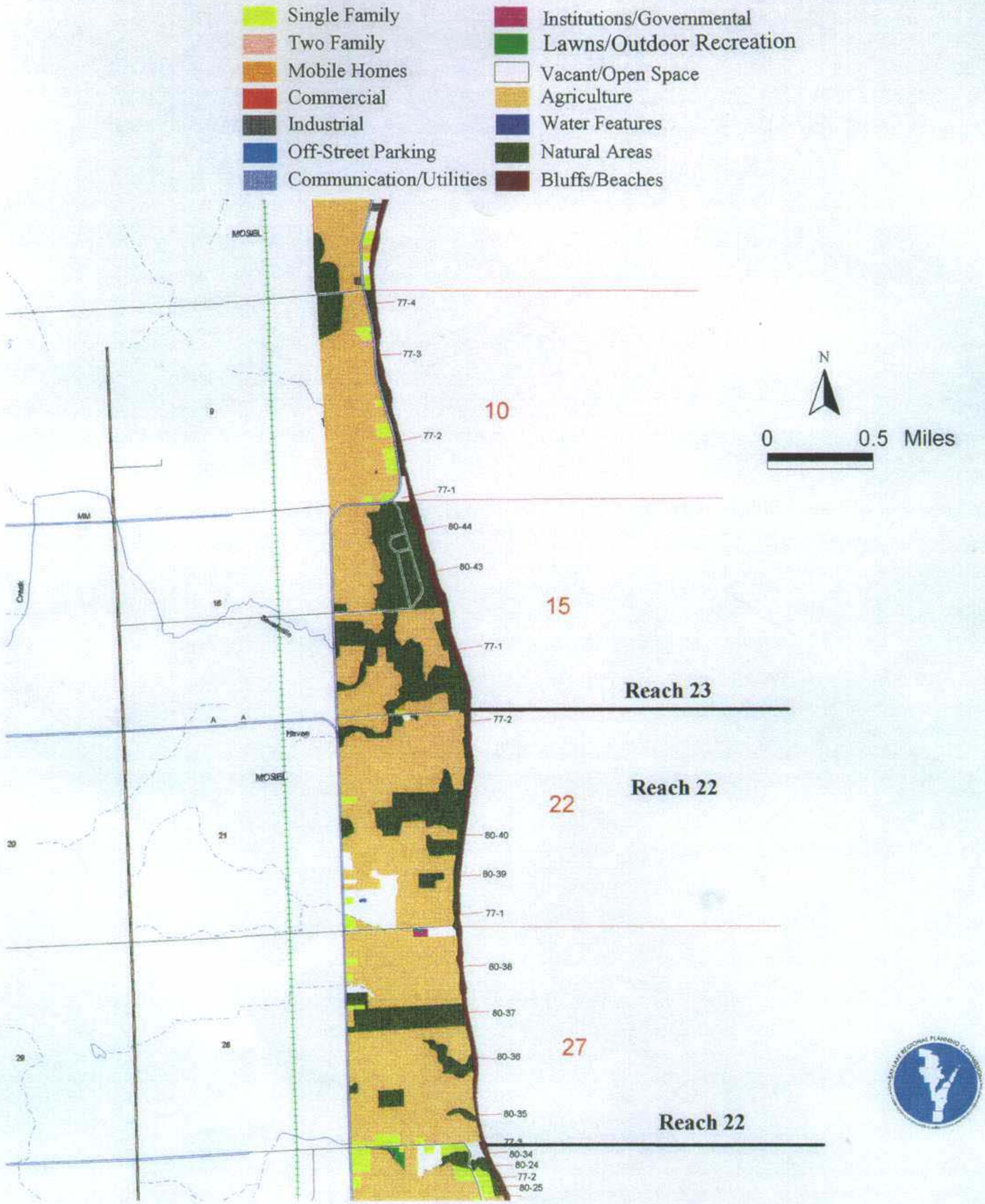
Source: D.M. Mickelson and T.B. Edil; Bay-Lake Regional Planning Commission, 1997

Map III-2a
Bluff Land Use and Profiles within Reach 21



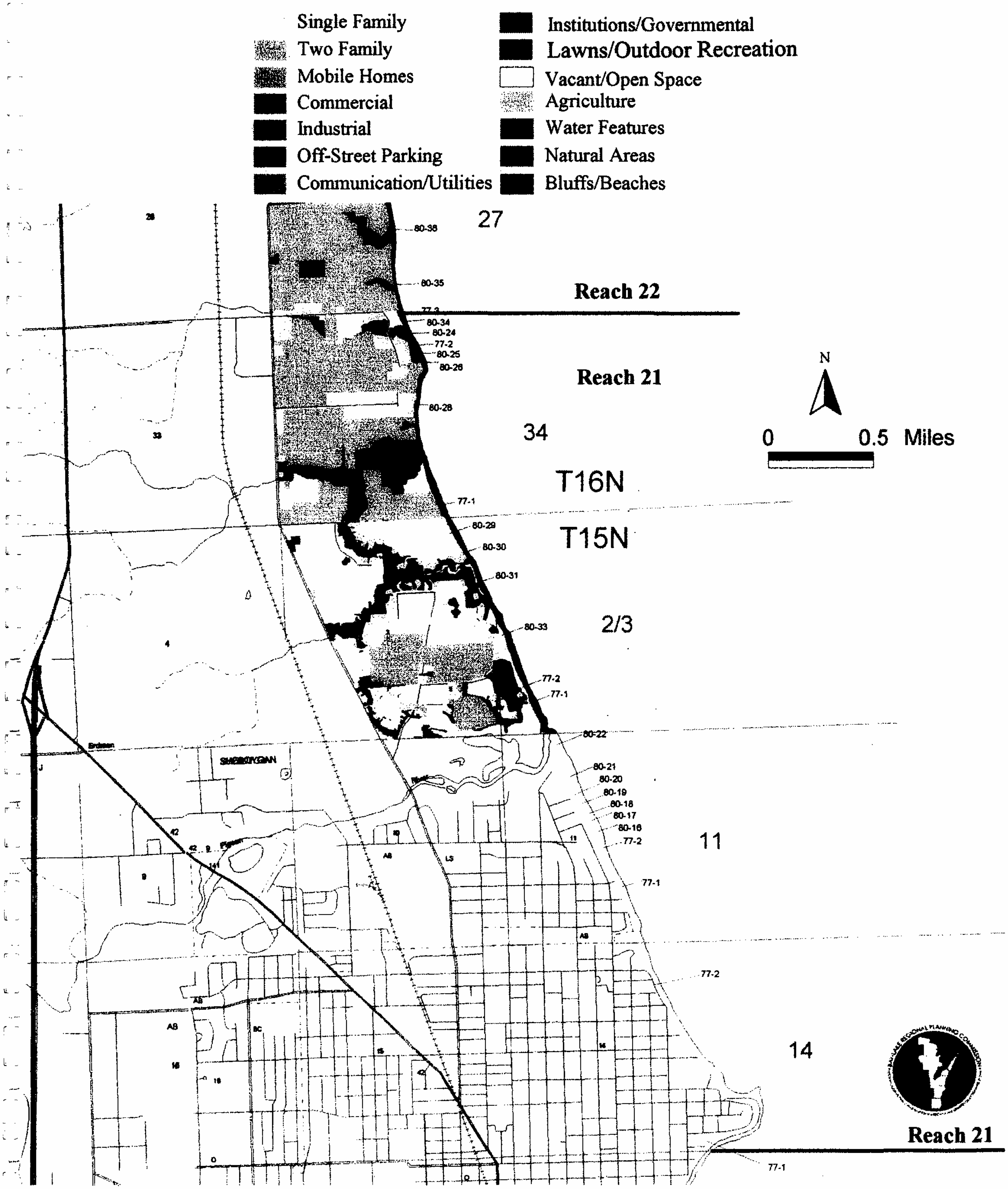
Source: Bay Lake Regional Planning Commission, 1996

Map III-2b
Bluff Land Use and Profiles within Reaches 22 and 23



Source: Bay Lake Regional Planning Commission, 1996

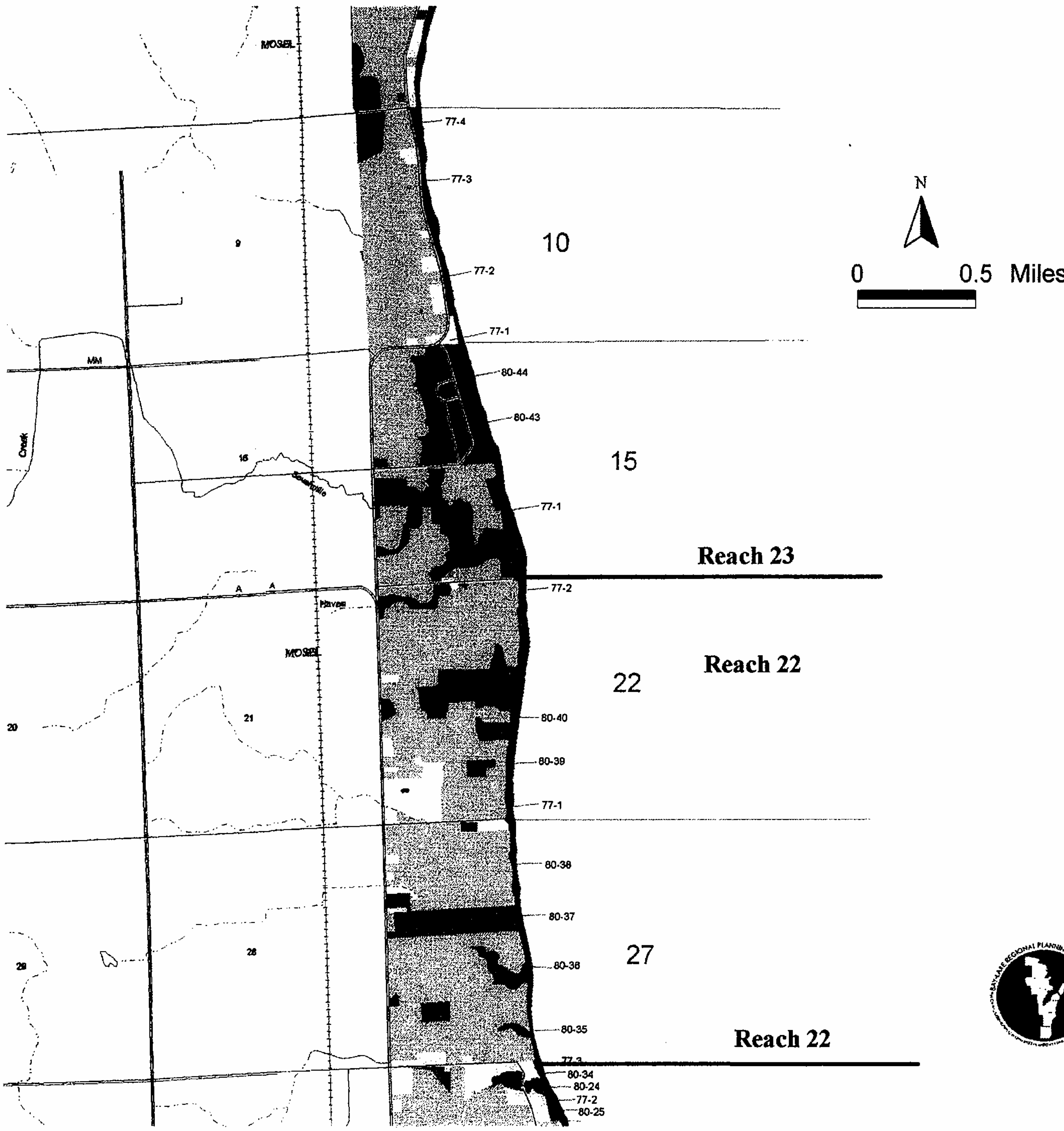
Map III-2a
Bluff Land Use and Profiles within Reach 21



Source: Bay Lake Regional Planning Commission, 1996

Map III-2b
Bluff Land Use and Profiles within Reaches 22 and 23

- Single Family
- Two Family
- Mobile Homes
- Commercial
- Industrial
- Off-Street Parking
- Communication/Utilities
- Institutions/Governmental
- Lawns/Outdoor Recreation
- Vacant/Open Space
- Agriculture
- Water Features
- Natural Areas
- Bluffs/Beaches



Source: Bay Lake Regional Planning Commission, 1996

In 1996 the beach width was reported to be 10 to 20 feet and made of sand and pebbles. In 1977 the beach width was reported as being between five and 50 feet and made of cobbles..

Shoreline recession data for Section 27 were estimated at one location. These data indicated a recession of 20 feet or 1.4 feet per year occurred between 1978 and 1992. The 1977 study reported a long term recession rate of one foot per year for this section.

T16N R23E SEC.22: Sheboygan County

Section 22 lies between Rowe Rd. in the south to Lake Rd. in the north (Map III-2). The north edge of the section is also the north edge of Reach 22. The bluffs in Section 22 range from 45 to 50 feet in height. The bluffs consist of mostly of Haven till near the base and thin Valders till at or near the top of the bluff, with some discontinuous lacustrine sediments between the tills or at the bluff top. There is a 70 to 90 percent vegetation cover consisting of grasses and small shrubs. Seeps occur in the lacustrine sand near the top of the bluff. The bluff exhibits large rotational failures with some translational failures. The beach is made of sand and cobbles and ranges from nine to 16 feet in width. Land use in this section continues to be agricultural with some recreational use. All of the bluff in the section is actively eroding.

There are two erosion zones within this section. Erosion zone 22a extends from 22.0 to 22.2. This zone has steep bluffs exhibiting shallow, translational slides. Profile 77-1 had a factor of safety of 1.69 in 1977 (Appendix A). This profile has been modified by construction (present factor of safety is 1.12). The profile shows small translational failures and some bluff top recession since the 1970's. Zone 22b extends from 22.2 to the north end of the section. This zone exhibits large enechelon failures. Wave action is causing severe toe erosion. Profile 80-39 exhibits rotational failures and toe erosion. This profile, 80-39, has a current factor of safety of 0.74 with respect to rotational failures. Profile 80-40 also exhibits rotational and en-echelon failures and toe erosion. Profile 80-40 has a current factor of safety of 0.85 with respect to rotational failures. Profile 77-2, which was measured in 1977, has been modified by construction. This entire section has been modified by construction. The section appeared to have had decreasing stability before construction. The post construction condition is assumed to be unlikely to fail by rotational or shallow translational failures.

In 1996 the beach width was reported to be nine to 16 feet and made of sand, cobble, and pebbles. In 1977 the beach width was reported as being between five and 35 feet and made of cobbles.

Shoreline recession data for Section 22 were estimated at two locations. These data indicated a recession rate of 20 to 35 feet or 1.4 to 2.5 feet per year occurred between 1978 and 1992. The 1977 study reported a long term recession rate of two feet per year for this section.

SHORELINE REACH 23: SHEBOYGAN COUNTY

Shoreline Reach 23 extends from the north edge of Section 22 in T16N, R23E 4.5 miles to the middle of T17N, R23E, Section 27 (Map III-3). Most of the land is agricultural except that a new golf course is being built in the southern part of the reach. In Sections 10 and 3 CTH LS borders the bluff top and is susceptible to damage due to erosion on the lake shore. This reach appears to be one that will have development pressure in the near future.

T16N R23E SEC.15: SHEBOYGAN COUNTY

Section 15 is bounded by Lake Rd. on the south and the extension of CTH MM to the lake on the north. This section is currently undergoing extensive modifications through construction of a golf course. The toe is protected by riprap and the engineered slopes appear stable. No profiles were measured in 1996 due to the building of the golf course. This location is where previous profiles were measured. The 1977 profiles are shown in. In 1997, the land use was agricultural and apparently was the site of an old NIKE missile base.

Shoreline recession data for Section 15 were estimated at 77-1. These data indicated that there was no recession between the years 1978 and 1992. The 1977 study reported a long term recession rate of two feet per year for this section. Recession more than likely did occur. However, due to minor technique inaccuracies, as outlined earlier in this chapter, recession was not apparent. For greater understanding of the recession history of this section, the area within the section should be re-evaluated.

T16N R23E SEC.10: SHEBOYGAN COUNTY

Section 10 is bounded by the extension of CTH MM to the lake on the south and the extension of Orchard Rd. to the lake on the north (Map III-). The bluffs within this section range from 45 to 55 feet in height. The bluffs are composed of 20 to 30 feet of reddish brown Haven till at the toe overlain by 10 feet of silt. This is overlain by 10 to 20 feet of sandy silt. Valders till is thin and discontinuous within this upper unit. There is a 50 to 90 percent cover of grasses, mature trees and shrubs. Seeps are variable within this section; they are present in the lower, middle, and upper bluffs. The bluffs exhibit old, large rotational failures but are currently failing by translational sliding and soil flows. There is a cobble beach, 12 to 20 feet in width. Land use within this section is residential and agricultural. CTH LS runs along the top of the bluff throughout this section.

There are four erosion zones within this section. Erosion zone 10a extends from 10.0 to 10.4. This zone has little vegetation cover and many shallow translational failures. Profile 77-1 had a factor of safety of 1.81 in 1977 (Appendix A). This analysis predicted a large circular failure. The profile has been modified and has therefore been replaced by a recent measurement labeled 96-1. This new profile is 100 percent vegetated and exhibits translational failures. Profile 96-1 has a factor of safety of 1.25 with respect to rotational failures. Profile 77-2 had a factor of safety of 0.31 in 1977. The 1977 analysis predicted failures in the upper slope. The profile currently shows translational failures and has a factor of safety of 1.40 with respect to rotational failures. In this zone rotational failures are possible, but translational failures are more likely to occur.

Erosion zone 10b extends from 10.4 to 10.7. This zone has large rotational slump blocks with mature trees. Erosion zone 10c extends from 10.7 to 10.85. This zone shows little vegetation and numerous translational failures. Profile 77-3 was determined to have a factor safety of 0.6 in 1977 (Appendix A & B). The 1977 analysis predicted translational failures in the upper slope. The profile is now modified by dumped rock. Profile 77-3 has a current deterministic factor of safety of 1.024 with respect to rotational failures. A probabilistic analysis was also performed on this profile, resulting in factors of safety ranging from 0.78 to 1.17. Of the 25 most critical situations, 32 percent resulted in unstable conditions, while 18.8 percent of the total situations resulted in unstable conditions. Zones 10b and 10c have possible rotational failures, but translational failures are more likely to occur.. Zone 10d extends from 10.85 to the north end of the section. The bluff in this zone has large, rotational slump blocks with vegetation of mature trees. Profile 77-4 appears relatively unchanged since 1977 except for some small soil flows and toe erosion due to wave action. Profile 77-4 has a current factor of safety of 1.52 with respect to rotational failures. Zone 10d is unlikely to have rotational or shallow translational failures.

In 1996 the beach width was reported to be 12 to 20 feet composed of mostly cobbles. In 1977 the beach width was reported as being 25 feet composed of cobbles and coarse sand. Land use within this section is agricultural with a number of farm houses, which is the same as in 1977.

Shoreline recession data for Section 10 were estimated at three locations. These data indicated a recession of between 10 to 20 feet or between 0.7 and 1.4 feet per year occurring between 1978 and 1992. No recession measurements were done in 1977.

T16N R23E SEC.3: SHEBOYGAN COUNTY

Section 3 extends from the intersection of CTH LS with Orchard Rd. in the south to the Sheboygan/Manitowoc County line. The bluff in this section has a consistent height of about 60 feet. The deposits are poorly exposed, but we estimate about 50 feet of reddish brown silty Haven till at the toe overlain by about 10 feet of lacustrine sand, silt and clay. The bluff exhibits rotational failures and no seepage is visible. Profile 77-1 currently is 90 percent vegetated with mature trees and grasses. This profile appears stable, having a factor of safety of 2.31 with respect to rotational failures (Appendix A & B). The vegetation cover on the bluff throughout the section varies from 20 to 90 percent. The bluff typically has a scarp near the top, possibly from slow movement on large rotational failure surfaces. The mid slope is heavily vegetated and is possibly the top of a large slump block. There are scarps at the toe of the bluff in some places along this section due to wave action.

There has been minimal bluff top recession since 1976, although the bluffs should still be considered unstable in the long term. Land use within this section is primarily agricultural with farm houses and single family residential with both year round and seasonal homes.

In 1996 the beaches are made of cobbles and range from 20 to 30 feet in width In 1977 the beach width was reported as being nonexistant to 30 feet and composed of sand, cobbles, and boulders.

Shoreline recession data for Section 3 was estimated at one location. These data indicated a recession of 40 feet or 2.9 feet per year between 1978 and 1992. The 1977 study reported recession rates of 0.3 feet per year for this section.

T17N R23E SEC.34: MANITOWOC COUNTY

Section 34 covers the mile immediately north of the southern Manitowoc County Line. The bluffs range from 45 to 60 feet high. The materials are poorly exposed, but the bluffs appear to be composed of about 30 to 40 feet of gray silt, part of which may be Haven till, overlain by five to 10 feet of sand, silt, clay and some thin, discontinuous Valders till layers. Land use within this section is primarily residential and agricultural with 50 percent of the land remaining as woodlots as in 1977. There is a 70 to 90 percent vegetation cover of grasses and shrubs. The beach is sand and cobbles and ranges from 10 to 20 feet wide.

There are three erosion zones in this section. Erosion zone 34a extends from 34.0 to 34.2. The bluff in this zone is poorly vegetated and the bluff exhibits shallow rotational and translational failures. There apparently has been 10 to 15 feet of bluff top recession since 1975. Seeps occur in the upper slope. Profile 80-2 has a deterministic factor of safety of 0.95 with respect to rotational failures (Appendix A & B). A probabilistic analysis of this profile resulted in factors of safety ranging from 0.57 to 1.24. Of the 25 most critical situations, 72 percent resulted in an unstable bluff, while 42.4 percent of all the of situations resulted in an unstable bluff. This zone is likely to have both rotational and shallow translational failures.

Erosion zone 34b extends from 34.2 to 34.6. The bluff in this zone is 80 to 90 percent vegetated with grasses and small trees. Profile 77-1 currently has a factor of safety of 1.16 with respect to rotational failures (Appendix A). There is a small scarp at the top of the bluff within this zone and wave action has also created a scarp at the toe. Translational failures are possible in zone 34b, while shallow translational failures are likely. Zone 34c extends from 34.6 to the north end of the section. This zone is characterized by large, rotational slump blocks and an extensive scarp exists along the upper edge. Mature trees are growing on slump blocks in the mid slope. There is also a scarp at the toe indicating recent wave erosion. Translational failures are likely at the bluff toe, and rotational failures are likely to continue higher in the bluff.

In 1996 the beach width was reported to be made of sand and cobbles and ranges from 10 to 20 feet wide. In 1977 the beach width was reported as being between 20 and 35 feet and mostly made of sand and cobbles.

Shoreline recession data for Section 34 were estimated at one location. These data indicated a recession of 20 feet or 1.4 feet per year between 1978 and 1992. The 1977 study reported recession rates of one foot per year for this section.

T17N R23E SEC.27: SHEBOYGAN COUNTY

Section 27 extends from Cleveland Rd. north to the extension of North Ave. to the lake. The section straddles the boundary between Reach 23 and 24. The bluffs in Section 27 range from 10 to 50 feet high. The bluff is composed of 10 to 20 feet of reddish brown clayey Haven till at the toe overlain by 10 to 40 feet of sand, silt and clay. Thin Valders till is present locally near the bluff top. The bluff exhibits rotational failures and soil flows. Seeps are present in the upper bluff. The bluff is 40 to 90 percent vegetated with grasses and trees. The beaches are made of sand and cobbles and range from 10 to 15 feet wide. A road occupies the top of the bluff in this section. The land behind this road is primarily agricultural and residential. In the middle of the section, the land use is highly developed containing residential and commercial uses. Here is the location of the village of Hika Bay.

There are three erosion zones within this section. Erosion zone 27a extends from 27.0 to 27.2. The bluff in this zone has large scarps at the top. The mid section of the bluff is well vegetated and is possibly an old slump block. The toe is being eroded by waves. Profile 77-1 has a current factor of safety of 2.06 with respect to rotational failures (Appendix A & B). There has been less than two feet of bluff top recession since 1976. Rotational failures are unlikely, buy shallow translational failures are possible, especially at the toe.

Erosion zone 27b extends from 27.2 to 27.6. The bluffs in this zone exhibit shallow translational failures. The upper slope of the bluff shows little erosion in the last 20 years, but there has been significant erosion along the lower face. Profile 80-1 has a current factor of safety of 1.41 with respect to rotational failures (Appendix A & B). Zone 27c extends from 27.6 to the north end of the section. This zone has a low terrace that is well vegetated and protected. The shoreline is armored by riprap on the north end of the beach in this section. Zone 27b is unlikely to have rotational failures, but shallow translational failures are likely at the toe. Zone 27c appears unlikely to have failures.

In 1996 the beach width was reported to be made of sand and cobbles and ranges from 10 to 15 feet wide. In 1977 the beach width was reported as being between 10 to 40 feet and made of sand, and cobbles.

Shoreline recession data for Section 27 were estimated at one location. These data indicated a recession of 20 feet or 1.4 feet per year between 1978 and 1992 at 77-1. The 1977 study reported recession rates of 0.7 foot per year for this section.

SHORELINE REACH 24: MANITOWOC COUNTY

The south boundary of Reach 24 is at Centerville Creek, about in the middle of Section 27 (Map III-3). The north boundary is at Point Creek, at the Section 11/12-Section 1 boundary. The southern mile is low terrace, mostly protected by riprap. Further north the bluff has moderate height and is eroding. Land use is similar in the south as the section described above with Hika Bay being located to the south. Mostly agricultural and woodlots exist in the middle and northern portion of the section with a number of seasonal and year round single family structures located along the bluff. No recession or other measurements were done for northern half of Section 27 by the field party in 1977 or 1996.

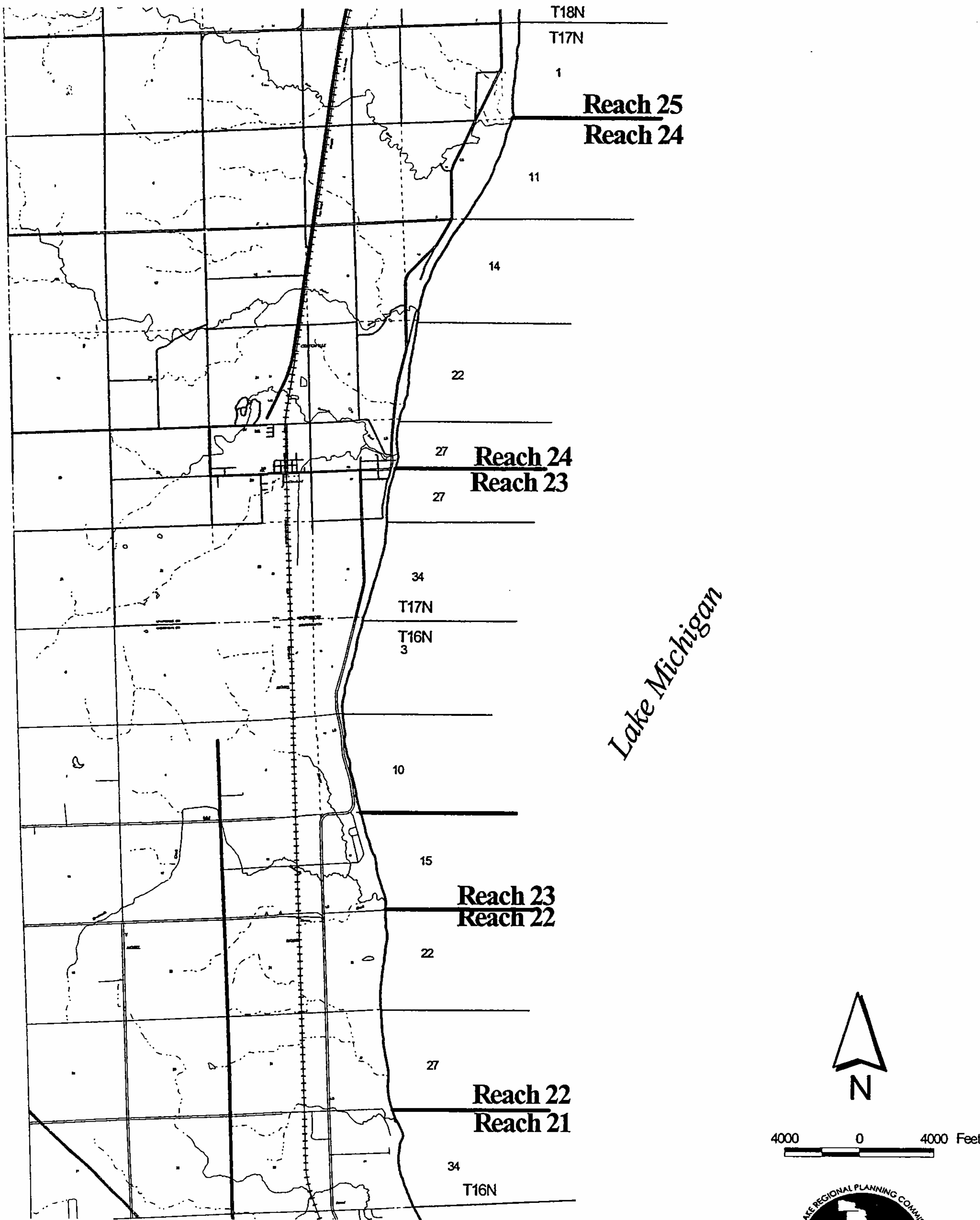
T17N R23E SEC.22: MANITOWOC COUNTY

Section 22 extends from the extension of North Ave. to the lake on the north side of Cleveland. The northern boundary is the extension of Fisher Creek Rd. to the lake, at the south edge of Fisher Creek. The southern 0.6 miles of the section, erosion zone 22a, is a low sand terrace that is mostly residential. The shoreline is protected by riprap and wide beaches.

Erosion zone 22b extends from 22.6 to 22.9. The bluffs in this zone range from 45 to 50 feet high. The bluff materials consist of 10 to 20 feet of silty Haven till at the toe overlain by 10 to 20 feet of silt and clay. This is in turn overlain by about 15 feet of sand. There is a 10 to 80 percent vegetation cover consisting of grasses, horse tails, and small aspen trees. Seeps occur in the mid

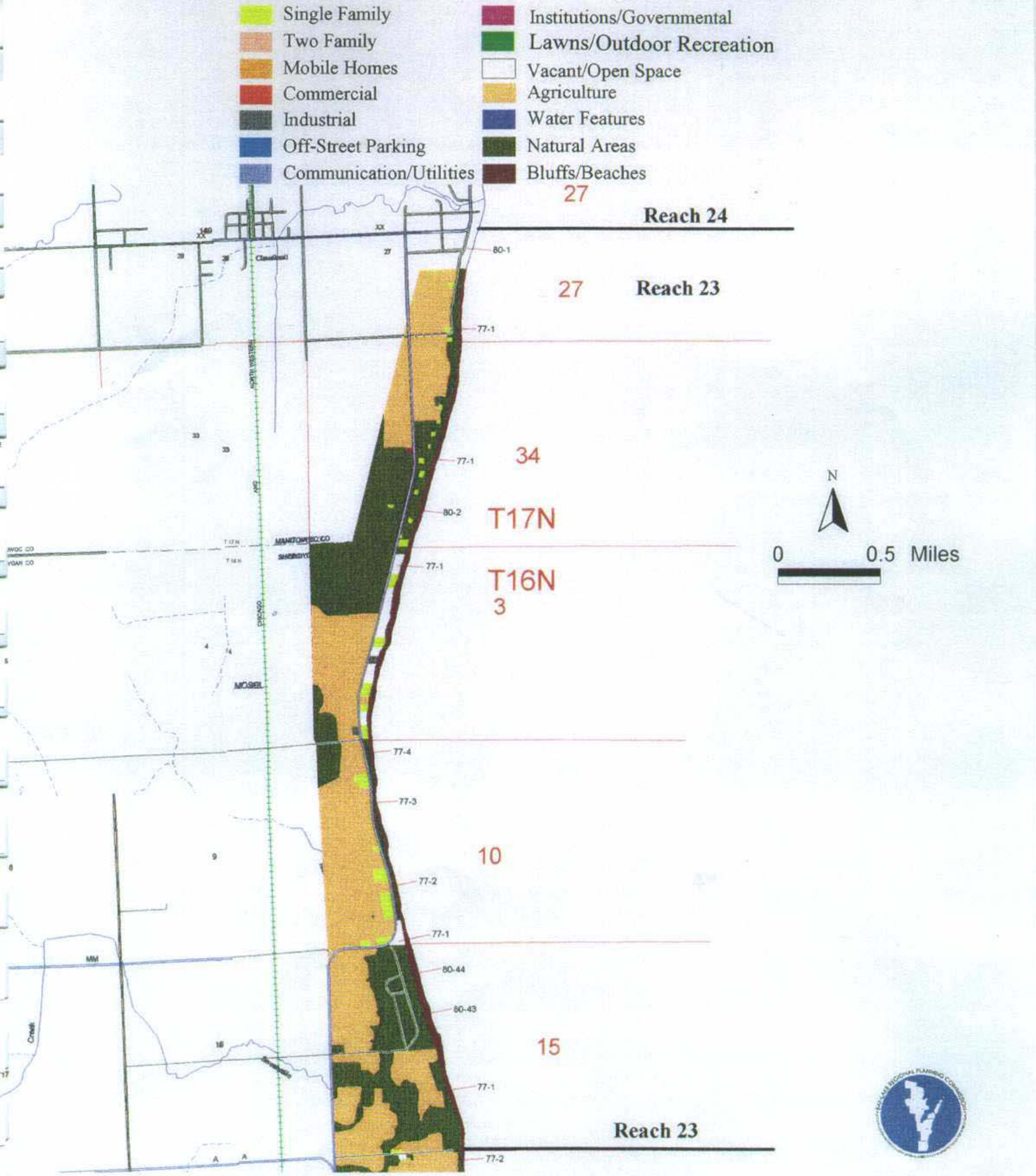
Map III-3

Bluff Analysis Sections Within Reach 23 & 24



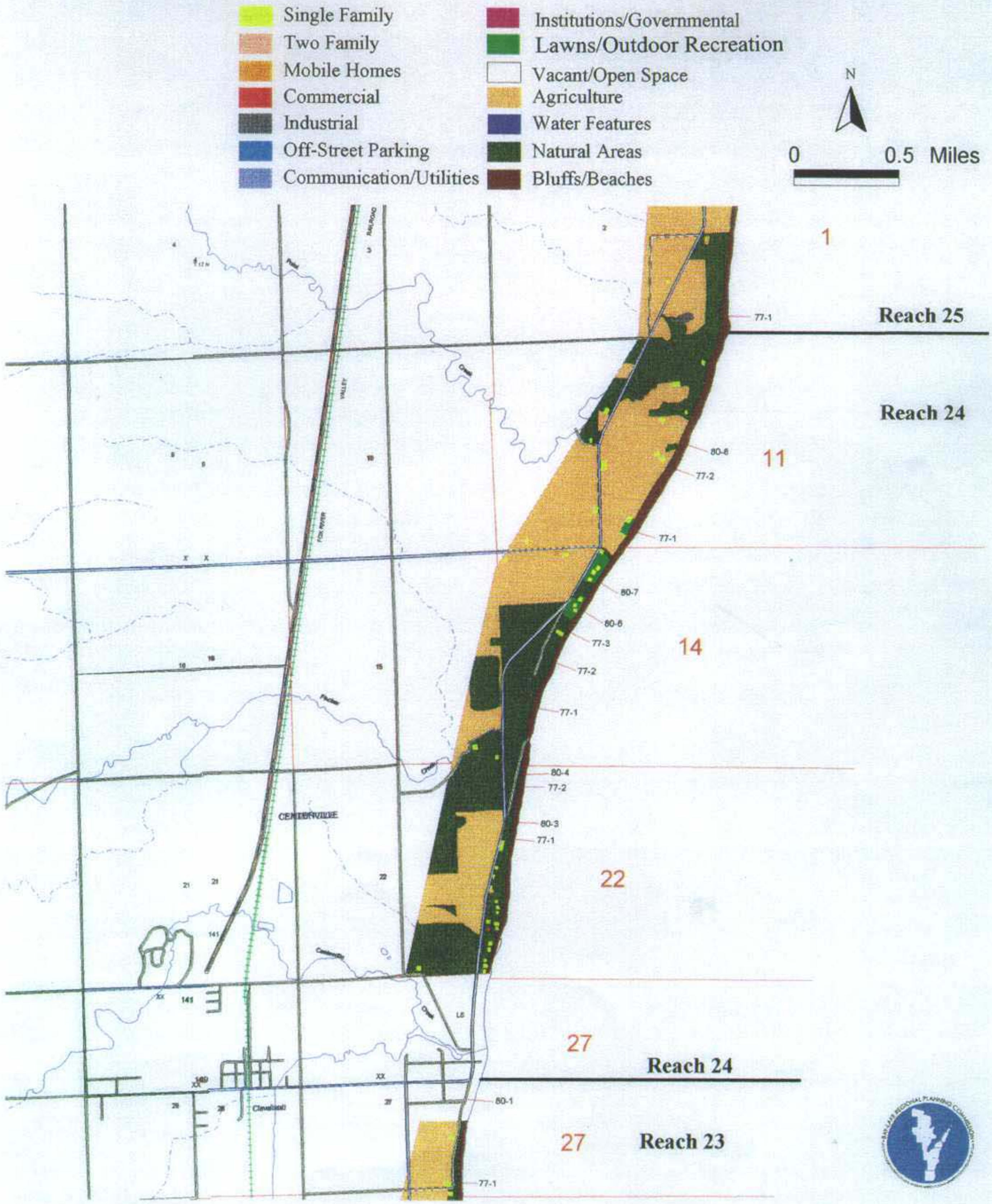
Source: D.M. Mickelson and T.B. Edil; Bay-Lake Regional Planning Commission, 1997

Map III-3a
Bluff Land Use and Profiles within Reach 23



Source: Bay Lake Regional Planning Commission, 1996

Map III-3b
Bluff Land Use and Profiles within Reach 24



Source: Bay Lake Regional Planning Commission, 1996

to upper slope. The bluff exhibits translational and shallow rotational failures. There are two profiles in this zone. Profile 77-1 had a factor of safety of 1.41 in 1977 (Appendix A & B). This analysis predicted failure to occur throughout the entire slope. The bluff now shows translational failures and little vegetation and has a factor of safety of 0.54 with respect to rotational failures. Profile 77-2 had a factor of safety of 1.42 in 1977 and was also predicted to have a large circular failure throughout the entire slope. This bluff now exhibits translational failures and is 80 percent vegetated. Profile 77-2 has a current factor of safety of 1.22 with respect to rotational failures. There appears to have been five to eight feet of bluff top recession since 1975 at this profile. Profile 80-4 exhibits translational failures and five to eight feet of bluff top recession since 1975. Profile 80-4 currently has a factor of safety of 1.26 with respect to rotational failures (Appendix A & B).

Erosion zone 22b has a sand and pebble beach ranging from 15 to 20 feet wide. Riprap exists sporadically along the bluff toe in this zone. Rotational failures are possible in this zone, and shallow translational failures are likely to occur.

Erosion zone, 22c, extends from 22.9 to the north end of the section. This zone is a low sand terrace near the mouth of Fisher Creek and is unlikely to have failures.

In 1996 the beach width was reported to be 14 to 22 feet and made of sand and pebbles. In 1977 the beach width was reported as being nonexistant to 25 feet and was made of mostly sand, cobbles and revetments.

No shoreline recession measurements were taken during 1996 for Section 22. The 1977 study reported a recession rate of 0.3 feet per year for this section.

T17N R23E SEC.14: MANITOWOC COUNTY

Section 14 extends from Fisher Creek to CTH X. The bluffs within this section range from 18 to 45 feet high. The bluff is composed of five to 15 feet of sand at the toe, overlain by 10 to 20 feet of silt and clay with a cap of wind blown sand. Along most of the bluff top the sand is thin, but back from the bluff top dune sand is probably over 20 feet thick. There is a discontinuous till layer (probably Valders) within the lacustrine silt and clay unit. The beach is made of sand and varies from 30 to 50 feet wide. Land use in the northern part of this section has eight single family properties surrounded by woodlots as in 1977. The southern half is now Manitowoc County park lands.

In 1977 there were two erosion zones for this section, 14a and 14b. The northernmost zone, 14b, was characterized by a better vegetated bluff. This northern zone has experienced a decrease in vegetation since 1977. The bluff throughout the entire section is now uniform and can be described as a single erosion zone. The bluffs are 70 to 90 percent vegetated with horse tails, grasses and some small aspen trees. Seeps are present in the mid to upper bluff within this section. The bluffs exhibit translational and shallow, rotational failures along with some soil flows.

Three stability analyses were performed in 1977 (Appendix A & B). Profile 77-1 had a factor of safety of 1.56 in 1977. This analysis predicted a large, rotational failure throughout the entire slope. There has been three feet or less of bluff top recession since 1975. The bluff currently has translational failures and a factor of safety of 1.47 with respect to rotational failures. Profile 77-2 was determined to have a factor of safety of 1.28 in 1977. Currently this profile has translational failures and a factor of safety of 0.87 with respect to rotational failures. Profile 77-3 was determined to have a factor of safety of 0.96 in 1977. This 1977 analysis predicted a shallow rotational failure in the upper bluff. Currently there are translational failures near the upper slope, and a factor of safety of 0.68 with respect to rotational failures. Profile 80-6 had a factor of safety of 0.79 with respect to rotational failures. Profile 80-7 has a deterministic factor of safety of 0.99 with respect to rotational failures. A probabilistic analysis of profile 80-7 resulted in factors of safety ranging from 0.79 to 1.46. Of the 25 most critical situations, 60 percent resulted in failures, while 23.6 percent of the total situations resulted in failures. There has been minimal bluff top recession since 1975 at profile 80-7. Both rotational and shallow translational failures are likely to occur in this section, although the rotational failures may not occur frequently.

In 1996 the beach width was reported to vary from 30 to 50 feet wide and made of sands. In 1977 the beach width was reported as being between nonexistant to 45 feet and made of sand.

Shoreline recession data for Section 14 were estimated at three locations. These data indicated a recession of between 50 and 70 feet or between 3.6 and five feet per year occurred between 1978 and 1992. No recession measurements were done in 1977.

T17N R23E SEC.11: MANITOWOC COUNTY

Section 11 lies between County Trunk X and Point Creek Road. The bluff height within this mile ranges from 40 to 60 feet. The bluffs consist of five to 20 feet of silt and clay or till at the toe overlain by two to 15 feet of sand. To the north the bluffs appear to become all sand. The bluffs are 30 percent to 90 percent vegetated with grasses and some trees. There is highly variable seepage throughout this section; the bluffs vary from dry to very wet. Seeps are in the lower bluff when present, probably at the bottom of the sand and at the top of the silt or till units. The bluff exhibits shallow translational failures. The beach is composed of sand and is 14 to 40 feet wide.

Erosion zone 11a extends from 11.0 to 11.4. This zone is about 30 percent vegetated, is dominated by translational failures and has active seepage. Profile 77-1 had a factor of safety of 0.91 in 1977 and was predicted to have an upper rotational failure (Appendix A & B). The bluff currently shows translational failures and approximately 20 feet of bluff top recession since 1975. Profile 77-1 currently has a factor of safety of 1.36 with respect to rotational failures. Profile 77-2 had a factor of safety of 0.76 in 1977, with rotational failures predicted for the middle slope. The bluff currently has translational failures, and has a factor of safety of 0.90 with respect to rotational failures. Survey data shows that 65 feet of bluff top recession has occurred between the years 1965 and 1992 at this location. Profile 80-8 had a deterministic factor of safety of 0.96 in 1996. A probabilistic analysis of profile 80-8 resulted in factors of safety ranging from 0.99 to 1.53. Of the 25 most critical situations, four percent resulted in failures, while 0.4 percent of the total situations resulted in failures (Appendix A & B). Shallow translational failures are likely and rotational failures are possible within this zone.

Erosion zone 11b extends from 11.4 to the north end of the section. This zone is 50 to 90 percent of vegetated. The upper bluff appears to be temporarily unlikely to fail, but toe erosion is producing a steeper slope that is encroaching on it from below. The slopes appear dry, without seepage. There is no bluff top recession apparent since 1975, but there has been significant toe erosion. Translational failures are possible, becoming more likely in the future and resulting in more bluff top recession.

Land use in 1996 remained similar to that in 1977. Agricultural fields, buildings, and homes make up this section's land use along with numerous acres of woodlots.

In 1996 the beach width was reported to be 14 to 40 feet and composed of sand. In 1977 the beach width was reported as being between 30 to 80 feet and made of sand and gravel.

Shoreline recession data for Section 11 were estimated at one location. These data indicated a recession of 65 feet or 4.6 feet per year between 1978 and 1992. No recession measurements were done in 1977.

SHORELINE REACH 25: MANITOWOC COUNTY

Shoreline Reach 25 is about six miles long and includes T.17 N., Section 1 through T.18 N., Section 7 in southern Manitowoc County (Map-4). Land use is a mixture of agriculture and residential. All of the reach shows some signs of erosion on the bluff, although conditions are variable. The bluff is generally 40 to 80 feet high and the geology of the bluffs is complex. Generally Haven till is in the lower part of the bluffs and in many areas sand or sand and gravel are present above. Seeps are common on the contact between the two. Most of the bluff toe is unprotected. Land use is similar to that in 1977 with mostly agricultural uses throughout the reach with clusters of residential development in the central and northern sections. Extractive uses are located in Section 24 of Reach 25.

T17N R23E SEC.1: MANITOWOC COUNTY

Section 1 extends from Point Creek Road to CTH F (Map III-). The bluffs within this section range from 50 to 70 feet high. The geology consists of reddish brown, silty Haven till in the lower bluff overlain by sand and gravel. The bluffs have a 50 to 60 percent cover of grasses, shrubs, and aspen and other trees. The bluffs either exhibit shallow translational failures and a sparse vegetation cover of grasses or the they exhibit a scarp along the upper edge of the bluff with thick tree cover throughout the mid bluff. The thicker vegetation is growing on an old slump blocks. Because the two dominant failure types are intermixed, the section is considered to be one erosion zone. This section also shows significant toe erosion throughout much of its length.

Profile 77-1 (Appendix A & B) was determined to have a factor of safety of 1.28 in 1977. This analysis predicted a large, shallow circular failure. Currently we see little bluff top recession but significant face erosion, suggesting that the 1977 predicted failure surface was accurate, but the factor of safety was too conservative. Profile 77-1 now has a factor of safety of 1.36 with respect to rotational failures. This suggests that the failure surface predicted in 1977 was accurate yet the factor of safety was too high. Profile 77-2 had a factor of safety of 1.38 in 1977. Deep rotational failures are unlikely, while shallow translational failures are likely to occur in this section. This analysis predicted a failure to occur along a large circular surface within the entire bluff. The slope currently shows circular failures and soil flows, having a factor of safety of 1.52 with respect to rotational failures. No bluff top recession appears to have occurred at profile 77-2 since 1975 land use is primarily agricultural fields and wood lots.

In 1996 the beach width was reported to be between 30 and 50 feet and the beach is made of sand. In 1977 the beach width was reported as being between 30 and 55 feet and the beach was made of sand and some gravel.

Shoreline recession data for Section 1 were estimated at one location. These data indicated a recession of 40 feet or 2.9 feet per year occurred between 1978 and 1992. The 1977 study reported recession rates of two feet per year for this section.

T18N R23E SEC.36: MANITOWOC COUNTY

Section 36 extends from CTH F to CTH U at Northeim. The bluffs in this section range from 35 to 60 feet high. The bluffs are composed of reddish brown, silty clay till -- possibly Haven -- in the lower bluff overlain by lacustrine sand and silt. Much of the northern half of the section is poorly exposed. The bluffs have a 70 to 90 percent cover of grasses and shrubs. They are failing mostly by translational and shallow rotational slides. This section is mostly dry except for some seeps in the southern end of the section. The seeps exist above silty clay till found in the lower 15 feet of the bluffs.

Profile 77-1 had a factor of safety of 1.5 in 1977 and was predicted to have a large circular failure (Appendix A & B). Since then significant toe erosion yet no bluff top recession has occurred. Profile 77-1 has a current factor of safety of 1.41 with respect to rotational failures. Profile 77-2 exhibits translational failures yet is well vegetated. Profile 77-2 has a current factor of safety of 2.16 with respect to rotational failures. Section 36 has possible shallow translational failures, while rotational failures are unlikely. Land use within this section is primarily agricultural.

In 1996 the beach widths were reported as varying between 35 and 40 feet and made of sand. In 1977 the beach width was reported as being between 15 and 80 feet and made of sand.

Shoreline recession data for Section 36 were estimated at one location. These data indicated a recession of 100 feet or 7.1 feet per year occurred between 1978 and 1992. There were no recession rates for this section in 1977.

T18N R23E SEC.25: MANITOWOC COUNTY

This section extends from Northheim to CTH C. Bluff height ranges from 3S to 50 feet. The bluffs contain reddish brown, silty clay till (Haven) in the lower bluff overlain by sand and sandy gravel. The bluff is 70 to 100 percent vegetated with grasses and shrubs such as dogwood within this section and no seeps are visible. Land use within this section is primarily new large lot residential developments. In 1977 the land use was mostly woodlots.

Erosion zone 25a extends from 25.0 to 25.5. This zone has lower bluffs than in 25b and they are well vegetated and stable. Profile 80-15 currently has a factor of safety of 2.32 with respect to rotational failures.

Erosion zone 25b extends from 25.5 to the north end of the section. The bluffs within this zone are higher than in 25a and exhibit translational and shallow rotational failures. Two stability analysis were performed in this zone. Profile 77-1 had a factor of safety of 1.41 in 1977 (Appendix A & B). This profile now shows translational failures and has had minor bluff top recession since 1975. The factor of safety for 77-1 is currently 1.83 with respect to rotational failures. Profile 77-2 had a factor of safety of 0.82 in 1977 and was predicted to have circular failures in the upper bluff. The bluff currently shows rotational slump blocks and some bluff top recession since 1975. Profile 77-2 currently has a factor of safety of 1.76 with respect to rotational failures. Deep rotational failures are unlikely in this zone, while shallow translational failures are possible.

In 1996 the beach width was reported to have a width varying from 25 to 50 feet with sand and cobbles. In 1977 the beach width was reported as being between 30 and 50 feet with sand and gravel.

Shoreline recession data for Section 25 were estimated at two locations. These data indicated a recession of between 65 and 70 feet or between 4.6 and five feet per year occurred between 1978 and 1992. There were no recession rates for this section in 1977.

T18N R23E SEC.24: MANITOWOC COUNTY

Section 24 extends from CTH C to Carson Lake Road. Bluff height varies between 50 and 66 feet within this section. The bluffs are composed of 20 to 30 feet of red/brown silty Haven till low in the bluff overlain by sand and gravel. This section has a large amount of seepage above the silty till. The bluffs are 40 to 90 percent vegetated, mostly with grasses. Many areas show increased vegetation since 1976. The bluffs exhibit shallow rotational and translational failures. Severe toe erosion appears widespread in this section.

In 1977, profile 77-1 was determined to have a factor of safety of 1.1 (Appendix A & B). There has been some bluff top recession since that time, and profile 77-1 has a current factor of safety of 1.42 with respect to rotational failures. Profile 77-2 was determined to have a factor of safety of 1.3 in 1977. This profile now exhibits severe toe erosion and about a 40 percent vegetation cover.

In 1977, profile 77-2 has a current factor of safety of 1.81 (Appendix A & B) with respect to rotational failures. The profile measured in 1980 labeled 80-14 has experienced significant bluff top recession since 1975, possibly as much as 10 feet. Profile 80-14 has a factor of safety of 1.37 with respect to rotational failures. Large rotational failures are unlikely in this section, while shallow translational failures are likely to occur.

Throughout the section there are sand and cobble beaches with widths of about 25 to 30 feet. Land use is agricultural with some residential structures. Sand and gravel mining is also apparent from the surficial shallow pits. In 1977 the beach width was reported as being between 20 and 30 feet with a composition of cobbles.

Shoreline recession data for Section 24 were estimated at two locations. These data indicated a recession of between 70 and 110 feet or between five and 7.9 feet per year occurred between 1978 and 1992. There were no recession rates for this section in 1977.

T18N R23E SEC.18: MANITOWOC COUNTY

Section 18 extends from Parsons Lake Rd. to the extension of Clover Rd. to the lake at Calvin Creek. The bluff in this section ranges from 35 to 60 feet high. In the southern part of the section about 15 feet of reddish brown silty clay Haven till is capped by thin sand that has been locally mined. In the northern half of the section the till thickens to about 40 feet and is overlain by five to 15 feet of sand and gravel or sandy debris flow sediment. The bluffs have a 30 to 80 percent vegetation cover of horse tails and grasses. Seeps occur in the lower bluff along the upper till contact in the southern part of the section. Shallow translational failures are present throughout the bluffs in this section. Profile 80-13 has seeps at the toe and has experienced about 10 feet of bluff top recession since 1975. Profile 80-13 currently has a factor of safety of 2.14 with respect to rotational failures (Appendix A & B). Profile 77-1 had a factor of safety 1.04 in 1977 and was predicted to have large, circular failures. Currently this profile has a scarp along the upper bluff, translational failures, and a factor of safety of 1.90 with respect to rotational failures. More than five feet of bluff top recession has occurred since 1975.

Profile 80-12 has no defined seeps, but does have cattails, suggesting a wet soil. This profile was not analyzed, but has experienced more than five feet of bluff top recession since 1975. Profile 77-2 had a factor of safety of 0.88 in 1977 and was predicted to have a failure in the upper mid slope (Appendix A & B). This profile has experienced about five feet of top recession since 1975 and now has translational failures. Profile 77-2 currently has a deterministic factor of safety of 0.93 with respect to rotational failures. A probabilistic analysis of profile 77-2 gives factors of safety ranging from 0.80 to 1.51. Of the 25 most critical situations, 40 percent, of these resulted in unstable conditions, while 25.2 percent of the total situations result in unstable conditions. Rotational failures are possible, and more likely in the northern end of this section. Shallow translational failures are also likely.

In 1996 the beach was reported to be made of sand and had varying widths between 15 and 50 feet. In 1977 the beach width was reported as being between five and 50 feet and made of sand sized materials.

Shoreline recession data for Section 18 were estimated at two locations. These data indicated a recession of between 30 and 40 feet or between 2.1 and 2.9 feet per year occurred between 1978 and 1992. There were no recession rates for this section in 1977.

T18N R23E SEC.7/8: MANITOWOC COUNTY

This section covers the mile from Calvin Creek at the extension of Clover Rd. to the lake and Silver Creek Rd. The bluffs in this section range from 60 to 70 feet high. The geology of the bluff in this section is complex and varies considerably from south to north. The bluff is composed of 30 to 50 feet of Haven till in the lower bluff throughout the southern half of the section. This is overlain by 10 to 20 feet of lacustrine silt and clay with interbeds of Valders till. Thick layers of sand and gravel are present above and below the Valders till in the north end of the section. The lower part of this section is covered. There are seeps near the middle of the slope along this section of the bluff, suggesting that there is till below the sand and gravel. Vegetation cover ranges from 30 to 80 percent and consists of grasses and shrubs. The slope appears to have shallow rotational and translational failures throughout the section. A small area at 7.2 has denser vegetation cover and larger slump blocks than the rest of the section.

In 1977, an analysis performed at profile 77-1 had a factor of safety of 1.27 (Appendix A & B). This profile now has about a 80 percent vegetation cover, shallow slides and rotational failures, and a deterministic factor of safety of 1.09 with respect to rotational failures. A probabilistic analysis of the profile resulted in factors of safety ranging from 0.81 to 1.29. of the 25 most critical situations, 56 percent of resulted in failures, while 36.4 percent of the total situations resulted in failures. There is a scarp at the top edge of the bluff. No markers were available for recession analysis at this profile.

Bluff profile 80-11 has had significant bluff top recession since 1980; approximately eight to 10 feet of recession has occurred. Profile 80-11 now has a factor of safety of 1.47 with respect to rotational failures (Appendix A & B). Rotational and shallow translational failures are likely in this section.

The beach varies from three to 30 feet in width and is made of sand and cobbles. Land use within these sections are primarily large lot residential with some agricultural fields remaining in use in Section 7 and a residential strip in Section 8. In 1977 the beach width was reported as being between 20 and 50 feet.

Shoreline recession data for Section 7/8 were estimated at one location. These data indicated a recession of 20 feet or 1.4 feet per year occurred between 1978 and 1992. The 1977 study reported a recession rate of two feet per year for this section.

SHORELINE REACH 26: MANITOWOC COUNTY

The southern boundary of Reach 26 is the north section line of Section 7/8 in T.18 N., R. 23 E., about three miles south of downtown Manitowoc (Map III-4). Silver Creek and Red Arrow Parks are in this reach. The remainder is agricultural and residential. North of Red Arrow Park, the railroad follows the shore and the shoreline is protected. The north edge of the reach is the north harbor jetty in Manitowoc. The southernmost 1.5 miles is subject to erosion and bluff instability. The bluff is up to 44 feet high and partly vegetated. Geology of the bluffs is poorly known. In

1977, long term erosion rates have been measured at two points and both gave values of one foot per year.

T18N R23E SEC.5: MANITOWOC COUNTY

This section covers the mile from Silver Creek Road to Viebahn St. in the city of Manitowoc. The bluff reaches heights of 70 feet, and the deposits consists of about 50 feet of sand and gravel in the lower bluff, overlain by 10 feet of till, which is overlain by 10 to 15 feet of sand. This section has bluffs that are well vegetated. Vegetation coverage ranges from 20 percent to 100 percent and consists of grasses, shrubs, and some trees. Land use within this section is primarily residential and recreational as in 1977.

There are two erosion zones within this section. Zone 5a extends from 5.0 to 5.7. This zone has 70 foot high bluffs exhibiting shallow, rotational failures and translational failures. The bluff is vegetated with grasses, shrubs, and trees, many of which have slid down the bluff. There appears to have been some minor bluff top recession since 1975. One profile was measured in 1977, but no safety factor was calculated for this profile in 1977. Profile 77-1 currently has a deterministic factor of safety of 1.07 with respect to rotational failures (Appendix A & B). A probabilistic analysis of this profile resulted in factors of safety ranging from 0.81 to 1.47. Of the 25 most critical situations, 80 percent resulted in failures, while 14.8 percent of the total situations resulted in failures. Profile 80-9 has a factor of safety of 0.85 with respect to rotational failures. Erosion zone 5a is likely to have both rotational and shallow translational failures. Erosion zone 5b extends from 5.7 to the north end of the section. This zone consists of low bluffs and a river mouth. This zone appears unlikely to have failures and is well vegetated.

In 1996 the beach width was reported to be 23 to 54 and made of sand. In 1977 the beach width was reported as being between 20 and 40 feet and made of mostly sand with some cobbles.

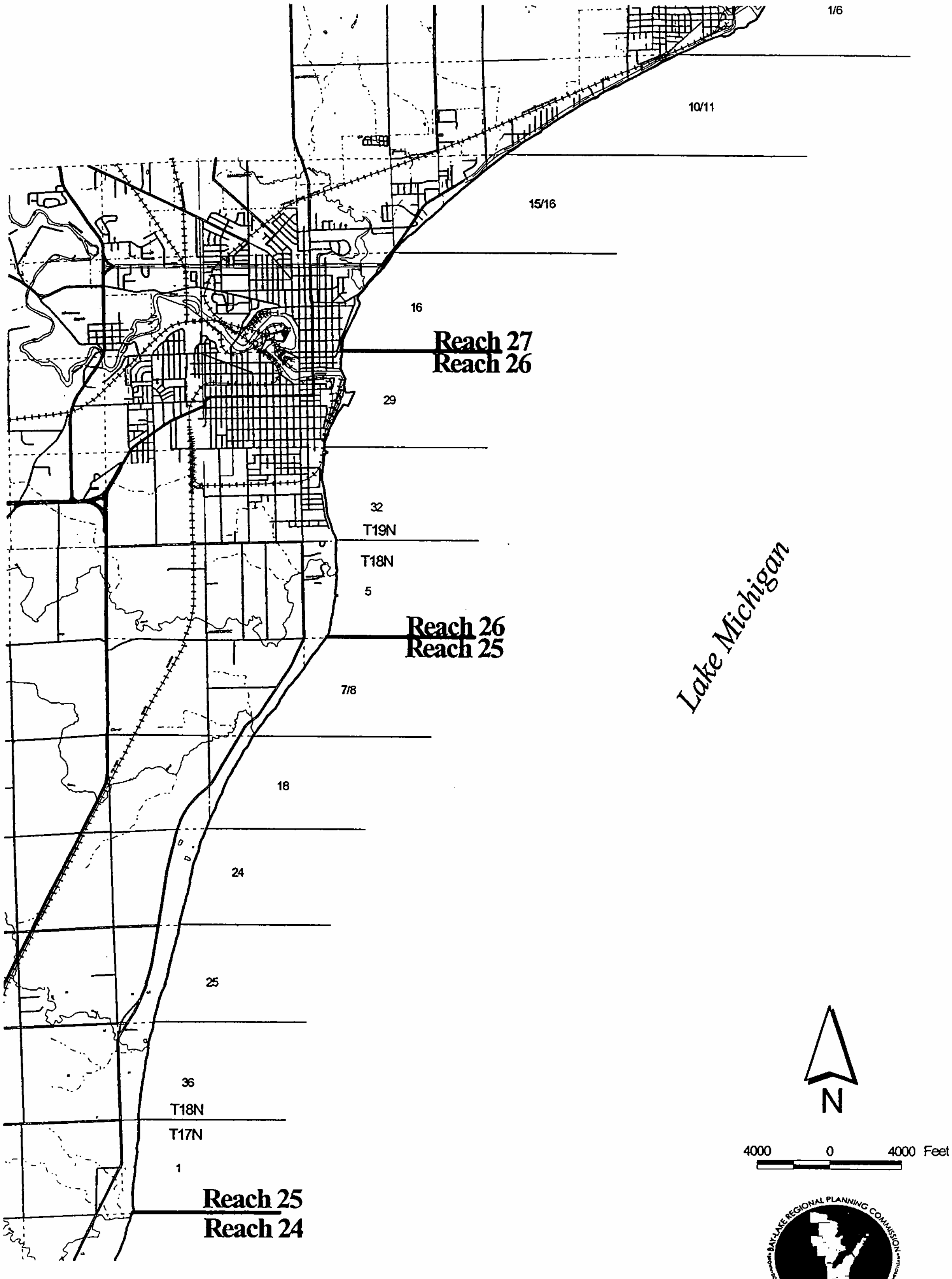
No measurements were conducted in regards to recession in 1996 for this section.. The 1977 study reported a recession rate of one foot per year for this section.

T19N R24E SEC.32: MANITOWOC COUNTY

This section lies within the City of Manitowoc, extending from County Road CL to Lincoln High School. The bluff height reaches 40 feet. The geology in this section appears to be 25 feet of sand near the base of the bluff overlain by Haven till. There is a 70 to 100 percent vegetation cover of grasses, shrubs and some trees. There are no seeps visible within the bluff. Land use within this section is primarily residential in the south, park in the central part, and industrial in the north.

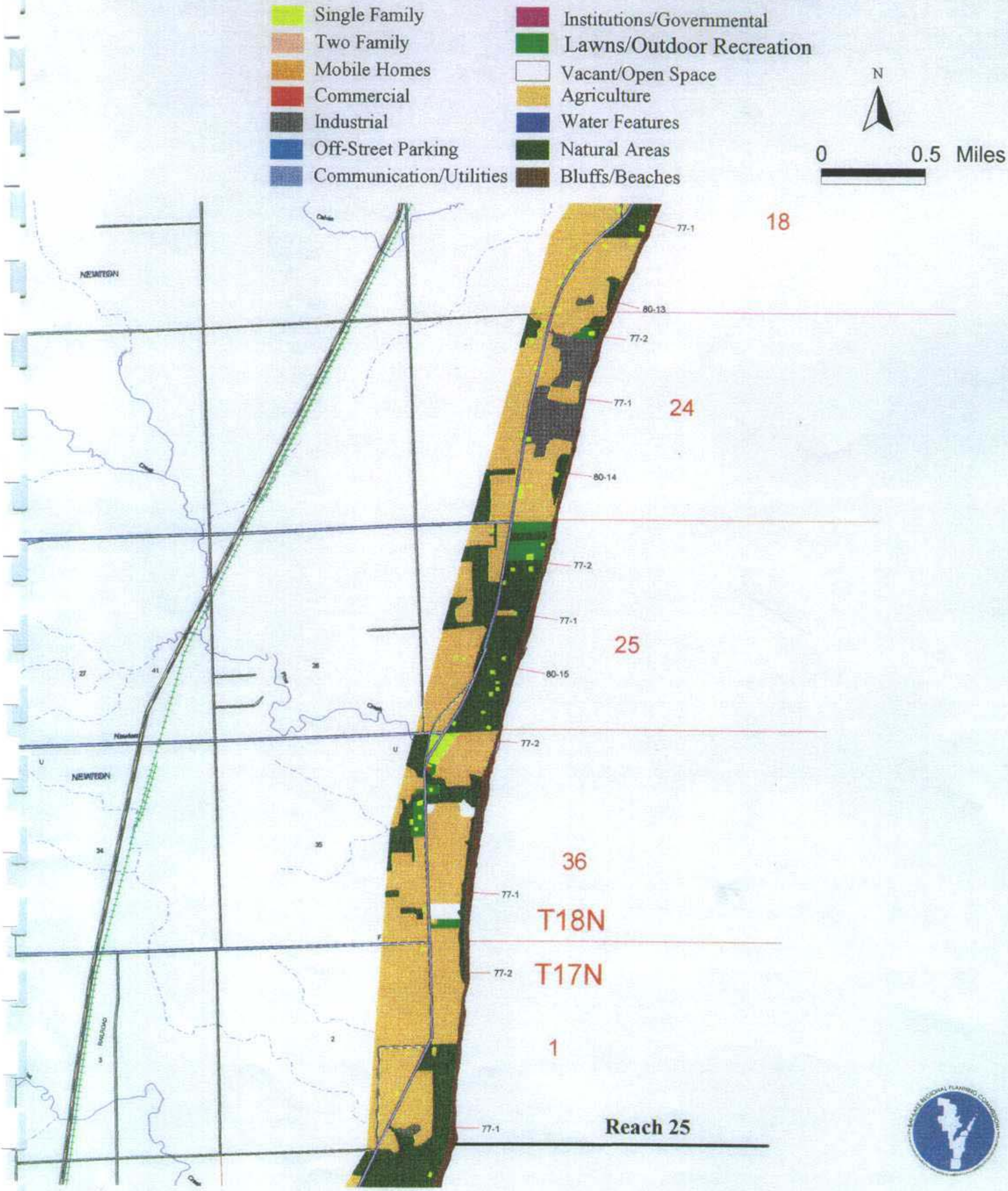
There are two erosion zones within this section. Zone 32a extends from 32.0 to 32.5. This zone has bluffs ranging from 30 to 50 feet high. The bluffs are 80 percent vegetated with grasses and trees and they show some shallow translational failures. Profile 77-1 had a factor of safety of 0.63 in 1977 (Appendix A & B). This profile currently has a factor of safety of 1.66 with respect to rotational failures, indicating that the slope has flattened considerably. Zone 32a is unlikely to have rotational failures, but translational failures are possible. Erosion zone 32b extends from 32.5 to the north end of the section. The shoreline in this zone is a low sandy terrace that is vegetated and unlikely to have failures.

Map III-4
Bluff Analysis Sections Within Reach 25 & 26



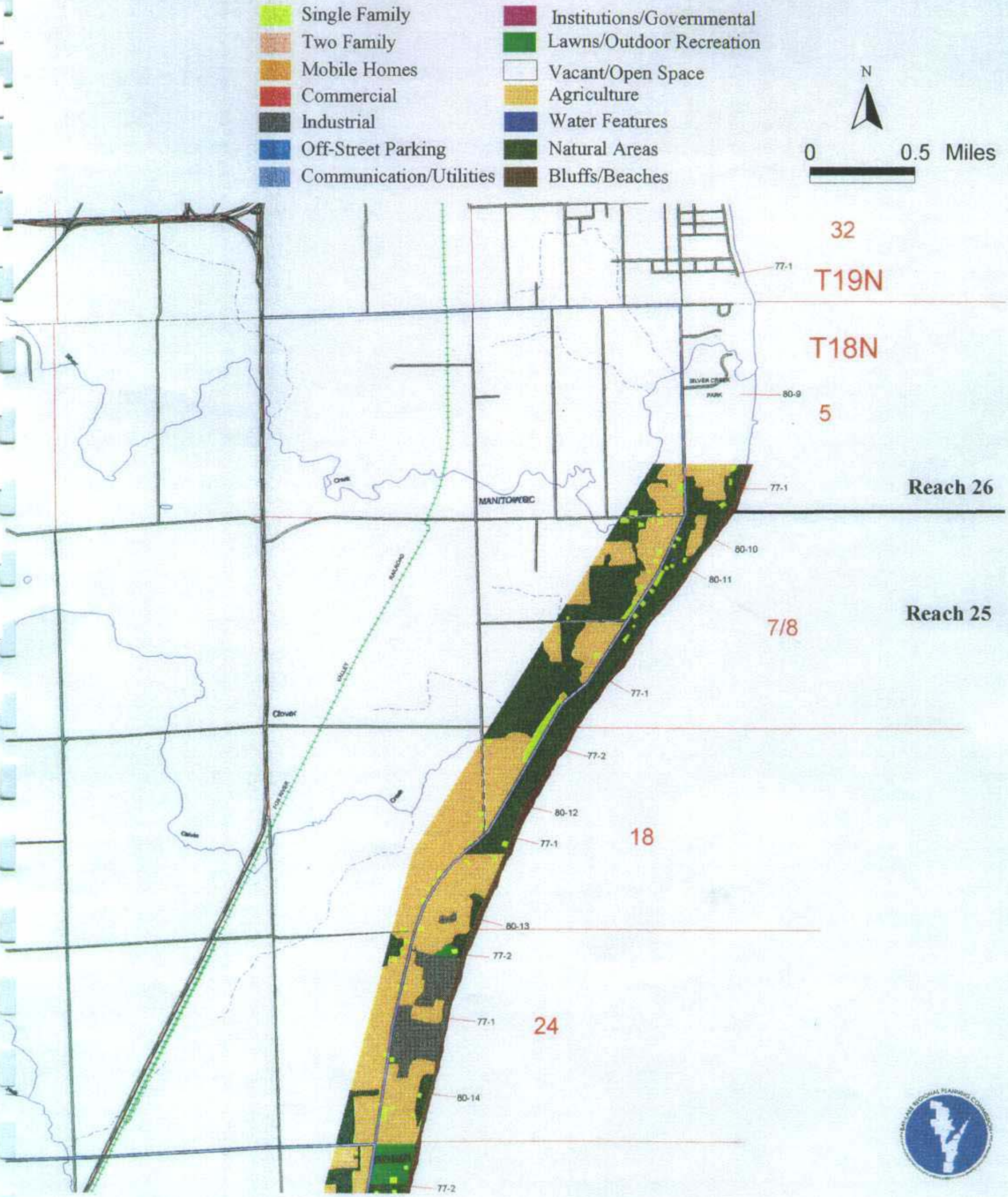
Source: D.M. Mickelson and T.B. Edil; Bay-Lake Regional Planning Commission, 1997

Map III-4a
Bluff Land Use and Profiles within Reach 25



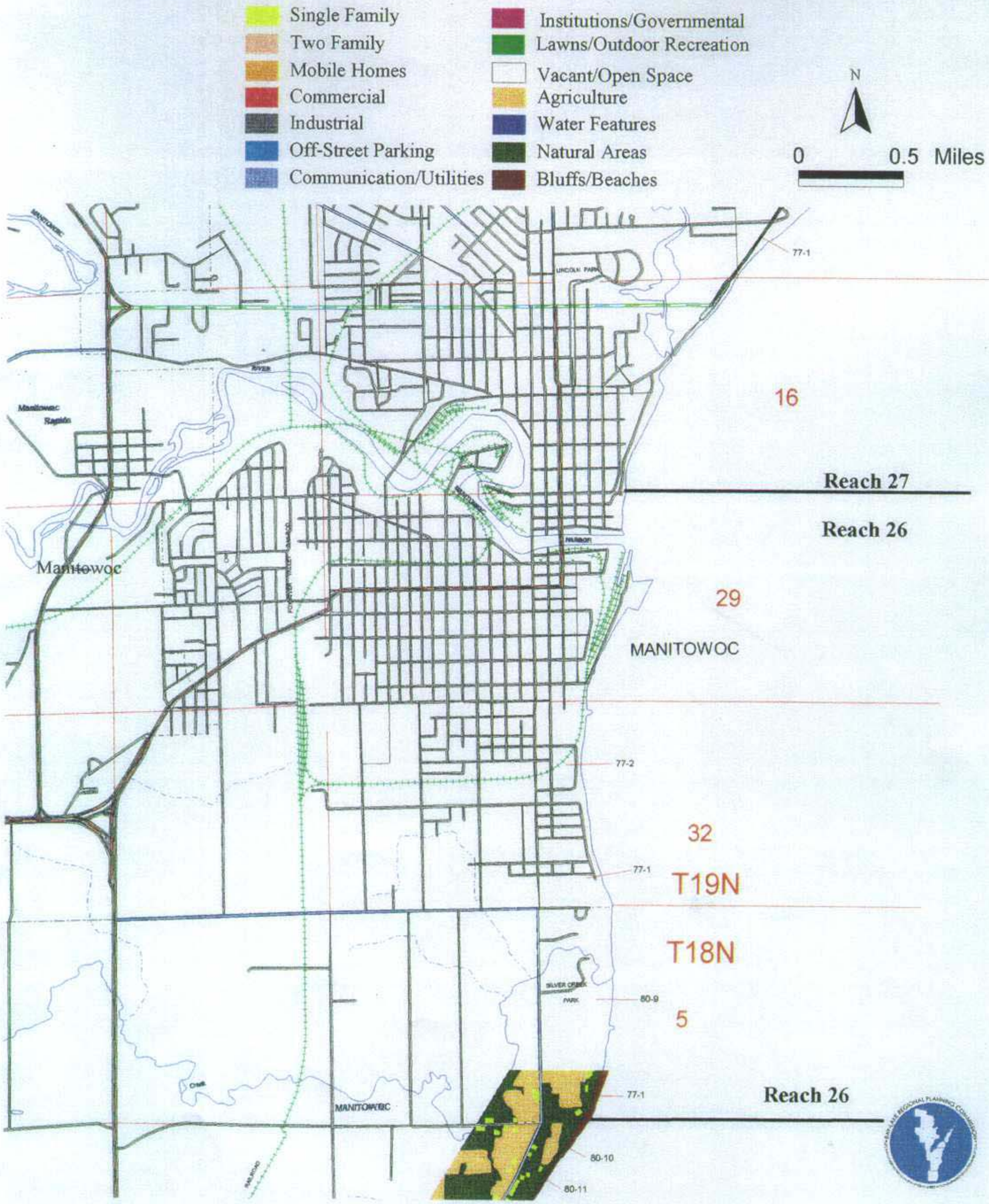
Source: Bay Lake Regional Planning Commission, 1996

Map III-4b
Bluff Land Use and Profiles within Reach 25



Source: Bay Lake Regional Planning Commission, 1996

Map III-4c
Bluff Land Use and Profiles within Reach 26



Source: Bay Lake Regional Planning Commission, 1996

In 1996 the beach width was reported from 60 to 200 feet and consists mainly of sand. In 1977 the beach width was reported as being between nonexistant and 50 feet and made of sand.

No measurements were conducted in regards to recession in 1996 for this section. The 1977 study reported a recession rate of one foot per year for this section.

T19N R24E SEC.29: MANITOWOC COUNTY

This section is occupied by Manitowoc Harbor. This section is protected by several structures and has no bluffs. Due to the section being fully protected by revetments or bulkheads, this section was not investigated further in 1977 or in 1996.

SHORELINE REACH 27: MANITOWOC COUNTY

Shoreline Reach 27 extends from the north jetty of Manitowoc Harbor to the West Twin River in downtown Two Rivers (Map III-5). Almost all of the reach has a shoreline which is protected by riprap. The bluffs in these sections are also low and stable. Only Section 16 was measured in 1977 and 1996. Due to the existing shoreline protection and the existence of low stable bluffs, the other sections were not further investigated.

T19N R24E SEC.16: MANITOWOC COUNTY

This section extends from the intersection of Johnson Drive with Hwy. 42 to the intersection of Woodland Drive with Hwy. 42. The bluff within this section is up to 30 feet high, discontinuous, and mostly protected. The bluff is composed of sand in the lower bluff overlain by a thin till layer, that is in turn overlain by silty clay, till and sand. The bluffs have 90 to 100 percent vegetation coverage of grass and burdock. No seeps are visible within this section. The bluffs are mostly protected by riprap and/or beaches throughout this entire section. The bluff top is occupied by Highway 42 and wayside rest stops.

Profile 77-1 had a factor of safety of 0.70 in 1977 (Appendix A & B). There was a shallow, rotational failure predicted to occur in the upper slope. This site currently has a thick vegetation cover and has a deterministic factor of safety of 0.861 with respect to rotational failures, although it appears stable. A probabilistic analysis of this profile resulted in factors of safety from 1.16 to 3.82. None of the trial situations resulted in unstable conditions.

The second stability analysis, at profile 77-2, had a factor of safety of 0.79 in 1977 (Appendix A & B). There was a shallow, rotational failure in the mid slope predicted for this site. This site currently appears relatively stable with some irregularities caused by surface wash and erosion. Profile 77-2 currently has a factor of safety of 1.12 with respect to rotational failures. Rotational and shallow translational failures are both possible in this section.

In 1996 the beach width was reported to be 20 feet and made of sand and pebbles. In 1977 the beach width was reported as being between nonexistant and 30 feet and made of sand.

Shoreline recession data for Section 16 were estimated at two locations. These data indicated a recession of between none and five feet or between 0.0 and 0.4 feet per year occurred between 1978 and 1992. No recession rates were made for 1977.

SHORELINE REACH 28: MANITOWOC COUNTY

There are no bluffs in Shoreline Reach 28 and no measurements were taken during 1977 and 1996 studies by the field party (Map III-5). Most of the reach is occupied by Point Beach State Forest, although there is a public beach in the city of Two Rivers along with some private lands. The reach extends from the city of Two Rivers to about one mile north of Rawley Point, where the shore becomes distinctly northeast facing. Beaches vary in width from 20 to 100 feet. The offshore is gently sloping with numerous sand bars. This is an area of net sand accumulation, and has been for over 5,000 years as evidenced by the beach ridge complex behind the beach. Sand dunes cap many of the beach ridges above the active beach. Where beaches are not present, there is riprap protecting the shoreline.

SHORELINE REACH 29: MANITOWOC COUNTY

Shoreline Reach 29 extends from the north edge of Section 9 in T.20 N. to about 25.75 in T.21N (Map III-6). The southern part is sandy beach with dunes behind. A low bluff develops in Sec. 25/30 and extends to the north end of the section. Land use is residential, agricultural, and woodlots as in 1977 with the addition of newer single family residential in the north and south of the reach. Section 4 of Reach 29 was not measured by field parties in 1977 or in 1996 due to the lack of any bluffs within the section.

T21N R24E SEC.31: MANITOWOC COUNTY

Section 31 consists mostly of sand banks and dunes ranging from zero to 10 feet in height. No profiles were measured during 1977 and 1996 by the field party. These shoreline areas have about a 60 percent cover of shrubs and grasses. The bluffs in this section appear stable. Land use is residential as it was in 1977.

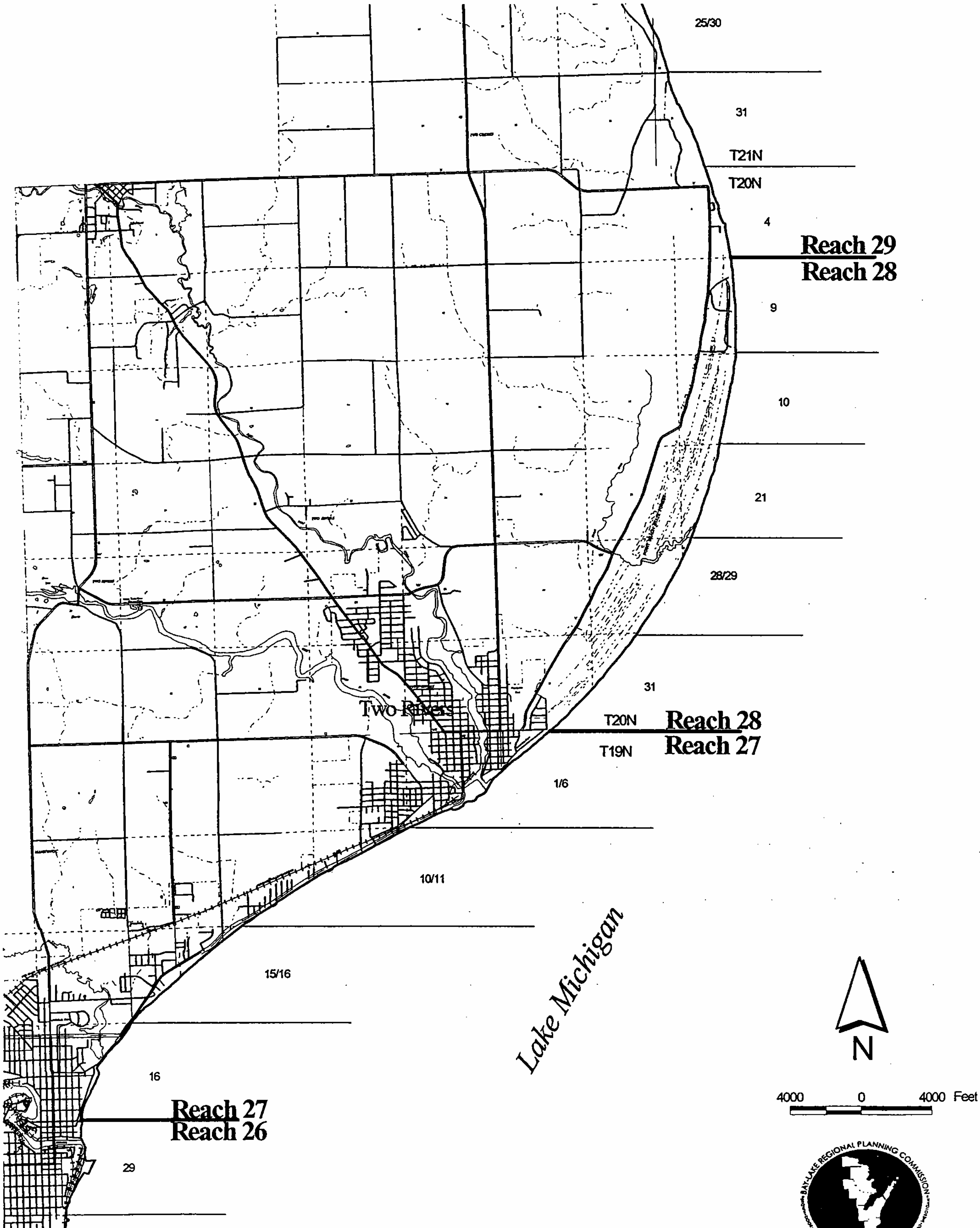
T21N R24E SEC.25/30: MANITOWOC COUNTY

Section 25/30 extends from Irish Rd. north to Nuclear Rd. and has both bluffs and a terrace with a wide beach. The bluff height is up to 30 feet. The bluff is composed of four to 10 feet of Haven Till at the toe overlain by sand which is overlain by a discontinuous layer of Two Rivers till. This section shows complex soil structures. In 1996 as well as in 1977, the land use within this section remains primarily agricultural and residential.

Erosion zone 30a extends from 30.0 to 30.6. This zone is bordered by a low terrace which is well vegetated and stable. The beach is wide enough to protect the terrace under most lake level conditions.

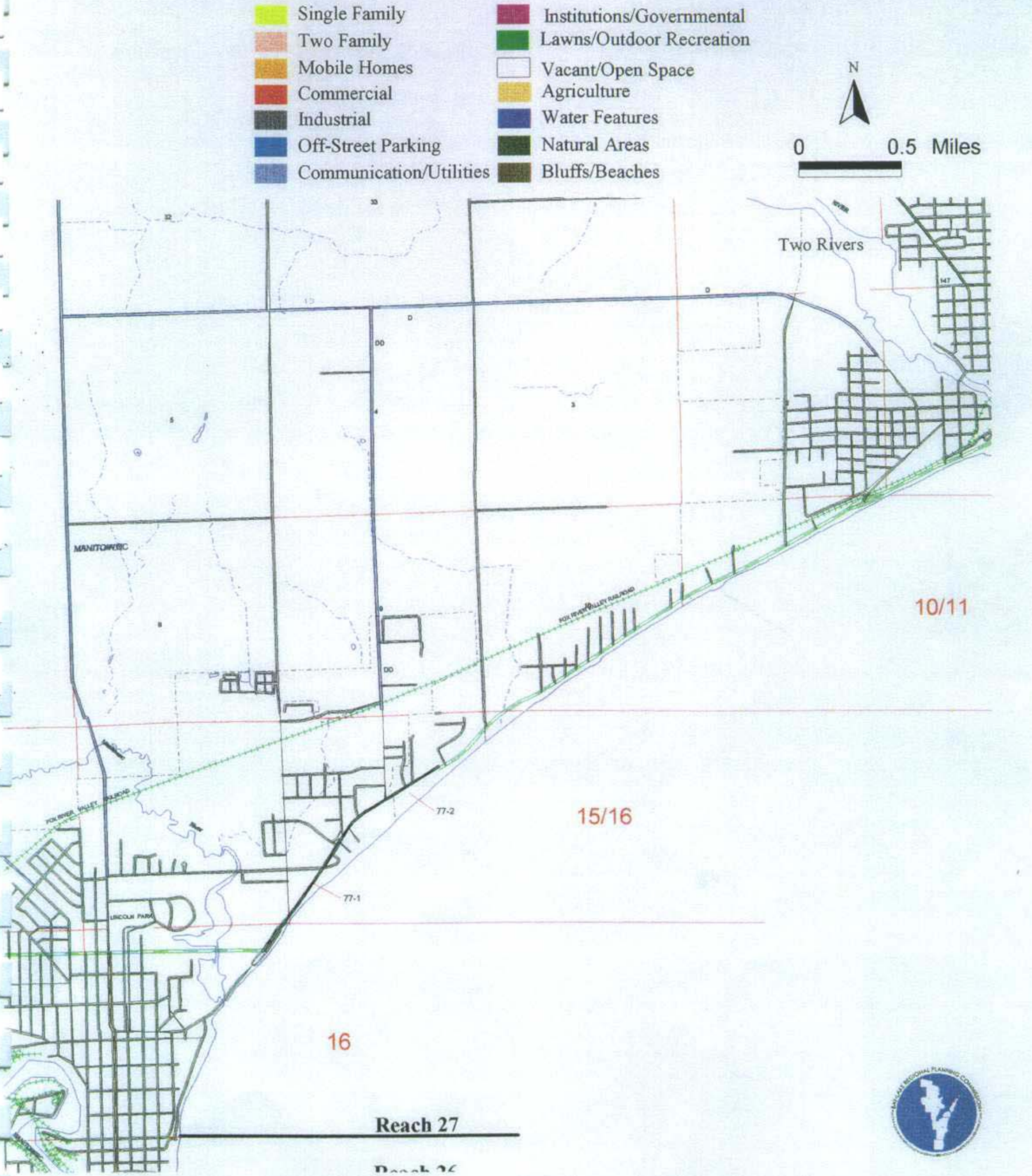
Erosion zone 30b extends from 30.2 to 30.6. There is a bluff up to 30 feet high that is poorly vegetated, with less than 40 percent vegetation cover of grasses. The bluff in this zone is failing by block slides, block falls, and translational failures. Seeps are present in the upper three feet of

Map III-5
Bluff Analysis Sections Within Reach 27 & 28



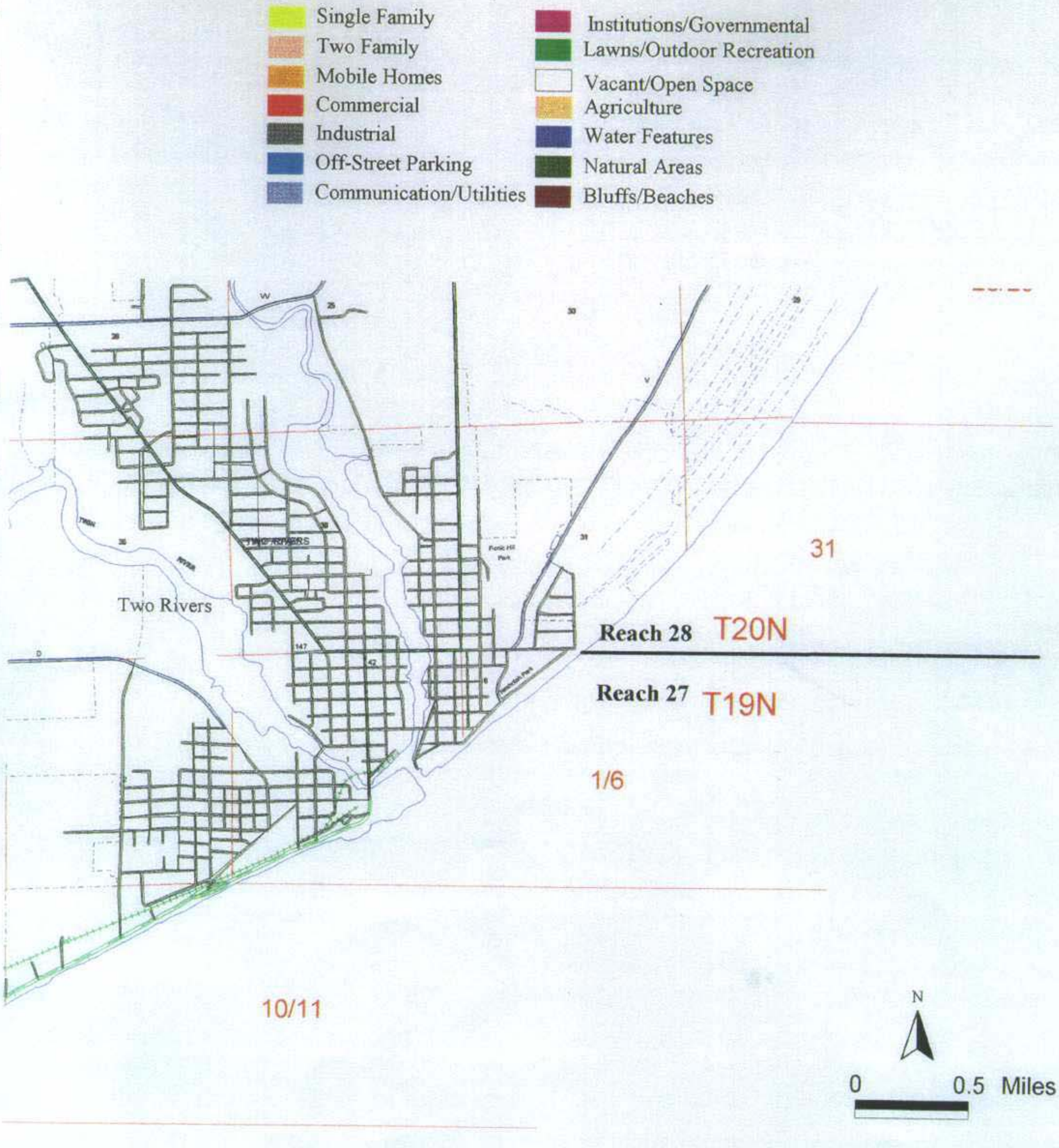
Source: D.M. Mickelson and T.B. Edil; Bay-Lake Regional Planning Commission, 1997

Map III-5a
Bluff Land Use and Profiles within Reach 27



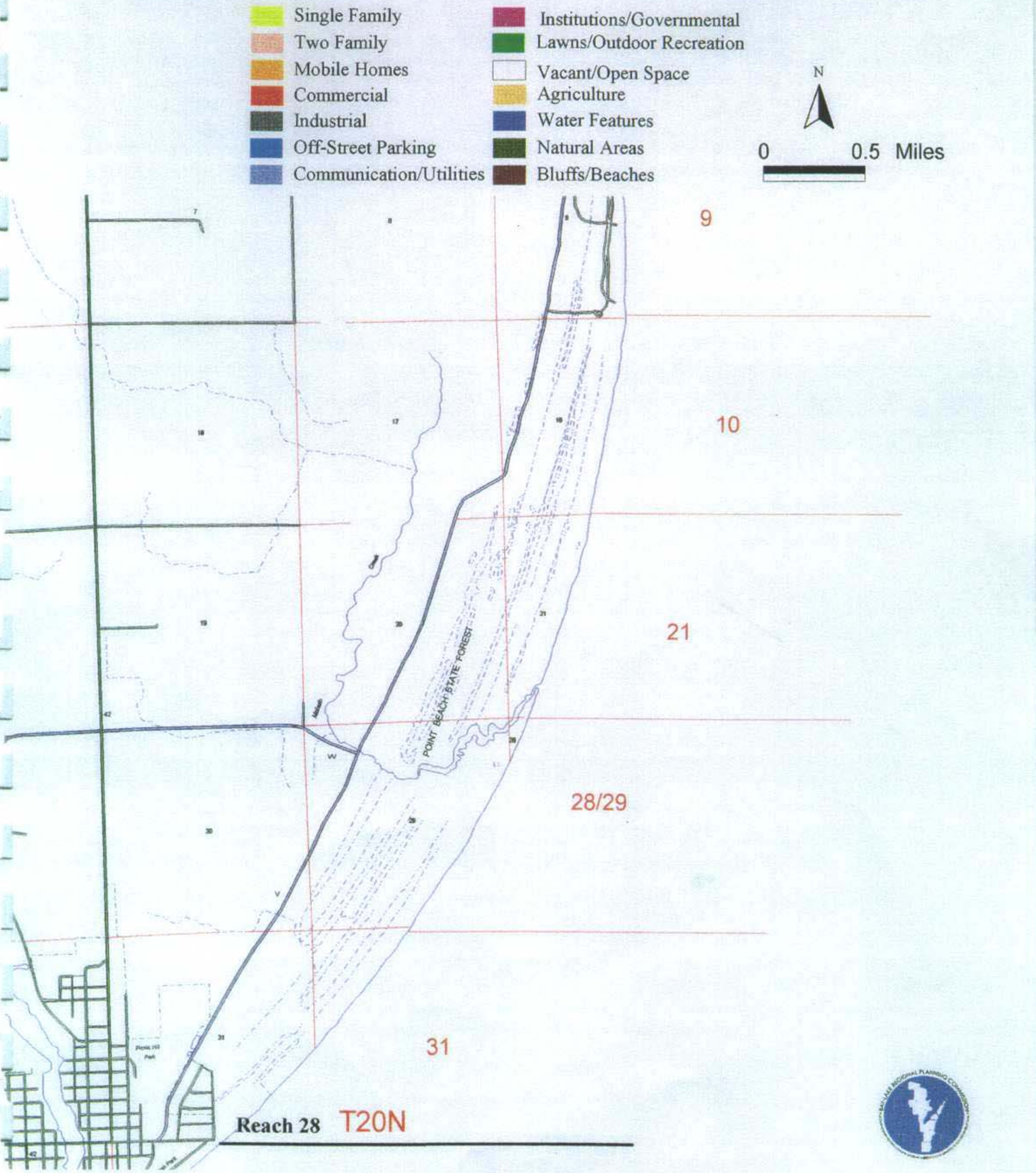
Source: Bay Lake Regional Planning Commission, 1996

Map III-5b
Bluff Land Use and Profiles within Reach 27



Source: Bay Lake Regional Planning Commission, 1996

Map III-5c
Bluff Land Use and Profiles within Reach 28



Source: Bay Lake Regional Planning Commission, 1996

the bluff and toe erosion appears to be driving the slope failures. Profile 77-1 currently has a factor of safety of 1.3 with respect to rotational failures (Appendix A & B). The factor of safety was 1.97 for this profile in 1977. Zone 30b is likely to have shallow translational failures, and smaller rotational failures are also possible. There is an estimated 15 feet of bluff top recession since 1975 for this zone.

Erosion zone 30c extends from 30.6 to the north end of the section. There are no bluffs along this low terraced shoreline.

In 1996 the beach width was reported to be 30 feet and made of sand. In 1977 the beach width was reported as being between 20 and 70 feet and made of small dunes and near the mouth of the stream where it is made up of alluvium.

In 1996 shoreline recession data for Section 30/25 were estimated at one location. These data indicated a recession of 50 feet or 3.6 feet per year occurred between 1978 and 1992. There was no recession rates calculated in 1977 for this section.

SHORELINE REACH 30: MANITOWOC COUNTY

Shoreline Reach 30 extends from T.21 N., sec. 30.6 north to the north edge of sec. 36 in T.22 N (Map III-6). From its southern edge to the Point Beach Nuclear Power Plant property it has no bluff. This property takes up much of Section 24.

T21N R24E SEC.24: MANITOWOC COUNTY

This section has no bluffs. The power plant is protected by wide beaches in front of and north of the two jetties in front of the plant. The remainder of the property is protected by riprap.

No measurements were taken in 1977 or 1996 for Section 24.

T21N R24E SEC.13: MANITOWOC COUNTY

This section covers the area from Tapawingo Rd. (power plant entrance) to 0.4 miles south of the Two Creeks public access. Section 13 has bluffs from 30 to 50 feet high. The bluffs contain about 20 feet of lacustrine clay and silt near the toe overlain by zero to five feet of what appears to be Haven till. This is overlain by a thin, two - three foot thick, sand layer which is overlain by Two Rivers till. The bluffs themselves exhibit translational and shallow rotational failures. They appear generally vegetated with grasses. No structures exist at the bluff toe. The bluff tops in this section are used for agricultural purposes as in 1977.

Two profiles were measured in this section in 1977. The first profile measured was 77-1 which had a factor of safety of 1.96 (Appendix A & B). Profile 77-1 was reanalyzed in 1996 and determined to have a factor of safety of 2.16 with respect to rotational failures. The second profile measured was 77-2 which had a factor of safety of 1.93 in 1977. The factor of safety for rotational failures for this profile was determined to be 2.24 in 1996. An additional deterministic analysis was performed in 1996, labeled 80-16, and resulted in a factor of safety of 0.96. A probabilistic analysis was also performed for profile 80-16 in 1996. This probabilistic analysis gave a range of factors of safety from 0.73 to 1.32, with 100 percent of the most critical conditions resulting in failure and 48.4 percent of the total conditions resulting in failures. Translational failures are likely and deep rotational failures are possible in this section.

In 1996 the beach width was 30 to 40 feet wide and made of sand. In 1977 the beach width was reported as being between five and 20 feet and made of sand.

In 1996 shoreline recession data for Section 13 were estimated at one location. These data indicated a recession of 25 feet or 1.8 feet per year occurred between 1978 and 1992. No recession data were reported in 1977.

T21N R24E SEC.11: MANITOWOC COUNTY

Section 11 covers the area from about 0.4 miles south of the public lake access at Two Creeks to the extension of Zander Rd. to the lake. The bluff height in this section ranges from 20 feet at the south end to about 40 feet at the north end. The stratigraphy along this section consists of lacustrine sediment at the toe which is mostly covered by slumped material. The lacustrine sediment is locally overlain by the Two Creeks Forest Bed, which in turn is overlain by lacustrine silt. The Two Rivers till is exposed near the bluff top. The bluff is about 40 percent vegetated with grasses. The slopes exhibit translational failures and seeps are visible in the lower third of the slope. There has been an estimated 30 feet of bluff top recession between 1975 and 1996. Land use in this section is mostly agricultural.

Two profiles were measured in 1977. The first is 77-1, which had a factor of safety of 0.7 in 1977 (Appendix A & B). The failure predicted in 1977 was to occur in the upper slope, which apparently has happened. This profile currently has a factor of safety of 1.76. Profile 77-2 had a factor of safety of 0.7 in 1977 and again this stability analysis predicted an upper slope failure that probably occurred, flattening the slope. The profile currently has a factor of safety of 1.57. Presently, rotational failures appear unlikely, while translational failures should be considered likely to occur.

In 1996 the beach was 30 feet wide and made of sand and gravelly sand. In 1977 the beach width was reported as being between 18 and 20 feet wide and made of sand and pebbles.

Shoreline recession data for Section 11 were estimated at two locations. These data indicated a recession of between 65 and 70 feet or between 4.6 and five feet per year occurred between 1978 and 1992. No recession rate was reported in 1977.

T21N R24E SEC.2: MANITOWOC COUNTY

This section covers the area from the extension of Zander Rd. to the lake northward to the Manitowoc-Kewaunee County line. The bluff height in Section 2 ranges from about 25 to 30 feet. The Haven Till makes up the lower part of the bluff, but it is often covered by slumped material. This is overlain by lake sediment that contains the Two Creeks Forest Bed. This is in turn overlain by sand and silt, which is overlain by the Two Rivers Till. Locally there is one or two feet of sand above the Two Rivers till. The land use in this section is primarily agricultural, except for the Two Creeks unit of Wisconsin's Ice Age Scientific Reserve, which extends from 2.6 to the north section line.

There are two erosion zones in this section. Zone 2a extends from 2.0 to 2.5. This erosion zone has about a 20 percent vegetation cover consisting mostly of grasses. The slopes exhibit translational failures with seeps present half way up the slope. The beach is approximately 40 feet wide and is made of sand. In 1977 profile 77-1 had a factor of safety of .75 and predicted failure of the upper slope (Appendix A & B). The profile currently has a factor of safety of 2.21 with respect to rotational failures. Rotational failures are unlikely, while translational failures are likely to occur.

Erosion zone 2b extends from 2.5 to 2.7. The area behind the bluff in this zone is drained by a stream and is steeper due to the drained nature of the soil. Profile 77-2 has been mostly eroded by the lake, so was not measured in 1996. The beach in this section is 50 feet wide and made of sand. Translational failures are likely to occur in this zone, while rotational failures are unlikely.

Erosion zone 2c extends from 2.7 to the north end of the section. This zone failing mostly by rotational failures. The slump blocks are vegetated on top, but the face is barren. Seeps occur along low in the bluff and above fine grained lake sediment near the top of the bluff in places. A stability analysis of profile 77-3 resulted in a factor of safety of 0.96 in 1977 (Appendix A & B). This profile currently has a factor of safety of 2.37 with respect to rotational failures. Rotational failures are possible in this zone, while translational failures are unlikely.

In 1996 the beach width was reported to be 25 feet to 50 feet and made of sand and cobbles. In 1977 the beach width was reported as being between 10 and 20 feet and is made of sand and scattered pebbles.

Shoreline recession data for Section 2 were estimated at one location. These data indicated a recession of 65 feet or 4.6 feet per year occurred between 1978 and 1992. The 1977 study did not report a recession rate.

T22N R24E SEC.36: KEWAUNEE COUNTY

Section 36 extends northward from the Manitowoc-Kewaunee County line at CTH BB to the Kewaunee Powerplant. The bluff ranges from 20 to 40 feet high. Haven till presumably makes up the bluff toe, although it is covered throughout. This is overlain by 20 to 25 feet of lacustrine silt and some sand with the Two Creeks Forest Bed preserved locally within it. The Two Rivers Till is six to 12 feet thick and is capped in places by one to two feet of sand. The land use within this section is mostly agricultural.

Erosion zone 36a extends from 36.0 to 36.7. The bluff in this erosion zone is about 80 percent vegetated with grasses and has translational failures. Two profiles were measured in 1977. Profile 77-1 currently appears stable. The 1977 analysis had a factor of safety of 1.62. Profile 77-1 currently has a factor of safety of 2.06 (Appendix A & B). The second stability analysis, profile 77-2, resulted in a factor of safety of 1.95 in 1977. This profile is now protected by riprap, having a factor of safety of 2.79 with respect to rotational failures. There are large seeps at the profile.

Zone 36a is unlikely to have rotational failures, while shallow translational failures are likely. Erosion zone 36b extends to the north section line and the Kewaunee Powerplant. No profiles were measured in zone 36b.

In 1996 the beach was reported to range in width from 11 to 40 feet and made of sand. In 1977 the beach width was reported as being 25 feet and made of sand, pebbles, and cobbles.

Shoreline recession data for Section 36 were estimated at one location. These data indicated a recession of 35 feet or 2.5 feet per year occurred between 1978 and 1992. The 1977 study did not report a recession rate.

SHORELINE REACH 31: KEWAUNEE COUNTY

Shoreline Reach 31 extends from the Kewaunee Power plant northward to the middle of Section 18 (Map III-6). A change in shoreline orientation is the reason for the reach boundaries and the bluff in this reach is similar to those to the north and south. The bluff is up to 80 feet high and failing in many places. Most of the land use is agricultural as in 1977.

T22N R24E SEC.25: KEWAUNEE COUNTY

Section 25 covers the area from the Kewaunee Powerplant north one mile to the extension of sandy Bay Rd. to the lake. There is no road at the section line. The bluff height in Section 25 ranges from 10 to 40 feet. It appears that 20 to 30 feet of gray silt and clay is present in the lower bluff, overlain by sand and Two Rivers Till. There could be Haven till at the beach level, but it is covered. The slopes are 80 percent vegetated with grasses and exhibit translational failures. Land use in this section is agricultural. The bluff is uniform throughout and the section is a single erosion zone.

Two profiles were measured in 1977. Profile 77-1 had a factor of safety of 0.75 in 1977. Seeps are present near this profile close to the toe. This profile currently has a factor of safety of 2.24 for rotational failures (Appendix A & B) although the upper bluff still looks unstable because of lack of vegetation. Seeps are present higher in the bluff towards the center of the section, north of profile 77-1. Profile 77-2, had a factor of safety of 0.6 in 1977. This slope does not show any seeps. Profile 77-2, currently has a factor of safety of 2.35 for rotational failures. Deep rotational failures are unlikely in this section, while shallow translational failures are unlikely.

In 1996 the beach width was between 10 and 40 feet and was sand and gravelly sand. In 1977 the beach width was reported as being between 20 and 45 feet and made of sand and pebbles.

Shoreline recession data for Section 25 were estimated at one location. These data indicated a recession of 70 feet or five feet per year occurred between 1978 and 1992. The 1977 study reported recession rates of 1.5 to 1.8 feet per year for this section.

T22N R24E SEC. 24: KEWAUNEE COUNTY

The southern boundary of Section 24 is the extension of Sandy Bay Rd. to the lake. The northern boundary is the extension of the east-west part of Lakeshore Rd to the lake. In Section 24 bluff height ranges from 50 to 80 feet. The lower bluff is composed of 25 to 30 feet of gray silt and clay. This is overlain by 20 to 40 feet of sand and a cap of six to 12 feet of Two Rivers Till. Haven till probably is present near beach level. All of the bluff is unstable and failing. Vegetation cover is 20 to 60 percent. The lower bluff is mostly vegetation free, suggesting that the bluffs will show top retreat even if there is no erosion at the base. The beach is typically 15 to 30 feet wide and is made of sand. In places, however, recent bluff failures have covered the beach entirely. Land use in this section is primarily agricultural.

The bluffs are divided into two erosion zones. Erosion zone 24a extends from 24.0 to 24.4. The bluff in this zone is sparsely vegetated with horsetails and grasses. The bluff exhibits translational failures and soil flows. Seeps are occurring near the middle of the bluff face, at the base of the sand unit and on top of the silt and clay. Profile 77-1 had a factor of safety of 1.19 in 1977 and was predicted to have a large rotational failure (Appendix A & B). The profile currently has a factor of safety of 1.25 for rotational failures. Profile 80-1, also in zone 24a, was found to have a factor of safety of 1.63 with respect to rotational failures in 1996. Deep rotational failures are possible, but shallow translational failures are more likely.

Erosion zone 24b extends from 24.4 to the north end of the section. In this zone the upper bluff is typically well vegetated while the lower bluff contains only 20 percent vegetation of grasses. The bluff exhibits soil flows and translational failures near the toe. The factor of safety of profile 77-2 was 1.49 in 1977 (Appendix A & B). This profile currently has a factor of safety of 1.23 for rotational failures. Profile 80-2 was analyzed in 1996, and determined to have a factor of safety of 1.67 for rotational failures. There does not appear to be any significant bluff top recession in either erosion zone although erosion is occurring along the toe of the slope and slowly working its way up towards the bluff top. Translational failures are likely in this zone and may encroach upwards on the bluff in time. Both erosion zones, 24a and 24b, will experience considerable bluff top retreat in the coming years.

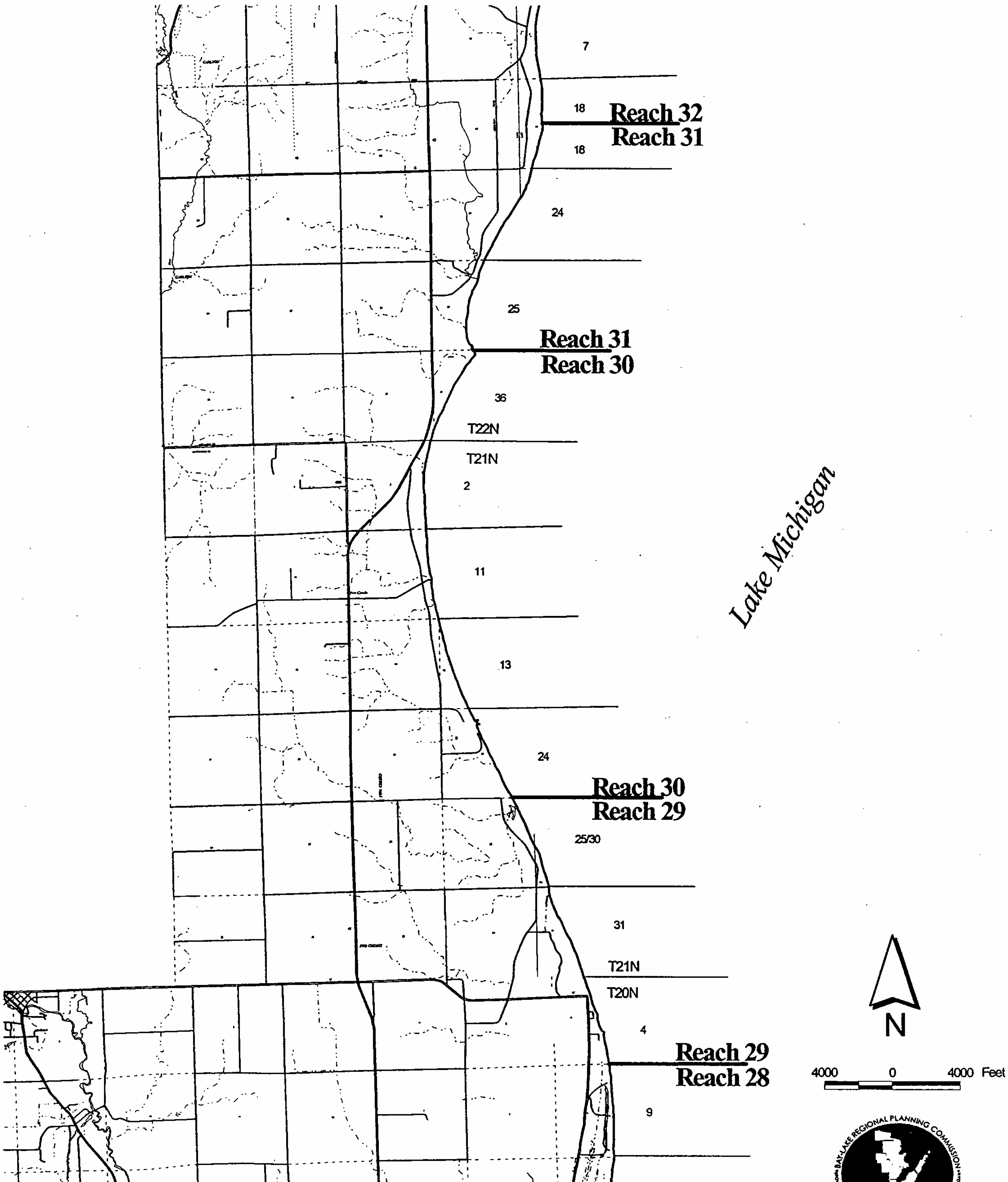
In 1996 the beach width was reported to be from 6.5 feet to 9.5 feet and made of sand. In 1977 the beach width was reported as being 20 feet and made of sand, cobbles, pebbles, and boulders.

Shoreline recession data for Section 24 were estimated at two locations. These data indicated a recession of between 30 and 70 feet or between 2.4 and five feet per year occurred between 1978 and 1992. The 1977 study reported recession rate of two feet per year for this section.

T22N R22E SEC.18: KEWAUNEE COUNTY

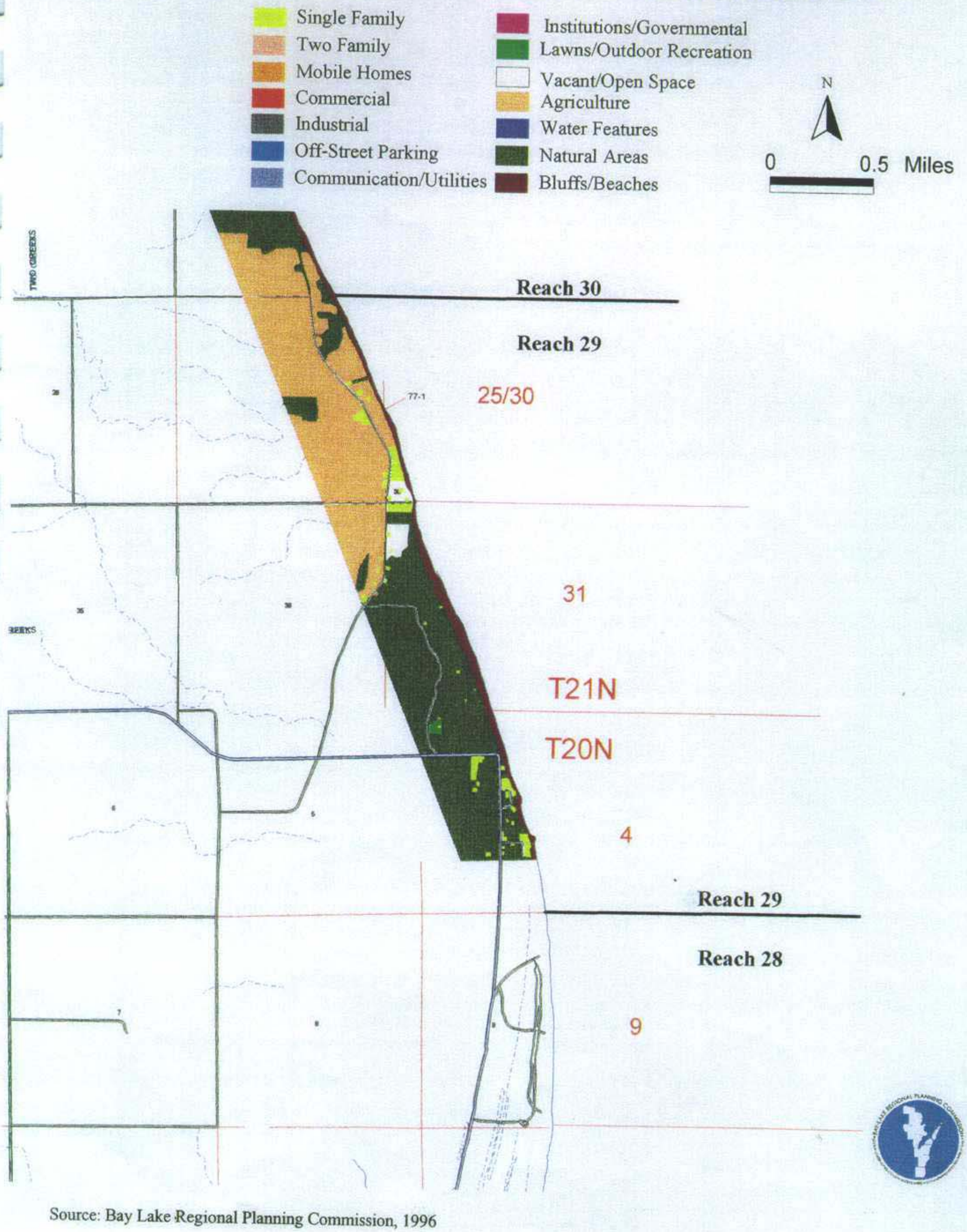
Section 18 is bounded on the south by the extension of Lakeshore Rd. to the lake. The northern boundary is the extension of Settler's Rd. to the lake. The bluff in this section ranges from 60 to 80 feet high. The lower bluff is made up of Ozaukee till to a height of about 20 feet above the beach. This is overlain by 20 to 35 feet of lacustrine clay and silt overlain by 10 to 40 feet of sand. Less than five feet of Two Rivers till occurs at the top of the bluff. The bluff is typically 20 to 30 percent vegetated with horsetails and grasses, although some areas are up to 90 percent vegetated with grass and mature trees. The beach ranges from nine to 40 feet in width and is made of sand and some cobbles. The bluff currently shows significant toe erosion, but there has been little to no

Map III-6
Bluff Analysis Sections Within Reach 29, 30, & 31



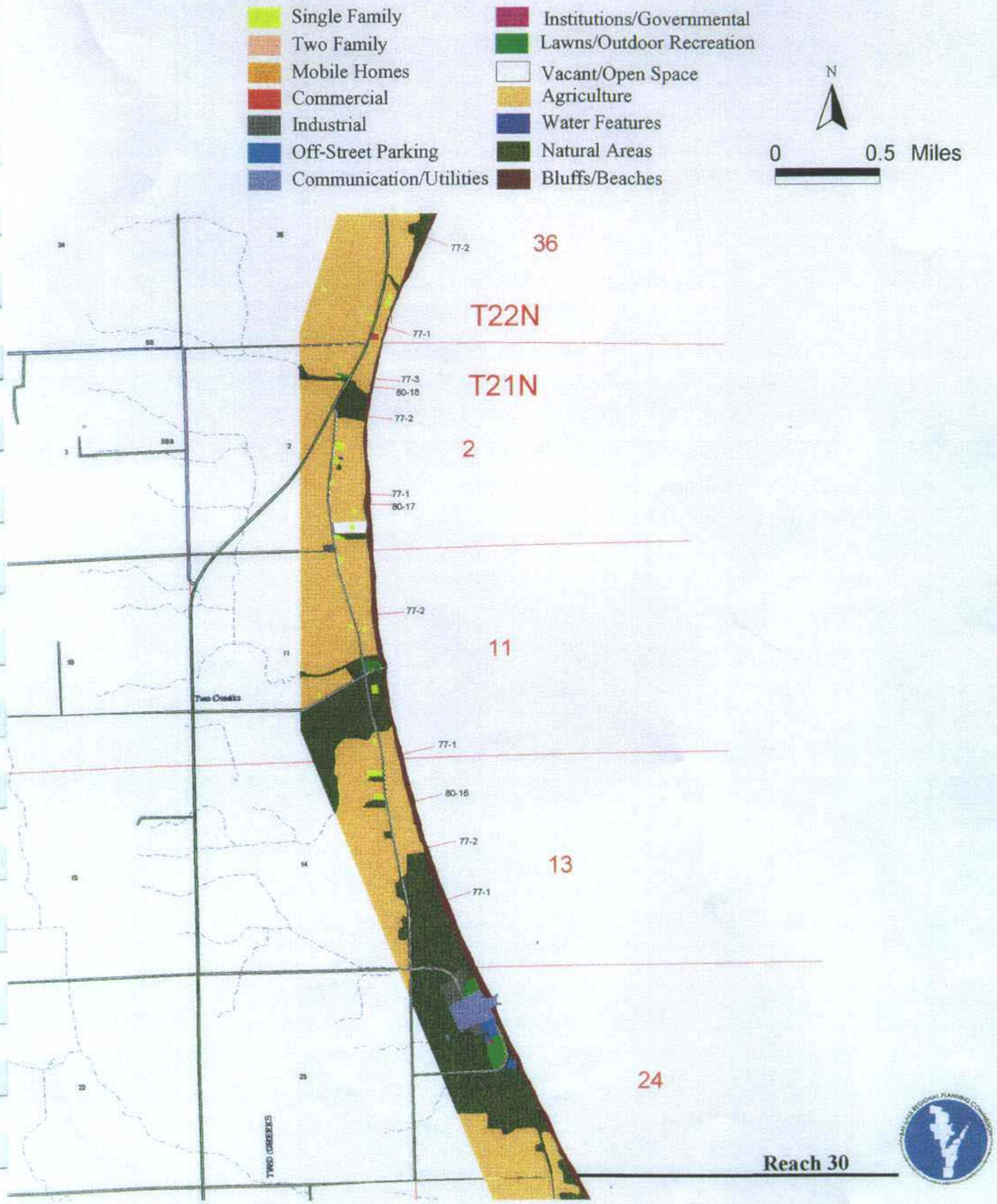
Source: D.M. Mickelson and T.B. Edil; Bay-Lake Regional Planning Commission, 1997

Map III-6a
Bluff Land Use and Profiles within Reach 29



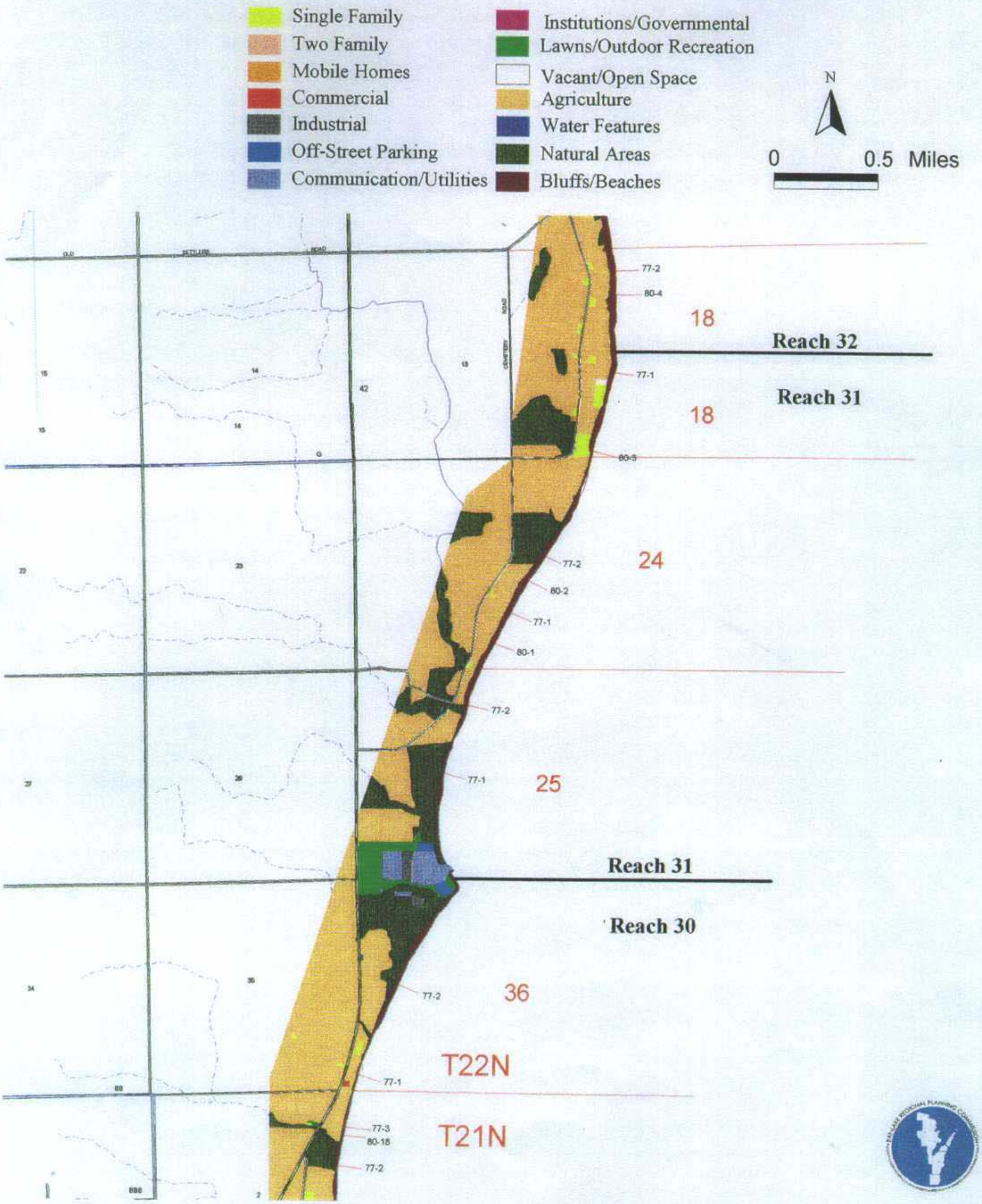
Source: Bay Lake Regional Planning Commission, 1996

Map III-6b
Bluff Land Use and Profiles within Reach 30



Source: Bay Lake Regional Planning Commission, 1996

Map III-6c
Bluff Land Use and Profiles within Reach 31



Source: Bay Lake Regional Planning Commission, 1996

bluff top recession since 1975. Land use within this section is primarily agricultural and residential.

Profiles 77-1 and 77-2 resulted in factors of safety of 0.7 and 1.07 in 1977 respectively (Appendix A & B). The profiles were reanalyzed in 1996, and resulted in factors of safety of 1.89 and 0.85 when analyzed for rotational failures respectively. Two additional analyses, 80-4 and 80-3 were performed in 1996. These analyses resulted in factors of safety of 0.79 and 1.19 for rotational failures respectively. Rotational failures are possible in this section, but translational failures are more likely. The translational failures at the bluff toe may encroach upwards on the bluff with time.

In 1996 the beach width was reported to be from nine feet to 43 feet and made of sand and cobbles. In 1977 the beach width was reported as being between five to 20 feet made of sand.

Shoreline recession data for Section 18 were estimated at four locations. These data indicated a recession of between 15 and 60 feet or between 1.1 and 4.3 feet per year occurred between 1978 and 1992. The 1977 study reported recession rates of 0.7 to 1.6 feet per year for this section.

SHORELINE REACH 32: KEWAUNEE COUNTY

Shoreline Reach 32 begins midway through Section 18 in T.22N. and extends 2.1 miles to Section 6.4 where a small point makes its boundary with Reach 33 (Map III-7). The bluff in the reach is 50 to 90 feet high, composed of till and lake sediments. It is all eroding. Most of the top land is agricultural, but there are newer houses along the bluff top.

T22N R25E SEC.7: KEWAUNEE COUNTY

No roads mark the northern and southern boundaries of the section. The bluff in this section ranges from 45 to 90 feet high. The bluffs are composed of about 20 feet of Ozaukee till at the base. This is overlain by up to 30 feet of lacustrine silt and clay. Haven Till is present above this unit along most of the section where the bluff is visible. This is covered by five to 20 feet of sand. This is all overlain by up to six feet of Two Rivers till at the top of the bluff. The bluff is 20 percent vegetated with grasses except for a densely vegetated area in the north end of the section where mature trees are growing. The bluff shows translational failures on the lower bluff and there is apparently little bluff top recession since 1975. The upper bluff has not changed since 1975 toward the north end of the section. Seeps were present in the middle third of the slopes except for on the north end of the section where no seeps are visible. All of the bluff is eroding. Significant top retreat can be expected to occur here in the future as the upper bluff becomes more unstable. The beach varies between 10 to 40 feet in width and is made primarily of cobbles. The land use within this section is primarily agricultural and residential.

Stability analyses were performed on profiles 77-1 and 77-2. These resulted in factors of safety of 0.9 and 0.95 respectively in 1977 (Appendix A & B). Profile 77-1 currently has a deterministic factor of safety of 1.05 for rotational failures. A probabilistic analysis of 77-1 resulted in a range of factors of safety from 0.55 to 1.13. Of the 25 most critical conditions, 84 percent resulted in failures, while 75.2 percent of the total conditions resulted in failures. Profile 77-2 currently has a factor of safety of .99 for rotational failures. A probabilistic analysis of 77-2 resulted in a range of factors of safety from 0.75 to 1.29. Of the 25 most critical conditions, 56 percent resulted in failures, while 41.2 percent of the total conditions resulted in failures. This section is likely to have both rotational and shallow translational failures.

In 1996 the beach width was reported to be from nine feet to 22 feet and made of cobbles. In 1977 the beach width was reported as being between five to 20 feet and made of sand and pebbles to the south and sand, cobbles, and dolomite boulders to the north of the section.

Shoreline recession data for Section 7 were estimated at two locations. These data indicated a recession of between 25 and 35 feet or between 1.8 and 2.5 feet per year occurred between 1978 and 1992. The 1977 study reported recession rate of 0.6 feet per year for this section.

T22N R25E SEC.6: KEWAUNEE COUNTY

There is no road along the south boundary of Section 6. The north edge is marked by Townline Rd. Section 6 has bluffs which are 45 to 90 feet in high. Ozaukee till occurs at the toe of the bluff. This is overlain by 10 to 30 feet of silt and clay. Above the silt and clay is about 10 feet of Haven Till and this is overlain by three to 20 feet of sand. Locally, this is overlain by four to six feet of Two Rivers till. Vegetation is variable throughout the section. The bluff is 10 to 20 percent vegetated with grasses at the toe, while in many places the upper bluff is 100 percent vegetated with grasses and mature trees. The slope exhibits translational failures in the southern end while the northern end shows shallow rotational failures low in the bluff. Seeps are present from the sand layer above the Haven till. The beach is 15 to 30 feet wide and is made up of gravelly sand except around the point of land that occurs at 6.4, where boulders are abundant on the beach and in the nearshore area. Little bluff top recession appears to have occurred since 1975. Land use within this section is primarily agricultural and residential.

Two profiles were measured in 1977. The first is 77-1, which had a factor of safety of 0.9 and was predicted to have deep rotational failures (Appendix A & B). This profile currently has a deterministic factor of safety of 0.94 for rotational failures. A probabilistic analysis of 77-1 resulted in factors of safety from 0.66 to 1.22. Of the 25 most critical analyses, 92 percent of these resulted in failures, while 65.6 percent of the total analyses resulted in failures. Profile 77-2 was determined to have a factor of safety of 1.28 in 1977. This profile currently has a factor of safety of 0.85 for rotational failures. At this location the land owner has installed drain tile in the fields, which should dry out some of the slope and reduce seepage. Analysis of profile 80-5 resulted in a factor of safety of 0.72 for rotational failures. Rotational failures and shallow translational failures are both likely to occur in this section.

In 1996 the beach width was reported to be from 21 feet to 40 feet and made of sand. The beach width was not measured by the field part in 1977.

Shoreline recession data for Section 6 were estimated at three locations. These data indicated a recession of between 30 and 35 feet or between 2.1 and 2.5 feet per year occurred between 1978 and 1992. The 1977 study reported recession rates of 0.4 to 0.8 feet per year for this section.

SHORELINE REACH 33: KEWAUNEE COUNTY

Shoreline Reach 33 extends from a small point in Section 6 at 6.4 northward to the south edge of the City of Kewaunee (Map III-7). Bluffs are up to 100 feet high and are mostly failing. Land use is agricultural, but residential areas are expanding, particularly south of Kewaunee.

T23N R25E SEC.31: KEWAUNEE COUNTY

Section 31 covers the area from the extension of Townline Rd. to the lake to the extension of Krok Rd. to the lake. The bluff in Section 31 ranges from 50 to 90 feet in high. The deposits consist of about 20 feet of silt and clay in the lower bluff, most of which is covered by slumped material. This is overlain by 10 to 20 feet of the Haven Till. In the northern part of the section, Ozaukee till may be present in the bluff just below the Haven till. This is overlain by about 20 feet of sand and five to 10 feet of Two Rivers till. The bluff is 20 to 60 percent vegetated with grasses and shrubs, although one short length of bluff has nearly a complete cover of mature trees. The beach ranges from 10 to 20 feet in width and is made of sand and gravelly sand. Land use within this section is primarily agricultural and residential.

Erosion zone 31a extends from 31.0 to 31.8. The bluff ranges from 70 to 90 feet high and the top is scalloped. Translational failures are present throughout this zone and some deep rotational failures have also occurred recently. Significant recession has occurred within the scallops since 1975. Seeps occur in the middle to upper slopes throughout this zone. Two profiles were measured in 1977. Profile 77-1 had a factor of safety of 0.97 (Appendix A & B). Failure was predicted to occur in the upper slope. This profile currently has a factor of safety of 1.23 for rotational failures. There appears to have been no bluff top recession at this profile since 1975. Profile 77-2 had a factor of safety of 0.94 in 1977 and was predicted to have a large circular failure throughout the slope. The profile currently has a deterministic factor of safety of 1.083 with respect to rotational failures. A probabilistic analysis of 77-2 resulted in factors of safety ranging from 0.35 to 0.72. All of the analyses resulted in failures; of the 250 analyses, 100 percent had factors of safety below one. The slope is likely to have both deep rotational failures and shallow translational failures.

Zone 31b extends from 31.8 to the north end of the section. This erosion zone has bluffs about 50 feet in high that are drained by a nearby stream. The bluff is interrupted by the stream channel. This area is well vegetated and appears unlikely to have bluff failures.

In 1996 the beach width was reported to be from 13 feet to 18 feet and made of sand and cobbles. In 1977 the beach width was reported as being 10 to 15 feet wide and made of sand, concentrations of pebbles, cobbles, and scattered boulders.

Shoreline recession data for Section 31 were estimated at two locations. These data indicated a recession of between 30 and 35 feet or between 2.1 and 2.5 feet per year occurred between 1978 and 1992. The 1977 study reported recession rates of 0.6 to 1.4 feet per year for this section.

T23N R25E SEC.30: KEWAUNEE COUNTY

Section 30 extends from Krok Rd. north to an unmarked section line. The bluffs in Section 30 range from 50 to 80 feet in height. The lower bluff consists of 10 to 50 feet of silt, sand, and Haven and possibly Ozaukee till. These units are overlain by a unit of deltaic sand and gravel that thickens from about 10 feet near the south section line to about 40 feet at the north edge. This is overlain by about six feet of Two Rivers till. The vegetation cover within this section varies from five to 100 percent. and consists mainly of grasses, horsetails and some locust trees. Water appears to be seeping from the bluff along the middle of the slope. The bluff is failing by translational slides and soil flows. The bluff face and toe have experienced significant erosion since 1975, while bluff top recession appears to be minimal since 1975. The beach ranges from 16 to 36 feet in width and is made of sand and some cobbles. Land use within this section is primarily agricultural and residential. The section is more residential than 1975.

Profile 77-1 had a factor of safety of 0.9 in 1977 with predicted failure in the upper slope (Appendix A & B). This profile currently has a factor of safety of 0.96 for rotational failures. A probabilistic analysis of 77-1 resulted in factors of safety ranging from 0.93 to 1.57. Of the 25 most critical analyses performed 12 percent resulted in failures, while 1.6 percent of the total analyses resulted in failures. Profile 77-2 had a factor of safety of 0.96 in 1977. This profile was predicted to have a large circular failure in the upper slope. Profile 77-2 has a factor of safety of 0.94 in 1996 when analyzed for rotational failures. A probabalistic analysis of this profile resulted in factors of safety ranging from 1.23 to 0.71. Of the 25 most critical situations, 92 percent were unstable, while 50.4 percent of the 250 total situations were unstable. Profile 80-6 had a factor of safety of 0.93 for rotational failure in 1996. Rotational and shallow translational failures are both likely to occur.

In 1996 the beach width was reported to be from 21 feet to 36 feet and made of sand and gravel. In 1977 the beach width was reported as being between 10 and 30 feet and made of sand and cobbles.

Shoreline recession data for Section 30 were estimated at two locations. These data indicated a recession of 25 to 30 feet or 1.7 to 2.1 feet per year occurred between 1978 and 1992. The 1977 study reported a recession rate of one foot per year for this section.

T23N R25E SEC.19: KEWAUNEE COUNTY

Section 19 extends from an unmarked section line north to the south jetty of Kewaunee Harbor. The bluffs range from 80 to 100 feet high at the southern end of Section 19 and taper down to a terrace on the northern end of the section. The geology within this section consists of an unknown thickness of Ozaukee Till at the toe of the bluff. This may be interbedded with lacustrine sediments but exposure is too poor to tell. This is overlain by gravel, Haven Till and sand. The gravel unit thins to the north in the section. Above this is discontinuous layer of Two Creeks Forest bed, which is overlain by six to 10 feet of Two Rivers Till. The beach is about 20 feet wide in the south to central parts of the section and widens to the north.

The section is divided into three erosion zones. Erosion zone 19a extends from 19.0 to 19.4. This zone has bluffs that are 80 to 100 feet high. The slopes are failing by translational failures and soil flows within this section. The bluffs are 30 percent vegetated with grasses at the toe of the bluff. There is an active seep immediately below the Two Rivers Till. One profile was measured in 1977. Profile 77-1 had a factor of safety of 0.97 in 1977 (Appendix A & B). This profile was predicted to have a large circular failure. The profile currently has a factor of safety of 0.90 against rotational failures. The beach ranges from 16 to 30 feet in width and consists of sand and cobbles. The land use within this zone is primarily residential. The bluff in this erosion zone is likely to have rotational failures, while shallow translational failures are possible.

Erosion zone 19b extends from 19.4 to 19.8. The bluff in this zone is about 90 percent vegetated. The bluff tapers down to a terrace in the northern part of this zone. The beach is 50 feet wide. Erosion zone 19c extends from 19.8 to the north end of the section. This zone is entirely a terrace having a 50 toot wide beach or riprap.

In 1996 the beach width was reported to be 16 feet and made of sand and cobbles. In 1977 the beach width was reported as being between 15 and 50 feet and composed of sand, cobbles, pebbles, and some boulders.

No shoreline recession estimates for Section 19 were estimated in 1996. The 1977 study reported a recession rate of 1.3 feet per year for this section.

SHORELINE REACH 34: KEWAUNEE COUNTY

Shoreline Reach 34 begins at 19.4, where the bluff becomes more stable and the beach wider as described above (Map III-7). It covers the downtown Kewaunee waterfront where there are no profiles.

T23N R25E SEC.17: KEWAUNEE COUNTY

The southern half of Section 17 (to 17.5), erosion zone 17a, is occupied by the Kewaunee Harbor. The northern half of the section, erosion zone 17b, has bluffs from 40 to 50 feet high. They are zero to 10 percent vegetated with grasses. The lower bluff consists of gray, probably Ozaukee till covered 10 feet of sand and gravel and silt. This is overlain by five to 10 feet of the Haven Till, which is in turn overlain by 10 to 15 feet of sand and gravel. Five to 10 feet of Two Rivers Till is present at the top of the bluff. Seeps occur in the sand at the mid slope. The beach width is approximately 16 feet and the beach is made of sand and gravel. Land use within this section is primarily agricultural, residential and industrial.

Profile 77-1 had a factor of safety of 0.91 in 1977 (Appendix A & B). The predicted failure was a large, circular failure. The bluff currently shows translational failures and soil flows. The current factor of safety with respect rotational failures is 1.03. A probabilistic analysis of this profile in 1996 resulted in factors of safety ranging from 0.66 to 1.13. Of the 25 most critical conditions, 100 percent of these resulted in failures, while 86.4 percent of the total analyses resulted in failures. Deep rotational failures are possible in this section, while shallow translational failures are more likely to occur.

In 1996 the beach width was reported to be 16 feet and made of sand and cobbles. In 1977 the beach width was reported as being between five and 10 feet and made of sand with pebbles and occasional boulders.

Shoreline recession data for Section 17 were estimated at one location. These data indicated a recession of 30 feet or 2.1 feet per year occurred between 1978 and 1992. The 1977 study reported a recession rate of 2.6 feet per year for this section.

SHORELINE REACH 35: KEWAUNEE COUNTY

Shoreline Reach 35 begins at the south end of bluff in Section 17, described above and extends 4.5 miles north to a minor change in shoreline orientation at the north edge of Section 28 in T.24N (Map III-7). The 40 to 60 foot bluff is lower than in southern Kewaunee County, but slopes are for the most part actively failing. Land use is almost exclusively agriculture.

T23N R25E SEC.8: KEWAUNEE COUNTY

Section 8 extends from lst Rd. north to the extension of CTH F to the lake. The bluffs in the section range from 40 to 50 feet in high. The bluff toe is mostly covered by debris. The lower bluff is probably Ozaukee till 10 to 15 feet thick overlain by 10 to 20 feet of sand, silt and gravel. Haven till is present locally in this unit. The bluff top is made up of Two Rivers till about 10 feet thick. There is a 20 percent to 30 percent cover of grasses. The beach ranges from 10 to 40 feet in width and is mostly cobbles. Land use within this section is agricultural and residential.

Profile 77-1 had a factor of safety of 1.1 in 1977 and was predicted to have large circular failures (Appendix A & B). The profile currently has a deterministic factor of safety of 1.03 when analyzed for rotational failures. A probabilistic analysis of 77-1 resulted in factors of safety ranging from 0.75 to 1.23. Of the 25 most critical conditions, 72 percent resulted in failures, while 58 percent of the total analyses resulted in failures. The second profile, 77-2, was determined to have a factor of safety of 1.0 in 1977 and was predicted to have a large circular failure as well. The bluff currently has translational failures and soil flows, but there has been no apparent bluff top recession since 1975 although slope erosion has occurred.

Profile 77-2 now has a factor of safety of 0.92 for rotational failures (Appendix A & B). Profile 80-7 currently has a deterministic factor of safety of 0.98 for rotational failures. A probabilistic analysis of 80-7 resulted in factors of safety ranging from 0.19 to 0.63. Of the 250 different condition trials, all resulted in failures. Deep rotational failures and shallow translational failures are likely to occur in this section.

In 1996 the beach width was reported to be from nine feet to 40 feet and made of cobbles. In 1977 the beach width was reported as being between 10 and 30 feet and made of pebbles and cobbles to the south and pebbles with sand near the northern end of the section.

Shoreline recession data for Section 8 were estimated at two locations. These data indicated a recession of between 50 and 85 feet or between 3.5 and 6.1 feet per year occurred between 1978 and 1992. The 1977 study reported a recession rate of 1.1 feet per year for this section.

T23N R2SE SEC.5: KEWAUNEE COUNTY

Section 5 covers the area from the extension of CTH F to the lake north to where Mashek Creek enters the lake. The bluffs in Section 5 range from 12 to 50 feet high. Most of the lower bluff is covered, but there is likely five to 20 feet of sand and silt overlain by six to 12 feet of Haven till. The top of the bluff is capped by two to six feet of Two Rivers till. The beach is approximately 20 feet wide and is made of sand and pebbles. Land use within this section is primarily agricultural and residential.

There are three erosion zones in this section. The southernmost erosion zone, 5a, extends from 5.0 to 5.1. This zone has bluffs 40 to 50 feet in high. The bluffs are failing in en-echelon slump blocks. The bluffs have 70 percent cover of grasses and show no visible seeps. Profile 80-8 had a deterministic factor of safety of 1.03 against rotational failures in 1996 (Appendix A & B). A probabilistic analysis of profile 80-8 resulted in factors of safety ranging from 1.15 to 1.57. None of the 250 trials resulted in failing conditions. This zone is likely to have translational failures, while deep rotational failures are unlikely.

Erosion zone 5b extends from 5.1 to 5.6. These bluffs are 40 to 50 feet in height and are 30 percent vegetated. The vegetation consists primarily of grasses. This vegetation cover increases to 100 percent in ravines. These bluffs are subject to translational failures and show extensive bluff top recession since 1975. Estimates of bluff top recession range from five to 10 feet. There is one stability analysis within this section, labeled 77-1. This profile had a factor of safety of 0.93 in 1977 and was predicted to have large circular failures. The profile currently has a deterministic factor of safety of 0.94 when analyzed for rotational failures. A probabilistic analysis of 77-1 resulted in factors of safety ranging from 1.02 to 1.86. None of the 250 trial conditions resulted in failures. Deep rotational failures and shallow translational failures are both likely to occur in this zone.

Erosion zone 5c extends from 5.6 to the north end of the section. This zone is primarily a low vegetated terrace with a wide beach. No failures are likely to occur in this zone.

In 1996 the beach width was reported to be from 19.5 feet to 21 feet and made of sand, cobbles, and pebbles. In 1977 the beach width was reported as being between five and 30 feet and made of sand and pebbles.

No shoreline recession data for Section 5 were estimated during 1996. The 1977 study reported a recession rate of 3.2 feet per year for this section.

T24N R25E SEC.32: KEWAUNEE COUNTY

Section 32 extends from lst Rd. to 2nd Rd. The bluffs in this section range from five to 50 feet high. The lower slope contains slide debris, probably covering Ozaukee till and lacustrine sediment. The upper slope contains Haven till overlain by Two Rivers till. The beach ranges from to 20 feet in width and is made primarily of pebbles and cobbles. Land use within this section is primarily agricultural and residential.

This section is divided into three erosion zones. Erosion zone 32a extends from 32.0 to 32.2. This zone has low bluffs that are 100 percent vegetated. The toe of these bluffs is protected by riprap and this section is occupied by a pumping station.

Erosion zone 32b extends from 32.2 to 32.9. This zone has bluffs with a height of 35 to 45 feet. A stability analysis was performed in the southern end of this zone in 1977. This profile, labeled 77-1, had a factor of safety of 0.97 in 1977 and was predicted to fail at the toe (Appendix A & B). The area near the profile currently shows translational failures. There are no visible seeps and there is about a 50 percent grass cover. The current factor of safety is 0.94 when analyzed for rotational failures. A probabilistic analysis of this profile resulted in factors of safety ranging from 0.83 to 1.38. Of the 25 most critical trails, 28 percent resulted in failures, while 20 percent of the total trials resulted in failures. There is five to 10 feet of bluff top recession estimated since 1975 at profile 77-1. This zone is unlikely to have shallow translational failures, while deep rotational failures are possible.

At the northern end of this erosion zone an additional stability analysis was performed in 1977. This profile is labeled 77-2 and had a factor of safety of 0.97 in 1977. This analysis predicted a large circular failure. This profile now has rotational failures, and about a 50 percent vegetation cover of grasses. There are several seeps within the middle bluff. Currently, profile 77-2 has a factor of safety of 0.99 for rotational failures. A probabilistic analysis of this profile resulted in factors of safety ranging from 0.91 to 1.60. Of the 25 most critical situations, 12 percent resulted in failures, while 11.2 percent of the total situations resulted in failures. Five feet of bluff top recession has been estimated since 1975 at this profile.

The third erosion zone, 32c, extends from 32.9 to the north end of the section. This zone has bluffs that are 40 to 50 feet high, well vegetated with trees, and relatively unchanged since 1975. This zone is unlikely to have bluff failures.

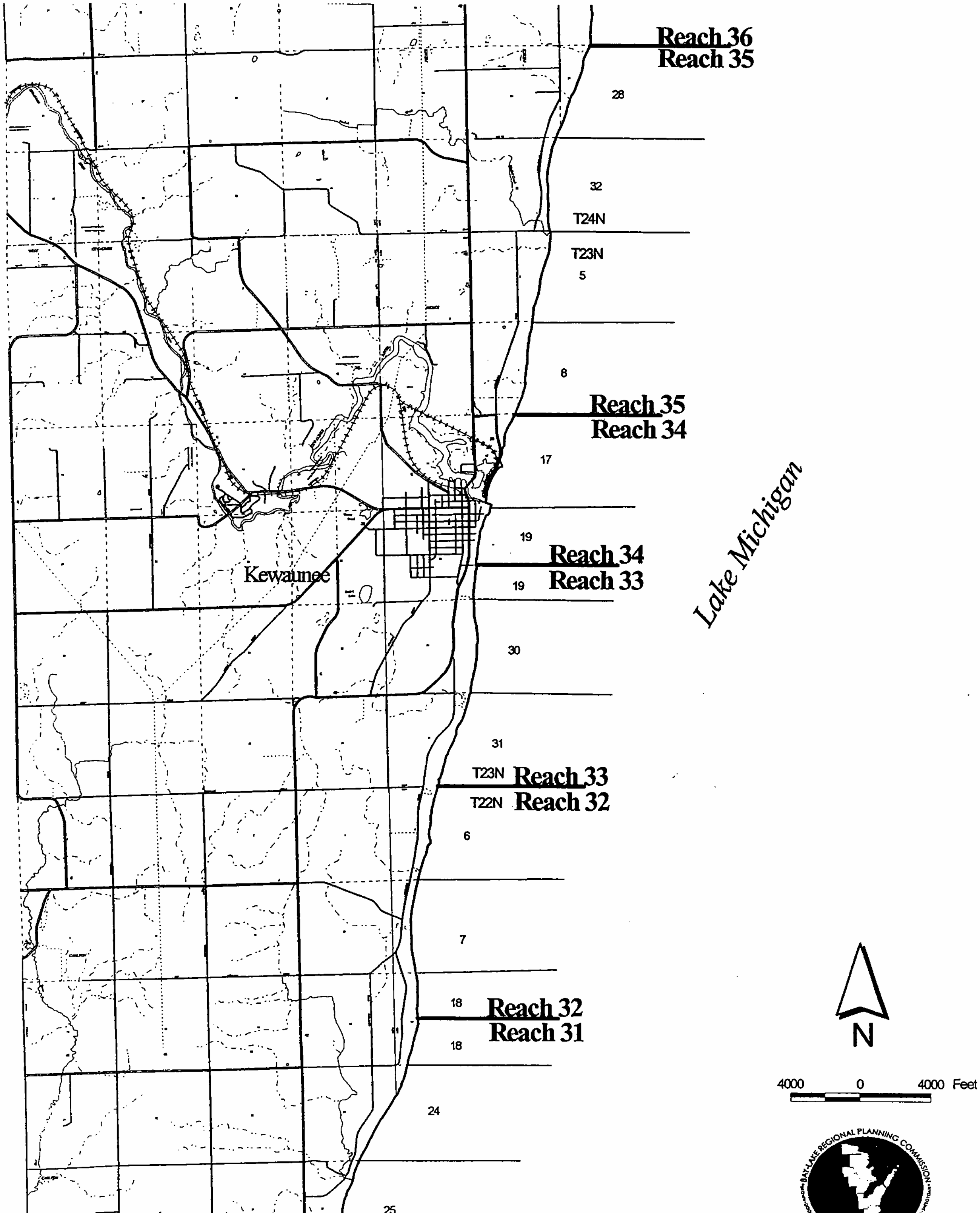
In 1996 the beach width was reported to be 16.5 and made of sand, cobbles, and pebbles. In 1977 the beach width was reported as being between five and 15 feet and made of sand with occasional cobbles and boulders.

Shoreline recession data for Section 32 were estimated at two locations. These data indicated a recession of between 15 and 25 feet or between 1.1 and 1.8 feet per year occurred between 1978 and 1992. The 1977 study reported a recession rate of 1.7 feet per year for this section.

<u>T24N R25E SEC.28 KEWAUNEE COUNTY</u>

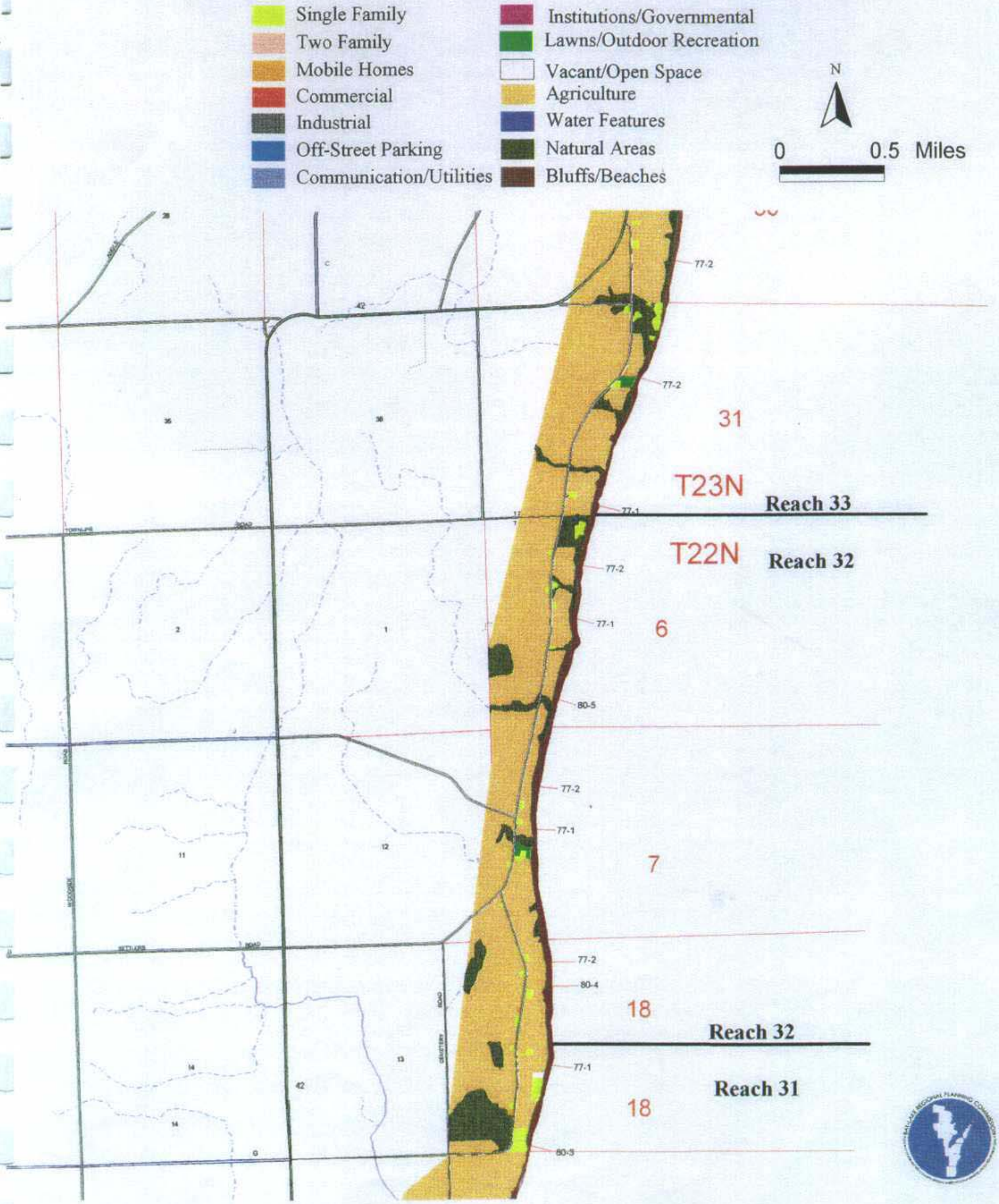
This section extends from 2nd Rd. to 4th Rd. The bluff in Section 28/29 is 40 to 60 feet in high. The in-place deposits at the toe are covered by slide debris. Above this debris there is five to 10 feet of Haven till overlain by five to 10 feet of Two Rivers till. In the northern end of the section, layers and lenses of sand and gravel are found between the two till units. Beach width ranges from

Map III-7
Bluff Analysis Sections Within Reach 32, 33, 34, & 35



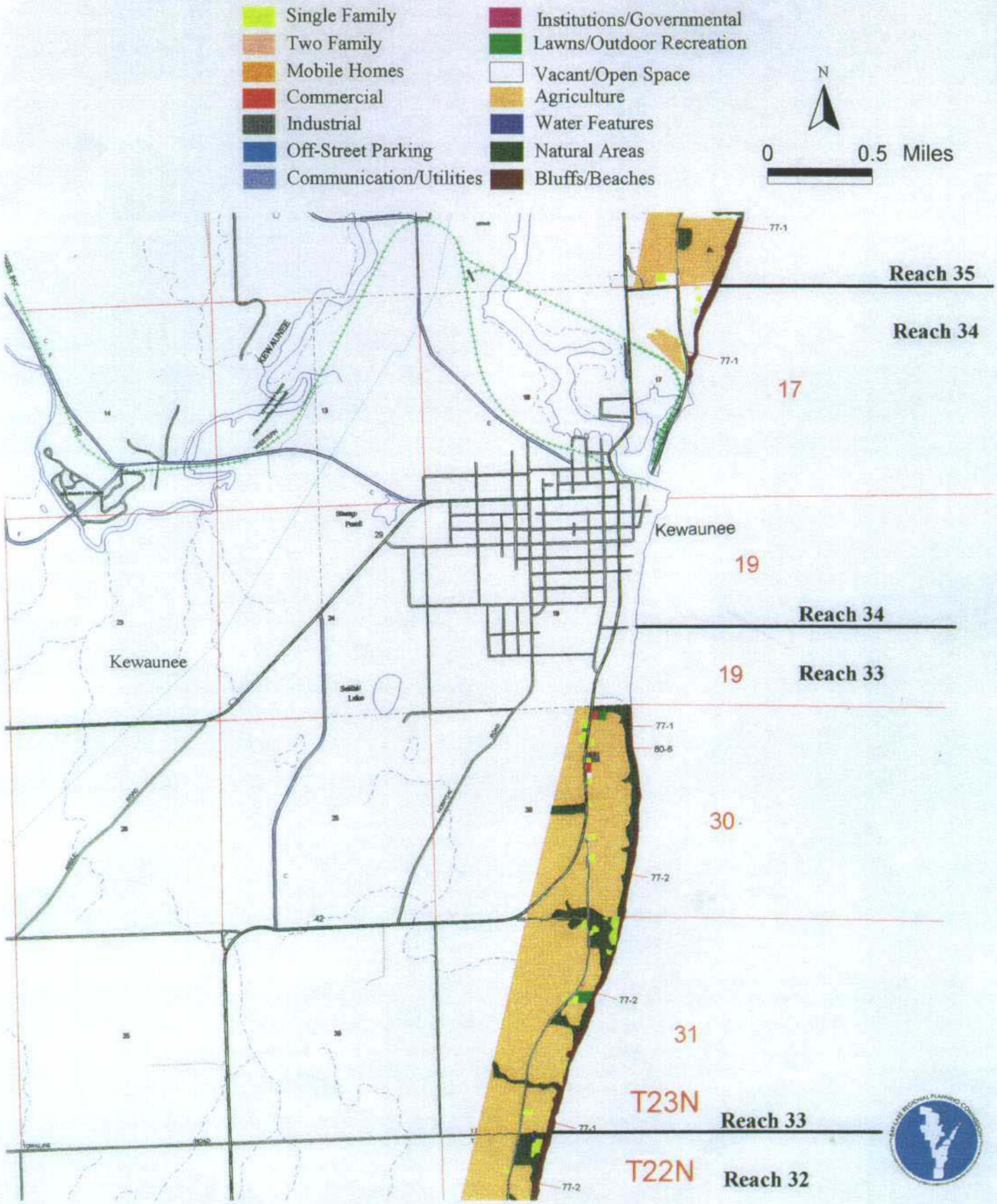
Source: D.M. Mickelson and T.B. Edil; Bay-Lake Regional Planning Commission, 1997

Map III-7a
Bluff Land Use and Profiles within Reach 32



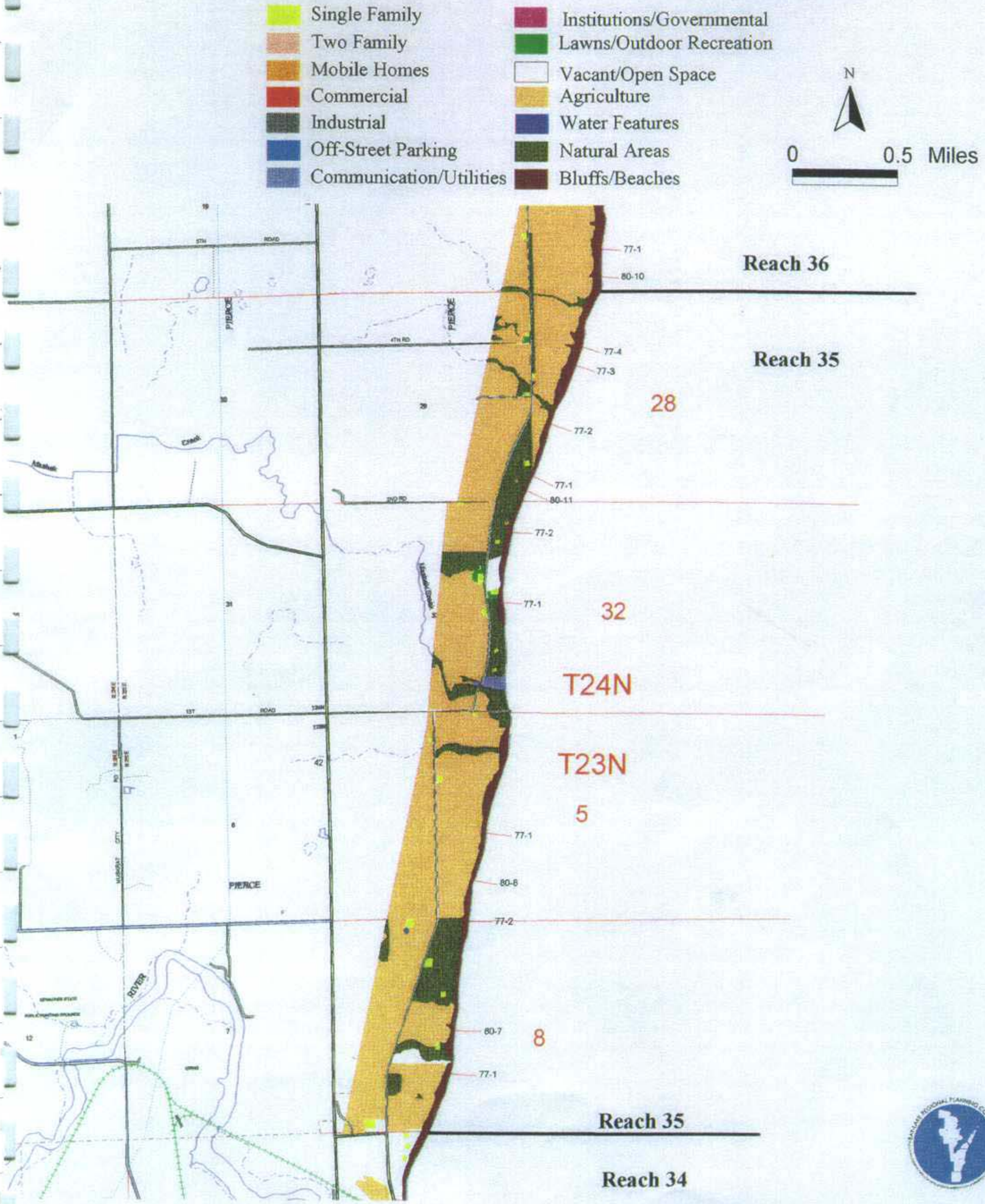
Source: Bay Lake Regional Planning Commission, 1996

Map III-7b
Bluff Land Use and Profiles within Reach 33 & 34



Source: Bay Lake Regional Planning Commission, 1996

Map III-7c
Bluff Land Use and Profiles within Reach 35



Source: Bay Lake Regional Planning Commission, 1996

20 to 40 feet and the beach consists of cobbles and sand. Land use in this section is agricultural and residential.

Erosion zone 28a extends from the south end of the section to 28.3. This zone is 70 percent vegetated with grasses, shrubs, and trees. There was one stability analysis performed in 1977 in this zone. Profile 77-1 was predicted to have a large circular failure and had a factor of safety of 0.98 in 1977 (Appendix A & B). The 1996 factor of safety is 0.72 when analyzed for rotational failures. The bluff currently exhibits shallow rotational failures. Few seeps are present. We estimate about five feet of recession since 1975 in the scalloped heads of slumps. Profile 80-11 had a factor of safety of 0.86 for rotational failures in 1996. Rotational failures and shallow translational failures are both likely to occur in this zone.

Erosion zone 28b extends from 28.3 to the north end of the section. This zone has a 30 percent cover of grasses and horsetails. There is little seepage visible within this zone. Three stability analysis were performed in 1977. Profile 77-2 had a factor of safety of 0.99 in 1977, and 0.98 in 1996, when analyzed for rotational failures (Appendix A & B). Failure was predicted to occur as a circular failure in the middle of the slope. This profile currently exhibits shallow rotational failures. It has experienced about five feet of bluff top recession since 1975. A probabilistic analysis of profile 77-2 resulted in factors of safety ranging from 1.03 to 1.91. Out of the 250 trial conditions, zero percent were unstable.

Profile 77-3 had a factor of safety of 0.95 in 1977 and was predicted to fail by circular failure in the mid slope (Appendix A & B). It currently has a factor of safety of 0.77 with respect to circular failures. This profile currently has shallow, rotational failures. Recession of five to 10 feet on the bluff top appears to have occurred since 1975. There has been substantial erosion along the face of the bluff at this location since 1975. Profile 77-4 had a factor of safety of 0.9 in 1977. It currently has a factor of safety of 0.78 against rotational failures. The profile was predicted to fail by a large circular failure covering the entire slope. The profile currently shows translational failures and minor bluff top recession since 1975. Bluff top recession has been less than five feet. Rotational failures and shallow translational failures are both likely to occur in this zone.

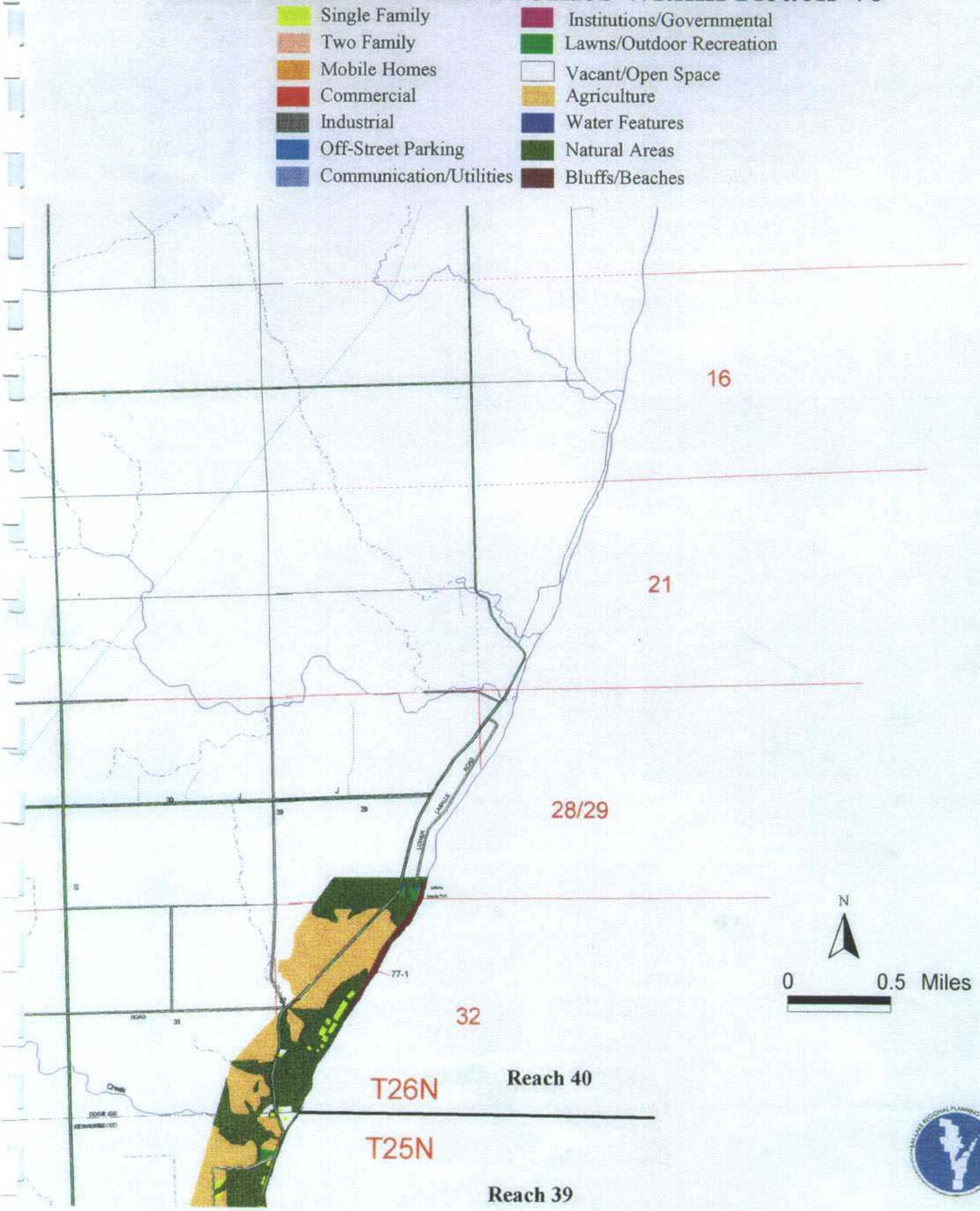
In 1996 the beach width was reported to be from 18 feet to 31 feet and made of cobbles and gravel. In 1977 the beach width was reported as being between 20 and 30 feet and made of sand.

Shoreline recession data for Section 28/29 were estimated at three locations. These data indicated a recession of between 25 and 70 feet or between 1.8 and five feet per year occurred between 1978 and 1992. The 1977 study reported recession rates of 2.3 to 3.8 feet per year for this section.

SHORELINE REACH 36: KEWAUNEE COUNTY

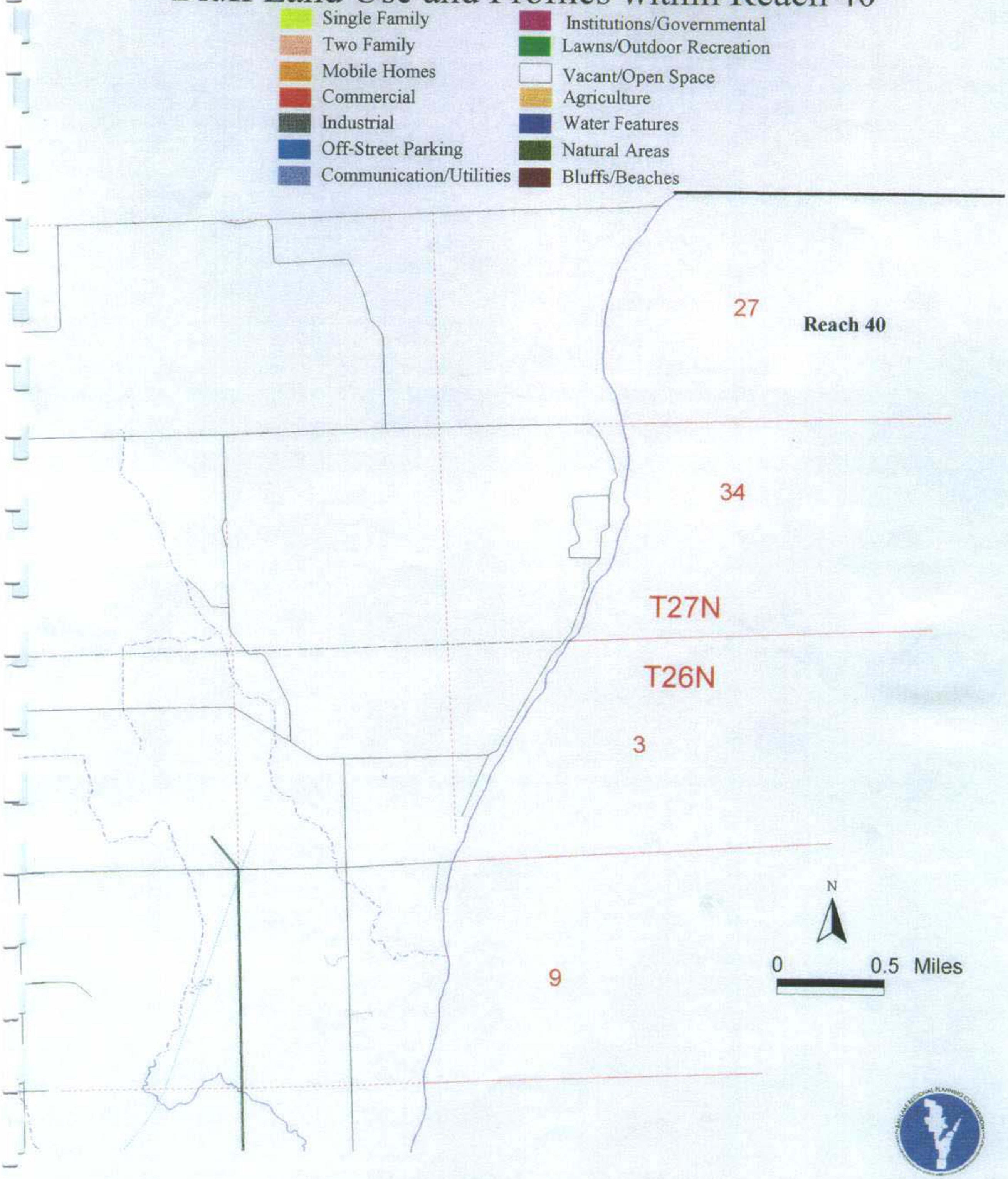
Shoreline Reach 36 extends from a small point and minor change in shoreline orientation at the north end of Section 28/29 to midway through Section 24 in T. 25 N. on the south side of Algoma (Map III-8). The bluff is up to 60 feet high in the southern part of the reach. It is very low in the central part, and high again in the north. Most of the bluff is eroding. Land use is agricultural, with some residential or seasonal dwellings as in 1977.

Map III-9a
Bluff Land Use and Profiles within Reach 40



Source: Bay Lake Regional Planning Commission, 1996

Map III-9b
Bluff Land Use and Profiles within Reach 40



Source: Bay Lake Regional Planning Commission, 1996

T24N R25E SEC.21: KEWAUNEE COUNTY

Section 21 has no roads at either section line. The bluffs in the section are about 65 to 70 feet in height. The stratigraphy of the lower bluff is obscured by slide debris. Above this debris is 40 feet of Haven till overlain by five to 10 feet of Two Rivers till. These till units locally separated by gravel, sand, silt, and clay. Vegetation cover ranges from five percent to 30 percent, vegetation consisting of grasses, shrubs, and some trees. There appears to be less vegetation than in 1975. Seeps are present in the upper slope of the bluff. The beach width ranges from 16 to 20 feet and consists of cobbles and sand. The land use in this section is agricultural.

Profile 77-1 had a factor of safety of 0.72 in 1977 and was predicted to have large circular failures (Appendix A & B). Profile 77-1 currently has a deterministic factor of safety of 0.92 with respect to rotational failures. This profile currently has shallow rotational failures and has had about five feet of bluff top recession since 1975. The second profile, 77-2, had a factor of safety of 0.97 in 1977. This slope currently shows translational and soil flows and a factor of safety of 0.72 with respect to rotational failures. This profile was predicted to have a circular failure in the toe of the bluff. There appears to have been significant face erosion and minor bluff top recession in the vicinity of this profile since 1975. Profile 80-10 was not analyzed. Shallow translational failures are likely to occur in this section, resulting in bluff top recession. Rotational failures are also possible.

In 1996 the beach width was reported to be from 16 feet to 26 feet and made of sand, cobbles, and gravel. In 1977 the beach width was reported as being 15 feet wide and made of cobbles and boulders in the southern one-third and sand in the northern two-thirds of the section.

Shoreline recession data for Section 21 were estimated at two locations. These data indicated a recession of between 105 and 120 feet or between 7.5 and 8.6 feet per year occurred between 1978 and 1992. The 1977 study reported a recession rate of 0.3 feet per year for this section.

T24N R25E SEC.16: KEWAUNEE COUNTY

Section 16 has no road at along the southern section line and extends north to 8th Pd. Bluffs in this section are about 60 feet high in the south and drop to about 20 feet high in the north. About 10 to 40 feet of sand and gravel is present low in the bluff at the south end of the section. This is overlain by lacustrine sediment, and up to 20 feet of Two Rivers till. There are no apparent seeps. The bluff is 70 percent vegetated with grasses and some aspen and cedar trees. There are two riprap structures near the north end of the section. The beach is about 20 feet wide in most of the section and consists of cobbles, although in some areas the beach is almost absent. Land use in this section is agricultural and residential.

Two stability analyses were performed in 1977. Profile 77-1 had a factor of safety of 0.94 in 1977 (Appendix A & B). This stability analysis predicted a large circular failure along the entire slope. The profile currently shows shallow rotational failures. Profile 77-1 currently has a factor of safety of 1.08 with respect to rotational failures. A probabilistic analysis of this profile resulted in factors of safety ranging from 0.98 to 1.32. Of the 25 most critical situations, eight percent resulted in failures, while two percent of the total situations resulted in failures. There has been significant face erosion, but the bluff at this profile has experienced little bluff top recession since 1975.

Profile 77-2 had a factor of safety of 0.82 in 1977 (Appendix A & B). This stability analysis predicted a failure in the upper slope. The profile currently shows scarps at the upper edge of the bluff and is well vegetated. Profile 77-2 currently has a factor of safety of 1.71 when analyzed for rotational failures. This profile was bounded on either side by riprap although at the actual profile, the beach is exposed to the waves. Profile 80-9 was also analyzed in 1996. This profile was determined to have a factor of safety of 1.57 against rotational failures. Deep rotational failures and shallow translational failures are both possible in this zone.

In 1996 the beach width was reported to be from 15 feet to 21 feet and made of cobbles. In 1977 the beach width was reported as being 20 feet and made of sand with pebbles, cobbles, and a few boulders.

Shoreline recession data for Section 16 were estimated at two locations. These data indicated a recession of between 20 and 35 feet or between 1.4 and 2.5 feet per year occurred between 1978 and 1992. The 1977 study reported a recession rate of 0.2 feet per year for this section.

T24N R25E SEC.10: KEWAUNEE COUNTY

Section 10 extends from 8th Rd. to 10th Rd. The bluffs in Section 10 range from absent to 20 feet in height. The bluff deposits consist of Ozaukee till near the toe overlain by a loose, pink sandy till. This is overlain by about two feet of Two Rivers till, which is in turn overlain by sand. There do not appear to be any seeps in the bluff. The beach ranges from 10 to 25 feet wide and is made of sand and cobbles. The land in this section is used for residential purposes.

The section is divided into three erosion zones. Erosion zone 10a extends from 10.0 to 10.2. This zone consists of a moderately stable, poorly-vegetated low-terrace with no bluff. Erosion zone 10b extends from 10.2 to 10.6. This zone has about a 20-foot bluff. Profile 77-1 had a factor of safety of 1.03 in 1977 and was predicted to have a shallow circular failure in the upper slope (Appendix A & B). Current field analysis was unable to determine any failure mode. The current factor of safety is 1.41 with respect to rotational failures. The bluff currently is well vegetated with grasses. There appears to have been five to 10 feet of bluff top recession since 1975. Zone 10b is likely to have translational failures, while deep rotational failures are unlikely.

Erosion zone 10c extends from 10.6 to the north end of the section. This zone consists of low terraces with no bluff.

In 1996 the beach width was reported to be 23 feet and made of cobbles. In 1977 the beach width was reported as being between 10 and 25 feet and is made of 50 percent sand and 50 percent pebbles and cobbles.

No shoreline recession rates were estimated for this section by the field party in 1996. In 1977 the field party reported an estimated recession rate of 3.8 feet per year for this section.

T24N R25E SEC.3: KEWAUNEE COUNTY

Section 3 is characterized by low, flat terraces protected by wide beaches. No significant bluffs exist within this section. Land use within this section is primarily residential as in 1977. No beach measurements of recession estimates were made for this section by the field party in 1996. In 1977 the beach width was 20 to 70 feet wide and made of sand.

T25N R25E SEC.34: KEWAUNEE COUNTY

Section 34 covers the area from CTH K north to Jefferson St. in Algoma (Map III-8). The bluffs in this section range up to 60 feet in height. No seeps are visible within the bluff. This section has about a 30 foot wide beach made of cobbles. The bluff top is used for primarily residential purposes.

Bluff erosion zone 34a extends from 34.0 to 34.3. This zone consists of a low terrace that is well vegetated. Erosion zone 34b extends from 33.3 to 33.6. This zone has a 60 foot high bluff that is about 90 percent covered with trees and grasses. Profile 77-1 had a factor of safety of 1.0 in 1977. This profile currently has a factor of safety of 0.82 with respect to rotational failures (Appendix A & B). This bluff is well vegetated and shows minimal bluff top recession since 1975, probably less than three feet. Zone 34b is likely to have rotational failures, while shallow translational failures are possible. The northernmost zone in Section 34c, extends from 34.6 to the north end of the section. This zone has low terraces that are well vegetated.

In 1996 the beach width was reported to be 30 feet and made of sand and gravel. In 1977 the beach width was reported as being between 10 and 30 feet and made of sand.

No shoreline recession rates were estimated by the field parties for this section in 1996 or 1977.

SHORELINE REACH 37: KEWAUNEE COUNTY

Shoreline Reach 37 extends from the middle of Section 34 (described above) north to a small point and minor change in shoreline orientation in Section 26 (Map III-8). It includes bluff shoreline south of the city of Algoma for about 0.3 miles, the low terrace in the city of Algoma itself, and about 0.4 miles of bluff shoreline north of the city of Algoma. Each bluff area is described in sections below and above.

T25N R25E SEC.26: KEWAUNEE COUNTY

Section 26 extends from Jefferson Street in the city of Algoma north to Bay Road. The southern part of the section, erosion zone 26a, is occupied by the Algoma Harbor and is protected by riprap and a breakwater which extends to 26.2.

The northernmost erosion zone 26b, extends from 26.2 to the north end of the section. This zone has bluffs ranging from 30 to 40 feet high. It appears that Haven till is in place at the toe and is overlain by red stony till. Seeps are present in the upper bluff. The vegetation cover ranges from zero percent to 60 percent and consists of grasses and horsetails. Beach width varies from 20 to 30 feet and is made of cobbles. This zone has primarily residential land use along the bluff top as in 1977.

Two stability analysis were performed in 1977 (Appendix A & B). Profile 77-1 resulted in a factor of safety of 1.5. This profile now exhibits soil flows and its 1996 factor of safety is 2.20 with respect to rotational failures. The second stability analysis, profile 77-2 had a factor of safety of 1.5 in 1977. This profile now shows soil flows and a vegetation free slope. Profile 77-2 currently has a factor of safety of 1.16 with respect to rotational failures. Zone 26b is unlikely to have rotational failures, while shallow translational failures are possible.

In 1996 the beach width was reported to be from 20 feet to 30 feet and made of cobbles. In 1977 the beach width was reported as being 20 feet and made of cobbles.

Shoreline recession data for Section 26 were estimated at two locations. These data indicated a recession of 15 feet or 1.1 feet per year occurred between 1978 and 1992. No recession rates were estimated in 1977 by the field party.

SHORELINE REACH 38: KEWAUNEE COUNTY

Shoreline Reach 38 extends from a break in shoreline orientation at 26.8, north about 1.9 miles to another break in shoreline orientation at about 13/18.7 (Map III-8). there is a low bluff in the southern part, but most of the reach is a low terrace with no bluff. Much of the terrace is residential as in 1977.

T25N R25E SEC.23/24: KEWAUNEE COUNTY

Section 23/24 extends from Bay Road one mile north to a section line not marked with a road. The bluffs in this section range up to 40 feet in height. The geology consists of Ozaukee till overlain by Haven till, which is overlain by Two Rivers till. Land use in this section is primarily residential as in 1977.

The southern part of this section, erosion zone 24a, extends from 24.0 to 24.2 (Fig 117). This zone consists of 40 foot high bluffs having little vegetation. A large portion of this zone is currently covered with dumped rock and has no beach. Profile 77-1 had a factor of safety of 0.7 in 1977, and was predicted to have a large circular failure in the entire slope (Appendix A & B). This profile is now modified by rock and appears to have had less than three feet of bluff top recession since 1975. This profile currently has a factor of safety of 1.10 with respect to rotational failures. Erosion zone 24a is unlikely to have deep rotational failures, but shallow translational failures are possible. Erosion zone 24b extends from 24.2 to the north end of this section. This zone consists of a flat, sandy terrace with no bluff.

The 1996 field party reported no beach in this section. No shoreline recession rates were estimated for this section in 1996 or 1977 by the field parties.

SHORELINE REACH 39: KEWAUNEE COUNTY/DOOR COUNTY

Shoreline Reach 39 extends from a break in shoreline orientation in Section 18 and extends north into Door Co. Sections 13/18, 7, and 6 of T. 25 N. consist of flat, sandy terraces that are commonly wooded and protected by wide beaches (Map III-8). Parts are residential. There is only one small bluff within these sections and it appears stable. No recession measurements were taken by the field parties in 1996 or in 1977 for these sections.

SHORELINE REACH 40: KEWAUNEE COUNTY/DOOR COUNTY

Shoreline Reach 40 extends from north of the mouth of Stoney Creek to the Sturgeon Bay Canal. The land use is residential with wide beaches (Map III-9). Of the ten sections within this reach, only Section 32 has a bluff. Section 32 was the only section to be measured in 1977 and 1996.

T26N R26E SEC.32: DOOR COUNTY

Section 32 extends from just north of the mouth of Stoney Creek to LaSalle County Park in Door County. This section has bluffs up to 60 feet high. The toe of the bluff is covered by debris. Above the debris is 15 feet of sand overlain by about 30 feet of Haven till overlain by the Two Rivers till. Land use in this section is agricultural and residential as in 1977.

Erosion zone 32a extends from 32.0 to 32.7. This zone has low sandy terraces with little erosion. Erosion zone 32b extends from 32.7 to the north end of the section. This zone has 60 foot high bluffs. Some seeps are visible near the top of the bluff. These bluffs have a 10 percent cover of horse tails and grasses. The very north end of this section appears stable directly adjacent to a stream ravine.

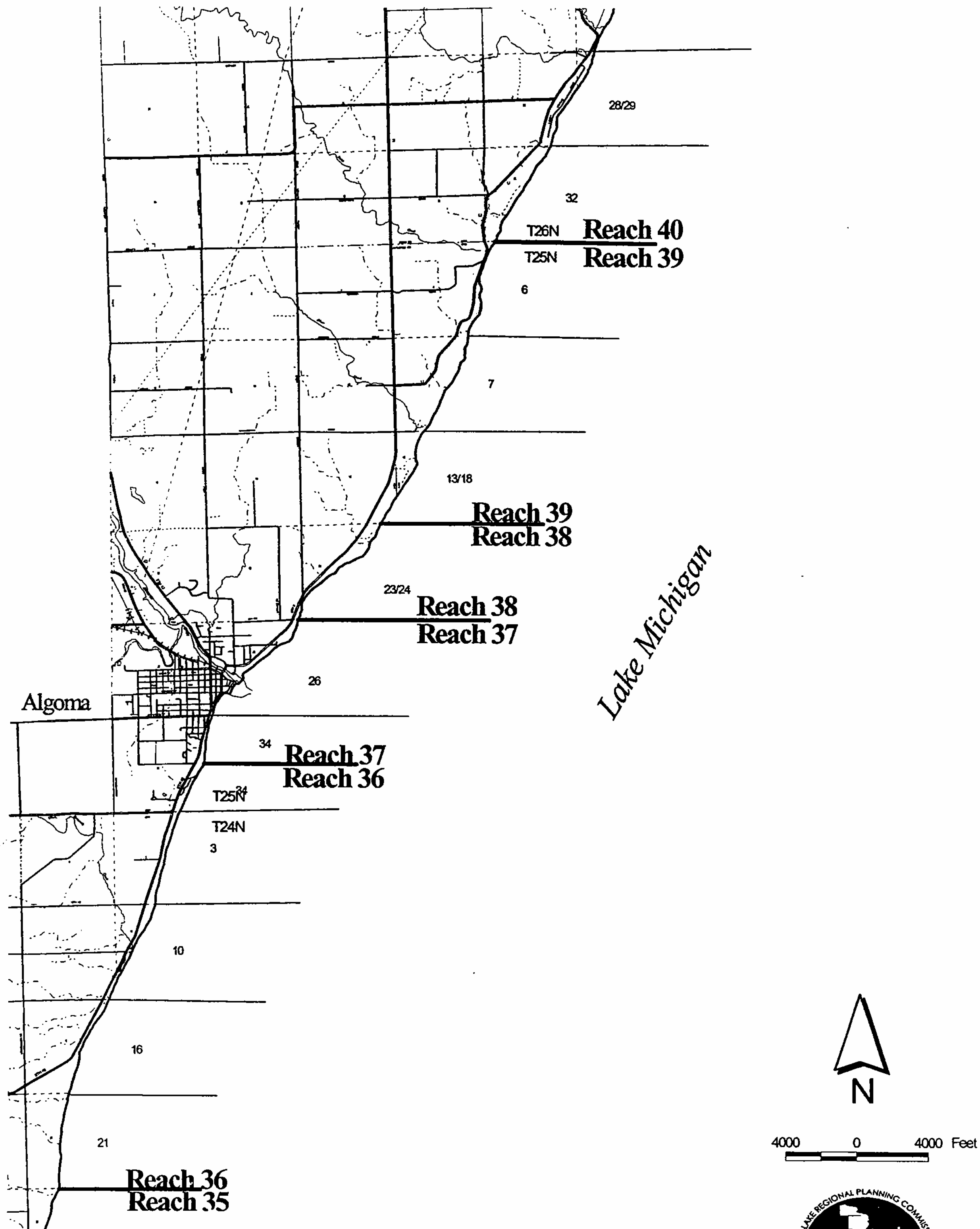
Profile 77-1 had a factor of safety of 1.1 in 1977, and was predicted to have a large circular failure throughout the entire slope (Appendix A & B). This profile now has soil flows and translational failures, with a deterministic factor of safety of 1.06 with respect to rotational failures. A probabilistic analysis of this profile resulted in factors of safety ranging from 0.084 to 1.36. Of the 25 most critical situations, 23 percent of these resulted in failures, while 9.2 percent of the total situations resulted in failures. This area has possibly seen 15-20 feet of recession in a most recessed part of the bluff top since 1975.

In 1996 the beach was reported to be 17 feet in width and made of cobbles. In 1977 the beach width was reported as being between 15 and 20 feet and made of cobbles. No shoreline recession rates were estimated for this section in 1996 or 1977 by the field parties.

T26N R26E SEC.29, 28, 21, 16, 9, 4 and 3, T27N R26E SEC.34, 27: DOOR COUNTY

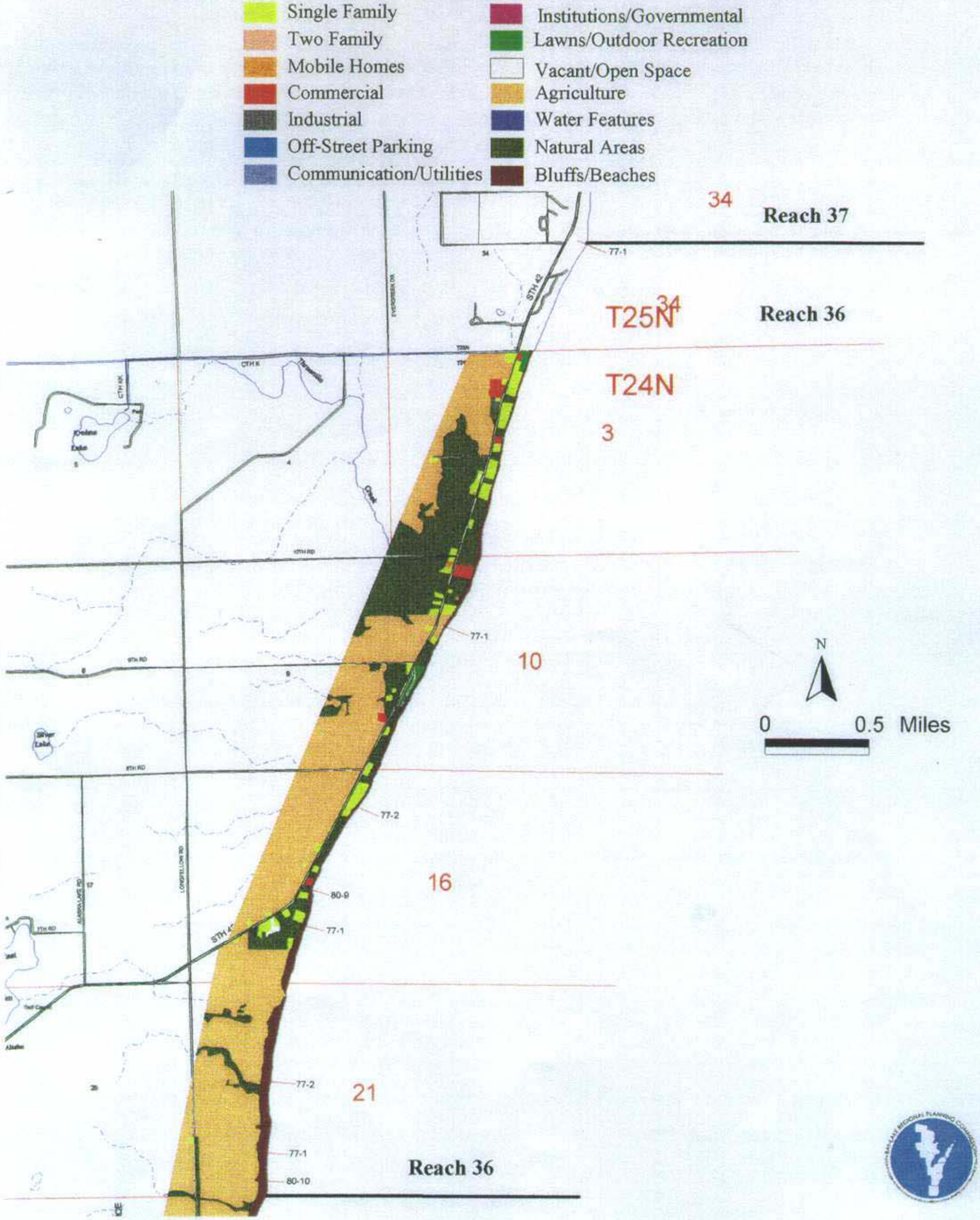
These nine sections consist of wide, flat terraces protected by wide beaches. Bedrock outcrops are often seen within these wide beaches. These sections appear unlikely to have bluff failures and are not subject to significant erosion.

Map III-8
Bluff Analysis Sections Within Reach 36, 37, 38, & 39



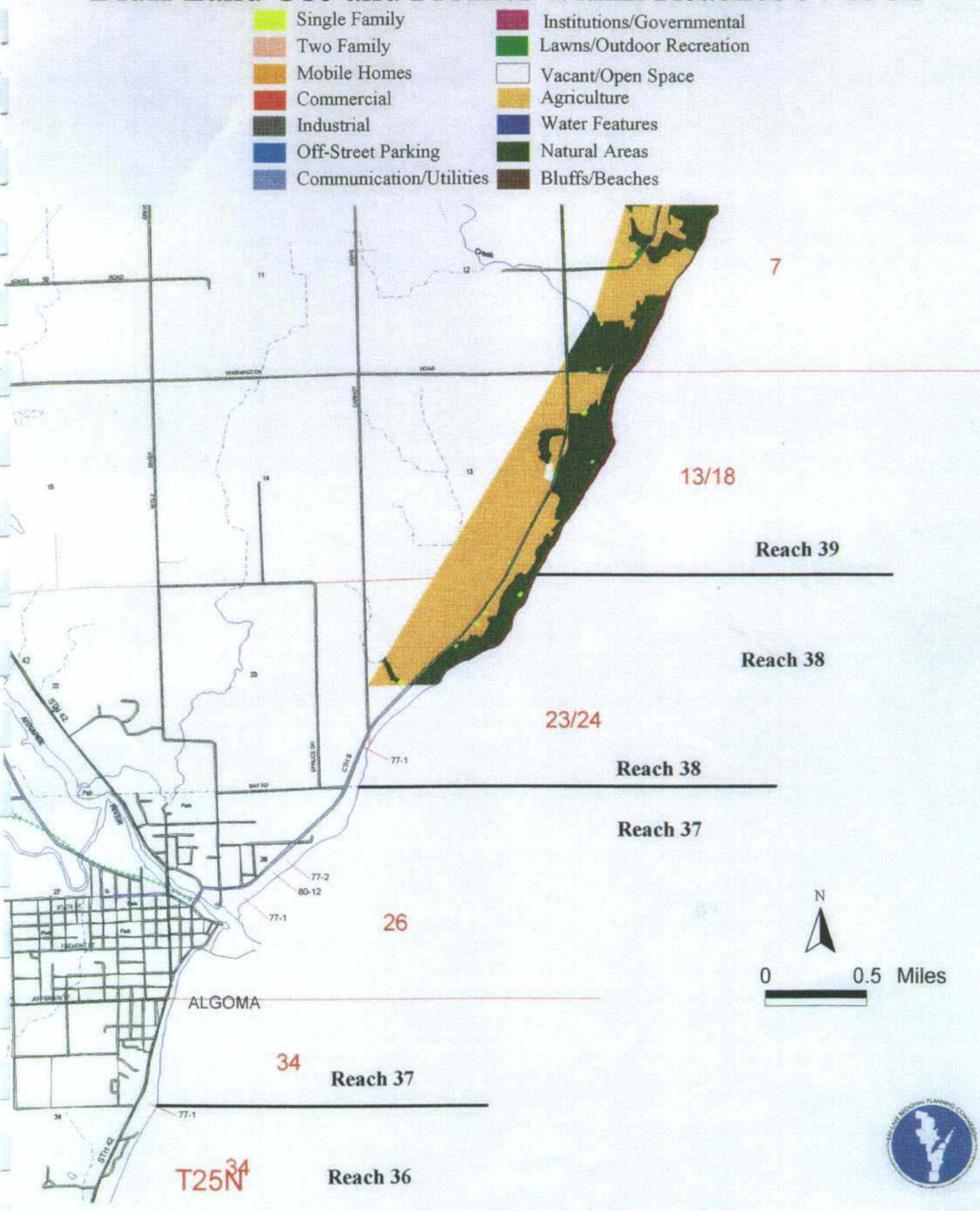
Source: D.M. Mickelson and T.B. Edil; Bay-Lake Regional Planning Commission, 1997

Map III-8a
Bluff Land Use and Profiles within Reach 36



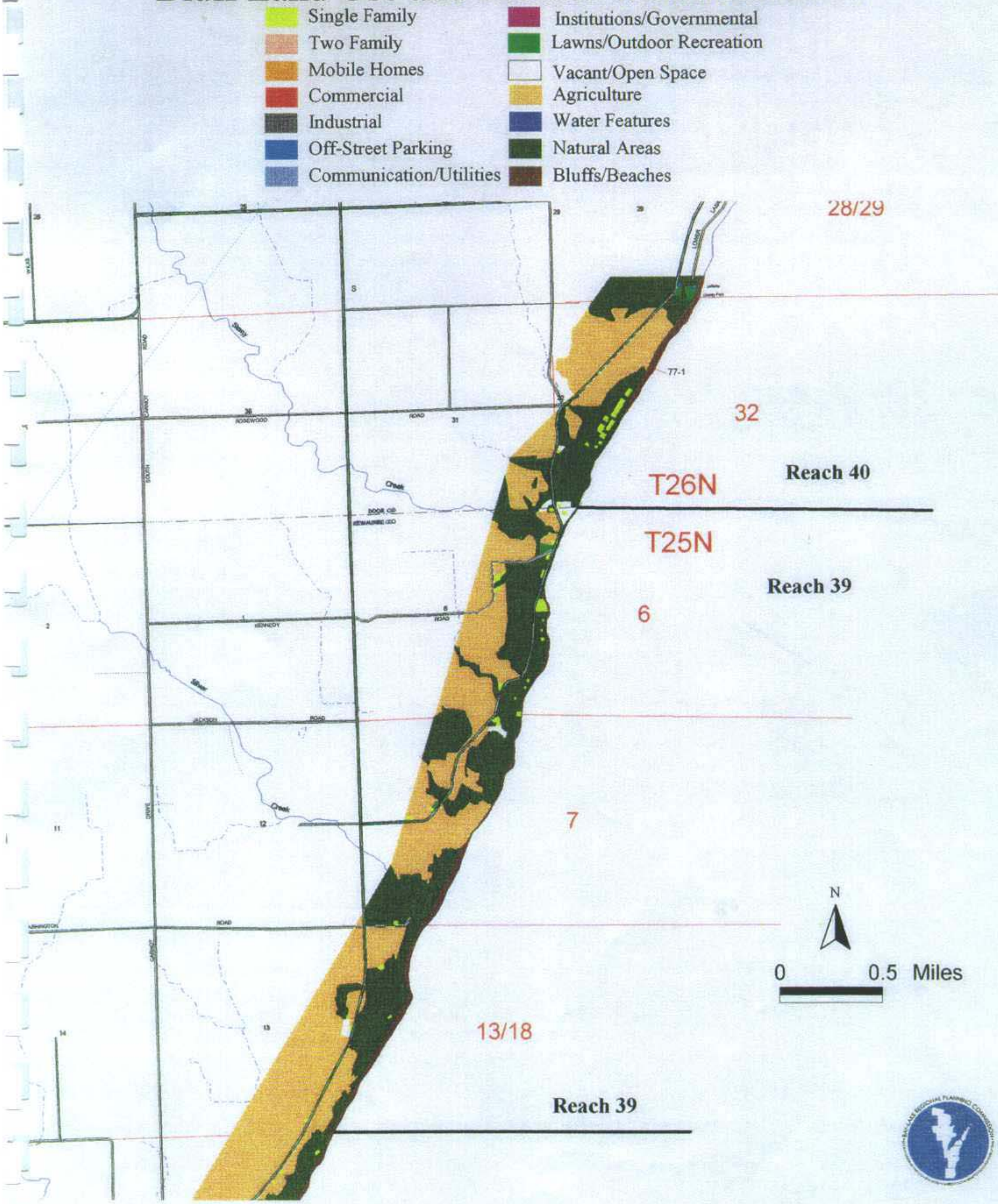
Source: Bay Lake Regional Planning Commission, 1996

Map III-8b
Bluff Land Use and Profiles within Reaches 37 & 38



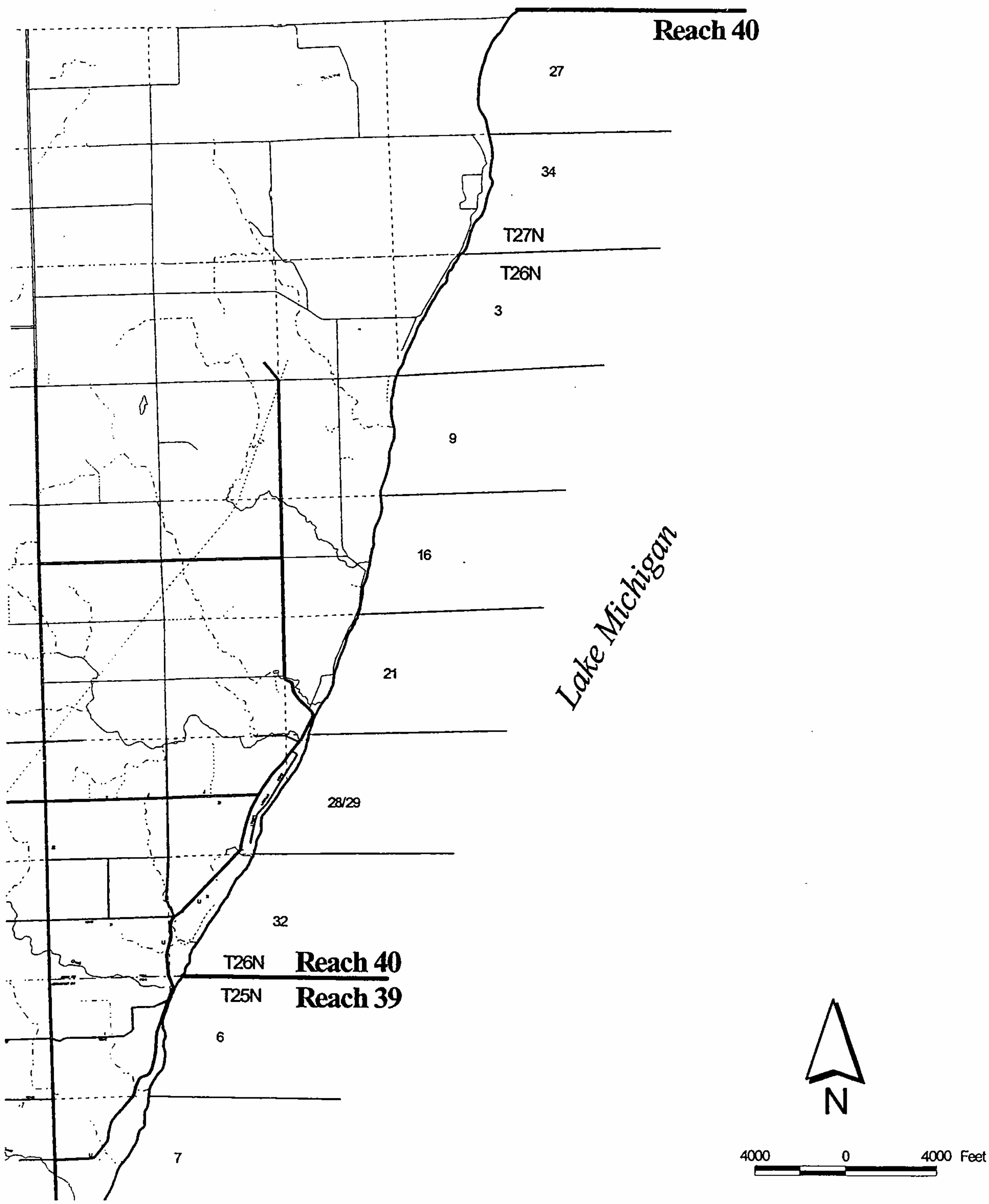
Source: Bay Lake Regional Planning Commission, 1996

Map III-8c
Bluff Land Use and Profiles within Reach 39



Source: Bay Lake Regional Planning Commission, 1996

Map III-9
Bluff Analysis Sections Within Reach 40



Source: D.M. Mickelson and T.B. Edil; Bay-Lake Regional Planning Commission, 1997

LAKE MICHIGAN SHORELINE DATA
COMPILED JUNE 1996

REACH	#	LOCATION	BORE SAMPLE	PROFILE	DETERMINISTIC FS PRIOR (77)	DETERMINISTIC FS LOCATION	DETERMINISTIC FS CURRENT (96)	MEASURED RECESSION 1978-1992	RECESSION RATE	ESTIMATED RECESSION (BLUFF TOP FIELD ESTIMATE) SINCE 1975	1996 OBSERVED FAILURE TYPE	LOCATION	BLUFF HEIGHT FEET	BEACH WIDTH FEET	ANGLE	COMPOSITION	% VEGETATION	SEEP LOCATION	STRUCTURES
		T13N R23E SEC 31		NONE															
		T13N R23E SEC 30		NONE															
		T13N R23E SEC 19/20		NONE															
		T13N R23E SEC 8/9		NONE															
18		T13N R23E SEC 4		NONE															
		T14N R23E SEC 33/34		NONE															
		T14N R23E SEC 27		NONE															
		T14N R23E SEC 22/23		NONE															
		T14N R23E SEC 14		NONE															
		T14N R23E SEC 11		NONE															
19		T14N R23E SEC 2		NONE															
	1	T15N R23E SEC 35		77-1	1.5	WHOLE	3.43			0	stable		25	16	9	rip rap	100	toe	rip rap
	2		GT 11	77-2	1.53	UPPER	0.96				stable		60	0	0	rip rap	80	mid	rip rap
	3	T15N R23E SEC 14		77-1			2.11			0	stable		40	58	45	sand & groin	100	none	road
	4		GT 12	77-2	1.5		2.36	5	0.357		rotational (old)		40	29	10	rip rap	100	toe	rip rap
	5	T15N R23E SEC 11		77-1	2.2		2.82	0	0.000		stable		25	33	8.5	rip rap	80	mid	rip rap
				77-2	1.5			10	0.714		not measured								
				80-16							not measured								
				80-17							not measured								
	6			80-18			1.77				translational (stable)		42	0	0	rip rap	90		rip rap
				80-19							not measured								
				80-20							not measured								
	7			80-21			1.106			15	Translational & flows		55	25	7	cobbles	30	mid	
	8			80-22			1.824			20	translational		42	0	0	rip rap	80	none	rip rap
	9	T15N R23E SEC 2/3		77-1	1.02		1.413	50	3.571				33	0	0	rip rap	30	none	rip rap
	10			77-2	0.79		1.564	10	0.714		translational		45	37	6	sand & cobbles	30	none	
21	11			80-33			1.606				Translational & flows		50	25	5	sand & cobbles	20	none	
				80-32							not measured								
				80-31							not measured								
	12			80-30			1.442				translational		22	33.5	5	cobbles & sand	60	upper	
				80-29							not measured								
	13	T16N R23E SEC 34		77-1	1.42		1.278	30	2.143		shallow rotational & flows		50	53	6	sand & pebble	90	mid	
				80-28							not measured								
				80-27							not measured								
	14			80-26			1.728			10	translational		43	23	9	pebble	20	none	
	15			80-25			1.848			10	translational		37	20.5	9	sand & pebble	30	none	
	16			77-2	0.82		1.941	20	1.429	10	translational		35	17.5	9	pebble & cobble	30	none	
				80-24							not measured								
				80-23							not measured								
				80-34							not measured								
	17			77-3	1		1.305	25	1.786		shallow rotational	whole	40	14.5	7	sand & pebble	5	upper	
	18	T16N R23E SEC 27		80-35			1.24				Translational & flows		35	18.5	8	sand & pebble	0	mid	
	19			80-36			2.127			10	flows		23	15	4	pebble	20	mid	
	20			80-37			1.203			25	Translational & flows		43	14	11	sand & cobbles	30	mid	
22	21			80-38			1.8			1	rotational	face	45	17.5	11.5	sand & pebble	90	mid	
	22	T16N R23E SEC 22		77-1	1.69		1.123	35	2.500		Translational & flows		50	16	12	cobble & pebble	90	upper	construction
	23			80-39			0.736				rotational (translational)	top (toe)	55	12	9	cobble	70	upper	
			GT 14	77-2	1.14 (.77)	WHOLE (TOE)					not measured - golf course								
		T16N R23E SEC 15		80-42			modified for golf course												
				77-1	1.95		modified for golf course	0	0.000										
				80-43			modified for golf course												
				80-44			modified for golf course												
		T16N R23E SEC 10	GT 13	77-1	1.06 (1.81)	TOP (WHOLE)	modified for golf course	20	1.429										
23	25			96-1			1.247				Translational		50			cobble	100		rip rap
	26			77-2	1.243 (.312)	WHOLE (TOP)	1.398	10	0.714		Translational & rotational		52	22	8	cobble	95	upper	none

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

LAKE MICHIGAN SHORELINE DATA
COMPILED JUNE 1996 (Continued)

REACH	#	LOCATION	BORE SAMPLE	PROFILE	DETERMINISTIC FS PRIOR (77)	DETERMINISTIC FS LOCATION	DETERMINISTIC FS CURRENT (96)	MEASURED RECESSION 1978-1992	RECESSION RATE	ESTIMATED RECESSION (BLUFF TOP FIELD ESTIMATE) SINCE 1975	1996 OBSERVED FAILURE TYPE	LOCATION	BLUFF HEIGHT FEET	BEACH WIDTH FEET	ANGLE	COMPOSITION	% VEGETATION	SEEP LOCATION	STRUCTURES
	27			77-3	.61 (.93)	TOP (LG TOP)	1.024	15	1.071		stable?		75	13	13	cobble & debris	30	mid	debris
	28		BAD LOCATION	77-4			1.517				Translational		50	19	9	cobble	90	lower	none
	29	T16N R23E SEC 3	BAD LOCATION	77-1			2.306	40	2.857	1	rotational		55	27	6	cobble	90	none	none
23	30	T17N R23E SEC 34		80-2			0.945			15	rotational		68	19	9	cobble	80	upper	none
	31		BAD LOCATION	77-1			1.159	20	1.429		rotational		57	15	7	cobble & sand	90	mid	none
	32	T17N R23E SEC 27		77-1	1.47		2.056	20	1.429		rotational		60	7	8	cobble	90	upper	none
	33			80-1			1.41			2	flows		33	14	7	cobble & sand	40	upper	none
	34	T17N R23E SEC 22		77-1	1.41	WHOLE	0.536				Translational		50	21	8	sand & pebble	0	upper	none
				80-3			not measured in 1996												
	35		GT 15/16	77-2	1.42	WHOLE	1.217			8	shallow rotational		53	17	9	sand & pebble	80	mid	rip rap
	36			80-4			1.259			8	Translational flows		48	15	10	sand & pebble	80	mid	rip rap
	37	T17N R23E SEC 14		77-1	1.56	WHOLE	1.467	50	3.571	3	Translational		33	42	5	sand	80	mid	none
24	38			77-2 (80-2)	1.28	WHOLE	0.865	70	5.000		Translational		25	43.5	7		60	mid	none
	39			77-3	0.96	UPPER WHOLE	0.678	55	3.929	1	Translational		37	37	4	rip rap	90	mid	rip rap, I beams
	40			80-6			0.791			15	shallow rotational		35	29.5	5.5	sand	70	mid	none
	41			80-7			0.994				Translational	toe (face)	45	54	4.5	sand	70	none	none
	42	T17N R23E SEC 11		77-1	0.91	UPPER	1.36			27	Translational		44	14	9	sand & cobble	30	lower	none
	43			77-2	0.76	MID	0.9	65	4.643	27	Translational		55	14	7.5	sand	30	lower	none
	44			80-8			0.962			0	Translational	toe	35	41	7	sand	90	no	none
	45	T17N R23E SEC 1		77-1	1.28	WHOLE	1.36			1	Translational	face	80	47	3.5	sand	50	no	none
	46			77-2	1.38	WHOLE	1.515	40	2.857	1	rotational	toe	60	30	6.5	sand	20	toe	none
	47	T18N R23E SEC 36		77-1	1.5	WHOLE	1.406			0	Translational	toe	50	38	6	sand	90	mid	none
	48		BAD LOCATION	77-2	STABLE	B=20	2.158	100	7.143		shallow rotational		20	37	6	sand	90	.no	none
	49	T18N R23E SEC 25		80-15			2.323			0	stable		25	49	5.5	sand & cobble	100	no	none
	50			77-1	1.41		1.83	70	5.000	1	Translational		35	34	8	sand	90	no	none
	51			77-2	0.82	UPPER	1.757	65	4.643	big	rotational	whole	45	22	11	sand & cobble	80	no	none
	52	T18N R23E SEC 24		80-14			1.37			10	shallow rotational		50	23	9	sand	90	mid	none
25	53		(GT -18)	77-1	1.1		1.421	70	5.000	2	Translational		50	29	5.5	sand	90	toe	none
	54		(GT-17)	77-2	1.3		1.808	110	7.857		Translational		35	25	7.5	cobble & sand	40	toe	none
	55	T18N R24E SEC 18		80-13			2.135			10	Translational		30	13	10	sand	5	toe	none
	56			77-1	0.88 (.94)	UPPER (MID)	1.903	30	2.143	5	Translational		25	40	5		90	lower	none
	57			80-12						5	rotational		40	36	5	sand	30		none
	58			77-2	1.04 (1.1)	WHOLE (MID)	0.928	40	2.857	5	Translational		65	50	5	sand	70		none
	59	T18N R24E SEC 7/8		77-1	1.27		1.085	20	1.429		shallow rotational		75	3	5	sand & cobble	80	mid	none
	60			80-11			1.47				Translational		75	30	7	sand & pebble	30		none
				80-10							not measured in 1996								
	61	T18N R24E SEC 5		77-1			1.068			1	Translational		44	23	6	sand	100	none	none
	62			80-9			0.851				shallow rotational		34	54	2	sand	70		none
26	63	T19N R24E SEC 32	(GT 19)	77-1	0.63		1.657			?	Translational		35	62	4	sand	90	none	none
	64			77-2	STABLE					0	stable		15	200	3	sand	100	none	none
		T19N R24E SEC 20		NONE															
27	65	T19N R24E SEC 16	(GT 20)	77-1	0.7 (.86)	MID (UPPER)	0.861	0	0.000	0	stable		20	38	5	rip rap	100	none	rip rap
	66			77-2	0.79 (.95)	MID (MID)	1.115	5	0.357	0	stable		30	23	8.5	gravel & pebble	90	none	debris
		T19N R24E SEC 10/15		NONE															
		T19N R24E SEC 11		NONE															
29		T19N R25E SEC 1		NONE															
		T20N R25E ALL SECTIONS		NONE															
	67	T21N R25E SEC 25/30		77-1	1.97	WHOLE	1.296	50	3.571	15	Translational & falls	face	23	31	4	sand	0	lower	none
		T21N R24E SEC 24		NONE															
	68	T21N R24E SEC 13		77-1	1.96	WHOLE	2.16	25	1.786		Rotational & translational		26	52	4	sand	30	mid	none
	69			77-2	1.93	WHOLE	2.248				shallow rotational		25	39	5.5	sand	80	mid	none
	70			80-16			0.966				Translational		32	29	3.5	sand	100	mid	none
	71	T21N R24E SEC 11		77-1	0.7	UPPER	1.769	70	5.000		Translational		36	39	12		40	mid	none
	72			77-2	0.7	UPPER	1.571	65	4.643		Translational		27	30.5	5	sand	2	mid	none
30		T21N R24E SEC 2		80-17	same as 77-1														
	73			77-1	0.75	UPPER	2.211	65	4.643		Translational		22	40	4	sand	10	mid	none
	74			77-2	0.6	UPPER				backwards!	erosion by river		8	50	4	sand	10	none	none
	75			80-18			2.135				rotational		33	25.5	6	cobble	100	tow	none
	76			77-3	0.96	MID	2.369	30	2.143		rotational		34	31	8.5	cobble		mid	none

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

LAKE MICHIGAN SHORELINE DATA
COMPILED JUNE 1996 (Continued)

REACH	#	LOCATION	BORE SAMPLE	PROFILE	DETERMINISTIC FS PRIOR (77)	DETERMINISTIC FS LOCATION	DETERMINISTIC FS CURRENT (96)	MEASURED RECESSION 1978-1992	RECESSION RATE	ESTIMATED RECESSION (BLUFF TOP FIELD ESTIMATE) SINCE 1975	1996 OBSERVED FAILURE TYPE	LOCATION	BLUFF HEIGHT FEET	BEACH WIDTH FEET	ANGLE	COMPOSITION	% VEGETATION	SEEP LOCATION	STRUCTURES
	77	T22N R24E SEC 35/36		77-1	1.62	WHOLE	2.057	35	2.500		stable		35	38.5	6	sand	80	none	none
30	78			77-2	1.95	WHOLE	2.788			little	stable, translational		27	11	5	sand	90	mid	riprap
	79	T22N R24E SEC 25		77-1	2.06	WHOLE	2.235						32	33.7	5	sand	80	toe	none
	80			77-2	2.02	WHOLE	2.345	70	5.000		Translational		30	50	4	sand	90	none	none
	81	T22N R24E SEC 24/19		80-1			1.628				flows		40	42.7	6.5	sand	90	mid	none
	82			77-1	1.19	WHOLE	1.247	70	5.000		flows unstable	active	70	14	9.5		60	mid	none
31	83			80-2			1.67				flows	active	68	17	8	sand	40	mid	none
	84			77-2	1.49	WHOLE	1.229	30	2.143		flows	active	60	33	7	sand	20	mid	none
	85	T22N R25E SEC 18		77-2	1.07	WHOLE	0.853	30	2.143	1	Translational	active!	67	9	7	sand & cobble	90	lower	none
	86			80-4			0.788	20	1.429		Translational	toe	45	27.5	8		80	none	none
	87			77-1	0.7	WHOLE	1.891	15	1.071	no	Translational	active!	40	16	6		20	none	none
	88			80-3			1.19	60	4.286	1	rotational & flows	upper	50	43	6.5	sand	90	mid	none
	89	T22N R25E SEC 7		77-1	0.9	WHOLE	1.048	25	1.786		Translational		77	9	7	cobble	20	upper	none
	90			77-2	0.95	WHOLE	0.0986	35	2.500		Translational	toe	65	22	5	cobble	80	mid	none
32	91	T22N R25E SEC 6		80-5			0.772	30	2.143	no	toe erosion		42	40	3.5	sand	100	none	none
	92			77-1	0.9	WHOLE	0.941	30	2.143	no	Translational		68	23	6	sand	10	low	none
	93			77-2	1.28	WHOLE	0.845	35	2.500	no	shallow rotational		58	21	7	sand	100	mid	none
	94	T23N R25E SEC 31		77-1	0.97	UPPER	1.227	30	2.143	5	rotational & flows	whole	67	18	8	cobble & sand	20	mid	none
	95			77-2	0.94	WHOLE	1.083	35	2.500		Translational		72	13	7	sand	60	mid	none
33	96	T23N R25E SEC 30		77-2	0.96	UPPER		30	2.143	minimal	Translational		90	36	7	sand	5	mid	none
	97			80-6			0.93				Translational		74	21	6.5	sand & gravel	5	mid	none
	98			77-1	0.9	MID WHOLE	0.962	25	1.786	none	Translational		58	33	5	sand	100	mid	none
	99	T23N R25E SEC19		77-1	0.97	WHOLE	0.9				Translational		68	16	8	sand & cobble	30	mid	none
34	100	T23N R25E SEC 17		77-1	0.91	WHOLE	1.028	30	2.143		Translational		47	16	6.5	sand & cobble	5	mid	none
	101	T23N R25E SEC 8		77-1	1.1	WHOLE	0.994	85	6.071	none	Translational		50	9	14	cobble	20	mid	none
	102			80-7			0.978			none	Translational		50	40	9	cobble	30	upper	none
	103			77-2	1	WHOLE	0.915	50	3.571	5	Translational		45	14.5	13	cobble	40	none	none
	104	T23N R25E SEC 5		80-8			1.03				rotational		47	19.5	8.5	sand & pebble	70	none	none
	105			77-1	0.93	WHOLE	0.939			10	Translational		53	21	7.5	cobble & sand	30	upper	none
35	106	T24N R25E SEC 32		77-1	0.97	TOE	0.935	25	1.786	10	Translational		48	16.5	10	pebble & cobble	50	none	none
	107			77-2	0.97	WHOLE	0.987	15	1.071	5	Rotational		57	16.5	10	sand & pebble	50	mid, top	none
	108	T24N R25E SEC 28/29		80-11			0.864			2	shallow rotational		52	39	7.5	sand & gravel	70	none	none
	109			77-1	0.98	WHOLE	0.717			5	shallow rotational		55	30	5	sand & gravel	30	lower	none
	110			77-2	0.99	MID	0.978	25	1.786	5	shallow rotational	upper	43	33.5	8	cobble & gravel	40	upper	none
	111			77-3	0.95	MID	0.767	60	4.286	5-10	shallow rotational	face	56	18	6.5	cobble & gravel	30	none	none
	112			77-4	0.9	WHOLE	0.775	70	5.000	4	translational		37	21.5	6	cobble & gravel	30	none	none
	113	T24N R25E SEC 21		80-10						3-4	shallow rotational	face	50	19.5	7	sand & gravel	10	none	none
	114			77-1	0.719	WHOLE	0.916	120	8.571	5	shallow rotational		57	16	5.5	cobble	30	upper	none
	115			77-2	0.97	WHOLE TOE	0.723	105	7.500	2	translational, flows	face	64	26	6	sand & gravel	5	none	none
	116	T24N R25E SEC 16		77-1	0.94	WHOLE	1.082	20	1.429	1	shallow rotational	face	47	21	6.5	cobble	70	none	none
36	117			80-9			1.578			10	translational		44	21	9.5	cobble	70	none	none
	118			77-2	0.82	UPPER	1.708	35	2.500		parallel retreat	face	32	15	9	cobble	90	none	none
	119	T24N R25E SEC 9/10		77-1	1.03	UPPER	1.412			5-10	parallel retreat	face	12	23	8.5	cobble	100	none	none
		T24N R25E SEC 3		NONE															
	120	T25N R25E SEC 34		77-1	1	UPPER	0.822			3	unstable?		55	30	8	sand & gravel	100	none	none
	121	T25T R25E SEC 26		77-1	1.5	WHOLE	2.198	15	1.071		flows		25	27.5	8.5	cobble	100	none	none
37				80-12							not measured in 1996								
	122			77-2	1.5	WHOLE	1.158	15	1.071		flows		42	20	9	cobble	0	none	none
38	123	T25T R25E SEC 23/24		77-1	0.7	WHOLE	1.103	0	0.000	3	modified, stable		47	0	0		0	toe	none
		T25T R25E SEC 13/18		NONE															
39		T25T R26E SEC 7		NONE															
		T25T R26E SEC 6/5		NONE															
	124	T26T R26E SEC 32		77-1	1.1	WHOLE	1.059	85	6.071	15-20	Translational, flows		54	16.5	11		10	none	none
		T26T R26E SEC 29		NONE															
		T26T R26E SEC 21		NONE															
		T26T R26E SEC 16		NONE															
40		T26T R26E SEC 9		NONE															
		T26T R26E SEC 3		NONE															
		T27T R26E SEC 34		NONE															
		T27T R26E SEC 27		NONE															

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

2 11x17 before this page

LAKE MICHIGAN SHORELINE RECESSION AND
BLUFF STABILITY IN NORTHEASTERN WISCONSIN: 1996

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 cohesiveness 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, and INSLOPE-FOSM, [6] based upon the first order second moment analytical methodology. All four models were applied using input data collected by the Bay-Lake Regional Planning Commission for the Lake Michigan shoreline within the Northeastern Wisconsin Region under the current study; in a similar study being conducted by the Southeastern Wisconsin 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 Bay-Lake 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, 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"

---

[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. JHRP75-9, 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.

[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] Bay-Lake Regional Planning Commission, Kewaunee County Coastal Hazard Management Plan, August 1988.

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 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 was 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 IV-1.

The results of the analyses, set forth in Table IV-1, 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 group interface elevations, soil strata slopes, and groundwater levels.

Data to evaluate the ability of the Monte Carlo Simulation of Bishop's Method to predict bluff slope stability was available for 64 sites. The results of the analyses, set forth in Table IV-2, 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

Table IV-1

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.*

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 IV-3. 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 results of the analyses, set forth in Table IV-4, 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 IV-5, 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 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

Table IV-2

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	81.3	79.7	64
Rotationally Failing Bluffs	80.0	80.0	15
Translationally Failing Bluffs	78.1	82.9	41
Nonfailing Bluffs	100.0	62.5	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 IV-3

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	89.1	87.5	64
Rotationally Failing Bluffs	86.7	86.7	15
Translationally Failing Bluffs	90.2	92.7	41
Nonfailing Bluffs	87.5	62.5	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 IV-4

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	84.8	115
Translationally Failing Bluffs	85.1	74
Shallow Rotationally Failing Bluffs	100.0	11
Rotationally Failing Bluffs	90.9	11
Nonfailing Bluffs	55.5	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.

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 IV-5. 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 IV-5. 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.

Table IV-5

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	51.4	84.8	115
Translationally Failing Bluffs	48.6	85.1	74
Shallow Rotationally Failing Bluffs	45.4	100.0	11
Rotationally Failing Bluffs	69.2	90.9	11
Nonfailing Bluffs	53.8	55.5	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.

LAKE MICHIGAN SHORELINE RECESSION AND
BLUFF STABILITY IN NORTHEASTERN WISCONSIN: 1996

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 Northeastern Wisconsin were surveyed in a number of studies conducted in 1977[1], 1980[2], and 1988.[3] 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 seashore 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 (SEWRPC) 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. The Bay-Lake Regional Planning Commission (BLRPC) was a joint applicant in receiving Federal funding to conduct a somewhat similar study for the shoreline of Lake Michigan in Northeastern Wisconsin. Bay-Lake's study, though less detailed, would be used to compare existing bluff conditions along the shoreline of Lake Michigan with those reported conditions in earlier studies. The information gained from this study would be published in similar forms by both Commissions. Three separate documents will be produced under this study. The Southeastern Wisconsin Regional Planning Commission's document details the findings and recommendations for the four coastal counties in Southeastern Wisconsin--Kenosha, Racine, Milwaukee, and Ozaukee. This document details the findings and recommendations for the four coastal counties in Northeastern Wisconsin--Sheboygan, Manitowoc, Kewaunee, and Door. The third document details the results of two methods used to project erosion of the bluffs and determine their stability for the coastlines in both Southeastern and Northeastern Wisconsin.

---

[1] D. M. Mickelson, L. Acomb, N. Brouwer, T. Edil, C. Fricke, B. Haas, D. Hadlev, C. Hess, R. Klauk, N. Lasca, and A.F. Schneider, Shore Erosion Study, Technical Report Appendix 5, 6, Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin, Wisconsin Coastal Management Program, February 1977.

[2] D. M. Mickelson, L. Acomb, N. Brouwer, T. Edil, C. Fricke, B. Haas, D. Hadlev, C. Hess, R. Klauk, N. Lasca, and A.F. Schneider, Shore Erosion Study, Technical Report 7, Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin, Wisconsin Coastal Management Program, July 1980.

[3] Bay-Lake Regional Planning Commission, Kewaunee County Coastal Hazard Management Plan , August 1988.

The Lake Michigan coastal erosion and bluff stability study area in Northeastern Wisconsin consists of the lands along the Lake Michigan shoreline in Sheboygan, Manitowoc, Kewaunee, and Door Counties. The coastal area for Northeastern Wisconsin extends approximately 77 miles from the Sheboygan-Ozaukee county line to the Kewaunee-Door county line. For analytical purposes, the Lake Michigan shoreline was divided into 23 reaches, as shown on Map I-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 Sheboygan, Manitowoc, Kewaunee, and Door 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.

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.

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 Northeastern 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 Fig. II-6.

Types of Slope Failure

The two forms of slides common along the Northeastern 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. 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.

Flow, or fluidization slope failures, occur when large amounts of water are present and the soil mass actually liquefies and moves like a 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 intergranular 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. Solifluction is the slow, viscous downslope flow of water-saturated material over an impermeable base. Solifluction is often 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.

Rock or soil fall 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.

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 Fig. II-8, 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 Wisconsin coastline, 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 FINDINGS

The findings of the inventory and analysis relating to bluff and beach conditions are summarized below. Appendix A details data gathered for the sections. Maps V-1, 2, and 3 detail recession, beach width and Factor of Safety.

Shoreline Reach 18: Sheboygan County
Shoreline Reach 18 extends from the Ozaukee-Sheboygan County line north to the north edge of T.14N., R.23E., Section 14, at the north edge of Kohler-Andre State Park. Residential development continues to makeup most of the land use today. In 1977 housing density range from 18 houses per square mile in the southern portion of the reach to over 45 houses per square mile to the north. Numerous protective barriers were emplaced along this reach. In 1977, beach widths within Reach 18 varied from nonexistent to 100 feet. All of the reach is low sandy shore with no bluffs. This part of the shoreline was not studied by the field party in 1996.

Shoreline Reach 19: Sheboygan County
Shoreline Reach 19 is about four miles long, extending from the north edge of Kohler-Andre State Park into downtown Sheboygan. The southern shoreline in Reach 19 is low and sandy with beaches ranging from nonexistent to 37 feet. These areas were not studied by the field party in 1996. The bluff does develop in the north and continues to the middle of the reach. Land use within this reach is primarily residential and recreational, as this reach lies within the urban area of the city of Sheboygan. Riprap emplacements protect almost an entire mile of shoreline within the southern part of the reach. The bluff disappears in the northern part of the reach and the shoreline is low, mostly underlain by lake and river sediments. All of the shoreline is protected within this northern half. No measurements or observations were made in the urban area in the northern part of the reach in 1996.

The bluffs in this reach range from 30 to 50 feet in height. In the southern half of the reach it was determined to have a factor of safety of 1.5 in 1977 and predicted to have a circular failure in the upper slope. This area is now well vegetated with seeps occurring near the toe. This southern half is protected by riprap and has had no bluff top recession since 1975. It now appears stable and unlikely to fail, having a factor of safety of 3.4 with respect to rotational failures. The mid section of the reach had a factor of safety of 1.53 in 1977 and was predicted to have a large, circular failure throughout the slope. This area has now been regraded and is protected by riprap. This area currently has a factor of safety of 0.96 with respect to rotational failures based on calculations. In 1996 the beach width is recorded as being nonexistent to 16 feet. No shoreline recession rates were measured in 1996.

Shoreline Reach 20: Sheboygan County
Shoreline Reach 20 includes all of section 23 in R.15N., R.23E. in downtown Sheboygan. It is mostly protected by the harbor breakwater and is made up of a combination of beach and riprap. Land use within this reach is made up of mostly commercial and residential structures to include the Sheboygan Yacht Club, Marina and Coast Guard Station. No measurements or observations were made here by the field party in 1977 or 1996.

Shoreline Reach 21: Sheboygan County

Shoreline Reach 21 extends from the south edge of Section 14 north of Superior Ave. to about two thirds of the way through Section 34 in T.16N., R.23E. In 1996, the land use in the southern part of the reach was urban with mixed uses of residential, commercial, and public open spaces. The northern end of this reach was suburban and agricultural. This land use is similar to that which existed in 1977. The height of the bluffs in this reach range from 22 feet to 50 feet. The beach width for this section range from nonexistent to 58 feet. In 1996 the observed failure types included rotational, translational and flows. The factor of safety for this reach range from 0.96 to 2.82. Recession rates are between none to 3.571 feet per year.

Shoreline Reach 22: Sheboygan County

The major reason for this reach designation is the orientation of the shoreline. Bluff characteristics and conditions continue much as they are in Reach 21. Land use in the area is predominantly agricultural as in 1977. The height of the bluffs in this reach range from 23 feet to 55 feet. The beach width for this reach range from 12 to 18.5 feet. In 1996 the observed failure types included rotational, translational and flows. The factor of safety for this reach range from 0.73 to 2.12. Recession rate is 2.5 feet per year.

Shoreline Reach 23: Sheboygan County

Shoreline Reach 23 extends from the north edge of Section 22 in T16N, R23E 4.5 miles to the middle of T17N, R23E, Section 27. Most of the land is agricultural except that a new golf course is being built in the southern part of the reach. CTH LS borders the bluff top and is susceptible to damage due to erosion on the lake shore. This reach appears to be one that will have development pressure in the near future. The height of the bluffs in this reach range from 33 feet to 75 feet. The beach width for this reach range from seven to 27 feet. In 1996 the observed failure types included rotational, translational, and flows. The factor of safety for this reach range from 0.945 to 2.306. Recession rates are between none and 2.857.

Shoreline Reach 24: Manitowoc County

The south boundary of Reach 24 is at Centerville Creek and the north boundary is at Point Creek. The southern mile is low terrace, mostly protected by riprap. Further north the bluff has moderate height and is eroding. Hika Bay is located in the southern portion of the reach. Mostly agricultural and woodlots exist in the middle and northern portion of the section with a number of seasonal and year round single family structures located along the bluff. The height of the bluffs in this reach range from 25 feet to 55 feet. The beach width for this reach range from 14 to 54 feet. In 1996 the observed failure types included rotational, translational and flows. The factor of safety for this reach range from 0.678 to 1.467. Recession rates are between 3.571 to five feet per year.

Shoreline Reach 25: Manitowoc County

Shoreline Reach 25 is about six miles long and includes T.17 N., Section 1 through T.18 N., Section 7 in southern Manitowoc County. Land use is a mixture of agriculture and residential. All of the reach shows some signs of erosion on the bluff, although conditions are variable. The bluff is generally 40 to 80 feet high and the geology of the bluffs is complex. Generally Haven till is in the lower part of the bluffs and in many areas sand or sand and gravel are present above. Seeps are common on the contact between the two. Most of the bluff toe is unprotected. Land use is similar to that in 1977 with mostly agricultural uses throughout the reach with clusters of residential development in the central and northern sections. Extractive uses are located in the middle of Reach 25. The height of the bluffs in this reach range from 20 feet to 80 feet. The beach width for this reach range from three to 49 feet. In 1996 the observed failure types included rotational and translational. The factor of safety for this reach range from 0.928 to 2.323. Recession rates are between 1.429 and 7.857 feet per year.

Shoreline Reach 26: Manitowoc County

The southern boundary of Reach 26 is the north section line of Section 7/8 in T.18 N., R. 23 E., about three miles south of downtown Manitowoc. Silver Creek and Red Arrow Parks are in this reach. The remainder is agricultural and residential. North of Red Arrow Park, the railroad follows the shore and the shoreline is protected. The north edge of the reach is the north harbor jetty in Manitowoc. The southernmost 1.5 miles is subject to erosion and bluff instability. The bluff is up to 44 feet high and partly vegetated. Geology of the bluffs is poorly known. In 1977, long term erosion rates have been measured at two points and both gave values of one foot per year. The height of the bluffs in this reach range from 15 feet to 44 feet. The beach width for this reach range from 23 to 200 feet. In 1996 the observed failure types included rotational and translational. The factor of safety for this reach range from 0.851 to 1.657. No recession rates were measured for this reach.

Shoreline Reach 27: Manitowoc County

Shoreline Reach 27 extends from the north jetty of Manitowoc Harbor to the West Twin River in downtown Two Rivers. Almost all of the reach has a shoreline which is protected by riprap. The bluffs in these sections are also low and stable. Only Section 16 was measured in 1977 and 1996. Due to the existing shoreline protection and the existence of low stable bluffs, the other sections were not further investigated. The height of the bluff in this reach is 20 feet. The beach width for this reach is 38 feet. The factor of safety for this reach is 0.861.

Shoreline Reach 28: Manitowoc County

There are no bluffs in Shoreline Reach 28 and no measurements were taken during 1977 and 1996 studies by the field party. Most of the reach is occupied by Point Beach State Forest, although there is a public beach in the city of Two Rivers along with some private lands. The reach extends from the city of Two Rivers to about one mile north of Rawley Point, where the shore becomes distinctly northeast facing. Beaches vary in width from 20 to 100 feet. The offshore is gently sloping with numerous sand bars. This is an area of net sand accumulation, and has been for over 5,000 years as evidenced by the beach ridge complex behind the beach. Sand dunes cap many of the beach ridges above the active beach. Where beaches are not present, there is riprap protecting the shoreline.

Shoreline Reach 29: Manitowoc County

Shoreline Reach 29 extends from the north edge of Section 9 in T.20 N. to about 25.75 in T.21N. The southern part is sandy beach with dunes behind. A low bluff develops mid way through the reach. Land use is residential, agricultural, and woodlots as in 1977 with the addition of newer single family residential in the north and south of the reach. The height of the bluff in this reach range from 23 feet to 30 feet. The beach width for this reach range from 23 to 30 feet. In 1996 the observed failure types included translational and falls. The factor of safety for this reach range from 1.115 to 1.296. Recession rates are between none and 3.571 feet per year.

Shoreline Reach 30: Manitowoc County

Shoreline Reach 30 extends from T.21 N., sec. 30.6 north to the north edge of sec. 36 in T.22 N. From its south edge to the Point Beach Nuclear Power Plant property it has no bluff. The height of the bluffs in this reach range from eight feet to 36 feet. The beach width for this reach range from 11 to 52 feet. In 1996 the observed failure types included rotational, translational and erosion by the river. The factor of safety for this reach range from 0.966 to 2.788. Recession rates are between 1.786 and five feet per year.

Shoreline Reach 31: Kewaunee County

Shoreline Reach 31 extends from the Kewaunee Power plant northward to the middle of Section 18. A change in shoreline orientation is the reason for the reach boundaries and the bluff in this reach is similar to those to the north and south. The bluff is up to 68 feet and failing in many places. Most of the land use is agricultural as in 1977. The height of the bluffs in this reach range from 30 feet to 68 feet. The beach width for this reach range from nine to 43 feet. In 1996 the observed failure types included rotational, translational and flows. The factor of safety for this reach range from 0.788 to 2.345. Recession rates are between 1.071 and five feet per year.

Shoreline Reach 32: Kewaunee County

Shoreline Reach 32 begins midway through Section 18 in T.22N. and extends 2.1 miles to Section 6.4 where a small point makes its boundary with Reach 33. The bluff in the reach is 50 to 90 feet high, composed of till and lake sediments. It is all eroding. Most of the top land is agricultural, but there are newer houses along the bluff top. The beach width for this reach range from nine to 40 feet. In 1996 the observed failure types included toe erosion, rotational, and translational. The factor of safety for this reach range from 0.986 to 1.048. Recession rates are between 1.786 and 2.5 feet per year.

Shoreline Reach 33: Kewaunee County

Shoreline Reach 33 extends from a small point in Section 6 at 6.4 northward to the south edge of the City of Kewaunee. Bluffs are up to 90 feet high and are mostly failing. Land use is agricultural, but residential areas are expanding, particularly south of Kewaunee. The height of the bluffs in this reach range from 58 feet to 90 feet. The beach width for this reach range from 13 to 36 feet. In 1996 the observed failure types included rotational, translational and flows. The factor of safety for this reach range from 0.9 to 1.227. Recession rates are between 1.786 and 2.5.

Shoreline Reach 34: Kewaunee County

Shoreline Reach covers the downtown Kewaunee waterfront where there are no profiles. The height of the bluff in this reach is 47 feet. The beach width for this reach is 16 feet. In 1996 the observed failure type was translational. The factor of safety for this reach is 1.028. Recession rate is 2.143 feet per year.

Shoreline Reach 35: Kewaunee County

Shoreline Reach 35 begins at the south end of the bluff in Section 17 and extends 4.5 miles north to a minor change in shoreline orientation at the north edge of Section 28 in T.24N. The 57 foot bluff is lower than in southern Kewaunee County, but slopes are for the most part actively failing. Land use is almost exclusively agriculture. The height of the bluffs in this reach range from 37 feet to 57 feet. The beach width for this reach range from nine to 40 feet. In 1996 the observed failure types included rotational and translational. The factor of safety for this reach range from 0.717 to 1.03. Recession rates are between 1.071 and 6.071 feet per year.

Shoreline Reach 36: Kewaunee County

Shoreline Reach 36 extends from a small point and minor change in shoreline orientation at the north end of Section 28/29 to midway through Section 24 in T. 25 N. on the south side of Algoma. The bluff is up to 64 feet high in the southern part of the reach. It is very low in the central part, and high again in the north. Most of the bluff is eroding. Land use is agricultural, with some residential or seasonal dwellings as in 1977. The height of the bluffs in this reach range from 12 feet to 64 feet. The beach width for this reach range from 15 to 30 feet. In 1996 the observed failure types included parallel retreat, rotational, translational and flows. The factor of safety for this reach range from 0.723 to 1.708. Recession rates are between 1.429 and 8.571 feet per year.

Shoreline Reach 37: Kewaunee County

Shoreline Reach 37 extends from the middle of Section 34 north to a small point and minor change in shoreline orientation in Section 26. It includes bluff shoreline south of the city of Algoma for about 0.3 miles, the low terrace in the city of Algoma itself, and about 0.4 miles of bluff shoreline north of the city of Algoma. The height of the bluffs in this reach range from 25 feet to 42 feet. The beach width for this reach range from 20 to 27.5 feet. In 1996 the observed failure type included flows. The factor of safety for this reach range from 1.158 to 2.198. Recession rate is 1.071 feet per year.

Shoreline Reach 38: Kewaunee County

Shoreline Reach 38 extends from a break in shoreline orientation at 26.8, north about 1.9 miles to another break in shoreline orientation at about 13/18.7. There is a low bluff in the southern part, but most of the reach is a low terrace with no bluffs. Much of the terrace is residential as in 1977. The height of the bluff in this reach is 47 feet. No beach was located within this reach. In 1996 the observed failure types included modified and stable. The factor of safety for this reach is 1.103. Recession was almost nonexistent in this reach.

Shoreline Reach 39: Kewaunee County/Door County

Shoreline Reach 39 extends from a break in shoreline orientation in Section 18 and extends north into Door Co. Sections 13/18, 7, and 6 of T. 25 N. consist of flat, sandy terraces that are commonly wooded and protected by wide beaches. Parts are residential. There is only one small bluff within these sections and it appears stable. No recession measurements were taken by the field parties in 1996 or in 1977 for these sections. No recession rates were measured in this reach.

Shoreline Reach 40: Door County

Shoreline Reach 40 extends from north of the mouth of Stoney Creek to the Sturgeon Bay Canal. The land use is residential with wide beaches. Of the ten sections within this reach, only Section 36 has a bluff. Section 36 was the only section to be measured in 1977 and 1996. This bluff was 54 feet in height and the beach was 16.5 feet wide. In 1996 the observed failure types included translational and flows. The factor of safety for this bluff is 1.059. The remaining area consisted of wide, flat terraces protected by wide beaches. Bedrock outcrops are often seen within these wide beaches. These sections appear unlikely to have bluff failures and are not subject to significant erosion. Recession rate is 6.071 feet per year.

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 Maps V-1 through V-5 have indicated that much of the Lake Michigan shoreline was in a more stable condition during the 1996 field surveys than during the 1977 study. This may be attributed to the placement of shoreline protection structures and the regrading of unstable bluff slopes. Notwithstanding this achievement, portions of the Lake Michigan shoreline, particularly in the central and northern portion of the planning area, 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.

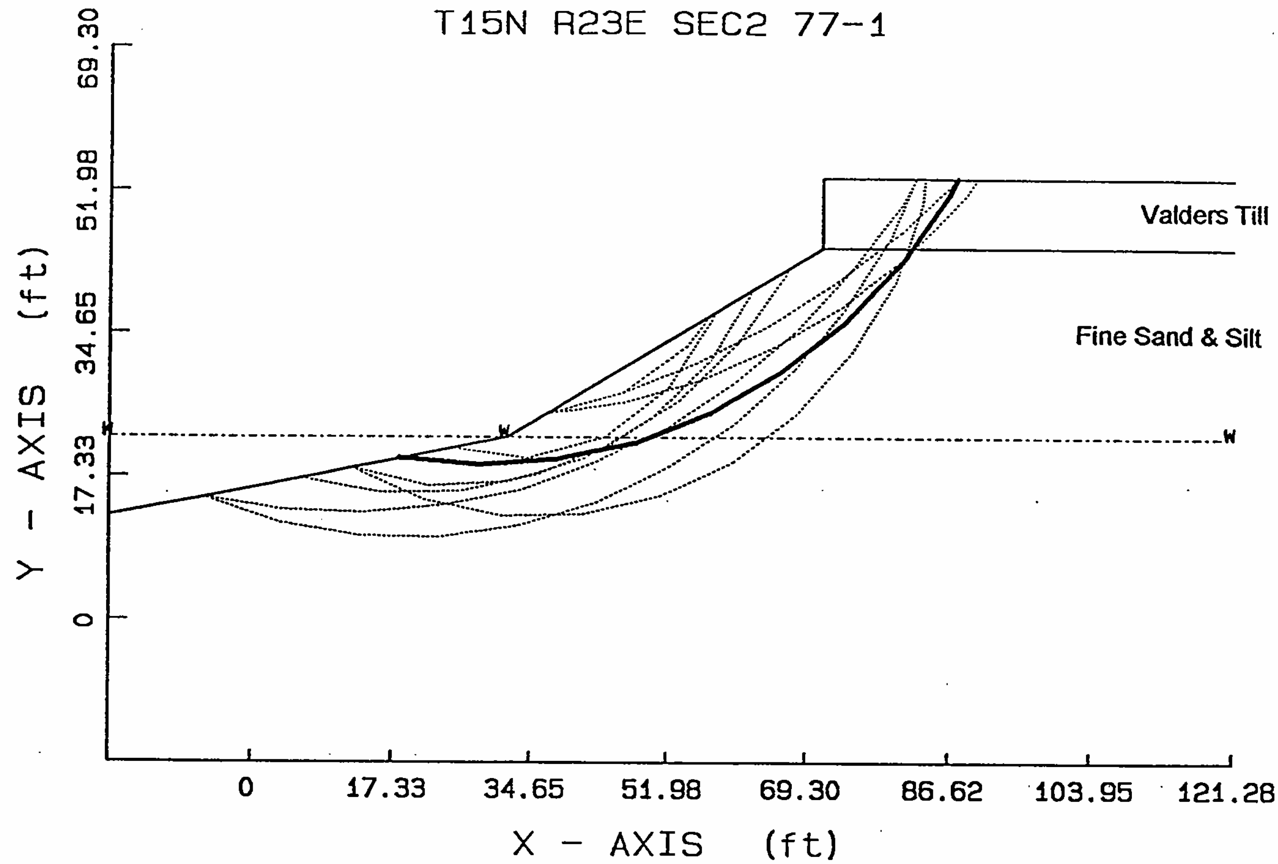
The data and analyses presented herein will serve as a data base for system-level shoreland development and preservation planning programs. The data on shoreline recession and bluff stability for the periods 1977 through 1996, as summarized in Appendix A are intended to be useful in defining the risk 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.

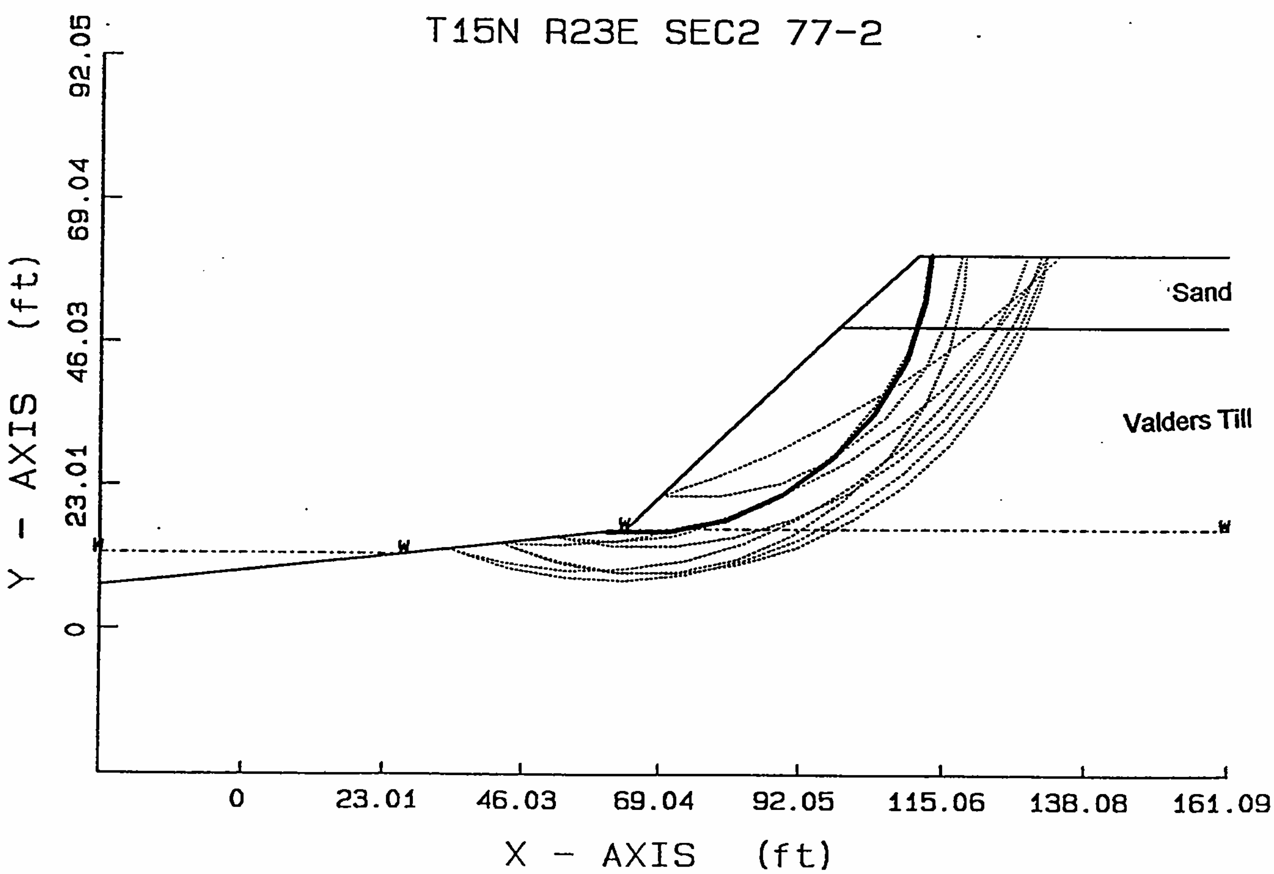
APPENDIX A
Tables Detailing Reach/Section/Profile Data

Percent Deviation From U.S.G.S.
Topographic Quadrangles

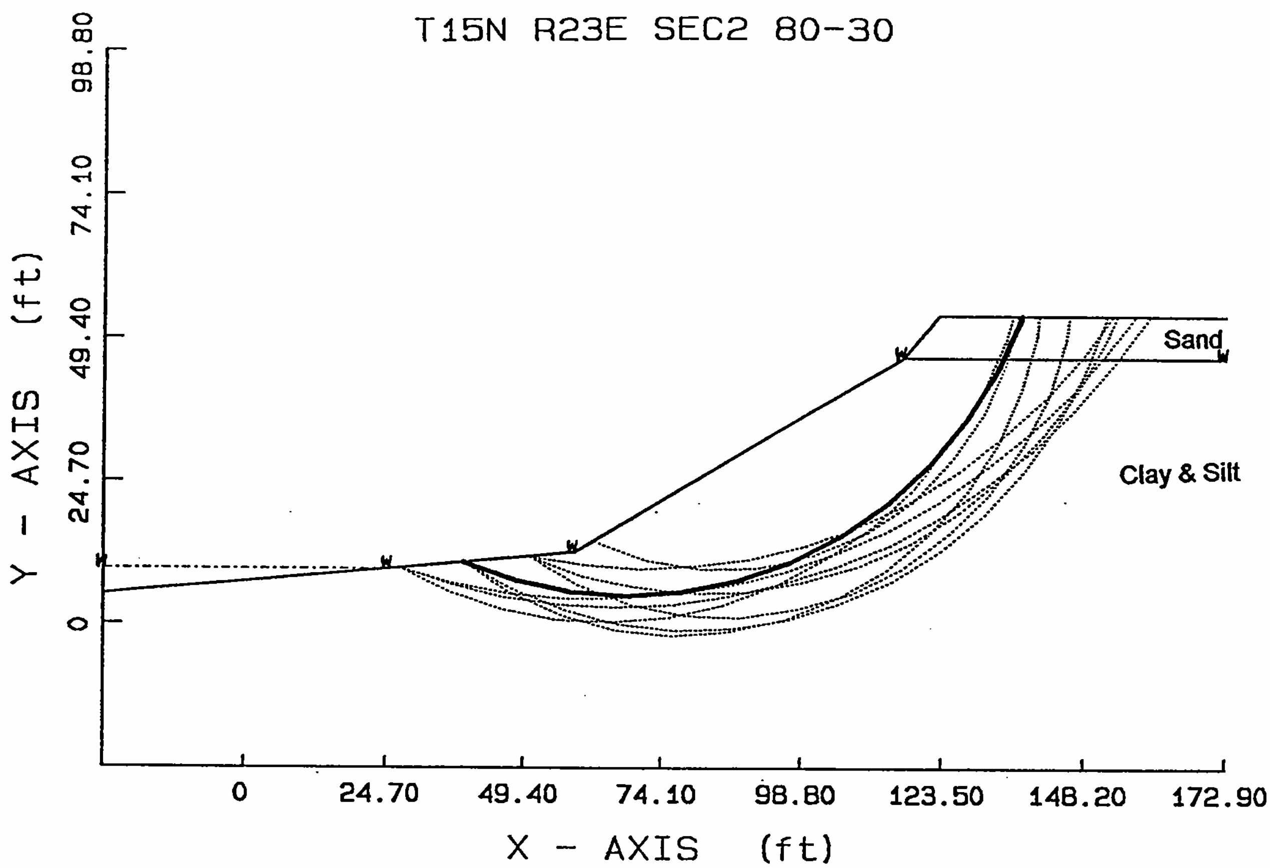
County	1978 Photographs			1992 Photographs		
Door	1.3%	to	3.9%	-1.1%	to	-3.6%
Kewaunee	-1.5%	to	2.1%	-5.4%	to	-9.6%
Manitowoc	-1.7%	to	2.0%	-6.4%	to	-7.4%
Sheboygan	-2.5%	to	4.6%	-1.2%	to	-3.0%
Mean		1.03%			-4.71%	

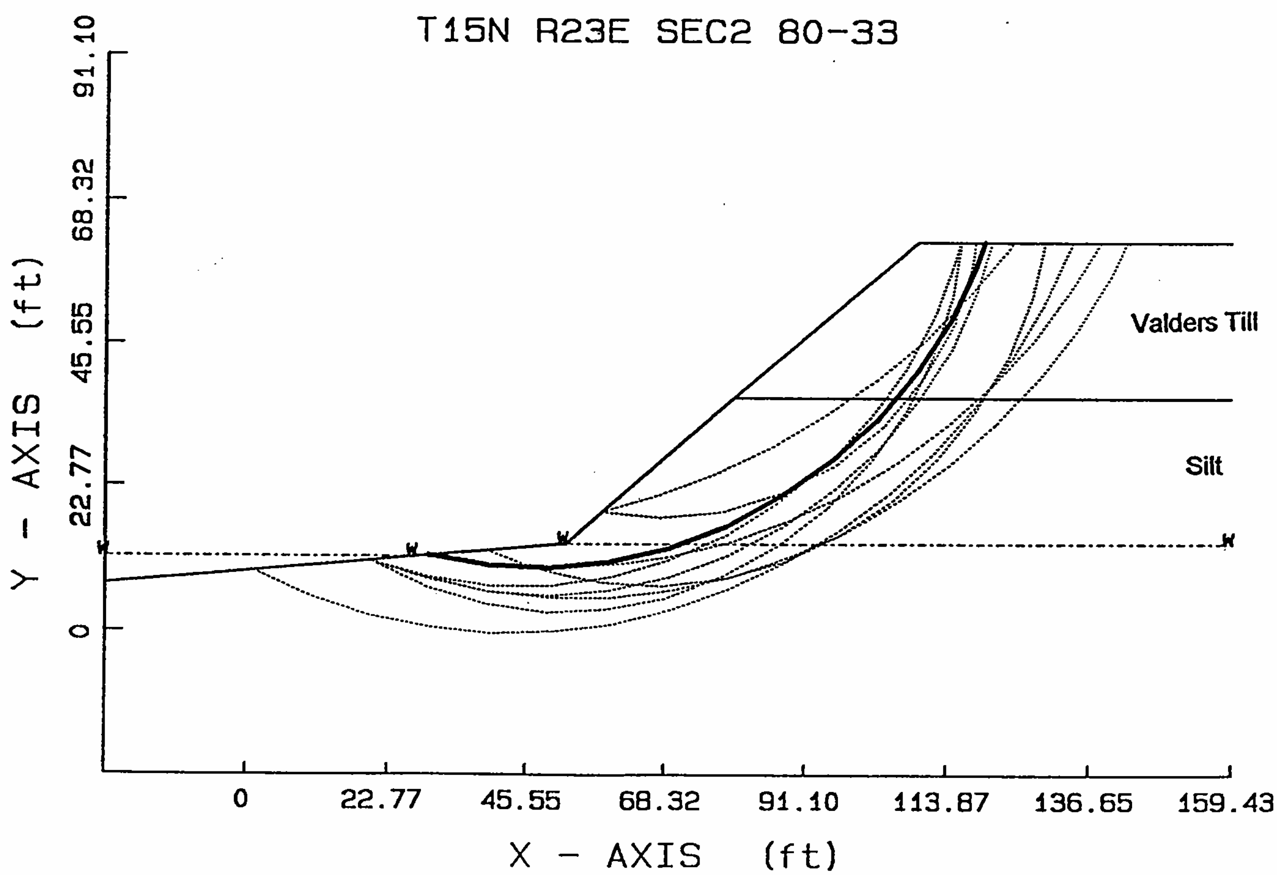
APPENDIX B
Profile Cross-sections



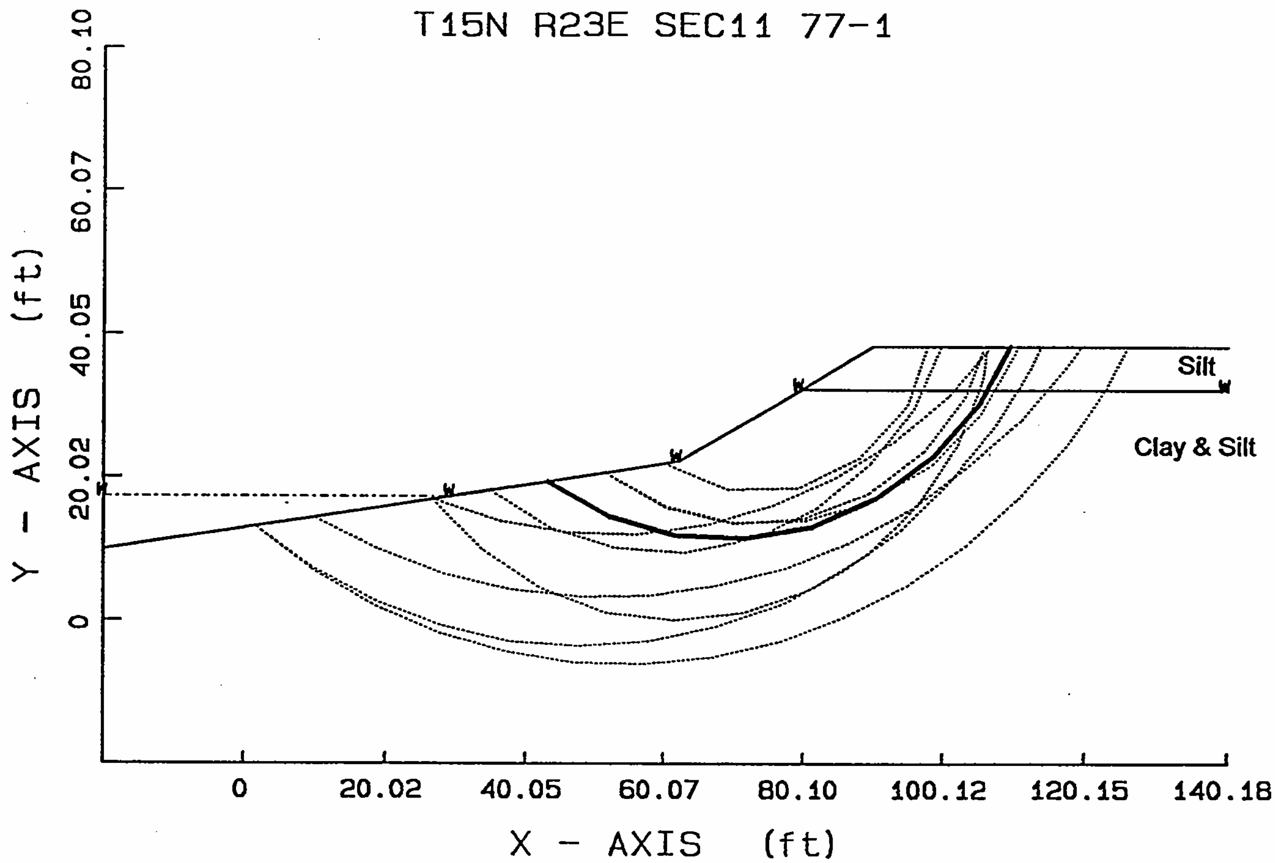


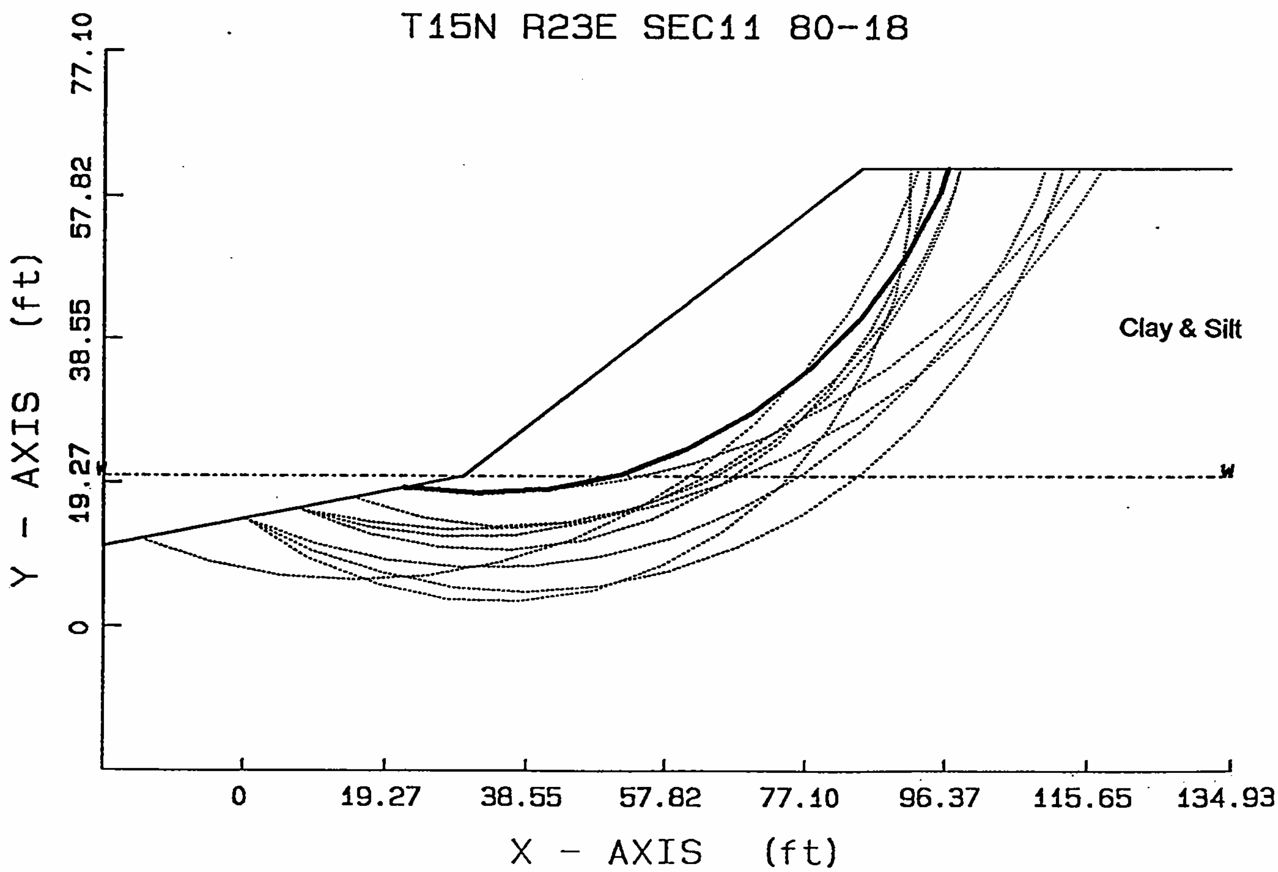
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



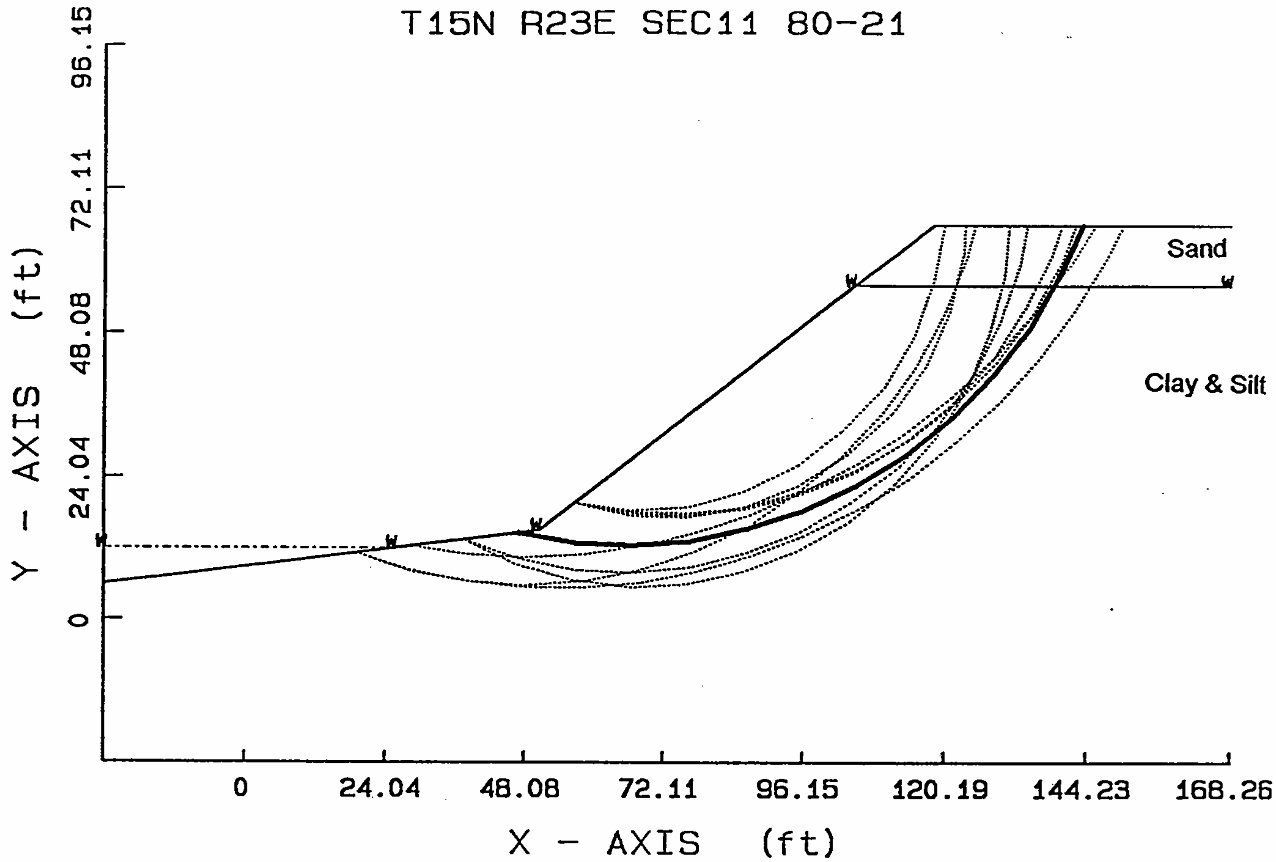


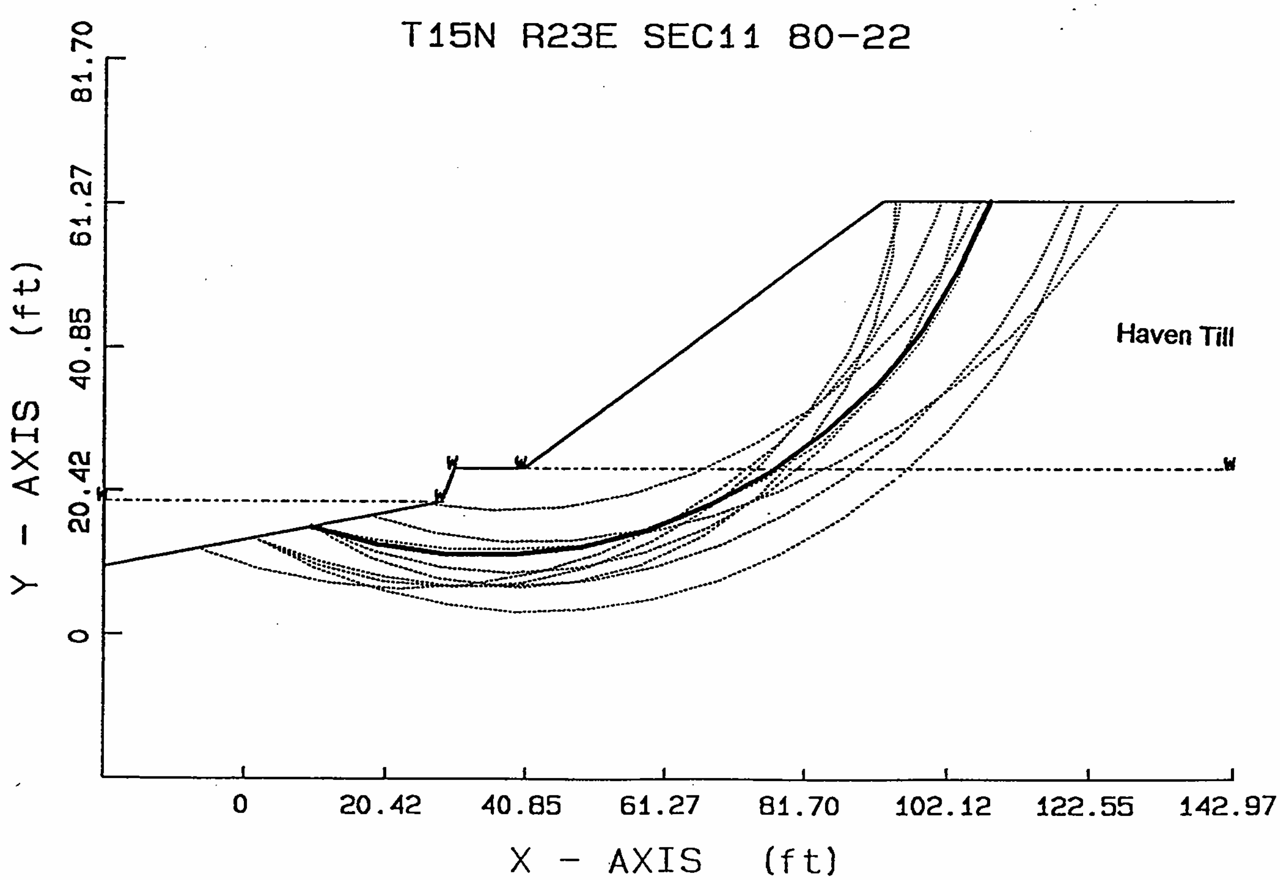
ource: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



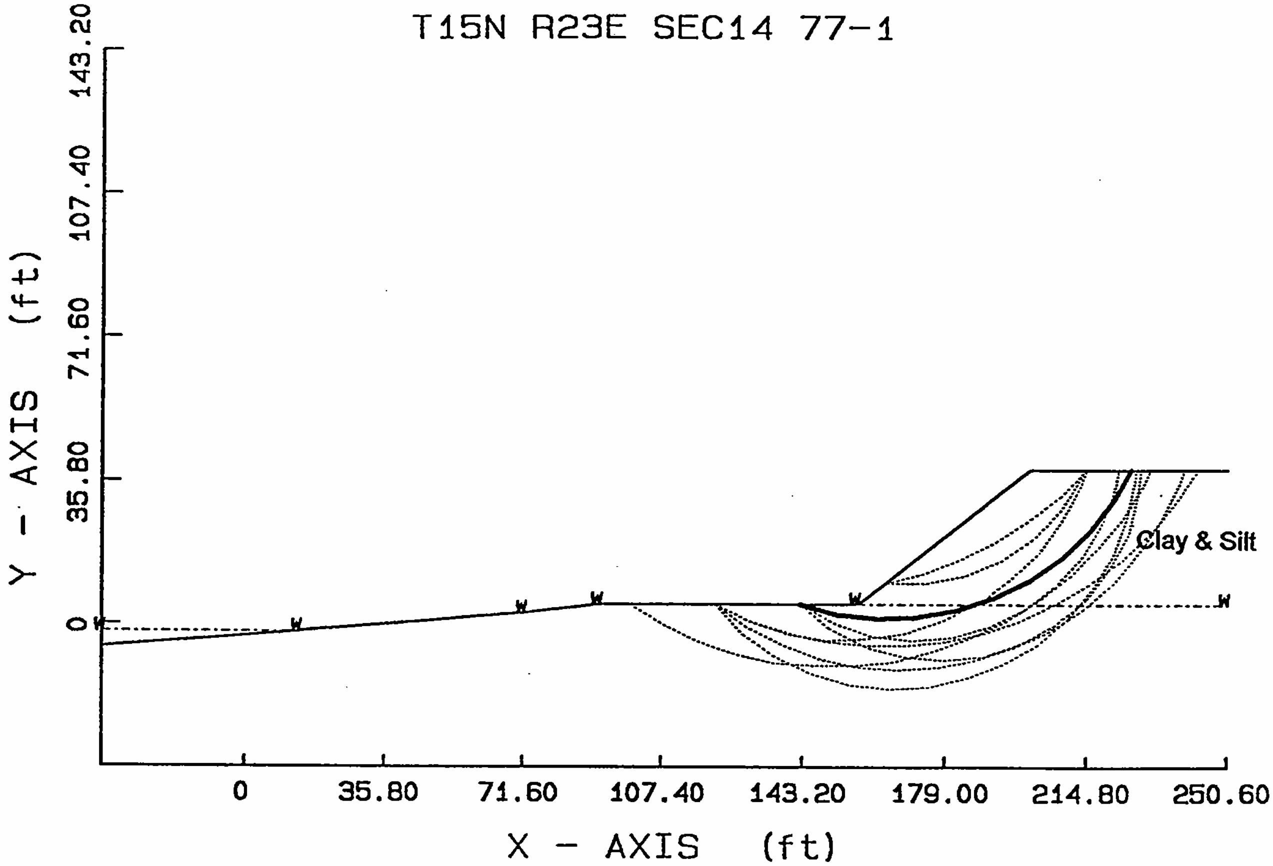


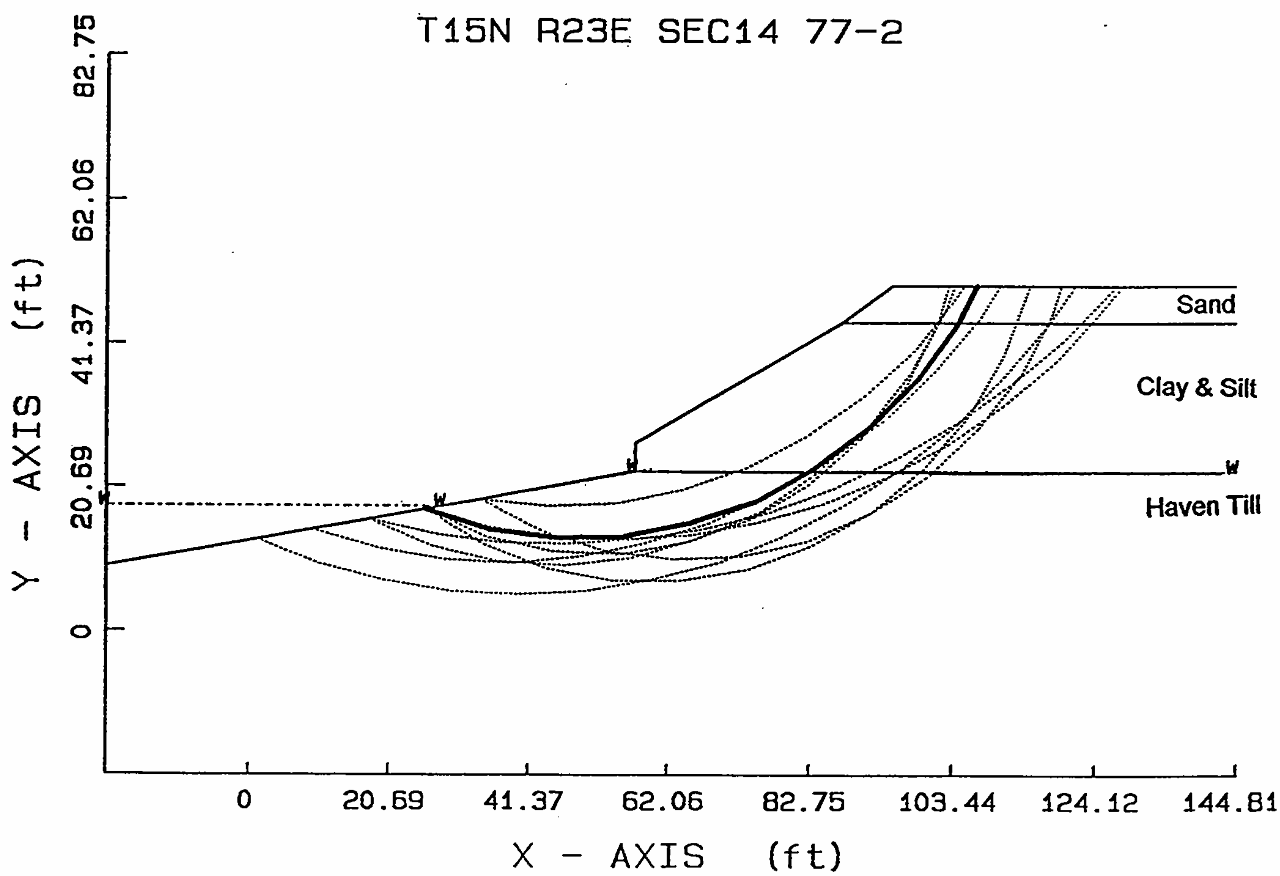
ource: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



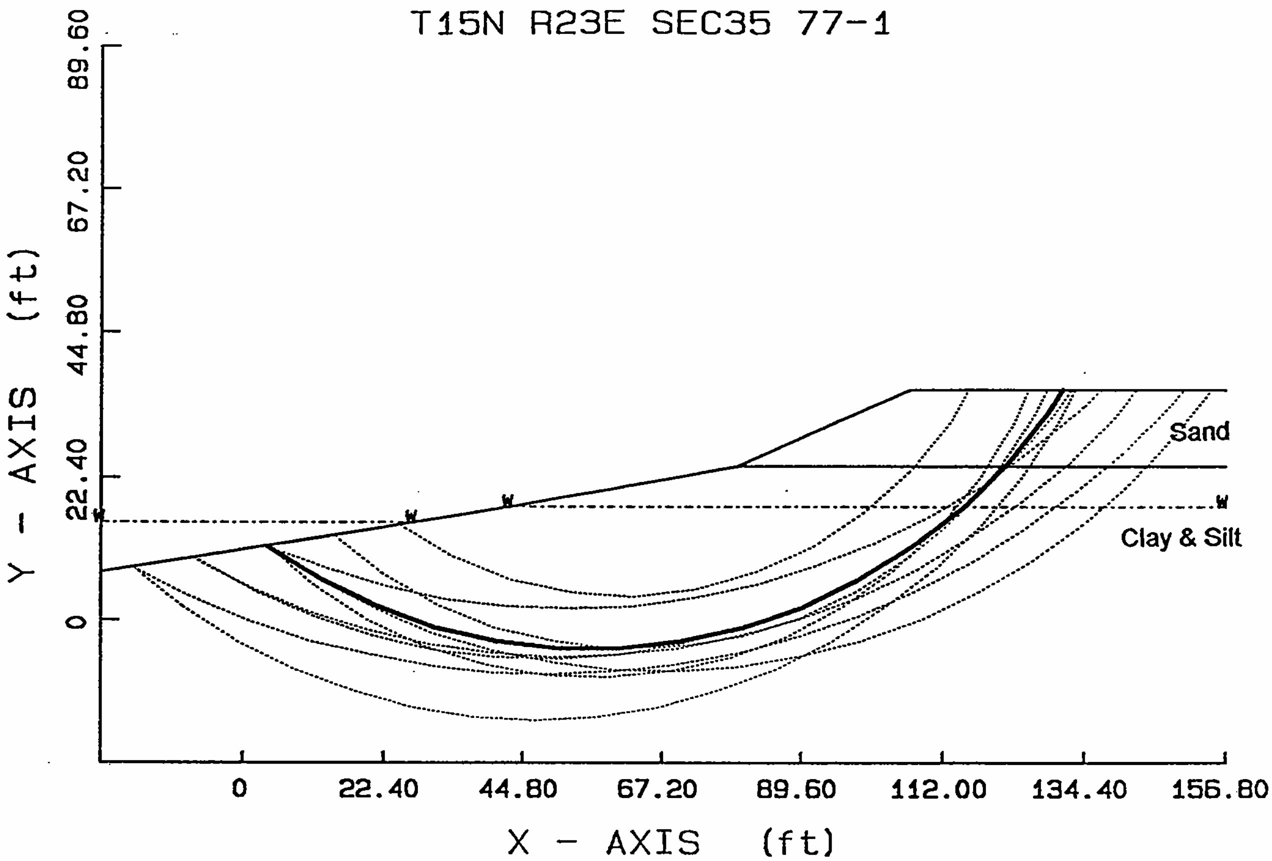


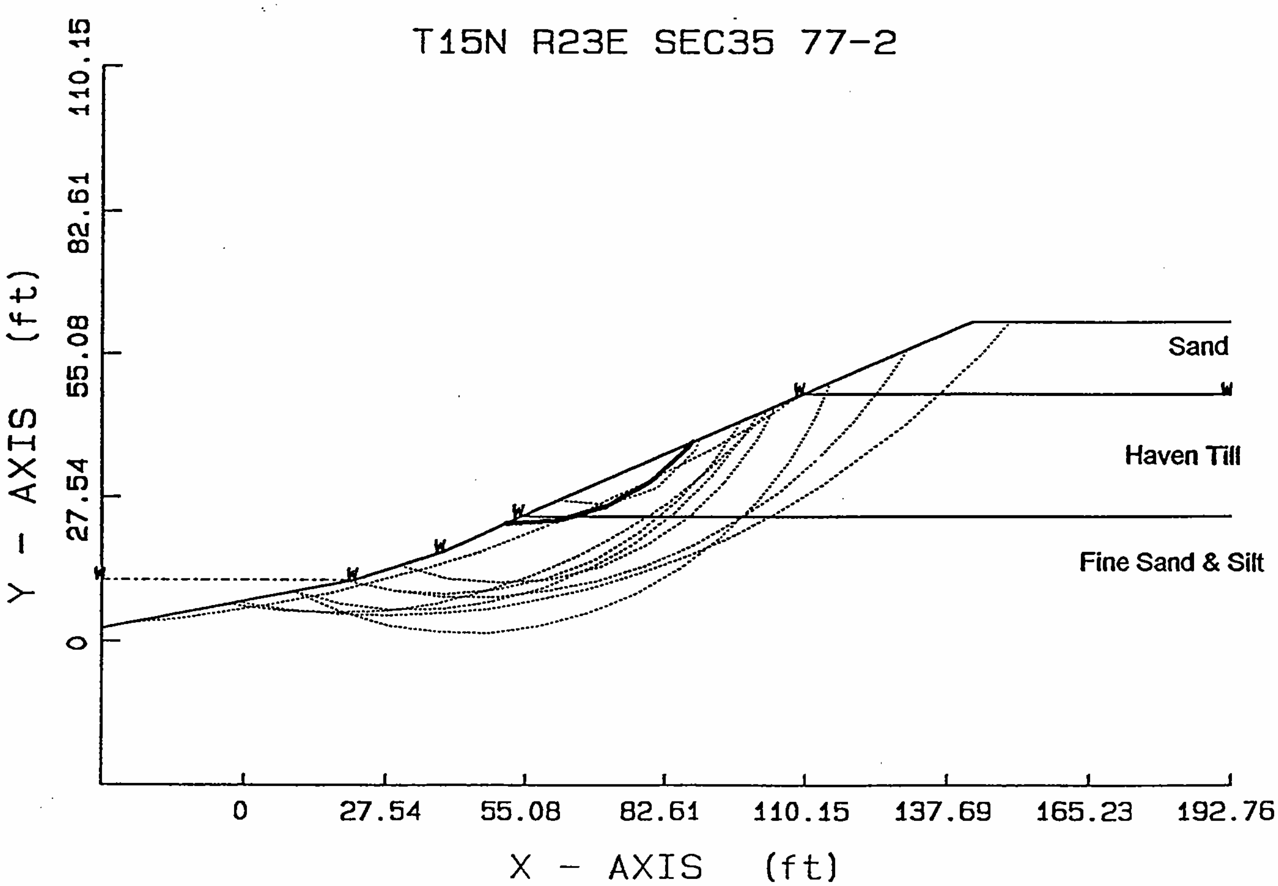
ource: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997





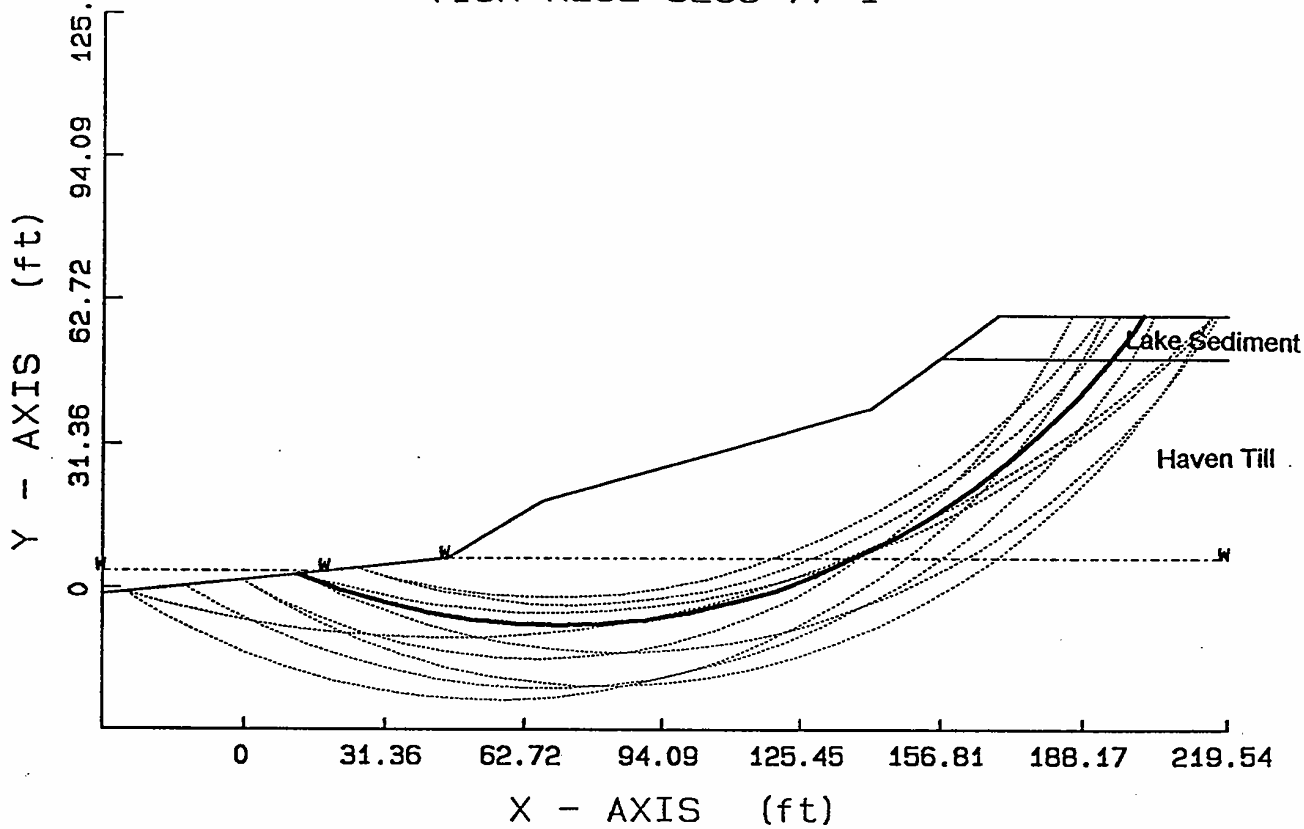
:: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



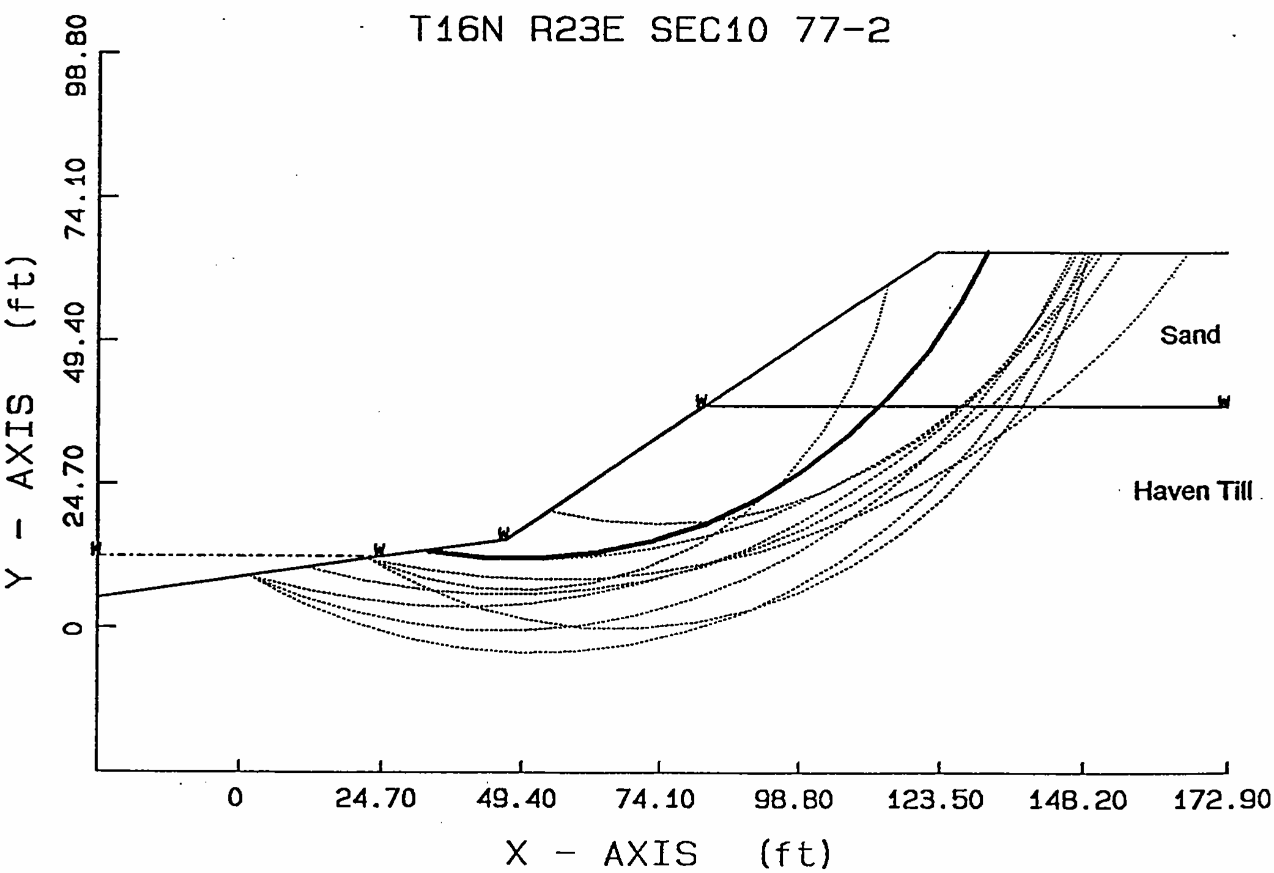


Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

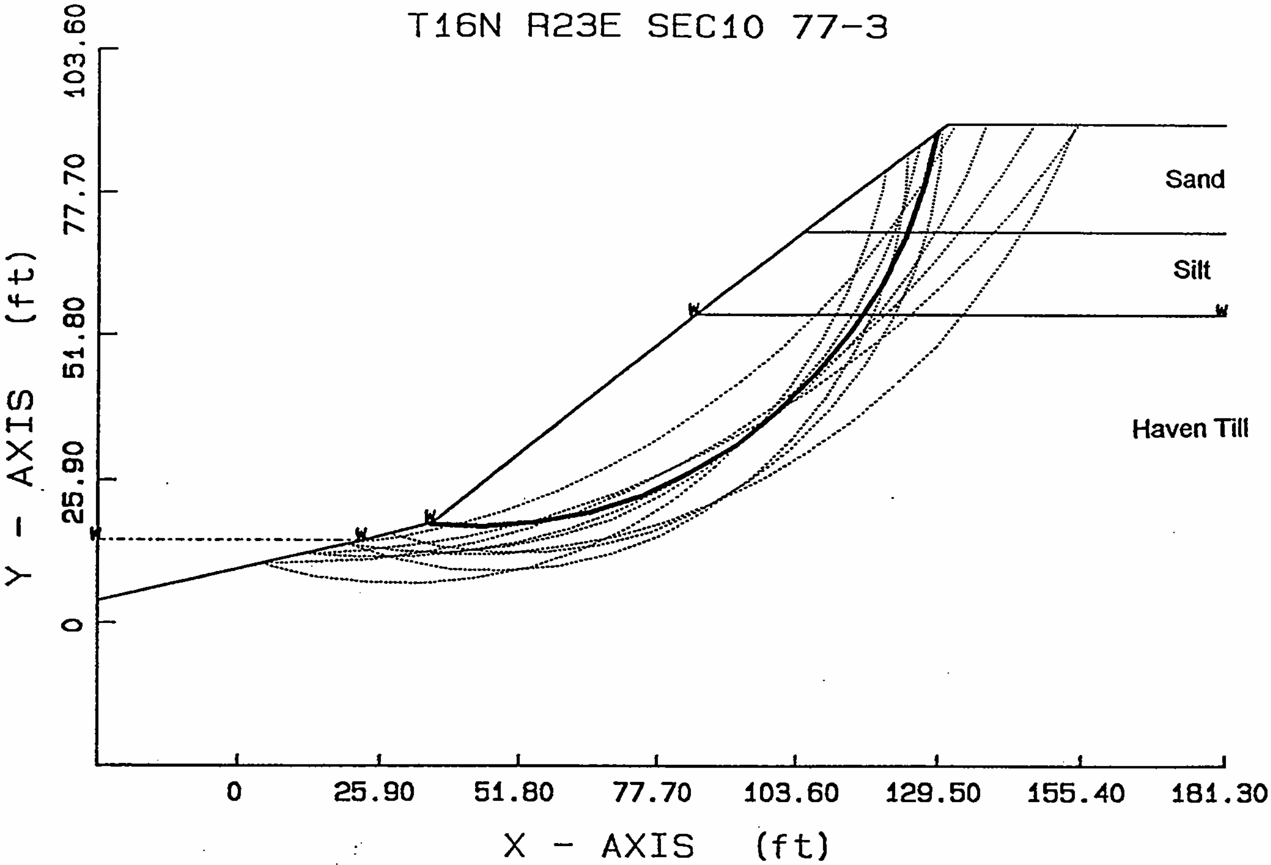
T16N R23E SEC3 77-1

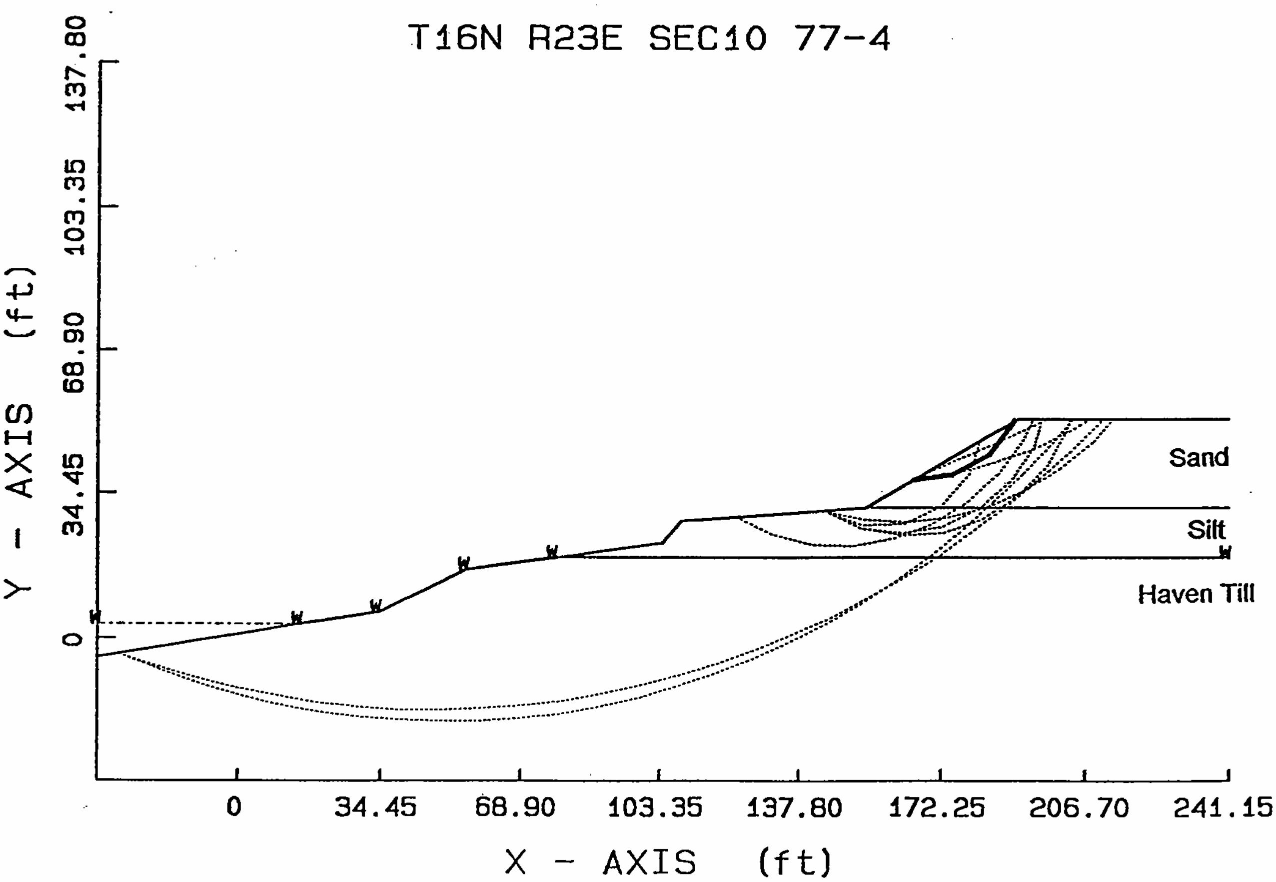


T16N R23E SEC10 77-2

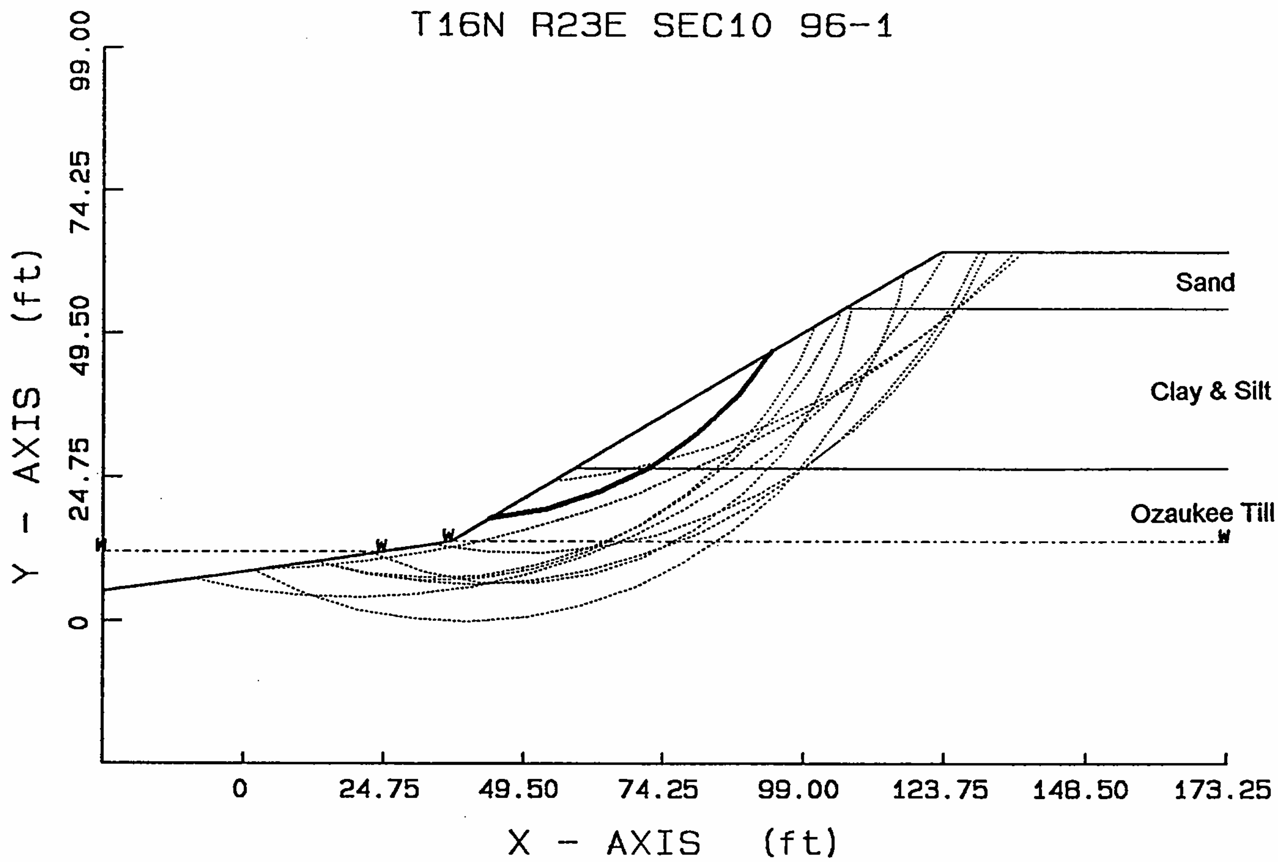


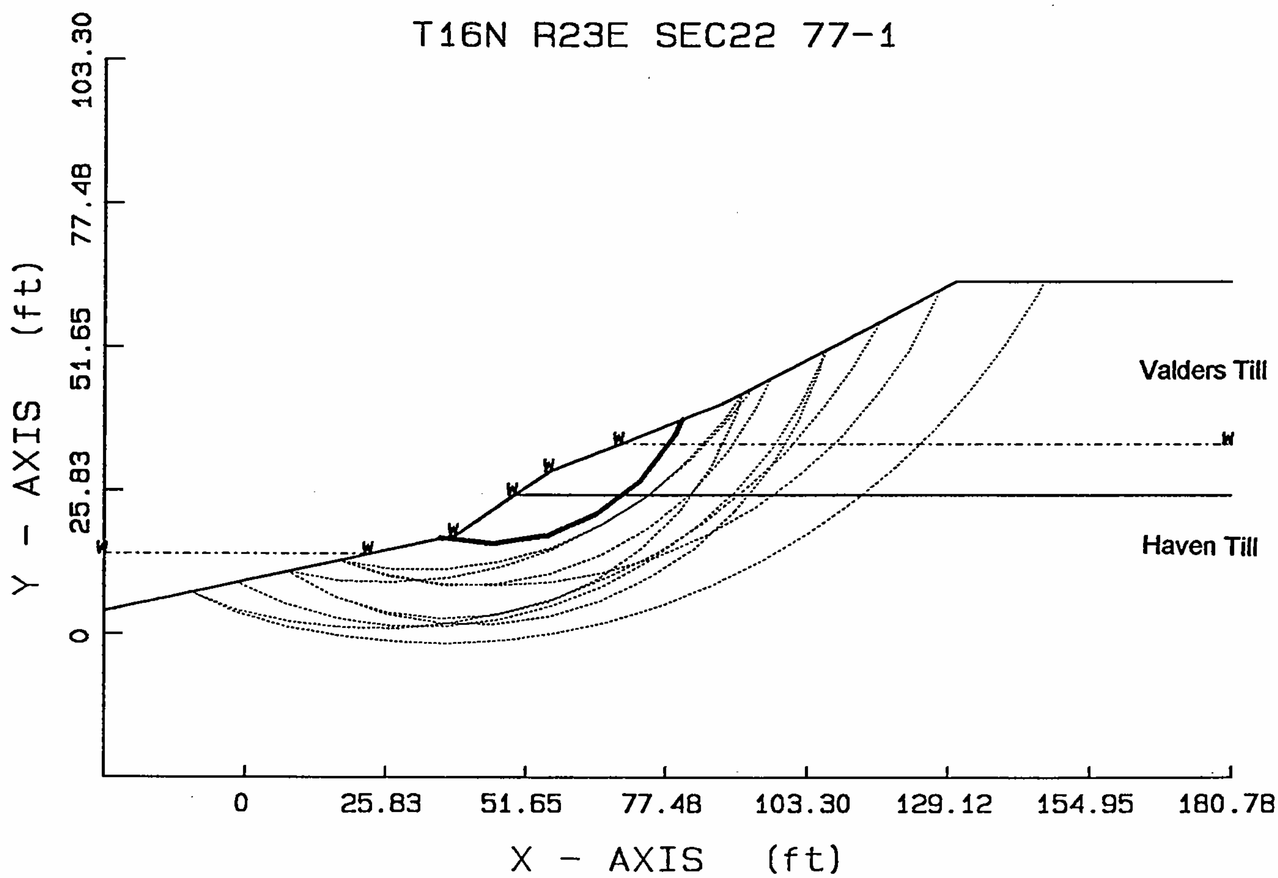
;e: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



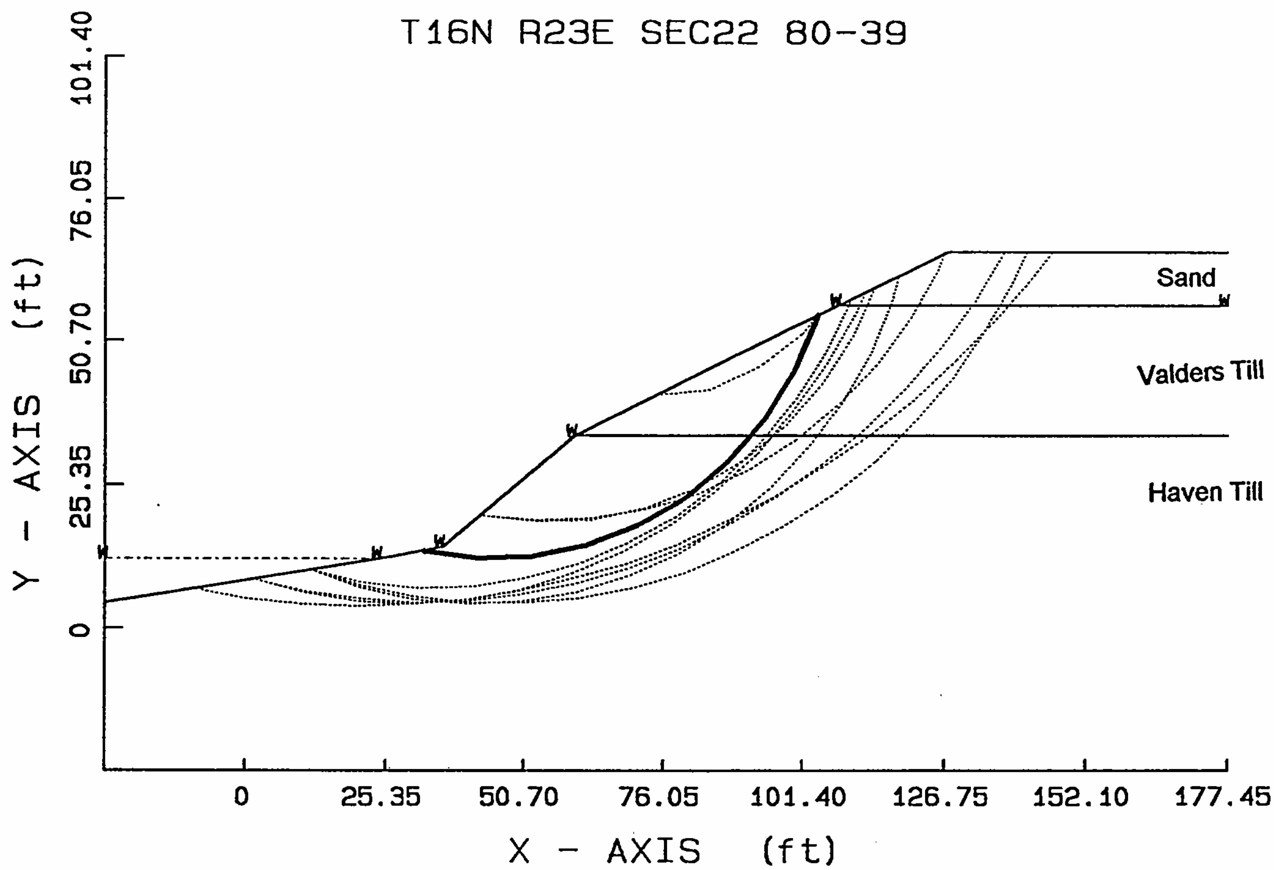


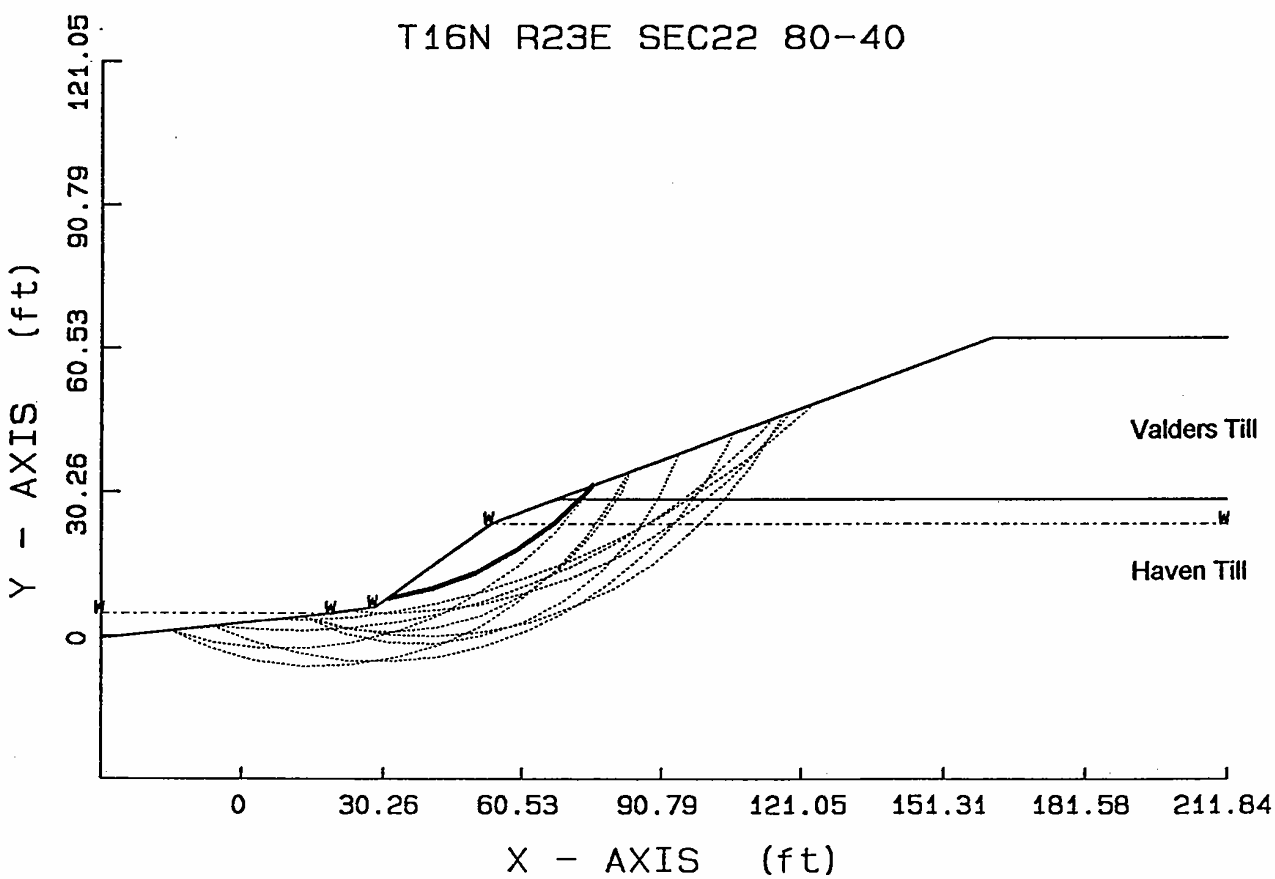
:ce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



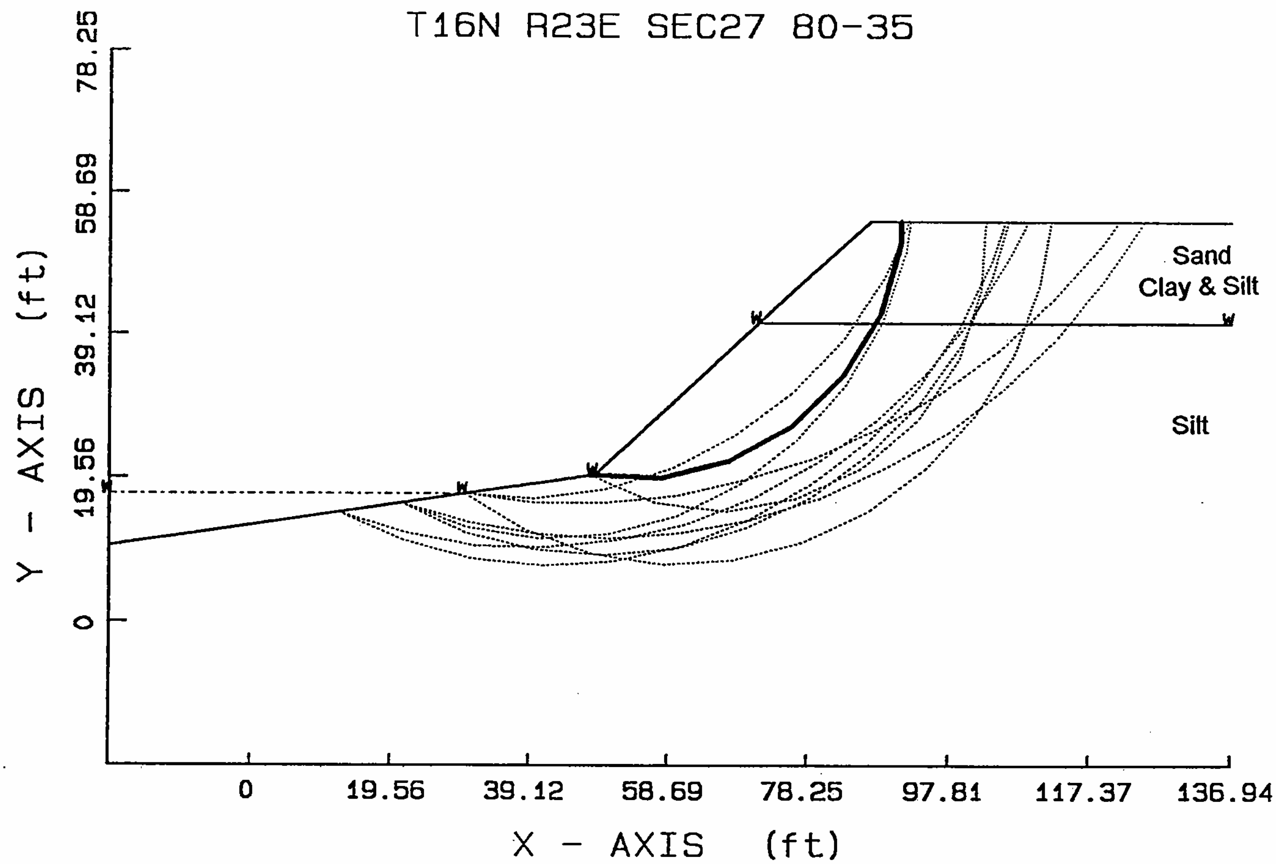


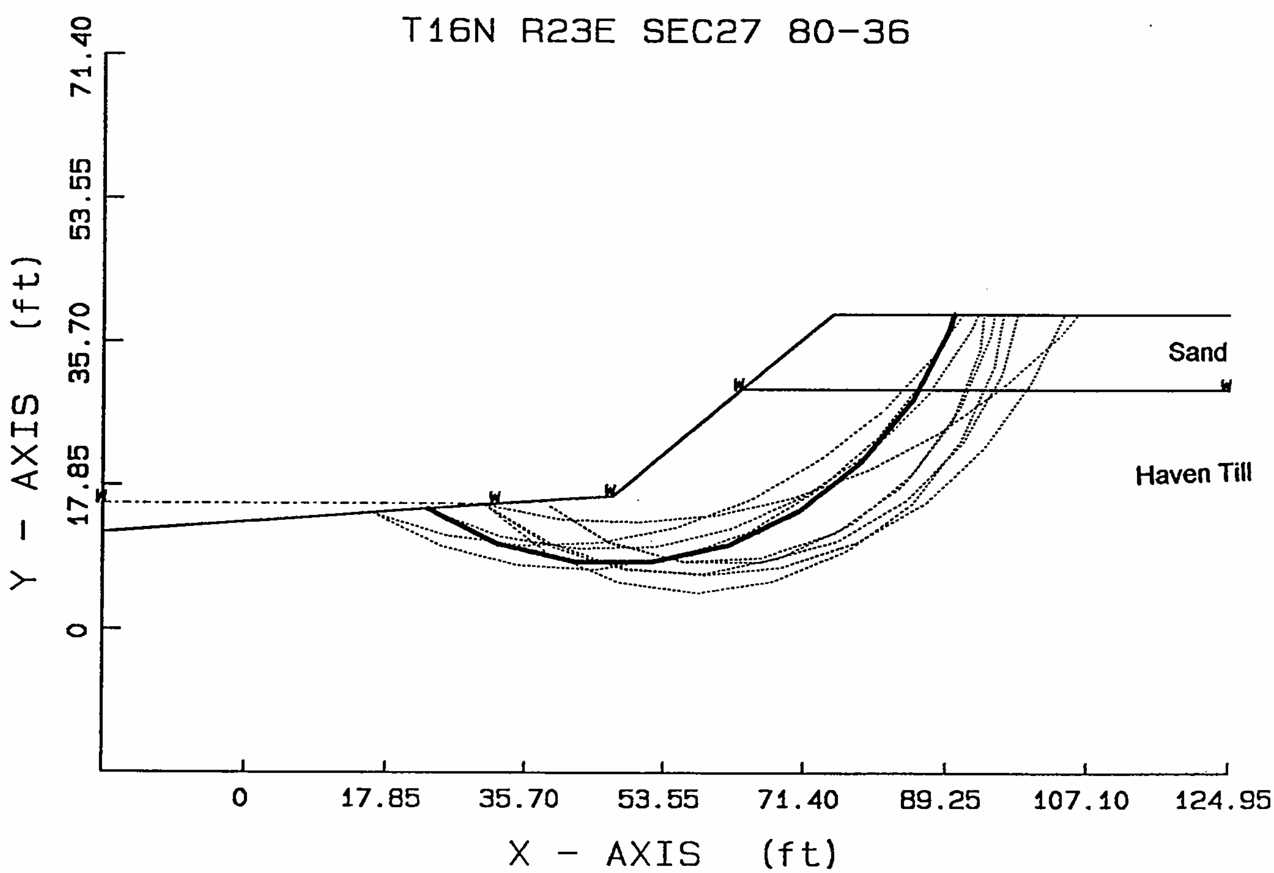
›urce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



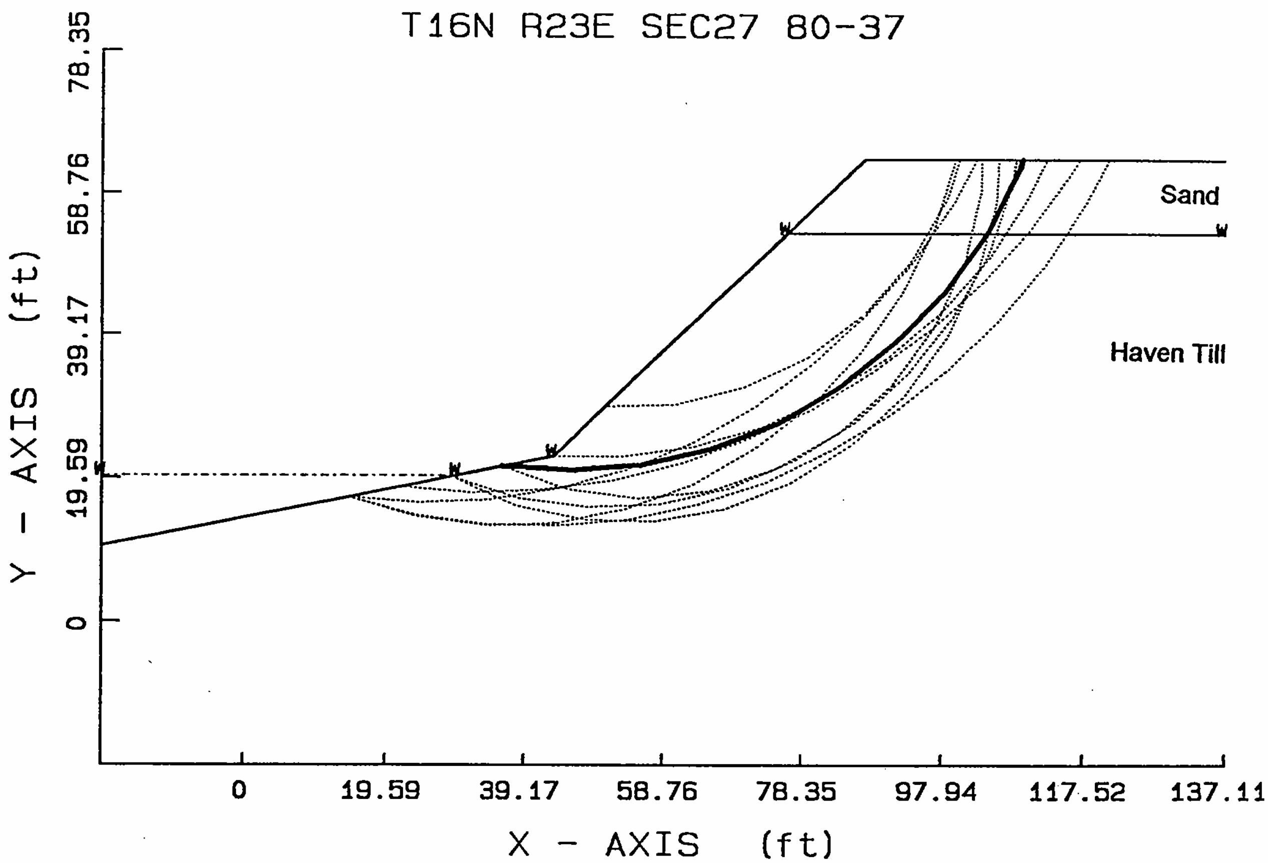


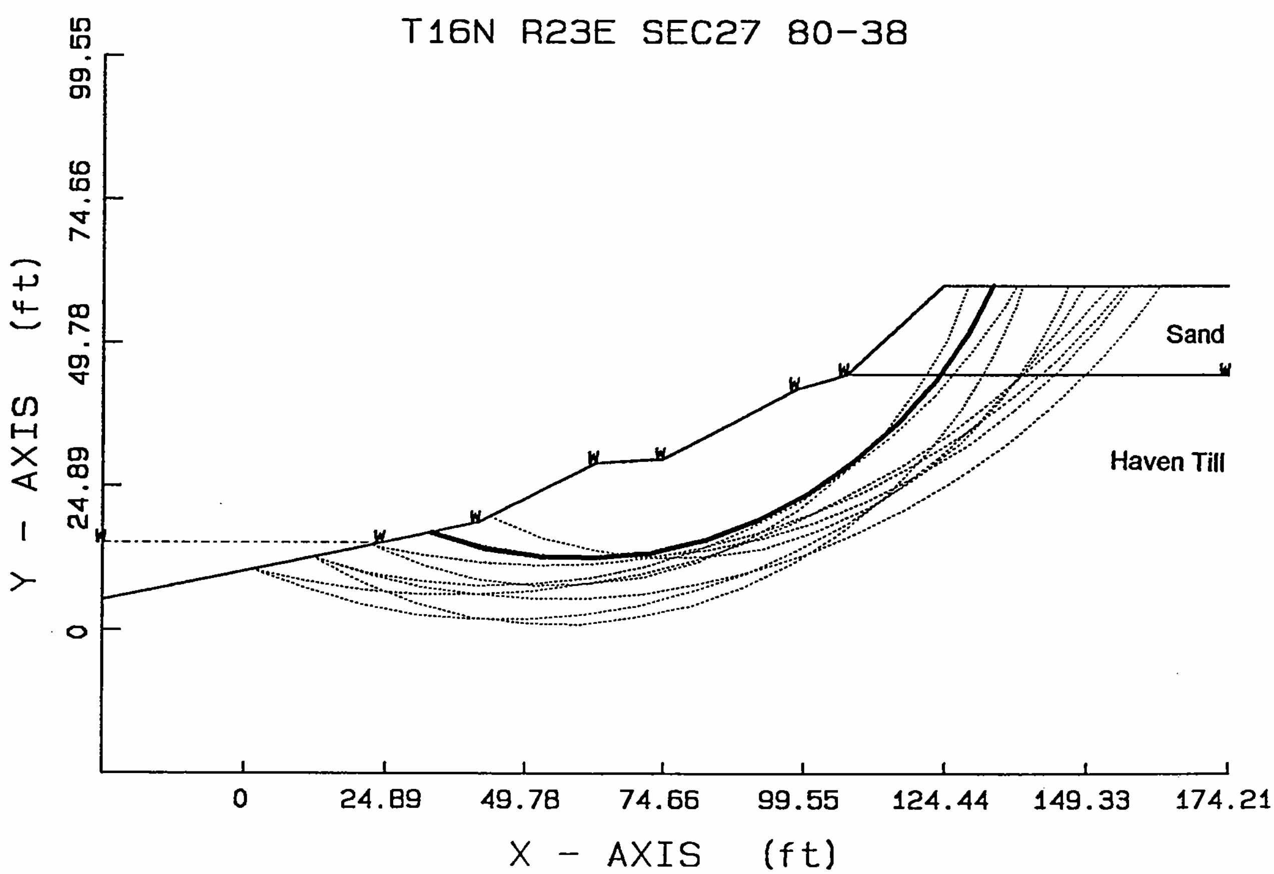
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



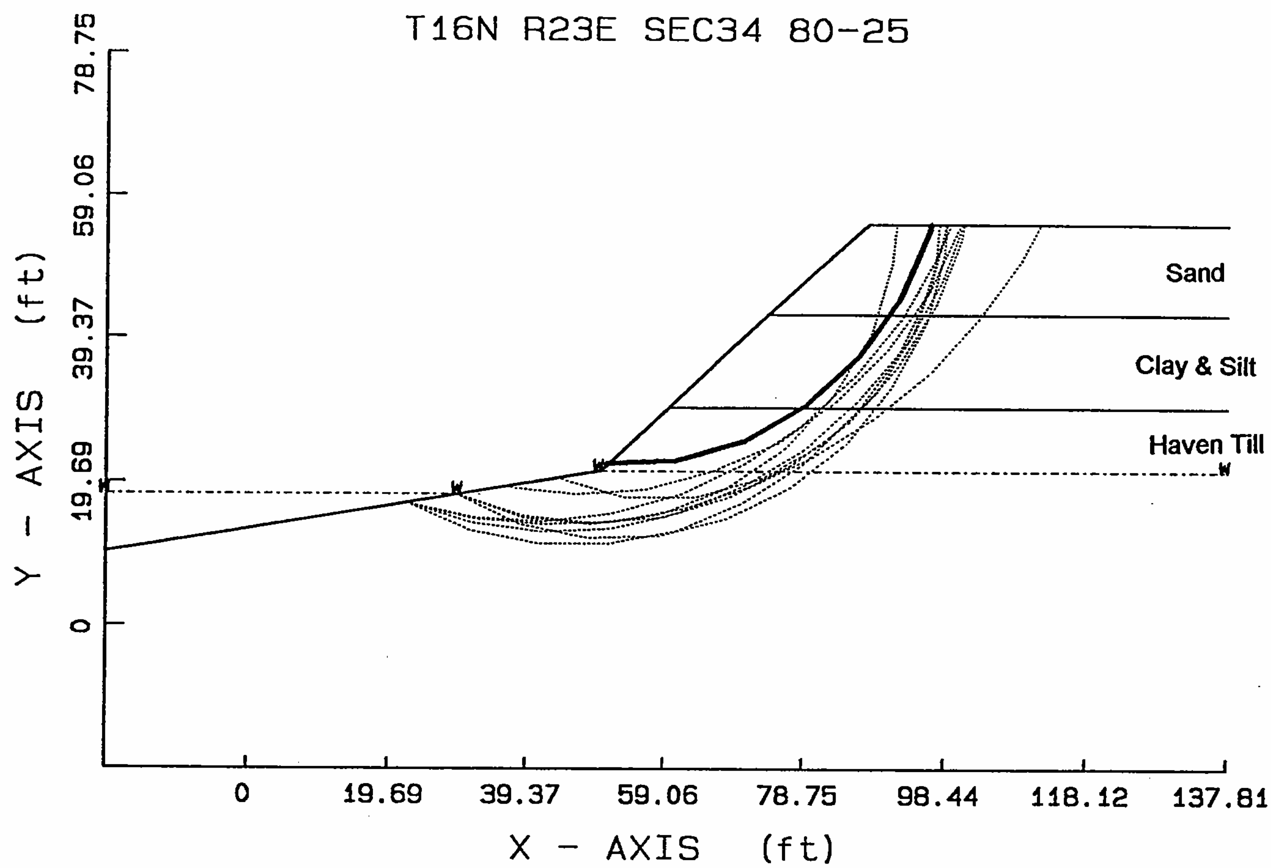


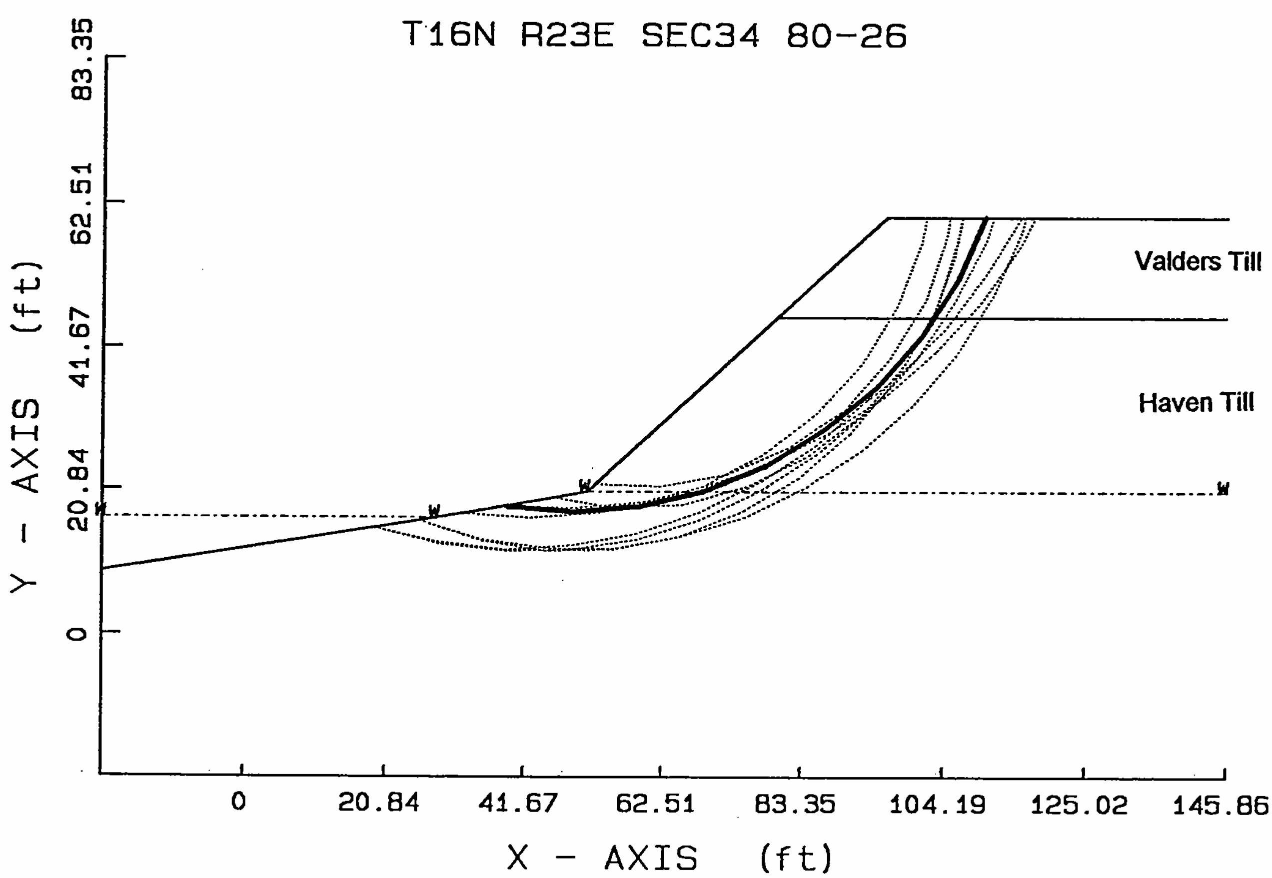
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



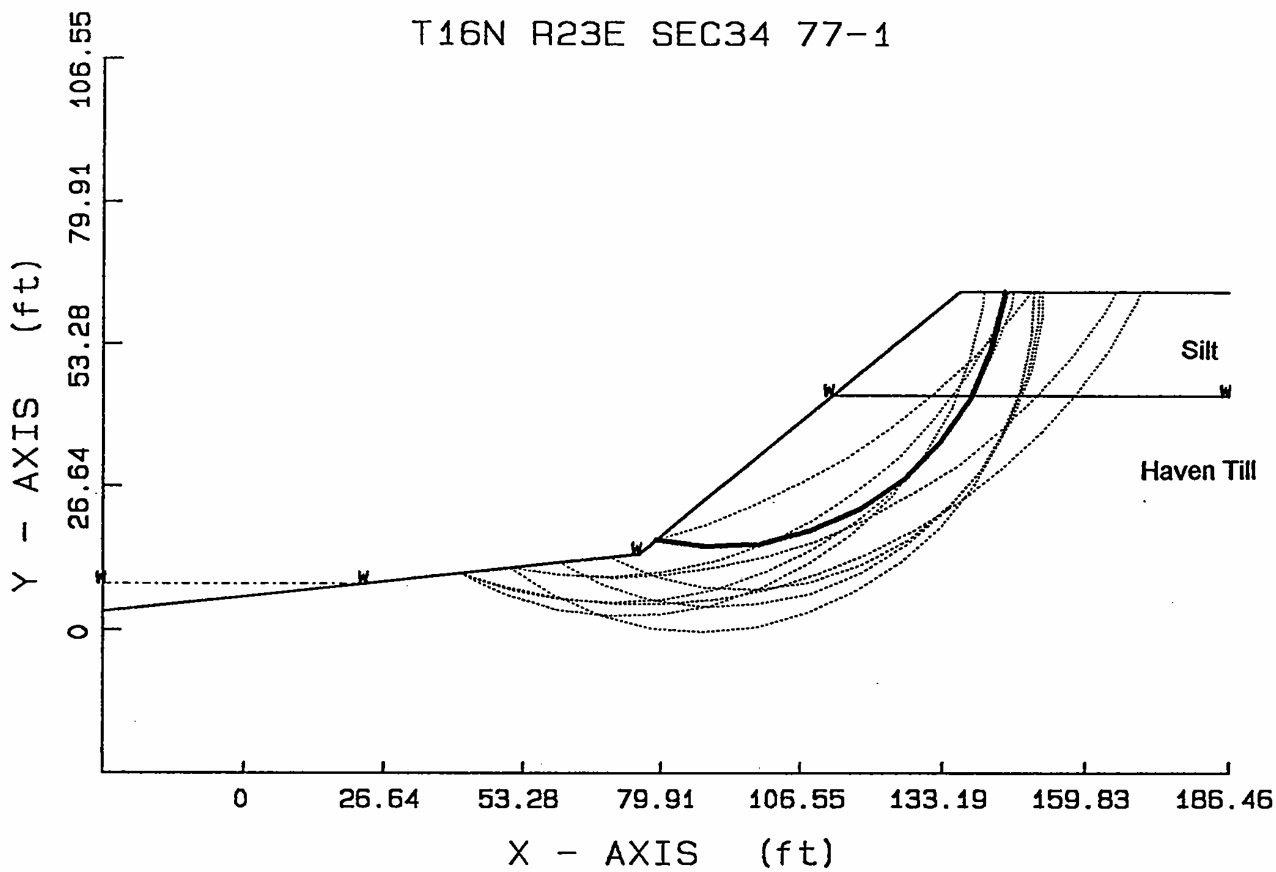


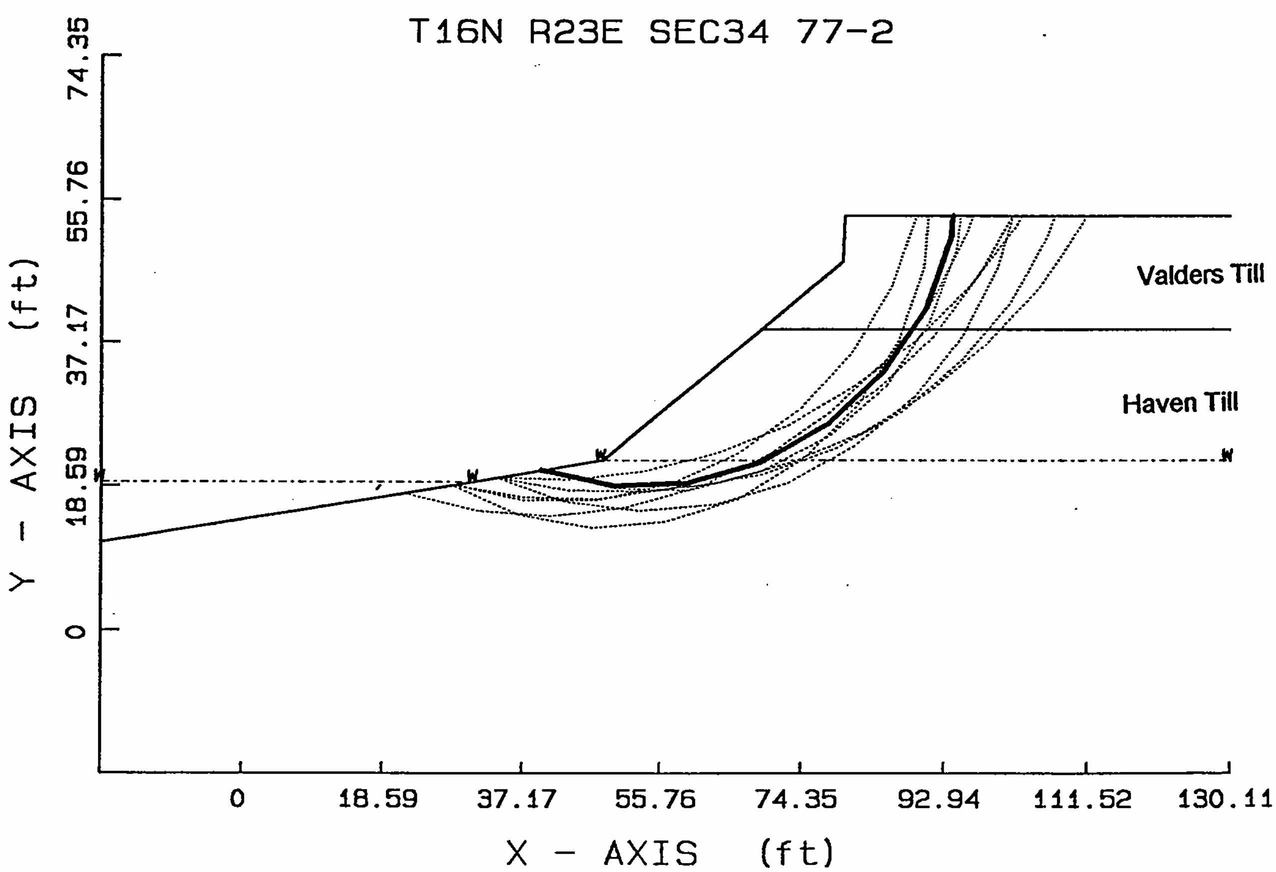
rce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



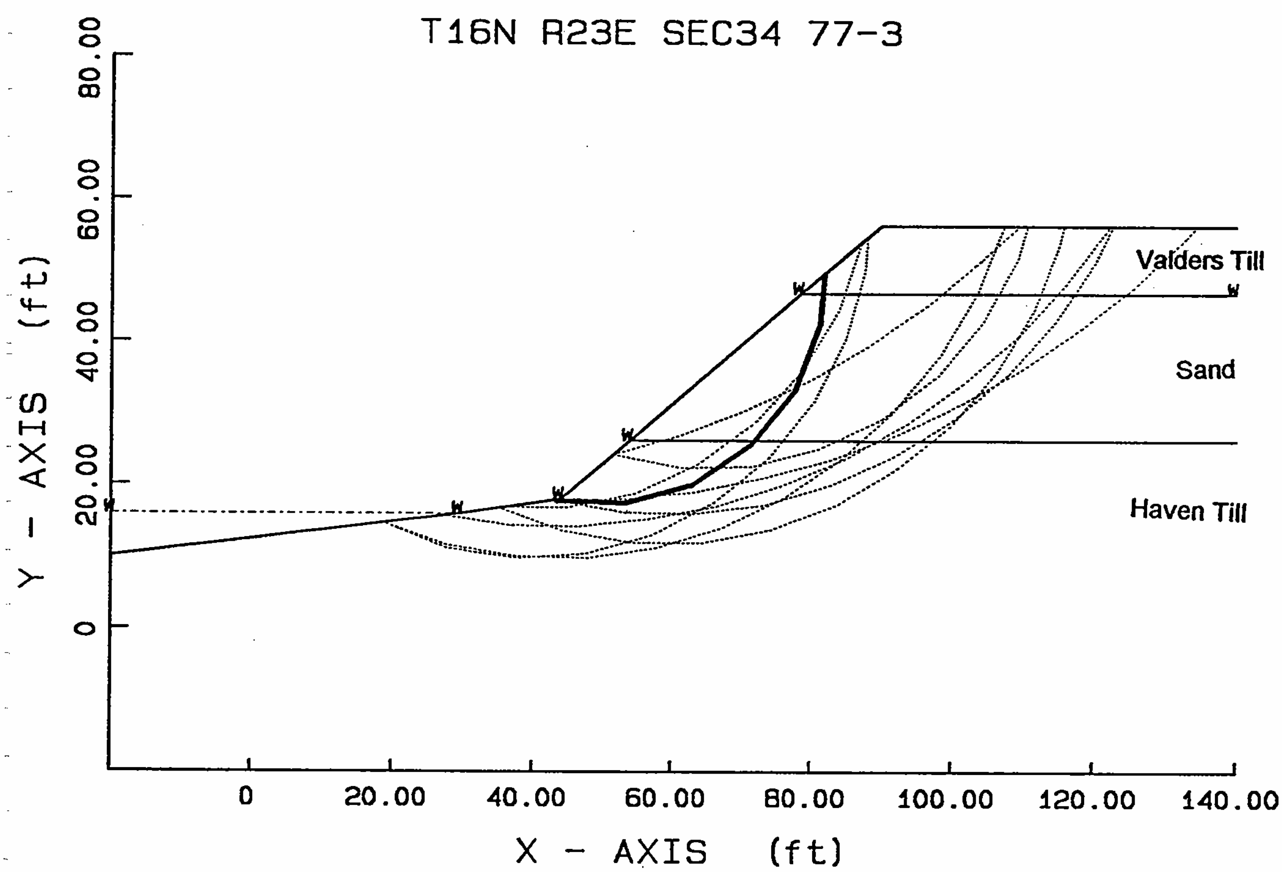


Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

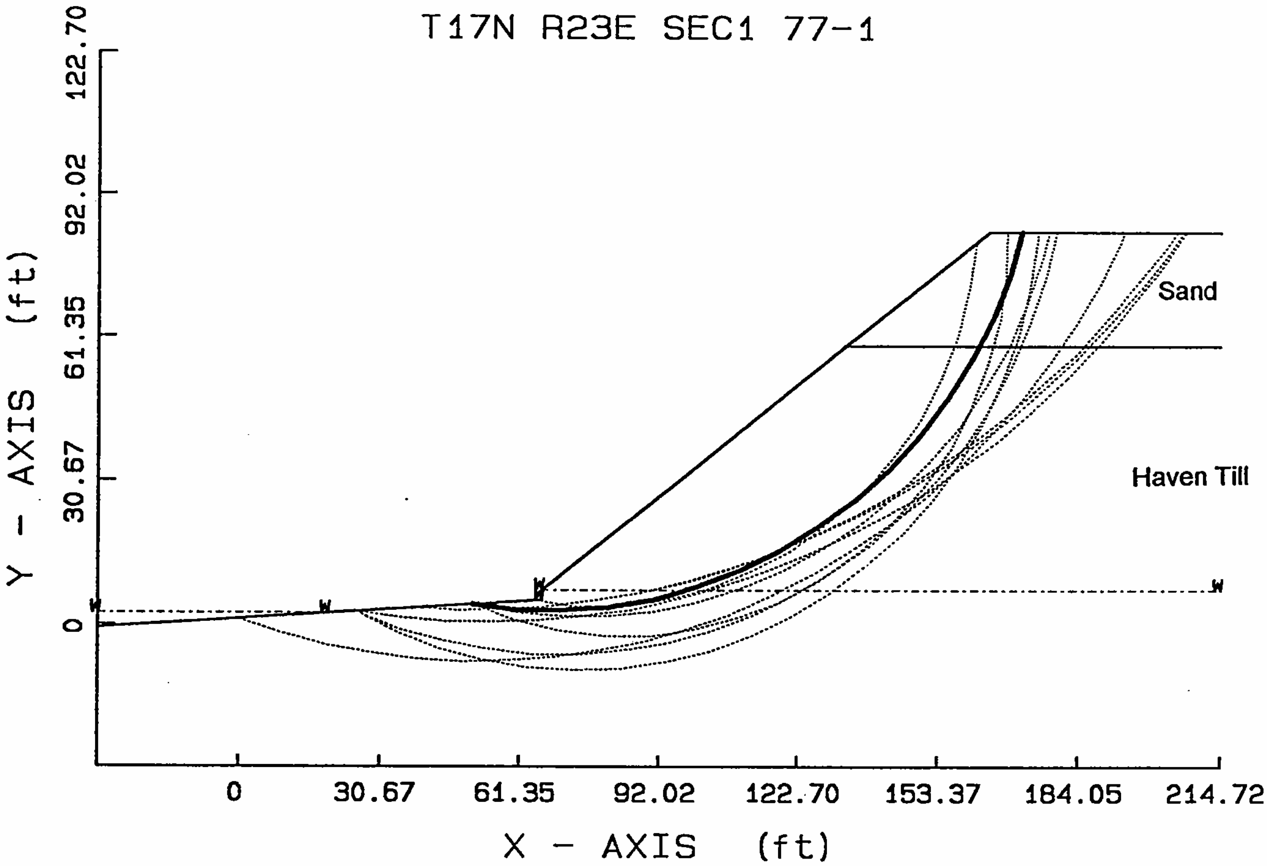


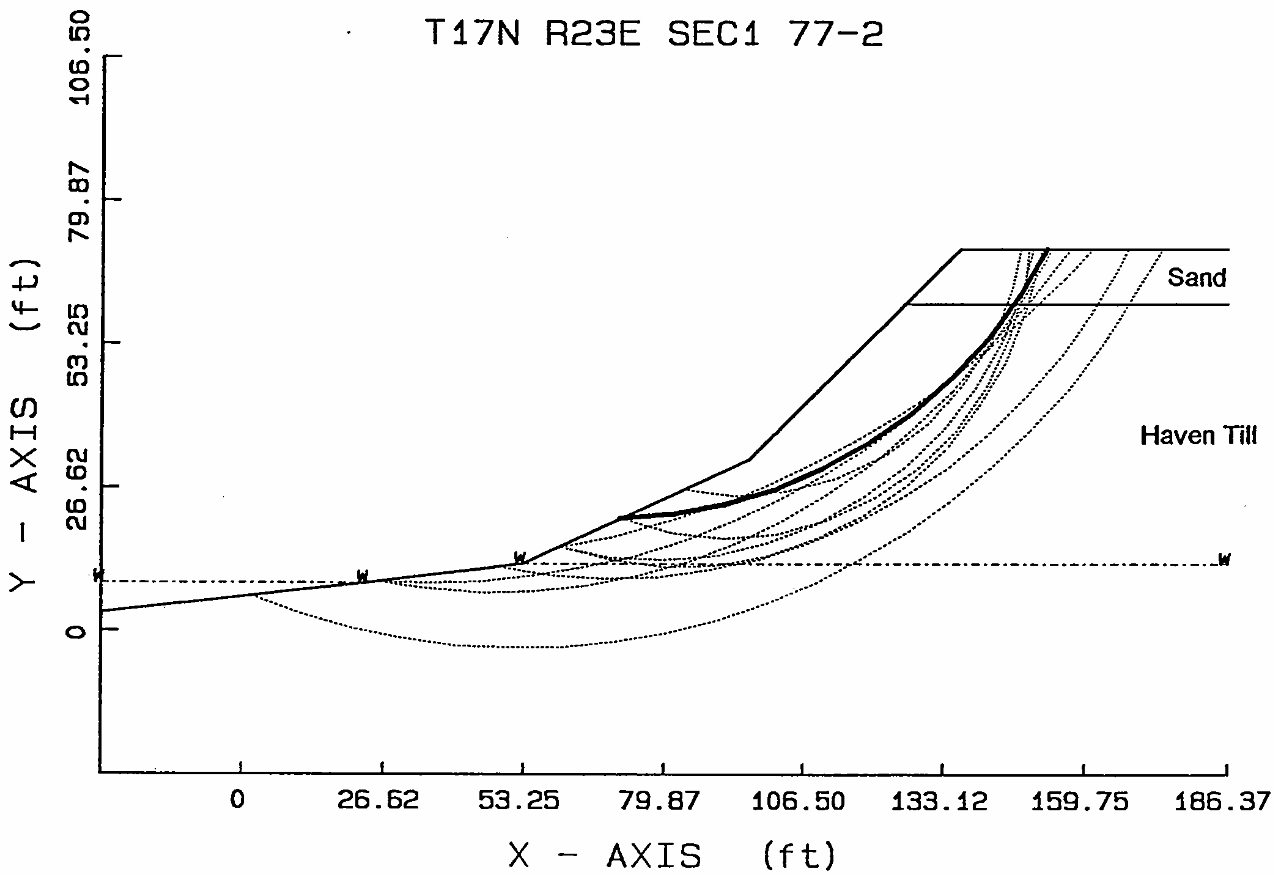


urce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

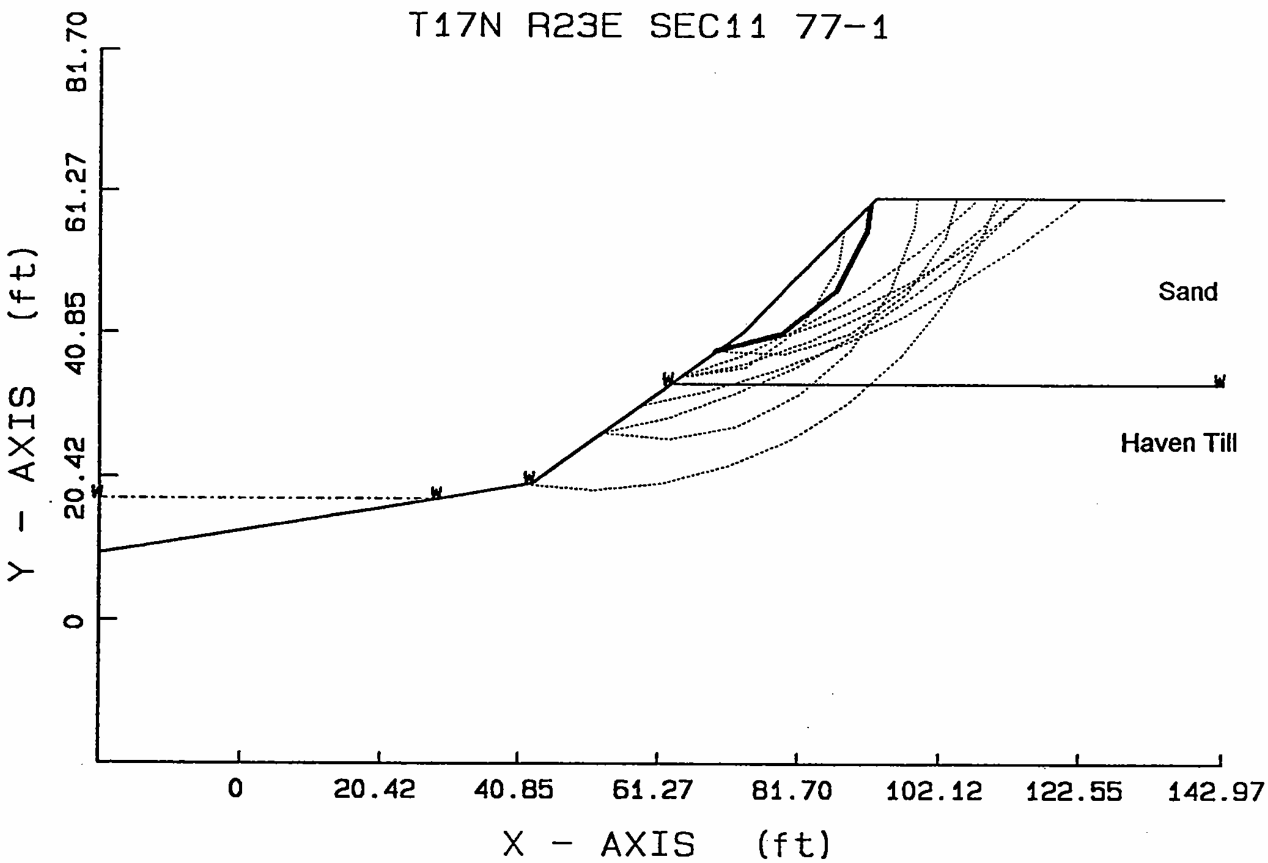


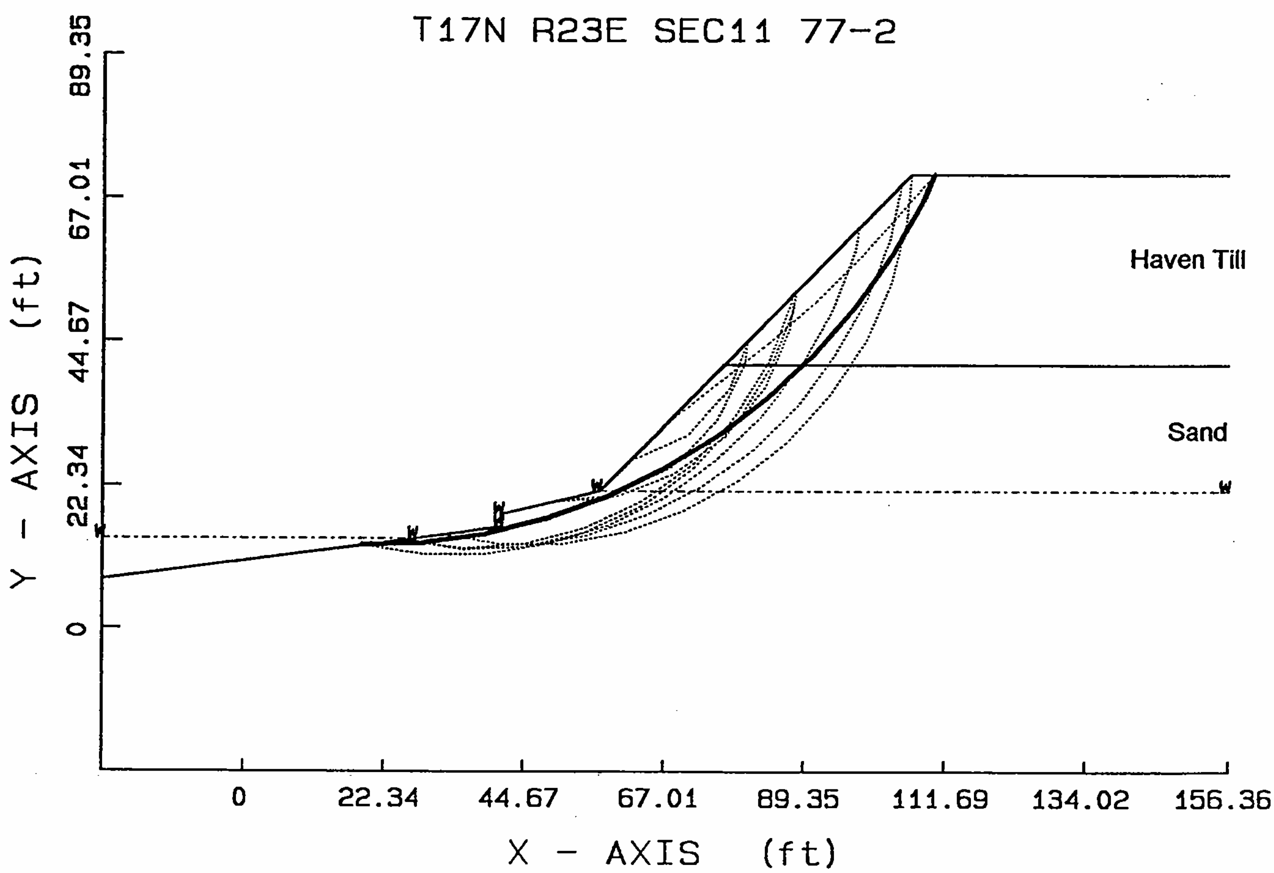
ource: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



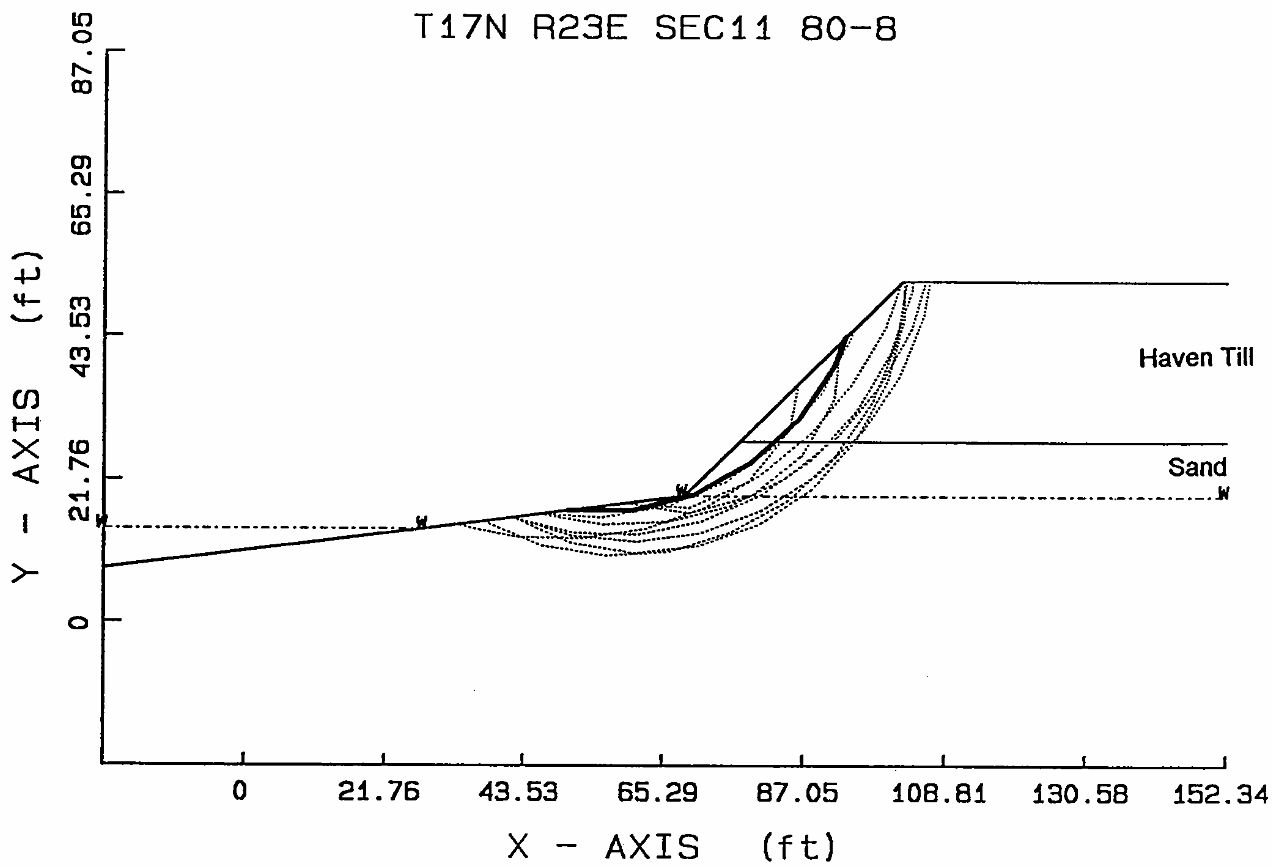


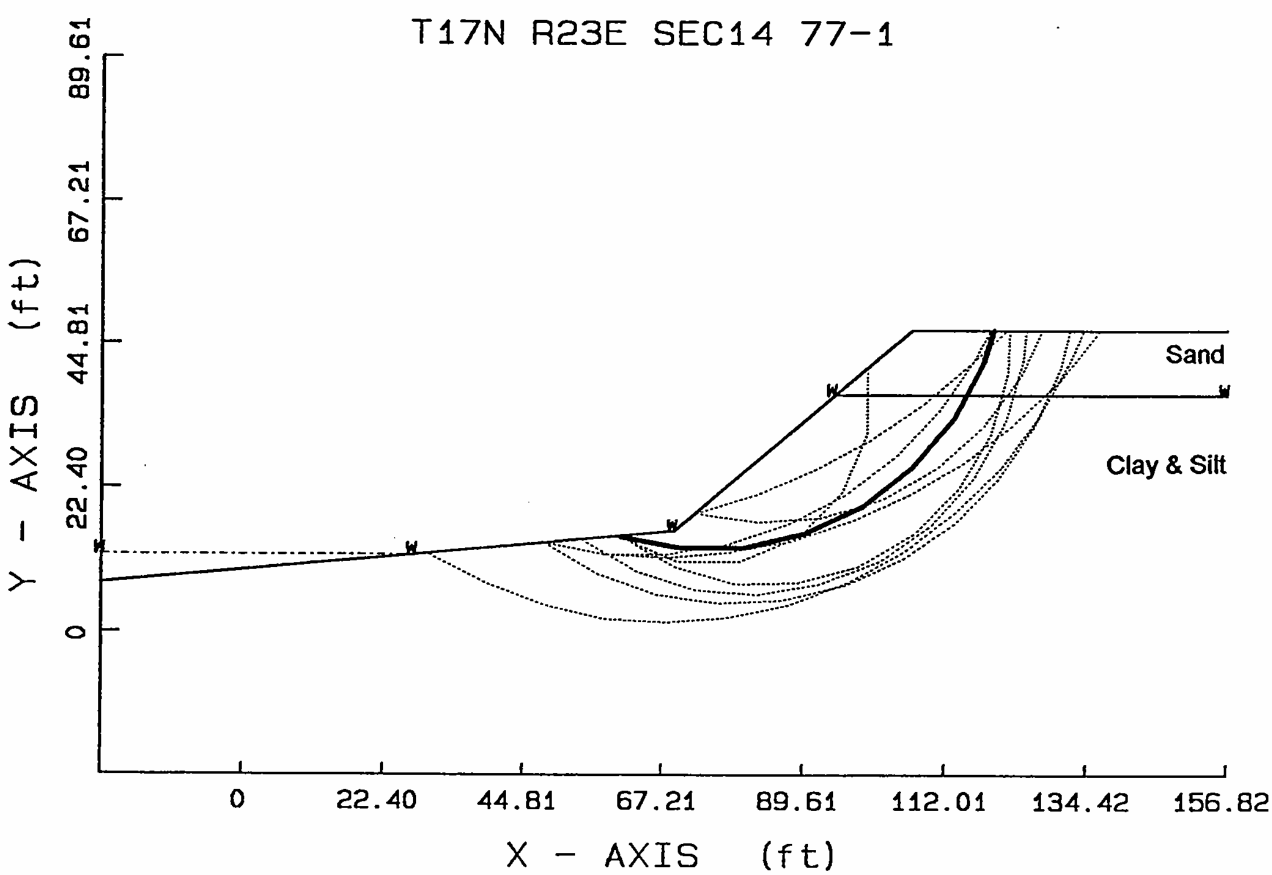
ɔurce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



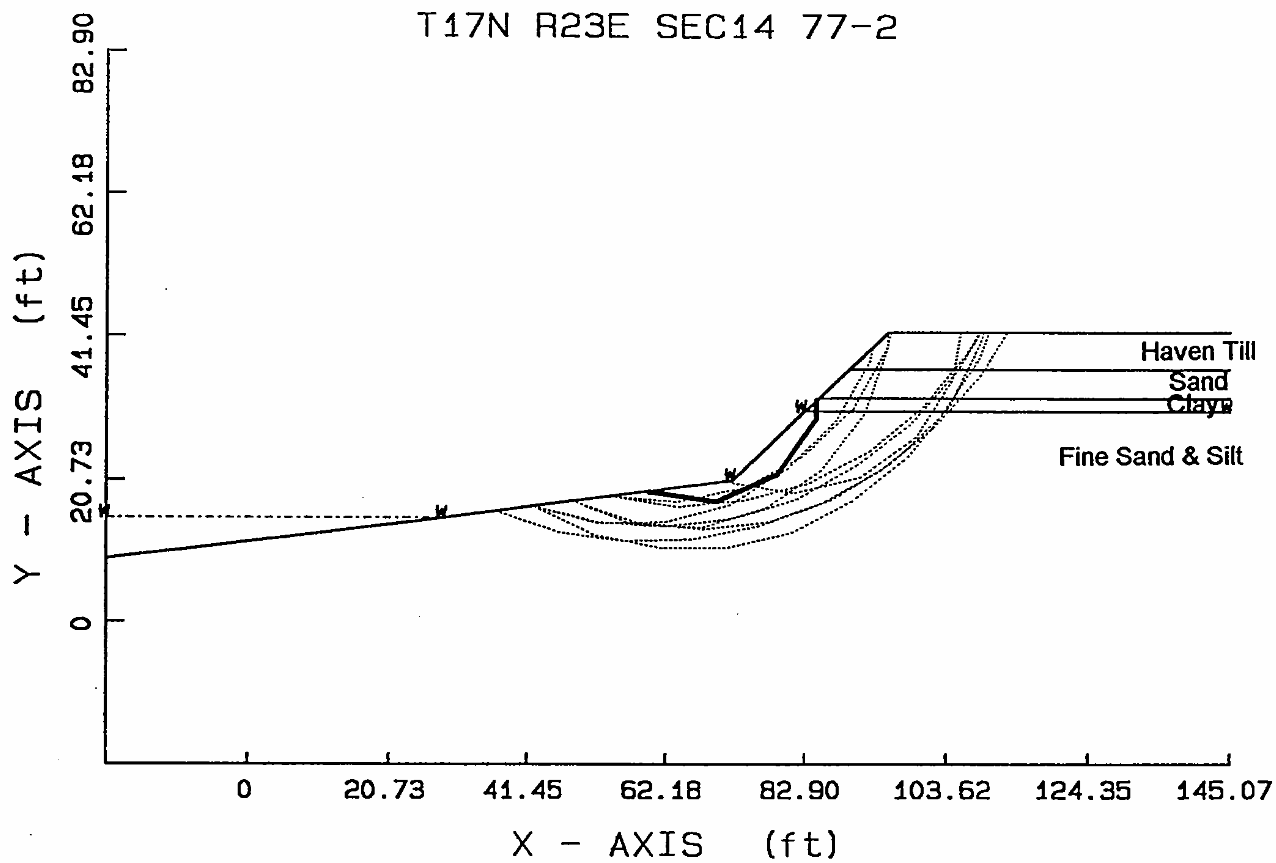


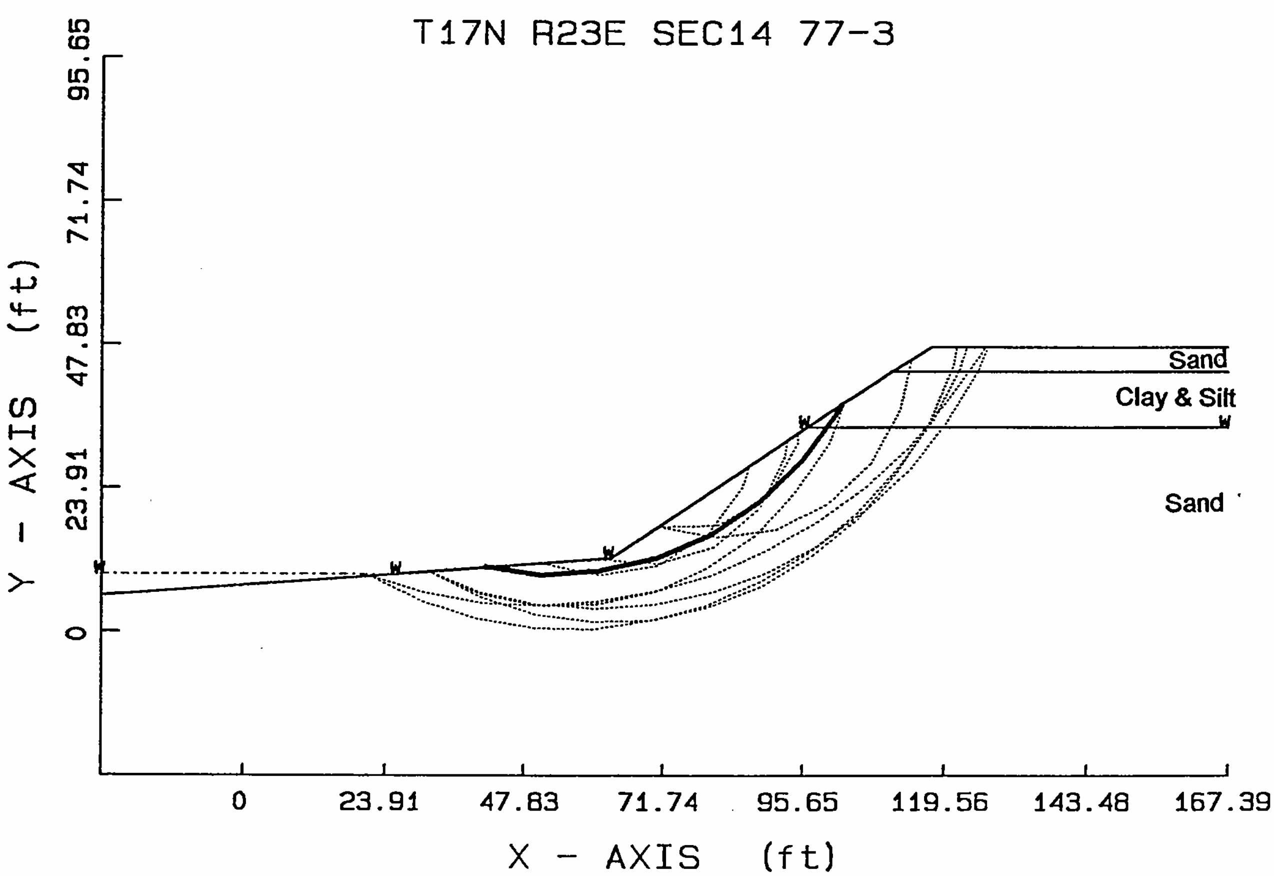
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



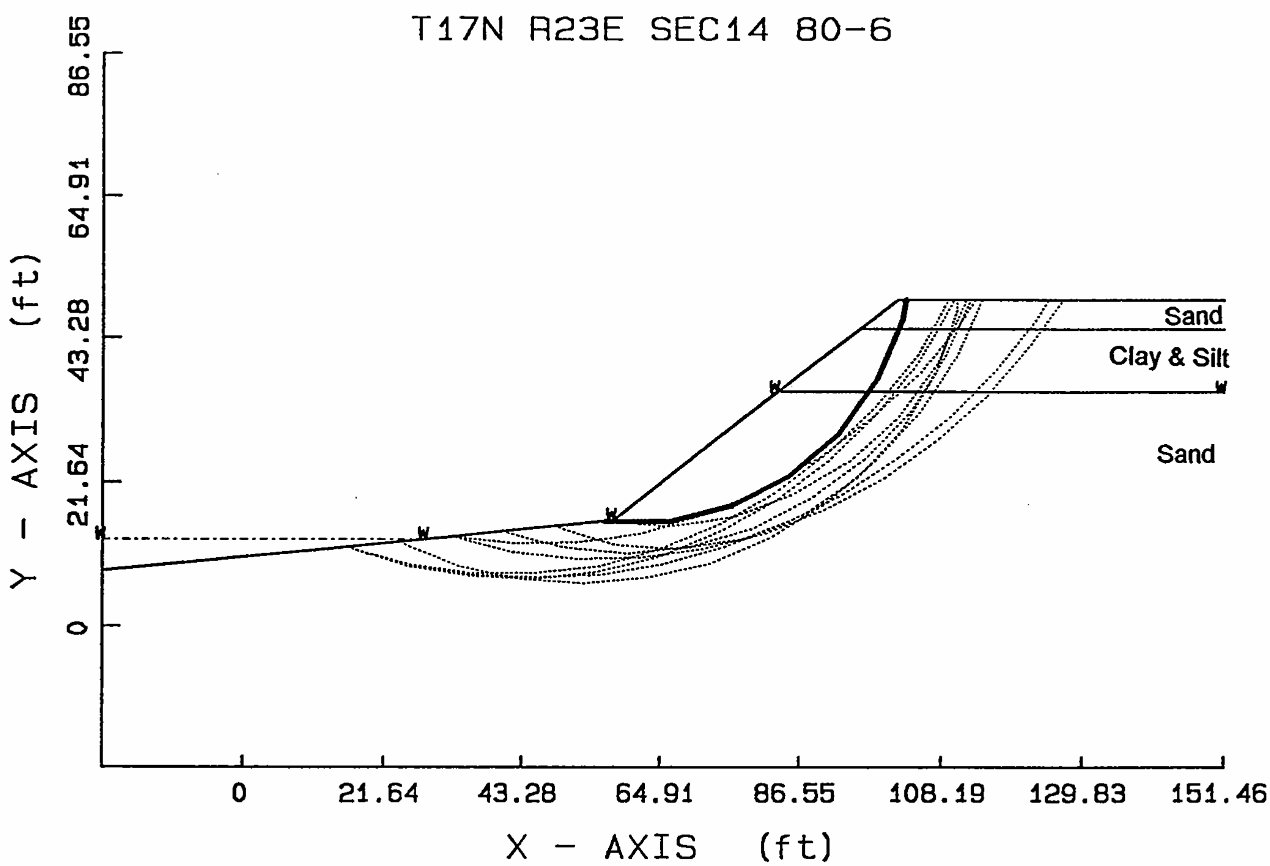


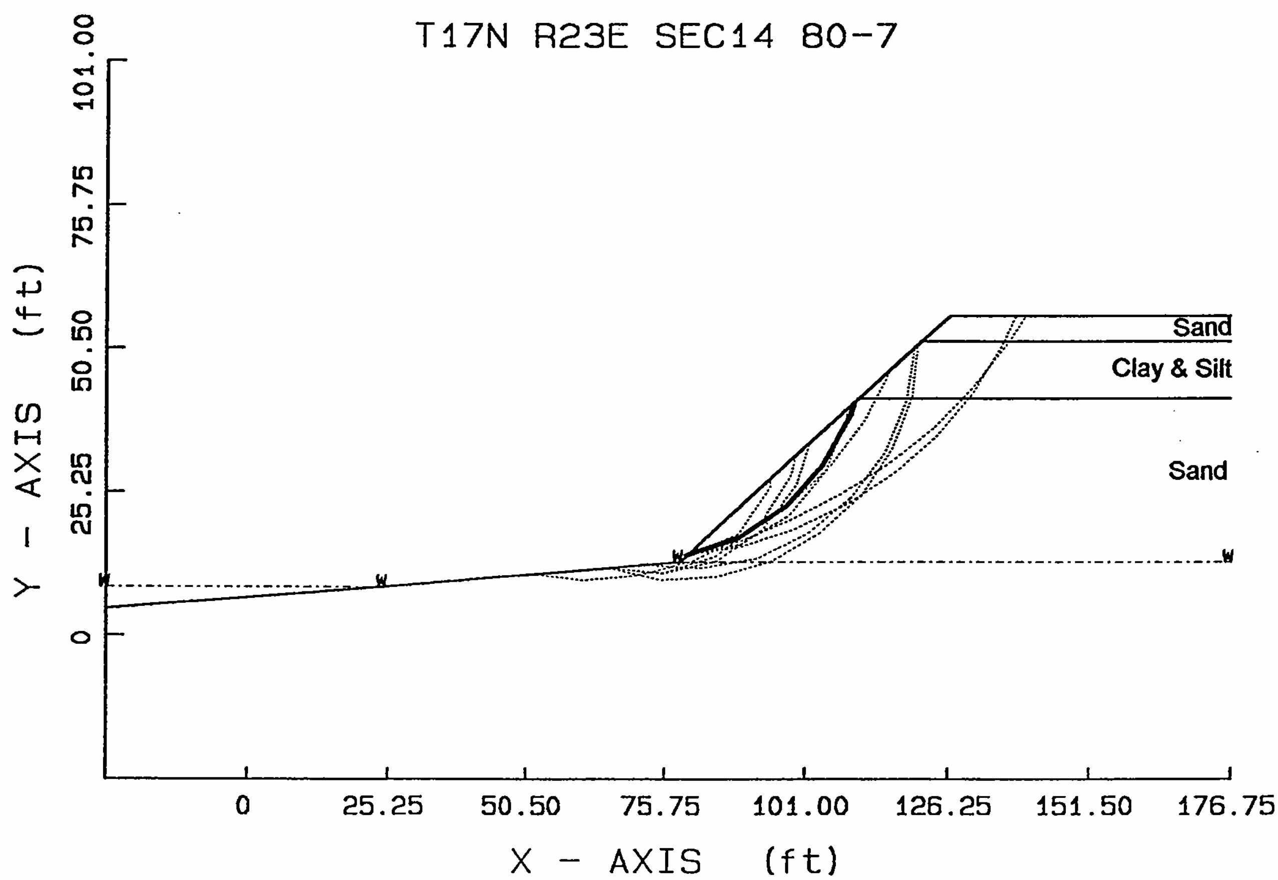
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



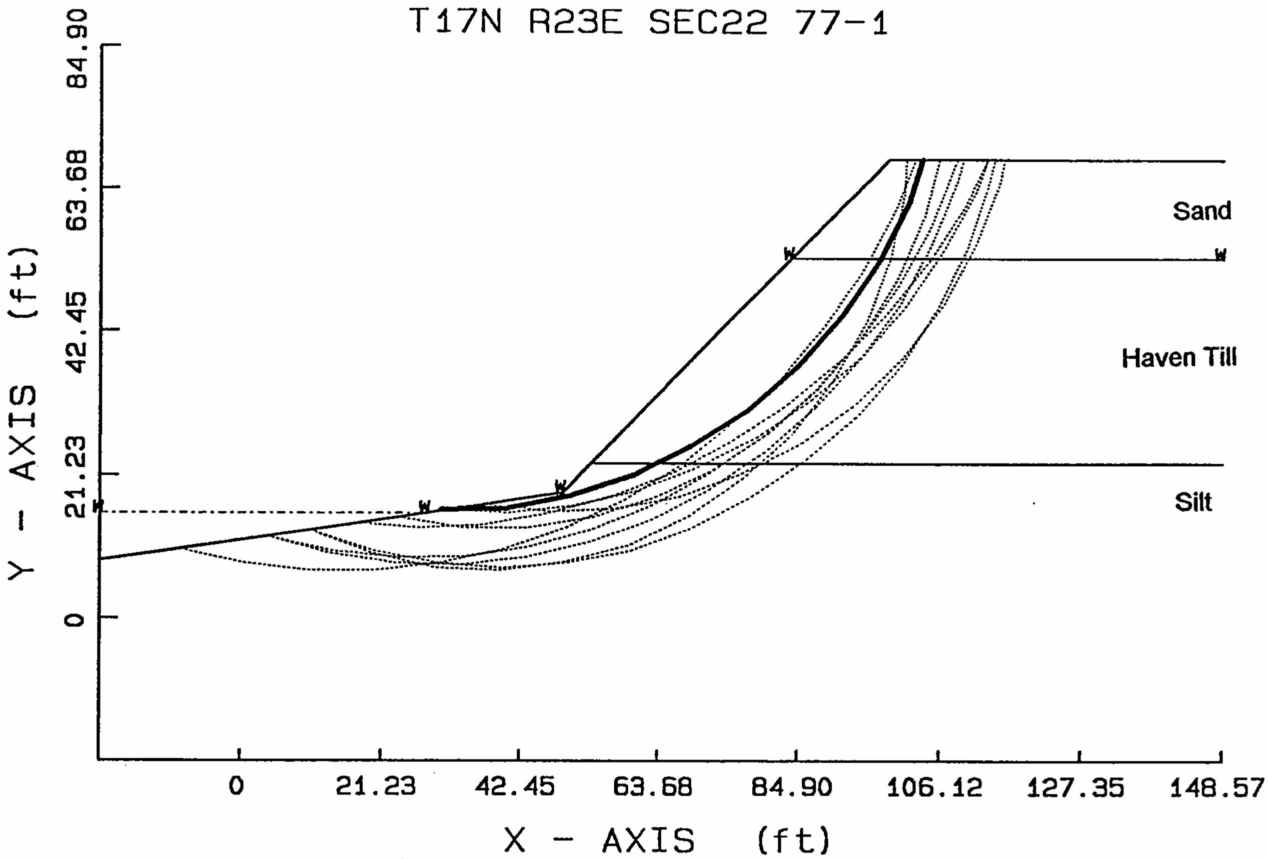


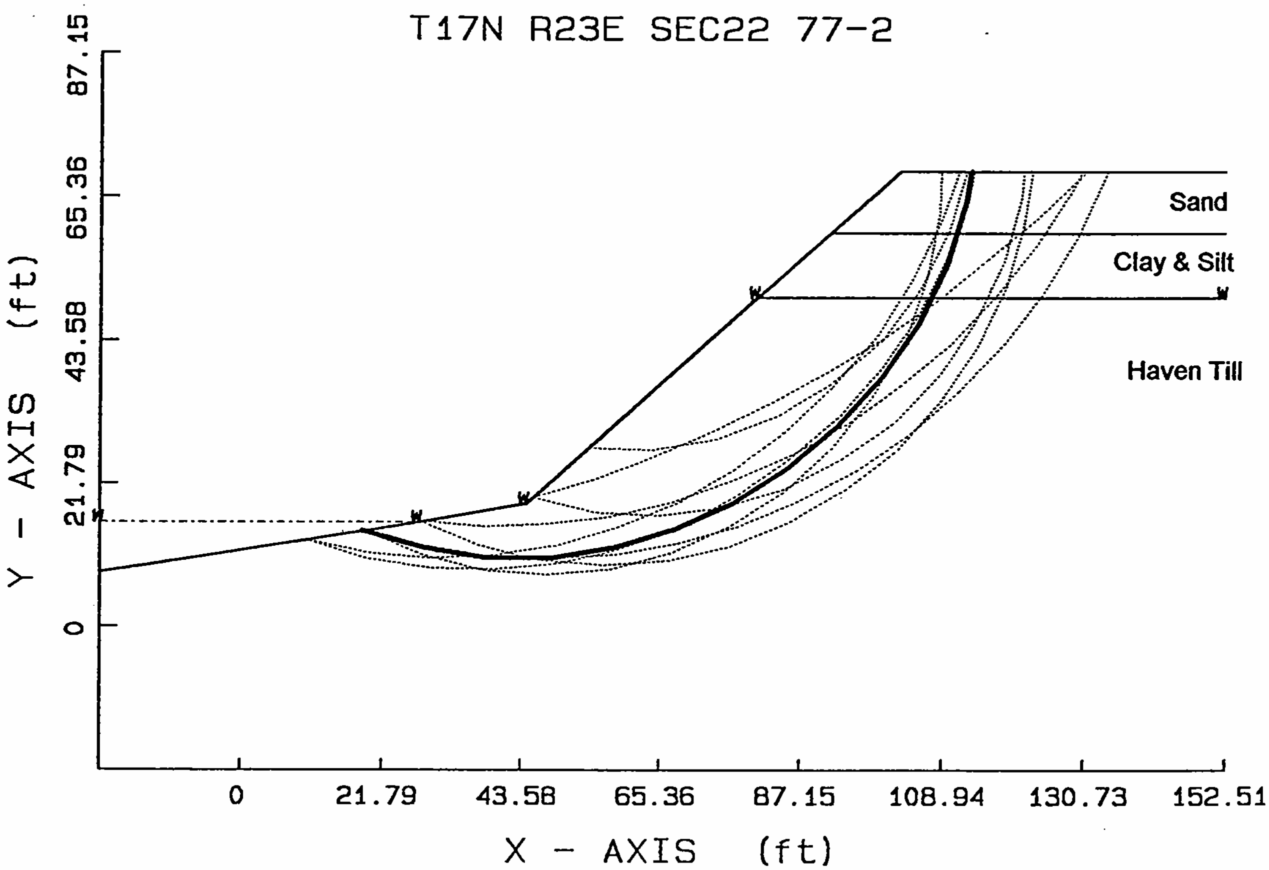
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



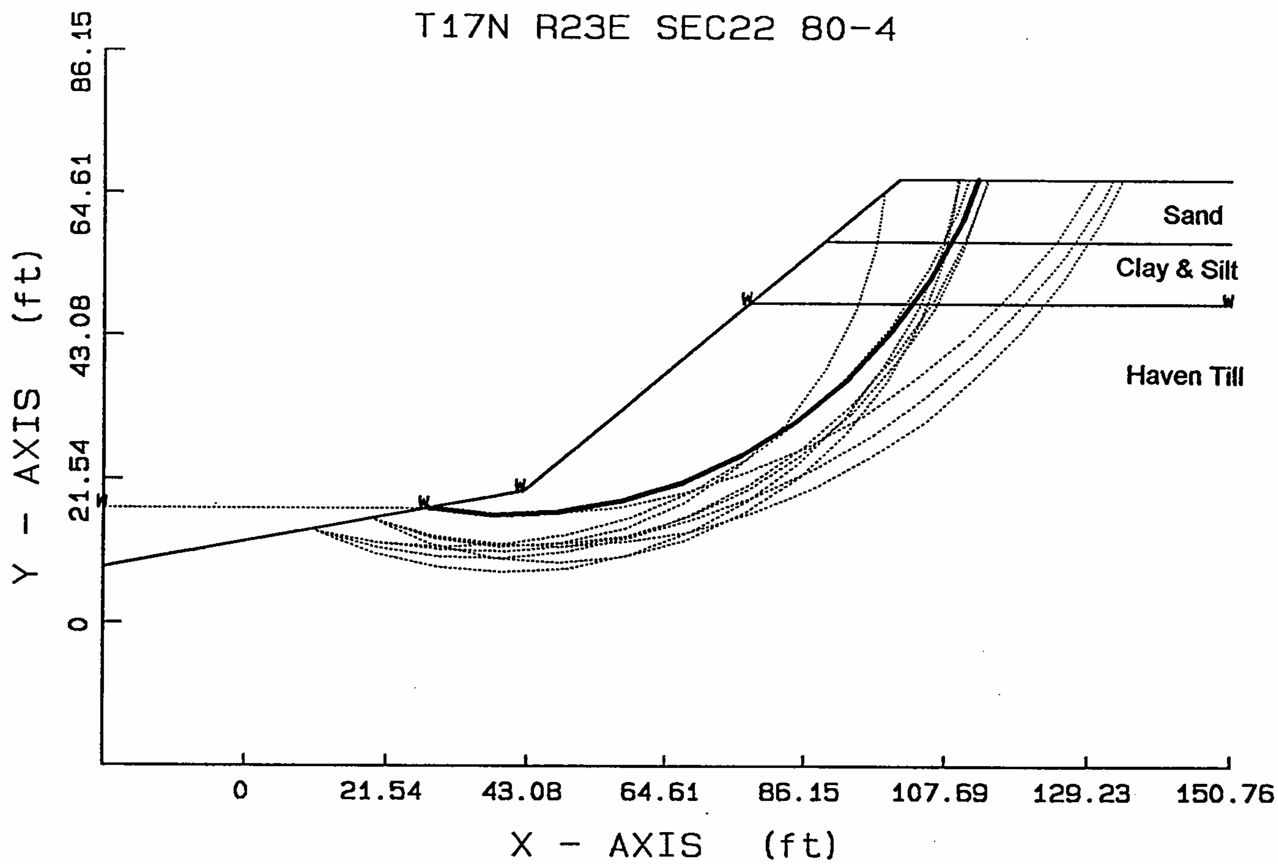


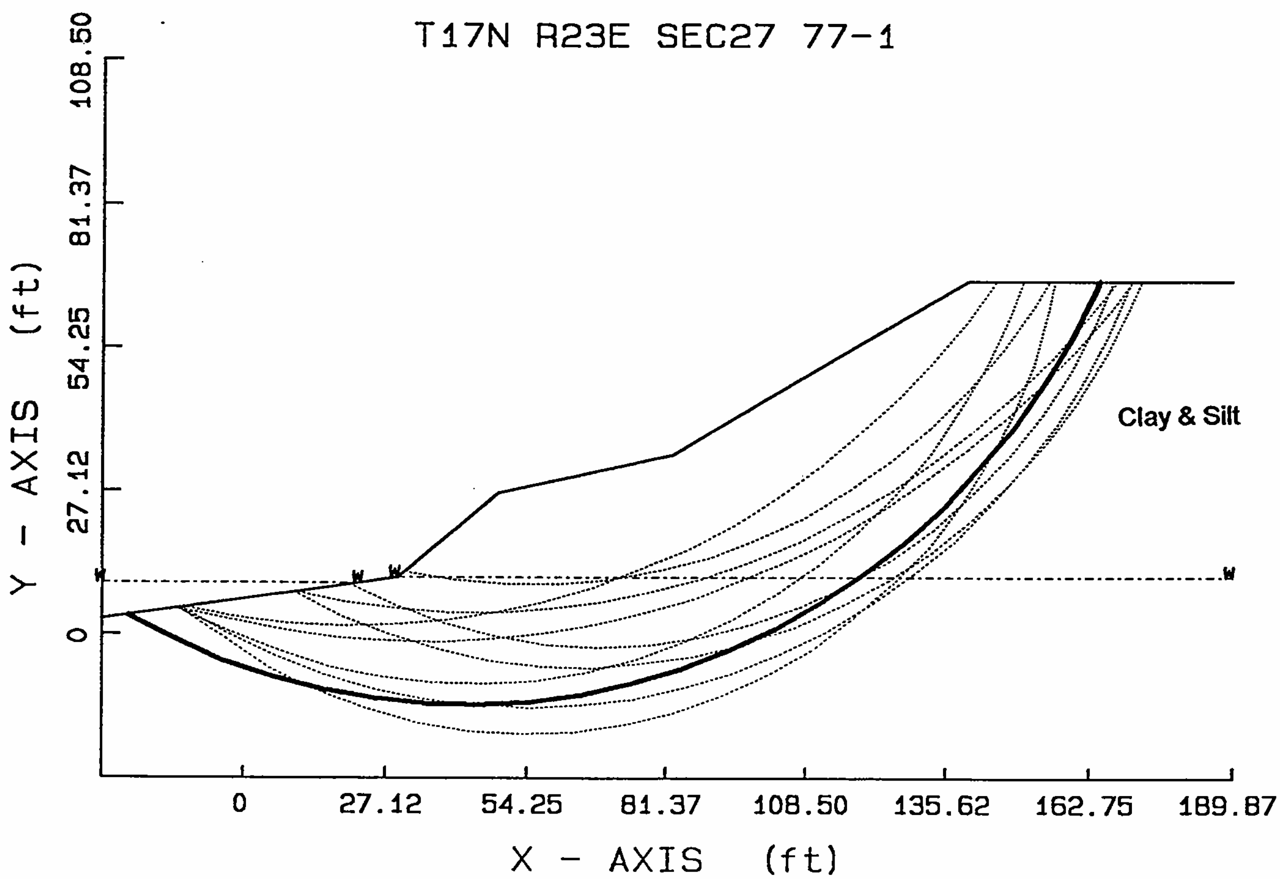
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



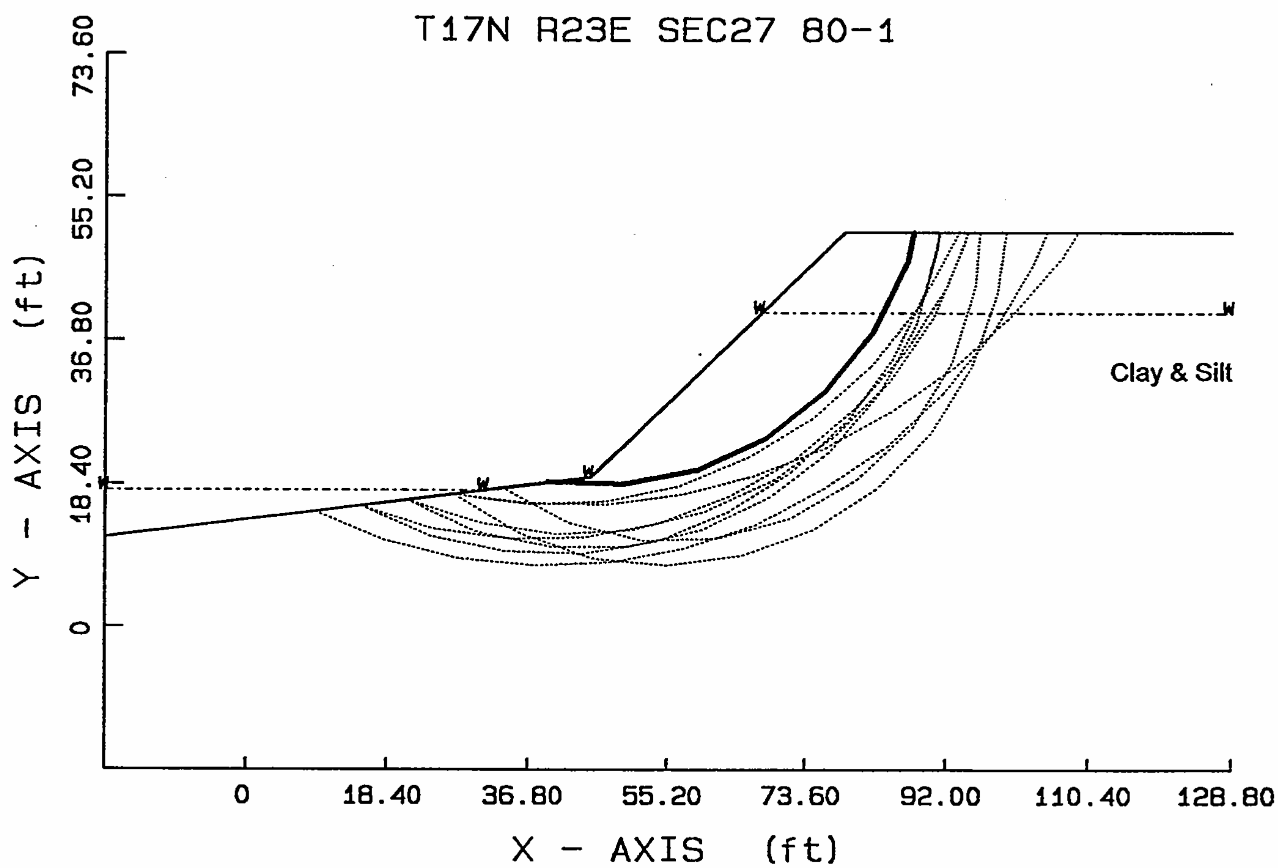


Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

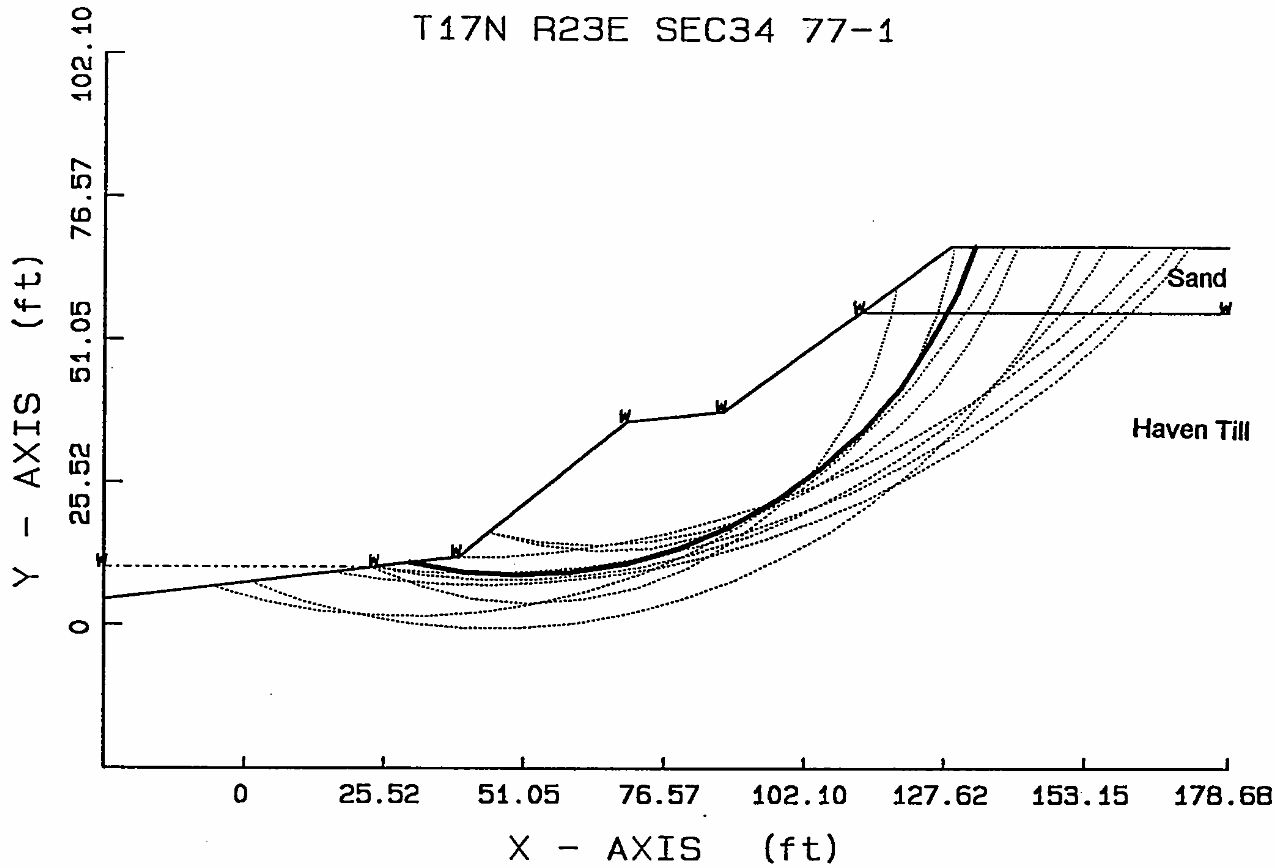


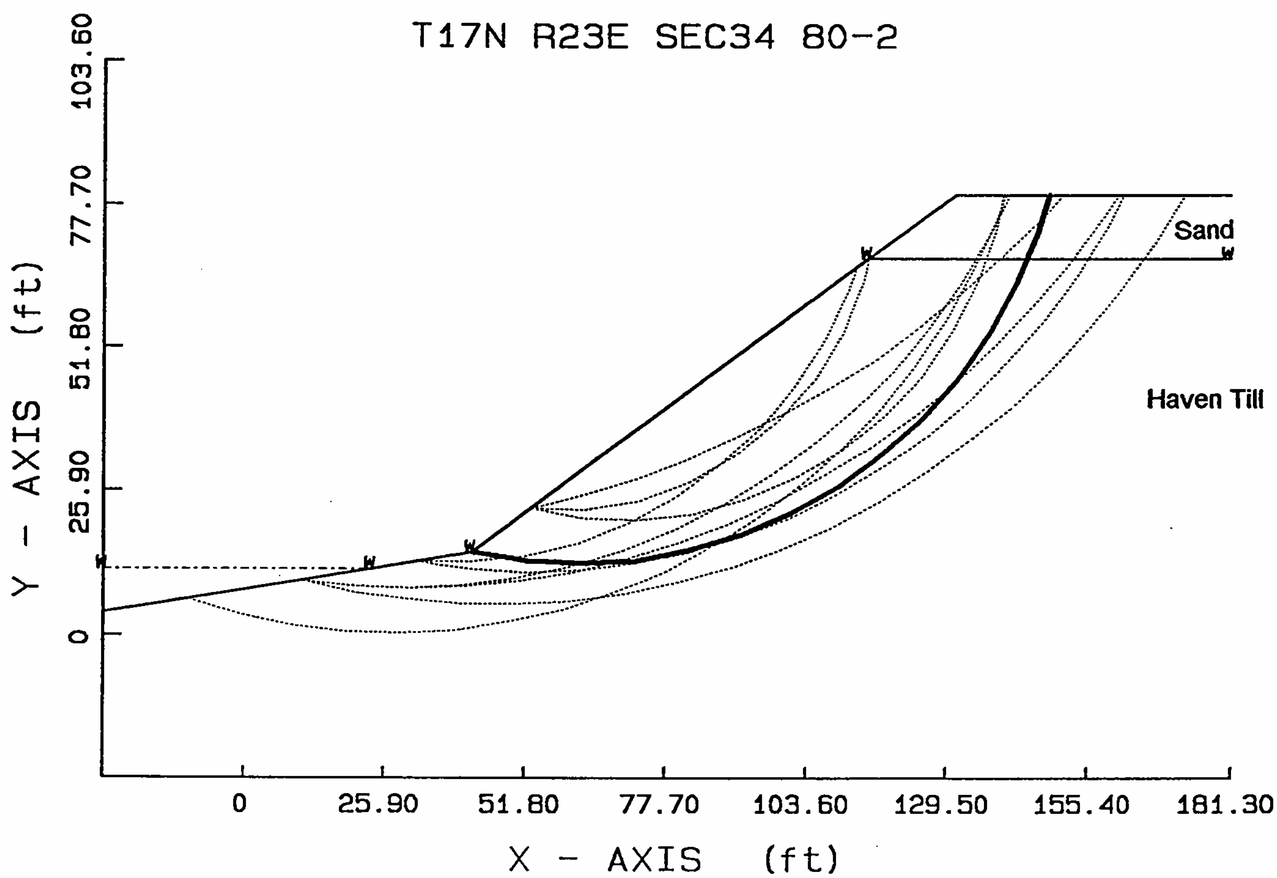


Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

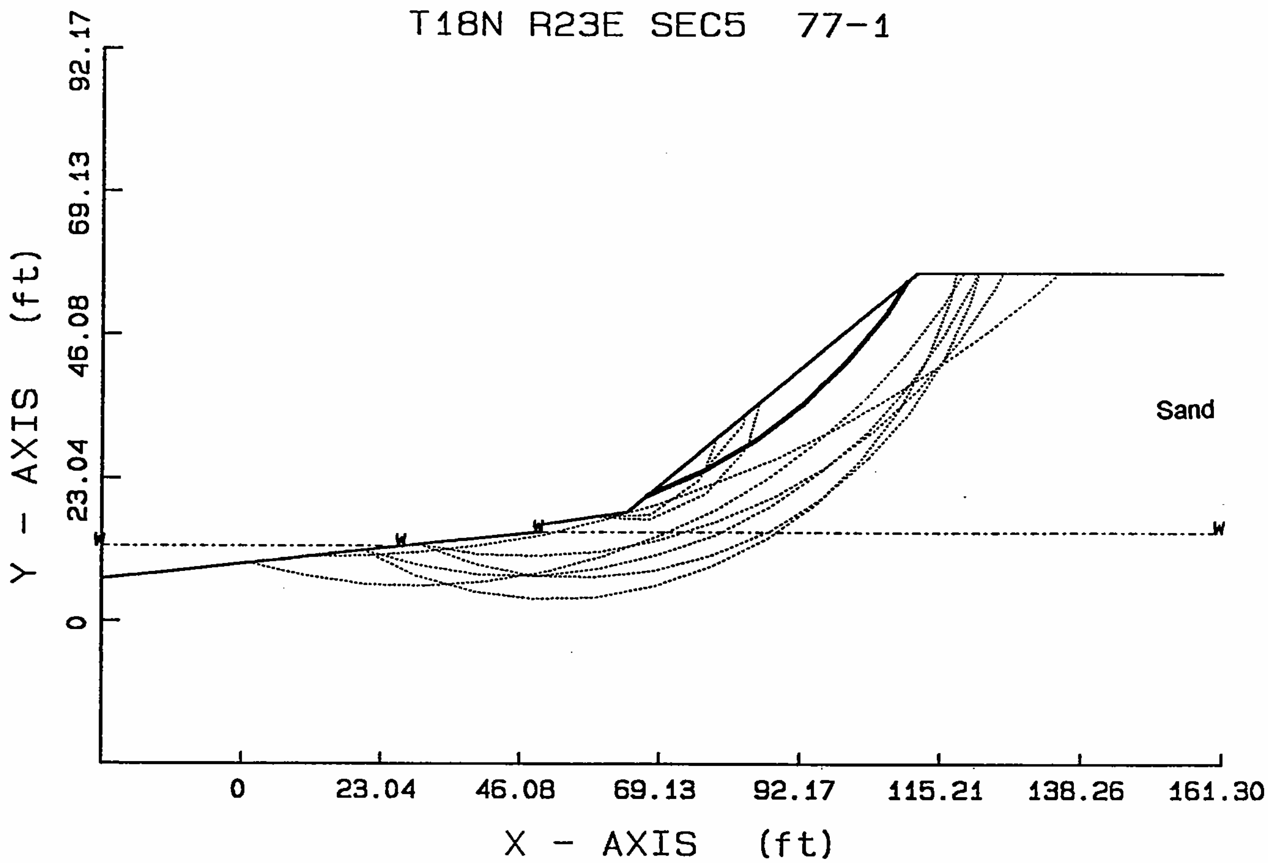


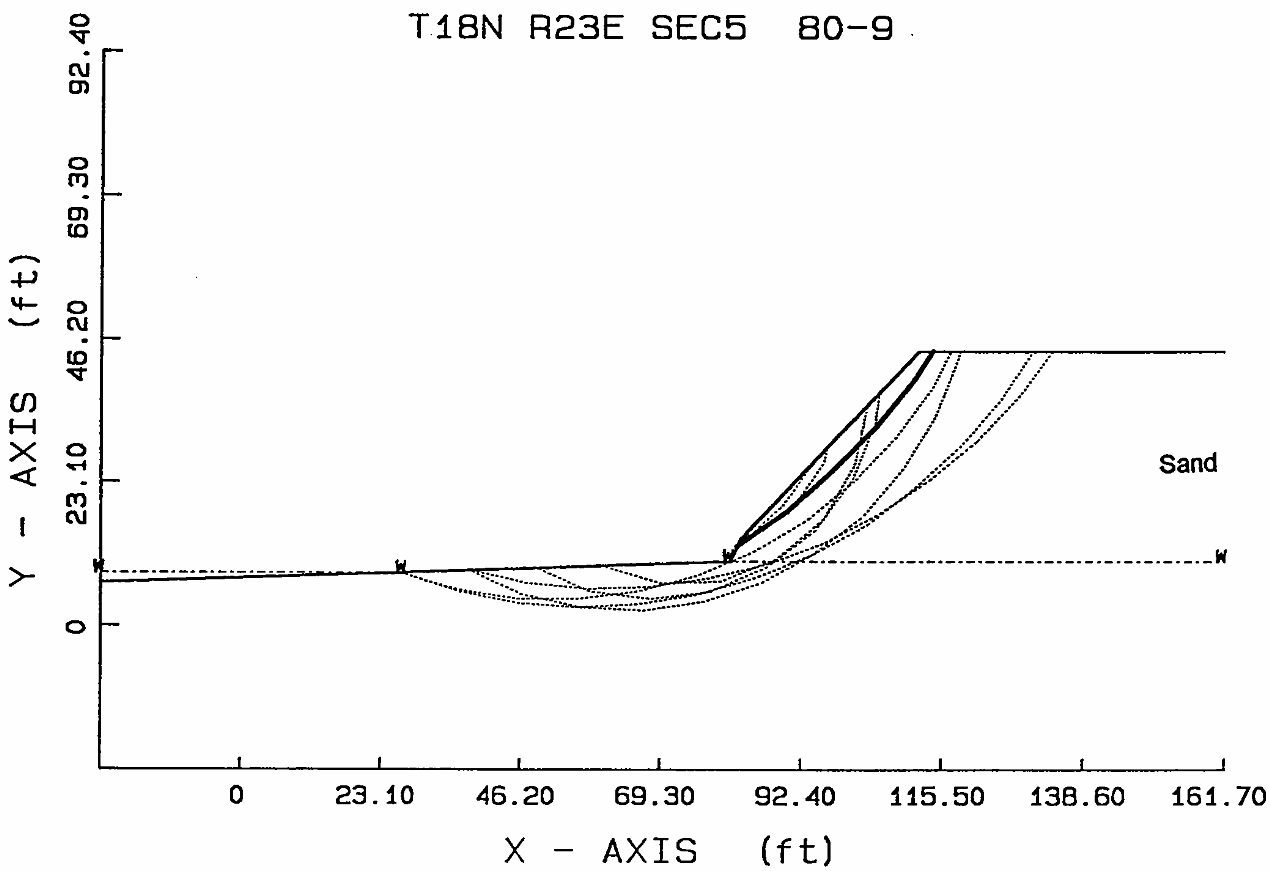
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



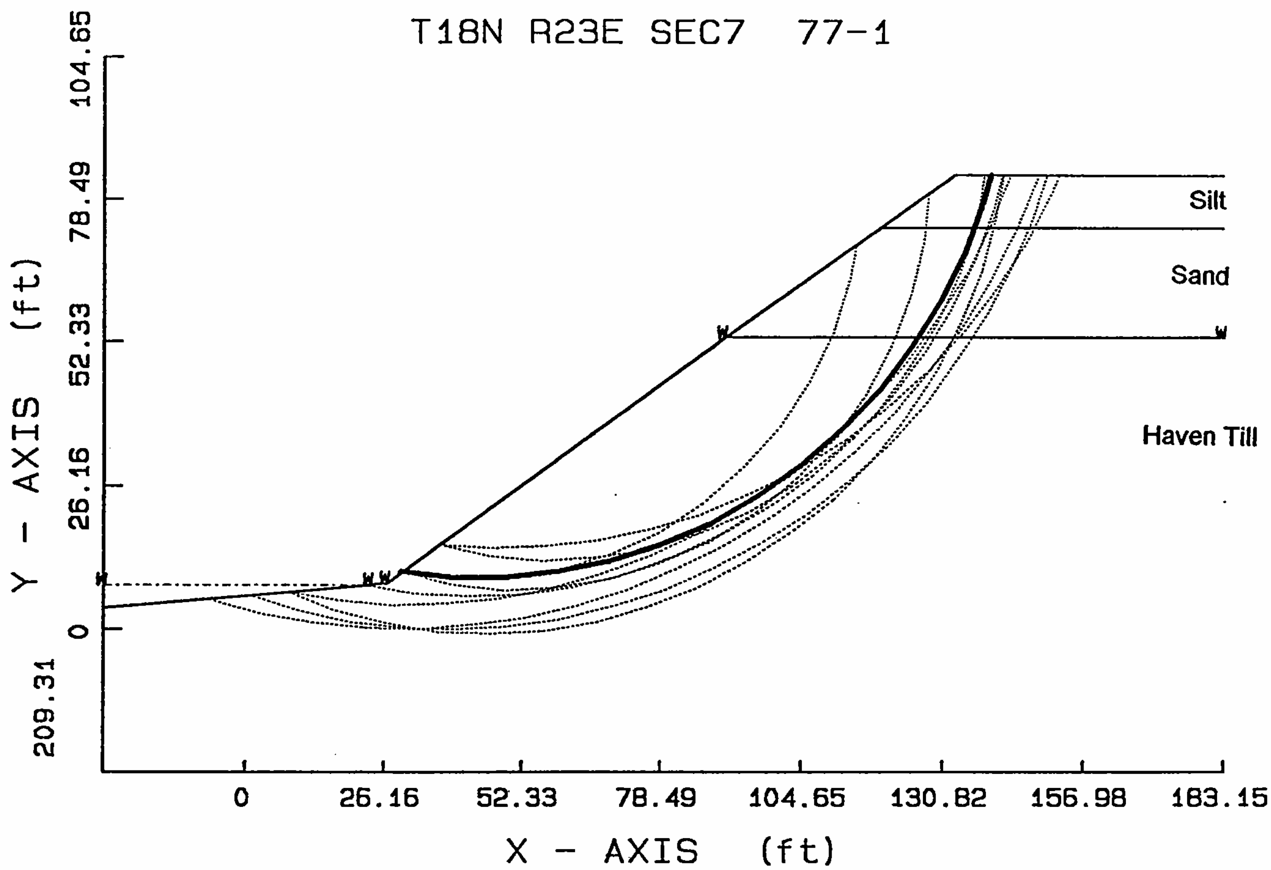


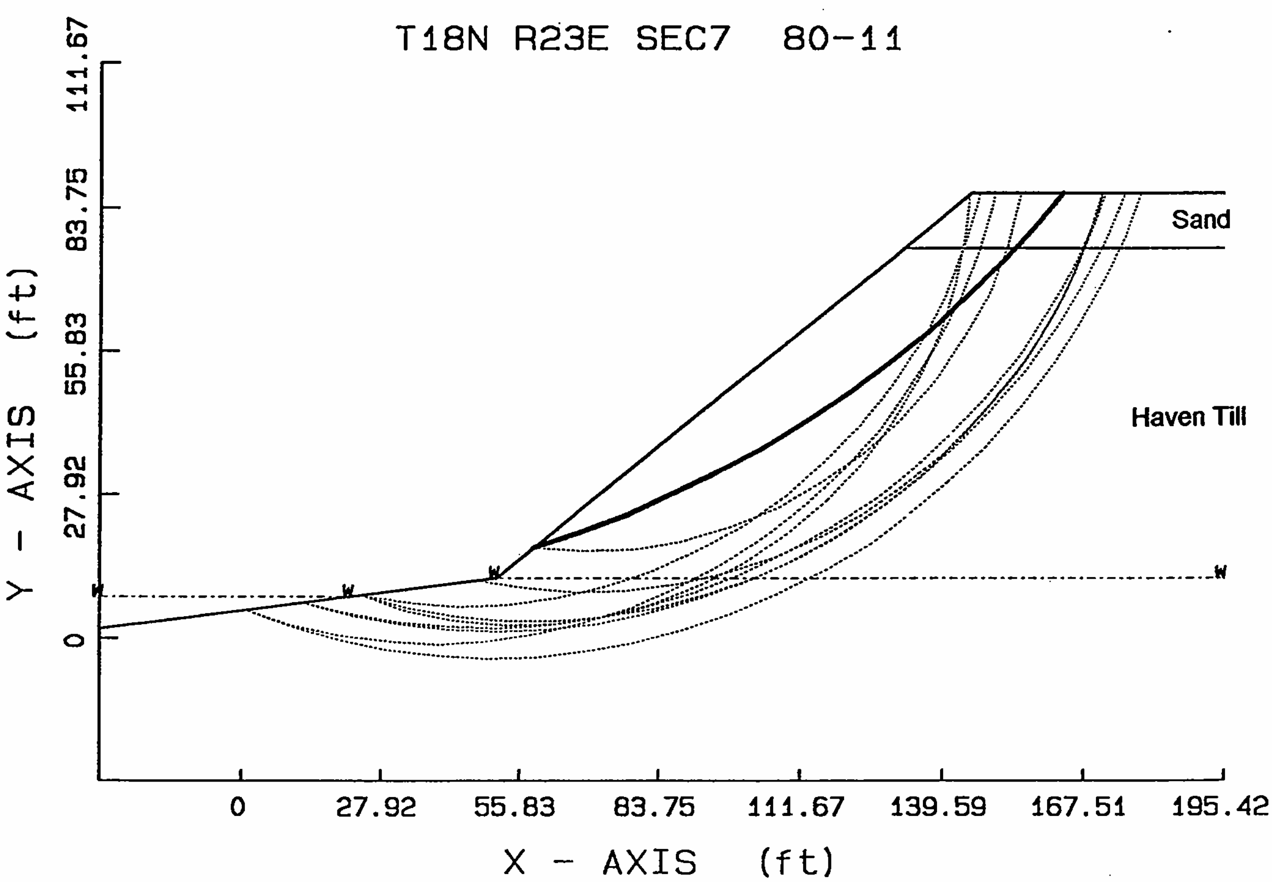
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



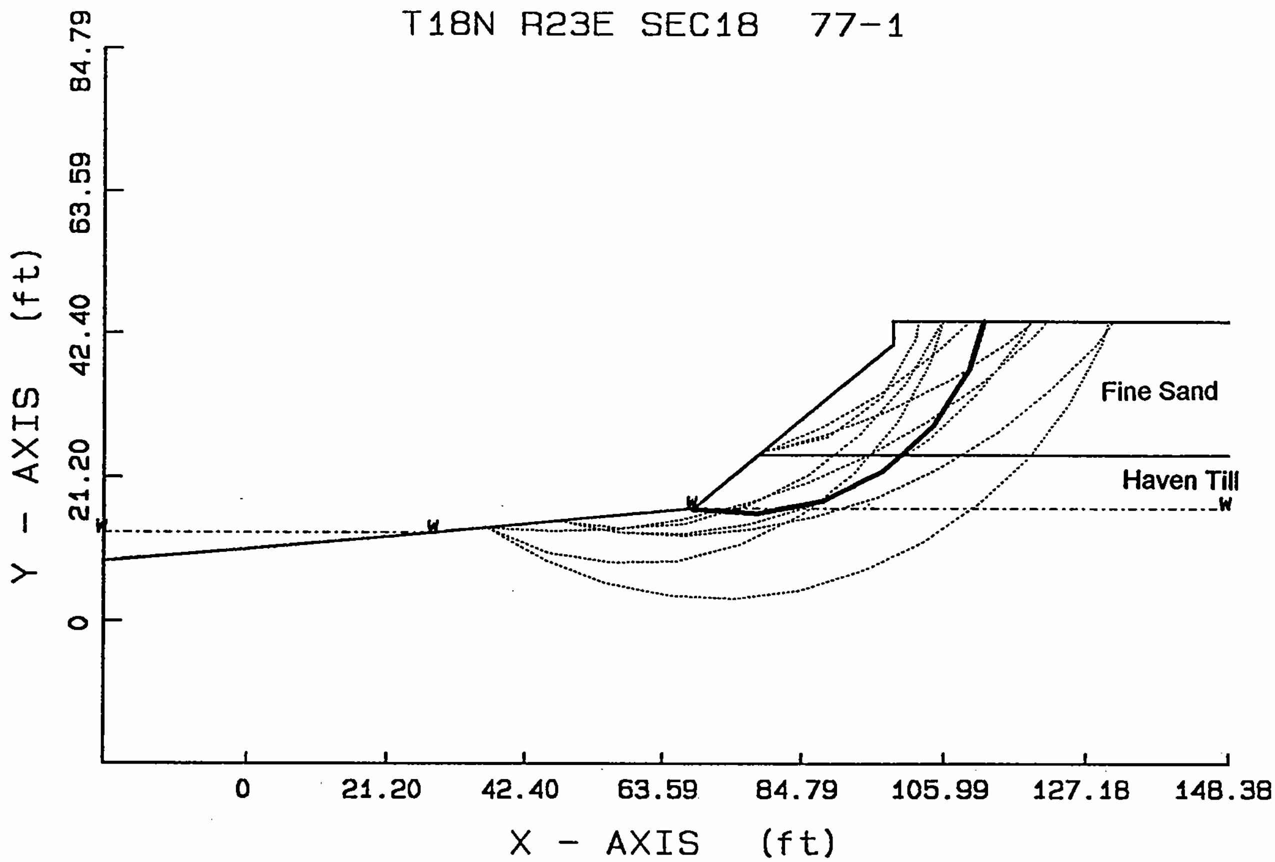


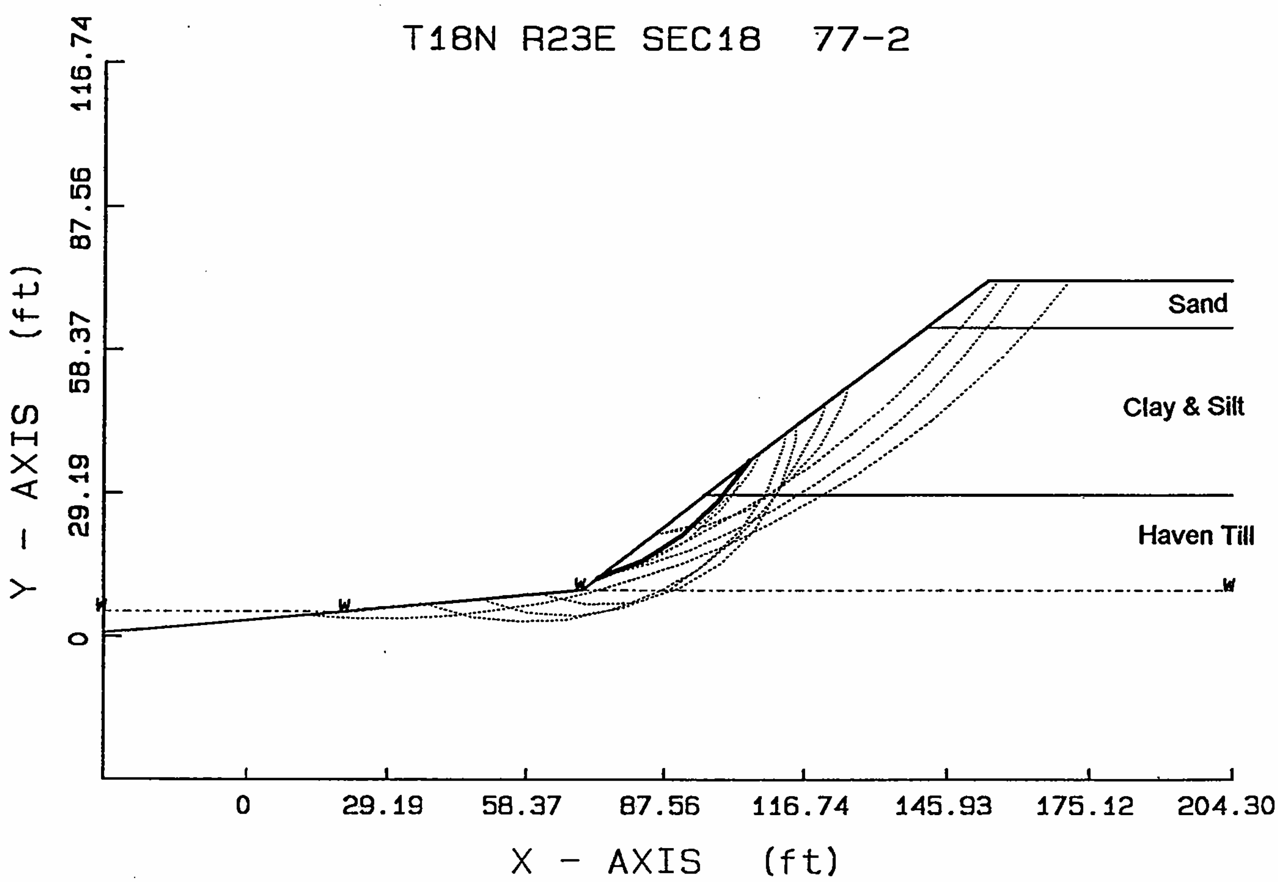
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



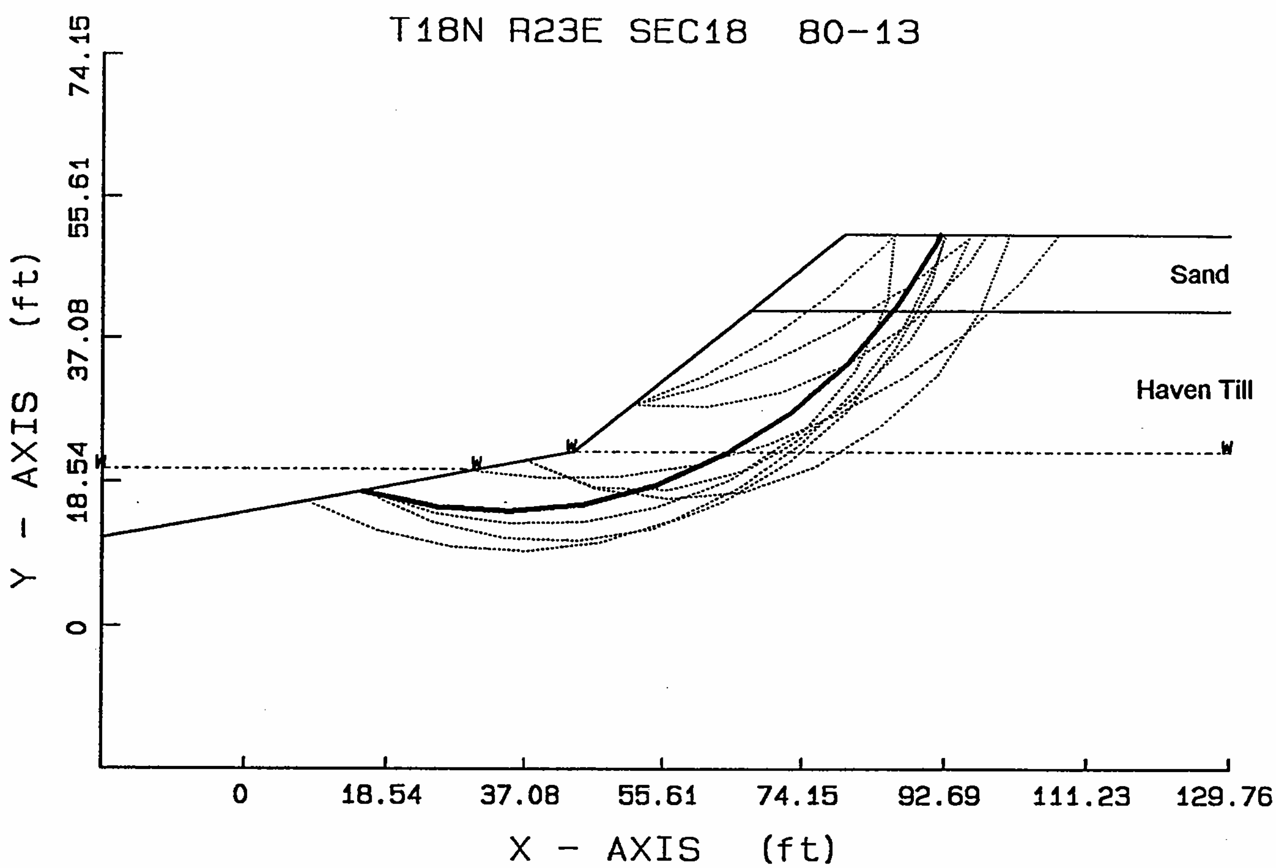


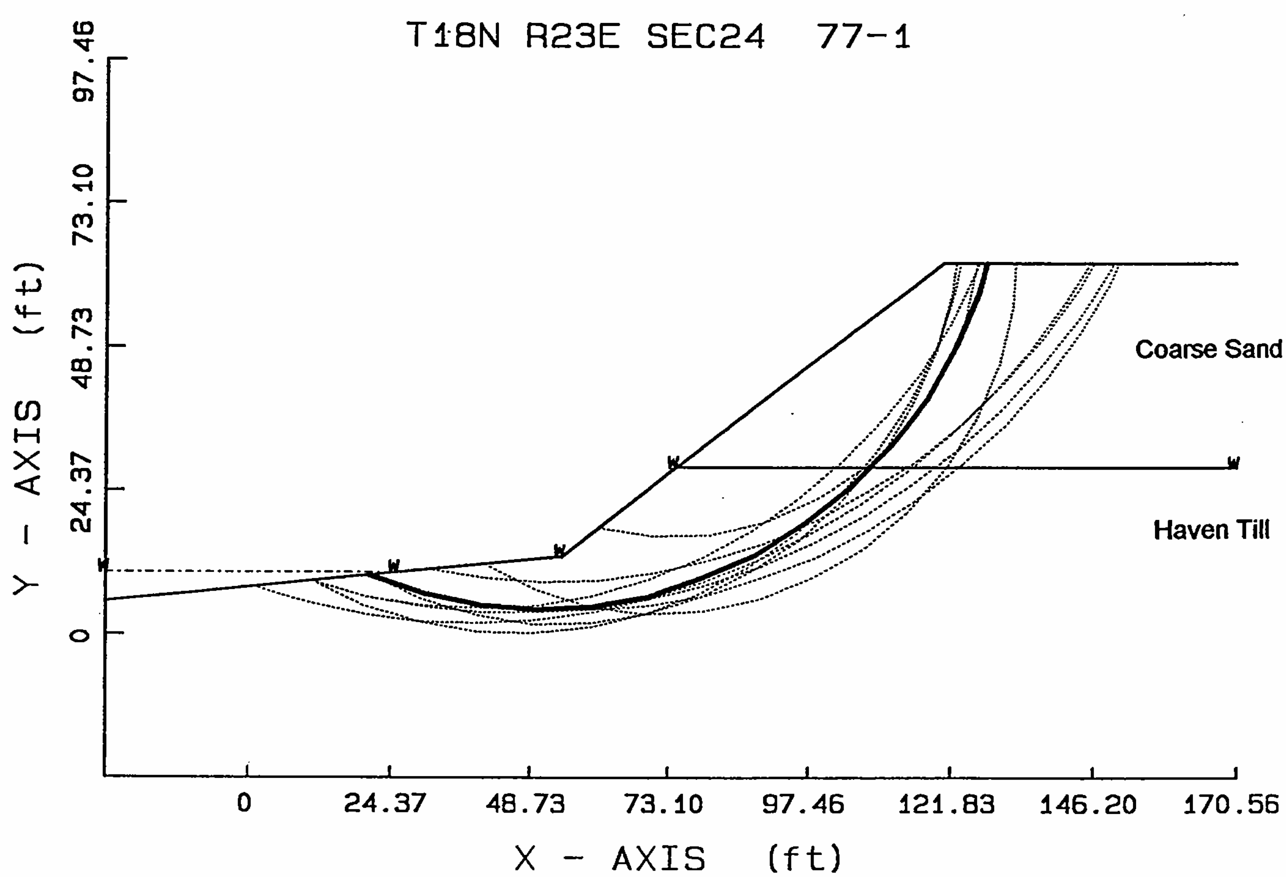
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



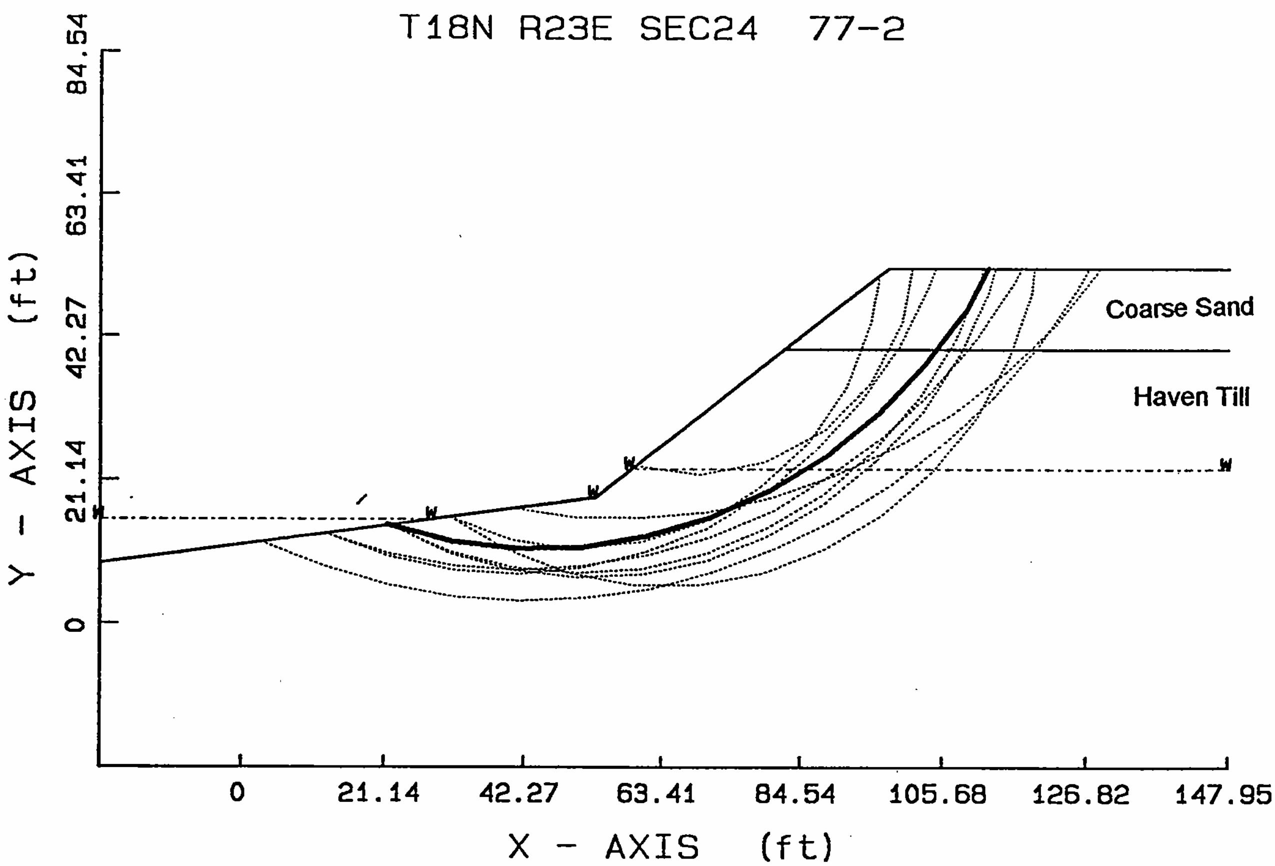


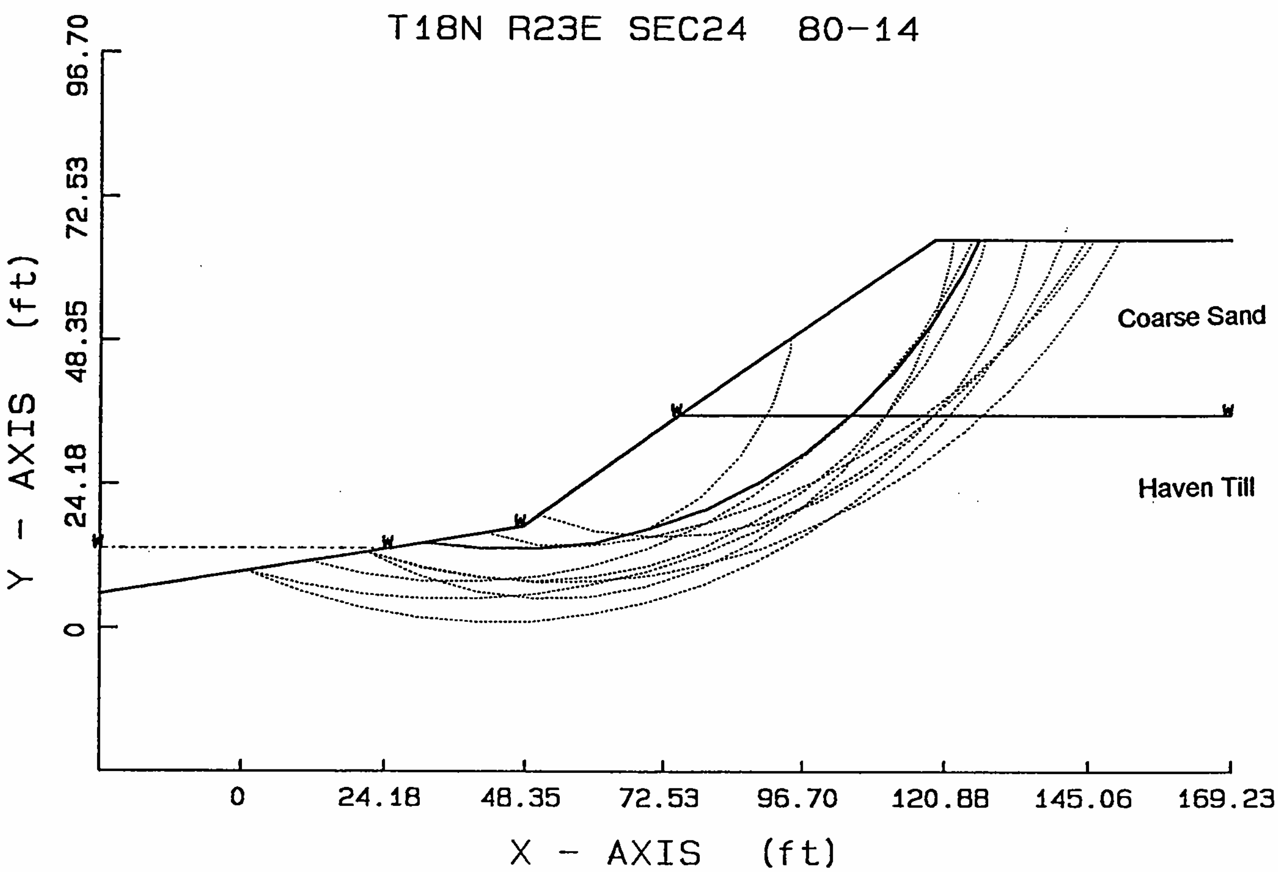
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



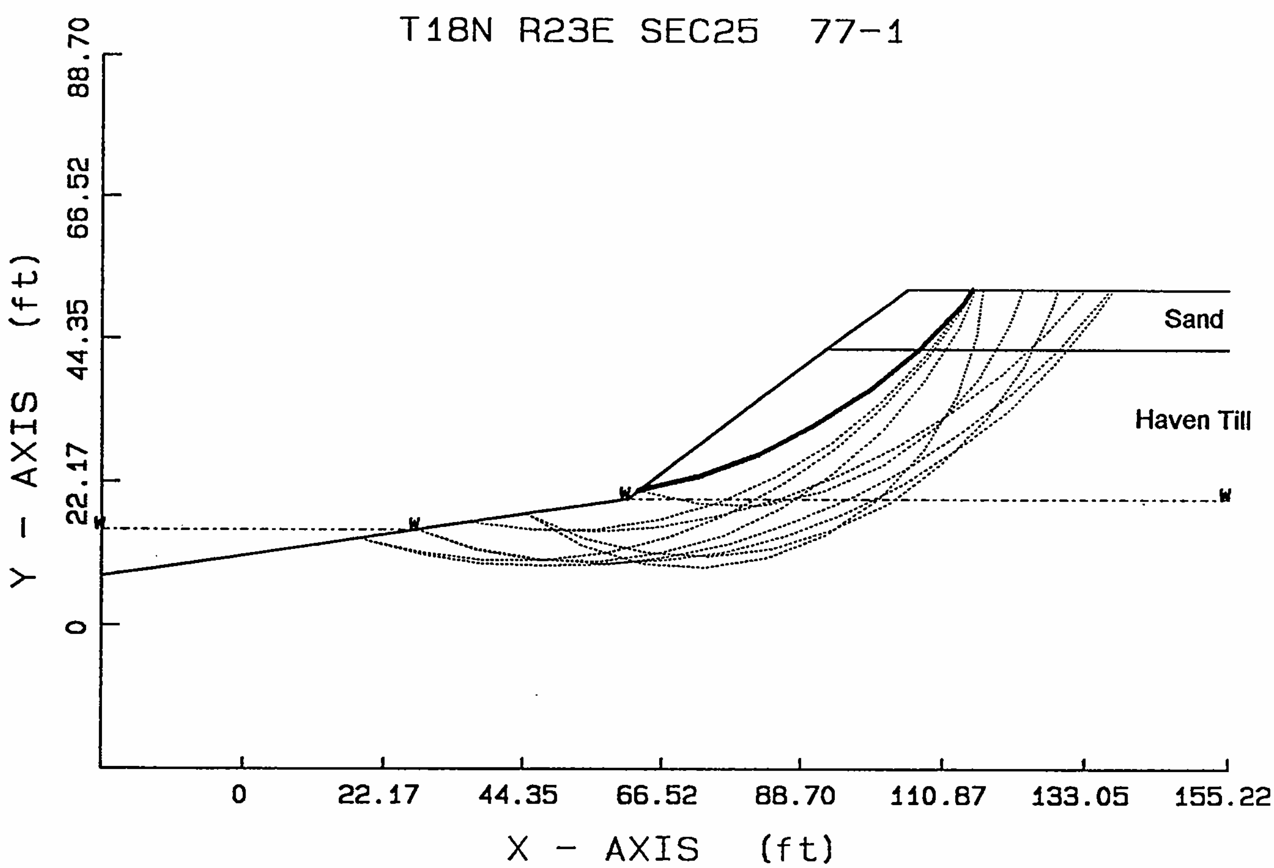


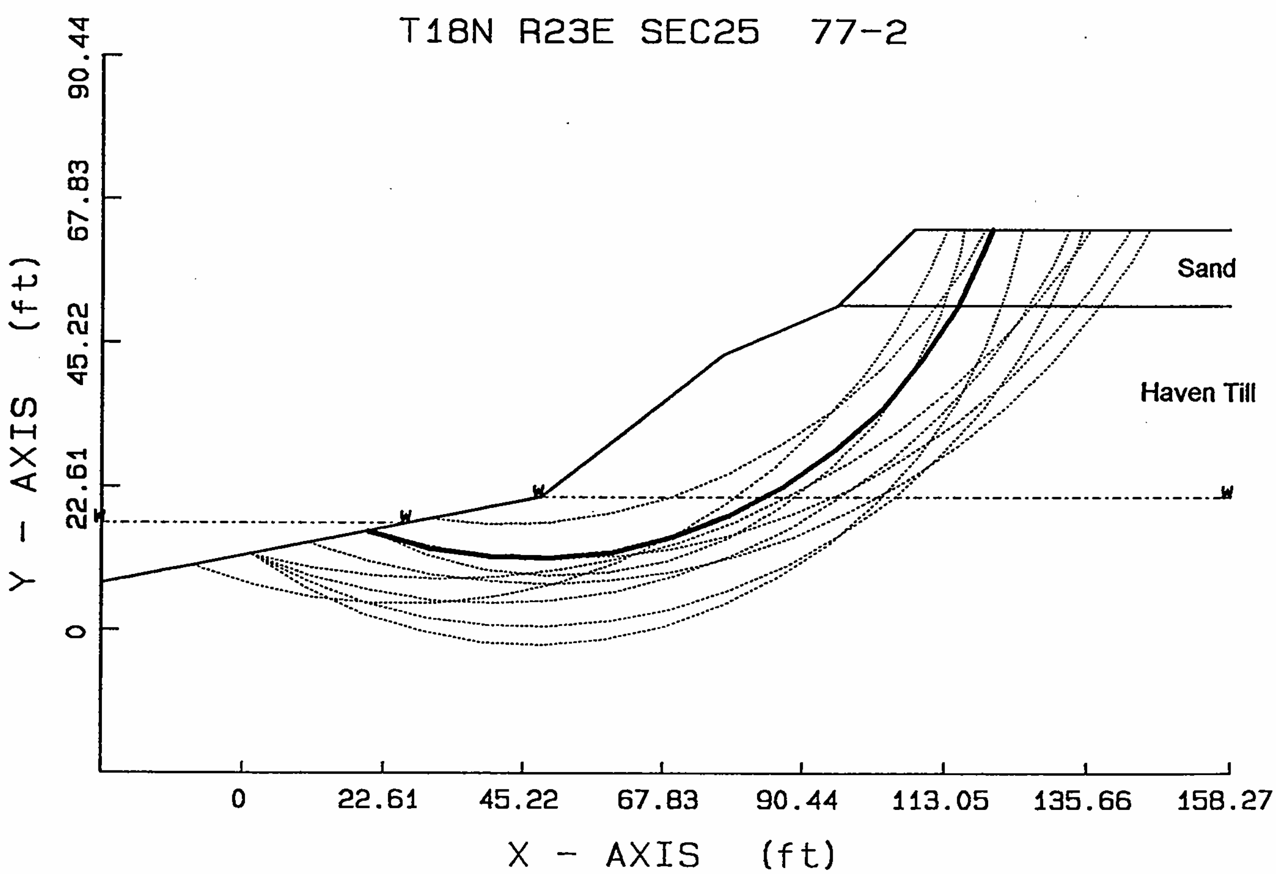
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



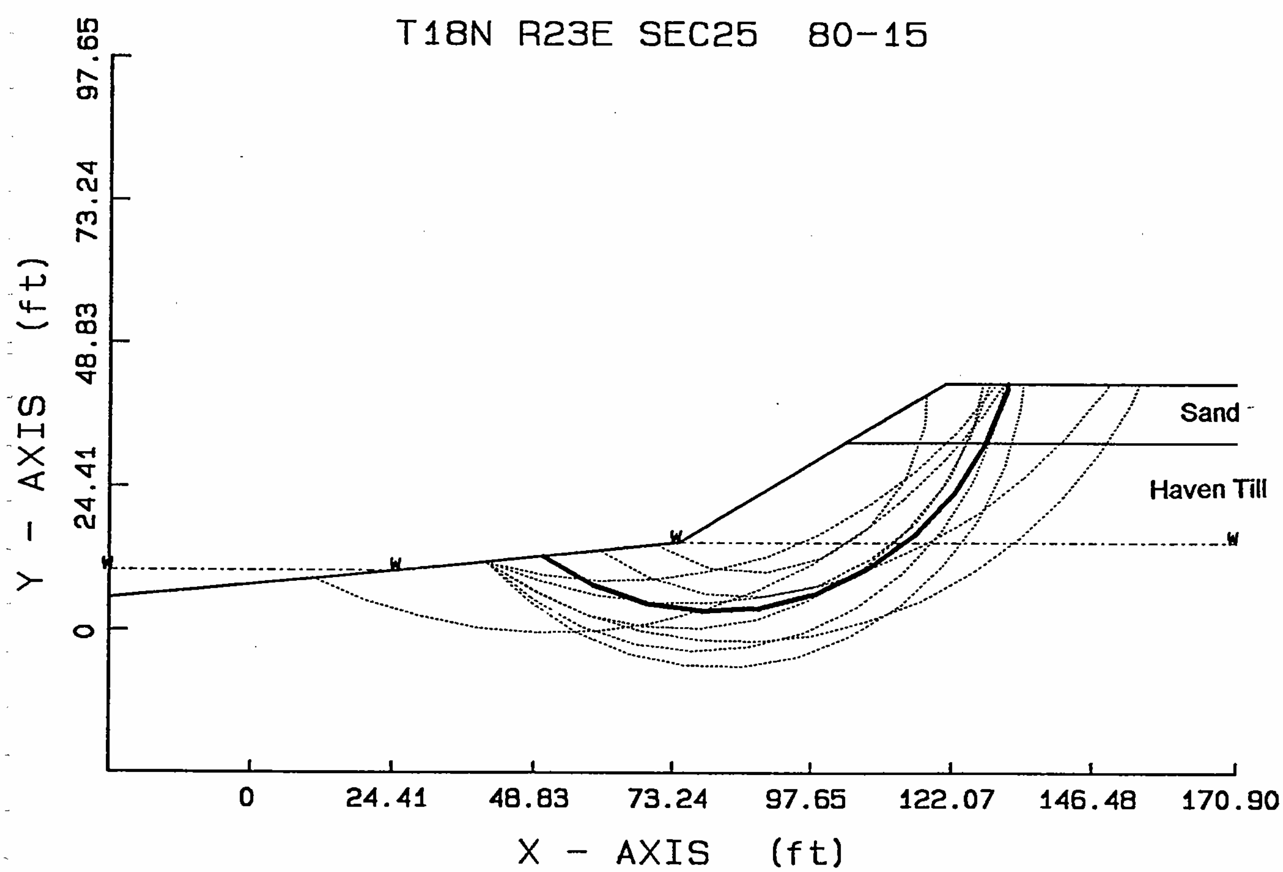


Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

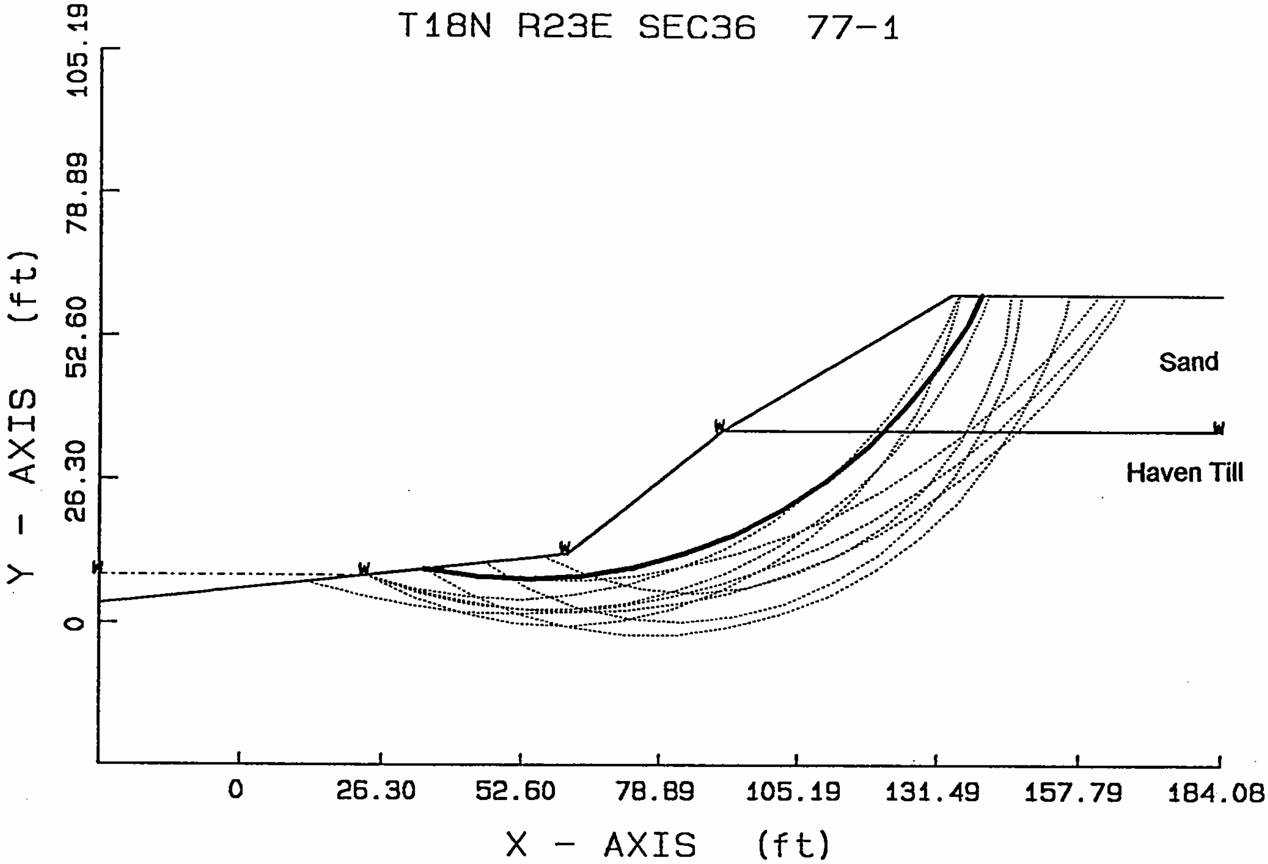


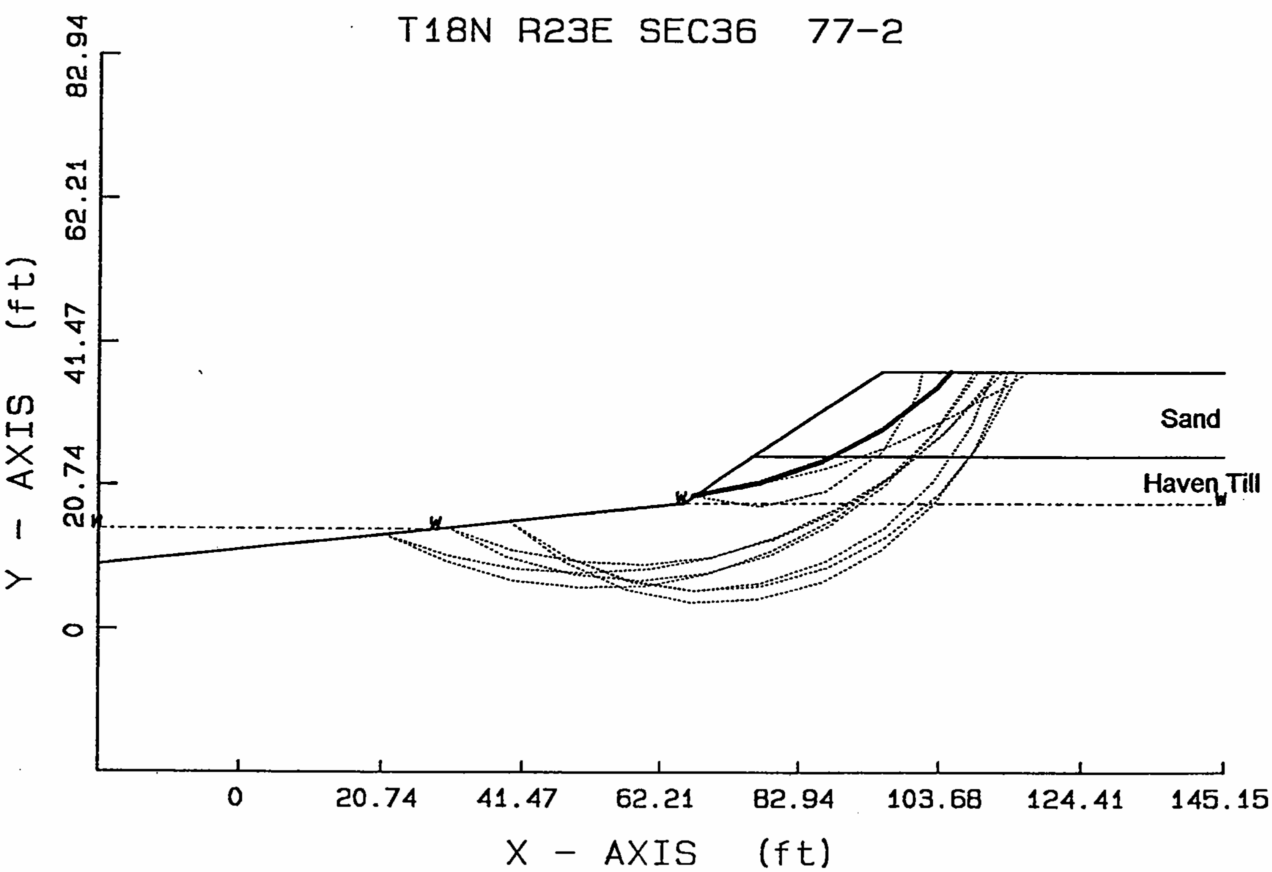


Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

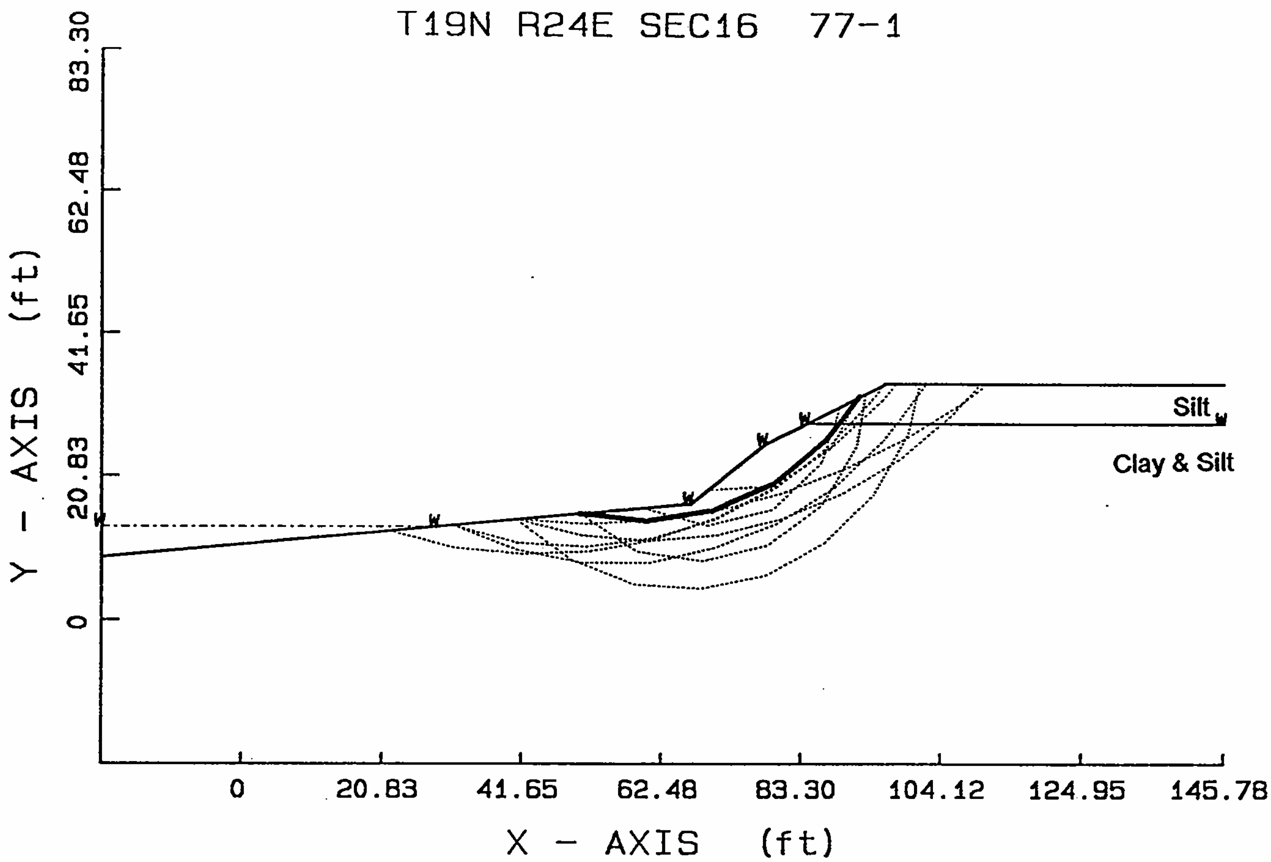


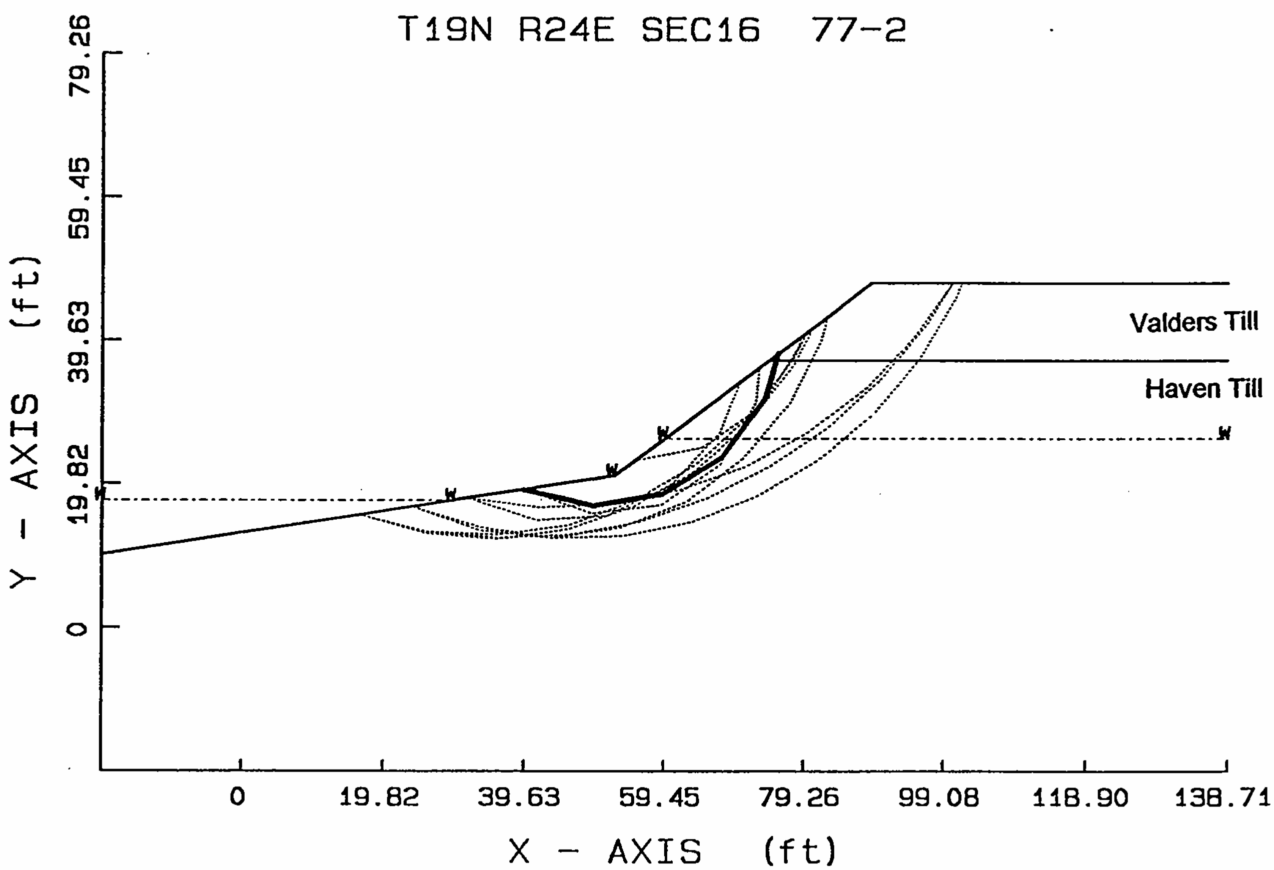
ce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



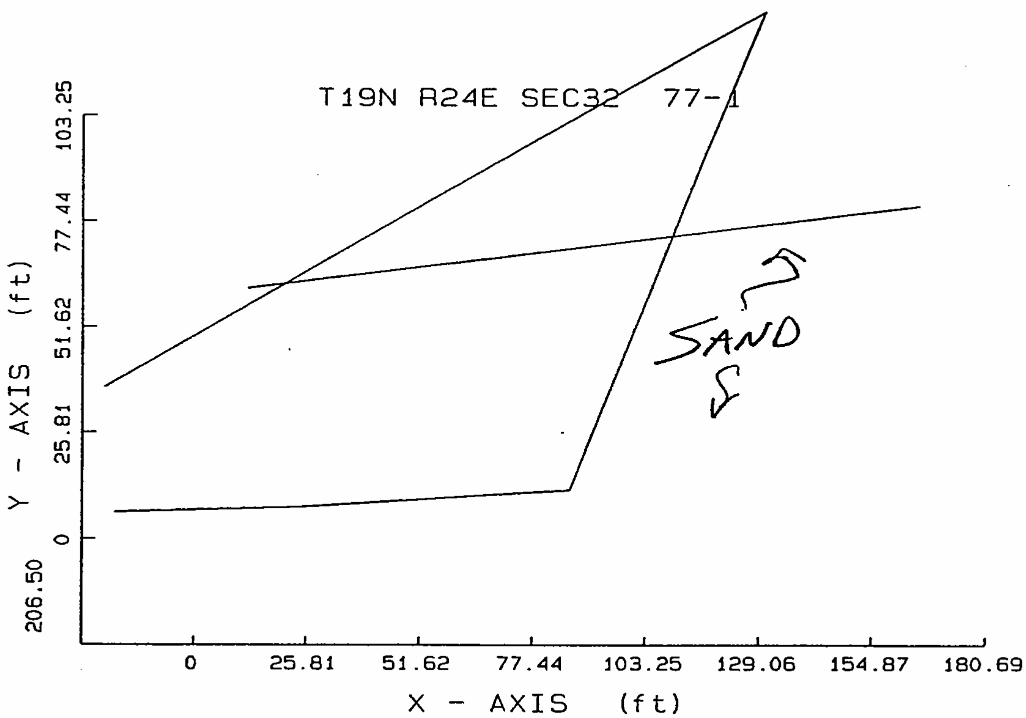


urce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

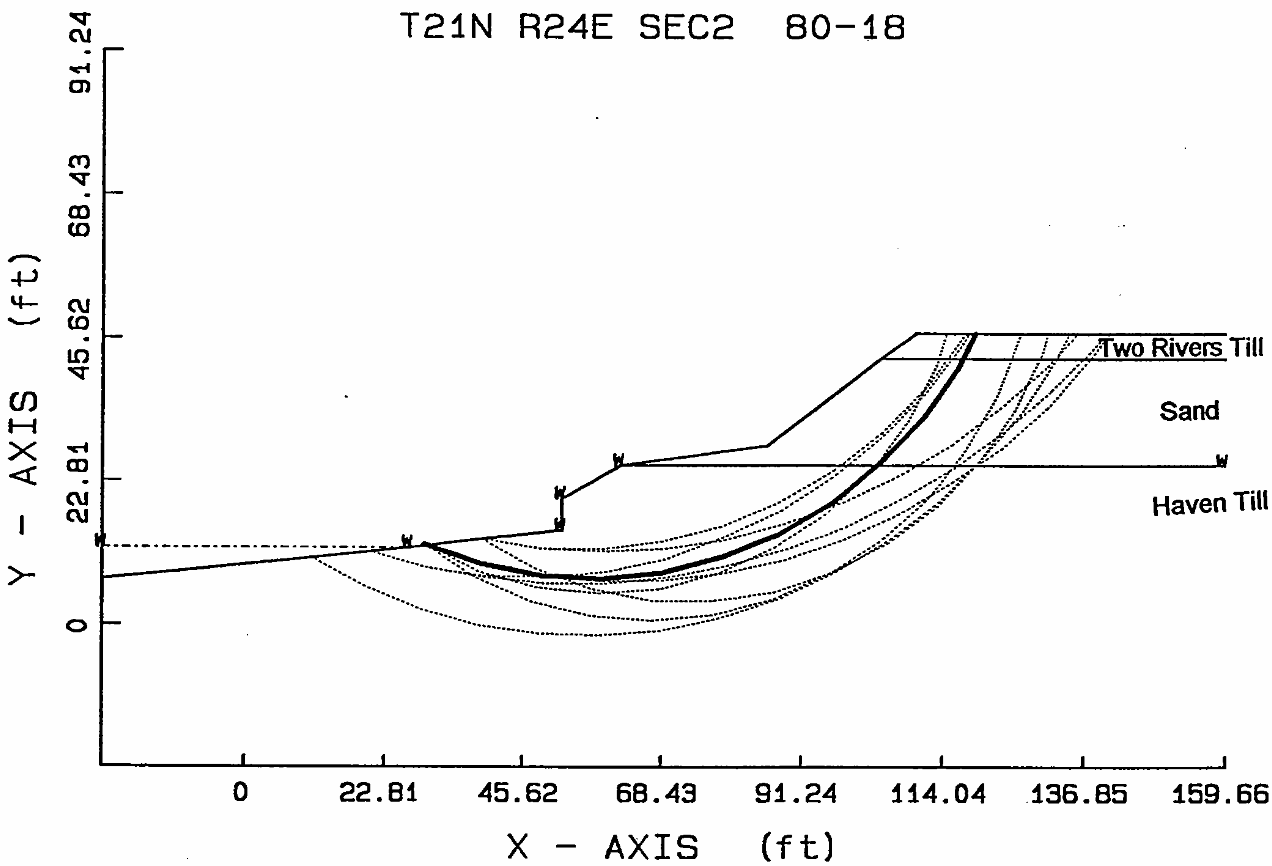




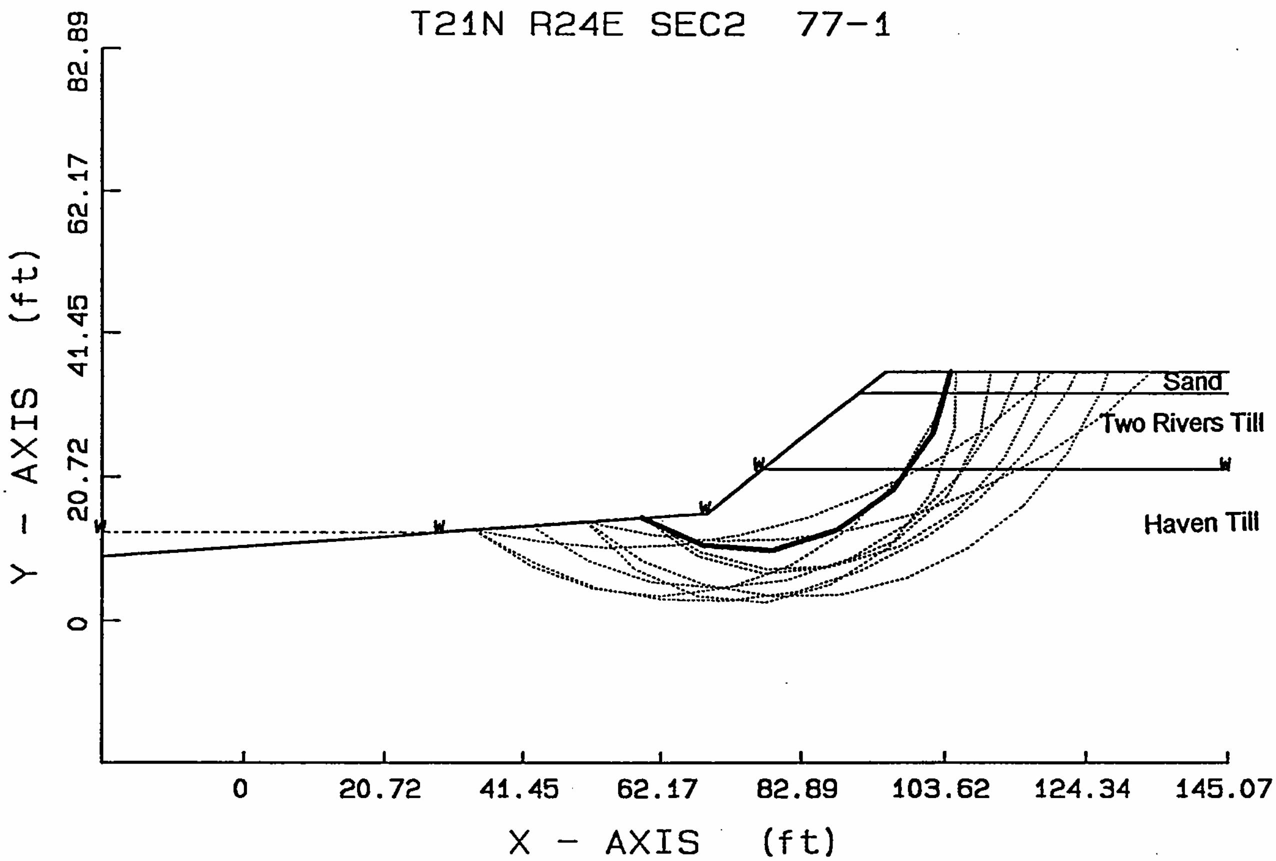
ource: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

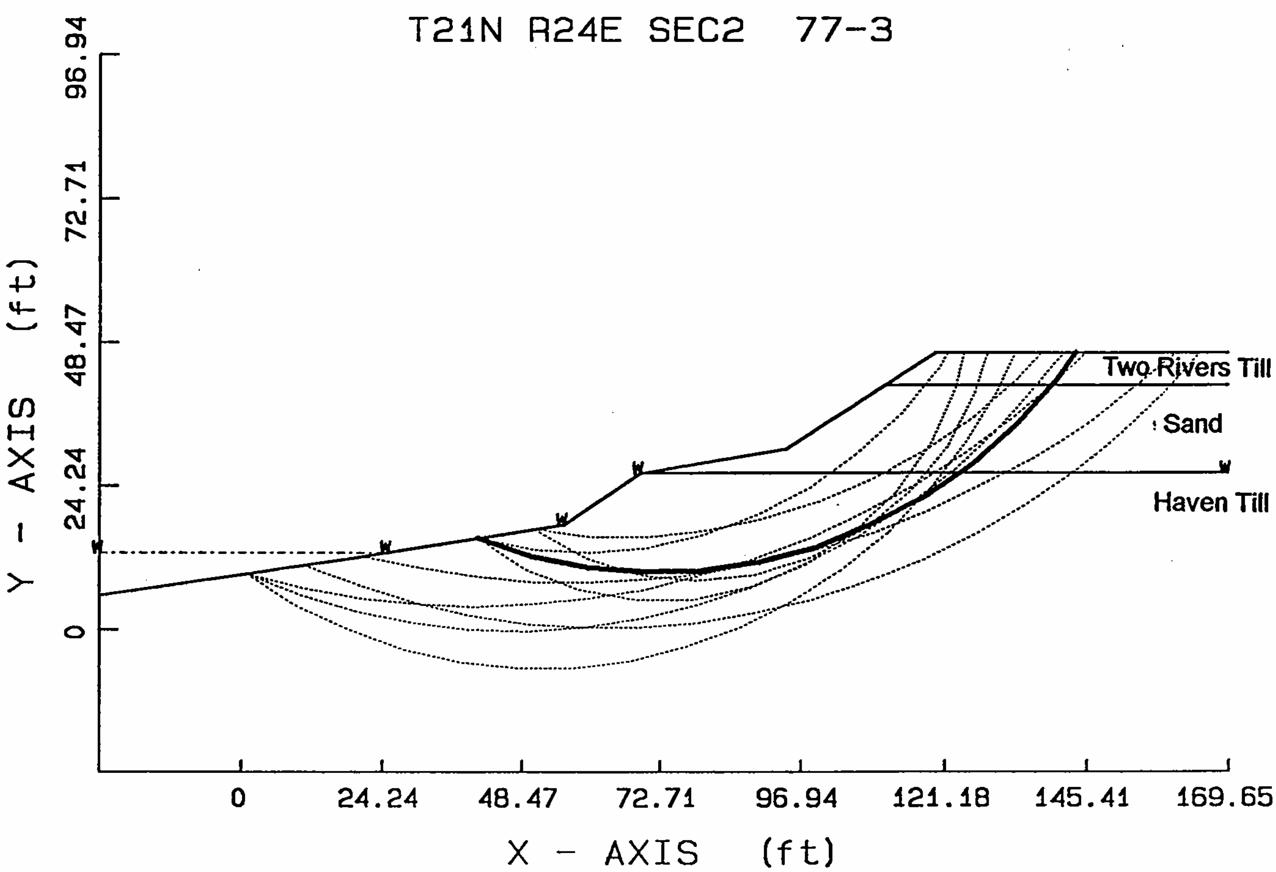


;e: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

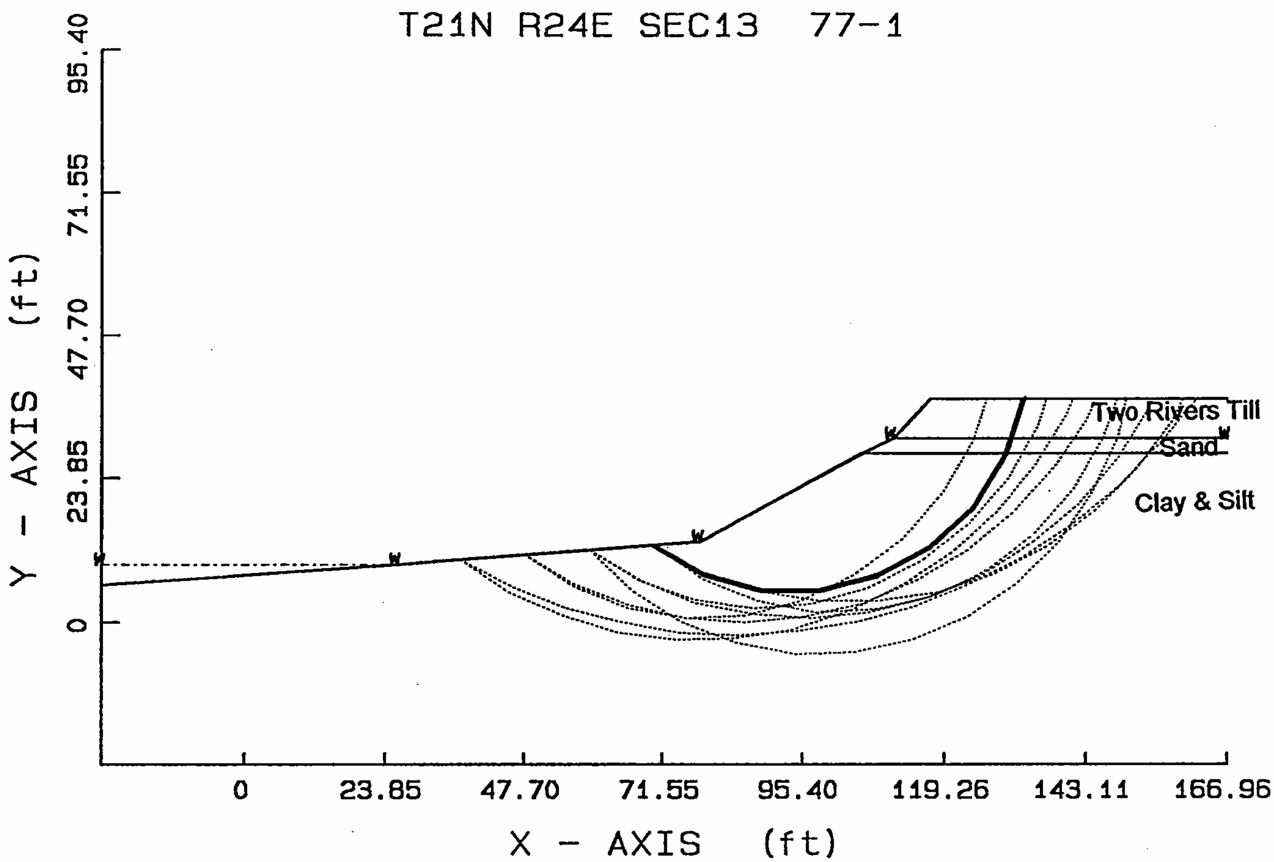


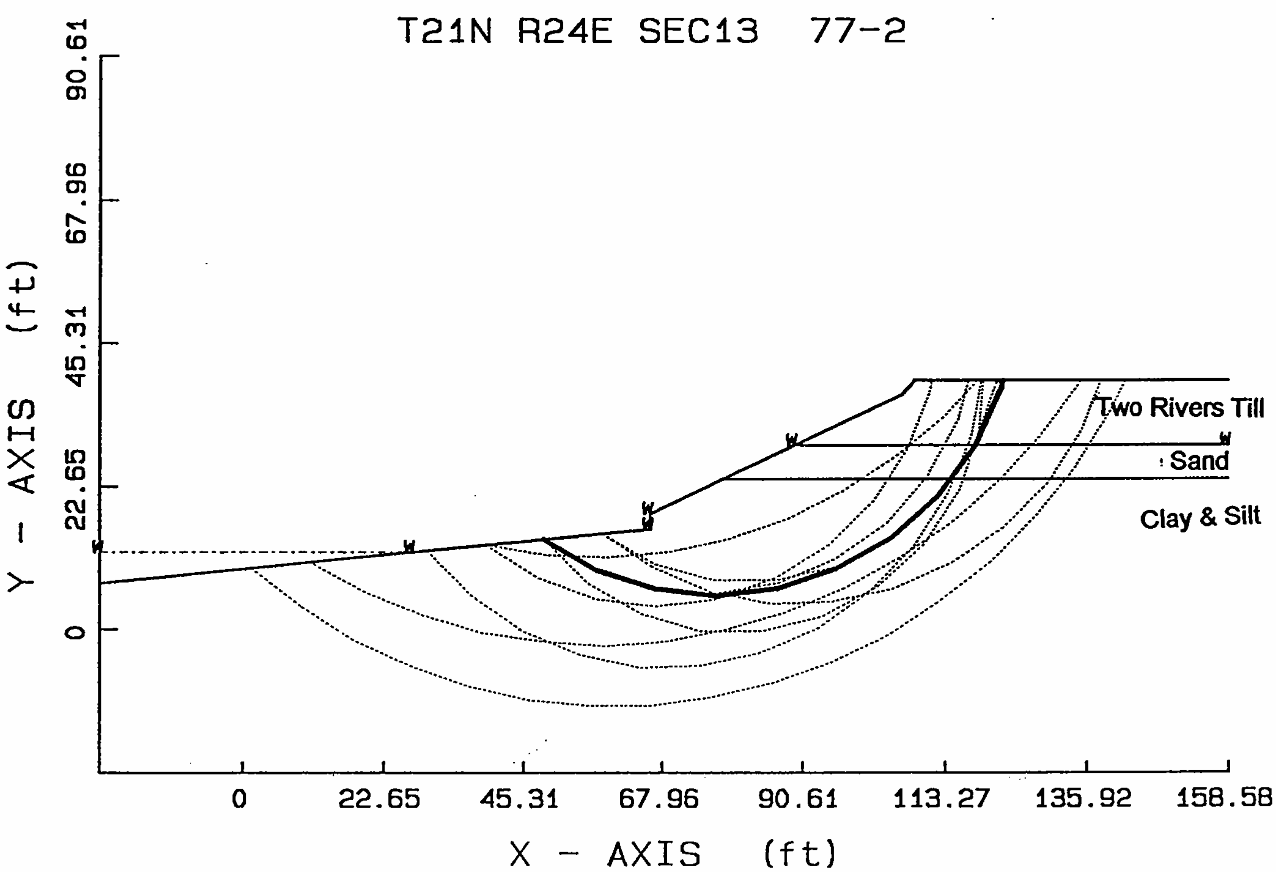
ource: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



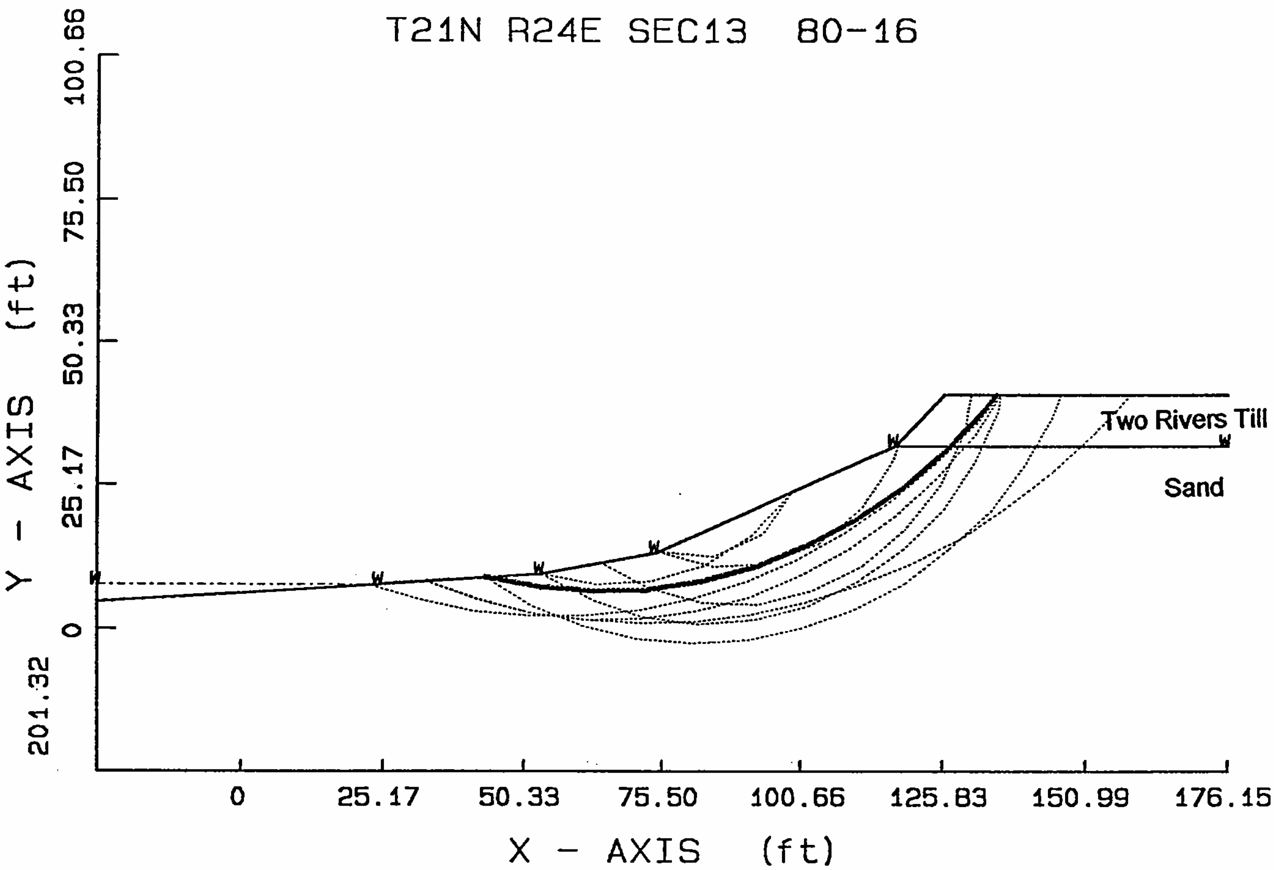


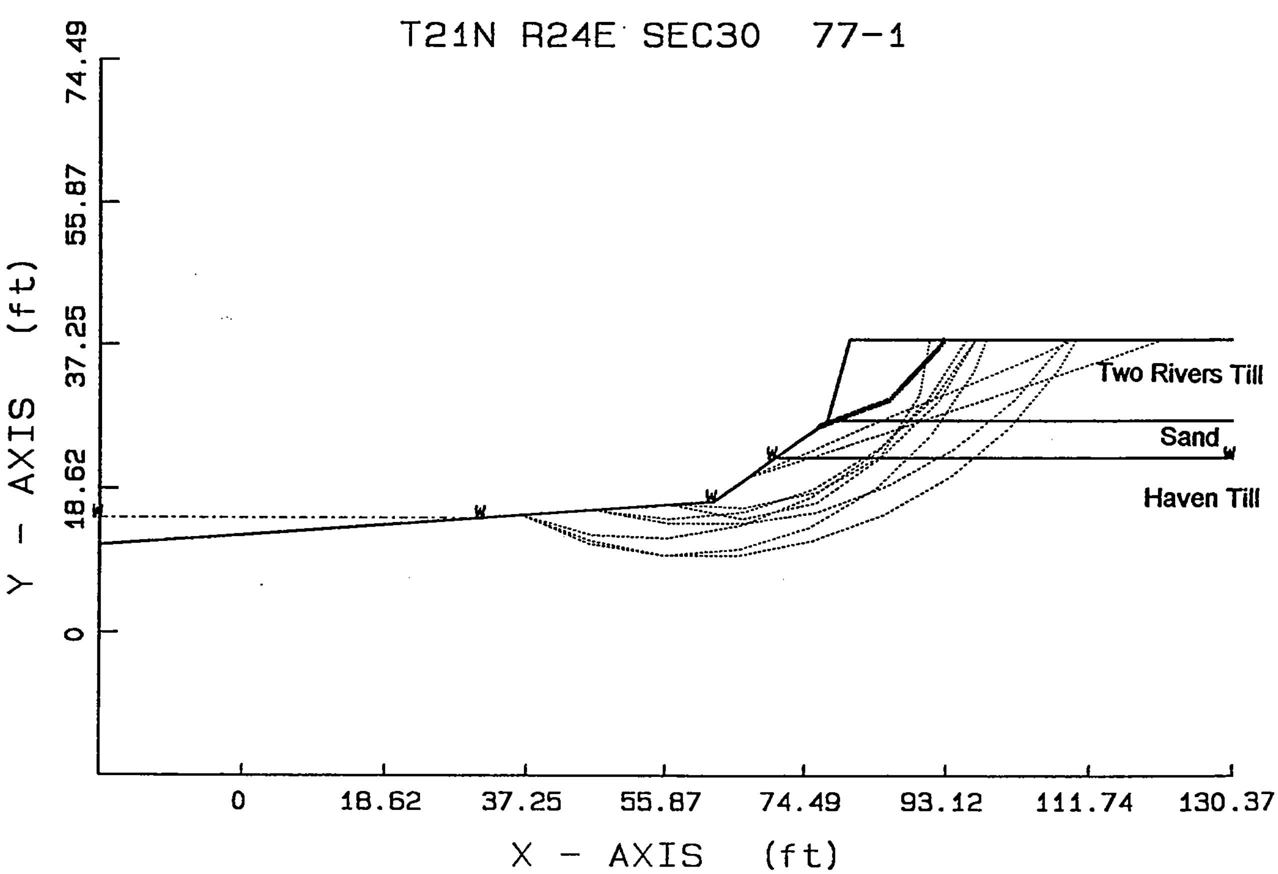
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



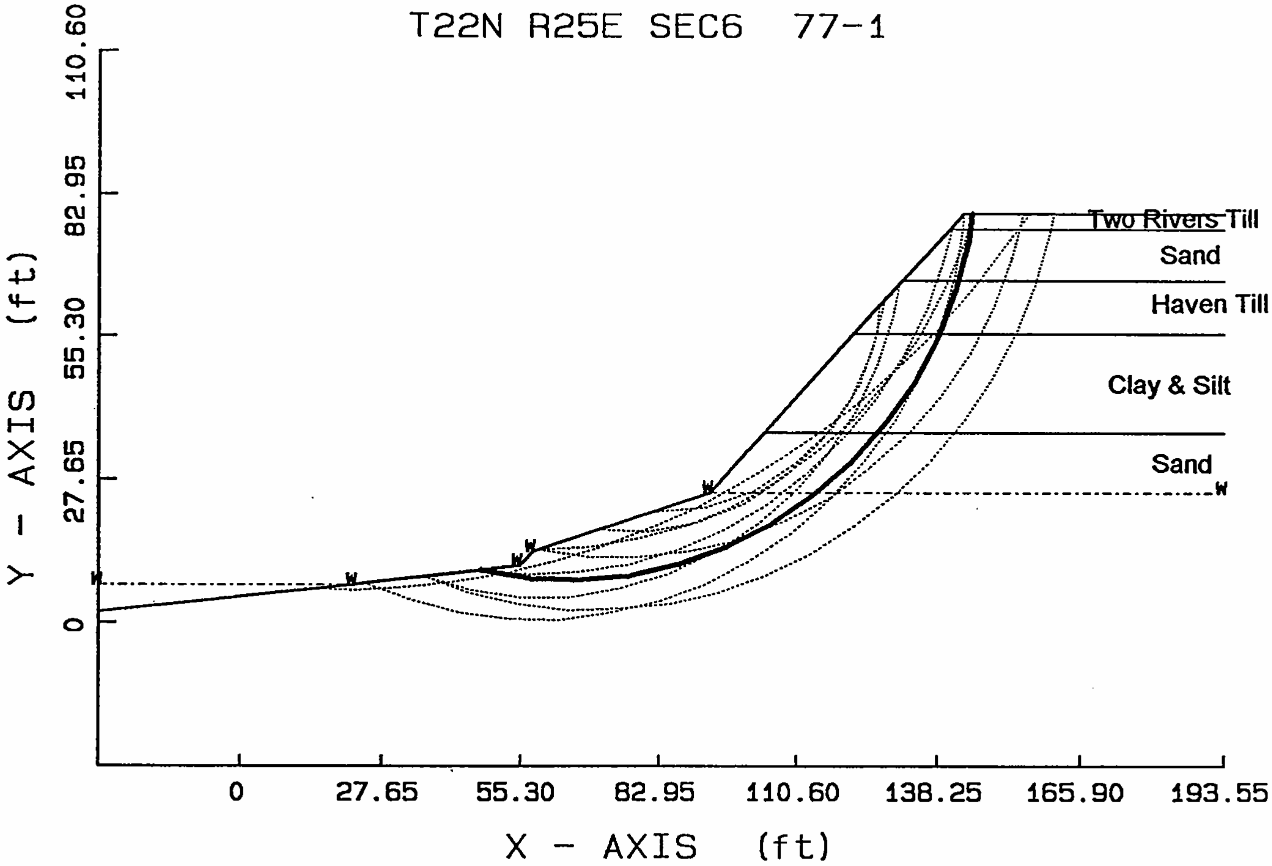


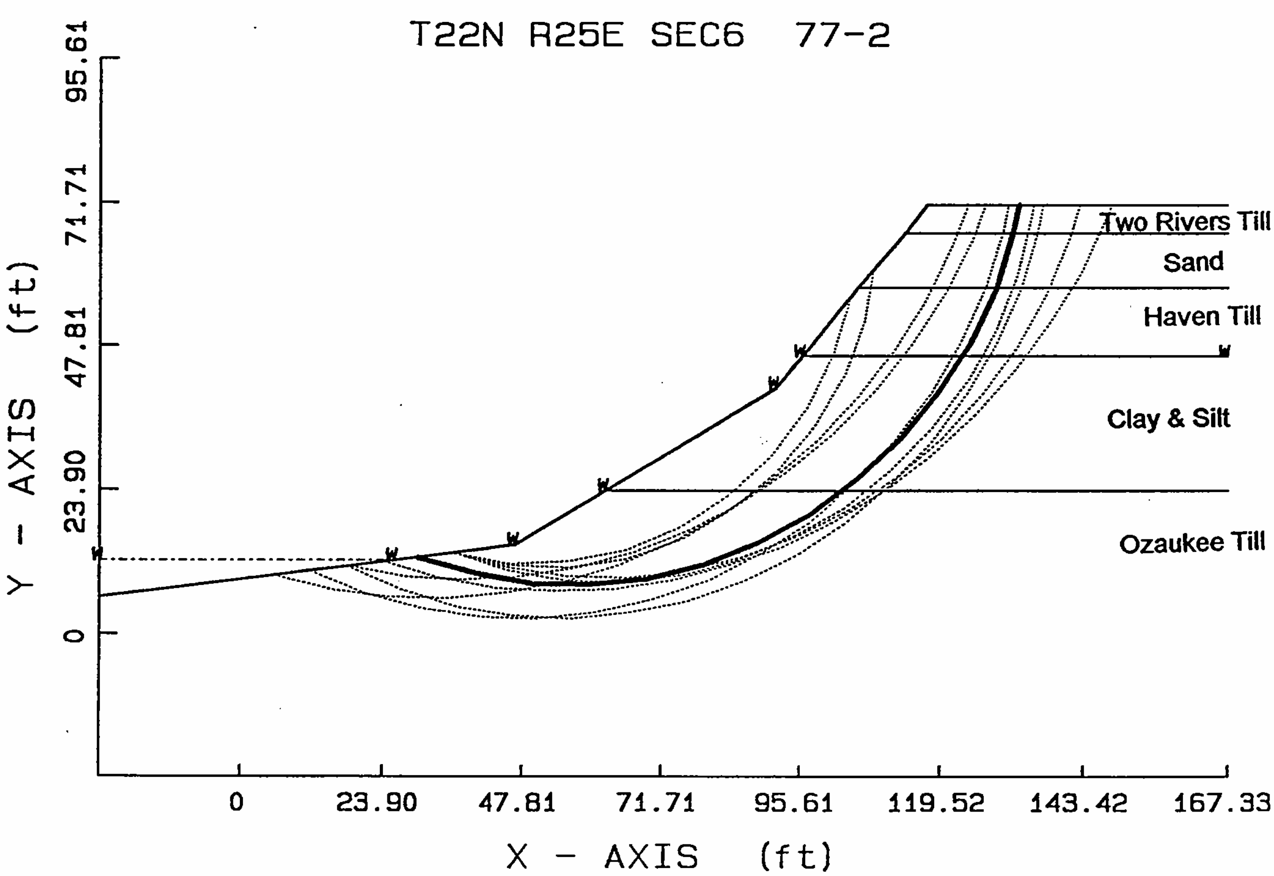
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



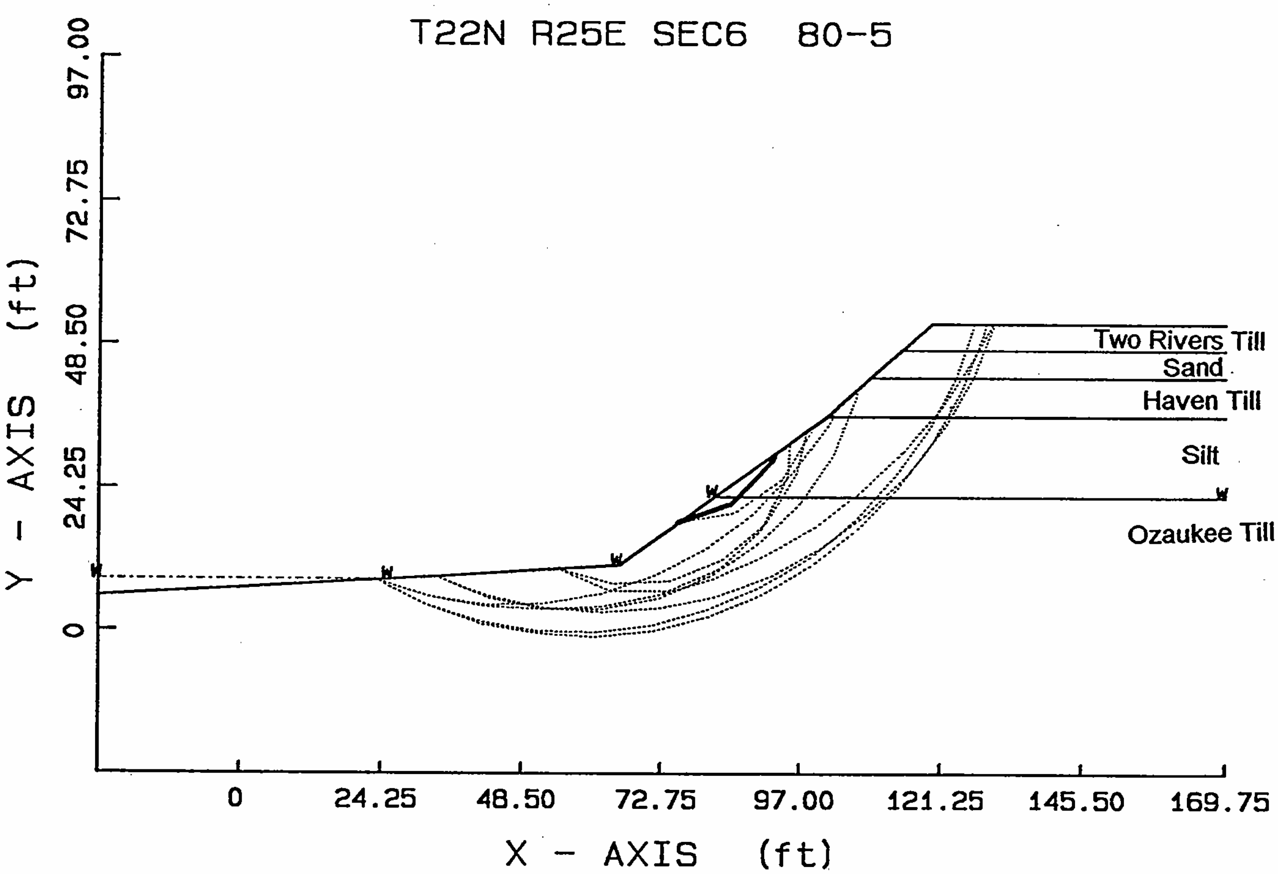


Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

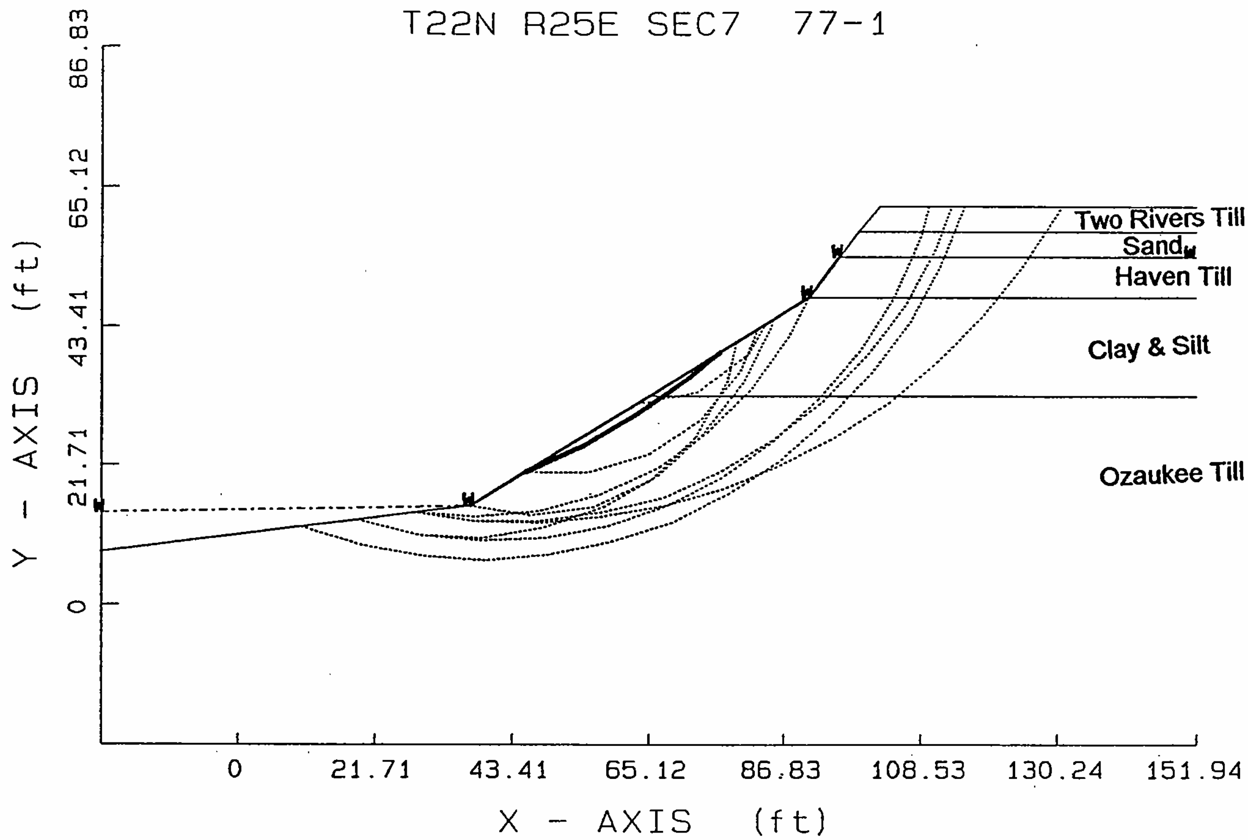


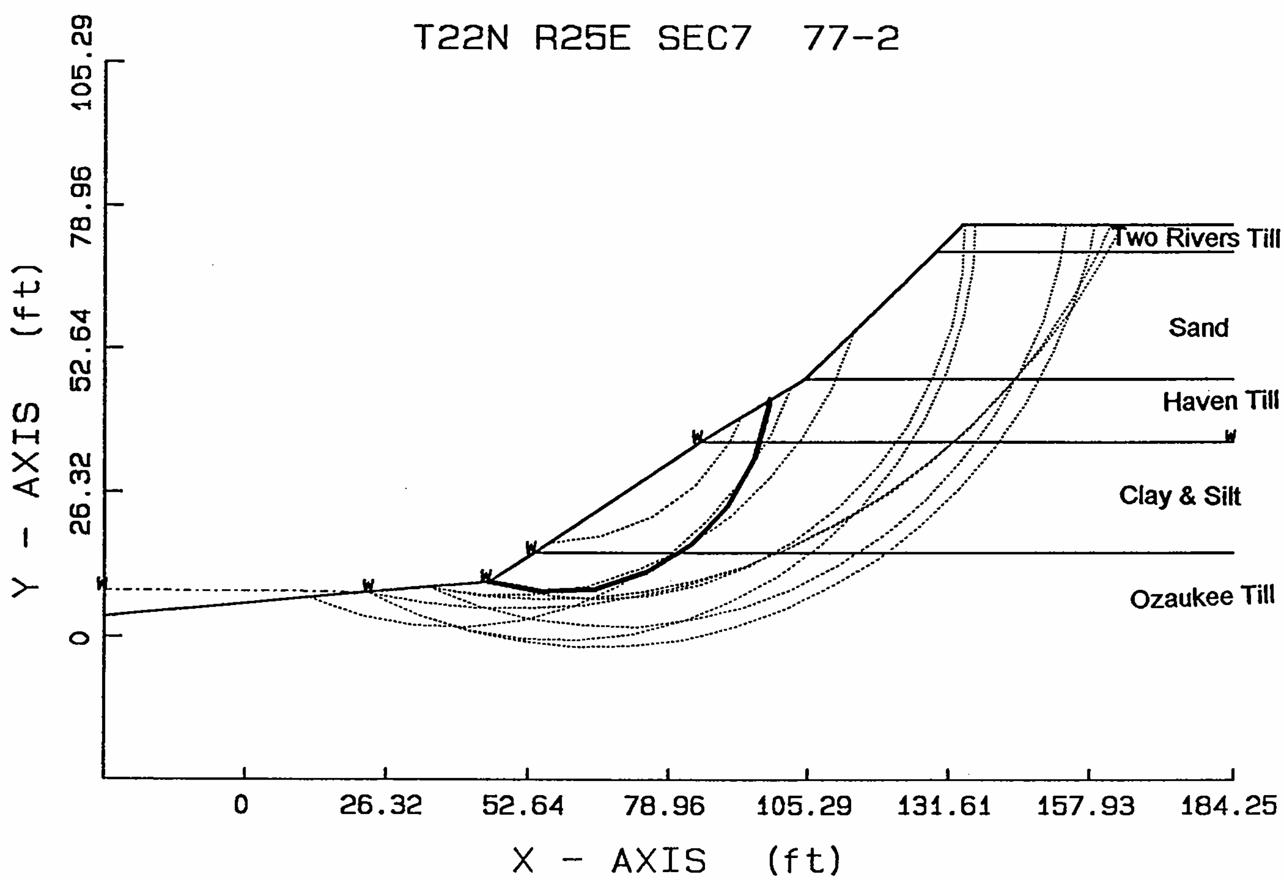


ce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

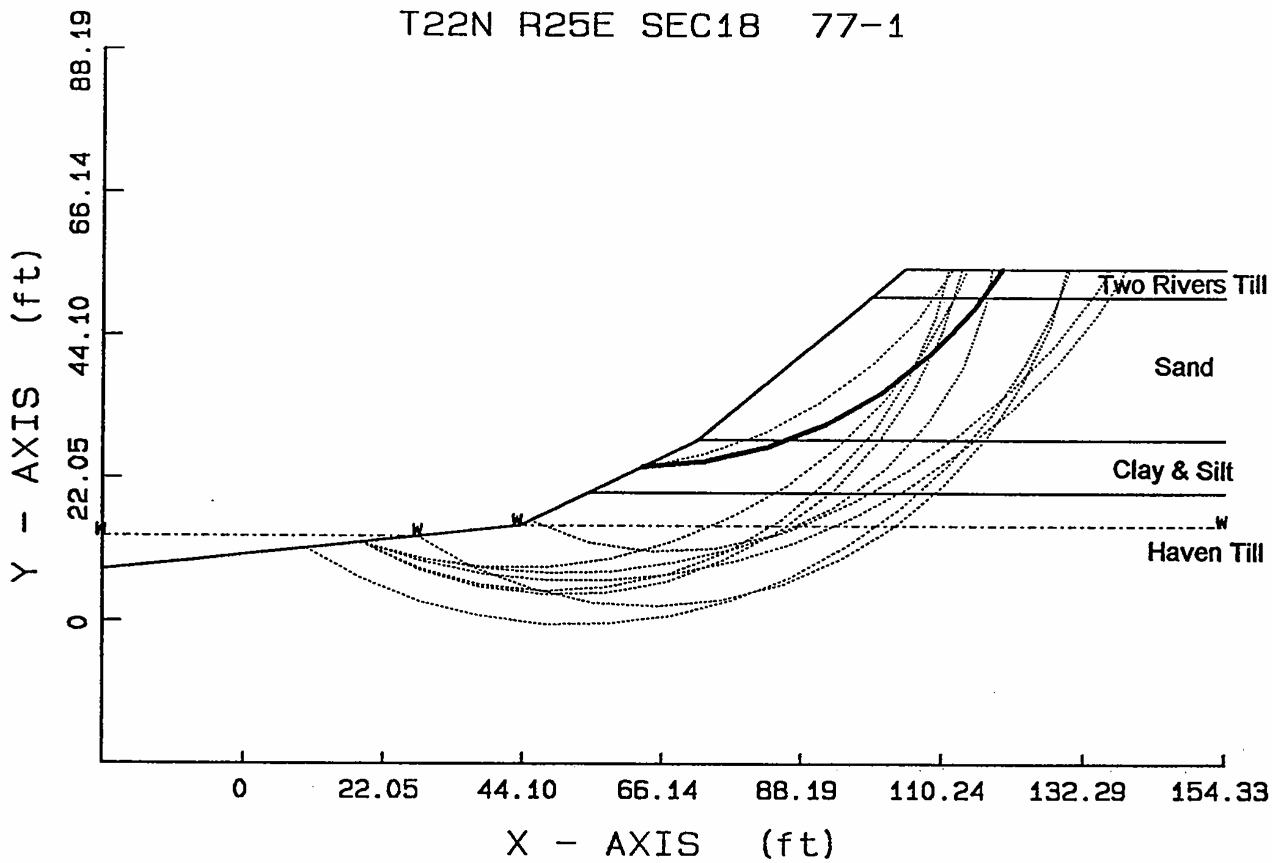


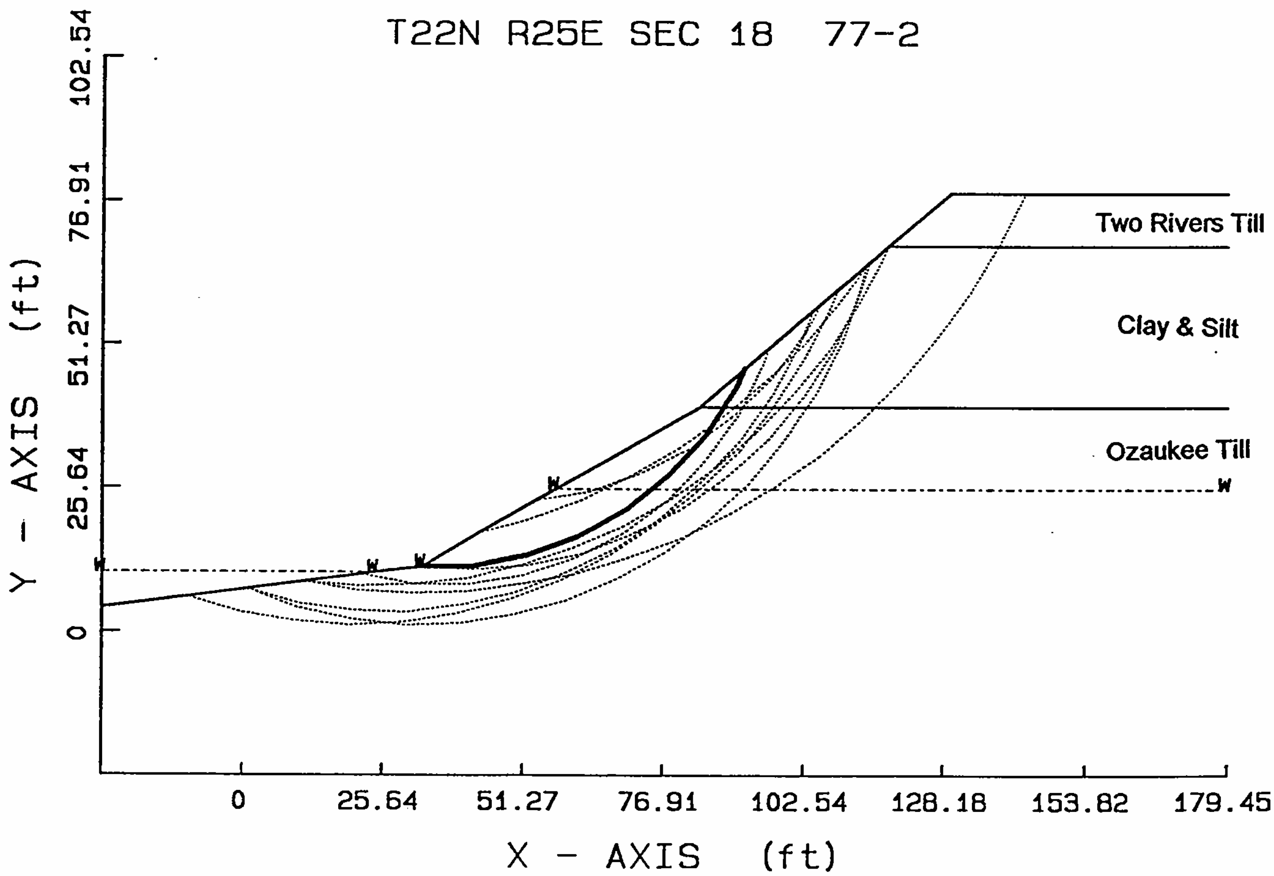
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



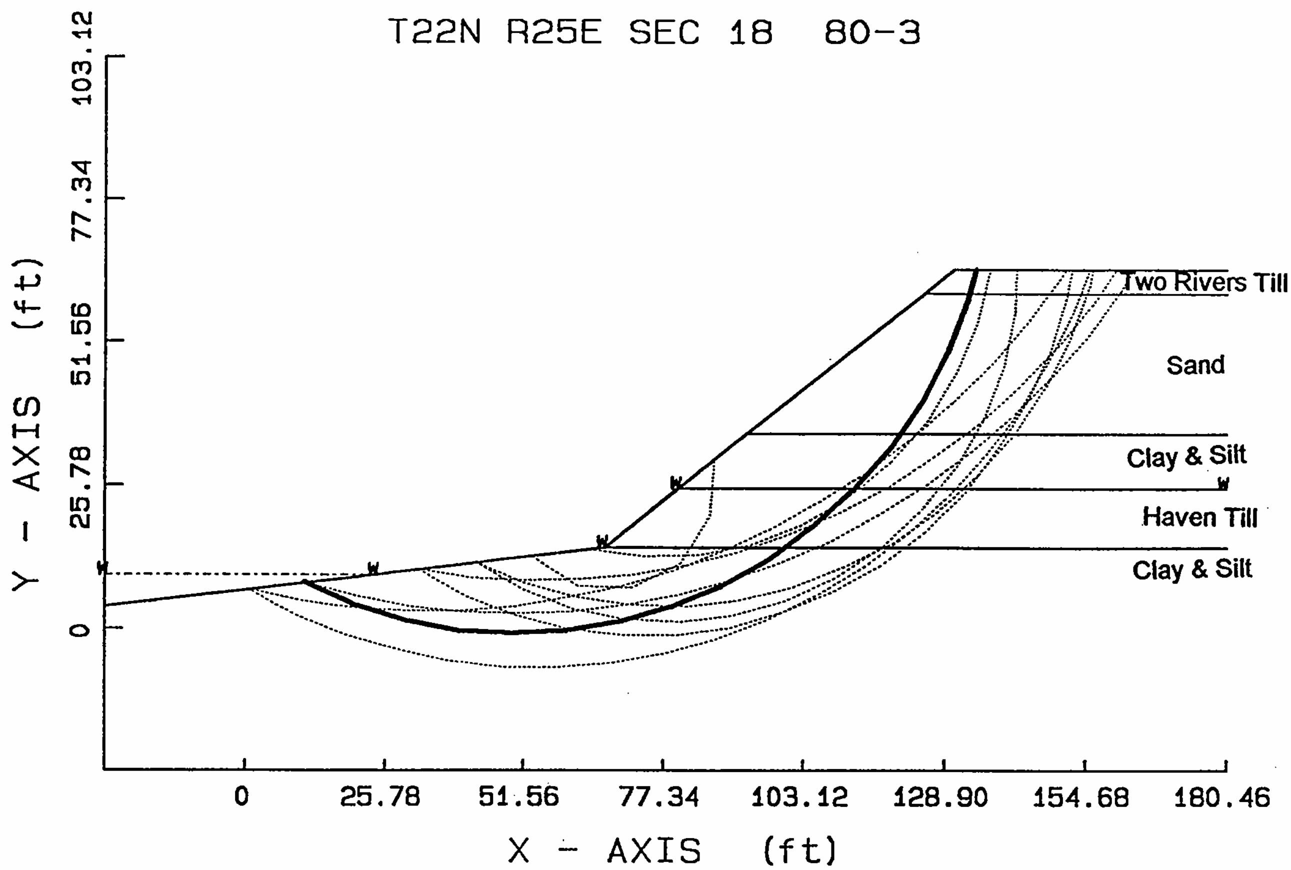


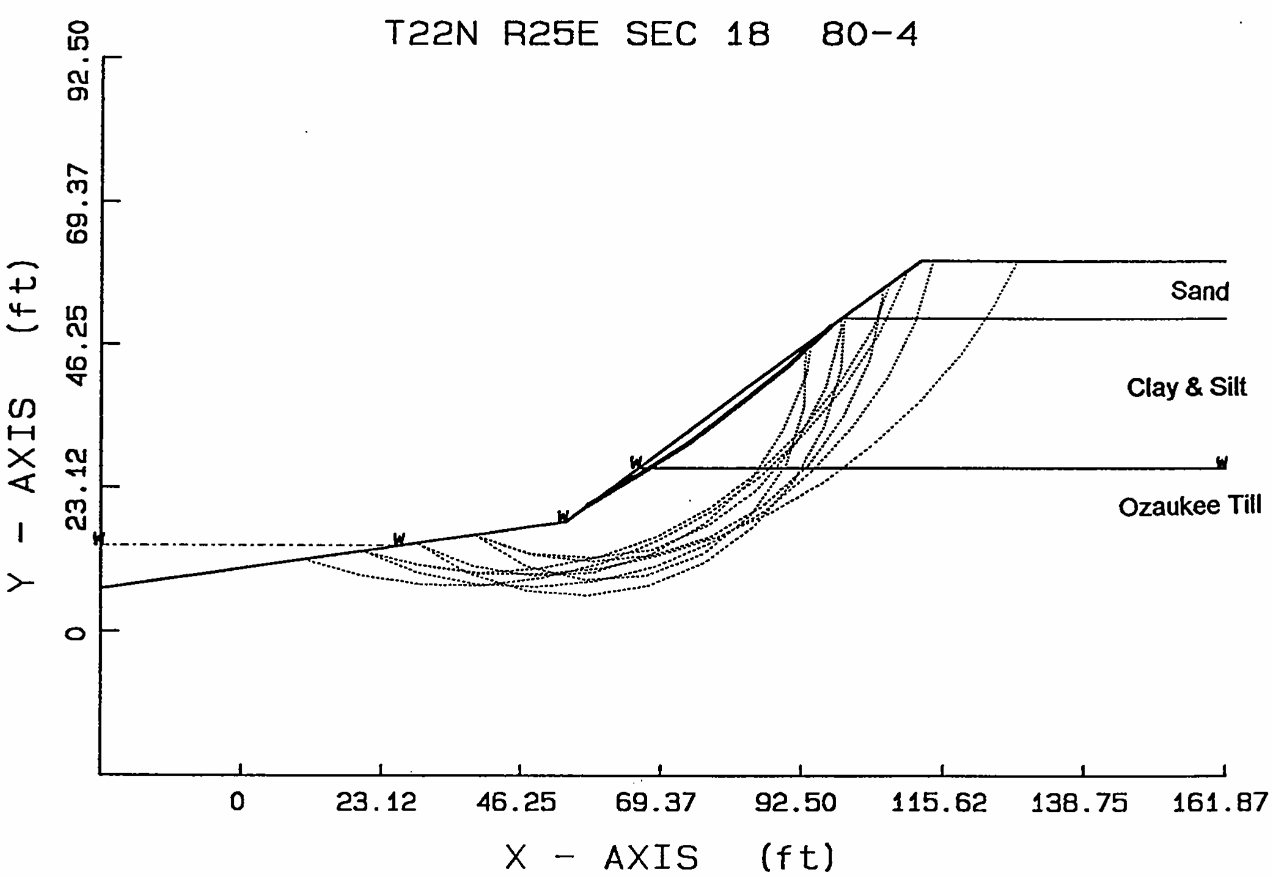
ce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



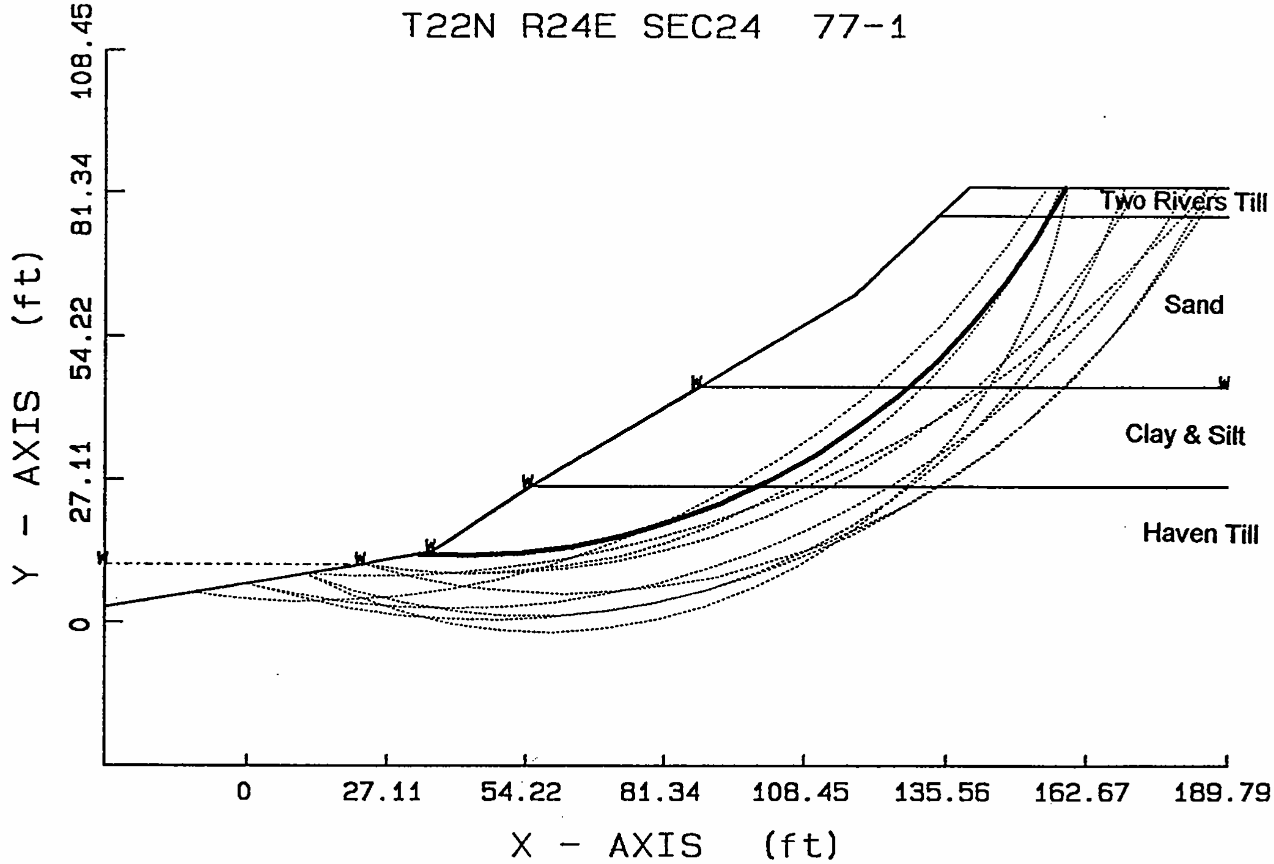


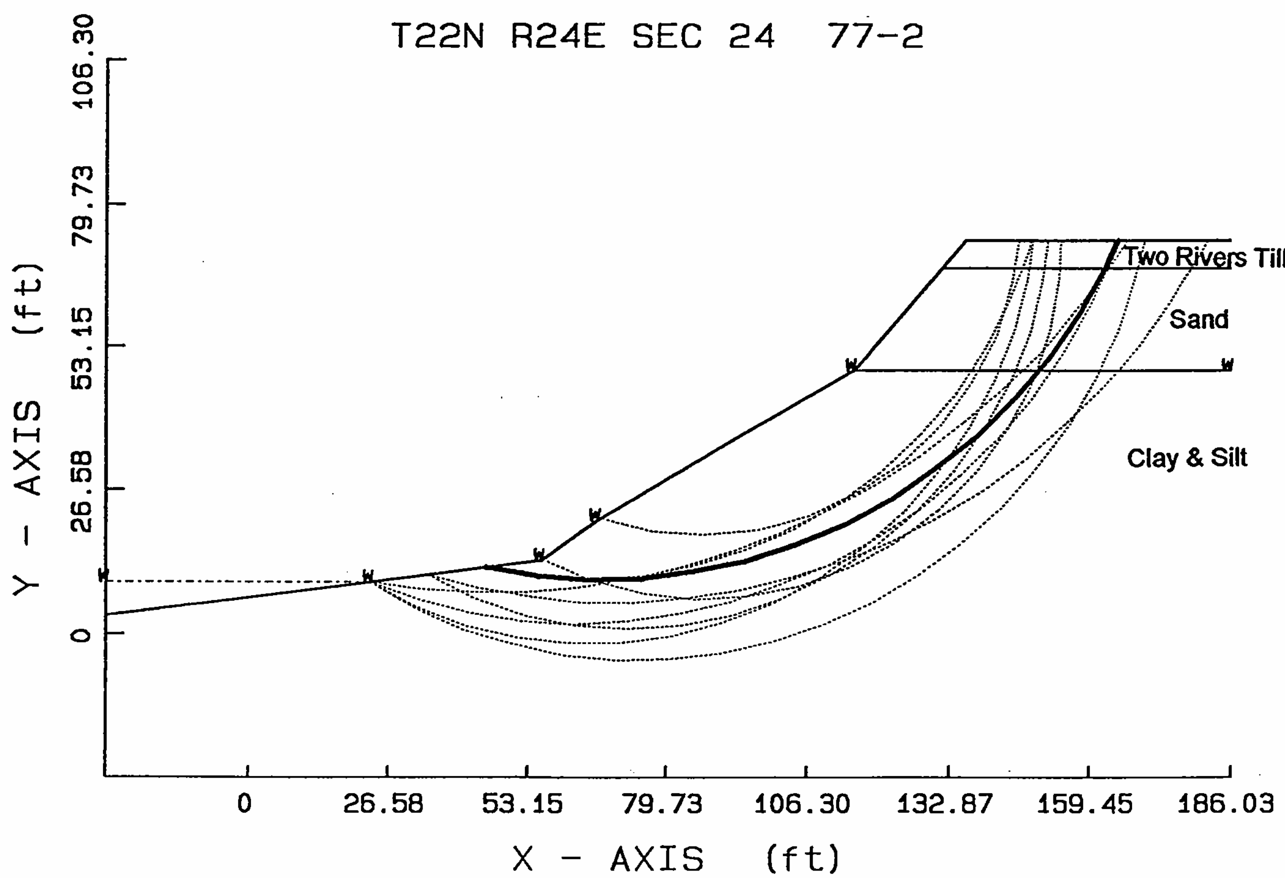
ırce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



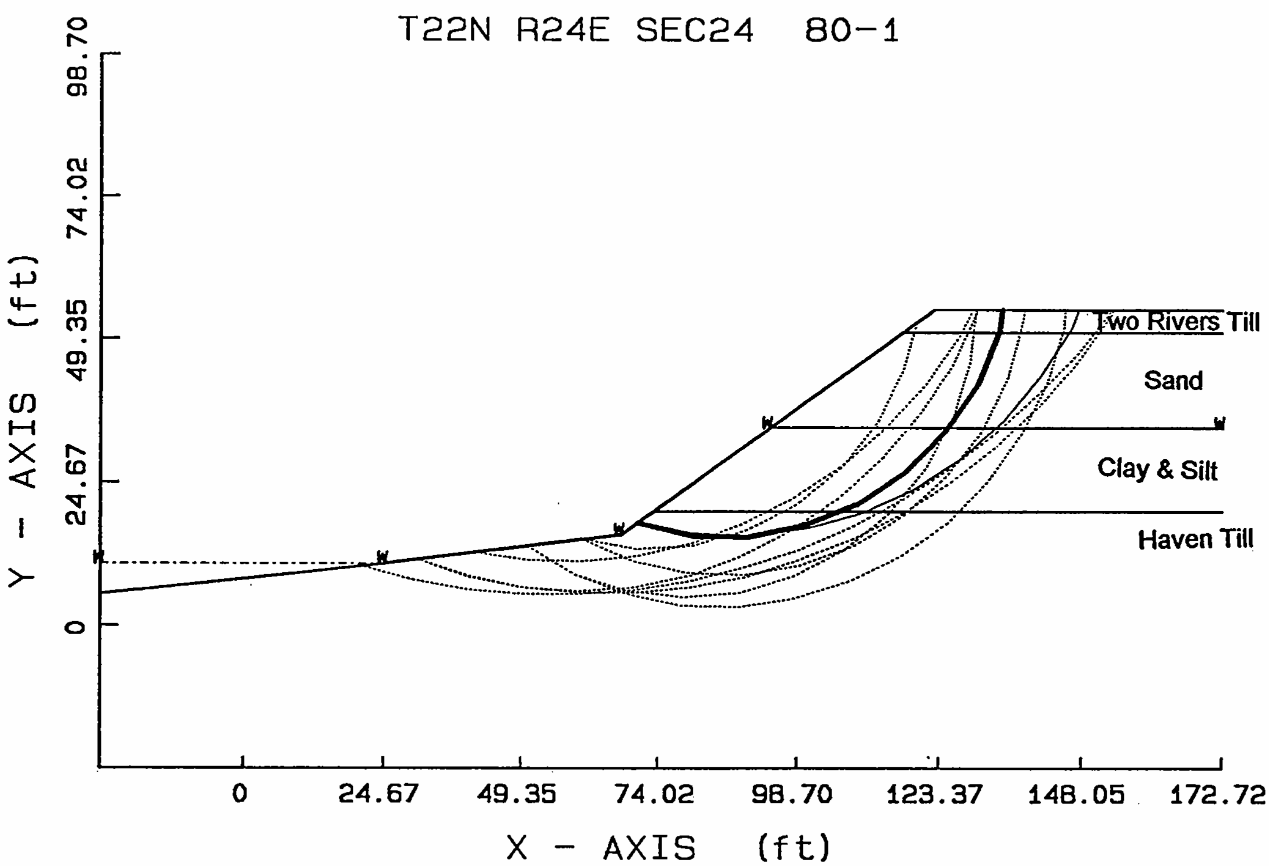


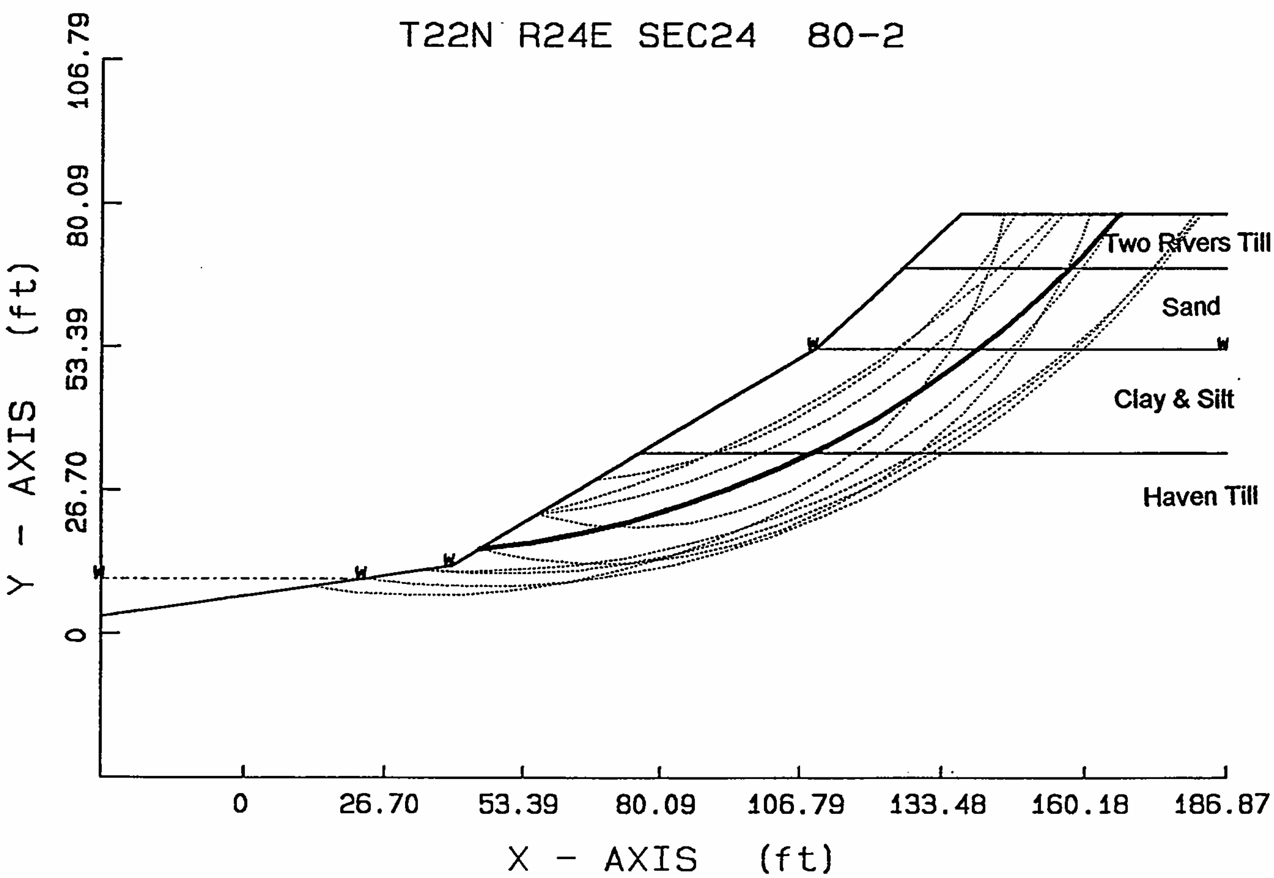
urce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



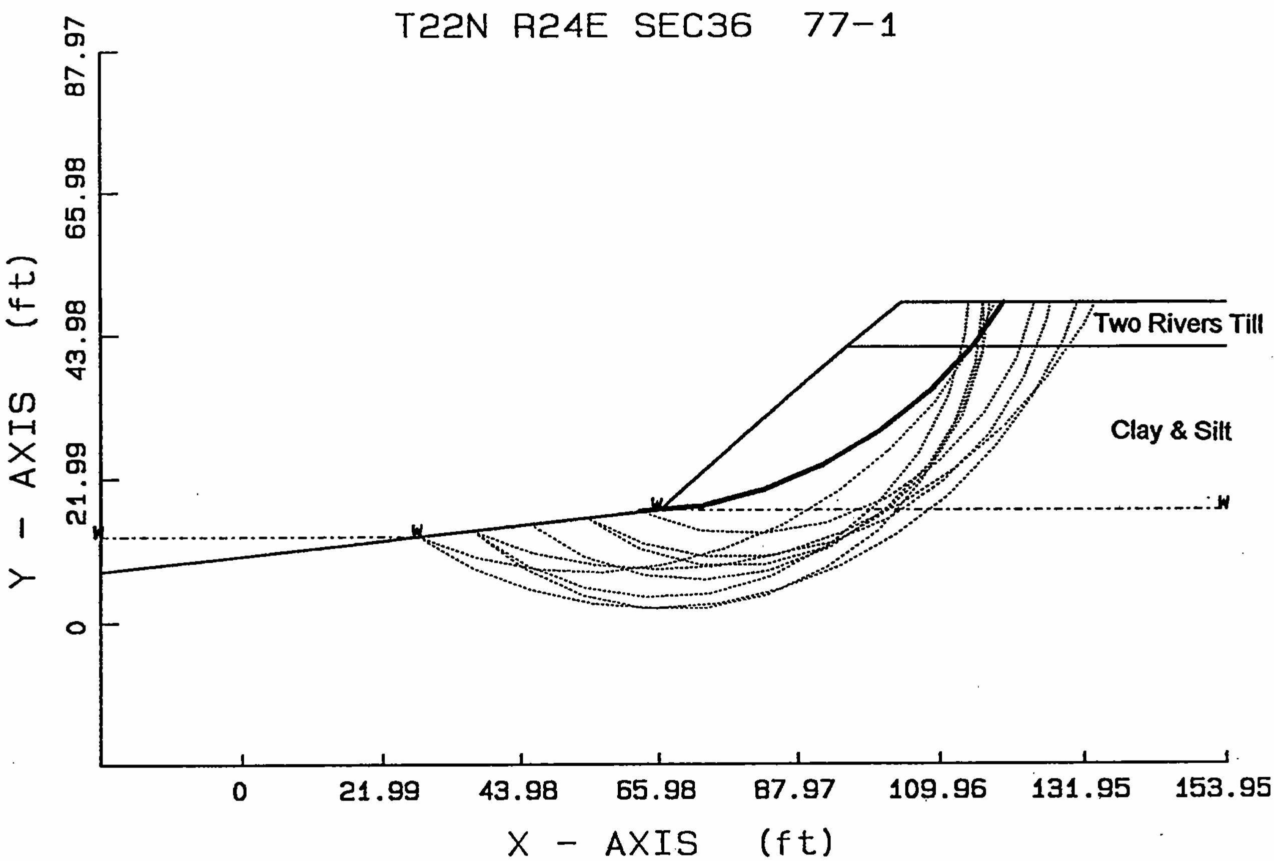


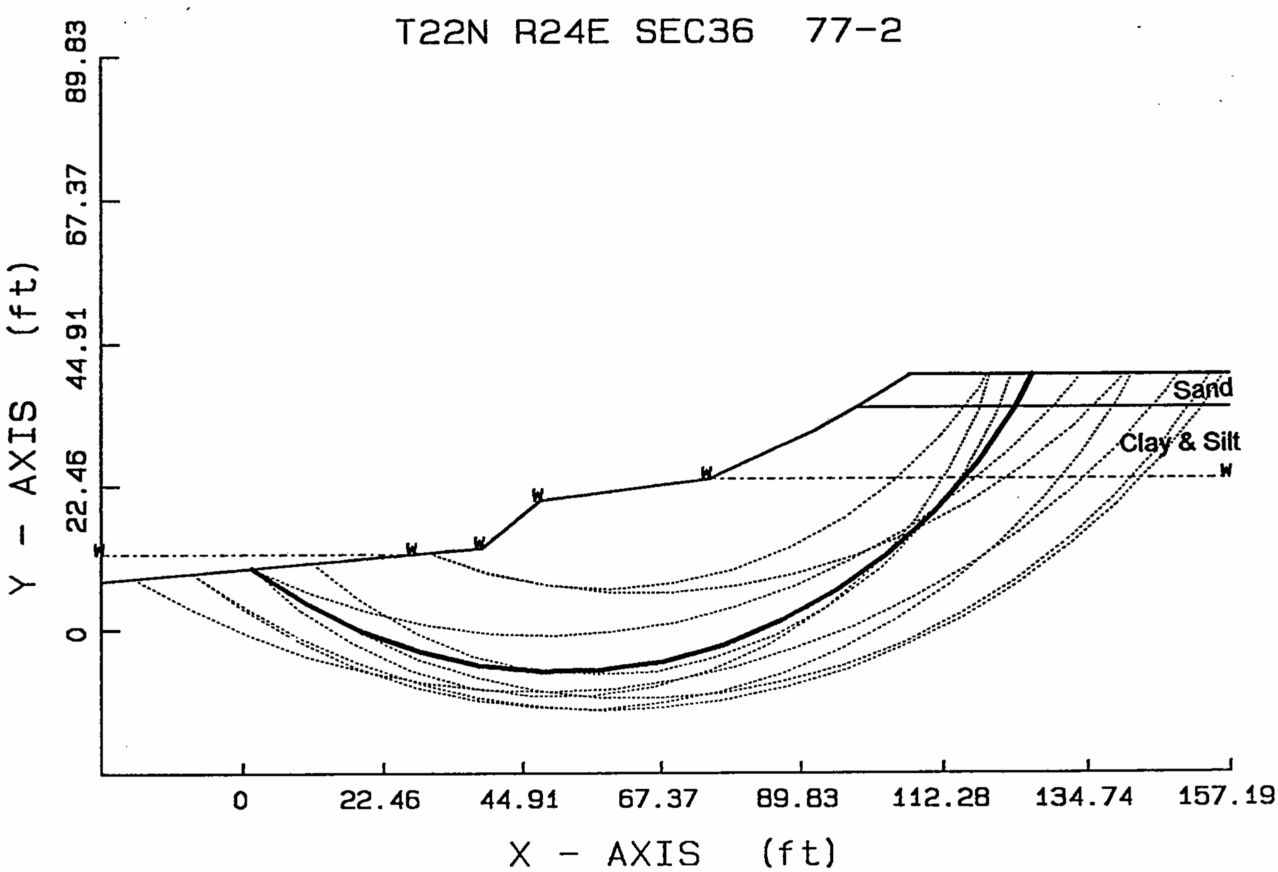
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



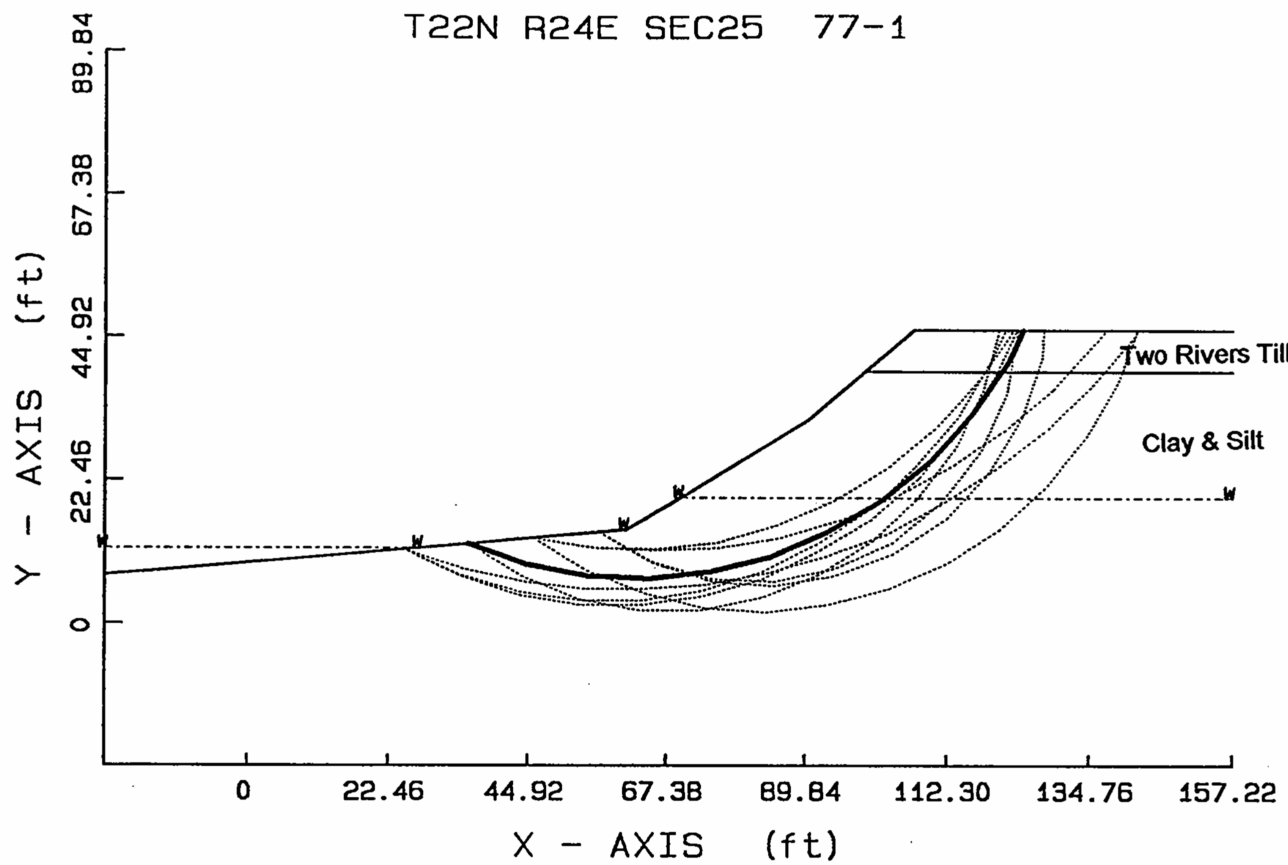


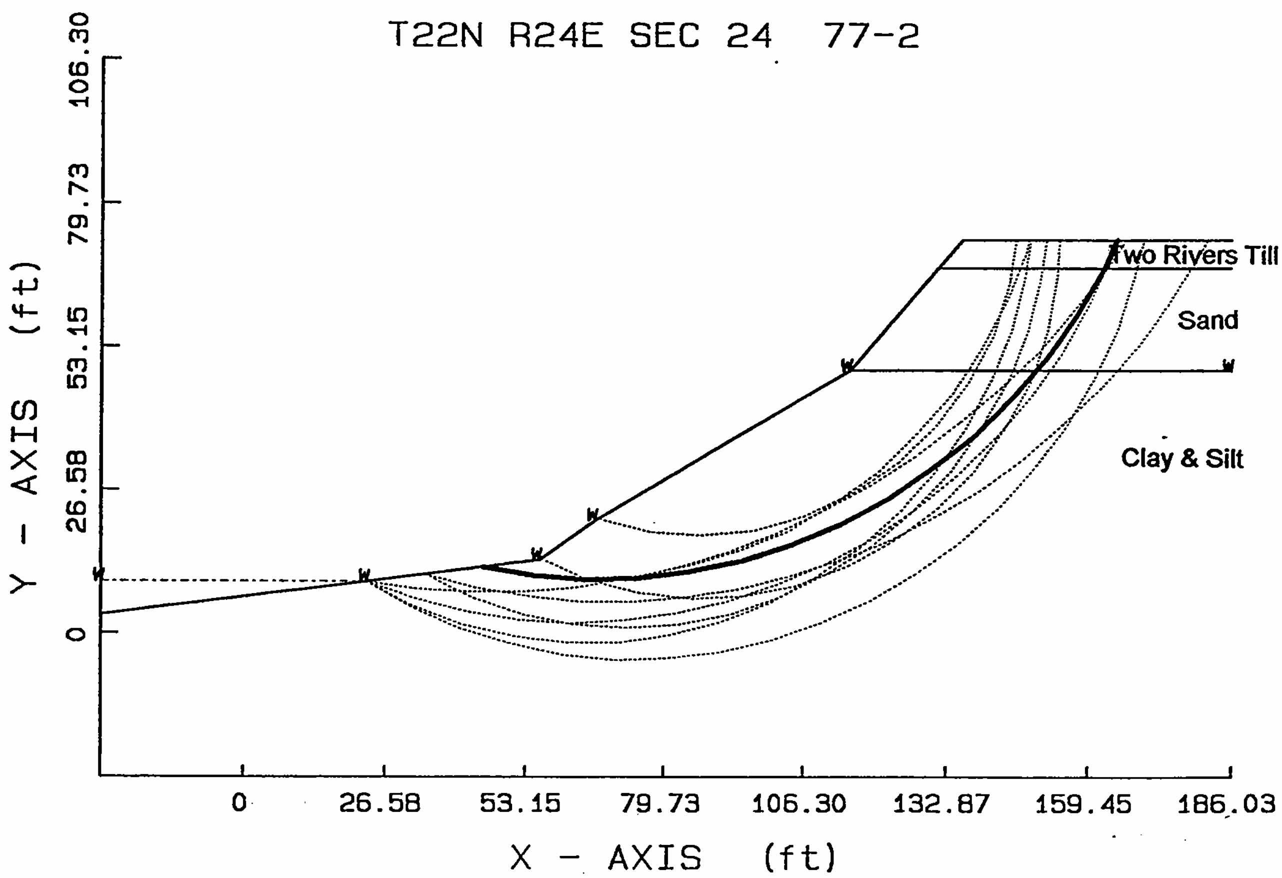
ırce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



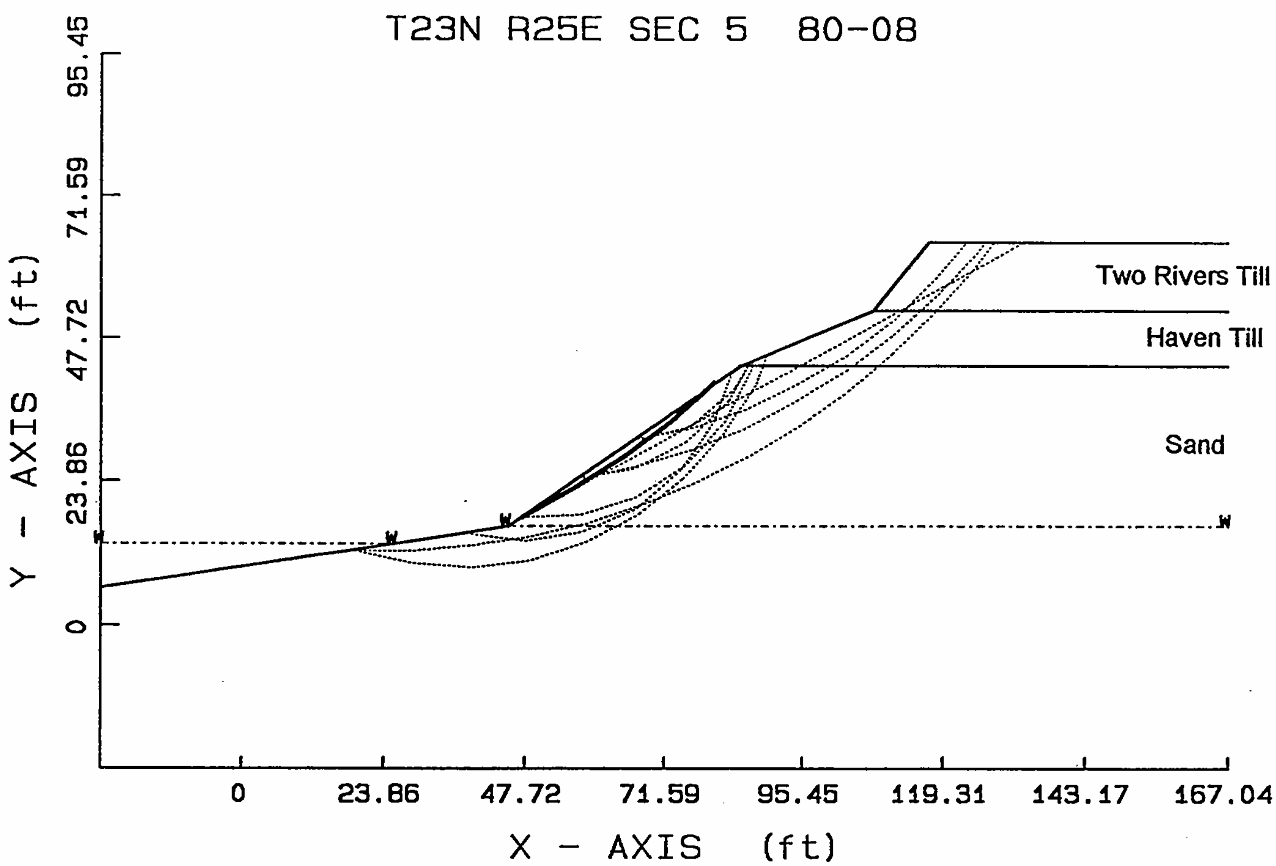


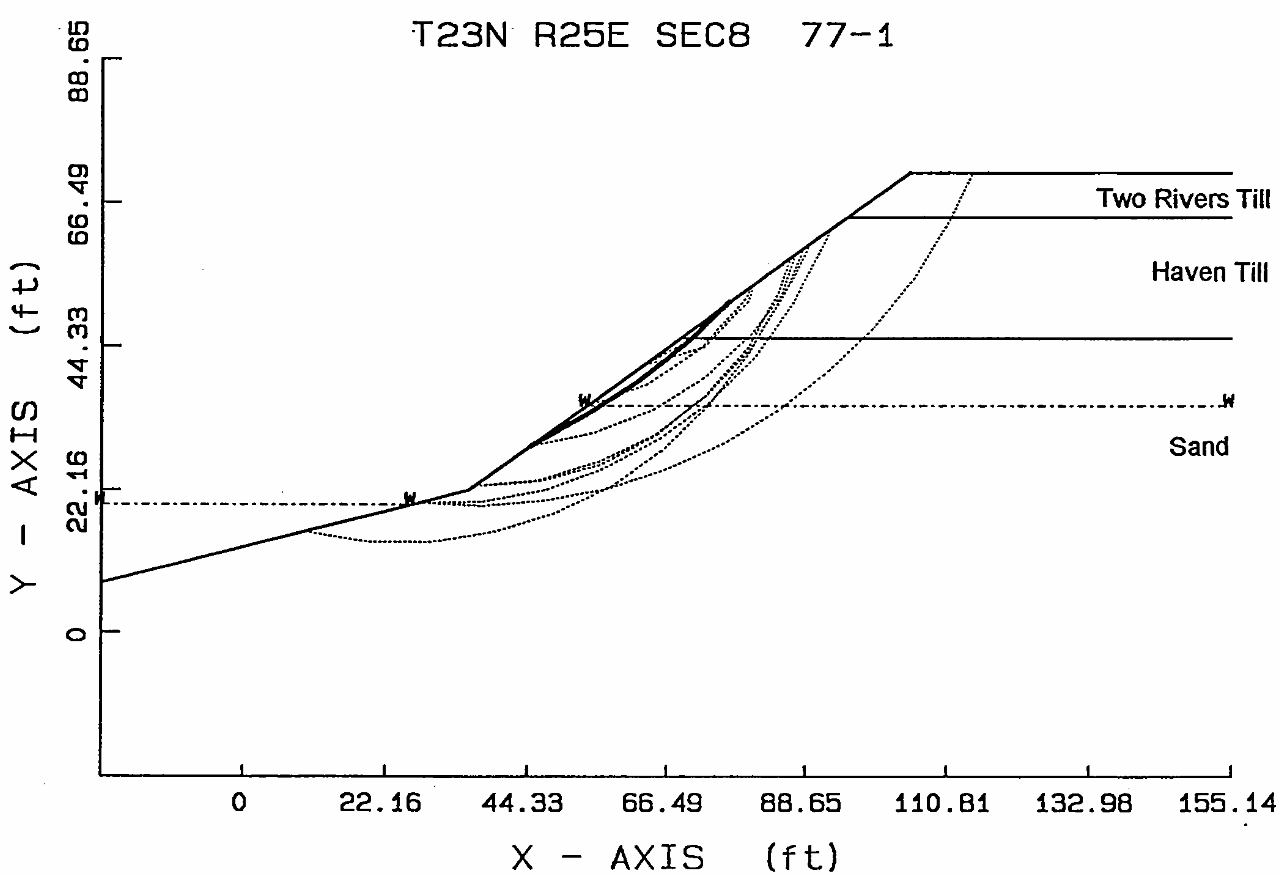
:e: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



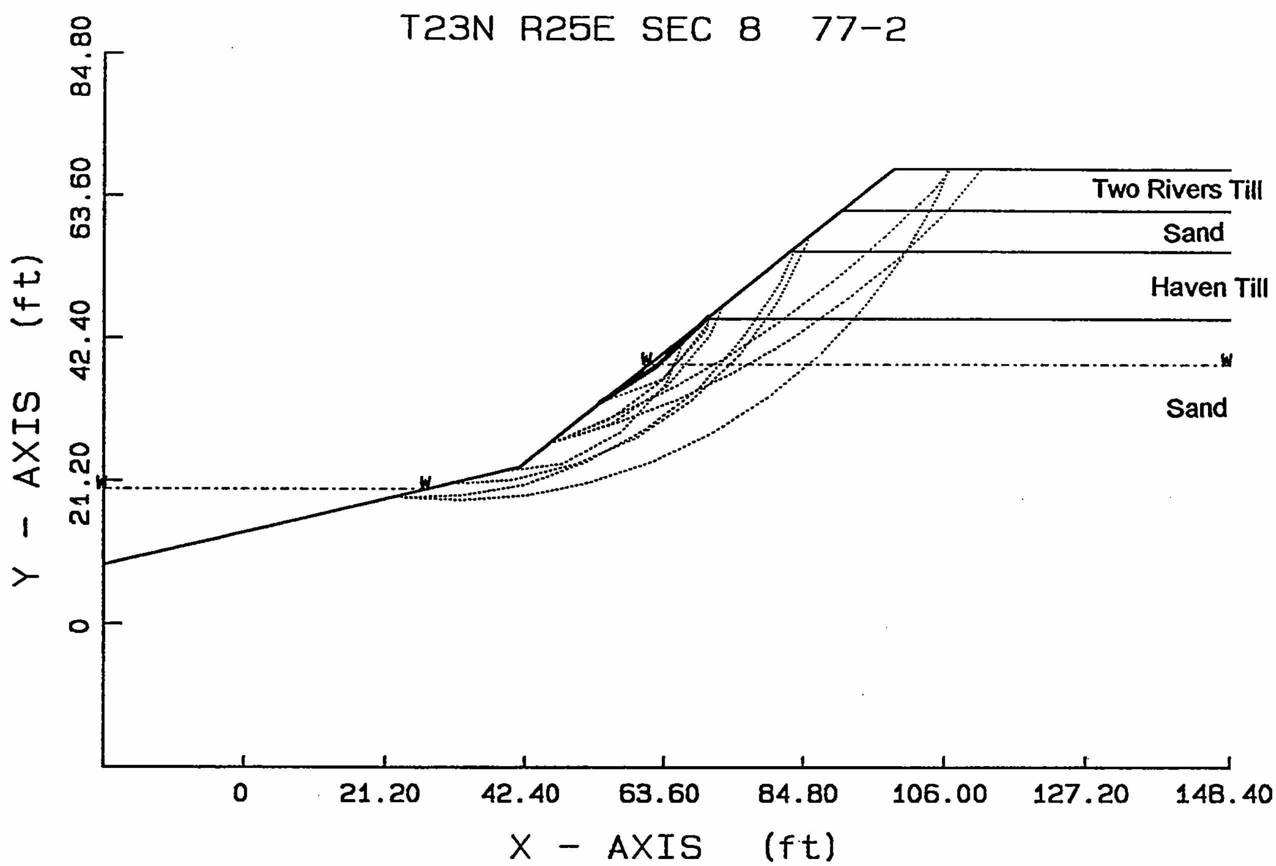


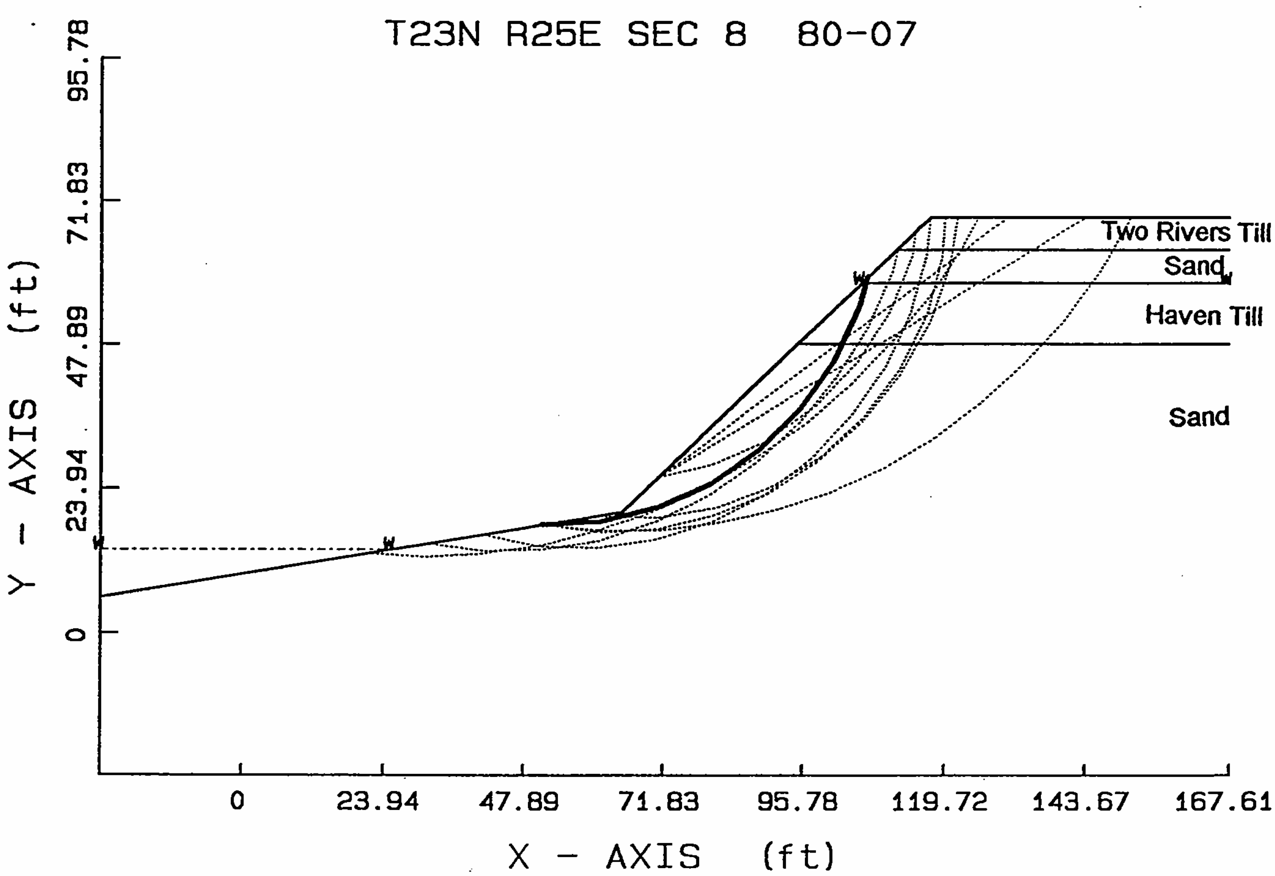
ce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



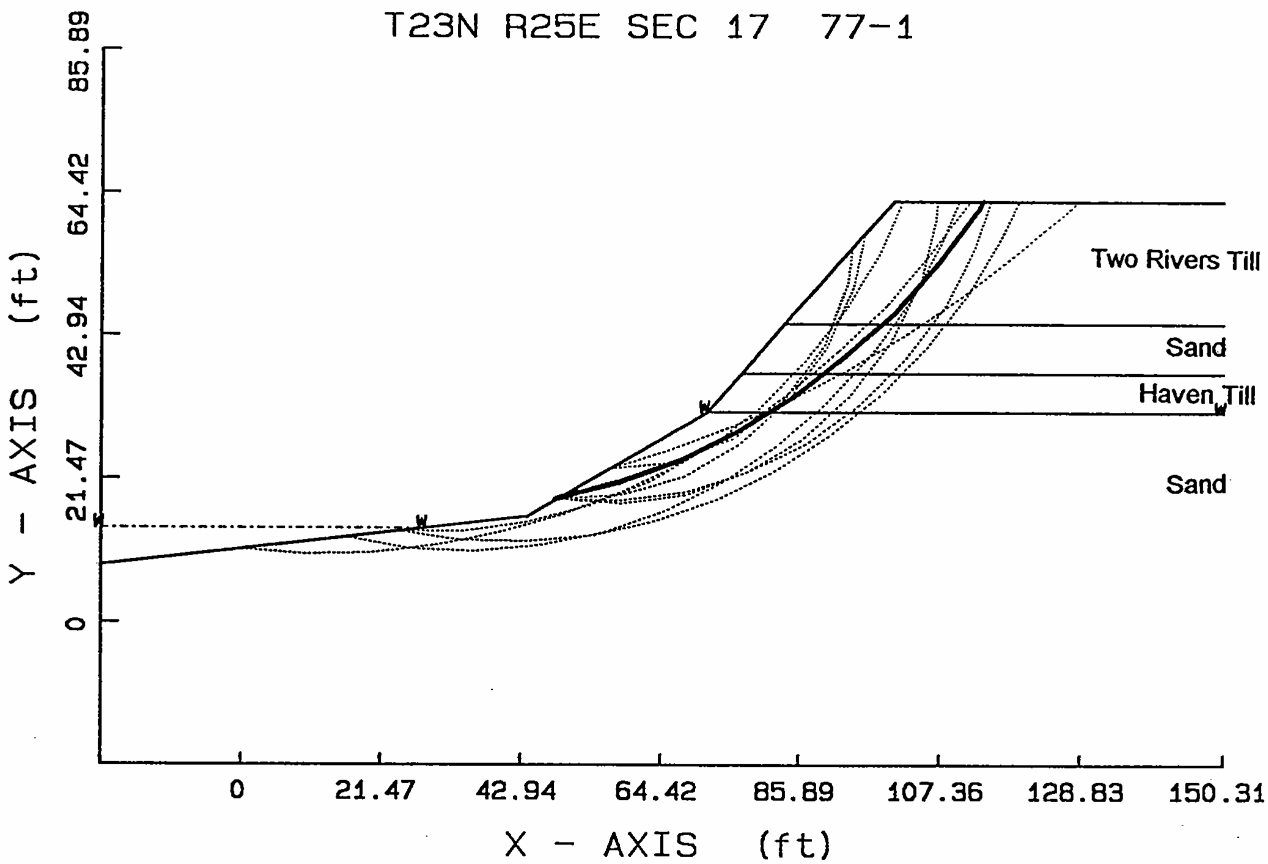


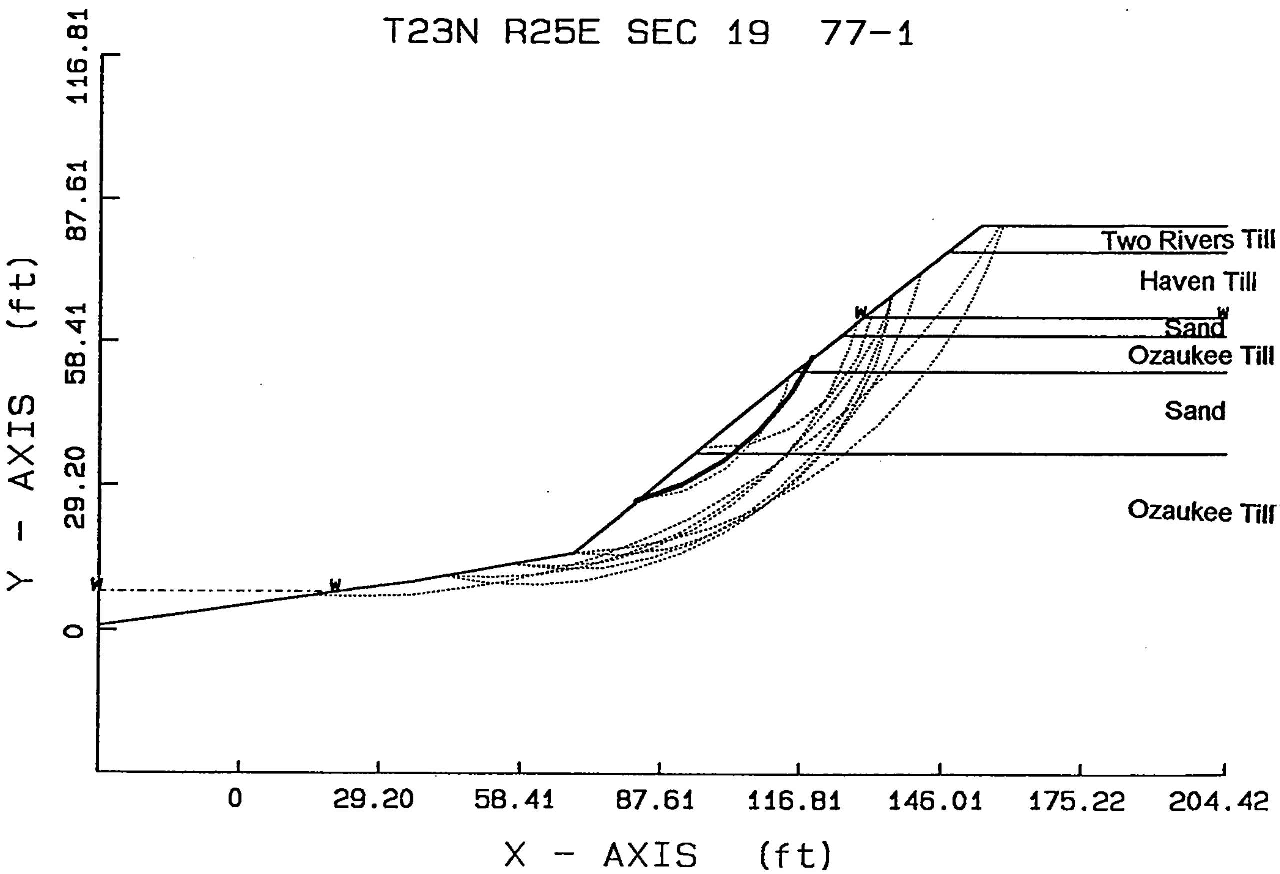
ce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



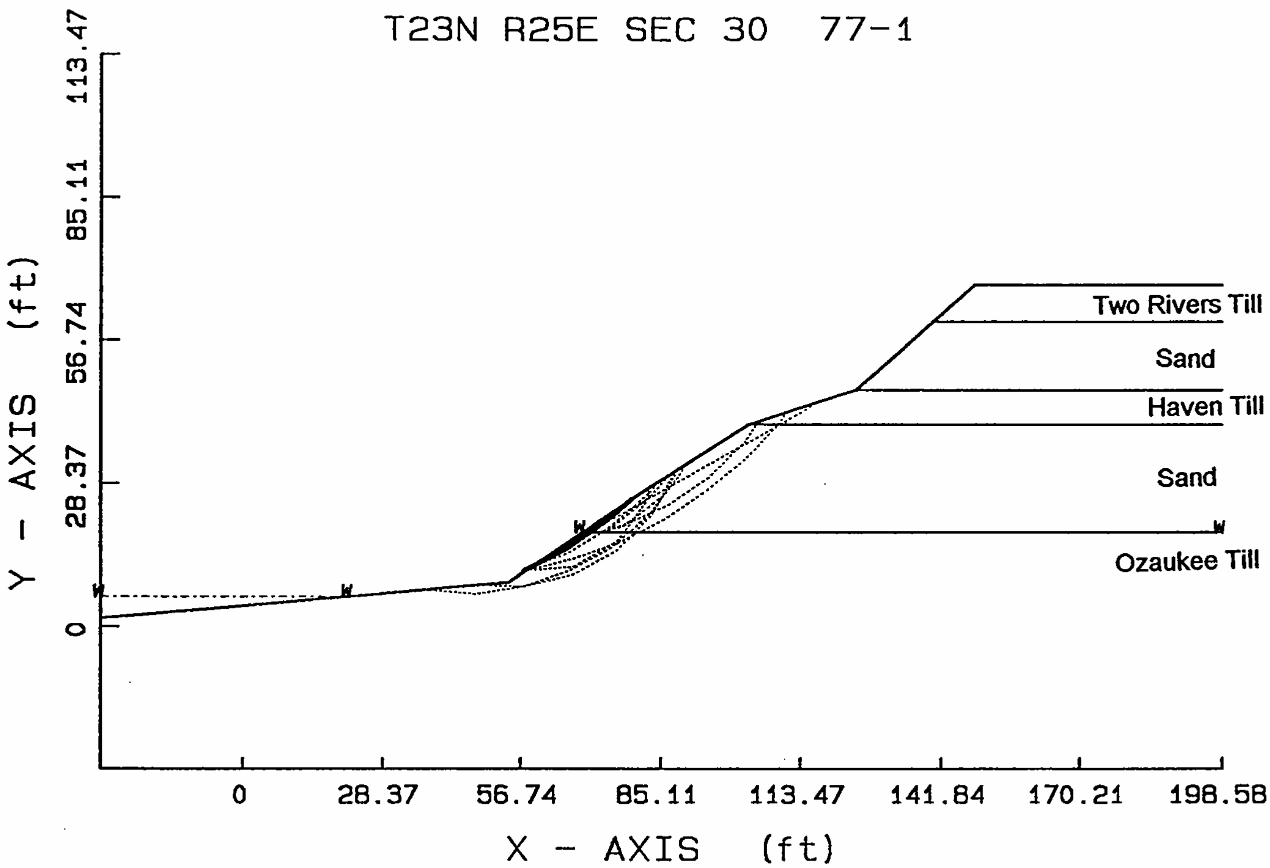


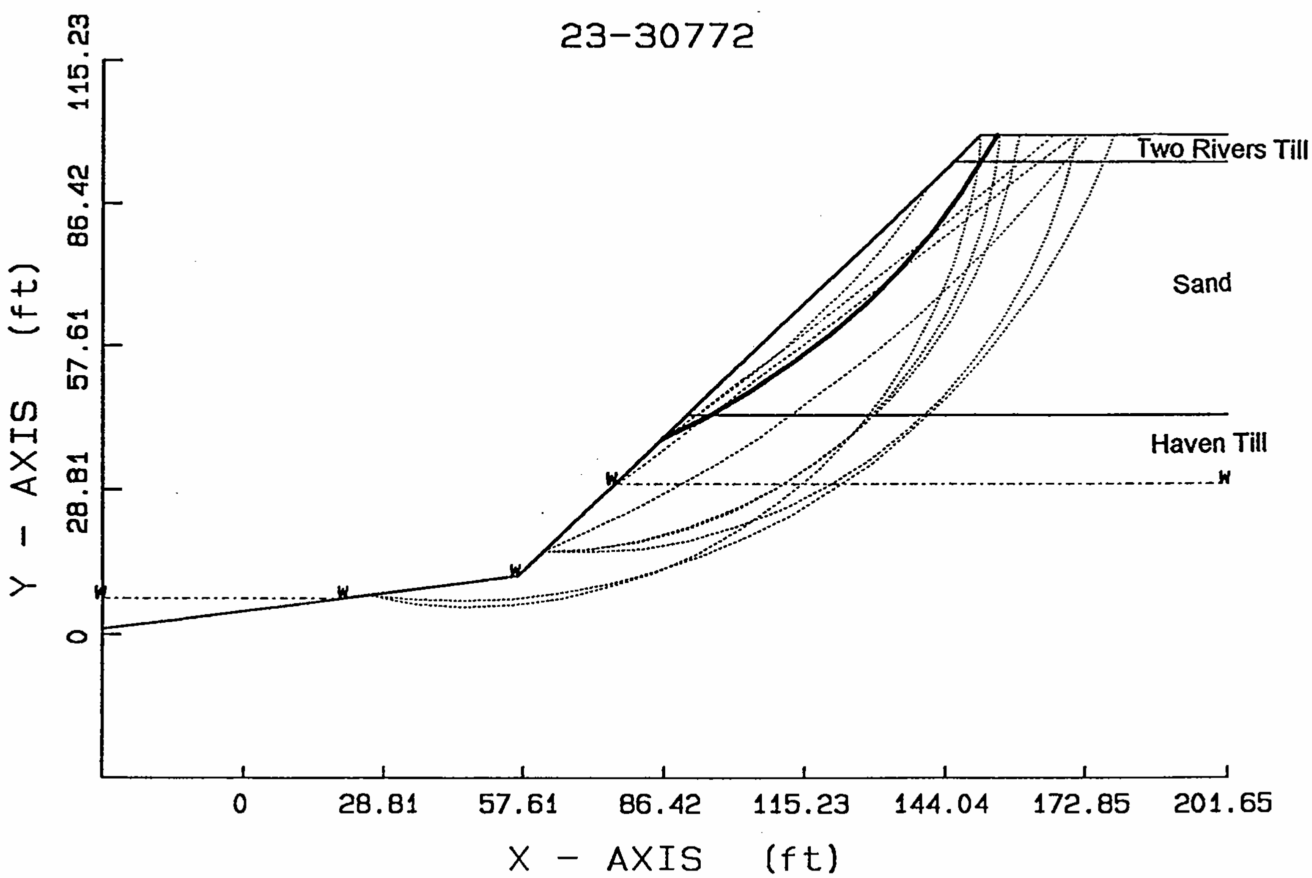
urce: T.B. Edil, D.M: Mickelson, and Bay Lake Regional Planning Commission, 1997



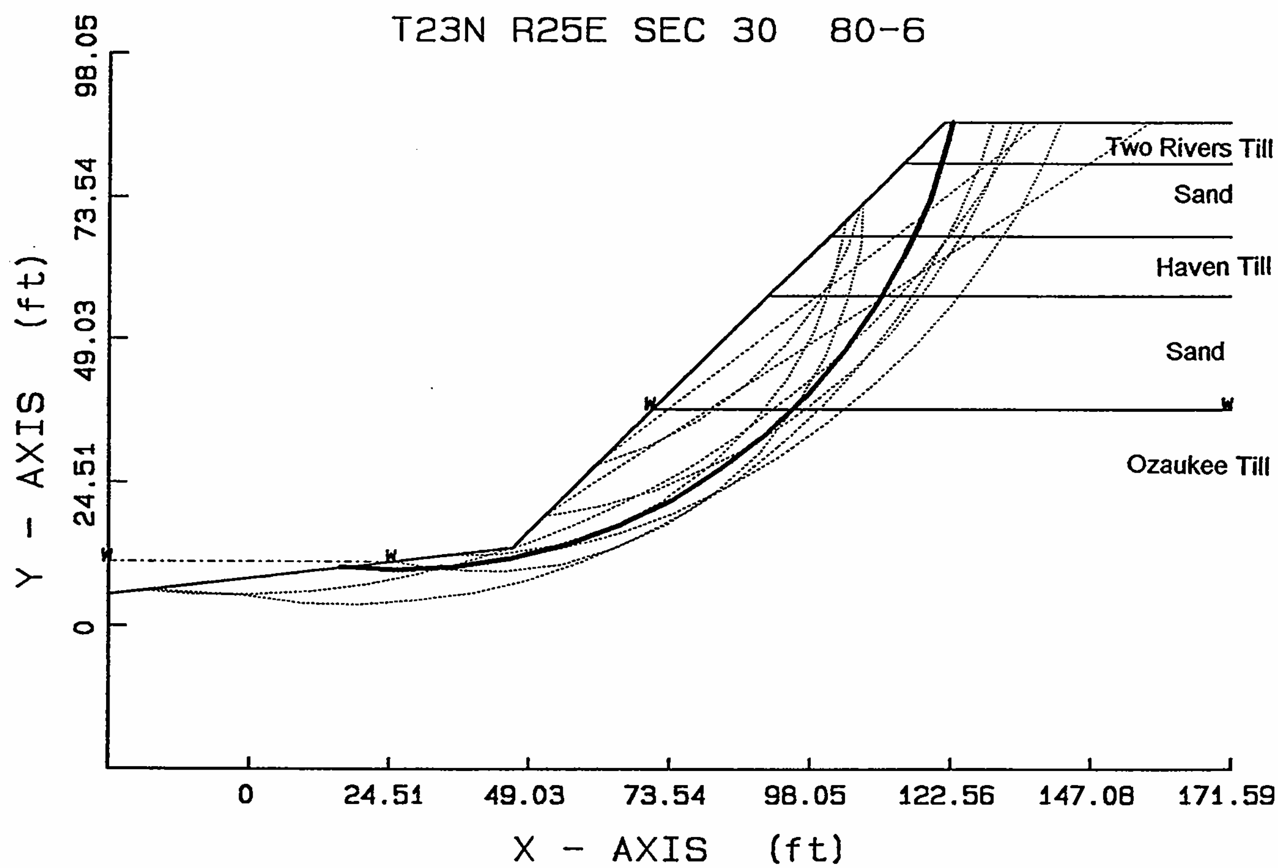


ce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

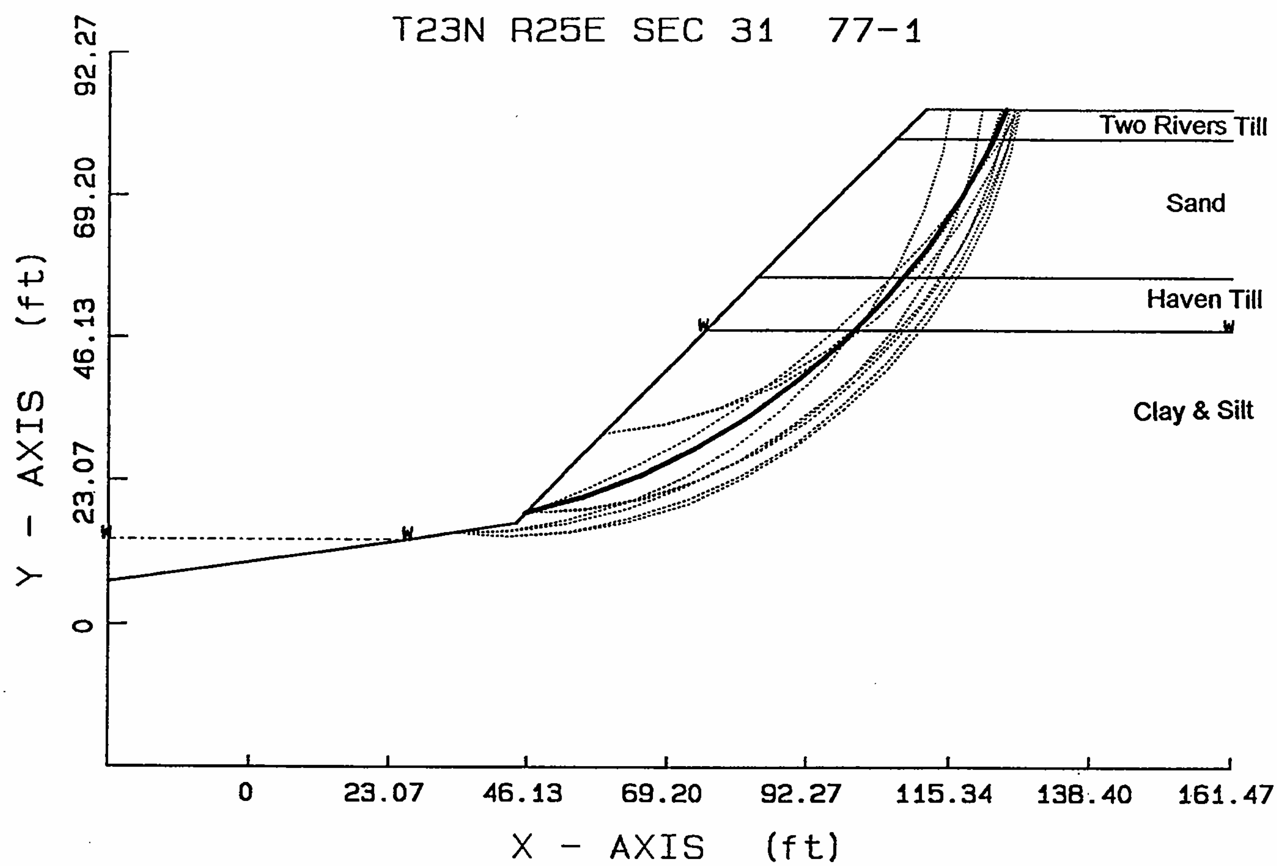


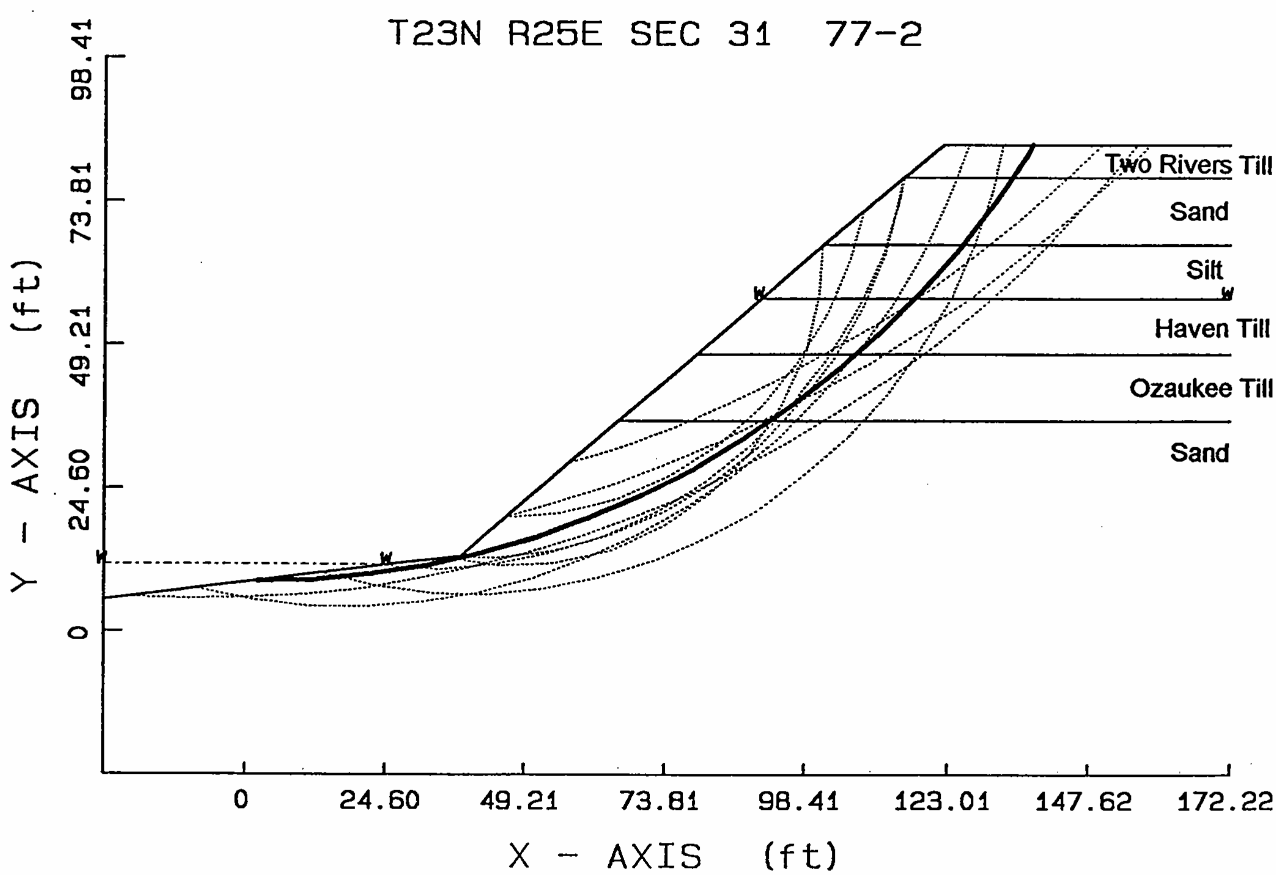


rce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

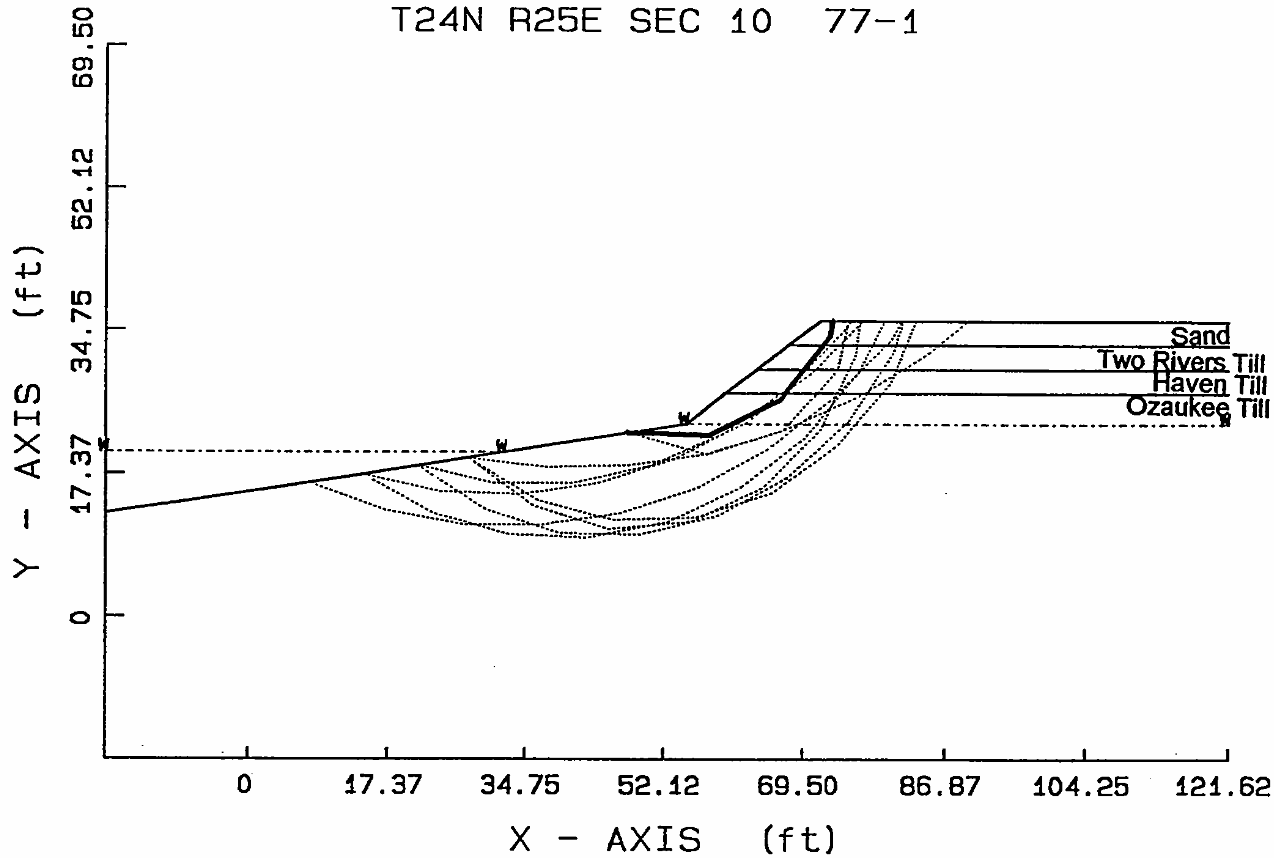


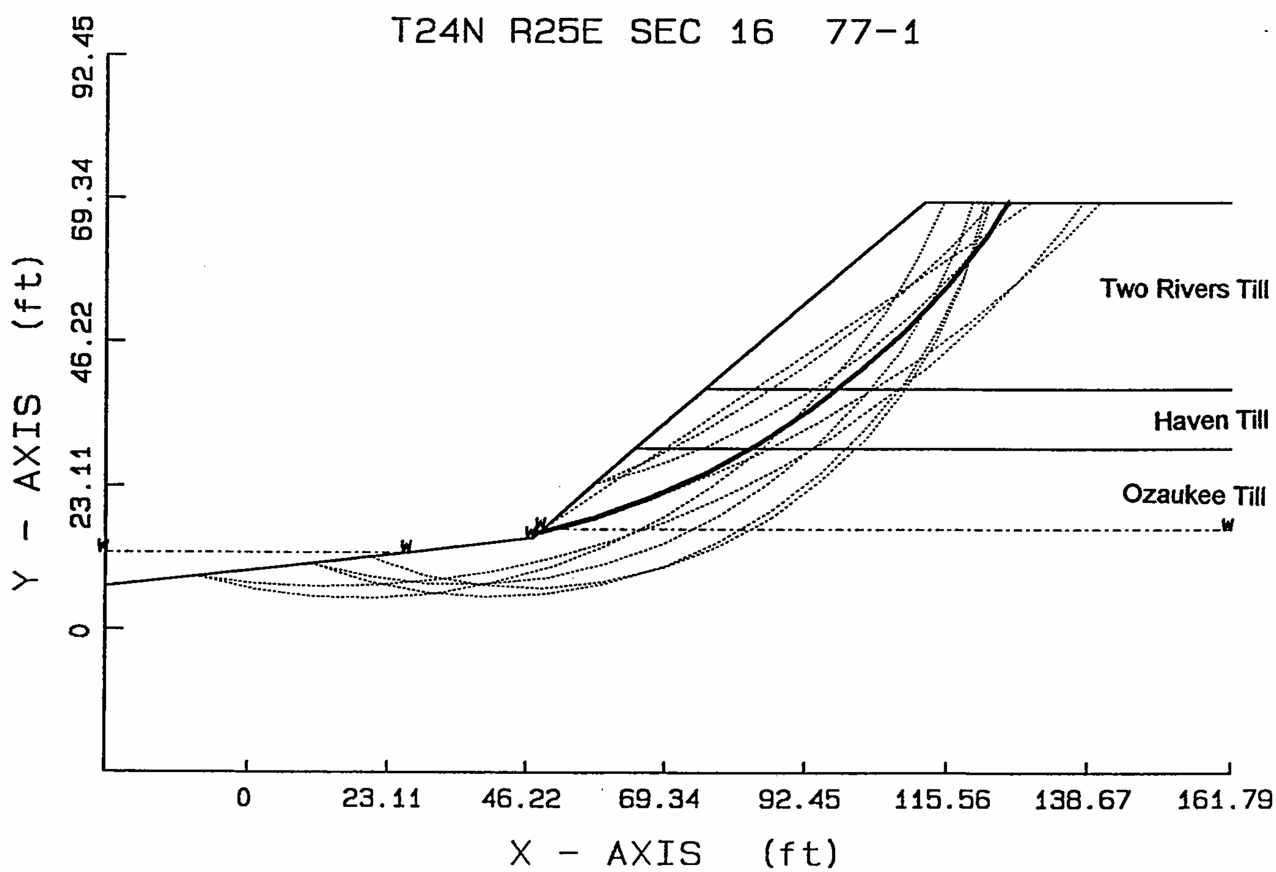
rce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



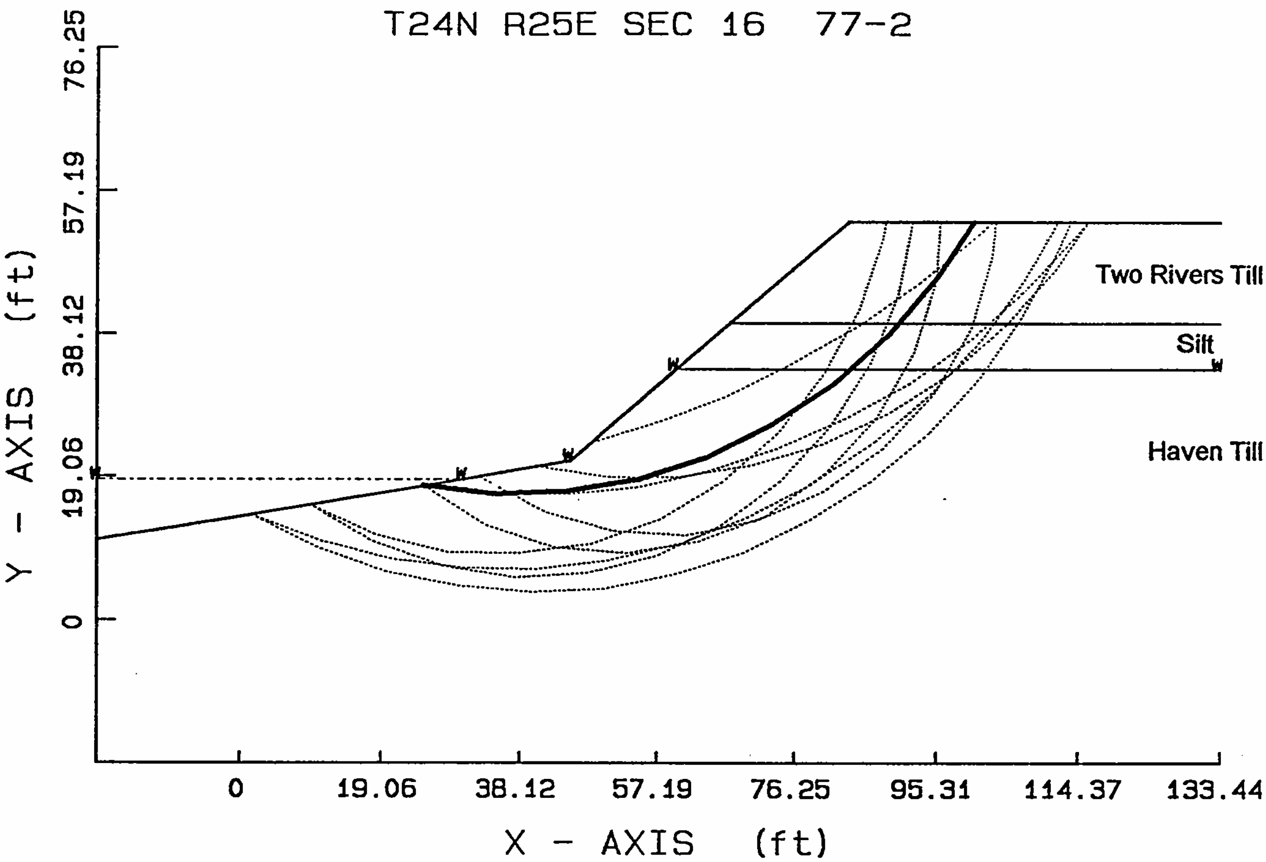


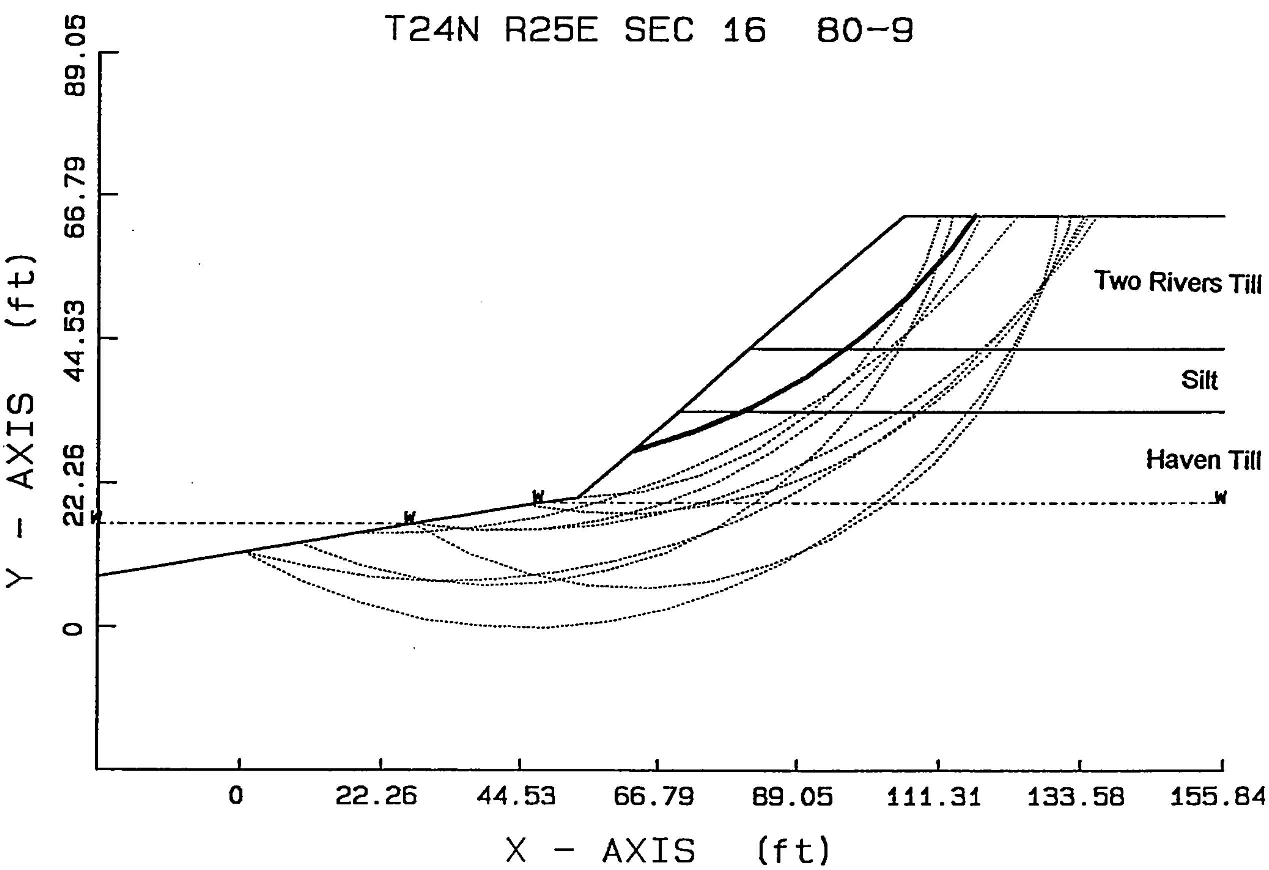
ource: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



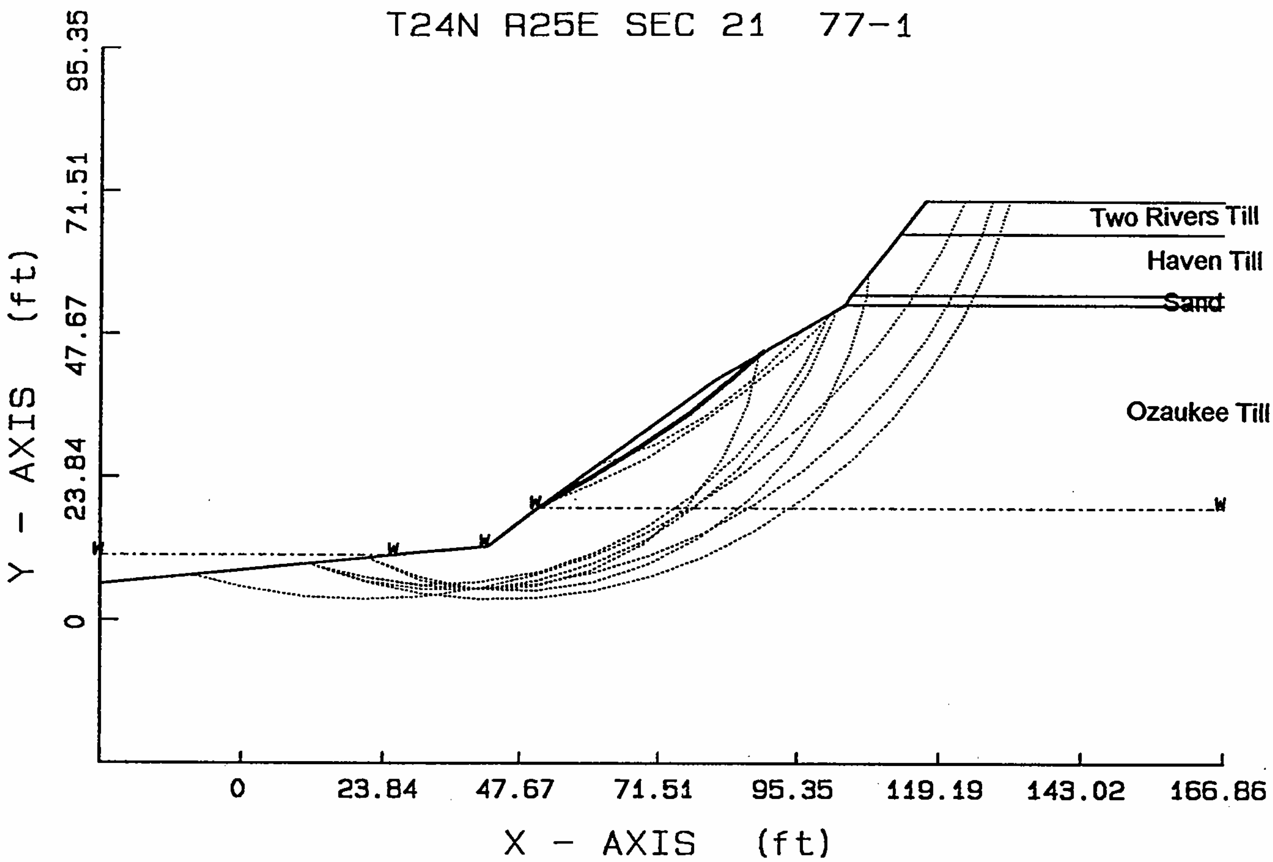


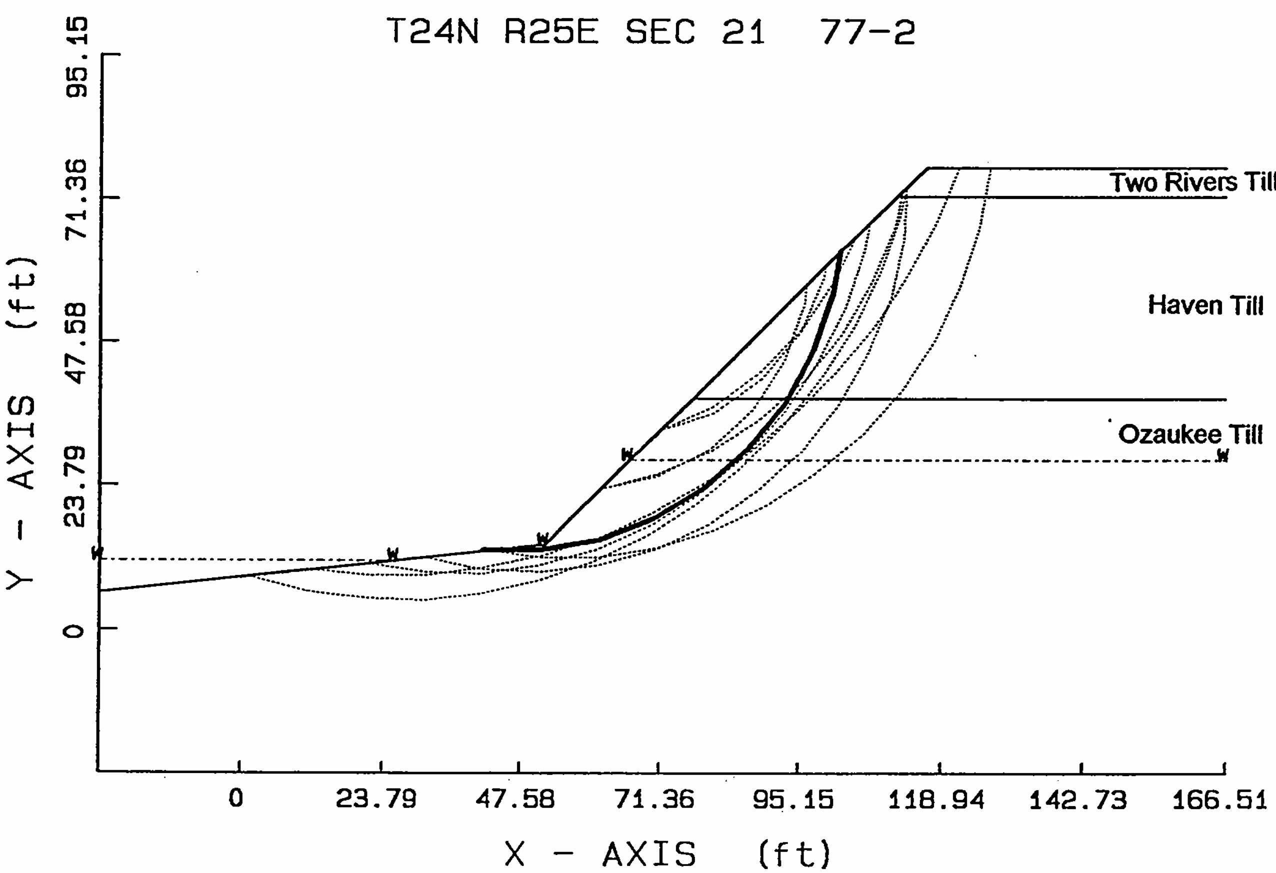
ırce: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



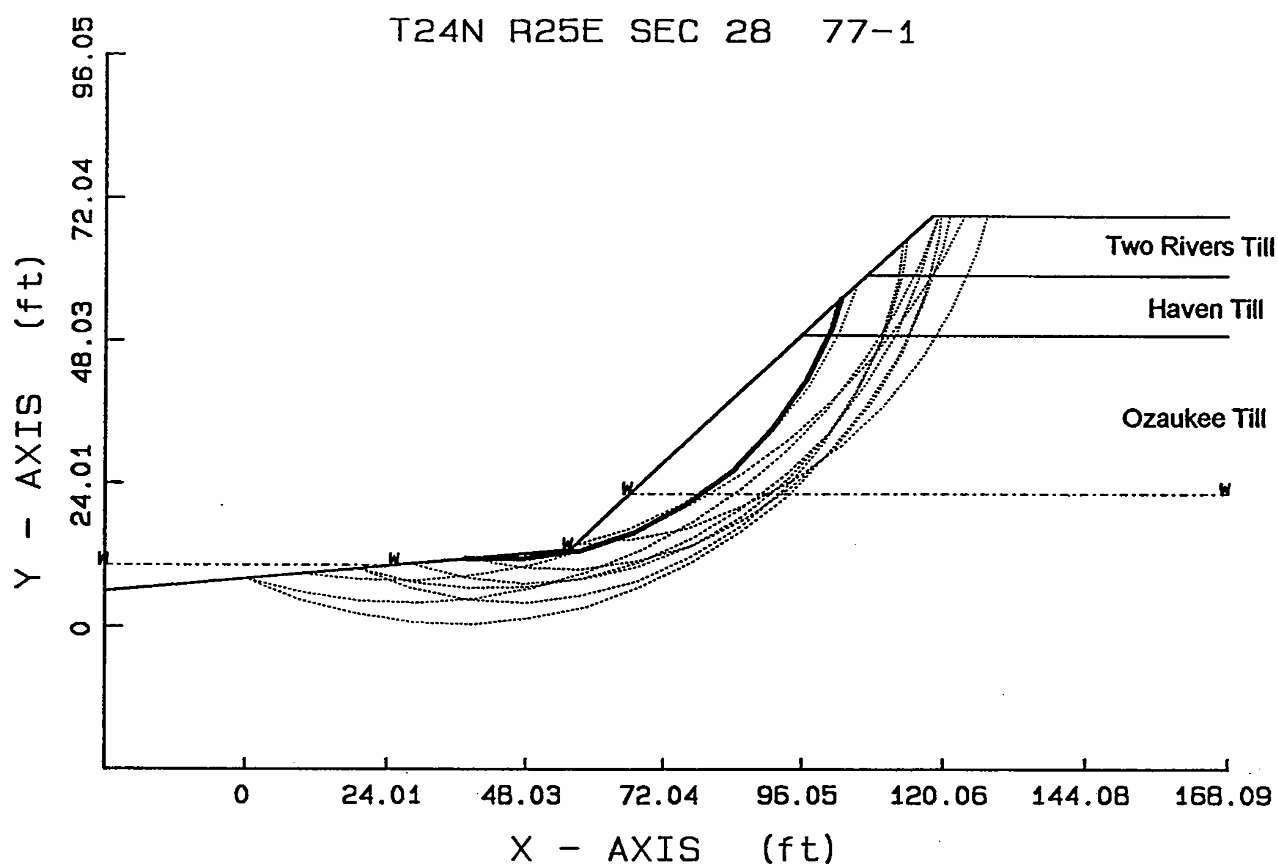


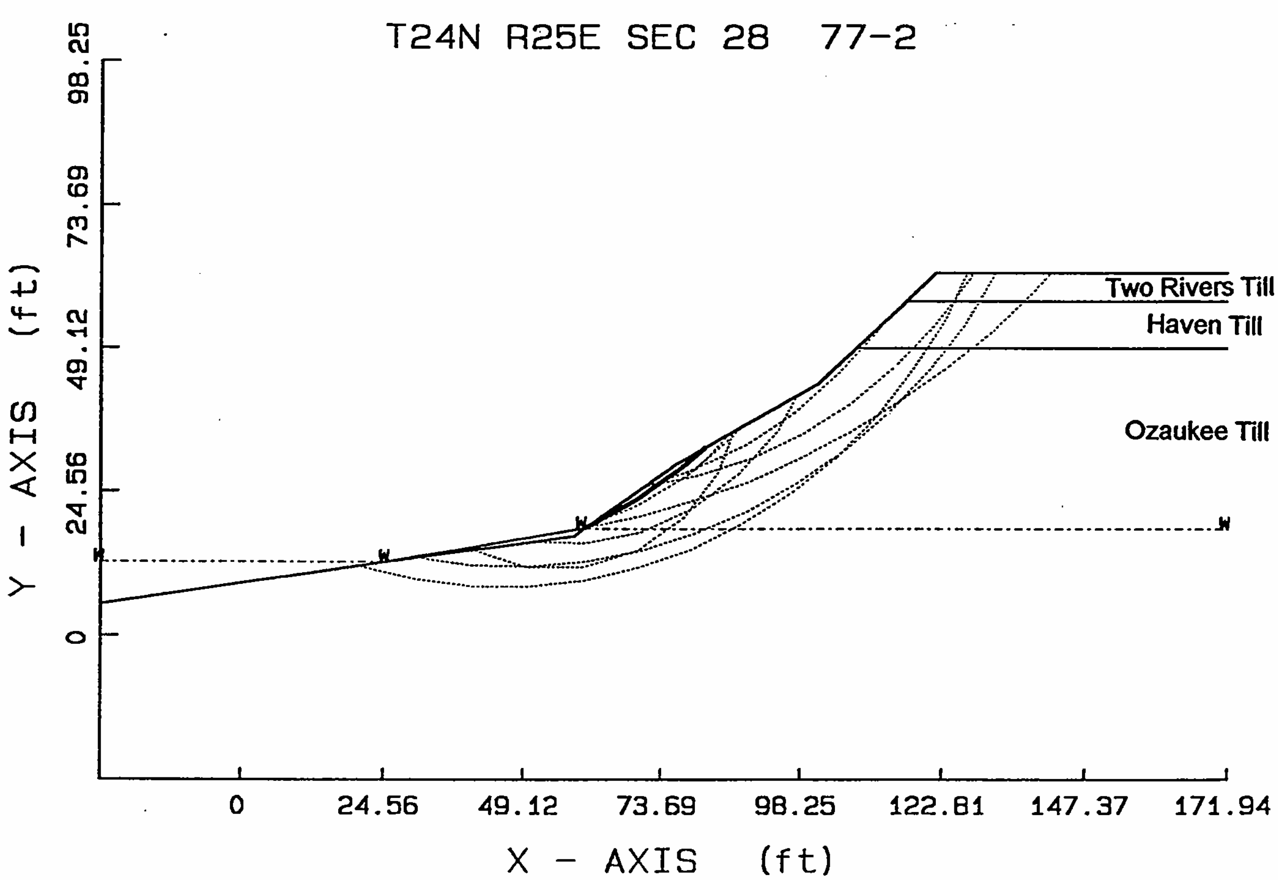
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



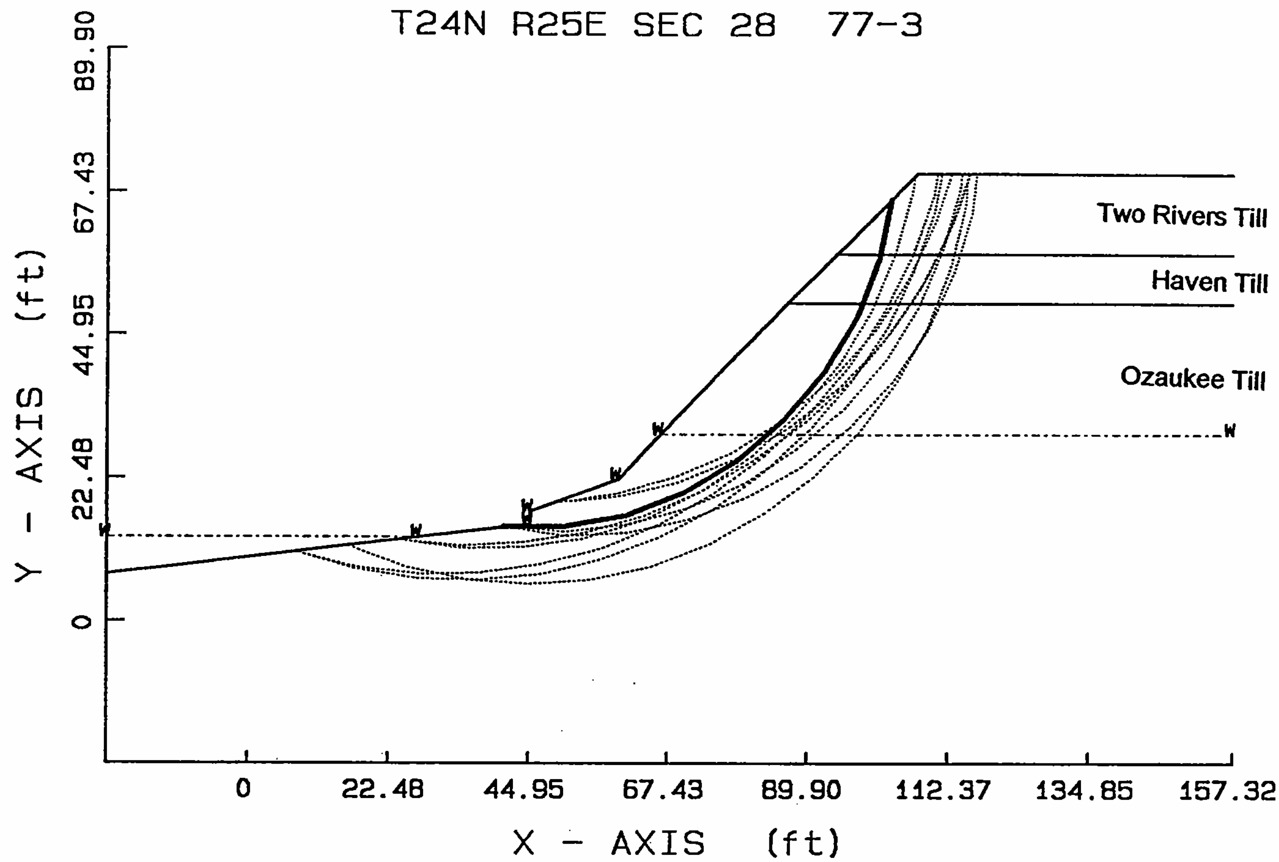


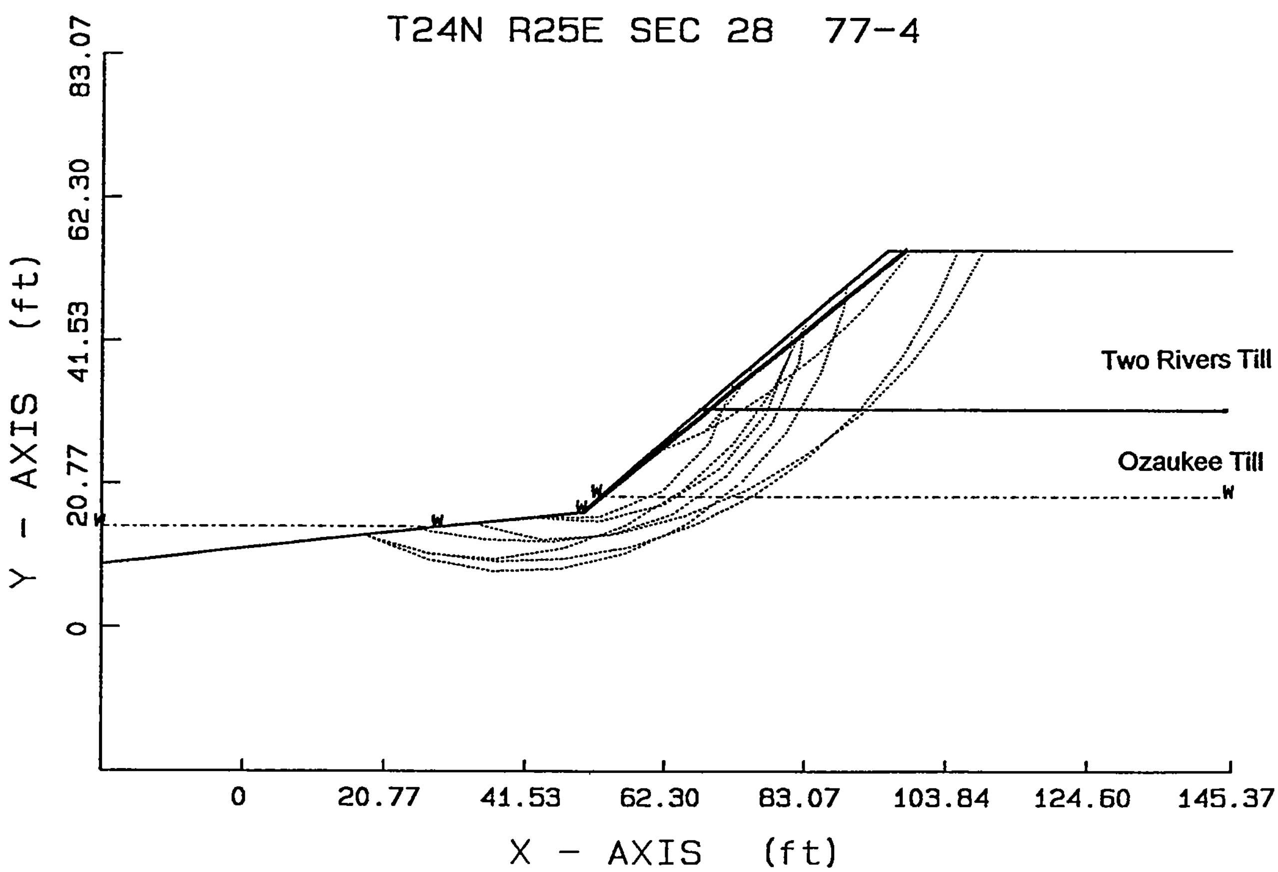
ource: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



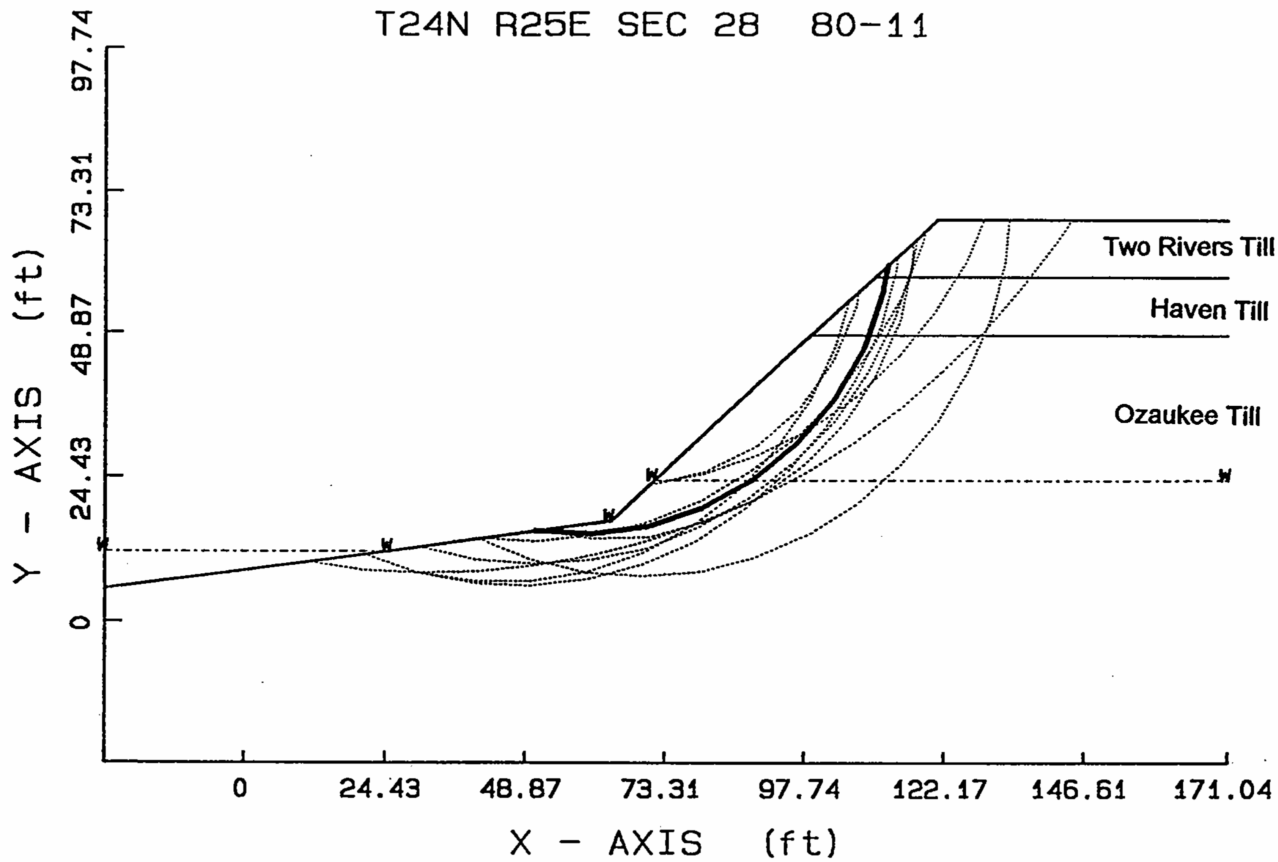


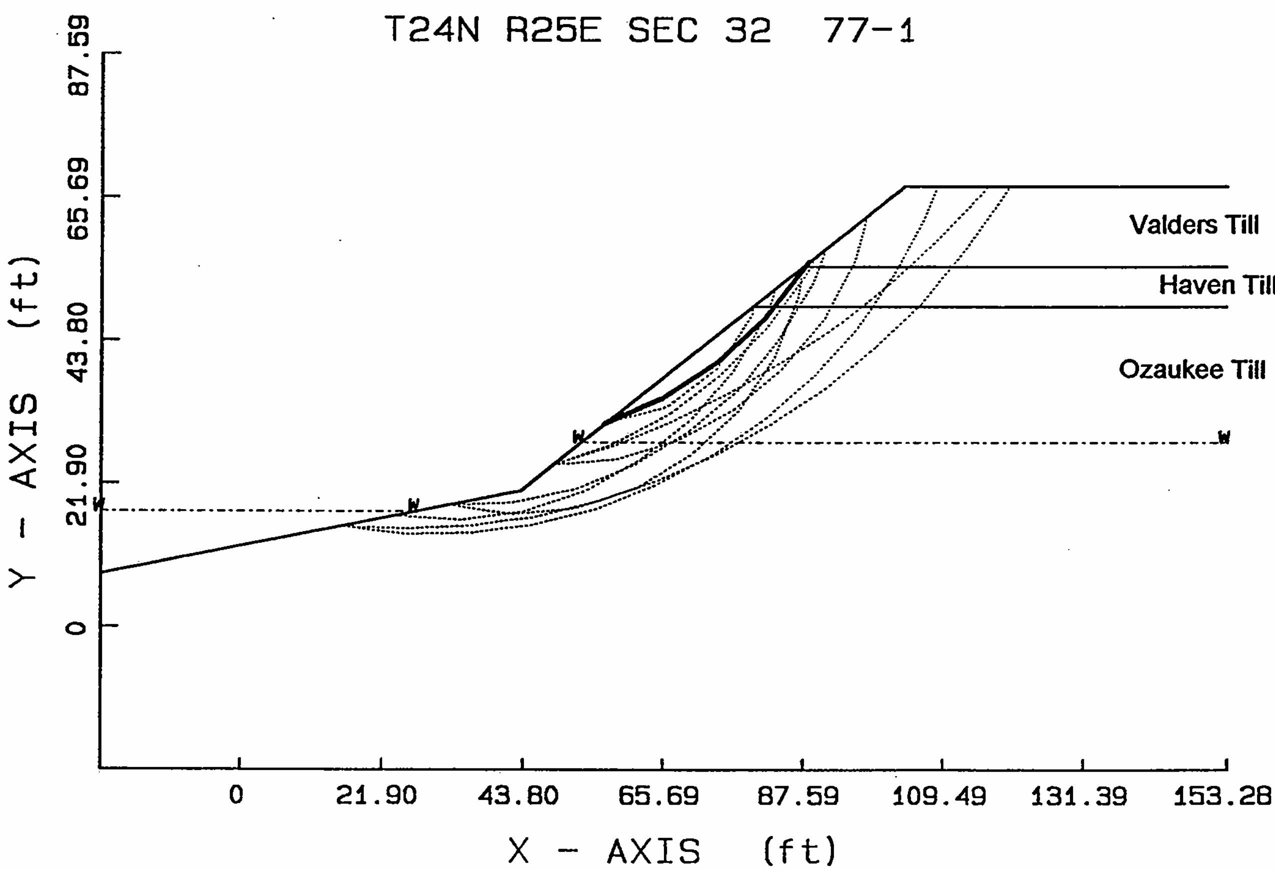
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



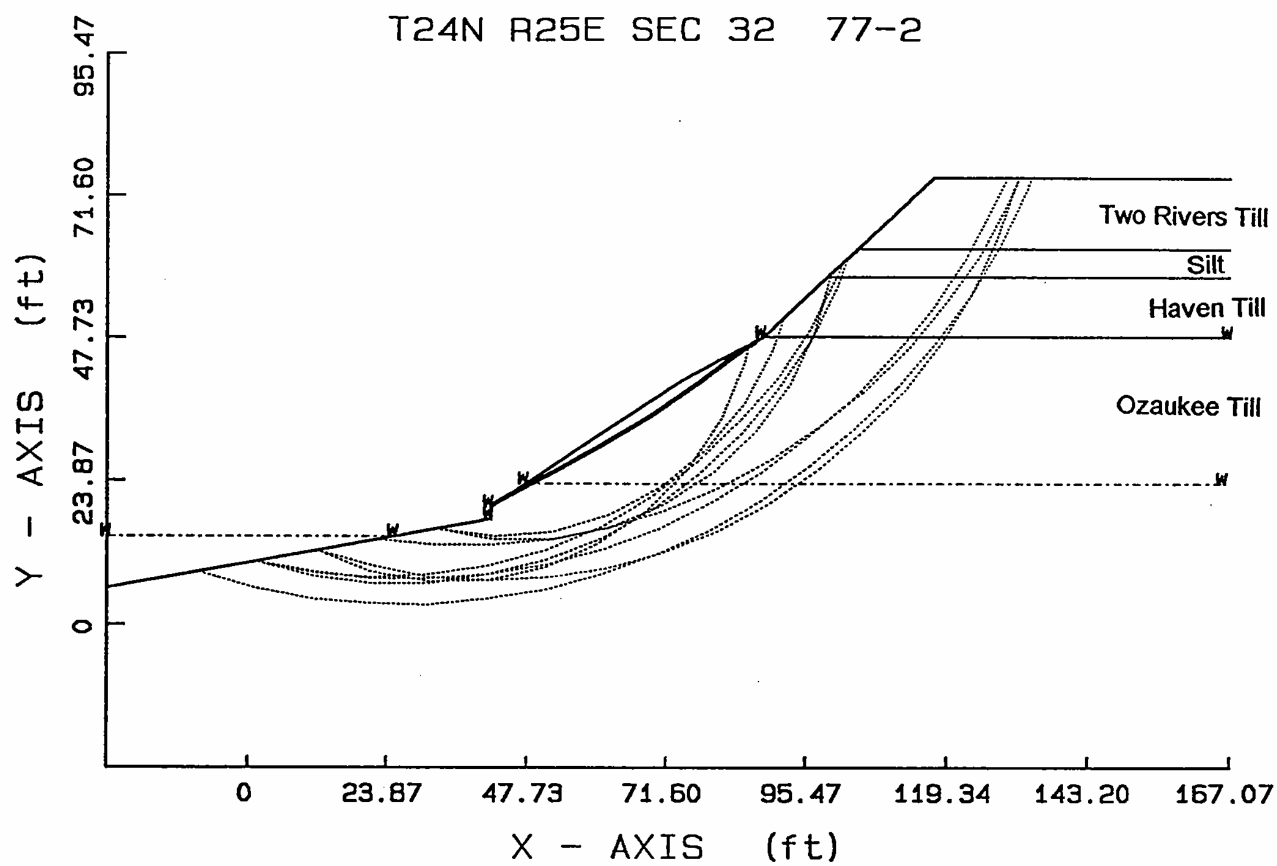


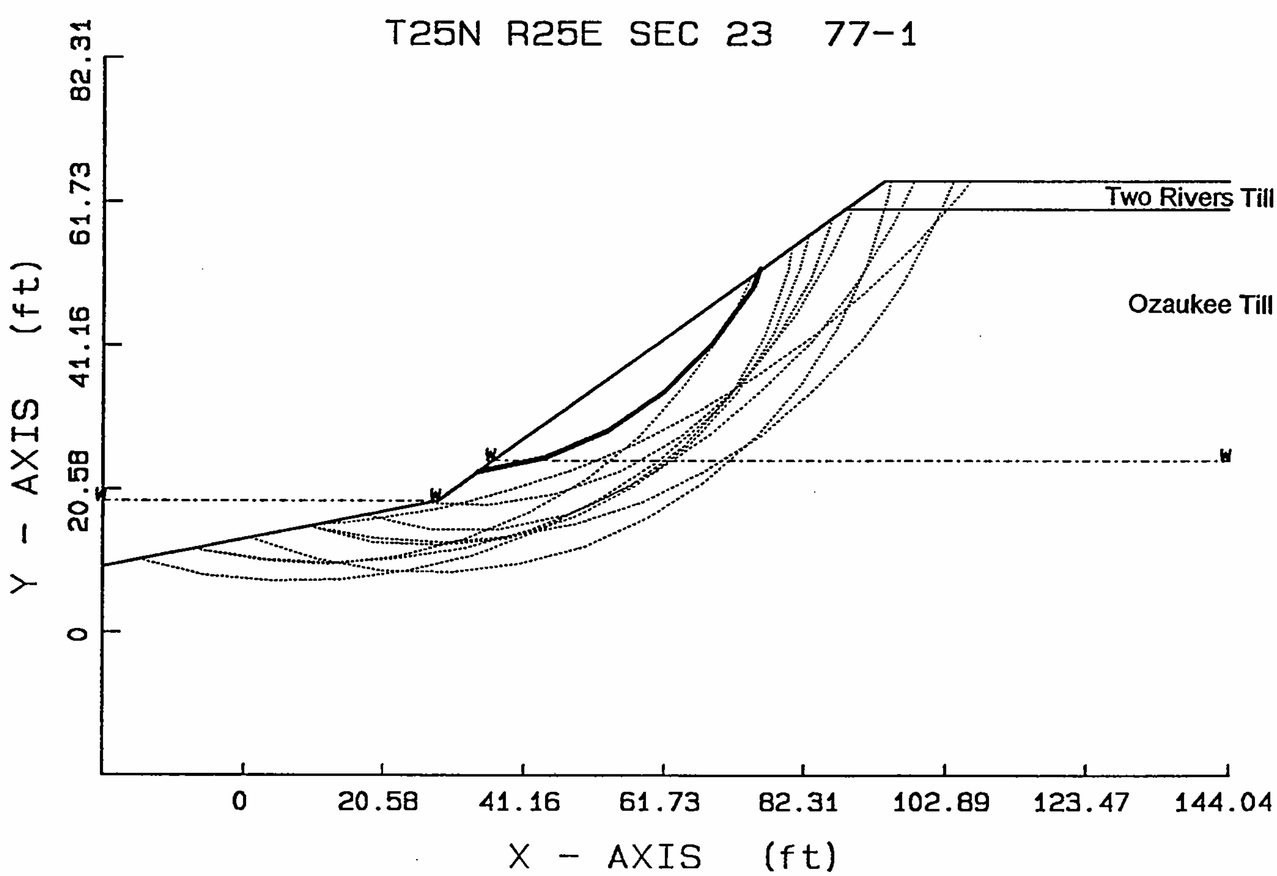
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



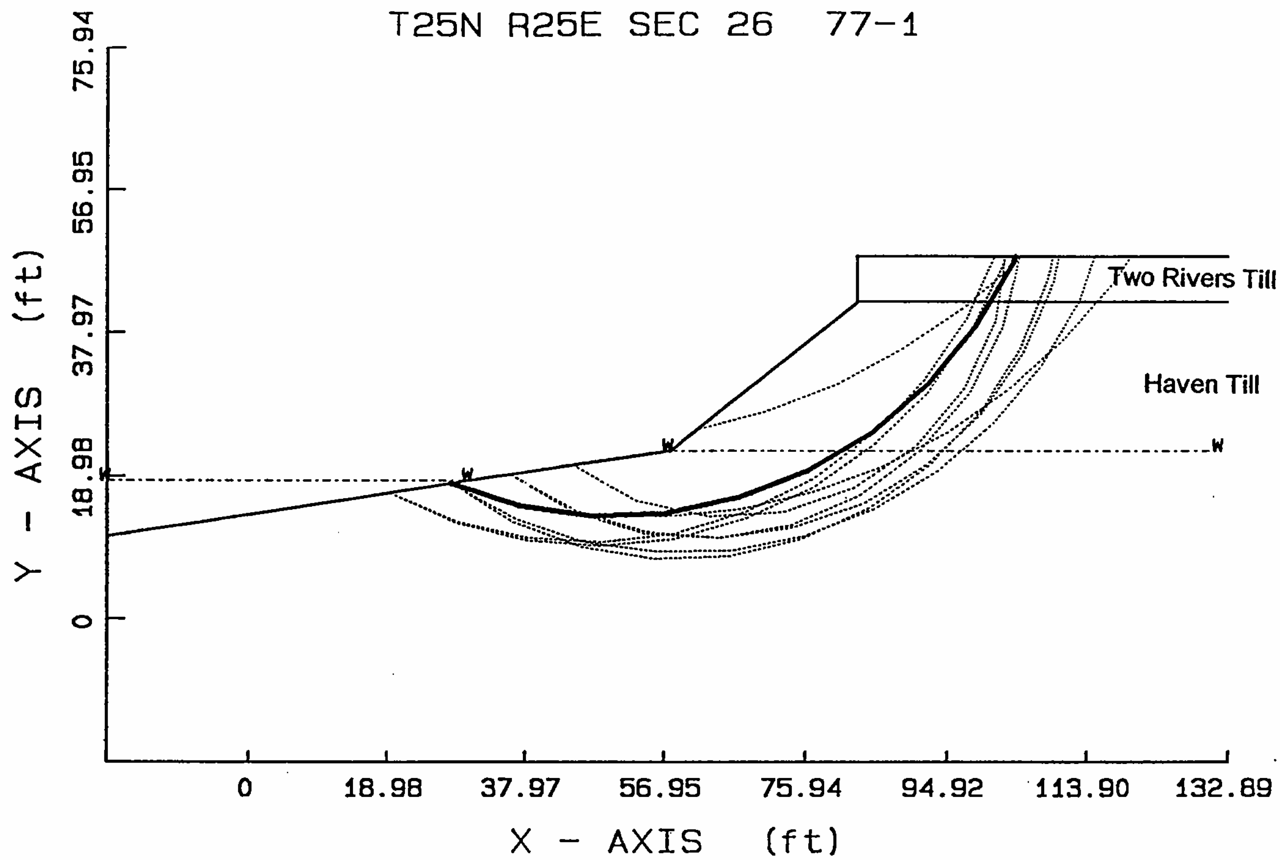


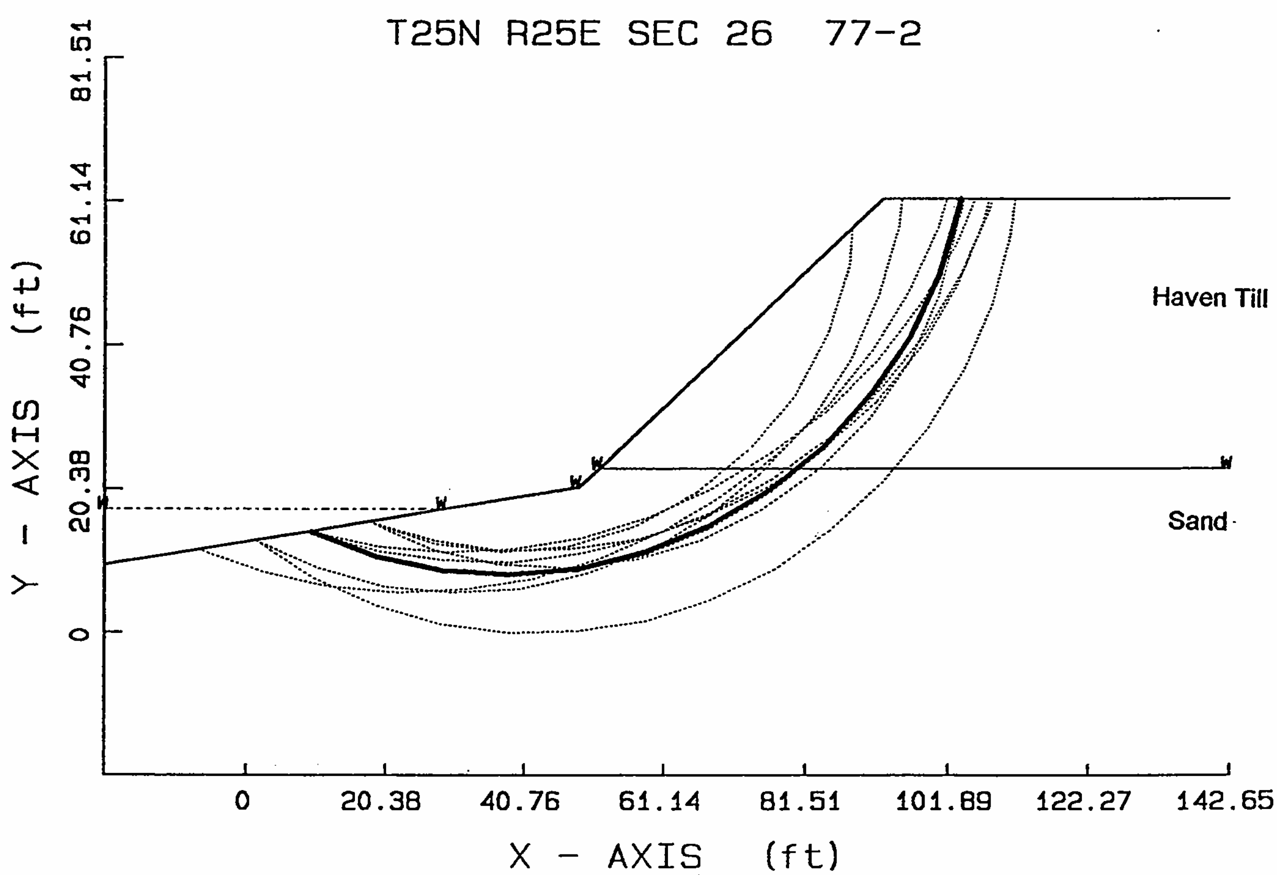
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997



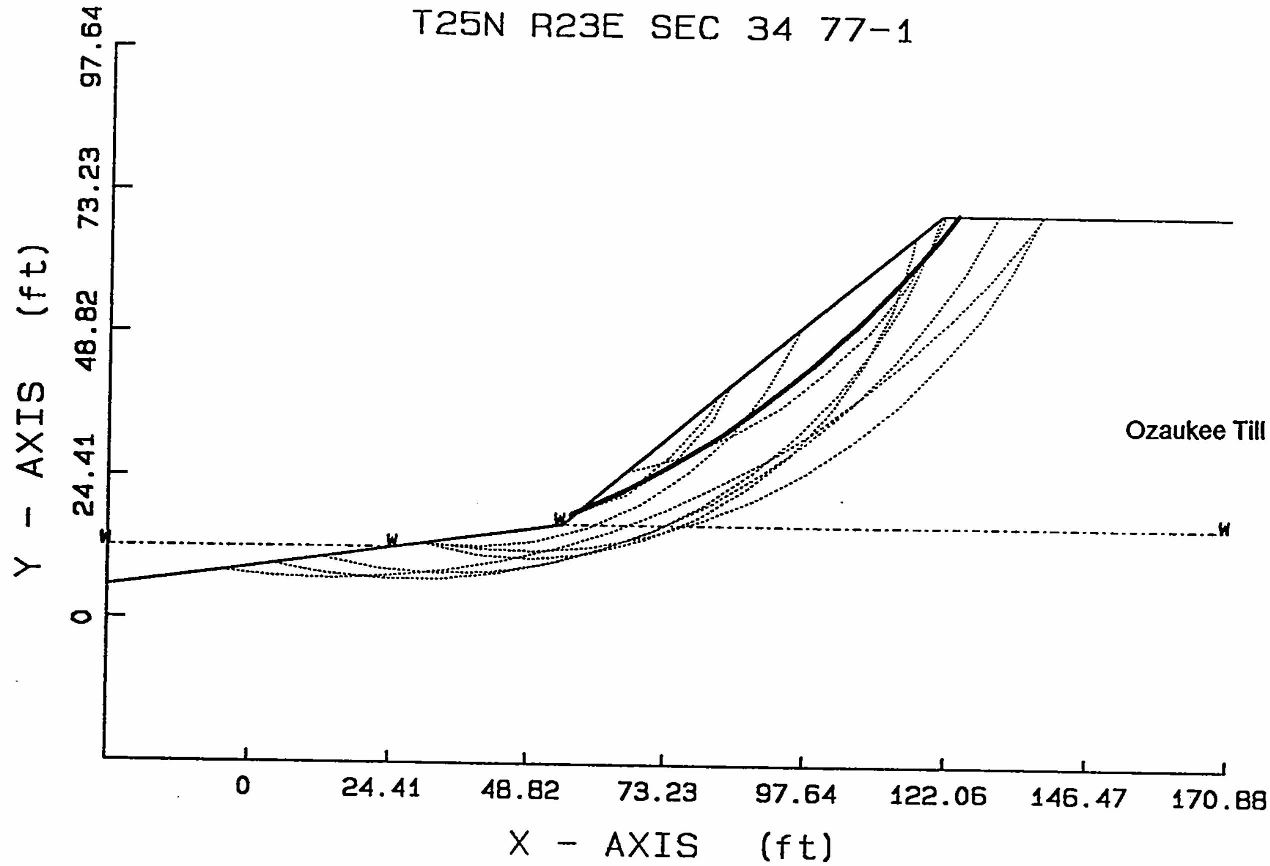


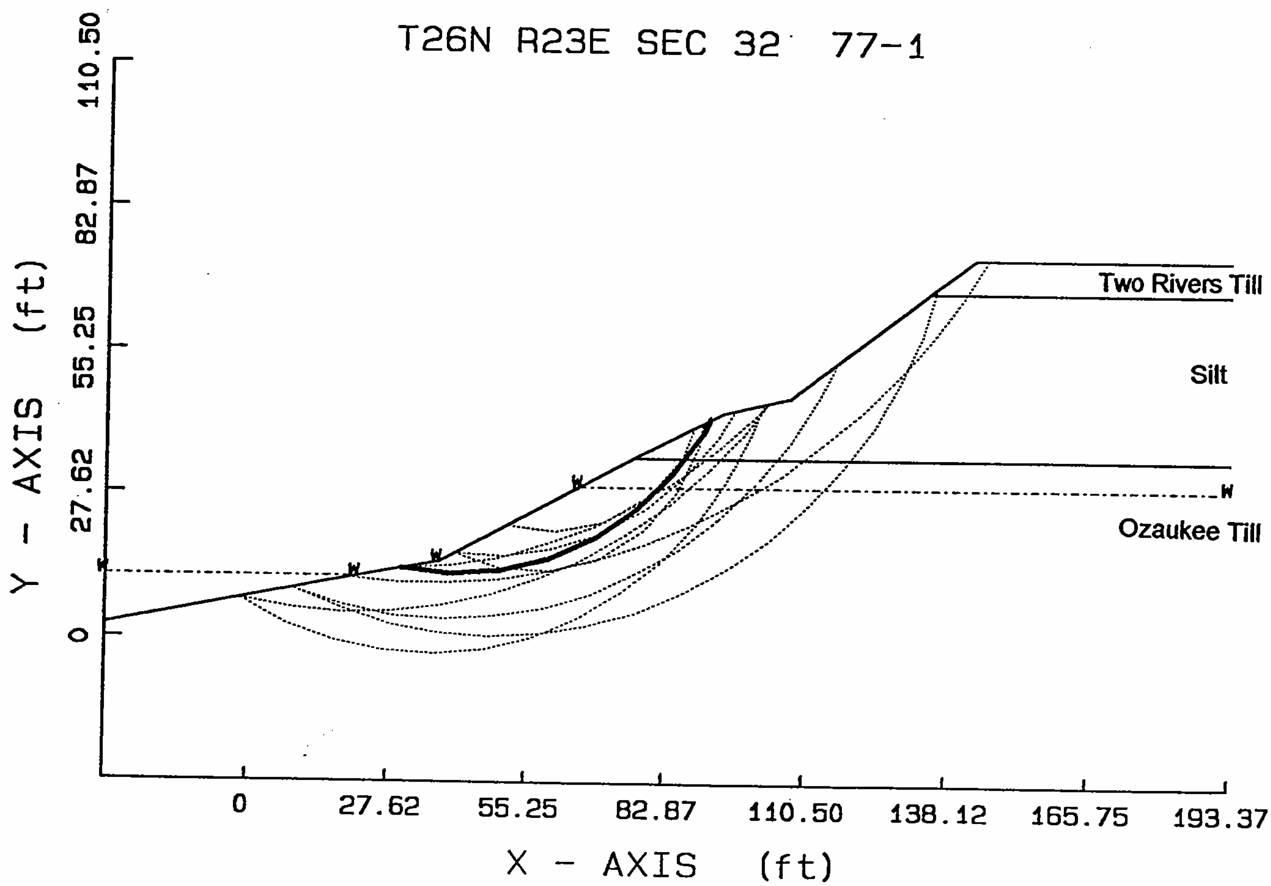
Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997





Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997





Source: T.B. Edil, D.M. Mickelson, and Bay Lake Regional Planning Commission, 1997

BAY-LAKE REGIONAL PLANNING COMMISSION

COMMISSION MEMBERS

BROWN COUNTY
WILLIAM M. CLANCY
PAUL JADIN

DOOR COUNTY
L. GEORGE EVENSON
CHARLES JARMAN
NORBERT D. SCHACHTNER

FLORENCE COUNTY
BRUCE OSTERBERG
JOHN ZOELLER

KEWAUNEE COUNTY
ROBERT ENTRINGER, VICE-CHAIRPERSON
CLARENCE C. IHLENFELDT
PAUL J. WOLSKE, CHAIRPERSON

MANITOWOC COUNTY
GREGORY E. BUCKLEY
KEVIN M. CRAWFORD
DONALD C. MARKWARDT

MARINETTE COUNTY
FLORENCE MAGNUSON
CHERYL R. MAXWELL
MARY G. MEYER

OCONTO COUNTY
DONALD A. GLYNN
AUSTIN C. MAKHOLM
LOIS L. TREVER

SHEBOYGAN COUNTY
JAMES E. GILLIGAN, SEC./TREASURER
J. CURTIS MCKAY
RICHARD J. SCHNEIDER

WISCONSIN DEPARTMENT OF DEVELOPMENT
SEC. WILLIAM MCCOSHEN, EX-OFFICIO MEMBER

STAFF

MARTIN W. HOLDEN
EXECUTIVE DIRECTOR

JEFFREY C. AGEE-AGUAYO, AICP
TRANSPORTATION PLANNER III

JANE M. BOUCHONVILLE
OFFICE ACCOUNTS COORDINATOR

DALE W. MOHR
COMMUNITY PLANNER

BRENDA L. REHBERG
CLERK-TYPIST

JAMES J. VANLAANEN
TRANSPORTATION PLANNER

MARK A. WALTER
GIS COORDINATOR

CINDY J. WOJTCZAK
ECONOMIC PLANNER II

AARON M. SCHUETTE
GIS ASSISTANT

REPORT PRODUCTION STAFF
DALE W. MOHR
ALEX M. JERABEK

GRAPHICS
ERIC C. ANDERSON
ALEX M. JERABEK
DALE W. MOHR
AARON M. SCHUETTE
MARK A. WALTER

LAKE M
(

REACH	#	LOCATION	BORE SAMPLE	PROFILE	DETERMINISTIC FS PRIOR (77)	DETERMINISTIC FS LOCATION	DETERMINISTIC FS CURRENT (96)	MEASURED RECESSION 1978-1992	RE
		T13N R23E SEC 31		NONE					
		T13N R23E SEC 30		NONE					
		T13N R23E SEC 19/20		NONE					
		T13N R23E SEC 8/9		NONE					
18		T13N R23E SEC 4		NONE					
		T14N R23E SEC 33/34		NONE					
		T14N R23E SEC 27		NONE					
		T14N R23E SEC 22/23		NONE					
		T14N R23E SEC 14		NONE					
		T14N R23E SEC 11		NONE					
19		T14N R23E SEC 2		NONE					
	1	T15N R23E SEC 35		77-1	1.5	WHOLE	3.43		
	2		GT 11	77-2	1.53	UPPER	0.96		
	3	T15N R23E SEC 14		77-1			2.11		
	4		GT 12	77-2	1.5		2.36	5	
	5	T15N R23E SEC 11		77-1	2.2		2.82	0	
				77-2	1.5			10	
				80-16					
				80-17					
	6			80-18			1.77		
				80-19					
				80-20					
	7			80-21			1.106		
	8			80-22			1.824		
	9	T15N R23E SEC 2/3		77-1	1.02		1.413	50	
	10			77-2	0.79		1.564	10	
21	11			80-33			1.606		
				80-32					
				80-31					
	12			80-30			1.442		
				80-29					
	13	T16N R23E SEC 34		77-1	1.42		1.278	30	
				80-28					
				80-27					
	14			80-26			1.728		
	15			80-25			1.848		
	16			77-2	0.82		1.941	20	
				80-24					
				80-23					
				80-34					
	17			77-3	1		1.305	25	1
	18	T16N R23E SEC 27		80-35			1.24		
	19			80-36			2.127		
	20			80-37			1.203		
22	21			80-38			1.8		
	22	T16N R23E SEC 22		77-1	1.69		1.123	35	2
	23			80-39			0.736		
			GT 14	77-2	1.14 (.77)	WHOLE (TOE)			
		T16N R23E SEC 15		80-42			modified for golf course		
				77-1	1.95		modified for golf course	0	0
				80-43			modified for golf course		
				80-44			modified for golf course		
		T16N R23E SEC 10	GT 13	77-1	1.06 (1.81)	TOP (WHOLE)	modified for golf course	20	1
23	25			96-1			1.247		
	26			77-2	1.243 (.312)	WHOLE (TOP)	1.398	10	0

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

REACH	#	LOCATION	BORE SAMPLE	PROFILE	DETERMINISTIC FS PRIOR (77)	DETERMINISTIC FS LOCATION	DETERMINISTIC FS CURRENT (96)	MEASURED RECESSION 1978-1992	RI
23	27			77-3	.61 (.93)	TOP (LG TOP)	1.024	15	
	28		BAD LOCATION	77-4			1.517		
	29	T16N R23E SEC 3	BAD LOCATION	77-1			2.306	40	
	30	T17N R23E SEC 34		80-2			0.945		
	31		BAD LOCATION	77-1			1.159	20	
	32	T17N R23E SEC 27		77-1	1.47		2.056	20	
	33			80-1			1.41		
24	34	T17N R23E SEC 22		77-1	1.41	WHOLE	0.536		
				80-3			not measured in 1996		
	35		GT 15/16	77-2	1.42	WHOLE	1.217		
	36			80-4			1.259		
	37	T17N R23E SEC 14		77-1	1.56	WHOLE	1.467	50	
	38			77-2 (80-2)	1.28	WHOLE	0.865	70	
	39			77-3	0.96	UPPER WHOLE	0.678	55	
	40			80-6			0.791		
	41			80-7			0.994		
	42	T17N R23E SEC 11		77-1	0.91	UPPER	1.36		
	43			77-2	0.76	MID	0.9	65	
	44			80-8			0.962		
25	45	T17N R23E SEC 1		77-1	1.28	WHOLE	1.36		
	46			77-2	1.38	WHOLE	1.515	40	
	47	T18N R23E SEC 36		77-1	1.5	WHOLE	1.406		
	48		BAD LOCATION	77-2	STABLE	B=20	2.158	100	
	49	T18N R23E SEC 25		80-15			2.323		
	50			77-1	1.41		1.83	70	
	51			77-2	0.82	UPPER	1.757	65	
	52	T18N R23E SEC 24		80-14			1.37		
	53		(GT -18)	77-1	1.1		1.421	70	
	54		(GT-17)	77-2	1.3		1.808	110	
	55	T18N R24E SEC 18		80-13			2.135		
	56			77-1	0.88 (.94)	UPPER (MID)	1.903	30	
	57			80-12					
	58			77-2	1.04 (1.1)	WHOLE (MID)	0.928	40	
	59	T18N R24E SEC 7/8		77-1	1.27		1.085	20	
	60			80-11			1.47		
				80-10					
26	61	T18N R24E SEC 5		77-1			1.068		
	62			80-9			0.851		
	63	T19N R24E SEC 32	(GT 19)	77-1	0.63		1.657		
	64			77-2	STABLE				
		T19N R24E SEC 20		NONE					
27	65	T19N R24E SEC 16	(GT 20)	77-1	0.7 (.86)	MID (UPPER)	0.861	0	
29	66			77-2	0.79 (.95)	MID (MID)	1.115	5	
		T19N R24E SEC 10/15		NONE					
		T19N R24E SEC 11		NONE					
		T19N R25E SEC 1		NONE					
		T20N R25E ALL SECTIONS		NONE					
	67	T21N R25E SEC 25/30		77-1	1.97	WHOLE	1.296	50	
		T21N R24E SEC 24		NONE					
30	68	T21N R24E SEC 13		77-1	1.96	WHOLE	2.16	25	
	69			77-2	1.93	WHOLE	2.248		
	70			80-16			0.966		
	71	T21N R24E SEC 11		77-1	0.7	UPPER	1.769	70	
	72			77-2	0.7	UPPER	1.571	65	
		T21N R24E SEC 2		80-17	same as 77-1				
	73			77-1	0.75	UPPER	2.211	65	
	74			77-2	0.6	UPPER			
	75			80-18			2.135		
	76			77-3	0.96	MID	2.369	30	

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

REACH	#	LOCATION	BORE SAMPLE	PROFILE	DETERMINISTIC FS PRIOR (77)	DETERMINISTIC FS LOCATION	DETERMINISTIC FS CURRENT (96)	MEASURED RECESSION 1978-1992	RE
	77	T22N R24E SEC 35/36		77-1	1.62	WHOLE	2.057	35	
30	78			77-2	1.95	WHOLE	2.788		
	79	T22N R24E SEC 25		77-1	2.06	WHOLE	2.235		
	80			77-2	2.02	WHOLE	2.345	70	
	81	T22N R24E SEC 24/19		80-1			1.628		
	82			77-1	1.19	WHOLE	1.247	70	
31	83			80-2			1.67		
	84			77-2	1.49	WHOLE	1.229	30	
	85	T22N R25E SEC 18		77-2	1.07	WHOLE	0.853	30	
	86			80-4			0.788	20	
	87			77-1	0.7	WHOLE	1.891	15	
	88			80-3			1.19	60	
	89	T22N R25E SEC 7		77-1	0.9	WHOLE	1.048	25	
	90			77-2	0.95	WHOLE	0.0986	35	
32	91	T22N R25E SEC 6		80-5			0.772	30	
	92			77-1	0.9	WHOLE	0.941	30	
	93			77-2	1.28	WHOLE	0.845	35	
	94	T23N R25E SEC 31		77-1	0.97	UPPER	1.227	30	
	95			77-2	0.94	WHOLE	1.083	35	
33	96	T23N R25E SEC 30		77-2	0.96	UPPER		30	
	97			80-6			0.93		
	98			77-1	0.9	MID WHOLE	0.962	25	
	99	T23N R25E SEC19		77-1	0.97	WHOLE	0.9		
34	100	T23N R25E SEC 17		77-1	0.91	WHOLE	1.028	30	
	101	T23N R25E SEC 8		77-1	1.1	WHOLE	0.994	85	
	102			80-7			0.978		
	103			77-2	1	WHOLE	0.915	50	
	104	T23N R25E SEC 5		80-8			1.03		
	105			77-1	0.93	WHOLE	0.939		
35	106	T24N R25E SEC 32		77-1	0.97	TOE	0.935	25	
	107			77-2	0.97	WHOLE	0.987	15	
	108	T24N R25E SEC 28/29		80-11			0.864		
	109			77-1	0.98	WHOLE	0.717		
	110			77-2	0.99	MID	0.978	25	
	111			77-3	0.95	MID	0.767	60	
	112			77-4	0.9	WHOLE	0.775	70	
	113	T24N R25E SEC 21		80-10					
	114			77-1	0.719	WHOLE	0.916	120	
	115			77-2	0.97	WHOLE TOE	0.723	105	
	116	T24N R25E SEC 16		77-1	0.94	WHOLE	1.082	20	
36	117			80-9			1.578		
	118			77-2	0.82	UPPER	1.708	35	
	119	T24N R25E SEC 9/10		77-1	1.03	UPPER	1.412		
		T24N R25E SEC 3		NONE					
	120	T25N R25E SEC 34		77-1	1	UPPER	0.822		
	121	T25T R25E SEC 26		77-1	1.5	WHOLE	2.198	15	
37				80-12					
	122			77-2	1.5	WHOLE	1.158	15	
38	123	T25T R25E SEC 23/24		77-1	0.7	WHOLE	1.103	0	(
		T25T R25E SEC 13/18		NONE					
39		T25T R26E SEC 7		NONE					
		T25T R26E SEC 6/5		NONE					
	124	T26T R26E SEC 32		77-1	1.1	WHOLE	1.059	85	(
		T26T R26E SEC 29		NONE					
		T26T R26E SEC 21		NONE					
		T26T R26E SEC 16		NONE					
40		T26T R26E SEC 9		NONE					
		T26T R26E SEC 3		NONE					
		T27T R26E SEC 34		NONE					
		T27T R26E SEC 27		NONE					

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