# UNITED STATES GREAT LAKES SHORELINE RECESSION RATE DATA

## FINAL REPORT

Prepared For:


**U.S. Army Corps of Engineers**
**Waterways Experiment Section, Coastal Engineering Research Center**
3909 Halls Ferry Road, Vicksburg, Mississippi, USA, 39180-6199

and

**U.S. Army Corps of Engineers - Detroit District**
477 Michigan Avenue, 6th Floor, Detroit, Michigan, USA, 48231-1027

**Contract #: DACW39-93-M-6861 and DACW39-94-M-3972**

Prepared By:

Christian J. Stewart, Coastal Resource Scientist
**Christian J. Stewart Consulting**
**Coastal Resource Specialists and Geographers**
22 Glenwood Avenue, Guelph, Ontario, CANADA, N1H 4L3

**May 16, 1994**

# TABLE OF CONTENTS

## LIST OF TABLES

## ACKNOWLEDGEMENTS

This work was conducted under the supervision of the United States Army Corps of Engineers Coastal Engineering Research Center (CERC) and Detroit District Office (DDO). I am grateful to Ms. Joan Pope (CERC) and Mr. Dave Schweiger (DDO) for their overall guidance and input to the project. Mr. Roger Gauthier and Mr. Charles L. Thompson, both of the DDO, also provided numerous suggestions as to data base format and provided many of the original data sets for inclusion. Mr. Thompson was also responsible for the compilation of the original recession rate data set from which this work evolved.

I would also like to thank a variety of people who provided additional data sets, reports and general information - all of which has gone into updating the recession rate data base and completing this report. They include: Mr. Dan Retka, Minnesota Department of Natural Resources; Ms. Carol Johnston, University of Minnesota; Mr. Richard Sigel, Lake County, Minnesota Planning Director; Mr. Philip Keillor, University of Wisconsin-Madison; Mr. Oscar Herrera and Mr. Gary Schultz, Wisconsin Coastal Zone Management Program; Mr. Kurt Bauer, Southeastern Wisconsin Regional Planning Commission; Mr. Robert Fisher, Bay-Lake Regional Planning Commission, Wisconsin; Mr. Randall Jibson, U.S. Geological Survey; Mr. William Wood, Purdue University; Mr. Steve Davis, Indiana Department of Natural Resources; Mr. Martin Jannereth and Ms. Penny Holt, Michigan Department of Natural Resources; Mr. William Buckler, Youngstown State University; Mr. Scudder Mackey and Mr. Don Guy, Ohio Department of Natural Resources; Mr. Charles Herdendorf, Ohio State University; Ms. Melissa Gross, Pennsylvania Department of Environmental Resources; Mr. Paul Knuth, Edinboro State College; Mr. Roman Rackozy, New York Department of Environmental Conservation; Mr. Fred Anders, New York State Department of State - Coastal Zone Management Program; Mr. Parker Calkin, University of Buffalo; Mr. Dan Palm and Mr. Tom Cutter, St. Lawrence - Eastern Ontario Commission; and Mr. Tom Bender and Mr. Michael Mohr, USACE Buffalo District.

Christian J. Stewart
May 16, 1994

## METRIC CONVERSION

It should be noted that the majority of the shoreline recession data and information used to compile this report was usually reported in the original reference in Imperial units (i.e. feet, inches, miles, etc.). For purposes of scientific convention, all data reported here has been converted to metric (S.I.) values. A conversion table is provided below for reference purposes.

| METRIC CONVERSION TABLE | | | |
|---|---|---|---|
| **Imperial** | **Metric** | **Metric** | **Imperial** |
| 1 Inch (in) | = 2.540 centimeters (cm) | 1 centimeter (cm) | = 0.3937 inch (in) |
| 1 foot (ft) | = 0.3048 meter (m) | 1 meter (m) | = 3.281 feet (ft) |
| 1 yard (yd) | = 0.9144 meter (m) | 1 meter (m) | = 1.094 yards (yd) |
| 1 mile (mi) | = 1.609 kilometer (km) | 1 kilometer (km) | = 0.6214 mile (mi) |

# 1.0INTRODUCTION

## 1.1Background

In 1993, the International Joint Commission (IJC) completed the Great Lakes - St. Lawrence River Water Levels Reference Study (Levels Reference Study Board, 1993) which examined methods to alleviate the adverse consequences of fluctuating water levels on a number of interest groups and the natural environment. The U.S. Army Corps of Engineers (USACE) and Environment Canada, as lead federal agencies for this study, conducted investigations into a variety of topics, ranging from the design of new water level control structures, to the analysis of water level impacts on fish habitat and wetlands.

In order to address one key component of the Reference Study, staff of the USACE Coastal Engineering Research Center (CERC) and the Detroit District office, in close association with Canadian researchers and Environment Canada, carried out a geomorphic classification of the entire Great Lakes - St. Lawrence River shoreline, and an "erosion sensitivity" analysis of the degree to which the recession rate of each shore type defined might change if water levels on the lakes were reduced (Stewart and Pope, 1993a and b; Pope, Stewart and Nairn, 1993; and Stewart, 1993). Results of this work provided a quantification of the various shore types that exist in the basin, as well as a quantification of those shore types that might undergo a reduction in recession as a result of a reduction in water level range. The results have also helped researchers, coastal managers and the general public better understand the impacts of long-term and short-term water level fluctuations on erosion rates and processes.

As part of the classification and erosion sensitivity work, recession rate data for various shoreline types throughout the Great Lakes - St. Lawrence River basin were collected and entered into a Great Lakes - St. Lawrence River Geographic Information System (GIS), which resides in the Detroit District USACE office. Unfortunately, time and budget allocated to the IJC study did not allow for detailed data collection, nor was good quality recession monitoring data obtained for all of the shore types defined in the classification scheme (Stewart and Pope, 1993b). As a result of these gaps in the recession rate data base, certain assumptions had to be made and certain limitations to the classification and erosion sensitivity exercise existed. Despite these limitations, results of the work were sufficient to answer the questions regarding shoreline erosion posed within the context of the IJC Water Levels Reference Study. However, it was felt by Stewart and Pope that additional, consistent and comprehensive data on historical recession rates of a variety of Great Lakes -St. Lawrence River shore types would greatly improve the understanding of those parameters affecting shoreline erosion and in developing tools which could be used to better predict future shoreline response. In regard to the work by Stewart and Pope (1993a and b) and Pope, Stewart and Nairn (1993), a comprehensive record of shoreline recession rates would serve to improve the application of their approach for other scenarios and its use for site specific coastal management decision making.

The incorporation of additional recession rate data into the already existing Great Lakes - St. Lawrence River GIS, would provide a readily available shoreline data base for use by shoreline managers and agencies throughout the Great Lakes - St. Lawrence River basin, as well as the capability to efficiently update any

information that may change in the future. Combinations of this data base with others that already exist reflecting current and future land use, or wave climate (see Hubertz, Driver and Reinhard, 1991 for example), will assist shoreline planners and managers in making sound and informed decisions regarding use and/or protection of the Great Lakes - St. Lawrence River shoreline zone.

These types of improvements in Great Lakes shoreline recession data have also been echoed by the International Joint Commission, who, in their final report on the water level study to the governments of Canada and the United States (International Joint Commission, 1993), recommended, among other items, that, "governments undertake long-term monitoring of shoreline erosion and bluff recession and that the information and methodologies developed under this (water level) study be used to improve erosion damage assessment capabilities." The IJC further recommended that governments "undertake without delay, programs to identify shoreline areas particularly vulnerable to storm surge activity, as well as to identify shore and near-shore facilities at risk" to flooding or erosion events and that "all hazard areas along the Great Lakes - St. Lawrence River System, be incorporated into GIS data bases".

## 1.2Nature of This Project

In light of the IJC recommendations and the data deficiencies identified by Stewart and Pope (1993 a and b), the Detroit District office of the USACE, in co-operation with USACE's Coastal Engineering Research Center, initiated a project in the summer of 1993 to create a comprehensive recession rate data base and associated "bibliography" for the U.S. shorelines of all the Great Lakes and Lake St. Clair. This data base would include the original data collected during the IJC Levels Study, but would also incorporate any additional studies that could not be collected initially due to time and budget constraints.

To collect this data, much of which resides with various federal, state and municipal agencies and departments, non-government organizations (e.g. State Sea Grant Organizations, Great Lakes Commission), universities/colleges, consulting firms and other commercial/industrial businesses who have jurisdiction or conduct research in the Great Lakes - St. Lawrence River shore zone, CERC and USACE - Detroit District retained the services of **Christian J. Stewart Consulting** to contact these agencies and to prepare the comprehensive recession rate data base and associated report/bibliography.

## 1.3Objectives of the Project

There were three key objectives to this project:

1)Gather, analyze and coordinate all existing comprehensive shoreline recession rate data for each of the Great Lakes and Lake St. Clair, for each of the eight Great Lakes States: Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania and New York;

2)Prepare a comprehensive report/bibliography for use as a reference document when utilizing the Great Lakes - St. Lawrence River GIS data base; and

3)Update and create a comprehensive recession rate data base and appropriate documentation for use in conjunction with existing USACE GIS data bases on land use, shore protection, shore type, etc., in order to make sound shoreline management, planning and engineering decisions along the Great Lakes - St. Lawrence River shoreline.

It should be noted here that collection of shoreline recession data took place for mainland shorelines only. Islands and connecting channels (e.g. St. Mary's River) were not included, as there is little, if any, data that exists for these areas.

## 1.4Format of This Report

Section 2.0 of this report will provide a brief summary of the methodology and approach utilized to obtain recession rate data and information that has been included in the USACE data base. Section 3.0 is the main portion of the report and provides detail on all of the data sources used to develop the lake-by-lake recession rate data base, as well as a section on gaps in recession rate data. Finally, Section 4.0 will provide a brief summary along with some concluding remarks.

## 2.0APPROACH AND METHODOLOGY

There were four key components to the approach for this project:

1)Start-Up Activities
2)Collection of Background Information
3)Preparation of Annotated Bibliography/Report
4)Incorporation of Data Into GIS Data Base

Each component is described briefly below.

## 2.1Start-Up Activities

The first step in this project was to hold a start-up meeting with appropriate staff of both the Detroit District USACE and the Coastal Engineering Research Center. The purpose of the meeting was to:

- review the nature, goals, objectives and approach of the project;
- review the current status of the Detroit USACE GIS data base, especially the status of existing information/data on recession rates;
- identify areas where recession rate data needs to be improved, or is lacking;
- collect any relevant data and literature from Detroit USACE or CERC staff;
- review project scheduling milestones, logistics and products; and
- finalize any contracting details.

## 2.2Collection of Background Information and Recession Rate Data

Following the meeting, detailed collection of recession rate information and data began. Three main activities were involved: 1) initial agency contact; 2) a literature review; and 3) agency visitation and follow-up.

### 2.2.1Initial Agency Contact

A comprehensive list of all possible agencies/organizations was prepared, listing locations, addresses, phone numbers, and points of contact. This list was relatively straightforward to compile, using various directories, as well as personal knowledge of appropriate contacts possessed by both the consultant and staff of USACE. Such agencies/organizations included, but were not limited to:

- State Departments of Natural Resources, Environment, Water Resources, Environmental Conservation, etc.;
- State Coastal Zone Management Programs;

- State Geological Surveys;
- Other USACE District Offices (Buffalo, Chicago, St. Paul)
- United States Geological Survey;
- Non-Government Organizations such as Great Lakes United, The Great Lakes Commission, and the Center For The Great Lakes;
- State Sea Grant Colleges and Programs;
- Universities/Colleges active in coastal research (Purdue, Wisconsin, Kent State, SUNY, Michigan, Ohio State, etc.); and
- Coastal Engineering Consulting Firms.

For all agencies/organizations listed, a letter was sent to the point of contact outlining the nature of the project and requesting information on the amount and type of recession rate data available for shorelines under their jurisdiction, or where they have conducted previous research. Copies of any relevant reports or publications were requested, along with a request for the provision of the recession rate data in both diskette and hard copy formats.

In conjunction with the letter of request, follow-up and reminder telephone calls were made to all agencies to ensure that the requests for data had been received and that they were being acted upon. This was also an opportunity to gather any preliminary information on data availability directly from the point of contact.

All information received through letter responses and in telephone conversations was carefully recorded and formed the basis for monthly progress reports, as well as the final bibliography (see Section 3.0). Data sets on loan from various agencies were carefully noted so as to ensure prompt return upon completion of the contract.

### 2.2.2Literature Review

A review of the Great Lakes coastal literature was also undertaken to identify any site specific, or broad-based studies of shoreline recession that have been undertaken by government, university or private researchers. Journals, publications and literature reference lists were examined.

Literature search information was also provided through the USACE Coastal Engineering Research Center and the United States Geological Survey. These provided listings of a number of useful reports and data sets.

### 2.2.3Agency Visitation

Although the majority of information was acquired through the two steps outlined above, where required, visits to various agencies/organizations identified also took place in order to gather data, literature, and other

information directly from the points of contact. This allowed access to information and data sets currently in preparation and which were not yet part of the current literature. It also ensured that the most up-to-date recession rate information was being acquired. Once again, any information obtained was carefully recorded and documented.

## 2.3Preparation of Annotated Bibliography/Report

All information and data collected was compiled into a comprehensive recession rate data bibliography. This information is found in Section 3.0 of this report. For each recession rate study/data set obtained, information is provided where possible on:

- the source and method of measurement of the recession rate data;
- the geographical extent of recession rate data;
- the nature and types of data (e.g. point, ranges, averages, profile data, visual estimations)
- the time frame for data collection (weekly, monthly, yearly, once, etc.);
- the quality, reliability and accuracy of the data.

This section also identifies remaining gaps in the recession rate data base and suggests future work required to fill any of these gaps.

## 2.4Incorporation of Data Into GIS Data Base

All recession rate data obtained was entered directly into the GIS recession rate data base of the USACE Detroit District. This data base consists of a series of lake-by-lake Lotus 1-2-3 spreadsheet files. Data contained in these files is broken down by 1 kilometer segments numbered clockwise along the shoreline, with each kilometer segment representing one row in the data base structure. For each kilometer entry, the following information was provided where available:

- **mean recession rate (meters/year)** - the average recession rate of all samples (data points) falling within the kilometer reach;

- **median recession rate (meters/year)** - the mid-point recession rate value calculated from all samples (data points) falling within the kilometer reach;

- **maximum recession rate (meters/year) -** the highest recession rate value of all samples (data points) within the kilometer reach;

- **minimum recession rate (meters/year)** - the lowest recession rate value of all samples (data points) within

the kilometer reach;

- **variance -** the variability of all samples (data points) about the mean recession value;

- **number of samples** - the total number of samples (data points) within the kilometer reach;

- **years of record** - the number of years of record over which the recession values have been calculated. Different years of record may exist within kilometer reaches (see below);

- **data type** - the nature of the data as reported in the original source material (e.g. point location - discrete value);

- **confidence** - a ranking of the original source data based on it's accuracy and reliability (e.g. moderately certain, or poor); and

- **remarks** - general remarks about the data set (e.g. specific dates of data coverage, source, locational reference).

These form the corresponding columns in the data base structure. More complete definitions of "data type" and "confidence" are found in the "Notes" section of each lake-by-lake data base appended to this report.

Where new data for a kilometer segment was encountered, it was entered as a separate line entry in the data base. Data covering different periods of record, or for the same period of record but from different sources, were also entered separately. This usually resulted in a large number of line entries for a specific reach or reaches. Where this occurs, the remarks column provides the specific dates for the period of record covered by the data, as well as the source. In addition, these data are sorted in descending order according to the number of years of record (i.e. the first line entry for the reach will contain the longest period of record). Other specific data base considerations are discussed for each data set in Section 3.0 below.

### 2.4.1The End Product

The end result of this exercise was a series of updated spreadsheet files, which contain comprehensive recession rate information for the entire Great Lakes shoreline. These are provided as lake-by-lake hardcopy printouts, which are appended to this report.

It should be emphasized here that the majority of the individual recession data sets (sources) utilized to comprise the lake-by-lake data bases were developed based on different input sources, with different assumptions, to different levels of accuracy. For example, differences in ways of defining the shoreline may exist, with some studies measuring recession as the difference between bluff crest positions, while others may measure recession as the difference between "shoreline" positions, thereby introducing a degree of error dependant on the water level stage at the time of the air photo or map. Similarly, differences in the methods

used to calculate the recession will vary, with some studies utilizing direct field measurements, and others utilizing aerial photography or historic mapping (with their inherent scale differences and accuracy problems) to calculate changes in shoreline position. To account for this in the data base, the criteria used to define both the "accuracy" and "confidence" rankings take into account such factors as the method of measurement (see "Notes" section in Appendices). In addition, different data sources within a kilometer reach will always be listed as two separate line items.

# 3.0BIBLIOGRAPHY OF GREAT LAKES SHORELINE RECESSION RATE DATA

## 3.1Introduction

This section will summarize each of the data sets that have been utilized to create the USACE recession rate data base. This will include those data sets originally entered as part of the IJC Water Level Reference Study, as well as those data sets entered subsequently as part of this project. The discussion that follows proceeds in a lake-by-lake and state-by-state fashion (beginning with Lake Superior), with four key components to each data set: 1) a general description of the research that was carried out and the data generated; 2) a discussion of the methodology utilized to determine the recession rates; 3) a discussion of the reliability and accuracy of the data collected; and 4) a discussion of any specific issues that arose when entering the data into the USACE data base.

The last sub-section within each state-by-state breakdown will include a brief summary of other recession rate studies that have been reviewed, but are not incorporated into the USACE data base, either because they are too site specific, because they were less comprehensive then those that are included, or because the data obtained was not suitable for incorporation into the data base. They are described in this report in order to provide as complete a listing as possible of recession rate studies conducted along the U.S. shoreline of the Great Lakes.

## 3.2Lake-By-Lake Discussion

### 3.2.1Lake Superior

### Minnesota

#### *A.University of Minnesota / Minnesota Sea Grant Data (Johnston, 1994)*

##### *General*

This study provides rates of shoreline erosion for the entire Lake Superior shoreline of Minnesota from Duluth to Grand Portage. The study combines air photo interpretation with analysis of shoreline geology to produce long-term rates of erosion for the periods 1930-1975 and 1975-1988/89. Data is provided as a series of 39 map sheets indicating erosion potential of the shoreline (high, low and unknown) along with specific rates of erosion for a number of individual sites.

##### *Method of Calculation*

Shoreline location was determined at selected sites using aerial photographs taken in the 1930's, 1975 and

1988/89. The distance over which the shoreline receded during the time period between air photo dates was divided by the number of years between photos to figure an annual erosion rate for these sites. Recession rates below the detection limits of the measurement method used were marked as "BD" (below detection) on the maps. Values less than 0.09 m/yr were below detection for the 1930-1975 time period, and values less than 0.18 m/yr were below detection for the 1975-1988/89 time period.

Erosion potential of the shoreline was calculated by statistically comparing recession rates with coastal characteristics. As would be expected, the presence or absence of bedrock was found to be the best predictor of erosion, with those areas composed of resistant bedrock having "low" erosion potential and those areas composed of glacial deposits, post-glacial beach deposits, clay bluffs, and peat deposits, having the "highest" potential for erosion.

***Data Accuracy and Reliability***

Photogrammetric determination of recession rates is one of the most common methods of recession rate determination and can be regarded as being generally accurate. As mentioned above, rates below 0.09 m/yr (1930-1975) and below 0.18 m/yr (1975-1988/89) could not be determined reliably. Where rates are calculated, they are described as "moderately certain" in the data base.

***Data Base Considerations***

Where specific values of shoreline recession are provided, they are utilized to provided a recession value for the reach. If the listed value is "BD" for below detection, a value of 0.09 m/yr was used for 1930-1975 data and a value of 0..18 m/yr was used for 1975-1988/89 data (this is based on data provided by Johnston (1994)). In areas where only an "erosion sensitivity" ranking was provided (based on shoreline geology), the following rates were used:

AverageMaximum
High Erosion Potential (1930-1975)0.14 m/yr 0 .33 m/yr
Low Erosion Potential (1930-1975)0.05 m/yr 0.20 m/yr

It should also be noted that while some reaches may consist predominantly of bedrock, small pockets of erodible areas within the reach necessitated the provision of a recession rate for the entire reach. Similarly, a number of "erosion sensitivity" rankings occurred in one reach. Where this occurred, a judgement was made as to which was more predominant, and the reach classified accordingly. This will be a factor to keep in mind when utilizing the data base for any future site specific applications.

***B.Shore Property Owner Survey Recession Rates (Baker and Otterson, 1987)***

***General***

In response to high water levels in the mid-1980's, coastal property owners on Minnesota's North Shore were surveyed in 1986. The survey had five objectives: 1) determine if coastal erosion was a major concern among coastal property owners; 2) identify areas where erosion was a problem; 3) estimate long-term and 1986 erosion rates for each county; 4) determine whether the loss of buildings was a major concern; and 5) assess the educational needs of the property owners regarding erosion and it's control. Three hundred and forty-one sites between the Duluth city limits and the Canadian Border were visited, with 199 property owners responding.

***Method of Calculation***

Landowners were asked to estimate the depth of shoreland lost during 1986, as well as the total depth lost since their purchase of the property. Long-term annual erosion rates were calculated by dividing the total estimated loss by the number of years of property ownership. Long-term recession rate data from each of the surveys, along with property owner information, was then plotted by hand on to a Minnesota Department of Transport strip map.

***Data Accuracy and Reliability***

Baker and Otterson (1987) report that the long-term estimates are considerably lower than those reported for 1986 and that there were two reasons for this. The first, is that people can more easily recall recent losses than those occurring over the past 10-15 years. Second, erosion rates during 1986 were likely accelerated due to higher water levels, and heavy rainfall in early 1986 oversaturated many clay banks, causing them to slump. Although many of their reported recession rates fell within the range of those reported in earlier studies, Baker and Otterson (1987) felt that additional studies were needed to substantiate the estimates.
The data itself had to be read off of poor quality map sheets. Some of the information was difficult to read and precise locations of transects were difficult to determine. While this data has been considered as "reasonable" to "poor" (values largely judgemental) in the USACE data base, overall caution should be used if utilizing this data for any type of analysis.

***Data Base Considerations***

Survey sites are not uniform along the shoreline, thus the number of samples within a USACE reach may vary. In addition, the DOT map received only extended from Duluth to Grand Marais and included 154 of the 199 property responses. Information for the 45 profiles that are assumed to exist between Grand Marais and the Canadian border have not been included in the USACE data base. Also, some of the 154 surveys plotted did not have any recession rate data attached to them.

Period of record information for each individual profile was not provided, but was averaged for the total number of responses received for each county. This average value has been utilized in the period of record column in the data base. It should thus be noted that the actual period of record at the specific sites (and hence for each individual reach) may vary considerably from these averages.

The DOT strip map (which was approximately 4.5 meters in length) was of fairly poor quality and it was sometimes difficult to accurately determine USACE reach boundaries. In addition, handwritten notes and recession rate information were difficult to read and the transect lines were often barely visible, making it difficult to accurately pinpoint their location on the shoreline. As such, some errors may occur in the data base in this regard.

Some of the field notes however, were useful in providing recession rate information where a specific rate did not exist. In most cases, this occurred where the researcher had written "stable shoreline" or some similar note on the map along with an arrow pointing to the shoreline. This type of information has also been included in the USACE data base and is indicated by the term "Field Notes" in the remarks column and a data type listed as "linear zone, discrete value (3)".

The Baker and Otterson (1987) summary report utilizes the site specific survey information to provide an overall average of average annual recession rates for each of the three counties along the Minnesota shoreline for both long-term periods and for 1986. While this information is useful for the general targeting of recession problems, it was felt that it was too broad (compared to the site specific profile information and the Johnston (1994) data) to be included as "linear zone" data in the USACE data base. As such, only the site specific recession rate data recorded on the DOT map (154 profiles) has been utilized and included in the USACE data base.

***C.Other Minnesota Studies Not Incorporated Into Data Base***

Two additional reports describing erosion hazard areas along the Minnesota shoreline were obtained for review. The first, "Northshore Management Plan" (North Shore Management Board, 1988) mapped those areas deemed to have "high potential for erosion" (which were those areas having rates greater than 0.3 meters per year). Erosion hazard areas were defined based on 199 surveys from a 1986 shoreline erosion study (see B above). No additional quantitative recession rate information was provided and thus it was not sufficient for inclusion in the USACE data base.

The second report is a document prepared for Lake County, describing lakeshore erosion along this county's Lake Superior shoreline (DeLaRosby, 1991). A detailed literature review and a descriptive field study were completed to determine the limits of the erosion hazard areas as defined in the North Shore Management Plan. Additional erosion hazard areas were also defined. The report however, provides no quantitative measurement of recession rates for the county, and in fact utilizes recession rate information already prepared by other authors (see A and B above). As such, the information contained in it was not included in the USACE data

base.

## Wisconsin

### *A.Lake Superior Recession Rate Data, 1852-1966 (Hess, 1973)*

#### *General*

This report describes a shoreline erosion study of the western arm of Lake Superior, between Superior Entry and Bark Point, Wisconsin. Field surveys of shoreline heights were combined with measured changes in shoreline position, derived from maps and aerial photographs, to produce estimates of the volume of material eroded by coastal processes. The overall purpose of the study was to facilitate a comparison between the volume of eroded material and the volume of tailings introduced into Lake Superior at Silver Bay, Minnesota.

Measurements of changes in shoreline position were compiled for two inclusive time periods. The longer time period represents changes in shoreline position between 1852 and 1966, a period of 114 years. The difference represents two data sources, the plat sheets of the first land survey in 1852 and 1966 air photos flown for the Agricultural Stabilization Service. The shorter time period changes are derived from the oldest available air photos flown (1938-1939) and the 1966 coverage.

#### *Method of Calculation*

Measurements were first made on the topographic maps with the object of using these measurements and their scaled distances for scale determination of the aerial photographs. Measurements were made of recognizable ground features discernable on both the maps and the aerial photographs. Multiple measurements were made in areas corresponding to each photograph and care was exercised in selecting points of measurement at approximately the same elevation so as to minimize relief distortion inherent in the photographic image.

Shoreline measurements were made on the maps from section lines along north-south profiles spaced approximately 305 meters apart. The same profiles were scribed on the aerial photographs together with the base section line, and measurements were made of the position of backbeach, bank-edge and shoreline.

#### *Data Accuracy and Reliability*

The paper does not provide any discussion of errors involved in the methodology or analysis. It is assumed that the values calculated are as accurate as any other calculated using air photo analysis. Other authors (e.g. Anders and Byrnes, 1991; Crowell et al, 1991) however, have reported on a number of errors associated with the use of maps created prior to the use of aerial photography (i.e. 1800's-1930's) for recession rate analysis and suggest that worst case ground distance errors of 8.5 meters or more may occur. In light of this, this data is

listed as "moderately certain" in the USACE data base.

#### *Data Base Considerations*

As profiles were located along Section lines, their position relative to USACE reaches was very easy to determine. Values in the report were provided in total amount of recession over the time period and had to first be converted to an average annual value before calculating means for the appropriate reach. This data supplements recession rate data for the same area that was calculated by Need et al. (1980) for the Wisconsin Coastal Zone Management Program (see B below).

### *B.Wisconsin Coastal Management Program Recession Rate Data (Need et al., 1980)*

#### *General*

In the mid-to-late 1970's, the Wisconsin Coastal Management Program (CMP) initiated a comprehensive study of the shoreline conditions existing along the Lake Michigan and Superior coastlines. Information collected included data on erosion rates, bluff heights and characteristics, shore protection structures present, previous shore damages, number of houses present, beach characteristics, bluff slope angles, safety factors and confidence limits. A main report and nine appendices were produced. Appendix 9 - Douglas and Western Bayfield Counties (Need et al., 1980), while containing no discussion of methodology, presents mapped recession rates for the periods 1938-1966, 1966-1975, and 1938-1975 and was useful for input to the USACE data base.

#### *Method of Calculation*

The Southeastern Wisconsin Regional Planning Commission (SEWRPC) (1982) report that the long-term Wisconsin CMP data were developed from a variety of sources, including original U.S. Public Land Survey notes and maps, and by data from the U.S. Army Corps of Engineers. Short-term data were measured from aerial photographs at a scale of 1:12,000 to 1:20,000 that were taken over a period of 10-15 years. Measurements were made by plotting shoreline positions from the older photograph onto the most recent photograph and measuring the distance of recession to the nearest 0.001 centimeter.

#### *Data Accuracy and Reliability*

Data accuracy was not specified, but is assumed to be reasonable given the comprehensiveness of the study. Other authors (e.g. Anders and Byrnes, 1991; Crowell et al, 1991) however, have reported on a number of errors associated with the use of maps created prior to the use of aerial photography (i.e. 1800's-1930's) for recession rate analysis and suggest that worst case ground distance errors of 8.5 meters or more may occur.

In light of this, where data was entered, it has been ranked as "moderately certain".

#### *Data Base Considerations*

As part of the Wisconsin CMP work, a series of "public information" maps were produced for each county indicating sections of shoreline where "high" and "low to moderate" erosion potential exist. The corresponding recession rate values assigned to each category were estimated using shore type, damage, protection and other information collected by Springman and Born (1979) (P. Keillor, University of Wisconsin Sea Grant, personal communication) and are as follows:

High Erosion Potential>0.61 meters per year
Moderate Erosion Potential0.3-0.61 meters per year
Low Erosion Potential<0.3 meters per year

These maps were used in the USACE data base to provide values of recession **only** for sections of the shoreline where no other data exists (e.g. Ashland and Iron Counties) or for those areas where the information provided in the Wisconsin CMP reports was unreadable. For the purposes of the USACE data base, this map information is considered "linear zone, linear range" data and is considered "reasonable." As moderate and low erosion potential are combined as one category on these maps, the USACE data base will indicate values of either >0.61, or <0.61 in the mean recession column. This data is indicated by "Wisconsin CZM 1979 MAP" in the remarks column.

#### *C.Other Wisconsin Studies Not Incorporated Into Data Base*

None reviewed.

### Michigan (Upper Peninsula)

#### *A.Michigan Department of Natural Resources Recession Rate Data*

##### *General*

The Land and Water Management Division of the Michigan Department of Natural Resources is responsible for the determination of erosion setbacks for development along the shoreline. To calculate these setbacks, they have determined detailed recession rates for many areas of the shoreline. The USACE data base contains a very small amount of this data for the Lake Superior shoreline, including portions of Gogebic, Ontonagon, Houghton, Keweenaw, Baraga, Marquette, Alger, Luce and Chippewa Counties.

***Method of Calculation***

The MDNR recession rate data were determined at representative sites (usually those where erosion threatens, or could threaten development) by comparing bluff crest locations on historic aerial photographs with the location on recent photography. The long-term rate is simply the total landward displacement measured between the two photos, divided by the time period (in years) separating the photos. In areas where recession rate data were calculated, distances between sites (profiles) were normally between 152-305 meters, however distances between some sites range up to 402 meters.

The scale of the aerial photography was determined by field measurements of identifiable landmarks found on both the ground and the air photo. All scale measurements were made in approximately the same direction as the bluff recession measurements to minimize possible errors. Where measurements of landmarks could not be obtained, scale was calculated as an average of adjacent photographs which were flown in the same flight line over similar terrain.

Data for each profile was recorded in tabular format, as well as indicated on topographic map sheets for reference purposes.

***Data Accuracy and Reliability***

Photogrammetric determination of recession rates is one of the most common methods of recession rate determination and can be regarded as being generally accurate, although MDNR reported some problems in delineating the bluff crest on smaller scale, or poor quality aerial photographs. This problem was alleviated somewhat on more recent larger scale aerial photographs which provided improved image resolution and contrast over the imagery used in the original calculations. In addition, field reconnaissance was also sometimes used to assist in determination of bluff position. Despite such problems, the method of calculation is consistent for all counties and townships and is reliable enough to be utilized in the calculation of setbacks for development. Because of this, the data is considered "highly certain" in the USACE data base.

***Data Base Considerations***

None of note.

***B.Other Michigan (U.P.) Studies Not Incorporated Into Data Base***

None reviewed.

### 3.2.2Lake Michigan

### Wisconsin

#### *A.Wisconsin Coastal Management Program Recession Rate Data*

##### *General*

In the mid-to-late 1970's, the Wisconsin Coastal Management Program (CMP) initiated a comprehensive study of the shoreline conditions existing along the Lake Michigan and Superior coastlines. Information collected included data on erosion rates, bluff heights and characteristics, shore protection structures present, previous shore damages, number of houses present, beach characteristics, bluff slope angles, safety factors and confidence limits. A main report and nine appendices were produced. These are listed in Table 3.1. Appendix 9, Douglas and Western Bayfield Counties, was described previously in the section on Lake Superior.

All appendices, except for Number 8, contain information on recession rates along these shorelines for both the long-term (100 years) and the short-term (10 years). Unfortunately however, the appendices do not indicate the start or end dates of these two time periods. In addition, the appendices present results only - there is no discussion of how the recession rates were calculated, nor is there any discussion of their accuracy.

##### *Method of Calculation*

The Southeastern Wisconsin Regional Planning Commission (SEWRPC) (1982) report that the long-term data for Racine County were developed from a variety of sources, including the original U.S. Public Land Survey notes and maps, and by data from the U.S. Army Corps of Engineers. Short-term data were measured from aerial photographs at a scale of 1:12,000 to 1:20,000 that were taken over a period of 10-15 years. Measurements were made by plotting shoreline positions from the older photograph onto the most recent photograph and measuring the distance of recession to the nearest 0.001 centimeter.

It is assumed here that data for other counties were obtained in a similar fashion.

**Table 3.1: WCMP Shore Erosion Study Reports, 1977-1980**

| Appendix | County | Date Published | Authors |
|---|---|---|---|
| 1 | Kenosha | February 1977 | Schneider, Edil and Haas |
| 2 | Racine | February 1977 | Schneider, Edil and Haas |
| 3 | Milwaukee | February 1977 | Mickelson, Klauk, Acomb, Edil and Haas |
| 4 | Ozaukee | February 1977 | Acomb, Klauk, Mickelson, Edil and Haas |
| 5 | Sheboygan | April 1977 | Hadley, Fricke, Edil and Haas |
| 6 | South and Central Manitowoc | April 1977 | Hadley, Fricke, Edil and Haas |
| 7 | Northern Manitowoc, Kewaunee and Door | July 1980 | Dagle, Mickelson, Acomb, Edil and Pulley |
| 8 | Milwaukee | February 1977 | Klauk |
| 9 | Douglas and Western Bayfield | July 1980 | Need, Johnson, Schultz, Pulley, Mickleson, Edil, DeGroot and Bagchi |

***Data Accuracy and Reliability***

This is not known, but was assumed to be reasonable given the comprehensiveness of the study. Other authors (e.g. Anders and Byrnes, 1991; Crowell et al, 1991) however, have reported on a number of errors associated with the use of maps created prior to the use of aerial photography (i.e. 1800's-1930's) for recession rate analysis and suggest that worst case ground distance errors of 8.5 meters or more may occur. In light of this, where data was entered, it has been ranked as "moderately certain" or "reasonable" depending on county.

***Data Base Considerations***

This data (except for Milwaukee County and Racine County) was originally input to the USACE data base. As such, all data was checked and corrections and modifications were made as required. Milwaukee County and Racine County data were entered in the data base and supplement SEWRPC (1982, 1984, and 1989) or other data originally input. The data presented in the Wisconsin CZM appendices is in map form only and was sometimes difficult to read on the copies obtained. In addition, data points did not always appear to coincide exactly with section lines, or alternatively, the scale of the map was such that a specific location was difficult to determine, so their inclusion in a particular reach was approximated. In some cases the data produced by this study was reproduced by other authors (e.g. Keillor and Miller, 1987; SEWRPC, 1982), and was thus modified/corrected from these sources.

For data base entry purposes, it was assumed that the 100 year period represented a time frame from approximately 1875 to 1975, and that the 10 year rate represented a time frame from approximately 1965 to 1975. The remarks column of the data base has been altered to reflect these time periods.

As part of the Wisconsin CMP work, a series of "public information" maps were produced for each county indicating sections of shoreline where "high" and "low to moderate" erosion potential exist. The corresponding recession rate values assigned to each category were estimated using shore type, damage, protection and other information collected by Springman and Born (1979) (P. Keillor, University of Wisconsin Sea Grant, personal communication) and are as follows:

High Erosion Potential>0.61 meters per year
Moderate Erosion Potential0.3-0.61 meters per year
Low Erosion Potential<0.61 meters per year

These maps were used in the USACE data base to provide values of recession **only** for sections of the shoreline where no other data exists (e.g. Ashland and Iron Counties) or for those areas where the information provided in the Wisconsin CMP reports was unreadable. For the purposes of the USACE data base, this map information is considered "linear zone, linear range" data and is considered "reasonable." As moderate and low erosion potential are combined as one category on these maps, the USACE data base will indicate values of either >0.61, or <0.61in the mean recession column. This data is indicated by "Wisconsin CZM 1979 MAP" in the remarks column.

***B.Lake Michigan Shoreline Recession Rate Data (Buckler and Others 1975-1988)***

***General***

This section will describe a number of data sets that cover the Lake Michigan shoreline from Kenosha County in the south, to Door County in the north. The data is culled from two academic studies conducted primarily by Professor W.R. Buckler, currently of Youngstown State University in Ohio, and others (Buckler, 1981; Buckler and Winters, 1983). These studies represent a comprehensive data set along this shoreline. The first of these studies examined long-term (1830's-1973) recession rates for 62 sites along the Lake Michigan shoreline. In addition, Buckler (1981) also provided a more detailed analysis of shoreline recession rates for a case study site in Kenosha County.

***Method of Calculation***

The initial studies by Buckler (1981) made use of U.S. Government General Land Office (GLO) surveys. These provided the first abundant quantitative data regarding former positions of Lake Michigan Bluff crests. GLO survey lines were established through a procedure that was independent of shore zone characteristics. Precise distances from section and quarter-section corners within 1.6 kilometers of the Lake Michigan "meander line" (top edge of the shore zone bluff) were recorded in these surveys.

Within the study area the GLO surveys date between 1833 and 1836. Field and archival data were examined for every initial government survey line that extends to the shore zone to identify all places where remeasurement was feasible. This was accomplished for 62 sites. Long-term bluff line changes were then ascertained for these sites by comparing modern measurements with the nineteenth-century survey records.

Modern data were derived from resurveys conducted in 1976 and 1977 (Buckler, 1981). All of these measurements followed the true bearing of the section lines as closely as possible, and distances were established by using measuring tape and standard surveying procedures. Some distances were obtained from previous surveys conducted by registered land surveyors (RLS). All measurements were to the crest of the lakeshore bluff. At places where pedestrian or vehicular traffic had obviously notched the bluff's upper boundary, the resurvey was carried to a projected line connecting the bluff edge on either side of the site. At places where the bluff crest was rounded, a somewhat arbitrary edge position was established.

For the Kenosha case study, Buckler (1981) compared bluff crest positions on 1941 air photography with positions on 1969 and 1975 photography in a manner consistent with previous studies. Twenty-two sites (profiles) were selected for analysis.

***Data Accuracy and Reliability***

Buckler (1981) reports that probable errors in resurvey measurement ranged from 0.3 meters in 1.5 kilometers for the RLS distances to an inaccuracy of approximately 0.25 percent or less for the stadia method. Where bluff edges were arbitrarily established, estimated error was less than 0.91 meters. Generally speaking, the data is very reliable and if any errors do exist, they are very few and small in

magnitude. Other authors (e.g. Anders and Byrnes, 1991; Crowell et al, 1991) however, have reported on a number of errors associated with the use of maps created prior to the use of aerial photography (i.e. 1800's-1930's) for recession rate analysis and suggest that worst case ground distance errors of 8.5 meters or more may occur. In light of this, values from these studies listed in the data base are considered "moderately certain" for data calculated using 1800's vintage maps and "highly certain" for more recent periods of record.

#### *Data Base Considerations*

The large number of profiles surveyed, plus the variations in periods of record in each has resulted in a large number of line entries in the Lake Michigan data base for many of the Wisconsin reaches, as each different period of record requires a separate line of data.

### *C.Kewaunee County Coastal Hazard Management Plan Recession Rate Data (Bay-Lake Regional Planning Commission, 1988)*

#### *General*

In 1987, Kewaunee County, in association with the Bay-Lake Regional Planning Commission and under the guidance of an advisory committee, developed and recommended a shoreline erosion control plan for the Lake Michigan shoreline. The study includes an inventory and analysis of the existing shoreline erosion and bluff conditions, and provides recommendations for erosion control in the County. Shoreline erosion data utilized in this plan were taken from previous work by Dagle et al. (1980), under the Wisconsin Coastal Management Program (WCMP) (See A Above). The map copies of the WCMP data were of poor quality and were very difficult to read however, so for the purposes of data entry, recession rate data for Kewaunee County was taken from the present management plan.

#### *Method of Calculation*

Long-term (100 year) recession rates were developed for limited locations along the shoreline. These were developed by determining the mean recession rate during periods of both high and low erosion rates over an approximately 100 year interval.

Short-term recession rates were measured on large-scale aerial photographs taken during an approximately 10-year period from the mid to late 1960's to the late 1970's. The distance from a stationary landmark to the bluff edge were measured to 0.0001 centimeters on each set of aerial photographs. The amount of recession was then divided by the time interval of the photography to obtain the site-specific bluff recession rate.

***Data Accuracy and Reliability***

There is no discussion of data accuracy in this report. It is assumed that the data is as accurate and reliable as any other determined using aerial photographs.

***Data Base Considerations***

It appears that the data already in the data base was derived from the Wisconsin CMP source data. As such, it was checked with the data contained in the Kewaunee County Hazard Plan and any corrections or modifications were made.

***D.Manitowoc County Recession Rate Data, 1938-1975 (Peters, 1982)***

***General***

This report provides recession rate data for Manitowoc County which was used (or at least considered) for the adoption of a coastal zone setback ordinance. Two sources of data were utilized. First, an approximately 40 year recession rate was calculated by using aerial photographs from 1938 and 1975. Second, 100+ year recession rates were calculated where section lines intersect the shoreline by comparing bluff edge positions from old surveys to present-day (1953 and 1978) topographic maps. Data were provided for the area south of Manitowoc to the southern county line, and for the area from the northern end of Point Beach State Forest to the northern county line.

***Method of Calculation***

The 40 year recession rates were determined by comparing the respective positions of the bluff edge from 1938 and 1975 aerial photography. Photos were viewed with a stereoplotter, and both sets of photos were enlarged to approximately a 1:6000 scale. This allowed the bluff edge from both sets of photos to be plotted on the same map, and the amount of bluff edge recession from 1938-1975 was measured directly from this. Two or three common points on each set of photos provided ground control, and true ground distances between control points were determined from USGS 1:24,000 scale topographic maps. Point recession measurements were made 5-10 times per 1.6 kilometers, in a perpendicular direction from the shoreline so that the rates represent a perpendicular bluff edge loss.

The 100 year recession rates were made at the intersection of section lines with the bluff edge. The original Wisconsin land surveys from 1834 and 1835 were used for the initial bluff position and compared to bluff edge positions for USGS 1:24,000 scale topographic maps from 1953 and 1978. Distances were measured along section lines, which didn't always intersect the bluff at a right angle. To compensate for

this, and determine perpendicular recession, a correction factor was applied.

#### *Data Accuracy and Reliability*

Peters (1982) provides a good discussion of the possible error in the above methods, and highlights three major sources of error in calculating the 40 year recession rates: 1) photos were viewed monoscopically, not stereoscopically, thus there is distortion due to using non-rectified photos; 2) lack of good control points and the inability to accurately locate existing ones; and 3) measurement error, both in tracing the bluff and measuring recession. The net result of these is that error could be as great as ±8.5 meters over the period 1938-1975. This represents an error of ±0.23 m/yr. This is a serious problem since most of the 40 year recession rates are under 0.61 m./yr. Even at 0.61 m/yr, this represents a 38% error in measurement.

The error on the 100 year recession rates is minimized because of the long time period involved. Assuming that the original surveys are accurate, the error is due to locating the bluff edge on the topographic map. This error was approximately 0.4 mm, which equals about 9.1 meters on the ground. This represents a recession rate error of ±0.08 m/yr when the 1952 topographic maps were used and ±0.06 m/yr when the 1978 topographic maps were used.

Other authors (e.g. Anders and Byrnes, 1991; Crowell et al, 1991) have also reported on a number of errors associated with the use of maps created prior to the use of aerial photography (i.e. 1800's-1930's) for recession rate analysis and suggest that worst case ground distance errors of 8.5 meters or more may occur.

Because of these possible errors, these data have been listed as "moderately certain" in the confidence section of the data base.

#### *Data Base Considerations*

Data is identified by "Peters (1982)" in the remarks column.

### *E.Milwaukee County Recession Rate Data 1836-1944*

#### *General*

This data consists of a table listing historic recession rate data from 1836-1944 that was taken from a report called "Lake Michigan Shore Erosion, Milwaukee County, Wisconsin" (Report of Committee, 1945). Rates listed in this table were determined by re-occupying section corners and comparing measurements to the bluff edge made in 1836, 1874 and 1944. While details are not provided in the report, Keillor (1993, personal communication) maintains that the values produced by this analysis are very accurate. These data have been incorporated into the USACE data base.

### *F.Racine County, Milwaukee County and City of St. Francis Recession Rate Data (Southeastern Wisconsin Regional Planning Commission (SEWRPC), 1982, 1989 and 1984)*

#### *General*

The three reports referenced here provide comprehensive information on the nature of the shoreline in these three areas. The studies: identify the extent of shoreline and bluff recession which historically has occurred; quantify potential property losses which may be expected to occur from future recession; identify erosion risk distances and recommend setback distances; recommend regulations to restrict certain land uses and practices; and provide recommendations on proper shore protection methods.

As part of the work, SEWRPC conducted a thorough recession measurement program in these areas. The period of record analyzed and the number of recession profiles measured in each county are summarized in Table 3.2.

#### *Method of Calculation*

Shoreline recession rates were measured using Regional Planning Commission ratioed and rectified, 1:4800 scale, aerial photographs taken in 1963 and 1985 (Milwaukee County), 1963, 1975 and 1980 (Racine County), and 1963, 1970 and 1983 (City of St. Francis). All measurements were made parallel to the east-west U.S. Public Survey Section line which formed the southern boundary of the study area. The measurements were corrected for minor variations in air photo scale and for the angle of the shoreline in order to represent recession perpendicular to the shoreline. Shoreline recession was measured at intervals of approximately 61 meters - the interval length being measured perpendicular to the section line - along the entire study area shorelines.

**Table 3.2:SEWRPC Recession Profile Information - Milwaukee Co., Racine Co., and City of St. Francis**

| County | Period of Record | No. of Profiles Measured |
|---|---|---|
| Milwaukee | 1836-1985<br>1963-1985 | 19<br>638 |
| Racine | 1975-1980*<br>1963-1980 | 101<br>101 |
| City of St. Francis | 1963-1980 | 19 |

| | | |
|---|---|---|
| | 1970-1980 | 19 |

***Note:** The Racine County Report also presents 10-15 year and 100-110 year recession rate data from WCZM (Schneider et al., 1977) and 1968-1971/75 data from Keillor and DeGroot (1978). Both these data sets are discussed elsewhere in this section.

In Milwaukee County, long-term recession rates over the period 1836-1985 were also calculated. These long-term rates are based on the original U.S. Public Land Survey field notes made in 1836, SEWRPC 1980-1987 topographic maps, and the related control survey network which locates and monuments all U.S. Public Land Survey corners and places these corners on the State Plane Coordinate System. The long-term recession rates were calculated at 19 U.S. Public Land Survey Section lines which did not lie within areas of extensive filling since the original survey.

***Data Accuracy and Reliability***

A discussion of error analysis is provided in the Racine County report only (SEWRPC, 1982) but it applies to all recession rates calculated. Aerial photographs were corrected for tilt and vertical distortion by the ratio and rectification procedures. However, minor variations in scale and relief displacement errors occurred on the maps. Therefore, minor variations in scale were corrected by determining the exact scale of the map within each coastal erosion analysis reach. Exact scale was determined by comparing the distance between two known points on the map to the same distance as measured on large scale topographic maps. Relief displacement errors could be significant if the elevation of the top edge of the bluff changed by more than approximately 6.1 meters over the measurement period. However, bluff changes were found to be very minor, generally less than 1.2 meters. Consequently, relief displacement errors were not significant. Other errors related to instrument use, operator procedures, and cartographic procedures would be similar to those reported by Keillor and DeGroot (1978) (See G Below).

***Data Base Considerations***

For Milwaukee County, the 1963-1985 data was previously input to the data base. No modifications or corrections to this data were made as it was assumed the initial data entry was accurate. It should be noted that the median and variance for these values has not been calculated for all reaches. Data covering the period 1836-1985 for 19 profiles was added however, and supplements the shorter term data.

City of St. Francis data (Reaches 1137-1140) was added for both the 17 and 10 year periods of record.

Racine County data was originally input to the data base for the 17 year period of record. This data was checked and corrected where required and data for the 5 year period of record was also input.

### *G.Racine County Recession Rate Data (Keillor and DeGroot, 1978)*

#### *General*

This report provides documentation of erosion rates in Racine County over the eight year period of 1968-1976, a period of rising water levels on the Great Lakes[1]. It was carried out by members of Wisconsin's Sea Grant Program at the request of the Racine County Coastal Management Technical Advisory Committee. A substantial part of the work was also to characterize the storm wave energy eroding the Racine coastline during the period covered by the recession measurements.

#### *Method of Calculation*

Recession measurements were made on 1:2,400 scale topographic maps which had been compiled from aerial photography flown in 1968, 1969, 1970 and 1971. These maps were then compared to maps compiled from 1976 photography in order to determine shoreline changes occurring between the various time periods. A coordinate grid system was placed under the maps and was used for lateral and vertical control for all measurements. Locations for measurement sites were determined by both a constant measurement interval and the location of monumented survey points. The measurement interval established was approximately 60 meters for the north part of the county (due to the severity of the erosion) and approximately 150 meters for the remainder. Gaps in the data occurred where measurement locations could not be identified, or where gullying of the bluff edge made measurement impossible. Recession was determined by calculating the change in position of the bluff edge, bluff toe, and shoreline relative to a permanent unchanging location (usually a road, building, monument, bench mark, or section line). The average annual bluff edge recession rate was calculated by dividing the measured recession by the time interval of the map products. Bluff edge is defined as the linear retreat measured perpendicular to the bluff edge. Since the majority of the measurements made here were at an oblique angle to the shoreline, a correction was made to standardize the measurements. Tables are presented in the report showing line locations and the average annual recession rate calculated for each. Additional tables also show volumetric bluff loss at these same locations.

#### *Data Accuracy and Reliability*

[1] The report also contains a table listing historic recession data from 1836-1946 that was taken from a report called "Beach Erosion Control Report - Cooperative Study of Racine County." Rates listed in this table were determined by re-occupying section corners and comparing measurements to the bluff edge made in 1836, 1874 and 1946. While details are not provided in the report, Keillor (1993, personal communication) maintains that the values produced by this analysis are very accurate. These data have also been incorporated into the USACE data base.

Keillor and DeGroot (1978) provide a good discussion of the possible types of error in this analysis. Instrument accuracy, operator error and map reproduction were found to produce very small errors and were not of major importance. Obscured bluff edge, and human interventions along the shoreline produced inconsistencies in the recession measurements, but these factors were readily identifiable. Cartographic procedures and bluff definitions were found to be the largest cause of error, with the maximum error approximated at ±0.53 meters per measurement, or ±1.06 meters per location, since two measurements were made at each location. This error was found to be small for steep slopes and large for shallow slopes. Given the maximum error, and the shortest time interval, the maximum error possible for any recession rate would be ±0.24 meters per year.

Although ±0.24 meters per year is the maximum error calculated, it is greater than the "likely" error. Slope angles of $30^{o}$ appear only in the protected area north of the breakwater at Racine where the bluff is generally stable. Slopes of the bluff face for the rest of the county have a minimum value of $40^{o}$. Using this value, the maximum error ranged between ±0.17 meters per year to ±0.09 meters per year, depending on the time interval involved.

The data is marked as "moderately certain" in the data base.

#### *Data Base Considerations*

Addition of the Beach Erosion Control Report data and the Keillor and DeGroot data has resulted in the addition of a number of new "line items" to the data base.

### *H.Other Wisconsin Studies Not Incorporated Into Data Base*

A number of smaller, site specific recession studies have been conducted along the Wisconsin shoreline of Lake Michigan, including an air photo interpretation and physical model study of erosion in the villages of Whitefish Bay, Fox Point and Shorewood (Frankovic, 1975), and studies of erosion along the southern Wisconsin shoreline (Hadley, 1976; Pezzetta and Moore, 1978). Other recession studies have been related to the examination of bluff processes and landslides (Edil and Vallejo, 1976; Sterrett, 1980; and Vallejo and Degroot, 1988). A more recent study is one by Rovey (1992) who examined bluff formation and long-term recession rates along the southwestern shoreline of Lake Michigan.

## Illinois

### *A.Jibson and Staude (1992) Recession Rate Data*

***General***

Jibson and Staude (1992) address the practical effects of bluff recession by documenting the amount and rate of bluff retreat from 1872 to 1987 at 100 meter intervals along the Lake Michigan shoreline from Wilmette to Waukegan, Illinois. They also measure retreat rates for two subdivisions of this period, 1872-1937 and 1937-1987, to measure temporal changes in retreat rates. They then relate observed temporal and spatial variations in retreat rates to temporal changes in lake level and precipitation and to spatial differences in bluff height, bluff lithology, and construction of shore protection works.

***Method of Calculation***

The shoreline was first divided into 300 segments, each 100 meters long. Segments were defined by projecting perpendicular lines from a baseline bearing N 20$^{o}$W and were numbered from south to north. Recession rates were then calculated by comparing bluff positions on historical maps and air photos of different ages. While this technique is common, the density of measurements is much greater than in most previous studies. Bluff positions were compared from three data sources: 1:20,000 scale topographic maps made in 1872 by the U.S. Army Corps of Engineers; 1:14,400 scale air photos taken in 1936; and 1:14,400 scale air photos taken in 1987. The bluff edge from all sources was traced onto U.S.G.S. topographic quadrangles enlarged to 1:12,000 scale. Bluff recession for each segment was then calculated by measuring the distance from the three bluff positions to a reference feature - the Chicago and Northwestern railroad grade - and then comparing the distances between each pair of data sources.

***Data Accuracy and Reliability***

Primary sources of location error include inherent air photo distortion and imperfect registration of the map and air photo on the zoom-transfer scope used. Jibson and Staude (1992) estimate that the combined location error from all sources for single features plotted from air photos does not exceed 3 meters; thus distances measured between any two features are accurate within 6 meters, and comparisons of two such distances are accurate within 12 meters. Measurements from the 1872 maps are estimated to be accurate within 5 meters; comparisons with measurements from air photos are thus accurate within 11 meters. If location errors are random, they should have little net effect on regional averages calculated from the large data base.

This data has been considered as "moderately certain" in the USACE data base.

***Data Base Considerations***

Recession rate data for each segment, for each of the time periods is presented in Jibson and Staude

(1992) in graphical format and is it was impossible to determine precise values for each segment. The tabular data presented summarizes (averages) recession rates for groups of segments (e.g. 1-52, 53-233, 234-284, and 285-300), for each of the time periods. While this is more useful than the graphs, the location map of the segments was poorly done, and it was still difficult to accurately determine locations of these reaches.

To resolve these problems, detailed tabular data for each segment was obtained directly from the authors and provided annual average recession rates for each segment, for each period of record. A good quality location map was still not provided however, so the exact reaches covered by the groups of segments still had to be estimated off of the topographic quadrangles.

Data for the longest period of record (1872-1987) had originally been entered in the data base for these reaches (1015-1049). However, as it was also necessary to input data for the other periods of record provided, the reaches covered by the data had to be re-determined so that there was consistency for all three periods of record. This resulted in some changes to the 115 year recession rate values previously determined for these reaches, as well as the number of samples that occurred in each reach. Given the large number of samples, and the accuracy of the data, however, it is anticipated that these changes will be relatively minor. In addition, despite the presence of harbor structures, or artificial shoreline in a reach, a recession rate is still provided in the data base. This is based on discussion by Jibson and Staude (1992) that the presence of such structures has had relatively little influence on regional rates of bluff retreat. This also resulted to changes in recession rate values for a few of the reaches in the study area.

For each USACE reach covered by this data, three line entries will exist in the data base - one for each period of record listed above.

***B.Additional Illinois Data***

The majority of the Illinois shoreline, from the Indiana border to Wilmette (which includes the City of Chicago), has been given a mean recession rate of 0.00 in the data base, as this section of shoreline is heavily protected and will likely remain so in the future (Charles Thompson, USACE Detroit, Personal Communication). No other recession rate data sources were identified for this shoreline.

***C.Other Illinois Studies Not Incorporated Into Data Base***

An early study of the Illinois shoreline (Hardin and Booth, 1952) provided a general description of the physical geology of the shoreline, including a discussion of erosion problems and shore protection structures. In 1973, Larsen presented a theoretical method for approximating the accelerated erosion associated with high water levels so that other causes of increased erosion could then be identified. Using

the section of shoreline between Wilmette and Waukegan as his study area, Larsen (1973) established profiles at scales of 1:30,000 and 1:36,000 with a resolution of 7.6 meters. On these profiles he estimated bluff erosion by determining changes in shoreline position. Berg and Collinson (1976), working in the same area, improved upon Larsen's technique somewhat by utilizing 1:2400 scale base maps and measuring bluffline positions relative to cultural features found on the maps. Berg and Collinson (1976) also examined recession changes for this area over a number of different periods of record including 1872-1910, 1910-1975, 1872-1975, 1964-1975 and 1947-1975.

The Illinois State Geological Survey has also been active in examining shoreline recession having produced reports dealing with coastal geology and coastal zone management (Illinois State Geological Survey, 1977) and an atlas of the Illinois shore highlighting shore features, damaged areas and shore protection structures (Illinois State Geological Survey, 1988). In addition, they have conducted surveys for 28 profiles offshore of Chicago's Lincoln Park taken in 1976 and again in 1987 (reported in Nairn, 1992), and for 20 profiles at North Point Marina near the Illinois/Wisconsin state line taken annually between 1988 and 1991 (Chrzastowski and Riggs, 1989). Shabica et al (1991) also present profile surveys for several sites between Fort Sheridan and Evanston documenting the loss of sand cover between 1975 and 1989.

Finally, a number of other smaller scale erosion related studies taking place along the Illinois shoreline have been summarized by Folger et al (1990) in the proceedings of the 2nd Southern Lake Michigan Coastal Erosion Study Workshop.

## Indiana

### *A.Indiana Shoreline/Coastal Situation Reports (Davis et al, 1981; Wood and Davis, 1986; Wood et al, 1988)*

#### *General*

These three reports describe work that has been carried out by the Great Lakes Coastal Research Laboratory (GLCRL), Purdue University, and assesses shoreline conditions and lake dynamics along Indiana's 64 kilometers of Lake Michigan shoreline. The first two of these (Davis et al, 1981; Wood and Davis, 1986), describe comprehensive investigations on specific sections of Indiana's coastline (LaPorte County and Indiana Dunes National Lakeshore). The third report (Wood et al, 1988) presents similar detailed information on the remainder of the shoreline. While recession data was determined in each of these studies, the data presented in the Wood et al (1988) report provides a unified evaluation of shoreline change along the Indiana Coast and incorporates recession values calculated in the previous studies. As such, the data contained in it was used for data base entry purposes.

#### *Method of Calculation*

A series of base maps showing bluff crest and water's edge positions were compiled primarily from aerial

photographs and were verified at specific locations with beach survey data collected by GLCRL from 1975 to 1988. Maps for the majority of the shoreline were drawn for the period 1976-1978 (depending on availability) to 1987. Maps for the section of the shoreline containing Indiana Dunes State Park were drawn for the period 1969-1987. Where 1938 aerial photographs were available, they were also used.

On these maps, eighty-seven locations were established and used to determine recession and water's edge movements for the various time periods. These locations were selected to correspond to well-established beach survey lines, important coastal features, or easily recognizable landmarks.

#### *Data Accuracy and Reliability*

Given that the aerial photographs were verified with beach survey data and that control points were selected to correspond to well established beach survey lines, this data has been rated as "highly certain" in the "confidence" column of the data base.

#### *Data Base Considerations*

Due to the number of different periods of record examined, multiple line entries exist for reaches where data was available. These are sorted in the data base in descending order by period of record. Data is identified by "Wood et al (1988)" in the "remarks" column.

### *B.Other Indiana Studies Not Incorporated Into Data Base*

A number of smaller scale erosion related studies taking place along the Indiana shoreline have been summarized by Folger et al (1990) in the proceedings of the 2nd Southern Lake Michigan Coastal Erosion Study Workshop.

## Michigan

### *A.Michigan Department of Natural Resources (MDNR) Recession Rate Data*

#### *General*

The Land and Water Management Division of the Michigan Department of Natural Resources is responsible for the determination of erosion setbacks for development along the shoreline. To calculate these setbacks, they have determined detailed recession rates for most of the Lake Michigan shoreline, although coverage in most of the northernmost counties (Delta, Schoolcraft, Mackinac, Emmet, Charlevoix, Grand Traverse and Leelanau) is somewhat limited. The USACE data base originally contained a large amount of this data, however a number of gaps existed and some of the data has been updated since original incorporation. To fill some of these gaps and to provide updated values, new recession rate data was obtained for a number of counties and townships (Table 3.3).

***Method of Calculation***

The MDNR recession rate data were determined at representative sites by comparing bluff crest locations on historic aerial photographs with the location on recent photography. The long-term rate is simply the total landward displacement measured between the two photos, divided by the time period (in years) separating the photos. In areas where recession rate data were calculated, distances between sites (profiles) were normally between 152-305 meters, however distances between some sites range up to 402 meters.

The scale of the aerial photography was determined by field measurements of identifiable landmarks found on both the ground and the air photo. All scale measurements were made in approximately the same direction as the bluff recession measurements to minimize possible errors. Where measurements of landmarks could not be obtained, scale was calculated as an average of adjacent photographs which were flown in the same flight line over similar terrain.

Data for each profile was recorded in tabular format, as well as indicated on topographic map sheets for reference purposes.

**Table 3.3:Counties and Townships For Which New or Updated MDNR Recession Rate Data Was Obtained**

| County | Townships | Updated? | New? |
|---|---|---|---|
| Leelanau | Empire and Village, Glen Arbor, Leelanau, Sutton's Bay, Bingham, Elmwood | _ | _ |
| Grand Traverse | City of Traverse City, Peninsula, East Bay, Acme | _ | _ |
| Charlevoix | Norwood, Charlevoix, Hayes | _ | _ |

| | | | |
|---|---|---|---|
| Antrim | Banks, Torch Lake, Milton, Elk Rapids | _ | _ |
| Emmet | Wawatan, Resort, Bear Creek, Little Traverse, West Traverse, Friendship, Readmond, Cross Village, Bliss | _ | _ |
| Ottawa | City of Ferrysburg, Spring Lake, Grand Haven, Port Sheldon | | _ |
| Manistee | Arcadia, City of Manistee, Onekama, Manistee, Filer | _ | |
| Benzie | Blaine, Crystal Lake, City of Frankfort, Lake, Gilmore, Village of Elberta | _ | |
| Muskegon | White River, City of Muskegon, City of Norton Shores, Laketon, Fruitland | _ | |

***Data Accuracy and Reliability***

Photogrammetric determination of recession rates is one of the most common methods of recession rate determination and can be regarded as being generally accurate, although MDNR reported some problems in delineating the bluff crest on smaller scale, or poor quality aerial photographs. This problem was alleviated somewhat on more recent larger scale aerial photographs which provided improved image resolution and contrast over the imagery used in the original calculations. In addition, field reconnaissance was also sometimes used to assist in determination of bluff position. Despite such problems, the method of calculation is consistent for all counties and townships and is reliable enough to be utilized in the calculation of setbacks for development. Because of this, the data is considered "highly certain" in the data base.

***Data Base Considerations***

Where sites within the 1 kilometer reaches have different periods of record, they were reported as two different line items within that reach. For example, if 10 sites were present in the reach, 6 with a 40 year period of record, and 4 with a 20 year period, then mean, median, maximum and minimum recession rates would be recorded for the 6 profiles and the 4 profiles individually, and two recession rate “records” would be listed for that reach.

***B.Berrien County Recession Rate Data (Birkemeier, 1980)***

***General***

This study (reported in Raphael and Kureth, 1988) examined bluff recession rates for five reaches from

south of St. Joseph to Warren Dunes State Park. A four year period (1970-1974) was examined.

***Method of Calculation***

Rates of bluff recession and shoreline change from 1970-1974 were made along five 1.6 kilometer beaches using aerial photographs with an approximate scale of 1:3600. Annual measurements were made at 30.5 meter intervals, except for two adjacent reaches where biannual measurements were made. There is no information provided on control points, or the number of "profiles" utilized to calculate a recession value for each reach. It is anticipated that this information is contained in the Birkemeier (1980) report, although this report was not obtained for confirmation.

***Data Accuracy and Reliability***

Photogrammetric determination of recession rates is one of the most common methods of recession rate determination and can be regarded as being generally accurate.

***Data Base Considerations***

Exact locations of the Birkemeier sites was difficult to determine from the map figure provided in Raphael and Kureth (1988). Only one value of average annual recession was provided for each of Birkemeier's sites. As these sites cover more than one USACE reach (e.g., Site 5 covers Reach 825 and 826), the recession value for the USACE reaches covered by the site will all be the same. In the data base, these values are identified by "Birkemeier (1980)" in the remarks column.

***C.Berrien County Recession Rate Data (Raphael and Kureth, 1988)***

***General***

As part of an overall project to examine the economic impact of coastal bluff line recession to Berrien County, Raphael and Kureth (1988) calculated recession rates using three data sources: 1) data provided by property owners in a formal questionnaire; 2) eyewitness accounts in two specific areas; and 3) air photograph analysis of bluff line recession between 1980-1987. The study focussed on the northern coastal sector of the county where population densities are quite high. In addition to their own data generation, Raphael and Kureth (1988) discuss recession rate data provided by Birkemeier (1980) (see above), as well as that provided by the Michigan Department of Natural Resources.

The primary purpose of this work was to provided more information on short-term erosion rates (seven years of record), particularly during a period of rising water levels. The report contrasts the short-term rates

obtained, with the longer-term rates commonly used in establishing shoreline management policy.

***Method of Calculation***

As mentioned, three data sources were utilized. The first was a shore property owner questionnaire, which saw 106 residents respond to two questions concerning bluff recession. These were, "What is the extent of bluff loss due to erosion in the past five years?" and, "How much of this bluff loss has occurred in the last two years?" Data obtained from this survey was combined to provide 2-year (1985-1987) and 5-year (1982-1987) average annual recession rates for each of the three study areas (North, Central and South) defined. Details were not provided on the location of the 106 residents, nor on the specific erosion rate reported by each, although maximum and minimum recession rates were reported for both the 2-year and 5-year period.

The second method was eyewitness accounts of bluff recession at Stevensville and Shoreham by long-time residents of the area. At Stevensville, observations covering four time periods were obtained: 1972-1984; 1980-1984; 1973-1980; and 1972-1973. At Shoreham, observations from five time periods were reported: 1916-1973; 1967-1973; 1955-1967; 1940-1953; and 1916-1940.

The third method utilized was an analysis of very large scale (1:6000) aerial photographs from 1980, 1985 and 1987. In the "North" study area (Mizpah Park), the coastal reach was subdivided into 16 points spaced approximately 150 metres apart. At each point, the bluff line position in 1980 and 1987 was determined and mapped. In the "Central" area (south of St. Joseph including Shoreham), 21 points were utilized to calculate the 1980-1987 recession rates. In the "South" study area (Grand Mere Lakes), 17 sites were utilized with a period of record from 1980-1985. Total recession and an average annual rate were provided for each of the sites.

***Data Accuracy and Reliability***

Data obtained from resident surveys and eyewitness accounts is largely judgemental and is only reliable if the residents providing the information have a sound understanding of the nature of coastal processes and if they have utilized some kind of control point in their "measurement" of bluff line position over the years. As human memory of events occurring in the past is often limited, it is often difficult to remember just where the bluff line was five years ago unless there was some documentation that the homeowner can refer to. This tends to be rare in many Great Lakes locations. Another problem with this method of analysis is that it represent only one evaluation at one specific site, and thus, may not necessarily be representative of bluff line recession rates for longer reaches within the county. Also, if there has been a large amount of erosion that has had a severe negative impact on a property, the actual amount of erosion may tend to be overestimated by the property owner because of the emotional impact that they have experienced. Perception of what constitutes recession can also be a problem. One may view the loss of a beach during

a high water period as recession (even though the beach comes back at a lower water period), while another may more properly view recession as the total retreat of the bluff crest over that same time period.

Despite such limitations, Raphael and Kureth (1988) view the estimates of recession obtained in this manner as being relatively reliable since they include on-site measurements of shore property by concerned homeowners. In addition, a correlation of values reported in the questionnaire with those they determined by air photo analysis tended to be relatively close. It is their feeling as well, that eyewitness and questionnaire data of this type document significant erosion particularly during high lake levels, and that they reveal actual periods and characteristics of bluff line recession rather than calculated averages.

Of the three methods utilized, the air photo analysis is deemed here to be the most reliable. Reasons for this include the large scale of photo utilized, the fact that bluff crests were easily visible on the photos (photos taken in early April and May with little foliage present), and that air photo scales were checked more accurately through ground measurement of select features such as roads. Despite this, some problems were encountered. For example, in areas of dune shoreline, bluff crests of foredunes were often indistinct and difficult to determine due to the presence of blowouts or vegetation.

***Data Base Considerations***

Sites established by Raphael and Kureth (1988) along with the corresponding USACE reaches are indicated in Table 3.4, as are the USACE reaches for which eyewitness and questionnaire data are provided. For the sites utilized in the air photo analysis, the presence of a number of sites within a USACE reach allowed for the calculation of mean, median, maximum and minimum recession rates, as well as the variance. Eyewitness account data is for USACE reach 808 and 812 only. It should also be noted that a precise location for the eyewitness account data was not provided and that these two reach locations are approximated. Questionnaire data was summarized by study area (north, central, south) and no details were provided as to exact locations of respondents. As such the recession rate listed will be the same for all USACE reaches comprising the north, central and south study areas.

**Table 3.4:Raphael and Kureth (1988) Sites and Corresponding USACE Data Base Reaches**

| Study Area | Site Numbers | USACE Reach | Eyewitness | Questionnaire |
|---|---|---|---|---|
| North | 1-6 | 793 | | 793 |
| | 7-14 | 794 | | 794 |
| | 15-16 | 795 | | 795 |
| Central | 1-5 | 808 | 808 | 808 |

| | | | | |
|---|---|---|---|---|
| | 6-13 | 809 | | 809 |
| | 14-20 | 810 | 812 | 810 |
| South | 1-8 | 813 | | 813 |
| | 9-15 | 814 | | 814 |
| | 16-17 | 815 | | 815 |

***D.Lake Michigan Shoreline Recession Rate Data (Buckler and Others 1975-1988)***

***General***

This section will describe a number of data sets that cover the Lake Michigan shoreline from Berrien County in the south, to Leelanau County in the north. The data is culled from five separate academic studies conducted primarily by Professor W.R. Buckler, currently of Youngstown State University in Ohio, and others (Buckler and Winters, 1975; Buckler, 1981; Buckler and Winters, 1983; Buckler, 1987; and Buckler, Winters and LaMoe, 1988). These studies represent a comprehensive data set along this shoreline - one that has been continually updated in some locations over the years. The first of these studies (Buckler and Winters, 1975) examined long-term (1830-1973) recession rates for seven locations in Berrien, Van Buren, Allegan, Ottawa and Muskegon counties. The methods utilized in this early study provided the foundation for an examination by Buckler (1981) and Buckler and Winters (1983) of recession rates for 56 sites along the Lake Michigan shoreline. In addition, Buckler (1981) also provided a more detailed analysis of shoreline recession for case study sites at Shoreham in Berrien County. The subsequent studies by Buckler (1987) and Buckler, Winters and LaMoe (1988) provided updates to the Shoreham case study data, and a number of the Buckler (1981) sites respectively.

***Method of Calculation***

The initial studies by Buckler and Winters (1975) and Buckler (1981) made use of U.S. Government General Land Office (GLO) surveys. These provided the first abundant quantitative data regarding former positions of Lake Michigan Bluff crests. GLO survey lines were established through a procedure that was independent of shore zone characteristics. Precise distances from section and quarter-section corners within 1.6 kilometers of the Lake Michigan "meander line" (top edge of the shore zone bluff) were recorded in these surveys.

Within the study area the GLO surveys date between 1829 and 1855. Field and archival data were examined for every initial government survey line that extends to the shore zone to identify all places where

remeasurement was feasible. This was accomplished for 56 sites. Long-term bluff line changes were then ascertained for these sites by comparing modern measurements with the nineteenth-century survey records.

Modern data were derived from resurveys conducted in 1973 (Buckler and Winters, 1975), 1976 and 1977 (Buckler, 1981). All of these measurements followed the true bearing of the section lines as closely as possible, and distances were established by using measuring tape and standard surveying procedures. Some distances were obtained from previous surveys conducted by registered land surveyors (RLS). All measurements were to the crest of the lakeshore bluff. At places where pedestrian or vehicular traffic had obviously notched the bluff's upper boundary, the resurvey was carried to a projected line connecting the bluff edge on either side of the site. At places where the bluff crest was rounded, a somewhat arbitrary edge position was established.

For the Shoreham case study, Buckler (1981) compared bluff crest positions on 1938 air photography with positions on 1967 and 1977 photography in a manner consistent with previous studies. Fifteen sites (profiles) were selected for analysis. These sites were updated by Buckler (1987) to include comparisons with 1984 and 1986 aerial photography. In addition, Buckler (1987) established a network of 20 ground survey sites in 1985 and resurveyed these sites in 1986 to provide a one-year recession rate during a period of high water. In a similar manner, Buckler, Winters and LaMoe (1988) utilized 1986 air photography to update recession rates for 20 sites initially surveyed by Buckler (1981).

***Data Accuracy and Reliability***

For the Buckler and Winters (1975) and Buckler (1981) studies, probable errors in resurvey measurement ranged from 0.3 meters in 1.5 kilometers for the RLS distances to an inaccuracy of approximately 0.25 percent or less for the stadia method. Where bluff edges were arbitrarily established, estimated error was less than 0.91 meters. Generally speaking, the data is very reliable and if any errors do exist, they are very few and small in magnitude. Similar degrees of error also apply to the update studies carried out. All were done with good quality control, and where air photos were used, technological advances in equipment allowed for a high degree of certainty in bluff crest positions. Other authors (e.g. Anders and Byrnes, 1991; Crowell et al, 1991) however, have reported on a number of errors associated with the use of maps created prior to the use of aerial photography (i.e. 1800's-1930's) for recession rate analysis and suggest that worst case ground distance errors of 8.5 meters or more may occur. In light of this, values from these studies listed in the data base are considered "moderately certain" for data calculated using 1800's vintage maps and "highly certain" for more recent periods of record.

***Data Base Considerations***

The numerous updates carried out by Buckler et al. in the five studies listed, plus the variations in periods

of record in each has resulted in a large number of line entries in the Lake Michigan data base for many of the reaches, as each different period of record required a separate line of data. As an example, reach 808, which not only contains a number of the data sites examined by Buckler, but also others looked at by Raphael and Kureth (1988), now contains over 25 entries in the data base.

#### *E.Other Michigan Studies Not Incorporated Into Data Base*

A large number of smaller recession related studies conducted along the Michigan shoreline have not been incorporated into the USACE data base. Perhaps the most extensive of these are a series of projects conducted by Hands (1970, 1976, 1979, 1980, 1981, and 1983) who describes the monitoring of a series of profiles along the southeastern shore of Lake Michigan between 1967-1976 and who utilizes the data collected to predict shoreline response to changes in water level stages. Davis (1975, 1976) also carried out monthly surveys of Lake Michigan beaches between 1970 and 1973 in the same general area as Hands, and along with Fox (Fox and Davis, 1970 and 1973) developed a simulation model for relating storm cycles and beach erosion. Tanner (1975) also studied beach processes and erosion along portions of the shoreline in Berrien County.

The University of Michigan has also played an active role in measuring shoreline recession. Seibel (1972) examined shore erosion at selected sites along the Lake Michigan and Huron shorelines. Maresca (1975) looked at the passage of storm events and their influence on changes in bluffline recession, beach position and nearshore profile shape. Stoker (1976) evaluated the usefulness of aerial photographs in the determination of coastal erosion rates for a portion of the shoreline in Muskegon County. Gray and Wilkinson (1979) examined a 10 kilometer segment of shoreline near Glenn to determine the influence of nearshore till lithology on lateral variations in coastline recession rates. Finally, the Department of Naval Architecture and Marine Engineering has been involved in the coordination of a workshop on coastal erosion research needs (Meadows, 1988), and in cooperation with the Michigan Department of Natural Resources, has conducted a coastal monitoring program, including regular surveying of beach profiles, for a number of locations along the Lake Michigan and Huron shorelines (University of Michigan Ocean Engineering Laboratory, 1989).

### 3.2.3Lake Huron

### Michigan

#### *A.Michigan Department of Natural Resources (MDNR) Recession Rate Data*

##### *General*

The Land and Water Management Division of the Michigan Department of Natural Resources is

responsible for the determination of erosion setbacks for development along the shoreline. To calculate these setbacks, they have determined detailed recession rates for various areas of the Lake Huron shoreline. Except for St. Clair and Sanilac Counties, coverage is relatively limited along the entire shoreline. The USACE data base originally contained this data, however a number of gaps existed and some of the data has been updated since original incorporation. To fill some of these gaps and to provide updated values, new or updated recession rate data was obtained for St. Clair, Huron, Bay and Alcona Counties.

***Method of Calculation***

The MDNR recession rate data were determined at representative sites by comparing bluff crest locations on historic aerial photographs with the location on recent photography. The long-term rate is simply the total landward displacement measured between the two photos, divided by the time period (in years) separating the photos. In areas where recession rate data were calculated, distances between sites (profiles) were normally between 152-305 meters, however distances between some sites range up to 402 meters.

The scale of the aerial photography was determined by field measurements of identifiable landmarks found on both the ground and the air photo. All scale measurements were made in approximately the same direction as the bluff recession measurements to minimize possible errors. Where measurements of landmarks could not be obtained, scale was calculated as an average of adjacent photographs which were flown in the same flight line over similar terrain.

Data for each profile was recorded in tabular format, as well as indicated on topographic map sheets for reference purposes.

***Data Accuracy and Reliability***

Photogrammetric determination of recession rates is one of the most common methods of recession rate determination and can be regarded as being generally accurate, although MDNR reported some problems in delineating the bluff crest on smaller scale, or poor quality aerial photographs. This problem was alleviated somewhat on more recent larger scale aerial photographs which provided improved image resolution and contrast over the imagery used in the original calculations. In addition, field reconnaissance was also sometimes used to assist in determination of bluff position. Despite such problems, the method of calculation is consistent for all counties and townships and is reliable enough to be utilized in the calculation of setbacks for development. Because of this, this data is considered "highly certain" in the data base.

***Data Base Considerations***

Where sites within the 1 kilometer reaches have different periods of record, they were reported as two different line items within that reach. For example, if 10 sites were present in the reach, 6 with a 40 year period of record, and 4 with a 20 year period, then mean, median, maximum and minimum recession rates would be recorded for the 6 profiles and the 4 profiles individually, and two recession rate "records" would be listed for that reach.

#### *B.Other Michigan Studies Not Incorporated Into Data Base*

Other than the coastal monitoring program carried out by the University of Michigan Ocean Engineering Laboratory (1989), no other studies were reviewed.

### 3.2.4Lake St. Clair

### Michigan

At present there is no recession rate data available for the Lake St. Clair shoreline, which includes all of Macomb County and portions of Wayne and St. Clair Counties.

### 3.2.5Lake Erie

### Michigan

At present there is no recession rate data available for this portion of the Lake Erie shoreline, which includes all of Monroe County and a small portion of Wayne County.

### Ohio

#### *A.Herdendorf (1993), Huron, Ohio Site*

##### *General*

As a follow-up activity to the construction of a marina and condominium development in Huron Ohio, Herdendorf (1993) monitored shoreline changes over the period 1987-1992 to determine the effects the marina breakwaters and associated shoreline protection were having on the sedimentation/recession rates of the shoreline.

***Method of Calculation***

Seventeen profile lines were established extending approximately 180 meters east and west of the marina. Over the five year period, a total of thirteen hydrographic surveys were performed, extending approximately 180 meters offshore. These were combined with land based surveys of the nearshore zone. For the hydrographic surveys, soundings were taken every 6.1 meters, at 30 meter intervals, from the approximate high water mark (1.28 meters above Low Water Datum) to 180 meters offshore using calibrated electronic depth sounders for offshore measurements and a sounding pole for nearshore readings. Soundings within the marina basin were typically taken with calibrated sounding poles to avoid false bottoms resulting from submerged plants. Surveys were performed during calm lake conditions, with a benchmark on the northwest corner of the breakwater used for vertical control throughout the surveys. All individual profile lines were then computer plotted and overlaid by season to determine shoreline change.

Results have shown that the marina has had a stabilizing influence on the shore, with net changes in bottom depths and sediment deposits to the west and east of the marina being negligible. The mean depth east of the marina decreased by 0.06 meters over the five year period, while west of the marina, it declined by less than 0.03 meters.

***Data Accuracy and Reliability***

Herdendorf (1993) states that because these depth changes are so small, they are at the accuracy limits of the field methods utilized and that differences in mean depths can not be considered statistically significant. Given the procedures used and the use of a benchmark for vertical control of all surveys, the data produced is considered reliable.

***Data Base Considerations***

The marina in question appears to fall within Reach 482 based on a "pencilled-in" diagram of the marina breakwaters found on the Huron Topographic Quadrangle. The data provided by Herdendorf (1993) does not measure recession directly, but instead measures changes in shore profile, particularly the offshore component. In all cases, it was very apparent on the profiles provided, that since construction of the marina, the shoreline position has been stable and that there has been no recession. This is what is reflected in the data base for Reach 482, although it should be noted that the marina is located at the west end of the reach and that the shore protection present does not likely extend the full length of the reach.

***B.Ohio Department of Natural Resources (Division of Geological Survey) Recession Rate Data, 1870,s-1990.***

***General***

As part of their shoreline management initiatives, the Ohio Department of Natural Resources have recently completed the calculation of comprehensive recession rate data along the Lake Erie shoreline. Periods of record covered by the data are primarily: 1870's-1973; 1973-1990; and 1870's-1990. Some shorter periods of record exist where 1870 map information was unavailable or of inferior quality.

***Method of Calculation***

These data were acquired digitally using 1870 vintage Lake Survey Charts and aerial photographs acquired in 1973 and 1990. Digital transects were spaced at 30 meter intervals along the shoreline, resulting in over 12,000 data points. These transects are numbered sequentially from east to west. There are gaps in the data where river floodplains are present and across large coastal embayments. Recession values of zero were recorded where recession has not occurred, either due to natural causes or due to the presence of filled lands. Measurements were made along the bluff crest or point of highest elevation along a barrier beach. Zones of accretion were not mapped in this study.

***Data Accuracy and Reliability***

The Ohio DNR does not guarantee the accuracy of the data provided, as they have not been verified in the field and are subject to revision. Other authors (e.g. Anders and Byrnes, 1991; Crowell et al, 1991) however, have reported on a number of errors associated with the use of maps created prior to the use of aerial photography (i.e. 1800's-1930's) for recession rate analysis and suggest that worst case ground distance errors of 8.5 meters or more may occur. In light of this, data generated using the 1870 vintage maps has been considered "moderately certain" and data generated from maps or air photos subsequent to 1938-1940 are considered "highly certain" for purposes of entry into the USACE data base.

***Data Base Considerations***

The 12,000 data points provided first had to be assigned into their appropriate USACE reaches in order to be included in the data base. This was accomplished with the aid of a series of index maps provided by Ohio DNR, which indicated profile numbers at approximately 0.75-1.0 kilometer intervals. Reach boundaries were superimposed on these maps and the profile numbers associated with each reach boundary were estimated using the index profiles as a guide. While the designation of reach boundaries, and the number of profiles falling within each reach is generally felt to be accurate, some errors and variations may exist, due to scale limitations, as well as the configuration of the shoreline (i.e. as not all profiles were indicated on the index maps, it was sometimes difficult to determine precisely the profile number corresponding to the reach boundary, and hence the number of profiles falling within each reach. This was often the case in urban areas, where docks and other artificial structures created a highly

indented shoreline). Given the large number of data points however, and the averaging that takes place for each reach, this is not expected to have a severe effect on the overall recession rate assigned to each reach.

Once reaches were defined, the raw data (ASCII format) provided by Ohio DNR was imported into a Quattro Pro spreadsheet program and divided into it's appropriate reaches. Detailed statistics were then calculated for the profiles falling in each reach. These statistics were then input to the USACE data base. Both the ASCII data and the Quattro Pro data, showing all Ohio DNR profiles broken down by reach (with appropriate statistics) have been provided to the Detroit District USACE as a separate product to this report.

Three new line entries will appear in the USACE data base - one for each of the periods of record outlined above.

***C.1876-1973 Recession Rate Data, Lake County (Carter, 1976)***
***D.1877-1974 Recession Rate Data, Lucas County (Benson, 1978)***
***E.1877-1973 Recession Rate Data, Erie and Sandusky Counties (Carter and Guy, 1980)***
***F.1876-1973 Recession Rate Data, Ashtabula County (Carter and Guy, 1983)***

***General***

These reports were the first prepared by the Ohio Division of Geological Survey to provide a comprehensive examination of recession rates along the Ohio shoreline of Lake Erie and to provide comprehensive investigations of erosion problems at a scale useful to the individual property owner. Maps and photographs from a number of different periods - 1876, 1937 and 1973 (Carter, 1976); 1877, 1940, 1957, 1968 and 1973 (Benson, 1978); 1877, 1905, late-1930's and 1973 (Carter and Guy, 1980); and 1876, 1938 and 1973 (Carter and Guy, 1983) - were selected for use in determining recession rates.

***Method of Calculation***

The methodology utilized in all studies was essentially identical and involved a three step process to the determination of recession rates. First, 1973, 1:4,800 scale Ohio Department of Transportation aerial photographs were used to prepare an overlay map on acetate, showing the position of the 1973 recession line (bluff line), as well as certain roads, water towers, houses and other prominent geographic features that could be used as control points. Second, 1876-1877 (and 1905), 1:10,000 scale USACE Lake Survey Charts were projected and enlarged to the same scale as 1937, 1:7,900 scale U.S. Agricultural Administration aerial photographs (or 1940, 1957 and 1968 aerial photos) and the 1876-1877 (or 1905) recession line was transferred on to the photos. Third, the interim photos (and the 1876-1877 or 1905

recession line) were projected and enlarged to the same scale as the 1973 aerial photos and the 1876-1877 (or 1905) and 1937 (or other interim photos) recession lines were transferred to the 1973 acetate base map. Recession rates at given locations were then calculated simply by measuring the distance between recession lines for two different years and dividing this distance by the period of record defined by the recession lines.

***Data Accuracy and Reliability***

Carter (1976) provides a good deal of discussion on the accuracy of this methodology. While some variations will exist between the four different studies, this discussion is essentially consistent enough to apply to all studies and is presented here.

Accurate horizontal control between the 1876 maps and the 1937 photographs and between the 1937 photographs and the 1973 photographs was maintained by correlation of geographic control points and lines. The Ohio shoreline was sufficiently developed by the 1870's so that control points found on these maps were adequate for correlation with the 1937 photos. Similarly, a greater number of points on the 1937 photos could be correlated with control points on the 1973 photos.

Accuracy of the position of the recession lines was unknown, although Carter (1976) suggests that the lines are accurate to within approximately 10 meters at a given location. He also claims that the greatest sources of error appear to be human, which means that errors in drawing the recession lines would probably be random and thus deviations would tend to even out along the shoreline.

Overall, Carter (1976) states that the map and photographic scales were quite consistent and that transfer of recession lines between all maps and photos was done at essentially the same amount of enlargement.

Other authors (e.g. Anders and Byrnes, 1991; Crowell et al, 1991) report a number of errors associated with the use of maps created prior to the use of aerial photography (i.e. 1800's-1930's) for recession rate analysis and suggest that worst case ground distance errors of 8.5 meters or more may occur. While the data generated by these four studies seems to be somewhat more accurate than this, it has been listed as "moderately certain" in the USACE data base.

***Data Base Considerations***

All four studies provided descriptive and range values for recession rates as follows:

| **Descriptive Phrase** | **Range Value** |
|---|---|
| Very Slow | 0.0-0.3 meters/year |
| Slow | 0.31-0.91 meters/year |

Moderate0.92-1.52 meters/year
Rapid1.53-2.13 meters/year
Very Rapid2.13-2.74 meters/year

In addition, these descriptive and range values were provided for a linear distance along the shoreline, as opposed to a discrete point on the shoreline. As a result, the data type has been listed in the USACE data base as "4/6" indicating both "linear zone-range value" and "linear zone-descriptive value."

For the Carter (1976), Carter and Guy (1980) and Carter and Guy (1983) reports, only data for the 35-36 year period from 1937-1938 to 1973 has been incorporated into the data base. Data for the period 1876-1877 to 1973 has been revised and included in the more recent work by the Ohio DNR (see B above) and is already incorporated in the data base under this data source. For the Benson (1978) report, only data for the 96 year period from 1877-1973 was incorporated into the data base.

***G.1876-1973 Recession Rate Data, Lorain, Cuyahoga and Ottawa Counties (Guy, 1992).***

***General***

This is a set of unpublished and provisional data that was provided to Detroit District USACE during the initial preparation of the recession rate data base. The period of record analyzed (and incorporated into the data base) was 1876-1973 for Cuyahoga and Lorain Counties, and 1877-1973 (96 years), 1877-1939 (62 years), 1939-1957 (18 years), 1957-1968 (11 years) and 1968-1973 (5 years) for Ottawa County.

***Method of Calculation***

Information was not available, but the method is assumed to be consistent with that used above in calculating 1877-1973 recession rates for the other counties.

***Data Accuracy and Reliability***

Again, information was not available, but it is likely as accurate as the data calculated for the other counties and has been rated as "moderately certain" in the data base.

***Data Base Considerations***

This data is listed as "linear zone-discrete value" in the data type column.

### *H.Other Ohio Studies Not Incorporated Into Data Base*

While the recent work of the Ohio Department of Natural Resources has provided perhaps the most comprehensive recession data for this shoreline, the State of Ohio has a long history of recession data collection and there are a number of studies that are not included in the USACE data base. In what might be the earliest investigation along this shoreline, Wells (1952) and Pincus et al (1953) examined shoreline geology and erosion problems that were occurring. In 1961, the Ohio Division of Shore Erosion prepared a preliminary report on erosion and accretion and provided erosion rates for individual portions of the shoreline and listed critical areas of erosion. In 1975, Carter et al documented shoreline and bathymetrical changes in and around Sandusky Bay from 1905-1974. In 1981, these same authors looked at the number of shore protection structures along the Ohio shoreline in order to determine their effect on recession rates and beaches from the 1870's to the 1970's. Some site specific studies have also been conducted by researchers at Kent State University. Schmidt (1980) looked at shoreline erosion at Painesville Township Park in Lake County, while Amin (1990) attempted to determine the relationship between erosion at the toe of the bluff to overall recession of the bluff crest for a small section of shoreline at the Ohio-Pennsylvania border.

A good deal of recession related work along the Ohio shoreline relates to projects being conducted by the U.S. Army Corps of Engineers. An excellent example of this is a series of reports (Zorich, 1981; Zorich and Mammosser, 1981; Mammoser and Butler, 1982a and b; and U.S. Army Corps of Engineers, 1983a, b, c, and d) describing the initiation and design of a major recreational facility and associated shoreline protection at Maumee Bay State Park.

## Pennsylvania

### *A.Lake Erie Bluff Recession Rate Data Update (Knuth, 1987): Pennsylvania Coastal Zone Management Division*

#### *General*

This report provides measurements from established control points to the bluff crest for a series of 71 sites along the Pennsylvania shoreline east and west of the Presque Isle headland. Control points were established in 1982, and remeasured again in late 1986 and early 1987, providing approximately a five year period of record.

#### *Method of Calculation*

The control points established in 1982 were determined by using a one kilometer grid for the reach. Data gathered included a distance from the control point (along a magnetic bearing determined as most normal to the bluff) to the bluff crest. In most cases, a steel pin was driven to 5.1 centimeters below the surface to

mark the location of the control point. The pin was located and relocated by measuring from two or more landmarks with two 15 meter tapes. The pin is at the intersection of the recorded distance from the landmarks. Further, a magnetic bearing is given for each reference.

In 1987, additional control points on a 0.5 kilometer grid spacing were established and initial distances to bluff crest measured. No follow up measurements were recorded for these newer control points.

The Knuth (1987) report only provides measured distances to the bluff crests for 1982 and 1986/87. Total recession over that period, the exact period of record and the average annual recession rate had to be calculated by this author.

#### *Data Accuracy and Reliability*

The methodology for placing and re-creating control points is deemed sound by Knuth (1987) as all but four of the control pins buried in 1982 were actually discovered in 1986/87. The four not recovered were lost due to erosion or construction. Given this, and the method of measurement utilized, the data is deemed as "accurate" in the data base.

Knuth (1987) cautions however that the values provided should not be averaged over any particular reach of shoreline. For example, at one site, over 12 meters of bluff has been lost, but this occurred in one year as a result of site specific rotational slumping. Applying this value to an entire reach may distort the data. Similarly, while recession on a number of the eastern sites was zero, there was ample evidence east and west of the sites, that recession was occurring.

#### *Data Base Considerations*

In most cases, a single control point site falls within a single reach in the USACE data base and is thus representative of that one kilometer section. The actual period of record in most cases was 4.7 years. This value was entered into the data base, however, as the "years of record" column may round off to zero decimal places (thus indicating 5 years), it should be noted that in this case, the recession rate listed will not be a true 5-year recession rate.

### *B.Pennsylvania CZM 1975 Data (Knuth and Crowe, 1975; Great Lakes Institute, 1975)*

#### *General*

In preparation of a technical report for the State's Coastal Zone Management Plan, an inventory of shoreline features was undertaken utilizing aerial photographs from 1939-1975, reconnaissance flights and

field studies (Knuth and Crowe, 1975; Great Lakes Research Institute, 1975; Knuth, 1976). A further step in this baseline study was to develop a bluff recession rate analysis using aerial imagery and precision measurement to determine a historical recession rate for the study area.

#### *Method of Calculation*

Control points were established at 89 locations along the shoreline. Measurements of bluff positions were taken from 1938-1939 and 1975 aerial photography and compared. Total shore change was divided by the 36 year period of record to establish long-term average annual recession rates for each control point. The average long-term rate for all points was calculated at approximately 0.3 meters per year, with actual rates ranging between 0.05 to 0.53 meters per year.

#### *Data Accuracy and Reliability*

No discussion is provided in the sources, but the method is assumed to be as accurate as any other utilizing air photo analysis. It is rated as "moderately certain" in the data base.

#### *Data Base Considerations*

This data has been identified by "1936-1975, Knuth and Crowe (1975)" in the Remarks column of the data base.

### *C.Other Pennsylvania Studies Not Incorporated Into Data Base*

The Pennsylvania Department of Environmental Resources Division of Coastal Programs (1982) has completed one other study that provided an evaluation of the shoreline with respect to geology and physiography. In addition, the U.S. Army Corps of Engineers, Buffalo District has long been involved in the examination of shoreline erosion problems and shore stability at Presque Isle (see for example Mohr and Ippolito, 1991; and Mohr, 1994).

## New York

### *A.New York Department of Environmental Conservation Recession Rate Data (1875-1979)*

#### *General*

In order to determine erosion hazard areas along the Lake Erie shoreline in New York State, the

Department of Environmental Conservation (DEC) has calculated long-term recession rates for the period 1875-1979.

***Method of Calculation***

Comparisons were made between shoreline positions on 1875 Hydrographic Survey maps with the shoreline position on 1979 aerial photographs. Baselines were established on the 1875 maps using road intersections and other landmarks that also exist on the 1979 air photos. Transects were established approximately every 244 meters along the baseline and baseline to bluff-crest measurements were made for each. Similar measurements were made along the same transects on the 1979 photos, and the net shoreline change was calculated by subtracting the two values. Appropriate scale adjustments were made in order to allow accurate comparisons between the maps and the air photos, and average annual recession rates were calculated simply by dividing the total shoreline change by the 104 year period of record. In some areas of Lake Erie, 1875 hydrographic charts were not available and 1938 air photos were utilized and compared with the 1979 maps, producing a 40 year period of record.

***Data Accuracy and Reliability***

"Confidence level" values are provided for the Lake Erie data, but it is unclear as to how these were calculated, or what they actually mean. Other authors (e.g. Anders and Byrnes, 1991; Crowell et al, 1991) however, have reported on a number of errors associated with the use of maps created prior to the use of aerial photography (i.e. 1800's-1930's) for recession rate analysis and suggest that worst case ground distance errors of 8.5 meters or more may occur. Give this, and given that this data is likely as accurate as any other determined through air photo analysis, it is rated as "moderately certain" in the data base.

***Data Base Considerations***

The data received for Lake Erie included transects plotted on the 1875 maps. Determining USACE reach boundaries on these sources was sometimes difficult, as ground information on the USGS Topographic maps had changed substantially since 1875.

***B.Lake Erie Recession Rate Data (Geier and Calkin, 1983)***

***General***

Severe erosion along the Lake Erie coast and general flooding in other parts of New York State led to proposals for shoreline stabilization or lake level control programs. This study was undertaken to supply some of the data needed by management for decisions concerning such measures. Short-term (1938-

1974) and long-term (1875-1974) bluff recession rates along the New York Lake Erie coast were measured at 116 locations between Buffalo and the Pennsylvania State Line.

***Method of Calculation***

Recession measurements were made on 1:10,000 scale 1875 Lake Survey maps, and 1:4,800 scale 1938 and 1974 aerial photographs. Measurements were made with an optical micro-rule at 116 locations spaced as equally as possible along the coast. Constraints on profile location included the need to use locations where suitable control points such as road intersections and field lines could be aligned perpendicular to the coastline. In addition, control points were only used if they could be accurately located on the map set and both sets of aerial photos.

The map or photo distance between each control point and the bluffline was then measured and multiplied by the appropriate scale of the map or photo to determine the actual ground distance. The distance measured on the 1974 photographs was subtracted from the similarly determined ground distance on the 1875 map to obtain the amount of long-term recession. Similarly, the 1974 distance was subtracted from that obtained on the 1938 photo set to obtain the short-term recession. The recession rate was then determined by dividing this total recession by the number of years defined by the maps and photo sets (i.e. 99 or 36 years respectively).

***Data Accuracy and Reliability***

Geier and Calkin (1983) report that measurements from the maps and air photos using the micro-rule are accurate to 0.025 millimeters and that radial distortion in the air photos was minimal due to the flat terrain of the study area and the use of only the central part of the photo. No other discussion of error is provided.

Other authors (e.g. Anders and Byrnes, 1991; Crowell et al, 1991) however, have reported on a number of errors associated with the use of maps created prior to the use of aerial photography (i.e. 1800's-1930's) for recession rate analysis and suggest that worst case ground distance errors of 8.5 meters or more may occur. In light of this, the Geier and Calkin (1983) data has been listed as "moderately certain" in the data base.

***Data Base Considerations***

Detailed average annual recession rate values for each of the 116 profiles (locations) were provided only for the long-term data (i.e. 1875-1974). Short-term data was summarized for each of a series of 10-10 kilometer reaches which were established along the shore, but were not provided for each of the 116 sites. As such, only the long-term (99 year) recession rate data has been incorporated into the USACE data

base.

#### *C.Other New York Studies Not Incorporated Into Data Base*

None reviewed.

### 3.2.6Lake Ontario

### New York

#### *A.New York Department of Environmental Conservation Recession Rate Data (1875-1979)*

##### *General*

In order to determine erosion hazard areas along the Lake Ontario shoreline in New York State, the Department of Environmental Conservation (DEC) has calculated long-term recession rates for the period 1875-1979.

##### *Method of Calculation*

Comparisons were made between shoreline positions on 1875 Hydrographic Survey maps with the shoreline position on 1979 aerial photographs. Baselines were established on the 1875 maps using road intersections and other landmarks that also exist on the 1979 air photos. Transects were established approximately every 244 meters along the baseline and baseline to bluff-crest measurements were made for each. Similar measurements were made along the same transects on the 1979 photos, and the net shoreline change was calculated by subtracting the two values. Appropriate scale adjustments were made in order to allow accurate comparisons between the maps and the air photos, and average annual recession rates were calculated simply by dividing the total shoreline change by the 104 year period of record.

##### *Data Accuracy and Reliability*

Recession rate data for Lake Ontario had to be read off of large graph sheets. Thus, small errors in estimating recession rate values from these sheets may occur, in addition to any errors involved in the initial calculation of this data by New York DEC. Information on other calculation errors, or accuracy of the Lake Ontario data was not provided. For the most part, this data is likely as accurate as any other

determined through air photo analysis and is rated as "moderately certain" in the data base.

#### *Data Base Considerations*

The data received for Lake Ontario (except for the majority of Jefferson County), included transects plotted on the 1875 maps. Determining USACE reach boundaries on these sources was sometimes difficult, as ground information on the USGS Topographic maps had changed substantially since 1875. For Jefferson County, 1875 maps were not available and transect location and coordination with USACE reach boundaries had to be made utilizing the minimal geographic information contained on the large graph sheets (i.e. distance from county line and some landmark information) and reference to the USGS topographic maps. As a result, the number of transects falling within one USACE reach may not be entirely accurate for this section of shoreline.

### *B.Lake Ontario Recession Rate Data (Drexhage and Calkin, 1981)*

#### *General*

This study measured rates of bluff line recession at 250 sites in six counties along the Lake Ontario coastline in order to determine historic rates of recession and to provide information on their spatial and temporal distribution as well as on those factors that influence local differences in recession rates. Long-term recession rates were determined for the 99 year period from 1875-1974 and for the 13 year period from 1938-1951.

#### *Method of Calculation*

Short-term (13 year) recession rates were calculated using 1938 and 1951-1955 U.S. Department of Agriculture aerial photographs. A Bausch and Lomb optical micro-rule was used to directly measure distances between fixed points on land and the bluff line. Measurement locations were indicated on USGS topographic quadrangles. Distances along the east side of a convenient road (or other recognizable line) leading to the shore from a road intersection (or other suitable landmark visible in both sets of photos) to the bluff line were then computed. According to the scale of the photos, the distances determined were then converted to true distances in meters. The difference between distances was then determined and divided by the number of years between photos to give a mean recession rate at that point.

Long-term recession changes were determined using 1:10,000 scale 1874-1875 U.S. Army Corps of Engineers Lake Survey Sheets and 1:9,000 scale 1974 U.S. Army Corps of Engineers aerial photographs. Bluff line positions on the 1875 maps were traced onto a transparent overlay. The bluff line position from the 1974 air photos was projected and traced to scale on the same overlay with the aid of an overhead projector. Sufficient development of the Lake Ontario coastal area by 1875 made correlation with present

landmarks for scale matching relatively easy. Sites utilized in the short-term rate determinations were then transferred onto the overlay and recession rates were then determined for the 1875-1974 period for these sites.

***Data Accuracy and Reliability***

Drexhage and Calkin (1981) provide a good discussion of error in their report and outline a number of potential limitations:

1)The available air photo coverage limited the selection of sites for determining short-term recession rates. Also limited was the selection of measurement sites to the location where landmarks had not changed between photos. In areas where common landmarks could not be found, profile locations had to be spaced further apart resulting in an uneven distribution along the shoreline.

2)The micro-rule utilized was divided into increments of 0.025 millimeters, enabling the repetition of photographic measurements to within 0.05 millimeters. Checks showed that on the photos, a distance of 1.6 kilometers could be measured within ±0.9 meters. Most distances measured for determining recession were much less than 1.6 kilometers, allowing for greater accuracy.

3)Bluff line position was also a possible source of error. It was usually identified by a dark shadow on the photographs, indicating an abrupt change in the slope of land. When trees obscured the bluff line (20% of cases), the bluff line position was taken as 33% of the tree's diameter inland. Long-term measurements were subject to similar sources of error. The 1875 maps had landmarks and roads that could be matched with about 90% of the 1974 photos. Where no bluff line was indicated, it was assumed that the bluff generally paralleled the shore and was at the landward edge of the beach (clear on all maps). Thus, while the 1875 bluff position is approximate, it was assumed that errors in it's position are slight and random.

Other authors (e.g. Anders and Byrnes, 1991; Crowell et al, 1991) have reported a number of errors associated with the use of maps created prior to the use of aerial photography (i.e. 1800's-1930's) for recession rate analysis and suggest that worst case ground distance errors of 8.5 meters or more may occur.

In light of these possible errors, the Drexhage and Calkin (1981) data has been listed as "moderately certain" in the data base.

***Data Base Considerations***

Both the 13 year (1938-1951) and 99 year (1875-1974) data have been incorporated into the data base.

It should be noted that Drexhage and Calkin (1981) did not provide discrete values of recession for each data point, but rather a descriptive and range value. That is, recession rates listed in the report are as follows:

**Descriptive PhraseRange Value**

Very Slow0.0-0.3 meters/year
Slow0.31-0.6 meters/year
Moderate0.61-0.9 meters/year
Fast0.91-1.2 meters/year
Very Fast>1.2 meters/year

Given this, the data type is listed as "5/2" in the data base (indicating both point location-descriptive value and point location-range value data). In addition, the mean recession rate listed represents the mid-point of the particular range value. For example, if a particular location (and associated USACE reach) was deemed to have a "slow" recession rate, the value listed in the mean recession rate column would be 0.46 meters/year.

***C.Other New York Studies Not Incorporated Into Data Base***

Other than the comprehensive studies listed above, only a few researchers have examined the New York coast of Lake Ontario. The U.S. Army Corps of Engineers have undertaken most of the work in this area (e.g. U.S. Army Corps of Engineers, 1954, 1955 and 1970), having conducted a number of site specific erosion related investigations. Other studies have been conducted by: Palm (1975), who assessed 1938-1974 recession rates and high water damage along the Oswego County shoreline; Brownlie and Calkin (1981), who examined the relationship between the jetties constructed at Sodus Bay and shoreline recession; and Brennan and Calkin (1984), who investigated the sedimentology and one-year recession rates of bluffs along the southern coastline of Lake Ontario. Finally, a report by L.R. Johnston Associates (1989) provides a discussion of resources, problems and management guidelines for New York's Eastern Lake Ontario sand dunes, including descriptive discussions of various erosion problems.

### 3.2.7Other Information and Data Sets

***A.Erosion Processes Task Group Information (Stewart and Pope, 1993 a and b).***

***General***

As part of the International Joint Commission's Great Lakes Levels Reference Study, a comprehensive

classification and erosion sensitivity analysis of the Great Lakes shoreline was carried out (Stewart and Pope, 1993 a and b; Pope, Stewart and Nairn, 1993; Stewart, 1993). The classification included definitions of 16 different shore types including both **bedrock** and **artificial** (e.g. harbor structures, fill) shorelines. Where these shore types occurred, a scientific assumption was made that the erosion "sensitivity" of these shore types would be nil (i.e. there was no, and there would be no, recession occurring).

The original USACE recession data base did not reflect this assumption. In areas where data did not exist, even though many of these areas were predominantly bedrock shorelines (and could be assumed to have no recession), values of recession were not provided and significant data gaps existed.

In light of this, and in an attempt to fill some of the large data gaps existing in the data base, all reaches in the USACE data base without data associated with them (following input of all sources listed previously) were checked against the shore classification which was indicated on the USGS topographic maps utilized in the shoreline classification study. Where a reach was identified as falling completely within a bedrock or artificial classification, it was assigned a mean recession rate of 0.00.

It should be emphasized that this was **only** done in areas that had little or no other data associated with them. This included: the Wisconsin and Michigan shoreline of Lake Superior; the northern shoreline of Lake Michigan (Door, Brown, Oconto and Marinette Counties in Wisconsin and Delta, Schoolcraft, Mackinac, Emmet, Charlevoix, Antrim, Grand Traverse and Leelanau Counties in Michigan); the Michigan shoreline of Lake Huron; and the Jefferson County, New York shoreline of Lake Ontario.

***Data Accuracy and Reliability***

Given the absence of other recession data for these areas and the acceptance of the "nil erosion" assumption for bedrock and artificial shorelines by the Levels Reference Study Board (International Joint Commission, 1993), the assignment of a mean recession rate of 0.00 for these reaches can be considered reliable, particularly for the general targeting of regional recession rates. If site specific applications or analyses are required in any of the reaches designated, perhaps a more comprehensive review of site specific recession rates may be required. This data has been listed as "reasonable inference" in the "Confidence" column of the data base.

***Data Base Considerations***

Reaches that are designated as above are identified by the reference "(Stewart and Pope, 1993)" in the "Remarks" column.

***B.Seibel, Armstrong and Alexander (1976), Recession Rate Data***

***General***

In an effort to develop an estimate of the importance of shoreline erosion as a pollutant to the Great Lakes relative to other land associated pollutants, estimates of the annual volumetric contributions of eroded sediment, created by bluff recession, were derived for approximately 44% of the erodible U.S. Great Lakes shoreline.

***Method of Calculation***

The recession rate data presented in the Seibel, Armstrong and Alexander report were derived from the information available from agencies and individuals involved in recession rate determinations. A weighted average annual, maximum annual and minimum annual recession rate were estimated for each reach of the U.S. shoreline for which data were available. The average recession rate was calculated by a weighted average method using the following equation:

$\Sigma r_i * l_i / \Sigma l_i$

where $r_i$ was the recession rate and $l_i$ the corresponding length of shoreline.

***Data Accuracy and Reliability***

The data in this report was presented in a series of tables by reach number and referenced to a series of shoreline maps that showed locations of the reaches. The maps however, were very small in scale and it was often difficult to determine the precise location of the Seibel, Armstrong and Alexander reaches relative to the USACE kilometer-by-kilometer reaches. As a result, data "confidence" has been listed as "reasonable inference" in the USACE data base. Data type is listed as "linear zone-discrete value", as only one value of recession is provided for a specific length of shoreline.

In addition, the data presented did not have any linkages or references to the original source data, and as a result had no indication of the period of record utilized for the recession rate determination. As such, no indication of this can be included in the USACE data base.

***Data Base Considerations***

It should be noted that since the Seibel, Armstrong and Alexander data incorporated a number of studies already included in this USACE data base and described in this report, data was **only** added in areas that had little or no other data associated with them. This included: a number of areas along the Michigan shorelines of Lake Superior, Michigan and Huron; the Monroe County, Michigan shoreline of Lake Erie; and

a small portion of the Jefferson County, New York shoreline of Lake Ontario.

## 3.3Data Gaps

Table 3.5 identifies the significant data gaps that exist in the USACE data base by Lake, State, reach and geographic location. It is clear from the table that the most significant data gaps exist along the Michigan shorelines of Lake Superior, Lake Michigan and Lake Huron. The majority of these gaps occur on State or Federally owned properties, such as State Parks, or National Lakeshores, where development, and hence, erosion "hazards" are limited or non-existent. Michigan also has large data gaps along the shorelines of Lake St. Clair and Lake Erie - areas that have a high concentration of development.

### 3.3.1Suggested Approaches For Addressing Data Gaps

Given the data gaps outlined here, it is clear that the State of Michigan should take a lead role in the determination of recession rates for these areas. To a large extent this is already occurring, as new data is being calculated for many sections of the shore. However, with their focus on developed and developing areas, the State may not have the need (or the resources) to investigate recession in some of these other areas. In this case, perhaps consideration should be given to establishing some type of joint, coordinated program with the State, the USACE, and the National Park Service, which would see funds and/or staff made available to conduct recession rate analyses for these regions. Such a project could consist of three phases: 1) a reconnaissance study of the shoreline to accurately determine areas of bedrock shoreline and other areas where recession will be next to minimal or zero; 2) determination

**Table 3.5:Significant Gaps in USACE Great Lakes Shoreline Recession Rate Data Base (Note: ** indicates a number of exceptions).**

| Lake | State | USACE Reaches | Geographic Location |
|---|---|---|---|
| Superior | Minnesota | 1245-1256<br>1258-1263 | Minnesota Point<br>City of Duluth |
| | Wisconsin | 979-1033<br>1055-1059<br>1081-1083 | Chequamegon Point-Long Island<br>Siskiwit Bay<br>Sioux River Wetlands |
| | Michigan | 1-14**<br>19-29<br>45-68**<br>97-159**<br>190-198<br>198-264** | Munuscong State Forest<br>Back Bay-Bay Mills<br>Hiawatha National Forest<br>Lake Superior State Forest<br>Grand Marais-Harbor of Refuge<br>Pictured Rocks National Lakeshore |

**Table 3.5:Significant Gaps in USACE Great Lakes Shoreline Recession Rate Data Base (Note: ** indicates a number of exceptions).**

| Lake | State | USACE Reaches | Geographic Location |
|---|---|---|---|
| | | 271-299**<br>310-328<br>460-495<br>507-609**<br>620-652**<br>792-819**<br>912-921 | Christmas-Au Train<br>Laughing Fish Point-Shot Point<br>Huron Bay<br>Keweenaw Bay (Baraga)<br>Grand Traverse Bay-Point Isabelle<br>FiveMile Point-Elm River/Agate Beach<br>Porcupine Mountians State Park |
| Michigan | Wisconsin | 1361-1833** | Door, Brown, Oconto and Marinette Counties |
| | Illinois | None | --- |
| | Indiana | None | --- |
| | Michigan (Mainland) | 6-11<br>18-44<br>147-155<br>211-292**<br>335-376**<br>428-460** | Mackinac State Forest<br>Wilderness State Park<br>Fisherman's Island State Park<br>East & West Arms, Grand Traverse Bay<br>Stony Point -Lighthouse Point<br>Sleeping Bear Dunes National Lakeshore |
| | Michigan (Upper Peninsula) | 2003-2149<br>2173-2207<br>2208-2225<br>2246-2297**<br>2298-2395**<br>2412-2436 | Hiawatha National Forest<br>Lake Superior State Forest<br>Point O'Keefe-Pillows Point<br>Manistique-Port Inland<br>Mackinac State Forest<br>Point aux Chenes Bay-Mackinac Bridge |
| Huron | Michigan | 87-1099** | Whole Coast Has Many Significant Data Gaps |
| St. Clair | Michigan | All | Wayne, Macomb and St. Clair Counties |
| Erie | Michigan | 803-834 | Monroe and Wayne Counties |
| | Ohio | 557-581 | Muddy Creek Bay, Sandusky Harbor |
| | Pennsylvania | None | --- |
| | New York | None | --- |
| Ontario | New York | 131-148 | Jefferson County, Black River Bay |

| Table 3.5:Significant Gaps in USACE Great Lakes Shoreline Recession Rate Data Base (Note: ** indicates a number of exceptions). | | | |
|---|---|---|---|
| **Lake** | **State** | **USACE Reaches** | **Geographic Location** |
| | | 207-215 | Jefferson/Oswego County Barrier Complexes |

of historical recession rates utilizing historic and recent maps and aerial photographs for those areas not included in 1; and 3) establishment of a number of survey control points and profiles, along with initial measurements, that can then be updated on a regular (yearly) basis (similar to the work by Knuth (1987) for the Pennsylvania shoreline).

The USACE Detroit District and CERC can also play a direct role in filling these data gaps by clearly communicating to the Great Lakes research community (governments, academics, etc.) that recession rate data is needed in these areas and by ensuring that any subsequent data generated is obtained and incorporated into the data base on a continual and regular basis. Such communication might be facilitated through professional organizations, newsletters, conferences/workshops, or computerized information networks (e.g. The Great Lakes Information Network). The establishment of a nominal amount of funding resources in support of such research could also be contemplated and might prompt research institutions/agencies to conduct such research.

# 4.0SUMMARY AND GENERAL RECOMMENDATIONS

## 4.1General

This report provides a brief description of a number of data sources/sets utilized to create a comprehensive lake-by-lake recession rate data base for the shorelines of the U.S. Great Lakes and Lake St. Clair. Information included for each data set includes the methodology utilized to calculate the recession rates, the spatial and temporal extent of the data, and a brief review of its accuracy and reliability. Information is also provided on considerations taken into account when entering this data into the USACE data base.

The data base files themselves (attached as Appendices to this report), consist of a series of kilometer-by-kilometer spreadsheet files with data on mean, median, maximum and minimum recession rates provided for each. Information is also provided on the data type, confidence, number of samples and period of record. Multiple entries for a reach may exist, and are sorted in descending order by period of record.

This data base is a "benchmark" data set of sorts, in that it represents the only known effort to bring together, in a coordinated, uniform fashion, up-to-date recession rate data for the entire Great Lakes basin. While other individual data sets are certainly more comprehensive (e.g. the 1993 Ohio DNR data), no other such data set currently exists for the Great Lakes at this level of detail.

## 4.2Recommendations

This data base provides a comprehensive, readily accessible set of information for use by shoreline managers and researchers throughout the Great Lakes basin. In light of this, it is recommended that USACE Detroit take steps to ensure regular updates to the data base are carried out. Resources for such a task should be allocated at least once every two years, and requests for data sets and copies of any recession rate studies completed by other agencies and researchers should be communicated on a regular basis to the Great Lakes research community. Close coordination with those state agencies responsible for coastal zone management and measurement of recession rates should also be maintained.

While this data set provides unprecedented detail on recession rates for the U.S. shoreline of the Great Lakes, no such similar data set exists for the Canadian shoreline. Recession rate data for Ontario that was collected by Geomatics International (1992) during the IJC Reference Study was obtained largely from somewhat dated work by Environment Canada/Ontario Ministry of Natural Resources (1976) and Boyd (1981) . While some Conservation Authorities in Ontario have continued to monitor recession profiles established by Boyd (1981), no other comprehensive recession rate updates have occurred. It is thus recommended, that USACE Detroit, building upon their experience with this project, initiate discussions with appropriate staff of Environment Canada and the Ontario Ministry of Natural Resources regarding the creation of a similar, updated recession rate data base for the Canadian shoreline, which could be

coordinated and linked with the existing USACE data base to create one, overall, Great Lakes recession rate data base. While such an activity may be beyond the present directives of USACE, it follows directly upon recommendation made by the IJC to U.S. and Canadian Governments (International Joint Commission, 1993) and could be the first step in creating a truly coordinated U.S.-Canadian Great Lakes GIS.

The data contained in the Appendices should allow more thorough investigations of the relationship between water level stages and recession rates. Modelling efforts in this regard can take advantage of the various periods of record listed within a reach to determine differences between recession rates during high water periods and recession rates during lower water periods. Related to this, the recession rate data presented can be utilized to better identify erosion hazard areas and structures at risk along the shoreline and to provide consistent estimates of potential recession damages throughout the basin. The data can also be used to better highlight those undeveloped areas of the shoreline where recession rates are high, thereby helping to prevent hazard prone development in these areas. It is recommended that USACE spearhead such efforts, in close cooperation with appropriate state or municipal agencies.

The recession rate data lends itself nicely to the production of maps showing historic recession rates along the shoreline, or alternatively, areas of erosion hazard. Caution needs to be exercised in the use of the data for this purpose however, as there are key differences between the historic recession rate for an area, and the existing erosion hazard. For example, a reach may list a long-term average annual recession rate from 1900-1993 as being 1.0 meter per year. A second line entry for this reach may show a recession rate from 1973-1993 as being 0.0 meters per year because substantial shore protection was constructed and has been maintained, thereby reducing recession to zero. Thus, a map showing historic recession rates may lead many to thinking that a significant erosion problem exists for the reach, even though in actuality, no further recession is occurring. This could be a particularly sensitive issue in areas along the shoreline where significant infrastructure (e.g. nuclear power plants, other industries) has been developed. To account for this, it is recommended that prior to use of this data for any detailed mapping purpose, USACE thoroughly assesses the data presented for each reach and determine the most appropriate value to use for the particular mapping product.

# REFERENCES


Acomb, L., Klauk, R., Mickelson, D., Edil, T., and Haas, B., 1977. Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin: Ozaukee County - Shore Erosion Study Technical Report, Appendix 4. Wisconsin Coastal Zone Management, 165pp.

Amin, S.M.N., 1990. Modelling Toe Erosion on the Ohio Shore. In: Saunders, K.E. et al (eds.), Delineation of Erosion Hazard Shorelines, Workshop Summary, Cleveland, Ohio, June 21-23, 1990, pp.33-34.

Anders, F.J., and Byrnes, M.R., 1991. Accuracy of Shoreline Change Rates as Determined From Maps and Aerial Photographs. Shore and Beach, Vol. 59, No. 1: 17-26.

Baker, D., and Otterson, P., 1987. Slip Sliding Away: Erosion on Lake Superior's North Shore. Minnesota Sea Grant Extension Superior Advisory Note No. 25, University of Minnesota.

Bay-Lake Regional Planning Commission, 1988. Keewaunee County Coastal Hazard Management Plan, 103pp.

Benson, J., 1978. Lake Erie Shore Erosion and Flooding, Lucas County, Ohio. State of Ohio Department of Natural Resources, Division of Geological Survey, Report of Investigations No. 107, 99pp.

Berg, R.C., and Collinson, C., 1976. Bluff Erosion, Recession Rates and Volumetric Losses on the Lake Michigan Shoreline in Illinois. Illinois State Geological Survey, Environmental Geology Notes, No. 76, 33pp.

Birkemier, W.A., 1980. The Effect of Structures and Lake Level on Bluff and Shore Erosion in Berrien County, Michigan 1970-1974. Coastal Engineering Center, Miscellaneous Report 80-2, Fort Belvoir, VA., 77pp.

Boyd, G.L., 1981. Canada / Ontario Great Lakes Erosion Monitoring Programme, 1973-1980. Manuscript Report Series No. 12, Fisheries and Oceans Canada, Bayfield Laboratory For Marine Science and Surveys, Burlington, Ontario, 200pp.

Brennan, S.F., and Calkin, P.E., 1984. Analysis of Bluff Erosion Along the Southern Coastline of Lake Ontario, New York. New York Sea Grant Institute, Albany, New York, 74pp.

Brownlie, W.R., and Calkin, P.E., 1981. Great Lakes Coastal Geology. Effects of Jetties, Sodus Bay, New York. New York Sea Grant Institute, Albany, New York, 30pp.

Buckler, W.R., 1981. Rates and Implications of Bluff Recession Along the Lake Michigan Shore Zone of

Michigan and Wisconsin. Ph.D. Thesis, Michigan State University, Department of Geography, Lansing, Michigan, 206pp.

Buckler, W.R., 1987. High Water Levels and Bluff Recession: Lake Michigan's Southeast Shore. The East Lakes Geographer, Vol. 22: 157-177.

Buckler, W.R., and Winters, H.A., 1975. Rates of Bluff Recession at Selected Sites Along the Southeastern Shore of Lake Michigan. The Michigan Academician, Vol. 8 (2): 179-186.

Buckler, W.R., and Winters, H.A., 1983. Lake Michigan Bluff Recession. Annals of the Association of American Geographers, Vol. 73, No. 1: 89-110.

Buckler, W.R., Winters, H.A., and LaMoe, J.P., 1988. Bluff Crest Recession Along the Southwest Shore of Southern Michigan. In: Larson, G.J. and Monaghan, G.W., (eds.), Wisconsin and Holocene Stratigraphy in Southwestern Michigan, Proceedings, Midwest Friends of the Pleistocene 35th Field Conference, May 21-22: 51-60.

Carter, C.H., 1976. Lake Erie Shore Erosion, Lake County, Ohio: Setting, Processes and Recession Rates From 1876 to 1973. State of Ohio Department of Natural Resources, Division of Geological Survey, Report of Investigations No. 99, 105pp.

Carter, C.H., Benson, D.J., and Guy, D.E., 1975. Shoreline and Bathymetric Changes in and Around Upper Sandusky Bay Since 1905. In: Proceedings of Sandusky River Basin Symposium, Tiffin, Ohio, May 2-3: 335-357.

Carter, C.H., and Guy, D.E., 1980. Lake Erie Shore Erosion and Flooding, Erie and Sandusky Counties, Ohio: Setting, Processes and Recession Rates From 1877 to 1973. State of Ohio Department of Natural Resources, Division of Geological Survey, Report of Investigations No. 115, 130pp.

Carter, C.H., Benson, D.J., and Guy, D.E., 1981. Shore Protection Structures - Effects on Recession Rates and Beaches From the 1870's to the 1970's Along the Ohio Shore of Lake Erie. Environmental Geology, Vol. 3, No. 6:353-362.

Carter, C.H., and Guy, D.E., 1983. Lake Erie Shore Erosion, Ashtabula County, Ohio: Setting, Processes and Recession Rates From 1876 to 1973. State of Ohio Department of Natural Resources, Division of Geological Survey, Report of Investigations No. 122, 107pp.

Chrzastowski, M.J., and Riggs, M.H., 1989. Hydrographic Monitoring Program in Vicinity of North Point Marina on the Illinois Lake Michigan Shore. Geological Society of America, Abstracts with

Programs, North Central Section Meeting, April 20-21, Notr Dame, Indiana, p.6.

Crowell, M., Leatherman, S.P., and Buckley, M.K., 1991. Historical Shoreline Change: Error Analysis and Mapping Accuracy. Journal of Coastal Research, Vol. 7, No. 3: 839-852.

Dagle, M., Mickelson, D.M., Acomb, L., Edil, T., and Pulley, S., 1980. Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin: Norther Manitowoc, Kewaunee and Door County Shorelines of Lake Michigan in Wisconsin - Shore Erosion Study Technical Report, Appendix 7. Wisconsin Coastal Zone Management, 117pp.

Davis, R.A. Jr., 1975. Beach Profile Changes: East Coast of lake Michigan, 1970-1972. U.S. Army Corps of Engineers Coastal Engineering Research Center MP 10-75.

Davis, R.A., Jr., 1976. Coastal Changes, Eastern Lake Michigan, 1970-1973. U.S. Army Corps of Engineers Coastal Engineering Research Center Technical Paper 76-16.

DeLaRosby, L., 1991. An Evaluation of Erosion Hazard Areas on the Lake Superior Shoreline of lake County as Described in the North Shore Management Plan. Report Prepared for the North Shore Management Board and the Lake County Planning and Zoning Office, 45pp.

Drexhage, T., and Calkin, P.E., 1981. Historic Bluff Recession Along the Lake Ontario Coast, New York. New York Sea Grant Institute, Albany, New York, 123pp.

Edil, T.B., and Vallejo, L.E., 1976. Shoreline Erosion and Landslides in the Great Lakes. National Oceanic and Atmospheric Administration Report No. NOAA-76122903, 19pp.

Environment Canada and the Ontario Ministry of Natural Resources, 1976. Great Lakes Coastal Zone Atlas, Canada-Ontario Shore Damage Survey.

Folger, D.W., Coleman, S.M., and Barnes, P.W., (eds.), 1990. Proceedings of the 2nd Annual Southern Lake Michigan Coastal Erosion Study Workshop. United States Geological Survey Open File Report 90-272, St. Petersburg, Florida, 25pp.

Fox, W.T., and Davis, R.A., Jr., 1970. Profile of A Storm: Wind, Waves and Erosion on the Southeastern Shore of Lake Michigan. Proceedings of the 13th Conference on Great Lakes Research, IAGLR, Vol. 1, pp.233-241.

Fox, W.T., and Davis, R.A., Jr., 1973. Simulation Model for Storm Cycles and Beach Erosion on Lake Michigan. Bulletin of the Geological Society of America, Vol. 84, pp. 1769-1790.

Frankovic, E.A., 1975. An Aerial Photograph Interpretation and Physical Model Study of Lake Michigan Shoreline Erosion in the Villages of Whitefish Bay, Fox Point, and Shorewood, Wisconsin. Master's Thesis, University of Wisconsin - Milwaukee.

Geier, R.J., and Calkin, P.E., 1983. Stratigraphy and Bluff Recession Along the Lake Erie Coast, New York. New York Sea Grant Institute, Albany, New York, 58pp.

Gray, D.H., and Wilkinson, B.H., 1979. Influence of Nearshore Till Lithology on Lateral Variations in Coastline Recession Rate Along Southeastern Lake Michigan. Journal of Great Lakes Research, Vol. 5, No. 1: 78-83.

Great Lakes Research Institute, 1975. Shoreline Erosion and Flooding, Erie County. Pennsylvania Coastal Zone Management Program, Department of Environmental Resources, Office of Resources Management.

Guy, D.E., 1992. Unpublished and Provisional Data for Lorain, Cuyahoga and Ottawa Counties, Ohio. State of Ohio Department of Natural Resources, Division of Geological Survey, Sandusky, Ohio.

Hadley, D.W., 1976. Shoreline Erosion in Southeastern Wisconsin. University of Wisconsin, Geol. Nat. Hist. Surv., Special Report No. 5, 33p.

Hadley, D., Fricke, C., Edil, T., and Haas, B., 1977a. Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin: Sheboygan County - Shore Erosion Study Technical Report, Appendix 5. Wisconsin Coastal Zone Management, 118pp.

Hadley, D., Fricke, C., Edil, T., and Haas, B., 1977b. Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin: Southern and Central Manitowoc County - Shore Erosion Study Technical Report, Appendix 6. Wisconsin Coastal Zone Management, 97pp.

Hands, E.B., 1970. A Geomorphic Map of the Lake Michigan Shoreline. Proceedings of the 13th International Conference on Coastal Engineering, pp.250-265.

Hands, E.B., 1976. Observations of Barred Coastal Profiles Under the Influence of Rising Water Levels, Eastern Lake Michigan, 1967-1971. U.S. Army Corps of Engineers Coastal Engineering Research Center Technical Report TR 76-1.

Hands, E.B., 1979. Changes in Rates of Shore Retreat, Lake Michigan, 1967-1976. U.S. Army Corps of Engineers Coastal Engineering Research Center Technical Paper TP 79-4.

Hands, E.B., 1980. Prediction of Shore Retreat and Nearshore Profile Adjustments to Rising Water Levels on the Great Lakes. U.S. Army Corps of Engineers Coastal Engineering Research Center Technical Paper TP 80-7.

Hands, E.B., 1981. Predicting Adjustments in Shore and Offshore Sand Profiles on the Great Lakes. U.S. Army Corps of Engineers Coastal Engineering Research Center, CETA 81-4.

Hands, E.B., 1983. The Great Lakes as a Test Model For Profile Responses to Sea Level Changes. In: Komar, P.D. (ed.), CRC Handbook of Coastal Processes and Erosion, CRC Press, Boca Raton, Florida, pp.167-189.

Hardin, J.R., and Booth, W.H., 1952. Lake Michigan Erosion Studies. Am. Soc. Civil Engineers Proc., Vol. 78, Separate No. 115, 12pp.

Herdendorf, C.E., 1993. Analysis of Depth Changes at Beachwood Villas Marina, Huron Twp., Erie County, Ohio, 1987-1992. Summary Report Prepared for Beachwood Villa Marina Directors and the U.S. Army Corps of Engineers - Buffalo District.

Hess, C.S., 1973. Study of Shoreline Erosion on the Western Arm of Lake Superior. Department of Geography, University of Wisconsin, Madison, Wisconsin, 52pp.

Hubertz, J.M., Driver, D.B, and Reinhard, R.D., 1991. Wind Waves on The Great Lakes: A 32 Year Hindcast. Journal of Coastal Research, Vol.7, No. 4: 945-967.

Illinois State Geological Survey, 1977. The Illinois Coastal Zone Management Program. Third Year Work Product: Coastal Geological Studies. NOAA Report No. 78060520, 170pp.

Illinois State Geological Survey, 1988. Coastal Atlas, Illinois Shoreline of Lake Michigan, Revised 1987-1988.

International Joint Commission, 1993. 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, 53pp.

Jibson, R.W., and Staude, J.-M., 1992. Bluff Recession Rates Along the Lake Michigan Shoreline in Illinois. Bulletin of the Association of Engineering Geologists, Vol. 29, No. 2: 103-117.

Johnston, C.A., 1994. Erosion Hazard of Minnesota's Lake Superior Shoreline. Minnesota Sea Grant Research Bulletin #44.

Keillor, J.P., and DeGroot, R., 1978. Recent Recession of Lake Michigan Shorelines in Racine County, Wisconsin. Special Report Number 507, Wisconsin Sea Grant College Program, Madison, Wisconsin, Vols. I and II.

Keillor, J.P. and Miller, A.H., 1987. Coastal Processes Workbook. University of Wisconsin Sea Grant Institute Publication No. WIS-SG-87-431, 28pp.

Klauk, R., 1977. Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin: Milwaukee County, Summary of Engineering Boring Logs - Shore Erosion Study Technical Report, Appendix 8. Wisconsin Coastal Zone Management, 94pp.

Knuth, P.D., 1976. The Edinboro Foundation and The Commonwealth of Pennsylvania Coastal Research Activities. In: Rukavina, N.A., (ed.). Proceedings of a Workshop on Great Lakes Coastal Erosion and Sedimentation, Canada Centre for Inland Waters, Burlington, Ontario, November, 1976: 29-32.

Knuth, P.D., 1987. Lake Erie Bluff Recession Rate Data Update. Report Prepared By Coastal Research Associates for the Erie County, Pennsylvania Department of Planning and the Department of Environmental Resources, Coastal Zone Management Division, Harrisburg Pennsylvania.

Knuth, P.D., and Crowe, R.G., 1975. Identification and Analysis of Lake Erie Coastal Hazard Areas. Pennsylvania Department of Environmental Resources, Harrisburg, Pennsylvania.

Larsen, C.E., 1973. Variation in Bluff Recession in Relation to Lake Level Fluctuations Along the High Bluff Illinois Shore. Illinois Institute for Environmental Quality, Report No. IIEQ-73-14, 80pp.

L.R. Johnston Associates, 1989. New York's Eastern Lake Ontario Sand Dunes - Resources, Problems and Management Guidelines. New York State Department of State, Division of Coastal Resources and Waterfront Revitalization, 148pp.

Mammosser, R., and Butler, W., 1982a. Maumee Bay State Park, Ohio. Shoreline Erosion Beach Restoration Study, Volume I, Main Report. U.S. Army Corps of Engineers - Buffalo District.

Mammosser, R., and Butler, W., 1982b. Maumee Bay State Park, Ohio. Shoreline Erosion Beach Restoration Study, Volume II, Appendices. U.S. Army Corps of Engineers - Buffalo District.

Maresca, J.W., 1975. Bluffline Recession, Beach Change and Nearshore Change Related to Storm Passage Along Southeastern Lake Michigan. Ph.D. Thesis, University of Michigan, Ann Arbor.

Meadows, L.A. (ed.), 1988. Great Lakes Coastal Erosion Research Needs, Workshop Summary. Michigan Sea Grant Publication No. MICHU-SG-88-900, 63pp.

Mickelson, D.M., Klauk, R., Acomb, L., Edil, T., and Haas, B., 1977. Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin: Milwaukee County - Shore Erosion Study Technical Report, Appendix 3. Wisconsin Coastal Zone Management, 117pp.

Mohr, M.C., 1994. Presque Isle Shoreline Erosion Control Project. Shore and Beach, Vol. 62, No. 2, April 1994: 23-28.

Mohr, M.C., and Ippolito, M., 1991. Initial Shoreline Response at the Presque Isle Erosion Control Project. In: Coastal Sediments '91; Volume 2, Proceedings of a Special Conference on Quantitative Approaches to Coastal Sediment Processes, ASCE, New York: 1740-1754.

Nairn, R.B., 1992. Erosion Processes Evaluation Paper. Report Submitted to the Erosion Processes Task Group, Working Committee 2, Phase II, IJC Levels Reference Study Board, 165pp. plus Appendices.

Need, E., Johnson, M., Schultz, M., Pulley, S., Mickelson, D., Edil, T., DeGroot, R., and Bagchi, A., 1980. Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin: Douglas and Western Bayfield Counties, Wisconsin Point to Bark Bay - Shore Erosion Study Technical Report, Appendix 9. Wisconsin Coastal Zone Management, 272pp.

North Shore Management Board, 1988. North Shore Management Plan - A Shoreland Management Plan for Lake Superior's North Shore, 50pp.

Ohio Division of Shore Erosion, 1961. Preliminary Estimate of Erosion and Accretion Along the Ohio Shore of Lake Erie and Critical Erosion Areas. Technical Report No. 8, 13pp.

Palm, D.J., 1975. Engineering Studies for a Contract For Field Investigations of High Water Damage in Oswego County, New York. St. Lawrence - Eastern Ontario Commission, Watertown, New York.

Pennsylvania Department of Environmental Resources, Division of Coastal Programs, 1982. A Geotechnical Investigation of the Coastal Bluffs of Erie County, Pennsylvania, September 1982. Bureau of Land and Water Conservation.

Peters, C.S., 1982. Erosion Hazard Setback Recommendations for Manitowoc County, Wisconsin. Unpublished Draft Report, Wisconsin Sea Grant, University of Wisconsin, Madison, Wisconsin, 25pp.

Pezzetta, J.M., and Moore, J.R., 1978. Great Lakes Shoreline Erosion - Western Lake Michigan. Proceedings of the Marine Technology Society/IEEE 4th Annual Conf. On Oceans, Washington D.C., September 6-8, p.143-151.

Pincus, H.J., Bowman, R.S., Kleinhampl, F.J., Humphris, C.C., and Metter, R.E., 1953. 1951 Investigations of Lake Erie Shore Erosion. Ohio Division of Geological Survey Rept. Inv. No.18, 138pp.

Pope, J., Stewart, C.J., and Nairn, R.B., 1993. Impacts of Great Lakes - St. Lawrence River Water Level Fluctuations on Recession Rates and Coastal Processes. Proceedings of the 1993 Canadian Coastal Conference, Vancouver, British Columbia: 151-166.

Raphael, C.N., and Kureth, E.J.C., 1988. Bluff Line Recession and Economic Loss in Coastal Berrien County, Michigan. Report Prepared for the Whirlpool Foundation, Benton Harbor, Michigan, 131pp.

Report of Committee, 1945. Lake Michigan Shore Erosion, Milwaukee County, Wisconsin. October 1945.

Rovey, C.W., 1992. Bluff Formation and Long-Term Recession Rates, Southwestern Lake Michigan. In: Abstracts With Programs, Geological Society of America, 1992 Annual Meeting, Vol.24., No. 7.

Schmidt, M.L., 1980. Shoreline Erosion at Painesville Township Park, Lake County, Ohio. Compass of Sigma Gamma Epsilon, Vol. 57, No. 3: 89-100.

Schneider, A.F., Edil, T., and Haas, B., 1977a. Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin: Kenosha County - Shore Erosion Study Technical Report, Appendix 1. Wisconsin Coastal Zone Management, 80pp.

Schneider, A.F., Edil, T., and Haas, B., 1977b. Shoreline Erosion and Bluff Stability Along Lake Michigan and Lake Superior Shorelines of Wisconsin: Racine County - Shore Erosion Study Technical Report, Appendix 2. Wisconsin Coastal Zone Management, 71pp.

Seibel, E., 1972. Shore Erosion at Selected Sites Along Lakes Michigan and Huron. Ph.D. Thesis, University of Michigan, Ann Arbor, 175pp.

Seibel, E., Armstrong, J.M., and Alexander, C.L., 1976. Technical Report on Determination of Quantity and Quality of Great Lakes U.S. Shoreline Eroded Material. International Reference Group on Great Lakes Pollution From Land Use Activities, USEPA Contract No. 68-01-1598, 292pp.

Shabica, C., Pranschke, F., and Chrzastowski, M.J., 1991. Survey of Littoral Drift Sand Deposits Along the Illinois Shore of Lake Michigan from Fort Sheridan to Evanston. Illinois-Indiana Sea Grant Program, Report No. IL-IN-SG-R-91-3.

Southeastern Wisconsin Regional Planning Commission, 1982. A Lake Michigan Coastal Erosion Management Study for Racine County, Wisconsin. Community Assistance Planning Report

Number 86, SEWRPC and the Racine County Planning and Zoning Department, 149pp.

Southeastern Wisconsin Regional Planning Commission, 1984. A Lake Michigan Coastal Erosion and Related Land Use Study for the City of St. Francis, Wisconsin. Community Assistance Planning Report Number 110, SEWRPC and City of St. Francis.

Southeastern Wisconsin Regional Planning Commission, 1989. A Lake Michigan Shoreline Erosion Management Plan For Milwaukee County Wisconsin. Community Assistance Planning Report Number 163, SEWRPC and WCZM, 549pp.

Springman, R., and Born, S.M., 1979. Wisconsin's Shore Erosion Plan: An Appraisal of Options and Strategies. Report Prepared by the University of Wisconsin Geological and Natural History Survey and Department of Urban and Regional Planning for the Wisconsin Coastal Management Program, 178pp.

Sterrett, R.J., 1980. Factors and Mechanics of Bluff Erosion on Wisconsin's Great Lakes Shorelines. Ph.D. Thesis, University of Wisconsin-Madison, 390pp.

Stewart, C.J. (ed.), 1993. Working Committee 2 Final Report. Annex 2 - Levels Reference Study Board, Phase II, IJC Water Levels Reference Study.

Stewart, C.J., and Pope, J., 1993a. A Great Lakes - St. Lawrence River Shoreline Erodibility Classification System. Proceedings of the 1993 Canadian Coastal Conference, Vancouver British Columbia: 137-150.

Stewart, C.J., and Pope, J., 1993b. Erosion Processes Task Group Report. Report Submitted to Working Committee 2, Phase II, IJC Water Levels Reference Study.

Stoker, B.A., 1976. Pilot Study Program, Great Lakes Shoreland Damage Study, Appendix VII: Measurement of Coastal Bluff Erosion From Aerial Photographs, Muskegon County, Michigan. University of Michigan, Coastal Zone Laboratory, 67pp.

Tanner, W.F., 1975. Beach Processes, Berrien County, Michigan. Journal of Great Lakes Research, Vol. 1, No. 1.

United States Army Corps of Engineers, 1954, 1955. Cooperative Beach Erosion Studies, Fair Haven and Selkirk Shores State Park, Northeastern District.

United States Army Corps of Engineers, 1970. Beach Erosion Studies of Hamlin Beach and Braddock Bay State Parks. Northeastern District.

United States Army Corps of Engineers, 1983a. Maumee Bay State Park, Ohio. Shoreline Erosion Beach Restoration Study. Interim to Western Lake Erie Shore Study, Volume 1, Main Report, Revision. USACE - Buffalo District.

United States Army Corps of Engineers, 1983b. Maumee Bay State Park, Ohio. Shoreline Erosion Beach Restoration Study. Interim to Western Lake Erie Shore Study, Volume 2, Appendices. USACE - Buffalo District.

United States Army Corps of Engineers, 1983c. Maumee Bay State Park, Ohio. Shoreline Erosion Beach Restoration Study. Final Feasibility Report and Final Environmental Impact Statement. Interim to Western Lake Erie Shore Study, Volume 1, Main Report, Revised. USACE - Buffalo District.

United States Army Corps of Engineers, 1983d. Maumee Bay State Park, Ohio. Shoreline Erosion Beach Restoration Study. Final Feasibility Report and Final Environmental Impact Statement. Interim to Western Lake Erie Shore Study, Volume 2, Appendices, Revised. USACE - Buffalo District.

University of Michigan Ocean Engineering Laboratory, 1989. Coastal Monitoring Program and Shoreline Evolution Model Year One: Report to the State of Michigan Department of Natural Resources. Department of Naval Architecture and Marine Engineering, Report No. OEL-8901-LWMD-10C-5, 48pp.

Vallejo, L.E. and Degroot, R., 1988. Bluff Response to Wave Action. Engineering Geology, Vol. 26, No. 1:1-16.

Wells, J.D., 1952. Erosion Problems on the Ohio Shore of Lake Erie. Shore and Beach, Vol. 20, No. 1: 5-8.

Zorich, J., 1981. Western Lake Erie Shore Study, Ohio. Reconnaissance Report (Stage 1) on Flood Protection and Shoreline Erosion Control. U.S. Army Corps of Engineers - Buffalo District.

Zorich, J., and Mammosser, R., 1981. Maumee Bay State Park, Ohio. Shoreline Erosion Beach Restoration Study. Preliminary Feasibility Report (Stage 2). Interim to Western lake Erie Shore Feasibility Study. U.S. Army Corps of Engineers - Buffalo District.