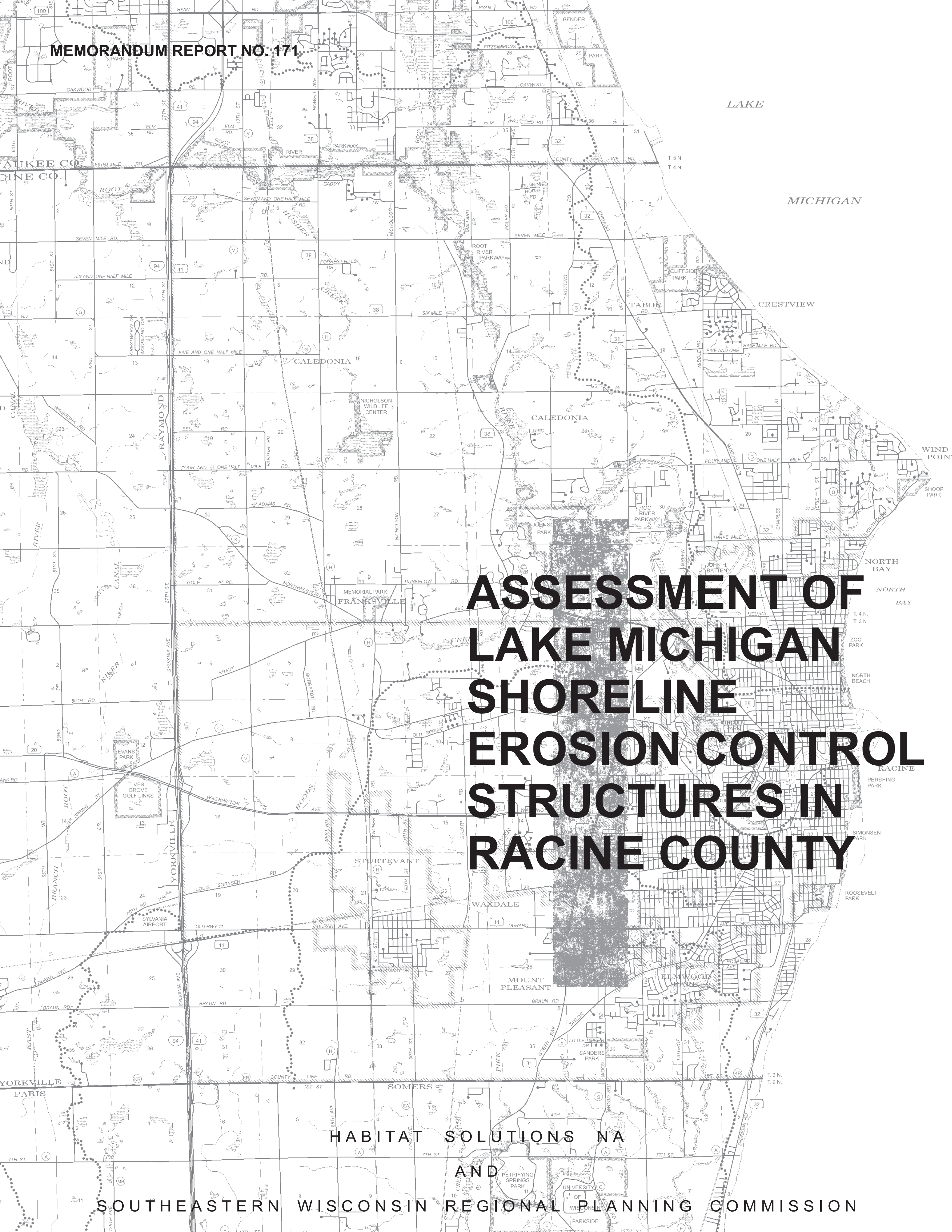
MEMORANDUM REPORT NO. 171



ASSESSMENT OF LAKE MICHIGAN SHORELINE EROSION CONTROL STRUCTURES IN RACINE COUNTY

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AND

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Prepared by the

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and
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The preparation of this report was funded in part by the Wisconsin Department of Natural Resources and the U.S. Environmental Protection Agency.

January 2008

$10.00

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ASSESSMENT OF LAKE MICHIGAN SHORELINE EROSION CONTROL STRUCTURES IN RACINE COUNTY

EXECUTIVE SUMMARY

Racine County includes about 14.8 miles of Lake Michigan shoreline, along which are more than 220 shoreline protection structures. Currently, the degree of shoreline armoring and cumulative effects of that armoring on coastal processes and the nearshore zone are poorly understood. In cooperation with SEWRPC, the Wisconsin Department of Natural Resources, and the Wisconsin Coastal Management Program, a Lake Michigan coastal structure data base and GIS system has been created for Racine County. The system includes information on the structure type, composition, condition, dimensions, elevation, and location collected during field surveys during the summer of 2005. Each structure was located using Global Positioning System (GPS) equipment and is evaluated as to its likely effectiveness for erosion control and potential effect on coastal processes, littoral drift, and nearshore habitat.

Data were collected for a total of 380 separate structures representing 222 individual or composite structures (or shore protection systems) along the Racine County shoreline. Approximately 73 percent of the Racine County shoreline was protected in 2005, with the remaining 27 percent unprotected (primarily north of Wind Point). Shore-normal groins are the most prevalent type of shore protection along the Racine County shoreline (37 percent), followed by shore-parallel revetments (29 percent), and seawalls or bulkheads (10 percent). The most common building materials are large dolomite/limestone blocks (35 percent) that are ubiquitous to both old and new structures found along the shoreline, and large granite/ metamorphic blocks (24 percent) that are typically associated with newer structures that have been built within the past two decades. Poured concrete seawalls, bulkheads, and solid groins are also common (15 percent).

In general, 70 percent of the structures are considered to be in “good” condition, 15 percent of these structures are in “fair” condition, and 12 percent are considered to be in “poor” condition. At current Lake Michigan water levels, the current effectiveness of these structures is high. For example, more than two-thirds of the shore-parallel structures are considered to be effective or highly effective at preventing erosion. Shore-normal structures (primarily groins) are designed to trap and retain littoral sediments in order to build wide beaches that absorb wave energy and protect the lower bluff and adjacent upland areas from Lake-related erosion. Therefore, it is not surprising that the elevations of these structures are generally less than shore-parallel structures, which are designed to directly absorb or deflect wave energy away from the shoreline. As Lake Michigan water levels increase, the effectiveness of these structures (both shore-parallel and shore-normal) will diminish. Even though many of these structures are in “good” condition, field data suggest that many of these structures will require maintenance within three to five years from 2005, especially if lake levels start to rise.

Twenty-eight separate unprotected shoreline reaches were identified, eight of which are actively eroding even at the relatively low current Lake Michigan water levels. These areas of active erosion (1.4 miles or 9.5 percent of

the Racine County shoreline) are considered to be high-risk erosion areas and it is likely that significant erosion will occur at these sites if the frequency and severity of storms and/or Lake Michigan water levels increase.

Even though erosion is generally thought to be a negative environmental factor, erosion is a natural coastal process that provides coarse-grained littoral sediments (sands and gravels) that create and maintain beaches. Beaches are a natural form of shore protection, and in combination with underlying glacially-derived cohesive clays and exposed bedrock areas near Wind Point, provide diverse nearshore aquatic habitats along the Racine County shoreline. It is likely that substantial changes in nearshore habitat composition and structure have occurred in the vicinity of the Racine Harbor structure and the Racine South littoral cell. The redirection of sediments offshore and trapping of littoral sands south of Pershing Park has completely eliminated any littoral sediment transport southward into the Racine South littoral cell. Moreover, the extensive hardening and loss of sediment supply in the Racine South littoral cell suggests that the adjacent nearshore habitats are now much more coarse-grained and heterogeneous than would have naturally been present along that reach of coastline. Rapid colonization by aquatic invasive species (such as *dreissenids*) of these artificial hard substrates may have significantly altered nearshore habitats along this reach of coastline.

The actively eroding unprotected sites between the Oak Creek Power Plant and Crestview Park within the Wind Point North reach are the primary source of sediment for beaches within the southern portion of the reach. Unless there is a compelling reason (loss of infrastructure or threat to public health and safety), it is recommended that erosion should be allowed to continue along this reach to serve as a long-term natural sediment supply to maintain beaches along the southern portion of the Wind Point North reach.

The development of the data base and GIS system documenting the characteristics of these structures and including an assessment of their effectiveness and impact will be a valuable tool to landowners and agencies involved in oversight, design, and construction of such facilities.

The data collected during this study will be used to establish a year 2005 baseline condition which will be analyzed in order to guide decision-makers in developing, permitting, and regulating future shoreline protection projects. This should result in more effective, cost-effective, and environmentally sound shoreline protection projects.

ASSESSMENT OF LAKE MICHIGAN SHORELINE EROSION CONTROL STRUCTURES IN RACINE COUNTY

INTRODUCTION

Racine County includes about 14.8 miles of Lake Michigan shoreline, along which are more than 220 shoreline protection structures. A 1982 Lake Michigan coastal erosion management study, prepared for Racine County by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) in 1982, with assistance from the Wisconsin Coastal Management Program, identified the extent of the erosion at 101 locations along the shoreline. The study identified erosion rates of up to 10 feet per year over the period 1963 to 1980, with an average rate of 1.5 feet per year. The study included estimates of the economic value of the land and facilities within the 25-year and 50-year erosion risk distances within the County at $6.4 million and $12.9 million, respectively, in 1980 dollars.

Currently, the degree of shoreline armoring and cumulative effects of that armoring on coastal processes and the nearshore zone are poorly understood. In cooperation with SEWRPC, the Wisconsin Department of Natural Resources (DNR), and the Wisconsin Coastal Management Program, a Lake Michigan coastal structure data base and GIS system has been created for Racine County. The system includes information on the structure type, composition, condition, dimensions, elevation, and location collected during field surveys during the summer of 2005. Each structure was located using GPS equipment and is evaluated as to its likely effectiveness for erosion control and potential effect on coastal processes, littoral drift, and nearshore habitat. A standardized set of procedures and criteria have been developed for data collection and analysis that can be applied to other coastal counties as well. These data have been summarized and plotted on year 2000 digital orthophotography of Racine County. The data developed is intended to be used as a tool to assess potential cumulative impacts and to guide decisions on shore erosion structure installation in the future.

Purpose

There are a large number of shoreline erosion control structures constructed at significant cost every year along the Lake Michigan shoreline in Wisconsin. There is not adequate information on the effectiveness, longevity, and nearshore habitat impact of these structures based upon the type and composition of the structure. The development of a data base and GIS system documenting the characteristics of these structures and including an assessment of their effectiveness and impact will be a valuable tool to landowners and agencies involved in oversight, design, and construction of such facilities. No such system is in place for the Southeastern Wisconsin Region where a large number of shoreline protection structures are permitted and constructed or repaired each year.

This study established a year 2005 baseline condition which was analyzed in order to guide decision-makers in developing, permitting, and regulating future shoreline protection projects. This should result in more effective, cost-effective, and environmentally sound shoreline protection projects.

This project was recommended to be developed as part of the the Racine County all-hazards mitigation plan (SEWRPC 2004) and in the initial Racine County land and water resource management plan (SEWRPC 2000). The data will be utilized by Racine County in its long-standing coastal management program which has been carried out since the 1970s under a variety of planning, educational, and regulatory programs. These programs have been carried out cooperatively with the Wisconsin Coastal Management Program, the Wisconsin Department of Natural Resources, the University of Wisconsin Sea Grant Institute, local communities, and citizens groups. The data developed was also made available to the WDNR which has regulatory and oversight responsibilities with respect to permit applications for new shoreline protection structures or modifications of existing structures along the Wisconsin Lake Michigan shoreline.

METHODS

Field Protocols

Prior to commencement of field work, digital orthophotography and local maps were used to identify access points to the shoreline, determine the locations and types of structures, identify any hazardous or restricted areas, and locate staging areas to spot vehicles and/or supplies necessary to carry out the field work. Once in the field, the field team would evaluate a shoreline reach to determine the types of structures present and the relationship of those structures to each other.

Typically, the field crew consisted of a minimum of two personnel, one operating the Trimble GPS unit and collecting GPS data points, while the second recorded attribute information on field data sheets, measured the width and elevation of the structures, performed a general assessment of the structure's condition, and then photographed the structure with a digital camera.[1]

A Structure ID numbering system was developed that sequentially identifies individual structures from the northern boundary of Racine County with Milwaukee County to the southern boundary with Kenosha County. The Structure ID consists of a County code—RAC for Racine County—then a unique number that identifies each individual structure. In the case of isolated, stand-alone structures, the task of assigning a Structure ID, collecting GPS data, and describing fundamental attributes of the structure is fairly straightforward. However, it is not uncommon to find multiple types of protection incorporated into a single structure, either by design, or by subsequent modification or addition to the original structure. In terms of identifying and classifying these types of structures, the following general definitions apply:

<u>Single Structure</u> - A single structure composed of a single or multiple devices or objects, generally of the *same type and size*, placed to reduce or prevent erosion due to mass wasting processes and/or the action of wind, water, or waves acting along a shoreline.

<u>Composite Structure</u> - A single structure composed of multiple devices or objects, generally of *two or more different types or sizes*, placed to reduce or prevent erosion due to mass wasting processes and/or the action of wind, water, or waves acting along a shoreline.

<u>Shore Protection Systems</u> - Multiple structures designed to work together to reduce or prevent erosion due to mass wasting processes and/or the action of wind, water, or waves acting along a shoreline.

Provision has been made in the database to identify *primary* and *secondary* structures, i.e., composite structures or shore protection systems that utilize more than one type of structure to protect a reach of shoreline. For the purposes of this inventory, a primary structure is either a single, stand-alone structure, or the dominant structure

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[1] A two-person field crew was required for safety reasons, and was necessary given the amount of data that had to be collected for each individual structure. The addition of a third crew member increased the speed and accuracy at which data could be collected, and it is recommended that there-person field team be used for additional shore structure inventory work along the Wisconsin Lake Michigan Shoreline.

(greater than 50 percent of lineal length and/or area of the total structure) of either a composite structure or a shore protection system. A primary structure may also be the "backbone" that connects and/or ties a shore protection system together, even though the lineal length and/or area of the structure are less than 50 percent. A secondary structure is generally a smaller structure or one of several structures attached or appended to a structure of a different type, shape, or orientation.

In the case of composite structures or shore protection systems, a sequential letter designation is typically applied to smaller secondary structures or features that are associated with a larger, main structure. For example, a shore-parallel revetment would be identified as RAC5, and associated shore-perpendicular groins would be identified as RAC5a, RAC5b, RAC5c… in sequence from north to south. This allows for the identification of smaller individual structures and associated feature attributes, while maintaining a linkage to a larger composite structure or shore protection system.

Where structures join one another to form a continuous zone of protection, subtle changes in the composition, size, shape, or other attributes (e.g., toe protection, slush cap, splash apron, or apparent age of the structure) can be used to distinguish individual structures for the purpose of identification. Even though many structures are defined by apparent property line boundaries, it is not uncommon to find single or composite structures that extend across multiple properties. This may be due to subsequent subdivision of the original property after the shore protection structure was emplaced, or a cooperative effort between property owners (such as a community association) to protect a broader reach of shoreline.

For comparison purposes, it is important that shore protection structures be identified and classified in a consistent manner throughout the life of the project. Past experience has shown that it is best to have the same individual identify and classify structures for the entire project. To assist in the identification process, a glossary of terms and definitions has been prepared and is included in Appendix A.

Field Data Collection

Field data were collected between July 15 and August 31, 2005. Follow-up boat work was completed on October 1, 2005. There were several structures that were not accessible by land (e.g., offshore breakwaters) that could only be accessed by boat.

Field Data Sheets

Attribute information for each of the structures was recorded on field data sheets. The information recorded includes: structure ID, date and time, field crew, structure type, composition, shape, condition, other attributes, dimensions (length, width, and elevation above lake level), and an area for comments. The data sheet also provides an area for a plan-view sketch of the structure, and an area for a cross-section sketch of both primary and/or secondary structures (if present). Data were recorded in pencil, which is waterproof and allows for easy correction/modification as the survey progresses. A copy of the Shore Structure Inventory data sheet is included in Appendix B of this report.

Global Positioning System (GPS) Equipment and Data Acquisition

A Trimble Pathfinder Pro XL GPS unit with real-time differential correction capability and TSC1 rover (data collector) were used to collect positional data for each individual shore protection structure. All positional data and horizontal coordinates were referenced to State Plane Coordinate System, Wisconsin South Zone North American Datum of 1927 (NAD27).

The overall objective of the GPS data collection effort was to capture the location, general extent, and shape of each individual structure by collecting a series of points in sequence to create a polyline feature, i.e., a series of points connected by a line. In most cases, data were collected along the center-line of the structure, except where access or walking was dangerous or difficult. Where access was difficult, data were collected either at the toe or crest of the structure. The only exceptions to this rule were for three types of structures—boat ramps, attached or offshore breakwaters or jetties, or large poured concrete structures, where the outline of the structure was captured as a polyline feature. A good example of these types of structures would be the large composite structures (poured concrete seawalls, revetments, and breakwaters) that protect the Racine Harbor and Marina complex.

The Trimble GPS TSC1 rover has a self-prompting menu system—a data dictionary—that can be designed by the user to collect and associate attribute data with a feature. Basic information included in the Racine County Shore Structure Inventory (SSI) data dictionary includes: structure ID; primary and secondary structure type, composition, and shape (orientation); toe attributes; condition; dimensions (length, width, and elevation above lake level); field team; and date and time the information was collected. Additional information related to the precision and accuracy of the GPS positional data are also recorded independently. A listing of specific attributes and information in the Racine County (SSI) data dictionary is provided in Appendix C of this report and digitally on the data CD attached to the inside back cover of this report.

For most structures, a minimum of five positions were acquired at each point at five second sampling intervals. Generally, a minimum of 10 positions were taken at each beginning and ending point that defined the lateral extent of an individual structure. Based on preliminary tests using the GPS equipment, this represented a compromise between the need for positional accuracy and the need to complete the field work in a timely manner. In general, dimensional data (width and elevation above water level) were measured directly using a tape measure in combination with a site level where necessary. In most cases, the large size of the structures precluded direct measurement of length. Thus, the lengths of individual structures were subsequently calculated from the GPS field data, compared with the digital orthophotography, and then manually entered into the feature attribute database using the Trimble Pathfinder Office software.

Digital Photography

Digital photographs of all of the structures were acquired at a 1600 x 1200 resolution using an Olympus D510 zoom digital camera. These images were stored in JPEG image format. Typically, two or more images were acquired for each structure in order to adequately capture the fundamental characteristics of the structure and to assist with post-field analyses. Additional photographs were taken of “trouble” spots where appropriate. Links to these images have been incorporated into the GIS database and the images can be accessed through the Hotlink feature in the ESRI ArcView Software. These images are also included on the enclosed data CD. If a future shore-structure inventory is completed, these images should prove to be a valuable resource for comparison purposes.

Digital orthophotography of the entire Racine County coastal area was provided by SEWRPC (GeoTiff format). These images were acquired in 2000 and therefore do not represent the condition of the Racine County shoreline in 2005. However, the digital orthophotography provides a base layer or “underlayment” over which the 2005 shore protection geospatial data layers can be plotted and displayed using the Trimble Pathfinder Office and/or ESRI ArcView-ArcInfo GIS software.

Field Data Integrity/Reduction

In addition to the hardcopy field data sheets, several different types of digital data files were produced during the field surveys. Digital data files include the Trimble GPS data dictionary files (SSF format) and high-resolution digital photographs of each of the shore protection structures (JPEG image format). Field data were downloaded from the data collector into a laptop (Panasonic Toughbook) at the end of each field day while still in the field. These data were then plotted on-site using the Trimble Pathfinder Office software to verify data integrity.

All of the raw data files have been archived on CD and were provided to SEWRPC. Field data sheets were reviewed and then scanned into a computer at 300 dpi resolution (both JPEG and TIF image formats). All of the field data sheets are available digitally and can be accessed through the Hotlink feature in the ESRI ArcView Software.

Quality Assurance

GPS data and associated feature attribute information were plotted on the year 2000 digital orthophotography using the Trimble Pathfinder Office software. The location of each structure was verified along with the feature attribute data. Information and data collected on the field data sheets were compared with the feature attribute data and high-resolution digital photographs to ensure data accuracy, integrity, and consistency. Where appropriate, the data were corrected and additional information entered based on post-field GPS calculations.

Once validated, the positional data were edited to reduce the total number of survey points for each line vertex to a single point. Originally, more than 9,726 GPS points were collected in the field. Each point grouping was examined visually and reduced to a single GPS point that best represents the true location by integrating the GPS data with the underlying digital orthophotography. This analysis reduced the number of positional records from 9,726 to approximately 1,772 positional records, of which 1,684 were differentially corrected and the balance manually entered and/or corrected due to inability to acquire the RTCM radio beacon while in the field. After real-time correction, the average horizontal positional error was +/- 1.5 feet (68 percent confidence interval) with a maximum error of approximately +/- 2.6 feet. These values are acceptable for a regional reconnaissance survey. Differential post-processing of the real-time data did not substantially improve horizontal positional accuracies.

GPS elevation data were not used in this study due to equipment limitations and large associated errors. Elevation data were collected by direct measurement relative to Lake Michigan water levels at the time GPS coordinates were acquired. Given the difficulty of estimating stillwater elevations during period of wave activity, the field elevation accuracies are estimated to be +/- 0.5 feet, even though in many cases, elevation measurements were taken in protected stillwater areas within porous structures. Conversion of these field measurements to International Great Lakes Datum (IGLD) 1985 and National Geodetic Vertical Datum of 1929 (NGVD29) elevations was accomplished by performing a water-level transfer between the NOAA water-level gages at Calumet Harbor and Milwaukee. A water-level transfer is based on a straight-line interpolation between the water-level gages at Calumet Harbor and Milwaukee.

Continuous water-level data were available at six-minute intervals at both gages for the duration of the study. Water-level data for each gage were downloaded for each of the field days in question. Water levels in the vicinity of Racine County were interpolated based on the approximate geographic location of the structures in question relative to the Calumet Harbor and Milwaukee water-level gages. In the vicinity of Racine County, interpolated differences in Lake Michigan water levels between the Calumet and Milwaukee gages ranged from -0.36 feet to 0.44 feet and averaged -0.02 feet. These differences are well within the accuracy limits of the field elevation data. A FORTRAN program was written to automatically interpolate the time and water level data for each of the survey dates and convert the measured elevation data into elevations IGLD 1985. IGLD 1985 elevations were then converted to NGVD29 for incorporation into the shore structure and GIS databases. All elevation data collected are referenced to NGVD29.

GIS/Database Development

Digital data collected using the Trimble TSC1 rover and Pathfinder Office software were automatically converted to ESRI shapefiles, which can be imported directly into ESRI ArcView or ArcInfo software. The data tables have been edited to include corrected structure elevations (NGVD29); elevated open-coast instantaneous Lake Michigan water-levels; and the results of associated freeboard calculations for the 100-year, 50-year, 10-year, and low water base case scenarios. Additional fields were added to incorporate the results of the effectiveness evaluation along with links to the scanned field data sheets and high-resolution digital images. SEWRPC provided the digital orthophotography which serves as the base layer and/or underlayment for the shore structure coverages.

The geospatial data is provided on CD as ESRI ArcView shapefiles, in a MS Access database, and in MS Excel spreadsheets. High-resolution digital images in .jpg and .gif image formats and scanned copies of the field data sheets in.jpg format are also included on the CD.

ANALYSIS

Statistical Summary

Data were collected on a total of 380 separate structures representing 222 individual or composite structures (or shore protection systems) along the Racine County shoreline, of which 198 were oriented shore-normal, 178 aligned parallel to the shore, and several having either a “T” or “L” shape orientation. A summary breakdown of primary and secondary structures by type, composition, and orientation is given in Tables 1 and 2.

Table 1

SUMMARY OF PRIMARY PROTECTION STRUCTURES ALONG THE RACINE COUNTY – LAKE MICHIGAN SHORELINE

Number of Structures	Primary Structure Type	Distribution (percent)
112	Revetments	29.5
104	Pervious Groins	27.4
38	Solid Groins	10.0
37	Seawalls/Bulkheads	9.7
30	Outfall Structures	7.9
28	Ad Hoc Rubble Structures	7.4
8	Piers	2.1
7	Retaining Walls	1.8
6	Boat Ramps (excl. Racine Harbor)	1.6
4	Attached Breakwaters or Jetties	1.6
3	Offshore (Detached) Breakwaters	0.8
3	Type Other	0.2
Total 380	- -	100.0

Number of Structures	Primary Structure Composition	Distribution (percent)
135	Dolomite/Limestone Blocks	35.5
91	Granite/Metamorphic Blocks	23.9
57	Poured Concrete	15.0
37	Concrete Rubble	9.7
15	Concrete Slabs	3.9
13	Steel Sheet Piling	3.4
12	Concrete Block	3.2
12	Composition Other	3.2
3	Rock-Filled Timber Cribs	0.8
2	Gabion Baskets	0.5
2	Modular Concrete Rings	0.5
1	Modular Concrete Cubes	0.4
Total 380	- -	100.0

Number of Structures	Primary Structure Orientation	Distribution (percent)
198	Shore Normal _|_	52.1
178	Shore Parallel ||	46.8
2	Shape Other	0.5
1	“T” Shape	0.3
1	“L” Shape	0.3
Total 380	- -	100.0

Number of Structures	Presence of Secondary Structure	Distribution (percent)
59	Secondary Structure	15.3
321	No Secondary Structure	84.7
Total 380	- -	100.0

Source: Habitat Solutions NA.

Table 2

SUMMARY OF SECONDARY PROTECTION STRUCTURES ALONG THE RACINE COUNTY – LAKE MICHIGAN SHORELINE

Number of Structures	Secondary Structure Type	Distribution (percent)
30	Pervious Groins	50.8
10	Solid Groins	16.9
7	Revetments	11.9
4	Seawalls/Bulkheads	6.8
4	Outfall Structures	6.8
2	Retaining Wall	3.4
1	Pier	1.7
1	Type Other	1.7
Total 59	- -	100.0

Number of Structures	Secondary Structure Composition	Distribution (percent)
23	Granite/Metamorphic Blocks	39.0
17	Dolomite/Limestone Blocks	28.8
10	Poured Concrete	16.9
3	Composition Other	5.1
2	Concrete Blocks	3.4
2	Rock-Filled Timber Cribs	3.4
1	Steel Sheet Piling	1.7
1	Steel Crib	1.7
Total 59	- -	100.0

Source: Habitat Solutions NA.

Table 3

DIMENSIONAL STATISTICS OF SHORELINE PROTECTION STRUCTURES ALONG THE RACINE COUNTY – LAKE MICHIGAN SHORELINE

Shore-Parallel Structures				
Statistic	Length (feet)	Width (feet)	Elevation above lake level (feet)	Elevation in feet above NGVD of 1929
Minimum	12	0.5	1	579.8
Maximum	2700	55	30	608.9
Mean	328.0	19.3	10.7	589.5

Shore-Normal Structures				
Statistic	Length (feet)	Width (feet)	Elevation above lake level (feet)	Elevation in feet above NGVD of 1929
Minimum	12	2	0.5	578.9
Maximum	2700	75	13	592.1
Mean	138.6	14.7	6.1	584.9

Source: Habitat Solutions NA.

Shore-normal groins are the most prevalent type of shore protection along the Racine County shoreline (37 percent), followed by shore-parallel revetments (29 percent), and seawalls or bulkheads (10 percent). "Ad hoc" concrete rubble structures are also prevalent (7 percent) along with outfall structures (8 percent). The most common building materials are large dolomite/limestone blocks (35 percent) that are ubiquitous to both old and new structures found along the shoreline, and large granite/metamorphic blocks (24 percent) that are typically associated with newer structures that have been built within the past two decades. Poured concrete seawalls, bulkheads, and solid groins are also common (15 percent). Eighty-five percent of primary structures are individual or stand-alone structures. Fifteen percent of the primary structures also have secondary structures – primarily groins oriented perpendicular to shore. Fifty percent of the secondary groins are pervious, i.e. they are somewhat permeable to water and sediment. Sixteen percent of the secondary groins are solid and impermeable.

Dimensional data for each of the structures was acquired by direct measurement in the field and by subsequent calculations of lineal length and elevation for each structure. These data were incorporated into the Racine County Shore Structure Inventory GIS and are also available in a MS Access database and MS Excel spreadsheet. Summary dimensional statistics are given in Table 3.

In general, shore-parallel structures are longer and higher than shore-perpendicular structures. This is not surprising in that the shore perpendicular structures are generally designed to trap littoral sediments in order to create wide beaches which, in turn, protect the lower bluff face and adjacent upland areas from lake-related erosion.

Distribution of Structures by Reach

It is convenient to subdivide the Racine County shoreline into reaches based upon shoreline geometry, coastal processes, and anthropogenic features. A similar approach was used in a study by SEWRPC *et al.* (1997) that focused on Lake Michigan shoreline recession and bluff stability in Southeastern Wisconsin in 1995. For the purposes of this study, four separate reaches were identified:

Wind Point North – this reach extends from the northern border of Racine County (at the Oak Creek Power Plant) southward to the Wind Point Lighthouse. This reach is equivalent to Reach 6 in the SEWRPC *et al.* (1997) study.

Table 4

ESTIMATED LINEAL LENGTH OF PROTECTED AND UNPROTECTED SHORELINE PROTECTED STRUCTURES ALONG THE RACINE COUNTY – LAKE MICHIGAN SHORELINE

	Protected		Unprotected		
Reach	Length (feet)	Percent	Length (feet)	Percent	Total Feet)
Wind Point North	29,200	63.2	10,760	36.8	29,200
Wind Point South	17,500	51.4	8,510	48.6	17,500
Racine Harbor[a]	10,500[a]	100.0	0	0	10,500
Racine South[a]	21,000[a]	91.5	1,775	8.5	21,000
Racine County	78,200	73.1	21,045	26.9	78,200

[a]*Does not include the attached and offshore breakwaters located south of Pershing Park and east of Simonsen Park.*

Source: Habitat Solutions NA.

Wind Point South – this reach extends from the Wind Point Lighthouse southward to the North Beach concession stand located north of Racine Harbor. This reach is equivalent to Reach 5 in the SEWRPC *et al.* (1997) study.

Racine Harbor Complex – this reach extends from the North Beach concession stand to the south edge of Pershing Park. The large breakwaters immediately south of Pershing Park are considered to be part of this complex. This reach is equivalent to the northern half of Reach 4 in the SEWRPC *et al.* (1997) study.

Racine South – this reach extends from the protected embayment just south of Pershing Park (west of the breakwaters) southward to the southern border of Racine County. This reach is equivalent to the southern half of Reach 4 and the northern third of Reach 3 in the SEWRPC *et al.* (1997) study.

The rationale for splitting Reach 3 and 4 of the SEWRPC study is based on the presence of both private and publicly-owned shore protection between Pershing Park and Roosevelt Park. The Racine Harbor Complex to the north is extensively protected by large public structures that are maintained by the U.S. Army Corps of Engineers (USCOE) and the City of Racine.

As part of the statistical analysis, unprotected areas were delineated using the shore structure inventory data and the year 2000 digital orthophotography provided by SEWRPC. These data were entered into a separate GIS database that complements the shore structure inventory. Twenty-eight separate unprotected zones were identified, eight of which are actively eroding even at relatively low current Lake Michigan water levels. The erosion status and other pertinent information are included in the "unprotected" GIS database. By combining these data with the data from the shore structure inventory, it is possible to calculate the lineal length of protected and unprotected shoreline in Racine County. This information is summarized by reach in Table 4.

Evaluation of Effectiveness

The effectiveness of shore protection structures can be determined by their ability to reduce or halt erosion of the shoreline and associated upland areas over extended periods of time. For the purposes of this inventory and assessment, the following paragraphs discuss factors that were incorporated into the analyses.

Structural Elevation

Open-coast flood levels and estimated storm surge and/or wave run-up values were used to calculate the "freeboard" of specific types of structures found along the Racine County shoreline. The importance of freeboard depends on the type of structure under consideration. In general, freeboard is more important for shore parallel structures such as bulkheads, seawalls, and revetments, where overtopping can result in catastrophic failure of the structure and significant erosion damage. Shore normal structures, such as groins, rely on trapping of littoral sediments, primarily sand, gravel, and cobbles to absorb wave energy and reduce erosive power of waves and water on adjacent upland areas. Of course, the elevation of the trapped sediments is controlled, in part, by the elevation of the trapping structure. But lower elevations may be mitigated, in part, by the width of the beach and the volume and erodibility of sediments trapped by these structures. Data for three scenarios will be provided:

1. Open-coast flood levels based on maximum instantaneous Lake Michigan water levels with recurrence probabilities of 1 percent per year, equivalent to the 100-year level as defined by the U.S. Army Corps of Engineers (1988) and Federal Emergency Management Agency (FEMA) (2002) for the western shore of Lake Michigan—584.6 feet NGVD29 South of Wind Point, 584.3 feet NGVD29 North of Wind Point.
2. Open-coast flood levels based on maximum instantaneous Lake Michigan water levels with recurrence probabilities of 2 percent per year, equivalent to the 50-year level as defined by the U.S. Army Corps of Engineers (1988) and FEMA (2002) for the western shore of Lake Michigan—584.2 feet NGVD29 South of Wind Point, 583.9 feet NDVD29 North of Wind Point.
3. Open-coast flood levels based on maximum instantaneous Lake Michigan water levels with recurrence probabilities of 10 percent per year, equivalent to the 10-year level as defined by the U.S. Army Corps of Engineers (1988) and FEMA (2002) for the western shore of Lake Michigan—583.1 feet NGVD29 South of Wind Point, 582.8 feet NDVD29 North of Wind Point.
4. Open-coast flood levels based on a low-water case (e.g., low water datum), which is representative of current Lake Michigan water levels—578.1 feet NGVD29. Low-water conditions will be considered to be the current "base case" scenario.

Added to these levels were estimated storm surge values based on a local moderate storm surge with a 20 percent probability provided by the U.S. Army Corps of Engineers and used by FEMA and the Wisconsin Sea Grant program for western Lake Michigan (1.2 feet above maximum instantaneous water levels). Wave run up is also a factor, but is highly dependent on the type and composition of the structure; nearshore water depth and roughness; beach width; and elevation of beach intersection point with the shore protection structure. Given the limited time frame and resources for this project, wave run-up values were not calculated for each shore structure in Racine County due to a lack of information on nearshore water depths, roughness, and the dynamic nature of beaches along the Racine County shoreline. The reader should be cognizant that wave run up may cause overtopping of structures with marginal freeboard, and that the freeboard estimates presented here do not include wave runup. A minimum 2 foot wave runup elevation is recommended for most shore protection structures and shoreline types, with a 3 foot wave runup elevation recommended for shore-parallel bulkheads and/or seawalls (Keillor 1998).

Condition of Structure

During the collection of field data, an inspection of the structure was performed to identify potential trouble spots and assess the overall integrity and condition of the structure. This inspection is not meant to be a detailed engineering assessment, but to provide a general characterization of overall structural integrity and ability to function as designed based on the physical and environmental characteristics present at the site. For the purposes of this study, four general condition levels were recognized – new, good, fair, and poor. These levels represent an integrated assessment of structural integrity combined with an evaluation of the ability of the structure to continue to function as originally designed.

"New" structures are in pristine condition, with no apparent loss of integrity or structural damage. These structures are 100 percent functional that were either recently constructed and have a reasonable remaining life span, or, are older structures that were initially well-designed, well-constructed, and have been well-maintained such that they have withstood the test of time.

"Good" structures are in serviceable condition, with some loss of integrity and some minor structural damage, but still have a significant remaining life span. These structures are generally performing as designed (greater than 70 percent functionality), but may show some signs of deterioration and loss of function, either due to minor damage

Table 5

SUMMARY OF SHORELINE PROTECTION STRUCTURE CONDITIONS ALONG THE RACINE COUNTY – LAKE MICHIGAN SHORELINE

Number of Structures	Condition of Structure	Distribution (percent)
5	New	1.3
268	Good	70.5
58	Fair	15.3
30	Poor-Ruins	7.9
9	Poor-Large Cracks	2.4
7	Poor-Submerged	1.8
3	Condition-Other	0.8
Total 380	- -	100.0

Source: Habitat Solutions NA.

and or changing external physical or environmental conditions. These structures will probably require some maintenance and repair within three to five years from 2005. This condition is typical of the majority of the structures in Racine County.

"Fair" structures are in marginal condition, with moderate to severe loss of integrity and moderate to major structural damage. These structures are only marginally functional (less than 50 percent functionality), with significant performance losses due either to major structural damage and/or to adverse physical or environmental conditions. Under high water-level conditions, these structures will have a short remaining life span (one to three years) and will require extensive monitoring, maintenance, and repair.

"Poor" structures are in poor condition, with severe loss of integrity and major structural damage. These structures may have large cracks, be falling apart, disarticulated, submerged, flanked or undermined, and/or may be in ruins. These structures are not functioning as designed, provide minimal erosion protection, have no remaining life span, and will likely require replacement.

There are numerous structures along the Racine County shoreline that are considered to be "ad hoc", i.e., materials dumped or placed along the shoreline to slow the rate erosion without any apparent engineering or design considerations. These types of structures include "bluff dumps" of earthen fill, concrete rubble, concrete slabs, and construction debris which can be considered to be a form of expendable shore protection. The action of waves winnows away fine-grained materials and shifts the rubble into an imbricate structure that in effect, armors the beach face and may slow erosion of the bluff toe. Conditional evaluations are problematic for these types of structures, as there are no design criteria available for comparison. However, it may be possible to evaluate the "structural integrity" of such "ad hoc" structures based on an assessment of relative stability and "natural" placement of materials along the shoreline. An attempt has been made to assign conditional values based on the assumption that no additional materials will be added to, or maintenance performed on, these "structures". A summary of the general condition of shore protection along the Racine County coastline is shown in Table 5.

Effectiveness of Shore Protection Structures

For the purposes of this study, the effectiveness of shore protection structures will be based on the integration of the three above factors: 1) elevation and freeboard of the structure as a function of type and orientation; 2) condition and structural integrity of the structure; and 3) functionality of the structure. The relative importance of structural condition and functionality is likely dependent upon varying water-levels. For example, due to current low Lake Michigan water levels, many groins in Racine County extend out to the waters edge, but no longer

Table 6

EVALUATION OF THE POTENTIAL EFFECTIVENESS OF SHORELINE PROTECTION STRUCTURES ALONG THE RACINE COUNTY – LAKE MICHIGAN SHORELINE

Structure Condition	Freeboard Height (Feet above the maximum instantaneous Lake Michigan stillwater level and storm surge elevation)			
	Greater than 3.0 feet	Greater than 2.0 feet	Greater than 0 feet	0 to -1.0 feet
Good	Highly Effective	Effective	Moderately Effective	Marginally Effective to Ineffective
Fair	Moderately Effective		Ineffective	
Poor	Ineffective			

Note: Decision table to determine relative potential effectiveness of shore protection structures along the Racine County shoreline. Freeboard calculations are based on USCOE open-coast flood elevations for four water-level scenarios and a storm surge based on a 20 percent probability of occurrence. Freeboard height is a way to account for potential effects of wave runup.

Source: Habitat Solutions NA.

continue to trap littoral sediments due to lower lake levels and the fact that most of the groins are no longer partially submerged. Moreover, due to structural damage and loss of integrity at the lakeward ends of the groins, the effective lengths of many groins have been reduced by 15 to 20 percent. However, the remaining portions of the groins are still intact and maintain a high degree of structural integrity. Even though there may be major damage at the lakeward ends of the groins, the groins are still considered to be in "good" condition as they still retain their functionality and will continue to trap and retain littoral sediments during periods of somewhat higher water levels. In fact, groin "shortening" provides unforeseen benefits in that littoral transport of sediments is no longer interrupted by many of these structures during periods of lower lake levels allowing for the creation and expansion of beaches along downdrift reaches of the Racine County shoreline.

In addition to structural integrity, how a structure functions under a range of physical and environmental conditions is also an important factor when considering effectiveness. For example, certain types of structures are designed and constructed with the specific intent of halting shoreline erosion by reflecting, redirecting, or absorbing wave energy as they impinge on the structure. Changes in nearshore water depth due to lakebed downcutting and/or the deposition of sand can significantly alter the function and effectiveness of these types of structures. Other types of structures are designed to create wide beaches by trapping and retaining littoral sediment. However, if the littoral sediment supply is disrupted, these types of structures will be ineffective at halting erosion even though they may be in excellent physical condition. Thus, functionality may be related to the condition of the structure, but may also be influenced by surrounding physical and environmental conditions.

The 2005 evaluations were made during a period of relatively low water level (near the base case condition), which does not necessarily reflect the best of conditions upon which to base an assessment of how a particular structure will perform during elevated water levels and/or during a major storm event. Recognizing this limitation, Table 6 was created to assist in evaluating the potential effectiveness of shore protection structures in Racine County.

This decision table incorporates the three fundamental elements of elevation and freeboard, condition and structural integrity, and functionality in a systematic way that provides some consistency in the way "effectiveness" is determined. The reader is cautioned that this decision table does not take into account local conditions that may influence the performance of an individual structure and is not meant to be applied to a single shore protection structure.

General descriptions of the five classes of potential effectiveness follow.

"Highly Effective" structures are in good to excellent condition, have adequate freeboard to account for a 20 percent probability storm surge and associated wave runup, and are highly functional. These structures will protect shoreline property for extended periods of time during periods of elevated water levels and should provide protection against erosion during the most severe storm conditions.

"Effective" structures may also be good to excellent condition, have moderate freeboard to account for a 20 percent probability storm surge and most wave runup conditions, and will generally function as designed. These structures will protect shoreline property for extended periods of time during periods of elevated water levels and should provide adequate protection against erosion during severe storm conditions.

"Moderately Effective" structures are in good to fair condition and may have adequate freeboard to account for elevated Lake Michigan water levels and a 20 percent probability storm surge, but may be overtopped by wave runup. These structures will retard or slow erosion for a reasonable period of time, but may be overtopped and will likely fail during extended periods of elevated water levels and/or severe storm conditions.

"Marginally Effective" structures may be in good condition, but do not have adequate freeboard to withstand elevated Lake Michigan water levels or a 20 percent probability storm surge. These structures may retard or slow erosion for short to intermediate periods of time, but will likely be overtopped and fail during periods of elevated water levels and/or severe storm conditions.

"Ineffective" structures are generally in poor condition, and do not have adequate freeboard to withstand elevated Lake Michigan water levels or a 20 percent probability storm surge. These structures may retard or slow erosion for a short period of time, but will be overtopped and fail during periods of elevated water levels and/or severe storm conditions.

Open-coast instantaneous water levels have been calculated for the 100-year, 50-year, 10-year, and low water datum (base case) scenarios. For each of these scenarios, the amount of freeboard has been calculated based on the measured elevations for each of the shore protection structures in Racine County and incorporated into the shore structure GIS and database. This will allow users of the database to evaluate the relative potential effectiveness of groups of structures along a selected reach of shoreline.

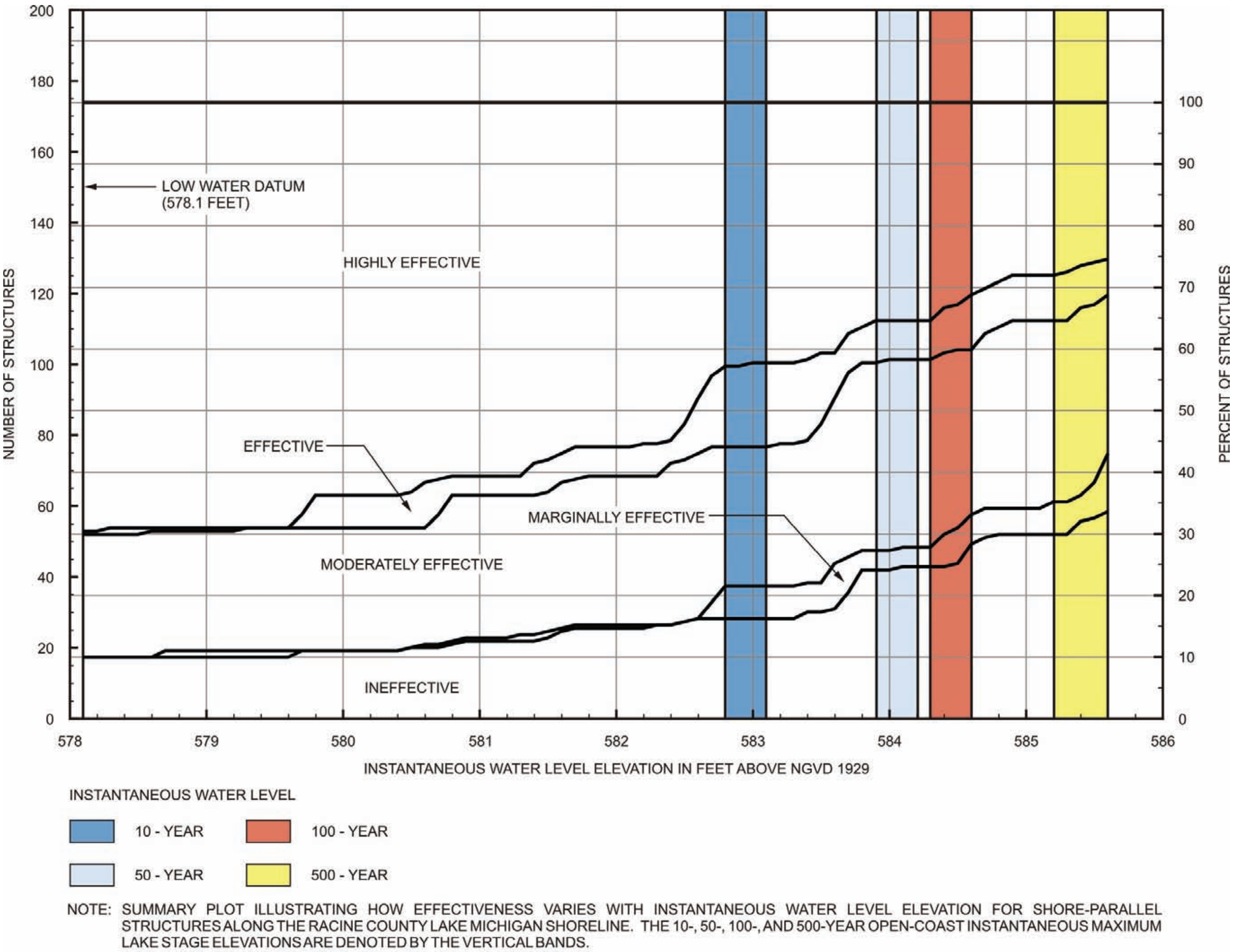
To more completely evaluate the potential effectiveness of erosion protection along Racine County, a FORTRAN program was written to calculate the number of shore protection structures that fall within the five major effectiveness classes based on the decision table described above. The program was designed to generate a table of values across a range of open-coast instantaneous water-level elevations. For the purpose of this study, open-coast instantaneous Lake Michigan water-level elevations were calculated from Low Water Datum 578.1 feet (NGVD29) to the 500-year instantaneous water level 585.6 feet (NGVD29) as published by the USCOE (1988). Calculations were performed at a 0.1 foot interval. The results of these calculations are plotted in Figures 1 and 2 for both shore parallel and shore normal structures.

As anticipated, as instantaneous water level elevations increase, the potential effectiveness of shore protection decreases. However, based on these analyses, more than half of the shore-parallel structures along the Racine County shoreline still retain some effectiveness even at the 500-year instantaneous maximum lake level. At current water levels, more than two-thirds of the shore-parallel structures could be considered to be effective or highly effective at preventing erosion. It would also appear as though many of the Racine County structures were originally designed for the equivalent of a 10- to 50-year lake level. A possible explanation is the fact the 1977 open-coast flood levels were recalculated in 1988 by the USCOE with a resulting 0.8 to 1.0 foot increase in the 100-year flood elevation for Lake Michigan (USCOE 1988). Also, many of the Racine County structures predate the 1977 and 1988 USCOE reports and may reflect historic water levels at the time they were constructed.

Similarly, as instantaneous water level elevations increase, the potential effectiveness of shore protection decreases for shore-normal structures as well. However, based on these analyses, very few shore-normal

Figure 1

POTENTIAL EFFECTIVENESS vs. INSTANTANEOUS WATER LEVEL FOR SHORELINE PARALLEL STRUCTURES



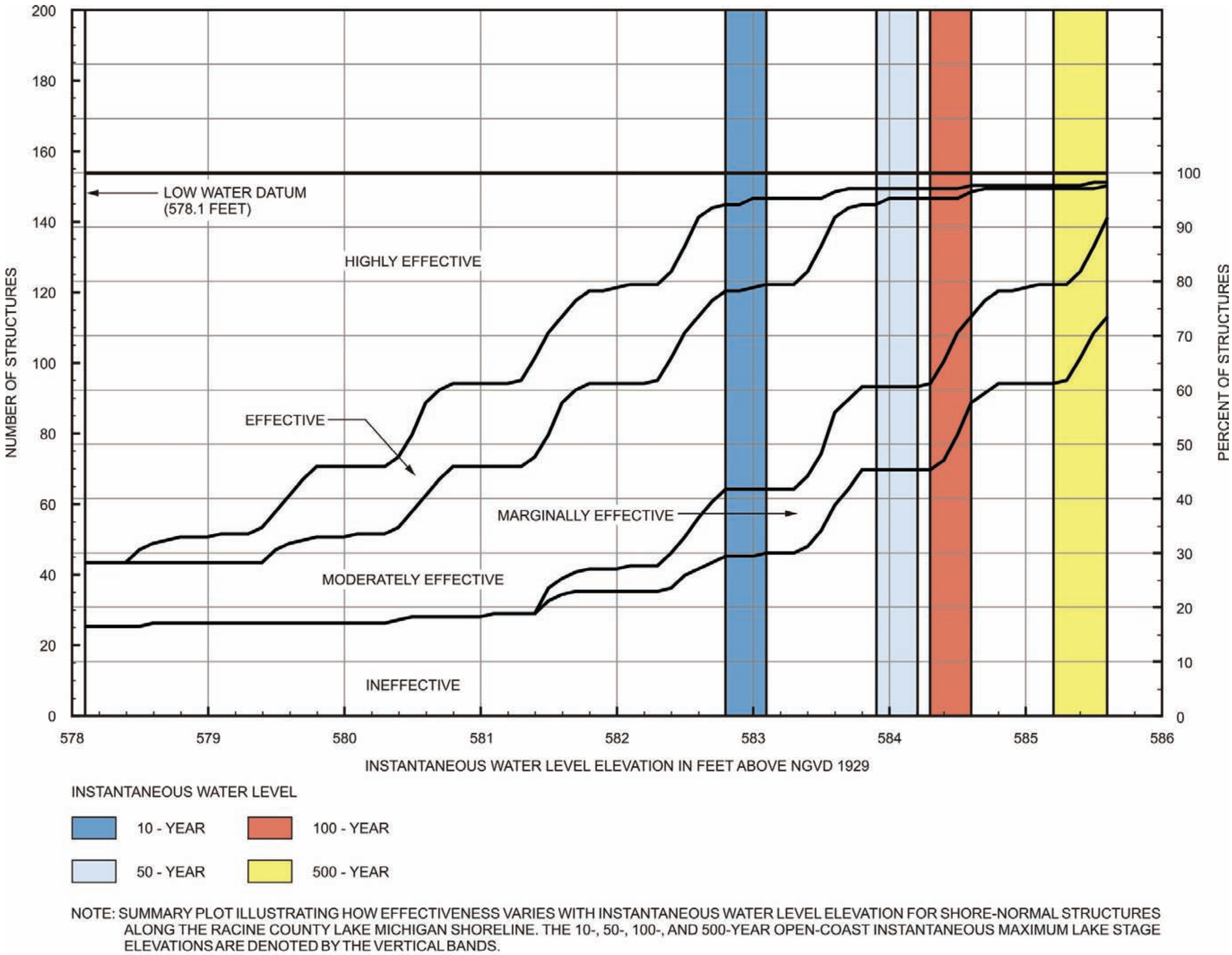
Source: Habitat Solutions NA.

structures retain their effectiveness at the 500-year open-coast instantaneous maximum lake level, and in fact, few structures retain their effectiveness at the 100- or 50-year open-coast lake levels. As has been described previously, shore-normal structures (e.g., groins) are designed to trap and retain littoral sediments in order to build wide beaches that absorb wave energy and protect the lower bluff and adjacent upland areas from Lake-related erosion. It is not surprising that the elevations of these structures are generally less than for shore-parallel structures which are designed to directly absorb or deflect wave energy away from the shoreline. It would also appear as though many of the Racine County's shore-normal structures were originally designed for the equivalent of a 10- to 50-year lake level. The same explanation as for shore parallel structures applies. Also, given that groins are not as "well-accepted" as they once were, it is likely that many of these shore-normal structures predate the 1977 and 1988 USCOE reports and may reflect historic water levels at the time they were constructed.

More importantly, the ability of groins and other shore-normal shore protection systems to halt erosion is directly related to available sediment supply, the texture and grain size of available sediments, and littoral sediment transport rates. Factors affecting available sediment supply include: 1) shoreline armoring and the emplacement

Figure 2

POTENTIAL EFFECTIVENESS vs. INSTANTANEOUS WATER LEVEL FOR SHORELINE NORMAL STRUCTURES



Source: Habitat Solutions NA.

of shore protection, 2) trapping and/or removal of sediment from the littoral system, 3) diversion of sediment by large structures (or features) into deeper offshore waters, and 4) lakebed downcutting where cohesive lakebed clays are eroded thereby increasing nearshore water depths, wave energy, and significantly increasing the volume of littoral sediment necessary to maintain beaches and nearshore sand cover in the littoral zone.

Nearshore Coastal Processes and Sediment Distribution

Sediment flux from the bluff is dynamic; delivery of sediment is highly variable and varies seasonally, annually, and with long-term changes in climate and water level. An analysis of the relationship between recession rates and water level changes demonstrates that there is a strong correlation between water level and recession rate for low-bluff shorelines (Brown 2000, Brown *et al*. 2005). Lower water levels generally mean lower recession rates for shorelines with low-relief bluffs. For shorelines with high bluffs, there are often long time lags between removal of material at the toe of the bluff and an erosion event at the top. The sediment flux from high bluffs is episodic, and related to wave impact height and the number and frequency of large bluff failure events along a reach of coastline. For high-bluff shorelines, recession rates are not directly influenced by shorter-term changes in water level (Mickelson and Edil 1998).

Sediment volumes contributed to the nearshore for a given reach of coastline can be calculated by combining changes in water level and historic recession rates. Since the stratigraphy and grain size distribution of bluff sediments are known, recession rate (either historical or predicted) can be translated into sediment volume delivered to the beach under certain wave impact height conditions. The proportions of sand and gravel measured in each stratigraphic unit were multiplied by the thickness of the stratigraphic unit (from Mickelson *et al*. 1977, Chapman *et al*. 1997a, Mackey 1995), to calculate the total volume of sand and gravel entering the beach from the bluff for a unit distance of recession. Assuming parallel bluff-face retreat and using the long-term bluff recession rates determined from aerial photographs, a determination of the average total amount of sand and gravel per linear meter of shoreline per year contributed by bluff erosion can be made. Sediment contributions due to erosion of the beach and nearshore areas can be made by assuming a constant geometry and shifting the bluff-beach-nearshore profile landward. This is, of course, constrained by the nature of the materials present on the lakebed.

There are at least three major littoral cells that operate along the Racine County coastline. The reaches identified and described earlier are, in part, based on these dominant littoral cells. Map 1 illustrates the location of the three major littoral cells in Racine County.

The actively eroding unprotected coastline between the Oak Creek Power Plant and Crestview serves as a source of sediment that feeds the Wind Point North littoral cell. The prevalence of groin fields in the southern portion of this cell along with the continued presence of substantial beaches suggests that there is an adequate supply of sediment being supplied, in part, by erosion of the coastal bluffs plus probable sediment bypass from the Oak Creek Power Plant. From a planning perspective, it would not be wise to shut off this sediment supply as doing so would adversely impact the functionality of the Wind Point North littoral cell.

The Wind Point South littoral cell begins south of Wind Point and extends to North Beach north of the Racine Harbor structure, and then south to the southern edge of Pershing Park. Wind Point rests upon a bedrock high, with extensive exposures of bedrock at the Wind Point Reef and in shallow nearshore waters both north and south of Wind Point. These materials erode at a very slow rate and do not contribute significantly to the littoral sediment supply. Abundant sand is available in the southern portion of the cell, but the northern portion of the cell is sediment starved (SEWRPC *et al.* 1995). Given the extent of shore protection, it is likely that littoral sediments are either relict (pre-existing and reworked), or are being derived from gradual lakebed downcutting in the nearshore zone. Littoral sediments have accumulated on the updrift side of the Racine Harbor structure and are transported past the outer edge of the structure in a southerly direction. It is likely that these sand deposits are gradually transported along the Pershing Park structure where they are trapped and interned in the shallow embayment behind the large attached and segmented breakwaters immediately south of Pershing Park. This area is a “sand hotel”, i.e., the sand ”checks in” but it doesn’t “check out”.

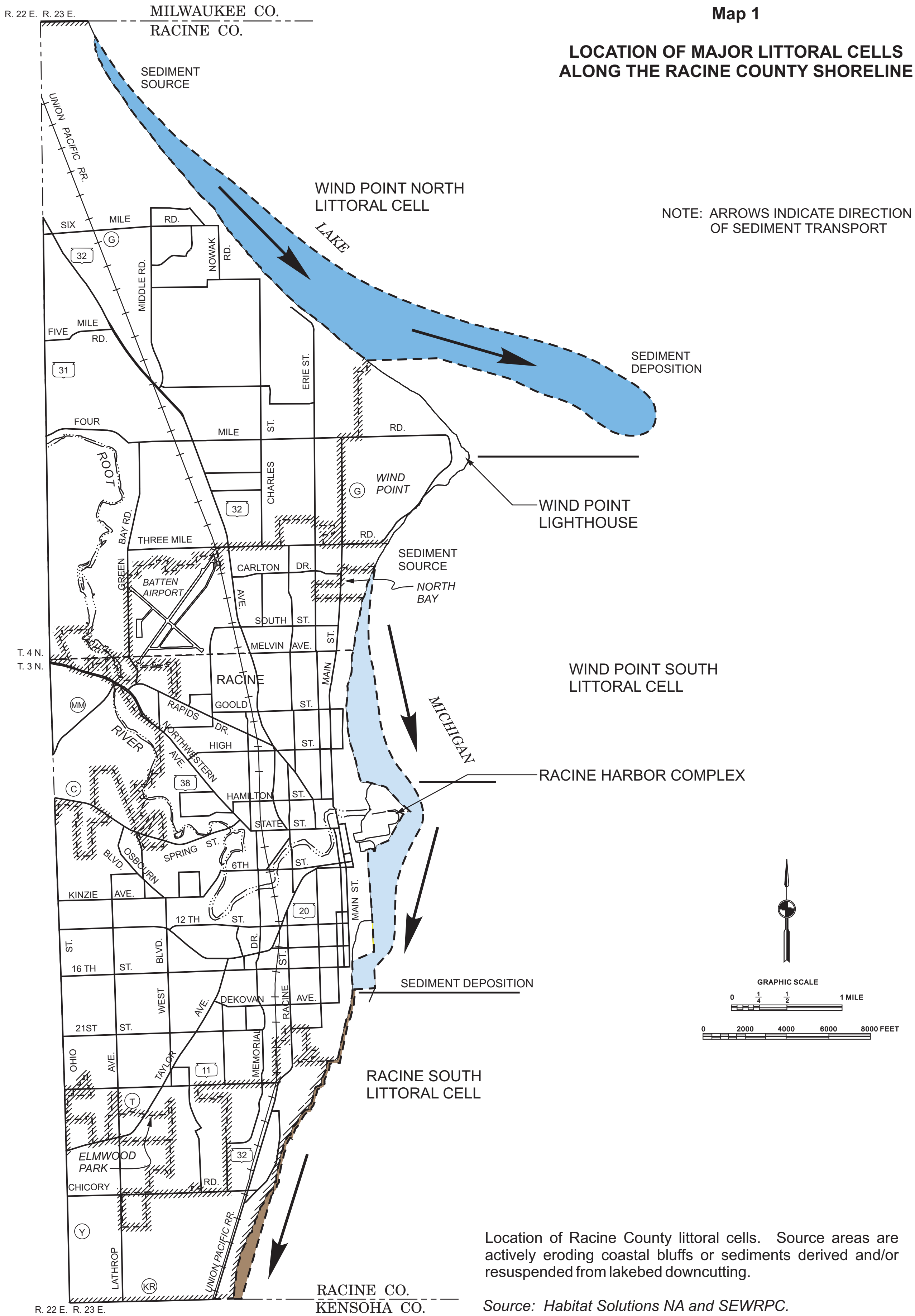
The Racine South littoral cell begins south of Pershing Park and extends southwards to the Kenosha County border. The extensive armoring and shore protection along the Racine South littoral cell has shut off the available “natural” sediment supply for that littoral cell. The narrow beaches are composed of coarse-grained materials (primarily eroded concrete debris) as there is little natural sediment remaining in the system to create sand beaches. This is not an area where groins or shore-perpendicular structures would be very effective due to a lack of available sediment supply.

Impact of Shore Protection on Nearshore and Coastal Habitats

Great Lakes coastlines have been subject to intensive coastal development (Christie *et al.* 1987, Steedman and Regier 1987, Edsall 1996, Edsall and Charlton 1997). In response to this development, Great Lakes nearshore areas have been altered to maintain commercial navigation and protect property threatened by coastal erosion. These alterations include the construction of large structures to protect harbors and adjacent commercial infrastructure, dredging of channels to maintain commercial and recreational navigation, and the placement of erosion-control structures to protect both private and public property. The net effect of these “improvements” has been to alter the natural coastal processes that create and maintain drive erosion and sediment transport, and, therefore, the nature and extent of nearshore habitats of Great Lakes shorelines.

Map 1

LOCATION OF MAJOR LITTORAL CELLS ALONG THE RACINE COUNTY SHORELINE



Location of Racine County littoral cells. Source areas are actively eroding coastal bluffs or sediments derived and/or resuspended from lakebed downcutting.

Source: Habitat Solutions NA and SEWRPC.

Table 7

IMPACTS OF SHORELINE PROTECTION ON AQUATIC HABITAT

Structure Orientation	Littoral Sediment	Substrate	Water Depth	Energy	Habitat
Shore-Normal (Updrift)	Trapping and Accumulation	Offshore Sand Diversion	Shallower	Higher-Energy	Loss/Lakeward Shift of Nearshore Habitats
Shore-Normal (Downdrift)	Starvation, Narrow Beaches, Lakebed Downcutting	Substrate Coarsening and Hardening	Deeper	Increased Wave Energy (Long-Term)	Increased Habitat Heterogeneity, Altered Nearshore Community Structure
Shore-Parallel	Reduced Littoral Sediment Supply	Possible Substrate Coarsening and Hardening	Deeper	Local Increase Reflection/ Refraction	Possible Increased Habitat Heterogeneity

Source: Habitat Solutions NA.

For example, shore protection structures, such as jetties, breakwalls, groins, revetments, and seawalls produce a measurable impact on the shoreline that extends for many times their length (e.g., Dean and Work 1993, Kraus 1988, Komar 1976, O'Brien and Johnson 1980, Shabica and Pranschke 1994, Nairn and Parson 1995, Parson et al. 1996, Nairn and Willis 2002). These structures typically reduce bluff recession, but over the long term, may lead to: 1) the reduction or elimination of beaches and barrier systems, 2) the loss of nearshore sand substrates, and an increase in lakebed down cutting, and 3) increased water depths in nearshore areas.

Shore-normal structures may impact a zone that may extend up to six to 10 times the overall length of the structure along the shoreline. These structures are designed to trap and accumulate littoral sediments updrift of the structure, thereby eliminating those sediments from the active littoral system. Water depths become shallower updrift of these structures and littoral sand may be eventually diverted offshore into deeper water. The downdrift reduction in available sediment supply results in a loss of protective sand cover, accelerates nearshore lakebed downcutting, increases nearshore water depth and incident wave energy impinging on the shoreline. Downdrift beaches become thinner and narrower, and rates of bluff-recession increase. These effects are initially local, but long-term permanent reductions in littoral sediment supplies will directly impact the entire downdrift shoreline reach.

Shore-parallel structures prevent erosion of the buff and therefore reduce the availability of coarse-grained sediments that create and maintain beaches. These structures may also locally concentrate wave energy in the nearshore zone (through reflection and/or refraction) thereby promoting the loss of sand cover and accelerating nearshore lakebed downcutting. Field data show that a loss of sand cover will typically result in thin lag deposits of coarse sand, gravel, and cobble-size material over an indurated cohesive clay or bedrock substrate (e.g., Shabica and Pranschke 1994, Nairn and Willis 2002, Meadows *et al.* 2005).

These changes alter the pattern and distribution of nearshore habitat (see Table 7). Loss of sand and gravel substrates can reduce potential spawning, nursery, and migratory fish habitats in nearshore areas (Goodyear et al. 1982). These structures also alter nearshore bathymetry and water circulation patterns, which may in turn affect water temperature, turbidity, available prey, and distributions of larval and juvenile fish. Moreover, both shore-parallel and shore-normal structures that are composed of irregular shaped blocks create artificial habitats that not only can be colonized by invasive species, but may also be used by piscivores (fish-eating fish) which may alter the nearshore fish community structure (R. Thoma – OEPA, personal communication). This may be particularly significant where these structures impinge on what was historically a nursery habitat for young-of-the-year fish.

These and other shoreline modifications directly threaten the Great Lakes ecosystem by impacting coastal marshes and wetlands, reducing Great Lakes water quality, altering habitat heterogeneity, and impacting fish spawning and nursery habitats (Regier and Hartman 1973, Steedman and Regier 1987, Leslie and Timmins 1994, Kelso et al. 1996, Brazner and Beals 1997). The destruction of barrier systems results in the loss of adjacent wetlands through direct erosion due to wave attack. Restoration or protection of these wetlands may involve armoring of the barrier system, which alters the connectivity, hydrology, and function of the wetland. The resulting loss of connectivity between coastal wetlands and nearshore areas can have serious implications for the reproductive and recruitment success of many Great Lakes fishes (Brazner et al. 2001).

Even though additional research is needed, it is likely that substantial changes in nearshore habitat substrate distributions have occurred in the vicinity of the Racine Harbor structure and the Racine South littoral cell. The redirection of sediments offshore and then into the "sand hotel" south of Pershing Park has completely eliminated any littoral sediment transport southward into the Racine South littoral cell. Moreover, the extensive hardening and loss of sediment supply in the Racine South littoral cell suggests that the adjacent nearshore habitats are now much more coarse-grained and heterogeneous than would have naturally been present along that reach of coastline. One of the impacts of these changes in substrate is the rapid colonization and spread of aquatic invasive species (such as dreissenids) that have adversely impacted food web-dynamics and the Great Lakes ecosystem. It is only now recognized that many of the physical changes that have occurred in the nearshore zones of the Great Lakes have provided the opportunity for massive expansion of these invasive species along with significant associated ecological impacts (e.g. Janssen et al. 2004, Meadows et al. 2005).

"At Risk" Shoreline Reaches

Many factors need to be considered when evaluating erosion risk. Reports by Chapman et al. (1997), SEWRPC et al. (1997), Brown et al. (2005), and Keillor (1998) provide a more in depth summary and description of these factors as they apply to the Wisconsin Lake Michigan shoreline. For this inventory, unprotected areas were delineated using the shore structure inventory data and the year 2000 digital orthophotography provided by SEWRPC.

Twenty-eight separate unprotected zones were identified, eight of which are actively eroding even at the relatively low current Lake Michigan water levels. Actively eroding unprotected areas can be considered to be high-risk erosion areas especially given current low Lake Michigan water levels. It is likely that significant erosion will occur at these sites if the frequency and severity of storms and/or Lake Michigan water levels increase.

Map 2 shows the location and extent of these actively eroding areas as of the summer of 2005. Even though erosion is generally thought to be a negative environmental factor, erosion is a natural coastal process that provides the coarse-grained littoral sediments (sands and gravels) that create and maintain beaches, which are a natural form of shore protection. The actively eroding unprotected sites between the Oak Creek Power Plant and Crestview Park within the Wind Point North reach are the primary source of sediment for beaches within the southern portion of the reach. Unless there is a compelling reason (loss of infrastructure), it is recommended that erosion be allowed to continue along this reach to serve as a long-term natural sediment supply to maintain beaches along the southern portion of the Wind Point North reach.

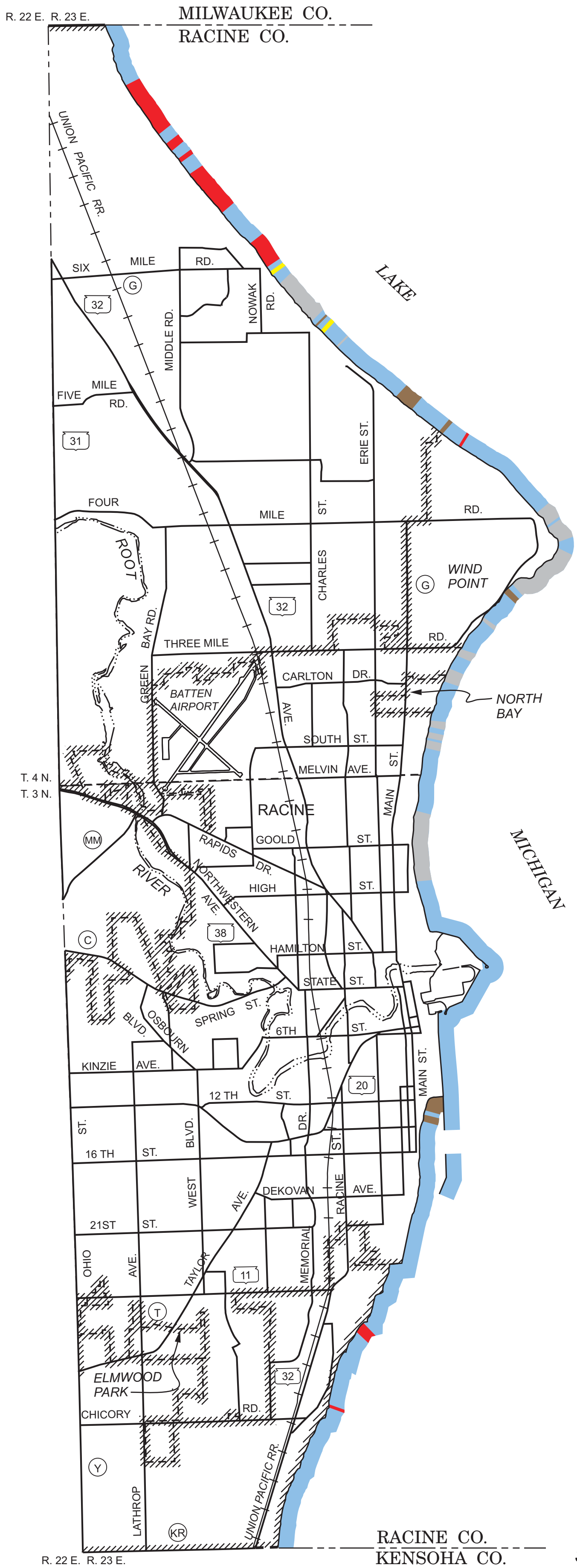
A summary of the lineal length and percentage of unprotected coastline that is actively eroding is given in Table 8. Based on summer of 2005 field evidence, approximately 1.4 miles or 9.5 percent of the Racine County coastline was undergoing active erosion. This percentage could increase significantly with an increase in storm severity and/or an increase in Lake Michigan water levels. It is likely that erosion would occur along additional unprotected reaches of coastline and in areas where shore protection is inadequate and/or in poor condition.

Conclusions

Racine County is a highly developed and urbanized County in southeastern Wisconsin. In many respects, Racine County mimics the western Lake Michigan shoreline along Wisconsin. The northern portion of the county is

Map 2

LAKE MICHIGAN SHORELINE EROSION PROTECTION IN RACINE COUNTY: 2005

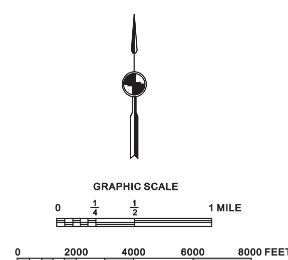


PROTECTED SHORELINE

- PROTECTED

UNPROTECTED SHORELINE

- ACTIVE EROSION
- MODERATE EROSION
- MINOR EROSION
- INACTIVE



Unprotected areas of Racine County. Areas of active erosion are considered to be high-risk areas given current low Lake Michigan water levels. Increase in storm severity and/or Lake Michigan water levels will likely reactivate erosion in unprotected areas.

Source: Habitat Solutions NA and SEWRPC.

Table 8

UNPROTECTED RACINE COUNTY COASTLINE

Erosion Status	Lineal length (feet)	Lineal length (miles)	Percent
Active	7,055	1.34	33.5
Moderate	350	0.07	1.6
Minor	2,575	0.50	12.3
Inactive	11,065	2.10	52.6
Total	21,045	4.00	100.0

Source: Habitat Solutions NA.

relatively undeveloped and unaltered. Natural processes are still being allowed to occur as active bluff erosion contributes sediments to the Wind Point North littoral cell and these sediments are transported southward towards Wind Point. Multiple groin fields have been emplaced along the southern reaches of the Wind Point littoral cell to take advantage of these littoral sediments moving through the system. Lower lake levels have minimized the impact of these groin fields on littoral sediment transport. In fact, it could be argued that the broad beaches that remain on the north shore of Racine County are due, in part, to the presence of littoral sediments trapped and retained by these groin fields. Even though local impacts of these structures may be significant, lakeward length limitations and adequate sediment supplies retain much of the natural character and coastal processes along this reach of coastline.

Extensive shoreline armoring south of Wind Point and the large Racine Harbor structures have severely impacted the littoral sediment supply and the pathways along which those sediments are transported. The Racine South littoral cell has been severely impacted by extensive shoreline armoring. Beaches have disappeared and coarse concrete rubble extends for many miles along this reach of shoreline. The nearshore zone is much coarser-grained and heterogeneous which has facilitated the establishment and spread of aquatic invasive species.

In terms of erosion protection, shore-normal groins appear to be the most prevalent structure along the Racine County shoreline. Shore parallel revetments are common as well. The dominant materials used for construction are large blocks of dolomite, limestone, granite, and metamorphic rock. Poured concrete structures and “ad hoc” concrete rubble structures are also common. In general, the condition of these structures is good to fair, and, with the advent of lower lake levels, the relative effectiveness of these structures is high. As Lake Michigan water levels increase, the effectiveness of these structures will diminish. Examination of these structures in the field suggests that many structures will require maintenance within three to five years from 2005, especially if lake levels start to rise. Unfortunately, lower lake levels reduce the threat of erosion, and property owners become less concerned about maintaining their investment in shore-protection.

An extensive GIS database has been created along with supporting documentation and materials. This database, along with the field data sheets and high-resolution digital photography will be an invaluable asset to the Southeastern Wisconsin Regional Planning Commission and the Wisconsin Department of Natural Resources. The data have been collected and organized in such a way that multiple queries can be made of the database to address current questions and those that will be asked in the future as well. It is recommended that similar protocols be used to collect and inventory shore structure data in other Wisconsin Lake Michigan Counties with the ultimate goal of creating a Statewide shore-structure GIS database for both the Lake Michigan and Lake Superior shorelines.

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APPENDICES

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Appendix A

GLOSSARY

Bluff Crest – Where the top of the bluff face intersects the natural topographic surface of the land.

Bluff Toe – Typically where the base of the bluff face intersects the water surface or beach face.

Erosion — The gradual wearing away or removal of land or sediment by wind, water, wave attack, and/or mass wasting processes.

Freeboard —Elevation, usually expressed in feet above a flood level, that provides a safety factor that compensates for factors that could contribute to flood heights greater than the heights estimated for a selected size flood.

Flood elevation — Height of the water surface above an established elevation datum such as the National Geodetic Vertical Datum, North American Vertical Datum, International Great Lakes Datum, or mean sea level.

Stillwater elevation — Projected elevation that flood waters would assume in the absence of waves, typically referenced to the National Geodetic Vertical Datum, North American Vertical Datum, International Great Lakes Datum, or mean sea level.

Storm surge — Rise in the water surface above normal water level on the open coast due to the action of wind stress and atmospheric pressure on the water surface.

Wave runup — Rush of water up a slope or structure due to wave action, typically measured in feet landward from the intersection of the beach face or berm with the base of the structure.

Littoral drift — Movement of sediment (predominately sand) by littoral or longshore currents in a direction parallel to the shore.

Structures

Revetment - A sloped structure of stone or concrete designed to protect a bluff or bank from erosion and wave attack. Usually oriented parallel to shore.

Rubble – Concrete or rock debris of varying sizes placed or dumped along the shore to provide protection. Broken concrete debris or slabs are dumped over the bluff edge as a form of expendable shore protection ("bluff dump"). Wave action may shift debris into an imbricate pattern that armors the beach face and toe of the bluff. Usually oriented parallel to shore.

Groin Solid - A shore protection structure built (usually perpendicular to the shoreline) to trap sand and retard erosion of the shore. Structure is solid and is impermeable to water and sediment. Usually oriented perpendicular to shore.

Groin Pervious – A shore protection structure built (usually perpendicular to the shoreline) to trap sand and retard erosion of the shore. Structure is porous and is permeable to water and sediment. Usually oriented perpendicular to shore.

Sea Wall/Bulkhead - A vertical structure, usually made of concrete, steel or wood beams, designed to protect a bluff or bank from erosion and wave attack. Usually oriented parallel to shore.

Retaining Wall – A vertical structure, usually made of concrete, steel, rock, or wood beams, designed to resist the lateral pressure of the material behind it and to prevent the downslope movement of material on a slope. May serve to protect bluff or bank from erosion. Usually oriented parallel to shore.

Jetty - Structure extending into a body of water designed to prevent shoaling of a navigation channel by littoral sediments. Typically built at the mouth of a river to help deepen and stabilize the channel. May also be called a breakwater. Usually oriented perpendicular to shore.

Breakwater (Breakwall) - A structure protecting a shore area, harbor, anchorage or basin from the action of waves, generally attached to the shore. May also be called a Jetty. May be oriented either parallel or perpendicular to shore.

Offshore Breakwater - A structure protecting shore area, harbor, anchorage or basin from the action of waves, but is not attached to the shore. May be oriented either parallel or perpendicular to shore.

Pier - A pier may be constructed as part of a breakwater, groin, or other structure used to protect a harbor or shore, or may be an elevated structure on pilings designed to provide access to the water and/or a landing place for vessels. Usually oriented perpendicular to shore.

Dock - A dock is a wharf or pier, generally shorter than a pier and typically located in protected waters (i.e., behind a jetty or breakwater). May be oriented either parallel or perpendicular to shore.

Boat Ramp - A gently sloping hard surface used for launching boats from trailers. Usually oriented perpendicular to shore.

Intake Structure – A structure or pipe extending into a body of water designed to collect and transport water inland for anthropogenic uses. Usually oriented perpendicular to shore.

Outfall Structure – A structure or pipe designed to release or discharge water (or other fluids) into a body of water. May include small stream mouths or channels. Usually oriented perpendicular to shore.

Stream Mouth – A natural or man made channel where water flows into a body of water, typically the confluence of a stream or river with the lake. Usually oriented perpendicular to shore.

Dike - A wall or mound built around a low-lying area to prevent flooding. May be oriented either parallel or perpendicular to shore.

Composition

Dolomite/Limestone Block - Cut or blasted blocks of dolomite and/or limestone, typically rectangular or angular in shape and individually placed.

Sandstone Block – Cut or blasted blocks of sandstone, typically rectangular or angular in shape and individually placed.

Granite/Metamorphic Block – Cut or blasted blocks of granite or metamorphic rock, typically rectangular or angular in shape and individually placed.

Concrete Block - Large poured concrete blocks that are placed in a regular pattern. May be notched, pinned, or cabled together.

Concrete Slabs - Cut slabs of concrete, roadway or sidewalk sections, typically associated with concrete rubble. May be placed or dumped to provide shore protection.

Concrete Rubble - Construction rubble and broken concrete debris placed or dumped, to provide shore protection.

Concrete (Poured) - Concrete poured into a form on site to control its shape.

Concrete Module - A module is a concrete structural component, a number of which when joined together create an integrated structure.

Campbell Modules - A specific type of stepped pre-cast concrete module for shore protection.

Concrete Cone and Wedge – Two-pieced form of interlocking pre-cast concrete modules for shore protection.

Concrete Bags or Tubes - Bags and/or tubes filled with poured concrete.

Concrete Rings - Large diameter concrete pipe sections.

Concrete Slabs - Cut slabs of concrete; typically roadway sections or sidewalks.

Concrete Cubes - Cube shape form-poured concrete modules.

Module Other - Single unit construction module that does not fit the specific types listed.

Steel Sheet Piling - Long, heavy sections of metal driven or jetted into the earth or seabed to serve as a support or protection.

Steel Plate - Flat sheets of steel positioned to provide protection.

Steel Crib - A bin-type retaining wall consisting of interlocking steel used to stabilize slopes.

Gabions - Specially designed containers, cylinders, or boxes of corrosion-resistant wire used to hold coarse rock or concrete aggregate that may be used to form a groin, seawall, or bulkhead.

Timber Crib - A bin-type retaining wall consisting of interlocking wood used to stabilize slopes.

Timber Pilings - Long, heavy sections of wood driven or jetted into the earth or seabed to serve as support or protection.

Earthen Fill - Soil, sand, gravel, or rock typically placed behind an engineered structure and/or placed along the shore as an expendable form of shore protection.

Attributes

Segmented - An attribute of the structure where the structure has significant changes in composition, condition, or dimension but is not inventoried as a separate structure.

Uniform - An attribute of the structure where the structure is relatively consistent in composition, dimension and condition.

Tapered - An attribute of the structure where the shape of the structure is considerably wider at one end than the other.

T or L shaped - An attribute of the structure where a structure has the shape of a letter "T" or "L".

Slush Cap - Concrete that has been poured onto small objects to collectively act as a bigger object.

Splash Apron - The hard material placed above the main structure and out of direct wave attack to reduce erosion above the structure due to water splashing on the native material.

Toe Protection - Material that has been placed adjacent to, but lakeward, of the structure to protect the base of the structure from direct wave attack. These materials may be partially or completely submerged.

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Appendix B

Field Data Sheet

Wisconsin Shore Structure Inventory Data Sheet

Structure Information: Structure ID ____________ Sketch of Structure (Optional)

County:____________ Collected by:____________

Time:_____:_____ ☐AM / ☐PM Date:_____/_____/________

1/4 Section ______ Section______ Township________ Range________

Primary Structure Type:
☐Revetment ☐Rubble ☐Groin ☐Seawall/Bulkhead ☐Jetty
☐Retaining Wall ☐Attached Breakwater ☐Offshore Breakwater
☐Dike ☐Retaining Wall ☐ Outfall Structure ☐ Stream Mouth
☐Pier ☐Dock ☐Boat Ramp ☐Other:____________

Composition:
☐Stone Block: (☐ Dolo/Limestone ☐Granite/Metamorphic ☐Sandstone)
☐Concrete: (☐ Poured ☐Slabs ☐Blocks ☐Rubble)
☐Steel Sheet Piling ☐Steel Plate ☐Steel Piling ☐Steel Crib
☐Timber Crib ☐Timber Pilings ☐Earthen Fill ☐Gabions
☐Concrete Cubes Concrete Modules: (☐Campbell ☐Cone & Wedge ☐Bags and Tubes ☐Rings ☐Slabs) ☐Other:____________

Attributes:
☐Segmented ☐Uniform ☐"L" or ☐"T" Shaped ☐Slush Cap ☐Splash Apron ☐Toe Protection: (☐Conc Rubble ☐Rock Rubble ☐Conc Slabs
☐Stone Block ☐Conc Block ☐Gabions ☐Other:____________)

Condition:
☐Excellent ☐Good ☐Fair ☐Poor: (☐Disarticulated ☐Submerged ☐Undermined ☐Ruins ☐Large Cracks ☐Flanked) ☐Other:____________

Function:
☐Excellent ☐Good ☐Fair ☐Poor ☐Other:____________

Dimensions of Structure: Primary Cross-Section Secondary Cross-Section
Length:__________ft. (shore ll)
Width: __________ft. (shore ll)
Length:__________ft. (shore _|_)
Width: __________ft. (shore _|_)
Height:__________ft. (from water to top of structure)

Notes:____________

Prepared By: Southeast Wisconsin Regional Planning Commission

Wisconsin shore structure field data sheet (modified), used to collect and record shore structure data in conjunction with Trimble Pathfinder data dictionary (Appendix C). Field data sheet allows field team to sketch pertinent details of both primary and secondary structures, and record additional data in hardcopy format for comparison and verification with digital data. Field data sheets are scanned and stored digitally along with high-resolutions digital photographs of each of the inventoried structures.

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Appendix C

TRIMBLE PATHFINDER DATA DICTIONARY FOR TSC1 ROVER

Rac_SSI - Racine County Shore Structure Inventory
Shore Structure – Polyline feature - Racine County Shore Structure
Structure ID – Structure Identification Number (e.g. RAC1, RAC2, RAC2a…)

<u>Primary Type</u> - Type of Shore Structure Revetment, default Rubble Groin Solid Groin Pervious Seawall/Bulkhead Retaining Wall Jetty Attached Breakwater Offshore Breakwater Pier Dock Boat Ramp Intake Structure Outfall Structure *Stream Mouth* Dike Type Other	**<u>Primary Comp</u> - Dominant Composition of Shore Structure** Dolo/Limestone Block, default Sandstone Block Granite/Meta Block Concrete Block Concrete Slabs Concrete Rubble Concrete Poured Mod Concrete Cubes Mod Concrete Rings Mod Concrete Tubes Mod Cone and Wedge Mod Campbell Mod Other Steel Sheet Piling *Steel Pilings* Steel Plate Steel Crib Gabions Timber Crib Timber Pilings Earthen Fill Composition Other
<u>Secondary Type</u> - Secondary Type of Shore Structure None, default Revetment Rubble Groin Solid Groin Pervious Seawall/Bulkhead Retaining Wall Jetty Attached Breakwater Offshore Breakwater Pier Dock Boat Ramp Intake Structure Outfall Structure *Stream Mouth* Dike Type Other	**<u>Secondary Comp</u> – Dominant Composition of Shore Structure** Dolo/Limestone Block, default Sandstone Block Granite/Meta Block Concrete Block Concrete Slabs Concrete Rubble Concrete Poured Mod Concrete Cubes Mod Concrete Rings Mod Concrete Tubes Mod Cone and Wedge Mod Campbell Mod Other Steel Sheet Piling *Steel Pilings* Steel Plate Steel Crib Gabions Timber Crib Timber Pilings Earthen Fill Composition Other

<u>Primary Shape</u> - Primary Structure Shape Shore ||, default Shore _|_ T Shaped L Shaped Shape Other	**<u>Secondary Shape</u> - Secondary Structure Shape** None, default Shore || Shore _|_ T Shaped L Shaped
<u>Toe Attributes</u> - Structure Shape and Features None, default Toe Concrete Rubble Toe Rock Rubble Toe Rock/Conc Block Toe Concrete Slabs Toe Poured Concrete Toe Gabions Toe Other	**<u>Drainage Attributes</u> - Structure Shape and Features** None, default Bluff Drainage Splash Apron Drain_Splash Apron Drainage Other Not Applicable
<u>Condition</u> - Structural Integrity Excellent Good, default Fair *Poor Disarticulated* Poor Submerged Poor Undermined Poor Ruins Poor Large Cracks Poor Flanked Poor Other Condition Other *Not Applicable*	***<u>Function</u> - Structure Functionality*** *Excellent* *Good, default* *Fair* *Poor* *Not Applicable*
|| <u>Length (ft)</u> - Shore Parallel Length (ft) **|| <u>Width (ft)</u> - Structure Shore Parallel Width (ft)** **|| <u>Elev (ft)</u> - Elevation above Lake Level (ft)**	**_|_ <u>Length (ft)</u> - Shore Perpendicular Length (ft)** **_|_ <u>Width (ft)</u> - Perpendicular Width (ft)** **_|_ <u>Elev (ft)</u> - Perpendicular Elevation (ft)**
<u>Outfall Diameter</u> - Pipe Diameter of Outfall Structure **<u>Field Team</u> - Last Name Field Team**	**<u>Inventory Date</u> - Field Inventory Date** **<u>Inventory Time</u> - Field Inventory Time**

Note: This data dictionary table has been modified to incorporate additional parameters that were not included in the original field survey. These parameters were added to the data dictionary in response to needs identified while in the field. To maintain data consistency, the data dictionary was <u>not</u> modified during the field survey. Additional parameters have been *italicized.*

Source: Habitat Solutions NA.

Instructions on How to Open ArcMap/ArcView Map and to View Hyperlink SSI Photos and Data Sheets

1. Note that ESRI ArcMap Software is required to access the Map Features on the CD.

2. Download or Copy the file folder "Rac_ShoreStructureInventory" to your C:\ Drive. (Note from this point on. Only use the files from the C:\ Drive and NOT the files on the CD.)

3. Open the file folder C:\Rac_ShoreStructureInventory. The contents of the folder should be; GIS folder and Pic folder.

4. Open the GIS folder. Select the ArcMap/ArcView file "Racine.mxd". This should launch the ArcMap program and open the ArcMap/ArcView Racine.mxd project. The Layers that should be open in the project are; racine_ssi.shp, racine_unprotected.shp, im2k0323.sid, and im2k0423.sid.

5. Right-click the racine_ssi layer. In the pull down menu select Properties.

6. Select the Display Tab in the Layer Properties window.

7. Under the Hyperlinks section. Check the "Support Hyperlinks using field:" (Note the word "none" should be in the box)

8. Check the "Document" circle. Then Select Apply and then OK.

9. Select the Identify Tool. With the Identify Tool click on a red line (racine_ssi Layer) on the map.

10. In the Identify Window scroll down until you see in the Field Column; FIELD_PIC1, FIELD_PIC2, AND FIELD_DAT2.

11. Click on any of the Values that have a Lighting Bolt next to it. The corresponding image will open up and appear in a new window.

12. To view the images that are Hyperlink to the Layer "racine_unprotected" Repeat steps 5-13, replacing "racine_ssi" for "racine_unprotected"

This CD is available from SEWRPC. Please contact:

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