ILLINOIS BEACH STATE PARK, LAKE COUNTY, ILLINOIS
SECTION 204 BENEFICIAL USE OF DREDGED MATERIAL

APPENDIX A – COASTAL ANALYSIS

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CHAPTER 1. INTRODUCTION

The proposed project involves the beneficial use of dredged material in support of beach nourishment along the Illinois Beach State Park shoreline, shown in Figure 1.1. The nearshore lake area consists of sand, gravel and cobble substrate overlaying a clay lens. Littoral input to the area is not sufficient to accommodate the amount of erosion currently experienced, resulting in a net loss of shoreline and a gradual decrease in the dry beach width. The goal of the project is to provide a recommendation for the most viable approach for utilizing the dredged material for beach nourishment, specifically through nearshore and beach placement.

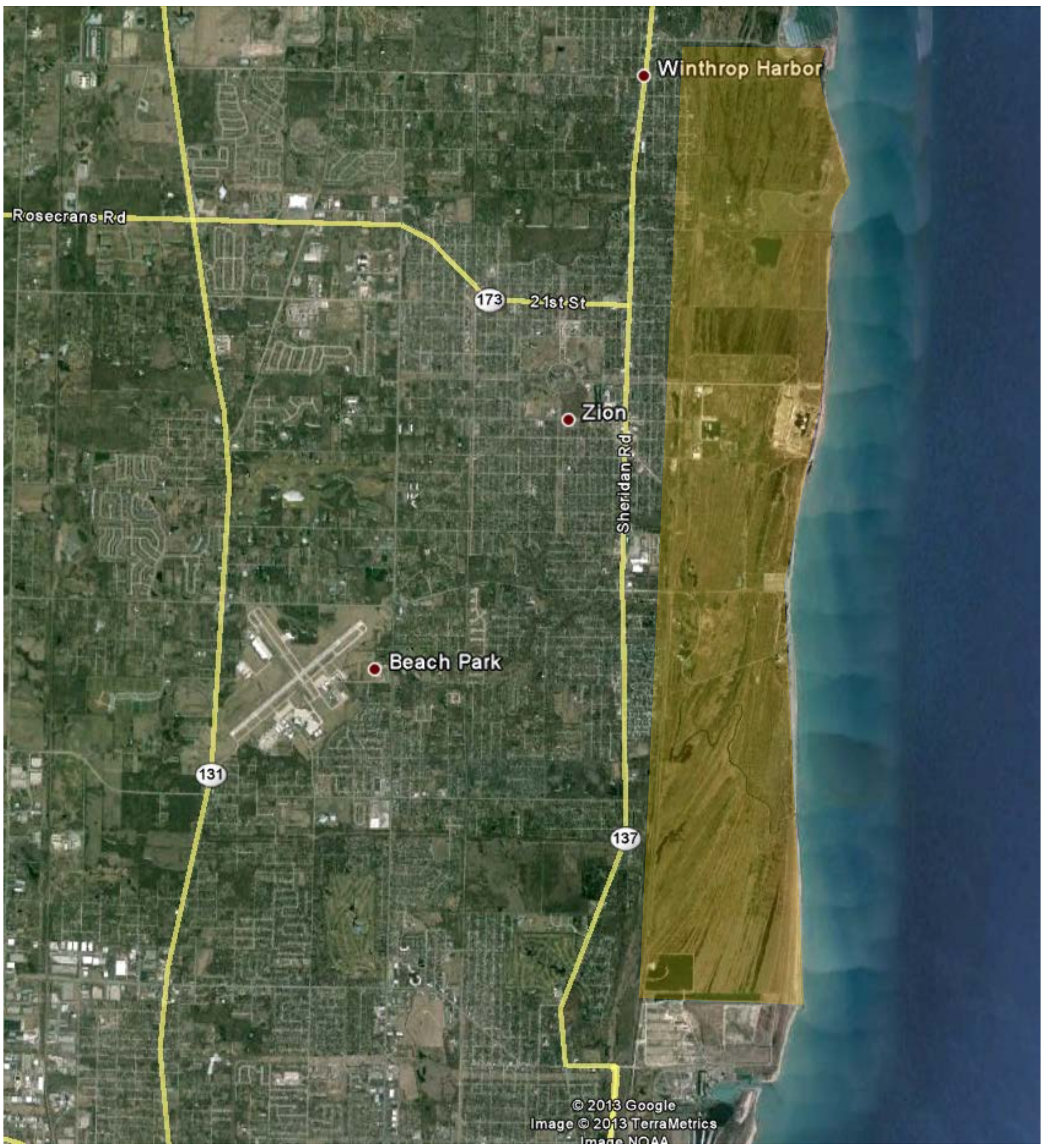

Figure 1.1 Illinois Beach State Park Project Area

CHAPTER 2. COASTAL CLIMATE

2.1. Lake Level Trends

The water level of Lake Michigan varies annually, seasonally, daily, and hourly. On an annual basis, the lake level generally varies by approximately 0.9 feet, with high water in summer and low water in winter, as shown in Figure 2.1. Seasonal and multi-year fluctuations in lake level are the result of long-term changes in the water cycle of the Great Lake system. Hourly and daily changes are the result of the wind shear acting upon the surface of the lake or differences in atmospheric pressure across the surface of the lake. Beginning in approximately 1973 and continuing to the present, an underlying lake level decline has been observed. Although it has been speculated to be correlated to a simultaneous evaporation increase, this link has not been confirmed (Sellinger et al. 2007).

A temporary rise in lake level known as setup can be caused by wind stress from onshore winds acting upon the water surface. Factors that determine the height of the setup include strength and duration of the wind, location on the shore, and fetch. The orientation of Lake Michigan and strength of the northerly winds make the southern tip of the lake most susceptible to storm setup, with the potential for setup diminishing northward along the Illinois shore. Maximum potential setup along the Indiana shoreline is 1.7 feet, reducing to 1.2 feet at Milwaukee, Wisconsin. Based on the location of Illinois Beach State Park relative to these two locations, the maximum setup along the park's shore would be expected to be approximately 1.4 feet (U.S. Army Corps of Engineers, 1978).

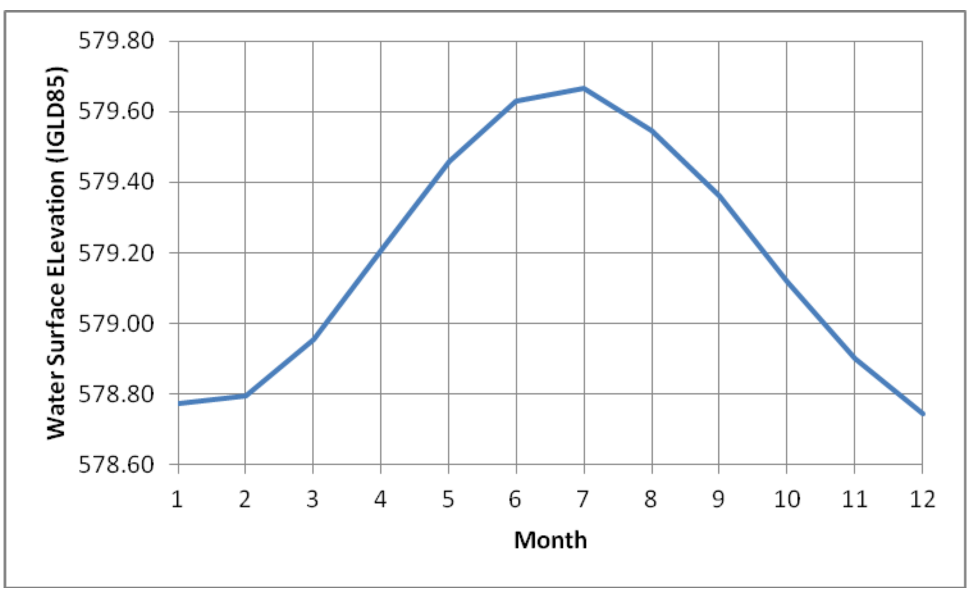

Figure 2.1 Calumet Harbor Gage Data – Period of Record Monthly Mean

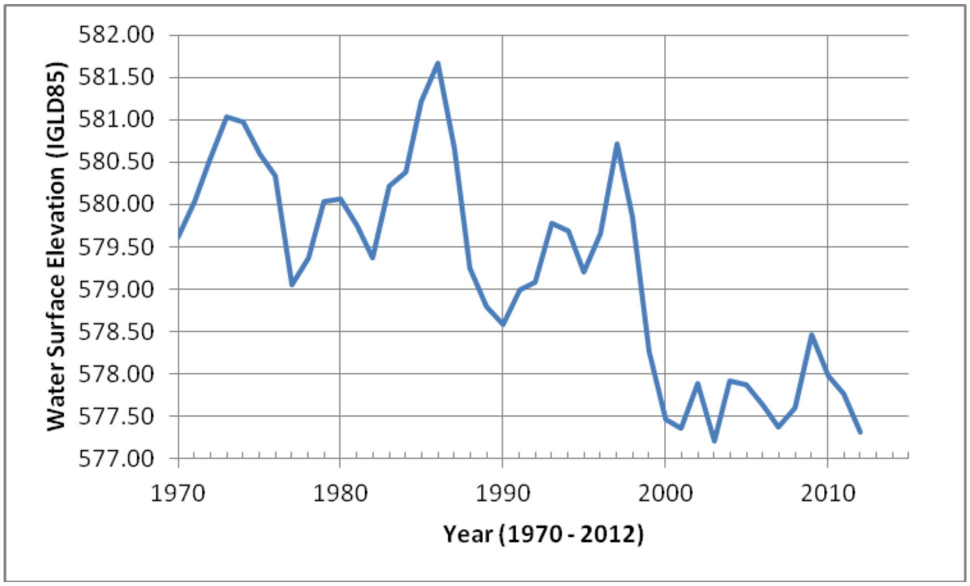

Figure 2.2 Calumet Harbor Gage Data – Annual Means for Period of Record

2.2. Local Wave Climate

There are several WIS hindcast stations located in the immediate vicinity of Illinois Beach State Park, the most proximate of which is Station 94034. The local wave climate at the park was established using wave data obtained from this location.

The Illinois Beach State Park shoreline is generally orientated due north and south. Localized variations between -15 to +7 degrees occur as the shoreline responds to several hardened locations within the park's boundaries. This typical configuration is divided into three approach angles, as illustrated in Figure 2.3, to define angle classes for the various incident waves.

The north-south orientation of the shore exposes it to waves approaching from the northeast, east, or southeast directions. Wave generation is a function of the fetch length and the wind speed, direction, and duration relative to the point in question. Because of the shape of Lake Michigan and the geographic location of Illinois Beach State Park, fetch length is greatest to the northeast.

Wave data for the shore at Illinois Beach State Park was evaluated as part of the WIS hindcast study using a 34-year record of observations along the Lake Michigan shore. Based on this analysis, the average wave along the shore has a height of 1.9 feet (0.6 m) and a period of 3.8 seconds. During storms, however, wave heights have been known to exceed 18 feet (5.5 m). Considering the occurrence of all waves approaching Illinois Beach State Park regardless of height, most waves are Class I (i.e. approach from the southeasterly direction). When considering wave height, however, Class III waves (i.e. those approaching from the northeastern direction) dominate. Class III waves account for 50% the waves that equal or exceed 3 feet in height, nearly 75% of the waves that equal or exceed 7 feet, and 90% of the waves that equal or exceed 10 feet. While most of the commonly observed winds and waves along the shore approach from a Class I angle, the long northerly fetch allows for waves from a Class III angle that generally have a significantly greater wave height. These waves will also have the greatest energy and will therefore have the greatest net effects on the shoreline (IDNR 2000).

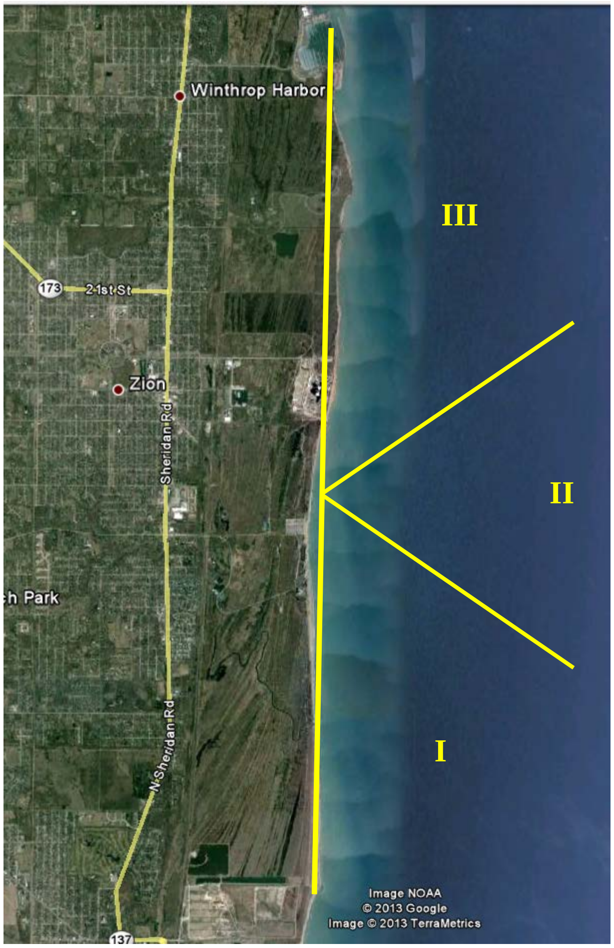

Figure 2.3 Definition of Site Wave Angle Classes

During the summer, the prevailing winds are towards the northeast. During the winter, however, the winds reverse and typically blow towards the south, generating the larger wave events. Since these storms also tend to move towards the east, their effects upon the lake surface are typically short-lived. It is during these brief periods of intense wave action that that most significant shoreline erosion is experienced (Booth 1994).

2.3. <u>Sediment Characteristics</u>

A detailed analysis of the characteristics of the nearshore sediment distribution was not conducted in conjunction with this project, but sufficient geologic studies have previously been completed to establish a general description of the area.

The existing foreshore is comprised of well-sorted medium sands in the dunes and localized deposits of concentrated coarse sand, pebbles, and cobbles along the beach. These sediments, generally overlaying glacial till, accumulated offshore in depths as great as 20 feet or more. These are overlain by medium to coarse sand and gravel that accumulated in the nearshore and eventually across the foreshore (Chrzastowski 2000).

The nearshore is defined as the zone between the shoreline and some distance offshore, typically taken as the depth of closure. An issue paper published by IDNR in 2009 indicates a depth of closure of approximately 18 feet was adopted for the Illinois coast, although the basis for this assumption was not specified. Chrzastowski and Trask, however, specify a regional closure depth of 20 feet in their 1995 paper. For the purposes of this study, a conservative assumption will be made that the closure depth occurs at an approximate depth of 18 feet. A typical cross-shore profile is shown in Figure 2.4.

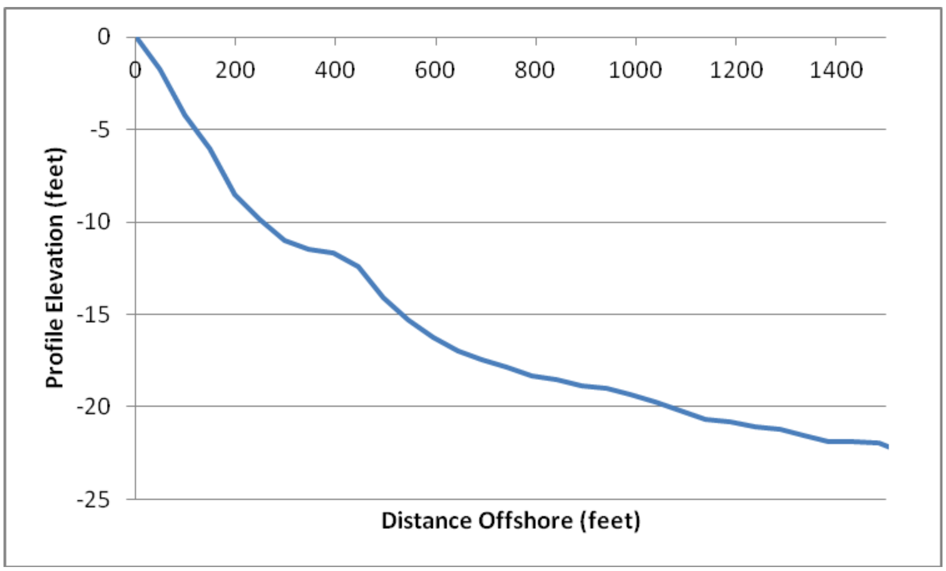

Figure 2.4 Typical Illinois Beach State Park Nearshore Profile

Substrate collected during the previous dredging cycle was described as poorly graded gravelly sand with little to no fines. Grain size analyses of several samples indicated a median grain size ranging from 0.10 to 0.13 mm. This size is consistent with the mean grain size within the nearshore area, typically 0.10 to 0.15 mm (Graf 1976).

CHAPTER 3. LITTORAL PROCESSES

3.1. Summary of Processes

Naturally wide beaches may have once existed along portions of the pre-settlement shores of northern Illinois, but historic photographs document well-developed groin fields on the Illinois lakeshore as early as 1897. Since that time, the construction of coastal structures and shoreline armoring over the last century have impounded a significant amount of the littoral supply and cut off a primary source of sand to the system. As more coastal structures are introduced, lakebed erosion and ravine input will remain the sole sources of new sand into the system (Shabica et. al 1994).

The North Point Marina was constructed between 1987 and 1988 and involved the excavation and dredging for the 72-acre marina basin. This structure represents the northern barrier to Illinois Beach State Park's littoral cell. The sediment crossing the state line, estimated to be about 10,000 cubic yards per year, supplies sediment to a beach that runs from the state line to the marina's north breakwater, and also provides a sediment source to bypass the north breakwater and shoal within the marina's entrance. Of this volume, on average about 8,000 cubic yards per year is trapped in the channel at Prairie Harbor Yacht Club to the immediate north of North Point Marina. The shore south of the marina is now the primary sediment source for the remainder of the park to the south due to reduced sediment passing the state line and is currently experiencing severe erosion. Recent studies of the sediment budget in this area by the Illinois State Geological Survey indicate that an average annual volume of 80,000 cubic yards would be necessary to have a balanced budget and no net loss of beach width (IDNR 2001).

3.2. Shoreline Erosion

Shoreline erosion along the Illinois coast occurs at all lake levels. Setup can contribute to accelerated erosion by allowing waves to reach further into the foreshore. In the case of Illinois Beach State Park, this could potentially result in the breaching of the dunes, causing the degradation and potential loss of unique habitat in the backshore. Although high lake levels, whether due to the hydrologic cycle of the lakes or temporary rises due to setup, are times when erosion is perceived as most problematic, these processes continue during times of low lake levels. The erosion simply shifts lakeward and impacts the nearshore lake bottom. Nearshore bars that formed during higher lake levels become subjected to these erosive forces, potentially drawing them further lakeward and out of the active cross-shore profile should lake levels rise (IDNR 2011).

The most severe long-term recession along the Illinois coast is documented within the project area averaging 10 feet per year (Jennings 1990). This erosion relates to the long-term southward migration of the aforementioned landform; erosion of the north unit provides the littoral supply for the nourishment of the south unit. This southward moving sediment supply contributes to a more balanced sediment budget toward the south, resulting in diminishing rates of shore erosion progressing southward from the null point, shown in Figure 3.1. Should the erosion of the north unit be halted (through the introduction of shoreline armoring, for example), the South Unit would become starved and begin to recede at rates as extreme as those observed along the North Unit. There is nothing inherent in the geology of the South Unit that contributes to the diminished erosion rates other than the littoral sediment supply from the north (IDNR 2009).

3.3. Lakebed Erosion

Much of the beach along Illinois Beach State Park is of a gradual slope, making it susceptible to large changes in beach width as the result of comparatively small variations in lake level. Higher lake levels will drown the backshore; lower lake levels will expose the lower beach and possibly the shallow nearshore. The process of lakebed erosion refers to the erosion of the cohesive clay layers that comprise the nearshore lakebed. These layers are typically overlain by sand that extend from the beach into the nearshore. Once erosion has exhausted this sand layer, these processes will begin to directly erode the clay underlayer. Alternatively, the wave action can induce an oscillatory motion of a thin layer of sand across the surface of the clay lakebed, thereby causing erosion through abrasion. The effects of lakebed erosion are irreversible, although the original cross-shore profile can be temporarily restored with a sufficient quantity of substrate.

When lake levels rise, the eroded profile creates deeper water in the nearshore which permits greater amounts of wave energy to reach closer to shore. This in turn accelerates the erosion of beaches and any adjacent bluff or dune areas. When lake levels rise, deeper water in the nearshore allows greater wave energy closer to shore, accelerating the erosion of beaches and any adjacent bluff or dune areas (IDNR 2009).

Multi-decade comparisons of beach and nearshore profiles and measurement of sand thickness along the state park have documented a long-term trend of sand loss resulting in the beach and nearshore consisting of a thinner and narrower lens of sand (Shabica and Pranschke 1994). Field data in other Great Lakes states has shown that a loss of sand cover will typically result in a thin lag deposit of coarse sand, gravel, and cobble-size material over an indurated cohesive clay or bedrock substrate (Nairn et al. 1997).

3.4. Winter Lakebed Erosion and Ice Rafting

A seasonal factor of coastal erosion that long was underestimated is ice. It was long assumed that the nearshore ice complex protected the shore from direct wave impact during winter storms. Recent studies, however, have found that a portion of the wave energy impacting the ice sheet can be directed downward, causing erosion.

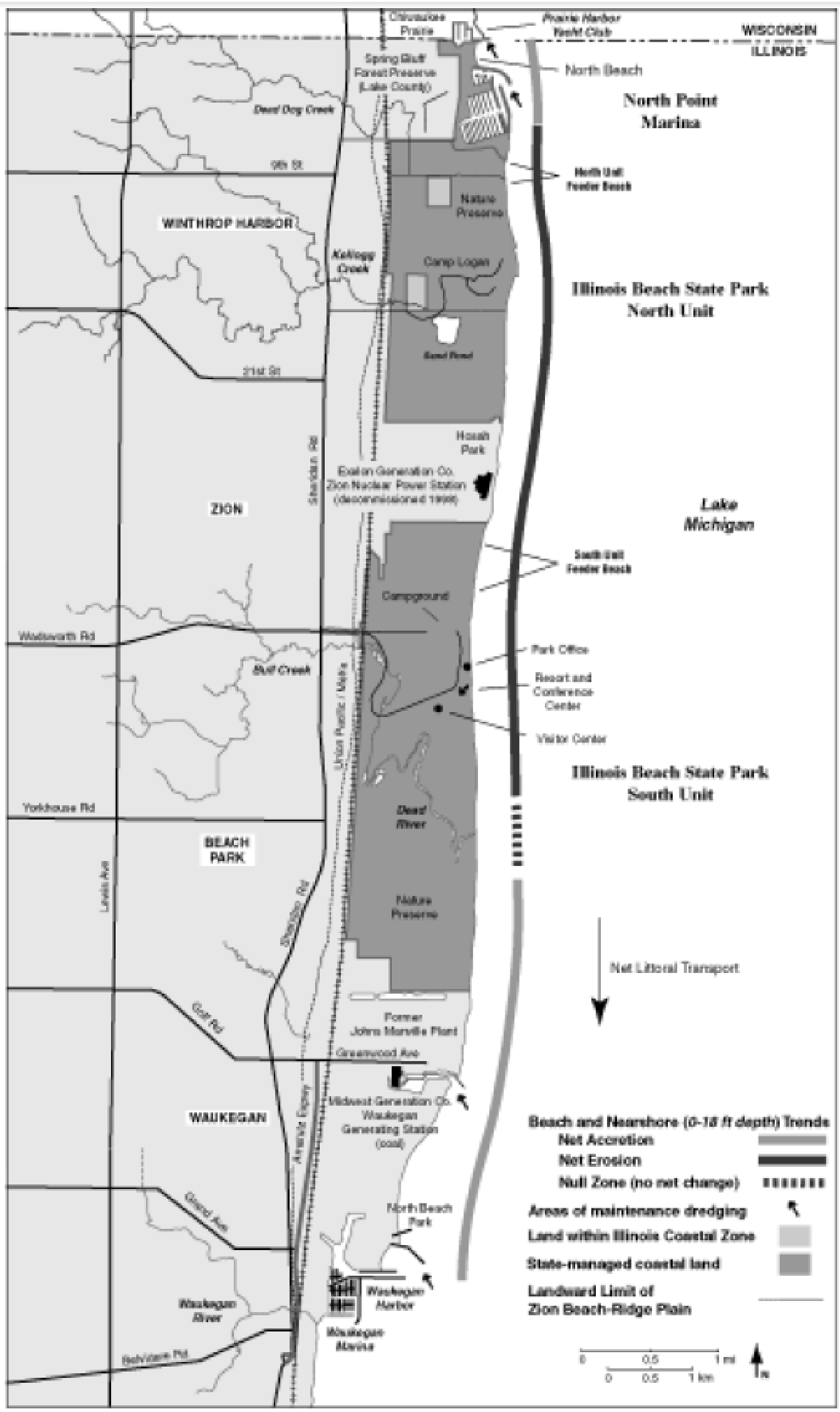

Figure 3.1 Erosion/Accretion Trends along Illinois Beach State Park

Favorable conditions for ice development along the shore at Illinois Beach State park occur from December into March, but the history of ice formation varies from year to year. Some winters may have only minimal ice while others have extensive ice development that can extend tens of feet offshore. The formation process begins on the beach, which freezes and forms the “ice foot”. Waves break against the ice foot, the splash of which can freeze and build up into an ice ridge. The ice complex grows lakeward as a sequence of shore-parallel ice ridges that form one after the next, separated by a short distance of shore-parallel, low-relief ice called an “ice lagoon”. Waves intercepting the lakeward ridge behave like waves impacting a seawall or breakwater – some of the wave energy is directed downward and causes lakebed erosion. Profile data and diver observations have documented that on the Illinois coast an erosional trough as deep as 1.6 feet and as wide as 6.5 to 9.8 feet develops lakeward of the ice. Some of the sediment is transported parallel to shore, but some is caught in the overwash and incorporated into the ice ridge. As a result, sand-impregnated ice, or “dirty ice”, is common along the ice ridges. Most winters have multiple events of ice formation, breakup, and redevelopment. Wave action is typically the cause of the breakup; rarely is the breakup a result of ice melting during the winter months. When the ice complex is broken into large fragments, ice thrust can damage shore structures or the foreshore. As the ice breaks up, the incorporated sand is rafted away under the influence of winds and currents (Barnes et al. 1994). Along the Illinois shore, studies have shown that most of the rated sediment drifts southward, but some also moves offshore, in some cases drifting as far as Indiana or Michigan before finally being redeposited. Data specific to Illinois Beach State Park is not available, but an extrapolation based on the available studies suggested that the annual volume of sediment that could be rafted from the state park coast could be as great as 3,000 cubic yards per mile of beach (Kempema et al. 1992). For the approximate 5.5 miles of shoreline, this process annually could permanently remove 16,500 cubic yards of nearshore sediment (IDNR 2000).

CHAPTER 4. PLACEMENT APROACHES

Prevention and remediation of the prevalent shore erosion along the north unit is necessary to mitigate the effects of the littoral interruption resulting from shoreline development to the north. Although it is recognized that Illinois Beach State Park was not in a state of equilibrium prior to the construction of North Point Marina and is, in fact, a migratory landform (IDNR 2010), the littoral processes can no longer be permitted to migrate south due to land ownership and coastal development. These processes are further exacerbated by the partial littoral barriers to the north of the state park. Both hard and soft remedies have a role in erosion management, but the preferred method at Illinois Beach State Park is beach nourishment. This approach is the best suited for maintaining an open shore free of shore structures and to preserve the setting of the state park shore.

The most reliable source of sediment is sand dredged from harbor entrances or other areas where undesirable sand accretion occurs. This material can then either be placed along the beaches or nearshore downdrift of the dredged area or returning the sand to the beach or nearshore in the updrift direction and thus recycling the sand along a specific reach of the shore (IDNR 2001).

4.1. Beach Placement

Since the late 1980s, the primary means of managing shore erosion along the North Unit has been beach nourishment. Sand has been stockpiled at a feeder beach along the shore at the north end of the North Unit immediately south of North Point Marina, shown in Figure 4.1.

Figure 4.1 North Unit Feeder Beach Location

The sand supplied to this feeder beach by truck during the late 1980s and 1990s was provided by dredging operations at North Point Marina, dredging at Prairie Harbor Yacht Club, dredging at the Waukegan Generating Station, or import of sand purchased from inland sources (Foyle et al. 1998). The volume of nourishment required for a balanced sediment budget has been supplied to the North Unit during several years, although the average provided volume has only been 20,000 cubic yards per year. In order to contain this entire volume, sediment was frequently stockpiled several feet high, as shown in Figure 4.2. Major obstacles in sustaining this beach placement nourishment program have been monetary constraints and meeting the current permit requirements.

Figure 4.2 Beach Nourishment at North Unit Feeder Beach

4.1.1. Advantages

Beach nourishment would allow for the most visible of the management options considered. This would afford the coordinating agencies to explain the role of beneficial reuse of dredged materials in shoreline management through soft measures and to improve the public perception of shoreline management within the vicinity of the park.

Material placed within the swash zone of the nearshore would quickly become incorporated into the nearshore littoral system while material placed in the foreshore would become accessible during periods of higher lake level (i.e. runup during storm events). This latter material would also provide a ‘reservoir of sand’ that would provide temporary protection to the backshore during storm events.

4.1.2. Disadvantages

It is likely that the elevation difference between the top of the fill and lakeshore and steep interface would limit any activities on the feeder beach; in-water activities would be precluded. This limitation of activities would continue even after erosion begins due to the likely formation of a scarp.

The D_{50} for the grain size distribution of samples collected during the last dredging cycle were consistent with that present in the deeper waters of the nearshore, but would be slightly smaller than that of typically found in the shallow waters along the shore. As the sediment is transported cross-shore it could potentially create a drop-off in the profile. The severity and likelihood of this occurring is dependent up on the existing cross-shore profile and quantity of nourishment fill available. Additional analyses would be required to develop a more quantitative estimate.

The existing foreshore of the North Unit feeder beach may have already experienced some measure of plant recruitment. Once the first nourishment operation commences, any gains within this area would be lost underneath several feet of fill. It could be expected that subsequent losses to erosion and continued operations would inhibit further reestablishment of vegetation within the active construction area of the feeder beach.

Material placed within the swash zone would be susceptible to ice rafting. The schedule of dredging and placement should be coordinated to avoid periods during which ice formation is probable. This limits the window during which dredging operations could be conducted while remaining compatible with this disposal approach.

Onshore placement of the material would require the handling of the material at least three times – once during dredging, once to remove from the dredge to place onshore into dump trucks, and once to spread the material on the feeder beach after the dump trucks have delivered the material. This number could increase further if a cost analysis finds it necessary to dewater the material prior to transport to the feeder beach.

4.2. Nearshore Placement

In addition to the beach placement at the feeder beach, sand has also been supplied to the nearshore area immediately adjacent to the North Unit feeder beach by hopper barge with sand collected during dredging operations from Waukegan Harbor or by slurry pipe from dredging at the entrance to North Point Marina. In this context, 'nearshore' is defined as being beyond the typical surf zone but within the depth of closure. The placement method would involve transporting dredged material to a maximum working depth of 18 feet and releasing it from a bottom-dump barge. This depth allows 14 feet for the scow, 2 feet for the underside doors, and one foot for clearance during uneven conditions. This would form a berm within the nearshore which would subsequently be suspended and introduced into the littoral system. Empirical methods have been developed to assess the rate and direction of migration of a nearshore berm for coastal applications, but the applicability of these equations within the Great Lakes has not been investigated or considered.

4.2.1. Advantages

Nearshore placement of dredged material would only require the handling of material a single time before it reaches its final disposition, yielding a significant economic benefit. It would also be less impactive to the foreshore ecosystem and may incidentally results in a temporary augmentation of a wave break. The sand placed in the nearshore would migrate rapidly toward shore within a few days or weeks after placement in a more natural fashion than through direct placement onto the dry beach (Brevard County 2010).

4.2.2. Disadvantages

One of the challenges of nearshore berm placement is specifying to what depth and with what longshore coverage the sand must be placed. In this application, however, placement is limited by the proximity of the minimum operating depth of the dredge vessels to the minimum depth of closure identified in applicable studies. Since the initial placement depth would not be representative for the final depth at the same location once the dredged material has been placed (due to the presence of the berm), bottom dumping at or around the minimum depth of closure should not prove to be an issue. Placement any deeper, however, could run the risk of losing a portion of the placement volume to the offshore profile.

CHAPTER 5. RECOMMENDATIONS

Of the two available options, nearshore placement of the dredged material is the most viable. Aside from the economic benefits of only handling the material a single time prior to final placement, the existing permits for beneficial reuse of dredged material are only applicable for beach placement in an area immediately adjacent to the North Unit feeder beach.

Pre- and post placement bathymetric surveys should be collected to ensure the placed volume is within the depth of closure. Periodic monitoring of the existing and post-placement dry beach width and shoreline position should be collected through detailed surveys at consistent transects. This will be important to assessing the impacts of the nearshore placement and to ensure the placement is not acting as an abrasive to the exposed clay lens.

REFERENCES

Booth, J.S. Wave climate and nearshore lakebed response, Illinois Beach State Park, Lake Michigan. *J. Great Lakes Res.* 1994. 20(1):163-178.

Brevard County Natural Resources Management Office. *A Study for Submerged Bar Beach Renourishment.* Olsen Associates, Inc., *Jacksonvile, FL:* 2010.

Chrzastowski, M.J.; Frankie, W.T. *Guide to the Geology of Illinois Beach State Park and the Zion Beach-Ridge Plain, Lake County, Illinois*. IDNR: 2000. Print.

Chrzastowski, M.J.; Thompson, T.A.; Trask, C.B. Coastal geomorphology and littoral cell divisions along the Illinois-Indiana coast of Lake Michigan. *J. of Great Lakes Res*. 1994. 20(1):27-43

Chrzastowski, M.J.; Trask, C.B. *Nearshore Geology and Geologic Processes Along the Illinois Shore of Lake Michigan from Waukegan Harbor to Wilmette Harbor*, 1995. Print.

Creque, S.M.; Stainbrook, K.M.; Glover, D.C.; Czesny, S.J.; Dettmers, J.M. Mapping bottom substrate in Illinois waters of Lake Michigan: linking substrate and biology. *J. Great Lakes Res.* 2010. 36(4): 780-789.

CUR. *Manual on Artificial Beach Nourishment*. CUR Rep. Balkema Press, Rotterdam: 1990. Print.

Davis, R.A.; Wang, P.; Silverman, B.R. Comparison of the performance of three adjacent and differently constructed beach nourishment projects on the gulf peninsula of Florida. *J. Coastal Research.* 2000. 16(2):396-407.

Douglass, S. Nearshore placement of sand. *Coastal Engineering Proceedings*. 2001. 25(1):3708-3721.

Foyle, A.M.; Chrzastowski, M.J., Trask, C.B. *Erosion and Accretion Trends Along the Lake Michigan Shore at North Point Marina and Illinois Beach State Park*, 1996. Print.

Foyle, A.M.; Chrzastowski, M.J., Trask, C.B. *Erosion and Accretion Trends Along the Lake Michigan Shore at North Point Marina and Illinois Beach State Park*, 1997. Print.

Foyle, A.M.; Chrzastowski, M.J., Trask, C.B. *Erosion and Accretion Trends Along the Lake Michigan Shore at North Point Marina and Illinois Beach State Park*, 1998. Print.

Fraser, G.S.; Hester, N.C. *Sediment Distribution in a Beach Ridge Complex and Its Application to Artificial Beach Replenishment.* Urbana: 1974. Print.

Graf, J.B. Comparison of measured and predicted nearshore sediment grain-size distribution patterns, Southwestern Lake Michigan, U.S.A. *Marine Geology.* 1976. 22:253-270.

Illinois Department of Natural Resources. *Long-Term Coastal Stewardship for the IDNR Shore of Lake Michigan at North Point Marina and Illinois Beach State Park.* IDNR Task Force for Coastal Stewardship, Springfield, IL: 2001. Unpublished.

Illinois Department of Natural Resources. *Coastal Erosion along the Illinois Coastal Zone, Issue Paper*. IDNR: 2011.

Illinois Department of Natural Resources. *Illinois Beach State Park and North Point Marina Including the Dead River and Kellogg Creek Watersheds, Issue Paper*. IDNR: 2011.

Illinois Department of Natural Resources. *Proposal Paper: Down-Drift Sand Entrapment Groin – Illinois Beach State Park.* IDNR: 2010.

Illinois Department of Natural Resources. *Proposal Paper: Lake Bottom Restoration at Illinois Beach State Park.* IDNR: 2010.

Illinois Department of Natural Resources. *Proposal Paper: Restoration of Illinois Beach State Park Beaches.* IDNR: 2010.

Illinois Department of Natural Resources. *Proposal Paper: Shore Protection at Illinois Beach State Park.* IDNR: 2010.

Illinois Department of Natural Resources. *State of Illinois: Coastal Management Program*. IDNR: 2011.

Jennings, J.R. 150 year erosion history at a beach ridge and plain on the Illinois Lake Michigan shore. *Proceedings of the 33rd Conf. Great Lakes Res.* 1990. p. 67. Internat. Assoc. Great Lakes Res.

Kaumphuis, J.W. Influence of sand or gravel on the erosion of cohesive sediment. *J. of Hydraulic Research.* 1990. 28(1):43-53

Larson, M.; Kraus, N.C. Analysis of cross-shore movement of natural longshore bars and material placed to create longshore bars. *Tech. Rep. DRP-92-5*, US Army Engrs. Wtwys. Exper. Sta., Vicksburg, MS: 1992.

McLaren, P.; Bowles, D. The effects of sediment transport on grain-size distributions. *J. Sedimentary Petrology.* 1985. 55(4)0457-0470.

Nairn, R.B.; Zuzek, P.; Morang, A.; Parson, L.E. Effectiveness of beach nourishment on cohesive shores, St. Joseph, Lake Michigan. *Tech. Rep. CHL-97-15*, US Army Engrs. Wtwys. Exper. Sta., Vicksburg, MS: 1997.

Sellinger, C.E.; Stow, C.A.; Lamon, E.C.; Qian, S.S. Recent water level declines in the Lake Michigan-Huron System. *Environ. Sci. Technol.* 2008. 42(2):367-373.

Shabica, C.; Pranschke, F. Survey of littoral drift sand deposits along the Illinois and Indiana shores of Lake Michigan. *J. Great Lakes Res.* 1994. 20(1):61-72.

US Army Corps of Engineers. Beach erosion analysis and protection plans for Illinois Beach State Park. *TC-3210*. Tetra Tech, Inc., Pasadena, CA: 1978.

Vallianos, L. Beach and nearshore placement of material dredged from federally authorized navigation projects. *90-PS-1*, US Army Engrs. Inst. For Water Res., Fort Belvoir, VA: 1990.

Vischer, G.S. Grain size distributions and depositional processes. *J. Sedimentary Petrology*. 1969. 39(3):1074-1106.