BASIS OF DESIGN

CDB #102-311-099
IDNR #2-20-044
SHORELINE STABILIZATION
ILLINOIS BEACH STATE PARK
300 LAKE FRONT DRIVE
ZION (LAKE COUNTY), ILLINOIS
CONTRACT: BRIDGING DOCUMENTS

State of Illinois

CAPITAL DEVELOPMENT BOARD

USING AGENCY: ILLINOIS DEPARTMENT OF NATURAL RESOURCES

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DATE: April 29, 2021

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CDB 102-311-099 / IDNR #217008: Stabilize Shoreline IDNR Illinois Beach State Park: Basis of Design

Rev	Description	Project Manager	Principal Reviewer	Client Approval	Date
A	Issued for Internal Review	______________ M. Boshek	______________ J. Cox	______________ M. Jones	27-Apr-20
B	Issued for Bridging Document Review	______________ M. Boshek	______________ R. Wright	______________ M. Jones	26-Feb-21
C	Issued for Bridging Document	______________ M. Boshek	______________ R. Wright	______________ M. Jones	29-Apr-21

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Abbreviations and Acronyms

BFE – Base Flood Elevation

BOD – Basis of Design

CEM – Coastal Engineering Manual

CD – Chart Datum

CDB – Illinois Capital Development Board

FEMA – Federal Emergency Management Agency

FIRM – Flood Insurance Rate Map

FIS – Flood Insurance Study

GLERL – Great Lakes Environmental Research Laboratory

Hs – Significant Wave Height

Hmo – Significant Wave Height Calculated from the Spectrum

IBSP – Illinois Beach State Park

IDNR – Illinois Department of Natural Resources

IGLD – International Great Lakes Datum

NAD - North American Datum

NAVD – North American Vertical Datum

NGVD – National Geodetic Vertical Datum

NOAA – National Oceanic and Atmospheric Administration

NOS – National Ocean Service

NWS – National Weather Service

OHWM – Ordinary High-Water Mark

SWL – Still Water Level

Tp – Spectral Peak Period

Ts – Significant Wave Period

USACE – U.S. Army Corps of Engineers

WIS – Wave Information Studies

WL – Water Line

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1 Introduction

1.1 Project Background

Illinois Beach State Park (State Park, IBSP) represents the final remaining natural, undeveloped lakefront in Illinois and has long experienced erosion of its shoreline. Because of the geologic creation of the park, the shoreline is transient by nature and if left unprotected, would naturally erode overtime.

Illinois Capital Development Board and Illinois Department of Natural Resources, which is responsible for the stewardship of the park, will be constructing shoreline stabilization structures in three locations within the park to mitigate erosion locally and holistically slow the transitory nature of the shoreline.

SmithGroup and Jack C. Cox P.E. developed the concept level solution for controlling the further loss of shoreline at the Park[1] (Phase 1). SmithGroup was subsequently retained to advance the conceptual designs developed in Phase 1 to the design development level which will fix the aspects of the design that influence the littoral transport throughout the park and provide guidelines for achieving the team's secondary goals of habitat protection/creation/enhancement and aesthetics.

1.2 Purpose of this Document

The Basis of Design (BOD) document provides a description of the Project scope and outlines the functional requirements to serve as a basis for guiding the design. It is to document the reasoning and decisions made during the design phase of the project. It presents the philosophy of approach, basic rationale and assumptions, criteria, logic, and considerations developed in evaluation of the design.

This document shall be the basis of furtherment of the design and construction by the selected design/build team.

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[1] SmithGroup and Jack C. Cox, P.E., (2019) "Illinois Beach State Park Shoreline Morphology Analysis & Stabilization Options", prepared for Illinois Department of Natural Resources, IDNR # 2-17-008.

Figure 1: Illinois Beach State Park

2 Project Definition

2.1 Location

Illinois Beach State Park is located in Zion, IL and stretches approximately 6 miles south from the border of Illinois/Wisconsin.

The given address is located at the Illinois Beach Resort and Conference Center:

300 Lake Front Dr
Zion, IL 60099

Longitude -87.805, Latitude 42.424

2.2 Owner Objective & Project Requirements

2.2.1 Description of Program

The State Park provides many recreational opportunities as well as provides invaluable habitat to a range of threatened and endangered species. It is the last remaining ‘natural’ shoreline within the state of Illinois. A historical review of the shoreline reveals that it is naturally transitory, and, without intervention, the shoreline will continue to erode landward as sand migrates to the south.

2.2.2 Project Goals

Below are the main goals of this project:

- Primary Goal: To develop shoreline erosion solutions that stabilize the shoreline, protect critical infrastructure, and reduce the natural transitory process.

- Secondary Goal: Shoreline protection works should fit the character and mission of the park. Implementations should remain within the aesthetics of the natural shoreline and not inhibit the user experience. However direct access to, or onto any of these structures by the public is not a goal and should be naturally discouraging in its design.

- Tertiary Goal: To the maximum extent possible within the technical performance limitations of the shore protection design, and within the available design and construction budget, the defense works shall be designed to embody intrinsic characteristics that are habitat enhancing or advancing.

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2.2.3 Design Preferences

Below are the client-defined design preferences of this project:

- Preference to implement offshore solutions
    - Offshore solutions to be low crested or submerged where possible to reduce visual impact
- Use natural materials native to NE Illinois and SE Wisconsin, if possible
- Configure shape and texture to be most natural in appearance
- Require minimal maintenance
- Remain functional and resilient within design water levels

2.2.4 Performance Metrics

The following metrics will be used as design targets.

2.2.4.1 Shoreline Morphology

For the basis of design, the following performance goals for the shoreline within the defined project Areas are set:

- After 20 years of conditions remaining within the given design criteria, the high water static location (defined as the waterline position on the shoreline with no waves, and not recently reshaped by a storm event) along the shoreline within areas being protected, shall not recede from its initial nourished position by more than 66 feet (20 meters).
- Natural shoreline morphological changes associated with varying water levels within the defined design criteria will not encroach within 33ft (10 meters) of existing buildings or critical utilities.
- The beach control structures and site improvements will not negatively impact other areas of IBSP not within this project nor will the improvements negatively impact adjacent property owners.

2.2.4.2 Habitat Creation & Sustainability

The habitat features to be integrated shall be targeted to be attractive to native and desired species as identified in section 5.4. For the BOD, the following performance goals are set:

1. Habitat will focus on both avian and aquatic biota, targeting first habitat for high value and endangered species.
2. Establish habitat spaces within project areas and monitor populations of targeted species. Goal will be considered met if an increase in aquatic species usage of habitat is observed within project area within 2 years and avian nesting within 5 years.
3. Habitat spaces will be resilient up to the service life goal, though not all habitat area is presumed to remain functional or constant in form at all water levels.

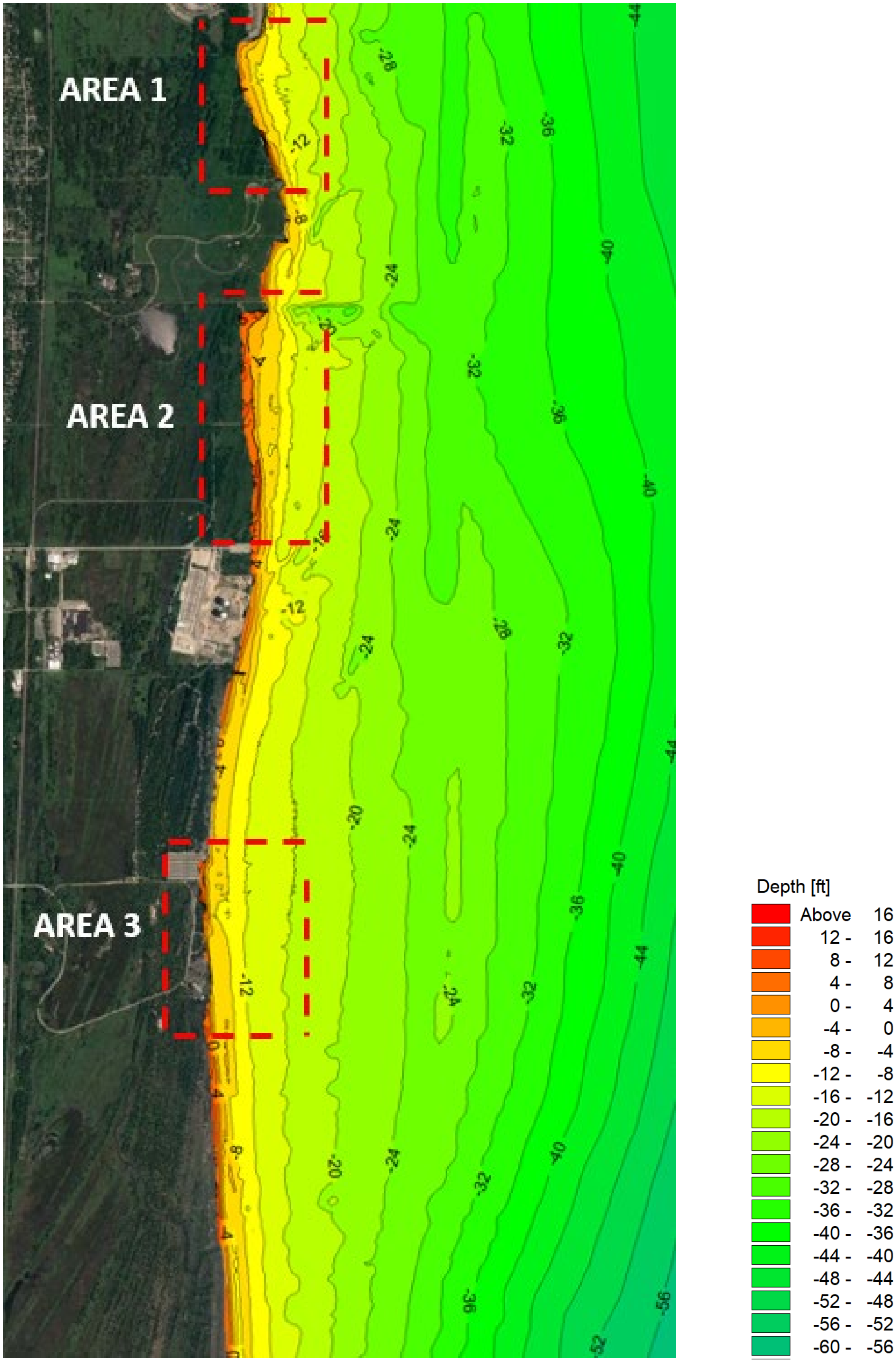

Figure 2: Bathymetric Information for the Project Site, May 2020 (ref. Chart Datum 577.5')

2.2.5 Prescribed Budget

The State of Illinois has allocated a Construction Budget for this project of $42,362,555.00.

3 Site Information and Conditions

3.1 Datums

The official datums used within this project are given below:

- Horizontal Datum: North American Datum of 1983 NAD83 Wisconsin State Planes, South Zone, US Foot.
- Vertical Datum: International Great Lakes Datum of 1985 (IGLD85), feet.

Vertical datum conversions to other referenced datums for the project site are the following:

- NAVD88 = IGLD85 + 0.53 ft
- NGVD29 = IGLD85 + 0.88 ft
- IGLD55 = IGLD85 - 0.7 ft

3.2 Bathymetric & Topographic Data

Bathymetric and topographic elevation information was compiled from several sources. The layering of information followed the order below:

- A selected grid from NOAA's Great Lakes Bathymetry database at 3 arc-second resolution (~295 ft) for the large-scale bathymetry.
- NOAA's more detailed nearshore bathymetry from LiDAR 2012[2].
- A bathymetric survey of the North Beach area collected in August 2018 by JSD Professional Services, Inc.
- Topograpic and bathymetric surveys of the Camp Logan area collected in October 2018 by Illinois State Geological Survey.
- A full project site survey of the north 5 miles of shoreline collected by JSD Professional Services, Inc. in April and May of 2020.

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[2] https://coast.noaa.gov/dataviewer/#/lidar/

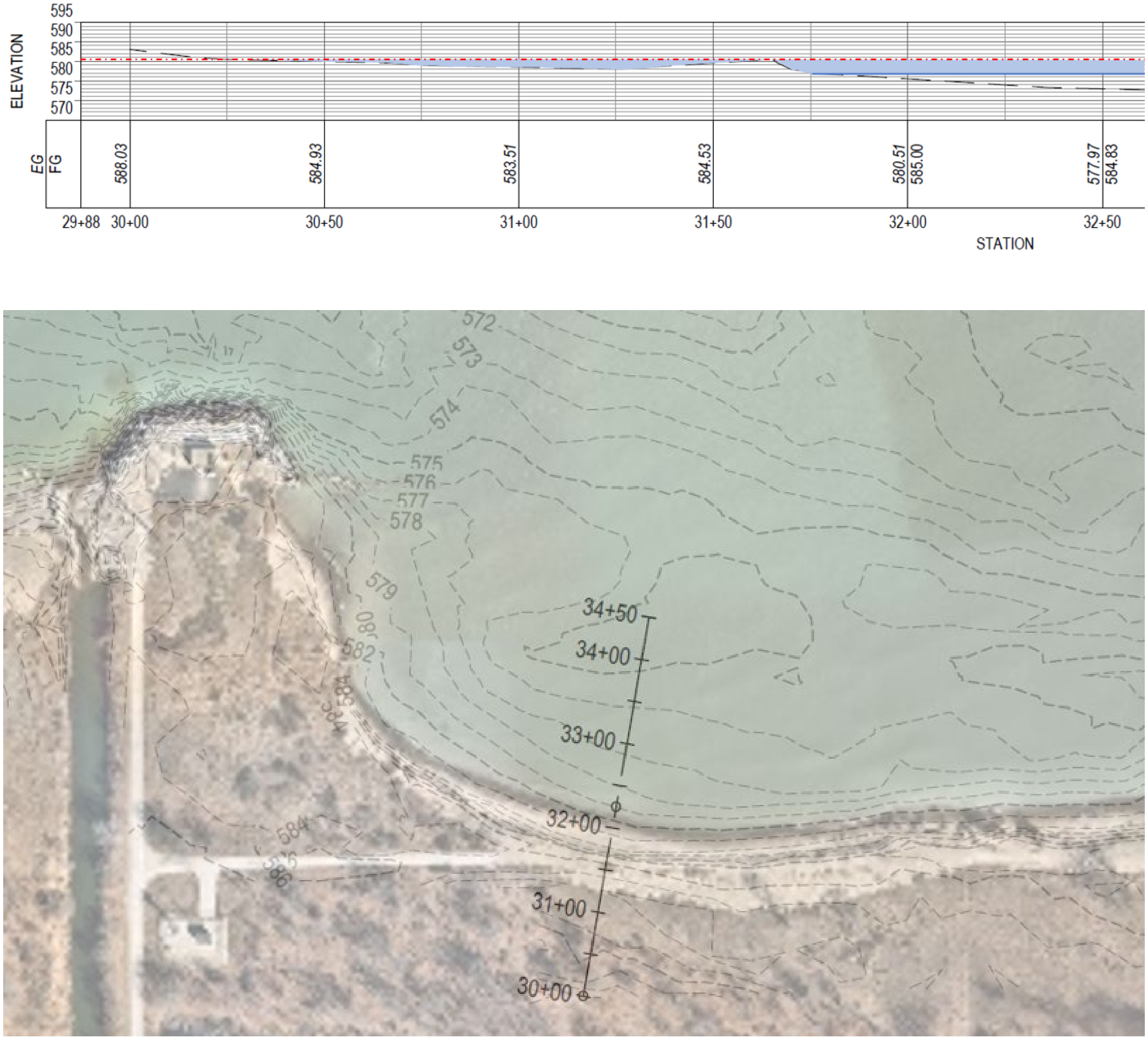

Figure 3: Area 2 Cross Section Depicting Flooding of Inland at 585.2 IGLD85

3.3 Limitations of the Project

Much of the park is low lying and beneath an elevation of 587 IGLD85. High water levels with large storm surge has the possibility of inundating these low-lying lands with flood waters. While offshore breakwaters will lessen wave energy reaching the shoreline during such an event, they do not have the ability to stop flood waters. Flood waters can only be kept out of the park through building of an impermeable dike along the shoreline. The dike would need to be tied into higher ground to prevent flood waters from circumventing the ends.

Figure 3 shows a cross section through the shoreline of Area 2. The shaded blue area depicts the area which would be flooded during a storm event where the combined high-water level plus surge would be at an elevation of 585.2; the severe water elevation used in this project.

Figure 4: Illinois Beach State Park Project Stationing

3.4 Site Stationing Established for Project

Stationing was established to provide spatial reference points for the shoreline areas and features for this project.

3.4.1 Full Park Shoreline

Reference points for the full park start on the north end of the park, within North Point Marina at 0+00, and ends at the south end of the park near Waukegan Generating Station at 365+00.

Table 1: Site Stationing Line

	Station	Latitude	Long
North Point Marina	0+00	42.483273°	-87.807312°
Waukegan Generating Station	365+00	42.383126°	-87.810848°

3.4.2 Stabilization Features

Stabilization features created as part of this project start at 1100+00 for the northernmost feature of Area 1, 2100+00 for the northernmost feature of Area 2, and 3100+00 for the northernmost feature of Area 3.

3.4.3 Identified Project Areas

The conceptual development phase established three areas of major shoreline retreat that threatened critical natural and built infrastructure. The station limits of the three project Areas as provided in Table 2.

Table 2: Identified Project Areas

Area	Stationing	Length
Area 1 – North Beach	12+50 through 45+00	3,250 ft
Area 2 – Camp Logan	66+00 through 115+00	4,900 ft
Area 3 – Swimming Beach	185+00 through 230+00	4,500 ft

Table 3: Shoreline Conditions Throughout Illinois Beach State Park

Station (appx)	Shoreline Type	Condition
5+00 through 12+50	Rubble Revetment	Stable
12+50 through 42+50	Natural - Sand	Eroding
42+50 through 48+50	Concrete Blocks & Rubble	Areas of Failure
48+50 through 55+50	Sheetpile	Stable
55+50 through 68+50	Concrete Blocks & Rubble	Areas of Failure, Eroding
68+50 through 69+00	Kellogg Creek	Stable
69+00 through 71+00	Concrete Blocks & Rubble	Stable
71+00 through 73+00	Concrete Blocks & Rubble	Failure & Leeside Erosion
73+00 through 128+00	Natural – Sand	Eroding
128+00 through 141+50	Rubble Revetment	Stable
141+50 through 148+50	Natural - Sand	Stable – Adjusts to WL
148+50	Intake Groin	Stable
148+50 through 163+00	Natural – Sand	Stable
163+00 through 174+00	Sand, Partially Buried Rubble Revetment	Stable
174+00 through 186+50	Exposed Rubble Revetment	Overtopped, some Damage
186+50 through 189+00	Destroyed Rubble Revetment	Damaged, Eroding
189+00 through 198+00	Natural – Sand	Eroding
198+00 through 207+00	Rubble Revetment at Water's Edge	Stable
207+00 through 210+00	Sand, Partially Buried Rubble Revetment	Eroding
210+00 through 212+50	Sand, Partially Buried Sheetpile Wall	Eroding
212+50 through 220+50	Exposed Sheetpile Wall with Rubble	Stable, Overtopped
220+50 through 247+00	Natural – Sand	Eroding
247+00 through 337+00	Natural – Sand	Stable, some Accretion
337+00 through 337+50	Rubble Crib Hardpoint	Accretion
337+50 through 365+00	Natural – Sand	Stable

3.4.4 Existing Infrastructure

The park includes several buildings, paved and unpaved pathways & roads, parking lots, and shoreline defenses within close proximity to Lake Michigan. Identified infrastructure is given in section 3.5.

3.4.5 Shoreline Protection

Table 2 gives a list of shoreline types and their current condition throughout the park. The condition assessment was generated by on-site inspections and/or review of historic aerial photos to evaluate the shoreline position. Figure 5 through Figure 8 were taken during an on-site inspection in August 2018.

Figure 5: Sheetpile seawall along the resort and conference center

Figure 6: Failing concrete blocks shoreline protection

Figure 7: Rubble revetment

Figure 8: Natural shoreline south of North Point Marina

Figure 9: Area 1 Identified Infrastructure

Figure 10: Area 2 Identified Infrastructure

Figure 11: Area 3 Identified Infrastructure

3.5 Critical Infrastructure

Erosion of the shoreline threatens natural wetlands/habitat and man-made infrastructure throughout the park. Some of these shoreline features are listed as ‘critical’ (Table 4) and are the focus of the long-term stabilization efforts. In addition to those listed below, the site contains a number of exposed utility lines (potable water, sanitary, power, and gas lines) that run parallel to the shoreline. The implementation of the project should minimize potential negative impacts to these features. Additional features within the park which may be impacted by this work is listed in Table 5.

Table 4: Identified Critical Infrastructure

Description / Name	Project Station
Buildings/Structures:	
Middle Creek & Lake Discharge Structure	43+00
Lake County Water District Intake Plant	70+00
Park Office & Visitor Center	206+00 through 207+50
Beach Resort & Conference Center	214+00 through 219+00
Recreation Areas & Parking Lots:	
Middle Creek Beach	38+00 through 43+00
Swimming Beach & Parking Area	187+00 through 194+00
Park Office & Visitor Center Parking Area	205+00 through 208+00
Resort & Conference Center Beach & Parking Area	210+00 through 219+00
Wetlands / Habitat:	
Area 1 Pannes	17+50 through 44+00
Area 2 Wetlands	97+00 through 120+00
Area 3 Perched Wetlands	221+00 through 228+00

Table 5: Additional Identified Infrastructure

Description / Name	Project Station
Buildings:	
Concession Building (in Construction)	187+00
Path & Roadways:	
North Dunes Nature Preserve Hiking Trails	16+00 through 42+00
Burnett Avenue	70+00 through 96+00
21st Street	96+00
Lakeshore Trail	194+00 through 212+00
Trail between the Resort and the Nature Center	217+00 through 225+00
Waterways & Water Intakes:	
Dead Dog Creek	17+00
Middle Creek	43+00
Kellogg Creek	68+50
Lake County Water District Intake Pipe	70+00

Figure 12: Area 1 Historic Shoreline and Residential Development

Figure 13: Area 2 Historic Shoreline and Residential Development

3.6 Park Characterization

3.6.1 Geology

Illinois Beach State Park is a beach-ridge plain landform that consists of linear, generally coast-parallel mounds of sand and gravel, characterized by a topography of sub-parallel ridges separated by low areas called swales. Two of these larger swales have evolved into pannes, or perched wetlands. These are rare formations of high ecological value and the only remaining two naturally formed in the State of Illinois. The design solution aims to preserve the pannes from any further damage due to shoreline erosion while minimizing the potential for negative impacts to their biological functions.

Within the park there are four natural streams, Dead Dog Creek, Middle Creek, Kellogg Creek, and the Dead River. Dead Dog Creek is located within Area 1, Middle Creek is located at the south end of Area 1, and Kellogg Creek is just north of Area 2. The project intends to avoid, to the extent feasible, negatively altering the hydraulic behavior of Dead Dog, Middle, and Kellogg Creeks by the implementation of project. Further south, the Dead River is well beyond the zone of influence of the Area 3 plan and is not considered a concern for the design.

3.6.2 Upland Historic Use

Up until the 70’s, the Area 1 and Area 2 shoreline areas contained residential neighborhoods, now removed and largely lost to the retreat of the shoreline. The shoreline and outline of these historical residences can be seen in Figure 12 & Figure 13. However, remnants and relics of the development still exist, now littering the beach and lakebed, including well pipe risers, collapsed street pavement, and broken granularized asbestos chunks. These are all residuals from construction materials and manufacturing used at that time. Some of these may be impediments to the planned mitigation and will need to be removed or capped as part of the construction effort.

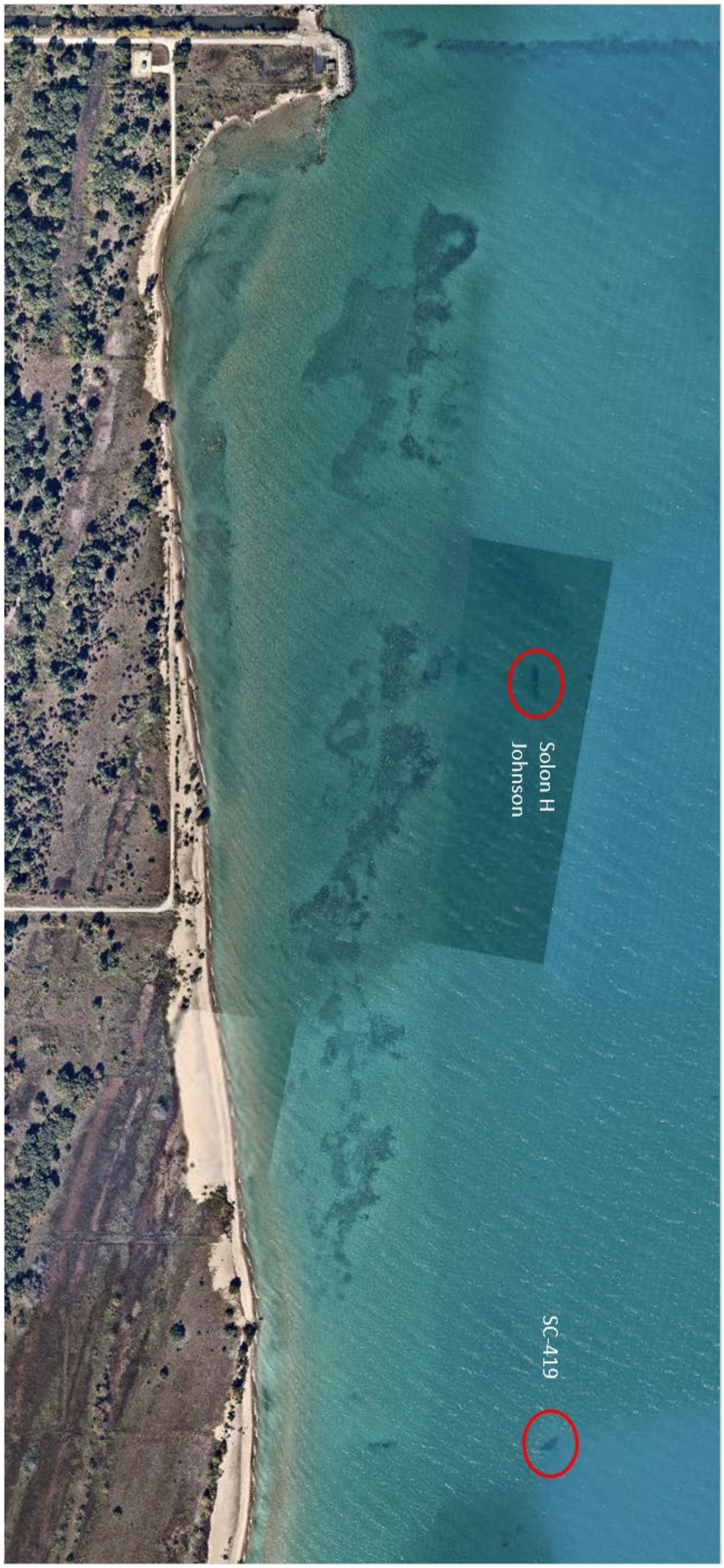

Figure 14: Shipwrecks Located in Area 2

3.6.3 Shipwrecks & Ruins

Two shipwrecks are located offshore of Illinois Beach State Park near Camp Logan in Area 2:

- Solon H Johnson: 42.452535N, -87.796740W
- SC-419: 42.458913N, -87.796902W

In addition, multiple ruins of the residential neighborhoods that were once located at this site remain offshore. The shipwrecks do not interfere with the designed beach control structures. While the residential ruins are not considered historically significant, the shipwrecks are to be protected. Construction within the area around the shipwrecks will be reviewed with Illinois State Historic Preservation Office.

3.6.4 Outfall Discharges

One stormwater outfall discharge structure has been identified, located at Middle Creek at the southern end of Area 1, shown in Figure 15. The implementation of project design should minimize potential negative impacts to the discharge of stormwater from the identified outfall.

Kellogg Creek is located at the north end of Area 2 and regularly suffers clogging due to migration of heavy cobble material. The project work includes construction of a groin feature north of the creek to minimize or eliminate clogging of the creek mouth to permit free flow.

Figure 15: Stormwater Outfall Structure in Area 1 (photo taken 1/7/2021)

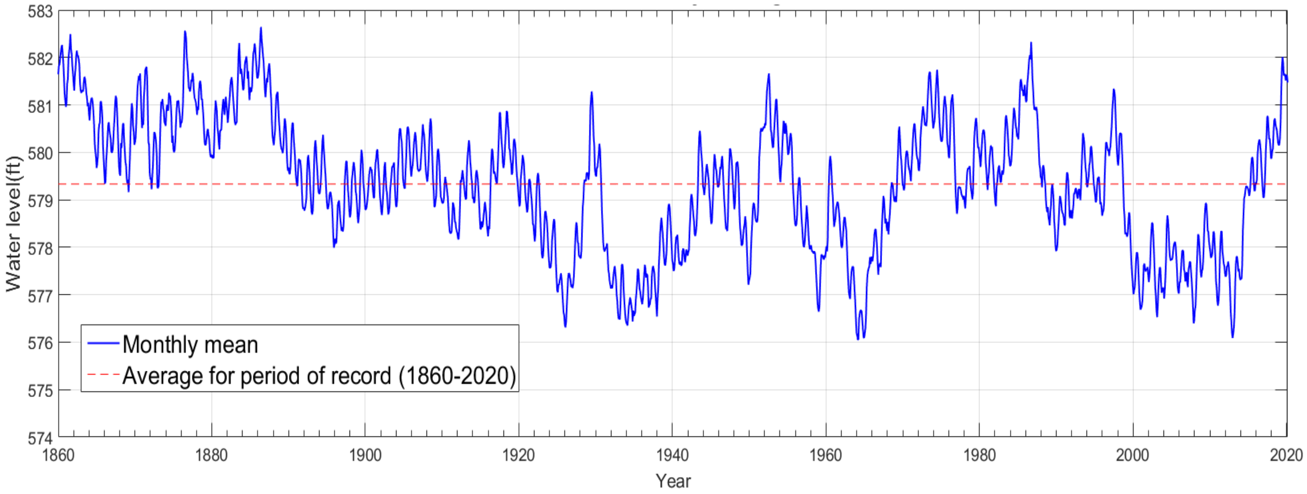

Figure 16: Monthly Average Water Levels, 1860 – Present, Harbor Beach, MI

Table 6: Monthly Average Water Levels

Data Sets	1860 - 2020	1918 - 2020
Lowest Recorded	576.02	576.02
5%	577.00	576.74
15%	577.69	577.40
25%	578.35	577.76
50%	579.41	578.87
75%	580.32	579.86
85%	580.84	580.31
95%	581.57	581.07
Max Recorded	582.64	582.35

Table 7: Record Water Levels

Lowest Recorded Monthly Average 1860-2020	576.02	January 2013
Highest Recorded Monthly Average 1860-1917	582.64	June 1886
Highest Recorded Monthly Average 1918-2020	582.35	October 1986

4 Design Criteria

4.1 Units of Measurement

The official unit of measurement for this project is English Imperial units.

4.2 Metocean Environment

The morphological changes of the shoreline are caused directly by the hydraulic influences of Lake Michigan which are both chronic and episodic. Sediment transport along the western side of Lake Michigan is driven by the effects of waves reaching the shoreline. The magnitude, direction, and frequency of these waves are defined by the wind climate and the hydrology of the Lake.

4.2.1 Water Levels

Water Level observations and statistical summaries are available through a variety of sources including:

- Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS)
- United States Army Corps of Engineers Studies
- National Oceanic and Atmospheric Administration (NOAA) Hydrological Stations

Design water levels will be a combination of still water high lake levels and storm surge.

4.2.1.1 Data Sources

4.2.1.1.1 NOAA / NOA Lake Wide Water Levels

The National Ocean Service (NOS) is a division of the National Oceanic and Atmospheric Administration (NOAA). In partnership with Great Lakes Environmental Research Laboratory (GLERL), NOAA provides monthly average water levels[3]. This data is separated into two data sets:

- 1860 – 1917: Monthly Average Water Levels referenced to Harbor Beach, Michigan (master gauge for Lake Michigan)
- 1918 – Present: Monthly Lake-Wide Average Water Levels

Data prior to 1918 is not considered as accurate because, before that time, there were too few gauges to calculate a reasonable lake-wide average. However, a review of the water levels prior to 1918 measured at Harbor Beach, MI reveal multiple years of high-water levels greater than those experienced post-1918.

Table 6 provides the percentile monthly average water levels for the 160 year and 102-year data sets.

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[3] https://www.glerl.noaa.gov/data/dashboard/data/

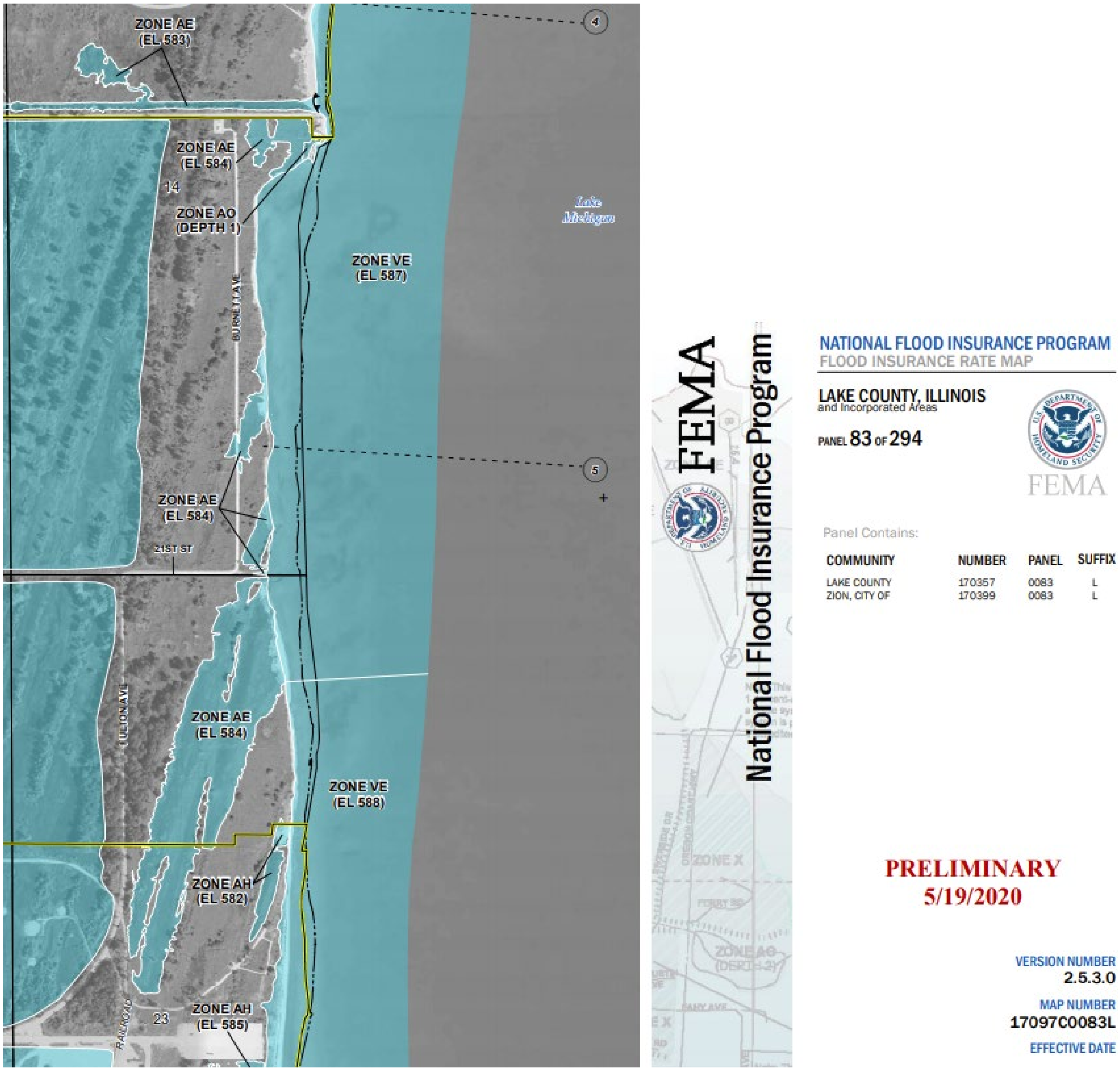

Figure 17: Preliminary 2020 FIRM (preliminary issue date: 5/19/2020)

4.2.1.1.2 USACE

The Detroit District of the US Army Corps of Engineers maintains water levels records for the Great Lakes. Their published water level benchmarks for Lake Michigan are as follows[4]:

- Ordinary High-Water Mark (OHWM) = 581.5 IGLD85
- Low Water Mark, Chart Datum (CD) = 577.5 IGLD85

Return period water levels were published in USACE Phase I Revised Report on Great Lakes Open-Coast Flood Levels 1988[5] and remain valid today. The elevation reflects the still-water elevation plus wind set up but does not include the contributions from wave crest and wave run-up.

Table 8: Open-Coast Flood Levels, USACE

10-Year RP	50-Year RP	100-Year RP	500-Year RP
582.6 IGLD85 (581.9 IGLD55)	583.7 IGLD85 (583.0 IGLD55)	584.1 IGLD85 (583.4 IGLD55)	585.0 IGLD85 (584.3 IGLD55)

4.2.1.1.3 FEMA Flood Elevation

The effective FEMA FIS 2016 for Lake County references the USACE Phase I Revised Report on Great Lakes Open-Coast Flood Levels 1988 as the basis for Lake Michigan 1% annual chance flood elevation. The stated flood elevation includes both a quasi-static lake level plus a wind surge, but wave effects are not included. The FIRMettes[6] for this region include 17097C0081K, 17097C0085K, and 17097C0095K. All became effective on 9/18/2013 and the shading no longer reflects the current shoreline edge. The whole shoreline of Illinois beach is classified as Zone AE. This value applies to all of Lake county.

- Base Flood Elevation – 1% Annual Chance of Flood Event = 584.47 IGLD85 (585 NAVD88)

Preliminary FEMA Flood Hazard Maps[7] for Lake County, Illinois were issued on 5/19/2020 and now include VE high risk -coastal areas which include the additional hazard associated with storm waves. The maps which cover the project areas include 17097C0081L, 17097C0083L, 17097C0091L.

- 1% or Greater Chance of Flooding and an Additional Hazard of Storm Waves
    - Area 1 = 587 NAVD88 (586.47 IGLD85)
    - Area 2 = 587 & 588 NAVD88 (586.47 & 587.47 IGLD85)
    - Area 3 = 587 NAVD88 (586.47 IGLD85)

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[4] US Army Corps of Engineers Detroit District Website: Ordinary High Water Mark and Low Water Datum - Table Of Values
[5] https://www.michigan.gov/documents/deq/wrd-nfip-great-lakes-flood-levels-part1_564793_7.pdf
[6] https://msc.fema.gov/portal/home
[7] https://hazards.fema.gov/femaportal/prelimdownload/

Table 9: Monthly Average Water Levels at Illinois Beach State Park

Illinois Beach State Park*	
Lowest Recorded	575.99
5%	576.95
15%	577.54
25%	578.03
50%	579.15
75%	580.06
85%	580.47
95%	581.18
Max Recorded	582.38

Table 10: Surge by Return Period at Illinois Beach State Park

Illinois Beach State Park*

Return Period	feet
1 yr.	1.33
2 yr.	1.49
5 yr.	1.71
10 yr.	1.87
20 yr	2.04
50 yr.	2.25
100 yr.	2.42
500 yr.	2.80

*Based on Interpolations between Milwaukee & Calumet Stations

4.2.1.1.4 NOAA's CO-OPS Stations

To update and expand upon the analysis conducted by the USACE, water level data was downloaded from NOAA's CO-OPS stations[8]:

- Station ID: 9087057 located in Milwaukee, WI
  - Monthly average water level data: 01/1970 – 02/2020
- Station ID: 9087044 located in Calumet Harbor, IL
  - Monthly average water level data: 02/1903 – 02/2020

Measurements taken over the course of a month are averaged to report the monthly average water level for the station. These differ from the full Lake Michigan monthly average water levels as they include local meteorological effects. The full lake reported monthly levels are the average of all reporting stations throughout the Lake.

Table 9 provides the percentile monthly average water levels for Illinois Beach State Park. The project site is approximately midway between these two locations and therefore an interpolation between the two facilities has been estimated.

4.2.1.2 Lake Surge

"Surge" refers to changes in water level that are of relatively short duration and are associated with the passage of meteorological events. Surge events on Lake Michigan can persist from a few minutes to a few hours. To estimate the magnitude of storm surge associated with various return period events, instantaneous (6-minute reporting) water levels from NOAA's CO-OPS stations were compared to monthly average lake levels. The difference was defined as the storm surge magnitude and was statistically analyzed to determine probability of occurrence assuming a Weibull distribution. The surge levels cannot be directly correlated to specific wind or wave events but offer a method to account for the storm surge in water level sensitive calculations. The return period surge heights at Illinois Beach State Park are shown in Table 10.

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[8] https://tidesandcurrents.noaa.gov/map/

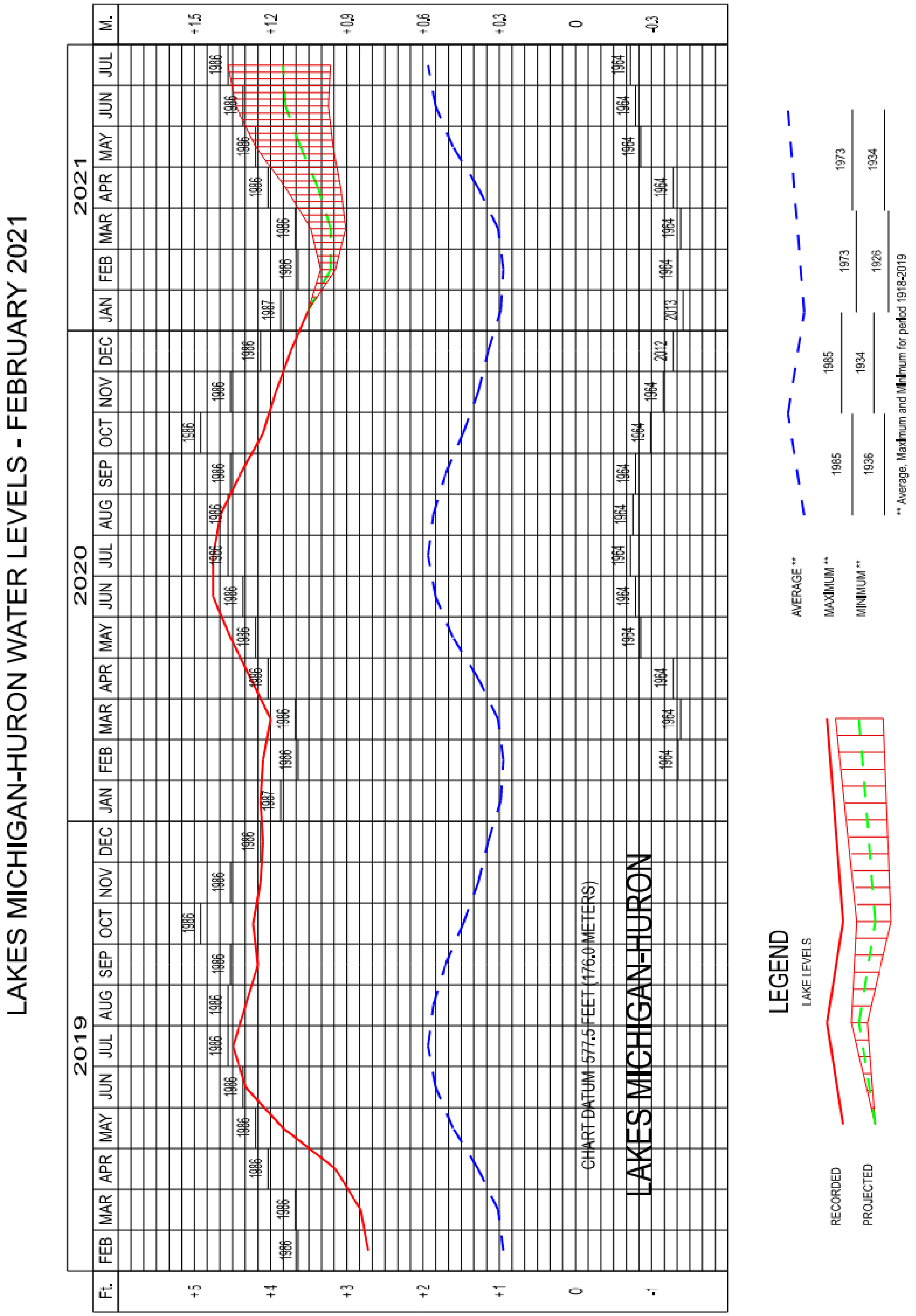

Figure 18: Lake Michigan-Huron 6-Month Forecast, February 2021

4.2.1.3 Short-Term Lake Level Forecasts

The Detroit District of the USACE provides water level forecasts for the Great Lakes basins. These forecasts are based on models updated monthly using forecasts of future weather from the National Weather Service (NWS) and the present condition of the lake basin.

The 6-month forecast[9] shown in Figure 18 shows a projected forecast of receding high-water levels. According to this forecast, the upper projection for summer 2021 is 581.99 in July which is 0.19 lower than July 2020. The average water levels of 2020 were higher than historic high-water levels for each month January through August.

USACE also publishes a water level scenarios summary[10] which illustrates water level outcomes that would occur under historical weather and water supply conditions. The grey shaded area in Figure 19 shows the range of possibilities based on these historical scenarios. The four highlighted seasons represent years with weather conditions similar to the current years' recent months. In the image shown, these years represent La Nina development during the summer/fall and warmer than normal global temperatures. According to this outlook, the upper outlook for summer 2021 could be as high as 582.6 in July.

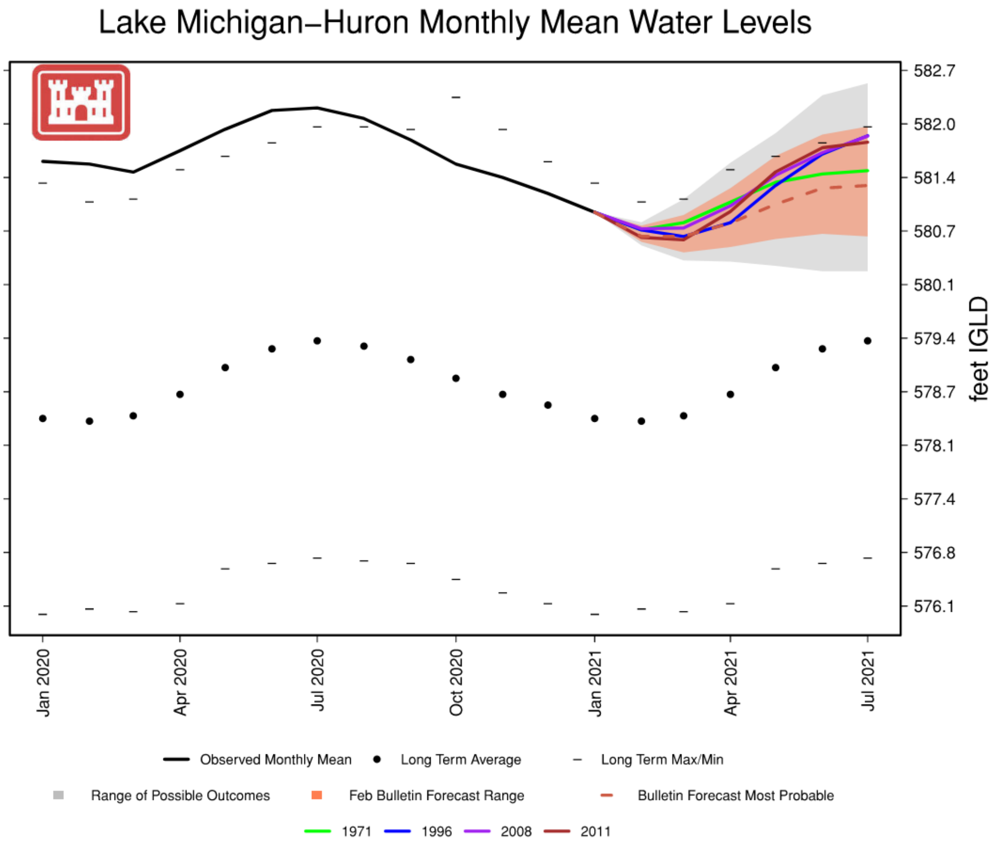

Figure 19: Lake Michigan-Huron 6-Month Outlook, Feb 2021

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[9] https://www.lre.usace.army.mil/Missions/Great-Lakes-Information/Great-Lakes-Water-Levels/Water-Level-Forecast/Monthly-Bulletin-of-Great-Lakes-Water-Levels/

[10] https://www.lre.usace.army.mil/Missions/Great-Lakes-Information/Great-Lakes-Water-Level-Future-Scenarios/

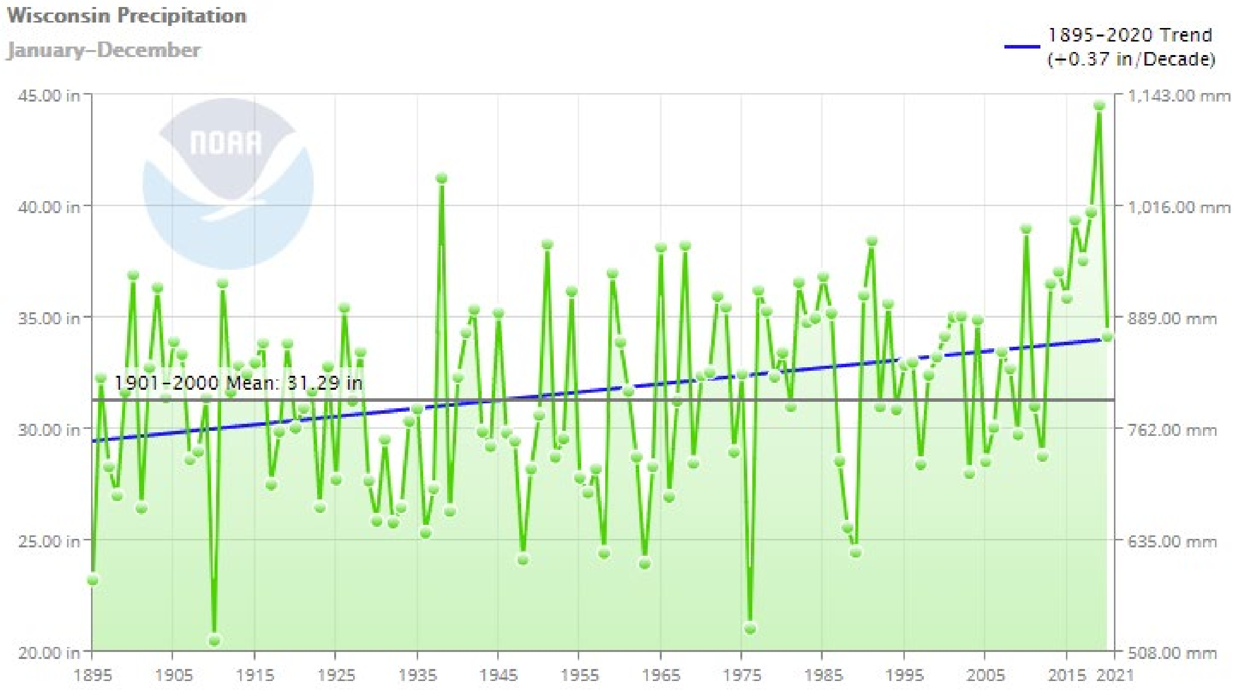

Figure 20: Wisconsin Annual Precipitation and Trend[11]

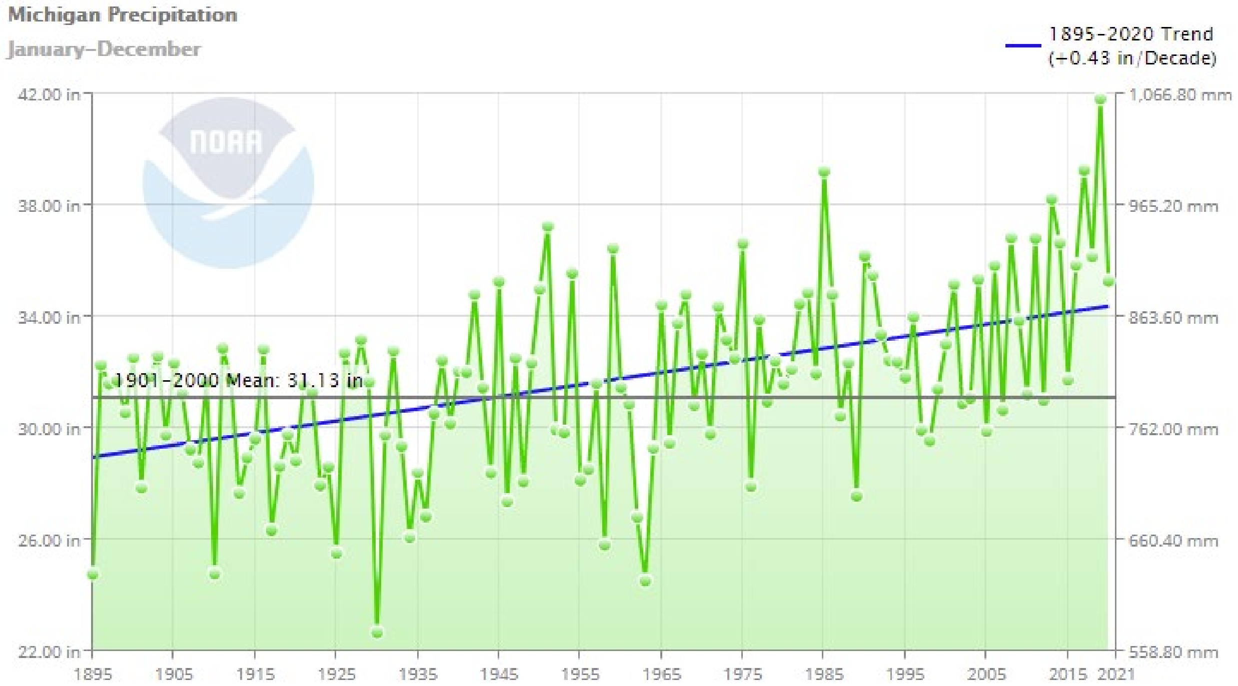

Figure 21: Michigan Annual Precipitation and Trend[11]

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[11] NOAA National Centers for Environmental information, Climate at a Glance: Statewide Time Series, published February 2021, retrieved on February 25, 2021 from https://www.ncdc.noaa.gov/cag/

4.2.1.4 Precipitation and Lake Level Trends and Correlation

Water budgets in each of the Great Lakes is balanced primarily by precipitation entering the lake, either by direct over lake precipitation or indirectly by land runoff, and evaporation. Cold and continuous wet years will cause water levels to rise whereas consecutive warm and dry years will cause water levels to decline.

Annual precipitation for Michigan and Wisconsin are shown in Figure 20 & Figure 21. The trend line shows and increase in annual precipitation with a spike over the past few years. The implication of an increasing precipitation trend will result in increasing water levels, possibly beyond historic levels.

Through mostly natural processes, the Great Lakes flow from Lake Superior to Lake Michigan/Huron, through St. Clair into Lake Erie, over Niagara Falls and into Lake Ontario. There it encounters the St. Lawrence series of river dams which make commerce on the Great Lakes possible. And while dam operators have the ability to open the dams to help empty the Great Lakes, the rate at which it can remove the water is minimal in comparison to the water entering the lakes from the watershed.

4.2.1.5 Design Water Levels

Based on the previous discussion, it is unclear when the present lake level trends will resolve going forward. The water level specification used by FEMA 2013 differs with the water level developed by the analytical/statistical approach using site specific historic records by roughly a half a foot. However, the FEMA analysis is developed for insurance purposes and uses a more global water level and was never intended for site specific design. Because the FEMA 2013 water level is less conservative in this situation, the statistically based water level values were selected. To account for the unknown future trend of high lake levels, a judgmental design water level overage allowance is also applied resulting in a final design elevation based on the highest recorded design water level, including surge, plus an additional 0.5 feet. Water levels used as the basis of design, are summarized in Table 11:

Table 11: Project Selected Design Water Levels, ref IGLD85

	Still-Water Level	Storm Surge (ft)	Future Proofing Allowance (ft)	Final Design Elevations
Design Low Water Level	576.0	-	-	576.0
Design Average Water Level	579.2	Return Period Storm Dependent	-	579.2 + Surge
Design High Water Level	582.4	2.3 (50yr RP)	0.5	585.2

It should be noted that FEMA 2020 VE zone water levels are in exceedance of the above selected project water levels. These water levels are a combination of still water level, storm surge, wave setup, and wave runup which is only valid along the shoreline and results in inland flooding. Offshore structures will locally reduce the effects of wave setup and wave runup along the shoreline but will not affect water levels associated with high water levels plus surge. This limitation was highlighted within section 3.3.

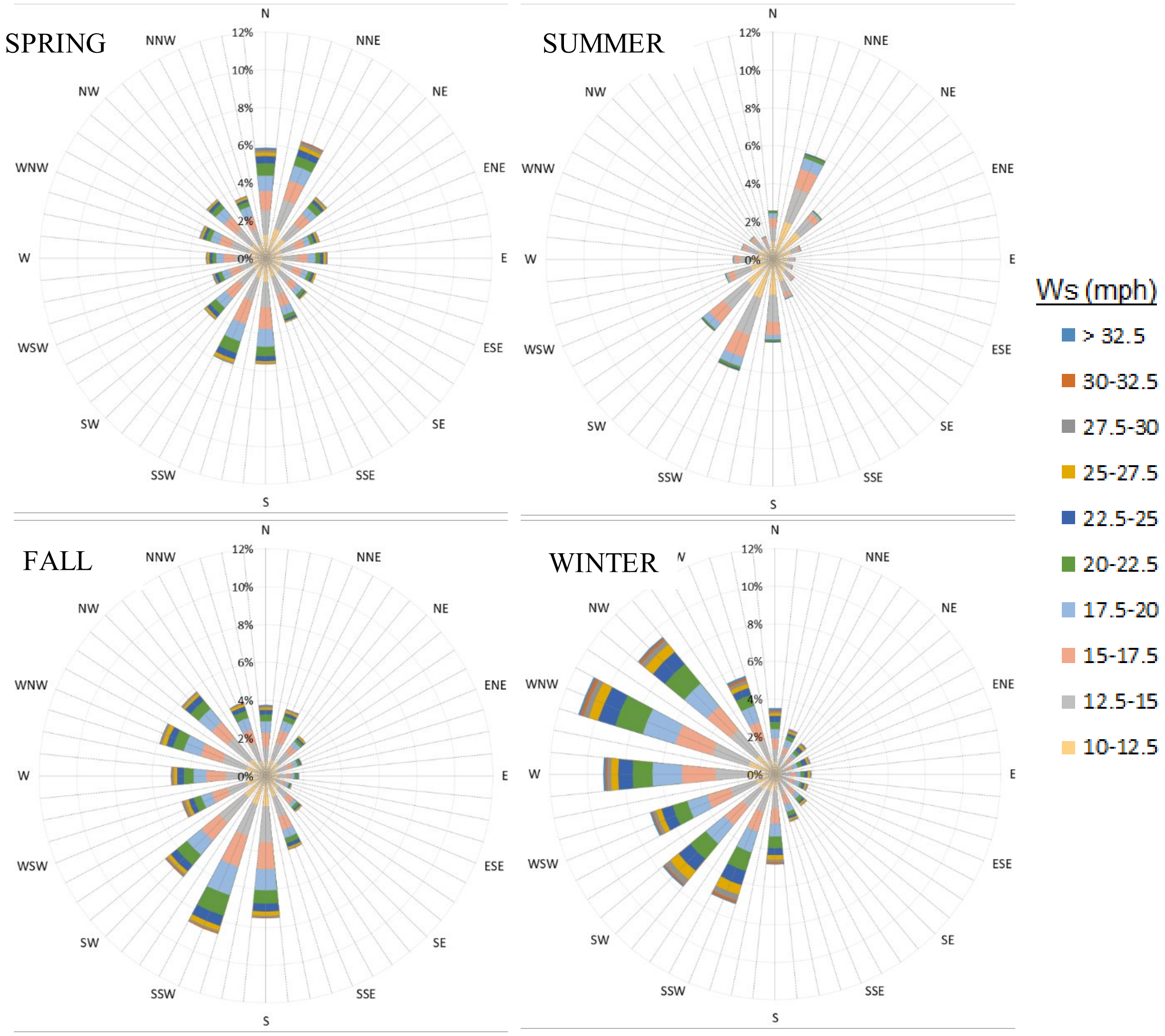

Figure 22: WIS Station 94033 Wind Rose by Season

Table 12: Hourly Wind Speeds by Direction & Return Period, mph, WIS ST94033

Return Periods	N	NNE	NE	ENE	E	ESE	SE	SSE
1 yr.	31.60	30.74	28.02	27.39	26.70	26.72	27.09	28.45
10 yr.	40.45	37.35	36.65	35.32	36.67	33.96	33.39	33.87
25 yr.	43.44	40.45	39.59	38.90	40.37	36.17	35.25	35.88
50 yr.	45.62	42.89	41.75	41.68	43.13	37.75	36.59	37.38
100 yr.	47.76	45.40	43.87	44.53	45.87	39.28	37.87	38.86

4.2.2 Winds

Historical recorded wind data was taken from the Wave Information Study (WIS) Station 94033 located offshore, approximately 4 miles east of the project site. This data includes 36 years of data from 1979 – 2014. The wind data was run through a Weibull distribution analysis to determine storm winds from 16 compass directions. Seasonal wind roses and return period storm winds are given in Figure 22 and Table 12. The roses show the summer to generally have less storm level wind events while the winter has the strongest and highest occurrence of storm winds.

4.2.2.1 Design Winds

For the purposes of design, the winds given in Table 12 are used to drive wave climate within the numerical models.

Wind-blown cross-shore and longshore transport of sands have not been taken account in this project and are not considered a larger driver of the longshore migration of the shoreline.

4.2.3 Currents

Currents along the shoreline of the park are driven primarily by winds and waves. Therefore, currents are strongest during storm events when waves are large and impact the shoreline at an angle. Longshore current, created by waves breaking along the shoreline, is the primary driver of longshore drift and longshore sediment transport. Longshore current is inherent to the sediment transport described in section 4.4.

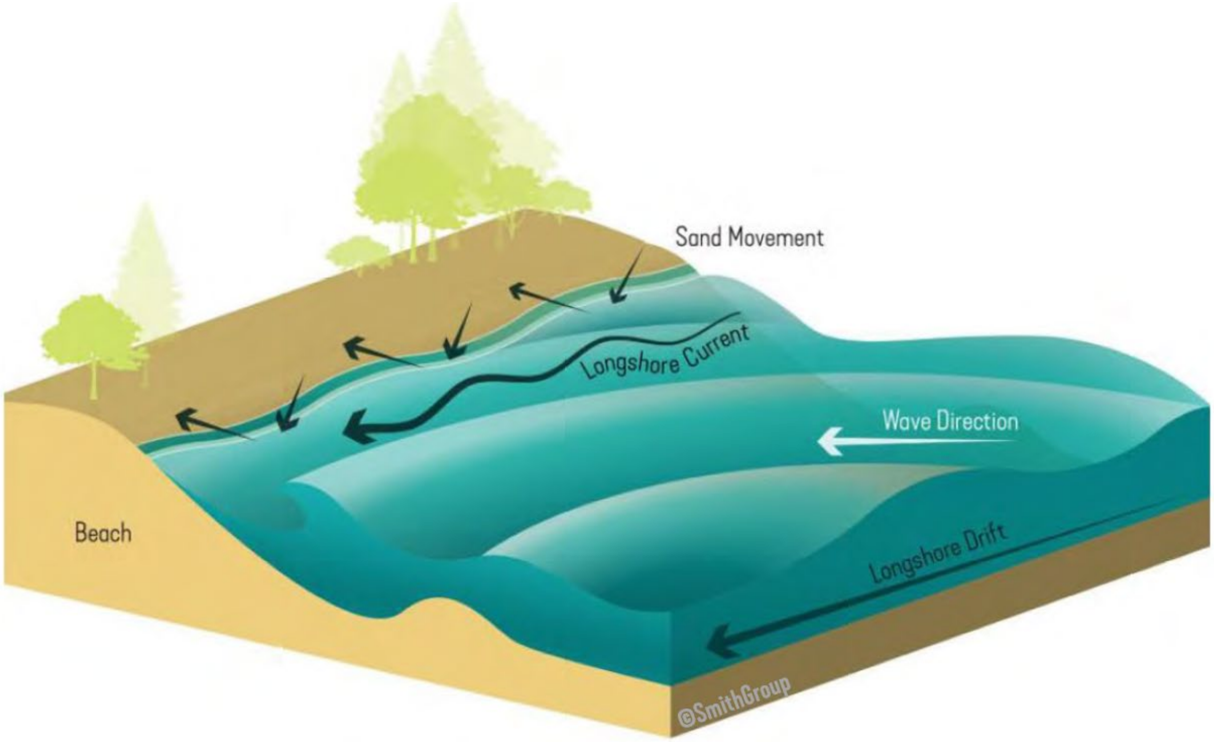

Figure 23: Longshore Transport due to Longshore Currents

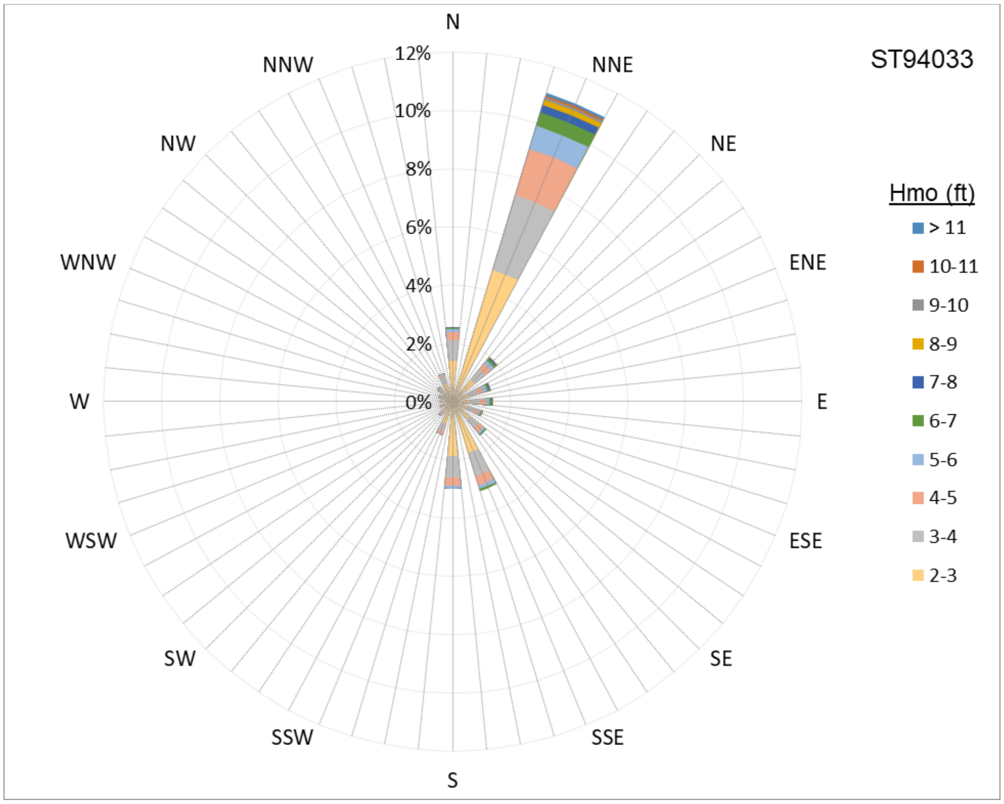

Figure 24: WIS Station 94033 Wave Rose

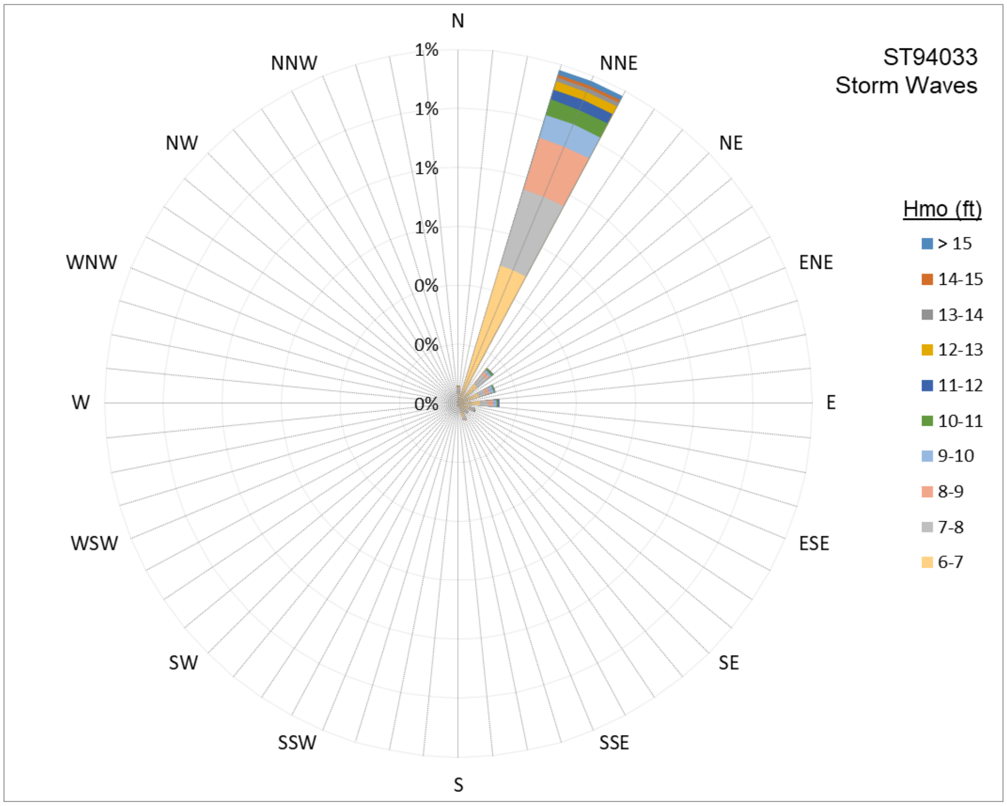

Figure 25: WIS Station 94033 Storm Wave (>6ft) Rose

4.2.4 Waves

Waves are the primary driver of longshore migration of the Illinois Beach State Park shoreline. While localized smaller studies of waves have been performed in the nearshore waters of the State Park, no consistent historical data set exists applicable to the full park shoreline. Therefore, offshore waves have been transformed to determine the nearshore wave climate through the use of empirical analysis and numerical models.

4.2.4.1 Deep Water Waves

Offshore wave conditions for the site were collected from USACE's Wave Information Studies (WIS) with a recorded period of 35 years (1979-2014). Data was extracted for WIS Station 94033 located approximately 4 miles east offshore the project site where the water depth is approximately 115 ft. The most common wave direction at the project site is from the north-northeast. Figure 24 shows the wave rose for all waves greater than 2ft.

Storm waves, here defined as greater than 6 ft in height, originate from the north-northeast 80% of the time compared with only 3% out of the south-southeast, as shown in Figure 25. Therefore, the highest energy and the most frequent waves come from the northeast quadrant which will drive currents and longshore transport to the south. Storms of this intensity are more frequent during winter and early spring months, as shown in Figure 26. The largest event on record occurred on 12/12/2010 with an offshore peak wave height of 18.8 ft.

Return period wave climates for each direction affecting the shoreline were developed using the offshore wave data and by performing a Weibull distribution analysis. These return period events can be seen in Table 13.

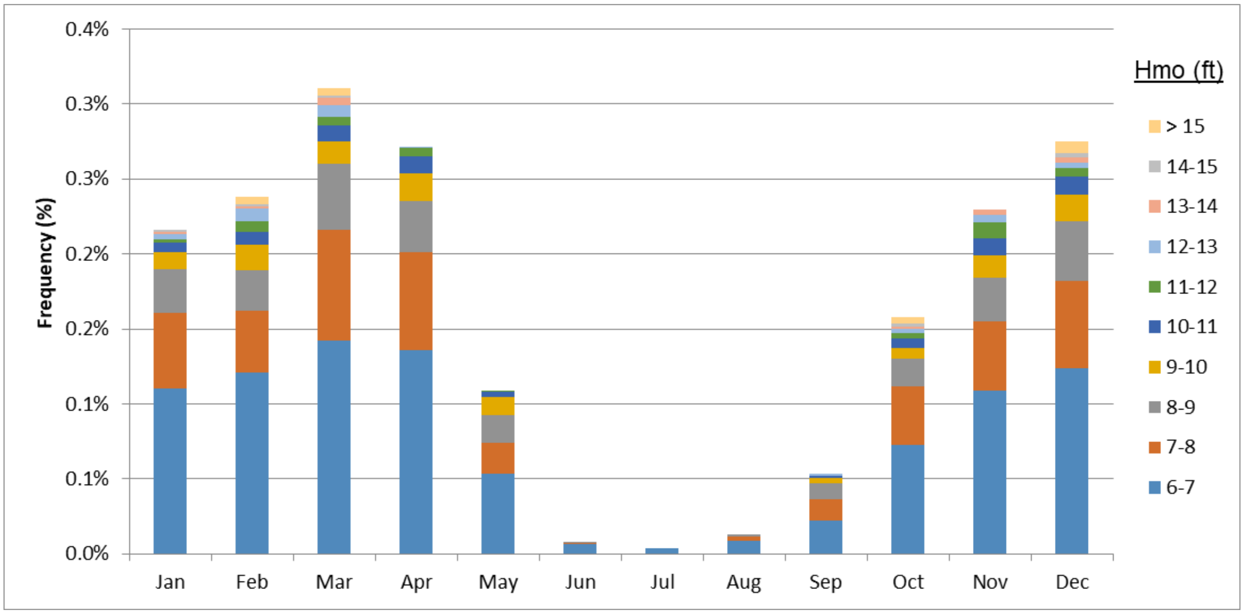

Figure 26: Monthly Distribution by Wave Height

Table 13: Return Period Wave Transformation from Offshore to Nearshore

		Offshore			-22 ft Depth		-12 ft Depth	
Return Period		Tp (s)	Hmo (ft)	Direction	Hs (ft)	Direction	Hs (ft)	Direction
1 yr	NNE	8	10.1	22.5	6.3	57.9	6.7	66.8
10 yr	NNE	10	16.1	22.5	10.5	64.7	*broken*	71.9
25 yr	NNE	10.5	17.9	22.5	11.9	66	*broken*	72.9
50 yr	NNE	11	19.2	22.5	12.9	67.2	*broken*	73.8
100 yr	NNE	11.5	20.5	22.5	*broken*	68.3	*broken*	74.6
1 yr	NE	6	7.5	45	6.2	58.6	6.4	66.4
10 yr	NE	7.5	10.7	45	9	64.5	*broken*	71.4
25 yr	NE	8	12.9	45	11	66.1	*broken*	72.6
50 yr	NE	8.5	14.9	45	12.8	67.5	*broken*	73.7
100 yr	NE	9	17.1	45	*broken*	68.8	*broken*	74.8
1 yr	ENE	6	6.7	67.5	6.1	73.8	6.4	77.9
10 yr	ENE	8	10.7	67.5	10.1	77.7	*broken*	81.3
25 yr	ENE	8.5	12.7	67.5	12.2	78.5	*broken*	81.9
50 yr	ENE	9	14.3	67.5	*broken*	79.2	*broken*	82.4
100 yr	ENE	9.5	16	67.5	*broken*	79.8	*broken*	82.9
1 yr	E	6	6.7	90	6.1	90.6	6.6	91
10 yr	E	7.5	11.3	90	10.9	90.9	*broken*	91.3
25 yr	E	8	13	90	12.7	91	*broken*	91.3
50 yr	E	8.5	14.2	90	*broken*	91.1	*broken*	91.4
100 yr	E	9	15.4	90	*broken*	91.1	*broken*	91.5
1 yr	ESE	5.5	5.8	112.5	5.3	108.5	5.5	105.2
10 yr	ESE	6.5	9.1	112.5	8.4	106.6	*broken*	103.5
25 yr	ESE	7.5	10.2	112.5	9.6	105.1	*broken*	102.1
50 yr	ESE	8	11.1	112.5	10.6	104.4	*broken*	101.6
100 yr	ESE	8.5	11.9	112.5	11.6	103.8	*broken*	101.1
1 yr	SE	5.5	5.7	135	4.9	125.4	4.9	118.2
10 yr	SE	6	8	135	6.8	123.3	7	116.2
25 yr	SE	6.5	8.5	135	7.3	121.3	*broken*	114.6
50 yr	SE	6.5	8.9	135	7.6	121.3	*broken*	114.6
100 yr	SE	7	9.3	135	8	119.6	*broken*	113.1
1 yr	SSE	6	6.2	157.5	4.4	135.9	4.3	125.2
10 yr	SSE	6	7.8	157.5	5.5	135.9	5.4	125.2
25 yr	SSE	6.5	8.3	157.5	5.8	132.8	5.8	122.8
50 yr	SSE	7	8.7	157.5	6	130.1	6.2	120.7
100 yr	SSE	7.5	9	157.5	6.2	127.8	6.5	118.8

*Red & Italicized cells represent broken waves due to depth-limitation (>60% water depth)

4.2.4.2 Wave Breaking

To calculate the breaking wave heights for irregular waves, the CEM (Part II, 2003) suggests a depth limited breaking criteria as

$$H_{mo,b} -= 0.1L \, tanh \; kd$$

For wave periods over the range of 7 to 11 seconds, and in 10 to 21 ft of water, which is the range where the offshore structures will be placed, this refinement gives a breaking coefficient ranging from 0.58 to 0.61. For the purposes of preliminary design, a value for $H_{mo,b} = 0.6d$ will be assumed.

It is important to note that the depth limited $H_{mo,b}$ value is not the maximum wave height to be experienced at the breaking depth. The maximum individual breaking wave height (Max H_1,b) will be up to 50% larger than the breaking significant wave height.[12] It is not common to design structures based on this maximum wave height but important to recognize that a rare wave of this height could impact the structure and result in damage. The percentage of damage this may produce is discussed in section 5.2.1.

In summary, the following breaking wave criteria has been used for design:

- Depth Limited Wave Height = 60% Water Depth
- Maximum Wave Height at Breaking Depth = 90% Water Depth

Note that the wave conditions at the site are not defined by the intensity of the storm event but rather by the lake level due to depth limited wave breaking. Therefore, the probability of meeting the design wave condition is given by the probability of the lake level supporting the wave.

4.2.4.3 Nearshore Waves

Deepwater wave conditions were manually transformed to the nearshore using linear shoaling and refraction assumptions. Limited MIKE 21SW runs were used to check veracity of the computed wave propagation values. Data from the WIS station 94033, was translated (shoaled and refracted) to the shoreline.

Table 13 presents the shoaled and refracted wave height, period, and local wave direction computed at depths of 22 ft and 12 ft. These depths were chosen as they are representative of the water depths where the offshore structures will be located.

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[12] Seelig, w., (1980) Maximum Wave Heights and Critical Water depths for Irregular Waves in the Surf Zone, USACE, CETA 80-1

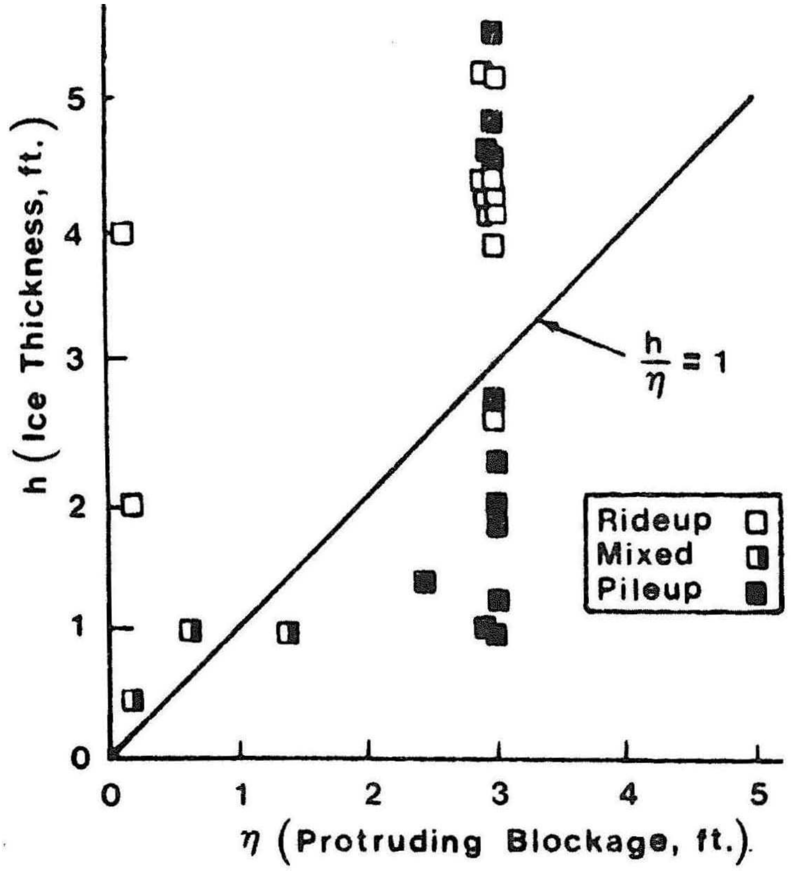

Figure 27: Relation of Ice Ride Up to Pile Up as a Function of Relative Surface Roughness[13]

Table 14: Average Weather Conditions in Waukegan, IL[14]

	Jan	Feb	Mar	Apr	May	Jun
Avg High Temp (°F)	29	33	43	55	67	77
Avg Low Temp (°F)	12	17	26	36	46	55
Avg Precip (in)	1.06	0.98	2.13	3.7	3.31	3.35

	Jul	Aug	Sep	Oct	Nov	Dec
Avg High Temp (°F)	82	80	73	62	47	34
Avg Low Temp (°F)	61	60	52	41	30	18
Avg Precip (in)	3.58	3.90	3.74	2.28	2.68	1.65

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[13] Cox, J., J. Lewis, R. Abdelnour, and D. Behnke, (1983) Assessment of Ice Rde up/Pile up on Slopes and Beaches, Proc. Port and Ocean engineering under Arctic Conditions, vol. 2.

[14] www.usclimatedata.com

4.2.4.4 Design Waves

The wave climates selected for design are related to how they are being used. Structural design must resist the forces of large storm events while the shoreline morphology is more directly related to an aggregate annual wave climate rather than a single storm event. Nearshore wave conditions at the 565 IGLD85 contour were determined based on offshore statistics. These wave conditions were used throughout the analysis and design of the structures. For more information about the selection of wave climate to represent morphology, see Section 4.4.

The following design wave events shown in Table 15 have been identified for design.

Table 15: Project Selected Design Wave Climates, ref 565 IGLD85 contour

Purpose		SWL (ft IGLD 85)	Tp (s)	Hmo (ft)	Dir (deg)
Morphology	Design Primary Morphology Wave Climate	582.4	9	4.9	61 or 65
Stability	Low Water, Nearshore Design Wave Climate	576.0	11.5	6.6	65
Stability	High Water, Nearshore Design Wave Climate	583.3	11.5	11.2	65
Stability	Extreme Water, Nearshore Design Wave Climate	585.2	11.5	12.1	65
Stability	Low Water, Nearshore Design Wave Climate	579.2	7.5	6.2	130
Stability	High Water, Nearshore Design Wave Climate	582.2	7.5	6.2	130

4.2.5 Ice

The ice thickness was estimated using methods recommended by the USACE. This methodology uses cumulated temperature, location, and ice cover conditions to estimate thickness.

Daily average temperature was collected from Waukegan National Airport, located approximately 3 miles southwest of the project site. Temperature data includes roughly 29 years of data ranging from 1989 – 2018. The coldest winter on record during this time occurred in 2013-2014. Based on the top 5 coldest winters on record, it is recommended that an ice thickness of 28 inches be used for design.

To minimize damage from ice ride-up against the shoreline protection structures, the diameter of stones place in exposed locations need to be larger than the thickness of the ice, as shown in Figure 27. Therefore, target stone diameters considering ice related stability need to be at least 30 inches, which equates to roughly a 1-ton stone.

4.2.6 Weather

Knowing the weather at the project site helps inform when certain events such as park usage, ice formation & melt, and flooding may take place. The weather shown in Table 14 was collected from U.S. Climate Data for Waukegan, IL.

Table 16: Beach Sand Samples, August 2020 & January 2021

Sample	Mean mm	% fines (P200)
NB-1	0.33	0.08
NB-2	0.49	0.01
NB-3	0.44	0.13
NB-4	0.44	0.18
NB-5	0.30	0.11
NB-6	0.52	0.04
NB-7	0.35	0.20
NB-8	0.35	0.30
Average	0.40	0.13

Table 17: Sand Thickness from Shallow Boreholes within IBSP[15]

Location	Easting	Northing	ISGS API no.	Top (m)	Bottom (m)	Description	Total sand (m)
IBSP	433765.22	4695690.66	120972524200	0	8.8	Mixed sand (fine to coarse) and gravel.	8.8
IBSP	433778.69	4696494.97	120972524300	0	8.8	Fine to very coarse sand. Till at 8.8 m.	8.8
IBSP	433811.83	4698108.29	120972526100	0	9.8	Fine to coarse sand. Till at 9.8 m.	9.8
Beach Park	433920.42	4698203.99	120972684900	0.9	10.7	Sand and gravel. Till at 10.7 m.	9.8
N. Beach Park	433926.69	4698606.14	120972684800	0.9	10.7	Sand and gravel. Boulder gravel at 10.7 m.	9.8
IBSP	434035.54	4698705.06	120972526000	0	9.1	Fine to medium sand. Till at 9.1 m.	9.1
IBSP	434030.68	4699112.76	120972524800	0	9.1	Fine to medium sand. Till at 9.1 m.	9.1

[a] The coordinates are presented in UTM (Universal Transverse Mercator) zone 16N (WGS 84) - EPSG:32616. See Figure 2 for location. ISGS, Illinois State Geological Survey; IBSP, Illinois Beach State Park

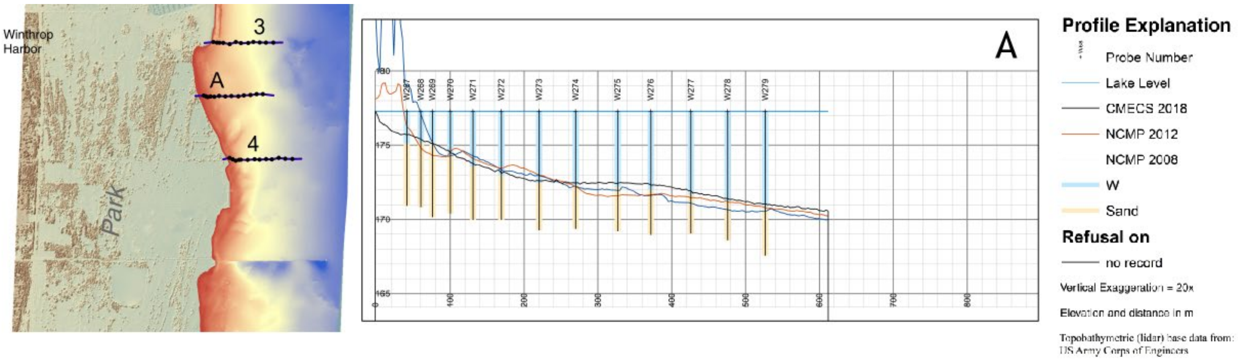

Figure 28: Littoral Sand Thickness Mapped by Hydraulic Jet[16]

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[15] Mwakanyamale, K., Brown, S., and Theuerkauf, K., (2020) Mapping Sand Distribution Along the Illinois Lake Michigan Shore Using an Airborne Electromagnetic Method, Illinois State Geological Survey

[16] Phillips, A., (2019) Contract Report Deliverable, Great Lakes Geologic Mapping Coalition FY2018 Three-Dimensional Mapping of Surficial Deposits Project 2. Offshore Lake County

4.3 Geotechnical Data

4.3.1 Sand Grain Size

The Illinois State Geological Survey and Illinois State Water Survey Sediment Laboratory collected 46 sand samples across the site and analyzed them for grain size distribution by laser diffraction in 2018.

A review of the sand samples shows the material ranges from 0.07mm to 14.3mm, with 0.3mm being the approximate median size.

Several sand samples of the beach were collected during the sand survey in August of 2020. Supplemental samples were collected in January of 2021 to further characterize the grain size statistics of the native beach sand. The samples collected during the sand survey yielded an average mean grain size of 0.40 mm and an average percent fines (#200 sieve) of 0.13%.

4.3.2 Sub-Surface Geology

A geotechnical survey was not conducted as part of this project. Many sub-surface investigations have been performed by the Illinois State Geological Survey which, in general, show an average of 29.5 ft (9m) depth of fine to coarse sand over a layer of till.

Compacted sand and till create a good foundation for breakwater construction. Initial consolidation of the sand is anticipated but with the composite geotextile geogrid and bedding layers of the breakwater design, the settlement is anticipated to be marginal. Lakebed surface breakwater toes have been included in the cross-section design to provide armor stability and limit toe erosion.

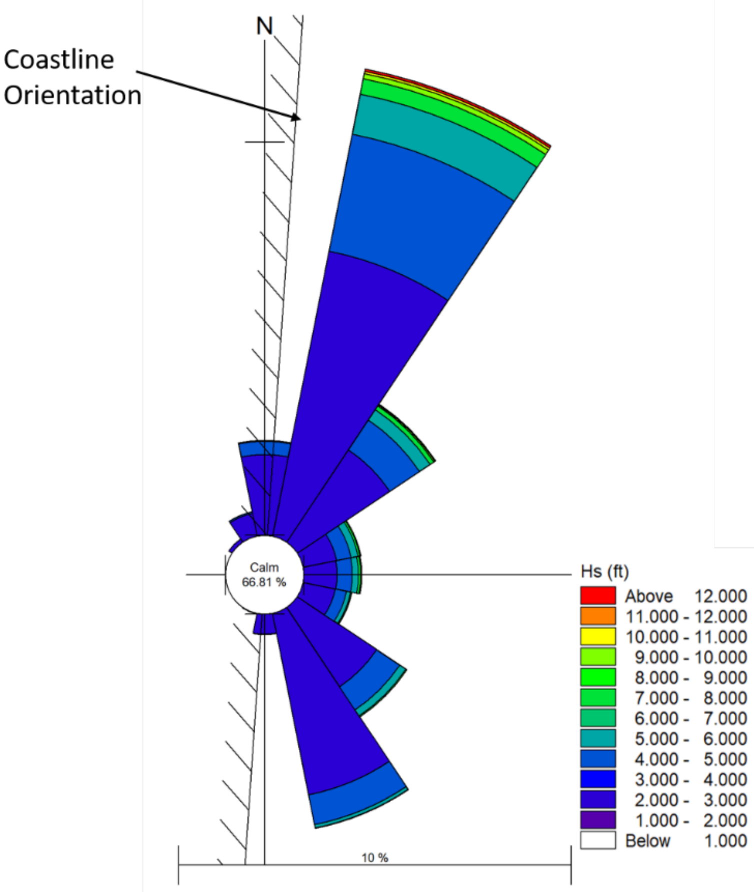


Figure 29: Offshore Wave Rose

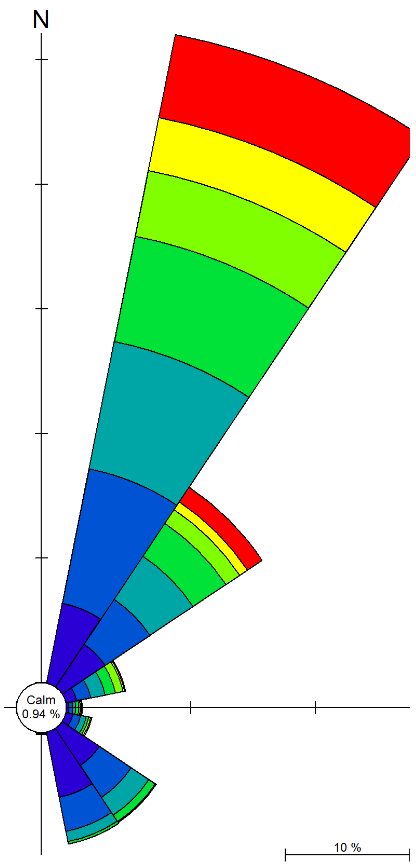


Figure 30: Sediment Transport Rose

4.4 Existing Sediment Transport

To calculate the existing annual net sediment transport, a representative nearshore wave climate was created using the 35 years of historical deep-water wave data and transforming it to the nearshore through refraction and shoaling. The offshore wave climate, shown in Figure 29, consists of several events, each described by its frequency of occurrence, propagation direction, and wave height. The summation of the occurrence of the individual wave climates has been assumed to be one average year and therefore this representative wave climate characterizes an average year of lake events.

The representative sediment transport rose associated with this wave climate, based on the orientation of the coastline, is shown in Figure 30. As shown, despite the percentage of events from the southeast, the larger storms and predominant wave direction from the northeast results in the largest percentage of sediment transport.

Table 18: Most Influential Wave Climates on Littoral Transport

		Offshore				
	Rank	**Hmo (ft)**	**Tp (s)**	**Wave Dir (deg)**	**Occurrence**	**Percentage Transport by Direction**
North to South	1	3.5	6	22.5	2.15%	7.5%
	2	5	6	22.5	0.90%	6.5%
	3	6.5	8	22.5	0.36%	5.4%
	4	8	8	22.5	0.20%	4.6%
	5	3.5	5	22.5	1.46%	4.3%
South to North	5	5	5	157.5	0.23%	5.0%
	4	3.5	5	135	0.33%	6.1%
	3	1.5	4	157.5	2.14%	6.5%
	2	3.5	4	157.5	0.86%	6.7%
	1	3.5	5	157.5	0.78%	9.1%

The wave climates for numerical and physical testing of the littoral transport at Illinois Beach State Park were different. This is due to the ability of the numerical model to run years of data within a number of hours whereas littoral transport was 'sped up' in the physical model by using a larger wave environment. These wave climates are given in Table 19.

Table 19: Design Offshore Wave Climate for Littoral Transport

	Hs (ft)	Tp (s)	Offshore Direction (deg)	Nearshore Direction (deg)
Most Influential Littoral Transport Wave Climate	4.5	6	22.5	55
Morphological Climate Used in Physical Modeling	4.9	9	22.5	65

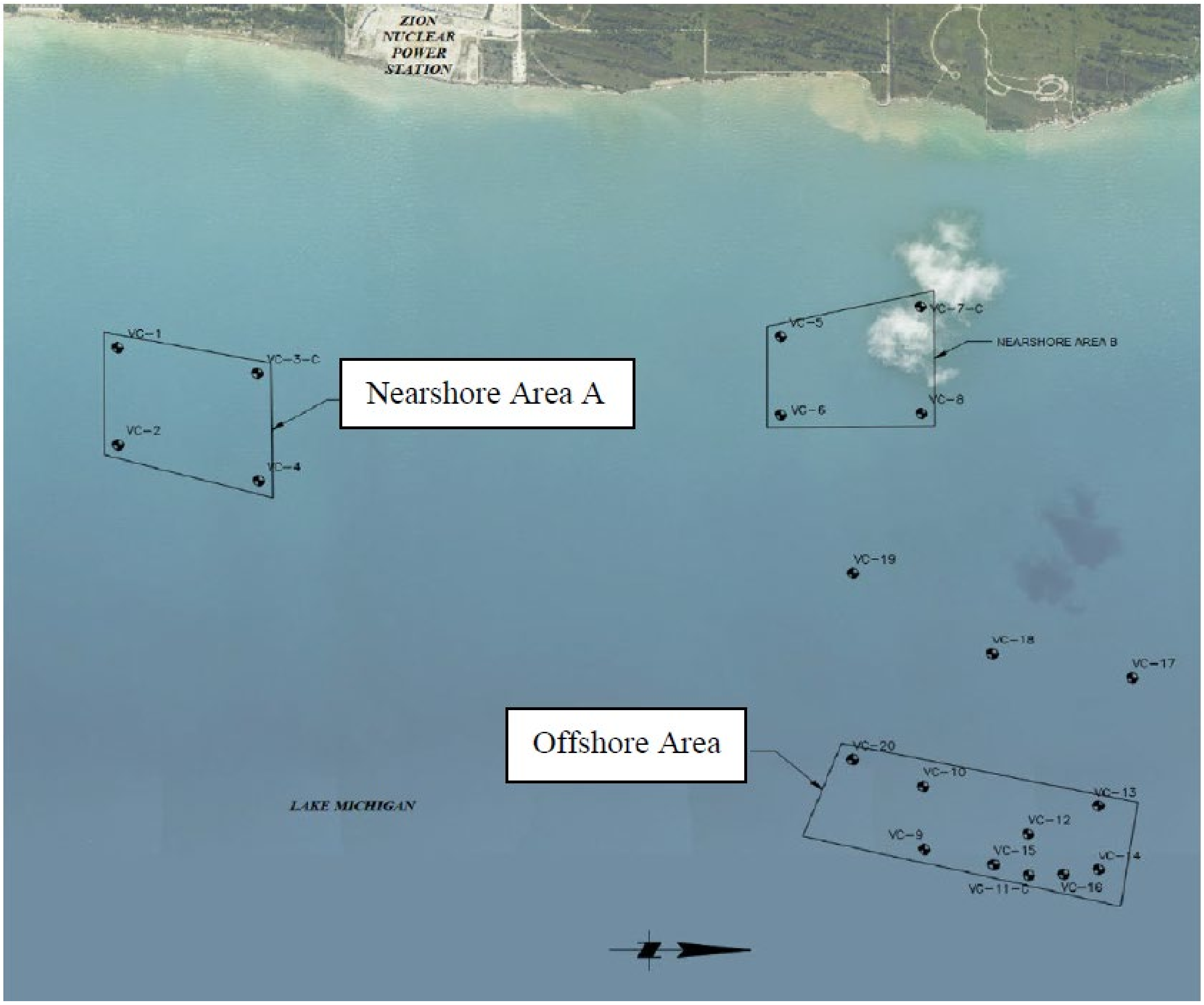


Figure 31: Potential Offshore Sand Borrow Source Areas

4.5 Construction Materials

4.5.1 Sand

Sand used within the design shall be all-natural material with a median size appropriate for location and function. Material shall be narrowly graded to promote water drainage to reduce surface retention.

Sand may be sourced from upland or offshore sources. Upland sources are limited to approved quarries with sufficient quantity and appropriate gradation. All efforts shall be made to find a single quarry to supply the full quantity needed to maintain color and consistency. Material relocated to the shoreline from within the park will not be allowed.

Gahagan and Bryant (GBA) was subcontracted by Edgewater Resources to perform a sand mining survey off the coast of Illinois Beach State Park. The objective was to find a potential borrow source of sand that could be used for beach nourishment as part of the proposed shoreline protection design at Illinois Beach State Park (IBSP). Generally, the location of the survey took place along the shoreline of Areas 1-3, from 100 feet off the beach to a water depth of approximately 60-65 feet. GBA used a fathometer and a sub bottom profiler to establish sand thickness, collected surficial grab samples, and advanced vibracore samples to accomplish the following goals:

- Estimate the thickness and volume of available sand layers
- Determine the grain size and percent fines for suitability as a borrow source

GBA identified three potential burrow source areas based on the sub bottom profile and surface grab samples, Figure 2. Twenty vibratory samples were advanced in these three areas. The suitability of the borrow source material was evaluated by comparing the grain size distribution data between the borrow source and the native beach sand at the areas where beach nourishment will be required. The full results of this study can be found in GBA report “Illinois Beach State Park Sand Source Survey” dated December 2020 with a summary cover letter provided by Edgewater Resources.

The findings of this study identified approximately 294,000 cubic yards of potential beach nourishment sand. However, based on a comparison with the existing shoreline sand, the overfill factor required would be between 1.62 – 2.75. If deemed cost effective, opportunities to use this sand include:

- Placement within newly sheltered areas
- Placement under a veneer layer with larger average grain size.
    - Preliminary analysis suggests a veneer of 6 feet would protect against storm waves of 6 feet and 9 second period.

Other sources beyond upland quarry suppliers should be investigated to offset environmental impact to the Nature Reserve created by numerous sand supply trucks. These sources may include beneficial reuse of dredge material once tested for contaminants.

Table 20: Project Established Armor Gradations

Armor	**Gradation**	6 - 10	3.5 - 7	2.5 - 5	1 – 2.5	0.5 - 1
	M85 (tn)	10	7	5	2.5	1
	M50	8	5.25	3.75	1.75	0.75
	M15	6	3.5	2.5	1	0.5
	D85 (ft)	*5.6*	*5.0*	*4.5*	*3.5*	*2.6*
	D50	*5.2*	*4.5*	*4.0*	*3.1*	*2.4*
	D15	*4.7*	*4.0*	*3.5*	*2.6*	*2.1*

Table 21: Project Established Filter Gradations

Filter	**Gradation**	500 - 4000	300 - 2750	200 - 2000	100 - 1000	20 - 400
	M85 (lb)	4000	2750	2000	1000	400
	M50	2250	1525	1100	550	225
	M15	500	300	200	100	50
	D85 (ft)	*3.3*	*2.9*	*2.6*	*2.1*	*1.5*
	D50	*2.7*	*2.4*	*2.1*	*1.7*	*1.3*
	D15	*1.6*	*1.4*	*1.2*	*1.0*	*0.8*

4.5.2 Armor Stone

An extensive amount of armor stone material will be required for this project. Armor stone material may be granite, limestone, dolomite, quartzite, or any other rock-type which fulfils the quality requirements outlined in the specifications. These quality requirements include, but are not limited to the following:

- Specific Gravity: ≥ 2.60, preferred
    - If the specific gravity of the stone is $2.56 < \gamma < 2.60$, the size of the stone will be increased by 10%.
- Absorption
- Resistance to Freeze/Thaw
- Abrasion Resistance / Drop Test for Larger Armor Stone
- Elongation Restrictions

Testing requirements are outlined within the specifications.

Stone gradations, shown in Table 20 & Table 21, were established for this project and follow internationally accepted standards for gradation ranges and sub-layer requirements. Deviations from these gradations may be allowed if the M_{50} is equal to or greater than that specified.

Due to the quantity of stone forecasted for this project, multiple quarries may be required to meet demand. Separately, the contractor may choose to set up a project specific quarry.

4.5.3 Steel

No steel may be used as a surficial construction component in the creation of the beach control structures. Where steel sheeting already exists, incidental steel material primarily in the form of additional sheeting, may be used to adapt or link new works with the existing.

Repairs to damaged sheetpile within the project areas is included in the scope of this work. This specifically includes the outfall discharge described in section 3.6.4 and the sheetpile wall wrapping around the conference center grounds. Sheetpile in this area should be repaired/replace prior to sand nourishment.

The proposed groin at Kellogg Creek has not been designed. If deemed appropriate, sheetpile may be used within the construction of the groin.

4.5.4 Wood

Structural timber shall not be used as part of the completed shore protection islands. Natural woody debris such as tree stumps and root wads, driftwood, and wrack may be included in the breakwater island creation. With Engineer approval, those stumps and logs may be partially anchored to the islands using chain and cable which has a life span of at least 50 years. The woody materials will be installed as a component of the final armor placement so as to be locked into the armor stone matrix, not appended later.

Figure 32: Concrete Blocks Located in Area 2

Figure 33: Large White Cobble near Kellogg Creek

4.5.5 Concrete

Use of concrete, particularly recycled concrete pavement slabs, shall not be used as an alternative armoring material. Concrete may be used to form specialized habitat inviting features and formations such as nesting pods, or, if properly embedded, concrete slabs may be used to create habitat ledges and overhangs for aquatic benefit provided there is no exposed reinforcing steel, and the slabs are structurally competent.

4.5.6 Geotextiles

Synthetic geotextile material can be used as an alternative to small granular filter material or as confinement casing to encapsulate fine grained material intended to perform a similar non-exposed structural role.

4.5.7 Impermeable Barrier

Impermeable beach control structures are more effective at reducing wave transmission than permeable versions. The design of the impermeable barrier is left as an alternative for the design-build team. This barrier can be constructed from steel (safely embedded within the structure) or concrete. Concrete options may include additional design features which benefit habitat creation or reuse onsite derelict materials. The impermeable barrier should restrict water flow through the armor and filter layers of the stone breakwater structure.

4.5.8 Reuse of Existing Materials

Material from historical shoreline protection structures no longer serving this purpose may be recycled and reused within the new beach control structures. Highlighted are the concrete block units (shown in Figure 32) located in both Area 2 & Area 3, as well as the large white cobble clogging Kellogg Creek outfall (shown in Figure 33). Derelict materials within the identified areas of construction not reused must be removed from the site.

4.6 Federal, State, and Local Regulations

State and Federal regulatory have been consulted throughout the Design Development process. Based on these discussions, the following design/construction decisions were made:

- Breakwater construction will not require any dredging of the lakebed. All structures will be constructed on top of existing lakebed.
- Sand materials brought to the site from sources other than upland quarries will require contamination testing.
- Though there has not been a record of offshore sand mining for the purposes of beach nourishment being performed in the State of Illinois, there are no regulations against this type of work.

Figure 34: Planview Location of Healthy Port Futures Pilot Project

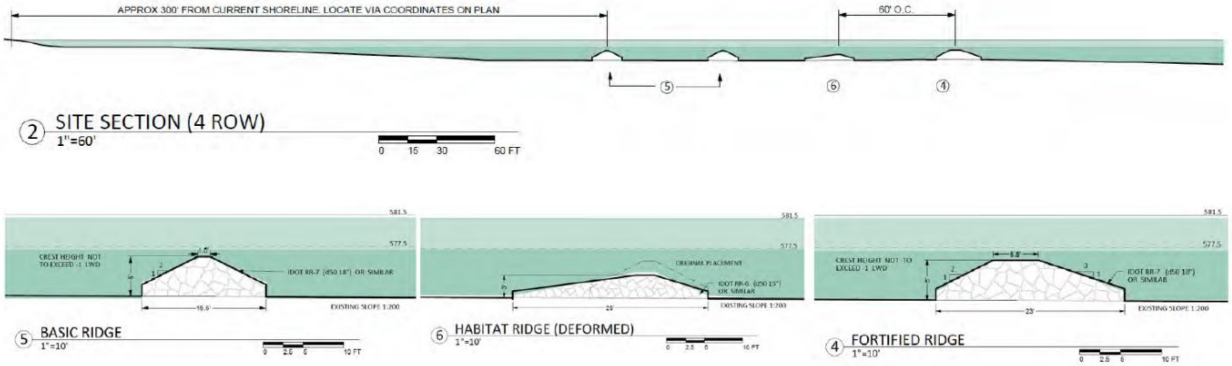


Figure 35: Cross Section of Healthy Port Futures

4.7 Other Factors of Importance

4.7.1 Constructability

Constructability, project phasing, and environmental protection are to be considered during the design process. Specifically, if the project must be undertaken in phases with completion delays between, or to partial levels of completion, how are the intended design objectives still met? Reviews for constructability, project phasing, and environmental protection should be considered.

4.7.2 Long-Term Operations & Maintenance

The main considerations for operations and maintenance include the following:

- Shoreline Protection Infrastructure: Structures will be subject to multiple destructive influences including wave impact, freeze-thaw cycling, ice impact and scour, toe scour, settlement, slope instability, human disturbance, and debris buildup. Shoreline structures will be designed to resist with little or no damage the 100yr storm at high water level as outlined within the Basis of Design. While annual or post-storm visual inspections are recommended, major regular maintenance is unacceptable.

- Beaches: Sandy material along the shoreline is considered dynamic and will shift with rising and lowering waters and storm events. The shoreline within Area 1 and Area 2 will not require regular maintenance or nourishment. Area 3 is a recreational swimming beach and as such, some grooming and maintenance will be required to maintain a clean and enjoyable recreational space. However, the intent is to avoid requiring major re-nourishment within the established service life. Regrading following a large storm event at higher water levels which results in shoreline flooding should be expected.

- Habitat: No long-term operations or maintenance requirements are proposed for the habitat installations. A short-term maintenance period may be required following construction to foster habitat creation and stabilization. In addition, supplemental removable fencing or netting may be considered during the nesting and fledgling season.

4.7.3 Healthy Port Futures

Healthy Port Futures is working with Illinois Department of Natural Resources, the Illinois Geologic Service, and the US Army Corps of Engineers to construct submarine ridges to slow sediment transport at the south end of Area 2. While this project also has the goal of stabilizing the shoreline, it is located outside of the defined construction area of Area 2 beach stabilization structures. It is likely the Healthy Port Futures project will be constructed prior to installation of the Area 2 breakwaters and therefore should be avoided during construction.

		Design Event (years)							
		1	5	10	25	50	100	250	500
Service Life (years)	10	100%	86%	63%	33%	18%	10%	4%	2%
	20	100%	98%	86%	55%	33%	18%	8%	4%
	50	100%	100%	99%	86%	63%	39%	18%	10%
	100	100%	100%	100%	98%	86%	63%	33%	18%

Risk

Table 22: Encounter Probability for Different Service Life Years

Table 23: Probability of Multiple 100yr Return Period Storms within Service Life

	Service Life (years)					
	1	5	10	25	50	100
0 Storms	99%	95%	90%	78%	61%	37%
1 Storm	1%	5%	10%	22%	39%	63%
2 Storms	0%	0%	0%	2%	8%	18%
3 Storms	0%	0%	0%	0%	1%	6%

Risk of a 1 in 100 Year Event

Table 24: Project Defined Service Life and Design Event

	Service Life (years)	Design Event (years)	Risk of Occurrence within Service Life
Breakwaters (submerged & emergent)	50	100	39%
Sand Beaches	10	25	33%

*The above design events have been assumed to occur at any water level.

5 Design Methodology

5.1 Design Event and Service Life

The probability of a particular return period event to occur during the lifetime of the project is a function of the service lifetime and the chosen extreme return period event. This probability was obtained using the equation:

$$E_1 = 1 - (1 - 1/T_1)^{L_1}$$

Where:

E_1 is the probability of occurrence of an event one time in period L_1

L_1 is the lifetime length (the number of years for the desired service life of the project)

T_1 is the return period event

A return period event does not suggest the storm event happens only once within a given number of years but rather is the inverse of the frequency of an event happening within any given year. For example, a 50yr return period event has a 1/50 (2%) probability of occurring every year. This means that even if a 50yr event were to happen this year, it still has a 2% probability of occurring next year. The probability of multiple storms within a given service life (100yr return period example) is shown in Table 23.

Breakwaters

Service life for breakwaters is presumed to be a minimum of 50 years without need for major rehabilitation. Based on Table 22, to achieve less than 50% probability of experiencing the design event during its service life, the design return period needs to be at least 100 years.

Beaches

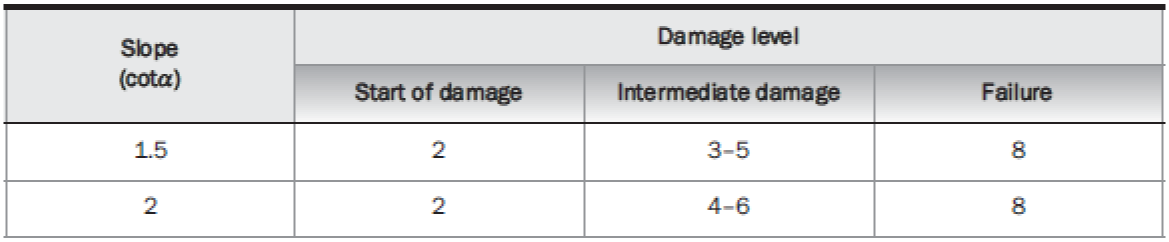
To maintain the character of the park's natural shoreline, sands similar to the existing shoreline will be used as nourishment. Cobble is not acceptable. This creates a dynamic shoreline which will shift and adapt under varying water levels and storm events. Because of this, the service life for design has been set at 10 years and should remain within the performance metrics outlined in section 2.2.4.

Habitat

Water level fluctuations and habitat sensitivity to water depth force migration and adjustment of certain species. While opportunities for habitat formation will be included within the design, they are inherently dynamic and may suffer damage due to extreme storm events. Resiliency in the form of elevation terracing should be included within the design.

Chosen service life and design events for the design are given in Table 24.

Table 25: Design Value Damage Parameter, van der Meer (1988)



Slope ($\cot\alpha$)	Damage level		
	Start of damage	Intermediate damage	Failure
1.5	2	3–5	8
2	2	4–6	8

5.2 Methodology for Developing Breakwater Structures

The following sections outline the methodology used for dimensioning and siting the nearshore and offshore breakwaters for the goal of shoreline stabilization.

For final design, further design objectives are to be investigated by the design-build team. Following are a list of design elements to be integrated as functionally possible.

1. Maintaining the projected area as designed within design development, island shapes may be modified in cross section to better dissipate wave energy and/or provide habitat opportunities.
2. Integrate smaller, round rock shapes on the lee side of the structures, where possible, to promote aquatic habitat.
3. Minimize overtopping within normal water levels, through geometry and absorption to support effective lee side habitat installation.

5.2.1 Material Sizing

Breakwaters, for the purpose of this project, fall into two categories: non- or marginally overtopped structures and low-crested and submerged structures. The sizing of the armor stone followed the guidance found in The Rock Manual[17] and was subsequently tested within the physical model for stability for scenarios within the design criteria.

Final armor selections are listed within the Design Development drawings.

5.2.1.1 Design Criteria Used for Breakwater Sizing

The design criteria used when determining armor layer stone sizing is listed below and tested in physical model testing. Deviations from these design criteria will require further review.

• Offshore Wave Climate	100yr Storm Event
o Wave Height:	Hs = 20.3 ft
o Wave Period:	Tp = 11.5 s
o Wave Direction:	Dir = 22.5 deg
o Storm Duration:	10 hours
• Depth Limited Breaking Coefficient:	0.6
• Specific Gravity of Armor:	2.6
• Damage Parameter:	
o Water Levels ≤ 582.75	"Start of Damage" ~ 5% stone movement
o Water Levels > 582.75	"Intermediate Damage" ~ 10% stone movement
• Permeability Factor:	0.4

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[17] CIRIA, CUR, CETMEF, (2007), The Rock Manual. The use of rock in hydraulic engineering (2nd edition). C683, CIRIA, London, ISBN 978-0-86017-683-1

Table 26: Recommended Crest Height, Standard Breakwater

Type	Emergent, Permeable	Emergent, Impermeable	Semi - Submerged
Crest Elevation, IGLD 85	586	584.5	580

Table 27: Recommended Crest Height, Habitat Breakwater

Type	Fish Street/Fish Finger, 20ft	Fish Street/Fish Finger, 40ft	Habitat/Lee-Side Pond, 70ft, Permeable	Habitat/Lee-Side Pond, 90ft, Permeable	Habitat/Lee-Side Pond, 70ft, Impermeable	Habitat/Lee-Side Pond, 90ft, Impermeable
Crest Elevation, IGLD 85	584	582	583	582	581.5	580.5

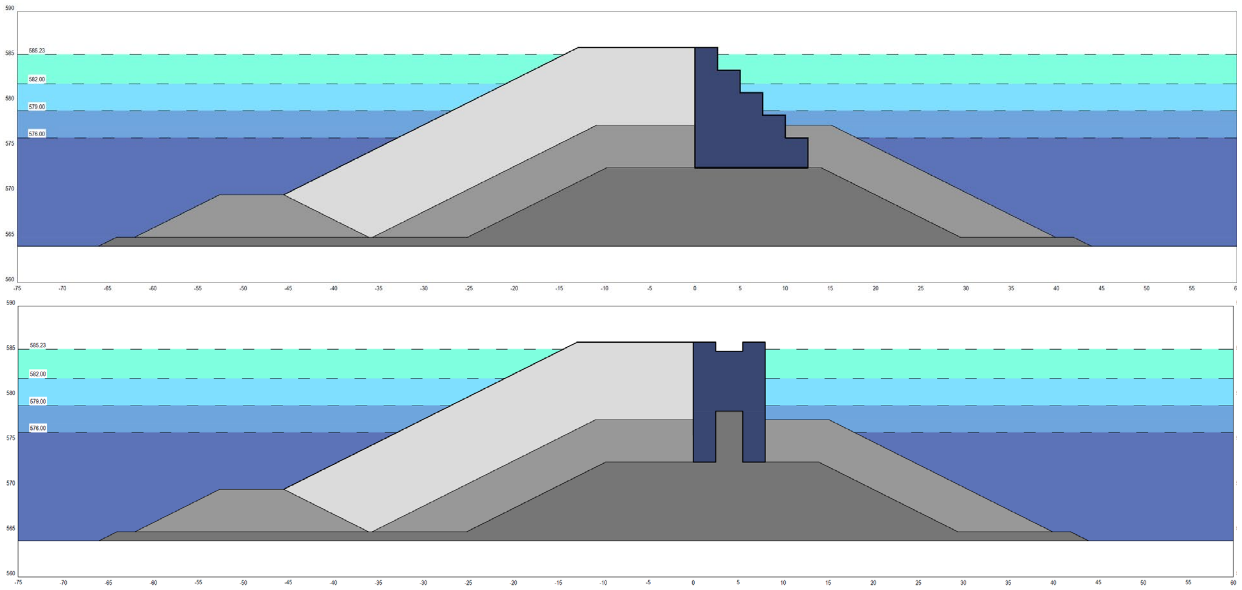

Figure 36 Potential Impermeable Structure Cross-Sections

5.2.1.2 Non- or Marginally Overtopped Structures

Breakwaters considered in this section have a crest elevation such that the stability of the front slope is not affected by wave overtopping or wave transmission. For this project, the van der Meer formula was the preferred method to calculate stone size followed by physical model testing.

5.2.1.3 Low-Crested and Submerged Structures

Structures designed to have crest heights within the water level fluctuation range will become submerged for possibly long periods of time allowing wave energy to pass over the crest of the structure. When emergent, low crested structures also allow for a large amount of overtopping. In both of these cases, waves do not only affect the stability of the front slope, but also the stability of the crest and rear slope.

Armor stone for overtopped structures was calculated using the method of Burger[18] and verified for stability through physical model testing.

5.2.2 Breakwater Cross Section

The breakwater cross section of shore protection structures can greatly impact their efficiency in maintaining the shoreline. Overly low crested structures which experience a large amount of overtopping at high water levels can result in undesirable agitation along the shoreline which promotes erosion and littoral transport. A high crested structure may adequately protect the shoreline but will create a visual barrier to the lake during periods of low lake level.

The primary goal of the beach control structures is the stabilization of the shoreline. As described in section 4.4, the primary driver of longshore sediment transport is oblique wave breaking. Therefore, to reduce the sediment transport rate, the wave agitation along the shoreline must also be reduced.

Physical model testing was performed on a number of breakwater cross sections to test for wave transmission. The permissible wave height along the shoreline in a high-water design scenario was set to 4ft. Based on the corresponding high-water design wave client, as given in Table 15, the permissible wave transmission coefficient was 0.35.

Based on this desired transmission coefficient, the crest elevations shown in Table 26 & Table 27 were established. For further definition of these breakwater types, refer to section 5.4 and the physical modeling reports.

Potential impermeable feature cross sections are shown in Figure 36.

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[18] Burger, G (1995). *Stability of low-crested breakwater: stability of front, crest and rear. Influence of rock shape and gradation.* Report H1879/H2415, WL | Delft Hydraulics, Delft; also MSc thesis, Delft University of Technology, Delft

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5.2.3 Layout

In addition to the height and width of the breakwater, the placement of the breakwater offshore and its relation to oncoming waves affects its efficiency to slow littoral transport. The following sections outline the practices used in design and tested in the physical model.

5.2.3.1 End Diffraction & Alignment

Waves diffract around solid objects. This creates a shadow zone behind the object where the agitation is reduced. The reduction in wave agitation creates zones were the littoral transport rate is decreased and therefore sediment slows down and will deposit within these areas. To maximize the shadow zone behind a breakwater, it should be angled facing toward the oncoming wave.

As discussed in section 4.4, offshore waves from the NNE are primarily responsible for the north to south littoral movement. As the primary purpose of this project is to slow this natural process to retain material along the shoreline for a longer period of time, angling the breakwaters toward the oncoming NNE will result in the largest projected shadow width along the shoreline. Because the rate of transport is directly related to the relative angle of the wave with the shoreline at the point of wave breaking, making the angle of the offshore structure nearly perpendicular to the wave breaker line reduces the transport rate offshore and within the shadow of the structure.

Aligning the breakwaters toward the northeast has the additional benefit of reducing the breakwater’s projected shadow width in relation to waves from the southeast. This allows these waves to impact the shoreline unfettered, temporarily reversing the littoral drift toward the north during such events.

5.2.3.2 Fish Tails

End diffraction locally changes the travel pathway of the wave as it wraps around the structure. This effect can be amplified by adding a second appendage, called a fish tail, which triggers double diffraction. This results in producing an opposing current behind the structure which locally reduces/reverses sediment drift.

5.2.3.3 Tombolos & Salients

As sand slows down and deposits within the shadow zone of the breakwater, it creates a salient; a build up of sand focused behind the structure. If the shadow zone is large enough, a tombolo forms where sand extends out to the offshore structure and creates a connective land mass. The negative aspect of tombolos is that they block downdrift transport and erosion immediately downdrift such a structure occurs. For Areas in which maintaining an open littoral cell was an objective, tombolo creation was discouraged.

Table 28: Relationship of Grain Size to the Average Slope of Beaches

Type of Beach Material	Grain Size (mm)	Average Slope of Beach
Very fine sand	0.0625-0.125	1°
Fine sand	0.125-0.25	3°
Medium Sand	**0.25-0.5**	**5°**
Coarse sand	**0.5-1.0**	**7°**
Very coarse sand	1.0-2.0	9°
Granules	2.0-4.0	11°
Pebbles	4.0-64	17°
Cobbles	64-526	24°

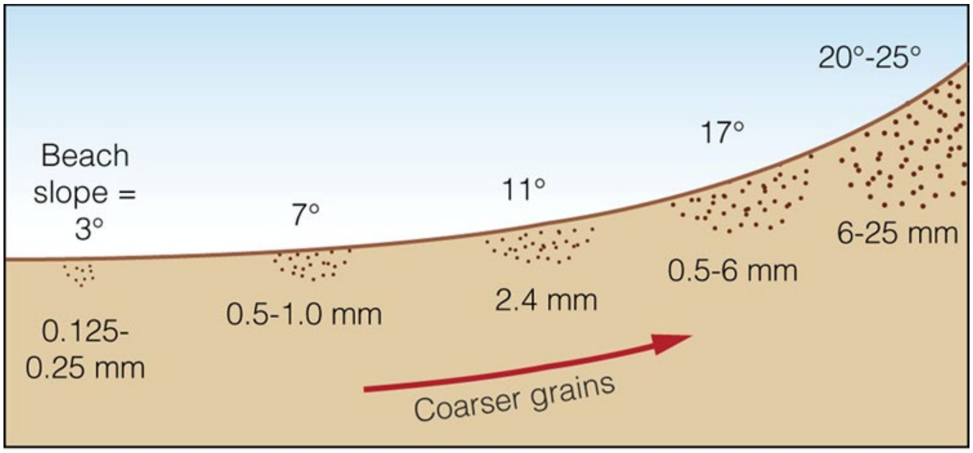


Figure 37: Relationship of Grain Size to the Average Slope of Beaches

5.2.3.4 Breakwater Curvature

Physical modeling highlighted a better performance when offshore structures were shaped convex versus concave (convex is bowing landward). However, concave structures can be more easily adapted to include lee-side habitat.

5.2.3.5 Saddles

Longer breakwater structures create large shadow zones. These structures can result in unintentional tombolo formation and therefore saddle areas of lower crest elevation were strategically included in the breakwater design to allow for more overtopping

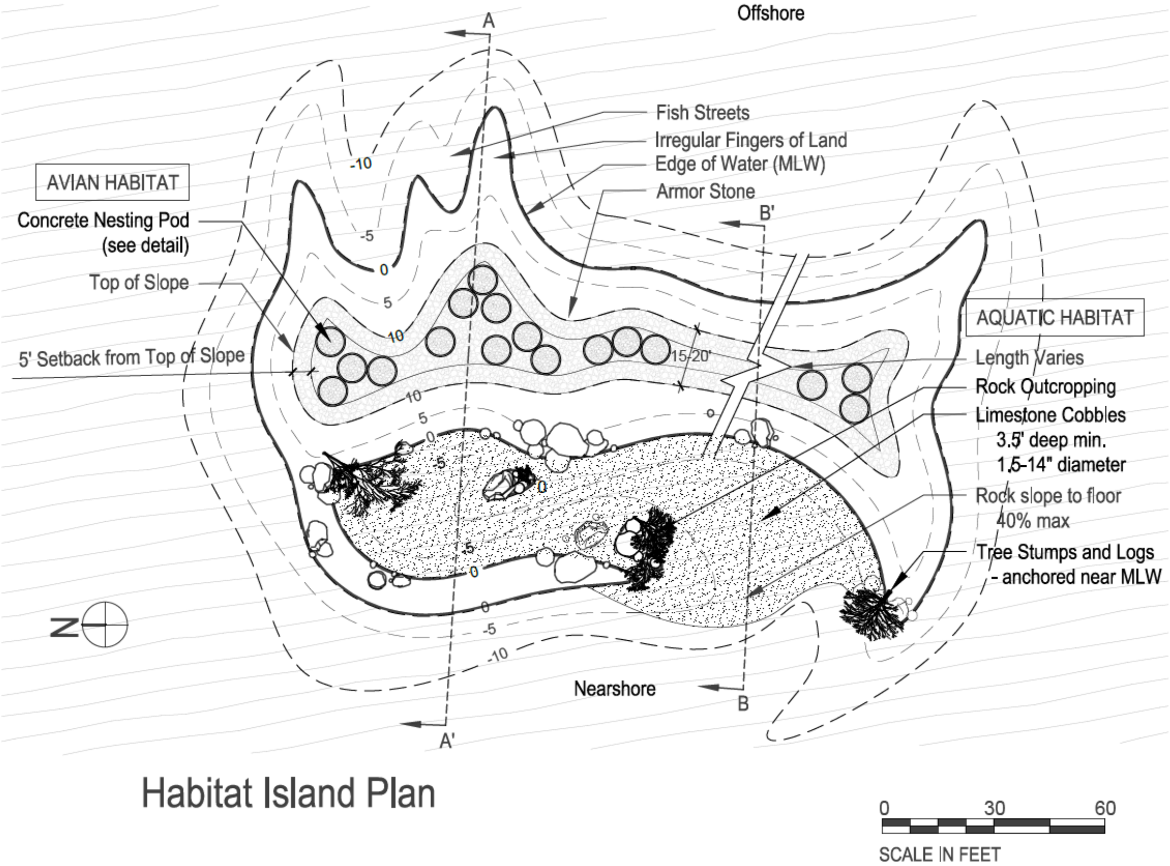
5.3 Methodology for Beach Design

Beach design was based upon the apparent high lake level equilibrium waterline. Beach nourishment should be composed of sand with a median grain size equal to or larger than the native material, listed in section 4.3.1. Ideally, the grain size distribution should closely match the native beach material. It is recognized that a perfect match/material may not be readily or economically available and therefore less than ideal borrow material may be used by increasing the quantity of fill material placed to offset losses. The natural slope of the beach will be determined according to the grain size as shown in Table 28 and can be seen in Figure 37.

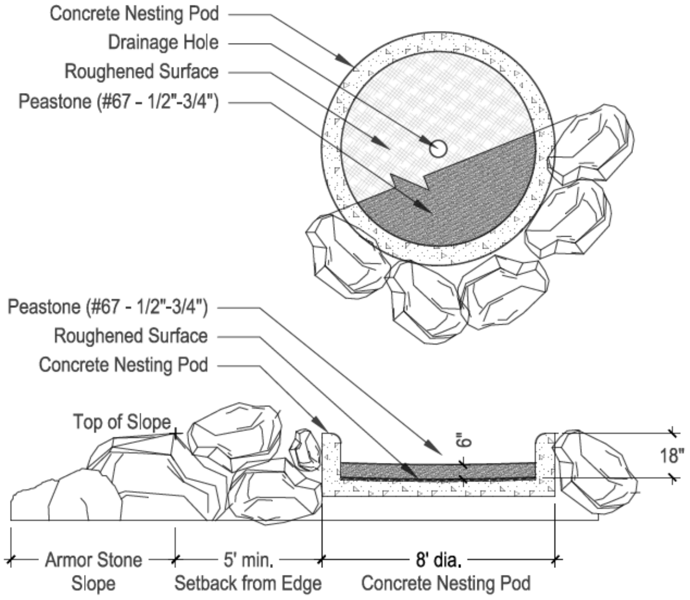
Source of the sand may either be from inland quarry, beneficial reuse of dredge material, or as a pumped slurry material harvested from an offshore borrow source. Particularly in the case of the offshore source, if the source D_{50} is smaller than native beach sand, the required sand volume shall include overfill volumes to offset losses and the beach slopes and geometry adjusted accordingly.

As stated in section 4.2.1.1.3 the flood elevation is higher than the existing topography. Sand is to be tied into to the highest elevation of the existing land. Where deemed appropriate to protect infrastructure, it is recommended that sand be placed at the back of the beach to create a dune system that will protect the leeside land from storm-related flood inundation.

The beach layouts shown within the Design Drawings depict the stabile beach profile following morphological testing within the physical modeling laboratory. A natural slope of 1V:15H was used to determine the pre-fill volume.



Habitat Island Plan



Concrete Nesting Pod

Figure 38: Typical Habitat Island Planform and Avian Features

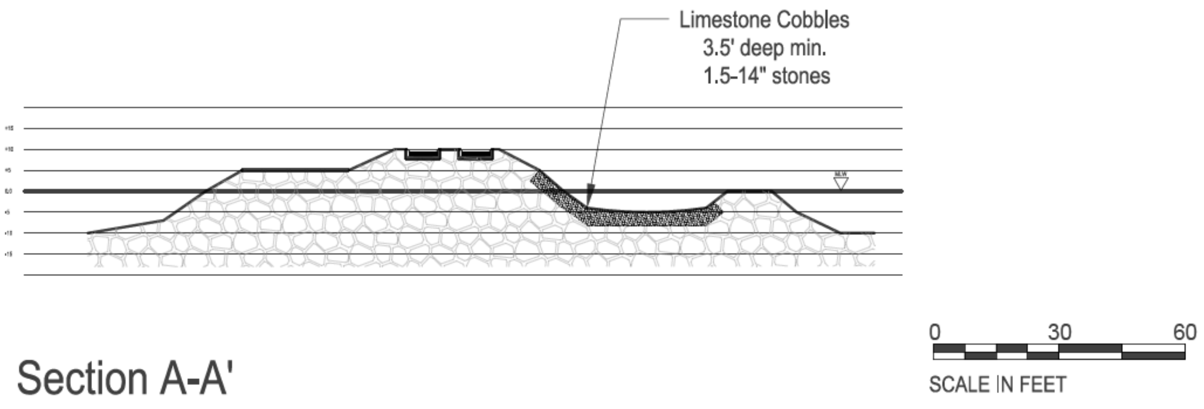
5.4 Habitat Improvement

5.4.1 Avian

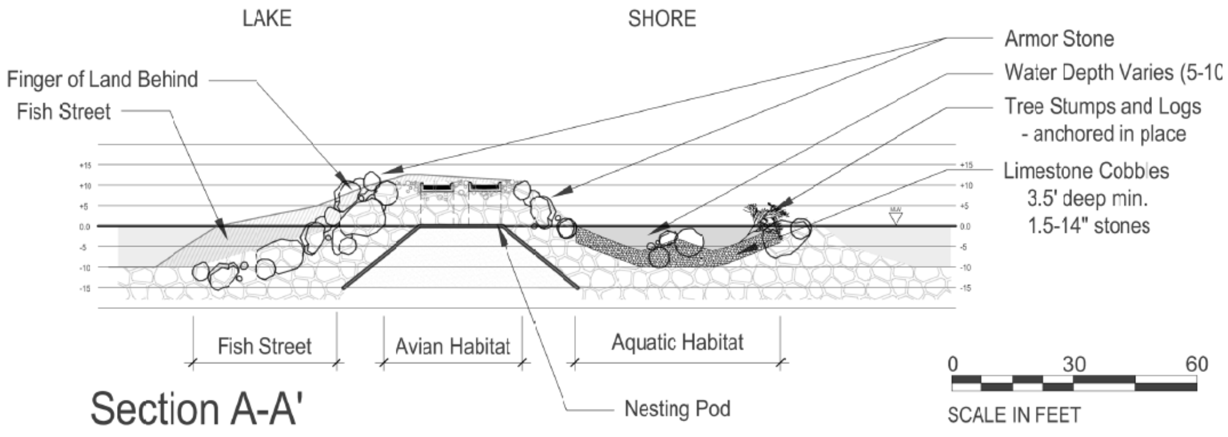
The Park attracts three coastal bird species considered of importance, the Piping Plover, the Common Tern and the Caspian Tern. The Piping Plover, (*Charadrius melodus*), is listed as an endangered species. The Plover uses sandy areas for nesting exclusively, but because a sand nesting environment will be difficult to maintain on a breakwater, the focus will be on providing new nesting for the Common Tern (*Sterna hirundo*) & Caspian Tern (*Hydroprogne caspia*). Common Terns nest on beach or islands with sparse vegetation (clover & thistle), sand, gravel, shell or cobbles less than 350 feet from the water, and Caspian Terns nest on sand, muddy or pebble shores with little vegetation

Desired Avian Habitat Features

- Prevent overwashing during breeding/nesting season (April-August)
    - Create pea gravel filled concrete nesting pods 8'x 8' square or 8 ft round with 18-inch (minimum) tall lip to retain gravel and confine baby terns
    - Pod floor surface roughened concrete or a gravel topcoat adhered or imbedded into concrete to keep covering pea gravel from shifting
    - Use #67 Pea size gravel (½" to ¾")
    - Recommend provisions for installation of tall pod perimeter fencing to deter predators and keep chicks from falling out into rocks or water
- Provide large driftwood anchored in a few spots for shelter



Section A-A' detailed typical



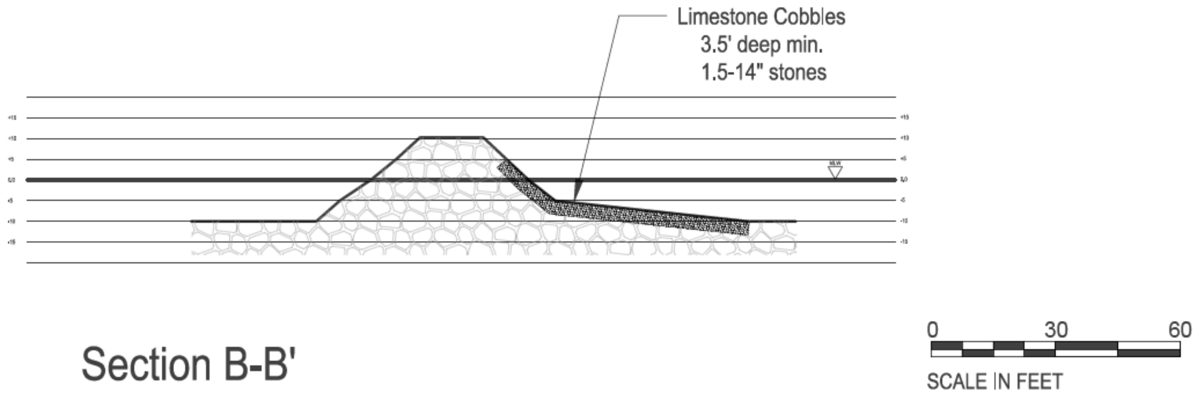


Figure 39: Typical Habitat Island Cross Sections

5.4.2 Aquatic

Much of the Great Lakes system suffers due to invasive species, both fish and mussels. Many of these compete for the same food source and habitat. At the present time little can be done to discourage colonization of habitat islands by these invasive species. However, the habitats to be created are targeted to be most conducive for use by the desired and endangered species in the Lake.

5.4.2.1 Targeted Aquatic Species:

Mudpuppy (*Necturus maculosus*): state threatened fully aquatic salamander.

- Reside under sunken logs, rocks, and vegetation in shallow waters up to water depths of 98 feet (30 meters).
- Mates in sheltered areas.
- Prefer water depth between 8 inches to 3 feet.
- Prefer shallow waters in spring & fall.
- Nests are made in nest cavities under areas of rocks, slabs, logs and debris during the fall season.
- Their nest cavities face downstream.
- They can eat invasive Round Gobys and Zebra Mussels.

Yellow Perch (*Perca flavescens*) is a favorite sport fish on Lake Michigan.

- Prefers water temperatures of 60-70 degrees F.
- Spawn in Lake shallows in the spring near aquatic plants or other cover and rocky substrate.
- Usually in deeper waters in the winter.
- Prefer vegetated bottom but will use sand, gravel, or rubble bottom and submerged trees.
- Tolerant of turbid conditions.
- Prefer pebble, cobble, and rubble (Phi values between -4 (16 mm) and –9 (~256 mm)) for spawning with lots of interstitial spaces.
- Eggs require protection from waves.

5.4.2.2 Desired Aquatic Habitat Features[19]

Mudpuppy habitat:

- Provide nesting interstices formed within 10-15inch cobble matrix situated between 0.7 ft and 3 ft in depth, preferably wetted in spring and fall. Face downstream.
- Locate in sheltered areas with slabs and overhangs

Yellow perch habitat:

- Juvenile: sheltered warm water on shelves and ledges no shallower than -5 ft, and on slopes between 22° and 31°.
- Adult: -10 ft and deeper. Generally active habitat zone moves vertically up or down with the 60-70degree F thermocline.
- Desired substrate for habitat is deep bed of rounded limestone cobble (mixture 1.5 to 14 inches inches) in sheltered area. Substrate bed to be at least 3.3 feet thick to provide a deep interstitial matrix optimal for egg incubation. This also allows eggs to settle away from invasive exotic predators, increasing survival.
- Large tree stumps or trunks to be added and anchored down if possible. Place within wetted zone.

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[19] Based on results from Grand Traverse Bay Artificial Reef study. Maximum current velocities for successful Lake trout, Cisco and Lake whitefish spawning at artificial reef was 4.05 (m/s) versus 2.18 (m/s) on a natural reference site.

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5.5 Other Considerations

5.5.1 Water Quality

Water shall not be allowed to become trapped within any area for a long period of time as to result in deterioration of water quality. While reduction of longshore currents is desired, they may not be eliminated from any area.

Sandy material must be narrowly graded to allow for quick absorption of water. Standing water anywhere on the beach above natural lake or groundwater elevations shall not be allowed.

5.5.2 Hazards

Access onto breakwater structures should be discouraged. Crests of shore connected structures shall be constructed jagged to reduce public interest.

Currents around the structures will not exceed 1.6 ft/s (0.5 m/s) in typical storm events, as experience suggests that currents that exceed that velocity should be considered hazardous for unprepared or inexperienced swimmers, and currents above 1 m/s are considered hazardous in all conditions[20].

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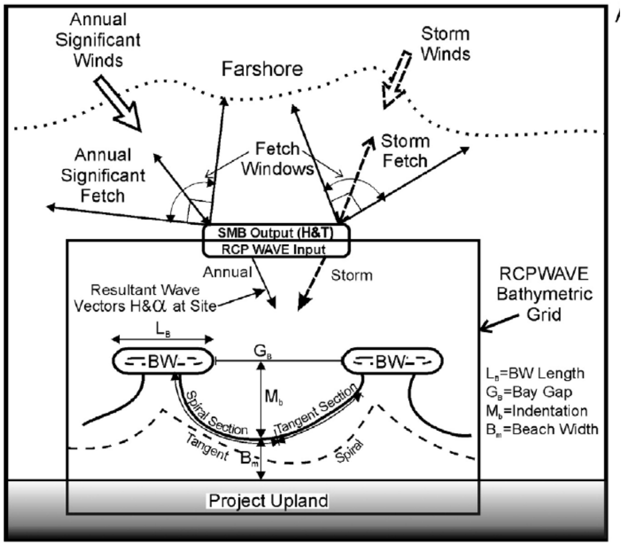
[20] Rip Currents, Robert A. Dalrymple, Jamie H. MacMahan, Ad J.H.M. Reniers, Varjola Nelko. Annual Review of Fluid Mechanics 2011 43:1, 551-581



L_b = breakwater length (from Hardaway and Gunn, 2000).
G_b = breakwater gap.
M_b = minimum bay indentation.

Figure 40: Relationship of Closed Cell Pocket Beaches with Breakwater Headlands

6 Design Development Philosophy

The overall approach to laying out a system of offshore structures is to tune them both in shape and orientation to best throttle the net southward sediment transport to an acceptable level both by maximizing the wave shadow projecting onto the shoreline in wave events that originate from the NNE, and minimizing wave shadow for waves from the SE which will tend to reverse the transport direction.

Because of the variability of lake levels, which influences the size of waves that can reach the shore, there is no ideal depth contour for structure placement. However, because maximum sediment transport occurs in the surf zone, and the concern about large transport rates is primarily during highest lake levels, the structures have been placed just lakeward of the surf zone at high water and were adjusted in size to give the appropriate shadow.

Nearshore structures can also function as a shunt to totally halt the transport of sediment out of a reach provided the structure shadow extends to outside the littoral movement zone. The shunt need not be a hard structure and can be simply an accretion zone in the shadow of an offshore feature as long as the zone is sufficiently wide so as not to be breached due to reversal of transport when wave directions shift.[21]

Objectives that guided the design of the beach control structures in each Area are listed below:

- Area 1: This area was designed to work as a closed cell due to the lack of sediment supply due to the marina to the north. The structures work to achieve a linear uniform beach width with minimal loss of sediment from the cell.
- Area 2: The structures in this area were designed to reduce the wave energy at the shoreline and reduce the sediment transport rate along the areas of importance. This area remains as an open littoral cell.
- Area 3: The structures in this area were designed to achieve minimum sustainable beach widths along the shoreline with wider pockets at strategic use areas. The goal was to minimize impacts to the viewshed from the conference center and protect the string of wetlands to the south. This area remains as an open littoral cell.

6.1 Final Design Enhancement

The breakwater layout developed within physical model testing was proven to stabilize the shoreline at high water levels. While the shadow zone created by these structures creates the desired reduction in sediment transport, modifications to the breakwater shape and cross section can be made to further promote habitat creation. Some recommendations are provided in the following sections.

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[21] Hardaway S, and J. Gunn, (2010), “Design and Performance of Headland Bays in Chesapeake Bay, USA” *Jour. Coastal Engineering, vol 57.*

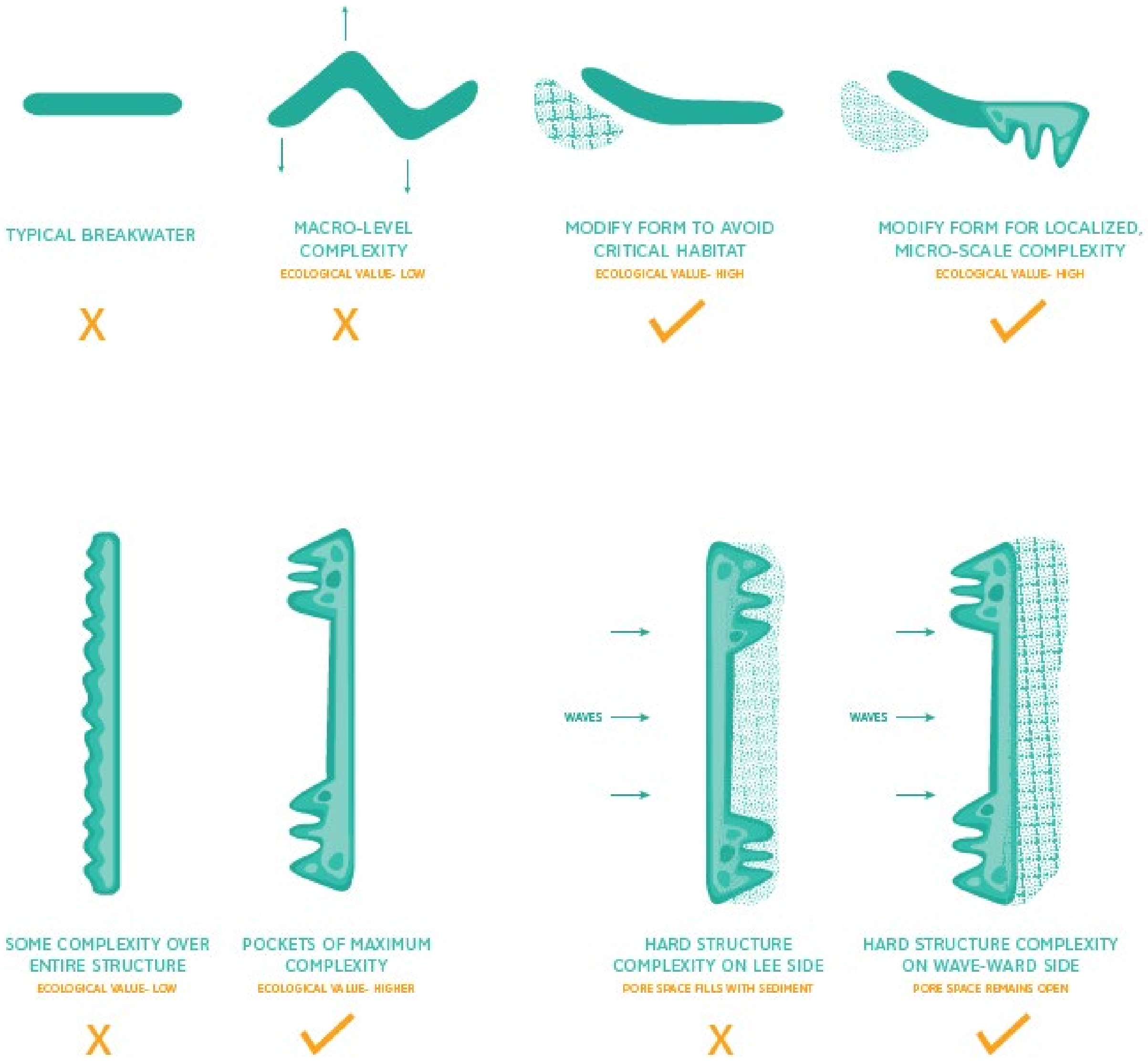

Figure 41: Preferred and Discouraged Island Shapes for Habitat Enhancement

6.1.1 Breakwater Shapes

The shape of the protective detached breakwater may assume any curvilinear shape provided the overall wave shadow for waves approaching from the NNE quadrant is largely unchanged from the simple linear shapes developed in the concept plan. In addition, the islands shall be deployed essentially as indicated at the prescribed depth, position, and orientation established by the modeling. The shape of each island may be formed to redirect currents or reflect or trap waves. Appending features may be integrated into the overall shape to aid in redirecting the wave or currents and offer potential habitat related benefits.

To offer maximum benefit from a habitat perspective, the island breakwater shapes need to be curvilinear to increase the total length of "edges" A few localized pockets of more exaggerated features such as long fingers, forming semi enclosed habitat "fish streets" are preferable versus more, but milder, simple undulating shapes.

6.1.2 Breakwater Sections

The cross sections of the islands are allowed and encouraged to be variable in height and width to emulate a more natural formed feature. The required net effect of raising, lowering, submerging, widening or narrowing of the cross section is to result in the same or better overall transmissivity as a simple trapezoidal section.

However, islands intended to also become bird rookeries shall have emergent crest surfaces conducive to attracting and nesting of targeted species. Such islands shall be designed to minimize the amount of wave overtopping that can occur to prevent eroding away of the preferred surface materials introduced for nesting. While the overall elevation of the island may vary, emergent structures shall not have "perch" features such as proud standing rocks or domed areas so as to prevent predator birds from congregating around the nesting pods.

Islands built for marine habitat shall have lee side sheltered pool areas at depths no shallower than -5 ft MLW datum, and preferably deeper, but may have shallow benches, ledges and overhanging slabs. Also preferred are slopes extending to the lakebed composed of round rock material sized from 5 to 15 inches in diameter to give desired size of interstitial spaces for protecting eggs and juvenile species

To assure adequate tranquility at the shore for virtually all water levels, the required freeboard is at least 8 feet above the design water level. No submerged breakwater, acting singly, will achieve the needed attenuation. If submerged structures are to be used, they must be designed with a special geometry to increase their attenuating properties such as by increasing width or introducing refractive behaviors.

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6.2 Design Modifications/Deviations

The following list of comprises the design modifications/deviations list for further design refinement by the Design-Build team:

- Access – No deviation from identified routes.
- Structures
  - Materials
    - Tonnage per armor stone classification is a minimum requirement based on structure's offshore location. Associated dimensions and layer thicknesses are based on a minimum specific gravity of 2.6 and an average diameter between a cube and a sphere.
    - Filter stone and core stone sizes may be adjusted with recognition of layer permeability.
    - Impermeable feature material not dictated.
    - Kellogg Creek groin material not dictated.
  - Cross sections
    - Crest height is based on a maximum overtopping/transmission allowance. Crest height may be altered due to changes to cross section as long as these maximum allowances are maintained.
    - Crest widths may be altered as long as maximum overtopping/transmission allowances are maintained.
    - Armor stone thickness based on a minimum two stone placement.
    - Filter and core thicknesses may be altered as long as functional purpose is maintained.
    - Offshore breakwaters dimensions are based on permeable cross sections. Impermeable features may be added to reduce lakebed impact, enhance habitat, or reduce structure cost.
    - Impermeable feature cross sectional shape or dimensions not dictated. May be included as part of value-added habitat features.
    - Impermeable feature must extend from elevation 585 down to the crest elevation of the core layer to limit transmission through the structure.
    - Kellogg Creek groin cross section not dictated.
    - Dredging of the existing lakebed is not allowed. All toes shall be placed on top of the lakebed.
    - Composite geotextile geogrid may be replaced with core stone bedding layer.
  - Layout
    - Layouts are based on physical modeled locations and shapes. Diffraction end points, based on high water, are fixed.
    - Modifications to the trunks of the structures may be altered to improve wave attenuation or enhance habitat features.
    - Changes to the lakebed impact will require permit modifications and approval.
    - Modifications to section and shape to enhance aesthetics and natural appearance is encouraged as long as overall performance is maintained.
- Sand
  - Sources of sand procurement have not been dictated.

- Sand characteristics provided in the specifications shall be considered minimums.
- Median grain size within recreational beach areas (south end of Area 1 and all of Area 3) shall remain within the ‘sand’ category. ‘Gravel’ nor ‘cobbles’ will be allowed.