ILLINOIS DEPARTMENT OF NATURAL RESOURCES

ILLINOIS BEACH STATE PARK

Shoreline Morphology Analysis & Stabilization Options

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SmithGroup Project Number: 10793.000

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1.0
EXECUTIVE SUMMARY

Illinois Beach State Park represents the final remaining natural, undeveloped shoreline in Illinois. Largely formed by a migrating beach-ridge, the park is transient by nature, and if left unprotected would naturally erode overtime. Lacking a steady supply of updrift sand due to shoreline construction and stabilization, the park suffers from accelerated erosion that threatens its rare panne wetlands and dedicated nature preserves. In addition to its habitat value, the park provides public recreational opportunities for over one million visitors per year, including bike and walking trails, fishing, swimming, and camping.

The Illinois Department of Natural Resources, which is responsible for the stewardship of the park, hired SmithGroup to study the shoreline and develop concepts for stabilization while remaining mindful of the park's mission to remain natural. This report documents the numerical modeling and design process undertaken to develop conceptual alternatives for shore stabilization structures; located in the three areas of greatest erosion, the proposed structures will reduce the net littoral transport throughout the park with the goal of creating a more stable shoreline.

Through joint discussions with Illinois Department of Natural Resources, the Illinois State Geological Survey, and the U.S. Army Corps of Engineers, accompanied by extensive technical analysis, three preferred alternatives were developed that combine nearshore and offshore emergent and submerged rubble breakwaters. Rubble breakwaters are more resilient than other coastal structures and have the added benefit of providing habitat for aquatic life. In addition to the rubble breakwaters, which will act to stabilize the shoreline, sands lost to high-water erosion will be replaced with clean nourishment sand; this will provide an additional barrier to the valuable habitat and

infrastructure located along the shoreline. The final design, testing, and construction of these preferred alternatives is estimated to cost $45 million.

The next phase of this project will take the breakwater alternatives into physical modeling, which will fine-tune how each structure works holistically to not only stabilize the shoreline within its immediate area but also contributes to a more uniform net littoral transport throughout the park. In addition, the physical-modeling phase will take the core rubble mound breakwaters shown within this report and incorporate additional design benefits not yet explored, such as stable habitat and public recreation opportunities. This testing and refinement phase will culminate in a set of construction technical specifications and drawings to help protect and preserve Illinois Beach State Park's shoreline, along with its invaluable natural resources and public recreational legacy.

2.0 INTRODUCTION

The Illinois Department of Natural Resources (IDNR) is responsible for stewardship of Illinois Beach State Park (IBSP) and the adjoining North Point Marina. This expanse of shoreline is the only remaining reach of natural, undeveloped Lake Michigan waterfront within the state and represents Illinois' last remnants of coastal dunes and panne wetlands which serve as habitat for rare and threatened or endangered species. The shoreline has a long history of retreat, however with recent and rapid increase in lake water levels, action to protect and stabilize this valuable asset has become urgent. Some areas have retreated as much as 245 ft within eight years, which is well beyond the shoreline position shift associated with water level changes alone. This persistent erosion has not only undermined the park's existing infrastructure but has also resulted in the loss of precious habitat and nesting grounds.

The goal of this project is to develop compatible shoreline erosion solutions that conform with natural processes and fit the character and mission of the park. The preference is to implement submerged offshore structural solutions that best preserve the park's natural aesthetics. However, these solutions must be robust, require minimal maintenance, and remain functional and resilient at all anticipated water levels.

2.1
HISTORY OF ILLINOIS BEACH STATE PARK

2.1.1. BEACH FORMATION

Illinois Beach State Park is a beach-ridge plain landform that consists of linear, generally coast-parallel mounds of sand and gravel that have been built up by wave action over time, extending the coast outwards into the lake. These coastal formations are characterized by a topography of sub-parallel ridges separated by low areas called swales (Chrzastowski and Frankie, 2000).

This geomorphic landform, apparent in Figure 1, is an infill feature left behind following accretion of the historic shoreline position approximately one mile inland.

The Illinois Beach State Park is part of the larger Zion beach-ridge plain that extends from Kenosha, Wisconsin to just north of Chicago, Illinois. Coastal processes including littoral transport, storm events, lake-level changes, and the influence of coastal ice have caused the Zion beach-ridge plain to migrate south from its starting position north of Kenosha to its current location over the course of 12,000 years (Chrzastowski and Frankie, 2000).

The historic growth and progression of the shoreline is summarized in Figure 2 and Figure 3, which shows that the park has currently reached its maximum width projecting into the lake. The park is therefore a transient feature, moving on a rapid geologic time scale. In a period of only 400 years, the center of this transient landform has moved from the Illinois/ Wisconsin border to the Zion area. The inference is that the park shoreline will, without intervention, continue to shift southward beyond the park's current position in a similar time period.

Figure 1: Aerial view of the ridges and swales of the Zion beach-ridge plain (map data: Google, TerraMetrics)

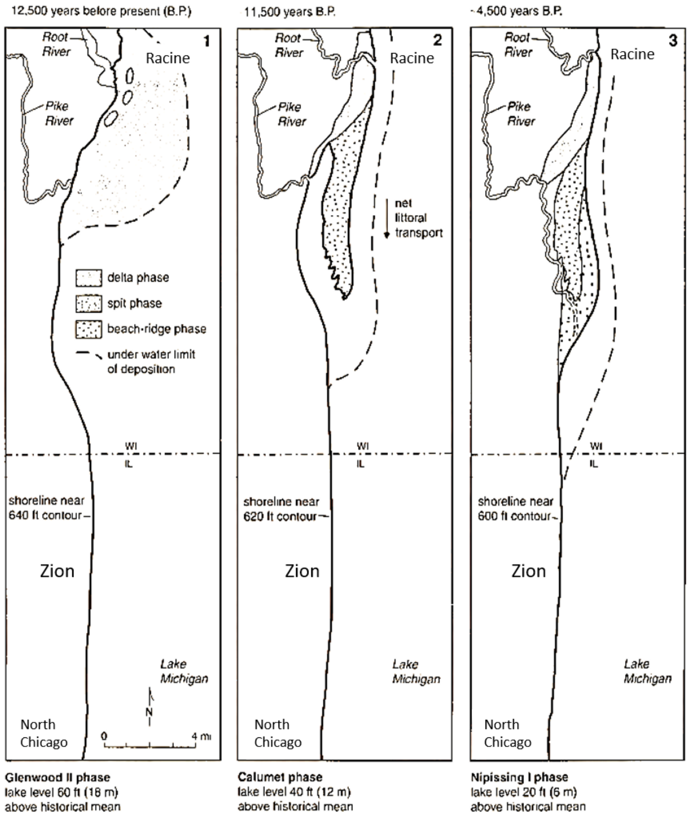


Figure 2: Coastal geography between Wisconsin and Illinois, 12,000 – 4,500 B.P. (Chrzastowski and Frankie, 2000)

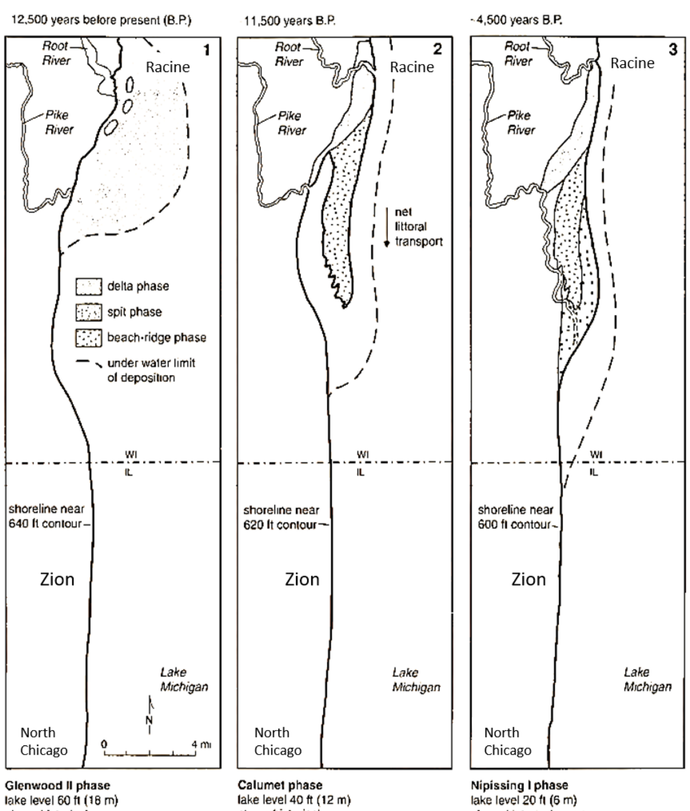


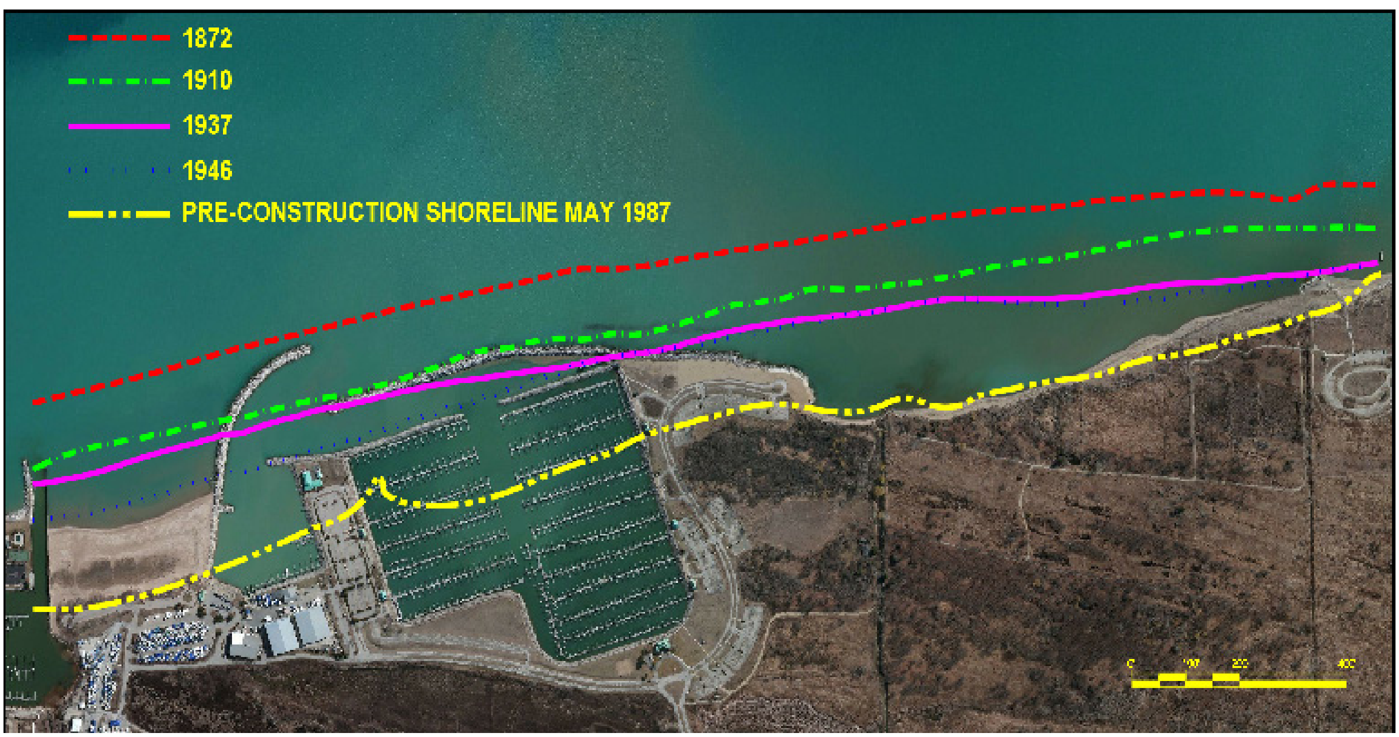
Figure 3: Coastal geography between Wisconsin and Illinois, 3,700 – 0 B.P. (Chrzastowski and Frankie, 2000)

Chrzastowski and Frankie concluded that "the migration of this coastal landform would continue to evolve if no human intervention occurred, and if present-day lake levels and coastal dynamics persisted. With time, the plain would continue to advance southward along the Illinois coast, while erosion continued along the northern part of the plain. Eventually, erosion would remove the last vestiges of the plain along more and more of its northern segment, and ultimately, the Zion beach-ridge plain would be no more than a migratory and ephemeral coastal feature in the post-glacial evolution of the Illinois coast." This implies that much of the loss of shoreline is attributable to natural forces, not just the result of human modifications.

2.1.2. NORTH POINT MARINA

North Point Marina is a state-owned and operated facility just south of the Illinois-Wisconsin state line. The 1500-slip marina was constructed between 1987-1989 in a region that had previously recorded the most severe erosion along the Illinois coast. Shoreline recession in this area had occurred at a long-term average rate of about 10 ft/year (Jennings, 1990; Chrzastowski and Frankie, 2000). The marina basin was created by excavating landward of the waterline so that only the protective breakwaters projected into the lake. Sand excavated from the basin was placed to the south of the project, primarily as parking lot fill, but some was returned to the littoral system.

Figure 4 shows the location of the shoreline in 1872, which is lakeward of the marina's breakwaters. By 1910 the shoreline had retreated approximately 130 ft (Chrzastowski and Frankie, 2000). The figures also show the shoreline position just prior to the construction of the marina, which is generally where the shoreline is located today. Therefore, on a system wide scale, the marina has not contributed to accelerated shoreline retreat. However, this does not mean that the marina development has not caused localized shoreline erosion, as the hardened shoreline has locally modified the wave patterns, refocusing wave energy along the adjacent natural shoreline.



Figures 4: Historical shorelines near North Point Marina (modified from Chrzastowski 1996, map data: Google, USDA Farm Service Agency)

2.1.3. DEVELOPMENT & USE

The land comprising Illinois Beach State Park has had many uses: lakefront residential communities, a short-lived industrial sector, railroad spurs, sand mining operations, farmland, military rifle training range, and a lakeside restaurant all occupied the land before Illinois Beach was legally designated as a state park on July 13, 1953 (Bannon-Nilles, 2003). The original park designation encompassed only the land south of the nuclear power plant, called the South Unit. In the area north of the nuclear power plant, called the North Unit, erosion and shoreline recession directly affected lakefront housing in the 1960s and 1970s. Despite attempts by homeowners to stabilize their shorelines, many homes suffered damage from severe erosion of their foundations and were abandoned (Figure 5). All properties in the North Unit were acquired by IDNR in the 1970s (ICMP, 2011) and the remaining structures were demolished to make room for the development of North Point Marina.

2.1.4 ASBESTOS

The housing development here has had a lasting effect on the coastline. Remnants of residential foundations and shore protection structures remain offshore and are visible on a clear day. These submerged structures influence present-day wave dynamics and sediment transport. Sewer lines, water pipes, sidewalks, foundations, and a variety of building materials were broken up by wave action and entered the lake. As a result, the sediments on the beach include a variety of housing debris, including asbestos-laden materials. These materials are not considered a health hazard because the asbestos fibers are bound within cement. Asbestos is generally only considered dangerous to health if airborne. However, asbestos contamination does disqualify the sand in this area from being reusable for nourishment purposes elsewhere. Asbestos-containing material that washes up on the beach is collected and disposed of properly by state park officials (Chrzastowski and Frankie, 2000).

Figure 5: Severe erosion within the North Unit (photo by Illinois State Geological Survey, April 1973)

2.2
LONGSHORE AND CROSS SHORE TRANSPORT

Sediment naturally moves along the shoreline in response to wave action. The degree to which movement occurs is dependent on both the grain size of the material and its cohesive properties, i.e. the degree to which the particles stick together. Typically sands and gravels are cohesion-less, while ultra-fine material, particularly clays, will be cohesive. The well-known Shields diagram shown in Figure 6 illustrates the water velocity required to cause these various sediments to start moving. As a common rule of thumb, beach sand, typically about 0.3 – 0.4 mm in grain size, will begin moving (eroding) if water velocity is in the range of 1 fps (30 cm/s). For water velocities below this threshold, the sand grains will not move and therefore the shoreline remains unchanged.

On a beach, sand may be transported in two ways: across the shore (in and out), or along the shoreline (left or right laterally). If sand only moves across the shore, there will be no erosion. The waterline location may shift up or down during storm events, but the mean position remains essentially constant as the beach sand migrates back after the storm. However, cross-shore movement alone essentially never takes place. Waves always reach the shoreline at some angle, even if a very small one. That angle results in a push on the sand that moves it left or right. That lateral movement is called longshore transport and is a function of both the strength of the wave and the angle at which that wave meets the shore.

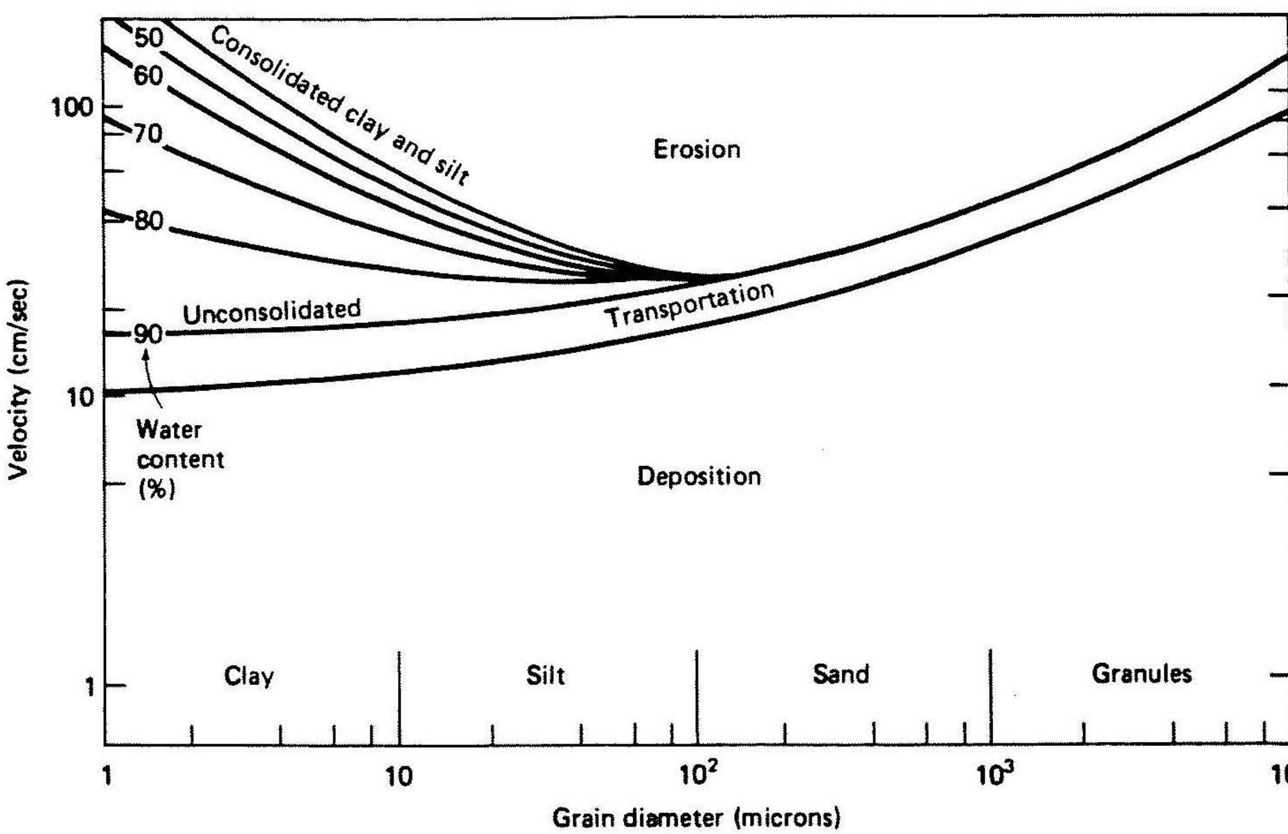


Figure 6: Shields Diagram

2.2.1. LONGSHORE TRANSPORT

At Illinois Beach State Park, longshore transport accounts for most of the changes to the shoreline. As shown in Figure 8, angled waves impacting the shoreline induce sediment transport within the nearshore current. This transport includes both suspended and bed-load sediment. On shore, swash and backwash move sediment downdrift in a scalloped pattern. However, longshore transport alone does not cause the shoreline retreat; it is only the process of how it happens. What causes the retreat is a change in the longshore transport rate along the shoreline. The rate of transport at a given location is strongly influenced by the breaking wave height and the angle the waves approach relative to the shoreline. If wave heights change along the shoreline, then the transport rate changes exponentially. This can result in sudden erosion or deposition at another location if the amount of sediment being deposited is not equal to the amount of sediment being eroded. Separately, if the angle of the shoreline relative to the incoming wave direction changes, the rate of the transport also changes.

Recognizing these dynamics of sediment transport, it becomes clear that a shoreline can suffer starvation or alternatively overfeeding, which causes the shoreline to advance or retreat. A shoreline can be stable or made stable regardless of the rate at which sediment is moving as long as there is a sufficient supply and a constant rate of sediment across that shoreline.

Figure 7: Waves approaching a natural shoreline at an angle.

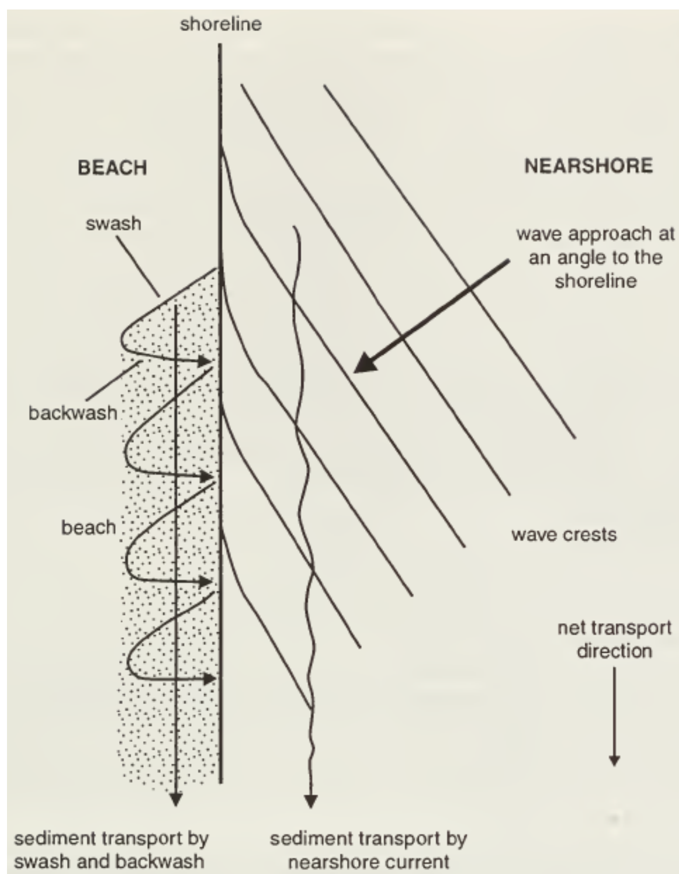


Figure 8: Dynamic components that contribute to littoral transport (Chrzastowski and Frankie, 2000)

2.2.2. CROSS SHORE TRANSPORT

In addition to longshore transport, cross-shore transport influences the apparent location of the waterline. Cross-shore transport typically relates to the morphology of the shoreline's profile in response to wave impacts and water levels. To a lesser extent, the cross-shore profile can also be influenced by high winds, particularly on sandy shorelines.

Figure 9 below depicts typical changes to the cross shore profile due to (a) storm events coupled with storm surge, and (b) increased water levels. Storm generated waves can attack the upper portions of the beach and sand is captured by the moving water and carried back into deeper water forming a sand bar. This makes the waterline appear to have retreated, giving the impression of erosion. Longshore transport will carry, in part, the newly formed sand bars downshore.

At the end of a storm, residual long period waves will begin to push the sand back up onto the dry each. This process may take a few days or even weeks or, if the sand was transported downshore and not replenished by sands from updrift, the beach may not ever fully recover. This process is currently occurring in IBSP where very little sediment is available from updrift sources and therefore sediments pulled offshore by storm waves are carried downdrift, never to return to their original location on the beach.

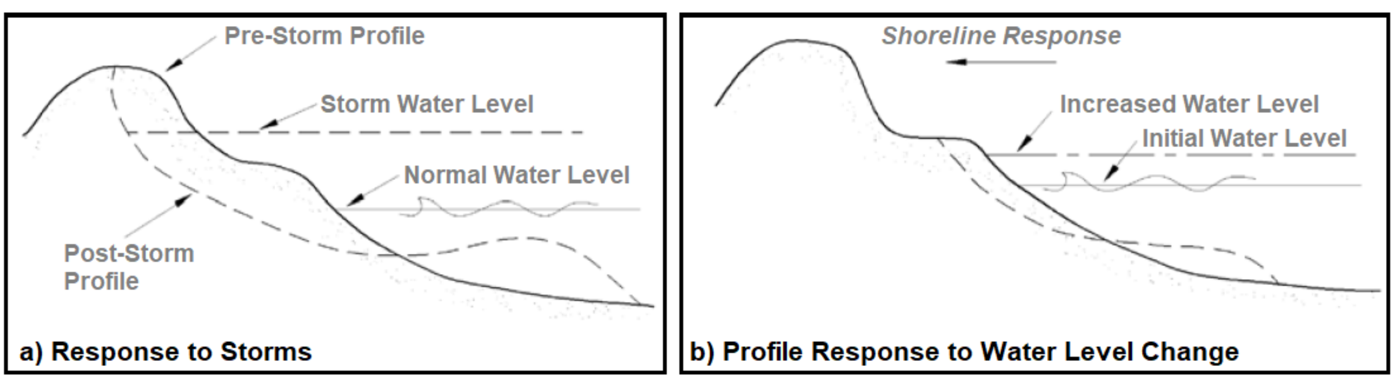


Figure 9: Issues arising from cross-shore sediment transport on the coastline (CEM, 2008).

2.3
SHORELINE FEATURES

Straight-line stationing was established to provide spatial reference points for the shoreline areas and features for this project. These reference points 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.

While Illinois Beach State Park is considered to be Illinois' last natural shoreline on Lake Michigan, many coastal structures have been installed throughout its history in an attempt to stabilize the shoreline's shape. A list of coastal conditions throughout the park delineated by approximate stationing is provided in Table 1 and shown graphically in Figure 10. The condition assessment was generated by either on-site visual inspection or review of historic aerial photos to evaluate shoreline position.

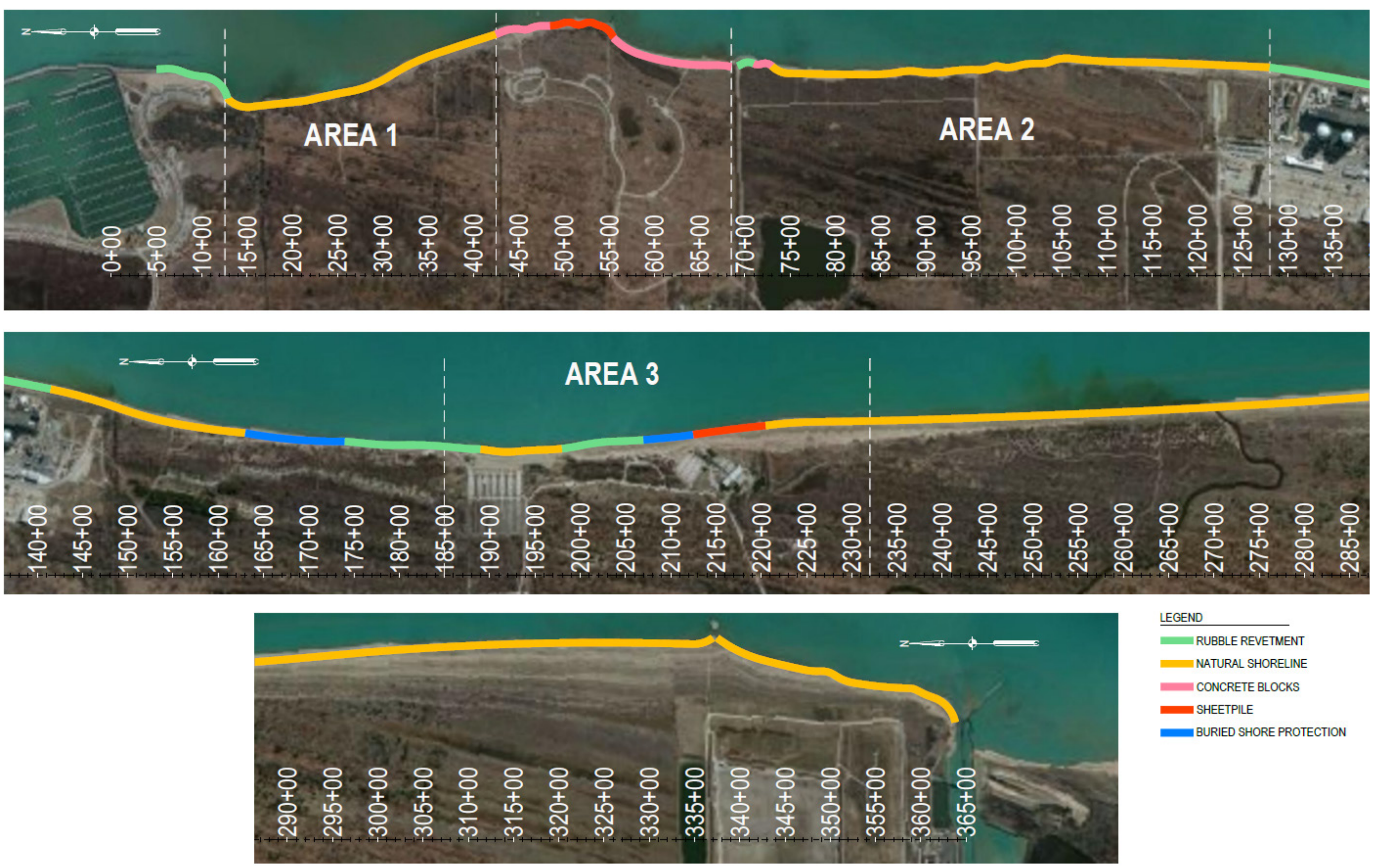


Figure 10: Stationing and shoreline conditions throughout IBSP (map data: Google, USDA Farm Service Agency)

STATION (APPX)	SHORELINE	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	Waterway Opening	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+00 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	Stable, Regular Maintenance
186+50 through 189+00	Destroyed Rubble Revetment	Damaged, Eroding
189+00 through 203+00	Natural - Sand	Eroding
203+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
220+50 though 337+00	Natural - Sand	Stable, some Accretion
337+00 through 337+50	Rubble Crib Hardpoint	Accretion
337+50 though 365+00	Natural - Sand	Stable

Table 1: Shoreline Conditions Throughout Illinois Beach State Park

2.4
IDENTIFIED AREAS OF STUDY

During the project kickoff meeting on June 4, 2018, three areas were identified as zones of special concern or sensitivity. These areas include valued habitat, have public recreational use value, and/or are essential for the stability and protection of nearby infrastructure (Figure 11 and Table 2). The selection of these three areas was also based on their high rate of erosion, evident from reviewing aerial photographs and discussions with IDNR. While the entire shoreline within the park was modeled and reviewed, the implementation of stabilization features ,was focused primarily on these three key areas.

On August 8, 2018, SmithGroup personnel visited the park to review the various erosion issues at these three locations, and to assess the current condition of the shoreline.

Figure 11: Identified areas of study. (map data: Google, USDA Farm Service Agency)

AREA	STATIONING	LENGTH
Area 1 - North Beach	12+50 through 42+50	3,000 ft
Area 2 - Camp Logan	71+00 though 128+00	5,700 ft
Area 3 - Swimming Beach	185+00 through 222+00	3,700 ft

Table 2: Areas of greatest concern within Illinois Beach State. Park.

2.4.1. AREA 1 – NORTH BEACH

The first area of study is located at North Beach, south of North Point Dr. parking lot, where the greatest shoreline recession has occurred. Little to none of the shoreline sediment located directly south of North Point Marina was deposited by natural coastal processes. At the time of the construction of North Point Marina, approximately 1.5 million cubic yards of sand and gravel from the basin were placed immediately south of the marina, and the land elevation was raised as much as 15 ft above the natural shoreline (ICMP, 2011). As these newly placed sediments eroded, more sediment needed to be brought in at regular intervals to replace what was lost. Therefore the natural beach at this site was buried beneath imported sand and gravel.

In response to the rapid erosion of the placed sediments following the construction of North Point Marina, a submerged breakwater was constructed in the 1990s in the nearshore area to reduce incoming wave energy. A revetment was also constructed along the eastern edge of the North Point Dr. shoreline to eliminate the threat to the south parking lot of North Point Marina (Figure 12).

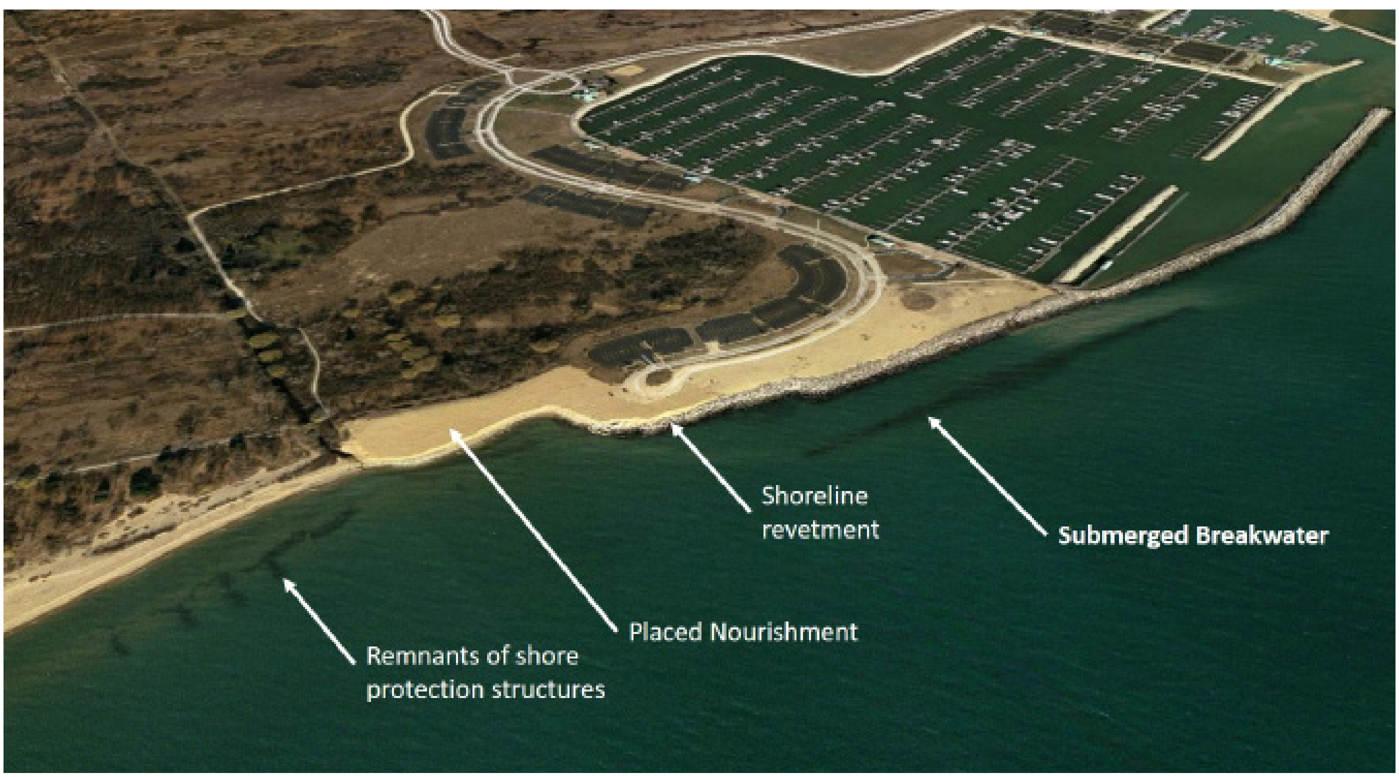


Figure 12: Aerial view of Area 1 (map data: Google, DigitalGlobe)

2.4.2. AREA 2 – CAMP LOGAN

The most severe rates of shoreline recession have occurred east of Sand Pond in Area 2. Aerial photographs from 1939 show this area consisted of a residential development with a few scattered homes. By 1953, houses were built close to the shoreline, leaving modest sandy beachfronts. Development continued and grew through the late 1960's. By that time, the original developments were already in a perilous position as the sand beneath them washed away.

Review of historical aerials and shoreline position does not suggest that this area was ever nourished directly. Remaining mostly natural, the sandy shoreline has steadily receded. From the earliest aerial photos taken in 1939, the shoreline appears to have receded as much as 985 feet to today. More recent erosion is shown in Figure 14 and Table 4 shows an approximate maximum extent of erosion since 1994. Photos of this area can be seen in Appendix E.

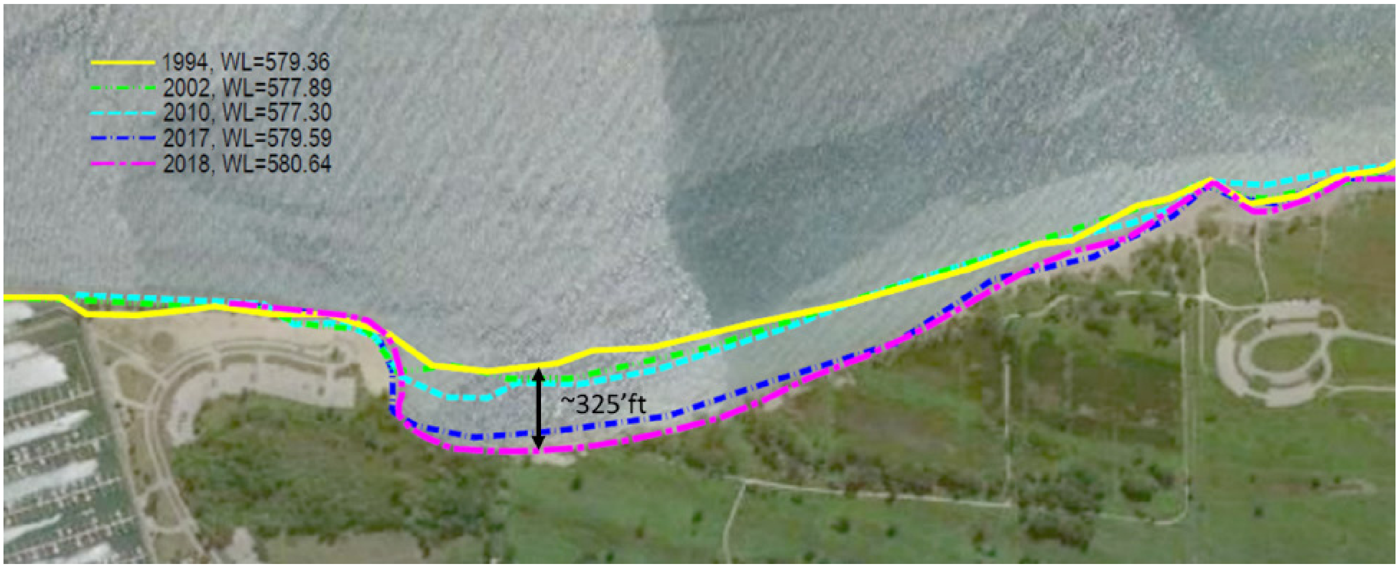


Figure 13: Historical shoreline retreat within Area 1 (map data: Google, USDA Farm Service Agency)

YEAR	RECESSION (ref 1994)
2002	50 ft
2010	65 ft
2017	255 ft
2018	325 ft

Table 3: Erosion of Area 1 since 1994.

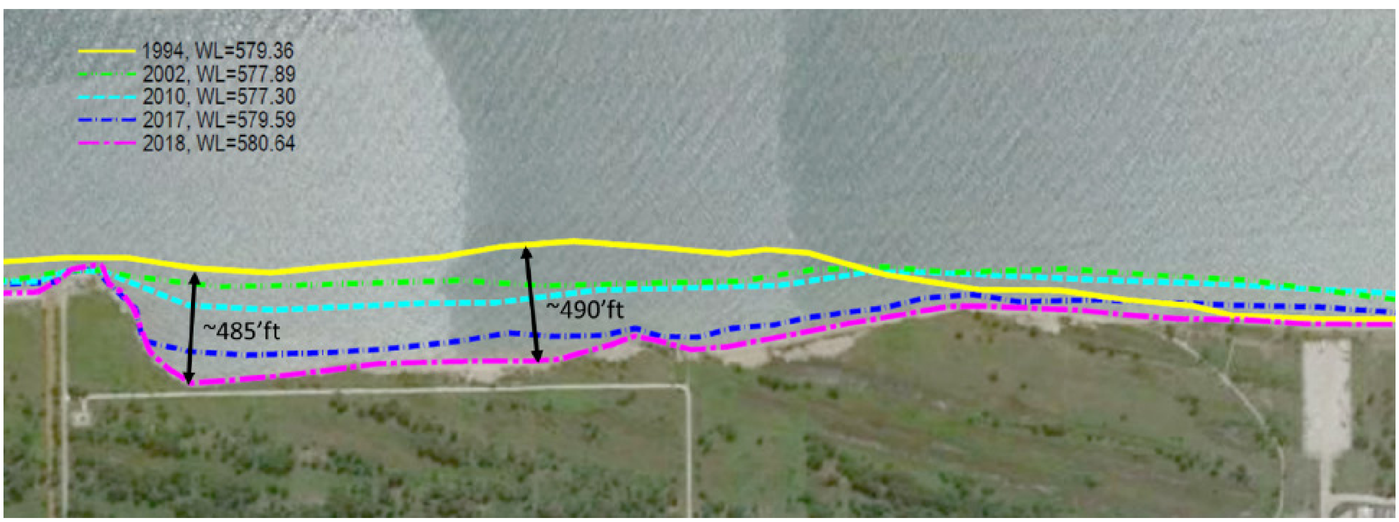


Figure 14: Historical shoreline retreat within Area 2 (map data: Google, USDA Farm Service Agency)

YEAR	RECESSION (ref 1994)
2002	175 ft
2010	225 ft
2017	385 ft
2018	490 ft

Table 4: Erosion of Area 2 since 1994.

2.4.3. AREA 3 – SWIMMING BEACH

The final area identified to be at high risk from erosion is located at the park's main swimming and recreational area. This area provides parking, picnic tables, restrooms, and walking access to the main swimming beach of Illinois Beach State Park. It also hosts a resort and conference center. As this area is a hub of activities, the risk of lost revenues and user attendance from shoreline erosion is greatest within this zone. In addition, the area directly to the south of the conference center is a dedicated nature preserve as well as a rare high quality panne wetland which cannot be impacted by shoreline changes.

Historically, this area has been used for recreational purposes since the 1950s. Similar to the two other areas, Area 3 has experienced its share of shoreline loss. In the 1970s, shoreline recession along the main swimming beach resulted in the demolition of the park's original bathhouse. In order to control the erosion, many shore stabilization structures were introduced, including concrete blocks, riprap revetments, and sheetpile walls.

Further to the north of the swimming beach, erosion has threatened the service road that runs along the lakeward side of two bath houses. In response, riprap was placed along much of the shoreline. As the shoreline shifts and sand moves southerly across this area, this riprap forms an edge that prevents further landward recession.

An easily accessible reach of shoreline north of the swimming beach was used for some time as a feeder beach where renourishing sand was placed and then allowed to erode naturally, providing a supply of sand to the otherwise starved shoreline. Nourishment was also intermittently placed directly at the swimming beach.

Review of the historical shoreline in this area, shown in Figure 15, shows waves of sand migrating down the shoreline, most likely attributable to the periodic placement of nourishment sands. Therefore, as given in Table 5, some years the beach has been larger due to a passing sand ridge, and once it passes, the beach recedes. As the shore along the swimming beach area is within the erosional zone of the beach-ridge plain, substantial shoreline recession has occurred since this area was originally developed.

Because this area has been periodically nourished, it is difficult to determine its natural rate of erosion. The current shoreline position is similar to the shoreline position in 1999. Periodic nourishment and receding lake levels resulted in a wider beach up until approximately 2015. Since that time, the shoreline has receded up to the coastal structures which hold the shoreline in place. High waves coupled with high water levels have resulted in some damage to the northern parking area shown within Figure 8 in Appendix E. Other photos of this area can also be seen in Appendix E.

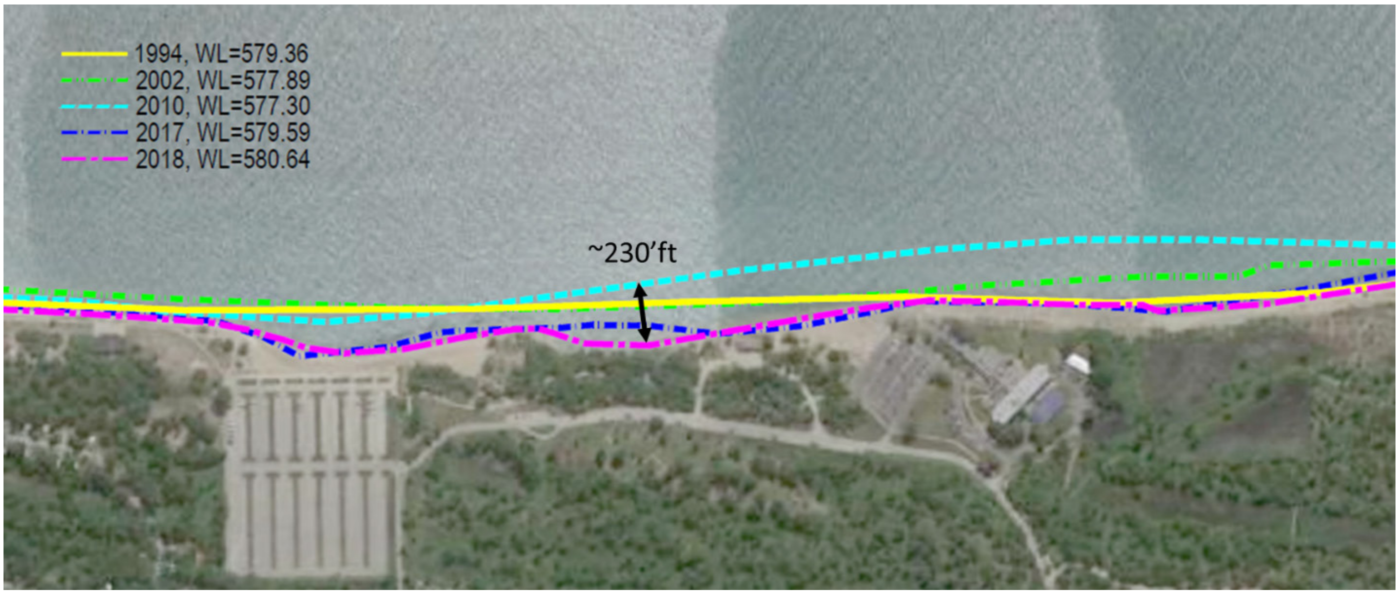


Figure 15: Historical shoreline retreat within Area 3. (map data: Google, USDA Farm Service Agency)

YEAR	RECESSION (ref 1994)
2002	12 ft
2010	-70 ft
2017	85 ft
2018	160 ft

Table 5: Erosion of Area 3 since 1994.

3.0
NUMERICAL MODELING

In order to determine the causes of the shoreline erosion and to design mitigative solutions to halt those effects, an understanding of the park's shoreline processes is required. SmithGroup created a numerical (computer) model of the site to analyze potential solutions.

Numerical modeling provides a computer simulation of sediment transport conditions, allowing designers to subsequently test a myriad of mitigative solutions in order to reduce or eliminate erosion within the identified areas and create a more stable shoreline. The model domain includes the entire length of the park; this allows the effects resulting from manipulations to the shoreline in one area to be evident elsewhere in the model, even if outside the areas targeted for stabilization.

To set up the numerical model to mimic current shoreline conditions, the following steps were taken:

1. Acquisition of an overall bathymetric survey (measurement of depths below water) for the park, compiled from various sources.
2. Performance of a wave climate analysis to determine conditions at the park.
3. Digital propagation of these waves from offshore to the nearshore using a spectral wave model. This allows the offshore waves to naturally bend, heighten, and even break over the shallow bathymetry as they enter the nearshore area of the model.
4. Preparation of a littoral drift model using the nearshore bathymetry and annual average wave climate.
5. Calibration and verification of the model's results.
6. Computation of the transport rates along the park's shoreline and the altered rates once coastal structures are implemented.

The following sections offer more detail on each of these steps.

All numerical modeling was completed using DHI's state-of-the-art software packages capable of simulating physical nearshore processes. The software package is a modular product that includes simulation engines for different applications, including wave modeling, hydrodynamics, and sediment transport dynamics.

The MIKE 21 Spectral Wave model (SW) and the MIKE Littoral Processes FM modules were used for this application.

3.1. BATHMYETRY

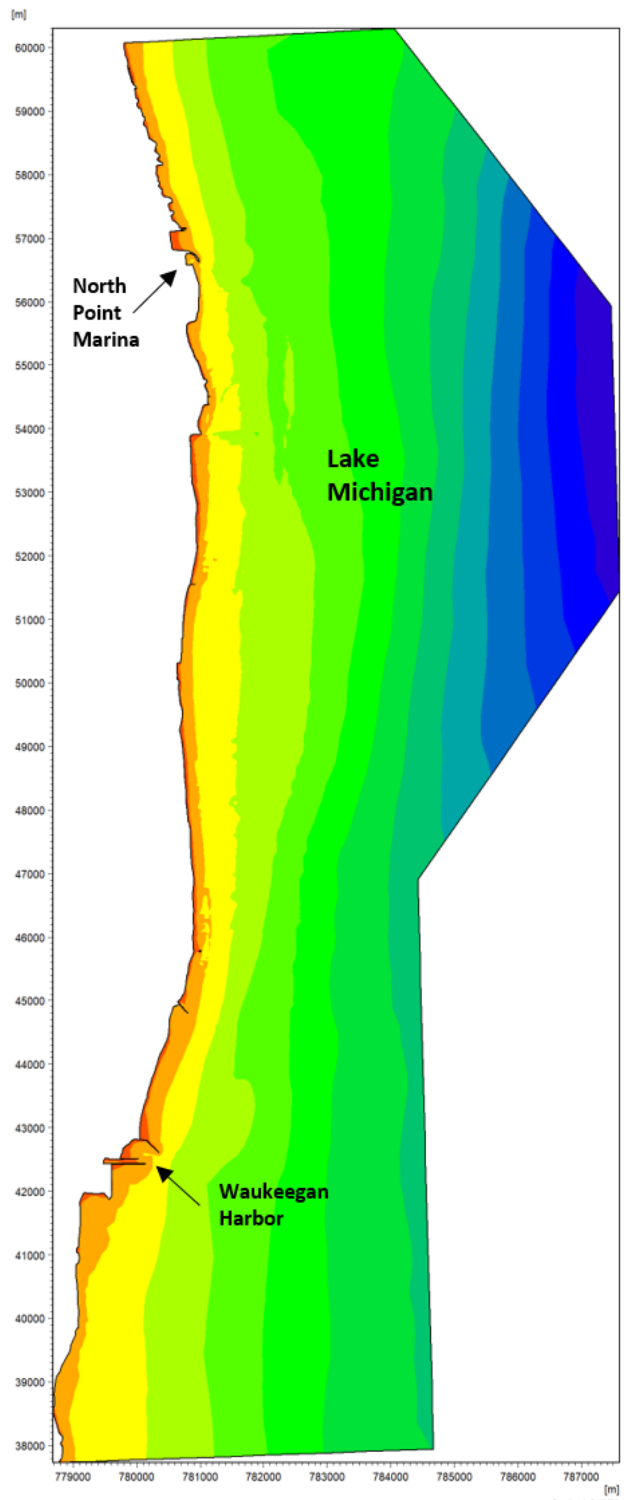
Bathymetric information was compiled from several sources:

a) A selected grid from NOAA's Great Lakes Bathymetry database at 3 arc-second resolution (~295 ft) for the large-scale bathymetry.

b) NOAA's more detailed nearshore bathymetry from LiDAR 2012 .

c) A field survey of the North Beach area that was performed on 08/08/2018.

Digital terrain boundaries were created for the numerical model. The boundary outline defining the model domain extends approximately 2.5 miles north, 4.5 miles south, and 4.3 miles offshore of the project site.



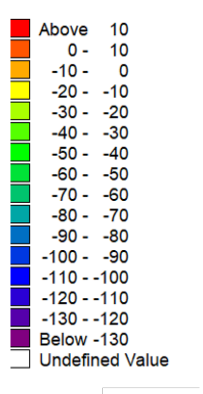


Figure 16: Large Scale Bathmymetry for the Study Area

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

Within the numerical model, the bathymetry was represented with a fine level of detail as shown in Figure 17. An unstructured mesh (varying in grid size) was created which provides a good degree of flexibility in the representation of complex subsurface geometries since small elements can be used in areas where more resolution is required, and larger elements used where less resolution is required; such as offshore. The mesh resolution greatly influences the accuracy and duration of the numerical simulation. For this study, the mesh sizes ranged from 10 ft close to the project site to 490 ft in the offshore deep-water areas.

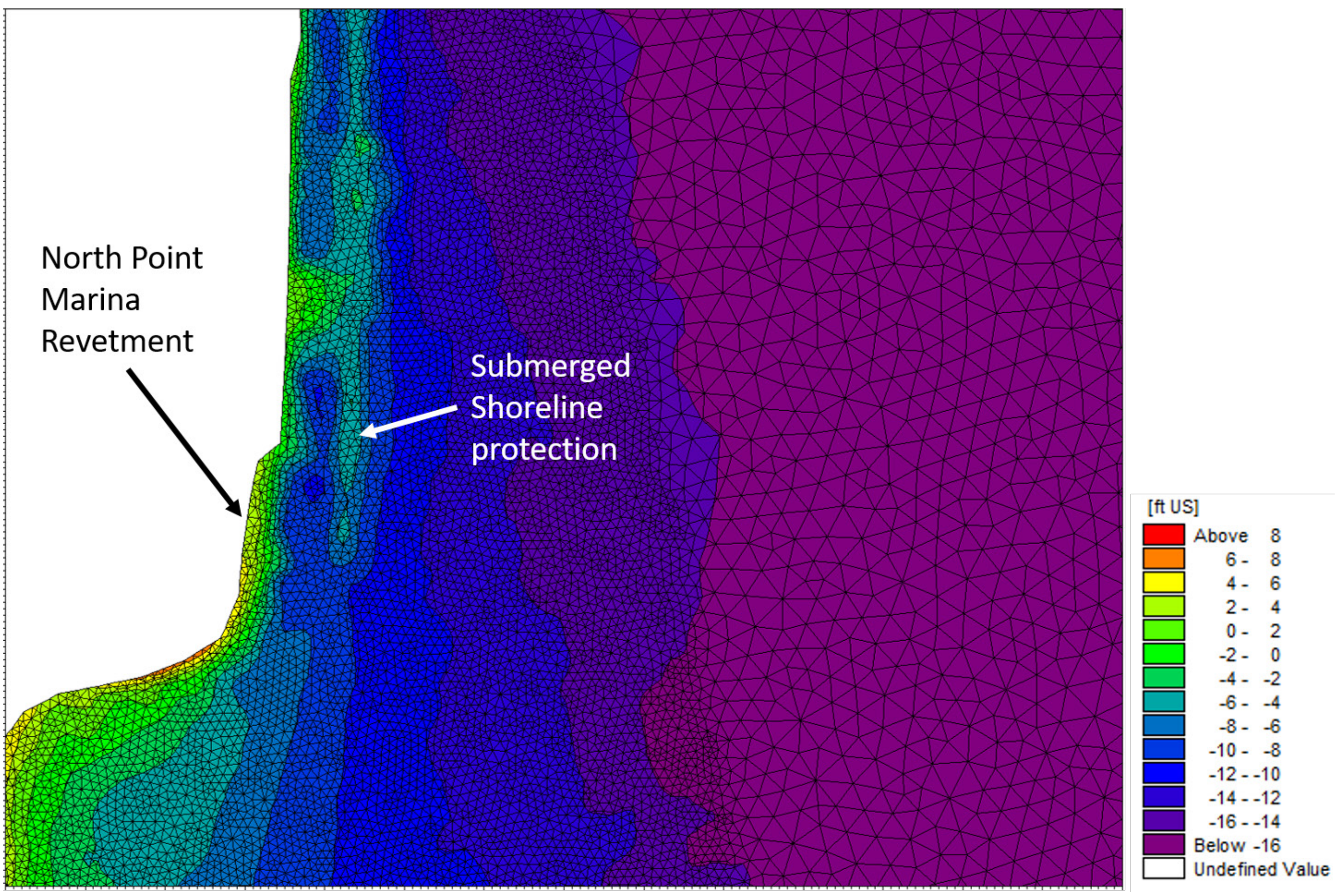


Figure 17: Fine Scale Bathymetry for the North End of the North Beach

3.2
CLIMATOLOGICAL CONDITIONS

This section provides a summary of the predominant climatological conditions that affect Illinois Beach State Park. Appendix B contains a more thorough explanation of the metocean (meteorological and oceanographic) analysis performed.

3.2.1. WATER LEVELS

For this analysis, monthly average water levels were the primary concern. The water levels referenced within the modeling for the project site near Zion are shown in Table 6.

MONTHLY MSL WATER LEVEL	IGLD85
LOWEST RECORDED	575.99
15%	577.53
50%	579.10
85%	580.37
MAX RECORDED	582.38

Table 6: Average monthly water levels in Zion, IL

3.2.2. WAVES

Wave data was taken from an offshore data point maintained by the U.S. Army Corps of Engineers (USACE) Wave Information Study (WIS). These waves represent offshore conditions and will transform through refraction and shoaling as they enter the nearshore. These processes are performed within the numerical modeling.

The most common wave directions offshore are given in Table 7 and can be seen in Figure 5 in Appendix B. For all waves over 7ft, which have an occurrence of only 1% of the time, over 80% of those waves come from the north-northeast compared to only 3% from the south-southeast. Therefore, the highest energy and the most frequent waves come from the north.

DIRECTION	OCCURRENCE
NORTH THROUGH NORTHEAST	42.75%
SOUTHWEST THROUGH SOUTH	24.56%

Table 7: Offshore wave occurrence by direction

3.3
WAVE PROPAGATION

MIKE 21SW, was used for wave propagation to the site. This software simulates the growth, decay, and transformation of wind-generated waves and swells, both in offshore and nearshore areas. Data from the WIS station 94033, which is located offshore where the water depth is 115 ft, were used to develop the wave input for analyzing the littoral drift. The 35-year time series of wave information provided by the station data was used to set boundary conditions for the wave model. This allowed the model to reproduce how deep-water waves, which aren't influenced by the lakebed, are transformed by the bathymetry they encounter in shallower waters (Figure 18).

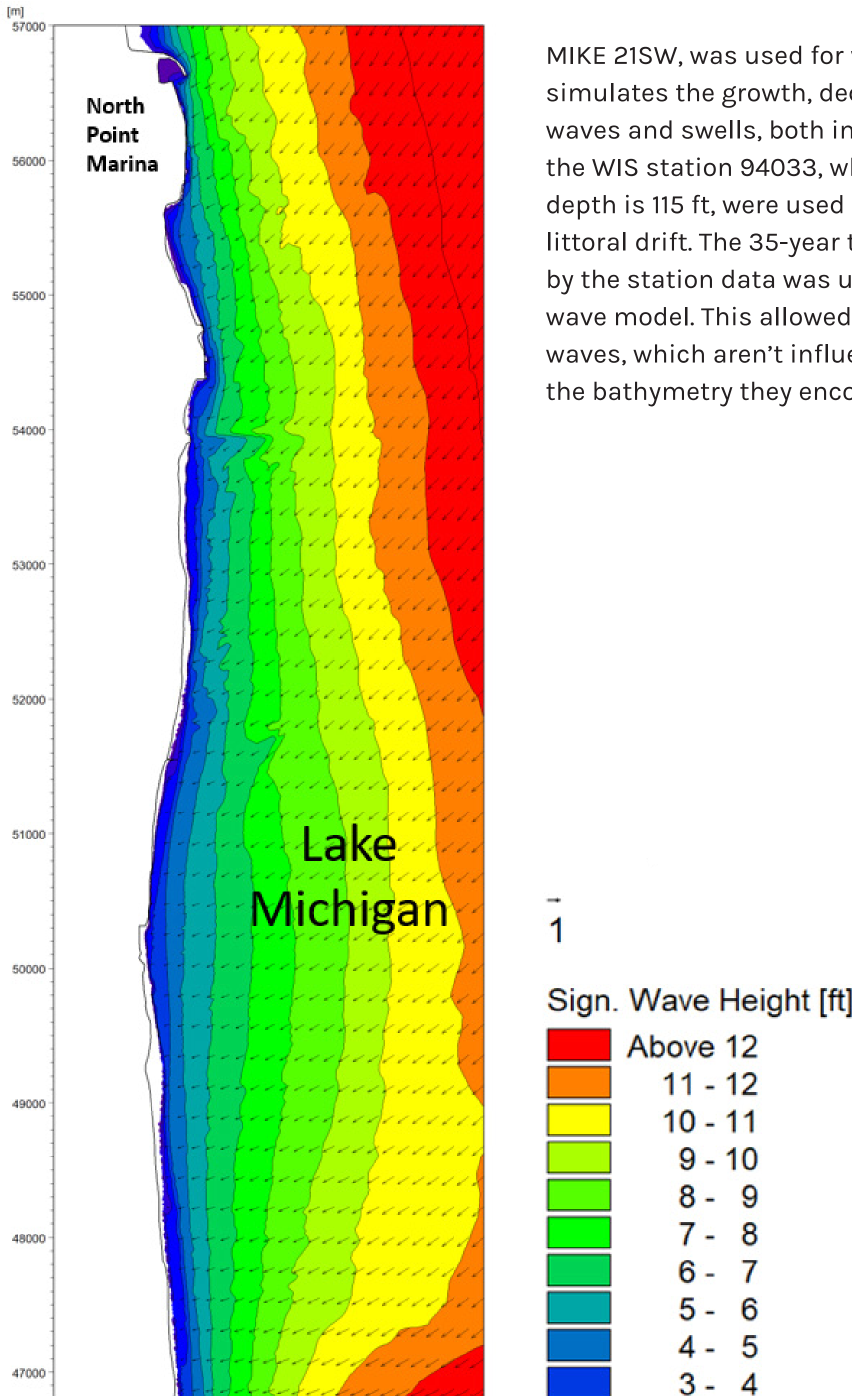


Figure 18: Model output of the significant wave height along Illinois Beach State Park for a NNE event.

3.4
LITTORAL PROCESSES

MIKE Littoral Processes FM is used for analysis involving non-cohesive longshore sediment transport and coastline evolution. This model assists in determining the sediment budget within a defined littoral cell or compartment, which is essential information for all coastal morphology studies. A littoral cell's sediment budget is a description of the sediment inputs and outputs throughout that cell which result in shoreline changes over time. A surplus of sediment results in accretion while a deficit results in erosion. A balanced sediment budget suggests the littoral cell is stable.

The first step for budget analysis is the calculation of the net longshore sediment transport or littoral drift along the coastline. The modeling of littoral transport consists of two parts: a hydrodynamic model to calculate the wave propagation towards the coast and resultant wave driven currents, and a sediment transport model to calculate the longshore transport.

3.4.1. SEDIMENT TRANSPORT

The main input parameters for the hydraulic computations are the wave properties: wave height, angle, and period for a given depth in the profile. From this position, the model will shoal and refract the waves across the profile into the coast and calculate the resulting longshore current across the profile.

To calculate the annual net sediment transport, a representative wave climate was created using the 35 years of historical wave data. The representative nearshore wave climate, shown in Figure 19, consists of a number of events, each described by its frequency of occurance, propogation direction, and nearshore wave height. The summation of the occurrence of the individual wave climates totals one year and therefore this representative wave climate epitomizes 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 20. 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. This signifies a net littoral movement from north to south along the park.

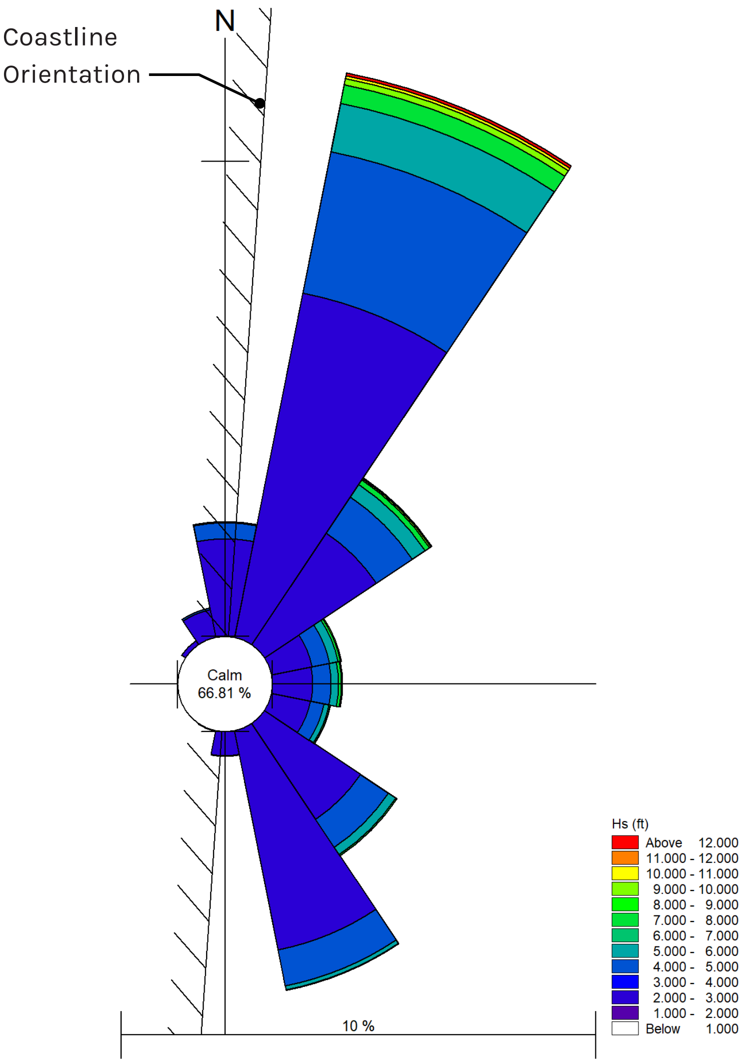


Figure 19: Offshore wave rose of the representative wave climate and its relation to the shoreline.

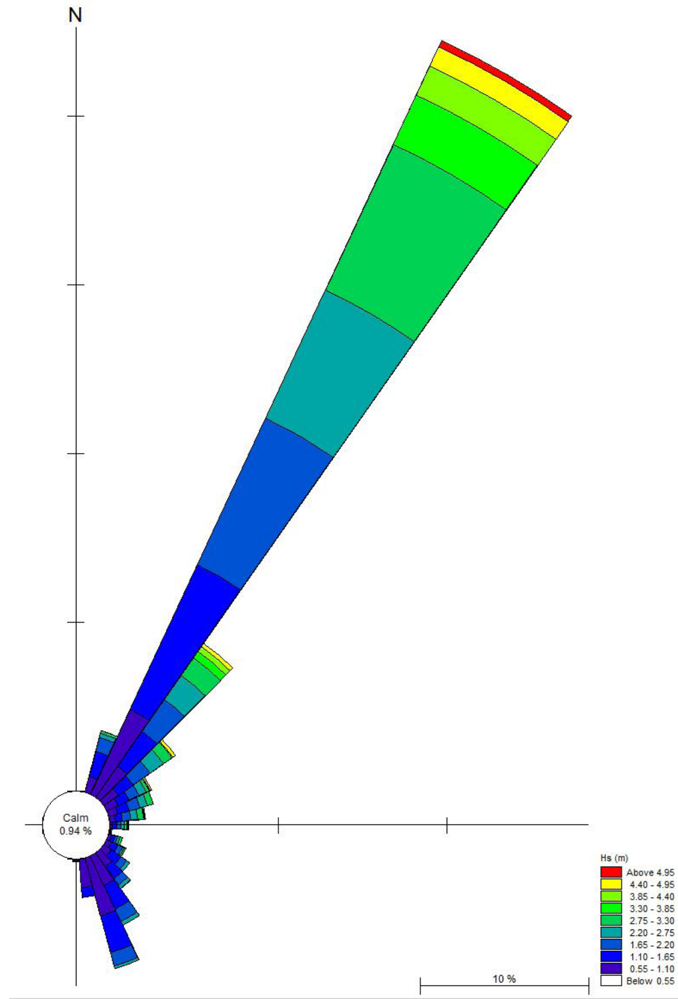
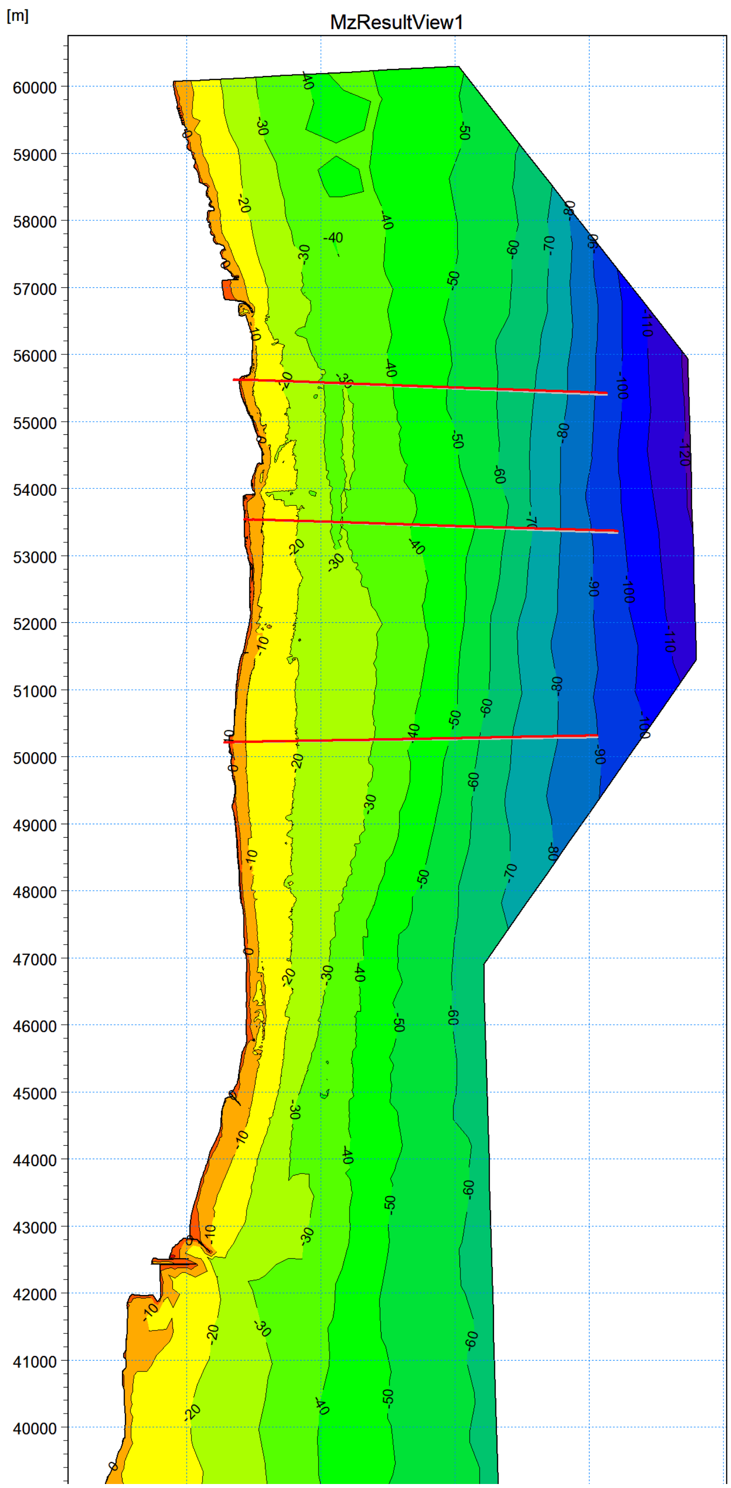


Figure 20: Sediment transport rose due to representative wave climate and its relation to the shoreline.



3.4.2. MODEL CALIBRATION

To minimize errors, the model was calibrated by tuning the model variables in order to reproduce known/measured conditions for a particular situation. Three representative profiles were extracted from the bathymetry, located at the three areas of concern (Figure 21). These profiles were then linked to associated wave propagation, wave climate, and storm surge data.

Longshore sediment transport potential was simulated by integrating the calculated sediment transport for every grid point across the profile, defined by local hydrodynamics and sedimentological conditions.

The selected profiles were extended to a depth of 82 ft, where wave-driven longshore currents generally become insignificant. Because transport rates depend on the steepness

Figure 21: Location of the three representative profiles along the coast.

of the cross-shore profile, the three profiles were conversely extended inland so that the last couple of grid points are always dry and therefore not affected by longshore currents.

Volume estimates for the net southward littoral transport passing through the Illinois Beach State Park generally range between 73,000 and 95,000 cubic yards per year (U.S. Army Corps of Engineers 1953, Tetra Tech 1978, Foyle et al. 1998). This range is based on dredge records for the area near Waukegan. The annual littoral drift was calculated along each profile to verify that the transport rates across the park resulting in the same order of magnitude as the reported estimate.

The annual sediment transport rate was calculated for each profile using the representative offshore wave climate and evaluated to determine how closely the model corresponded to the expected rate. After adjusting the model parameters so that the model output matched physical records, the transport rates shown in Table 8 were determined. Because a representative yearly wave climate was used, it was necessary to perform a sensitivity analysis of the influence of different water levels. It was determined that the difference in net transport was up to 140% greater for high-water levels compared to low-water levels. Therefore, a weighted average value of the net transport for the different water levels was generated; this value varies between 59,700 to 104,600 cubic yards/year.

After calculating the net annual transport rates, transport tables for the coastal evolution simulations were created. These tables summarize numerous littoral transport rates associated with a range of hydrodynamic conditions, providing representative littoral transport rates associated with various wave events.

PROFILE	ROUGHNESS	WL (M)	REDUCTION FACTOR	GAMMA	GRAIN SIZE (MM)	FALL VELOCITY	NET TRANSPORT YD^3	WEIGHTED AVERAGE YD^3
1	0.006	0.89	0.65	0.85	0.3	0.037	67,200	
1	0.006	0.45	0.65	0.85	0.3	0.037	58,100	
1	0.006	0	0.65	0.85	0.3	0.037	55,400	59,700
2	0.006	0.89	0.65	0.85	0.3	0.037	137,700	
2	0.006	0.45	0.65	0.85	0.3	0.037	68,900	
2	0.006	0	0.65	0.85	0.3	0.037	56,900	83,100
3	0.006	0.89	0.65	0.85	0.3	0.037	170,400	
3	0.006	0.45	0.65	0.85	0.3	0.037	88,700	
3	0.006	0	0.65	0.85	0.3	0.037	70,800	104,600

Table 8: Modeled transport rates

3.5
COASTLINE MORPHOLOGY

The coastal evolution model calculates the morphology of the coastline over time. To determine erosion rates along the entire coastline of the park, 35 years of wave information from WIS station 94033 was used to simulate wave-induced sediment transport in the numeric model. The potential longshore sediment transport (in yd3/year) identifying potential erosion, deposition, and stable zones are shown in Figure 22.

The results indicate that the potential net littoral drift along the shoreline from station 10+00 to station 40+00 increases, implying that section of the coastline will erode. In contrast, the net littoral drift rate decreases from station 40+00 to station 55+00, which indicates accretion. The three main areas of concern all exhibit portions of erosion, with a potential starvation of up to 36,000 yd3/year at Area 1: North Beach, 27,100 yd3/year at Area 2: Camp Logan, and 35,800 yd3/year at Area 3: Swimming Beach.

3.5.1
EROSION AT THE AREA 1 - NORTH BEACH

Historic documents show that North Beach was actively eroding prior to construction of the North Point Marina. The addition of the revetment and the offshore submerged breakwater following marina construction created a hard diffraction point that bends incoming waves around it. When combined with wave refraction, the bending of waves due to changes in water depth causes the shoreline to change in order to reach the equilibrium shape of a headland bay beach (Moreno and Kraus, 1999). This shoreline shape is common for a coast with a predominant wave direction, which is the case for Illinois Beach. When diffracting and refracting waves are perfectly aligned, there is no net movement of sediments laterally.

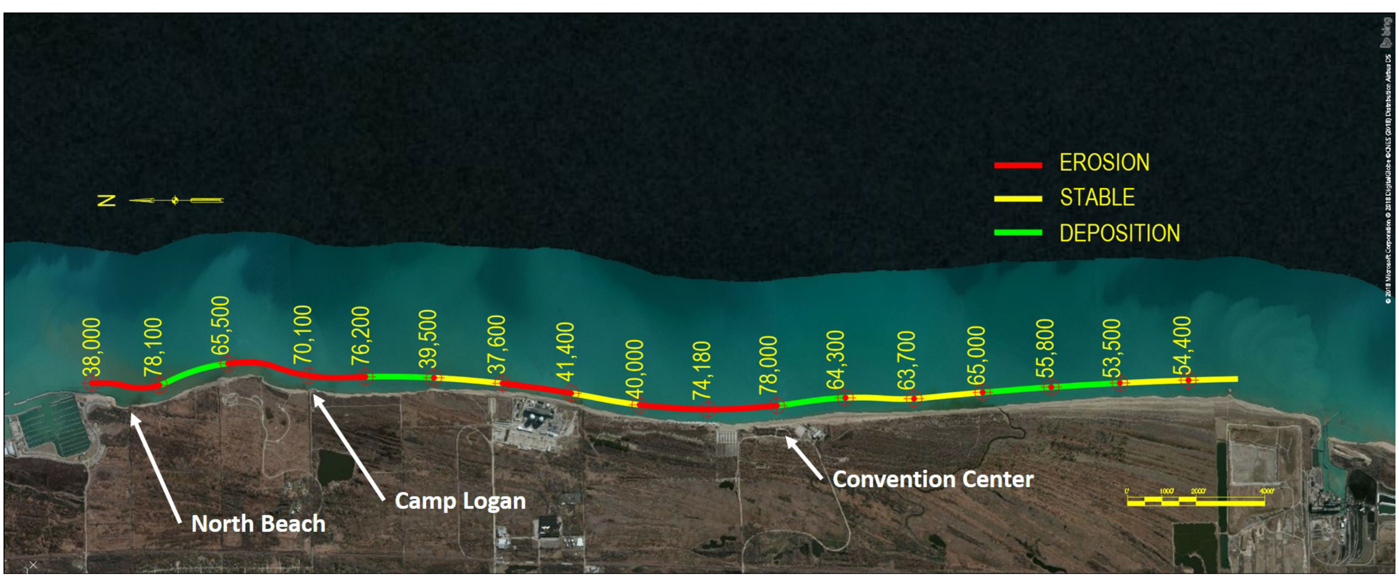


Figure 22: Potential net longshore sediment transport rates (in yd3/year) for the Illinois Beach State Park. (map data: Google, USDA Farm Service Agency)

Both the revetment south of the marina and the sheet pile and concrete blocks at the Camp Logan headland, shown in Figure 25 and Figure 27, hold the shoreline at a fixed position. When the waves approach from the NE sector, they encounter the shoreline protection, diffract around it, and the higher wave energy erodes the sandy, unprotected coast This can be seen in the wave propagation vectors in Figure 23.

Evidence of accelerated retreat can be found where shoreline recession has gone beyond the vegetation line and has carved into the beach face, forming steep slopes. The coastline evolution model was applied and analyzed for this stretch. Figure 24 suggests where the waterline could be after 5 years if no intervention were to take place.

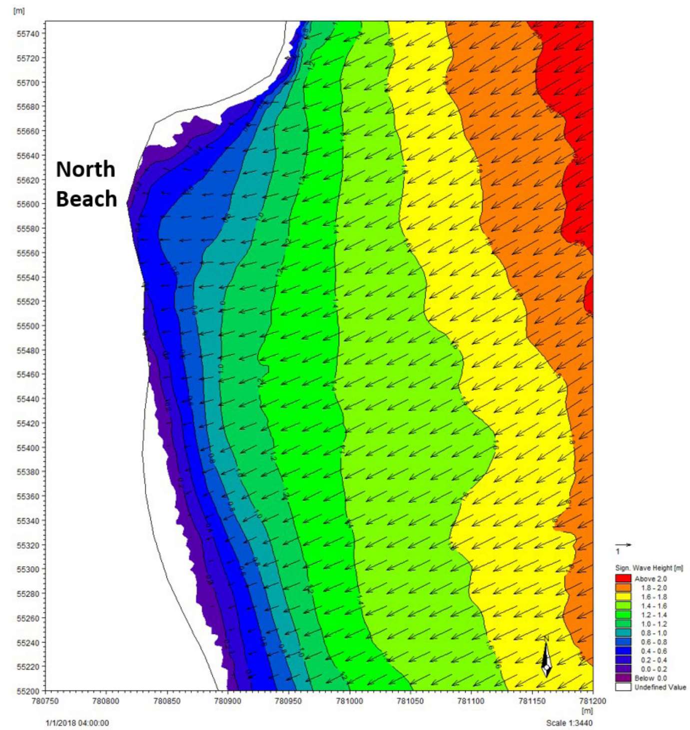


Figure 23: Spectral wave model showing waves from the NE diffracting into the shoreline at North Beach

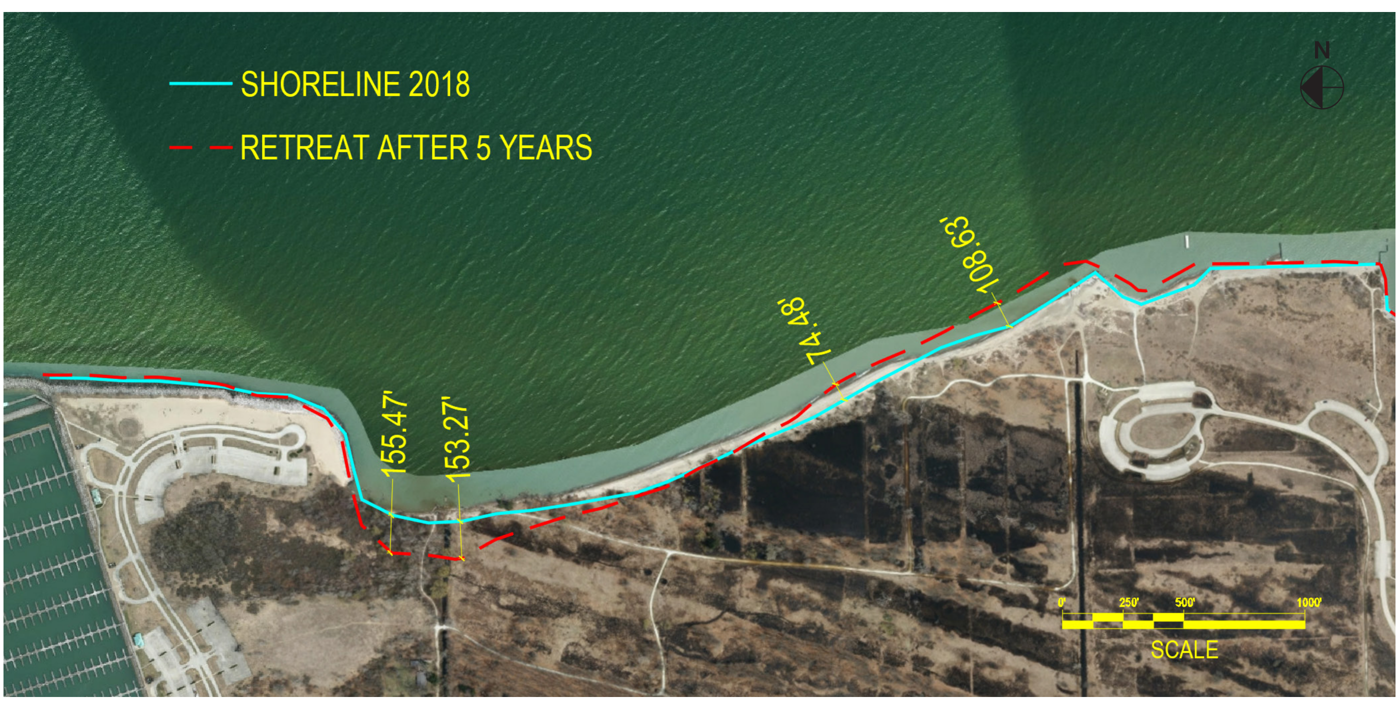


Figure 24: 5-year shoreline projection without mitigation, Area 1 (map data: Google, USDA Farm Service Agency)

Figure 25: Northern edge of Area 1

Figure 25 shows the area at the southern end of the shoreline revetment adjacent to the parking lot looking west and south, with photos taken on August 8, 2018. Erosion can be seen extending behind the revetment, resulting in slope failure that will extend north unless the shoreline is protected.

As seen in the site and aerial photos, erosion has already impacted recreational trails and larger shoreline trees that provided habitat for birds and other animals. Modeling suggests this trend will continue and therefore this area is in requirement of immediate intervention.

3.5.2. EROSION AT AREA 2 - CAMP LOGAN

The potential sediment transport rates for this area indicate erosion along the entire reach. Several shoreline protective measures have been used to control erosion northward of the Lake County water intake station, and include revetments, sheetpile, and concrete cubes. These structures have helped slow the erosion in this area, though many areas have now collapsed, and erosion is occurring along the leeside. Figures 26 & 27 show sections of damaged eco-block revetment and subsequent lee-side erosion.

The shoreline south of the Lake County water intake station is rapidly eroding. A dilapidated eco-block groin, which was destroyed between 2013 and 2015, extends south from the water intake station, shown in Figure 28. Historic aerials suggest this groin performed well for a number of years, holding the shoreline in place behind it. Following the groin's destruction, which occurred in conjunction with a rapid increase in water levels, the exposed land began to swiftly erode.

Figure 27: Camp Logan Headland north of Kellogg Creek

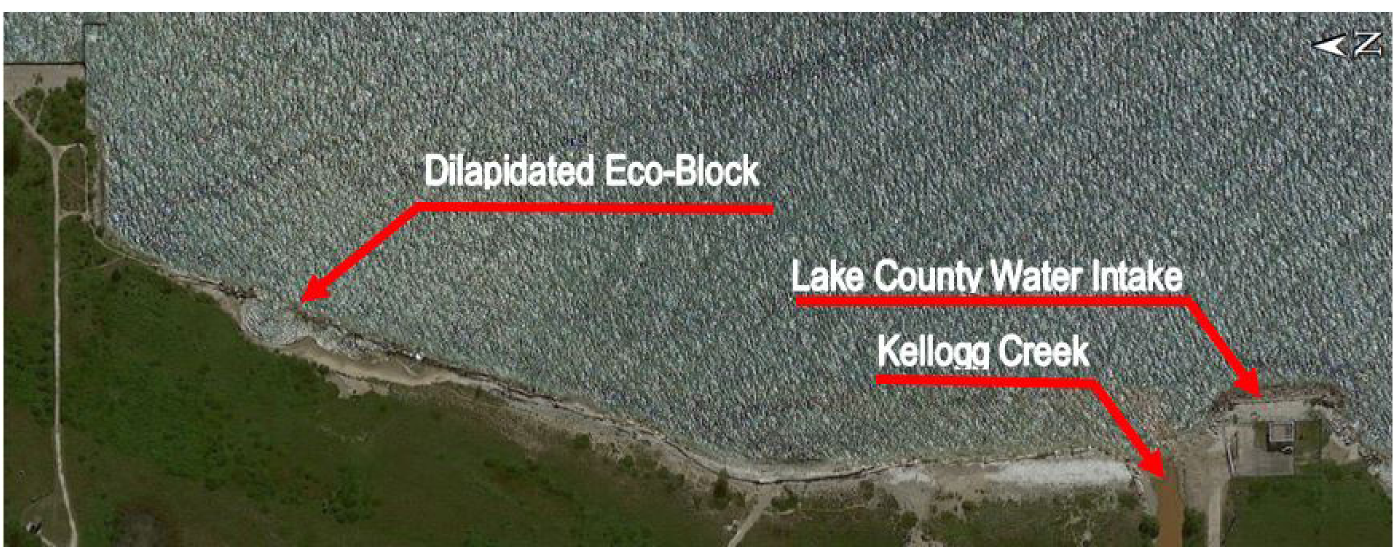


Figure 26: Damage and erosion of the shoreline north of the Lake County water intake station, (map data: Google, TerraMetrics)

Figure 28: Dilapidated Ecoblock adjacent to the Lake County water intake station (map data: Google, USDA Farm Service Agency)

Figure 29: 5-year shoreline projection without mitigation, Area 2 (map data: Google, USDA Farm Service Agency with Drone Overlay)

While the Lake County Public Water district water intake station is protected and stabilized by a rubble revetment, the area to the south, which contains recreational trails a Nature Preserve and RAMSAR wetlands, is threatened by the rapid erosion. Therefore, this area requires immediate action to protect and stabilize the shoreline.

The coastline evolution model was applied for the natural sandy shoreline south of the water intake station. Figure 29 suggests where the waterline could be after 5 years if no intervention were to take place.

3.9
EROSION AT AREA 3 - SWIMMING BEACH

Based on the coastline evolution model for the current shoreline, Area 3 is experiencing the highest rates of erosion. Erosion of this shoreline has necessitated the installation of a riprap revetment north of the recreational beaches to protect the beach walkway, shown in Figure 30. Additionally, beach nourishment has periodically been placed at the swimming beach to protect the parking lot and provide a wider recreational space for visitors. Because of this, the net cross-shore shoreline change is not as drastic as the other areas. Regardless, without these measures, the shoreline would have receded and threatened infrastructure.

Many sections in this area already have shoreline protection installed. The northern beach remains mostly sand, though a sheetpile wall has recently been installed along the back of the beach to protect the walkway and parking lot from being undermined. The shoreline south of the swimming beach is predominately lined with a rubble revetment, installed both at the water line and behind a small sandy beach. This "beach" is likely the remnants of previous sand nourishment installations that have migrated southward. Further south along the shoreline, the sand in front of the park office has eroded, exposing the deck's concrete foundations. Riprap has been placed in front of it in an attempt to stem the erosion. A sheetpile wall has been driven across the back of the convention-center beach in order to prevent erosion from extending landward. Although set back from the water's edge, this steel wall is highly visible and creates a large step to get down to the beach from the parking lot, as seen in Figure 32. The rest of the convention center's property to the south is protected by a sheetpile wall fronted by riprap, shown in Figure 33. The remainder of the park south of the sheetpile wall is natural shoreline with sandy beaches which protect the nature preserve.

Figure 30: Riprap placed to protect the sidewalk north of the Swimming Beach.

Figure 31: Exposed footing and riprap placed in front of the park office

Figure 32: Steel sheetpile across recreational beach

Figure 33: Sheetpile seawall along convention center

In addition to the features mentioned above, this area includes buildings and underground utilities which service the area's recreational activities. These two beaches have the highest attendance of anywhere in the park making the need for protection extremely high.

Using the coastline evolution model for Area 3, Figure 34 indicates where the waterline could be in 5 years if no additional erosion control measures are installed. As shown on the right side of this graphic, erosion will occur adjacent to the end of the sheetpile wall.

Figure 34: 5-year shoreline projection without mitigation, Area 3 (map data: Google, USDA Farm Service Agency)

4.0
SOLUTION ALTERNATIVES

The general strategy for stabilizing the lakefront is to control the transport rate along the entire shoreline, especially in areas of highest shoreline retreat. By controlling the transport rate, the shoreline will experience reduced erosion and ultimately reduced sediment loss, which ends up at Waukegan Harbor. Not only does this continued loss of sediment increase shoreline erosion at the park but it is also detrimental to Waukegan Harbor's operations.

The approach to controlling the transport aligns with the discussion in Section 2.2.1. In some cases, structures such as submerged reefs or barrier breakwater segments are utilized to limit the amount of wave energy that can reach the shore. These structures reduce the transport rate in their immediate shadow area. But more importantly, the solutions use the relative angle of incidence of the waves as they approach the shore to either slow the movement or, in some local zones, fully stop, or reverse the transport occurring. The latter is accomplished by introducing the concept of a "tuned" shoreline by orienting the structures to achieve a certain desired angle with the wave field. By rotating the structure alignment, the wave field reacts as if the shoreline was nearly perpendicular to it so that little or no transport is induced.

Figure 35 and Figure 36 show precedence to this approach using shore attached structures. In Figure 35, the shoreline was intentionally built in a sawtooth pattern to face perpendicular to the predominate waves and thus prevent sediment from moving around the point and causing sedimentation in the harbor. In Figure 36, the cells were filled with sand but then allowed to orient themselves to the wave fronts rather than trying to hold a shore parallel alignment. Both are highly successful in stabilizing the shoreline.

Figure 35: Structure scalloped shoreline - Perth, Australia (map data: Google, DigitalGlobe)

A similar approach is applied in the alternatives developed for Illinois Beach State Park, using offshore structures instead of shore attached structures. Based on the predominate wave direction and sediment transport rose that was developed through numerical modeling (shown in Figure 20), a better understanding of the effect the shoreline orientation has on transport potential can be graphically understood. Figure 37 depicts the net littoral transport rate based on the shoreline orientation. This figure suggests that a tuned shoreline of approximately 30 degrees, relative to the shoreline angle, will reduce the net littoral transport locally to approximately zero.

A net littoral transport of zero suggests that sediment does not erode nor accrete locally. As long as the area is 'full,' sediments traveling along the shoreline will move past the area, supplying sediments downdrift. The goal of a stable shoreline is to have a uniform transport rate throughout so that the net littoral transport is close to zero; meaning there are no areas of erosion or accretion.

Understanding there is a contribution of sediment resulting from south to north transport, the alternatives detailed in this report are configured to allow waves from the southeast to impact the shoreline which would drive sediment back north.

Many design solution alternatives were developed and tested for each area. Each alternative was reviewed by SmithGroup and the client to determine which most aligned with the goals of the project; preference for offshore, submerged, rubble structures, general aesthetics, cost, resiliency and maintenance, dual use as habitat, etc. All of the alternatives developed and tested can be reviewed in Appendix C. The following sections focuses solely on the selected preferred alternatives for the three areas.

Figure 36: Sand scalloped shoreline - Chicago, IL (map data: Google, TerraMetrics)

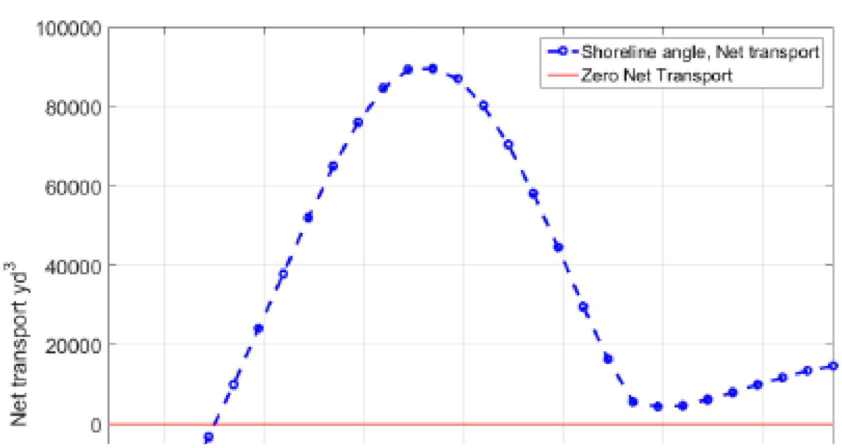


Figure 37: Net littoral transport potential versus shoreline orientation

5.0
PREFERRED ALTERNATIVES

Multiple permutations of shoreline structures were conceptually developed an analyzed using the shoreline morphology model. These alternatives for each area can be found in Appendix C. Following internal analysis and review discussion with IDNR and USACE, the preferred alternatives presented in the following sections were selected for their ability to slow sediment transport, aesthetics, and estimated cost.

Figure 38 below, a repeat of Figure 22 in Section 3.5, shows the potential net longshore transport rates for the existing shoreline. Figure 39 shows the potential net longshore transport rates following the construction of the preferred stabilization structures described in the following sections. As shown pictorially and in the provided rates, much of the shoreline has become stable and overall, there is a much more even transport rate. Areas exhibiting erosion tendencies are now aligned with sections of shoreline which are currently hardened by either rubble or ecoblock revetments. Outside of the areas manipulated by the installation of stabilizing structures, the transport rate largely remains the same as the existing condition. The model estimates that the mean transport across the entire park is 44,350 cy/year and 29,700 cy/year following the construction of stabilizing structures which results in a stable shoreline as long as upstream sediment sources remain unhindered.

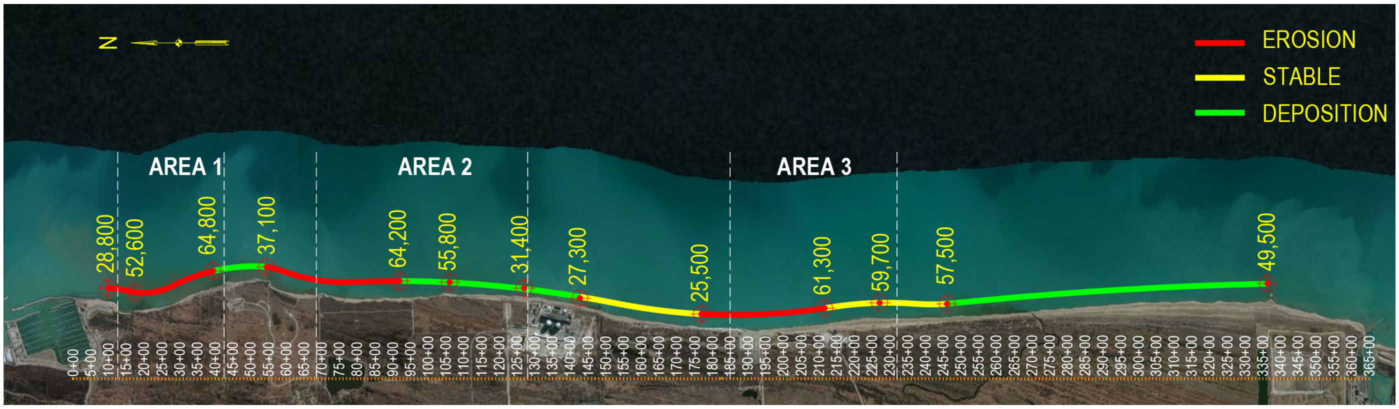


Figure 38: Potential net longshore sediment transport rates (in yd3/year) for IBSP (map data: Google, USDA Farm Service Agency)

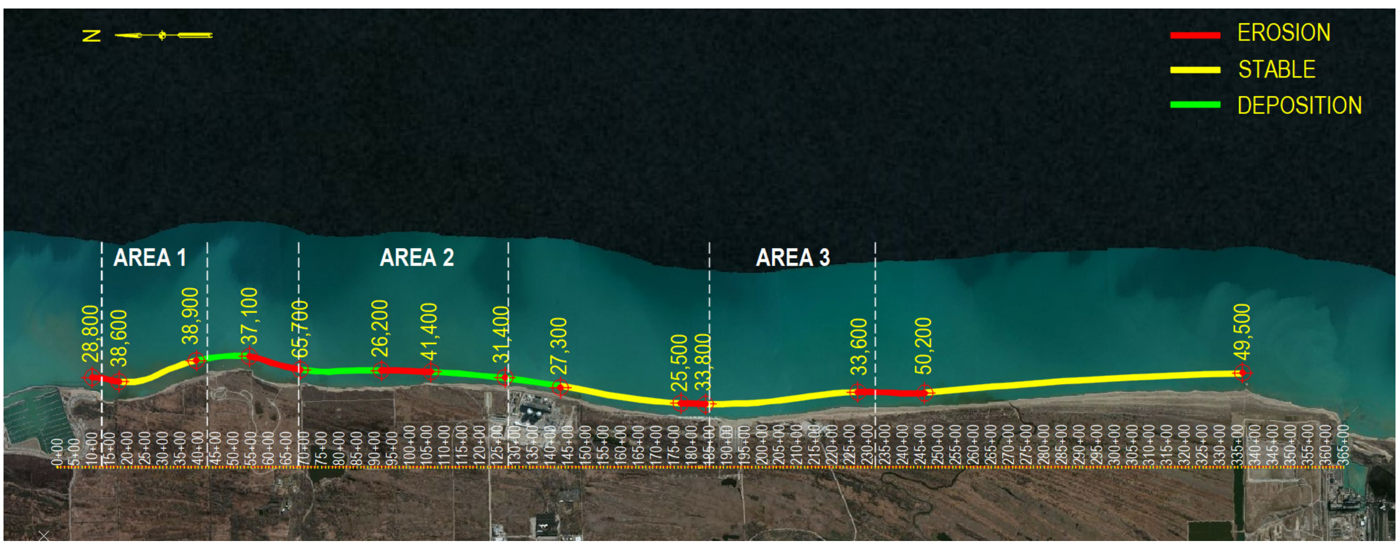


Figure 39: Potential net longshore sediment transport rates (in yd3/year) for the IBSP after installation of stabilization structures (map data: Google, USDA Farm Service Agency)

5.1
SOLUTION ALTERNATIVES FOR AREA 1

The preferred alternative for Area 1, shown in Figure 40, is comprised of four offshore emergent breakwaters which are tuned to the dominate wave direction in order to reduce longshore transport. The location of the offshore breakwaters are outside of the wave breaking zone at high water which results in the breakwaters themselves breaking the wave energy further offshore. To remove the high rate of erosion south of the Northpoint Marina parking lot revetment, a shoreline parallel breakwater creates a barrier to a nourished sand shoreline.

Figure 41 shows the littoral drift potential only within Area 1. The mean littoral drift without the offshore structures is approximately 51,500 cy/year while after the installation, this mean reduces by approximately 37% to 32,600 cy/year with the inclusion of the hard structures. The high rate of littoral drift shown between station 13+00 and 17+00 is against the shore parallel breakwater and therefore no erosion will take place.

Initial volume estimates for this construction are approximately 61,250 cy of stone and approximately 12,900 cy of coarse sand as initial nourishment.
As shown in Figure 40, very little movement of the shoreline occurs within 20 years.

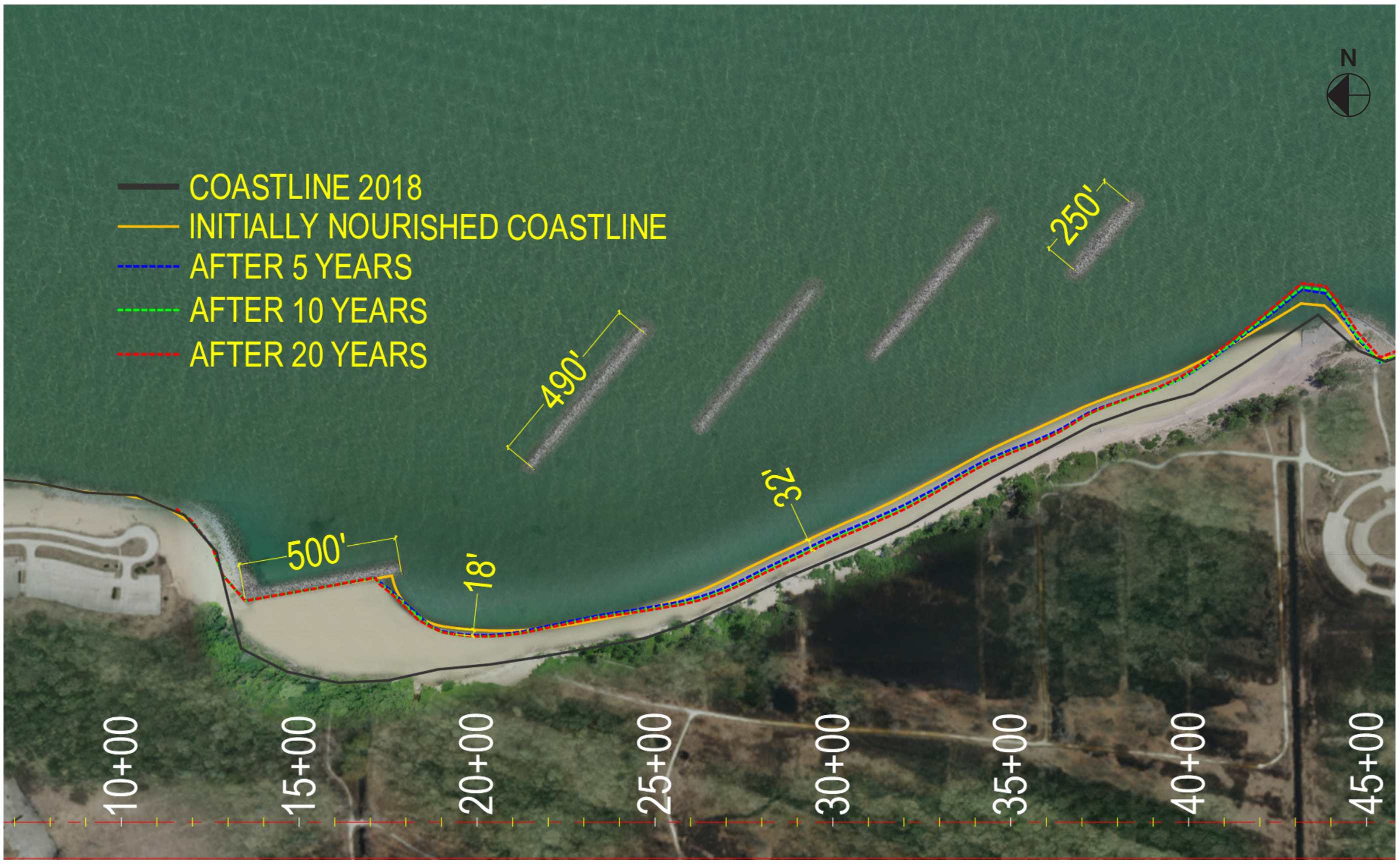


Figure 40: Preferred Alternative Area 1

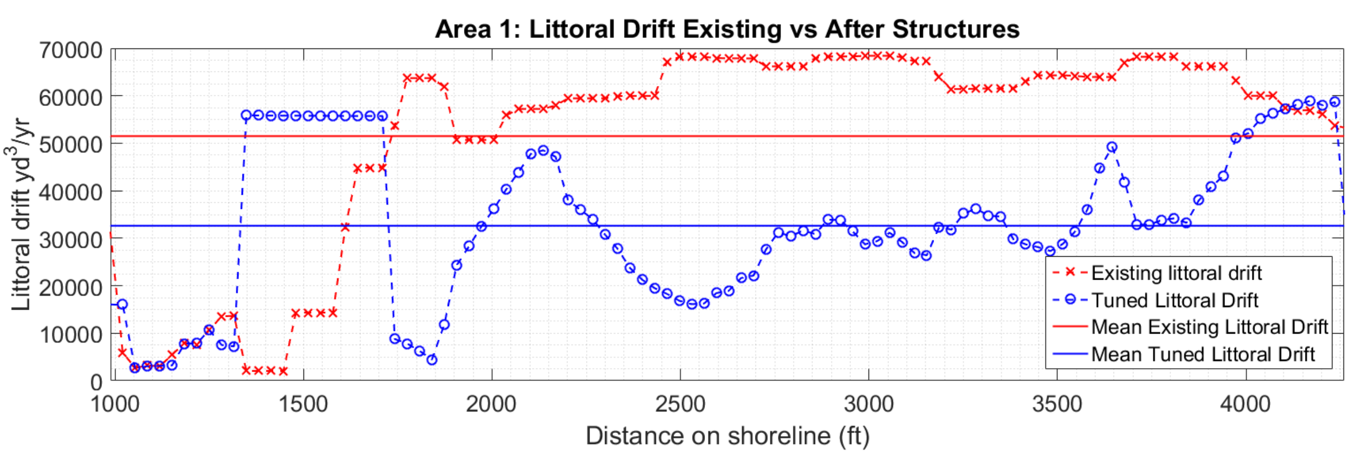


Figure 41: Littoral drift potential of the existing shoreline before and after the installation of structures, Area 1

5.2
SOLUTION ALTERNATIVES FOR AREA 2

The preferred alternative for Area 2, shown in Figure 42, consists of two emergent offshore breakwater which are tuned to the dominant wave direction. Like Area 1, the location of the offshore breakwaters is outside of the wave breaking zone at high water which results in the breakwaters themselves breaking the wave energy further offshore, reducing shoreline transport. A similar design was used south of the Lake County water intake with a shore parallel, attached breakwater which protects a nourished pocket beach. A second nearshore breakwater is located near station 100+00 to prevent lee-side erosion which can result if refracted wave energy is not mitigated beyond the ends of offshore structures. It can be expected that this structure will be surrounded by sand at low water and create a promontory headland at highwater, hindering downshore littoral drift.

Figure 43 shows the littoral drift potential only within Area 2. The mean littoral drift without the offshore structures is approximately 39,700 cy/year while after the structures are in place, transport reduces by approximately 41% to 23,300 cy/year.

Initial volume estimates for construction within Area 2 are approximately 41,900 cy of stone and approximately 70,300 cy of coarse sand as initial nourishment. As shown in Figure 42, very little movement of the shoreline occurs within 20 years.

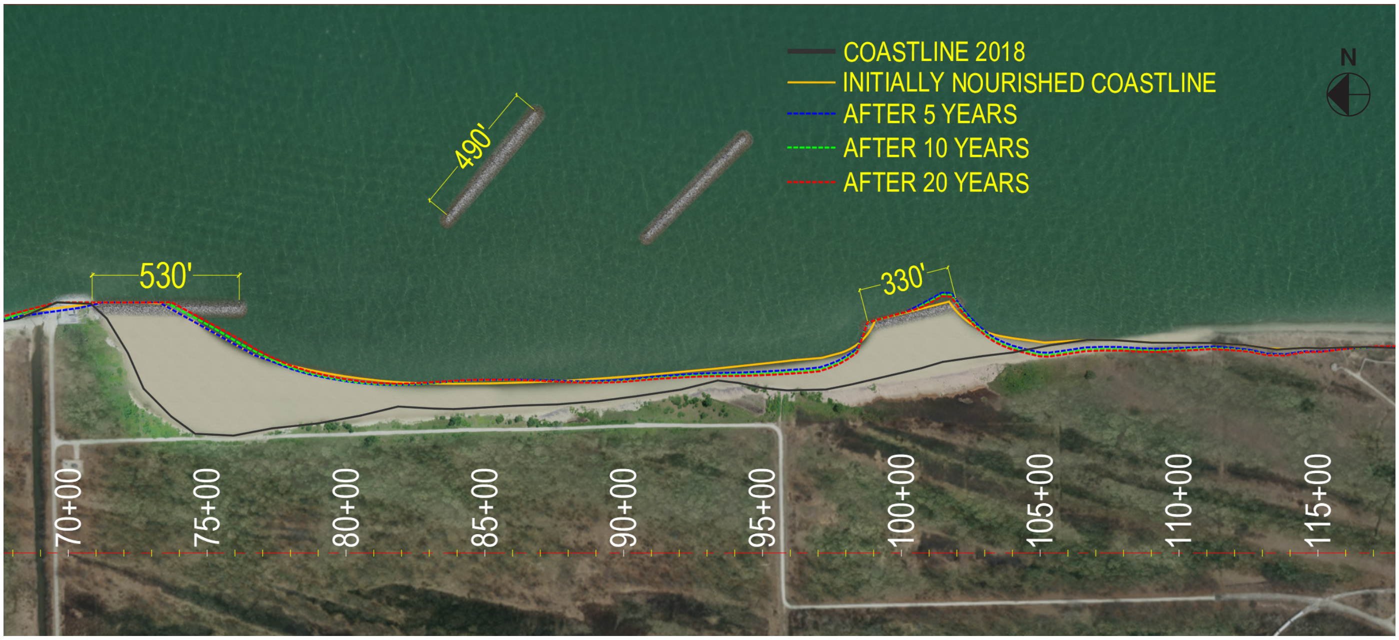


Figure 42: Preferred Alternative Area 2

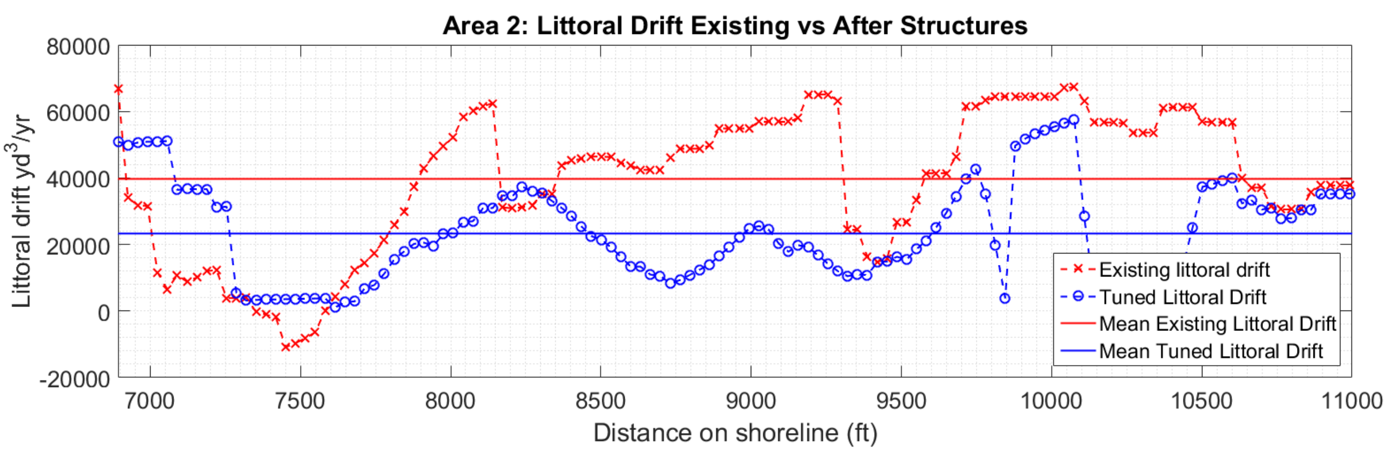


Figure 43: Littoral drift potential of the existing shoreline before and after the installation of structures, Area 2

5.3
SOLUTION ALTERNATIVES FOR AREA 3

The preferred alternative for Area 3, shown in Figure 44, consists of two offshore submerged breakwaters which may become slightly emergent at low water, shown in Figure 46. These breakwaters are located offshore and will cause waves to break as they pass over the top of the structures. This will result in a weakened longshore transport along the shoreline. However, because the structures are low-crested, transport behind these structures is higher than behind emergent structures and therefore they are not as effective in reducing wave energy. In order to provide additional containment of sand along this predominately recreational shoreline, updrift and downdrift structures anchor the beach on the north and south ends creating a closed cell beach system. The northern structure is shore connected to an existing revetment and allows southerly transported sediment to enter the cell but stops any sediment from being pushed north. The southerly nearshore breakwater, similar to the design in Area 2, will be surrounded by sand at low water but 'offshore' at high water hindering downshore littoral drift. This nearshore breakwater was strategically located to provide the most protection for the valuable panne wetland in this area.

Figure 45 shows the littoral drift potential only within Area 3. The mean littoral drift without the structures is approximately 41,900 cy/yr. After installation of the four structures, this mean reduces to 33,100 cy/yr; a 21% reduction.

Initial volume estimates for this construction are approximately 32,800 cy of stone and approximately 27,300 cy of coarse sand as initial nourishment. As shown in Figure 44, very little movement of the shoreline occurs within 20 years.

It should be noted that the numerical model used in this study does not address the behavior of submerged structures and therefore the results of the shoreline morphology are approximate. As there will be energy dissipation from wave over topping resulting in a calmer wave environment nearshore, this approximation is not considered conservative. The final shoreline shape due to the submerged structures will be determined through physical modeling.

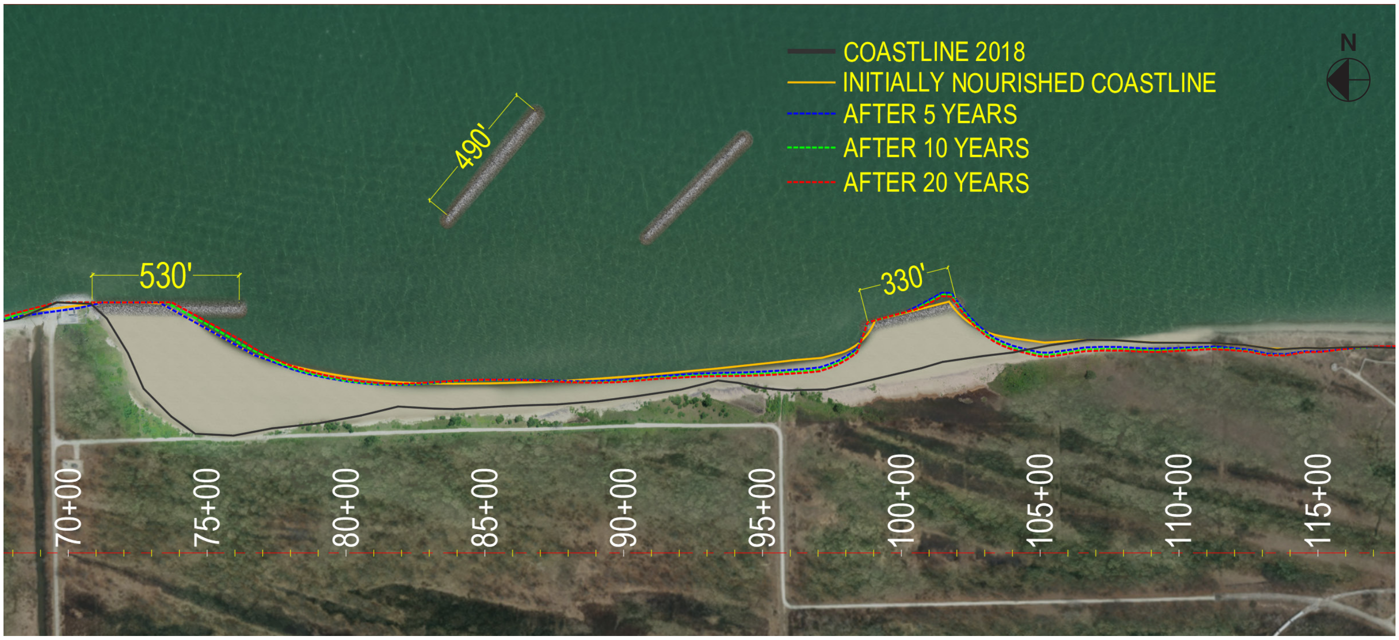


Figure 44: Preferred Alternative Area 3

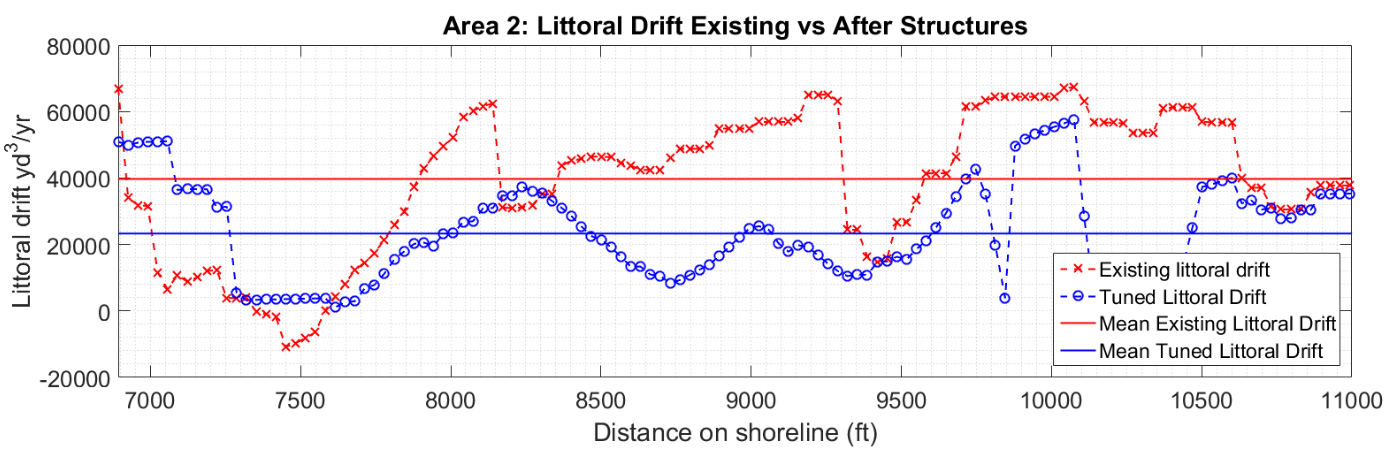


Figure 45: Littoral drift potential of the existing shoreline before and after the installation of structures, Area 3

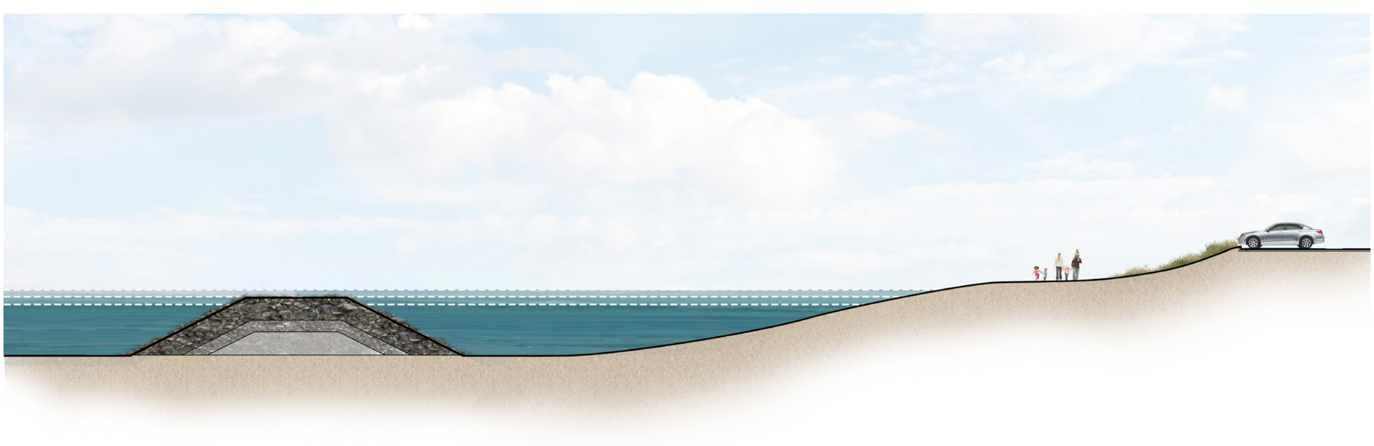


Figure 46: Idealized cross-section representation of a submerged breakwater and various water levels, not to scale

6.0
REGULATORY PERMITTING

Implementing the improvements proposed for Illinois Beach State Park will require obtaining permits from federal, state and local regulatory authorities. Our understanding of the review process and permit requirements are summarized below, they will be confirmed as the project and permit preparation process advances.

6.1
FEDERAL & STATE REVIEW AND PERMIT PROCESS & TIMELINE

Regulatory Permits will be required from the U.S. Army Corps of Engineers (USACE), the Illinois Department of Natural Resources/Office of Water Resources (IDNR/OWR) and the Illinois Environmental Protection Agency (IEPA). In addition, permit review will also be required from the Illinois State Historic Office and the McHenry-Lake County Soil and Water Conservation District. The joint permit submittal includes the joint application form, drawings, narrative and any additional support information necessary for review.

The U.S. Army Corps of Engineers (USACE) has regulatory authority of public waterways of the U.S. Under the Rivers and Harbors Act of 1899, revised in 1968, the review authority includes; navigation, fish and wildlife conservation, pollution, aesthetics, ecology and general welfare. The USACE's regulatory function was expanded with the passing of the Federal Water Pollution Control Act Amendments of 1972 and the Clean Water Amendments in 1977. The purpose of the Clean Water Pollution Act was to restore and maintain the chemical, physical and biological integrity of the nation's waters.

Section 404 of the Clean Water Act requires an Individual Permit to allow for construction of the proposed improvements. Pre-application conferences are typically held with USACE to discuss the initial design concepts, and formal permit application materials will be developed as part of the Design Development process. Their review typically takes approximately 5 months. However, there approval is not granted until IEPA approves the project which can take up to 15 months.

The IDNR/OWR regulatory authority is the Rivers, Lakes and Streams Act (615 ILCS, 1994). Under this authority, permits are required for any construction within a public body of water. All projects in Lake Michigan are subject to the Regulation of Public Waters rules (17 Illinois Administrative Code, Part 3704). In addition, IDNR/OWR is responsible for conserving and preserving the State's natural resources.

Section 401-IEPA

Section 401 of the Clean Water Act requires that a Water Quality Certificate be issued by Illinois EPA for any discharges of fill material into wetlands and other Waters of the United States. Section 401 reviews are typically done in conjunction with USACE Section 404 permitting processes. Concurrent with the Ohio EPA review, USFWS will review the area for any critical habitat. Ohio DNR will also review the project for any potential impacts to Natural Heritage Areas, significant breeding bird and endangered aquatic species concentrations. IEPA review process typically takes approximately 15 months.

The permits required from USACE, IDNR/OWR and IEPA are obtained by first submitting a joint application. Reviews are done concurrently by the various agencies, however, since the USACE approval is contingent on the IDNR/OWR and IEPA approval, the timeline to receive permits is contingent on IEPA which takes approximately 15 months. There is an expedited review process which can be obtained, however the fee for this expedited review is 5 times the fee for a normal review. The fee is based on the cost of the improvements.

6.2
MCHENRY-LAKE COUNTY SOIL & WATER CONSERVATION DISTRICT

The McHenry County SWCD has jurisdiction over Illinois Beach State park and has review authority for conservation of soil and water resources. A separate application will be required for their review. Their review typically takes approximately 2 months.

6.3
ILLINOIS HISTORIC PRESERVATION AGENCY

The Illinois Historic Preservation Agency (IHPA)is now part of the Illinois Department of Natural Resources and is responsible for protecting the natural and cultural resources in the State of Illinois. The IHPA reviews construction involving impacts on historic resources. Their review typically takes approximately 2 months.

7.0
STRUCTURE DESIGN

While there are a variety of breakwater types, one of the simplest to construct and most resilient to storm events is a layered rubble mound breakwater. For the purposes of preliminary planning and budgeting, each shore-stabilizing structure identified in Section 5 has been shown as a three layer rubble mound breakwater of trapezoidal cross section (Drawings found in Appendix J). Refinement of this design is anticipated in future engineering.

7.1
COST VS. RISK

Determining the correct level of protection for a site requires a deep understanding of the site and the client's ability/willingness to provide future maintenance. If under designed, a breakwater will fail resulting in damage to whatever it was built to protect and added cost of reconstruction. If over designed, initial costs of material and construction are considerably high needlessly. A well designed structure comes from balancing the client's acceptable risk against construction and maintenance costs.

Risk is defined as the probability an event will occur multiplied by the vulnerability of the object to be influenced by the event divided by any countermeasures installed or the object's ability to cope with the consequences. When money is a factor, such as with the design & construction of offshore structures, cost of repairs will further influence whether the risk associated with engineering to a specific design event is acceptable or not.

To forecast future storm conditions, historical data is compiled, and a statistical analysis is performed. The result of this analysis is a determination of 'return period events.' These events have names such as the 100-year event or 1000-year event but what they represent is a statistical likelihood of an event occurring. For example, a 100-year event has a 1% probability of occurrence on any given year and should such an event occur, the event still has a 1% probability of occurrence the following year.

Return period events are determined by performing a distribution analysis. Such an analysis can determine a return period event up to three times the length of the available historical data used with reasonable accuracy. Forecasting beyond this time limit results in loss of accuracy and confidence. Therefore, forecasting a 1000-year event with only 10 years of data is not advised.

While it is acceptable to design a structure to resist a high return period event, from a cost standpoint, this can be exceedingly expensive and therefore other factors should be considered which will influence the level of acceptable risk. These factors include how often the structure will be inspected, how easy is it to repair the structure, available construction materials, local cost of labor/materials, does failure of the structure reduce life safety, initial construction cost, etc. If the failure of a structure results in very little adverse effects, a higher level of risk is acceptable. If, on the other hand, the failure of a structure jeopardizes life, then the structure must be built very robust with low risk of failure. Or separately, if maintenance and repair of a remote structure is exceedingly difficult or costly, making the structure more robust during initial construction can alleviate maintenance down the road.

The determination of the correct level of risk for the structures at Illinois Beach State Park will be a marriage of coastal engineer's expertise and client's comfort level for risk. This decision can't and shouldn't be made without an understanding of the influencing factors and both parties weighing in.

7.2
DESIGN METHODOLOGY

Preliminary design calculations were performed using the methodology outlined in the Coastal Engineering Manual (CEM). Calculations used to design each structure are given in Appendix L. The set of design variables used in these calculations are based on engineering experience and are subject to refinement following consultations with the client and adjusted acceptable risk. Final breakwater sizes and volumes will be determined following additional engineering and physical model testing.

	CREST ELEVATION	VOLUME CY	ARMOR STONE	FILTER STONE
Nearshore Breakwater 1	587.5	7,952	2-3.5 TONS / 6.5 FT THICKNESS	3 FT. THICKNESS
Offshore Breakwater 2	585.0	15,254	5.5-9.5 TONS / 9 FT THICKNESS	4 FT. THICKNESS
Offshore Breakwater 3	585.0	14,645	5.5-9.5 TONS / 9 FT THICKNESS	4 FT. THICKNESS
Offshore Breakwater 4	585.0	15,485	6-9.5 TONS / 9 FT THICKNESS	4 FT. THICKNESS
Offshore Breakwater 5	585.0	8,187	3-4.5 TONS / 7 FT THICKNESS	3.5 FT. THICKNESS
Nearshore Breakwater 6	587.0	6,954	1.5-2.5 TONS / 6 FT THICKNESS	2.5 FT. THICKNESS
Offshore Breakwater 7	585.0	14,458	3-5 TONS / 7.5 FT THICKNESS	3.5 FT. THICKNESS
Offshore Breakwater 8	585.0	14,310	6-9.5 TONS / 9 FT THICKNESS	4 FT. THICKNESS
Nearshore Breakwater 9	587.0	6,386	2-3 TONS / 6 FT THICKNESS	3 FT. THICKNESS
Nearshore Breakwater 10	587.5	6,881	2-3 TONS / 6.5 FT THICKNESS	3 FT. THICKNESS
Submerged Breakwater 11	579.0	12,031	3.5-6 TONS / 7.5 FT THICKNESS	3.5 FT. THICKNESS
Submerged Breakwater 12	579.0	12,031	3.5 - 6 TONS / 7.5 FT THICKNESS	3.5 FT. THICKNESS
Nearshore Breakwater 13	587.0	2,000	2-3 TONS / 6 FT THICKNESS	3 FT. THICKNESS

Table 9: Summary of Preferred Alternative Breakwaters

8.0
STRUCTURE MAINTENANCE

All coastal structures require some amount of inspection and maintenance. Concrete and vertical sides structures, such as seawalls or concrete armor units, require more frequent inspection because once the structure starts to deteriorate, failure quickly follows. Rubble mount structures, like that proposed for the offshore breakwaters, are more resilient and can accommodate more movement and stone displacement before the structure is considered to have failed.

Breakwaters come in a variety of shapes, sizes, and materials. At this preliminary stage, each breakwater is shown as a linear rubble-mound structure which stabilizes the shoreline. While the placement and size are necessary for the primary purpose of shoreline stabilization, the final design of the breakwater will incorporate additional functions such as habitat creation, public fishing access, or event space. These alternative functions will be fleshed out in subsequent design and engineering.

No matter what the final layout and construction become, a maintenance procedure will need to be established which includes annual visual inspections and post-storm inspections to identify issues before they become irreparable. An annual fund should be established at the start of construction to help offset costs associated with inspection and eventual maintenance. It should be anticipated that costs associated with the maintenance and repair of coastal structures are greatest during periods of higher lake level when the shoreline is impacted by larger storm events.

9.0 CONCLUSIONS

Illinois Beach State Park (IBSP) is a dynamic environment with a rich history. Formed as part of a migratory beach-ridge plain, the park naturally wants to drift south and retreat from its current shoreline. As the park has become a State amenity and one of the only natural shorelines left in Illinois, there is great interest in holding the shoreline to its current position. To do this, engineers must manipulate environmental influences without causing negative impacts further down drift. This requires a balanced approach which is mindful of the shoreline system as a whole.

The full shoreline of IBSP was analyzed using historical information and aerial photography. Three area of high shoreline recession were identified. Each of these shorelines are sandy, natural beaches which are highly susceptible to the increase in water levels and extreme storm events which have occurred over the past 5-10 years. With Lake Michigan lake levels approaching historic levels, the erosion rates continue to increase, threatening infrastructure and cherished habitat.

A century of water level records and over 30 years of wave climate data was used to determine the lake environment along the shoreline. Waves at this location predominately arrive from the NNE sector and due to their angle with the shoreline, result in a north to south movement of sediment, called littoral drift.

Using numerical models, the nearshore wave climate and longshore currents were determined to assess potential longshore sediment transport. The site was characterized based on a shoreline review & inventory, available recent bathymetry, and an average grain size. Model input parameters were modified until the sediment transport rates were in the same order of magnitude as published volume estimates.

Longshore transport is heavily influenced by the predominate wave direction and shoreline orientation. Based on the model outputs providing sediment transport gradients, locations of potential erosion and accretion were identified. The areas of highest erosion potential along the existing shoreline coincided with the three areas identified for this study and were consistent with field observations.

Recognizing the strong potential for erosion, a series of alternatives were developed using hard rubble breakwaters in various locations, sizes, and heights. Using a coastal shoreline evolution model, nineteen different alternatives were tested across the three areas of highest concern. Preferred alternatives were selected for each of the areas. These alternatives were selected for their ability to reduce the sediment transport rate and hold the shoreline to a predetermined shape, general aesthetics, secondary benefits such as habitat creation and recreation, and overall costs.

The preferred alternative for Area 1, located directly south of Northpoint Marina, is given in Section 5.1. It consists of four offshore emergent breakwaters and one shore-attached breakwater which forms a stable pocket beach. This alternative reduced the overall littoral drift rate in this area by 37%.

The preferred alternative for Area 2, located adjacent to Camp Logan and directly south of the Lake County water intake, is given in Section 5.2. It consists of two offshore emergent breakwaters, one shore-attached breakwater which forms a stable pocket beach, and one downdrift nearshore breakwater which creates a closed cell. This alternative reduced the overall littoral drift rate in this area by 41%.

The preferred alternative for Area 3, located at the park office buildings, convention center, the park's main recreational swimming beaches, and an ecologically valuable perched wetland, is given in Section 5.3. It consists of two offshore submerged breakwaters, one shore-attached angled breakwater on the updrift end, and one downdrift nearshore breakwater which creates a closed cell which will assist in trapping sediment in this area during period of high lake level. This alternative reduced the overall littoral drift rate in this area by 21%.

A summary of the initial estimated volume of armor stone and nourishment sand is given in Table 10 below.

	ARMOR STONE (CUBIC YARDS)	NOURISHMENT SAND (CUBIC YARDS)
Area 1 - North Beach	61,250	12,900
Area 2 - Camp Logan	41,900	70,300
Area 3 - Swimming Beach	32,800	27,300
TOTALS	**135,950**	**110,500**

Table 10: Summary preferred alternative construction volumes

The primary goal of this project is to stabilize a historically erosive shoreline. In addition to reducing the potential transport rate within each of the identified areas, the whole shoreline became more stable with a more uniform transport rate throughout the park. As shown in Figure 47, the three areas north of Area 3 exhibiting erosion tendencies following the installation of the preferred alternatives are aligned with sections of shoreline which are currently hardened by either rubble or eco-block revetments. The area exhibiting erosion on the south end of Area 3 is related to a reconfiguration of the shoreline directly south of the terminus structure which will stabilize over time. Reviewing the full 6.5 miles of shoreline within IBSP, the improvements in the three areas of focus resulted in an overall stabilization of the net littoral transport. This means that the transport rate throughout the park is more uniform than it was prior to improvements. This results in a stable shoreline whose net morphological fluctuations result in neither erosion nor accretion.

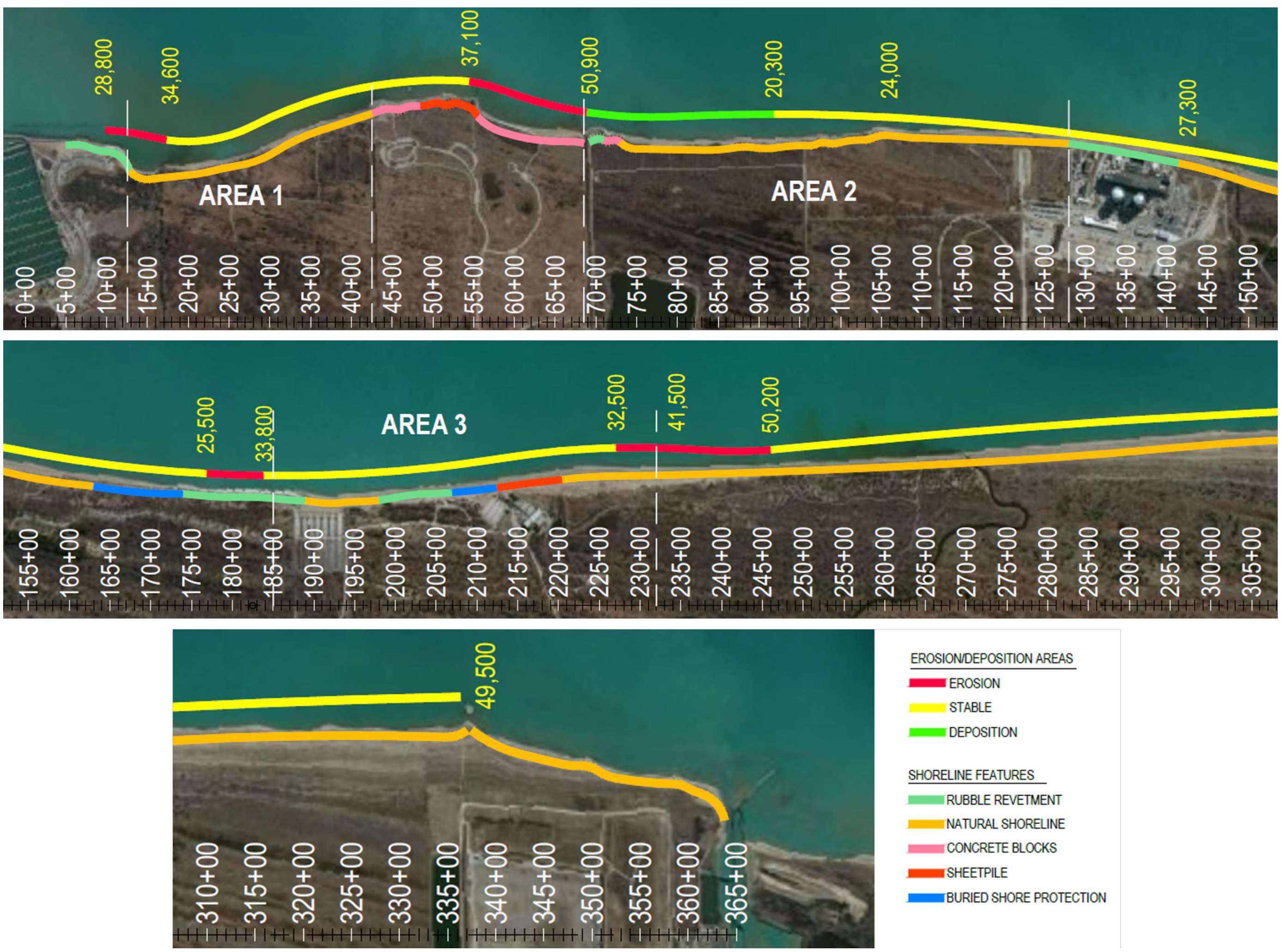


Figure 47: Potential net longshore sediment transport rates (in yd3/year) & shoreline conditions throughout IBSP following installation of the preferred alternatives (map data: Google, USDA Farm Service Agency)

10.0
NEXT STEPS

1. CURRENT BATHYMETRIC SURVEY

Illinois Beach State Park is a dynamic shoreline which has changed significantly with the rising lake levels since a historic low water level record was set in 2013. In order to accurately model the shoreline and the effectiveness of the various breakwater layout options as well as estimate the quantity of construction material, accurate bathymetry and topography is needed. As described in this report, bathymetry was stitched together from various sources taken during different years. In many locations, the shoreline had changed significantly resulting in smoothing between the two sources. As this does not represent the current physical environment, this allows for a degree of error in the modeling effort. To avoid this in the design stage and the physical model testing, it is recommended a full bathymetric survey study be performed.

2. STRUCTURE TUNING AND BIO ENHANCEMENT

The preliminary engineering outlined in this report focused on the primary project purpose of shoreline stabilization. This resulted in a structure of a given length and placement creating a shadow zone along the shoreline which allows for sediment retention. While the shadow zone and offshore placement of such a structure are important, future 'tuning' of the structure of allow for the integration of secondary purposes, such as bio enhancement, are anticipated. Such a refinement is shown in Appendix H. Tuning of the structures will occur within the design development stage and verified in physical model testing.

3. PHYSICAL MODELING

Due to the scale and complexity of the project, physical modeling is recommended to validate and refine engineered solutions. Why numerical models continue to become more advanced, nearshore phenomena is very complex and difficult to replicate. Physical modeling is the best technique for replicating offshore and nearshore processes.

Physical modeling is the scaling down of a physical site including the actual bathymetry and sediment in a large testing basin. Wave paddles, programed to create irregular waves similar to those at the project site, generate a series of wave events to test the solutions. For the physical modeling of Illinois Beach State Park, testing will focus on shoreline morphology and structure stability. Each of these tests require a different set of wave climate input. The wave climate at the offshore location represented by the wave paddles will be developed based on the climate data included in this report. Because Lake Michigan's weather is variable, these physical model tests will incorporate multiple lake events with varying wave height, period, and direction.

The physical modeling will be performed at two scales. First, a larger scale three-dimensional sediment transport model will look at refining structure shapes and position offshore. Secondly, a smaller scale two-dimensional model will look to examine the performance of individual structures in terms of interaction with the habitat created on the leeside of the breakwater. This will define the size of armor, substrate material, and the specific cross sectional geometry to provide sustainability and conformance with intent.

Project team members will be onsite during the physical model testing and will oversee the work. Structures found not to be functioning as intended will be modified by the engineering team and retested. This will result in a new set of alternatives. Each test and layout alternative will be documented within a physical modeling report generated by the laboratory.

Due to the size and complexity of the project, only a few laboratories are qualified to perform the proposed physical model test. The following physical modeling laboratories operate multi-directional wave basis and will be approached to prepare an estimate to perform this work.

- National Research Council Canada – Ocean, Coastal and River Engineering Research Centre – Ottawa, Canada
- HR Wallingford – Wallingford, England
- Oregon State University – O.H. Hinsdale Wave Research Laboratory – Corvallis, Oregon
- Flanders Hydraulics Research – Antwerp, Belgium
- Hydralab+ - Franzius-Institute for Waterways, Estuarine and Coastal Engineering – Hannover, Germany

4.PERMITTING

Any structure that is built along the Great Lakes shoreline or within its waters requires a permit. For the structures described within this report, an individual joint permit will be required which will be reviewed by the U.S. Army Corps of Engineers (USACE), the Illinois Department of Natural Resources/Office of Water Resources (IDNR/OWR) and the Illinois Environmental Protection Agency (IEPA). This process can take anywhere from a few months to a few years depending on the scale and complexity of the project. Pre-application meetings and documentation of numerical and physical modeling to show the effects on the adjacent shoreline will aid in the review of the application and its acceptance by the regulatory agencies.

Additional permitting requirements are outlined in Section 6.

5 FINAL DESIGN DOCUMENTS

Physical modeling will fine tune the structures to jointly protect the shoreline and create areas conducive to habitat formation. Once the shoreline improvements are tested and finalized, each area and structure will be documented in construction ready drawings and technical specifications. These documents will be accompanied by a refined opinion of probable construction cost.

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