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Appendix G – Sediment Transport Analysis

Draft Supplemental Environmental Assessment
Morgan Shoal Revetment Reconstruction (45th - 51st)

SEDIMENT TRANSPORT ANALYSIS

EXISTING LITTORAL SEDIMENT TRANSPORT

Littoral sediment transport is driven by the incoming waves, as they arrive to the shoreline at an angle and break in the shallows, wave breaking transports water and creates a differential water elevation that originate currents nearshore within the wave breakers. When there is sediment, as the waves break, creating turbulent motions, the finer sediment is placed in suspension and is transported by the nearshore currents. These currents also transport the coarser sediment in a slower mode as bedload transport. In many shorelines there is unlimited sediment supply, and we can estimate the sediment transport based on the wave climate, shore slope, bathymetry, sediment grain sizes and other parameters. This estimation is based on the assumption that there is unlimited sediment supply and is referred as, ***potential sediment transport rate***. The potential sediment transport rate is not equal to the actual transport rate if there is limited supply of sediment. The real sediment transport can be estimated calibrating the potential sediment transport rate against visible shoreline changes, dredge records and bathymetric comparisons. Typically, a sediment starved coast will suffer erosion if the potential sediment transport is larger than the existing sediment transport, as is the case on the south side of Chicago.

Southwest Lake Michigan's predominantly north and northeastern waves offshore create an overall north to south sediment transport along the project's shoreline. Because the limited sediment supply along southwest Lake Michigan's coast due to anthropogenic interventions to stabilize the coast, the actual sediment transport is less than the potential sediment transport rate. The estimated volume of littoral transport crossing the state line southward from Wisconsin into Illinois is 10,000 CY/YR (Foyle et al. 1998). South of Evanston much of the shoreline has been armored and artificially modified, especially from Evanston, IL, to Gary, IN, there is essentially no longshore transport in this zone (ERDC, Morang, Dunkin 2019). Further the southern (Chicago) shore is almost entirely engineered and artificial. The presence of numerous large in-lake structures (e.g., harbors, jetties, detached breakwaters) has created significant littoral barriers.

The stretch of coastline along the project is considered a sediment starved area and there is very little sediment moving along the shore. Potential sediment transport calculations indicate that if there was sediment within the system it would move from north to south. At the northern end of the project limits the potential sediment transport rate is approximately 6,000 cubic yards / year (cy/yr), where the shoreline is not sheltered by the shoal. Further south, where the shoal protects the shoreline, the sediment transport rate is reduced and varies with water level. Transport rates are estimated to be about 1,500 cy/yr north to south at high water level and about 200 cy/yr south to north at low water levels. The shoal acts to reverse the predominant transport direction during periods of low water levels, leading to the creation of a small pebble salient beach, often referred to as the 49^{th} Street "Pebble Beach". Figure A shows the estimated potential sediment transport rates along the project shoreline based on Van Rijn's equations, where negative values indicate north to south and positive south to north sediment transport directions.

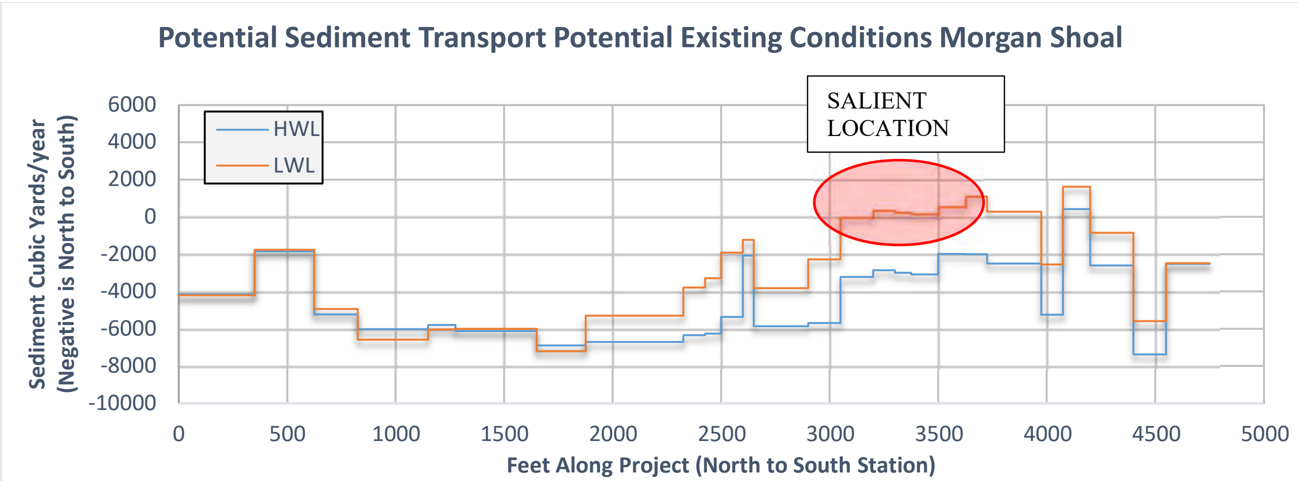

Figure A: Sediment Transport Potential under existing shoreline conditions

At the Shoal the waves suffer from refraction, and diffraction changing their angle of approach to the shoreline and depending on the water level these waves break dissipating wave energy. These wave transformation processes are very sensitive to water levels. Wave breaking, the main mechanism driving the nearshore currents occur when a wave reaches a water depth from 60 to 80% of its height. At a water depth of 10 feet, waves larger than 5 feet will start to break, while at a 6 feet water depth, waves larger than 3 feet will be breaking, these means that water levels will have a large effect on the nearshore littoral current's location and magnitude. During low water levels waves break at the Shoal and dissipate energy generating currents offshore, while at high water levels, larger waves will reach the shoreline and generate nearshore currents. These processes are illustrated in Figures B and C, showing on the upper left low water level wave induced currents, and on the right the stronger north to south wave induced currents nearshore that occur at high water levels.

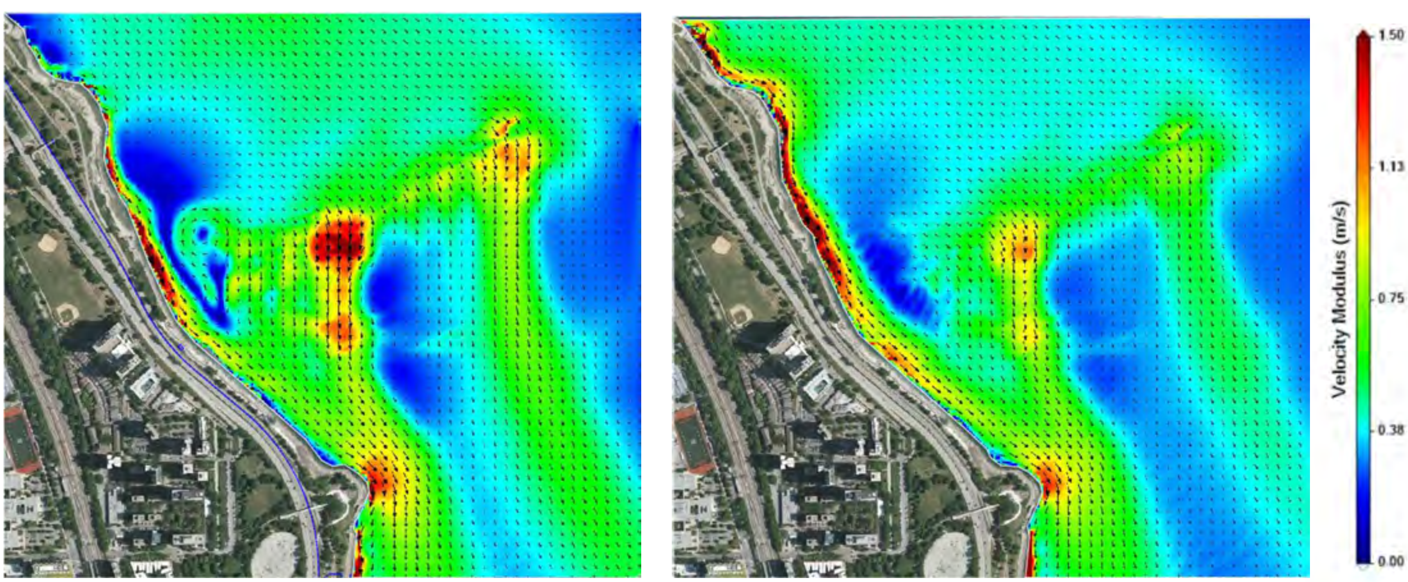

Figure B and **Figure C:** Wave induced currents, left: low water level, right: high water level.

During low water levels a small salient beach is formed which is visible in historical aerial imagery (Figure D). This salient is not visible with high water levels.

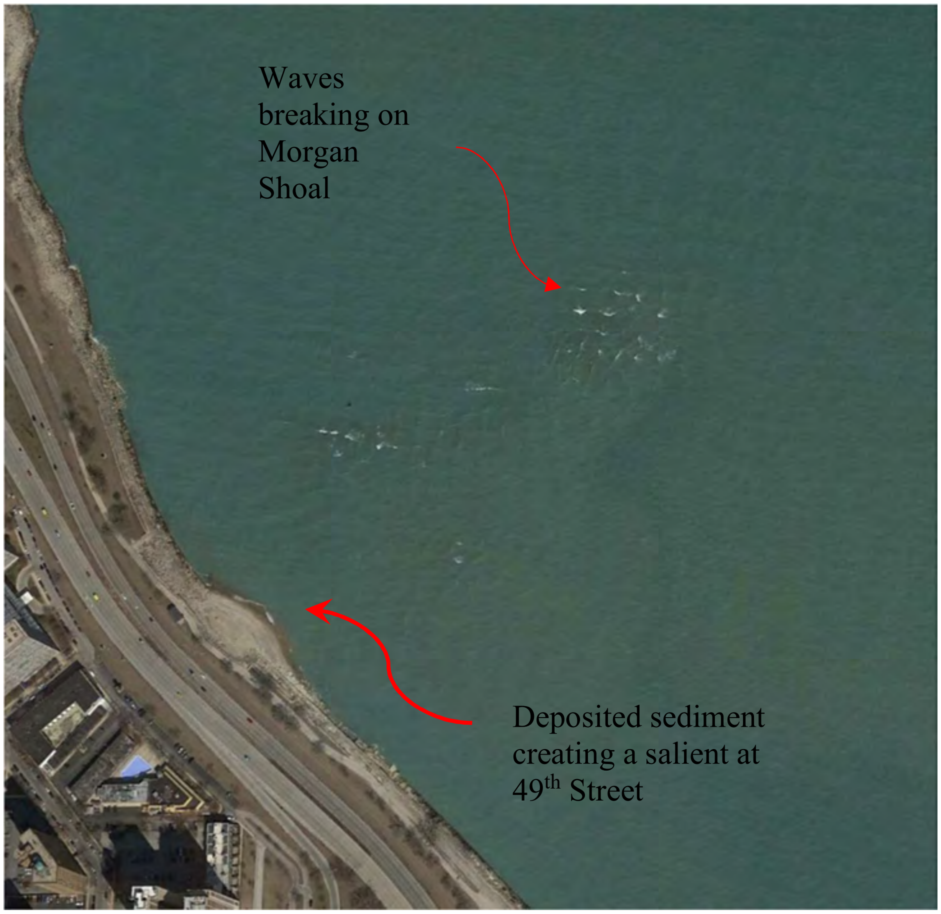

Figure D: Waves Breaking over Morgan Shoal and small salient formation April 2013 during low water levels.

To understand the effect that the different water levels have had on the shoreline the low water level 2012 USACE's lidar bathymetry was compared with the high water level 2022 survey. The comparison Figure E shows the differences in elevation between these two surveys. Negative values indicate erosion, while positive values indicate deposition. The purple color in Figure E indicates the largest erosion, between 3 and 8 feet of deepening while the cyan and green colors show differences between 0.5 and 1-foot. Changes of less than half a foot are not depicted in Figure E.

Figure E shows that between 2012 and 2022 the project's water has suffered from erosion focused within the salient's area. This zone shows erosion elevations between 3 to 6 feet in depth. The total volume of eroded sediment in this zone, is approximately 32,000 cubic yards. It is estimated that most of this erosion occurred during the high lake levels, between 2016 and 2022, indicating that during high lake levels the transport rate in this zone is close to 6,000 cy/yr. The high-water sediment transport rate of 6,000 cy/yr is neither linear nor constant as it depends on the water levels and the wave energy that reaches the shoreline each year.

SEDIMENT TRANSPORT ANALYSIS

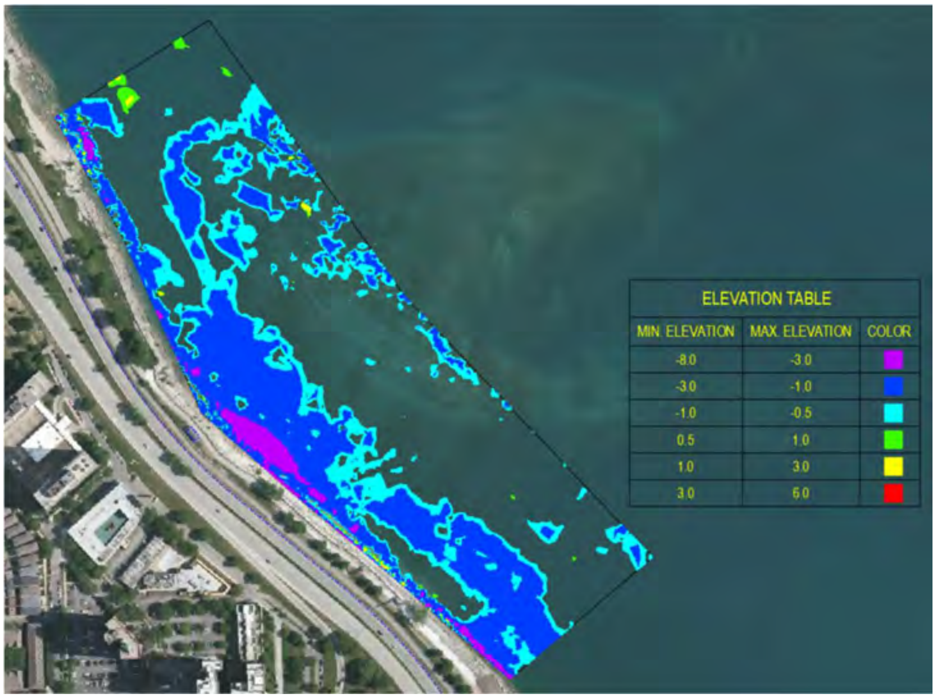

Figure E: Comparison between 2012 LIDAR and 2022 Survey Surfaces

PROPOSED PROJECT

To protect the shoreline, several coastal structural improvements have been proposed and designed. In the northern section, where the water is deeper, a stone armored revetment is being proposed ("North Rubble Mound Revetment"). In the middle shallower section, at the area sheltered from large waves by Morgan Shoal, a "Dynamic Revetment" with an "Underwater Breakwater" is being proposed. South of this section, where the water becomes deeper, another segment of Rubble Mound Revetment is proposed. Finally, on the southern end of the project near 51st Street, where the shoreline wraps around a headland, a vertical wall sheet pile section with a concrete stepped back is proposed (Figure F).

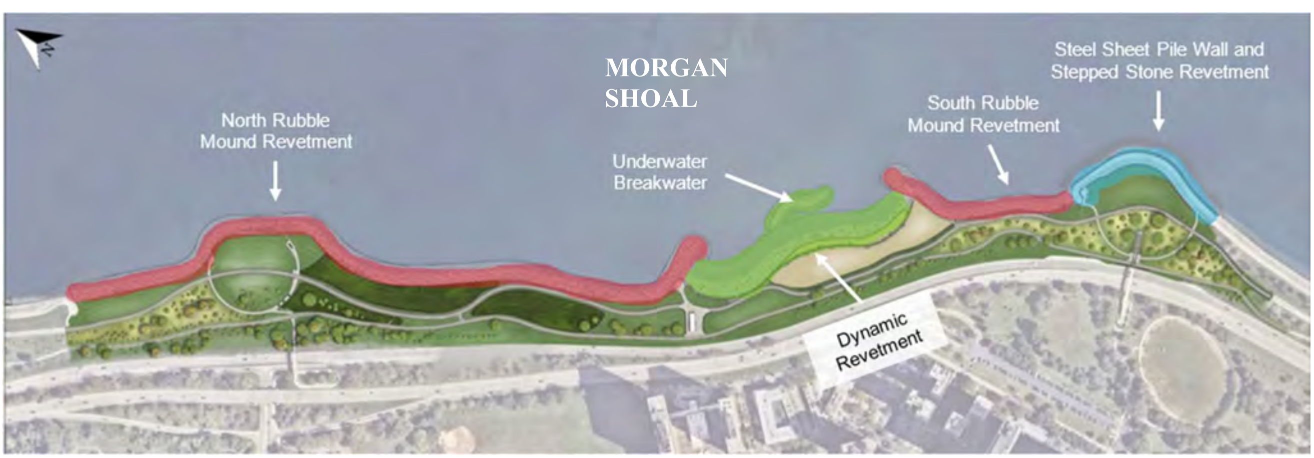

Figure F: Project Area showing Morgan Shoal

SEDIMENT TRANSPORT ANALYSIS

The proposed revetments and sheet pile structures have the effect of protecting the shoreline without having any impact on the sediment transport along the project. As was noted before this stretch of shoreline is sediment starved and suffers from coastal erosion. These revetments are designed with sufficiently large stones for to prevent coastal erosion

The dynamic revetment will be composed of 3-to-9-inch diameter cobble mixed with birds' eye sand, coarse 5mm grain sized sand. These smaller stones can move with the waves and currents and as such are to be placed in the area naturally sheltered by Morgan Shoal. Given the reduced sheltering the shoal has during high water levels the dynamic revetment's orientation was designed in such a way that the net alongshore sediment transport remained stable during low and high water levels. Numerical and physical modeling was carried out to refine this design and to understand the sediment transport along this stretch of shoreline (Figure G). Two small headlands were designed at both ends to reduce and deflect the incoming north to south current along this area, and a small low crested detached breakwater is being provided to reduce the wave energy during high water levels. With the proposed design the dynamic revetment is dynamically stable during low-, mean- and high-water level conditions not affecting the adjacent shorelines.

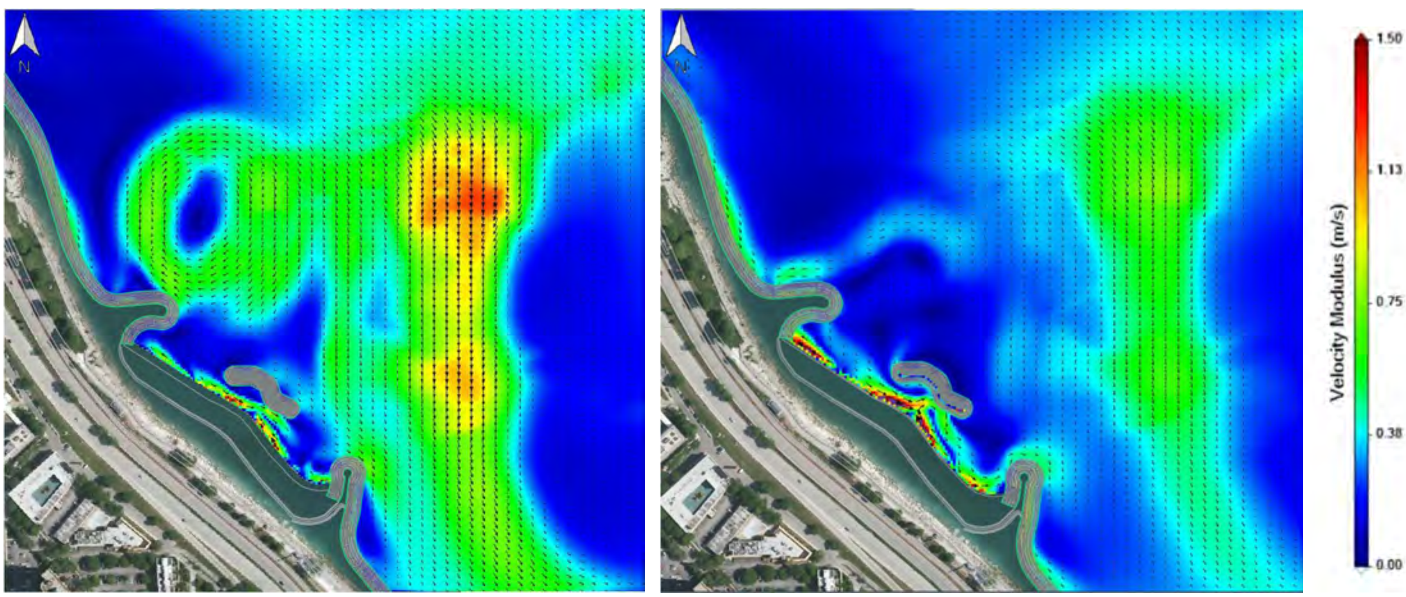

Figure G: Wave induced currents with the proposed project's dynamic revetment, left: low water level, right: high water level. Yearly Average Storm

Given the changes the sediment transport potential was estimated considering the project's design features (Figure H). The results show that the dynamic revetment will be stable and will not suffer erosion and the proposed prefilled cobble will not be transported south affecting the beaches south of the project.

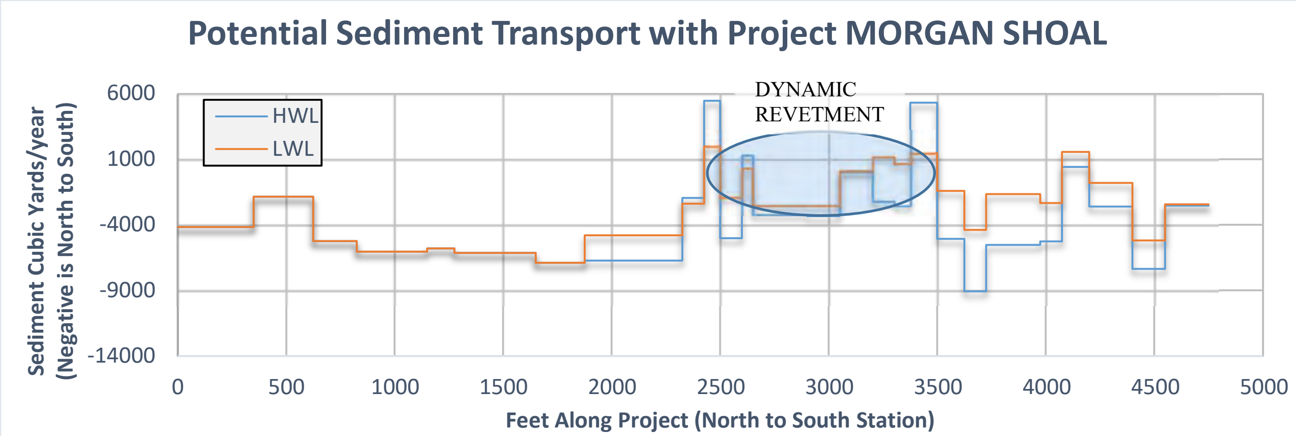

Figure H: Potential Sediment Transport with Project