PLANNING ASSISTANCE TO STATES (PAS) –
LITTORAL ANALYSIS AND SEDIMENT BUDGET STUDY
THE VILLAGE OF GRAND BEACH, MI

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1.0 Introduction

The New Buffalo littoral analysis and sediment budget study was initiated in 2008 by the Detroit District United States Army Corps of Engineers (USACE) at the request of a number of homeowner associations represented by the Village of Grand Beach, MI. The analysis is being done under the Planning Assistance to States (PAS) Program. Meetings with various representatives of the homeowner associations and the Village of Grand Beach in 2007 highlighted the importance of healthy shorelines to the communities south of New Buffalo. The objective of this study is to define sediment management techniques that will enhance littoral supplies to the region.

This study will employ a Regional Sediment Management (RSM) approach to the issues. RSM is a planning philosophy used to develop sediment management goals and action plans for entire natural sediment systems. Ideally, sediment from the nearshore, estuaries, rivers, and land are included in the plan development. By broadening the scope of the project beyond the southern shoreline, the likelihood of regional solutions being attained is increased. It is a goal of this study to find ways of linking harbor, marina, north shore, and south shore issues together to delineate a regional sediment management strategy.

The intent of this report is to be a coastal solution guide for the Village of Grand Beach. Utilizing the findings of this study will allow the village and homeowner associations to pursue effective coastal engineering solutions that will benefit all entities in the region. The conclusions of this study will be the basis of future engineering efforts.

1.1 Authority

Section 22 of the Water Resources Development Act (WRDA) of 1974 (Public Law 93-251), as amended, authorizes the Secretary of the Army, acting through the Chief of Engineers, to assist the States, as therein defined, in the preparation of comprehensive plans for the development, utilization and conservation of water and related resources of drainage basins, watersheds or ecosystems located within the boundaries of such State.

1.2 Objectives of Study

The Scope of Work for the New Buffalo littoral transport analysis outlined several key objectives, including:

- Assembly of existing geo-spatial data in an ArcGIS format;
- Evaluate rates of historic shoreline change and nearshore change and quantify sediment supply;
- Utilize the Coastal Modeling System developed by the USACE Engineering Research Development Center (ERDC) to identify longshore sediment transport patterns and deposition in sediment sinks;

- Complete a sediment budget for the regional shoreline;
- Evaluate potential sediment management solutions involving both nourishment programs and sediment retainment efforts.
- Summarize the sediment sources and sinks, sediment management solution pros, cons, and costs; and
- Deliver a final report addressing the findings of the study.

1.3 Study Site Location

The study site is located on the southeastern shores of Lake Michigan, in Berrien County, Michigan, approximately 45 miles due east of Chicago (Figure 1.1). New Buffalo is exposed to the full length of Lake Michigan from the north-northeast and north and has limited fetch exposure to the northwest and west. The study limits include shoreline stretching approximately 3.1 miles north and 4.4 miles south of the New Buffalo Harbor.

Figure 1.1: Study Site Location

1.4 Regional Site Conditions

A site visit was conducted July 8 and 9, 2008 by staff from the USACE and ERDC. During the site visit, various representatives from the homeowner associations, the Assistant New Buffalo City Manager, and past City Council members joined the workgroup. Based on the site visit, the shoreline from Townline Road to the north up to the Village of Grand Beach was observed and divided into eight reaches as shown in Figure 1.2.

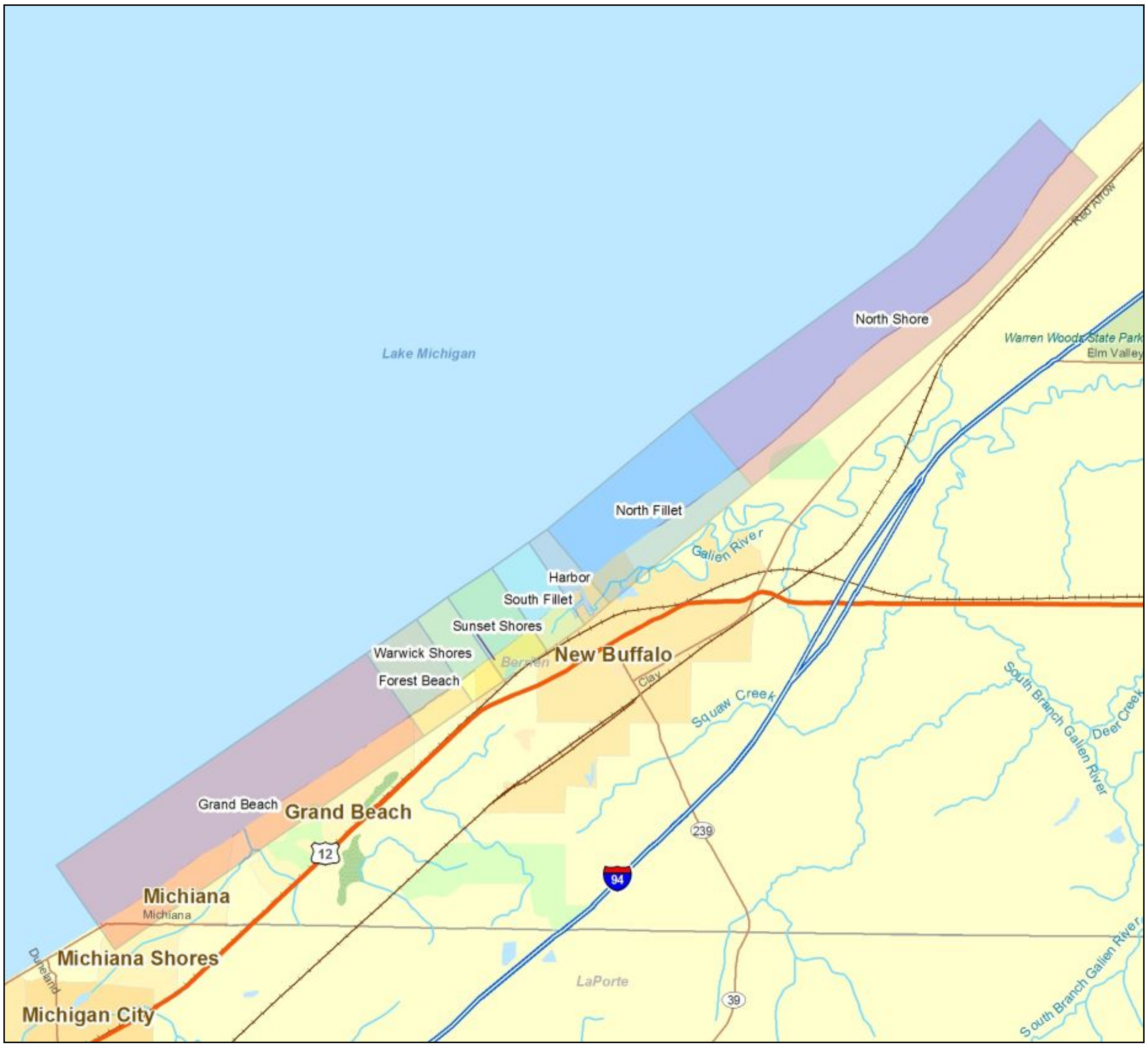

Figure 1.2: Delineation of Study Site

Lake Michigan water levels on the days of the site visit averaged around 578.22 feet IGLD-1985. This is below the long term average for the month of July (579.63 feet) and is slightly above the Low Water Datum (LWD) of 577.43 feet. Lake Michigan has been below the long term average since 1999, which does have a significant affect on the nearshore profile and beaches along the study site shoreline.

Wave conditions during the site visit fluctuated in both direction and intensity. Waves were initially from the south and were roughly 1 foot in height. By the end of the first day, however, the lake was calm. Wave activity increased to about 1.6 foot waves from the northwest on the second day.

1.4.1 Grand Beach Shoreline

The shoreline of Grand Beach is approximately 3.1 miles long. Figure 1.3 shows a series of photographs taken at the site. The community features newer style homes in the northern portion. As one walks south along the shoreline older homes can be seen. As shown in photographs 1 and 2 of Figure 1.3, the back beach is protected by a rock revetment. The beach is in relatively good condition and is approximately 40 feet wide. The beach widens moving south. There were no erosion features observed during the site visit, but the rock revetment to the north and the intermittent presence of steel sheet pile wall to the south (photograph 3) indicate this was an issue in the past. The presence of a significant groin at a small channel mouth can be seen in photographs 4 and 5. The build up of sand on both sides indicates littoral transport towards both north and south, though it is more dominant to the south.

While the beaches are in relatively good health, this may be attributable to low lake levels. It is reasonable to believe the beach would erode significantly during high water levels like those seen in the 1970's and 1980's. The construction of homes on the foredunes has interrupted any cross transport of sand from the back beach to the beach.

1.4.2 Forest Beach Shoreline

Just to the north of Grand Beach is Forest Beach and Forest Beach Estates. This shoreline is about 1/2 mile long. Much like the northern portion of Grand Beach, Forest Beach is made up of newer homes that are built on the top of a relic dune. The dunes have significant tree growth suggesting that they have been stable in the recent past (Figure 1.4, photograph 1). The beach is a little smaller than at Grand Beach, but it is in relatively good shape. There is a rock revetment at the base of the foredunes for most of the shoreline (photograph 2). In many spots this revetment is buried under sand (photograph 3). It is probable that the entire beach would disappear during high water events due to inundation. The stone revetment has probably discontinued any cross shore transport of sand from the back beach and beach.

1.4.3 Warwick Shores Shoreline

Warwick Shores is situated between Forest Beach to the south and the water intake structure to the north. The beach area juts out further into the lake than the adjacent Forest Beach shoreline and is steeper (Figure 1.5, photograph 3). This mainly is due to the low water levels and the presence of a groin field. The structure is showing signs of deterioration (photograph 4) and may not function properly when water levels rise. As seen in photograph 2, there is evidence that the foredunes backing the beach may be protected by a stone revetment that is buried under sand. The Warwick Shore beach terminates at the water intake structure (photograph 1) resulting in a beach with different grain size distributions to the north.

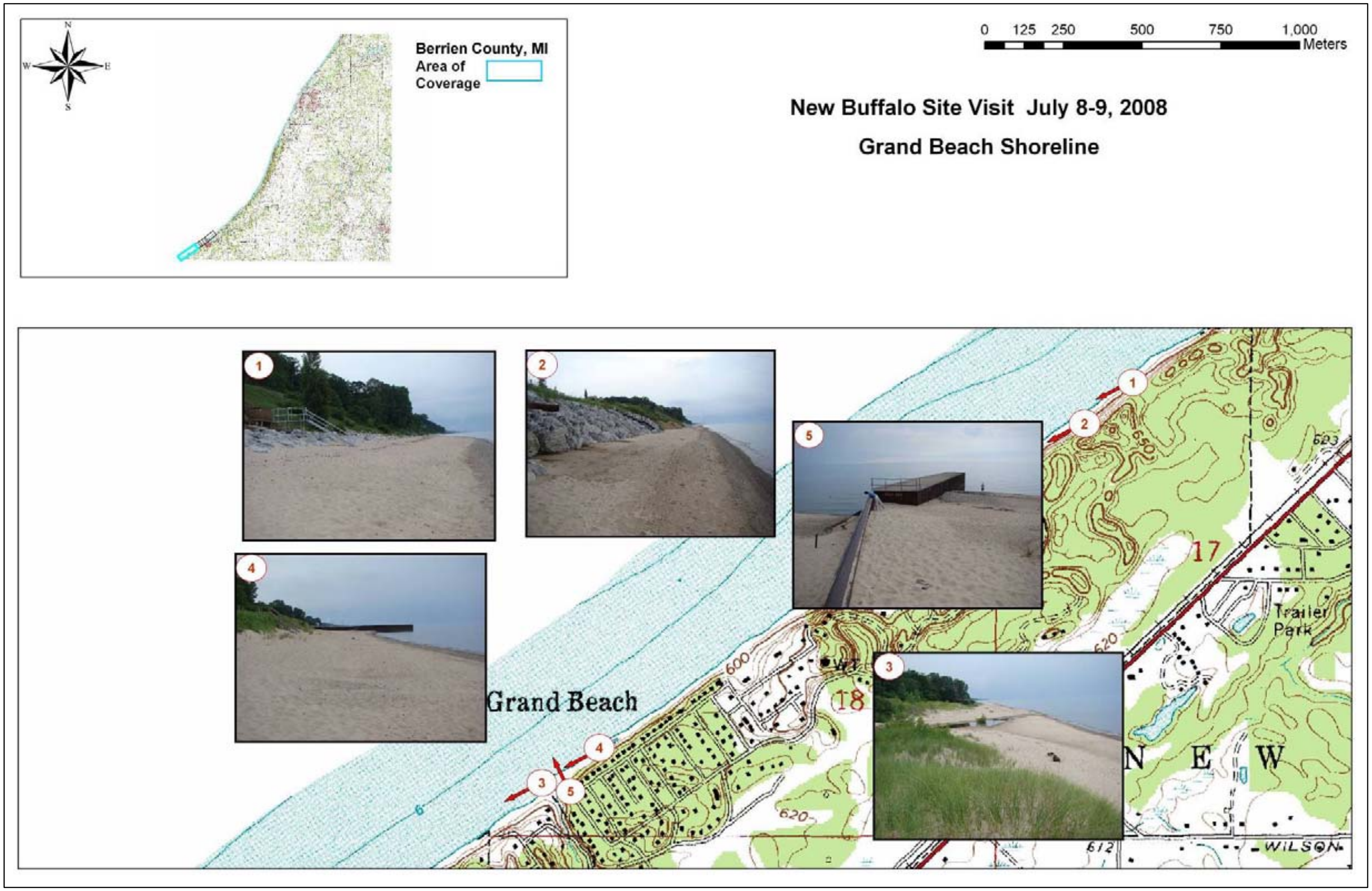

Figure 1.3: Photo Locations from July, 2008 Site Visit – Grand Beach

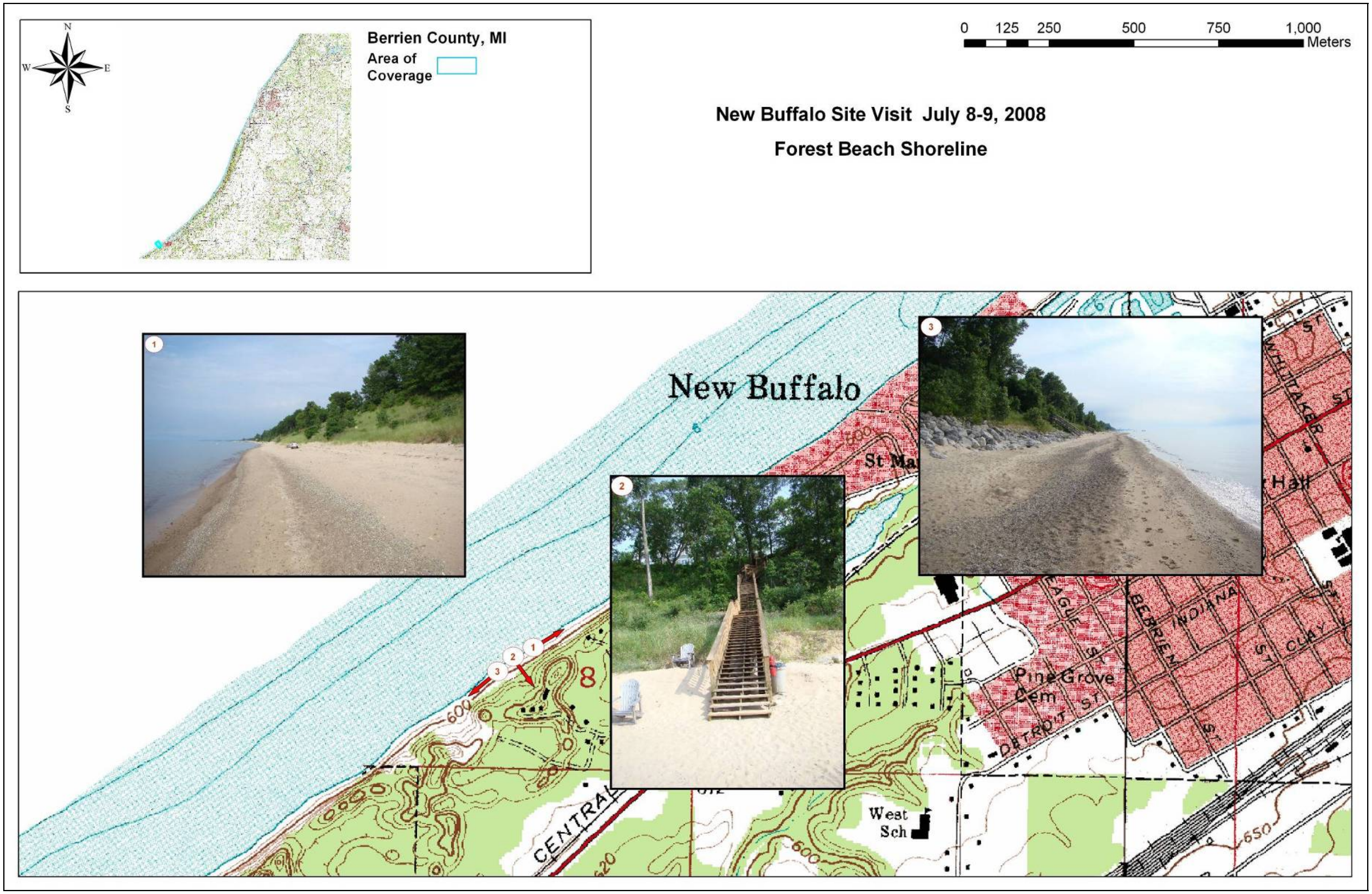

Figure 1.4: Photo Locations from July, 2008 Site Visit – Forest Beach

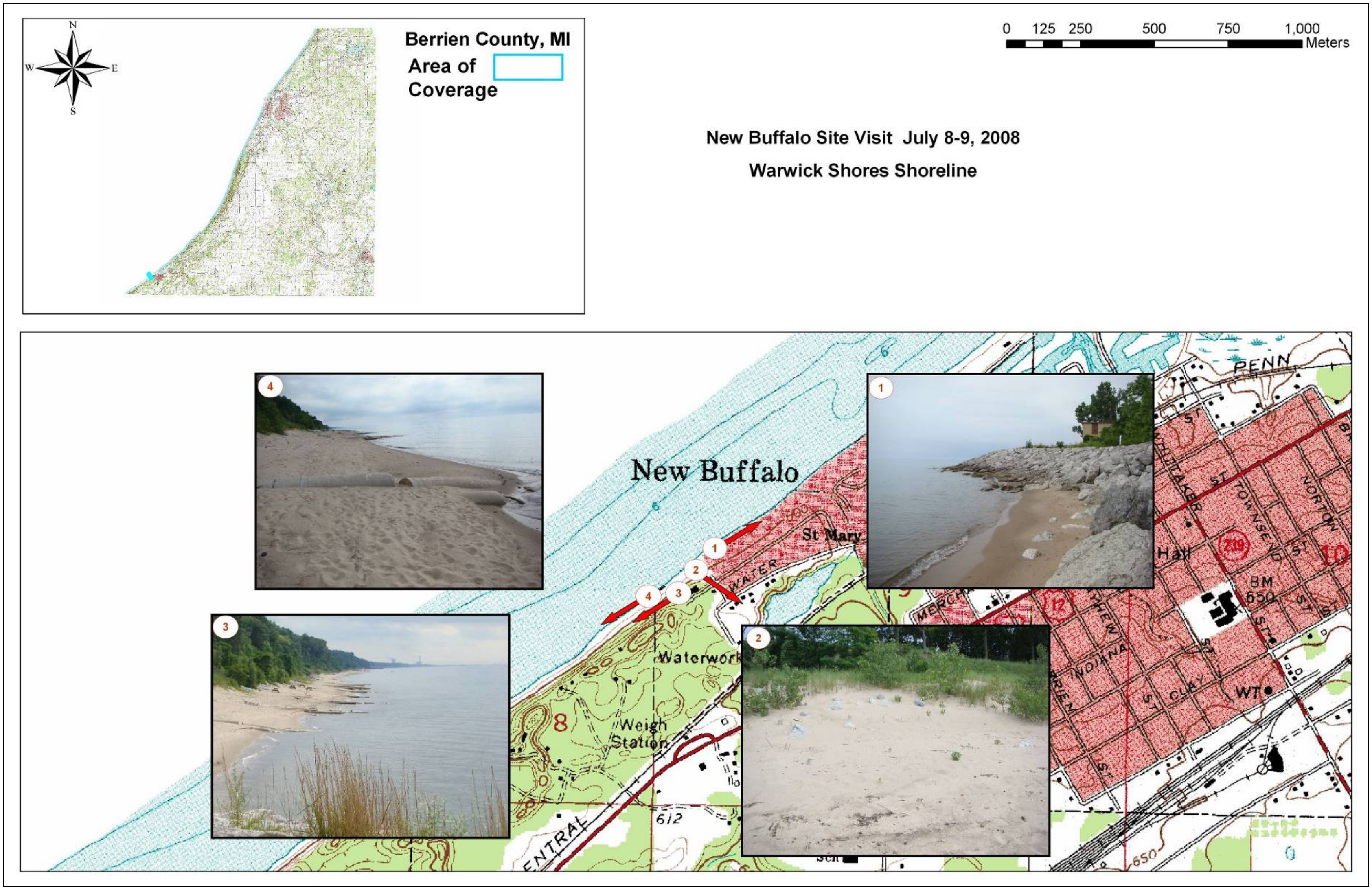

Figure 1.5: Photo Locations from July, 2008 Site Visit – Warwick Shores

1.4.4 Sunset Beach Shoreline

Sunset Shores is a 1/2 mile stretch of shoreline just south of the south accretion fillet. The beach can be described as a pocket beach and the beach at the water line is mainly composed of ½" to 3" diameter cobbles (Figure 1.6, photograph 1). The nearshore along the beach is also mainly comprised of this cobble material (photograph 2). The water treatment facility to the south seems to keep this material from making it to Warwick Shores to any substantial degree. The main beach is immediately backed by a rock revetment (photograph 4) for most of the shoreline. In a number of locations there is just rock revetment. On the north side of the shoreline there is a small creek adjacent to a seawall that is showing signs of failure (photograph 3). This shoreline can be characterized as an armoured shoreline. The natural movement of sand transported from beach to dune has been compromised in this stretch of shoreline.

1.4.5 South Accretion Fillet

The south accretion fillet is approximately 1/2 mile wide. It is a thin piece of land that stretches between Lake Michigan and the remnants of Lake Pottowottomee. As shown in Figure 1.7, photographs 1 and 2, the fillet beach terminates at the Sunset Shores rock revetment to the south. There is physical evidence that the foredune has recently eroded (photograph 3). This may be attributable to recent rises in water levels. In general, the beach looks thin, but the foredunes that have developed in this area are significant and would provide protection by eroding and providing sand to the nearshore during higher water levels. There seems to be sufficient sand out in the nearshore that provides a more convex shaped profile in the nearshore based on the spilling waves observed in photograph 4.

1.4.6 North Accretion Fillet

The north accretion fillet is significantly bigger than the south accretion fillet. It is about 1.5 miles long and is approximately twice as wide as the south fillet. The north accretion fillet is very well developed with a wide beach and large foredunes along the back beach (Figure 1.8). It could be seen out at the tip of the north breakwater that significant shoaling is occurring and a possible sand bypass bar has formed. During the site visit, people were wading out significant distances into the lake (photograph 3) indicating a fair amount of sand in the near shore region.

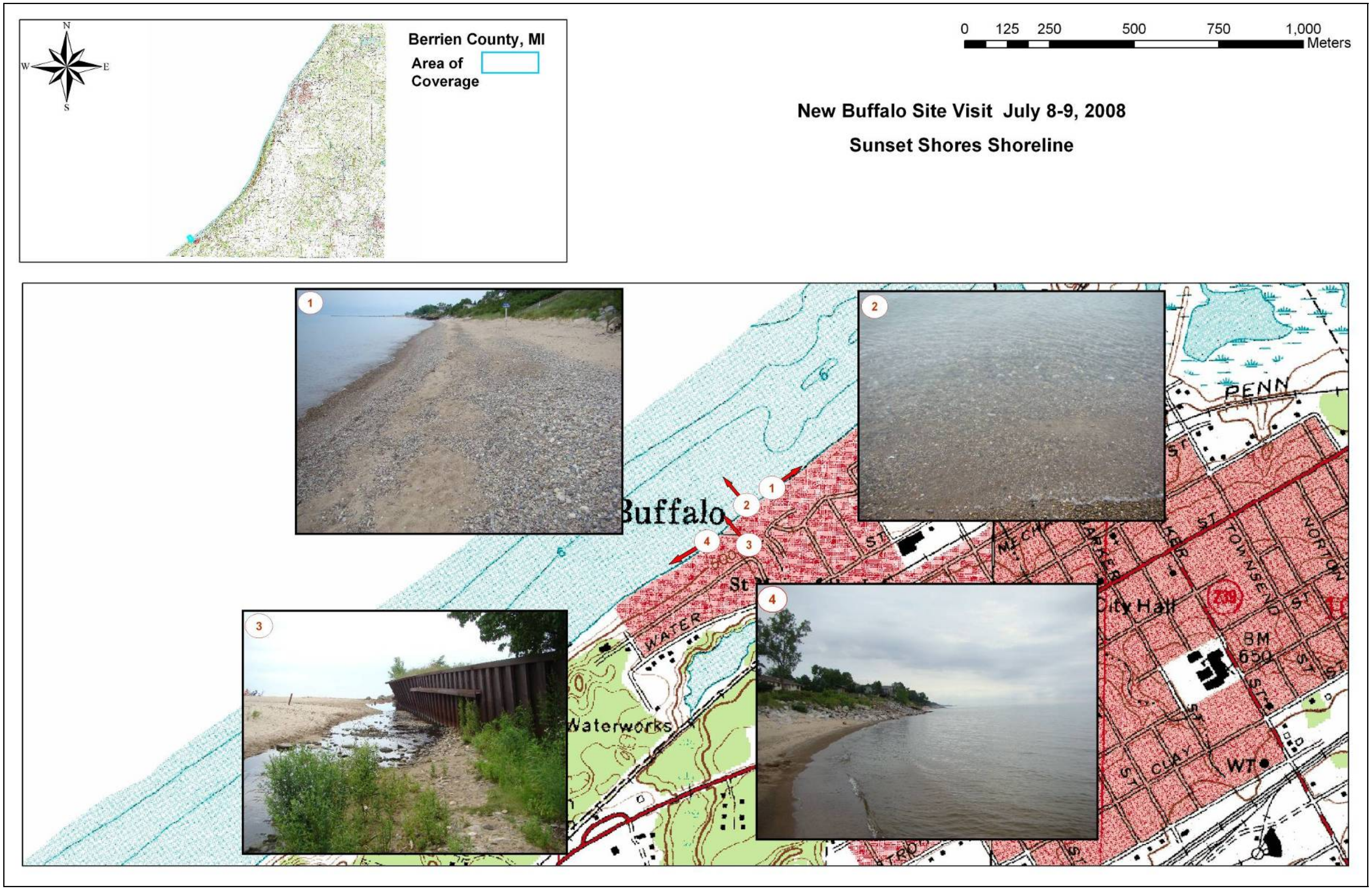

Figure 1.6: Photo Locations from July, 2008 Site Visit – Sunset Shores

Figure 1.7: Photo Locations from July, 2008 Site Visit – South Accretion Fillet

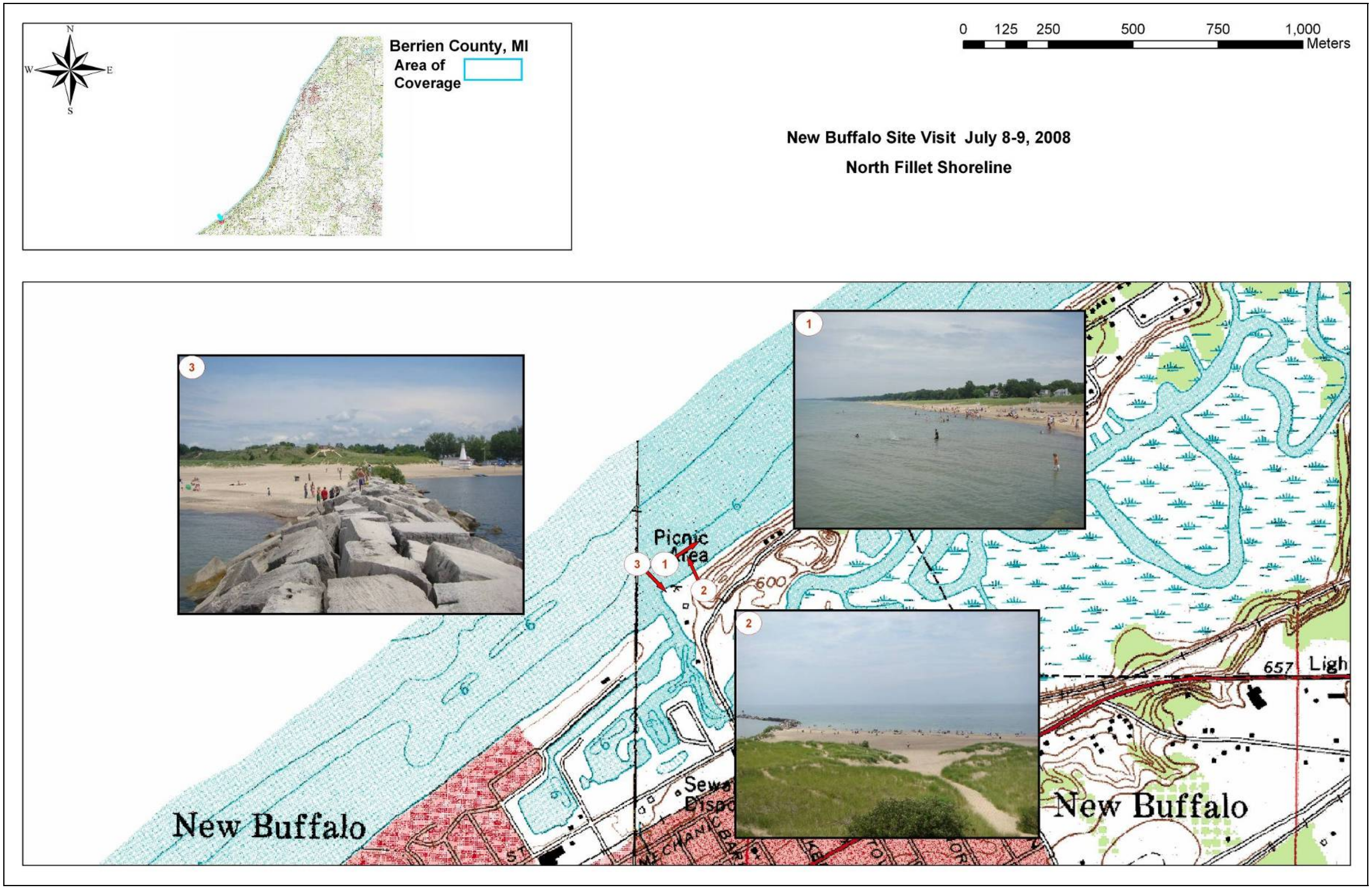

Figure 1.8: Photo Locations from July, 2008 Site Visit – North Accretion Fillet

1.4.7 North Shore

The most northern portion of the study site starts from the north accretion fillet and runs north about 3.5 miles (Figure 1. 9). There were three sites visited north of New Buffalo. The site at the end of Pier Street (photograph 1) exhibited a relatively wide beach backed by high relic dunes and vegetated foredunes. There was evidence of recent wave activity at the base of the foredunes as shown in photograph 2. The Berrien Street Access (photographs 3 and 4) was very similar to the beach at the end of Pier Street. It seemed a little wider with a gentler slope. The foredunes also were wider as well. The final site was Townline Rd. Access (photograph 5). This beach was identical to the Berrien Street Access beach. No shore protection could be seen at these three sites north of New Buffalo.

1.4.8 Site Visit Summary

In general, all the beaches during the site visit were relatively in good condition with the exception of Sunset Shores. The beaches to the north were observed as having no structures, to be more natural, consisting of a gently sloping beach and a grass covered foredune backed by a relic dune. The shorelines south of the harbor have significant shore protection that has altered the beach-dune system prohibiting beach growth during periods of low lake levels through cross beach transport. The federal harbor has likely helped the growth of both the south and north accretion fillets. Three or four sandbar features could be seen along the entire shoreline. It is reasonable to conclude that a significant amount of sand is moving along these features.

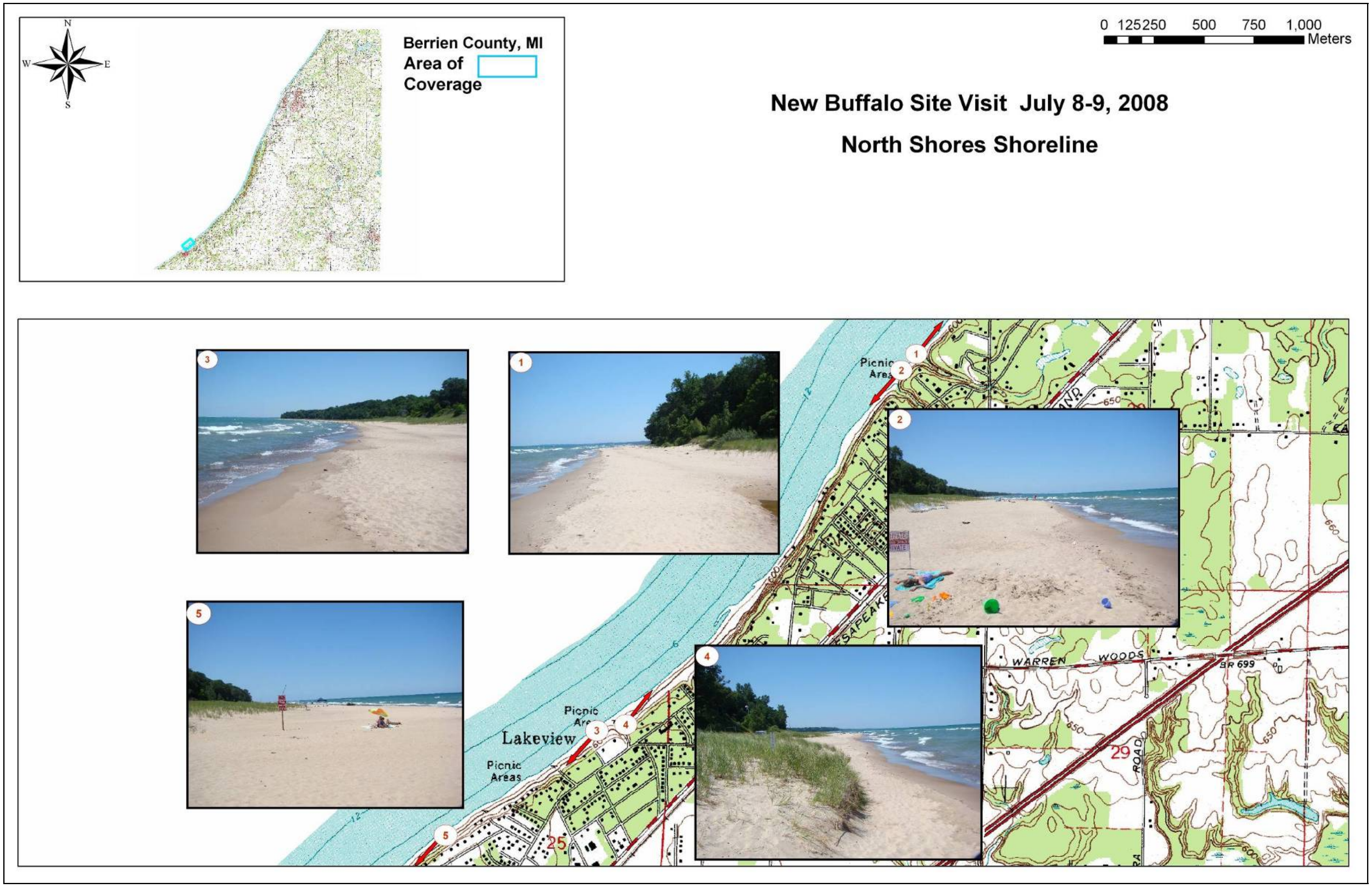

Figure 1.9: Photo Locations from July, 2008 Site Visit – North Shores

2.0 Historical Studies and Observations

This section of the report presents findings from past studies, outlines the history of the harbor, and provides historical observations made from aerial photography.

2.1 Past Studies

The southeast shoreline of Lake Michigan is a data rich area and has been part of numerous studies by the USACE and the Michigan Department of Environmental Quality (MDEQ). The following investigations have contributed data or advanced the knowledge of coastal processes in the general vicinity of the study.

1) RSM, Sediment Budget for St. Joseph, MI to Michigan City, IN
2) Evaluation of Dredged Material Management Plans for Michigan City, IN
3) Assessment of the Causes of Erosion in the Vicinity of St. Joseph Harbor, MI
4) MDEQ Berrien County High Risk Erosion Area (HREA) Update Study

It is understood through these studies that the New Buffalo study area is a sub-littoral cell along the southeast shoreline and part of a much larger littoral boundary that extends from Port Sheldon in Ottawa County, MI to Gary Harbor, IN. The limits of this large littoral cell are presented in Figure 2.1.

Figure 2.1: Definition of Littoral Cell for Southeast Lake Michigan

A number of key observations from these studies are summarized below.

- The net direction of Longshore Sediment Transport (LST) is from north to south (USACE, 2002).
- Shore perpendicular and shore parallel structures affect the volume of sediment available in the nearshore and on the beach.

- The MDEQ has recently updated the HREA mapping for Berrien County (Warner, 2007). HREAs are defined as areas along the shoreline where the recession rate as measured from the change in vegetation line position is greater than one foot per year. The percentage of shoreline south of the harbor that is defined as an HREA shoreline has reduced from 83% to 16% based on this study. The shoreline areas of Sunset Shores, Warwick Shores and Forest Beach are the only areas still designated as HREAs.
- The investigation at Michigan City, IN (USACE, 2004) found that sediment from the updrift accretion fillet could be bypassed around the harbor without negatively affecting the adjacent shorelines. Furthermore, it is expected that removal of some material from the adjacent shorelines could reduce dredging.
- The Michigan City, IN modeling effort found that the potential regional longshore transport (RLST) for the New Buffalo area ranges from approximately 209,000 yd^3/year towards the north to about 536,000 yd^3/year to the south for a net potential RLST of about 327,000 yd^3/year to the south.
- Profile comparisons done in the RSM study show that in general the nearshore has been relatively stable over the last 50 years to depths greater than 46 feet.

2.2 Harbor History

The first piers at New Buffalo were constructed sometime before 1857 by the Michigan Central Railroad Company. They extended approximately 700 feet from the 1857 shore and are assumed to have been pile supported structures. The only evidence of their existence can be seen on a U.S. Government survey conducted in September 1857 by Lieutenant Colonel J.D. Graham (Figure 2.2). The survey was conducted to investigate the possibility of constructing a harbor of refuge. The pile supported structures were located approximately 800 feet west of the present day harbor. The 1857 investigation resulted in the construction of a navigation channel 200 feet wide protected by a timber revetment along the north portion of the river connecting Lake Pottowottomee to Lake Michigan at the present day location. This constitutes the original federal project. By the 1900's this federal interest was abandoned.

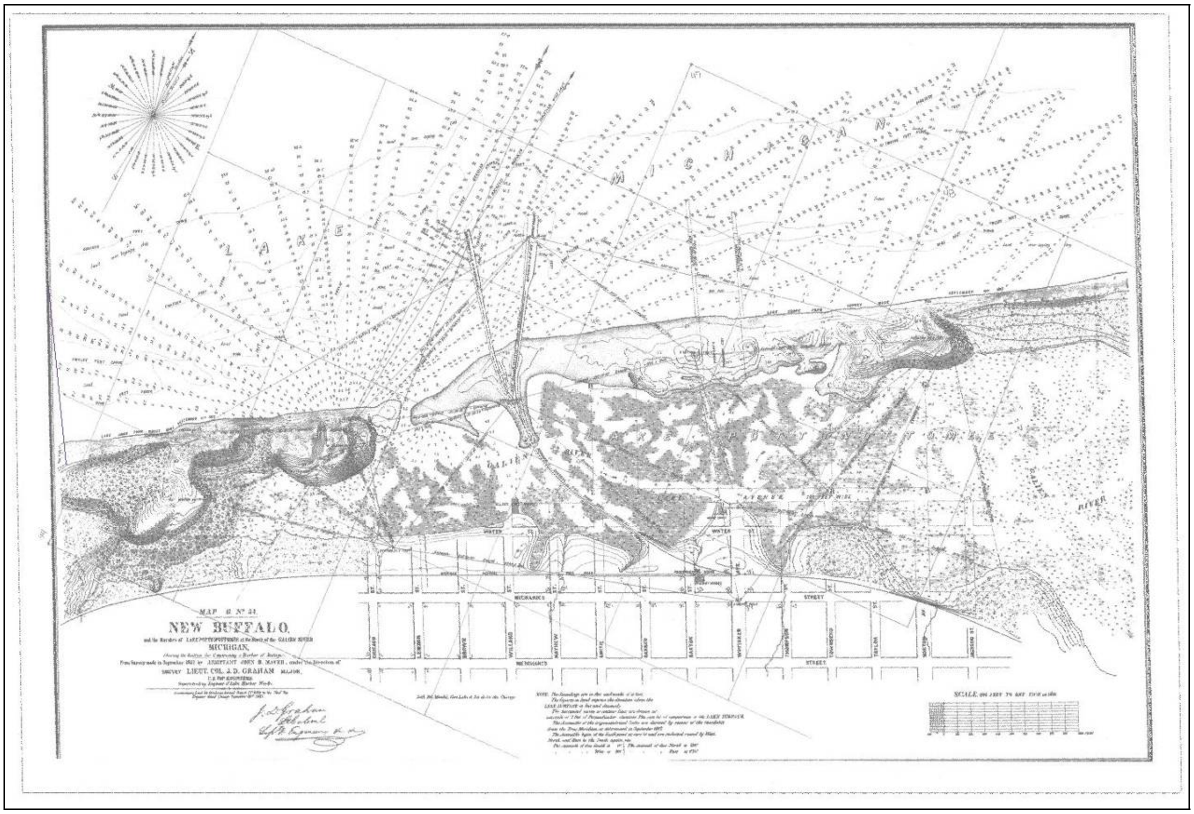

Figure 2.2: September 1857 U.S. Government Survey of New Buffalo, MI

Several House and Senate Documents proposed various navigation projects at New Buffalo, MI between 1857 and the present. A letter from the Secretary of War (Ex Doc No. 23, 47th Congress, 1st Session) dated October 10, 1881 is the first document that could be found suggesting that a harbor of refuge be constructed. However, this project and subsequent others were never constructed until after 1975. Sometime prior to 1954 local interests constructed a revetment on the south bank and a jetty on the north bank of the river mouth for navigation purposes. Sometime between 1967 and 1973 two shore perpendicular structures were built around the river mouth.

The harbor as it exists today was first authorized in 1958 under House Document No. 481, 87th Congress, 2d Session. Construction began in 1973 and was completed in November 1975 (Chief of Engineers Report, 1976). The authorization called for the construction of the jetties and deepening of the navigation channel to 10 feet in the outer portion of the harbor and 8 feet in the inner portion of the harbor. Included in the authorization was a stockpile site approximately 0.3 miles south of the harbor that would be nourished by upland sources to mitigate the impoundment of sand on the north side of the harbor. It was estimated that the north accretion fillet would be filled in five years. After this five year period, periodic nourishment would be accomplished by placing dredged sediment at the stockpile site. The harbor is presently dredged and maintained by the USACE.

2.3 Regional Development and Temporal Site Changes

It is unclear from historical documents how much private development has occurred around the mouth of the present day harbor. However, the letter from the Secretary of War in 1881 mentions that local interests began work on wood timber jetties at the mouth of the river. In addition, the Michigan Central Railroad Company had installed pile supported structures sometime before 1857. Information on the local area also can be obtained from aerial photography gathered in support of this study. For sections 2.4.1 to 2.4.6, Figures 2.3 and 2.4 can be referenced.

2.3.1 1938 Temporal Period

1938 aerial photography shows very little shoreline development for most of the New Buffalo region. The Village of Grand Beach area shows signs of development. A healthy beach and dune system in this stretch of shoreline is observed. The areas that are presently Forest Beach and Warwick shores looks to be mostly wooded and with a significantly healthy beach and dune system. There are some access roads to the shore, but no residential development is observed at this time. The areas that are presently Sunset Shores and the south accretion fillet are very sandy areas with little vegetation and no development. The beaches seem very wide. The aerial photography appears to show exposed sand dunes in this area. The areas north of New Buffalo seem to exhibit more residential properties, similar to the Village of Grand Beach. The shoreline is well vegetated and sandy. There are no shoreline structures observed along any stretch of shoreline during this time period and no significant structures at the mouth of the river.

2.3.2 1954 Temporal Period

1954 aerial photography, when compared to the 1938 photography, shows more residential development in some areas and all the beaches are viewed as narrower. This may be attributable to the general rise in water levels between the two periods. The Village of Grand Beach area is more developed and less sandy. Shore protection in the form of groins and seawalls are observed on the aerial photography. Moving north to the Forest Beach area there is less development. Some groins and seawalls can be seen, but the area is mainly wooded. The aerial photography of the Warwick Shores area shows no development and exposed sandy areas and forest cover are observed. Development in the area of Sunset Shores has started, and there are a couple of residential homes visible. Additionally, there is a sandy area seen in the 1938 photograph which now has roads going through. Roads can also be seen in the south accretion fillet area, but no real development has started. The mouth of the Galien River does show a jetty along the north edge and a revetment to the south. The areas north of New Buffalo are observed as relatively the same as they were in 1938 with less forest cover and thinner beaches.

Figure 2.3: Aerial History of Forest Beach and Grand Beach Area

Figure 2.4: Aerial History of Sunset Shores and Warwick Shores Area

2.3.3 1967 Temporal Period

1967 aerial photography is very similar to the 1954 photography. Water levels are a little lower and the beaches are a little wider on the whole. The Village of Grand Beach looks mostly unchanged except for the addition of a new development in the northern portion. Also, just north of this new development, a dune blowout has occurred and freshly exposed sand can be seen. The very northern portion of the Village of Grand Beach area is still largely undeveloped as are the areas of Forest Beach and Warwick Shores. Sunset Shores looks to be close to its present day development. There is no significant vegetation, the beach is observed as adequately wide and no shore protection is seen in the area at this time. The jetty structure at the mouth of the river has trapped sand and allowed for growth of the north accretion fillet. Development to the north looks relatively unchanged and the beach area is healthy.

2.3.4 1973 Temporal Period

Water levels in 1973 were approaching record high levels. As a result the beach width as a whole was very thin and non existent in parts. Development in the Village of Grand Beach continued to progress north. The dune blowout area seen in the 1967 aerial photography is now being developed. Shore protection structures can also be seen at various points along the shoreline. Residential properties can also be seen in the Forest Beach and Warwick Shores areas, though sparse. The beach along this stretch is relatively wide and the shoreline looks to have no shore protection structures. Just north of the water intake facility is a well developed Sunset Shores coastal community. The southern portion of the development consists of a healthy beach. One shore parallel structure can be seen just south of a creek. A completely different shoreline exists north of the creek. There are numerous shore protection structures along this stretch and the beach is relatively thin or totally consumed. This trend continues in the south accretion fillet area. The south end of this area consists of Sunset Shore residences, which all have shore protection. As we approach the mouth of the Galien River more foredunes are present and less development can be seen. The harbor structures are still not present at this time and the existing timber jetties look to be in disrepair. The beach just north of the river is sandy, but is thin relative to today’s accretion fillet. Some houses in this area are right at the waters edge and shore protection can be seen. Continuing north, the beach is wider than the beaches to the south and there are numerous shore protection structures.

2.3.5 1980 Temporal Period

From 1973 to 1980 the water levels of Lake Michigan dropped slightly. The 1980 aerial photography is also the first set of photos used in this analysis showing the shoreline after construction of the federal structures. The Village of Grand Beach shoreline is pretty well developed to the south. A number of the shore parallel structures seen in the 1973 aerial photography are now at the waters edge. The northern portion of the area still looks undeveloped and covered with forest. The residential property development in the

Forest Beach and Warwick Shores areas is observed as unchanged in seven years and the beach along this stretch is relatively healthy. No shore protection structures exist in the aerial photography. Similar to 1973, the shoreline of Sunset Shores starts out sandy in the southern portion of the area and becomes non-sandy and well protected to the north. The south accretion fillet area is now being developed. There are a couple residences built on the dunes. The beach in this area is relatively healthy and has grown since 1973. The north accretion fillet is beginning to grow directly adjacent to the harbor. Moving north, the beach resembles the 1967 beach. Over this time period residential development and shore protection structure construction is observed to not have increased.

2.3.6 2002 Temporal Period

A considerable amount of development has occurred between 1980 and 2002. In addition, the water level of Lake Michigan has dropped considerably over this temporal period. The north portion of the Village of Grand Beach has been fully developed. Much of the forest located in this area has disappeared. The beach is relatively wide and sandy; however, there is evidence of a new shore parallel structure in this area. The Forest Beach area is also well developed, and the presence of a shore parallel structure can be seen at various spots along the shore. Warwick Shores has changed from undeveloped to developed over this 22-year stretch. Shore perpendicular structures can be seen along the shoreline. The beach also looks relatively wide and healthy at this time. The Sunset Shores shoreline is for the most part well protected. Both shore perpendicular and shore parallel structures can be seen, and the beach is not very wide in this area. Just to the north, the south accretion fillet is now well developed with residential structures. Both the south and north accretion fillets have grown considerably and are very sandy. Continuing north, the beaches are very wide and the presence of past shore protection is not detectable.

3.0 Geo-Spatial Data

An important first step when analyzing shoreline changes and calculating sediment budgets is to obtain and organize geo-spatial information for use in determining recession rates, quantifying sources and sinks, and developing computation grids to determine longshore transport rates. For each dataset utilized in this study, available historic sources and existing information will be presented, along with a discussion of data quality and issues with incorporating the information in the analysis.

3.1 Bathymetric Data

Bathymetric data is required for the limits of the study area to complete the sediment budget investigation. With multiple datasets, preferably separated by a long temporal period (i.e. 30 to 50 years), it is possible to complete 3D, historic to recent, lake bed comparisons in GIS. This analysis can provide valuable information on sediment inputs from erosion and sediment sinks in depositional features, such as fillet beaches.

There are several sources of historic and recent bathymetric data for the southeast shore of Lake Michigan. Generally, the datasets fall into three categories: 1) historic NOAA track lines, 2) profiles for construction and monitoring of New Buffalo Harbor, and 3) LiDAR data collected since 1995. Table 3.1 summarizes the bathymetric data available for the southeast shore and incorporated in this investigation.

Figure 3.1 presents the raw soundings for the 1991 NOAA data, the profile lines from the 1964-66 survey, the 1999 SHOALS LiDAR points and 2002 LiDAR points at New Buffalo. The most obvious distinction between the three data types is the density or spacing of the soundings. The SHOALS and LiDAR points are high resolution data, while the profile lines are less dense with spacing between lines ranging from 165 to 650 feet. These significant differences in data density represent challenges for generating 3D grids in GIS, and completing bathymetry comparison.

Table 3.1 Historic and Recent Bathymetric Data

Year	Agency	Survey Method	Spatial Extent
1945-46	NOAA	Track Lines	Berrien County
1964-65	NOAA	Track Lines	Berrien County
1964-66	USACE	Profiles	New Buffalo
1991	NOAA	Track Lines	Berrien County
1999	USACE	SHOALS LiDAR	Berrien County
2000	USACE	SHOALS LiDAR	Berrien County
2001	Ocean Science	Profiles	New Buffalo

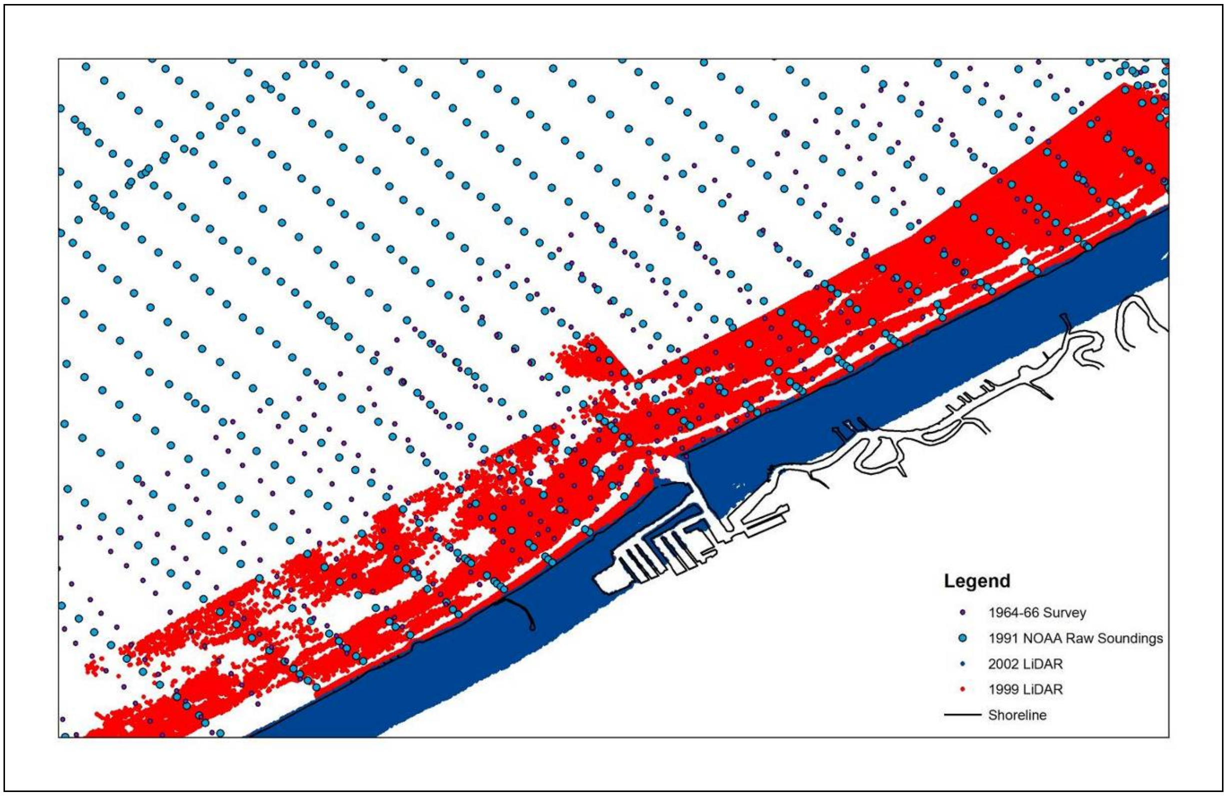

Figure 3.1: Bathymetric and LiDAR Data for New Buffalo

A limitation that exists with the SHOALS system technology is the inability to collect bathymetry in turbid water. Many times the system misses features in the swash zone due to breaking waves or around harbor mouths due to water clarity. These omissions in the data make it difficult to delineate important nearshore features, such as sand bars, that are key to our understanding of littoral transport processes.

3.2 Topographic Data

Topographic data was used to evaluate shoreline features that are not underwater. These data were utilized to measure changes in location of contours and bluff lines over temporal periods. In addition, volume changes in the accretion fillets were evaluated using these data.

3.2.1 Topographic LiDAR

2002 topographic LiDAR was collected by Western Air Maps in support of the USACE's assistance to the State of Michigan to map bluff lines. As shown in Figure 3.2 this data was extremely dense, which made visualization of bluff and shoreline features possible.

However, as also seen in Figure 3.2, the landward and lakeward extent of the data was relatively limited and only provided information for a small stretch of land.

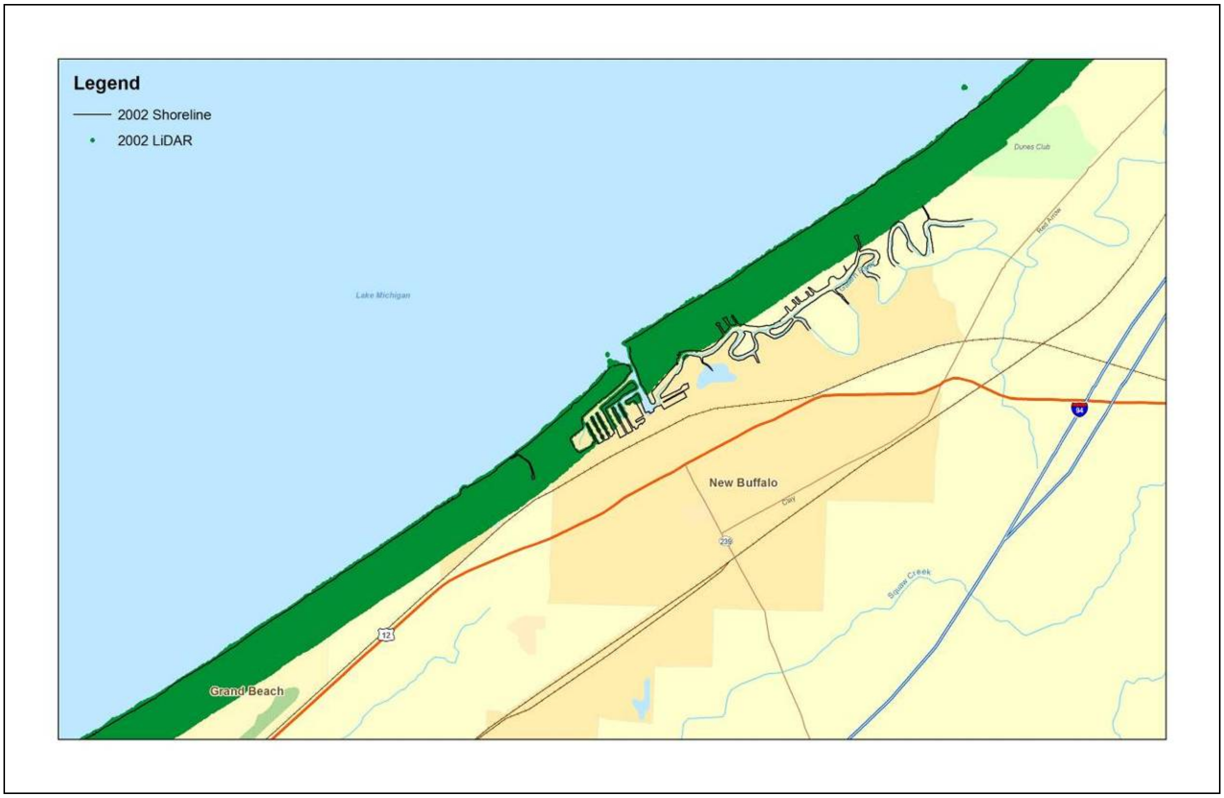

Figure 3.2: Example of LiDAR Coverage

3.2.2 Conventional Land Surveys

In addition to the LiDAR data, conventional land surveys from 1964, 1980, and 1983 were used. Actual survey data was unavailable, so contour maps representing 1980 and surveys from 1983 were used in this study. The 1964 survey data was obtained from design drawings for the construction of the harbor and digitized from the drawings.

3.3 Aerial Photography

Aerial photography was used in this analysis to provide historical information on the harbor, shoreline history, recession rate information, accretion rates, and boundary condition information for numerical modeling. Aerial photography for New Buffalo was available for numerous years from a variety of sources. Table 3.2 summarizes the aerial photography utilized in this effort.

Table 3.2 Historic and Recent Bathymetric Data

Year	Source	Scale	Spatial Extent
1938	USACE	~1 : 20,000	Berrien County
1954	USACE	~ 1 : 11,500	Berrien County
1967	MDEQ*	1 : 20,000	New Buffalo
1973	ERDC**	1 : 6,000	Berrien County
1980	MDEQ	1 : 6,000	Berrien County
1985	USACE	1 : 6,000	Berrien County
1991	USACE	1 : 6,000	New Buffalo
2002	MDEQ	1 : 6,000	Berrien County
2005	MDEQ	1 : 12,000	Berrien County

* Michigan Department of Environmental Quality (MDEQ)
** Engineering Research and Development Center (ERDC)

The 1967, 1980, and 2002 aerial photography was provided and orthorectified by the MDEQ in support of their effort to update high risk erosion areas in Berrien County. Any reference to the methodology may be found in the "Berrien County High Risk Erosion Area Update Study" (Jannereth, 2007) documentation by the MDEQ. The historical 1938, 1973, 1985, and 1991 aerials were scanned at a resolution of 300 dots per inch (dpi) and registered using ArcGIS 9.3. The 2005 orthorectified photography was obtained from the MDEQ website at http://www.mcgi.state.mi.us/mgdl/. A series of tiled 2002 and 1938 aerial photography are presented in Figure 3.3 for comparison.

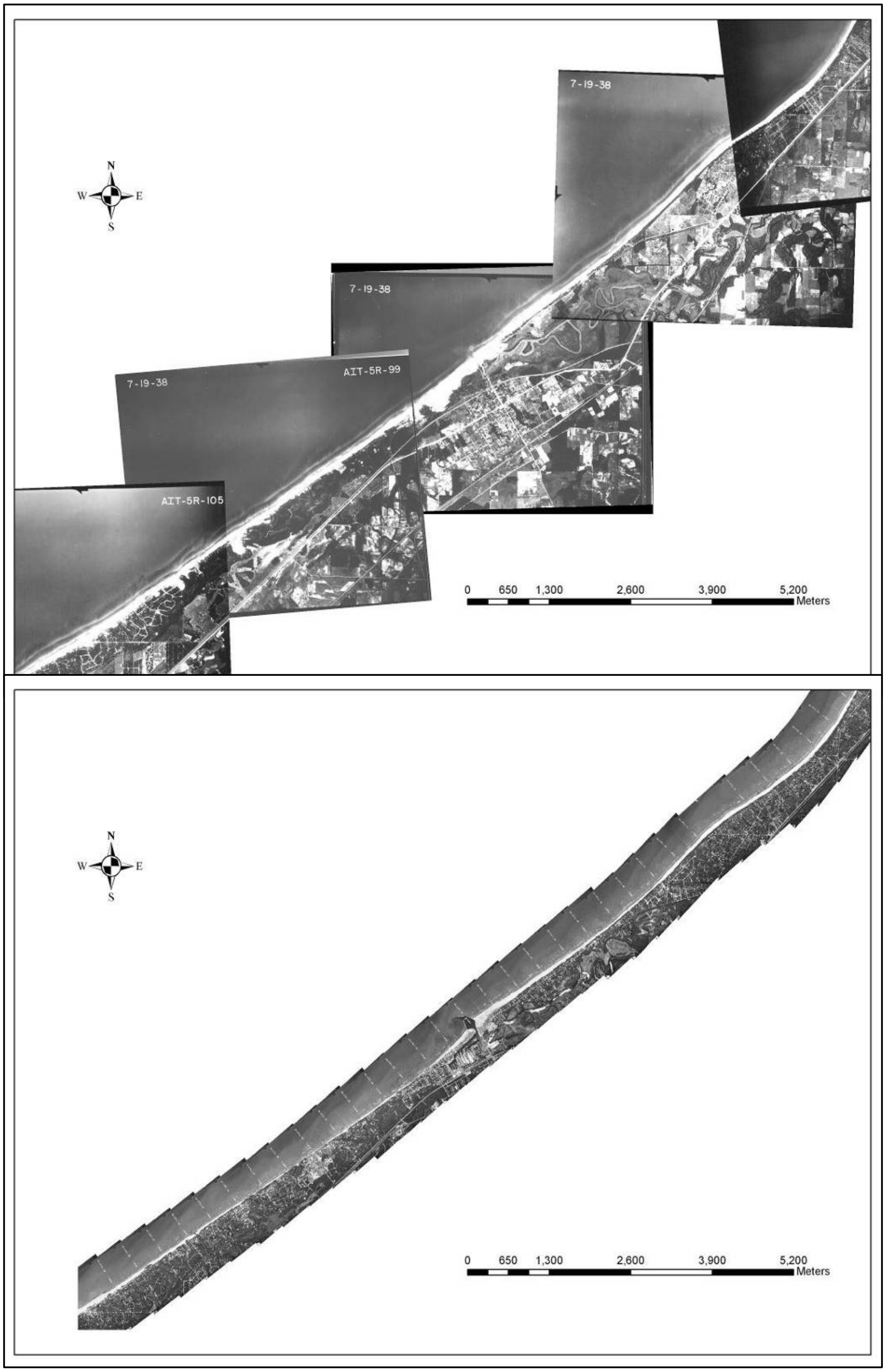

Figure 3.3: Comparison of 1938 and 2002 aerial photography mosaics

Aerial photography from 1954 was used in this analysis for visual purposes only. The photography was not geo-referenced for a quantitative analysis. However, it was useful in determining the history of development for the New Buffalo shoreline.

3.4 Historical Chart

As mentioned earlier, a historical chart was obtained from Nancy Smith of New Buffalo, Michigan during the site visit to the area in July 2008. The historical chart was from 1857 and was surveyed by the U.S. Top (Topographic) Engineers under the direction of Lieutenant Colonel J.D. Graham. The map was created to investigate the possibility of making Lake Pottowottomee into a harbor of refuge.

The data from this chart could not be used to quantify any recession rates or volumetric changes. Due to the limited information on the chart, only the roads could be used to geo-reference the drawing. This leads to some ambiguity in the actual location of the shoreline. In addition, it is unclear what vertical datum was used for reference of water depths. Given these issues with the chart, comparisons to current data should be made in only a general context. It was utilized in this analysis to acquire a qualitative understanding of the shoreline, river mouth, and nearshore changes that have occurred over the past 150 years.

4.0 Wave and Water Level Data

This section will provide information pertaining to the wave data and water level data used to support this analysis.

4.1 Wave Information Studies

A critical data set required in this analysis is wave data. The data provided for this analysis originated from Wave Information Studies (WIS) currently supported by ERDC. WIS were authorized in 1976 by the Office, Chief of Engineers, U.S. Army Corps of Engineers, to produce wave climate information for U.S. coastal waters. WIS information is generated by numerical simulation of past wind and wave conditions in a process called hindcasting. Knowledge of the wave climate is required to design and maintain the nation's coastal navigation and shore protection projects. Further information on this data set can be found at the Coastal and Hydraulics Laboratory (CHL) website (http://chl.erdc.usace.army.mil/).

Through the years, hindcasts were added and updated as wave modeling technology advanced and computer power increased. At the end of 1998, hindcasts for all U.S. coasts had been completed: the Atlantic Ocean for two different periods, 1956-1975 and 1976-1995; the Pacific Ocean for 1956-1975; the Gulf of Mexico for 1956-75 and 1976-1995;

the Great Lakes for 1956-1987, and an update of Lake Michigan for 1988-1997 (J.M Hubertz et. al., 1997). Hindcast information for this analysis was retrieved from the original Great Lakes study and the update to Lake Michigan. Wave data spanning from 1956 to 1997 was computed using the methods outlined above and collected at various node points, or stations, located on a computational grid of Lake Michigan. Each station provides 3-hourly significant wave heights (H_s) in meters, wave periods (T_p) in seconds, and wave direction (Θ). The closest station to the Grand Beach study site is Station LM0060 (Figure 4.1).

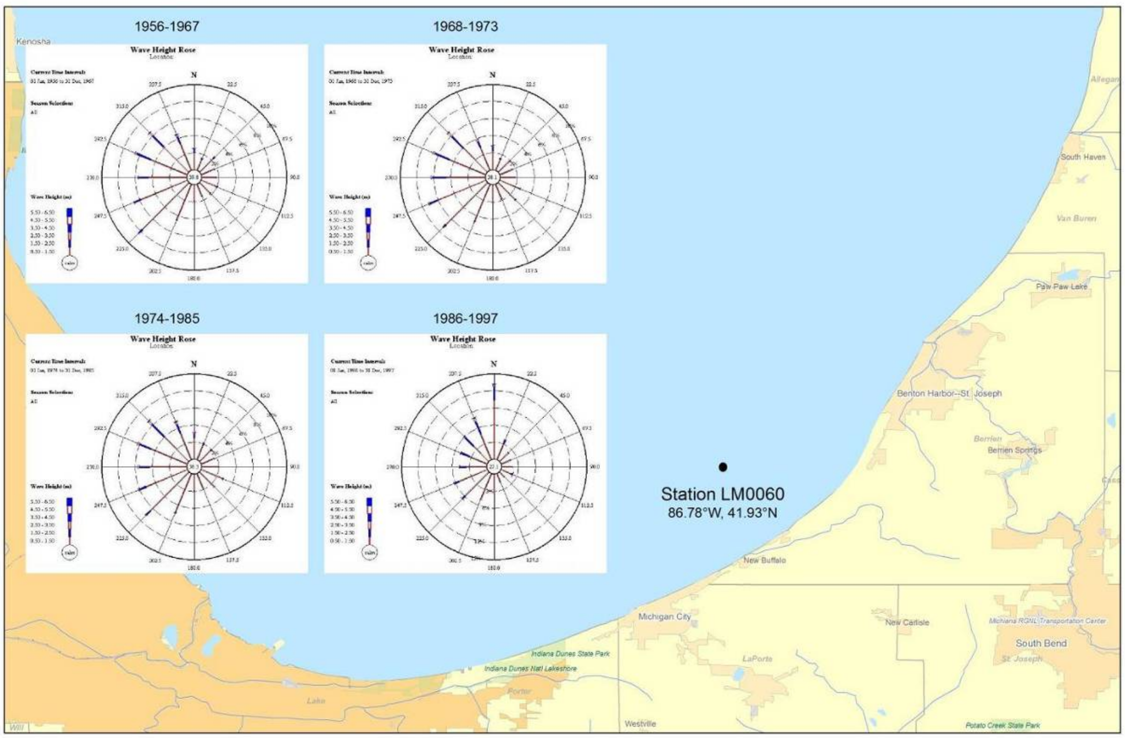

Figure 4.1: Wave Station Location and Wave Roses

4.1.1 Temporal Representation of Wave Data

During the process of organizing wave data, the information from Station LM0060 was sorted to correspond to the temporal periods established from the aerial photography. Referring to Figure 4.1, wave roses for the 1956-1967, 1968-1974, 1974-1985, and 1986-1997 temporal periods were developed. In addition, a wave rose for the entire time of coverage (1956-1997) was also created (not shown).

An observation was made involving the temporal period from 1986-1997. During this period the wave climate looks to be dominated by waves from the north. For all the other periods represented by wave roses, the wave climate of the region is observed to be dominated by waves out of the west to southwest. It is unclear whether this is due to a changing climate or whether this is a direct result from the different procedures used in the update of Lake Michigan (1988-1997).

4.1.2 Wave Data for Modeling Support

Referring to the entire period of record for WIS Station LM0060, it can be seen that waves for this region approach the shore from the north to the southwest. Figure 4.2 provides more detail of these percentages. It is critical to reduce these into percentages of wave heights from each direction and for various wave periods so that the numerical model utilized in this study can represent real conditions without excessive computing time.

There were a number of considerations used in this analysis. First, due to the orientation of the shoreline, only waves from the north-northeast to the west were considered. Waves outside of these wave angles are considered too oblique to cause significant sediment transport. Second, for each wave band that remained, wave heights were separated as a percentage of occurrences from its respective direction. Third, based on work accomplished at Michigan City, IN (Baird et. al., 2006) and the data at Station LM0060, wave periods were associated with wave heights and wave directions.

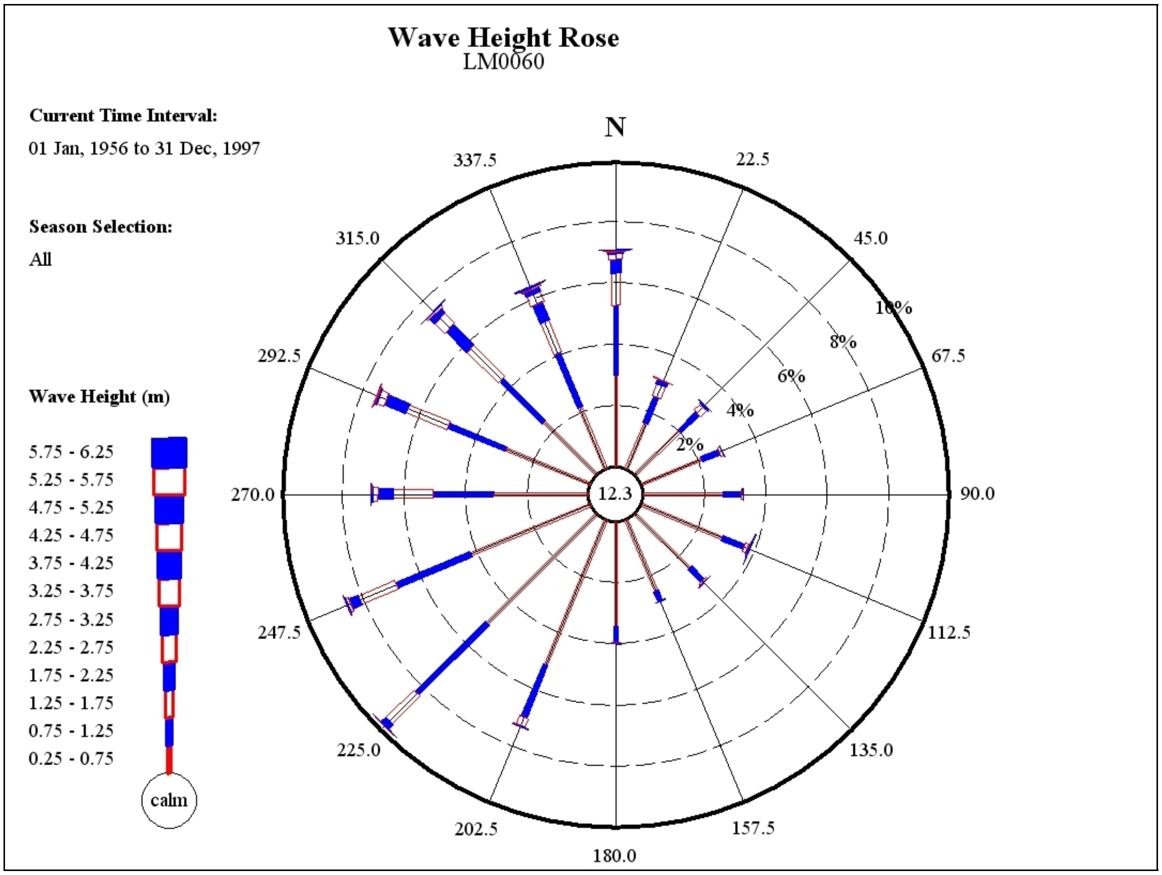

Figure 4.2: Percent Occurrence of Wave Heights based on Direction

The result of this data reduction can be seen in Table 4.1. 27 separate wave conditions from 6 different directions were tabulated and the percentage of occurrence was determined. As will be explained later, this is important in tying the model results to real lake conditions to represent sediment transport in the area.

Table 4.1 Wave Height Percentage of Occurrence of Occurrence Based on Direction and Period
***Total percentage of wave occurrence from six directions is 58.86%**

Wave Direction		Significant Wave Height, m (Percentage of Occurrence*)				
Direction	**Azimuth**	**0.5**	**1.5**	**3**	**4.5**	**6**
W	270°	3 (3.296)	5 (2.615)	7 (0.506)	7 (0.003)	
WNW	292.5°	3 (2.292)	5 (2.762)	7 (0.625)	7 (0.005)	
NW	315°	3 (2.577)	5 (3.337)	7 (0.990)	7 (0.010)	11 (0.007)
NNW	337.5°	3 (3.966)	7 (3.946)	9 (1.823)	9 (0.033)	11 (0.010)
N	360°	3 (15.53)	7 (7.960)	9 (1.825)	9 (0.060)	11 (0.003)
NNE	22.5°	3 (2.676)	7 (1.790)	9 (0.210)	9 (0.003)	

4.2 Water Levels

Lake-wide average water levels have been computed for Lake Michigan since 1918. Figure 4.3 provides a visual summary of the long term yearly cycles of rising and falling water levels in the past 90 years. The maximum monthly mean of 582.64 feet was recorded in June, 1986 while the lowest monthly mean was recorded in March, 1964 at 576.05 feet. The total range between the minimum and maximum monthly mean is approximately 6.59 feet.

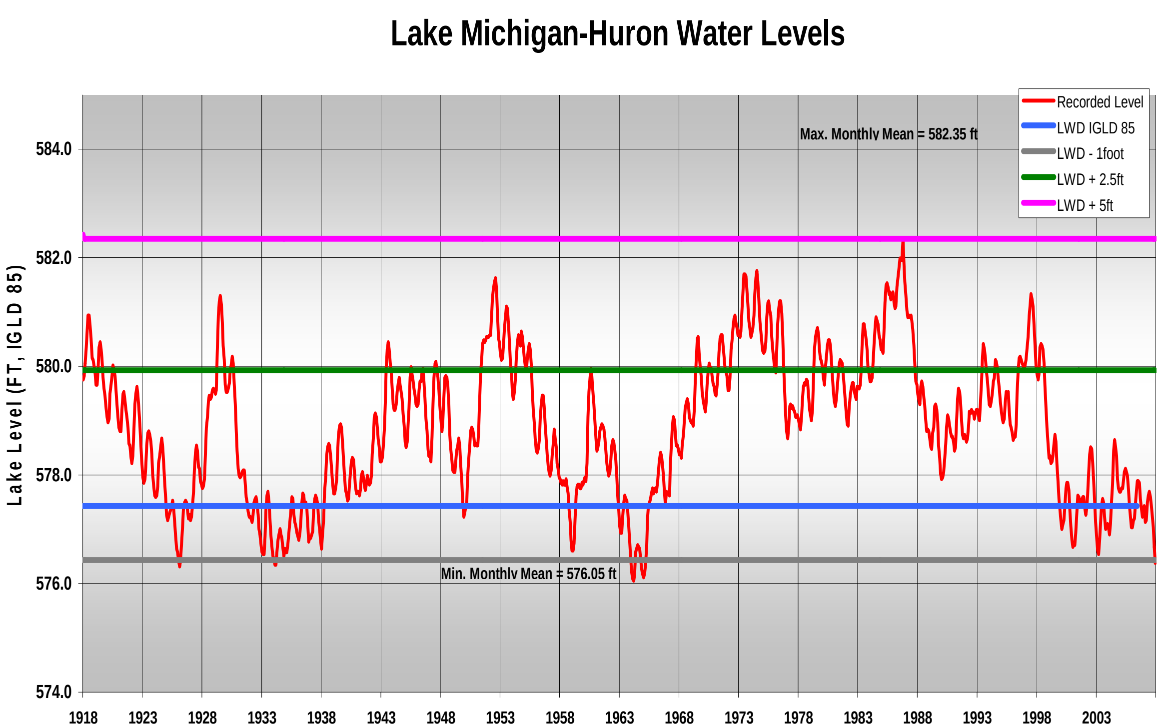

Figure 4.3: Water Level Data for Lake Michigan

An important aspect of this analysis involves understanding how changes in shoreline location correlate to water level changes. Table 4.2 lists monthly mean water levels associated with the time depicted in aerial photography used in this study. With the exception of the extreme high water levels in 1954, 1973 and 1985 and the low water level in 2002, all the levels were within approximately 1 foot. This consistency is an important issue when comparing shoreline locations, which will be discussed later.

Table 4.2 Water Level Elevations for Various Temporal Periods

Date of Aerial Photo	Mean Monthly Water Level	
Year	**Date**	**Elev (IGLD-1985) (feet)**
7/19/1938	July 1938	578.51
11/3/1954	November 1954	580.54
9/11/1967	August 1967	578.74
4/19/1973	April 1973	581.04
4/18/1980	April 1980	579.95
4/16/1985	April 1985	581.17
5/2/1991	May 1991	579.40
5/29/1996	May 1996	579.49
4/26/2002	April 2002	577.62

5.0 Dredging and Trucking

Since 1975 the navigation channel at New Buffalo Harbor has been maintained at a depth of 10 feet below Low Water Datum (LWD) in the outer portion and at 8 feet below LWD within the harbor. This section will analyze dredging rates and sediment quantities placed in the nearshore as beach nourishment after the construction of the harbor. This information is important in understanding the nature of sediment movement in the region.

5.1 Dredging

The USACE completed its first federally authorized navigation project in 1975 when the navigation channel was dredged to project depth. Approximately 49,000 yd^3 of sediment was dredged and placed in the nearshore south of the harbor. The harbor has been dredged thirteen times since 1975. As shown in Table 5.1, dredge quantities have ranged from approximately 2,907 to 19,028 yd^3 since the initial dredging. All 178,985 yd^3 of sediment was placed in the designated placement site established when the harbor was designed. Figure 5.1 shows the location of this placement site. The site is between 2,400 and 3,200 feet south of the harbor and placement of the sediment occurred between approximately the Ordinary High Water Mark (OHWM) of 581.36 feet and the 4 foot contour.

Table 5.1: Dredging History at New Buffalo Harbor

Year	Quantity (yd^3)
1975	49,048
1983	19,028
1985	9,795
1988	10,136
1990	14,920
1992	11,931
1994	8,492
1999	18,596
2001	4,157
2003	11,781
2005	11,107
2006	2,907
2008	7,135

While Table 5.1 shows considerable fluctuation in the amount of sediment dredged from the harbor, the rate at which sediment is removed on an average annual basis from the harbor is relatively constant. Figure 5.2 shows a graphical representation of the dredging data shown above. It is a total accumulation of the sediment dredged over the harbor's history, excluding the sediment from the initial dredging in 1975. The graph clearly shows that the overall dredging rate has been constant. If dredging was accomplished at this harbor every year, the government would remove on average 5,424 yd^3 / year from the navigation channel.

Figure 5.1: Dredge Placement Area South of New Buffalo Harbor

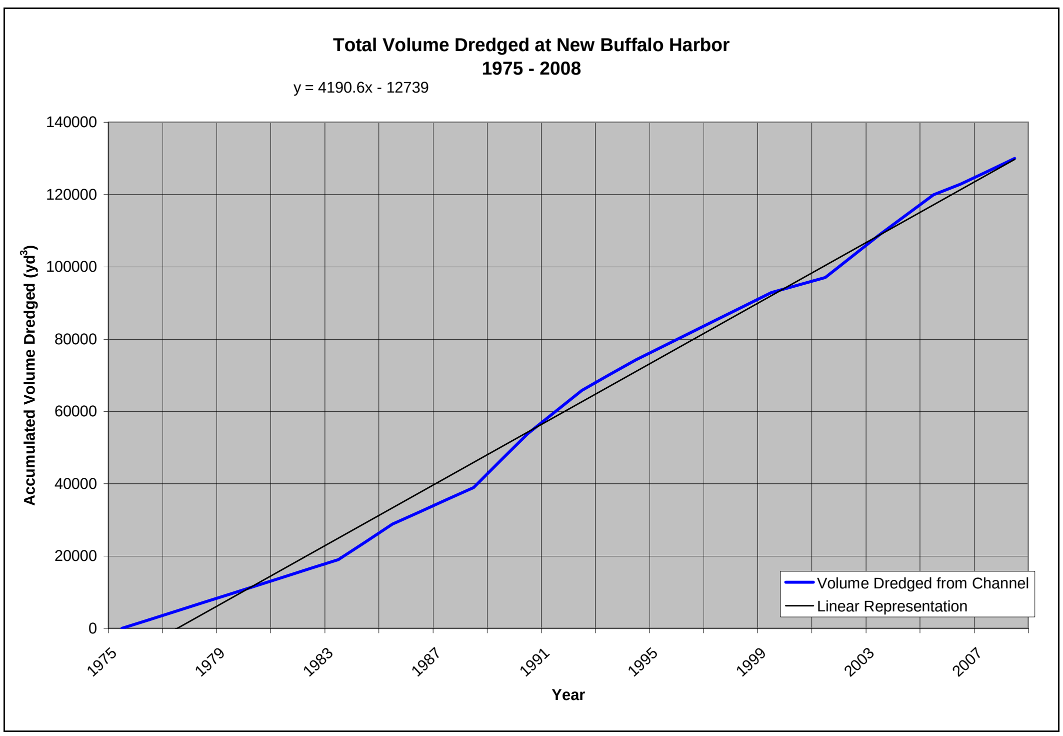

Figure 5.2: Graphical Representation of Dredging History at New Buffalo Harbor

5.2 Beach Nourishment from Upland Sources

Over the lifetime of New Buffalo Harbor, approximately 713,624 yd^3 of sediment from upland sources have been placed at the site shown in Figure 5.1. As indicated in Table 5.2, all of this material was placed south of the harbor over a 20-year period ranging from 1975 to 1995. The analysis supporting the design and construction of the harbor indicated that approximately 5 years of nourishment totalling roughly 457,800 yd^3 of sediment would need to be placed to counteract any effects by the newly constructed harbor.

Table 5.2: Upland Nourishment at New Buffalo Harbor

Year	Quantity (yd^3)
1975*	200,012
1979*	16,001
1980*	48,021
1981*	228,966
1985	120,007
1988	37,792
1991	64,008
1995	54,024

*** Denotes information based on reports and local articles**

Referring to Table 5.2 and averaging the quantities placed over this 20-year period results in a nourishment program of 43,674 yd^3/yr. As will be discussed in the next section, this program resulted in beneficial support of the local shoreline south of New Buffalo Harbor.

6.0 Morphologic Change Analysis

This section will focus on the morphologic change analyses accomplished for this study. There were three distinct analyses done: a shoreline change analysis, an accretion fillet growth analysis, and a nearshore change analysis.

6.1 Shoreline Change Analysis

Shoreline change analyses can be a daunting task for long temporal periods. To eliminate shoreline fluctuations due to water level rise and fall, mapping of the edge of bluff or a specific land contour is preferred. In this study, it was difficult to delineate the top of bluff for most of the area of interest due to tree cover in the referenced aerial photography, new development and changes in contours due to construction, and quality issues of the referenced aerial photography.

For this reason it was determined that mapping the waterline for the various temporal periods represented by the geo-referenced aerial photography would be applied. Figure 6.1 is an example of shoreline locations around the harbor for the temporal periods analyzed. The area around New Buffalo Harbor possessed the most coverage.

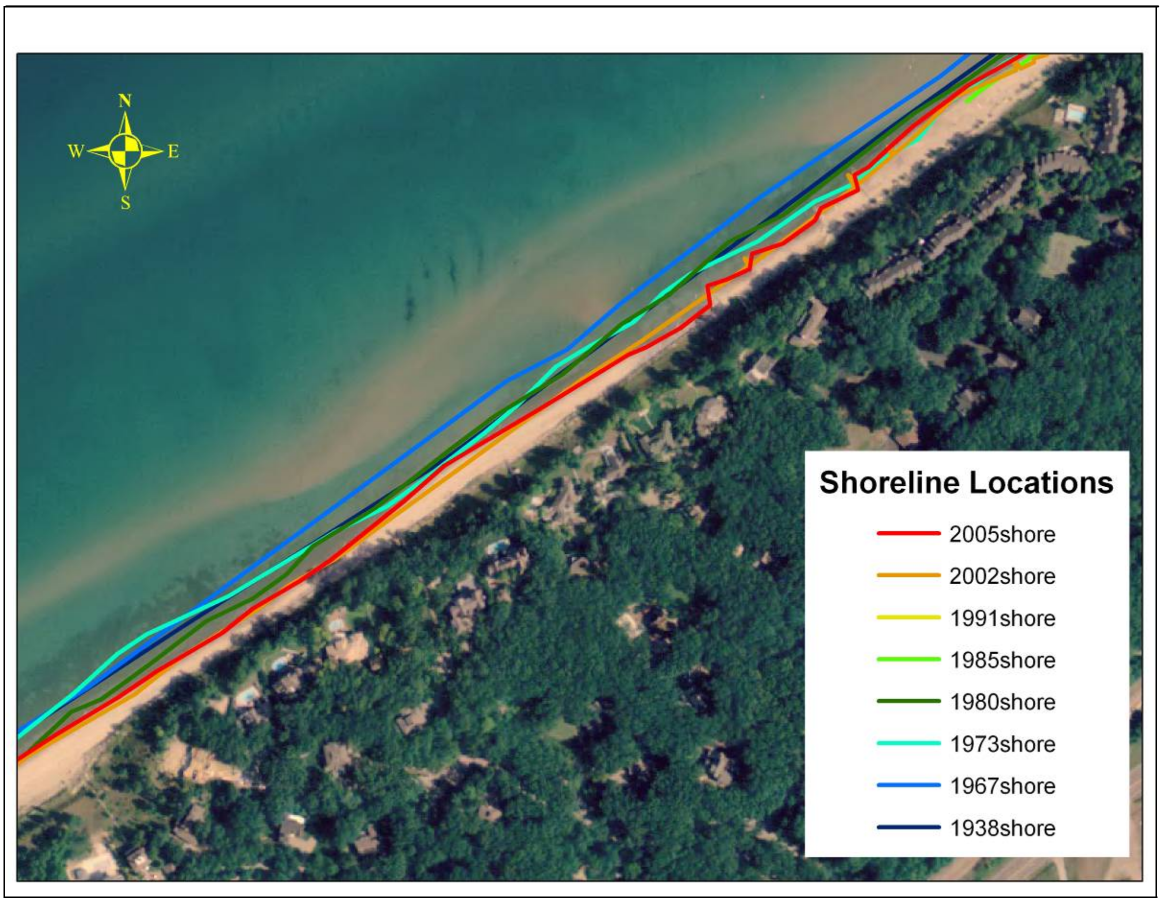

Figure 6.1: Shoreline Change Analysis at Forest Beach

In order to sufficiently calculate recession rates for the study area the U.S. Geological Survey's (USGS) Digital Shoreline Analysis System (DSAS) was utilized. DSAS is an ArcGIS extension that enables users to calculate shoreline rate-of-change statistics from a time series of multiple shoreline positions.

DSAS works by generating orthogonal transects at a user-defined separation and then calculates rates-of-change and associated statistics that are reported in an attribute table. For this analysis, transects were placed every 165 feet (Figure 6.2) for the whole study area. Analyses were conducted for the eight reaches defined in Section 1.4 as well as for the entire shoreline north and south. While eight separate temporal periods were mapped and reviewed, only four temporal periods were analyzed using DSAS. This was mainly due to time and cost constraints. However, the temporal periods not analyzed with DSAS provided significant information about the region and shoreline fluctuations discussed later.

6.1.1 Village of Grand Beach Shoreline Analysis

The Village of Grand Beach shoreline was the farthest southern reach analyzed in these 16,500 feet of shoreline. The shoreline is observed to recede significantly from its position in 1938 and then fluctuate from 1967 to 2005. The shoreline was significantly landward in 1973 as well as in 1985, which was its furthest position inland. Referring to Figure 6.2, it can be seen that from 1938 to 1967 the Average Recession Rate (ARR) was -3.366 feet/year. This increased significantly to -10.384 feet/year from 1967 to 1973. The shoreline in this area remained stable for 1973 to 1980 and then experienced moderate accretion from 1980 to 2002.

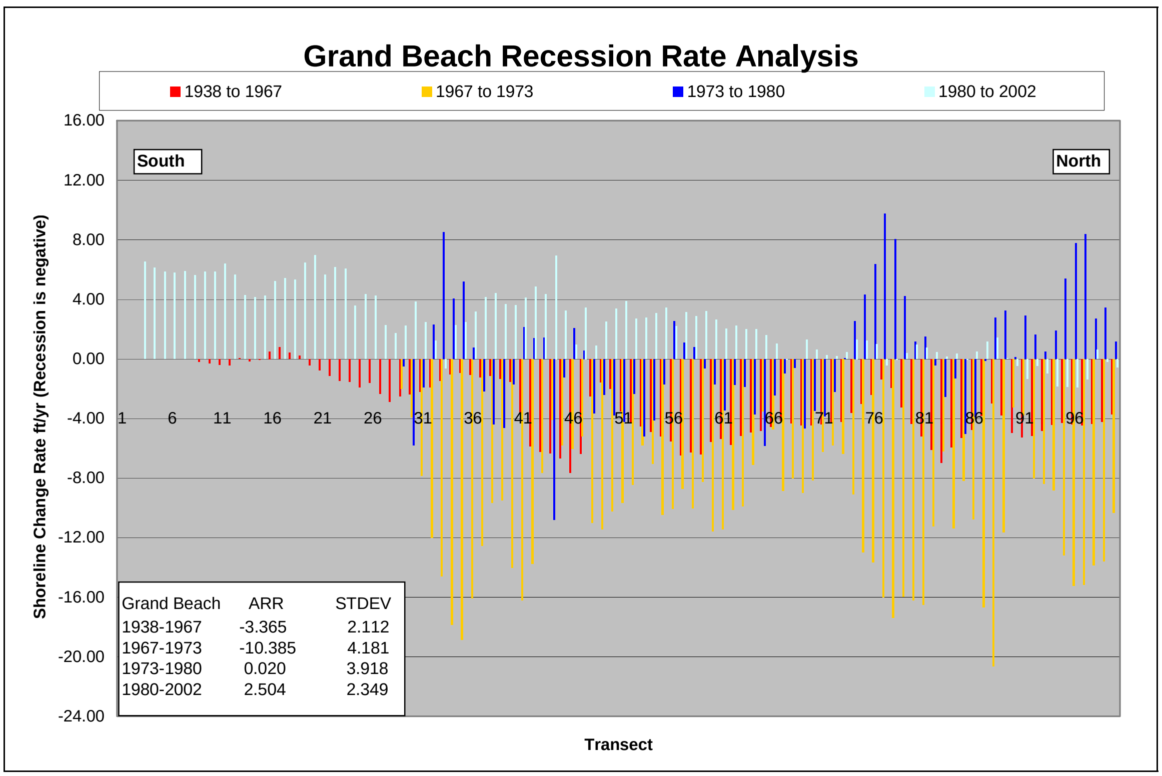

Figure 6.2: Recession Rate Analysis for Grand Beach

6.1.2 Forest Beach Shoreline Analysis

The Forest Beach shoreline is just north of Grand Beach. This shoreline stretches 2,500 feet along Lake Michigan and is represented by 15 transects. This shoreline has a slightly different history from Grand Beach. Most of the shoreline observed was relatively stable from 1938 to 1967. This changed drastically from 1967 to 1973 where the shoreline receded significantly. After 1973 the Forest Beach shoreline has remained relatively stable. Figure 6.3 shows that from 1938 to 1967 the ARR was about -0.358 feet/year. This increased significantly to -6.81 feet/year from 1967 to 1973. The shoreline continued to recede from 1973 to 1980 and from 1980 to 2002 at reduced rates of approximately -1.54 feet/year and -1.77 feet/year, respectively.

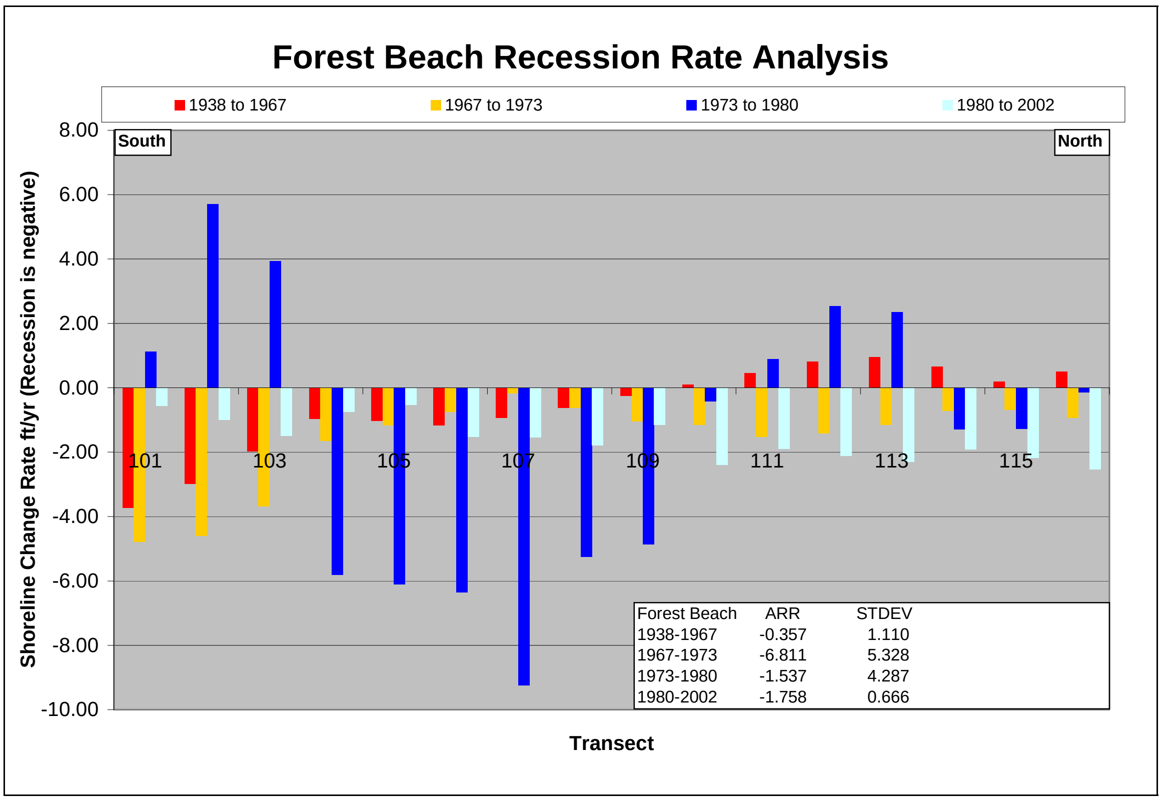

Figure 6.3: Recession Rate Analysis for Forest Beach

6.1.3 Warwick Shores Shoreline Analysis

Warwick Shores covers 1,500 feet and is covered by 9 transects. This shoreline has reacted significantly to short term fluctuations in water levels. It was relatively stable since 1973 after a significant landward shift in shoreline position from 1967 to 1973. The graph shown in Figure 6.4 shows that the thirty year period between 1938 and 1967 resulted in little shoreline movement (ARR= -0.141 feet/year). The shoreline drastically receded at a rate of -13.947 feet/year from 1967 to 1973. The shoreline was accretional between 1973 and 1980 when water levels were relatively stable, resulting in an ARR of 1.283 feet/year. This changed to moderate recession from 1980 to 2002 as indicated by the -1.614 feet/year ARR for this temporal period.

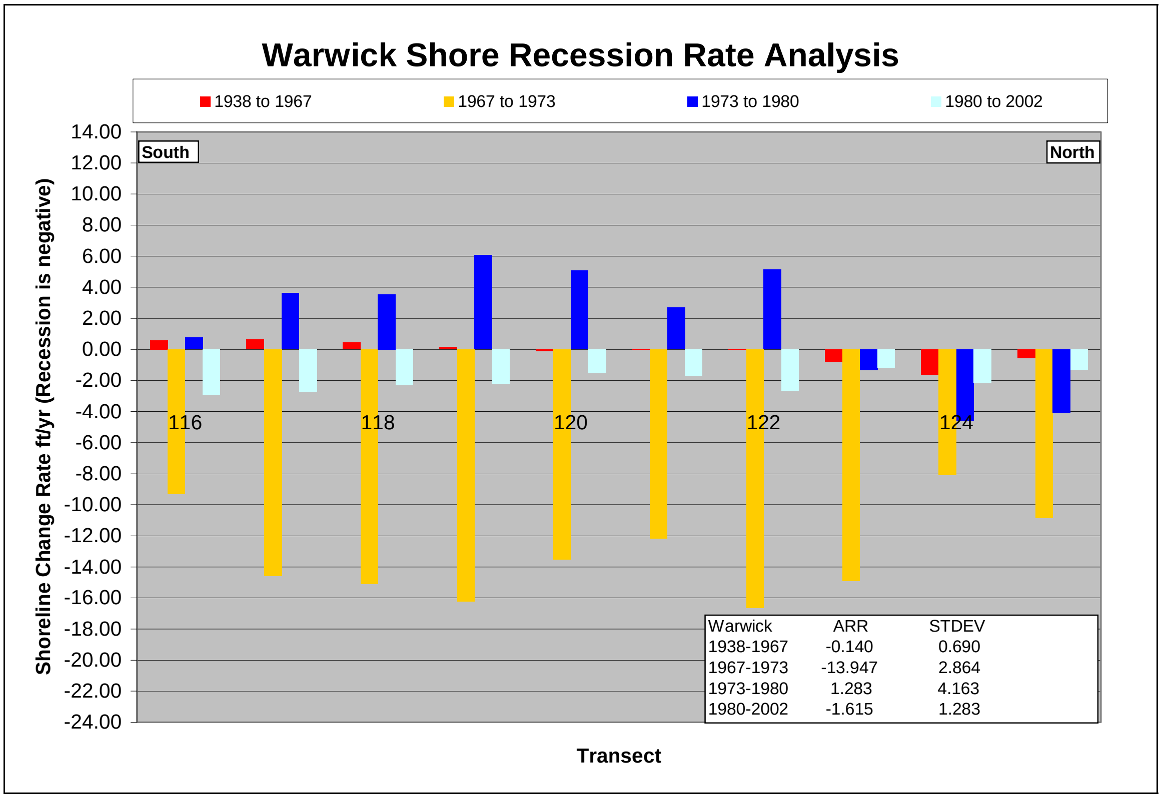

Figure 6.4: Recession Rate Analysis for Warwick Shores

6.1.4 Sunset Shores Shoreline Analysis

Sunset Shores is the 2,100 feet stretch of shoreline between Warwick Shores and the south accretion fillet. 13 transects were utilized to gain recession rate information at this location. The shoreline at Sunset Shores has been predominately recessional since 1938. Referring to Figure 6.5, for 30 years between 1938 and 1967 the shoreline has receded at an average rate of 1.345 feet/year. This increased significantly for a short time frame from 1967 to 1973, rising to an ARR of -14.708 feet/year. The average recession rate reduced over the next two temporal periods to -0.823 feet/year for 1973-1980 then to -0.266 feet/year from 1980 to 2002. The shoreline recession analysis for this entire project site indicates that Sunset Shores has the greatest recession of all the stretches of shoreline.

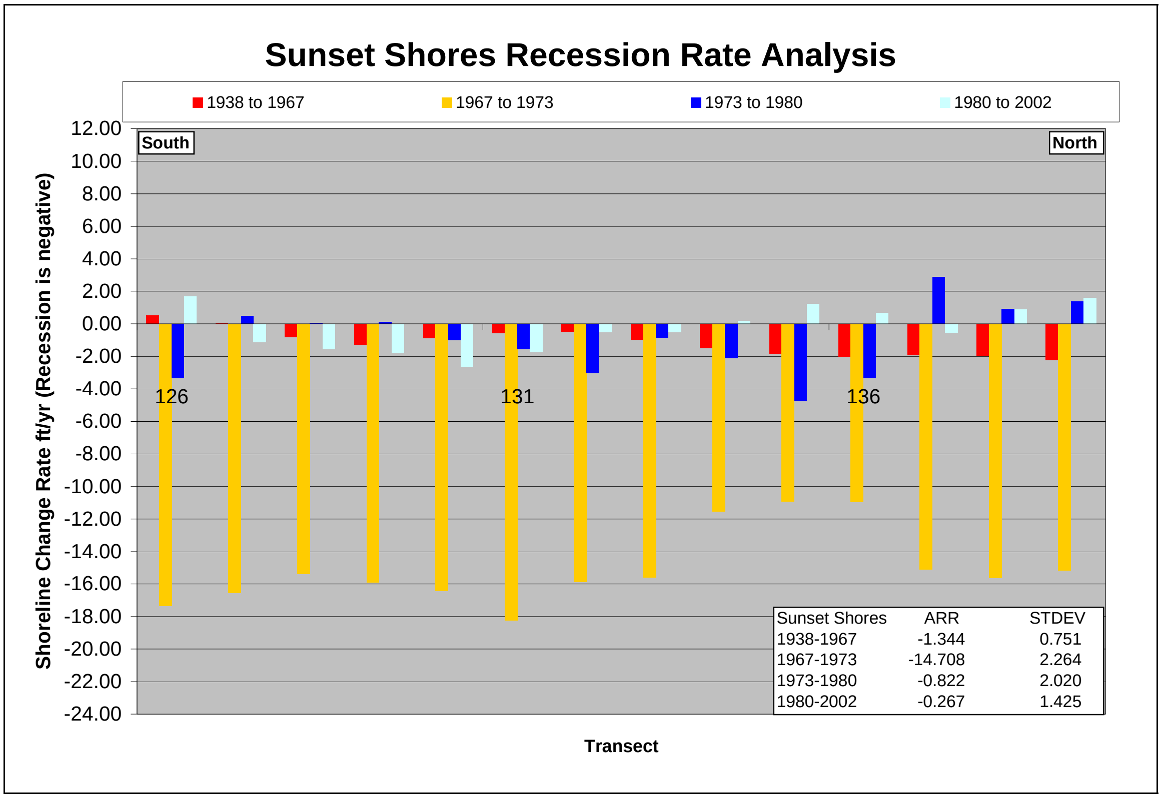

Figure 6.5: Recession Rate Analysis for Sunset Shores

6.1.5 North Shore Shoreline Analysis

This shoreline begins at the end of the north accretion fillet and stretches 7200 feet north and is covered by 44 transects. Similar to the shoreline reaches to the south, this area has been largely recessional for the past 70 years. As indicated in Figure 6.6, the shoreline saw moderate recession from 1938 to 1967 (ARR = -1.581 feet/year). Like all the other shorelines, this portion of shoreline also saw a substantial increase in recession from 1967 to 1973 (ARR = -7.080 feet/year). The ARR remained relatively high at -4.275 feet/year from 1973 to 1980. After 1980 the shoreline has become accretional, growing at a rate of 3.048 feet/year.

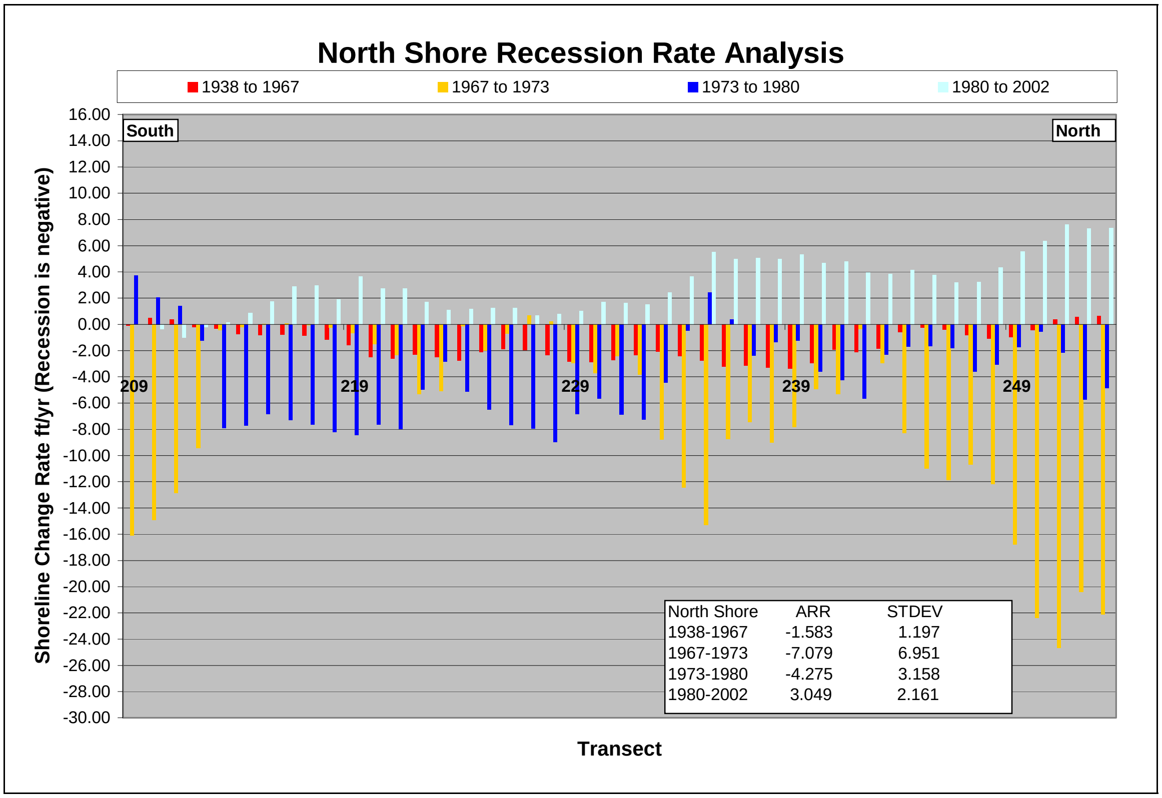

Figure 6.6: Recession Rate Analysis for North Shore

6.1.6 Overview of Shoreline Morphology

While there is value in understanding how each portion of the study area has reacted over various temporal periods, there were other observations made concerning shoreline morphology that identified important factors on the shorelines changes over time.

One pivotal understanding is how each portion of shoreline, as well as how the shoreline north and south of the harbor has reacted over time, has compared to the overall average rate of change for the study site. The overall average was calculated by averaging recessions rates over the transects with data. Referring to Table 6.1, it can be seen that from 1938 to 1967 a large portion of the study site had less recession than average. This changed drastically from 1967 to 1973 when water levels rose significantly. With the exception of Forest Beach, all the shorelines saw notably higher than average recession rates. This phenomenon reversed from 1973 to 1980 when Forest Beach experienced higher recession than the remainder of the study site and the North Shore experienced substantially higher accretion. The North Shore continued to have much higher than average shoreline accretion from 1980 to 2002. Grand Beach also had higher than average accretion, while the rest of the study area either had less accretion or some recession.

Table 6.1: ARR's For Each Portion of the Study Area Compared to Average

Temporal Period	Grand Beach	Forest Beach	Warwick Shores	Sunset Shores	North Shore	Study Average
1938 to 1967	-3.365	-0.357	-0.140	-1.344	-1.583	-2.328
1967 to 1973	-10.385	-6.811	-13.947	-14.708	-7.079	-9.734
1973 to 1980	0.020	-1.537	1.283	-0.822	-4.275	-1.221
1980 to 2002	2.504	-1.758	-1.615	-0.267	3.049	1.861

Based on the numbers presented in Table 6.1, the north shore changed from a recessional shoreline to an accretional shoreline after 1973. The accretional benefits north of the structures can be attributable to the placement of the harbor; however it is unclear how much effect the federal structures have had on the southern shoreline. The entire study area was recessional since at least 1938. The south shore has in some cases become less recessional since 1973. This may be due to impacts associated with development, equilibrium of the nearshore after the railroad piers degraded, nourishment, or other variables.

While it is unclear how these variables directly impact shoreline characteristics within the project area, it is worth noting that the nourishment program described in Section 5.2 shows promise that future nourishment programs will benefit the shorelines south of New Buffalo. Grand Beach became accretional after 1973 and became significantly more accretional through the major part of this nourishment program. Warwick Shores showed some accretion in the early part of the program and Sunset Shores exhibits less recession than it did prior to the nourishment program. No accretion has been observed at Forest Beach throughout the temporal period of this study. This will be discussed further when discussing nourishment solutions in Chapter 8.0.

However, as mentioned throughout this section, the effects of higher water levels cannot be overlooked. From 1967 to 1973, water levels rose approximately 2.3 feet. This caused substantial increases in recession rates. A similar event occurred from 1980 to 1985 when water levels rose 1.2 feet. Water levels rose even higher by 1987 where it reached a level of 582.35 feet in 1986. Table 6.2 compares the shoreline reactions to the north and south of the harbor for the 1967 to 1973 and 1980 to 1985 temporal periods.

Table 6.2: ARR's For the Shorelines South and North of the Harbor from 1967-1973 and 1980 -1983

Temporal Period	Shorelines South	Shorelines North
1967 to 1973	-10.715	-7.281
1980 to 1985	-3.944	-5.591

It can be seen that the effect of water level rise was more drastic from 1967 to 1973. There are a few factors that may have caused this to occur.

1. The water level rise for 1980 to 1985 was only slightly more than half of the rise from 1967 to 1973.
2. Shoreline protection along the southern shoreline in the vicinity of Sunset Shores had significantly increased between 1967 and 1973, which would halt further shoreline recession in the future.
3. After 1975, the federal harbor was constructed, which would have stabilized portions of the shoreline.
4. More severe storm activity occurred in the 1970's.

Taking this into account and ensuring that sufficient temporal periods are represented so that water level fluctuations do not drastically affect long-term ARR values, the temporal periods of 1938 to 1973 and 1973 to 2002 were compared for each stretch of shoreline and the results are shown in Table 6.3. As shown, recession rates have reduced significantly since 1973 for all the shoreline, with the exception of the Forest Beach shoreline. Furthermore, the shoreline north of New Buffalo Harbor and the shoreline at Grand Beach have shown accretion. This may be attributable to all the shore structures that have been placed within the study area.

Table 6.3: ARR's For the Shorelines South and North of the Harbor from 1938-1973 and 1973 -2002

Temporal Period	Grand Beach	Forest Beach	Warwick Shores	Sunset Shores	North Shore	Project Average
1938 to 1973	-4.568	-1.463	-2.507	-3.635	-4.528	-3.598
1973 to 2002	1.904	-1.704	-0.915	-0.401	5.692	1.117

6.1.7 1857 Shoreline

During the site visit conducted in July, 2008, representatives from the City of New Buffalo provided the Corps with an 1857 survey of the harbor area and adjacent shoreline. Attempts were made to geo-reference the drawing to present day aerial photography. Figure 6.7 illustrates the results of this effort. While this drawing could not be used to make quantitative measurements, it was very useful in gaining a qualitative understanding of the shoreline and its history.

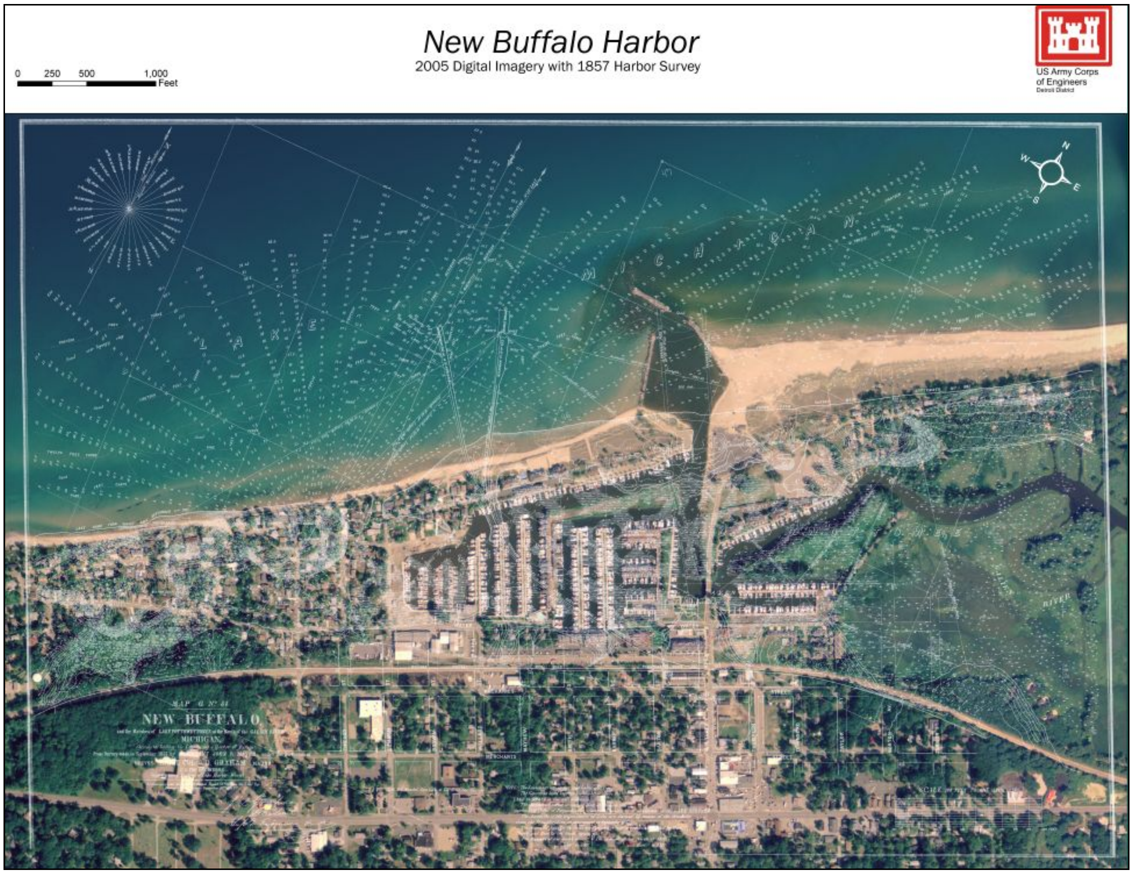

Figure 6.7: 1857 Survey Overlaid with 2002 Aerial Photography

The shoreline from 1857 was digitized and placed in the figure. There are a number of interesting observations that can be made. First, the present day location of the mouth of the Galien River is approximately 2300 feet east of where the river used to meet Lake Michigan. Inspection of the elevations at the present day location of the river shows that a cut had to be made through substantial sand dunes for the river to flow at this point. The shoreline immediately south of the present day harbor may have been an old accretion fillet of railroad piers that existed at New Buffalo back in 1857. It is unclear when, prior to 1938, these structures were removed. The last observation is that the shoreline north of the present day harbor has grown significantly in the immediate area of the harbor. To the immediate south, the shoreline has somewhat receded. However, as you move further north and south of the harbor, the shoreline seems to converge with the present day 2002 shoreline. This is more evident to the south of the harbor.

6.2 Nearshore Change Analyses

Section 6.2 of this report will address the shoreline and nearshore analyses conducted at the harbor to investigate potential bypassing activity.

6.2.1 Historic Shorelines at the Harbor

Figure 6.8 summarizes the historical shorelines organized at the New Buffalo Harbor for this study. There were a number of years added to this analysis that were not used for the entire project study area. Added to the 1938, 1967, 1973, 1980, and 2002 shoreline positions were the 1857, 1985, 1991, and 2005 shoreline positions.

Shoreline positioning updrift (northeast) of the harbor advanced lakeward slightly from the 1857 to 1938. After this timeframe, the shoreline advanced landward slightly or remained relatively constant until 1985. After 1985 the shoreline advanced steadily lakeward through 2002. It is unclear why the north accretion fillet took 10 years after construction of the harbor for significant growth to occur. It is most likely due to predominately high water levels during this period. Examination of the shoreline north of the harbor indicates that the north accretion fillet stretches approximately 7,500 feet north of the harbor. This is based on the observation that all the surveys tend to converge at this point signifying little change in shoreline positioning over time.

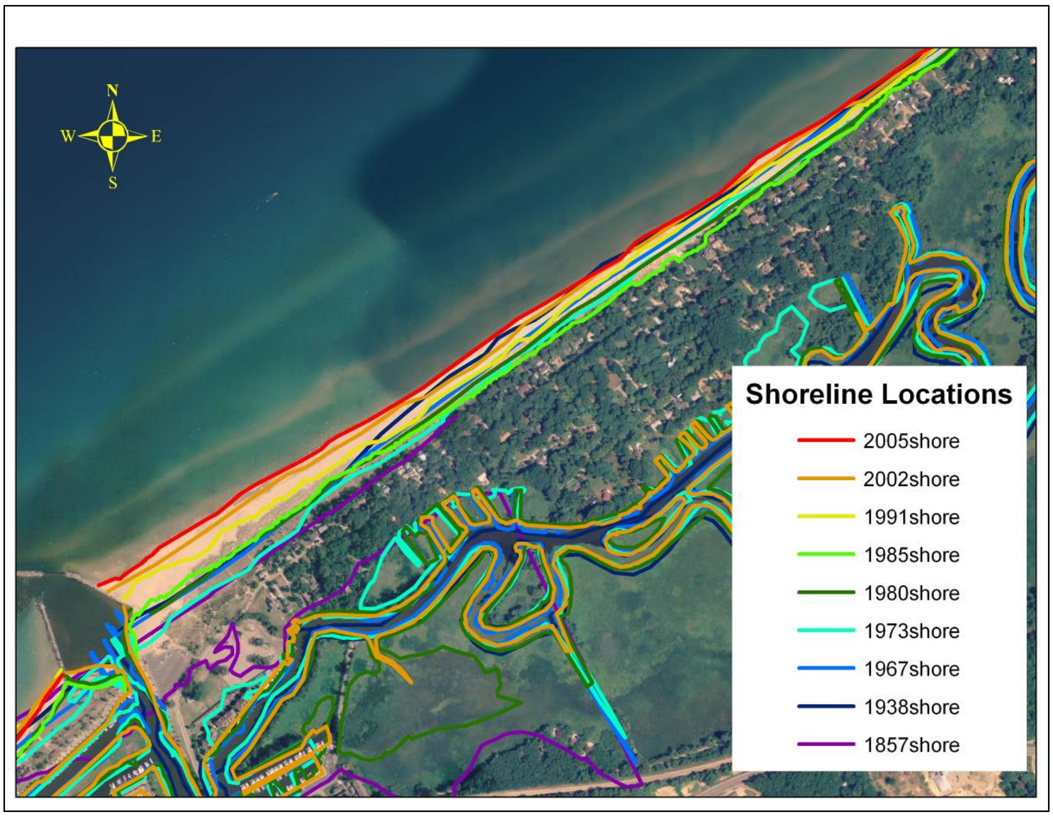

Figure 6.8: Shoreline History at the Present Day New Buffalo Harbor Location.

On the downdrift (southwest) side of the harbor, the shoreline went through its greatest change from 1857 to 1938. This was due to the removal of the old railroad piers, closure of the river mouth that had existed between the present location of Sunset Shores and the south accretion fillet, and opening of the river mouth at its present location. It seemed that built up sand on the updrift side of the railroad piers (see Figure 6.7) migrated south and evened out the shoreline in this location. The shoreline remained relatively constant from 1938 to 1967 with slight recession occurring near the mouth of the Galien River. As mentioned earlier, 1973 brought significant erosion to the area. The shoreline looks as though it moved back to the 1857 position that was present on the downdrift side of the old railroad piers. There was little lakeward movement of the shoreline from 1973 to 1985. However, after the high waters of the mid 1980's, the south accretion fillet grew significantly from 1985 to 1991. After this the south accretion fillet has remained relatively stable ever since. Based on the shoreline positioning over time, it looks like the south accretion fillet stretches approximately 2460 feet southeast of the south breakwater.

It is interesting to note that the portion of shoreline just southeast of the end of the accretion fillet shows that with the exception of the 1967 shoreline location, all the shoreline positions seem to be aligned, overlaying one another. The reason for this observation is unclear. This may be coincidental with water levels at a record low in 1964, which only marginally increased by 1967. However, the same situation existed in 1938.

6.2.2 Accretion Fillet Growth Analyses

Utilizing the shoreline positioning for the north and south accretion fillets, surface areas for various temporal periods could be calculated. As indicated in Section 6.3.1, there were distinct spots along the shoreline that marked the end of the accretion fillets. For the purposes of these analyses, the 1973 location was used for the base shoreline position to compare future shore positions. 1973 represents the closest period of time to when the harbor was built (1975). In addition, the 1985 and 2005 shorelines were not used because they were relatively close in time to other shorelines. Fluctuations in water levels would have caused problems in mapping long term fillet growth. For the purpose of these analyses, the 1980, 1991, and 2002 shorelines were used. This provided for almost a 10 year separation between shorelines.

Referring to Figure 6.9, it can be seen that the north accretion fillet has grown significantly. In 1980 the north accretion fillet grew to a surface area of 256,020 ft^2. The fillet continued to grow to 920,153 ft^2 by 1991 and then to 1,385,617 ft^2 in 2002. This was substantially more than the south accretion fillet. In 1980 the south accretion fillet had grown to 88,705 ft^2 and in 1991 it grew to 312,035 ft^2. Both of these values are about 33% of the surface area of the north accretion fillet in the same year. In 2002 the south accretion fillet was only about 25% of the size of the north accretion fillet at 332,379 ft^2.

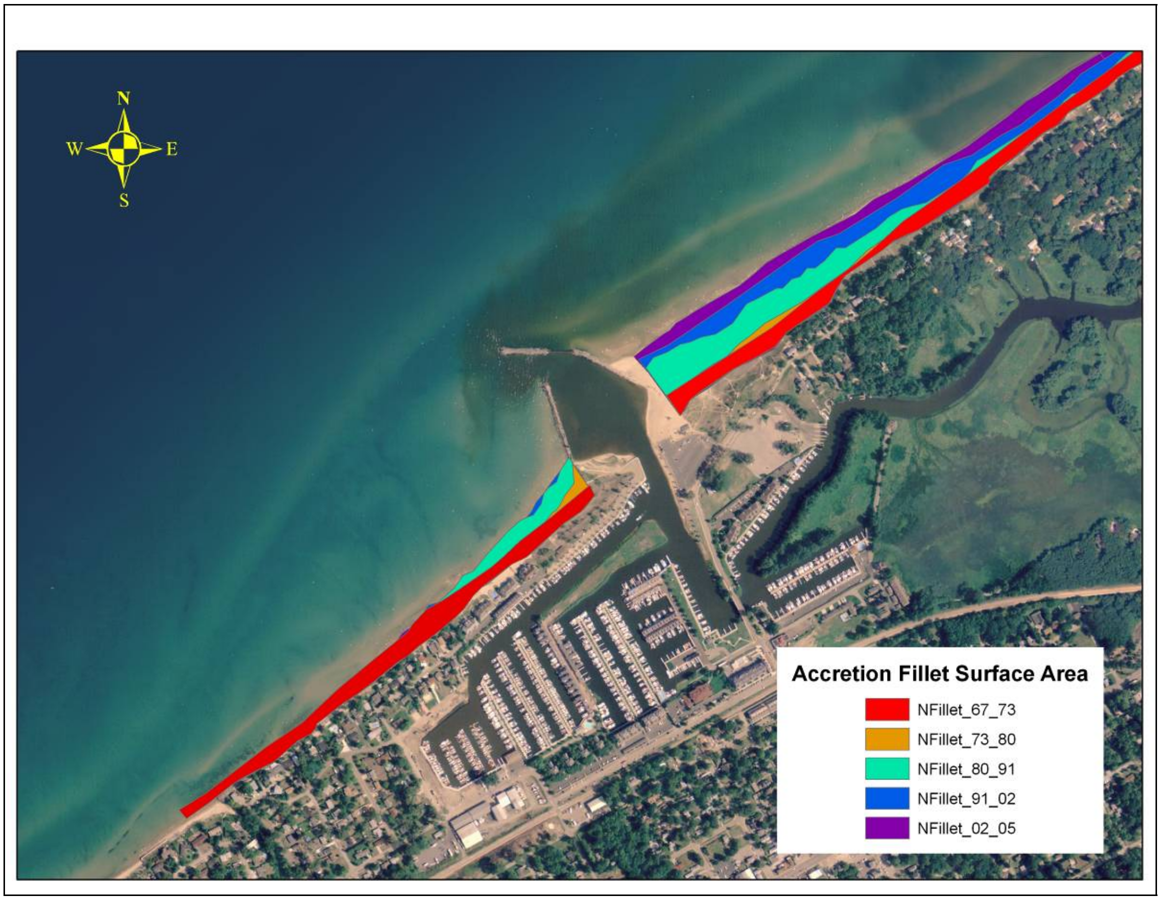

Figure 6.9: North and South Accretion Fillet Surface Areas.

Taking the surface area values and graphing them over time shows that the north accretion fillet is probably still growing, while the south accretion fillet is more than likely at capacity. Figures 6.10 and 6.11 illustrate these conclusions. Figure 6.10 shows how the north accretion fillet has grown over the last 30 years and provides a forecast of what it is expected to do over the future.

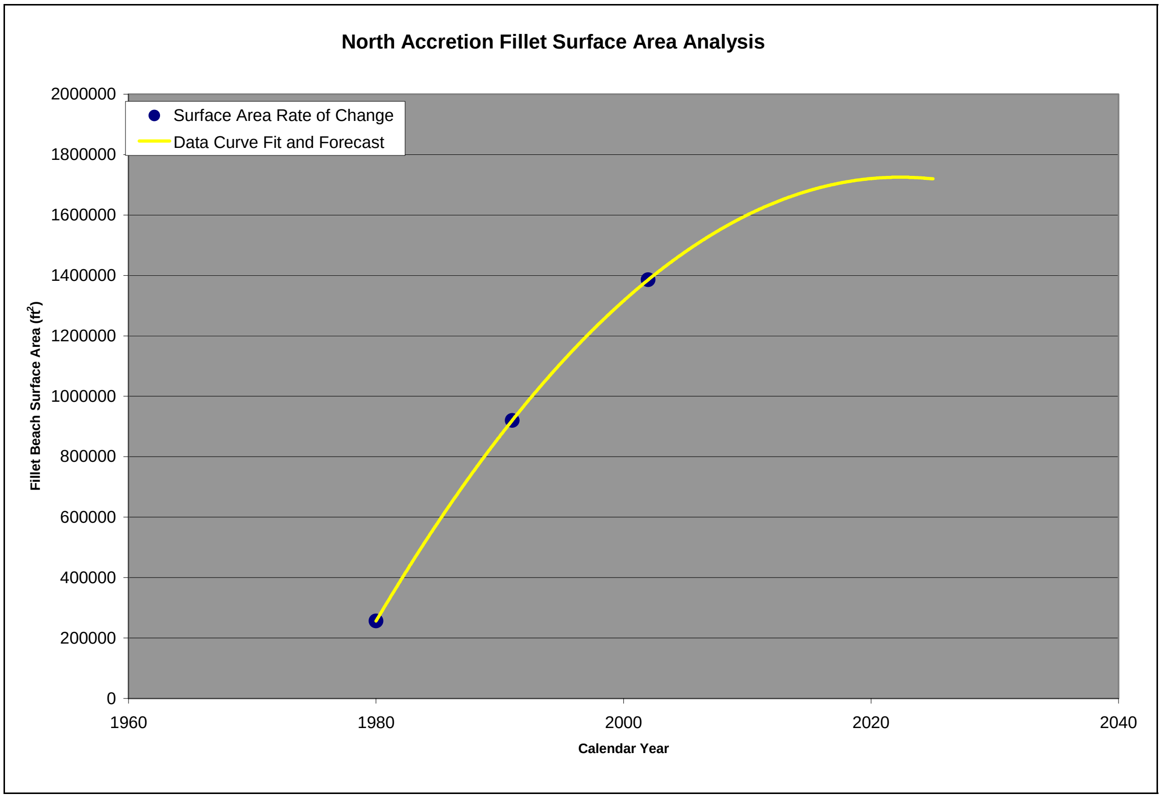

Figure 6.10: Graph Representing the Growth of the North Accretion Fillet Surface Area.

It is expected that the north accretion fillet will grow at a gradually lesser rate until approximately 2020 when it should reach a state of dynamic equilibrium. It is anticipated that the fillet may grow another 323,000 ft^2 to a surface area of about 1,722,000 ft^2.

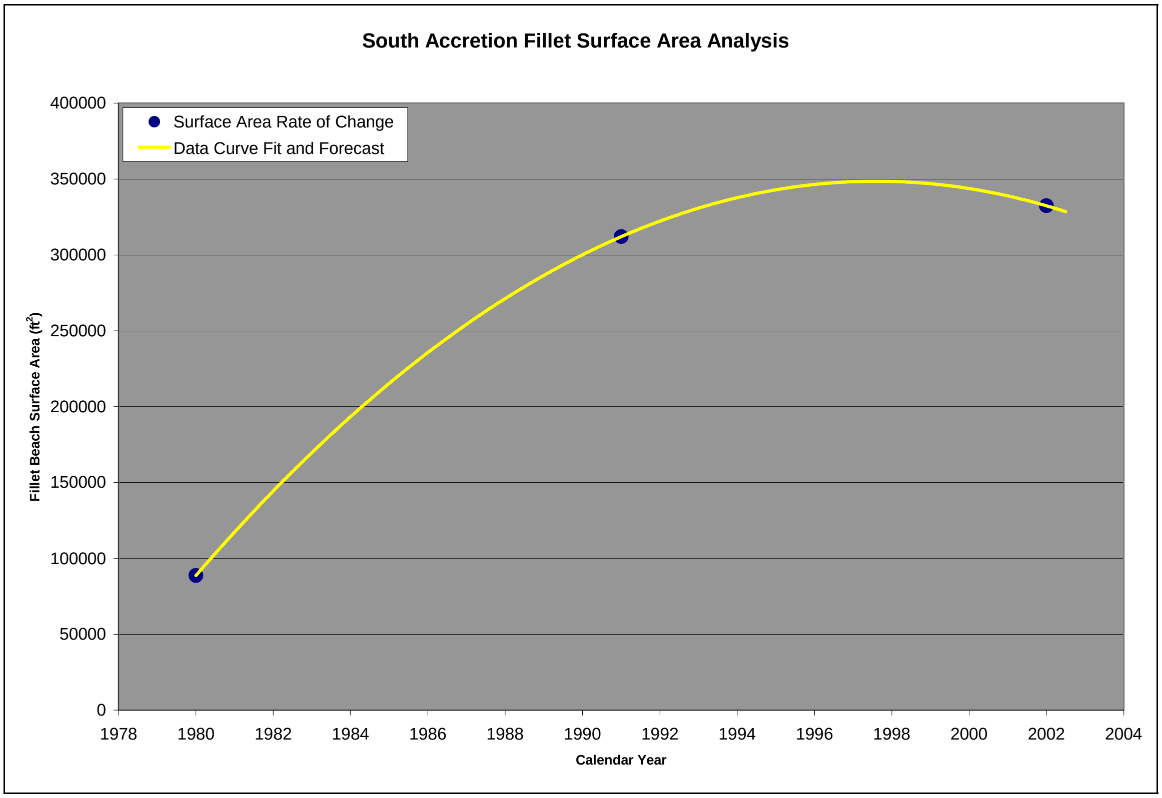

Figure 6.11: Graph Representing the Growth of the South Accretion Fillet Surface Area.

As shown in Figure 6.11 the south accretion fillet seems to have already reached a state of dynamic equilibrium. The south accretion fillet will fluctuate in size from year to year, but it is expected to remain near 323,000 ft^2.

6.2.3 Bypass Shoal Analysis

The spatial extents of the bypass shoal can be delineated from the bathymetric grid comparison of the 1991 bathymetry and the 1999-2000 SHOALS bathymetry (Figure 6.12). Three profiles were taken at this location to quantify and compare nearshore changes in the bypass shoal area. The profiles were taken just north, in front of, and just south of the federal structures. This was done to visualize any changes in the form of the bar as it passes the structures.

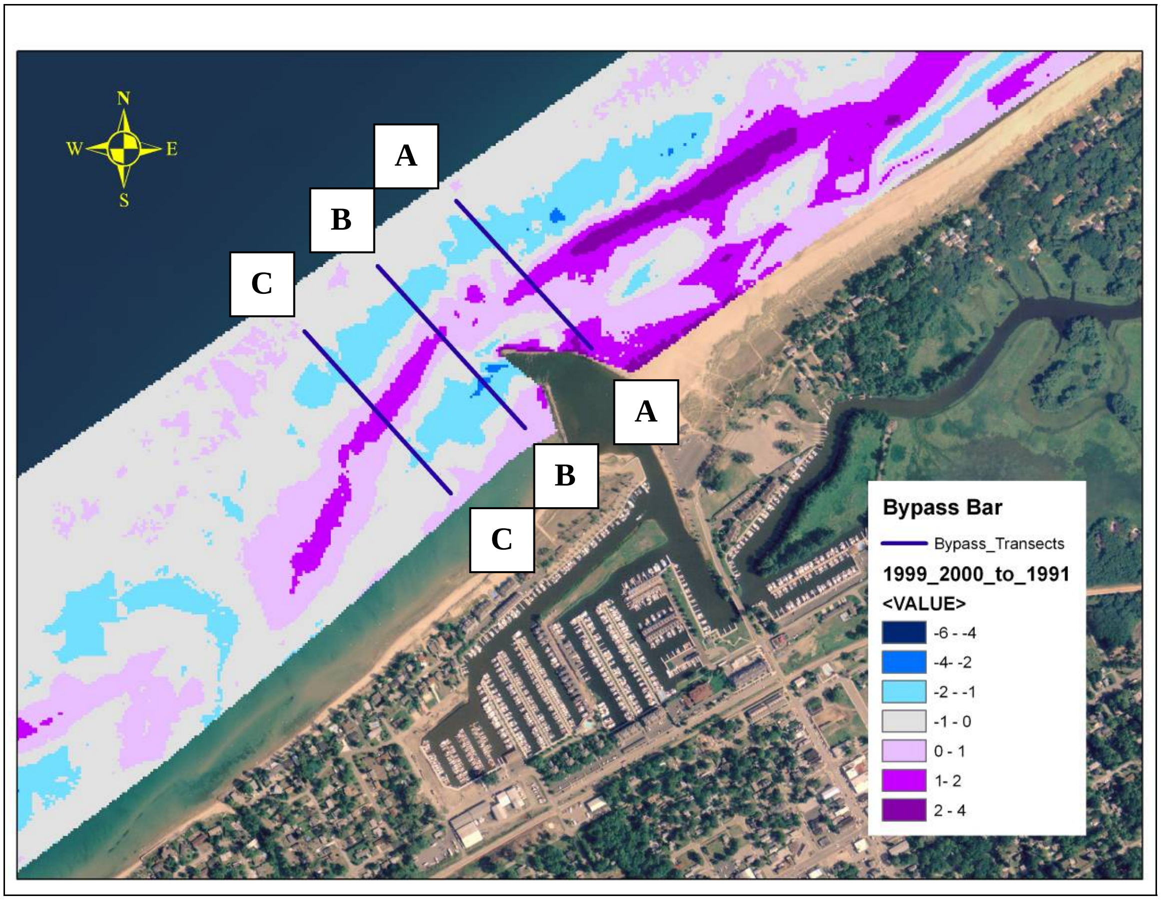

Figure 6.12: Spatial extents of the bypass shoal based on bathymetry.

Figures 6.13 to 6.15 display the data from each transect. Transect A-A clearly shows the growth of the bypass bar between 650 and 850 feet, which is roughly at the end of the northern breakwater. As would be expected, the bypass bar loses some form (Transect B-B) as sand bypasses the harbor and is affected by dredging projects. As the bypass bar passes the harbor (Transect C-C) it gains its form again at the 650 to 850 feet location.

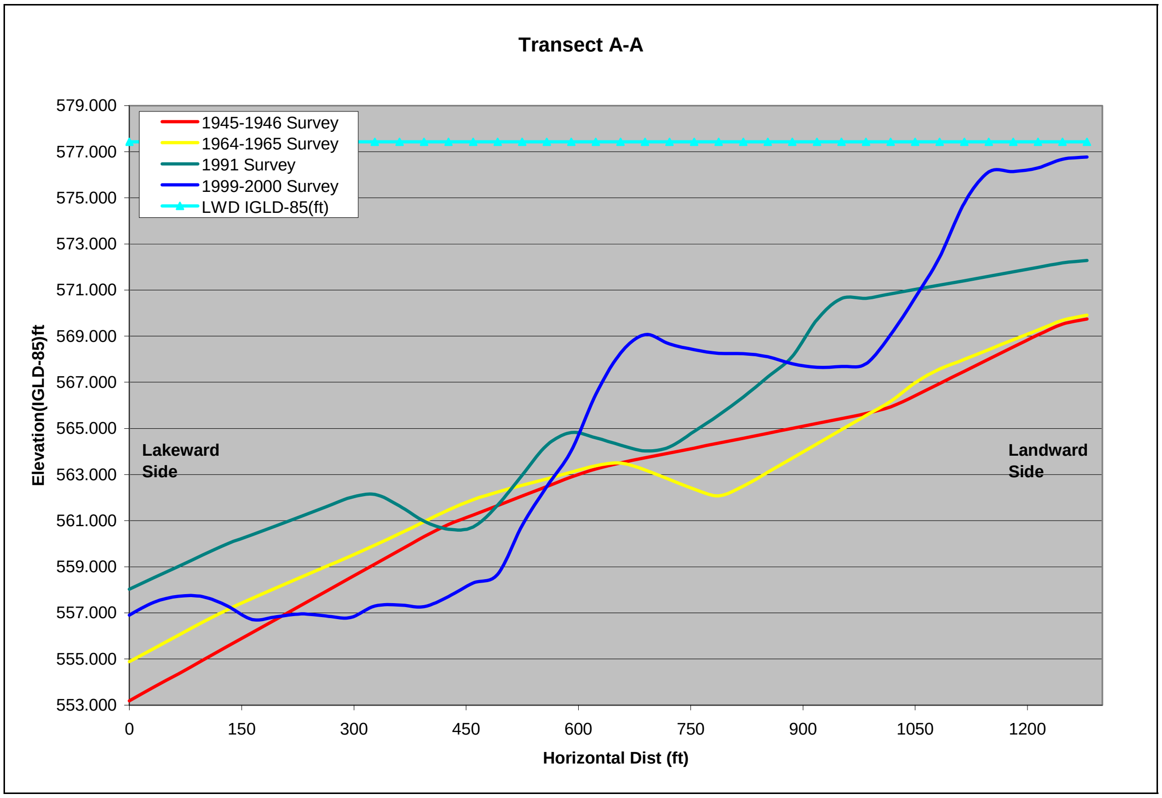

Figure 6.13: Transect A-A Just North of Harbor.

Some other interesting observations from the profiles can be seen from this data. First, the bypass bar is observed to react to water levels similarly on both sides of the harbor. When comparing the 1991 data with the 1999-2000 data, the bypass bar moves lakeward with lower water level and landward with higher water levels. (Note: Both the 1945-1946 and 1964-1965 data do not have enough resolution to provide sand bar location, only general lake bottom positions.) In addition, a significant amount of sediment either moved south or north from in front of the harbor (Transect B-B). Finally, it looks as though the lake bottom in the deeper portions of the nearshore has deepened significantly since 1945-46 for the transects north and south of the harbor. It is unclear why this occurred. Significant change occurred from 1945-46 to 1964-65. This process seemed to stop after 1965, with local shifting of the sand bar occurring in 1991 and 1999-2000. This process seemed to begin prior to installation of the harbor in 1975 and may be related to the removal of the railroad piers seen in the 1857 survey. These structures had created accretion fillets in the area. Once they were removed, the sand that was trapped around them may have taken time to redistribute. This could also explain how the river mouth location in 1857 was filled with sand as it is today. However, at this time there is no information on the removal of these structures that could support this hypothesis.

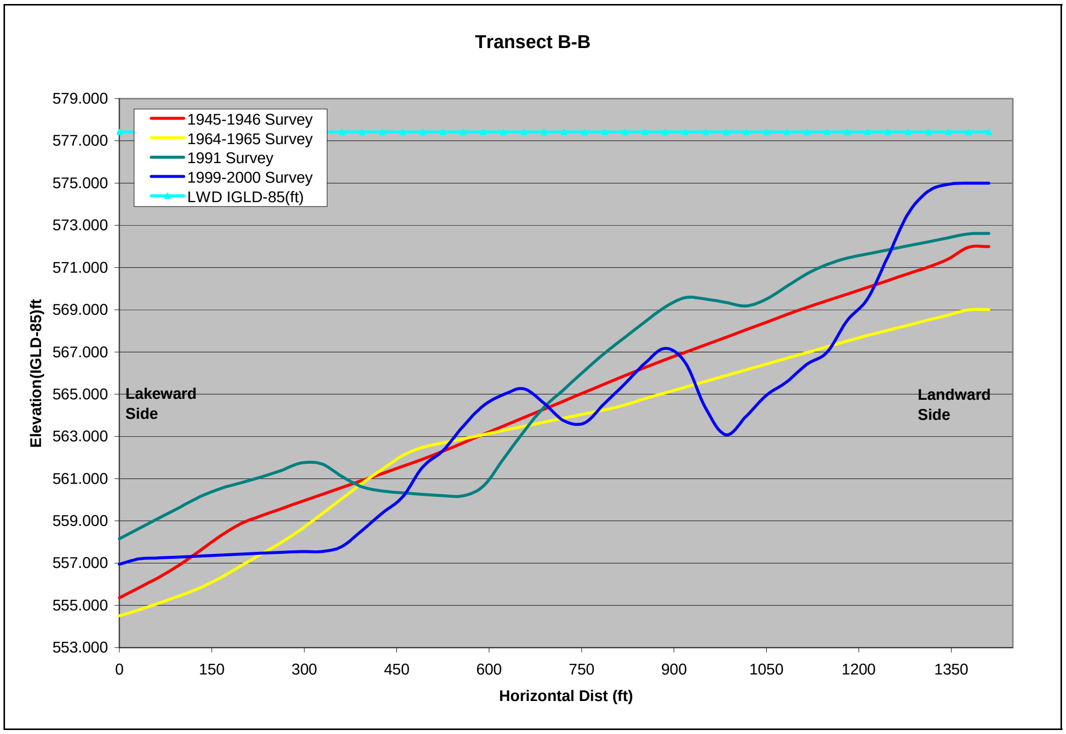

Figure 6.14: Transect B-B In Front of Harbor.

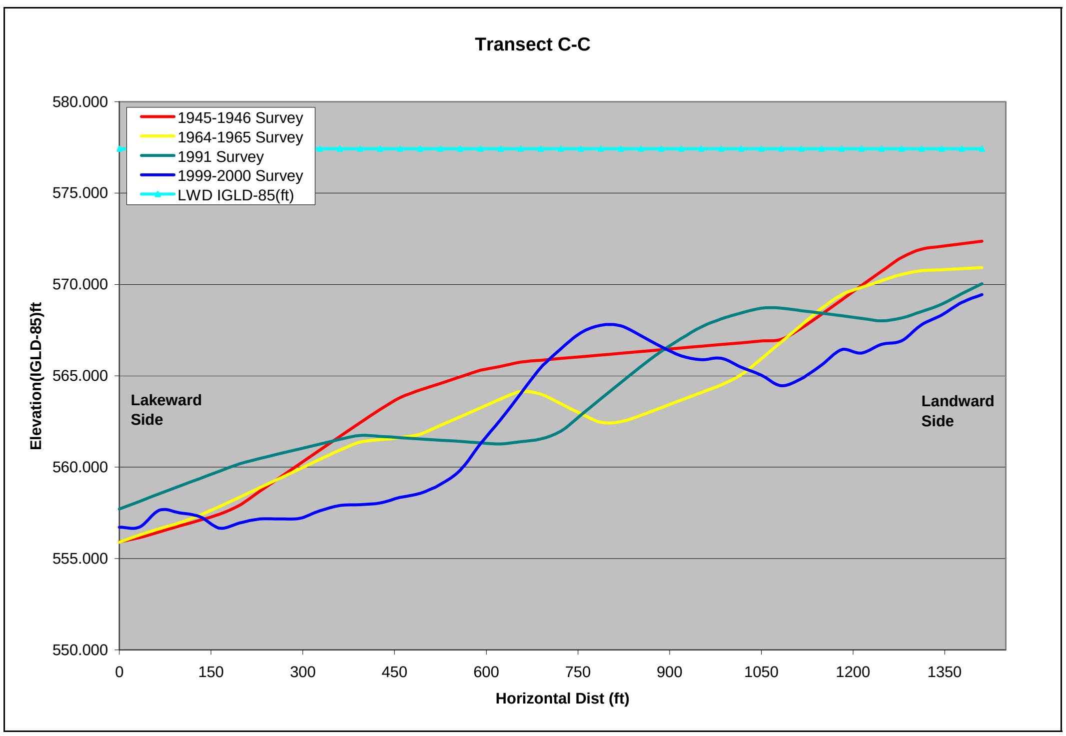

Figure 6.15: Transect C-C Just South of Harbor.

6.2.4 Nearshore Morphology

The last critical item that should be understood for developing a proper sediment budget is how the nearshore has changed over a sufficient temporal period. Figure 6.16 shows the results from comparing the 1964-1965 survey with the 1999-2000/2002 SHOALS/LiDAR surveys. Table 6.4 provides the volumetric changes that were calculated for each portion of shoreline. Due to the low resolution of the 1964/1965 survey there are significant accuracy issues with quantifying volume changes of the nearshore. This in conjunction with the fact that bathymetric surveys, in general, may have accuracy issues in quantifying volume changes. Consequently, the table shows a mainly erosional nearshore. The only portion of the project area that shows any significant accretion is the South Beach 2 zone. The South Beach zone is clearly the most erosional. It is surprising to see significant erosion in the north beach, considering the amount the north accretion fillet has grown over the last 35 years. This can be somewhat explained by inspecting Figure 6.22, where the north accretion fillet area has significant growth at the shoreline and erosion in the nearshore.

The data provides sufficient information to make qualitative observations. The South Beach 2 area mainly covers the northern reaches of Grand Beach. There has been little to no erosion of the nearshore over approximately 35 years. Over this same temporal period, the South Beach zone (Forest Beach, Warwick Shores, and Sunset Shores) has seen significant erosion in the nearshore. Both the South Inlet and North Inlet (accretion fillets) have seen accretion over this temporal period. Finally, the North Beach Zone, which encompasses the north beach outside of the accretion fillets, shows moderate to little erosion in the nearshore.

Another important item is that the nearshore is not entirely sand. The 1857 survey as well as other boring information from the harbor construction indicates the nearshore is mainly an exposed clay area with a thin veneer of sand. This clay can erode easily and may erode away completely. Much of the volume change may be attributed to the loss of this material and thus the erosion numbers shown in Table 6.4 may be slightly smaller.

One explanation for why the nearshore region seems so decidedly erosional may be linked to the railroad piers that existed in the 1850's. Over time they have decayed away and slowly lost their ability to hold sediment in the accretion fillets that developed there. As they became more and more irrelevant, the more erosion increased. This can be seen in the nearshore profiles and in the bypass bar data. This would also explain why the old river mouth in the area of the shoreline near present day Sunset Shores became a sandy shore.

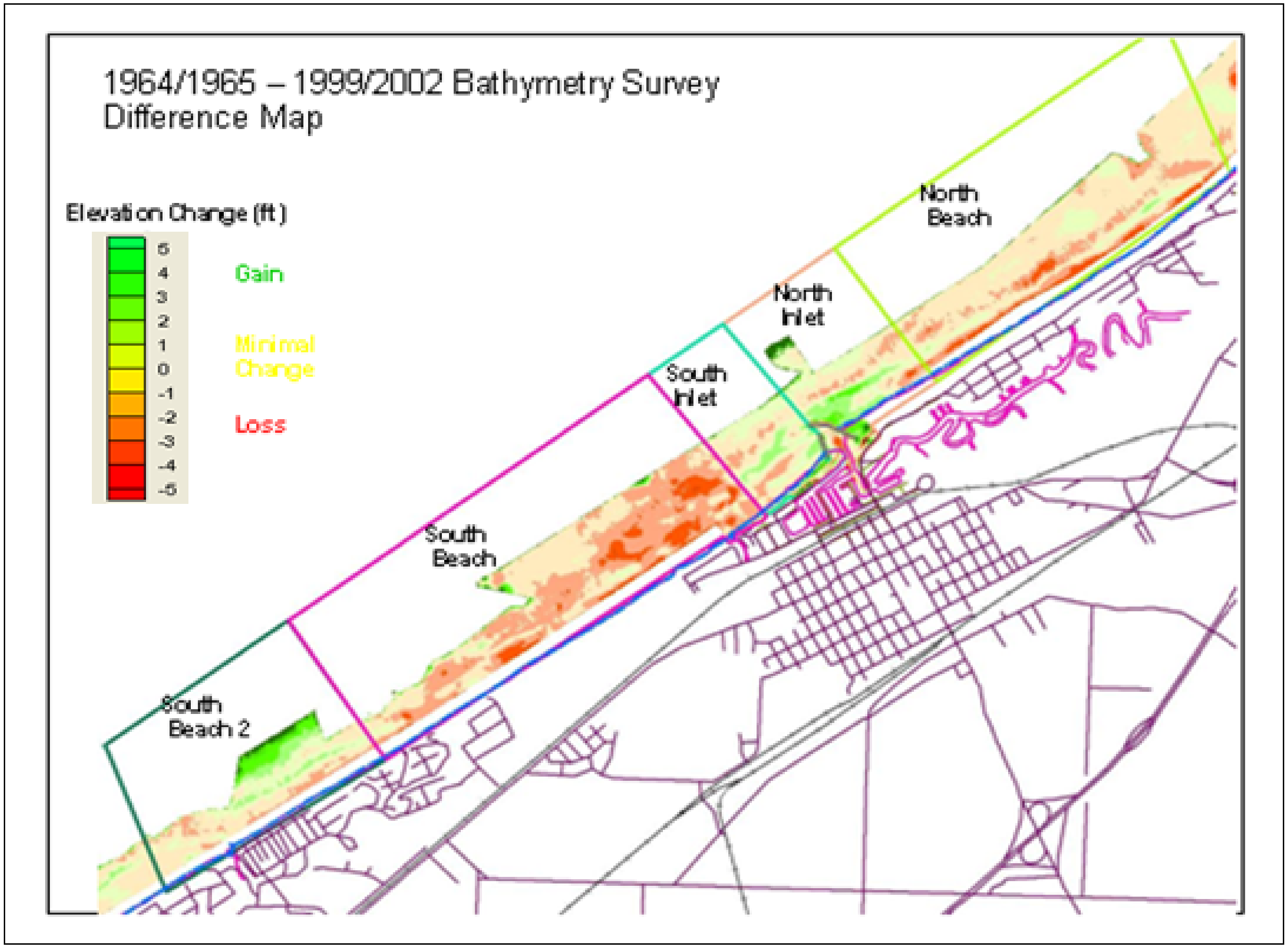

Figure 6.16: Nearshore Volumetric Changes based on 1964/1965 – 1999/2002 bathymetry.

Table 6.4: Nearshore Comparisons of 1964/1965 and 1999/2000 Bathymetric Data

Zone	Rate (yd^3/year)
North Beach	-18,981
North Inlet	-4,647
Channel	-1,152
South Inlet	456
South Beach	-70,809
South Beach 2	21,187

7.0 Sediment Budget Analysis

This section will describe the Coastal Modeling System (CMS) modeling effort and development of the sediment budget for use in delineating sediment flow around the harbor.

7.1 CMS Modeling

CMS was developed by the Coastal Inlets Research Program (CIRP) at the Coastal Hydraulic Laboratories (CHL). The CMS consists of a two-dimensional (2-D) circulation and sediment transport model coupled with a spectral wave model. The modeling utilized the wave data described in Section 4.1 and water level data to create equations at various areas along the shoreline.

The grid developed for this effort was based on the 1999-2000 SHOALS data. The grid resolution was refined near the harbor and near the shoreline so that transport could be calculated. Figure 7.1 shows an example of the grid and modeling results from the CMS utilizing a 19.7 feet deep-water wave from the north.

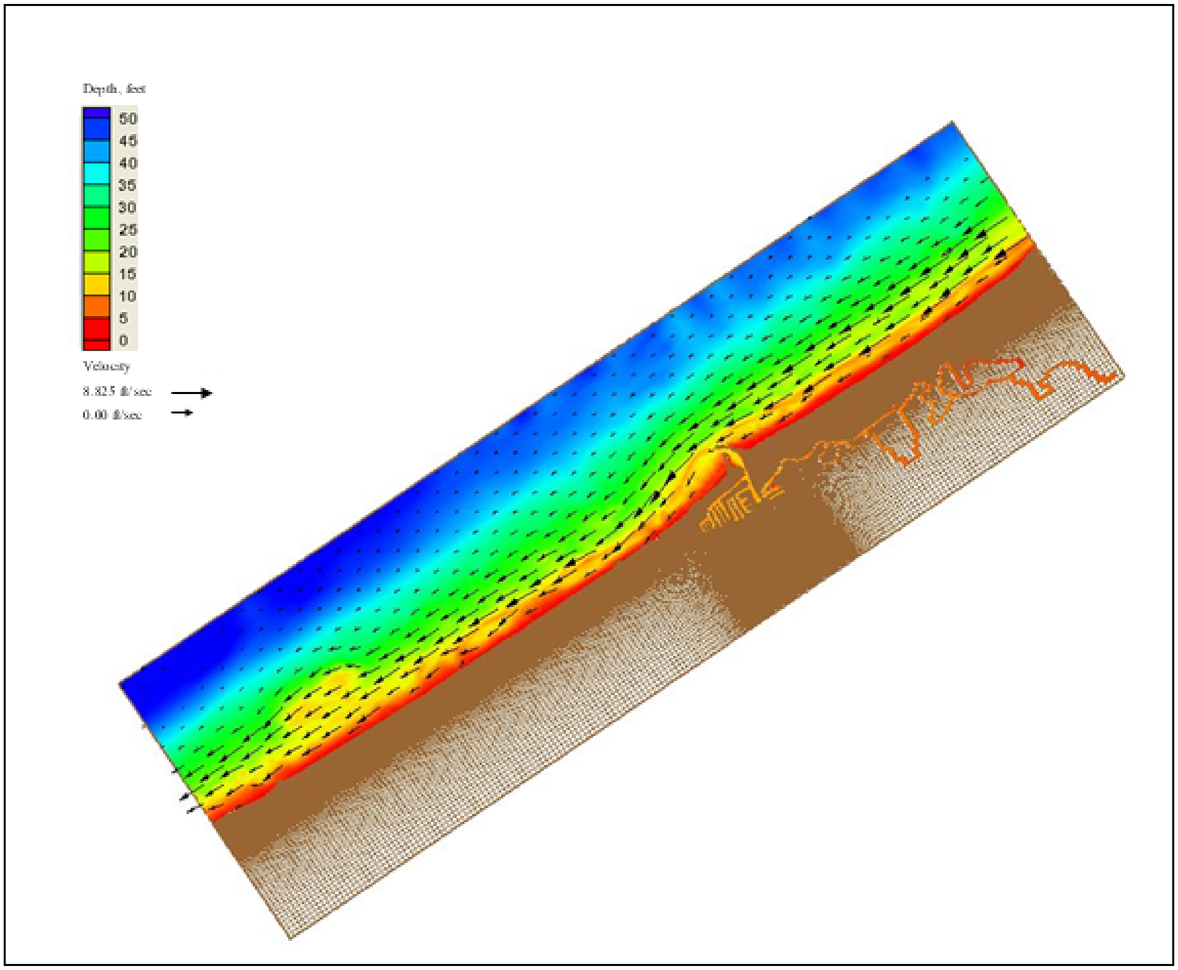

Figure 7.1: CMS Modeling Domain and Current results.

7.2 Longshore Transport (LST) Rate Determinations

The CMS model was run for 27 various wave conditions at four different water levels. Water levels of -0.82 foot, 0.00 foot, +2.46 foot, and +4.10 foot above or below LWD were chosen to represent the levels seen over the last 45 years. The wave data represented 5 different wave heights, 5 different wave periods, and 6 different directions. River flow was not used in this analysis.

In order to classify the results efficiently, this study used a method developed by Baird and Associates in a study done for the USACE (2004) to classify LST for Michigan City, IN. This method used research conducted by Kamphius (1991), which estimates longshore sediment transport using the following parameter:

$$\Theta = H^2 T^{1.5} \sin^{0.6}(2\alpha)$$

Where H, T, and α are the incident wave height, period, and wave angle to shore, respectively. There are a couple of items that need to be noted about this equation. First, the equation assumes the information about the wave is at the point of breaking. The wave characteristics used in this analysis represent deepwater waves. Since this is only being used to index the modeling results and not for actual littoral processes, there will be no issue with the underestimating littoral movement by not taking wave breaking into account. Secondly, the original Kamphius equation has a component that addresses sediment characteristics and bottom slope. It is assumed that these characteristics in the modeling would be the same as those used in the equation, and therefore would cancel out.

Figure 7.2 illustrates how the data from the model was compared to the calculated LST rates. Negative values of Θ represent LST to the south. This was calculated just south of the harbor, at the harbor, and north of the harbor.

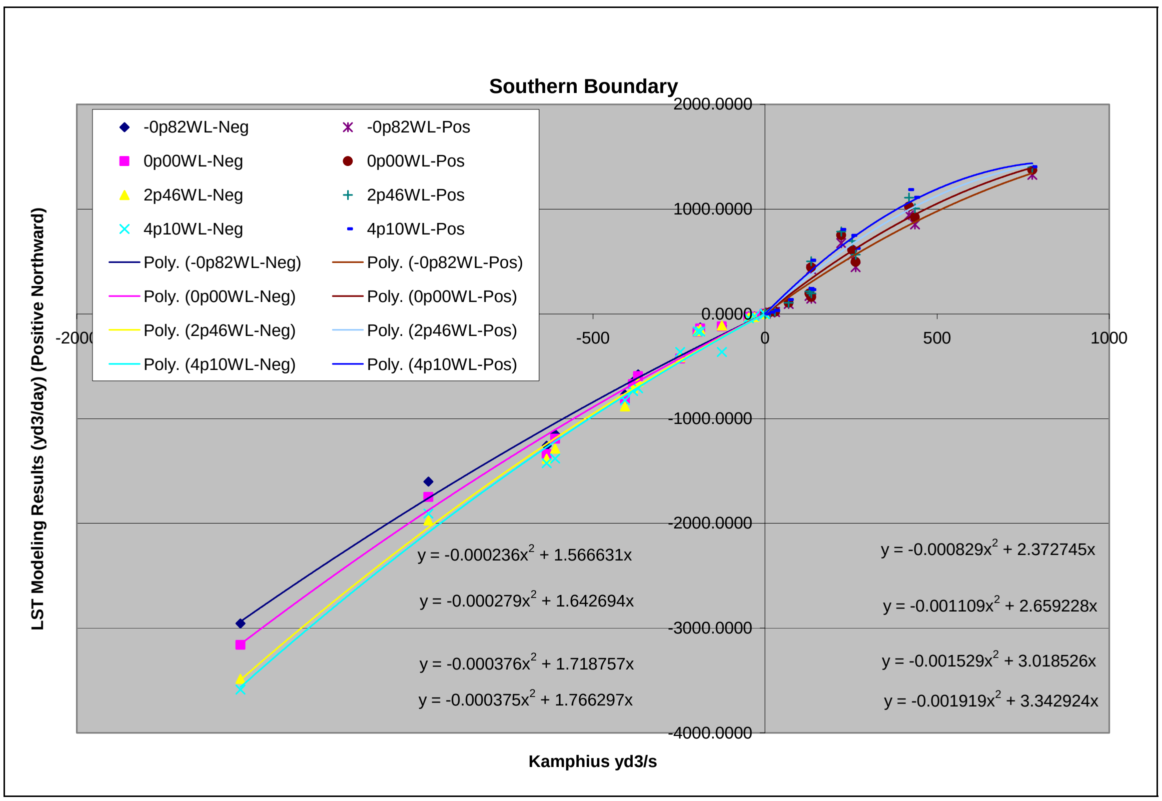

Figure 7.2: LST Calculations Utilizing Model Results and LST Index South of Harbor

The results of the calculations were calibrated to the analyses for Michigan City Harbor (USACE 2004) and for Southeast Lake Michigan (2002). It could be seen that the LST rate was dominant to the south. Approaching the harbor from the north saw LST rates reduce from a potential rate of 142,500 yd^3/year to the south to 127,000 yd^3/year to the south, resulting in a potential accumulation of 15,700 yd^3/year just north of the harbor. It should be noted that these results assume an unlimited supply of sand, which, based on interpretations of nearshore data, is not the case. As the focus of the analysis moves from north to south of the harbor, it could be seen that the rate of transport increased to 144,000 yd^3/year, which would result in a loss of about 17,000 yd^3/year at the mouth of the harbor. Moving further south of the harbor resulted in a reduction of LST to the south. The most southerly transect analyzed in this effort showed a net LST rate to the south of 96,800 yd^3/year. This would indicate the shoreline south of the harbor could potentially accrete at a rate of about 47,000 yd^3/year.

The final numbers presented here represent potential LST rates and do not necessarily represent real LST rates. In order to calculate real transport rates, bluff surveys and accurate nearshore surveys over a significant temporal period would need to be accomplished to quantify sediment input into the littoral transport system. While this was not possible, the results obtained in this study do provide LST trends that, coupled with the morphologic observations discussed in the previous section, can be used to develop a useful sediment budget. In addition, these results will be useful in gauging the efficiency of beach enhancement solutions.

7.3 Sediment Budget Development

A sediment budget is an attempt to define sources and sinks within a confined area. This approach allows for a better understanding of sediment pathways and how the nearshore and shore change based on supply and demand for sediment. This section will describe the assumptions and assessment of a sediment budget for conditions as they might be today. It will not take into account past nourishment projects or future shoreline solutions.

As mentioned earlier, the potential LST from the north at the northern boundary of the project area is approximately 143,000 yd^3/year and the potential LST from the north at the southern boundary is about 97,000 yd^3/year. Based on the transport rates calculated in the USACE 2002 Regional Sediment Management report, it seems that 97,000 yd^3/year is a more realistic LST. This could be an elevated number compared to actual LST rates for the area due to sediment supplies but is an adequate assumption for this analysis.

There were a few observations made during the morphologic assessment that need to be taken into account for this analysis. First, based on the accretion fillet growth analyses, there is enough data to support the assumption that the north fillet beach is growing at a rate of approximately 20,000 yd^3/year and the south fillet beach is growing at about 2,600 yd^3/year. It was clear in the nearshore assessments that the deeper portions of the accretion fillet areas were experiencing erosion at some level. Secondly, the shoreline, as indicated earlier, has been basically static for over 50 years. Based on this, there probably is not sufficient sediment supply from the erosion of the shoreline. Another important observation involved the growth of the sand bypass bar. Over the last 35 years it has grown at a rate of 9,200 yd^3/year. Finally, the shoaling rate within the harbor seems to be approximately 5,200 yd^3/year, based on dredging records.

Combining this information with the CMS modeling LST rates results in the sediment budget shown in Figure 7.3. The net LST coming from the north provides about 10,500 yd^3/year to the north accretion fillet. This is supplemented with another 9,200 yd^3/year from erosion of the deeper portion of the nearshore. 12,000 yd^3/year begins to bypass around the harbor, with 2,600 yd^3/year from this bypass bar making it into the harbor. This is supplemented by another 2,600 yd^3/year from the south accretion fillet nearshore that is eroded by waves from the south direction. As mentioned earlier, this 5,200 yd^3/year, on average, is dredged and placed in the Sunset Shores area. Referring to the LST rate, it drops approximately 11% as it passes the harbor and then gains it back by eroding material from the nearshore and from the placed dredged material.

Figure 7.3: Sediment Budget for Study Area

While this was a moderately substantial effort to create, there are further calibration and data observations that could be accomplished to increase the accuracy of this sediment budget. The LST rates from the CMS model could be improved by the addition of more transects. New high resolution bathymetric data from the CHARTS program would help in better grid refinement and nearshore volume quantifications. These issues may be considered if future funding is available.

8.0 Beach Enhancement Solutions

This section will discuss the potential beach enhancement solutions available to the Village of Grand Beach and home associations. Information on coastal processes identified as critical components to the decision making process will be discussed and engineering cost estimates will be provided and defined for future use and project planning.

8.1 Beach Enhancement Solutions Investigated

Table 8.1 provides a list of all the potential solutions investigated under this study. In general, there were four basic types of potential solutions identified: sand bypassing from north accretion fillet, beach nourishment, breakwater construction with beach nourishment, and groin fields with beach nourishment. Each of these solutions has various alternatives that were analyzed based on performance, cost, and logistics. Each type of solution will be discussed further in the following sections.

Table 8.1: Beach Enhancement Solutions Investigated

Nourishment Solutions

ID	QTY(cy)	Placement Area	Source of Material	Transport Method	
N1a	25,000	1500-3200ft South of S BW / Beach	Upland	Truck	
N1b	25,000	1500-3200ft South of S BW / Beach	Upland	Barge	
N1c	25,000	1500-3200ft South of S BW / Beach	Burns Harbor	Barge	
N1d	25,000	1500-3200ft South of S BW / Beach	Bypass from North Beach	Hydraulic Dredge	
N2a	65,000	1500-4300ft South of S BW / Beach	Upland	Truck	
N2b	65,000	1500-4300ft South of S BW / Beach	Upland	Barge	
N2c	65,000	1500-4300ft South of S BW / Beach	Burns Harbor	Barge	
N2d	65,000	1500-4300ft South of S BW / Beach	Bypass from North Beach	Hydraulic Dredge	
N3a	120,000	1500-6500ft South of S BW / Beach	Upland	Truck	
N3b	120,000	1500-6500ft South of S BW / Beach	Upland	Barge	
N3c	120,000	1500-6500ft South of S BW / Beach	Burns Harbor	Barge	
N4a	25,000	9000-10200ft South of S BW / Beach	Upland	Truck	
N4b	25,000	9000-10200ft South of S BW / Beach	Upland	Barge	
N4c	25,000	9000-10200ft South of S BW / Beach	Burns Harbor	Barge	
N5a	60,000	1500-4300ft South of S BW / (6 - 8ft contour)	Burns Harbor	Barge	
N5b	25,000	1500-3200ft South of S BW / (6 - 8ft contour)	Bypass from North Beach	Hydraulic Dredge	

Breakwater Solutions

ID	Type/Crest Elev	QTY	Length(ft)	Width(ft)	Nourishment (cy)
BW1	Rock/ -3.5ft LWD	3	180	20	25,000 on Beach
BW2	Rock/ -3.5ft LWD	5	180	20	65,000 on Beach
BW3	Rock/ -3.5ft LWD	8	180	20	90,000 on Beach
BW4	Rock/ -3.5ft LWD	25	180	20	75,000 on Beach

Groin Solutions

ID	Type	QTY	Length(ft)	Number of Locations	Nourishment (cy)
G1	Rock	5	100	1	25,000
G2	Rock	10	100	1	65,000
G3	Rock	10	100	2	65,000
G4	Rock	15	100	2	90,000
G5	Sheet Pile	5	100	1	25,000
G6	Sheet Pile	10	100	1	65,000
G7	Sheet Pile	10	100	2	65,000
G8	Sheet Pile	15	100	2	90,000

8.2 Coastal Processes and Design Considerations

A number of variables were taken into account when defining these solutions. The variables were based on both coastal processes and design considerations. The following is a list of items considered.

1. The numerical modeling showed that a local nodal point exists at the Sunset Shores/Warwick Shores location. This means that local currents tend to go both north and south as opposed to predominately going in one direction. For this reason, the Sunset/Warwick Shores location seems appropriate for placement of both beach nourishment and shore structures.
2. The sediment budget shows that roughly 26,000 yd^3/year accumulates near the harbor. The analysis of the north accretion fillet's surface area shows that it is still growing and that this rate would roughly stay constant over the next few years. This indicates that removal of some material may not hinder natural bypassing to a significant degree. Based on these analyses, it seems reasonable to remove 26,000 yd^3/year from the north accretion fillet and place it at Sunset Shores and Warwick Shores. Furthermore, based on the nearshore bathymetry and beach topography of the north accretion fillet, 26,000 yd^3 of sand may be removed from the three areas within the accretion fillet (Figure 8.1) for a total of 78,500 yd^3. This could, in theory, provide three years of accretional area north of the harbor for sediment to deposit. This could be done without developing large holes in the swimming area and creating a hazard and could help reduce shoaling within the navigation channel.
3. The minimum amount of sediment to be placed as nourishment is based on the bypassing potential and accretion rates. Higher volumes are based on both design considerations (groins and breakwaters) and quantities needed to gain more sediment in the system. All groin and breakwater designs require nourishment at regular cycles to result in healthy beach shorelines.
4. Breakwater designs are assumed in this analysis to have crest elevations below Low Water Datum (LWD), to be spaced to provide a sinusoidal shoreline, and to be placed just landward of the sand bar. The beach fill would be placed so that it would fill the area behind the breakwater to form a perched beach scenario (Figure 8.2).
5. Groin designs are assumed to be low profile and extend lakeward approximately 80 feet. The cells in-between would be pre-filled and maintained with nourishment.

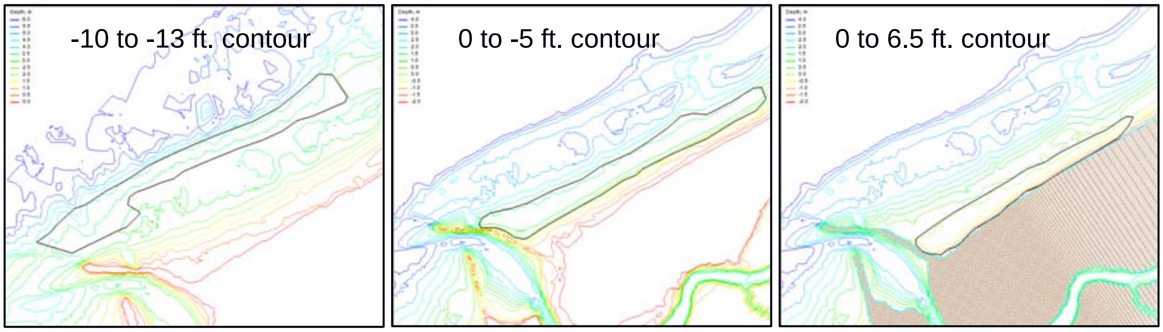

Figure 8.1: Potential Areas of Sand Removal from the North Accretion Fillet.

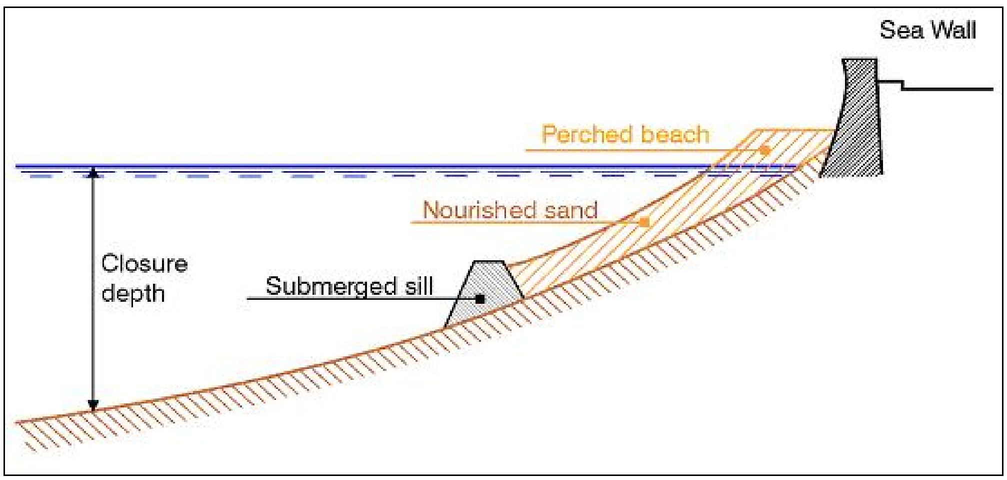

Figure 8.2: Example of a Perched Beach Design.

8.3 Solutions Defined

The following sections will explain the various solutions, with pros and cons defined.

8.3.1 Beach Nourishment (N1a, N1b, N1c, N2a, N2b, N2c, N3a, N3b, N4a, N4b, N4c)

Three basic nourishment projects have been investigated in this study. They are based on quantities of 26,000 yd^3/year, 65,000 yd^3/2-3 years, and 118,000 yd^3/4-5 years (Figure 8.3). All placements would occur between the southern limits of the south accretion fillet and the south limits of Warwick Shores and would generally extend lakeward from the waters edge to the first sand bar. As indicated earlier, this area of shoreline is a local nodal point and would promote more detainment of the nourishment. The minimum amount of nourishment was based on the sediment budget results that indicated roughly 26,000 yd^3 of sediment is building the accretion fillets around the harbor annually. The larger amounts were looked at to determine if long term cost savings could be obtained by placing more material at larger time intervals.

26,000 yd^3

65,000 yd^3

118,000 yd^3

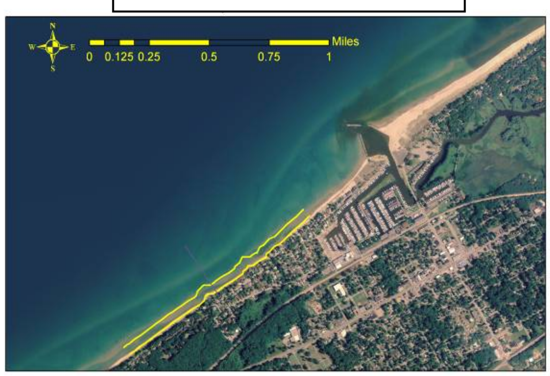

Figure 8.3: Locations of Proposed Beach Nourishment Locations (Indicated by Yellow lines)

There are two dependable sources from which beach suitable sand can be obtained, dredging and the water intakes at Burns Harbor and from an upland source at Grand Haven Harbor (Figure 8.4). Burns Harbor is approximately 20 miles to the south and is dredged annually to maintain water intakes for the local communities. Currently the sediment is placed on the shoreline just to the west of Burns Harbor. This material could be made available for the New Buffalo shoreline or more sediment could be dredged from the area and the excess placed in the New Buffalo area. The other practical source of sediment would be from a local mining operation at Grand Haven Harbor approximately 90 miles north. Material from Burns Harbor would require barging, while material from Grand Haven could either be barged or trucked to the required site. Other open lake sources were investigated, but due to weather and logistical issues, these sources would not be advantageous based on costs.

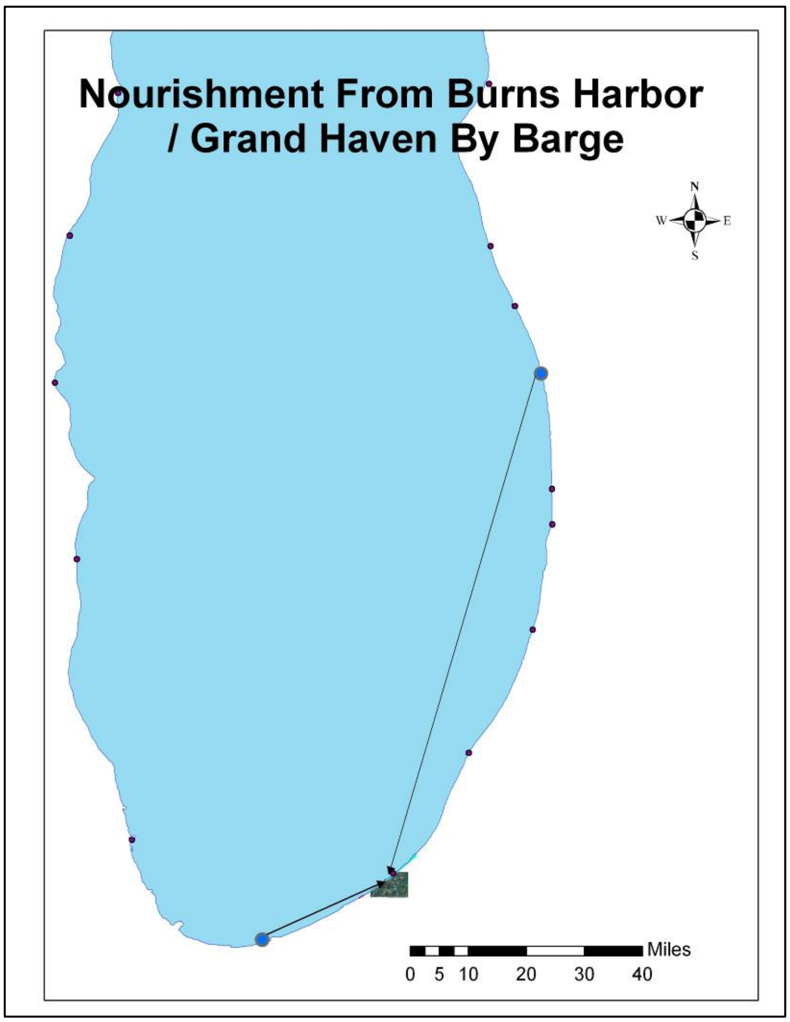

Figure 8.4: Locations of Proposed Sediment Sources on Lake Michigan

In general, trucking 26,000 and 52,000 yd^3 of material from Grand Haven may be the cheapest scenario, even when costs associated with street repairs are taken into account. However, barging material from Burns Harbor becomes more advantageous as quantities increase. Some of the disadvantages of trucking sediment include:

1. Damage to local streets and access points to the nearshore.
2. Nuisance of trucks coming and going from the area.
3. Lack of ability to combine nourishment project with other on going projects.

Barging costs can be affected by weather since it requires calmer lakes, but there are significant advantages to barging:

1. The benefit to cost ratio of placing sediment by barge improves with larger quantities.
2. There are potential cost savings combining these nourishment projects with dredging projects at Burns Harbor.

In addition to the placement sites shown in Figure 8.3, solutions N4a, N4b, and N4c involve placement of sediment at two locations, one at Sunset Shores and one at the northern edge of Grand Beach (Figure 8.5). These N4 solutions seem to benefit the area the same as solutions N1.

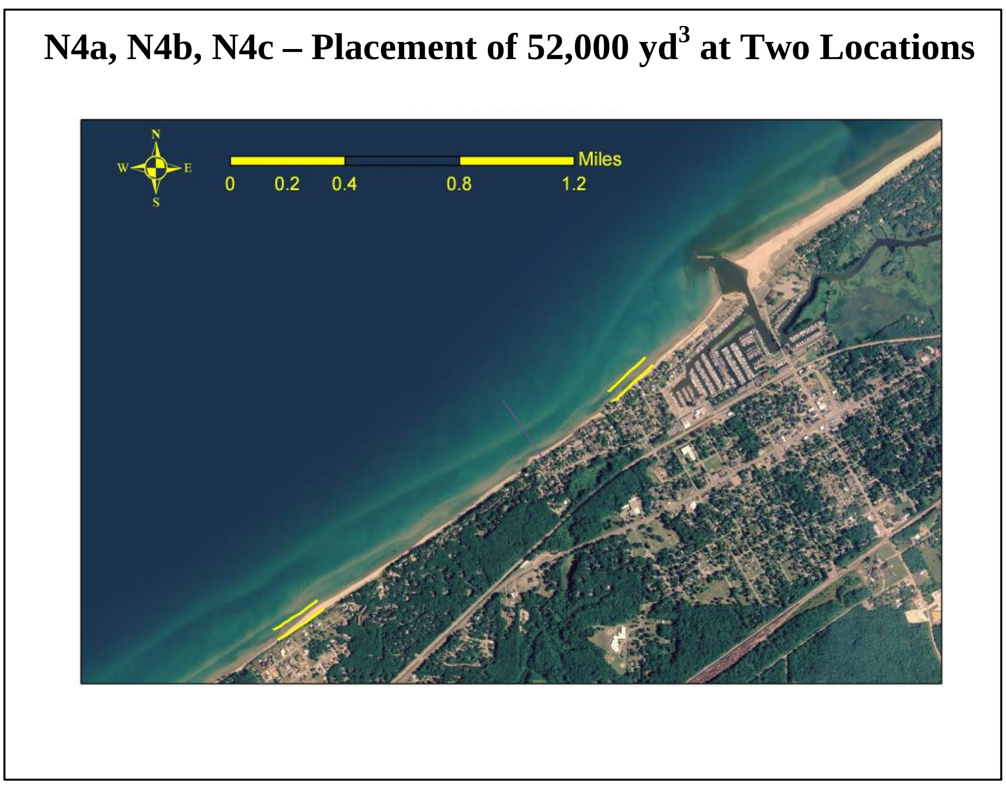

Figure 8.5: N4 Solutions involving Placement of 20,000m^3 at Sunset Shores and Grand Beach

8.3.2 Nearshore Nourishment (N5a, N5b)

Another solution investigated in this study involves barging 26,000 and 52,000 yd^3 of sediment from the sources defined in the earlier section and placed in the nearshore sandbar. The advantages to this would be fewer impacts due to less machinery, trucks, and handling of the material on shore. However, this method of sand placement results in less immediate protection of the shoreline and will not result in direct beach protection.

8.3.3 Sand Bypassing

Another option is that approximately 26,000 yd^3/year be bypassed around the harbor to Sunset and Warwick Shores (Figure 8.6). This could be accomplished in a couple of ways. A hydraulic dredge (a dredge that uses a pipe line to convey sand and water to a placement site) could be utilized, or a local authority could purchase a hydraulic dredge to conduct the sand bypassing. Any bypassing project would take into consideration safe swimming conditions at the public beach on the north side. Sand would be scraped from the surface of the north accretion fillet at a minimal depth. In addition, the sand bypass bar developing at the end of the north breakwater could be dredged and bypassed as well. This would limit sediment shoaling in the harbor and enhance the amount of sediment arriving to the south shores.

N6a (26,000 yd^3) & N6b (52,000 yd^3): Bypass From North Accretion Fillet

Figure 8.6: Illustration of Sand Bypassing Solution

Some of the advantages of bypassing sediment from the north to the south include:

1. Potential reduction in the amount of sediment shoaling in the harbor.
2. Reduction in beach width on north side to provide better access to the water.
3. Increased sediment to the south.
4. Minimal inconvenience associated with the project due to machinery.
5. Lower costs associated with less handling of material.

Some of the disadvantages of bypassing sediment from the north to the south include:

1. Potential reduction in the amount of sand naturally bypassing the harbor resulting in a dependency on mechanical bypassing.
2. Concern from homeowners north of the harbor about bypassing material from north to south.

While this study finds that on a long-term temporal basis this source of sediment is constant, it may not be available during short temporal periods. The sediment budget conducted in this study also points to the possibility of reducing shoaling in the harbor. It would be recommended that if this solution is pursued that these issues be monitored over time to insure the benefits out weigh the negatives.

8.3.4 Groin Fields (G1 G2, G5, G6)

Another solution type that was investigated was the use of groin fields. Groins are shore perpendicular structures that are designed to stabilize a beach by holding beach material in place (Figure 8.7). Unfortunately, they can also destabilize beaches on the downdrift side. In general, this occurs when a groin is placed in an area were littoral transport is in one dominate direction.

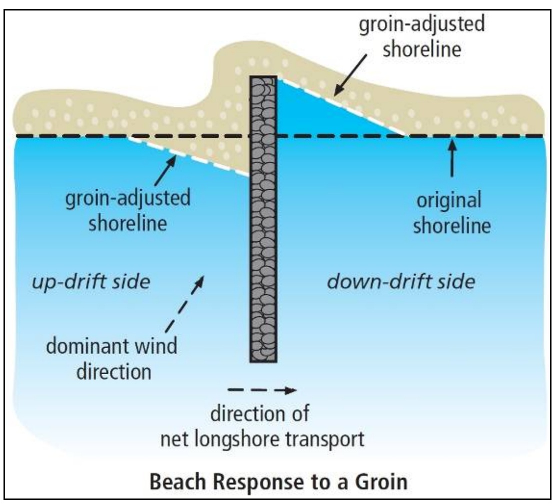

Figure 8.7: Typical Groin Design (Plan View)

The groins themselves are assumed to either be constructed of steel sheet pile (SSP) or rock. These only affect cost analyses and aesthetics but not function. There are four basic groin field designs analyzed in the study that differ in function. Each groin field will be designed using 5 groins with approximately 165 feet between groins. They are assumed to be about 65 feet long.

Figure 8.8 shows the locations of all the groins. The first layout (G1, G5) involves five groins placed at Sunset Shores. Next layout (G2, G6) involves installing five groins at both Warwick and Sunset Shores.

It should be noted that placement of groins at Grand Beach were looked at (G3, G4, G7, G8). However, these are not recommended and will not be described further in this report.

As indicated earlier, based on the CMS modeling conducted for this analysis, the area around Sunset Shores and Warwick Shores is a local nodal point. This means longshore transport in the area goes both north and south on a relatively consistent basis throughout the year. For this reasons, groin fields in the Sunset Shores and Warwick Shores area should only be considered.

Site visits to the area show that a type of groin field has been installed at Warwick Shores with mixed results. In comparing this shoreline to adjacent shorelines, the groins seem to reduce the recession of the shoreline. However, they are not capable of sustaining a healthy beach. In general, all groin field projects require nourishment on a regular basis to maintain a healthy beach. It is apparent that these structures are not currently nourished on a regular basis.

Figure 8.8: Illustration of Groin Field Placement South of New Buffalo

There are a couple of advantages and disadvantages associated with the installation of groins. Some of the advantages are:

1. Groins fields will reduce local LST rates resulting in material remaining in the immediate area for a longer time.
2. They typically are not a navigation hazard.

The disadvantages with groins are:

1. Appropriate engineering work is required to properly design the groins. Furthermore, proper placement can be difficult and result in a non-functioning design.
2. The added cost associated with implementing groins does not eliminate the costs associated with nourishment. It can only reduce costs over the design life of the project.
3. There are maintenance costs (typically 2% to 5% of the initial construction costs annually) that will need to be taken into account (Keillor et al, 2003).
4. There is still potential of negative impacts to adjacent shorelines due to groin installation.

5. Permitting of these structures could be problematic due to State regulations limiting the length and height of these structures.

All of these issues need to be addressed prior to finalizing a decision on this solution.

8.3.5 Detached Breakwater Solutions (BW1, BW2, BW4)

Another solution investigated was the use of breakwaters. Detached breakwaters are shore parallel structures that are in the water and not attached to the shoreline. Similar to the groin structures, they would be constructed as a group of breakwaters. These structures would consist of rock, would be approximately 165 feet long, spaced 230 feet from each other, and would have a crest elevation that would be 5 feet below LWD, resulting in a submerged structure.

Three breakwater layouts were analyzed in this study. BW1 consists of three breakwaters installed at Sunset Shores, BW2 consists of five breakwaters installed at Sunset Shores, and BW 4 consists of twenty-five breakwaters installed between Grand Beach and Sunset Shores. All three of these solutions will require nourishment so that a perched beach type design is accomplished. Figure 8.9 provides an overview of the breakwater layout BW1 analyzed in this report.

It should be noted that placement of eight breakwaters at Grand Beach was looked at (BW3). However, these breakwaters are not recommended at this time. Further analysis would need to be accomplished to determine if these types of structures at Grand Beach or along the entire length of the southern study area would adversely affect adjacent shorelines.

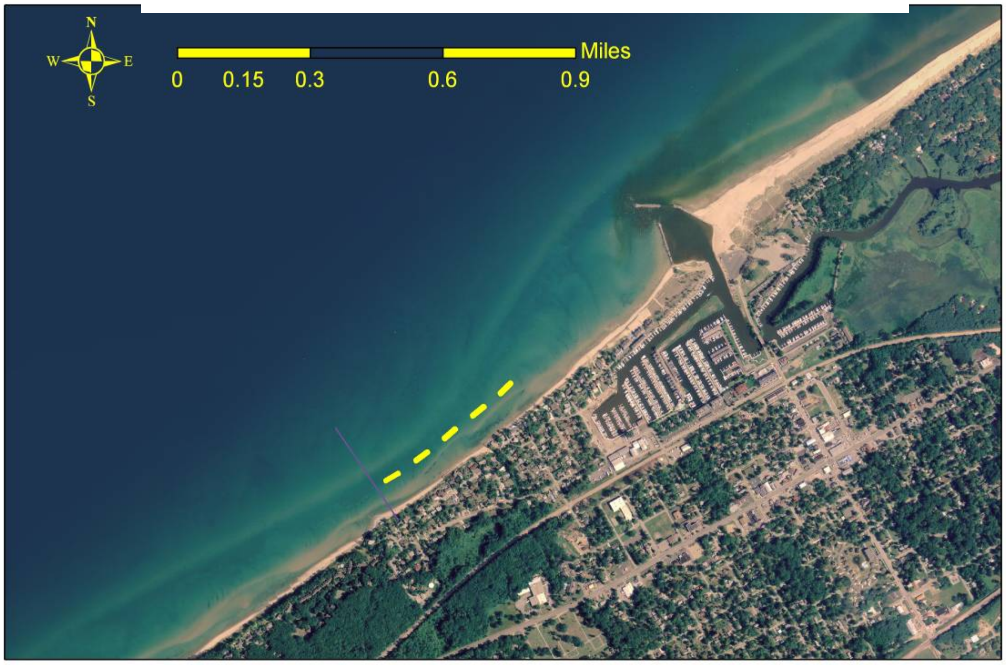

Figure 8.9: Illustration of Detached Breakwater Placement South of New Buffalo

Similar to the groin designs, the breakwaters are placed at the Sunset Shores area because of how currents are depicted in modeling. While these structures are not shore perpendicular, they will still interrupt sand transport to a certain degree and are recommended to be placed in areas that do not have a dominant littoral transport direction. All of these solutions require an initial beach fill and periodic nourishment over time.

There are a few advantages and disadvantages associated with the installation of breakwaters. Some of the advantages are:

1. Breakwaters will reduce local LST rates resulting in material remaining in the immediate area for a longer time. This may result in regional benefits.
2. They are not part of the shoreline and may result in a healthier beach as compared to a groin field.
3. Breakwaters will be submerged so they will have minimal impact on aesthetics.

The disadvantages with breakwaters are:

1. Appropriate engineering is required to properly design the breakwaters. Due to the movement of the nearshore sandbars, this could be very difficult.
2. The added cost associated with implementing breakwaters does not eliminate the costs associated with nourishment. It can only reduce costs over the design life of the project.
3. Since these structures are offshore, maintenance costs can be higher than those associated with groins (potentially 5% to 7% of the initial construction costs annually for breakwaters). This will need to be taken into account.
4. Submerged breakwaters could be navigation hazards and will require proper markings.

All of these issues need to be addressed prior to finalizing a decision on this solution.

8.4 Performance Analysis

An important factor in choosing a solution is its ability to provide a suitable beach over a period of time. Utilizing the results from the original CMS model runs along with sediment budget delineation, a potential performance was standardized for each solution. Figure 8.10 illustrates how changes in LST for each solution compare to the natural shoreline (E0) without nourishment. The various scenarios modeled included nourishment solutions N1 (26,000 yd^3), N2 (65,000 yd^3), N3 (120,000 yd^3), N4 (26,000 yd^3 at two locations), and N5 (65,000 yd^3 placed in the nearshore). Two groin solutions without nourishment were modeled representing 5 groins at Sunset Shores (G7) and 10 groins at Warwick Shores and Sunset Shores (G8). Finally, two breakwater scenarios were also modeled assuming ten breakwaters placed in front of Warwick and Sunset Shores without nourishment (B6) and with 91,500 yd^3 of nourishment (B10). It is noted that no groin solutions were modelled with nourishment included due to the model's inability to show any differences. This is attributable to grid resolution.

The graph represents transects 12 thru 18, which cover the Warwick and Sunset Shores shorelines. As shown in the graph, the most northerly transects show an increase in LST while the downdrift transects show a decrease, with the exception of N5, because the nourishment and structural solutions cause a temporary headland effect. This shelters some of the nourishment placed on the beach helping protect it from erosion to a certain degree. Solution N5 does not experience this because the material is placed directly in the nearshore resulting in no temporary headland feature.

By assuming the material that is eroded on the north side of the placement areas supplements the nourishment on the southern portions and considering the retention of material developed in the downdrift portions of the proposed solutions, the average reduction in LST over transects T12-T15 may control the overall performance of each solution. It should be noted that the transects only cover the updrift sides of the solutions. Most of the solutions involve nourishment placement further south of the transects. This provides for more opportunity for each solution to retain more sand than is depicted in Figure 8.10.

Taking this postulation and assuming that the normal rate of erosion is represented by the -15,700 yd^3/year just south of the harbor as shown in the sediment budget, one can develop a standardized performance represented by nourishment cycle in years for each solution, as shown in Table 8.2. The more material placed in the nourishment area, the greater potential for longevity of the enhanced beach as compared to current conditions. The structural solutions without beach nourishment showed very little improvement from existing conditions. B10 showed similar retainment of the nourishment material as seen in the nourishment solutions.

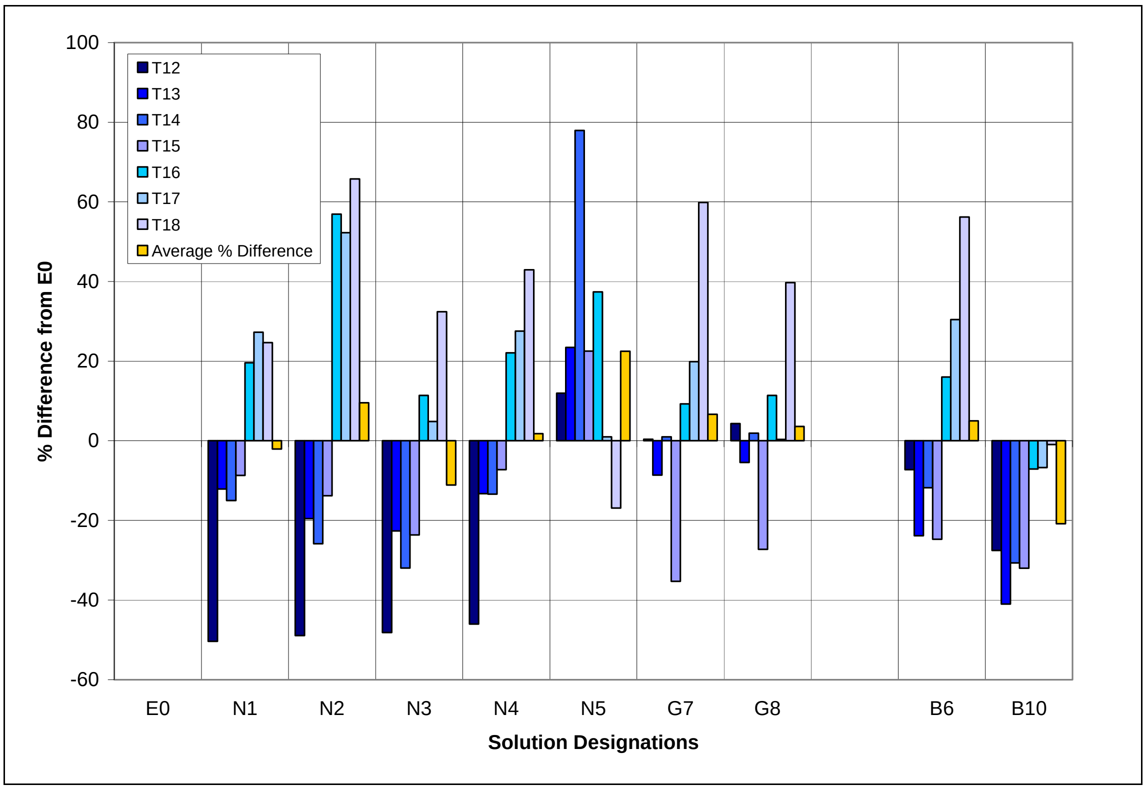

Figure 8.10: LST Rate Changes for Solutions

Table 8.2: Standardized Performance Rating Based on LST and Sediment Budget Analysis

Solution Type	% Difference (T12 - 15)	Nourishment Qty (yd^3/yr)	Plus Dredged (yd^3/yr)	Total Placed (yd^3/yr)	Est. Nourishment Cycle (yrs)
E0					
N1	-0.22	26000	5000	31000	2.5
N2	-0.27	65000	5000	70000	6.2
N3	-0.32	120000	5000	125000	11.7
N4	-0.2	26000	5000	31000	2.5
N5	0.34	65000	5000	70000	3.4
G7	-0.11	26000	5000	31000	2.2
G8	-0.07	65000	5000	70000	4.8
B6	-0.17	26000	5000	31000	2.4
B10	-0.33	65000	5000	70000	6.7

All of the nourishment solutions result in a beach that is 160 to 200 ft wider than the existing beach at the nourishment site assuming water levels are at low water datum (577.4 ft IGLD-85). For solution N1, the beach would reduce to approximately 100 ft wide in one year. Solution N2 would result in a beach that would reduce to approximately 100 ft wide in 3 years, Solution N3 would result in a 100 ft wide beach in 6 years and N4 would reduce to 100 ft wide in 1 year. All of these measurements are based on static water levels. Focusing on the groin solutions, beaches at these locations would tend to be steeper over time. Initial conditions would be 160 to 200 ft wide beaches and would erode to approximately 30 ft wide. The submerged breakwater solutions would have similar results to the groins. Beaches downdrift of all these solutions would generally find reduced recession rates over time. Based on the past nourishment program discussed in Section 5.2 and assuming that down-cutting of the exposed clays in the nearshore has not been significant, the beaches at Grand Beach and Forest Beach should become stable and remain at widths of between 30 to 65 ft for the nourishment solutions.

8.5 Specialized CMS Modeling Analysis of Beach Enhancement Solutions

A specialized CMS model analysis of several beach enhancement solutions was performed in order to determine quantifiable benefits or detriments to the shoreline to understand how the solutions provided would perform. This section of the report will look at four potential solutions for a one-year timeframe in order to calculate potential benefits to the shoreline in the area.

The specialized CMS modeling analysis involved a one year simulation of wave data from NOAA Buoy 45007 located in the southern portion of Lake Michigan. Three hour wave data was used to model the shoreline. The buoy data was transformed to the nearshore through the use of STWAVE so that a more accurate description of the wave climate could be visualized at the modeling boundary.

For the specialized CMS modeling analysis, only two water levels were also utilized to obtain information on how the beach solutions function in high and low water scenarios. The water levels were based on the +2.46 ft and -0.82 ft LWD IGLD 1985 levels.

The CMS model was upgraded by personnel at ERDC to specifically address the needs of this effort. Each beach enhancement solution was uploaded in the CMS modeling grid domain. The domain that was used extended 6.15 miles along the shoreline and 2 miles perpendicular to the shoreline forming a rectangular domain. This domain extended both north and south of the harbor to include harbor effects. Transects were spaced every 165 ft to retrieve modeling results.

The four beach enhancement solutions that were chosen to be analyzed under this effort are:

- Nourishment of 25,000cy placed between Sunset Shores and Dunewoods (Transects R50 and R53). This solution approximately represents placement of dredged sediment supplemented with north accretion sediment as needed to obtain 25,000cy of material.
- Nourishment of 120,000cy placed between Dunewoods and Warwick Shores (Transects R41and R53). This solution approximately represents placement of sediment trucked, barged, and/or bypassed from the north accretion fillet.
- Placement of five (5) submerged detached breakwaters at Sunset Shores and placement of 75,000 cy of sediment between Warwick Shores and Sunset Shores (Transects R46 and R53).
- Placement of twenty five (25) submerged detached breakwaters between Grand Beach and Sunset Shores and placement of 75,000 cy of sediment between Warwick Shores and Sunset Shores (Transects R46 and R53).

All of these solutions were modeled and the results from the one year wave analysis for both the -0.82 ft and + 2.46 ft LWD water levels were reported. Nearshore volume changes and shoreline changes were compared to conditions as represented in the 2000 bathymetry and 2002 LiDAR data with alterations based on nourishment placement.

The shoreline change analyses results for the four potential enhancement solutions are shown in Figures 8.11 to 8.14 and the nearshore volume change analyses results are shown in Figures 8.15 to 8.18.

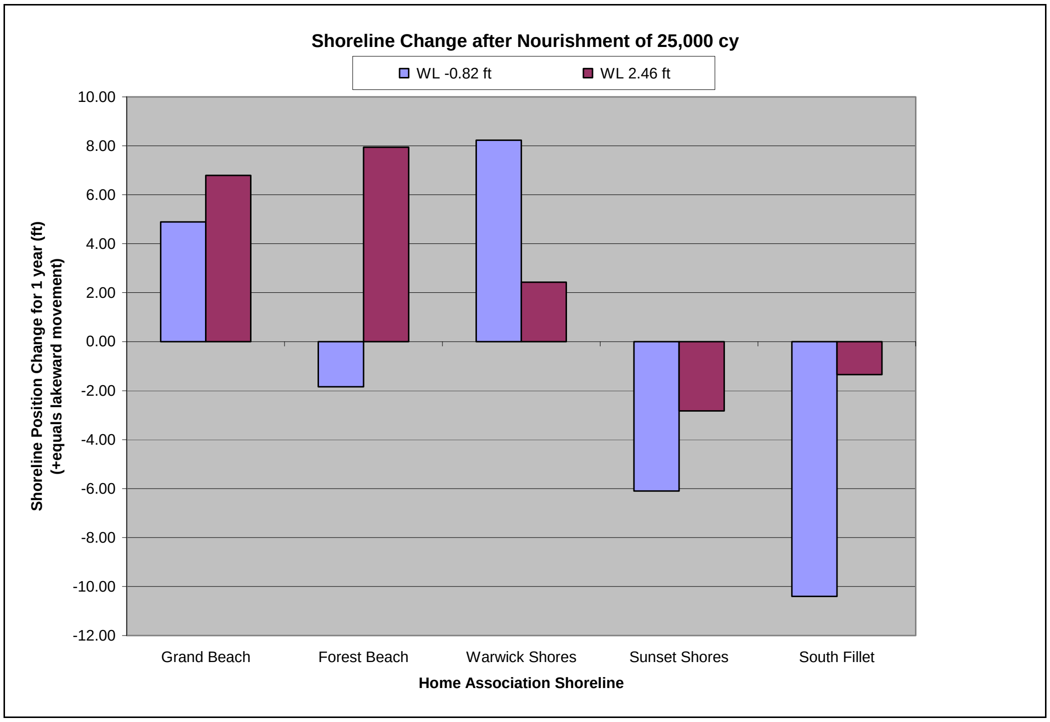

Figure: 8.11 – Shoreline Change for 25,000cy Nourishment Placement

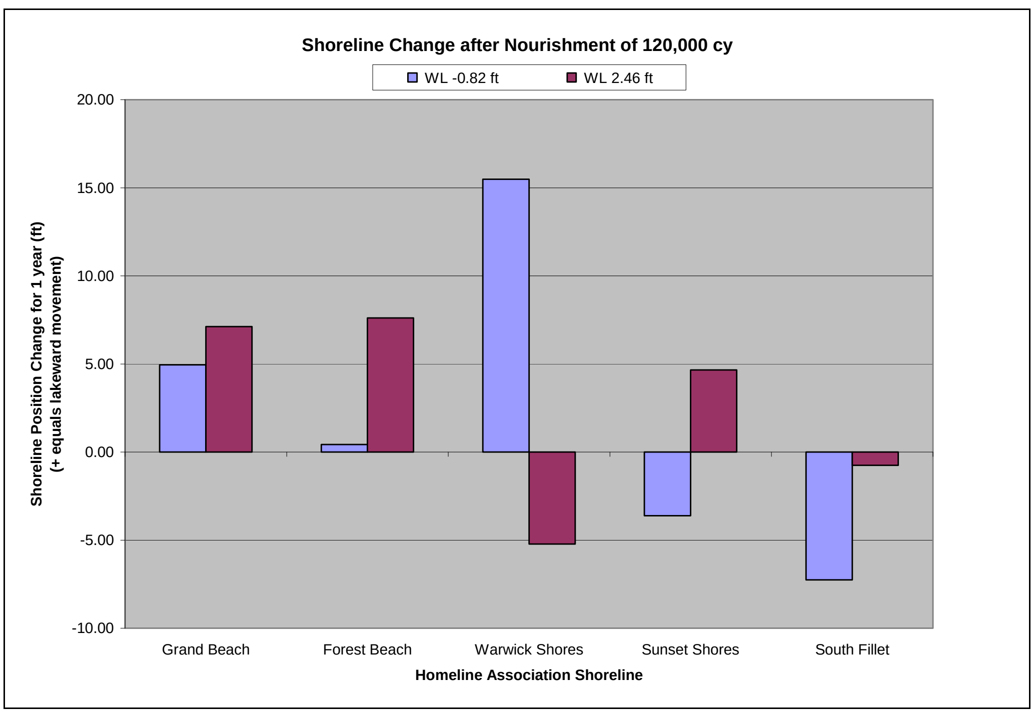

Figure: 8.12 – Shoreline Change for 120,000cy Nourishment Placement

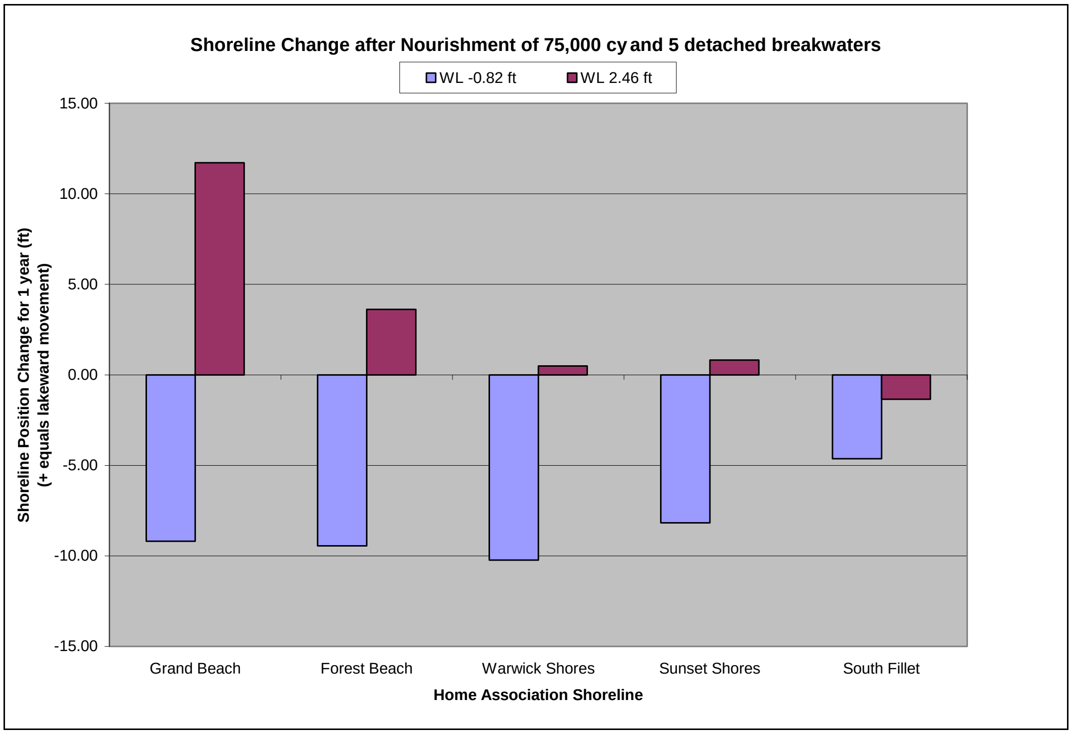

Figure: 8.13 – Shoreline Change for 5 Detached Breakwaters and Nourishment

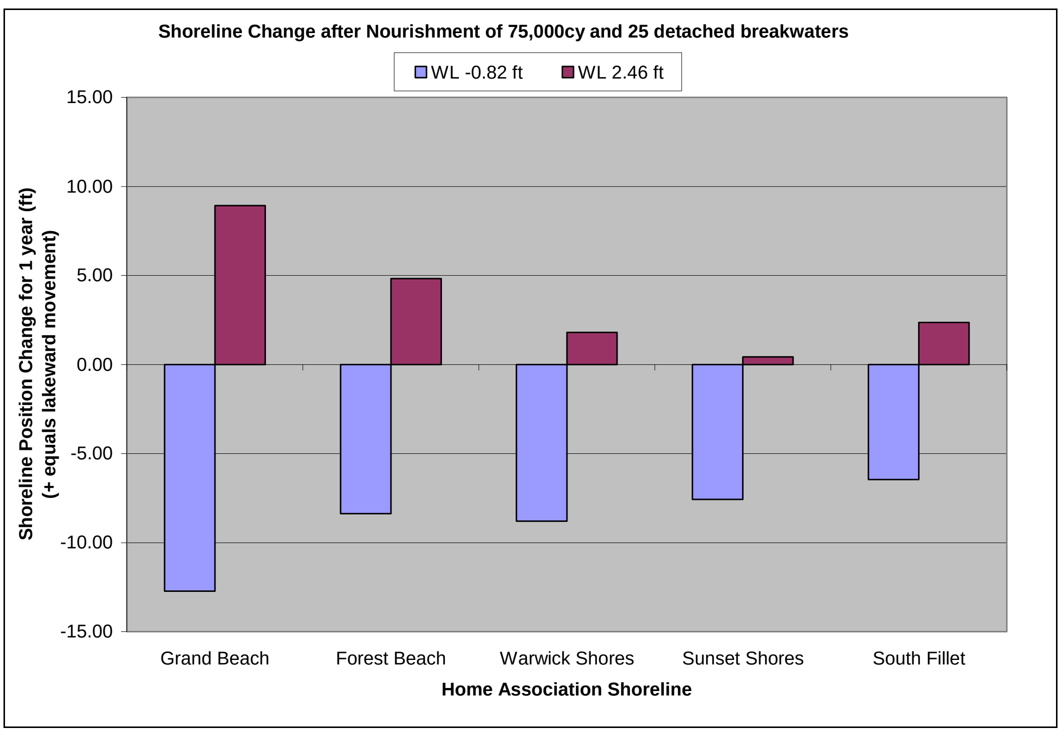

Figure: 8.14 – Shoreline Change for 25 Detached Breakwaters and Nourishment

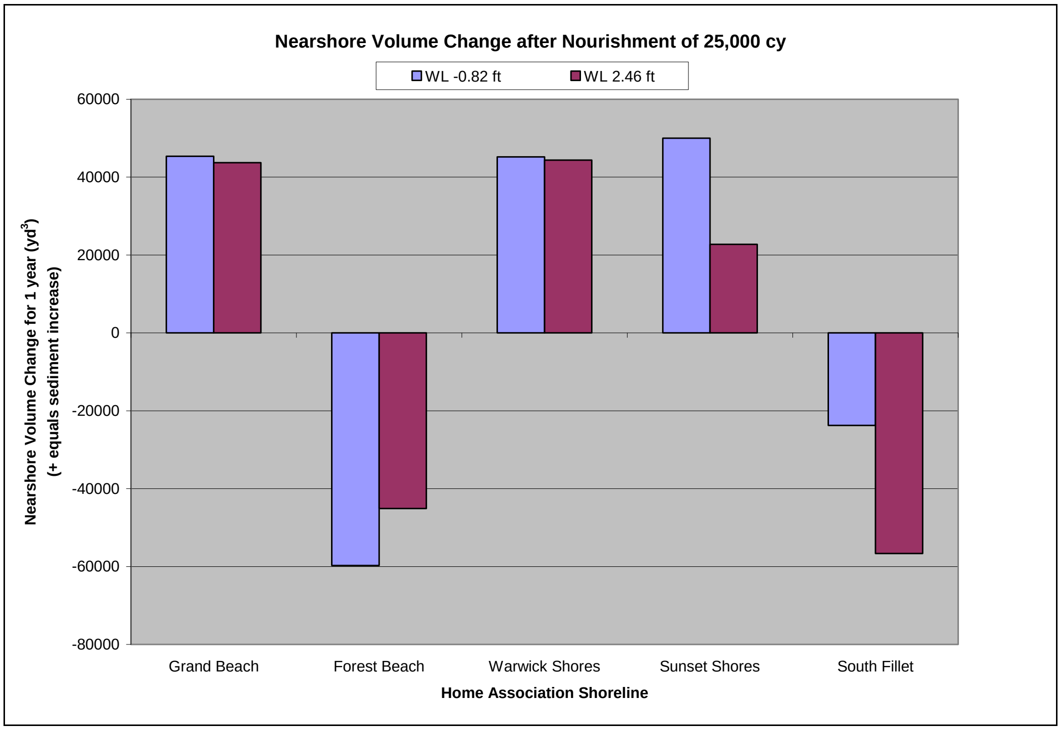

Figure: 8.15 – Nearshore Volume Change for 25,000cy Nourishment Placement

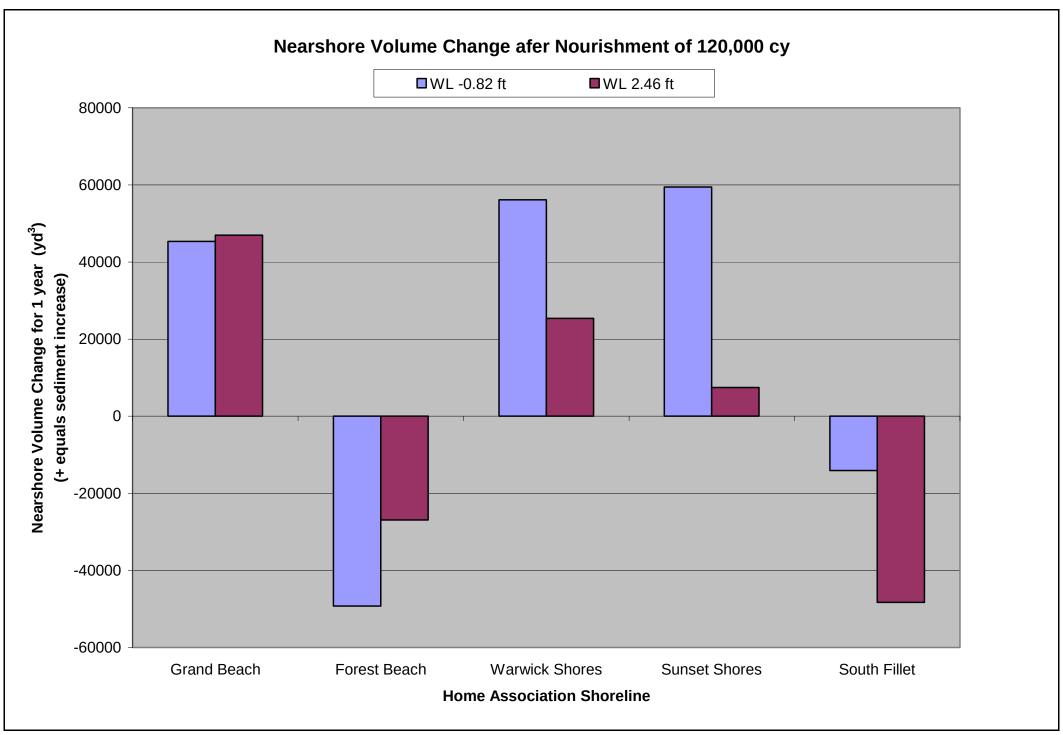

Figure: 8.16 – Nearshore Volume Change for 120,000cy Nourishment Placement

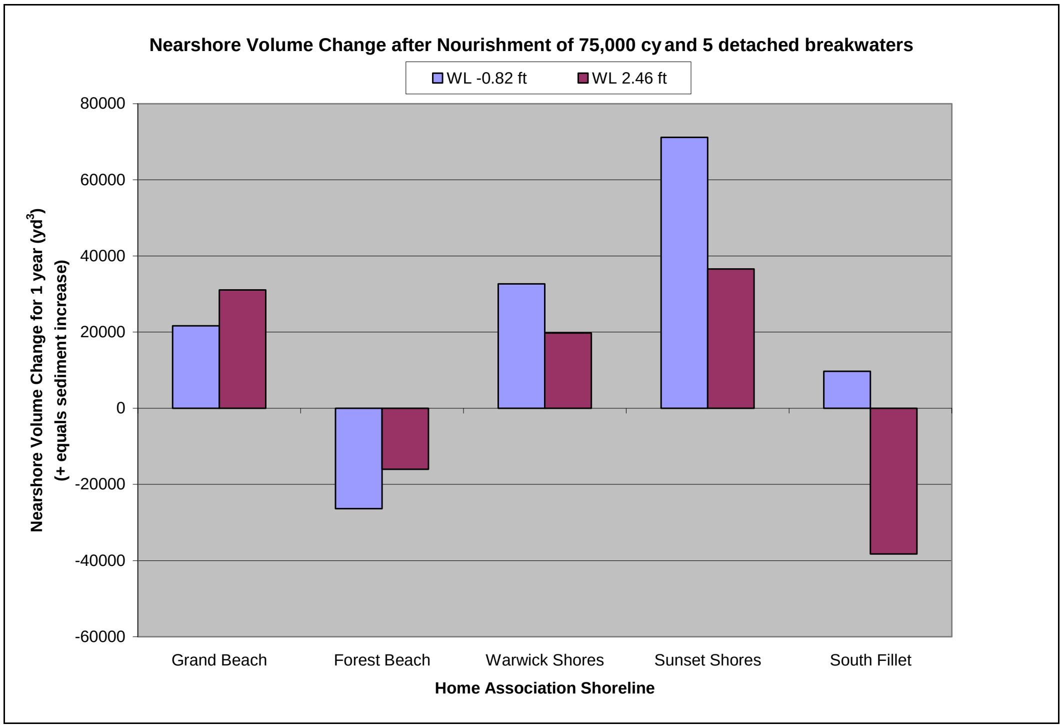

Figure: 8.17 – Nearshore Volume Change for 5 Detached Breakwaters and Nourishment

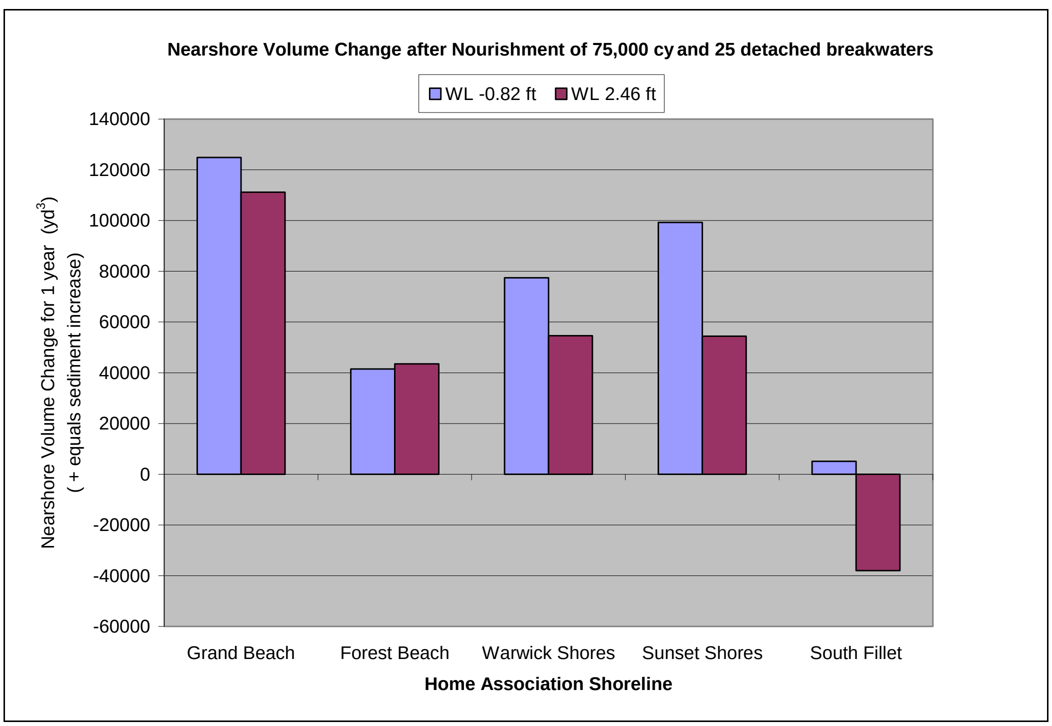

Figure: 8.18 – Nearshore Volume Change for 25 Detached Breakwaters and Nourishment

Reviewing these results does provide some general insight on how the shorelines react to the beach enhancement solutions. In general, the beaches tend to widen after nourishment placement (Figures 8.11-8.12). In contrast, the beaches do not tend to widen after installation of the submerged breakwaters (Figures 8.13-8.14). However, analyzing the nearshore volume changes paints a slightly different picture. The nourishment solutions do provide some enhancement of the nearshore, but not a consistent improvement. As can be seen in Figures 8.15 and 8.16, Forest Beach tends to lose nearshore volume in these scenarios. Referring to Figures 8.17 and 8.18, the submerged breakwater solutions clearly show nearshore volume increases. While this does not translate to an immediate increase in beach width, over time the increase in nearshore volume may translate to sustained increased beach width.

These results do provide some information on how the beaches respond to the various solutions, but one can not make a conclusion on the net benefit of these solutions until it is known how the shoreline would respond if no nourishment was placed or submerged breakwaters installed. To provide this baseline, one additional model run was completed to conceptualize how the natural shoreline would react to the same conditions modeled for the solutions. As shown in Figures 8.19 and 8.20, the non-enhanced shorelines show some accretion and some recession when exposed to the same conditions as the modeled solutions. In addition the nearshore volumes show a tendency to increase naturally. In order to gain an understanding of how much benefit the shorelines may gain from the solutions, Tables 8.3 and 8.4 were created to standardize all the modeling results to natural conditions.

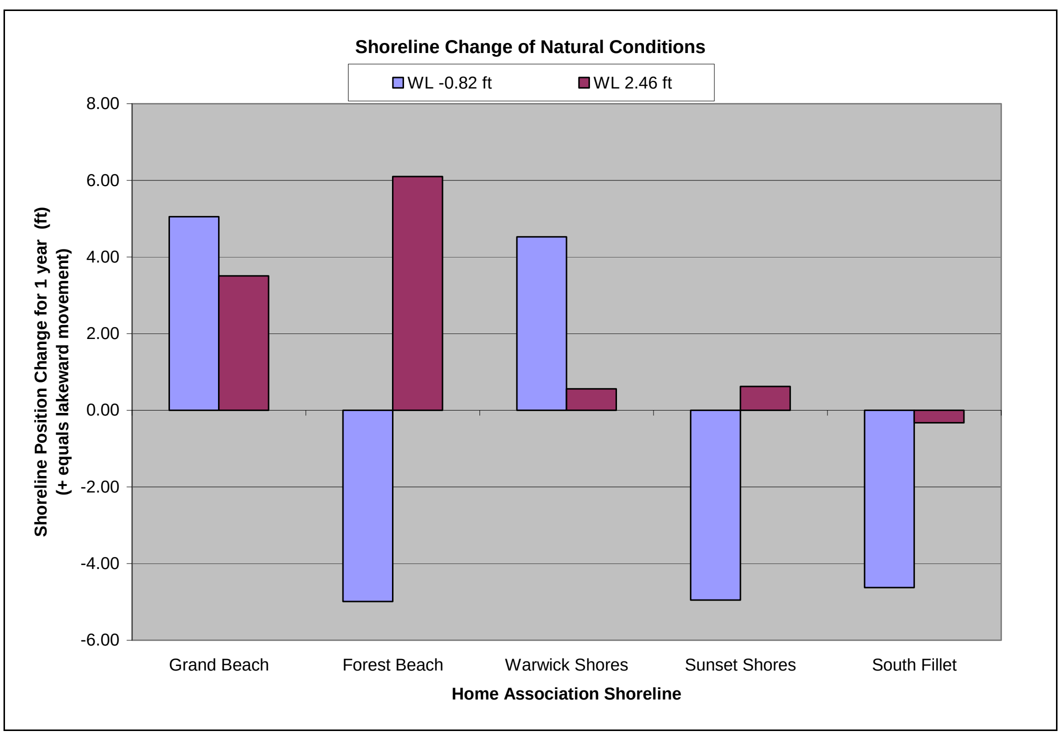

Figure: 8.19 – Shoreline Change for Natural Conditions

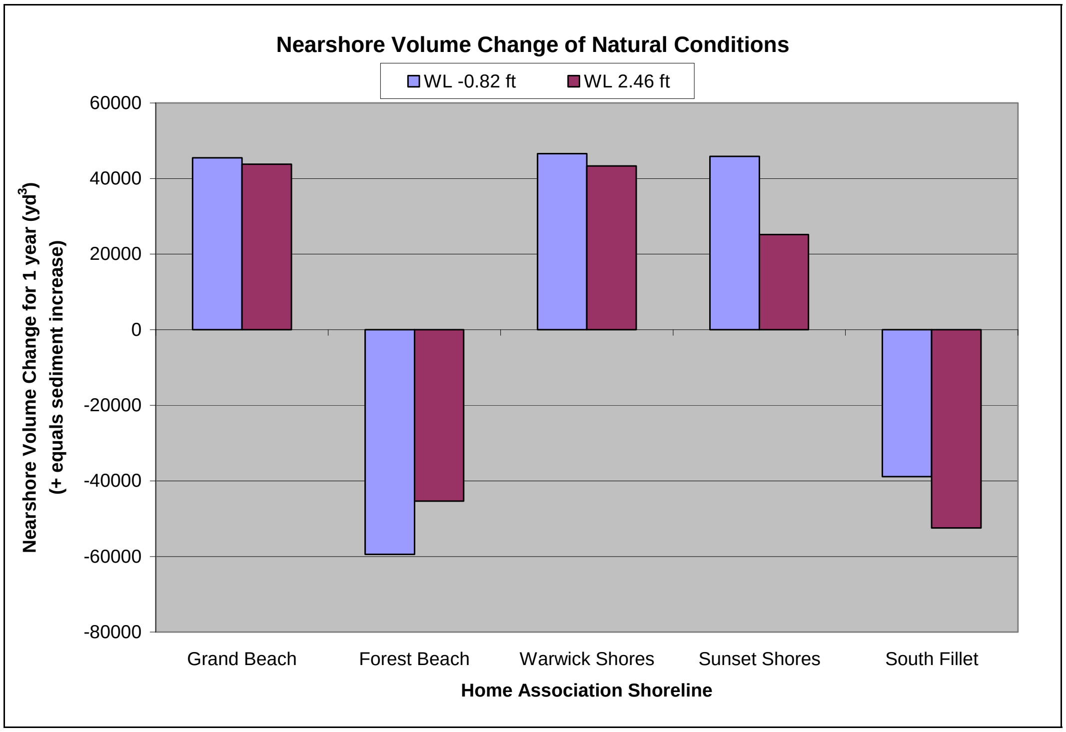

Figure: 8.20 – Nearshore Volume Change for Natural Conditions

Review of Tables 8.3 and 8.4 provide a much clearer picture of how the beach enhancement solutions may function. Taking into consideration the areas where nourishment is placed, it can be seen that both nourishment solutions provide immediate increases to the beach widths over natural responses. The 25,000 yd^3 placement provides on the order of 0.0 to 0.62 ft of added beach width over a year. The 120,000 yd^3 placement provides between 1.5 to 10 ft of added beach width over natural responses. In contrast, the breakwater solutions do not provide much benefit to beach width over a year period. However, upon review of the nearshore volume table (8.4), it is clear that the submerged breakwaters do provide considerable benefit when compared to natural responses. The solution involving the instalment of 25 submerged breakwaters increased the nearshore volume between 11,260 yd^3 and 100,870 yd^3 over the modelled year period. This means that while the benefits from this solution may not be immediately realized, over time the increase in beach width could be considerable.

Table 8.3 – Shoreline Recession and Accretion Standardized to Natural Conditions

SHORE CHANGE (ft/yr)	Nourishment 25K cy		Nourishment 120K cy		5 Submerged Breakwaters		25 Submerged Breakwaters	
Shoreline	WL -0.82 ft	WL 2.46 ft	WL -0.82 ft	WL 2.46 ft	WL -0.82 ft	WL 2.46 ft	WL -0.82 ft	WL 2.46 ft
Grand Beach	-0.16	3.28	-0.10	3.61	-14.24	8.20	-17.78	5.41
Forest Beach	3.15	1.84	5.41	1.51	-4.46	-2.49	-3.38	-1.28
Warwick Shores	3.71	1.87	10.96	-5.77	-14.76	-0.07	-13.32	1.25
Sunset Shores	-1.15	-3.44	1.35	4.04	-3.22	0.20	-2.62	-0.20
South Fillet	-5.77	-1.02	-2.62	-0.43	0.00	-1.02	-1.84	2.69

Table 8.4 – Nearshore Volume Change Standardized to Natural Conditions

VOLUMES (yd^3/yr)	Nourishment 25K cy		Nourishment 120K cy		5 Submerged Breakwaters		25 Submerged Breakwaters	
Shoreline	WL -0.82 ft	WL 2.46 ft	WL -0.82 ft	WL 2.46 ft	WL -0.82 ft	WL 2.46 ft	WL -0.82 ft	WL 2.46 ft
Grand Beach	-143.87	-78.48	-137.33	3178.32	-23824.32	-12706.74	79392.60	67385.62
Forest Beach	-307.37	228.89	10208.55	18448.64	33064.99	29285.01	100869.15	88809.85
Warwick Shores	-1360.27	1007.12	9593.82	-17964.70	-13864.28	-23595.43	30874.17	11261.45
Sunset Shores	4067.73	-2380.47	13530.75	-17709.65	25243.45	11464.19	53410.16	29291.55
South Fillet	15126.45	-4198.52	24805.28	4165.82	48577.29	14191.26	43947.14	14420.16

8.6 Cost Analysis of Solutions

Table 8.5 provides a USACE engineering cost estimate of the solutions presented in Table 8.1 and described in the previous sections. The table highlights the total cost that may be anticipated in the 2009 calendar year. These engineering estimates are based on the information available as of March 2009. Economic conditions could affect these costs dramatically. The reader should take this into account before making any final judgements related to project costs.

These estimates take into account a variety of variables including quantity of raw materials, mobilization and demobilization costs, transportation of material, dredging, hydraulic handling, road repair costs, and 20% contingency. These estimates do not take into consideration any engineering or design work that would need to be accomplished, permitting costs, or inflation. Cost reductions due to combining proposed nourishment efforts with ongoing dredging projects resulting in a “leveraging” of costs were also calculated.

Inspection of the cost breakdown for nourishment projects shows that N1a-trucking 25,000 yd^3 of sediment in from an upland source is the least costly alternative. However, on a per unit basis, N6b-bypass of 50,000 yd^3 of sediment from the north accretion fillet is the most cost efficient based on materials. The most expensive nourishment project is N3b-barging of 120,000 yd^3 of sediment from an upland source.

The structural solutions analyzed under this study were generally more expensive than basic nourishment projects. The breakwater designs ranged from $747,344 for BW1 to $1,287,857 for BW2. BW1 is the most costly on a per unit basis showing a $10 higher unit costs than BW2. It was assumed that the least costly method of nourishment would be used for each of these solutions.

Table 8.5: Beach Enhancement Solution Cost Analyses

Nourishment Solutions

ID	QTY(cy)	FY09 Total Cost	Reduced Cost by Leveraging	FY09 Total Unit Cost	Leveraged Unit Cost	Potential Nourishment Cycle (years)	Potential Cost per Year based on FY09 Costs
N1a	25000	$337,927.20	$337,927.20	$13.52	$13.52	3	$135,170.88
N1b	25000	$573,465.60	$573,465.60	$22.94	$22.94	3	$229,386.24
N1c	25000	$488,386.80	$219,022.80	$19.54	$8.76	3	$195,354.72
N2a	65000	$858,532.80	$858,532.80	$13.21	$13.21	6	$138,473.03
N2b	65000	$1,166,071.20	$1,166,071.20	$17.94	$17.94	6	$188,076.00
N2c	65000	$916,786.80	$498,922.80	$14.10	$7.68	6	$147,868.84
N3a	120000	$1,574,366.40	$1,574,366.40	$13.12	$13.12	12	$134,561.23
N3b	120000	$1,980,904.80	$1,980,904.80	$16.51	$16.51	12	$169,308.10
N3c	120000	$1,513,486.80	$888,247.80	$12.61	$7.40	12	$129,357.85
N4a	50000	$661,748.40	$661,748.40	$13.23	$13.23	3	$264,699.36
N4b	50000	$942,286.80	$942,286.80	$18.85	$18.85	3	$376,914.72
N4c	50000	$758,086.80	$395,097.80	$15.16	$7.90	3	$303,234.72
N5a	25000	$488,386.80	$219,022.80	$19.54	$8.76	3	$143,643.18
N5b	65000	$916,786.80	$498,922.80	$14.10	$7.68	3	$269,643.18
N6a	25000	$363,997.20	$257,416.20	$14.56	$10.30	3	$145,598.88
N6b	50000	$592,897.20	$486,316.20	$11.86	$9.73	6	$95,628.58

Breakwater Solutions

ID	Type/Crest Elev	FY09 Total Cost	Reduced Cost by Leveraging	FY09 Total Unit Cost	Leveraged Unit Cost	Potential Nourishment Cycle (years)	Potential Cost per Year based on FY09 Costs
BW1	Rock/ -3.5ft LWD	$747,343.80	$747,343.80	$29.89		3	$213,536.12
BW2	Rock/ -3.5ft LWD	$1,287,857.40	$1,287,857.40	$19.81		6	$170,166.02
BW3	Rock/ -3.5ft LWD	$1,789,763.40	$1,789,763.40	$19.89		9	$164,777.17
BW4	Rock/ -3.5ft LWD	$2,646,262.20	$2,646,262.20	$40.71		6	$263,282.48

Groin Solutions

ID	Type	FY09 Total Cost	Reduced Cost by Leveraging	FY09 Total Unit Cost	Leveraged Unit Cost	Potential Nourishment Cycle (years)	Potential Cost per Year based on FY09 Costs
G1	Rock	$545,527.80	$545,527.80	$21.82		3	$191,672.72
G2	Rock	$1,031,491.80	$1,031,491.80	$15.87		6	$152,592.57
G3	Rock	$1,031,491.80	$1,031,491.80	$15.87		6	$152,592.57
G4	Rock	$1,398,198.60	$1,398,198.60	$15.54		12	$113,092.65
G5	Sheet Pile	$775,024.20	$775,024.20	$31.00		3	$203,717.33
G6	Sheet Pile	$1,391,905.80	$1,391,905.80	$21.41		6	$156,627.47
G7	Sheet Pile	$1,391,905.80	$1,391,905.80	$21.41		6	$156,627.47
G8	Sheet Pile	$1,938,306.60	$1,938,306.60	$21.54		9	$142,651.12

As for the groin solutions, the rock designs are cheaper to pursue than the SSP designs. In addition, construction of the rock groins is generally less costly than breakwater construction. It was also assumed that the least costly method of nourishment would be used for each of these solutions.

An important item to consider when analyzing the cost breakdown table is cost reduction due to leveraging. Leveraging can be accomplished if the selected shore enhancement solution can be tied with another project, such as dredging. There were two main scenarios that were identified as potential leveraging situations: barging sediment from Burns Harbor and bypassing sediment from the north accretion fillet. Both of these solutions involve dredging and may provide an opportunity for numerous partners to gain cost savings on their projects while helping each other with their issues. As an example, if leveraging is used, solution N1c- barging 25,000 yd^3 of sediment from Burns Harbor becomes the cheapest solution. There may be other opportunities for leveraging that were not taken into account in this analysis. End users of this report are encouraged to pursue all options that may be available.

It should be noted that in general, the structural solutions did not show significant gains for the region. Beach enhancement would be expected for the shoreline immediately behind the structures. But, these solutions did not result in potential regional enhancements to the shorelines south of the harbor.

8.7 Sand Bank Solutions

All the solutions presented in this report are expensive projects to pursue. A single property owner would have a difficult time covering the costs associated with any individual solution. In general, a single property owner can only afford small scale projects that typically do not function well. Even with leveraged funds the costs will be high. Furthermore, maintenance costs will need to be addressed, which will add to the overall price for the project. All the solutions presented here are meant to be community based and not for individuals.

It would be ideal for the home associations and Village of Grand Beach who desire to implement a beach enhancement solution to pool their funds in a “Sand Bank” to fund projects and future maintenance. Table 8.5 breaks down the costs associated with example nourishment projects based on shoreline properties and inland properties. The table is based on information obtained from 2002-MDEQ maps. 266 shoreline homes and 452 inland homes (the first 2 rows of houses after the shoreline properties) were counted in New Buffalo Township and Grand Beach. It was assumed that the shoreline properties would incur 66% of the financial responsibility and the inland homes 33%. As Table 8.5 shows, if 120,000 yd^3 is placed along the shoreline every 6 years, inland property owners could pay \$184 per year and shoreline property owners could pay \$626 per year into the “Sand Bank” to fund future nourishment projects. This approach would greatly assist all home owners in the area to sustain beneficial nourishment projects.

Table 8.6 is merely an example of what could be accomplished. If a "Sand Bank" is utilized by the end users of this report, it is recommended that all legal and financial issues are investigated by the participants before implementation.

Table 8.6: Sand Bank Examples

Solution	Placement Rate (Year)	Cost per Shore Property ($)	Cost per Inland Property ($)
N1-25,000cy	1-year	$838	$247
	2-years	$419	$123
	3-years	$279	$82
	4-years	$210	$62
	6-years	$140	$41
N2-65,000cy	1-year	$2,097	$617
	2-years	$1,048	$308
	3-years	$699	$206
	4-years	$524	$154
	6-years	$355	$104
N3-120,000cy	1-year	$3,755	$1,105
	2-years	$1,878	$552
	3-years	$1,252	$368
	4-years	$939	$276
	6-years	$626	$184
N6-Bypass 50,000cy	1-year	$1,471	$433
	2-years	$736	$216
	3-years	$490	$144
	4-years	$368	$108
	6-years	$245	$72

9.0 Conclusions and Recommendations

Section 9.0 of this report provides study conclusions and recommendations for sediment management and beach enhancement solutions.

The following list is a summary of the major findings and recommendations of these analyses:

- The shoreline both in the northern and southern portions of the study site has seen little landward or lakeward movement over the past 70 years, with the exception of the north and south accretion fillets. In addition, the survey from 1857 suggests the relative location of the overall shoreline has been stable for over 100 years. There have been shoreline shifts over small temporal periods that coincide with lake level fluctuations.

- The nearshore change analysis indicates that the shoreline regions of the accretion fillets have been accretional, and the deeper portions of the accretion fillets have been erosional over the last 35 years. In general, the nearshore regions of the study site have been erosional over the last 35 years. There are some issues associated with data quality that need to be taken into account before making any final conclusions.
- Based on the 1857 survey there were railroad piers near the Sunset Shores area that no longer exist. No records are available to indicate these structures were removed. Assuming that they degraded over time may explain some of the nearshore changes that were found in both the accretion fillet analyses and the bypass bar analysis.
- The accretion fillet analyses indicate that the north accretion fillet is still growing at a rate of about 20,000 yd^3/year and the southern fillet may be growing at a rate of 0 - 2,600 yd^3/year. Based on a surface area analysis of both accretion fillets, the beach just north of the harbor may continue to grow until approximately 2020, where it is expected to reach a state of dynamic equilibrium. The south fillet seems to have reached a state of dynamic equilibrium, though there may be some room for future growth.
- A bypass bar has formed around the harbor and may continue to grow in the future. Currently, the bypass bar is growing at a rate of about 9,000 yd^3/year.
- A number of solutions were analyzed. In general, it is recommended that some type of nourishment program be implemented at the Warwick Shores/Sunset Shores location. CMS modeling indicates that this portion of shoreline would be best suited for providing long term benefits to the rest of the shoreline south of the harbor.
- While groins were analyzed under this study, it is not recommended that this type of solution be pursued. There does not seem to be a major advantage to implementing them and the existing groin structures along the shoreline do not seem to be beneficial at the present time. It is not recommended that any structures be placed south of Warwick Shores. The currents south of Warwick Shores are generally unidirectional to the south and would not promote overall health of the shorelines south of New Buffalo Harbor.
- Detached submerged breakwaters may be a structural solution as long as nourishment is also provided. Similar to the groin field solutions, it is not recommended at this time that any structures be placed south of Warwick Shores. Projects utilizing these types of structures at Presque Isle State Park in

Pennsylvania and Miami-Dade County in Florida have shown benefits in areas of unidirectional littoral drift.

- Bypassing material from the north of New Buffalo Harbor to the south provides a positive opportunity to enhance sediment supply to the south while potentially limiting the amount of shoaling in the harbor. Communities to the south and the City of New Buffalo may leverage funds to assist in maintaining their respective properties.
- The shoreline communities have the opportunity to obtain sediment by barge from either Burns Harbor or from a mining facility at Grand Haven. The Burns Harbor source may allow the home associations and The Village of Grand Beach to partner with the water treatment facility at Burns Harbor to dredge sediment from the intakes and bypass sediment to the Warwick Shores/Sunset Shores area.
- It is expected that areas of nourishment will gain 150 to 200 feet of beach with water levels at Low Water Datum (577.4 ft IGLD-85). These beaches will erode over time and will require periodic nourishment to maintain these levels. The beaches downdrift of the nourishment areas (Grand Beach and Forest Beach) should stabilize at 30 to 60 feet as they did during the nourishment projects of the late 1970's to early 1990's.
- All structural solutions presented in this analysis will require a nourishment program to properly function. In addition, any solution will require an engineering assessment focused on that solution for proper design. The information found in this report can be used to support the creation of design drawings and specifications or used for discussions with other potential partners on shoreline solutions.
- Both nourishment placement of 25,000 and 120,000 yd^3 of sediment show an increase in beach width when compared to natural conditions. The increases in beach widths are shown in Table 8.3.
- The 120,000 yd^3 beach nourishment solution shows the greatest increase in beach width over the modelled year period.
- Analyses of the modeling results indicate that results based only on beach width criteria will not result in the proper solution for long term beach enhancement. Nearshore volume change is a better indicator of long term improvements to the shoreline.
- Modeling results based on nearshore volume change indicates that installation of submerged breakwaters will provide the best long-term solution.
- Shoreline analyses over a longer time period should be conducted to ensure that the submerged breakwaters would work and not cause any adverse effects over a significant temporal period.

- Based on the volume increases of the nearshore, installation of submerged breakwaters does not show a need for a long term nourishment program. Nourishment would only be required for the first few years of the installation to ensure no adverse affects to adjacent properties.
- Of the two submerged breakwater installations analyzed, the 25 submerged breakwaters had the best results. It would be recommended that this solution be pursued by the homeowners associations.
- Based on prior cost analyses, it is expected that instalment of 25 submerged breakwaters and placement of 75,000 yd^3 of sediment would cost approximately $2,646,000.
- It is recommended that if the breakwater solutions are pursued, only 5-10 breakwaters with nourishment should be installed and monitored for a couple of years to ensure that they function appropriately. In addition, it would be recommended that a nourishment program be utilized for the first few years after installation to ensure success of the project. It is anticipated that this nourishment program would not be required indefinitely.