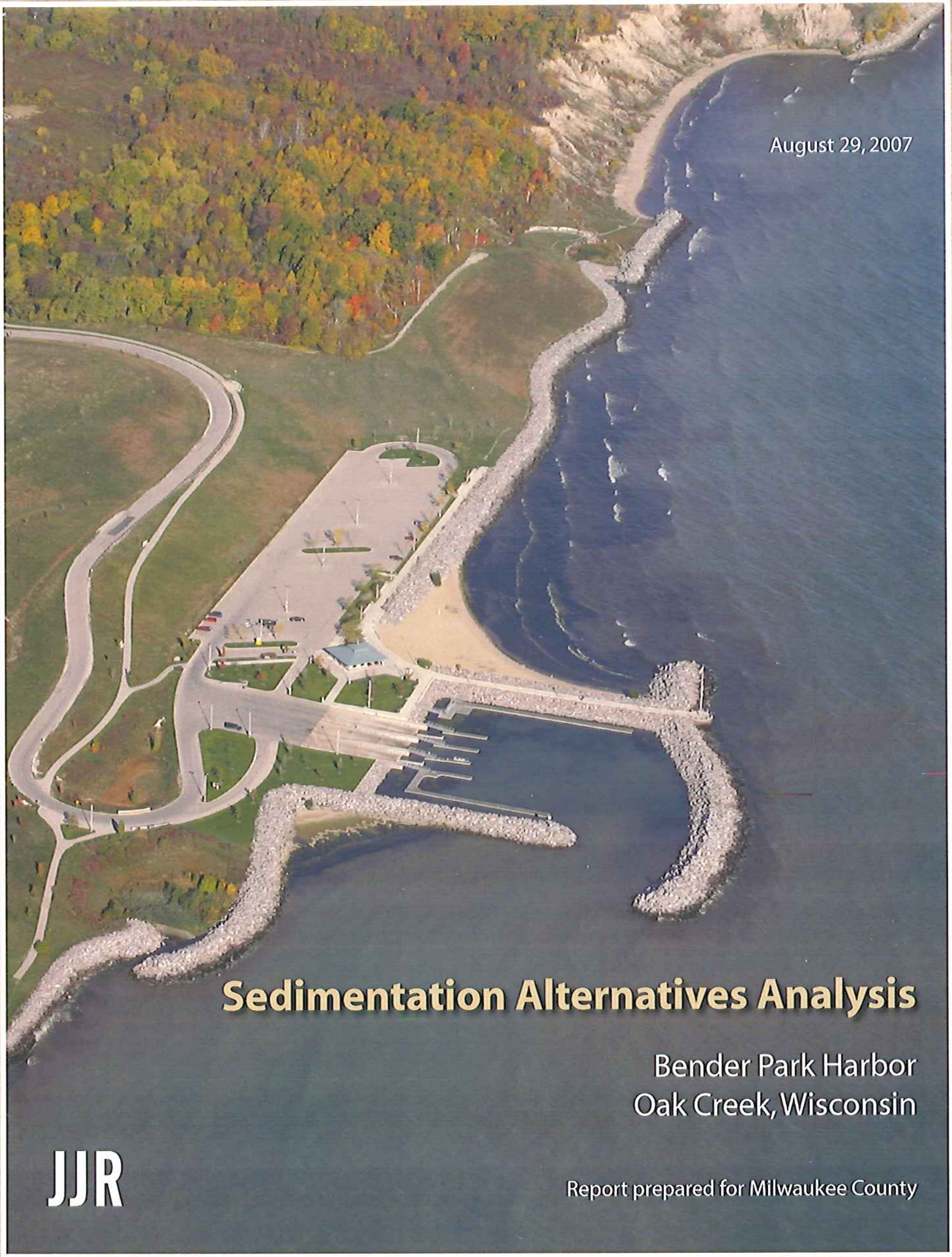

August 29, 2007

Sedimentation Alternatives Analysis

Bender Park Harbor
Oak Creek, Wisconsin

JJR

Report prepared for Milwaukee County

Sedimentation Alternatives Analysis
Bender Park Harbor
Oak Creek, Wisconsin

August 29, 2007

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Executive Summary

Bender Park Harbor in Oak Creek, Wisconsin, is a small safe harbor and boat launching facility on Lake Michigan which was completed in 1999. The harbor, like many other shallow water facilities on the lake, has been negatively impacted by lower than average water levels in recent years, causing premature sedimentation of the mouth of the harbor due to greater rates of littoral sediment transport.

A number of alternatives are being considered for Bender Park Harbor to help alleviate the need for frequent, long-term maintenance dredging under these lower water level conditions. These alternatives include various structural modifications to the existing coastal structures as well as maintenance dredging at varying time intervals. The alternatives considered, which are illustrated in Appendix A, range from small extensions of the existing coastal structures to create pockets for sediment trapping, to large-scale reconstruction of the main breakwater and south jetty to push the mouth of the harbor into deeper water, allowing more sediment to be diverted out of the littoral transport zone. In two alternatives, Alternatives 5 and 6, the opportunity to create more usable protected water space within the larger harbor was explored.

Planning-level computer modeling was performed to estimate the potential effects of each structural modification on sediment accumulation and dredging frequency. The model showed that at current rates of sediment transport, it is likely that all the alternatives proposed would require some maintenance dredging, however, the deeper the structures extend into the lake, the less accumulation potential around the mouth of the harbor, and the less frequently dredging is required. An alternative of annual dredging was also considered, Alternative 7, which included retrofitting the existing south jetty to accommodate land-based dredging equipment which has lower mobilization costs than water-based equipment.

The most appropriate solution for the harbor will depend on a number of factors, namely capital costs, potential funding sources, longevity, constructability, permitting, expected usage demands, operational costs, and other considerations. This report is intended to present a range of alternatives; discuss the feasibility of each alternative; as well as provide some preliminary comparative estimates of construction costs and the operational aspects for each alternative.

Introduction

This technical brief provides a discussion of the existing sedimentation problems at Bender Park Harbor in Oak Creek, Wisconsin, and the preliminary analysis of remedial options to extend the period between required maintenance dredging of the harbor.

Bender Park Harbor was constructed in 1999 following improvements to the adjacent shoreline areas approximately three years prior. The overall constructed works consisted of a shore-connected breakwater protecting against the northeasterly wave conditions, and a smaller groin protecting the southern access to the facility. A beach fill was also constructed along the northern arm of the shore-connected breakwater at the time of the facility construction. The present site configuration is presented for reference in Figure 1.

Figure 1. Aerial View of Bender Park

Physical and Environmental Site Characteristics

The shoreline of Lake Michigan in the area near Bender Park is relatively well protected by various structural measures, with occasional pockets of beach sediments in natural shoreline areas or fronting older structures built on the shoreline. The slope of the nearshore in this area is very mild and is in the order of one percent (1%).

A contoured representation of bathymetric survey information from the December 2006 survey, to 10 feet (ft) below datum, is presented in Figure 2. Datum for these purposes is referenced to National Geodetic Vertical Datum of 1929 (NGVD 1929), where 0.0 LWD (Low Water Datum) is equal to 578.4 NGVD 1929. Figure 3 shows a graphical representation of the sediment accumulation between the bathymetric survey conducted in 1994 prior to construction of the harbor and the bathymetric survey conducted in 2006. The contours of the figure represent positive or negative accumulation of sediment in feet.

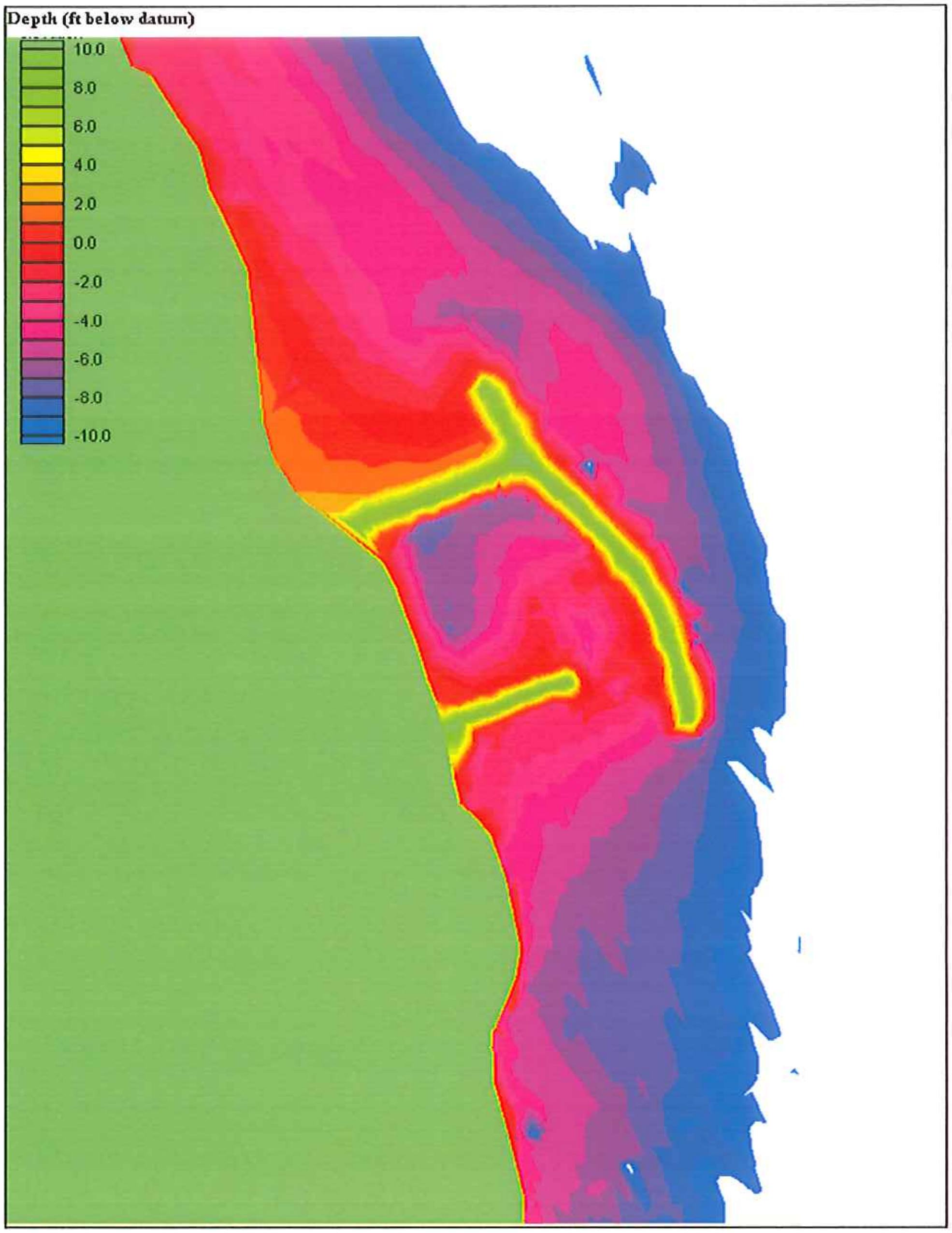


Figure 2. Contoured Representation of 2006 Bathymetric Survey

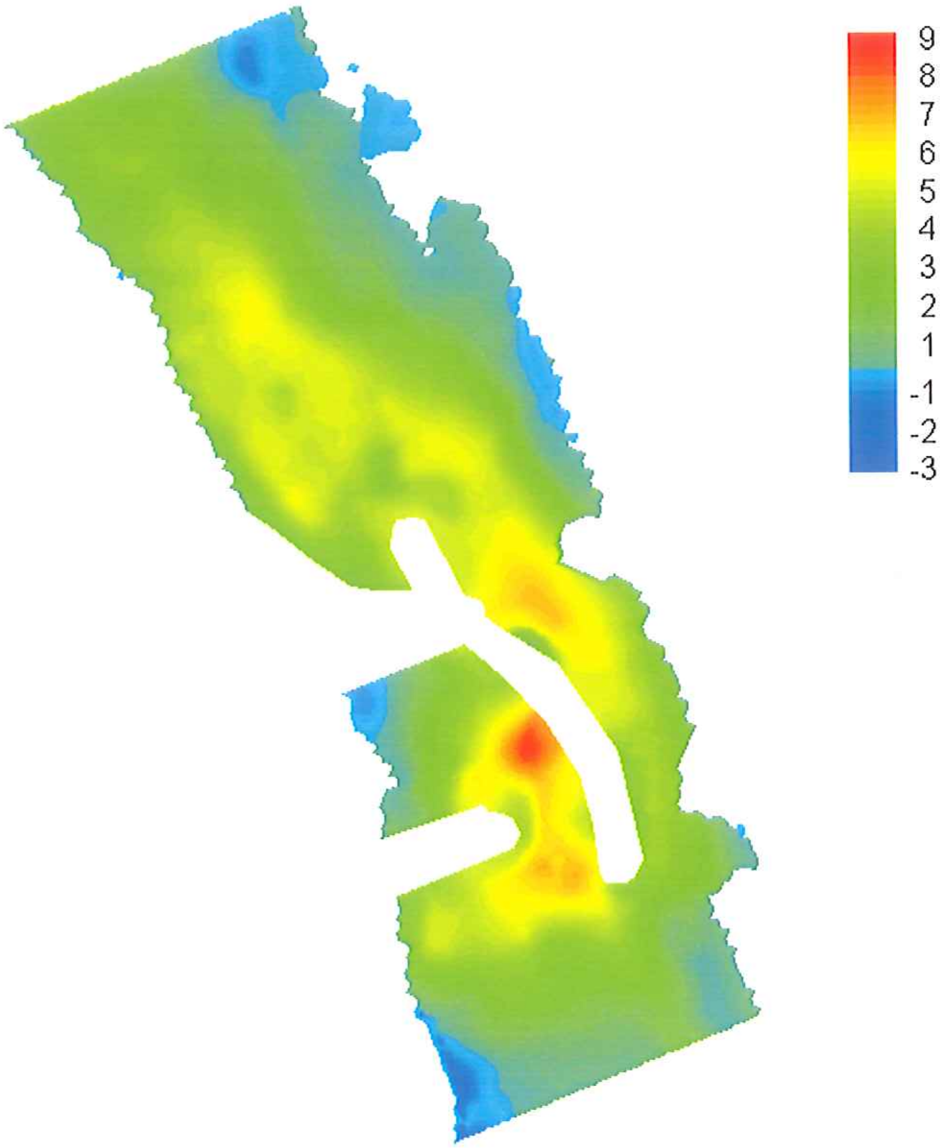


Figure 3. Contoured Representation of Sediment Accumulation, 1994 to 2006

Figure 3 shows the greatest sediment deposition in the entrance to the harbor, along the southern groin, and along the eastern side of the breakwater, near the north end of the breakwater structure.

The site is open to Lake Michigan winds and waves from the northerly, through west, to southerly directions, with fetches in excess of 80 miles in these directions. Wave conditions at the site were reviewed with reference to the National Oceanic and Atmospheric Administration (NOAA) Wave Information Study (WIS) Site 8 (in 18 meters of water) approximately 7.5 miles southeast of the site.

Annual wave height conditions at this station are summarized in Figure 4. The plot shows that the largest waves are experienced from the north/northeast, while waves from the south/southeast are smaller, but occur on a slightly more frequent basis.

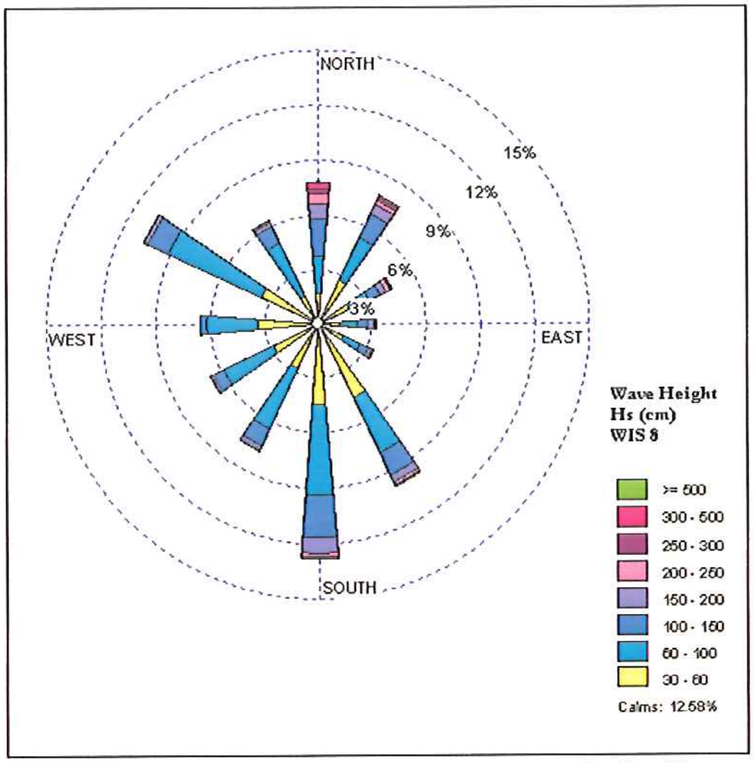


Figure 4. WIS Wave Hindcast Data (10 Years – Station 8)

Long-term water levels in the Great Lakes vary considerably, with historic high and low monthly water levels reaching 582.3 ft in October 1986 and 576.0 ft in March 1964, respectively (datum International Great Lakes Datum, or IGLD, 1985). For reference, NGVD 1929 datum is equal to IGLD 1985 datum plus 0.752 ft, so LWD in IGLD 1985 is 577.6 ft. The long-term monthly average for summer months is in the order of 579 ft. Recent monthly water levels have been more than a foot below the long-term summer monthly averages, and below datum on occasion. This trend has been observed since construction of the launch ramp facility. Monthly water level data for 1998 through 2006 is presented in Figure 5, where LWD refers to Low Water Datum (577.6 ft IGLD 1985).

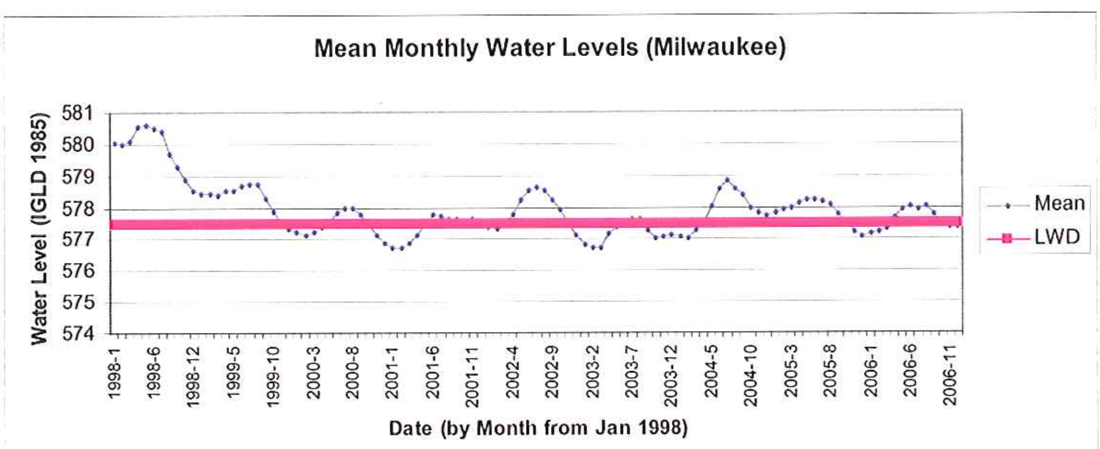


Figure 5. Monthly Water Level Trends – Lake Michigan, 1998 - 2006

It is important to recognize the relationship between water levels, wave conditions and nearshore sediment transport potentials. Sediment transport is maximum near the wave breaking line, and remains significant within the surf zone. Where nearshore areas are relatively deep, only the largest waves break in this area, and significant sediment transport potential is only occasionally realized. When depths are reduced, more waves break in this area, and significant sediment transport potential is realized on a more regular basis. Given the exposed nature of this site, and the sustained low water levels at the site, sediment transport potentials have remained higher than would typically be expected on average in recent years. It is expected that this natural condition is the primary reason for the sedimentation problems within the mooring facility entrance.

Previous estimates from the Southeast Wisconsin Regional Planning Commission (SEWRPC) of sediment transport potential in the region were in the order of 4,000 cubic yards per year (cy/yr). Sediment transport potential modeled in a scaled wave tank during design of the Bender Park Harbor provided similar predictions at that time. However, since those predictions were made the water levels in Lake Michigan have been consistently lower than the historic averages, resulting in increased sediment transport potential in the nearshore zone. Therefore, transport potential in the range of 5,000 to 7,000 cy/yr is more likely to be expected with the current lake level conditions.

Bathymetric surveys performed in and around the harbor in 1994, 1999, and 2006, provide an estimate of actual sedimentation rates experienced in the recent past in the harbor. The surveys indicate that approximately 60,000 cy of material have accumulated in the vicinity of the harbor structures since the original bathymetric survey was completed in 1994. This rate of accumulation is consistent with the predicted sediment transport potential rates based on the lower lake levels in recent years.

Alternatives Analysis

Seven alternatives were considered to help alleviate the current problem of sedimentation in Bender Park Harbor. These include various combinations of structural modifications to the existing coastal structures as well as maintenance dredging. These alternatives, which are described below, are illustrated in detail in Appendix A:

Alternative 1 – A 100-ft extension of the northerly breakwater section, to extend beyond the easterly arm of the breakwater and provide a partial interruption of transport from the north;

Alternative 2 – A 200-ft extension of the main (easterly) breakwater arm towards the south, to provide for increased protection of the entrance gap and extend the travel distance for transport from the north;

Alternative 3 – Over-dredging of the entrance area to provide a sediment trap to capture littoral materials delivered from the north and south;

Alternative 4 – A 500-ft extension and partial rebuild of the main breakwater out into deeper water to allow more of the littoral transport to be diverted into deeper water and reduce the sediment transport into the shallow harbor;

Alternative 5 – A 500-ft extension and partial rebuild of the main breakwater as in Alternative 4, and the relocation of the south jetty to create a larger protected harbor;

Alternative 6 – A 650-ft extension and partial rebuild of the main breakwater and relocation of the south jetty to create a larger protected harbor; and

(a) Alternative 1

(b) Alternative 2

(c) Alternative 3

(d) Alternative 4

(e) Alternative 5

(f) Alternative 6

Figure 6. Schematics of Alternatives 1 – 6

(Note: Alternative 7 not pictured, see Appendix A)

Alternative 7 – Retrofitting the existing south jetty to provide an access road for annual maintenance dredging of the harbor entrance from land, potentially simplifying the process of dredging the harbor and reducing equipment mobilization costs.

Alternatives 1, 2, 4, 5, 6, and 7 all would require an initial dredging effort at the time of construction to restore the harbor to original bathymetric contours. The most recent bathymetric survey conducted in late 2006 indicates that approximately 18,500 cy of material would need to be dredged to restore the harbor and surrounding entrance area to original depths. The small initial dredging operation that took place in spring 2007 removed approximately 1,500 cy to open the harbor for the 2007 fishing season. Therefore 17,000 cy remain to be dredged. Alternative 3 includes this volume plus an additional volume for the sediment containment pit.

Planning-level computer modeling analyses were undertaken for the different breakwater configurations, in addition to a "do-nothing" approach, to establish the relative potential for success in providing a significant extension in the inter-dredging window. A description of the planning-level modeling is provided in Appendix B.

Analysis Results

The results of the modeling, in addition to such considerations as relative costs, longevity, constructability, and feasibility are discussed below for each of the alternatives.

Do Nothing

The do-nothing approach was found to be unacceptable with respect to immediate navigation needs and with respect to future dredging requirements should Lake Michigan water levels remain low.

Alternative 1

Alternative 1, the 100-ft breakwater extension, would provide some temporary relief from sediment transport from the north given the potential to trap additional material, however, this extension would be constructed in relatively shallow water, and therefore the benefit with respect to the life of this sediment trap would be reduced. This alternative provides no protection against transport of littoral material from the south. The location of the extension shown in Appendix A (and in Figure 6) was chosen primarily due to the aesthetic nature of lining up the extension with the north breakwater, however, the extension would produce similar effects regardless of its location along the main breakwater structure due to the relatively uniform depths on the outside of the breakwater.

Due to the limited protection provided by this alternative, regular maintenance dredging would likely still be required during the 10-year interval to provide a safe open passage into the harbor. Therefore, Alternative 1 is not recommended as a viable option for reducing maintenance dredging in the harbor.

Alternative 2

Alternative 2, the 200-ft breakwater extension to the south, would not necessarily reduce the rate of transport along the main breakwater in the short term, but provides a longer transport path (and interim sediment sink) between the updrift source and the harbor entrance. The extension would also shelter the downdrift nearshore area to a greater degree, allowing for the natural generation of a more substantial nearshore beach area in this region by littoral material transported from the south, and therefore a larger sediment sink prior to the material being transported into the entrance by southerly waves. As sediment deposits on the east side of the breakwater structure, equilibrium would be obtained, and the accumulation potential in that location would be reduced, causing more sediment to pass along the structure and deposit south of the end of the breakwater. This would eventually cause the area south of the breakwater to fill in with sediment, and the navigational channel providing access to the harbor would be forced closer to shore. Some sediment accumulated in this location would be transported towards the mouth of the harbor from southerly wave activity. However, this accumulation at the end of the breakwater would occur further from the harbor entrance than the current configuration, allowing the entrance to stay open longer without dredging.

This alternative configuration appears to provide sufficient protection of the harbor entrance to limit maintenance dredging to approximately every 10 years or less frequently if water levels in Lake Michigan begin to rise again (although they are not projected to do so). At the current predicted sediment transport potential rates, in 10 years approximately 50,000 to 70,000 cy of material would accumulate along the structure and at the south end.

Alternative 3

Alternative 3, creation of a sediment containment pit through over-dredging of the harbor entrance, could provide immediate and short-term benefits in terms of navigation needs and could be sized to provide a significant design life under theoretical local transport rates.

Results of the model show that to be effective for 10 years, approximately 50,000 cy of material would need to be dredged for the containment pit. This dredge volume was assumed to include the 18,500 cy of material to restore original contours in the harbor, and then an additional 31,500 cy at the toe of the breakwater, as shown in Figure 8. The pit is estimated to be approximately 5-ft deep below the existing bed, over an area of approximately four acres.

It is estimated that the containment pit would need to be re-dredged approximately every 10 years. However, the relatively shallow depths of the adjacent nearshore areas suggest that cross-shore profile development may reduce the effectiveness of this option, and should local sedimentation patterns be disadvantageous, deposition may have impacts on navigation prior to the intended design life of the dredge.

Alternative 4

Alternative 4, a 500-ft extension and reconstruction of the main breakwater, would allow for some sediment accumulation on the north face as well as the diversion of a portion of the littoral transport out into deeper water, effectively removing it from the system. The greatest advantage of this alternative is that the deeper water structure (ending at approximately -14 ft below datum) prevents the accumulation of sediment at the end of the breakwater, which is currently near the mouth of the harbor. It also would lessen the impacts of southerly transport because there would be less material accumulated at the south end of the structure; however it still may leave the mouth of the harbor open to some transport from the south. In this alternative, the south jetty would remain in its current location, and the mouth of the harbor would be slightly larger than it is currently.

This alternative would appear to provide a window of approximately 12-18 years before maintenance dredging is required.

Alternative 5

Alternative 5 utilizes the same outer breakwater configuration as Alternative 4, and provides a practical use for the additional space created by the deeper water entrance by expanding the size of the protected harbor behind it. This alternative would relocate the south jetty approximately 200 ft to the south and extend it by approximately 135 ft.

This alternative would realize the same advantages as Alternative 4, namely the reduction of sediment transport potential created by the diverting breakwater structure. The new south jetty would also provide more protection to the harbor from southerly transport and allow for more accumulation of sediment on the south face of the jetty. This alternative could provide an operational window of up to 15-22 years before maintenance dredging.

Alternatives 4 and 5 could be implemented as a two-phased approach as funding sources become available; the breakwater could be extended first as in Alternative 4, and then the south jetty could be relocated at a later date.

Alternative 6

Alternative 6 is a larger version of Alternative 5, with a 650-ft extension and reconstruction of the main breakwater and a larger harbor with the relocation of the south jetty. The south jetty would be moved southward by approximately 350 ft and have a total new length of approximately 525 ft. The main breakwater would extend out to approximately the same water depth as that of Alternatives 4 and 5; however the additional 150 ft of breakwater provides additional sediment trapping potential as well as a greater protected harbor space.

This alternative provides the greatest protection against sedimentation within the basin as it provides the longest path for sediment to reach the mouth from both the north and south. It also provides entrance protection due to the final curvature of the outer breakwater. Modeling suggests that it is also the best alternative with regard to deposition along the south jetty. It is predicted that this alternative could provide a window of up to 18-25 years before maintenance dredging.

Alternative 7

Alternative 7 includes retrofitting the existing south groin or jetty to accommodate an access road on top of the revetment structure for the continual maintenance dredging of the mouth of the harbor as it is currently configured. While this alternative was not modeled, it was assumed from the predicted local transport rates that approximately 5,000 to 7,000 cy of material would need to be dredged from the mouth of the harbor annually. This maintenance dredging could also potentially be done on a bi-annual basis if it was determined that annual dredging was not required to maintain an open navigational channel.

For this alternative, the stone revetment on the south half of the south jetty would need to be removed temporarily to allow for additional core stone to be placed creating a wider jetty. It was assumed for these purposes that a 16-foot wide concrete road would accommodate the land-based dredging equipment (likely a crane for reach), although this would need to be verified with the dredging contractor to ensure adequate size.

The limitation of this configuration lies in the reach of the dredging equipment. A land-based crane or excavator has a much smaller radius of work than a similar barge-mounted piece of equipment, limiting the dredging area to a small area around the end of the south jetty. While this would be an effective means for keeping the mouth of the harbor open, this solution would not provide any measurable impact on the sediment accumulation near the south end of the main jetty and would not provide any sediment transport potential reduction.

Opinions of Probable Construction Cost

Preliminary opinions of probable construction cost were calculated for each of the alternatives, which are summarized in Table 1 on the following page.

The opinions of probable cost provided in Table 1 are based on conceptual plans, not on actual engineered designs. Unit costs are based on past experience with similar projects in the region, and do not factor in future inflation in construction materials. While the estimates try to account for most of the major capital improvement costs as well as operational costs, they are not all-inclusive, and a more detailed study would be required once a preferred alternative is chosen and designed.

Maintenance Dredging

The numerical modeling that was undertaken for this study is capable of producing *comparative* estimates for dredge volumes and frequency. In general, the alternatives (4, 5, and 6) that locate the harbor entrance out in deeper water will result in less frequent maintenance dredging than a shallow water entrance. In addition, lengthening and relocating the jetty to the south also provides more sediment storage capacity, requiring less frequent maintenance dredging.

Additional Considerations

The alternatives discussed above were deemed to be modifications to the existing structures that could be reasonably accommodated given the current budgetary resources for a harbor of this size. Larger harbors in Lake Michigan and the other Great Lakes are not experiencing the same magnitude of effects of lower lake levels primarily because these structures are often constructed in deeper water or have other protection offered by federal breakwaters or natural features. This site is particularly vulnerable due to its exposed location as well as its relatively shallow water environment. However, there are many other examples of small and large harbors requiring maintenance dredging in Lake Michigan due to the current low water conditions that would not have required maintenance under the conditions for which they were originally designed. Some areas along the east side of Lake Michigan are experiencing sediment transport potential rates on the orders of 20,000 cy/year, more than twice that experienced at Bender Park.

Additional sediment modeling would need to be performed at a much more extensive level in order to provide budget level accuracy for information identifying the length of time before a dredge effort is needed, the dredge volume and frequency. There are more detailed computer modeling programs that would allow more specific and precise predictions of sediment transport in and around the coastal structures at Bender Park for approximately $30,000 to 40,000. This level of additional analysis would need to be completed to provide meaningful life cycle costs for each alternative, and would likely be required prior to applying for permits from the WDNR and U.S. Army Corps. In addition to numerical modeling for sediment transport predictions, a physical model is recommended prior to final engineering for any of the alternatives described above. A physical model similar in scope and size to the one performed during the original design phase of the harbor for could be completed for around $75,000 to 100,000.

Table 1 - Opinion of Probable Costs Summary, Alternatives 1 - 7

	Alternative 1 100-ft Ext. on North Breakwater	Alternative 2 200-ft Ext. on Main Breakwater	Alternative 3 Over-Dredge Containment Pit	Alternative 4 500-ft Ext. on East Breakwater	Alternative 5 500 ft. Extension and New Jetty	Alternative 6 650 ft. Extension and New Jetty	Alternative 7 New Access Road & Annual Maintenance Dredging	
							Unit Price	Over 10 Years
Initial Dredging Costs								
Mobilization/Demobilization	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	--	$50,000
Dredging and Disposal[1]	$476,000	$476,000	$1,400,000	$476,000	$476,000	$476,000	--	$476,000
Subtotal	$526,000	$526,000	$1,450,000	$526,000	$526,000	$526,000	--	$526,000
Plus 25% Engineering & Contingency	$131,500	$131,500	$362,500	$131,500	$131,500	$131,500	--	$131,500
Total	*$657,500*	*$657,500*	*$1,812,500*	*$657,500*	*$657,500*	*$657,500*	--	*$657,500*
Maintenance Dredging Costs								
Mobilization/Demobilization	--	--	--	--	--	--	$5,000	$50,000
Dredging and Disposal[2]	--	--	--	--	--	--	$100,000	$1,000,000
Subtotal	--	--	--	--	--	--	$105,000	$1,050,000
Plus 25% Engineering & Contingency	--	--	--	--	--	--	$26,250	$262,500
Total	--	--	--	--	--	--	*$131,250*	*$1,312,500*
Construction Costs (Materials and Labor)								
Mobilization/Demobilization[3]	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	--	$50,000
Stone Revetment Construction	$502,350	$778,000	--	$1,769,740	$2,470,010	$3,231,000	--	$482,600
Concrete	--	--	--	--	--	--	--	$106,670
Subtotal	$552,350	$828,000	$50,000	$1,819,740	$2,520,010	$3,281,000	--	$639,270
Plus 25% Engineering & Contingency	$138,088	$207,000	$12,500	$454,935	$630,003	$820,250	--	$159,818
Total	*$690,438*	*$1,035,000*	*$62,500*	*$2,274,675*	*$3,150,013*	*$4,101,250*	--	*$799,088*
Grand Totals	**$1,348,000**	**$1,693,000**	**$1,875,000**	**$2,932,000**	**$3,808,000**	**$4,759,000**	--	**$2,769,000**

Notes:

[1] Dredging cost assumes $28/cy for water-based operation. Dredging volume for Alteratives 1, 2, 4, 5, 6, and 7 is 17,000 cy; volume for Alternative 3 is 50,000 cy.

[2] Dredging cost assumes $20/cy for land-based operationAnnual dredging assumes removal of approximately 5,000 cy of sediment per year.

[3] Mobilization/demobilization costs for water-based stone-placement operations could be combined with mobilization of initial dredging operation if the scheduling of the phases allows.

Appendix A

Illustrations of Alternatives

ALTERNATIVE 1

AUGUST 2007

0' 100' 200'

North

JJR

BENDER PARK SEDIMENTATION ALTERNATIVES ANALYSIS

ALTERNATIVE 2

AUGUST 2007

0' 100' 200'

North

JJR

BENDER PARK SEDIMENTATION ALTERNATIVES ANALYSIS

ALTERNATIVE 3

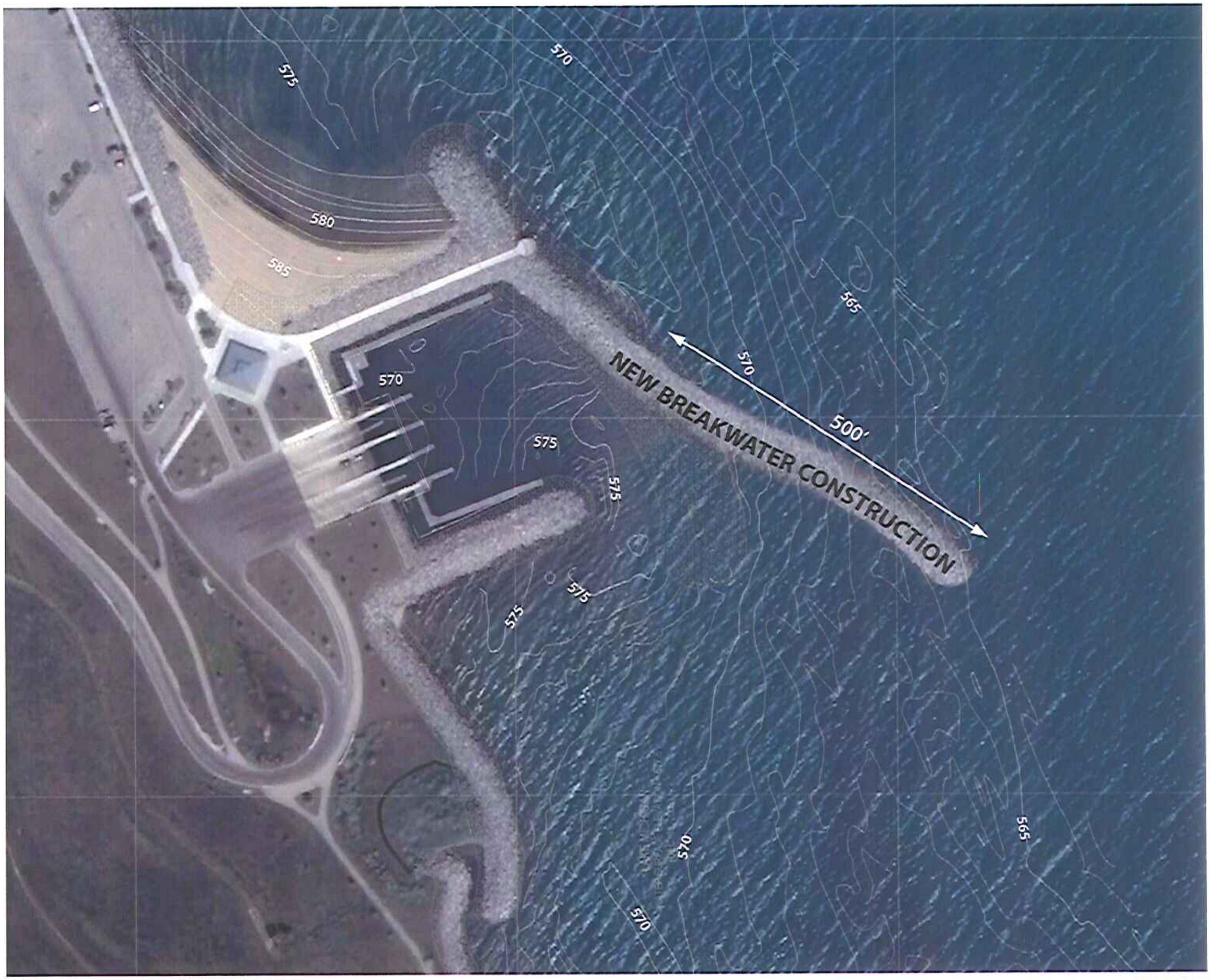
AUGUST 2007

0' 100' 200'

North

JJR

BENDER PARK SEDIMENTATION ALTERNATIVES ANALYSIS



ALTERNATIVE 4

AUGUST 2007

0' 100' 200'

North

JJR

BENDER PARK SEDIMENTATION ALTERNATIVES ANALYSIS

ALTERNATIVE 5

AUGUST 2007

0' 100' 200'

North

JJR

BENDER PARK SEDIMENTATION ALTERNATIVES ANALYSIS

ALTERNATIVE 6

AUGUST 2007

0' 100' 200'

North

JJR

BENDER PARK SEDIMENTATION ALTERNATIVES ANALYSIS

ALTERNATIVE 7

AUGUST 2007

0' 100' 200'

North

JJR

BENDER PARK SEDIMENTATION ALTERNATIVES ANALYSIS

Appendix B

Description of Planning-Level Numerical Modeling

The numerical modeling analysis was performed using a combination of STWAVE and GENESIS, two computer modeling programs. STWAVE was used to transform the offshore wave conditions to the nearshore area and GENESIS was used to estimate the impacts of the proposed alternatives on local sediment transport and local shoreline change. Bathymetric contours from the 2006 survey were used to represent the existing conditions. The wave transformation for Alternatives 1, 2, 4, 5 and 6 were all performed with the same bathymetric input, assuming an initial dredging of approximately 18,500 cy of material, the volume required to restore pre-construction contours in the harbor and throughout the harbor entrance area. Alternative 3 was modeled with a revised bathymetry reflecting the increased dredging in the entrance area for the sediment containment pit. The STWAVE results are transferred to the GENESIS nearshore wave model at the 15-ft depth contour.

The GENESIS model is a one-line shoreline change model, and to that end is subject to a number of limitations with respect to its ability to reflect the true distribution of local sediment transport and deposition processes. Generally, the model assumes a baseline which is divided into a number of cells in the alongshore direction, and a uniform shoreline profile which moves onshore or offshore within each cell given the net flux of littoral materials into a particular cell in a given time step. Structures are defined as obstructions to the alongshore movement of the littoral materials, with bypassing potential defined on the basis of the local wave height and depth at any given time.

A single sand characteristic (D_{50} and associated coefficients) is modeled in a given run. The GENESIS model in particular is very sensitive to grain size, represented by D_{50}, or the median grain size diameter. Sediment sampling in the Bender Park Harbor from 2006 indicates that local grain sizes range from 0.09 to 0.35 millimeters (mm). A D_{50} of 0.22 mm was first modeled, and showed relatively rapid beach movement, with tombolo formation (a deposition landform such as a spit or bar which forms a narrow piece of land) limiting the potential duration of the model run to about 4 years. Subsequently, a median grain size of 0.35 mm was modeled, and the less rapid sediment transport allowed for 10 years of wave conditions to be modeled.

Wave conditions were derived from the transformed WIS (Station 8) hindcast data, for years 1978 to 1987, with the four-year model run using 1984 to 1987 wave conditions. This is the most recent information available in the WIS (Station 8) hindcast.

The models assumed that the current low lake level conditions would be sustained for the indefinite future, as there is no evidence that the lake levels will be rising again anytime in the near future.