ERDC/CHL TR-12-16

Coastal and Hydraulics Laboratory

US Army Corps
of Engineers®
Engineer Research and
Development Center

Great Lakes Coastal Flood Study, 2012 Federal Inter-Agency Initiative

Lake Michigan: Prediction of Sand Beach and Dune Erosion for Flood Hazard Assessment

Bradley D. Johnson

August 2012

Great Lakes Coastal Flood Study, 2012
Federal Inter-Agency Initiative

ERDC/CHL TR-12-16
August 2012

Lake Michigan: Prediction of Sand Beach and Dune Erosion for Flood Hazard Assessment

Bradley D. Johnson

Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road,
Vicksburg, MS 39180-6199

U.S. DEPARTMENT OF HOMELAND SECURITY

FEMA

Great Lakes Coastal Flood Study, 2012 Federal Inter-Agency Initiative

Final report

Prepared for U.S. Army Corps of Engineers, Detroit District
Attention: CELRE-HH-E
P.O. Box 1027
Detroit, MI 48231-1027

Abstract

The present recommendations for dune removal or dune retreat on the Great Lakes for Federal Emergency Management Agency (FEMA) flood mapping purposes are based on a simple geometric method as outlined in FEMA (2009). The simple procedure establishes a relationship between dune survival and storm intensity. The method was adopted several decades ago when numerical models were inadequate for predicting beach profile change and dune retreat. Herein, a robust and efficient model for predicting nearshore waves, circulation, water levels, sediment transport, and nearshore morphology is provided as an option in replacing the geometric model. The numerical model is compared with results from the existing FEMA guidelines for storm-induced beach change at three sites with different nearshore characteristics. A typical storm with detailed modeled hydrodynamics has been used to provide a basis for boundary conditions, and use is made of scaling to approximate a variation in intensity. A change in water levels is also included in the analysis through a reasonable fluctuation of the static lake level. In general, the methodology in FEMA guidelines computes much larger eroded volume than the numerical model predictions. Additionally, the dependence of the volumes on recurrence interval is determined to be much stronger utilizing the FEMA method. Generalizations are difficult, however, and the predicted volume from the numerical model was larger for some cases of moderate storm intensity. The numerically predicted results were shown to depend on the details of both the subaqueous profiles and dune configuration, and simple universal predictions may suffer gross error.

Contents

Figures and Tables

Figures

Tables

Preface

This study has been supported by the Great Lakes Flood Hazard Mapping Study conducted by the U.S. Army Corps of Engineers Detroit District for the Federal Emergency Management Agency Region V. The work performed at CHL was under the general supervision of Dr. Ty V. Wamsley, Chief, Coastal Processes Branch; Bruce A. Ebersole, Chief, Coastal Flood and Storm Protection Division; and William R. Curtis, Technical Director for Flood and Coastal Storm Damage Reduction. The Director of the Coastal and Hydraulics Laboratory was Dr. William D. Martin.

COL Kevin J. Wilson was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was Director.

1 Introduction

The coast of Lake Michigan is a heterogeneous mix of rock and sand with variable nearshore morphology. Large stretches of the coast are comprised of deep sand beaches backed by expansive sand dunes. The east and southern coast of Lake Michigan, for instance, have wide beaches comprised of medium-sized sand. Essentially non-erodible coast is more typical on the north and west, including cliffs or rocky headlands and cobble beaches. The effort described herein is focused on predictions of storm-driven morphology change for the coast of Lake Michigan. The previously described variability in sediment and morphology makes simple generalizations about storm response difficult, and a numerical model is applied for beach profile change. The model CSHORE, introduced below, is a transect model that permits the specification of the actual beach profiles and sediment characteristics, thereby avoiding the ambiguity associated with the application of parametric models. In this focus study, an attempt is made to predict profile change under a range of realistic natural hydrodynamic conditions. A variation of storm surge and wave energy is included as primary independent parameters accompanied by a modulation of the lake level. In the following, the modeled profile response for three sites around Lake Michigan is provided. These results are compared with the predictions based on the present Federal Emergency Management Agency (FEMA) method for determining dune erosion and survivability.

The CSHORE numerical model has been under development for the past several years, approaching an efficient and accurate code that predicts beach evolution over the nearshore region. Computation times including nearshore morphology are typically 10^{-5} of the modeled time duration. The details of the CSHORE model are lengthy, and a full description of the development is available in Kobayashi et al. (2009). The combined wave and current model operates under the assumption of longshore uniformity and includes the effects of a wave roller and quadratic bottom shear stress. The numerical integration of the depth-averaged energy, momentum, and continuity equations results in predictions of wave height, water level, and wave-induced steady currents. The development of new and physically defensible sediment transport algorithms for a nearshore breaking wave environment has been the focus of the most recent research efforts. The model accounts for wave and current interaction, bedload, suspended load, and wave-related sediment transport. In a departure from conventional models that directly or indirectly relate transport to bottom shear, the CSHORE model represents total suspended sediment volume V_s with the expression

$$V_s = \frac{e_B D_B + e_f D_f}{\rho g (s-1) w_f} P_s \tag{1}$$

where e_B is the empirical efficiency of breaking, D_B is dissipation due to wave breaking, e_f is the empirical efficiency of bottom friction, D_f is the dissipation due to bottom friction, ρg is the unit weight of water, s is the sediment specific gravity, w_f is the grain fall velocity, and P_s represents the probability of sand suspension related to local turbulence levels.

Equation 1 is intuitively satisfying in that the transport is dependent on both bottom shear through D_f and the important wave breaking process through D_B. Laboratory investigations have indicated that efficiencies due to breaking and bottom shear are roughly 0.005 and 0.01, respectively. The cross-shore and longshore suspended sediment transport rates q_{sx} and q_{sy} are expressed as

$$q_{sx} = a\bar{U}V_s \qquad q_{sy} = \bar{V}V_s \tag{2}$$

where $\overline{U}$ and $\overline{V}$ are the cross-shore and longshore directed time-averaged velocities respectively, and a is an empirical suspended load parameter that accounts for onshore directed wave-related sediment transport through a reduction in the transport due to undertow. The laboratory scale efforts have indicated that $a \simeq 0.2$ is appropriate in the surf zone (Kobayashi et al. 2005).

The formulation for bedload has an inherent dependence on the energy dissipation for a wave-dominated nearshore environment. The simplified expression for cross-shore transport in the absence of longshore currents is given as

$$q_{bx} = \frac{b P_b {\sigma^3}_T}{g(s-1)} G_s \tag{3}$$

where b = empirical bedload parameter, P_b = probability of sediment movement under the wave and current velocity, σ_T = the standard deviation of the horizontal velocity G_s = empirical function of the bottom slope, and g = acceleration due to gravity. The full expression for cross-shore bedload including the secondary effect of longshore current is given in Kobayashi et al. (2009).

Throughout the development of the CSHORE model, the hydrodynamic and morphological change predictions have been calibrated and verified with approximately 20 large and small scale laboratory data sets. These include cases of beach erosion, wave overtopping, inundation, and equilibrium beaches with longshore transport. Recently, the model has been applied to natural beaches and storm conditions to determine the generality of the model formulation (Johnson et al. in press). Although the CSHORE model has a defensible physical basis, dependence on empirical parameters is inevitable in all practical sediment transport models. Model comparisons to the field data indicate that the storm-induced foreshore and dune change was well predicted by the model using the default model parameters (Johnson et al. 2009). Considering the complexity in predicting the morphological change, it is considered best if measured local storm response data are used to calibrate the model. Unfortunately, no appropriate storm-scale response data from the Great Lakes are available. Therefore, the following analysis is conducted with a set of default parameters as provided in Table 1.

Table 1. CSHORE sediment transport parameters.

e_B	0.005
e_f	0.01
a	0.2
b	0.001

2 Existing FEMA guidelines

FEMA has provided standardized methodologies for the computation of coastal hazard assessment for several decades. Inclusion of the effect of coastal erosion due to storms was introduced in 1986, and several updated methods have been provided subsequently. The present recommendations for dune removal or dune retreat on the Great Lakes are based on a simple geometric method as outlined in FEMA (2009). The simple procedure establishes a relationship between dune survival and storm intensity. For a storm event of 100 year return period, the FEMA method predicts dune survival if the cross-sectional area of the dune above the still-water elevation and seaward of the dune crest is larger than 540 ft^2. A generalization for the predictions for arbitrary recurrence intervals is provided in FEMA (2009) as

$$\begin{gathered} E_{WH} = 85.6\left[\text{RecurrenceInterval(yr)}\right]^{0.4} \\ E_{WL} = 85.6\left[\text{RecurrenceInterval(yr)}\right]^{0.4} \\ E_B = \sqrt{E_{WH} E_{WH}} \end{gathered} \qquad (4)$$

where the eroded areas E_{WH} and E_{WL}, are due to waves and water levels, and the total eroded area E_B is given in square feet. Along with the results of the CSHORE model, the predictions of eroded volume as a function of storm intensity for the demonstration sites are provided below.

Despite the simplicity of the geometric method, the application is complicated by uncertainty in properly specifying physical parameters that dictate, in part, the final eroded profile. For instance, the slopes of the post-storm profiles must be assumed, and guidance indicates the use of constant values without regard for grain size, storm characteristics, pre-storm geometry, etc. (FEMA 2007). Also, actual profiles deviate from the idealized dune model and are a source of ambiguity. In practice, a degree of flexibility is afforded in application of this model for site-specific factors and engineering judgment (FEMA 2007).

3 Demonstration sites

The morphological response evaluation will focus on representative measured profiles for the Great Lakes region using bathymetry data from three sandy beaches on Lake Michigan. Highly detailed LIDAR data are available for much of Lake Michigan from a 2008 US Army Corps of Engineers (USACE) National Coastal Mapping Program. Unfortunately, much of the north shore of the lake and the Green Bay water body was not covered in the LIDAR data set. The intention of this effort is to provide morphological prediction with the CSHORE transect model, so an attempt was made to choose locations with sandy shorelines and longshore uniformity. Three sites, each shown in Figure 1, provide the opportunity to examine morphological predictions over a range of nearshore profile types (see Figure 2).

The Holland, MI profile is typical of the east coast of Lake Michigan with barred beaches and high sandy bluffs. Storm response in this case is limited to bluff retreat and a flattening of the slope. The North Dunes Nature Preserve profile is characterized by a large dune with a crest elevation nearly 4 m above the mean lake level. Overtopping of this dune is possible for large storms, and the vulnerability is increased with an elevated lake level. The Cedar Grove beach exhibits multiple bars and a gently sloping nearshore bathymetry. The large primary dune is fronted by a lower dune with an elevation of 1.5 m above the mean lake level. Despite the protection of a dissipative beach, removal of this feature with a low crest and small volume is likely in large and moderate storms.

The use of a representative profile for a given a coastline reach is consistent with the FEMA (2009) guidelines. Naturally, this simplification is only appropriate for coastlines that have minor longshore variation. To show the degree of longshore non-uniformity for a demonstration site, the measured bathymetry near Holland, MI is depicted in Figure 3. The site is characterized by multiple bars at depths of approximately 3 m and 1.5 m. Although some degree of variation is evident, the assumptions of longshore uniformity are appropriate. For brevity, the other sites are not shown but demonstrate a similar uniformity.

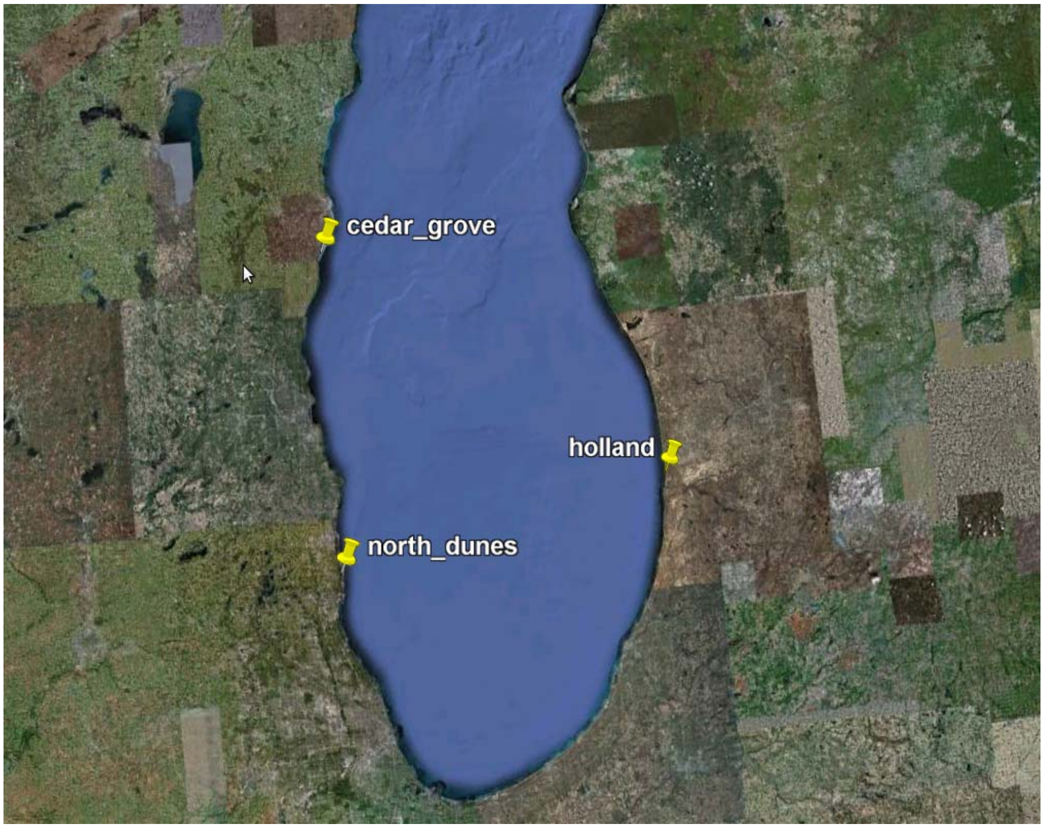

Figure 1. Three morphology modeling demonstration sites.

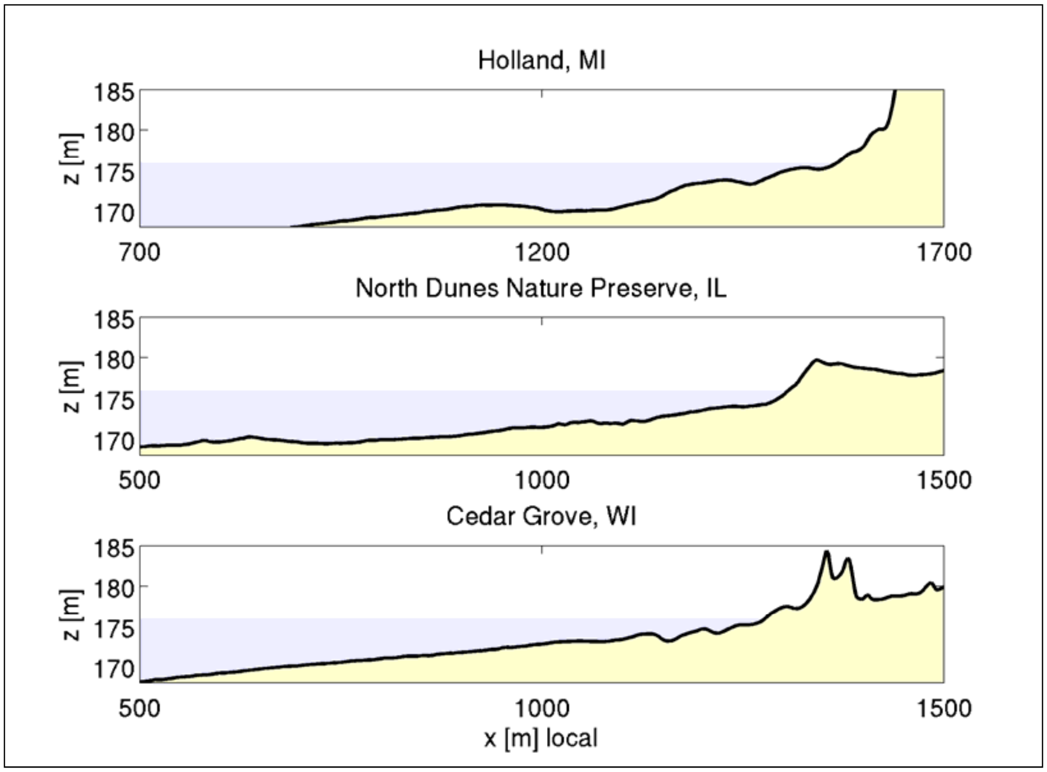

Figure 2. Representative beach profiles from three morphology modeling demonstration sites. Vertical datum – IGLD 1985.

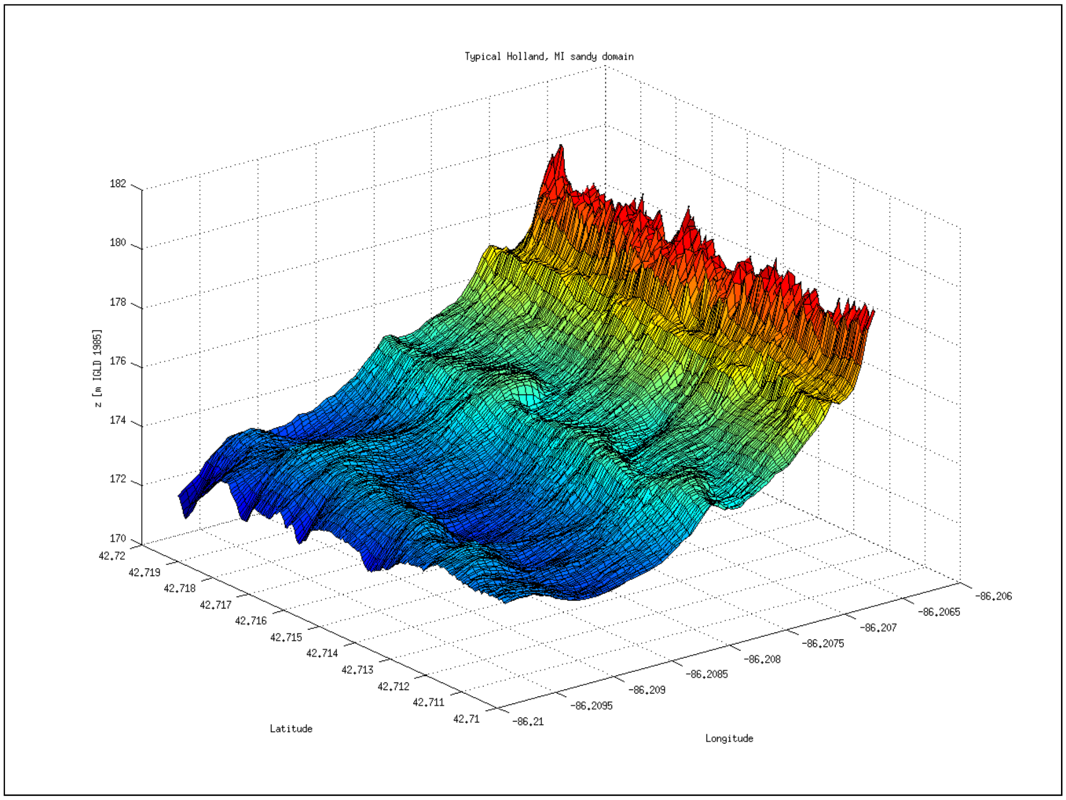

Figure 3. Holland, Michigan nearshore bathymetry.

4 Synthetic hydrodynamic conditions

The results provided herein are for purposes of model and method evaluation and should not be considered reliable results for details of a specific morphological response. Considering this objective, an attempt was made to use a range of storm conditions and lake levels and to examine the variation in model prediction. Naturally occurring storms have a multitude of characteristics but are commonly categorized by a scalar return period alone. Some variability in storms, however, can have an effect on morphological response. As an example, a storm of long duration will result in greater beach erosion than a fast-moving storm with identical return periods. To properly ascertain the model behavior for profile change without the ambiguity of using actual storm events, a set of simplifying assumptions in the specification of hydrodynamic condition is adopted. The hydrodynamic forcing is based on a single example of lake-scale model results for the storm of 9 December 2009. The details of the storm and the Lake Michigan modeling effort are provided in Jensen et al. (in press). The storm event is the 10th highest water level event over the record period at Holland, MI, and wave model results indicate an offshore H_{mo} wave height of more the 2.5 m. To provide a variation in recurrence intervals, the lake model results used as boundary conditions were scaled to the appropriate levels. The full details of storm selection and recurrence analysis are provided in Melby et al. (in press), and the appropriate relations for Holland, MI are utilized. The magnitudes of storm surge and wave height are provided in Figures 4 and 5, respectively.

Again, the storm specification is somewhat subjective, but the large December 2009 storm was selected as a basis with the intention to have a realistic storm hydrograph that can be appropriately scaled to provide the proper magnitude. A variation in wave energy to match the height and return period curves is achieved through a simple linear scaling. The wave height scaling, for instance, is depicted in Figure 6.

Scaled water levels are developed differently, where the peak surge is prescribed from the previously introduced surge-recurrence interval curves, but the excess surge is modified by a Gaussian window centered at the storm peak. The results, provided in Figure 7, show the time-variation of the excess surge for three cases.

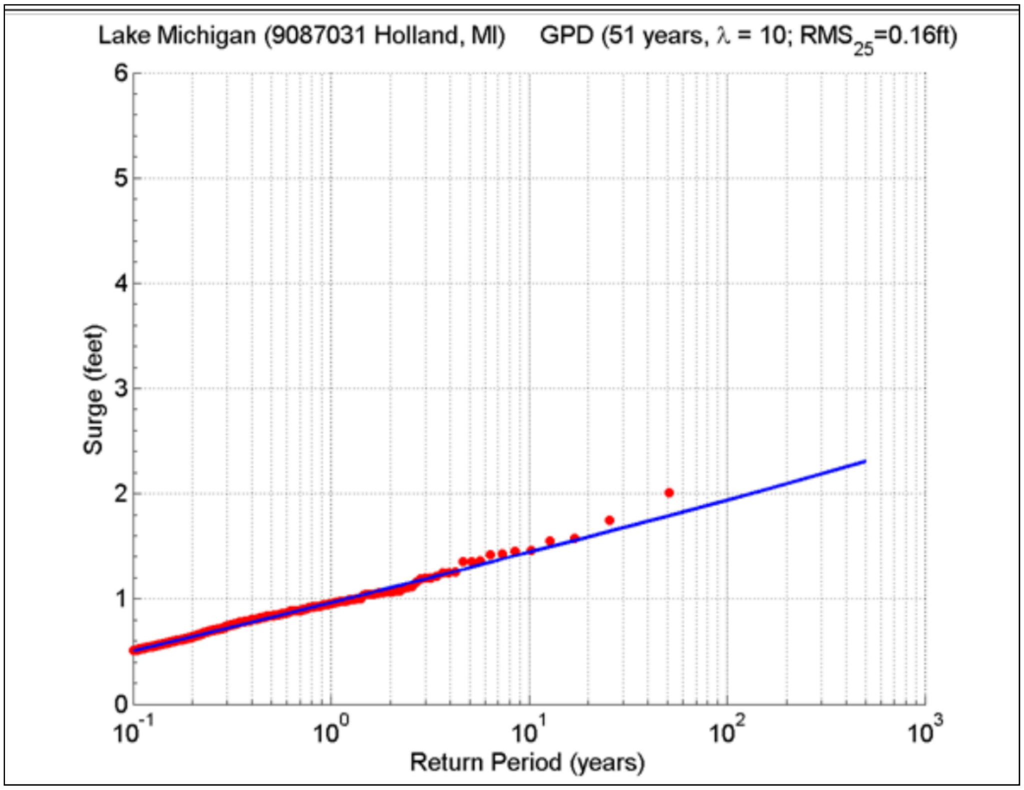

Figure 4. Storm surge magnitude and recurrence interval.

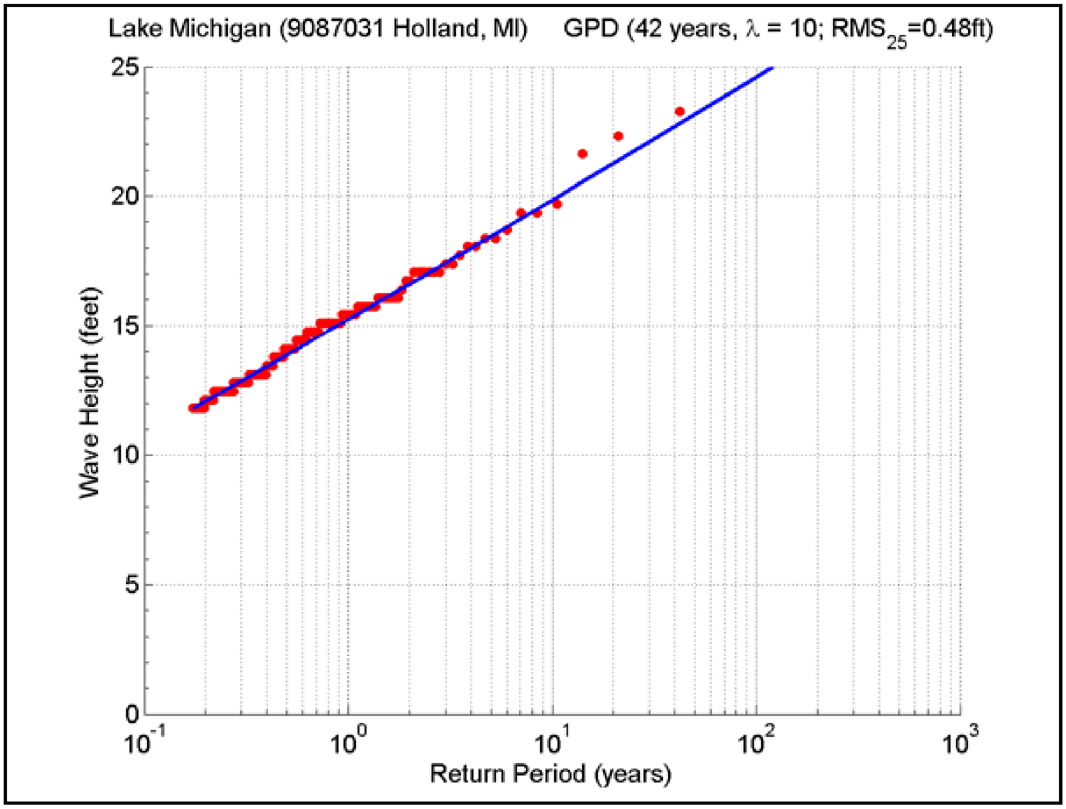

Figure 5. Wave height magnitude and recurrence interval.

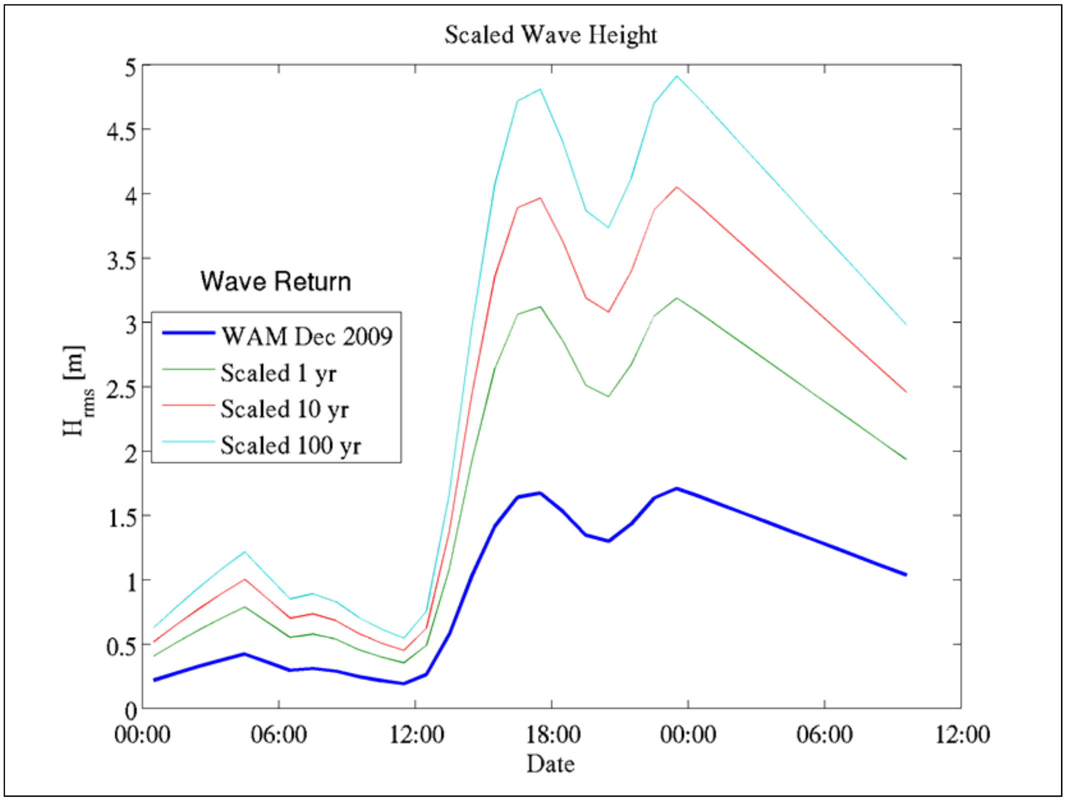

Figure 6. Synthetic wave height time-series.

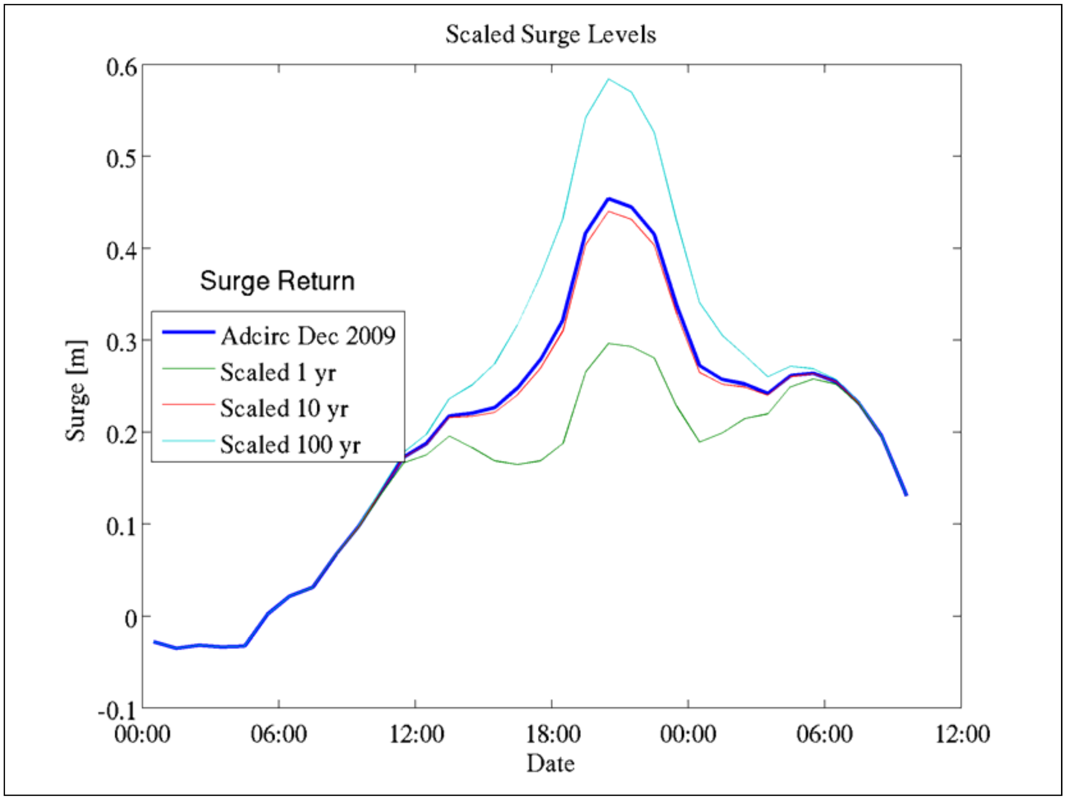

Figure 7. Synthetic surge time-series.

Recognizing the importance of water level in nearshore morphological response to storms, the previously introduced variations in waves and storm surge are applied to the demonstration sites for a range of lake levels. Again, the intention is to examine model response, and therefore no attempt has been made to alter the measured beach profiles in reaction to the lake level changes. The Lake Michigan water level has dropped over the past several decades and presently measures approximately 176 m IGLD85. This reduced level is approximately 0.5 m above the historic low measured in the 1960s. Conversely, high lake levels of more than 1 m above the present have been recorded numerous times over the past century. The CSHORE model is run for the present conditions with a lake level of 176 m IGDL85. Recognizing the inherent variability in the lake level, the following analysis also includes model predictions with a level that is increased by 1 m and a level lowered by 0.5 m.

5 CSHORE Model Results

With the suite of synthetic storm forcing conditions, the CSHORE model is applied for the range of conditions and lake levels at the three demonstration sites. For given hydrodynamic conditions, the sediment grain size is the principle factor in determination of nearshore sediment transport magnitude and profile shape (e.g. Dean and Dalrymple 2002). The sand grain size information for the sites was not available, however, and a single representative median diameter was used in obtaining all results. The FEMA method, on average, will be shown to predict larger eroded volumes when compared with the CSHORE results. To avoid exaggerating these differences with an unknown grain size, a fine grain sand with d_{50} = 0.2 mm is selected. This choice is consistent with the previous modeling study detailed in Nairn et al. (1997). It should be noted that the steeper slopes at the North Shore site are likely to be associated with a larger sediment size, although field data are not presently available and the variation is not considered herein.

Considering the numerous combinations of erosive storm conditions, presentation of the complete results for bathymetric response is not practical. To provide a sense of the typical finding, the predicted profile evolution with a storm of 100 year recurrence interval for waves and surge is provided herein. Figure 8 shows the predicted changes in the profiles at the present lake levels for three demonstration sites. In each case, the shoreline positions are relatively stable, but a general flattening of the nearshore slope is evident. The Holland, MI and Cedar Grove, WI profiles exhibit moderate dune erosion due to the dissipative bars that provide a measure of protection. The steeper beach in North Dunes, on the other hand, allows for greater wave penetration and has correspondingly greater dune erosion. It is also noted that the CSHORE model predicts moderate wave overtopping and dune crest lowering in this location.

Alterations in lake levels can have a dramatic effect on the characteristics of dune erosion, and the CSHORE model is applied to the demonstration sites to investigate the response to this variation. Figures 9 and 10 show nearshore morphological predictions for a reduced and an increased water level, respectively. For all demonstration sites, a lowered water level results in a reduction in wave energy in the inner surf and swash zones. Accordingly,

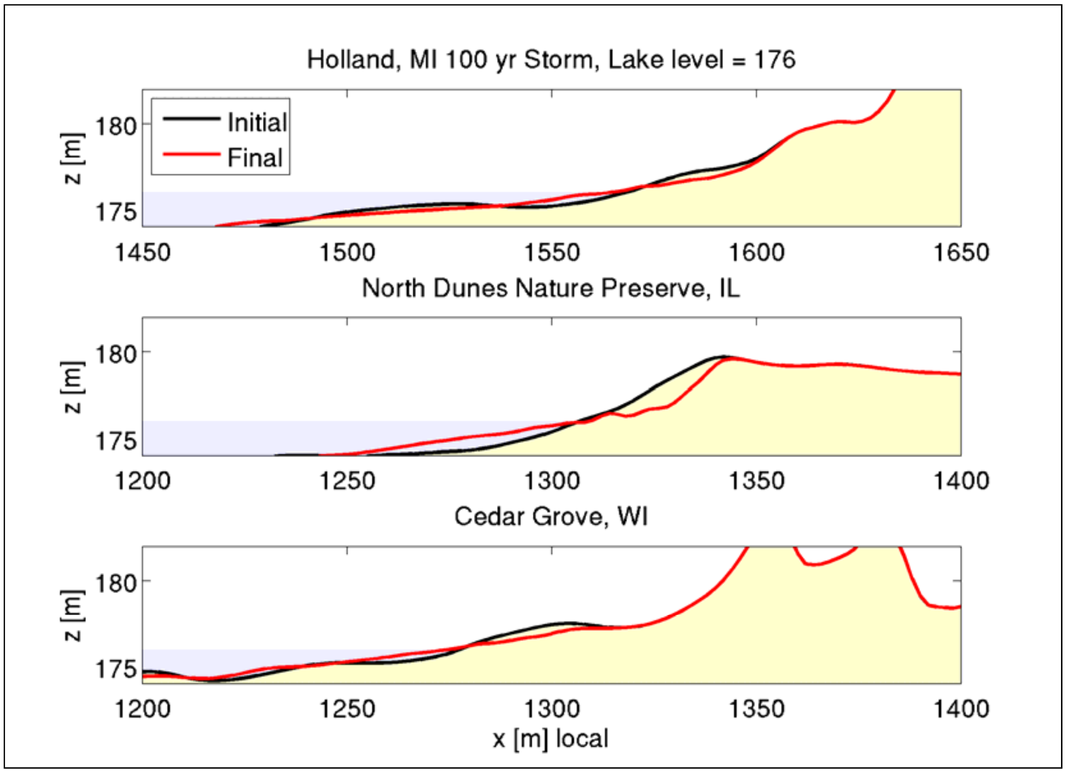

Figure 8. Predicted profile response with 100 year storm forcing and present lake level. Vertical datum – IGLD 1985.

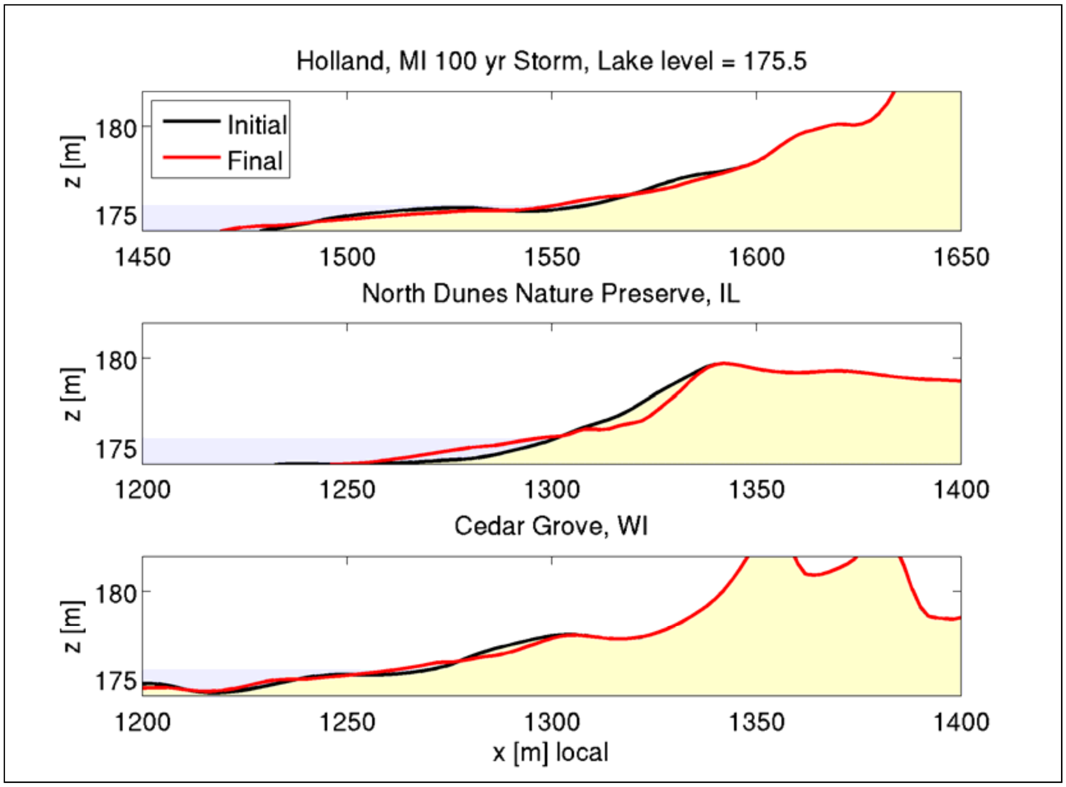

Figure 9. Predicted profile response with 100 year storm forcing and low lake level. Vertical datum – 1985.

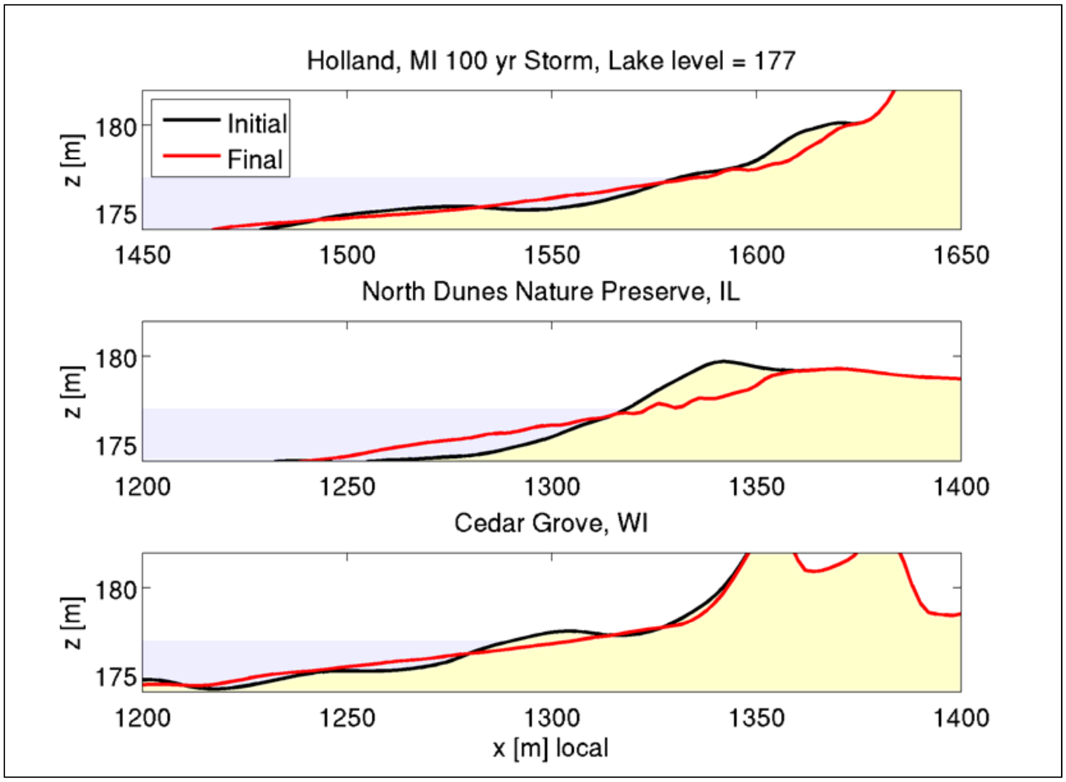

Figure 10. Predicted profile response with 100 year storm forcing and high lake level. Vertical datum – IGLD 1985.

the dune erosion and retreat is moderate when compared with the present water level cases. Even the small seaward secondary dune of Cedar Grove remains intact without a reduction in crest elevation with the lowered water level. Increased water levels, in contrast, result in predictions of markedly increased erosion. Sand from the dunes in Holland and Cedar Grove is transported seaward and produces a gently-sloping post-storm foreshore profile. A dramatic change is predicted for the North Dunes profile with the effective removal of the dune, where vertical beach lowering in excess of 2 m is predicted on the crest of the pre-storm dune.

The simple beach erosion guidelines used by FEMA are based on the empirically derived equation for erosion above the mean water level, as given in Equation 4. A comparison of the numerical model results and the FEMA method is provided over a wide range of storm wave and water levels. As previously mentioned, this analysis relies on the use of scaled storm hydrodynamics, and any particular storm may be vastly different from these synthetic storm conditions. Figure 11 shows the eroded volume above the lake level as predicted by the CSHORE model and by Equation 4 for the Holland, MI profile. Results are shown for a variation in both wave height and surge level recurrence intervals. Note that the results of the

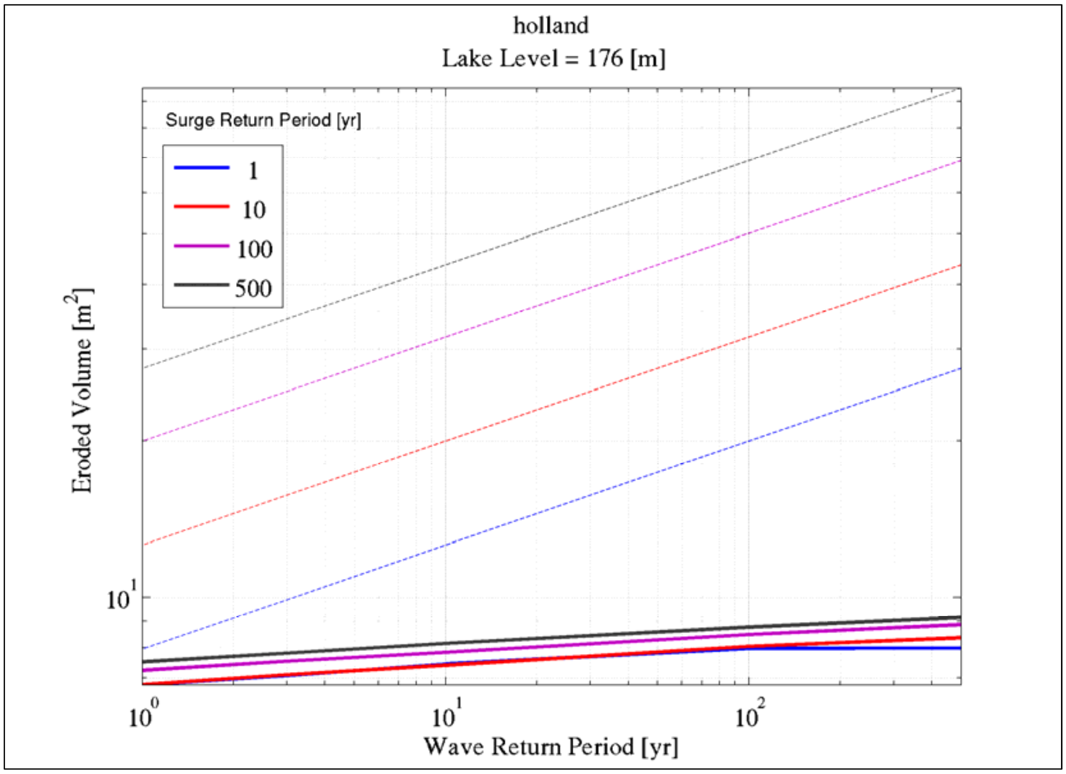

Figure 11. Predicted erosion volume above still water levels at Holland, MI using the present lake level. CSHORE predictions (thick solid lines) and FEMA results (dashed lines) are depicted.

FEMA method map to straight lines in the logarithmic plot, and 540 ft² is equal to approximately 50 m². The predictions of these two methods are markedly different both in magnitude and in functional dependence. For this case of large sandy dune of essentially infinite size, the FEMA guidance has eroded volumes that are approximately an order of magnitude larger than the numerically predicted volumes. The eroded volume of the 100 year storm, for instance, is predicted to be 50 and 8 m² applying the FEMA method and CSHORE model, respectively. Equation 4 has a direct functional dependence on recurrence interval. The CSHORE model, of course, has no similar explicit relation, but naturally exhibits increasing erosion volumes for larger events. Interestingly, the method disparity increases for larger storm waves and larger surge values, indicating that the strong dependence in Equation 4 is not inherent in the numerical model. It should also be noted that the numerical model results depicted in Figure 11 show a reduced slope for the most energetic storms where erosive conditions result in flatter beach profiles, and the wider dissipative beach acts to mitigate the dune retreat. In consequence, incremental increases in wave intensity result in smaller increases in eroded volumes. In contrast, the FEMA guidelines have no similar representation of profile flattening with reduction in erosive potential. This lack of fundamental underpinning in the present FEMA method may result in unreasonable results, especially when applied to energetic cases outside the range of the data sets used in the development of the empirical formula.

A notably different comparison of the methods is apparent in the North Dunes, case as shown in Figure 12. The eroded volumes for smaller events, both in terms of surge and wave height, are systematically smaller using the FEMA method. However, given the aforementioned differences in storm intensity dependence, the FEMA method predicts greater volumes for larger storms. The case depicted is for the present lake levels, and the large dune with ample volume does not undergo significant overwash. Essentially, the North Dunes and Holland profiles for the present lake level are similar cases in terms of sand supply, where sufficient sand is available and the supply is larger than the eroded volume. The substantial difference in the predicted erosion for these two sites is due to the steeper beach and the greater wave energy penetration into the inner surf at North Dunes. In short, the CSHORE differences in this case are almost entirely due to differences in the subaqueous profile. Conversely, the eroded volumes as predicted using the FEMA guidelines are constant for all cases with no dependency on profile shape.

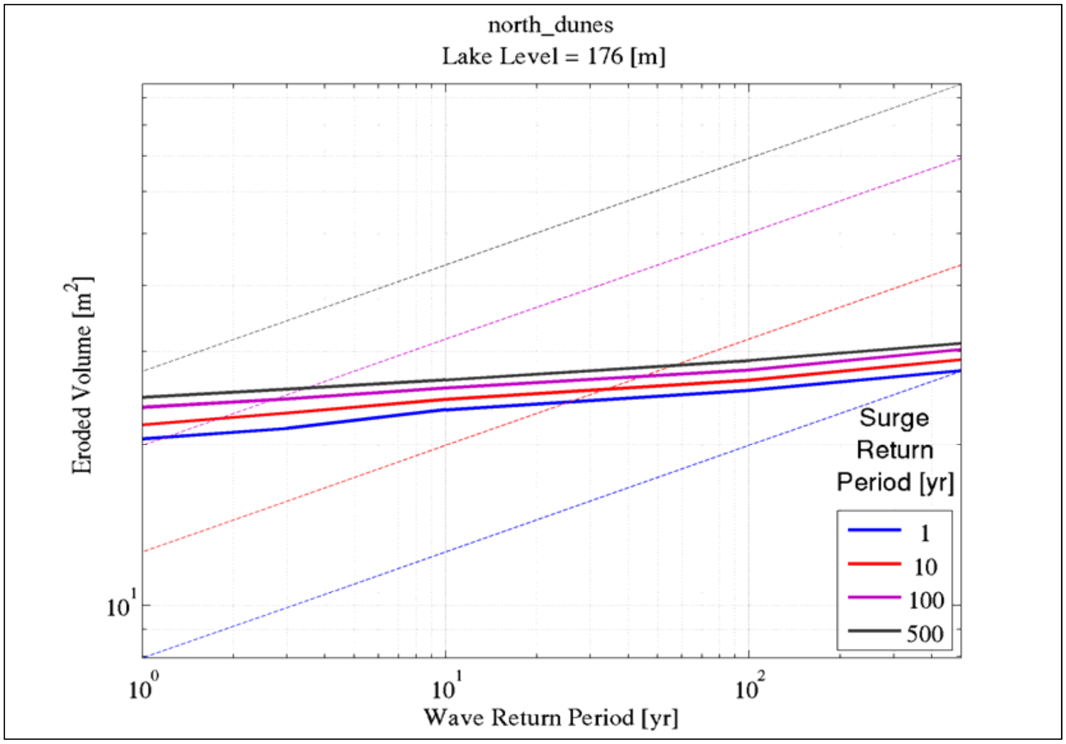

Figure 12. Predicted erosion volume above still water levels at North Dunes Nature Preserve using the present lake level. CSHORE predictions (thick solid lines) and FEMA results (dashed lines) are depicted.

The eroded volumes from the two methods at the Cedar Grove demonstration site are similar to the Holland case but are provided in Figure 13 for completeness. Again, the differences are moderate for smaller storm events and the disparity grows larger with greater intensity. For a 100 year storm event, for instance, the FEMA method predictions are nearly an order of magnitude larger than the CSHORE results. It is interesting to note the complex relations between volume and storm intensity computed by the CSHORE model. For instance, the eroded areas for low intensity storms do not have the expected dependency on surge recurrence. As seen in Figure 13, the predicted CSHORE results for the 1-year and 10-year surge levels are nearly identical. To interpret this finding, the details for these modeled profiles are provided in Figure 14 where results for the two surges using 10-year waves are shown. It is clear when examining the figure that the small fronting dune detailed in the second panel brings about the unexpected modeling trend. The smaller surge is sufficient to redistribute the sand from the vulnerable dune and create a gently sloping and stable foreshore. The larger storm also flattens the foreshore, but then the beach remains primarily static with the stable beach. Naturally, the surges associates with the 100- and 500-year events inundate this equilibrated foreshore and continue the erosion of the large backing dune. These results indicate the utility of a realistic numerical model in prediction of nearshore morphodynamics.

A similar analysis and comparison of the FEMA method and the CSHORE model is conducted with a realistic variation in lake levels. In general, a reduction in the level by 0.5 m results in a similar comparison. The FEMA method predictions are much larger, for instance, and the dependence on storm intensity is stronger. These findings are similar to the previously presented work, and they are omitted here for brevity. In contrast, an increase in the lake level can result in substantial differences. The results for Holland, MI are depicted in Figure 15. The magnitude is of similar order, in this case, but again the functional dependence is considerably different. The method comparison for North Dunes Nature Preserve is notable, where the FEMA method predicts a smaller eroded volume for most storm recurrence intervals, as shown in Figure 16. This finding is a striking departure from the other cases where the FEMA guidance typically results in larger estimates. Finally, the results at Cedar Grove, WI are similar to the previously presented cases. As shown in Figure 17, the FEMA values are substantially larger than those predicted with the CSHORE numerical model.

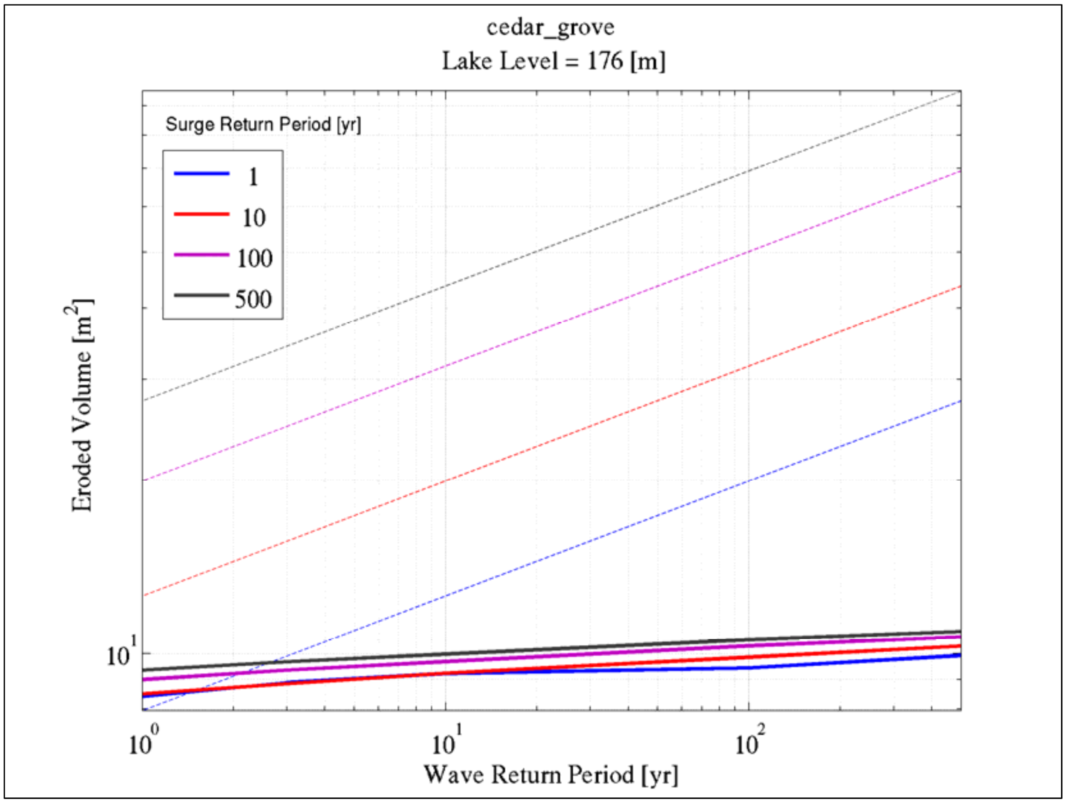

Figure 13. Predicted erosion volume above still water levels at Cedar Grove, WI using the present lake level. CSHORE predictions (thick solid lines) and FEMA results (dashed lines) are depicted.

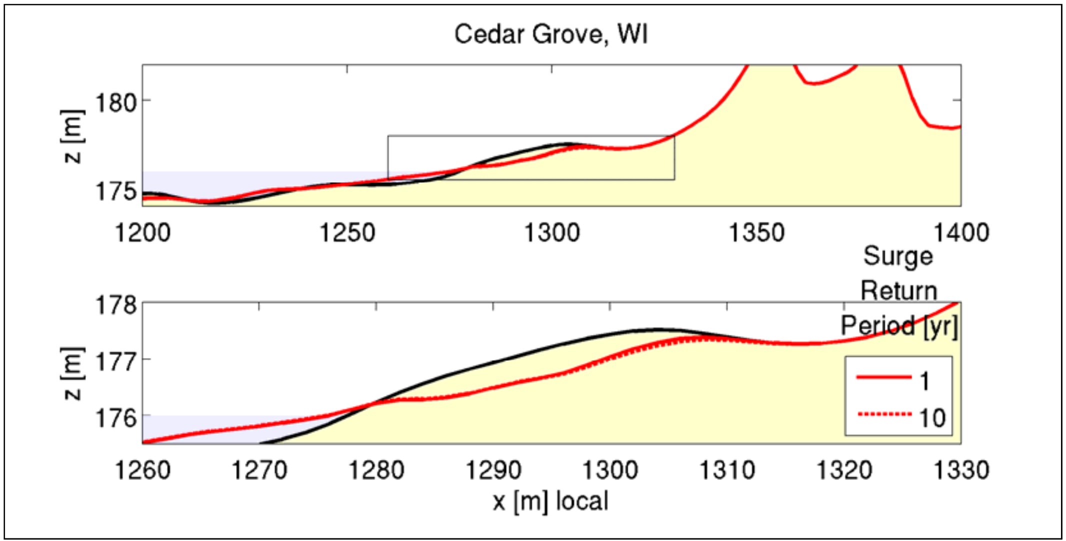

Figure 14. Eroded profiles for wave of 10-year recurrence interval. Vertical datum – IGLD 1985.

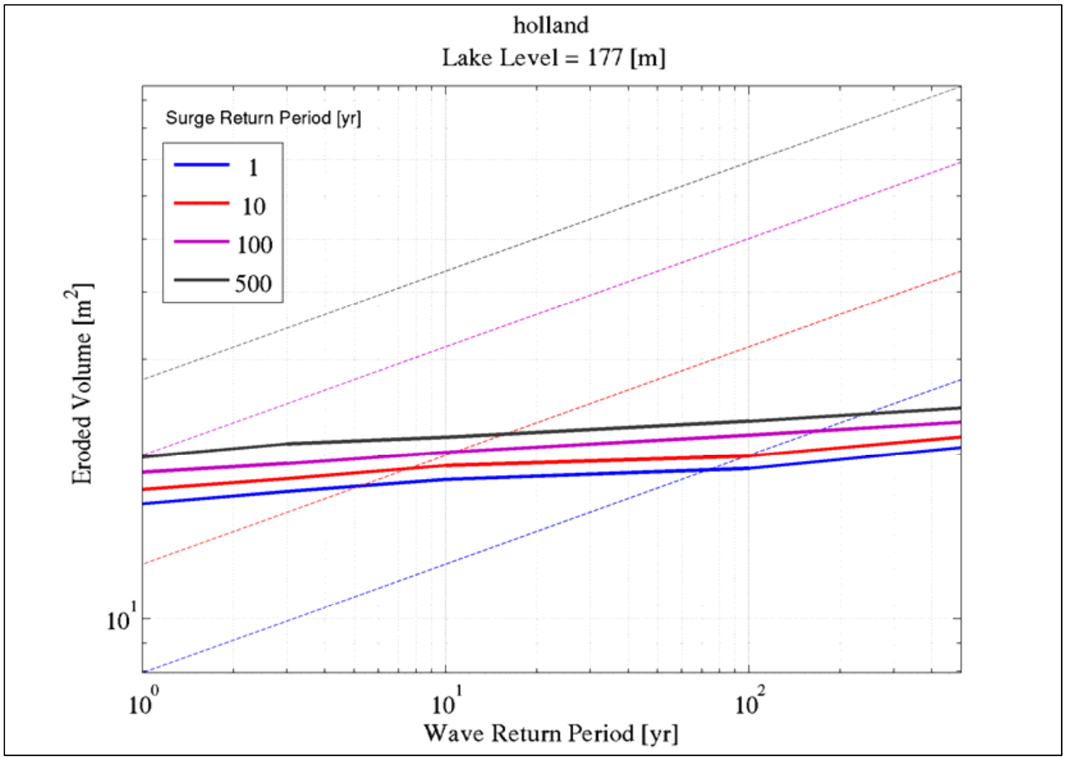

Figure 15. Predicted erosion volume above still water levels at Holland, MI using the elevated lake level. CSHORE predictions (thick solid lines) and FEMA results (dashed lines) are depicted.

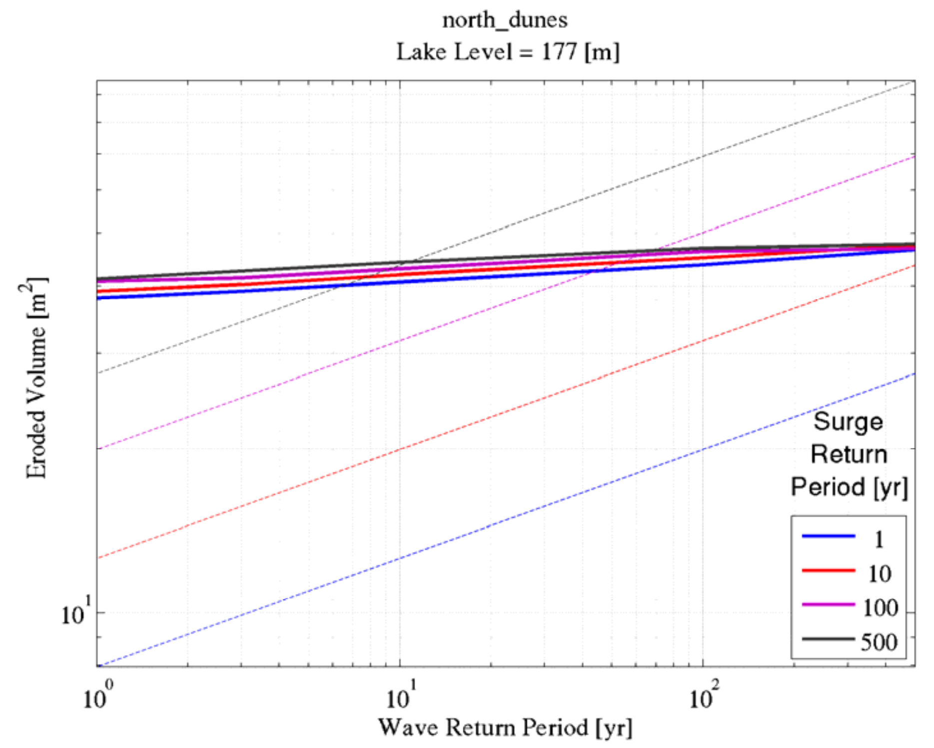

Figure 16. Predicted erosion volume above still water levels at North Dune Nature Preserve using the elevated lake level. CSHORE predictions (thick solid lines) and FEMA results (dashed lines) are depicted.

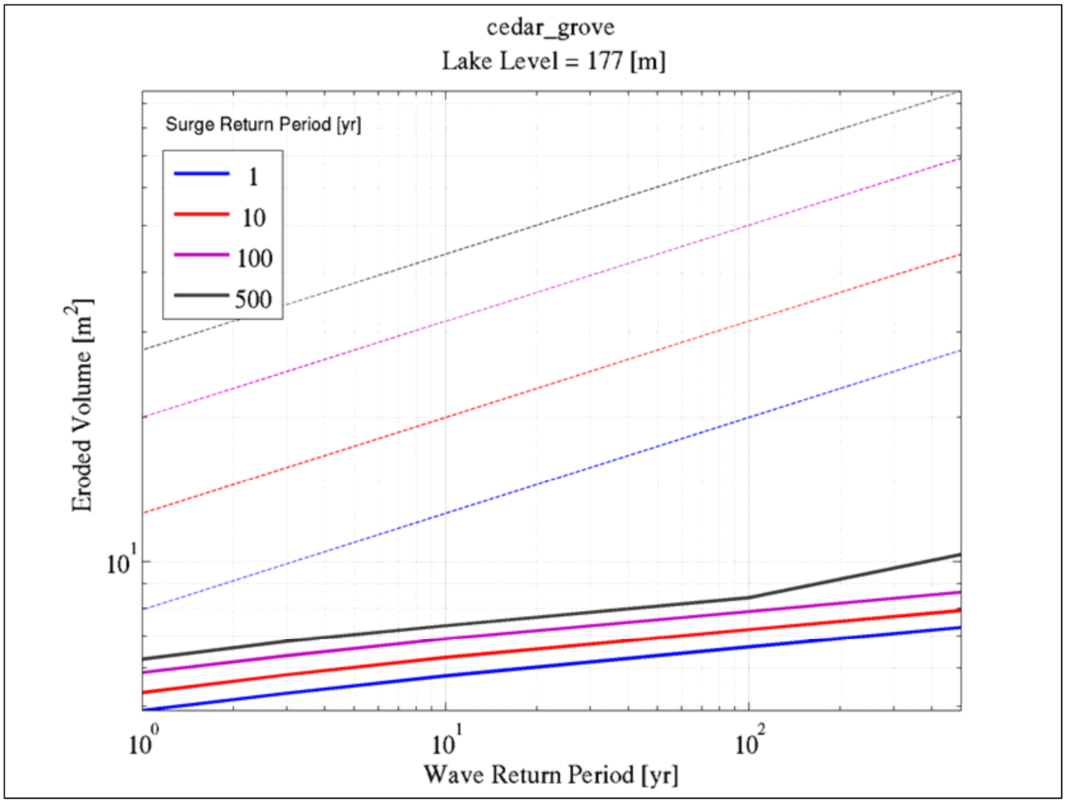

Figure 17. Predicted erosion volume above still water levels at Cedar Grove, WI using the elevated lake level. CSHORE predictions (thick solid lines) and FEMA results (dashed lines) are depicted.

6 Conclusions

The CSHORE model was based on a monolithic Fortran code that simultaneously predicts the wave field, circulation, water levels, sediment transport, and nearshore morphology. This transect model was robust and efficient, with computation times that are typically 10^{-5} of the storm duration. For instance, a 24 hour simulation for a single transect will take approximately 1 s on a modern computer core. The CSHORE model is compared to the existing FEMA guidelines for storm-induced beach change, which is a simple algebraic expression for eroded volume above the still water level. To facilitate the comparison with realistic beaches, three sites are introduced that exhibit different nearshore characteristics. A typical storm with detailed modeled hydrodynamics has been used to provide a basis for boundary conditions, and use is made of scaling to approximate a variation in intensity. A change in water levels is also included in the analysis through a reasonable fluctuation of the static lake level.

In a manner similar to the existing FEMA guidelines, the CSHORE model was applied on a cross-shore transect, taken as a line perpendicular to a defining contour, such as the mean lake level. The FEMA guidelines for eroded volume were, in many cases, much larger that the numerical model predictions. Additionally, the dependence of the volumes on recurrence interval was determined to be much stronger from the FEMA method. Generalizations were difficult, however, for this complex process. In fact, the CSHORE predicted results were larger for some cases of moderate storm intensity. The numerically predicted results were shown to depend on the details of both the subaqueous profiles and dune configuration. Simple universal predictions, such as the present FEMA method, may suffer gross error.

The presently used FEMA method were adopted several decades ago when numerical models were inadequate for predicting beach profile change and dune retreat. The progression in modeling technology has been significant, however, and the advantages in using a process-based model are generally recognized. The USACE recommends that the CSHORE model should be adopted in the Great Lakes remapping studies for calculation of storm-induced berm/dune erosion, including its use to assess the influence of erosion in determining wave runup, overtopping and dune degradation.

Some additional data are required in the application of the CSHORE model when compared with the present guidelines. Minimal sediment characteristics data are required, for instance. The sediment information can be obtained from a limited field campaign or can be inferred from the measured profile shape. CSHORE is readily applied to transect profiles from LIDAR data, and the model is appropriately initiated from lake-scale wave and water level predictions. With a basis in the physical processes, the CSHORE model can efficiently provide predictions of the hydrodynamics and morphology change across the nearshore region from outside of the surf zone to the upper swash.

References

Dean, R, and R. A. Dalrymple. 2002. Coastal Processes with Engineering Applications Cambridge University Press, New York; 475 pp.

FEMA . 2007. Coastal Hazard Analysis Modeling ProgramUsers Manual 2.0, http://www.fema.gov/plan/prevent/fhm/dl_champ.shtm.

FEMA . 2009. Great Lakes Coastal Guidelines Update. http://www.floodmaps.fema.gov/pdf/fhm/great_lakes_guidelines.pdf.

Jensen, R.E., M.A. Cialone, R. S. Chapman, B.A. Ebersole, M. Anderson, and L. Thomas. 2012. Lake Michigan: Storm Wave and Water Level Modeling. ERDC/CHL TR-12-X. Coastal and Hydraulics Laboratory, Engineer Research and Development Center, Vicksburg, MS.

Johnson, B., M. Gravens, T. Wamsley, and N. Kobayashi. 2009. A Predictive Model for Beach Profile Evolution. Proceedings of Coastal Dynamics 2009, Tokyo, Japan, Paper No. 64.

Johnson, B., N. Kobayashi, and M. Gravens. In Press. Cross-Shore Numerical Model CSHORE for Waves, Currents, Sediment Transport and Beach Profile Evolution. ERDC/CHL TR-12-x. Coastal and Hydraulics Laboratory, Engineer Research and Development Center, Vicksburg, MS.

Kobayashi, N., H. Zhao, and Y. Tega. 2005. Suspended Sand Transport in Surf Zones. Journal of Geophysical Research, 110, C12009, doi:10.1029/2004JC002853.

Kobayashi, N., A. Payo, and B.D. Johnson. 2009. Suspended Sand and Bed-load Transport on Beaches. Handbook of Coastal and Ocean Engineering, World Scientific, Singapore, Chapter 28, 807-823.

Melby, J.A., N.C. Nadal, and B. Ebersole. In Press. Lake Michigan and Lake St. Clair: Analysis of Wave Height and Water Level Variability. ERDC/CHL TR-12-x. Coastal and Hydraulics Laboratory, Engineer Research and Development Center, Vicksburg, MS.

Nairn, R,B., P. Zuzek, A. Morang, and L.E. Parson. 1997. Effectiveness of Beach Nourishment on Cohesive Shores, St. Joseph, Lake Michigan, US Army Corps of Engineers Technical Report Number: TR-CHL-97-15.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
August 2012

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Lake Michigan: Prediction of Sand Beach and Dune Erosion for Flood Hazard Assessment

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Bradley D. Johnson

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Coastal and Hydraulics Laboratory,
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road,
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC/CHL TR-12-16

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers, Detroit District
Attention: CELRE-HH-E
P.O. Box 1027
Detoit, MI 48231-1027

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The present recommendations for dune removal or dune retreat on the Great Lakes for Federal Emergency Management Agency (FEMA) flood mapping purposes are based on a simple geometric method as outlined in FEMA (2009). The simple procedure establishes a relationship between dune survival and storm intensity. The method was adopted several decades ago when numerical models were inadequate for predicting beach profile change and dune retreat. Herein, a robust and efficient model for predicting nearshore waves, circulation, water levels, sediment transport, and nearshore morphology is provided as an option in replacing the geometric model. The numerical model is compared with results from the existing FEMA guidelines for storm-induced beach change at three sites with different nearshore characteristics. A typical storm with detailed modeled hydrodynamics has been used to provide a basis for boundary conditions, and use is made of scaling to approximate a variation in intensity. A change in water levels is also included in the analysis through a reasonable fluctuation of the static lake level. In general, the methodology in FEMA guidelines computes much larger eroded volume than the numerical model predictions. Additionally, the dependence of the volumes on recurrence interval is determined to be much stronger utilizing the FEMA method. Generalizations are difficult, however, and the predicted volume from the numerical model was larger for some cases of moderate storm intensity. The numerically predicted results were shown to depend on the details of both the subaqueous profiles and dune configuration, and simple universal predictions may suffer gross error.

15. SUBJECT TERMS

	FEMA	Great Lakes
Beach erosion	Flood hazard	Lake Michigan
Dune erosion	Flood mapping	Storms

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON: Ty Wamsley**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
U	U	U	U	29	(601) 634-2099

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18