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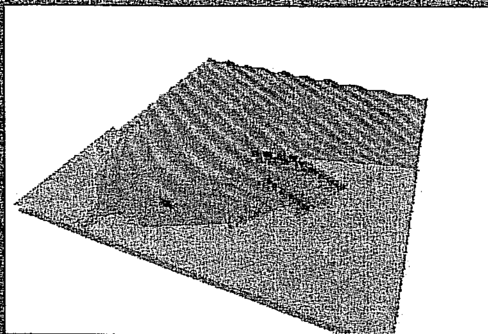

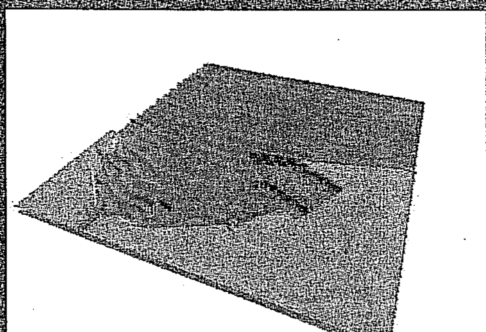

Boyne City, Michigan

Wave Climate Study

Draft Report
June 2005

The Abonmarche Group

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EXECUTIVE SUMMARY

Basis for Study

In January 2005, The Abonmarche Group (TAG) completed a Marina Master Plan for Boyne City F. Grant Moore Municipal Marina. In this Master Plan, several breakwater alternatives were presented. Michigan Department of Natural Resources (MDNR) requested that a computer modeling study be conducted to quantify the potential impacts of the various breakwater design alternatives. TAG and the University of Michigan utilized two computer models to determine the wave climate at the marina and to assist in the performance evaluation of the four breakwater alternatives. This report presents the findings of this study, which will be provided to MDNR, and any other regulatory agencies concerned with potential impacts of the proposed Harbor breakwaters.

Modeling Process

Two numerical computer models were utilized in this study, STWAVE and Bouss-2D. STWAVE is a large-scale model that computes significant wave heights. Bouss-2D is a smaller scale, but more precise model. STWAVE was utilized to obtain significant wave heights for all of Lake Charlevoix. These wave heights were then utilized as input files for Bouss-2D, focusing on the Harbor area.

Modeling Team

The modeling team is comprised of TAG (Dan Veriotti, P.E., Bradley R. Fausnacht, P.E., Ben Bifoss) and University of Michigan (Okey Nwogu, Ph.D.).

Modeling Methodology

The modeling process started with pre-modeling meetings attended by TAG staff and the City of Boyne City. Three fixed breakwater options, *Figure 5, Figure 7,* and *October 26,* were selected for modeling, as well as an additional floating breakwater layout, *Floating Attenuators*. Modeling methodology and protocol were determined and have been detailed in this study. Coordination on the computer modeling and study methodology with MDNR was necessary to select the most feasible study course of action. A design wave height of 1 ft is universally recognized as the largest allowable wave in a marina under normal conditions (ASCE). This value is the standard, which was utilized to apply the results of this study.

Model Results

The following is a summary of the results and the recommendations/conclusions made therefrom. Modeling was performed for average water level (579.0 IGLD85). The computer models employed showed that a very conservative incident significant wave height (2 ft with a 4-s period) would produce the worst-case impacts on the Marina Harbor. Two predominant incident wave directions (NW and W) were considered for the modeling. The NW direction represents the longest fetch over Lake Charlevoix (11 miles). The W direction has a fetch of only 2.3 miles, but directly impacts the Harbor area. The incident wave conditions were utilized with the four breakwater alternatives to determine the hydraulic impacts of each option. The analysis of modeling results shows that during the storms modeled, most of locations inside the marina basin exceed 1 foot significant wave heights for the existing marina configuration with and without the floating breakwaters. For the *Figure 5* layout, only the north side of the marina is well protected. The *Floating Attenuator* option performs in a similar way with the existing floating attenuators and provides adequate protection only to the north of the marina side. Both *Figure 7* and *October 26* provide wave heights inside the Marina of less than 1 foot under all conditions modeled.

Conclusion

Considering a boating criteria of 1 ft wave height or less inside the marina basin, *Figure 7* and *October* 26 layouts offer the best Harbor protection. These results were as expected, based on the geometry of these fixed breakwaters and the low transmission coefficient (ratio of incident wave amplitude to wave amplitude behind the structure). *Figure* 5 layout offers marginally adequate protection of the Harbor. This can be attributed to the short total length and curved geometry that allows propagation of wave energy along the structure inside the marina basin.

The *Floating Attenuators* alternative does not provide adequate Harbor protection at the study point locations. This is probably attributed to the 4-s period incident waves, which represents a worst-case scenario for the modeled storms. The structural response of a floating breakwater and the wave transmission coefficient quantify the performances of floating breakwaters. These parameters and the wave-incident dynamic pressures along the structure contribute to an undesirable transmission of wave energy inside the Marina. It was expected that the floating breakwater would not perform well with a 4-s period wave. However, during the normal boating season, for incident wave periods of 1-3 seconds, it is expected that the floating breakwater considered will provide adequate Harbor protection.

If a fixed breakwater is to be considered, either *Figure 7* or *October 26* meets design criteria. If a floating wave attenuator is to be considered, wave energy suppression expectations should not exceed the current conditions with the existing wave attenuators under the worst-case conditions.

I. INTRODUCTION

Situated at the very southeast end of Lake Charlevoix, Boyne City is the southern landside gateway of Lake Charlevoix (see Figure 1).

Boyne City operates the 42-slip Grant F. Moore Municipal Marina within Veteran's Memorial Park and a two-lane public boat launch off North Lake Street, approximately ¼ mile north of the marina. The City also maintains a "Shopper's Dock" for limited, short-term boat parking, just north of the mouth of the Boyne River.

In January 2005, TAG completed a Marina Master Plan for Boyne City. As a result of growing boating demand, Boyne City had retained TAG to complete the Master Plan to determine the feasibility of dock expansion. In this Master Plan, several dock layouts and breakwater alternatives for protection were presented. TAG and the University of Michigan utilized two computer models to determine the hydraulic impacts of three fixed breakwater alternatives and one floating breakwater. The alternatives analyzed are described as *Figure 5, Figure 7, October 26,* and *Floating Attenuator* (See Appendix B).

This report summarizes the modeling process, the methodology utilized, the results of the model and the conclusions and recommendations of TAG.

The effects of the proposed breakwater structures were analyzed utilizing two numerical computer models, Steady State Spectral Wave (STWAVE) and Bouss-2D.

Both models are utilized to study wave propagation and transformation in harbors and other near shore conditions. Bouss-2D is based on the depth-integrated, Boussinesq-type equations. STWAVE is a phase-averaged model, i.e. it assumes that changes in phase-averaged wave properties vary slowly over distances of the order of a wavelength.

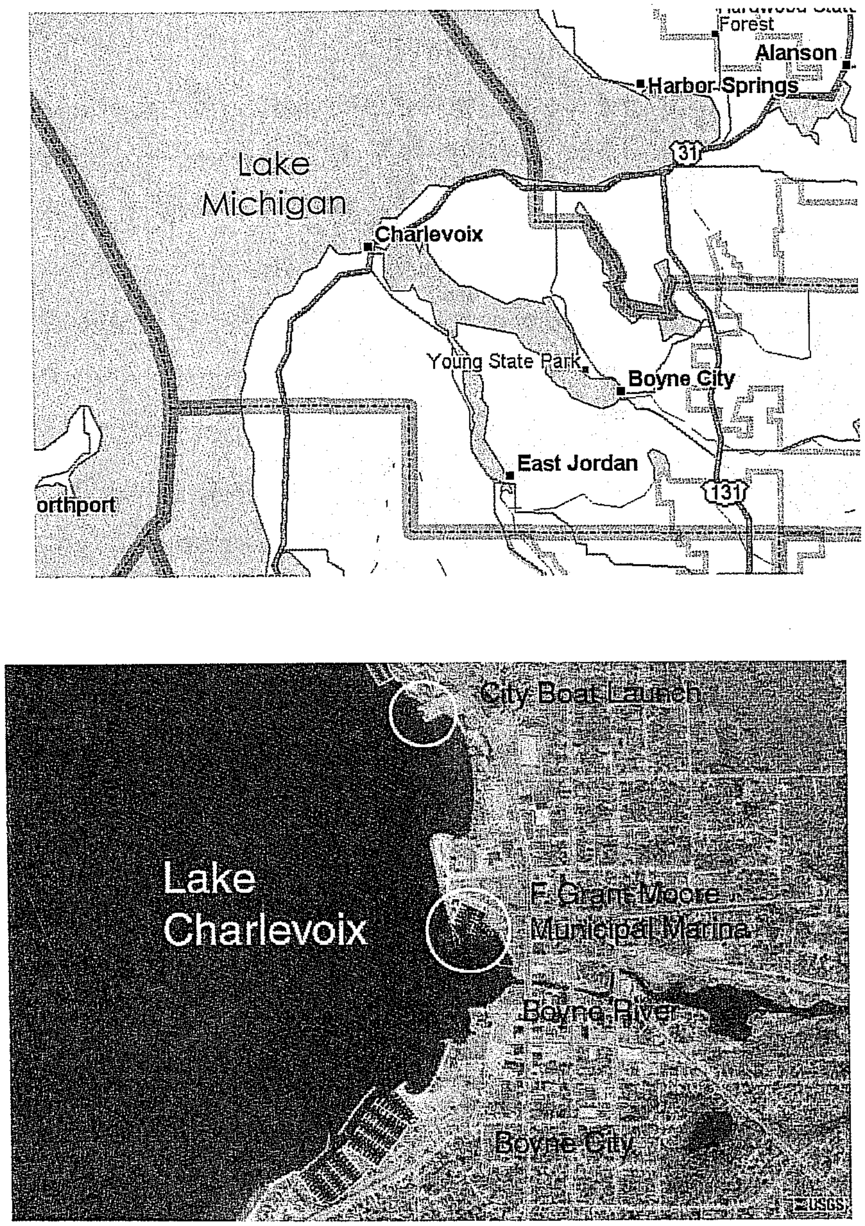


Figure 1 Location Map

Friday, March 03, 2006.max

II. MODELING DESCRIPTION

A. STWAVE

STWAVE, a spectral wind-wave model based on wave action conservation equation developed by the U.S. Army Corps of Engineers (Smith et al., 1999), was utilized in this project to predict the wind-generated wave climate over Lake Charlevoix. The model includes the effect of local wave generation due to wind; shoaling and refraction due to changes in bottom topography; energy dissipation due to wave breaking and bottom friction; and wave-current interaction. It is ideally suited to simulating wave propagation in open water where the processes of wind input, shoaling and refraction are dominant. STWAVE is also able to describe the effects of wave-current interaction and depth-induced breaking.

STWAVE utilizes a one-dimensional wave spectrum to determine the wave heights, at various locations. The spectrum is the distribution of energy density as a function of frequency. The area under the spectrum is equal to ¼ the wave height. To determine the wave dispersion relationship, the model utilizes a system of equations derived from the Linear Wave Theory.

The following assumptions are made with the STWAVE numerical model:

1. Mild bottom slope and negligible wave reflection
2. Spatially homogeneous offshore wave conditions
3. Steady-state waves, currents, and winds
4. Linear refraction and shoaling
5. Depth-uniform current
6. Bottom friction is neglected

These assumptions are generally valid for Lake Charlevoix.

There are three necessary input files for STWAVE, which consist of model parameters, bathymetry, and incident wave spectra. A rectangular grid is utilized to define the project area.

The bathymetry of Lake Charlevoix for the wind-wave model simulations was created using data retrieved from NOAA ENC® Direct to GIS data explorer at NOAA's National Ocean Service's (NOS) web site (http://nosdataexplorer.noaa.gov/nosdataexplorer). The grid covers an 11.6 mile by 10.1 mile region extending from 85.25°W to 85.02°W and 45.2°N to 44.32°N, at a resolution of 164 ft as shown in Figure 2. The bathymetry in the area close to the marina was supplemented with hydrographic survey data provided by TAG. The maximum water depth in the lake is about 121ft.

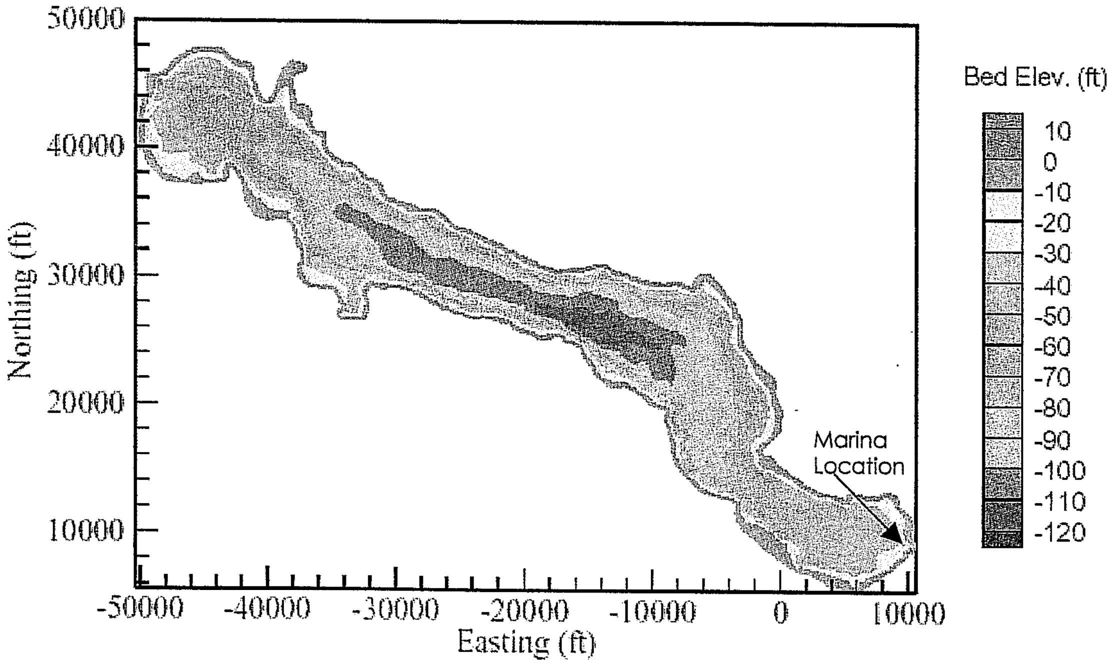


Figure 2. Lake Charlevoix Bathymetry Interpolated from NOAA Hydrographic Chart 14942 and TAG Survey

B. Bouss-2D

Bouss-2D, a wave propagation and reflection/diffraction analysis model, was also utilized in this study. This 2-Dimensional mathematical model utilizes Boussinesq equations originally derived by Peregrine and expanded by Nwogu and Wei, Kirbi, Grilli and Subramanya. The equations represent the depth-integrated equations for the conservation of mass and momentum for weakly nonlinear waves propagating in intermediate and shallow water depths. The model can simulate most of the wave transformation phenomena of interest in coastal regions and harbors including shoaling, refraction, diffraction, reflection, nonlinear wave-wave interactions, wave breaking and wave-induced currents. It is worthwhile to note that STWAVE has limited capabilities for modeling all these near shore wave processes.

BOUSS-2D solves the governing equations expressed in terms of the water surface elevation and two components of the horizontal velocity at a specified depth below the still water level using a time-domain, finite difference method (Nwogu and Demirbilek, 2001). The area of interest is discretized using a rectangular grid with the equation variables defined at every grid point in a staggered manner. Along offshore or internal generation boundaries, time histories of velocity fluxes corresponding to an incident storm condition are input. The incident wave conditions may be periodic or non-periodic, unidirectional or multidirectional.

Damping layers are placed around the perimeter of the computational domain to absorb outgoing waves. Damping and porosity layers are also used to model the reflection and transmission characteristics of breakwaters and harbor structures. The damping and porosity characteristics are initially calibrated in a one-dimensional numerical flume to match the desired reflection and transmission characteristics of breakwaters and harbor structures.

The bathymetry for the detailed marina wave model study was generated from hydrographic survey data provided by TAG. The soundings data were triangulated and interpolated onto a rectangular grid with uniform grid spacing of 3.3 ft. The grid covered a 1480 ft by 1300 ft area bounded by State Planar Coordinates 9200 to 10680 ft Easting and 8890 to 10190 ft Northing. Figures 3 and 4 respectively show 2-D and 3-D views of the bathymetry used for the near-field wave simulations.

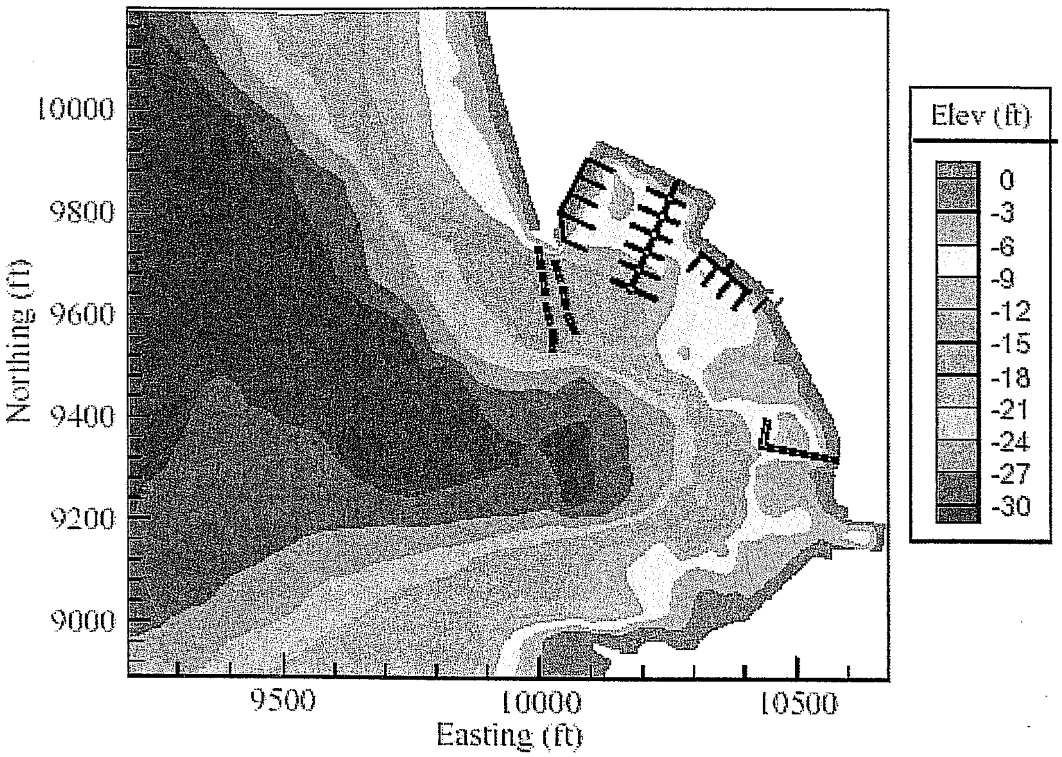


Figure 3. 2-D Map of Bathymetry used in Bouss-2D

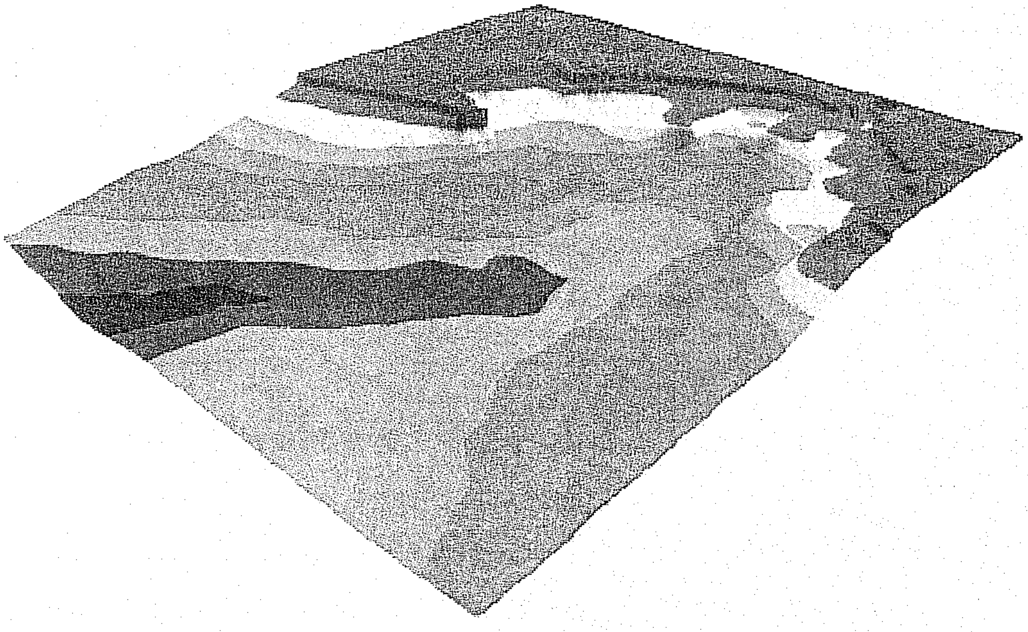


Figure 4. 3-D Map of Bathymetry used in Bouss-2D

III. MODELING METHODOLOGY

A. Breakwater Alternatives

As mentioned, the breakwater alternatives to be modeled were *Figure 5, Figure 7, October 26,* and *Floating Attenuator*. A comparison of these alternatives follows.

- *Figure 5:* This is a fixed breakwater, with two attached sections, north and south. The south allows for protection of proposed slips on the southern shoreline. The north provides better protection for the existing slips as well as additional proposed slips. The north section is approximately 300 feet long and the south section is 80 feet long.
- *Figure 7:* This fixed breakwater also allows for better protection of the marina as well as the addition of slips. There are two sections, north (580 feet) and south (80 feet). The north section is longer and thus provides protection of more of the Harbor area than *Figure 5*. It also allows for better utilization of the water area available behind the structure.

- *October 26:* This is a fixed breakwater, which is similar to the first two in that it has two sections (north: 840 feet long and south: 80 feet long) and allows for dock expansion. However, this option keeps a large entrance to the marina, but begins farther north on the shoreline in an area, which the marina does not currently utilize. This option has slips on the shoreline as well as on the breakwater's inner side.

The fixed alternatives involved the use of a double wall sheet-pile breakwater with a sand fill. Riprap protection is used to minimize wave reflection on the seaward side, while the walls on the marina side are fully reflecting. The seaward side will dissipate wave energy through absorption (turbulent run-up within and over the armor layer). Some of the remaining energy is converted to potential energy and also reflected seaward. The balance is transmitted to the leeward (marina) side. A sketch of the typical breakwater cross-section is shown in Figure 5.

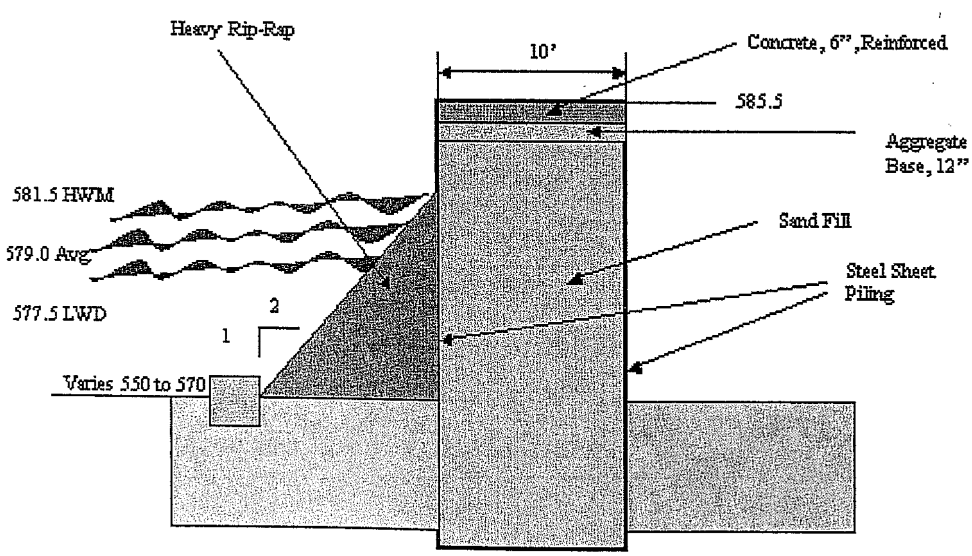


Figure 5. Typical Sheet-Pile Breakwater Cross-Section

- *Floating Attenuator:* This is a floating breakwater, 740 feet long. This alternative would keep the *October 26* layout slip configuration. These breakwaters are partially submerged structures, attached to the water bottom with different systems. They represent an economic alternative to the fixed breakwaters and they can be effective for attenuating moderate wave heights (as proven by previous modeling studies and field testing), with a practical limit for design wave period of 4 to 6 seconds. A picture of a typical floating breakwater is shown below.

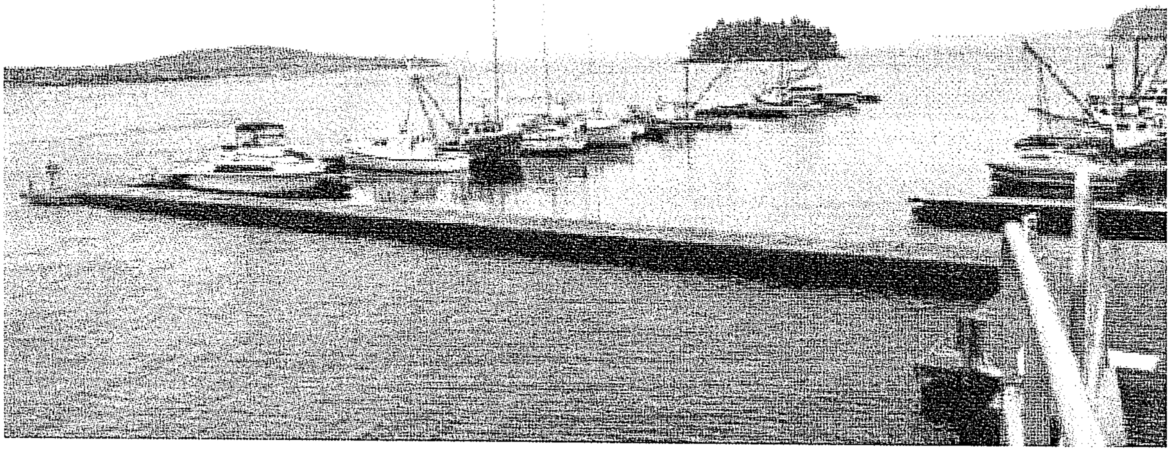


Figure 6. Typical Floating Breakwater

The Floating Attenuator option involves the use of 10-ft wide by 6-ft draft sections. Its reflection and transmission characteristics were evaluated using the boundary element code of Isaacson and Nwogu (1987) and plotted in Figure 7. The breakwater is effective (transmission coefficient < 50%) for incident wave periods less than 3.5-s. The transmission coefficient increases to 60% for extreme storm events with periods greater than 4-s.

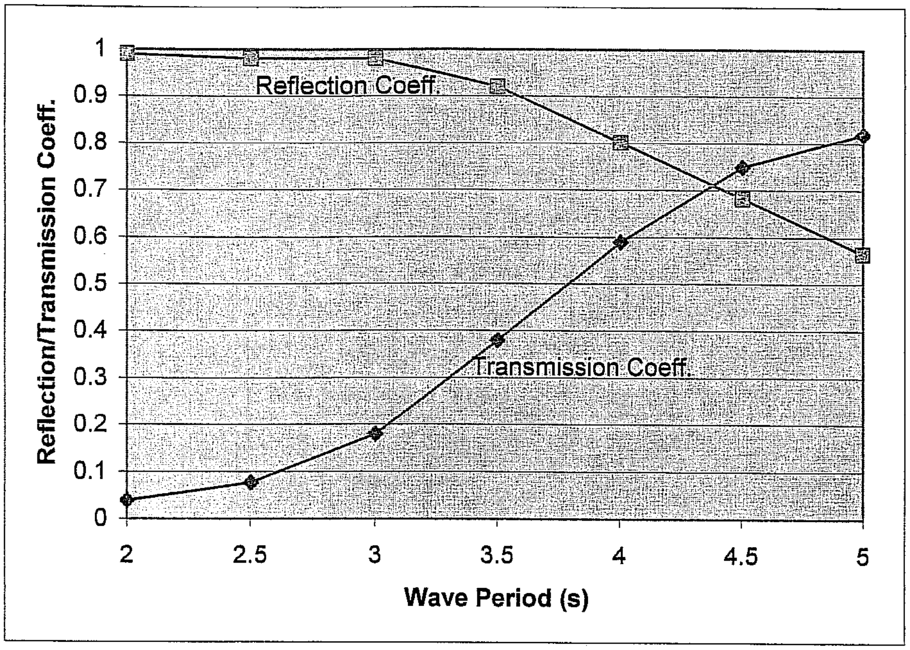


Figure 7. Reflection and Transmission Coefficients for a Rectangular Floating Breakwater (Beam = 10 ft, Draft=6 ft) in 20 ft of Water

Boyne City Marina is currently protected by seven rectangular floating attenuators, shown in Figure 8. The 2-D boundary element code (Isaacson and Nwogu, 1987) was utilized to evaluate the existing Boyne City floating attenuator performance as a function of wave period. Figure 9 shows a plot of the calculated reflected and transmission coefficients. Based on this, the existing Boyne City floating attenuator is relatively effective (transmission coefficient < 50%) for wave periods less than about 2.5-s but becomes ineffective (transmission coefficient > 90%) for long waves (T > 4-s) associated with extreme storm events.

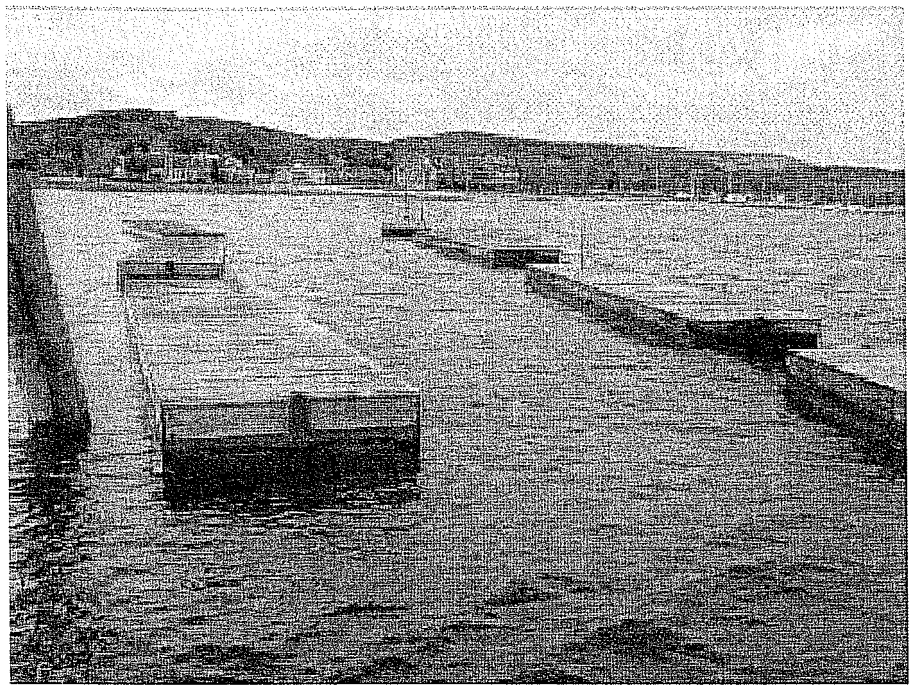


Figure 8. Picture of Existing Floating Attenuators

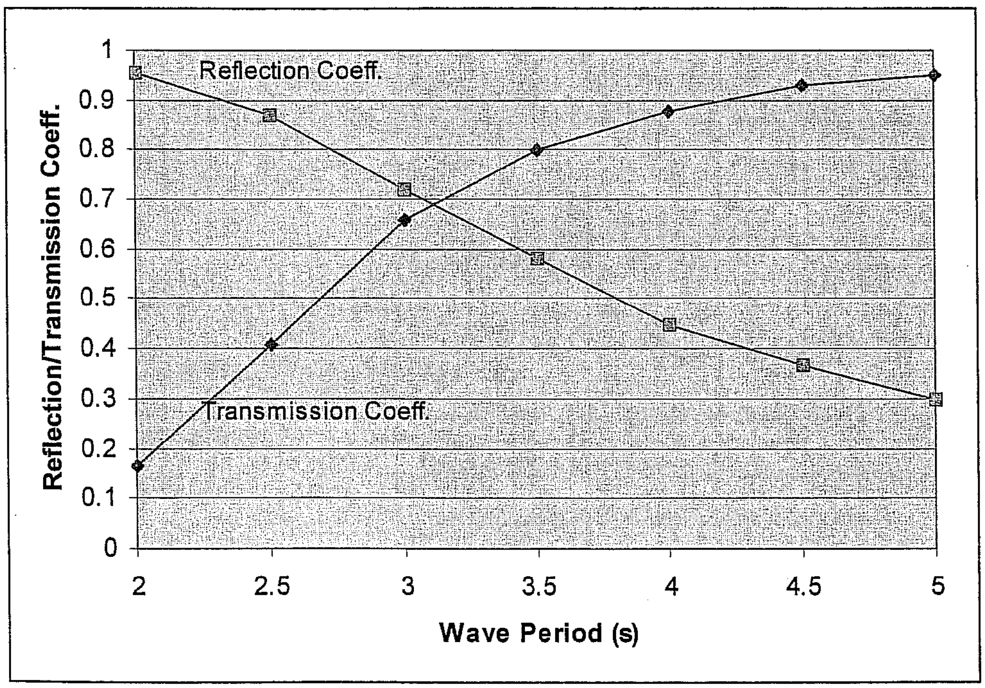


Figure 9. Reflection and Transmission Coefficients for a Rectangular Floating Breakwater in 20 ft of Water

B. Bathymetric Data

As mentioned, the bathymetric data utilized to characterize the existing conditions of the project area was adapted from NOAA and TAG surveys (Appendix C). The TAG survey was conducted in November of 2004 with transects spaced at 50 ft. This data was utilized as input data in the computer models.

C. Wind/Wave Climatology

Since there are no wave measurement stations within Lake Charlevoix, the local wind-generated wave climate at the marina had to be hind-cast from long-term wind data obtained from a nearby airport at Traverse City, MI (Station 14850: 44.741°N, 85.582°W). The wind data over an eight-year time period from 1984 to 1992 was analyzed to establish the percentage occurrences of wind speed for different wind speed ranges as presented in Figure 10. The associated wind-rose diagram showing both speed and directional relationships is shown in Figure 11.

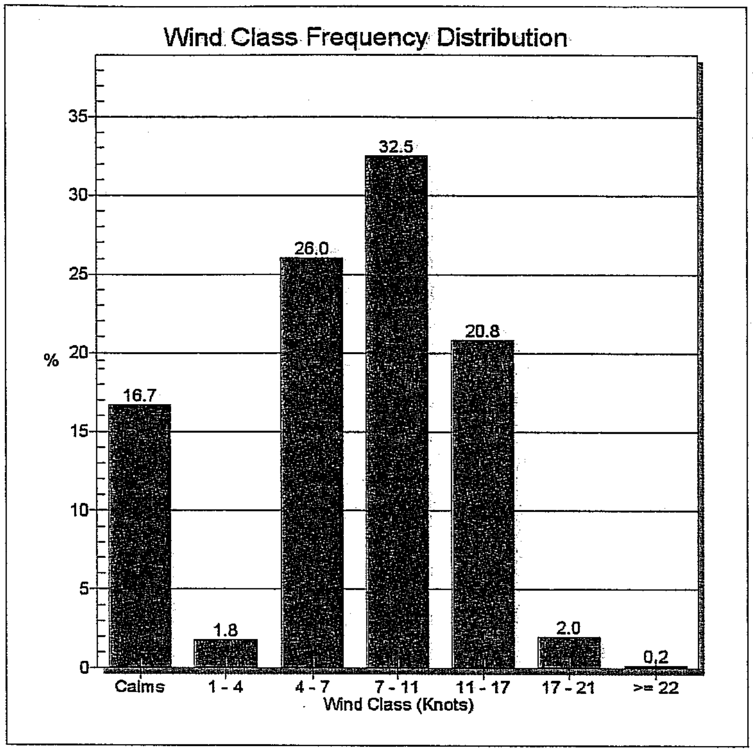


Figure 10. Wind Class Frequency (1984-1992/Airport Traverse City)

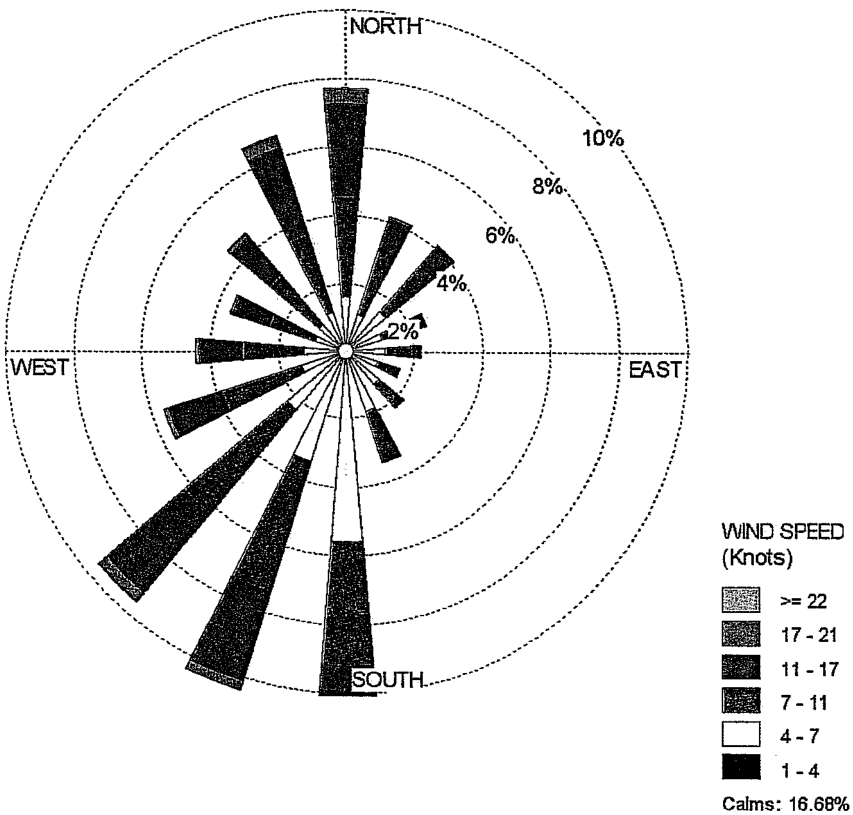


Figure 11. Wind Rose Plot at Traverse City Airport (10 years)

According to Figure 11, the predominant wind directions are from the south/southwest quadrants, while the highest speeds are recorded from the south direction.

Figure 10 shows that the recorded winds near the project area are most frequently 7-11 knots, and over 75% of the wind speeds are between 4-17 knots. Approximately 2% of the wind speeds recorded are 17-21 knots and only 0.2% are greater than 22 knots. However, in order to be conservative with the modeling, two wind speeds were selected: 20 and 40 knots. The most conservative modeling results produced by the 40-knot wind speed was selected.

IV. MODEL RESULTS

A. STWAVE

Given the orientation of Lake Charlevoix, it is anticipated that only winds from the W to NNW sector will generate any significant wave activity at the marina location due to the available fetch. Winds from the W to NNW occurred approximately 19% of the time. The model was initially run for a wind speed of 20 knots and wind directions of W30°N, W36°N, W40°N, W45°N, W50°N, W55°N, W60°N and W65°N to establish the wind direction that generates the largest wave height at the marina location. The predicted maximum significant wave heights and associated spectral peak periods close to the project site are summarized in Table 1. In general, wind directions below W30°N generated relatively little wave activity at the marina location due to the shape of lake and fetch blockage effects. The maximum wave heights were associated with wind directions from W35°N to W40°N.

Wind Direction	H_s (ft)	T_p (s)
W35°N	0.24	2.50
W36°N	0.62	3.16
W40°N	0.62	3.11
W45°N	0.55	2.89
W50°N	0.51	2.82
W55°N	0.43	2.74
W60°N	0.34	2.67
W65°N	0.29	2.56

Table 1. Predicted Significant Wave Height and Spectral Peak Period versus Wind Direction for 20-knot Winds

STWAVE was also run for an extreme storm event with a wind speed of 40 knots and direction of W36°N. A 2-D map of the significant wave height distribution over the lake is shown in Figure 12. A view of the wave height distribution and wave directions close to the marina site is shown in Figure 13. The complete set of STWAVE results can be found in Appendix D.

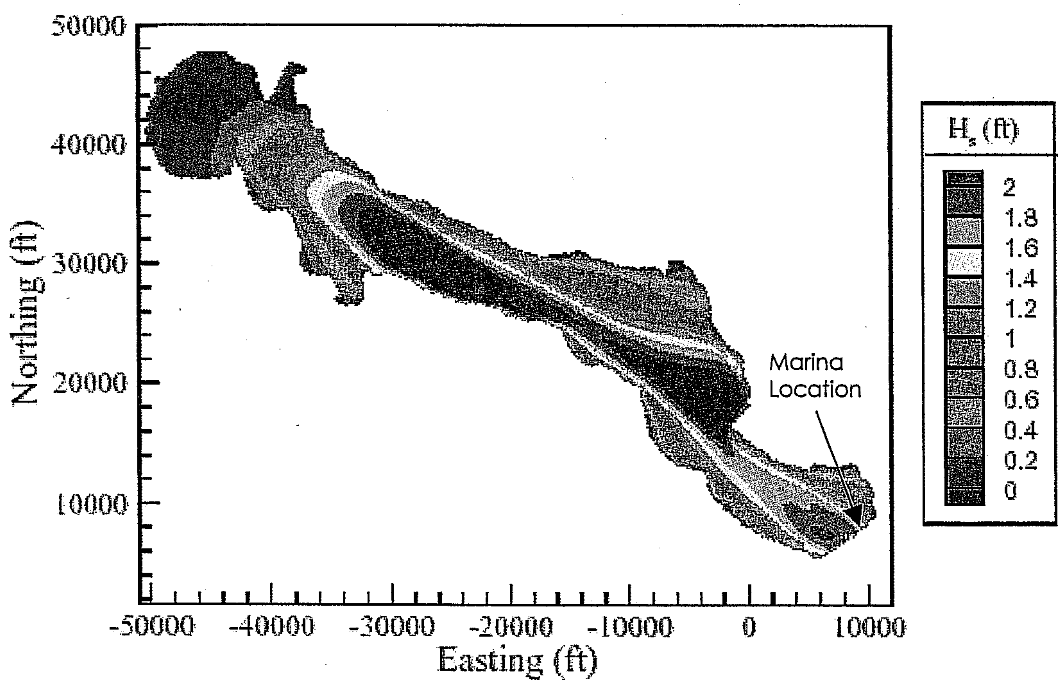


Figure 12. STWAVE Model Prediction of Significant Wave Height Distribution over Lake Charlevoix (U=40knots, Dir=W36°N)

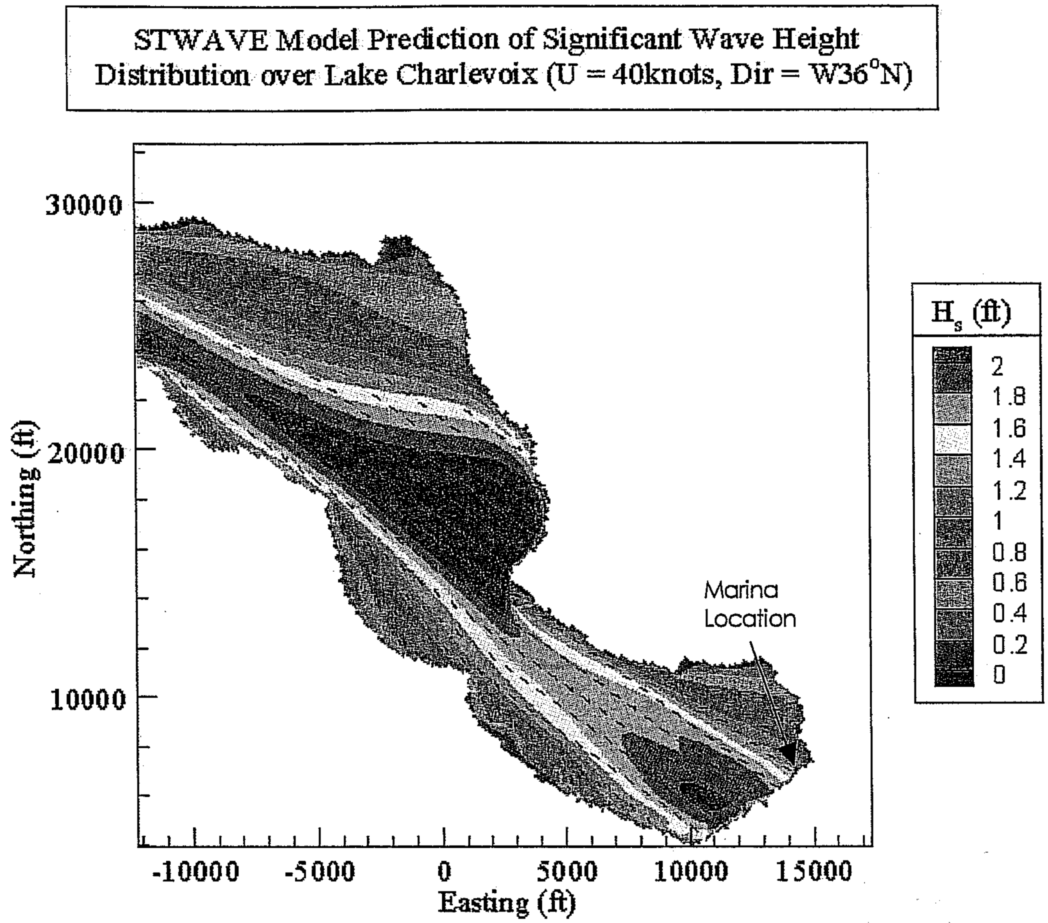


Figure 13. STWAVE Results at 40 knots in the NW (35°) direction

As can be seen in the above figure, with sustained NW wind (40 knots), the significant wave height experienced near Boyne City is approximately 2 ft, with a 4-s period. This is the most conservative result obtained from the model simulations, as it corresponds to the largest fetch over Lake Charlevoix.

B. Bouss-2D

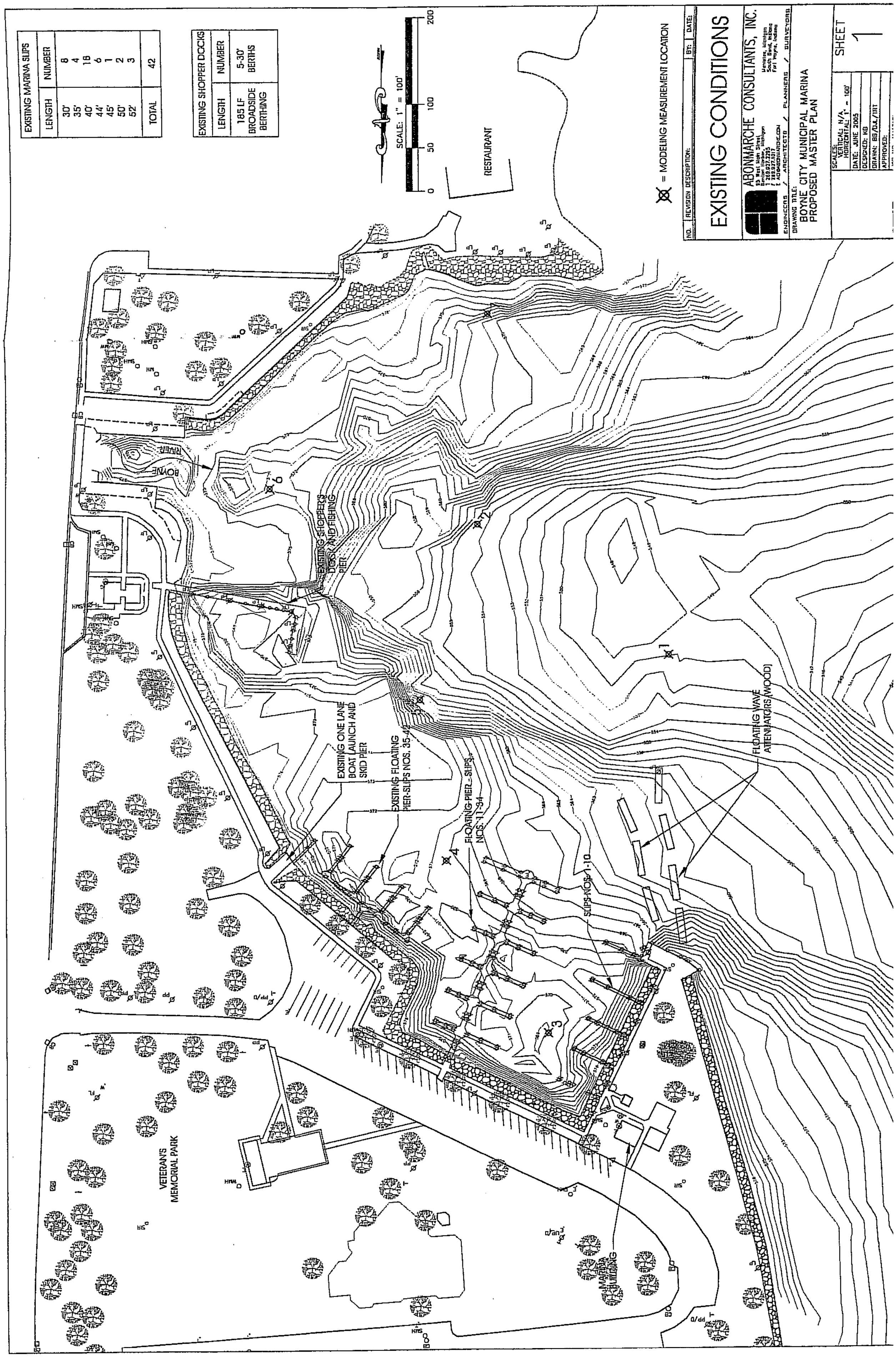
As mentioned previously, the significant wave heights utilized as input for Bouss-2D were obtained from STWAVE. According to the results from STWAVE, the worst-case scenario results is a significant wave height of 2 ft and a period of 4-s in the W and NW (35°) directions. These numbers were verified using the Shore Protection Manual's Shallow Water Formula calculations as well as with local observations, that provided a calibration verification of the model. Seven points in the project area were selected to compare the results for all design options modeled. Two points (1 and 2) were selected at the Harbor entrance to represent incident wave conditions and five points (3-7) were selected inside the Harbor area. These points can be described as the following:

1. Approximate midpoint at entrance between existing north and south shorelines
2. Inside basin approximately 350 feet west of Boyne River mouth
3. In protected corner area, near north shoreline, between main floating pier and the fixed slips
4. Open area approximately 115 feet from northeast shoreline, near the 44-foot floating slips
5. Open area, approximately 240 feet west of boat launch
6. Inside basin approximately 100 feet west of Boyne River
7. Open area, approximately 35 feet from south shoreline

The figures showing the location of these model points for the existing conditions as well as each of the alternative breakwater layouts are presented next.

EXISTING MARINA SLIPS	
LENGTH	NUMBER
30'	8
35'	4
40'	18
44'	6
45'	1
50'	2
52'	3
TOTAL	42

EXISTING SHOPPER DOCKS	
LENGTH	NUMBER
185 LF BROADSIDE BERTHING	5-30' BERTHS



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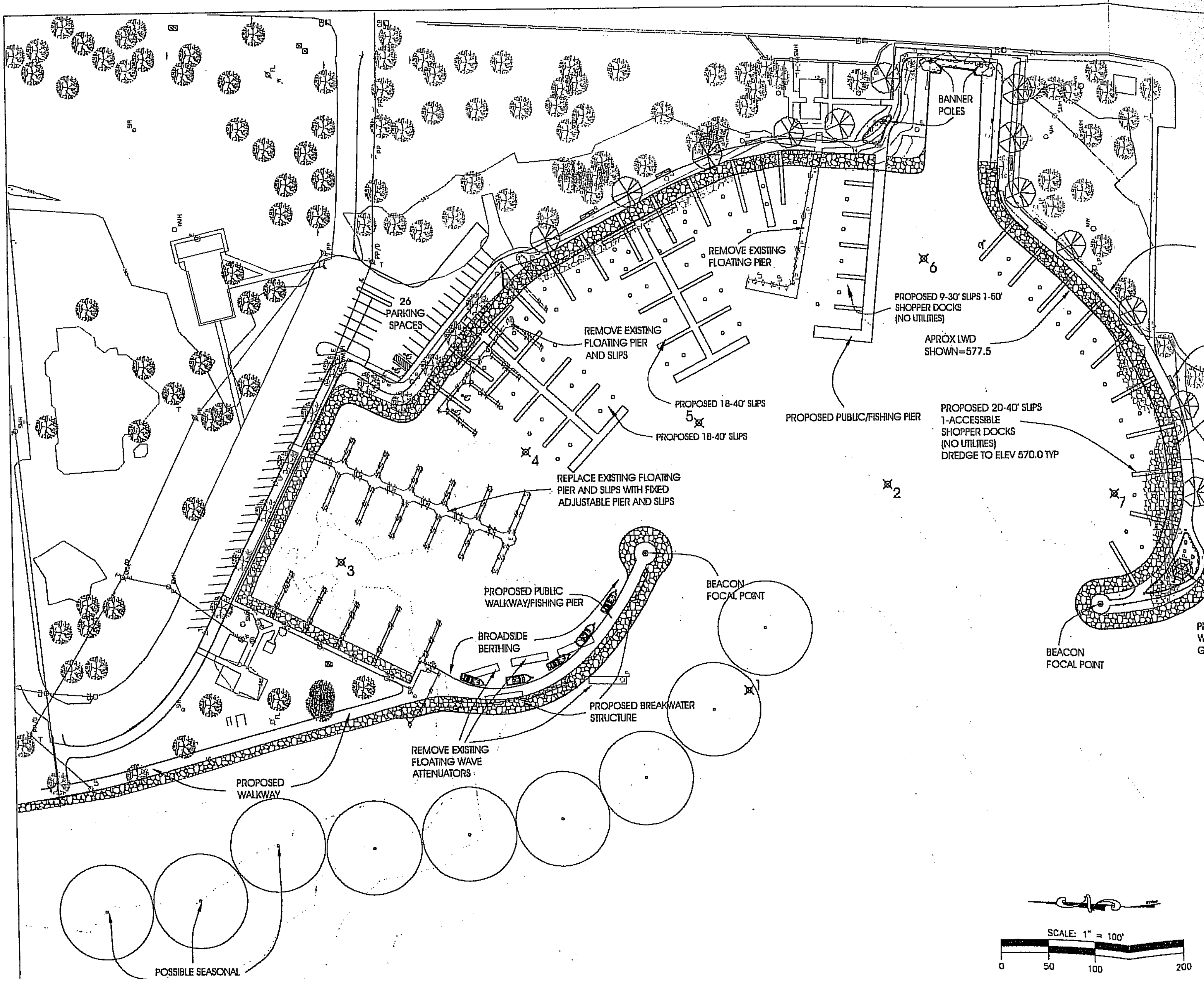


PROPOSED MARINA SLIPS	
LENGTH	NUMBER
30'	8
36'	8
38'	6
40'	42
45'	1
52'	3
BROADSIDE	4-5
TOTAL	60-61

PROPOSED SHOPPER DOCKS	
LENGTH	NUMBER
30'	9
40'	20
50'	1
TOTAL	30

HWD=581.5 (IGLD 1985)
LWD=577.5 (IGLD 1985)

⊠ = MODELING MEASUREMENT LOCATION

NO.	REVISION DESCRIPTION:	BY:	DATE:

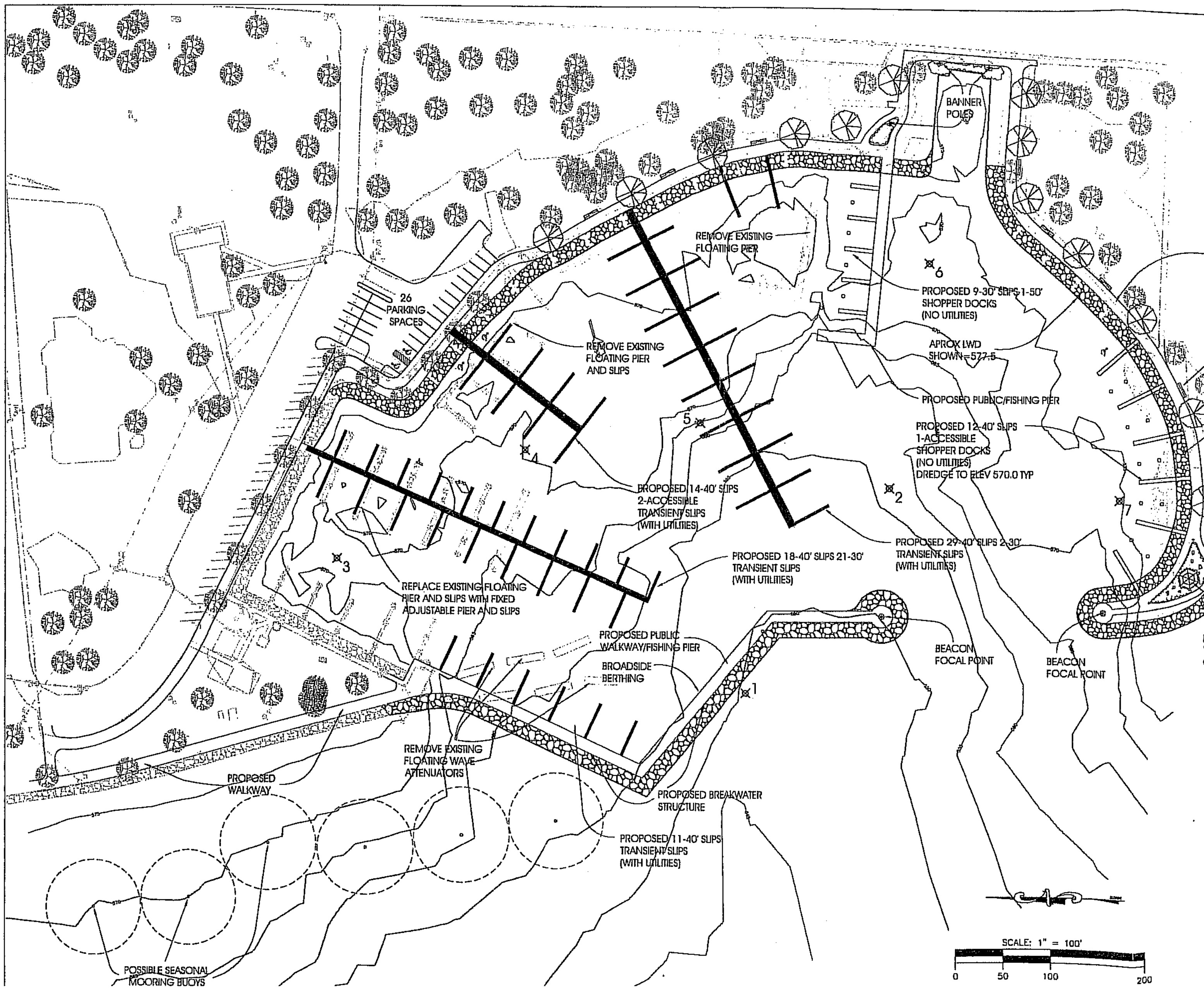
FIGURE 5

ABONMARCHE CONSULTANTS, INC.
95 West Main Street, Benton Harbor, Michigan — Manistee, Michigan; Grand Haven, Michigan; Portage, Michigan; South Bend, Indiana; Fort Wayne, Indiana
ENGINEERS / ARCHITECTS / PLANNERS / SURVEYORS

DRAWING TITLE:
BOYNE CITY MUNICIPAL MARINA
PROPOSED MASTER PLAN

SCALES: VERTICAL: N/A HORIZONTAL: 1" = 100'
DATE: JUNE 2005
DESIGNED: KB
DRAWN: BB/DJL/TRT
APPROVED:
JOB NO. M41318KB

SHEET 1 OF 4 SHEETS



PROPOSED MARINA SLIPS	
LENGTH	NUMBER
30'	24
40'	74
45'	1
52'	2
60'	1
80'	1
BROADSIDE	4-6
TOTAL	107-109

PROPOSED SHOPPER DOCKS	
LENGTH	NUMBER
30'	9
40'	12
50'	1
TOTAL	22

HWD=581.5 (IGLD 1985)
LWD=577.5 (IGLD 1985)

⊗ = MODELING MEASUREMENT LOCATION

NO.	REVISION DESCRIPTION:	BY:	DATE:

FIGURE 7

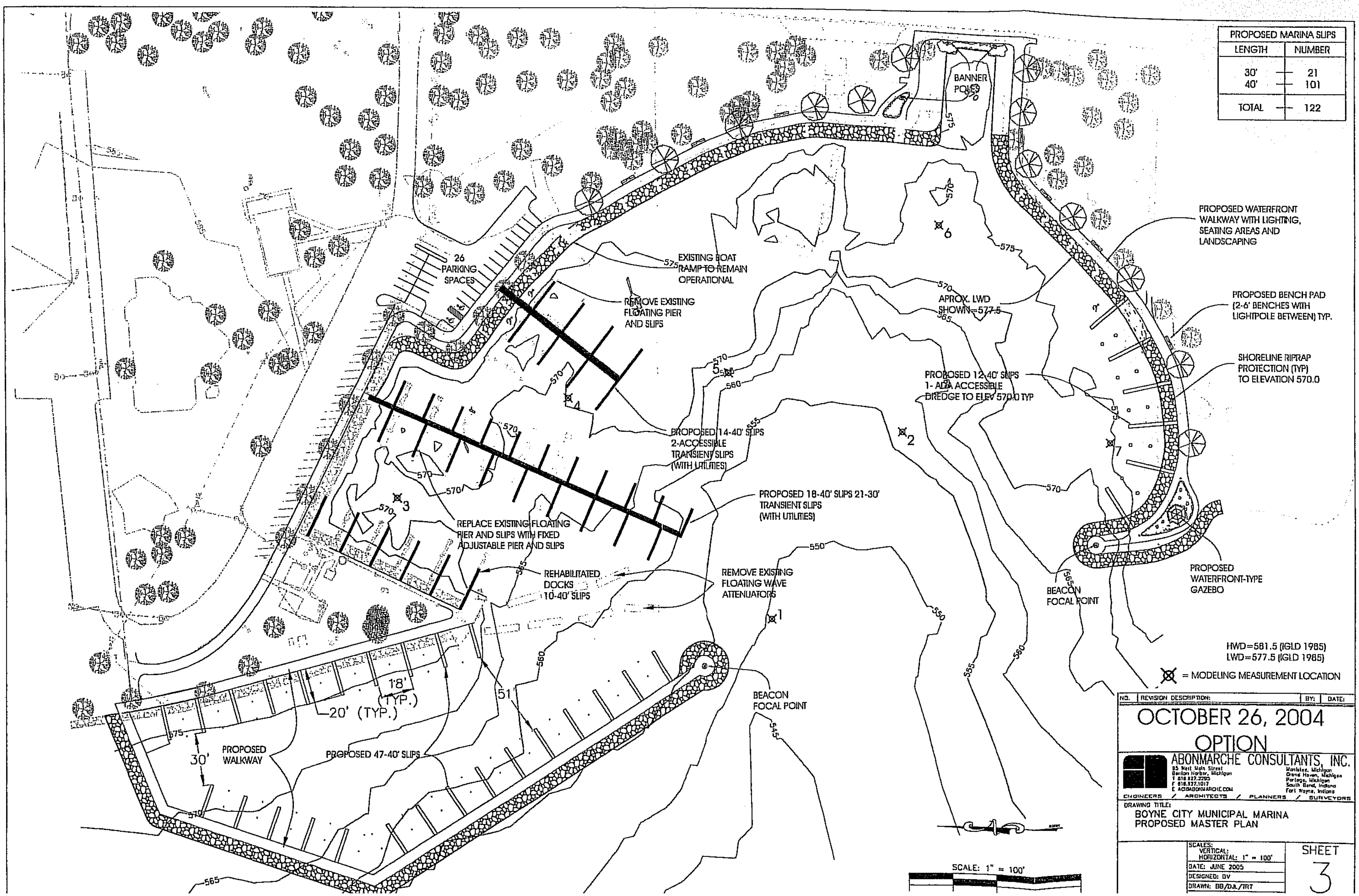
ABONMARCHE CONSULTANTS, INC.
95 West Main Street, Benton Harbor, Michigan
ENGINEERS / ARCHITECTS / PLANNERS / SURVEYORS

DRAWING TITLE:
BOYNE CITY MUNICIPAL MARINA
PROPOSED MASTER PLAN

SCALES: VERTICAL: HORIZONTAL: 1" = 100'
DATE: JUNE 2005
DESIGNED: KB
DRAWN: BB
APPROVED:

SHEET 2

:LAND PROJECTS R2\ENG PROJECTS\M41318\dwg\M41318tb.dwg, MARINA FIG-7 OPT-C 11X17 SHT 2 OF 4, 6/8/2005 1:27:41 PM, thomas, 1:1



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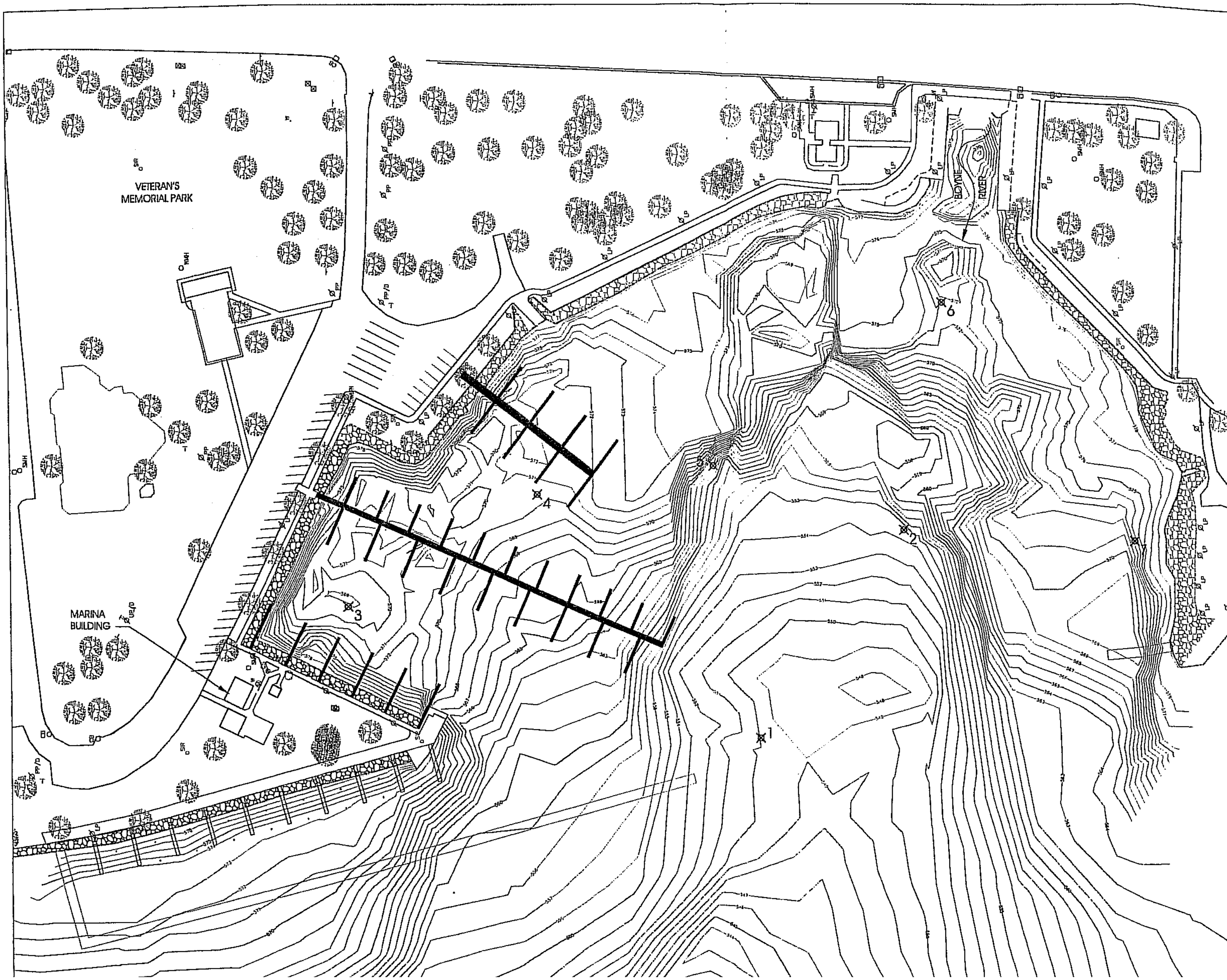

PROPOSED MARINA SLIPS	
LENGTH	NUMBER
30'	21
40'	72
TOTAL	42

⊠ = MODELING MEASUREMENT LOCATION

NO.	REVISION DESCRIPTION:	BY:	DATE:

FLOATING BREAKWATER OPTION

ABONMARCHE CONSULTANTS, INC.

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Manistee, Michigan
South Bend, Indiana
Fort Wayne, Indiana

ENGINEERS / ARCHITECTS / PLANNERS / SURVEYORS

DRAWING TITLE:
BOYNE CITY MUNICIPAL MARINA
PROPOSED MASTER PLAN

SCALES:
VERTICAL: N/A
HORIZONTAL: 1" = 100'
DATE: JUNE 2005
DESIGNED: KD
DRAWN: BD/DJL/TRT
APPROVED:

SHEET
4

The following figures are simulations that were produced using Bouss-2D.

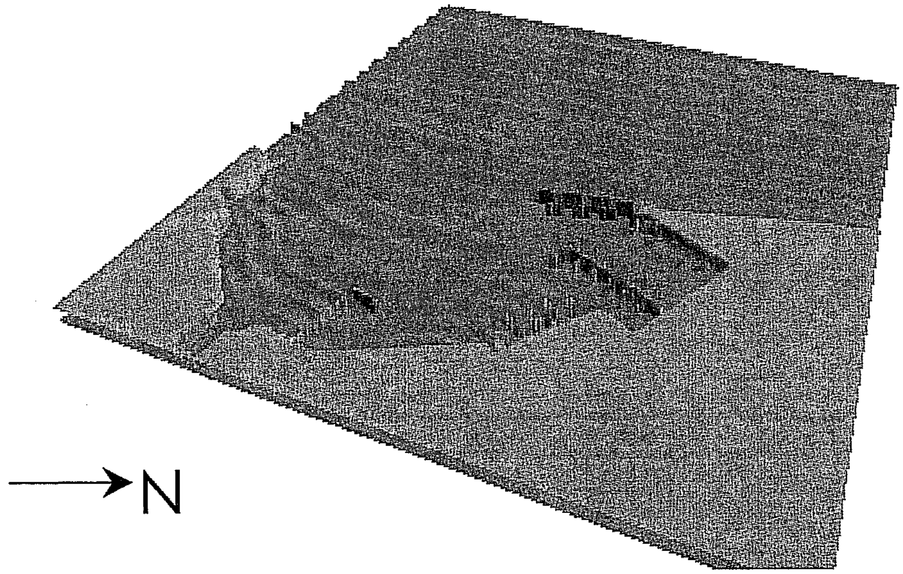


Figure 14. Bouss-2D Simulation of Existing Conditions with Floating Attenuators in the West Direction

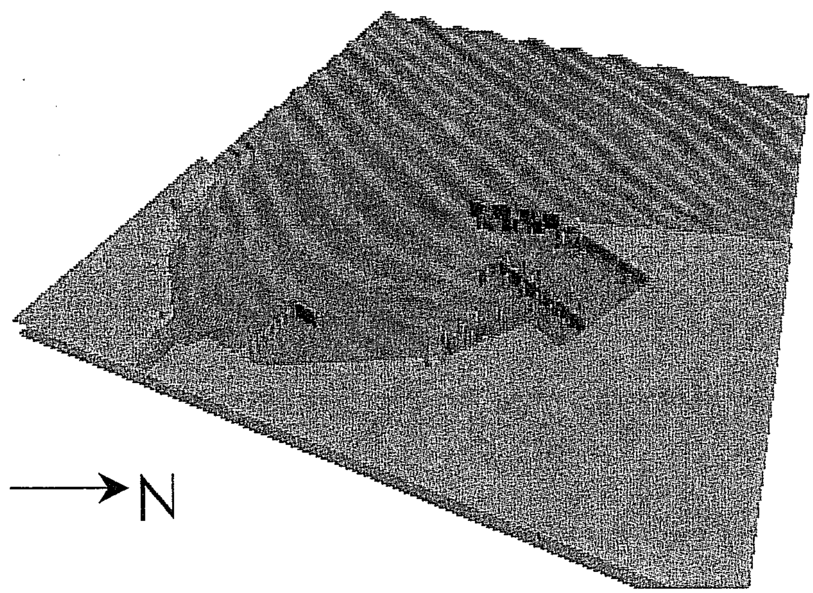


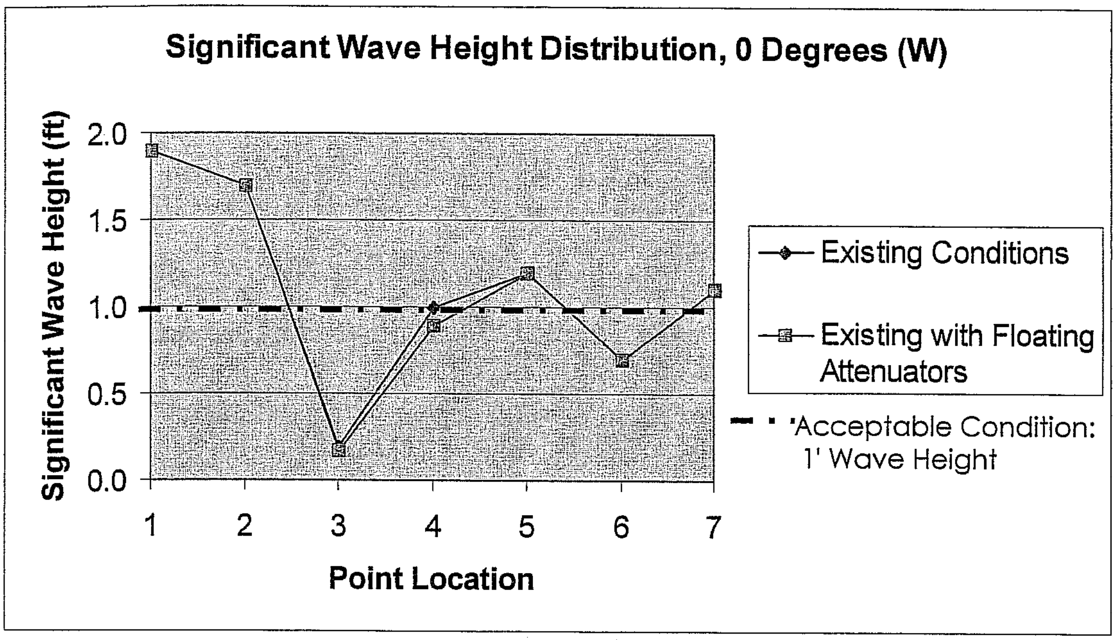
Figure 15. Bouss-2D Simulation of Existing Conditions with Floating Attenuators in the Northwest Direction

These figures show simulations of the Harbor area under existing conditions with the existing floating attenuators. Shoreline reflection/absorption is accounted for in these simulations and is well demonstrated in the figures presented.

The following table and figures summarize the Bouss-2D results. Complete Bouss 2-D results are found in Appendix E.

Wave Direction	Point Number	Existing Conditions	Existing with Floating Attenuators	Design Alternatives			
				Figure 5	Figure 7	October 26	Floating Attenuators
W (0)	1	1.9	1.9	1.9	2.3	2.0	2.0
	2	1.7	1.7	1.7	0.5	1.7	1.8
	3	0.2	0.2	0.1	0.1	0.1	0.2
	4	1.0	0.9	0.1	0.1	0.2	0.9
	5	1.2	1.2	1.0	0.2	0.8	1.2
	6	0.7	0.7	0.8	0.3	0.7	0.7
	7	1.1	1.1	0.6	0.6	0.6	0.6
NW (35)	1	1.9	1.9	2.0	1.2	1.5	1.6
	2	1.7	1.7	2.0	0.3	1.0	1.2
	3	0.1	0.1	0.1	0.1	0.1	0.1
	4	0.4	0.3	0.1	0.1	0.1	0.3
	5	1.3	1.2	0.4	0.1	0.3	1.2
	6	1.0	1.0	1.0	0.1	0.5	0.8
	7	1.0	1.0	0.7	0.9	0.8	0.7

Table 2. Bouss-2D Result Summary



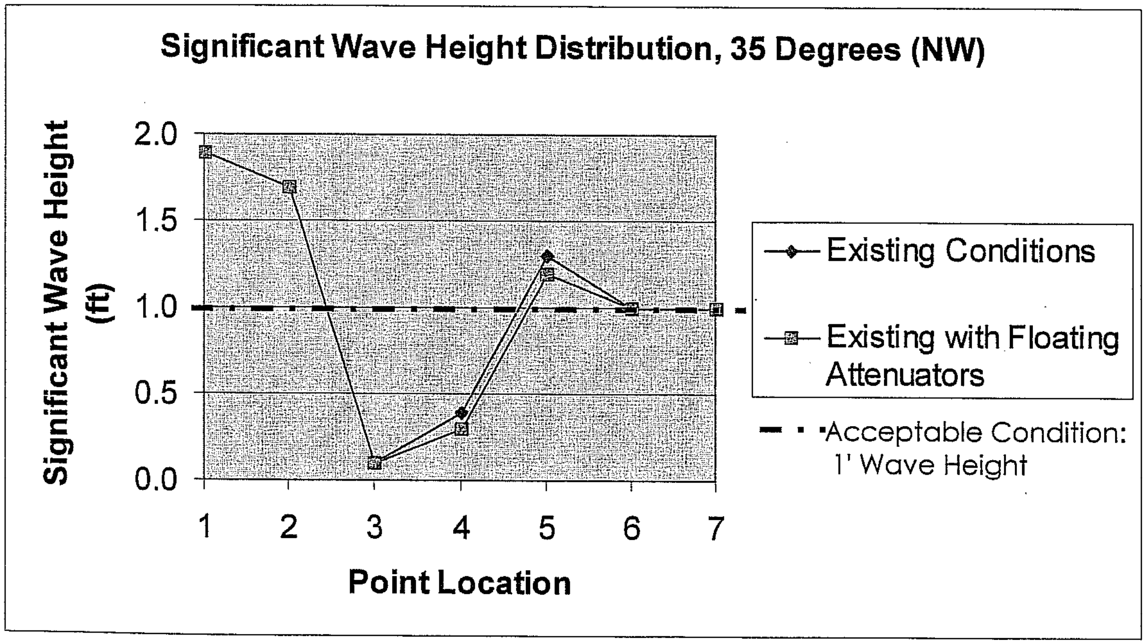
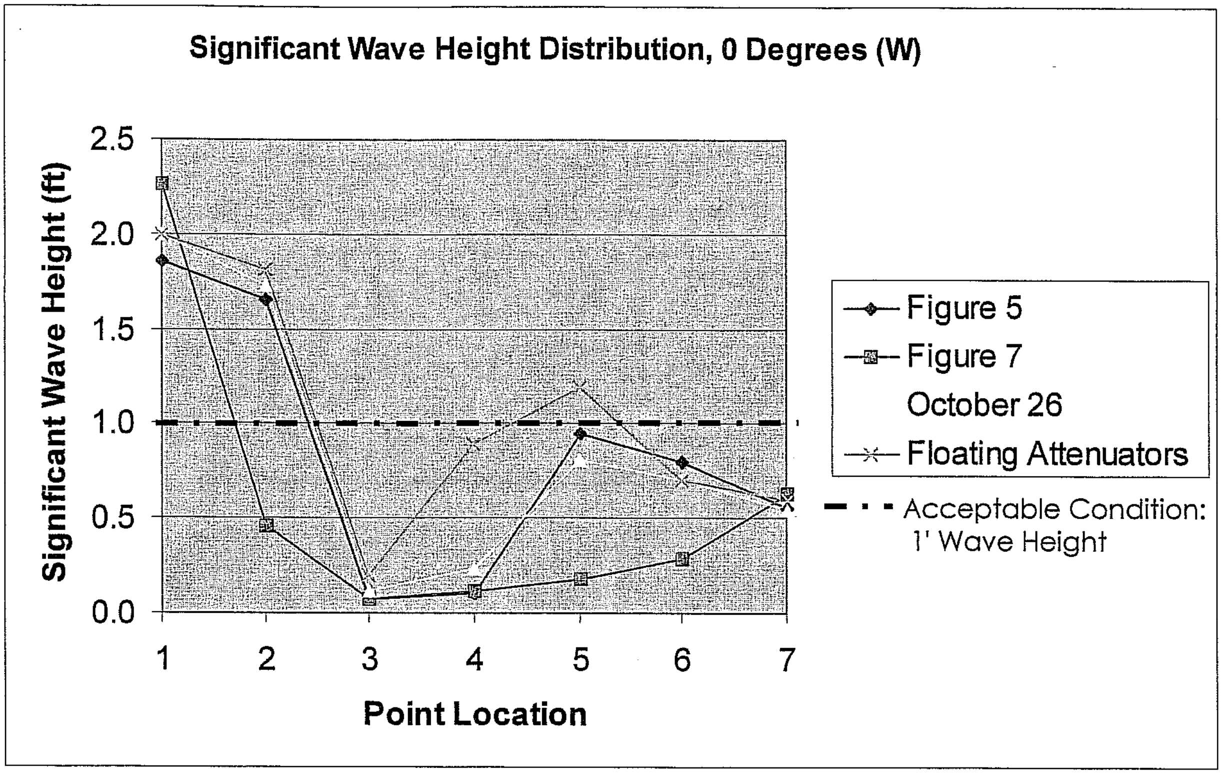


Figure 16. Bouss-2D Results Charts: Existing Conditions



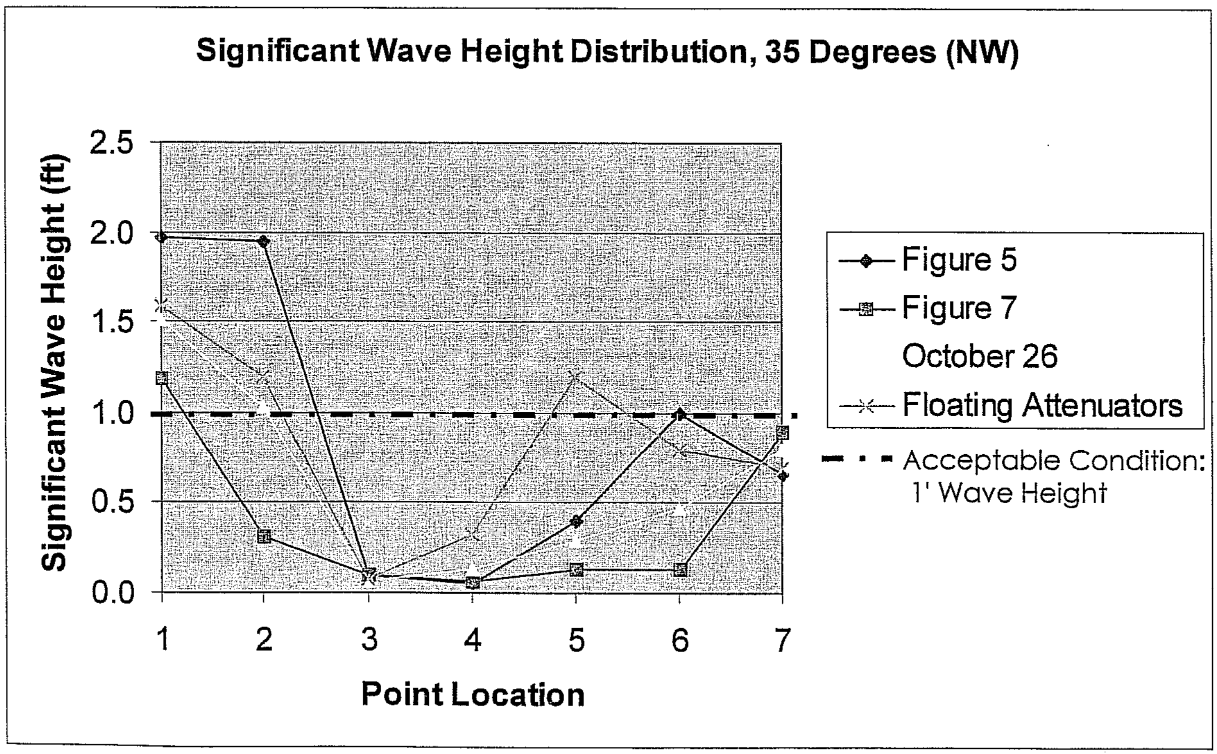


Figure 17. Bouss-2D Results Charts: Breakwater Alternatives

As can be seen from the Table 2, the existing conditions and existing conditions with floating wave attenuators result in very similar significant wave heights, and exceed the 1 ft standard at the same points. Therefore, these options demonstrate the need for a breakwater/wave attenuator that provides additional protection against waves entering the Harbor area. The *Floating Attenuator* alternative produces similar results. At points 3,4 and 6, the significant wave heights are less than 1 foot but exceed this value for locations 5 and 7. *Figure 5* also results in significantly large wave heights at points 5 and 6. In both modeling directions, *Figure 7* reduces the wave heights to less than 1 ft with the note that at point 7 it is marginal (0.9 ft) for the NW approach. *October 26* alternative produces similar results, with slightly higher wave heights at locations 5 and 6, but still within acceptable design criteria.

An example of Bouss-2D results is presented below (for *Figure 7* layout). Complete Bouss-2D results are presented in Appendix E.

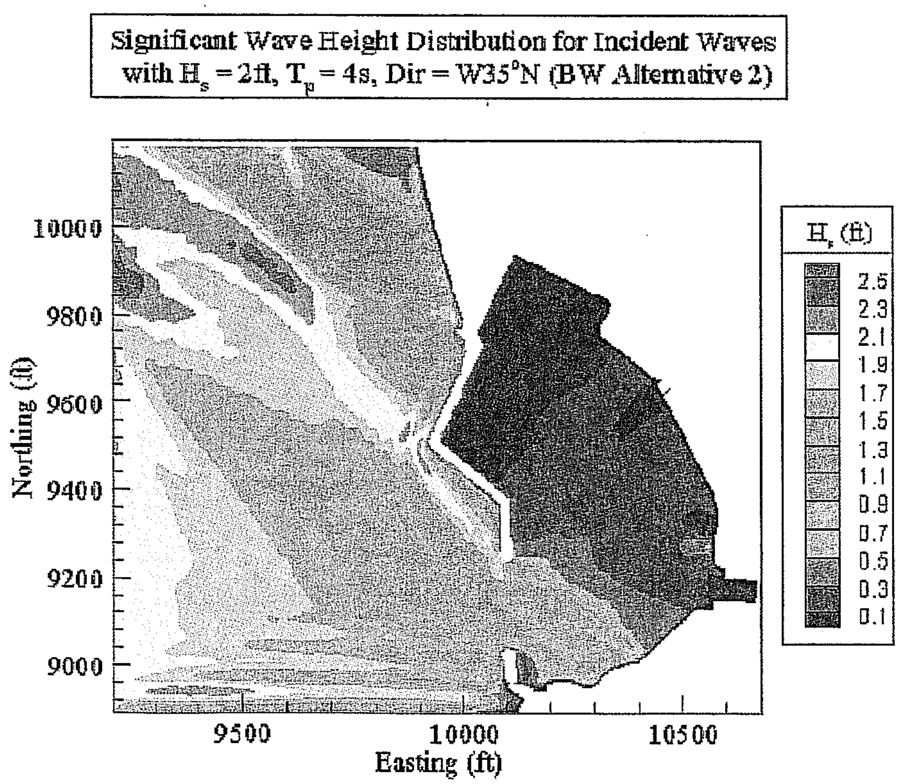


Figure 18. Bouss-2D Result for *Figure 7* in the NW direction.

V. SUMMARY

From STWAVE, input data for Bouss-2D was obtained, which resulted in a significant wave height of 2 ft and period of 4 s. This data produced the results presented in section IV. Design criteria for marina protection considers 1-foot as the maximum acceptable wave height within a marina basin.

As expected, the fixed breakwater configurations perform better than the floating wave attenuator in reducing wave energy inside the Marina for the conditions modeled. However Figure 5 did not perform well, this being attributed to its shorter total length and curved geometry.

Both the *Figure 7* and *October 26* options performed well with significant wave heights less than 1-foot under all conditions modeled, appreciably less under most conditions modeled. In addition, both these options demonstrated appreciable benefit in the area of the Shoppers Dock (Point 6). Other options modeled did not demonstrate this benefit.

Under the worst-case conditions, the *Floating Attenuator* evidenced results similar to the existing conditions with the current floating attenuators. For example, at Point 4 the current configuration demonstrates a .9-foot wave same as the new floating option with due west conditions. Only if the current level of wave suppression under worst-case conditions is considered acceptable should the new floating wave attenuator option be considered.

It is noted that the worst-case condition would occur approximately 2% of the time, or rarely during the boating season. For incident wave periods of 1-3 seconds or less, which would be the norm during the boating season, it is expected that the floating wave attenuator would provide adequate protection. If this option is selected, the two docks extending from shore on either side of Point 4 might be shortened (fewer slips) to bring them within a more protected area.

The southern breakwater failed to demonstrate appreciable benefit with waves from the northwest. Unless it is to be included for aesthetic purposes, the southern breakwater should not be included in future marina design considerations.

VI. CONCULSIONS AND RECOMMENDATIONS

As part of the evaluation of this hydraulic model study, TAG recommends the *Figure 7* or *October 26* breakwater alternatives, for the best protection of the Harbor area at point locations 3 through 7.

Only if the current level of wave suppression is considered acceptable under worst-case conditions should a new floating wave attenuator option be considered.

VII. REFERENCES

Nwogu, O. 1993. Alternative Form of Boussinesq Equations for Nearshore Wave Propagation. *Journal of Waterway, Port, Coastal and Ocean Engineering*, ASCE, **119**(6), 618-638.

Nwogu, O. 2005. Wave Climate Study for Boyne City Marina, Omega Hydrodynamics, LLC. Ann Arbor, MI.

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Isaacson, M., and Nwogu, O. 1987. Wave Loads and Motions of Long Structures in Directional Seas. *Journal of Offshore Mechanics and Arctic Engineering*, Trans. ASME, **109**(2), 126-132.

Smith, J.M., Resio, D.T. and Zundel, A.K. 1999. STWAVE: Steady-State Spectral Wave Model. *U.S. Army Waterways Experiment Station Technical Report CHL-99-1*, Vicksburg, MS.

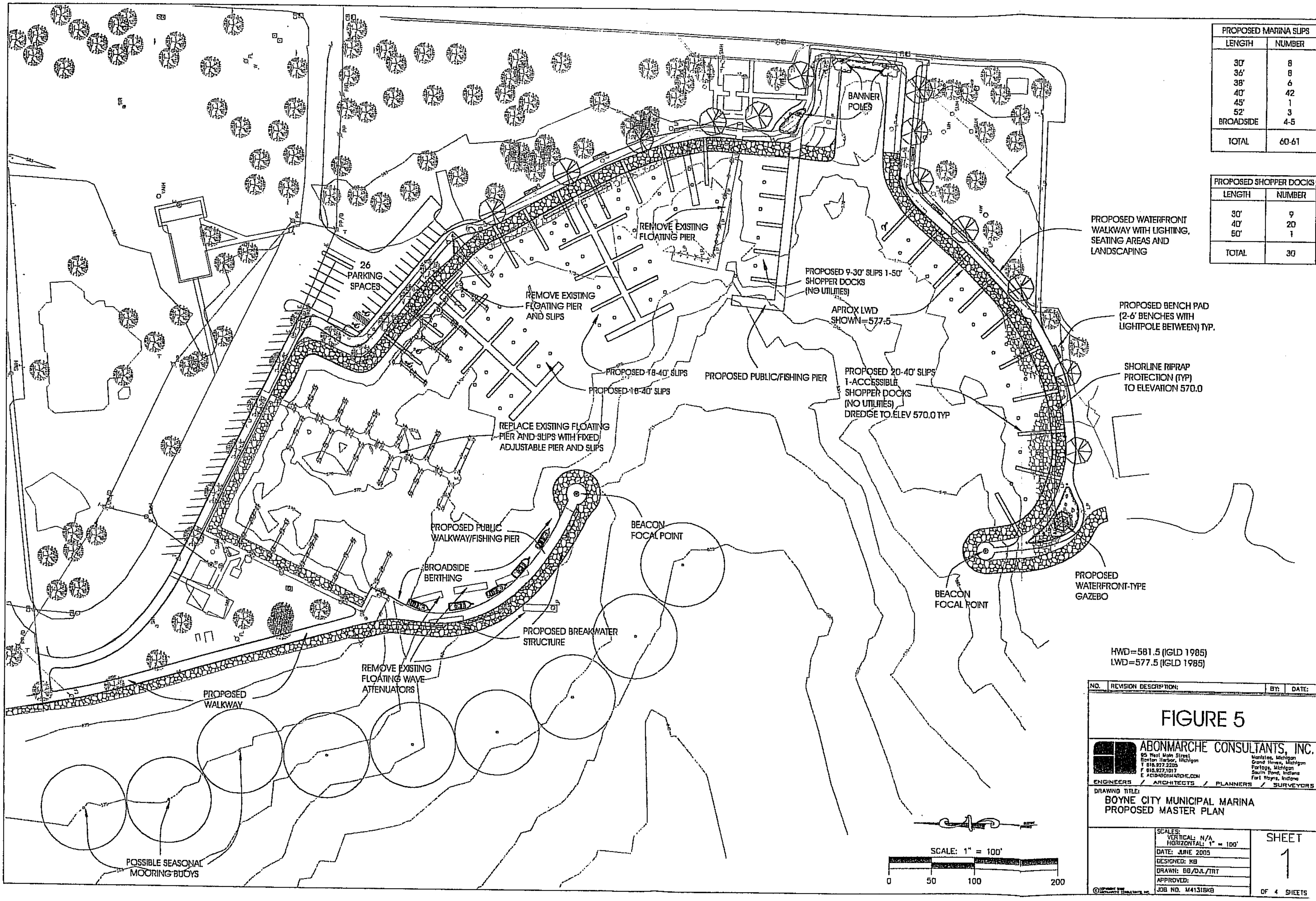
Task Committee on Marinas. 2000. Planning and Design Guidelines for Small Craft Harbors. American Society of Civil Engineers (ASCE).

US Army Engineer Waterways Experiment Station, Corps of Engineers. 1984. Shore Protection Manual. Vicksburg, MS.

Appendix A –Existing Harbor Conditions


EXISTING MARINA SLIPS
LENGTH NUMBER
30' 8
35' 4
40' 18
44' 6
45' 1
50' 2
52'
TOTAL
EXISTING SHOREFRONT DOCKS
LENGTH NUMBER
185 LF BROADSIDE BERTHING
6-30' BERTHS
VETERAN'S MEMORIAL PARK
MARINA BUILDING
RESTAURANT
0 50 100 200
NO. REVISION DESCRIPTION: BY: DATE:
EXISTING CONDITIONS
ABONMARCHE CONSULTANTS, INC.
ENGINEERS / ARCHITECTS / PLANNERS / SURVEYORS
DRAWING TITLE:
BOYNE CITY MUNICIPAL MARINA
PROPOSED MASTER PLAN
SCALES: VERTICAL: N/A HORIZONTAL: 1" = 100'
DATE: JUNE 2005
DESIGNED: KB
DRAWN: BD/DJL/TRT
APPROVED:
JOB NO. M41318bs
SHEET 1 OF 4 SHEETS
A1
E:\LAND PROJECTS R2\ENG PROJECTS\M41318\dwg\M41318bs.dwg, 11-17 Exist Conditions SHT1, 6/3/2005 11:41:42 AM, thomas, 1:1

Appendix B – Design Alternatives

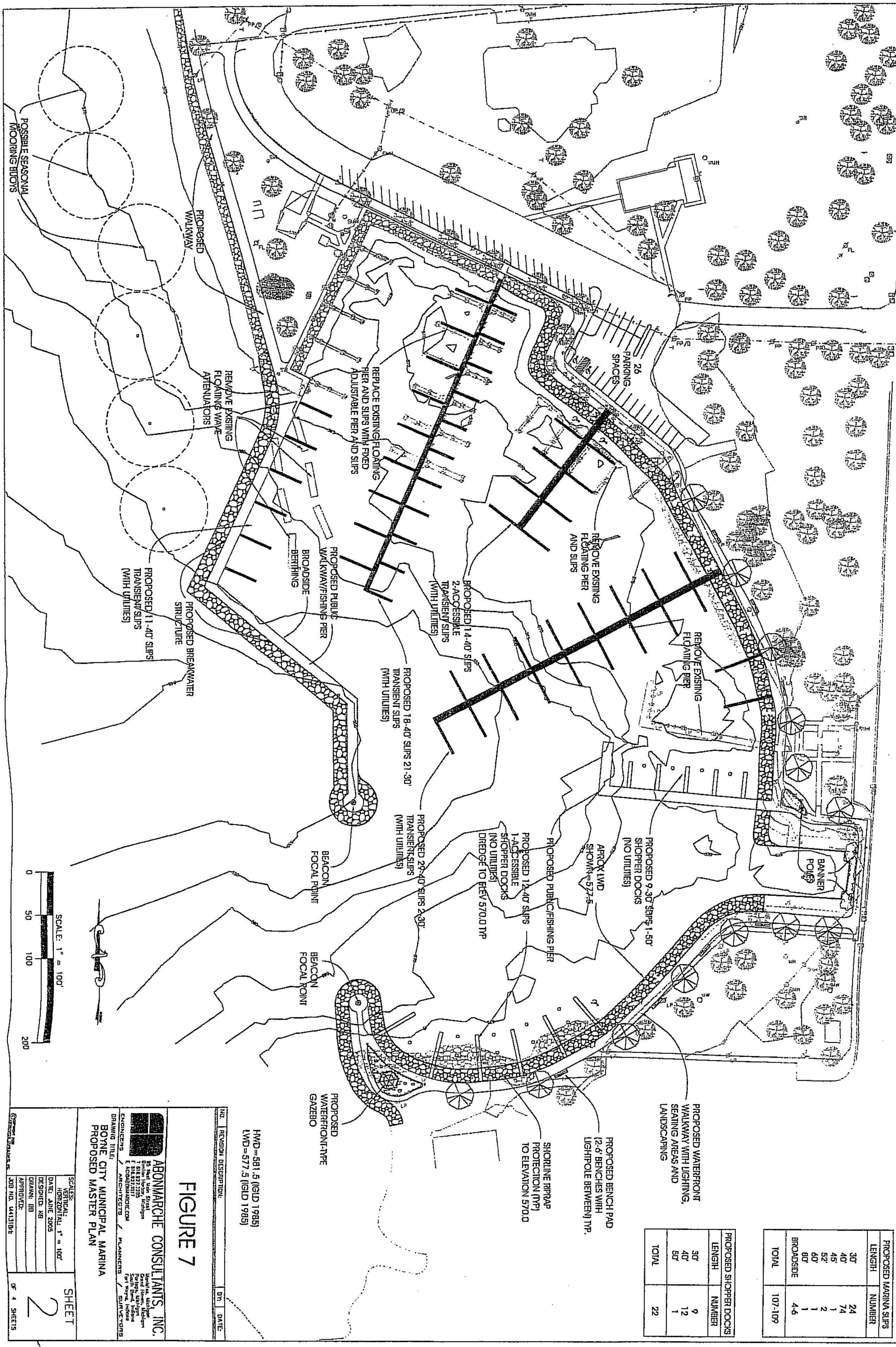


PROPOSED MARINA SLIPS	
LENGTH	NUMBER
30'	8
36'	8
38'	6
40'	42
45'	1
52'	3
BROADSIDE	4-5
TOTAL	60-61

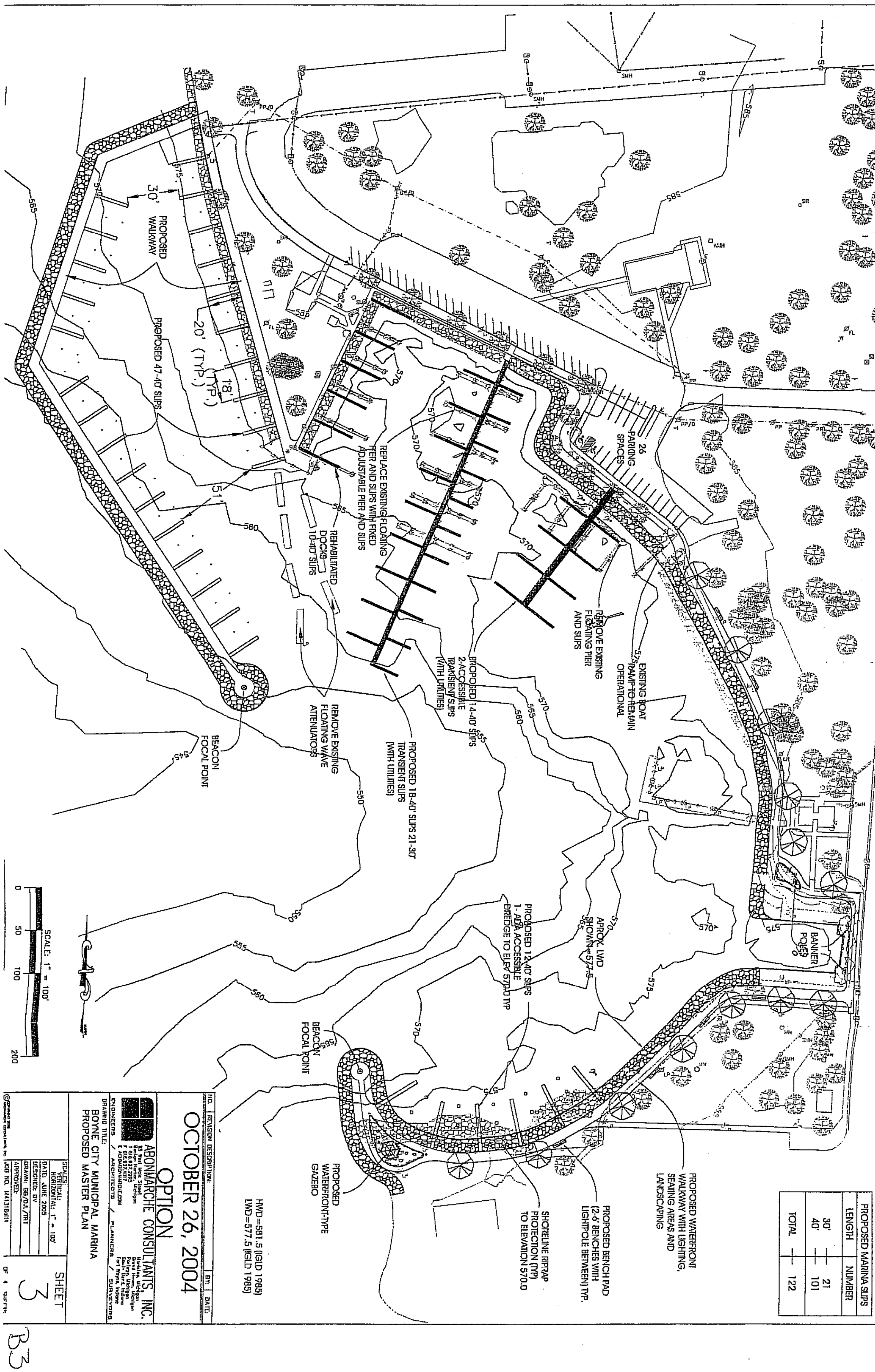
PROPOSED SHOPPER DOCKS	
LENGTH	NUMBER
30'	9
40'	20
50'	1
TOTAL	30

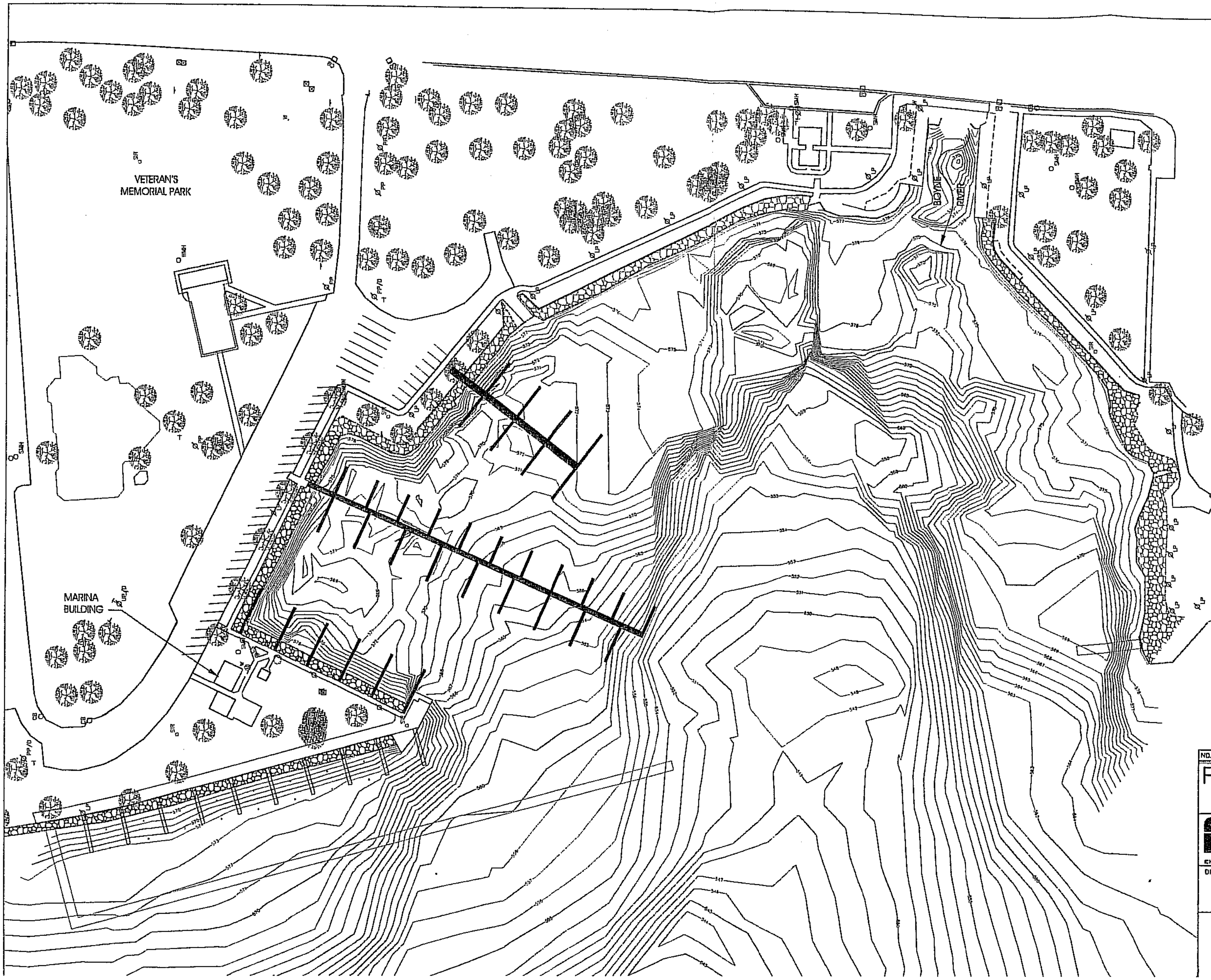
B

E:\LAND PROJECTS R2\ENG PROJECTS\M41318\dwg\M41318KB.dwg, MARINA FIG-5 OPT-B 11X17 SHT 1 OF 4, 6/2/2005 3:25:58 PM, thomas, 1:1


POSSIBLE SEASONAL MOORING BUOYS
PROPOSED WALKWAY
REMOVE EXISTING FLOATING WAVE ATTENUATORS
REPLACE EXISTING FLOATING PIER AND SLIPS WITH FIXED ADJUSTABLE PIER AND SLIPS
26 PARKING SPACES
REMOVE EXISTING FLOATING PIER AND SLIPS
PROPOSED PUBLIC WALKWAY/FISHING PIER
BROADSIDE BERTHING
PROPOSED 14-40' SLIPS 2-ACCESSIBLE TRANSIENT SLIPS (WITH UTILITIES)
PROPOSED 11-40' SLIPS TRANSIENT SLIPS (WITH UTILITIES)
PROPOSED BREAKWATER STRUCTURE
PROPOSED 18-40' SLIPS 21-30' TRANSIENT SLIPS (WITH UTILITIES)
REMOVE EXISTING FLOATING PIER
PROPOSED 29-40' SLIPS 2-30' TRANSIENT SLIPS (WITH UTILITIES)
PROPOSED 12-40' SLIPS 1-ACCESSIBLE SHOPPER DOCKS (NO UTILITIES) DREDGE TO ELEV 570.0 TYP
PROPOSED PUBLIC/FISHING PIER
APROX LWD SHOWN=577.5
PROPOSED 9-30' SLIPS 1-50' SHOPPER DOCKS (NO UTILITIES)
BANNER POLES
BEACON FOCAL POINT
BEACON FOCAL POINT
SCALE: 1" = 100'
0 50 100 200
PROPOSED WATERFRONT-TYPE GAZEBO
SHORELINE RIPRAP PROTECTION (TYP) TO ELEVATION 570.0
PROPOSED BENCH PAD (2-6' BENCHES WITH LIGHTPOLE BETWEEN) TYP.
PROPOSED WATERFRONT WALKWAY WITH LIGHTING, SEATING AREAS AND LANDSCAPING
PROPOSED MARINA SLIPS
LENGTH NUMBER
30' 24
40' 74
45' 1
52' 2
60' 1
80' 1
BROADSIDE 4-6
TOTAL 107-109
PROPOSED SHOPPER DOCKS
LENGTH NUMBER
30' 9
40' 12
50' 1
TOTAL 22
HWD=581.5 (IGLD 1985)
LWD=577.5 (IGLD 1985)
FIGURE 7
NO. REVISION DESCRIPTION: BY: DATE:
ABONMARCHE CONSULTANTS, INC.
ENGINEERS / ARCHITECTS / PLANNERS / SURVEYORS
DRAWING TITLE:
BOYNE CITY MUNICIPAL MARINA PROPOSED MASTER PLAN
SCALES: VERTICAL: HORIZONTAL: 1" = 100'
DATE: JUNE 2005
DESIGNED: KB
DRAWN: BB
APPROVED:
JOB NO. M41318rb
SHEET 2 OF 4 SHEETS

B2


PROPOSED MARINA SLIPS
LENGTH | NUMBER
30' — 21
40' — 101
TOTAL — 122
PROPOSED WALKWAY
30'
20' (TYP.)
18' (TYP.)
PROPOSED 47-40' SLIPS
51'
REPLACE EXISTING FLOATING PIER AND SLIPS WITH FIXED ADJUSTABLE PIER AND SLIPS
REHABILITATED DOCKS 10-40' SLIPS
REMOVE EXISTING FLOATING WAVE ATTENUATORS
BEACON FOCAL POINT
PROPOSED 18-40' SLIPS 21-30' TRANSIENT SLIPS (WITH UTILITIES)
PROPOSED 14-40' SLIPS 2-ACCESSIBLE TRANSIENT SLIPS (WITH UTILITIES)
REMOVE EXISTING FLOATING PIER AND SLIPS
EXISTING BOAT RAMP TO REMAIN OPERATIONAL
26 PARKING SPACES
APROX. LWD SHOWN=577.5
PROPOSED 12-40' SLIPS 1- ADA ACCESSIBLE BRIDGE TO ELEV 570.0 TYP
BANNER POLES
PROPOSED WATERFRONT WALKWAY WITH LIGHTING, SEATING AREAS AND LANDSCAPING
PROPOSED BENCH PAD (2-6' BENCHES WITH LIGHTPOLE BETWEEN) TYP.
SHORELINE RIPRAP PROTECTION (TYP) TO ELEVATION 570.0
PROPOSED WATERFRONT-TYPE GAZEBO
HWD=581.5 (IGLD 1985)
LWD=577.5 (IGLD 1985)
SCALE: 1" = 100'
0 50 100 200
OCTOBER 26, 2004
OPTION
ABONMARCHE CONSULTANTS, INC.
ENGINEERS / ARCHITECTS / PLANNERS / SURVEYORS
DRAWING TITLE:
BOYNE CITY MUNICIPAL MARINA
PROPOSED MASTER PLAN
SCALES: HORIZONTAL: 1" = 100'
DATE: JUNE 2005
SHEET 3
OF 4 SHEETS
B3



PROPOSED MARINA SLIPS	
LENGTH	NUMBER
30' 40'	21 72
TOTAL	42

NO.	REVISION DESCRIPTION:	BY:	DATE:

FLOATING BREAKWATER OPTION

ABONMARCHE CONSULTANTS, INC.
95 West Main Street, Benton Harbor, Michigan
T 269.927.2295
F 269.927.1017
E ACI@ABONMARCHE.COM
Manistee, Michigan
South Bend, Indiana
Fort Wayne, Indiana
ENGINEERS / ARCHITECTS / PLANNERS / SURVEYORS

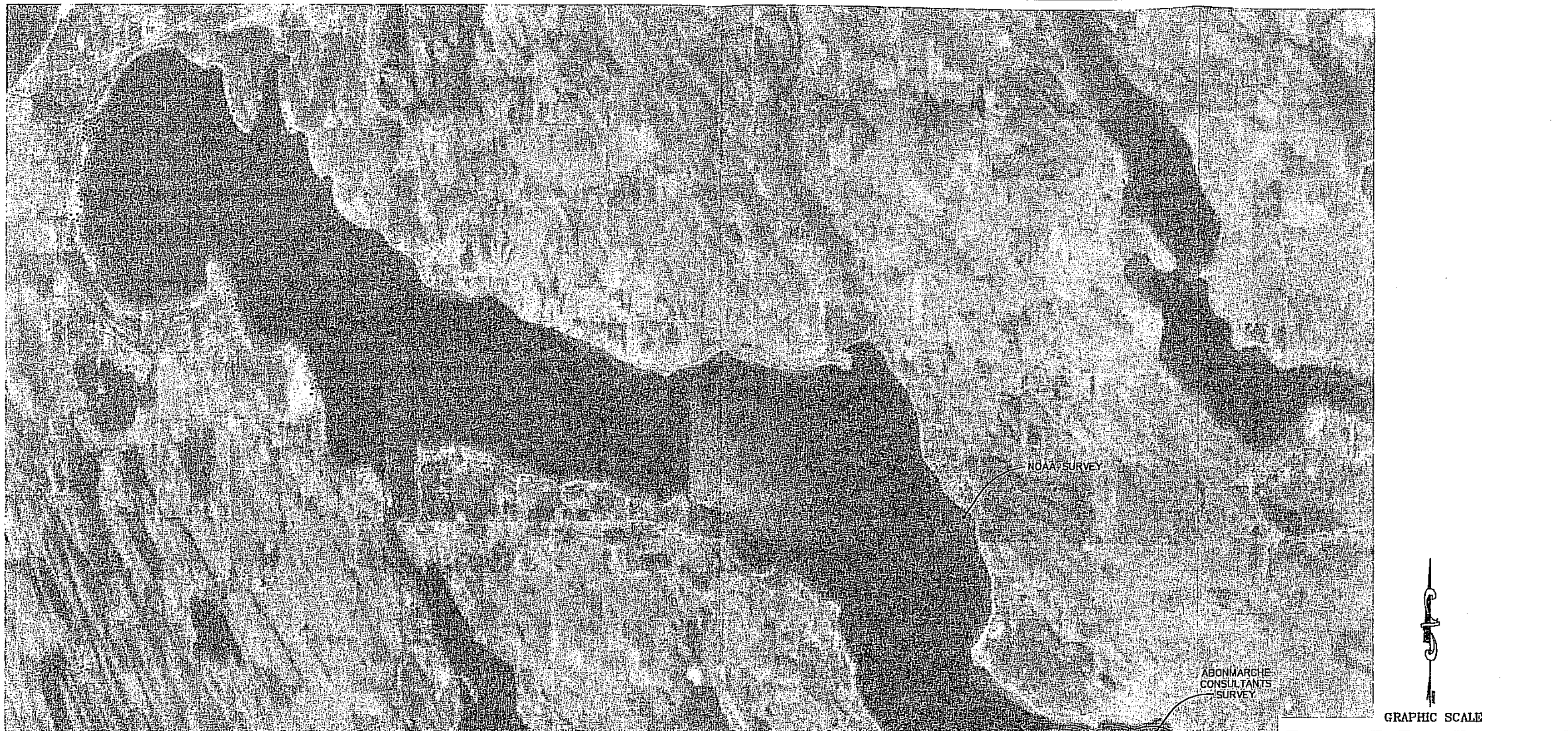
DRAWING TITLE:
BOYNE CITY MUNICIPAL MARINA
PROPOSED MASTER PLAN

SCALES:
VERTICAL: N/A
HORIZONTAL: 1" = 100'
DATE: JUNE 2005
DESIGNED: KB
DRAWN: BB/DJL/TRT
APPROVED:

SHEET 4

B4

Appendix C – Bathymetric Survey



NO.	REVISION DESCRIPTION:	BY:	DATE:

ABONMARCHE CONSULTANTS, INC.

Manistee, Michigan
South Bend, Indiana
Fort Wayne, Indiana

ENGINEERS / ARCHITECTS / PLANNERS / SURVEYORS

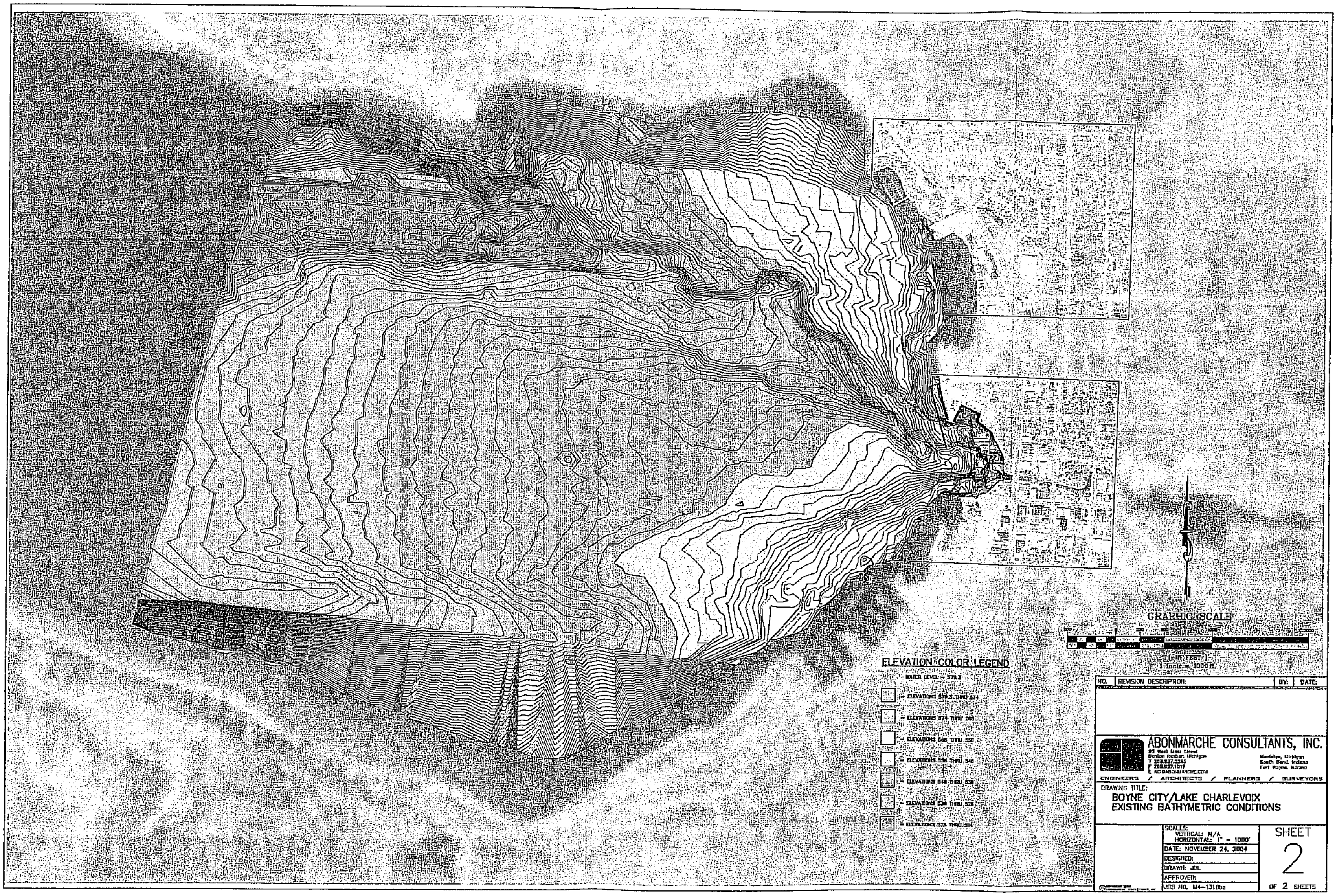
DRAWING TITLE:
LAKE CHARLEVOIX
BATHYMETRIC DATA

SCALES:
VERTICAL: N/A

DATE: FEBRUARY, 2005
DESIGNED:
DRAWN: JDL
APPROVED:
JOB NO. M4-1318NOAA

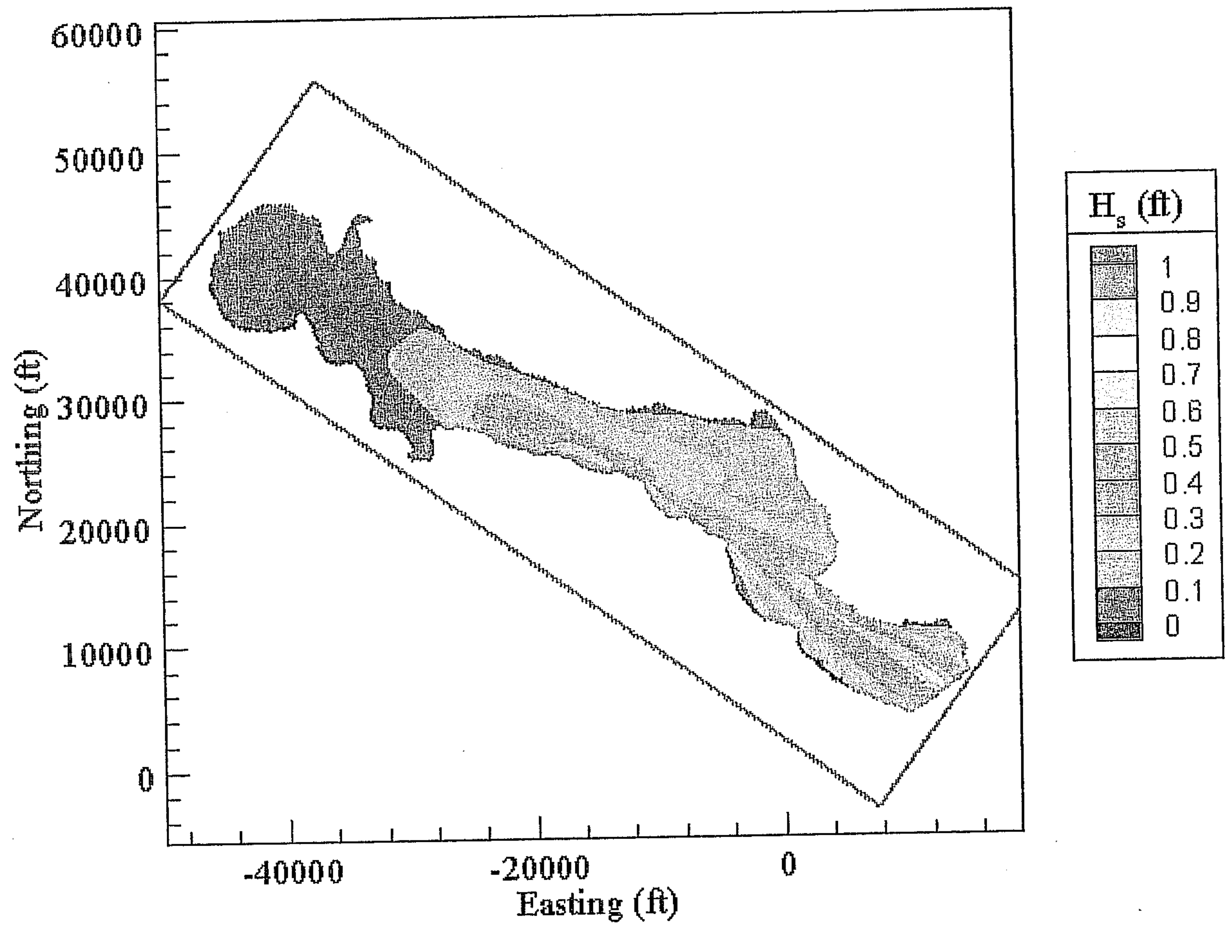
SHEET 1 OF 1 SHEETS

C1


GRAPHIC SCALE
(IN FEET)
1 inch = 1000 ft.
ELEVATION COLOR LEGEND
NO. REVISION DESCRIPTION: BY: DATE:
ABONMARCHE CONSULTANTS, INC.
Manistee, Michigan
South Bend, Indiana
Fort Wayne, Indiana
ENGINEERS / ARCHITECTS / PLANNERS / SURVEYORS
DRAWING TITLE:
BOYNE CITY/LAKE CHARLEVOIX
EXISTING BATHYMETRIC CONDITIONS
SCALES:
VERTICAL: N/A
HORIZONTAL: 1" = 1000'
DATE: NOVEMBER 24, 2004
DESIGNED:
DRAWN: JDL
APPROVED:
JOB NO. M4-1318bs
SHEET
2
OF 2 SHEETS

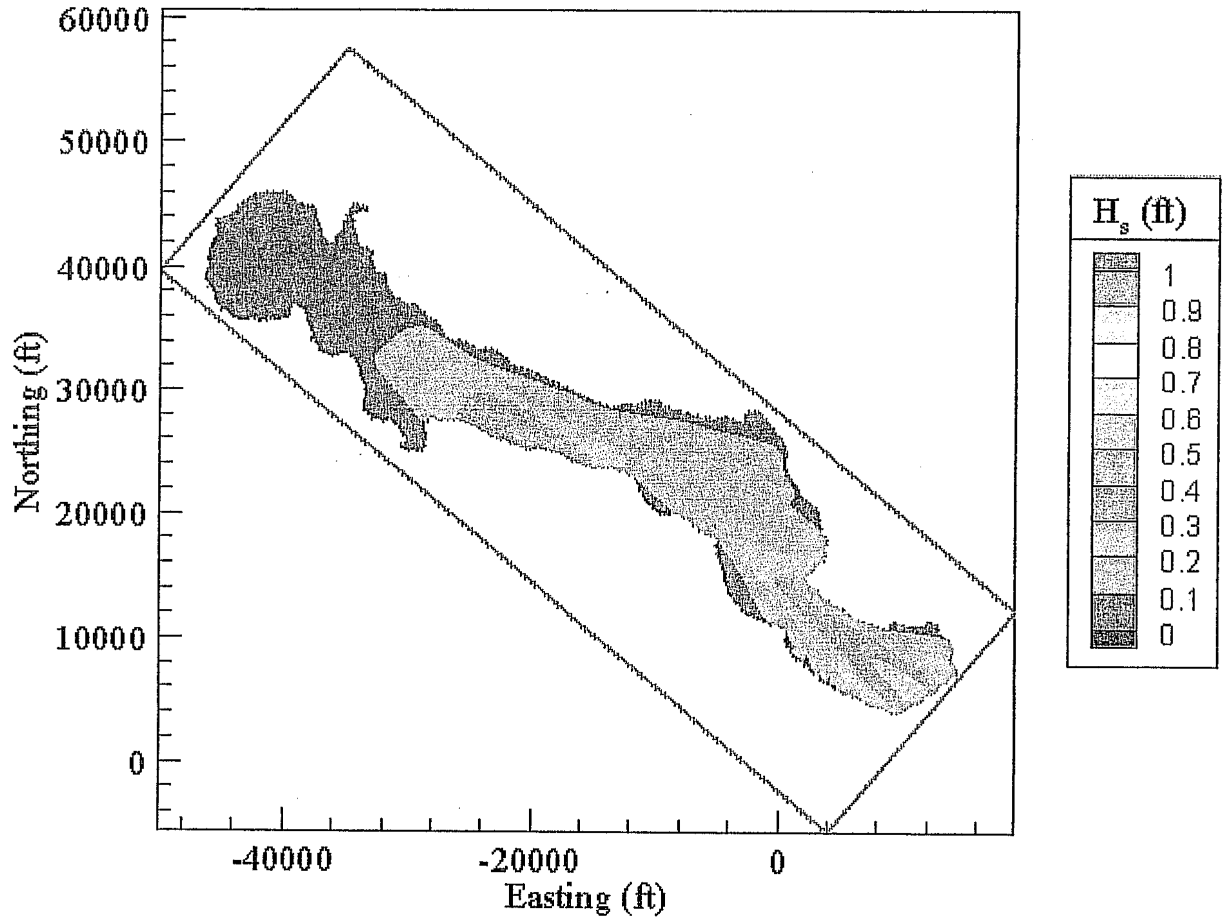
Appendix D – STWAVE Results

STWAVE Model Prediction of Significant Wave Height Distribution over Lake Charlevoix (U = 20knots, Dir = W36°N)



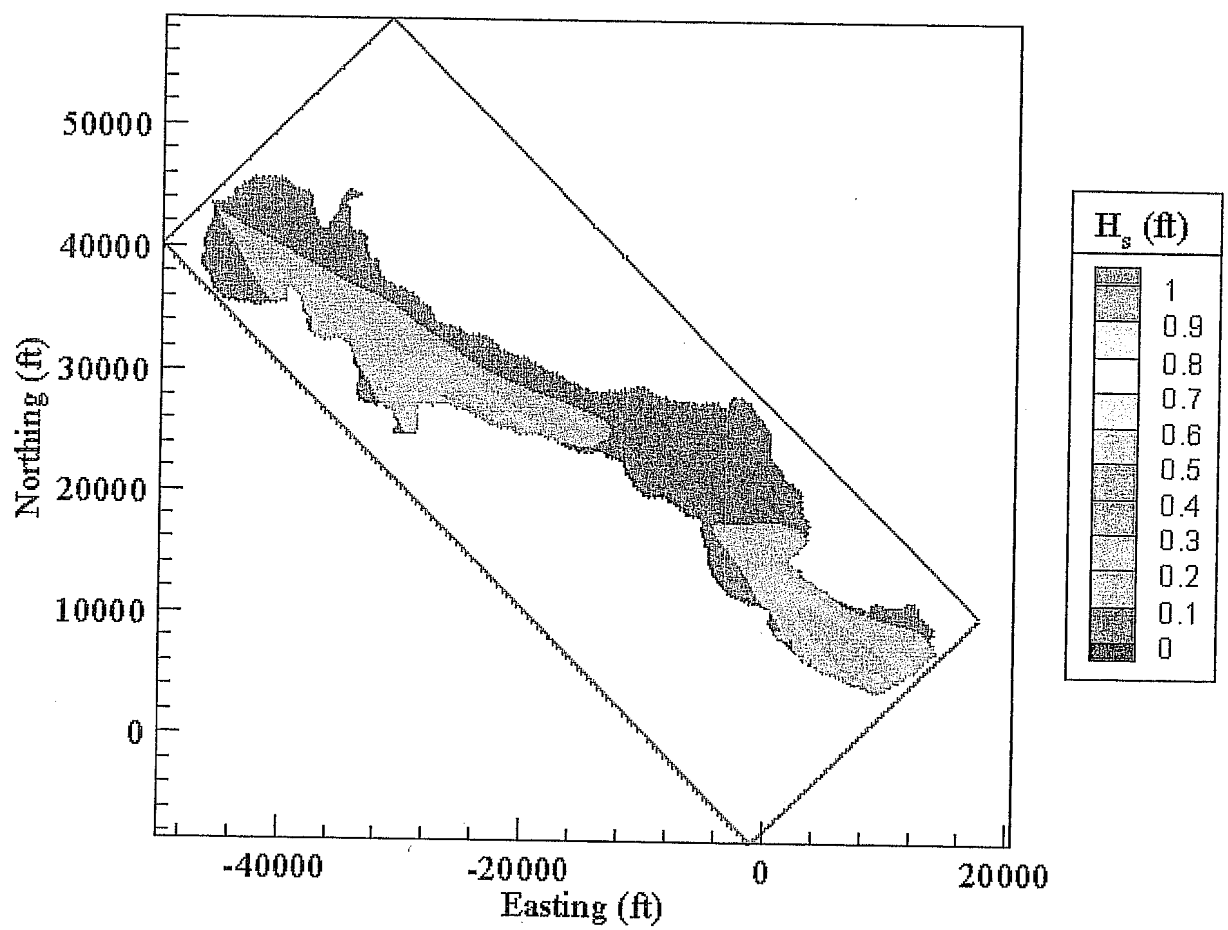
D

STWAVE Model Prediction of Significant Wave Height Distribution over Lake Charlevoix (U = 20knots, Dir = W40°N)

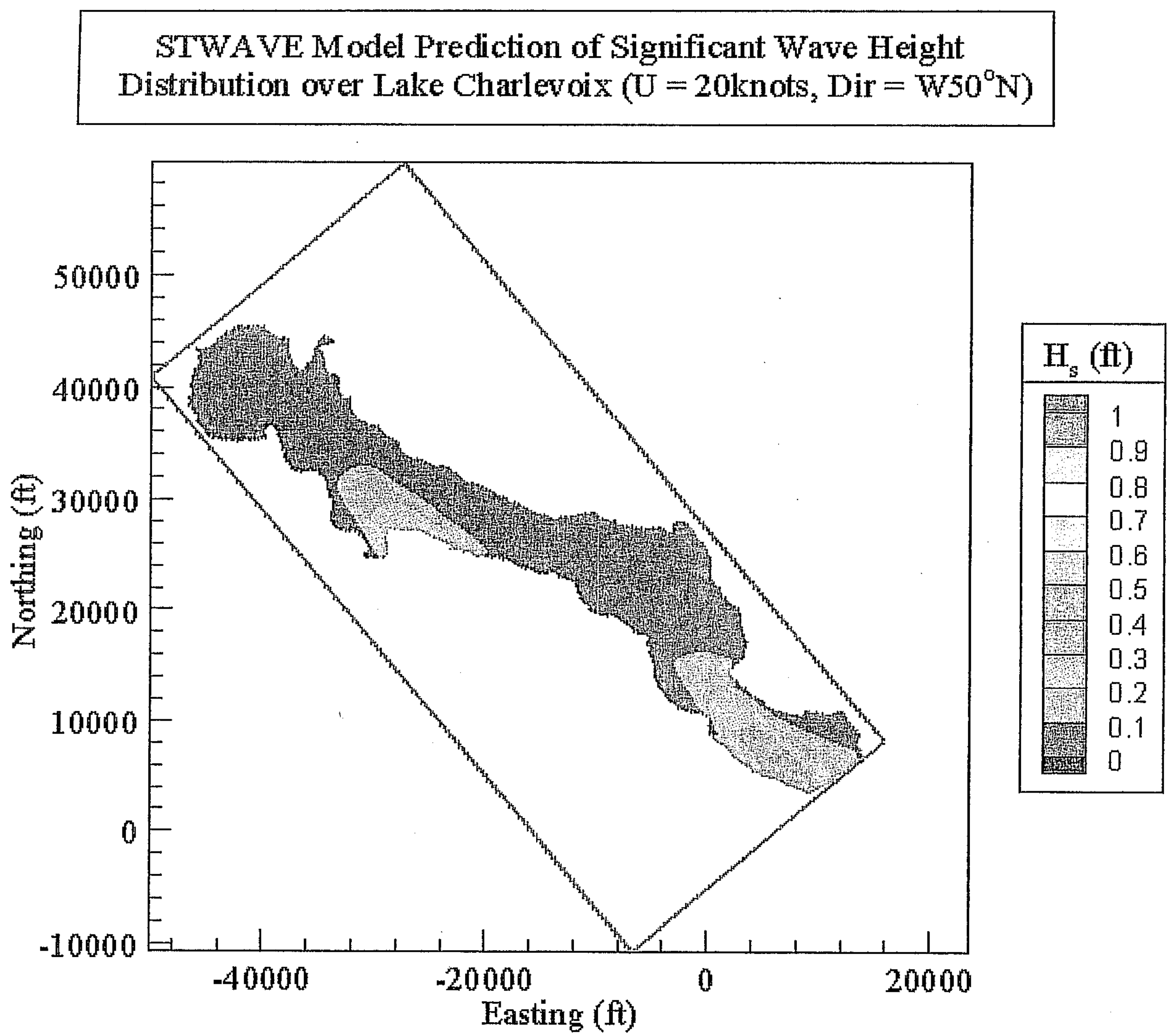


D2

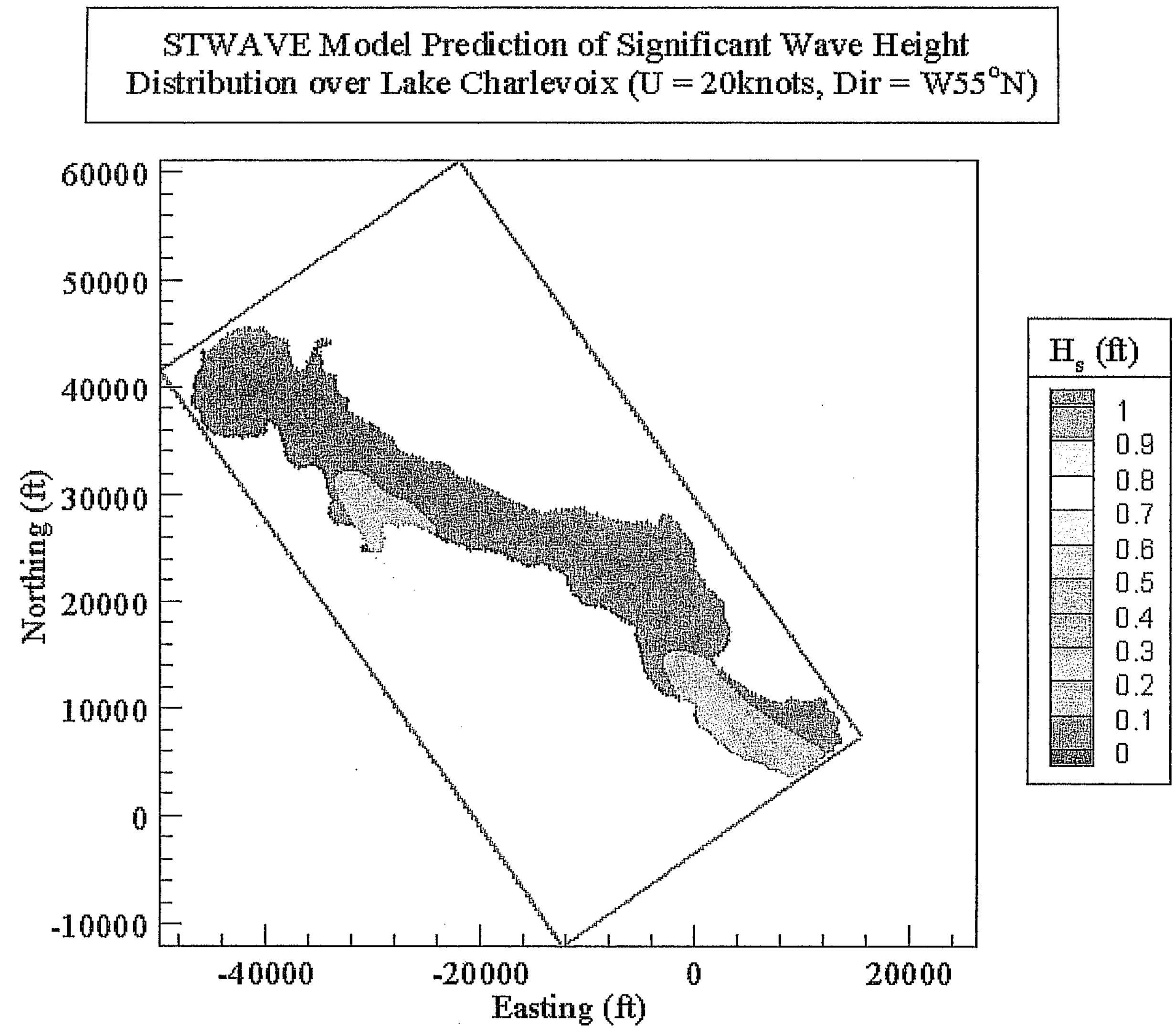
STWAVE Model Prediction of Significant Wave Height Distribution over Lake Charlevoix (U = 20knots, Dir = W45°N)



D3

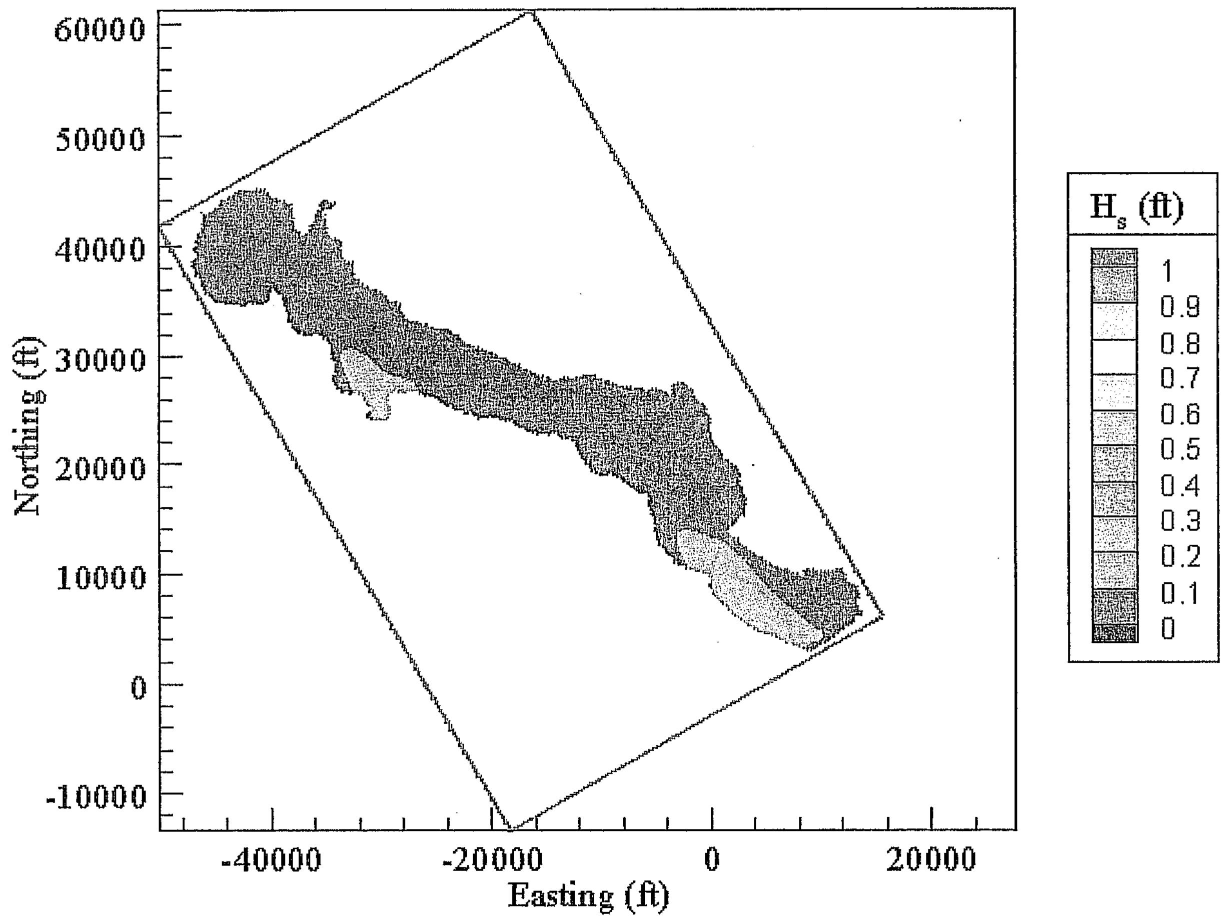

STWAVE Model Prediction of Significant Wave Height
Distribution over Lake Charlevoix (U = 20knots, Dir = W50°N)
50000
40000
30000
20000
10000
0
-10000
Northing (ft)
-40000
-20000
0
20000
Easting (ft)
Hs (ft)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

D4


STWAVE Model Prediction of Significant Wave Height
Distribution over Lake Charlevoix (U = 20knots, Dir = W55°N)
Northing (ft)
60000
50000
40000
30000
20000
10000
0
-10000
Easting (ft)
-40000
-20000
0
20000
Hs (ft)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

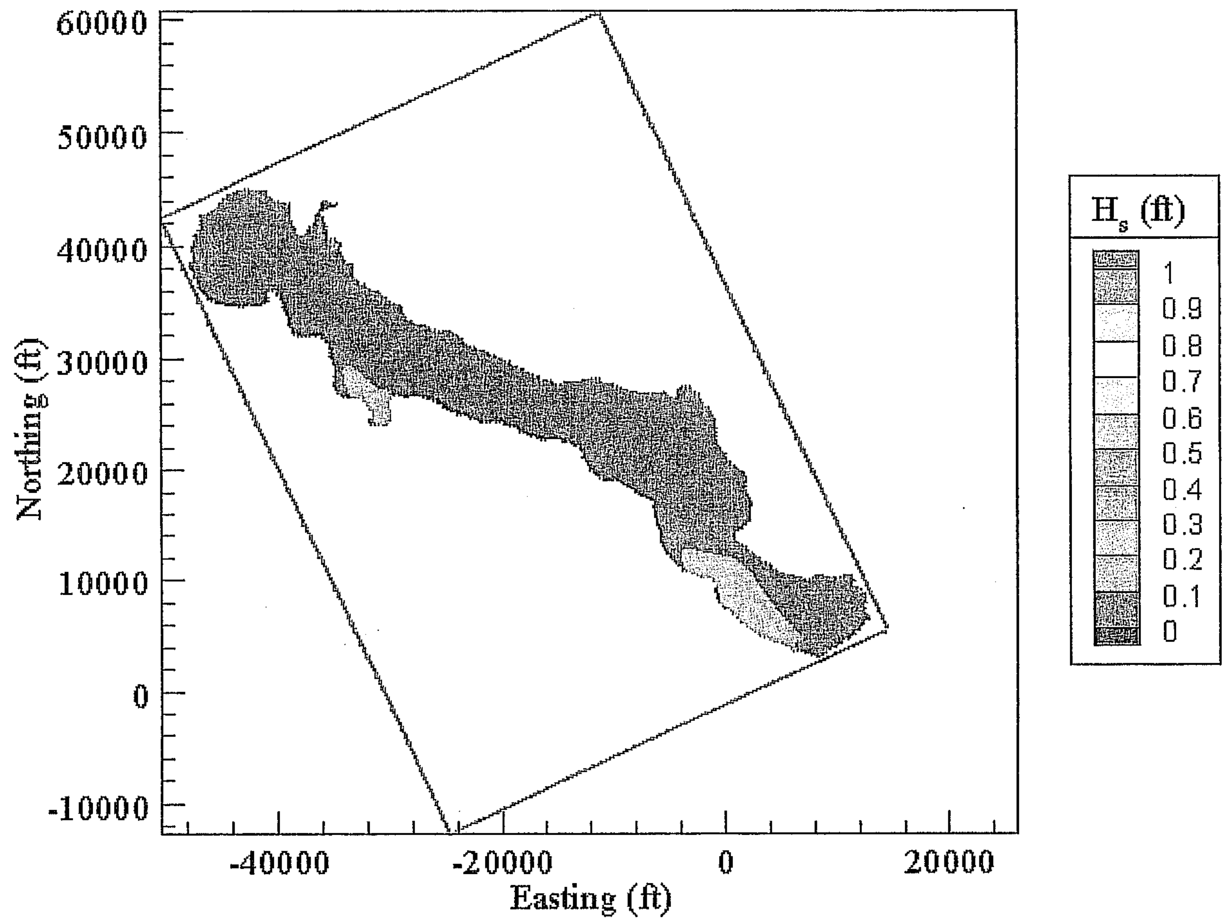
D5

STWAVE Model Prediction of Significant Wave Height Distribution over Lake Charlevoix (U = 20knots, Dir = W60°N)



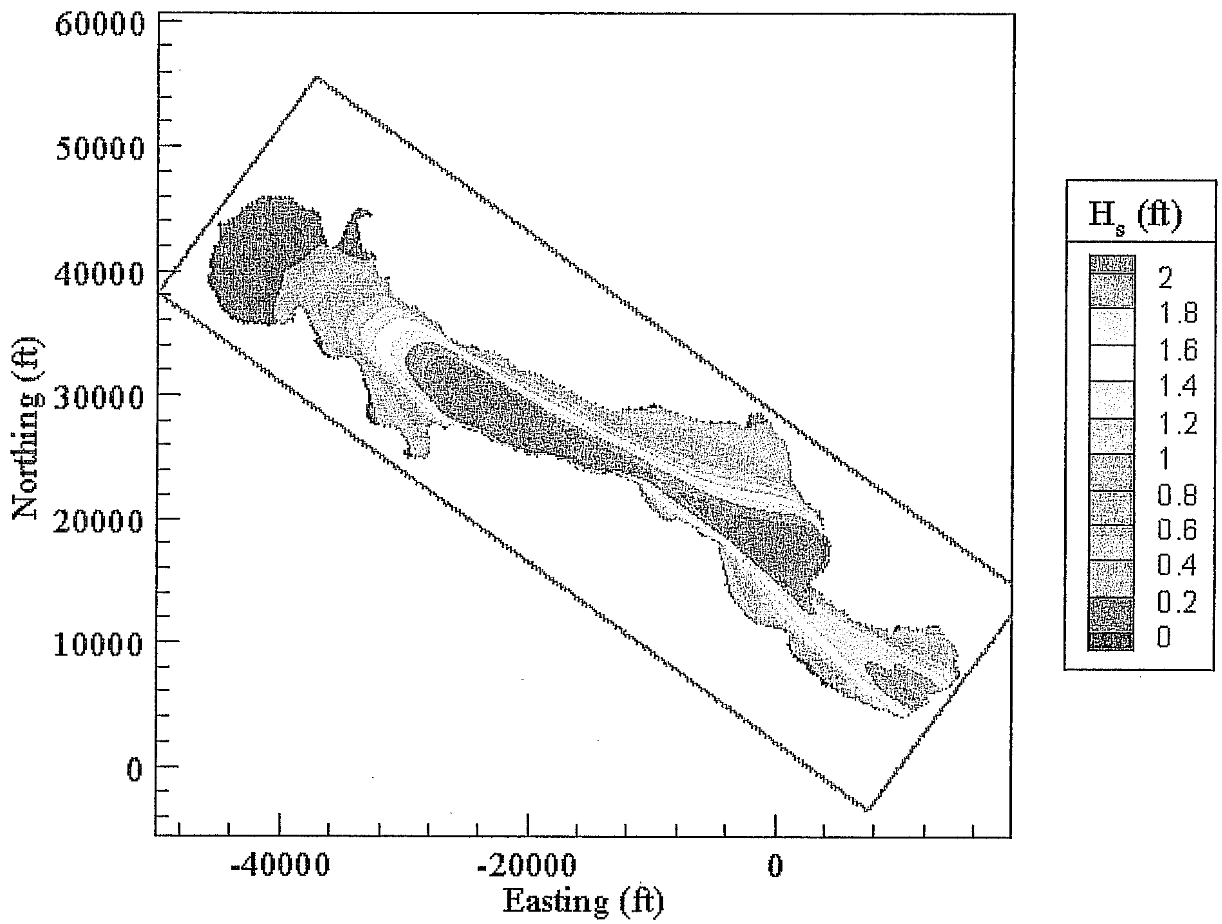
D6

STWAVE Model Prediction of Significant Wave Height Distribution over Lake Charlevoix (U = 20knots, Dir = W65°N)



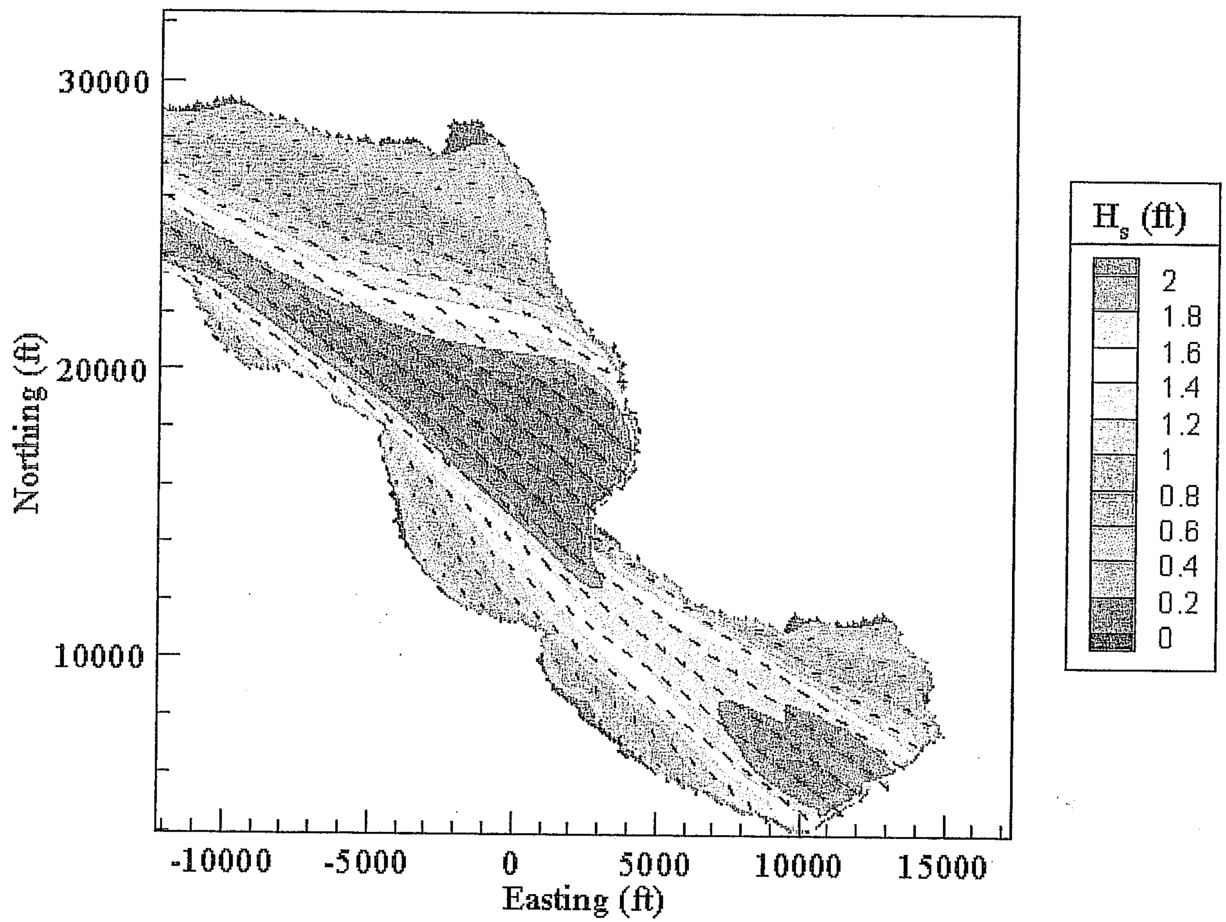
D7

STWAVE Model Prediction of Significant Wave Height Distribution over Lake Charlevoix (U = 40knots, Dir = W36°N)



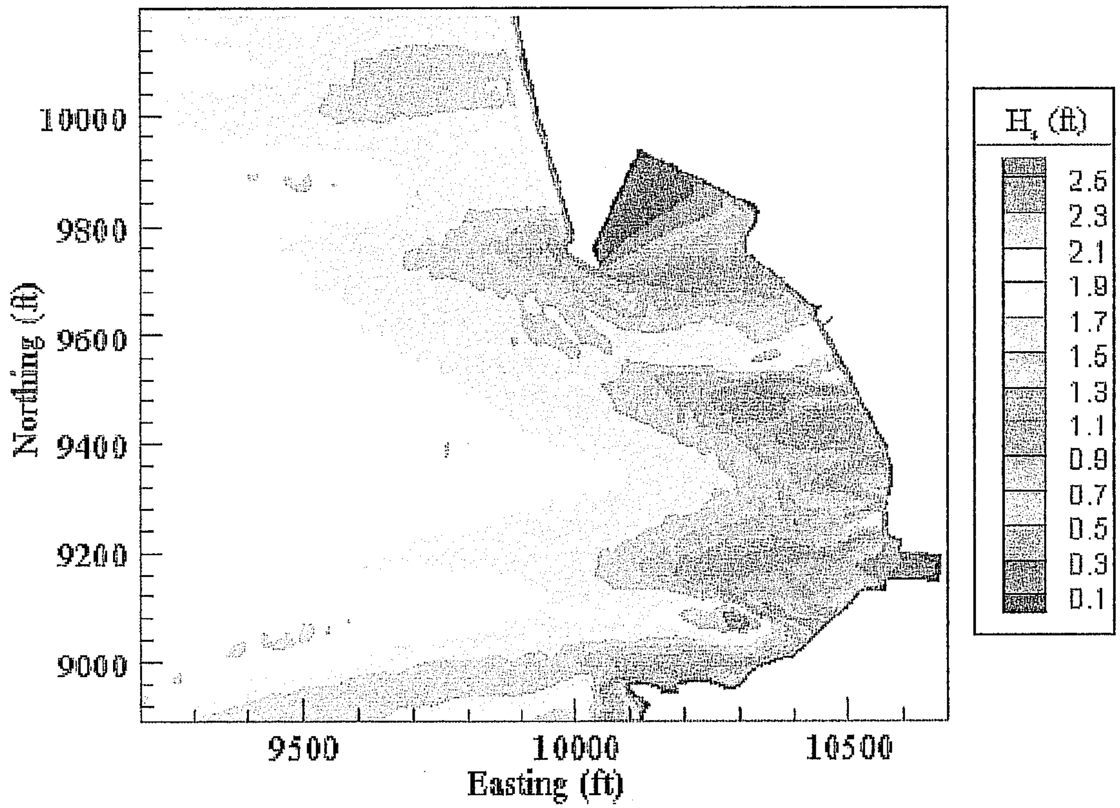
D8

STWAVE Model Prediction of Significant Wave Height Distribution over Lake Charlevoix (U = 40knots, Dir = W36°N)



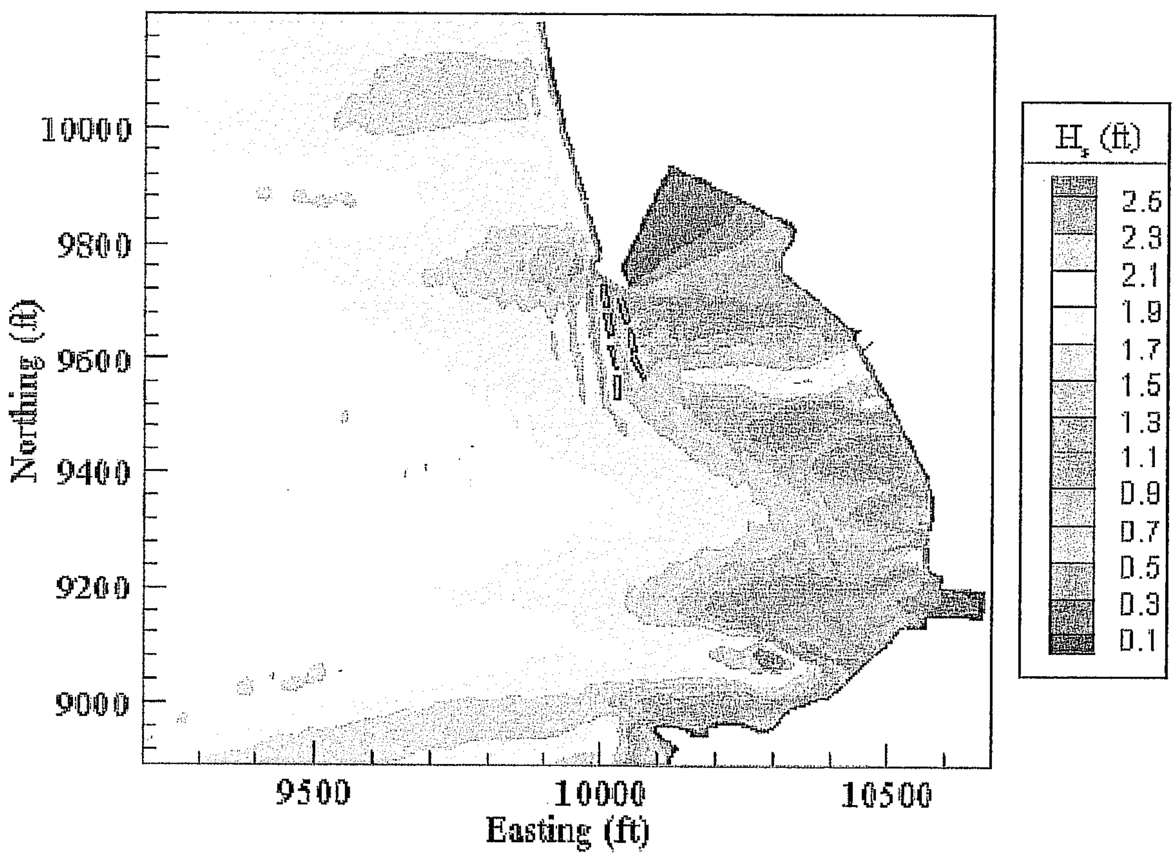
Appendix E – Bouss-2D Results

Significant Wave Height Distribution for Incident Waves with $H_s = 2ft$, $T_p = 4s$, Dir = W (Without Breakwaters)



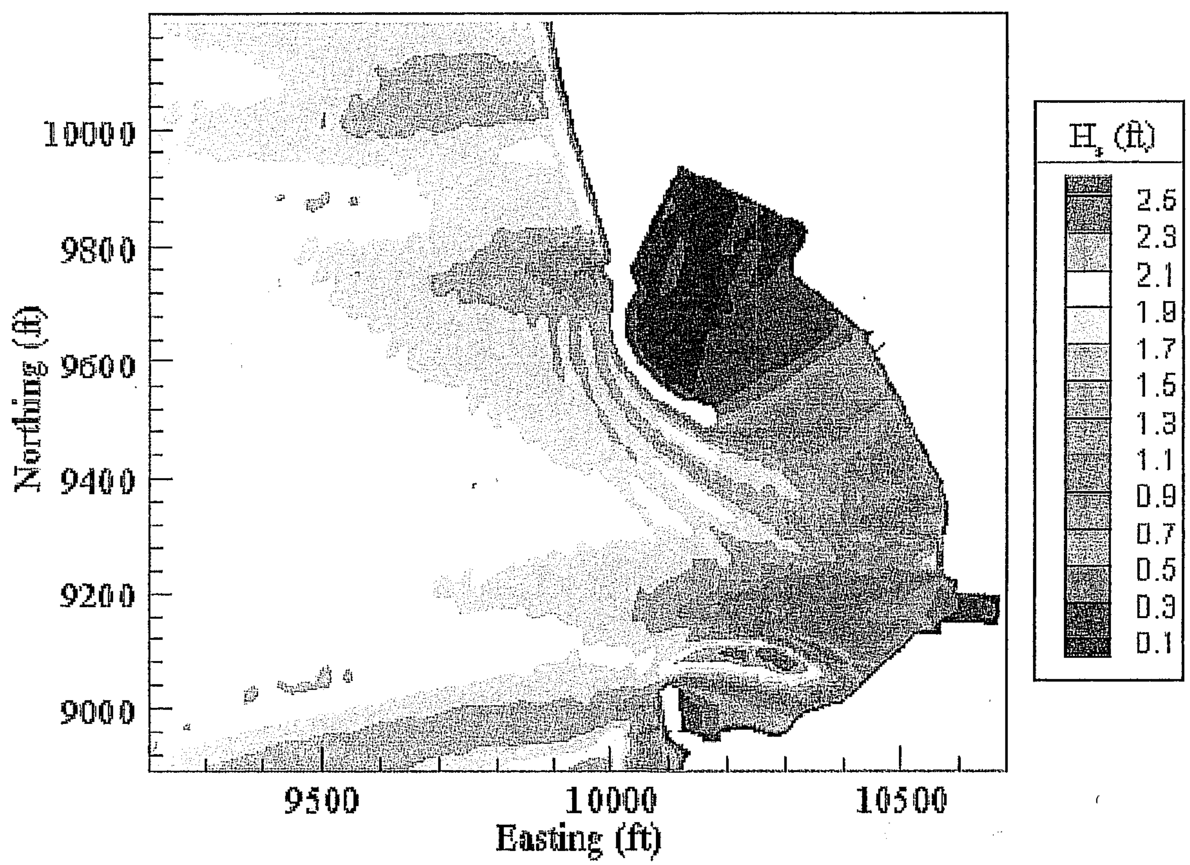
E1

Significant Wave Height Distribution for Incident Waves with H_s = 2ft, T_p = 4s, Dir = W (Floating Breakwaters)

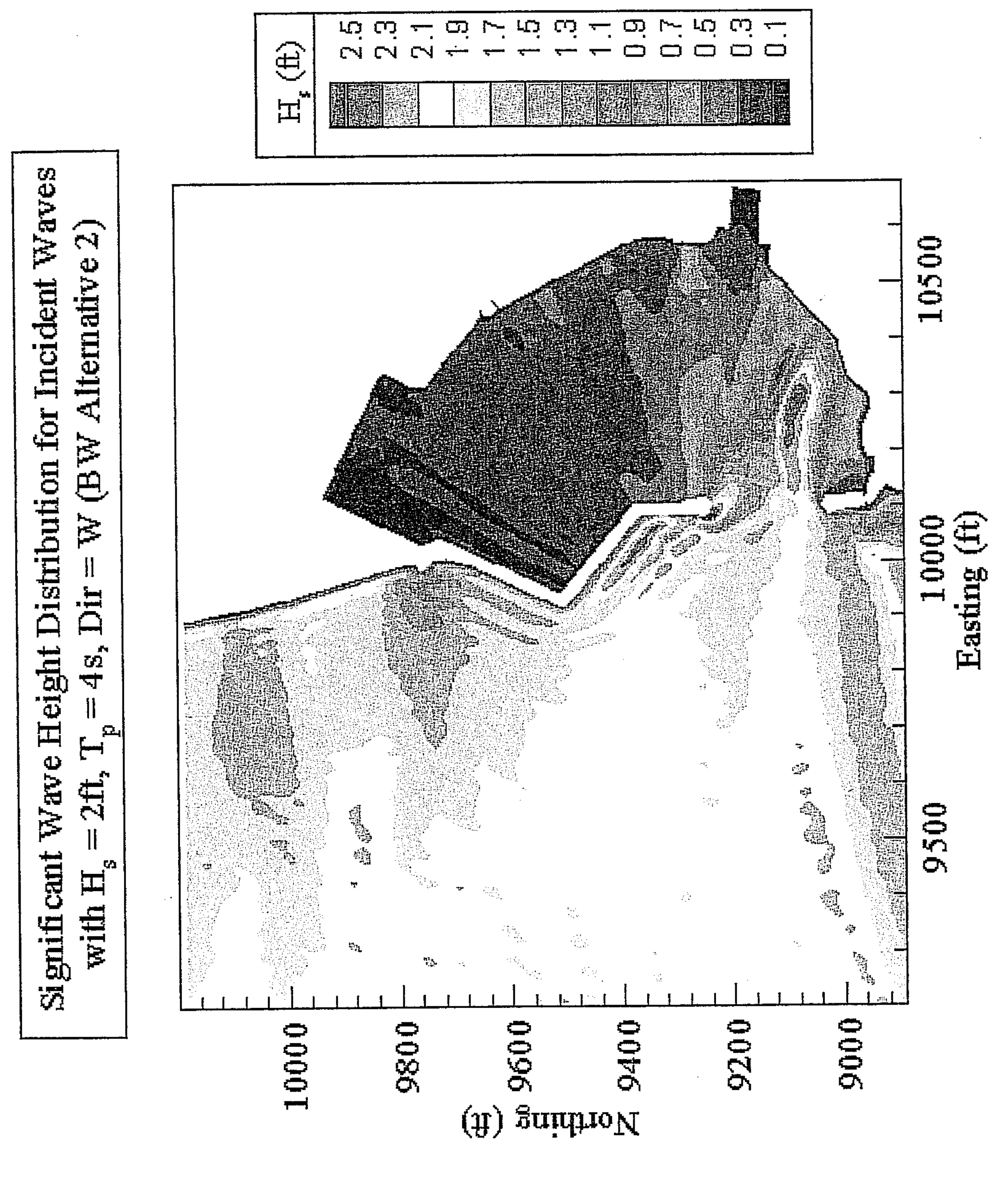


E2

Significant Wave Height Distribution for Incident Waves with $H_s = 2ft$, $T_p = 4s$, Dir = W (BW Alternative 1)

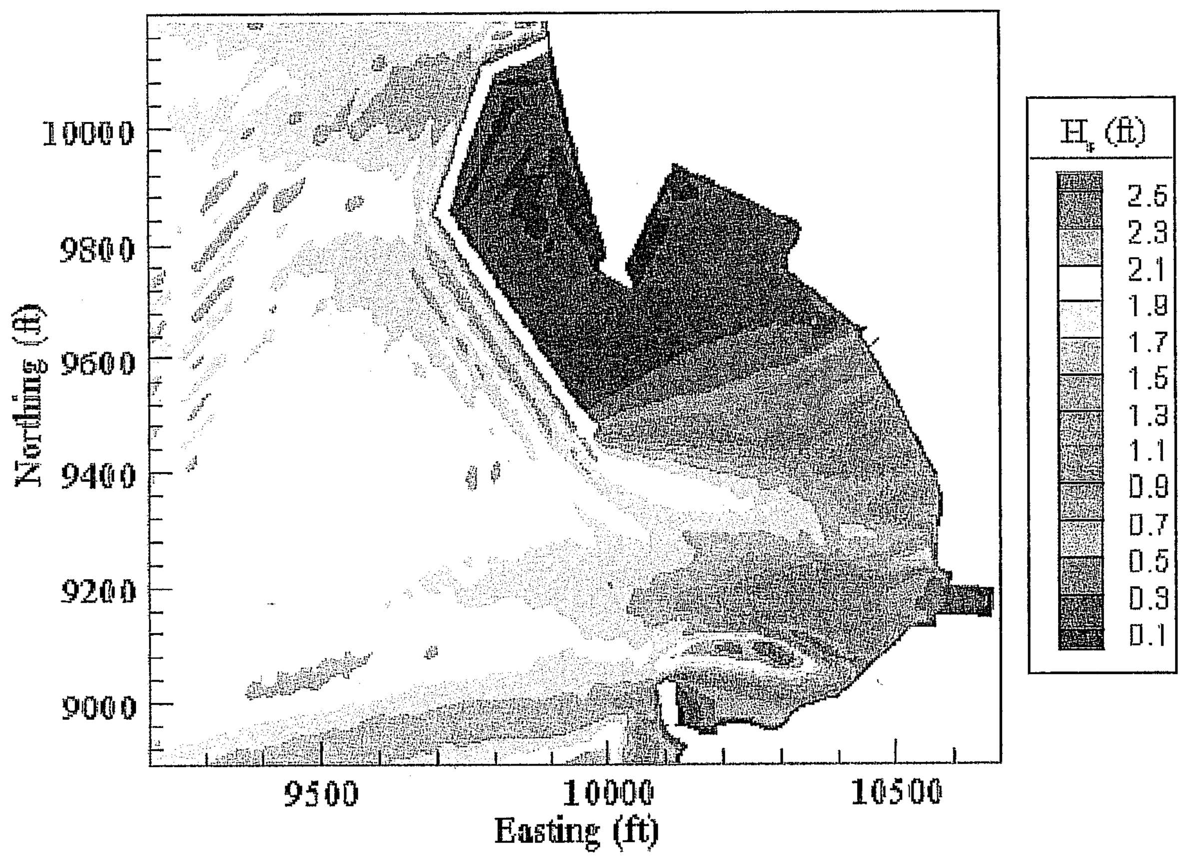


E3


Significant Wave Height Distribution for Incident Waves
with H_s = 2ft, T_p = 4s, Dir = W (BW Alternative 2)
H_s (ft)
2.5
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
Northing (ft)
10000
9800
9600
9400
9200
9000
Easting (ft)
9500
10000
10500

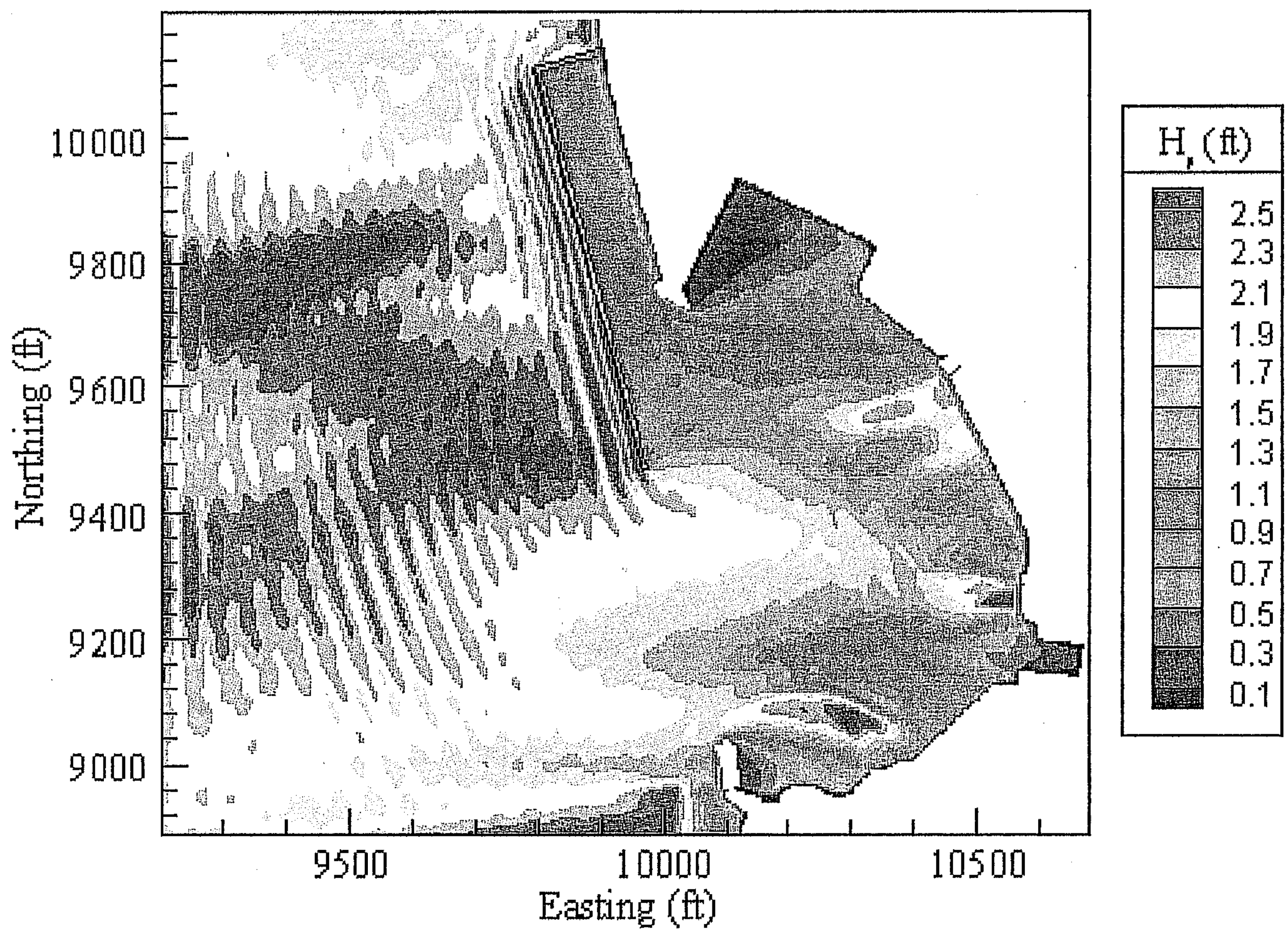
E4

Significant Wave Height Distribution for Incident Waves with H_s = 2ft, T_p = 4s, Dir = W (BW Alternative 3)

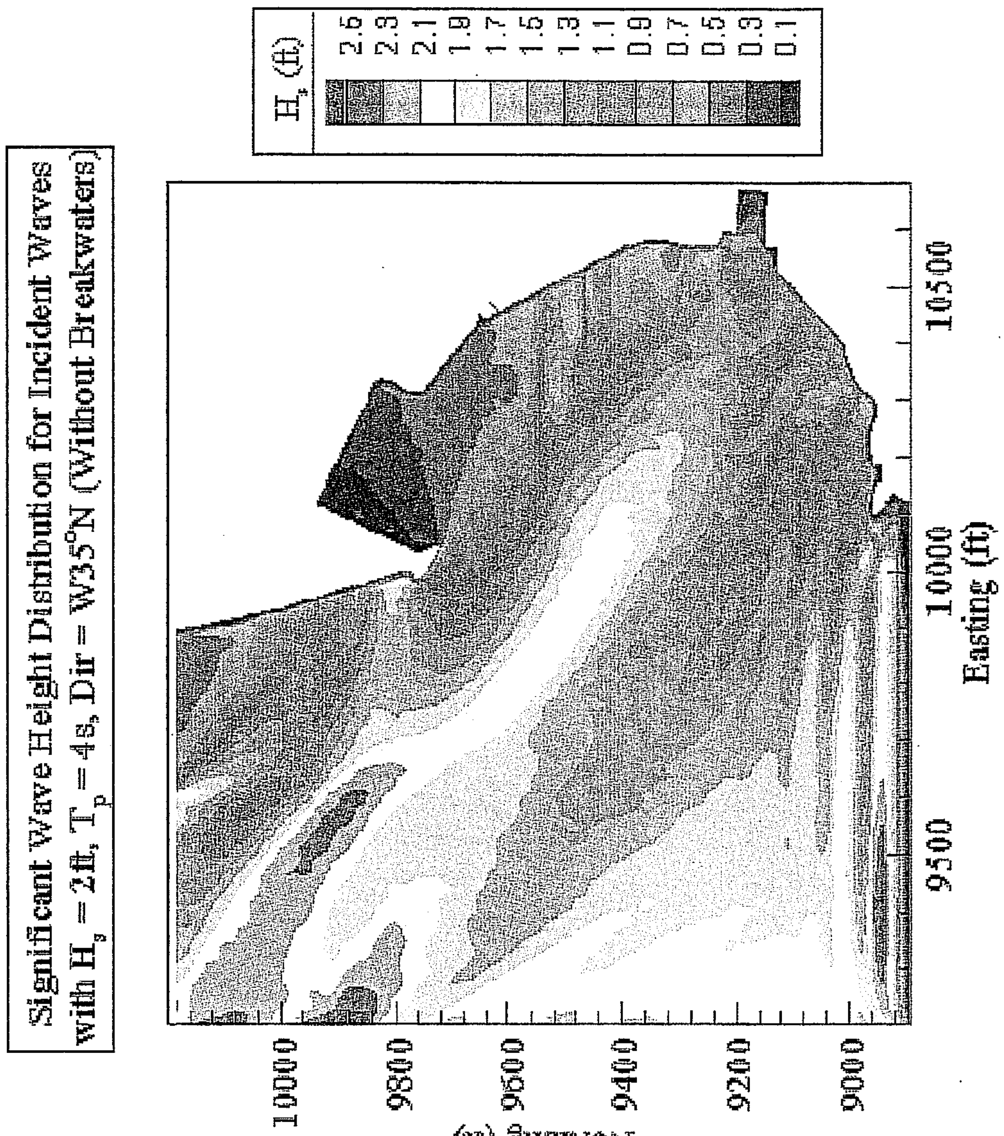


E5

Significant Wave Height Distribution for Incident Waves
with $H_s = 2$ ft, $T_p = 4$s, Dir = W
(Floating Breakwater Alternative)

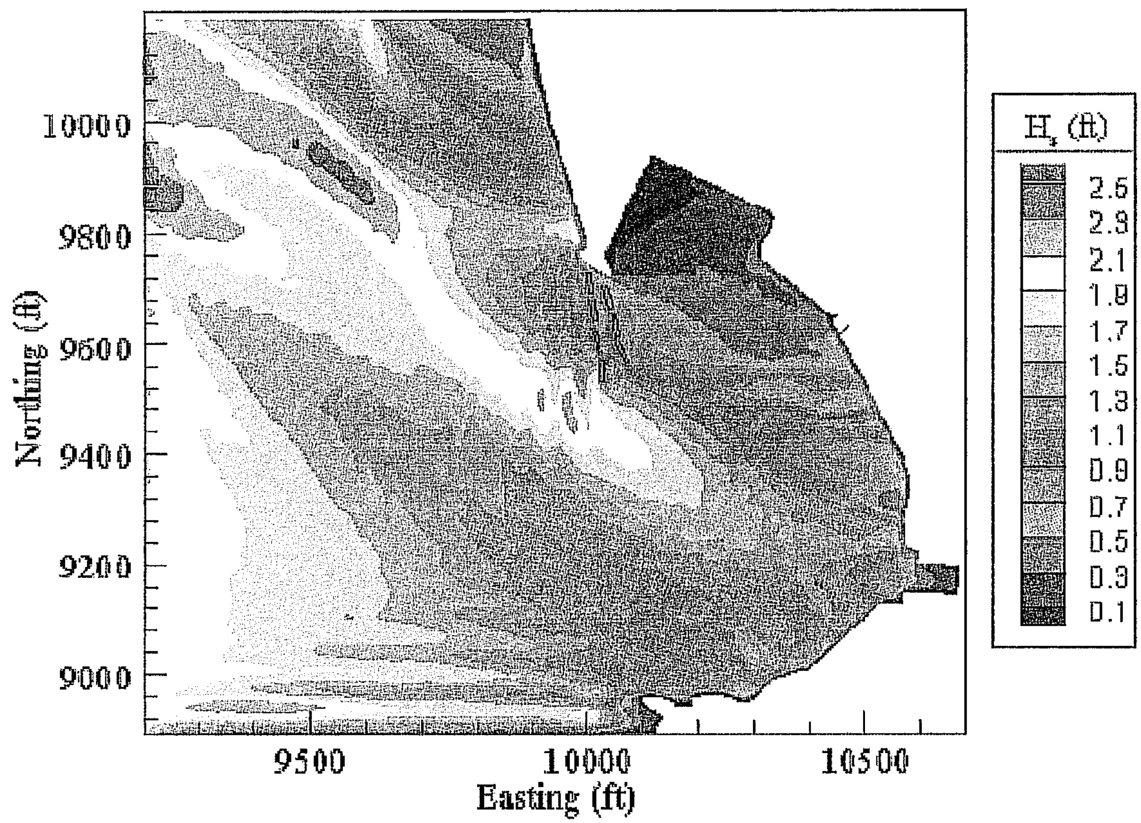


E6

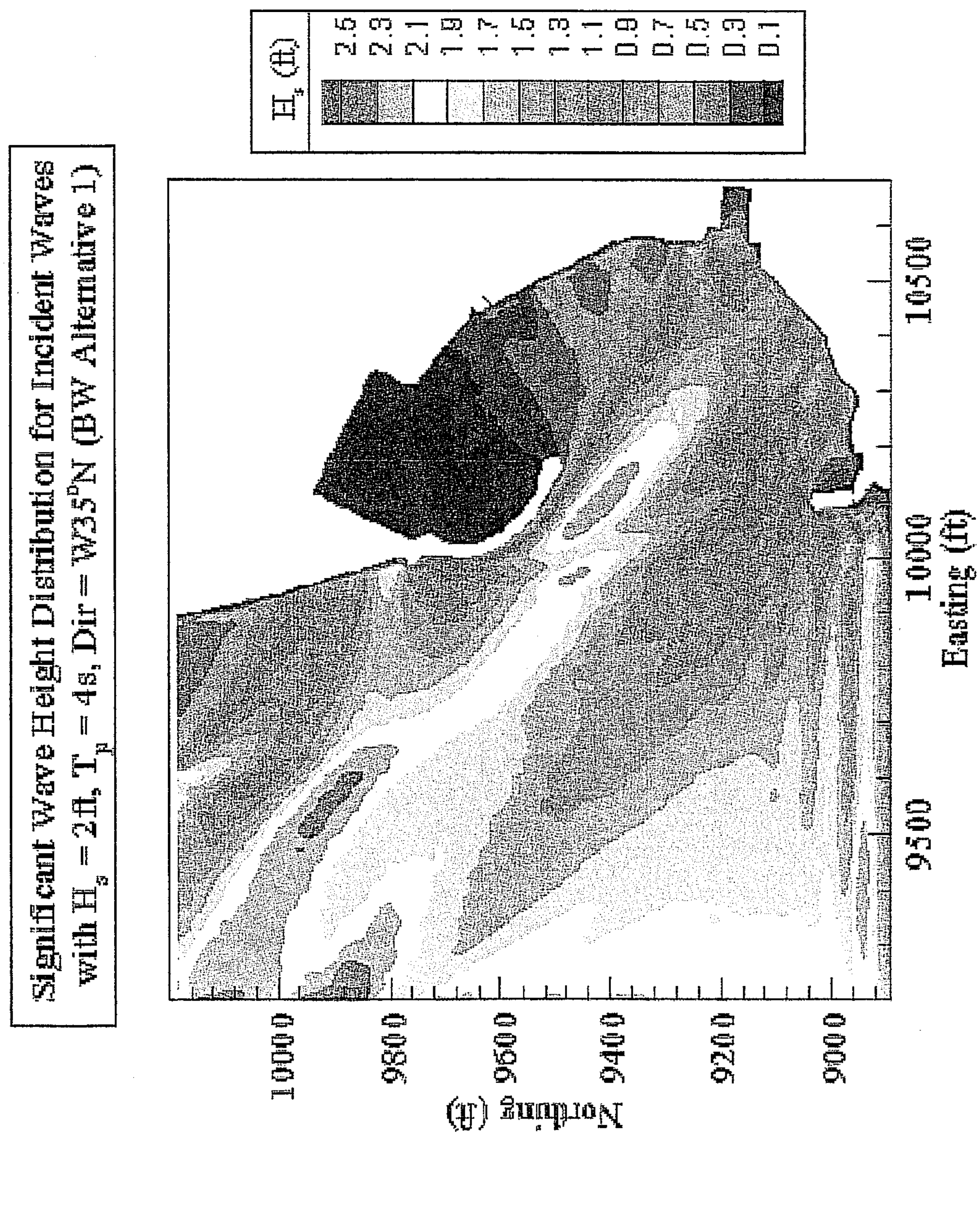

Significant Wave Height Distribution for Incident Waves
with H$_s$ = 2ft, T$_p$ = 4s, Dir = W35°N (Without Breakwaters)
H$_s$ (ft)
2.5
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
Northing (ft)
10000
9800
9600
9400
9200
9000
Easting (ft)
9500
10000
10500

E7

Significant Wave Height Distribution for Incident Waves with H_s = 2ft, T_p = 4s, Dir = W35°N (Floating Breakwaters)

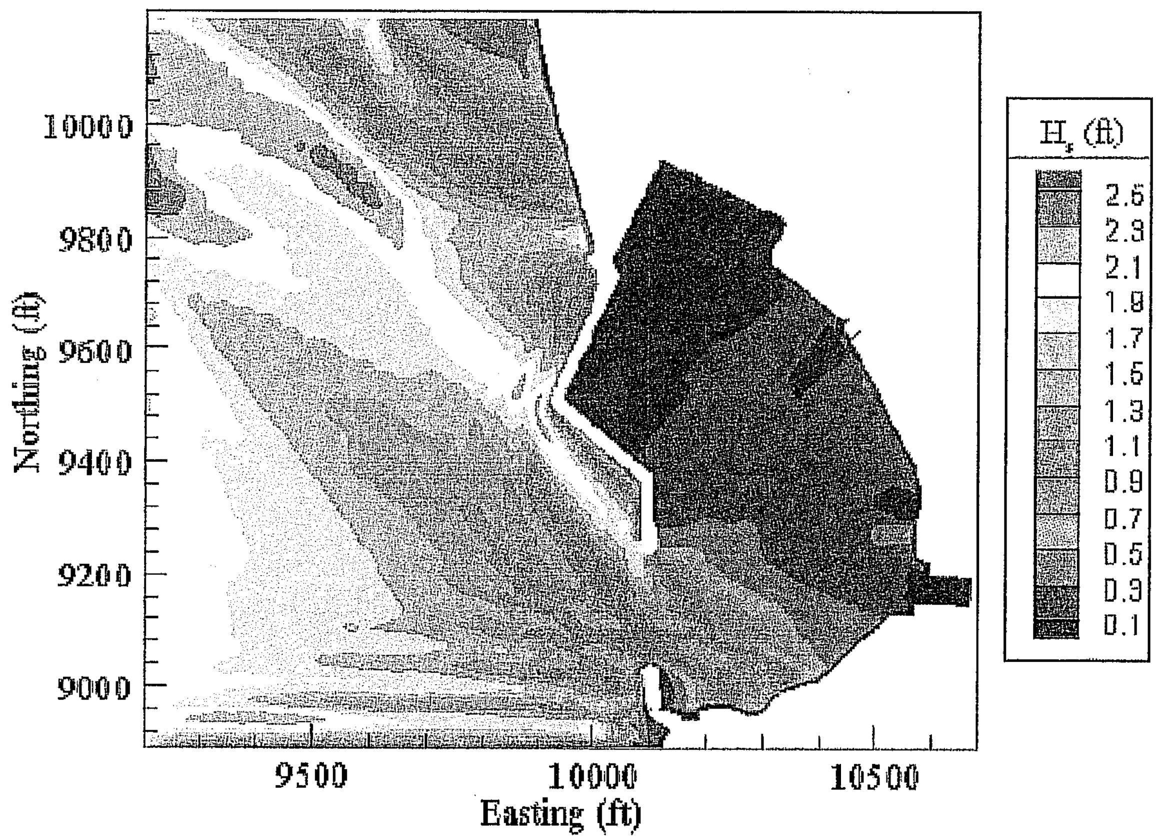


E8


Significant Wave Height Distribution for Incident Waves
with H_s = 2ft, T_p = 4s, Dir = W35°N (BW Alternative 1)
H_s (ft)
2.5
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
Northing (ft)
10000
9800
9600
9400
9200
9000
Easting (ft)
9500
10000
10500

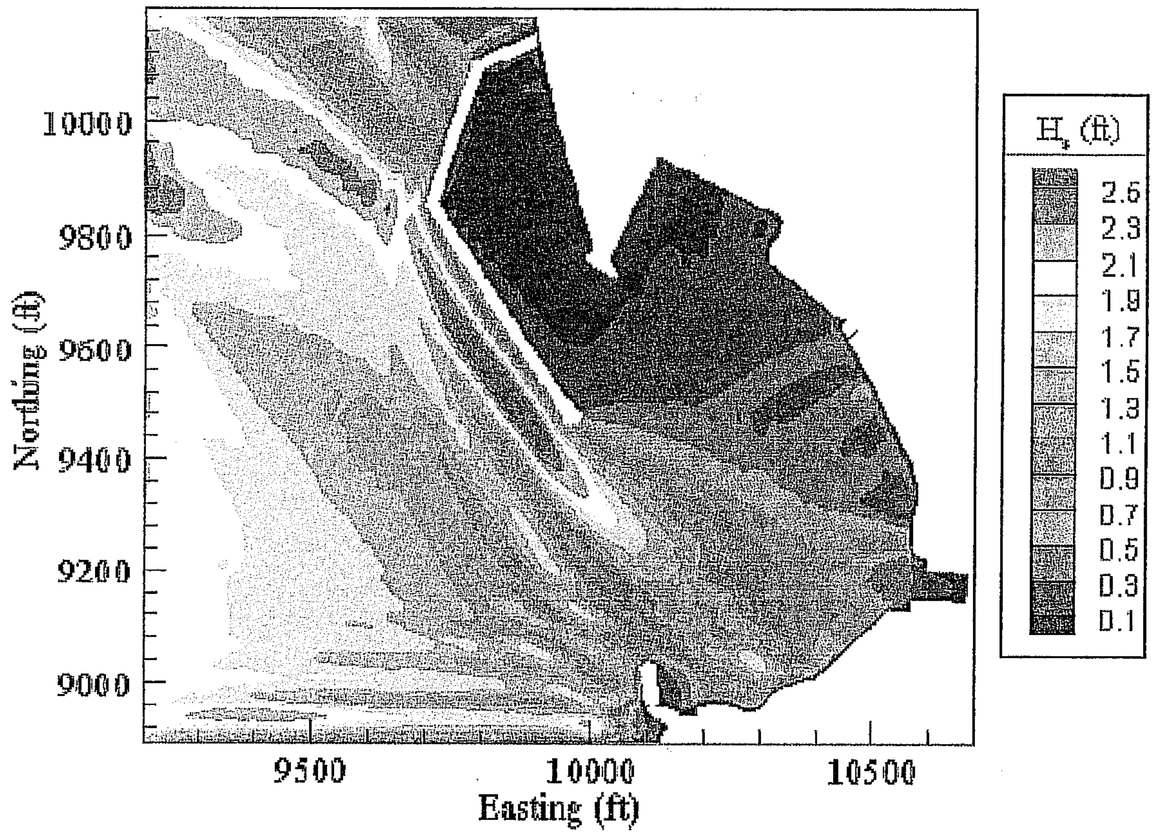
E9

Significant Wave Height Distribution for Incident Waves with $H_s = 2$ ft, $T_p = 4$s, Dir = W35°N (BW Alternative 2)



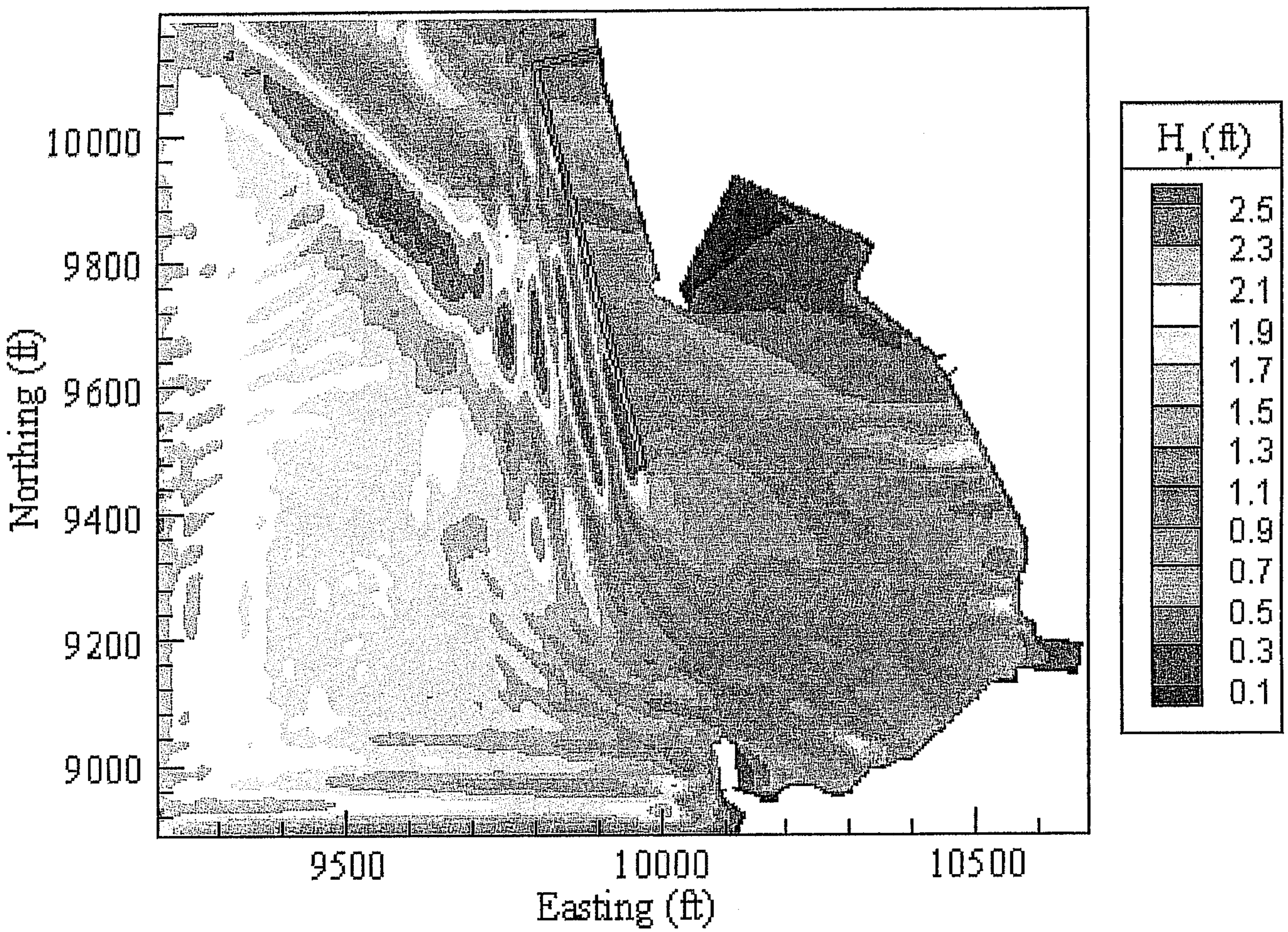
E10

Significant Wave Height Distribution for Incident Waves with $H_s = 2ft$, $T_p = 4s$, Dir = W35°N (BW Alternative 3)



E11

Significant Wave Height Distribution for Incident Waves with $H_s = 2$ ft, $T_p = 4$ s, Dir = W35°N (Floating Breakwater Alternative)



E12