# Blossom Heath Harbor/USCG Station St. Clair Shores
# Harbor Entrance Study

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**The University of Michigan**
**Ocean Engineering Laboratory**

Department of Naval Architecture and Marine Engineering
College of Engineering

Report OEL-0003

## Index

# 1. INTRODUCTION

## 1.1 Brief History and Problem Definition

Blossom Heath Harbor is located in the City of St. Clair Shores on Lake St. Clair in southeastern Michigan. Boat owners of the City of St. Clair Shores and the United States Coast Guard (USCG) Station St. Clair Shores share the harbor and use the channel for transit. The 52-foot wide channel is constructed with highly reflective vertical sheet piling. During strong wind and wave events, the harbor is severely impacted and the channel is unable to safely serve boating traffic. The harbor entrance is oriented in the direction of the longest fetch over Lake St. Clair, which is from the south east. Figures 1.1 and 1.2 show a satellite image of the area and the orientation of the harbor, respectively.

Numerous low cost engineering attempts have been made to try to abate the problem with little or no success. One attempt implemented in the late 1980's was a floating breakwater constructed of tires attached to poles by wires, to minimize the wave effects at the harbor entrance and inside the harbor. Many of the tires have broken loose over the years and have been removed from the bottom during recent dredging activities. The loose tires have been a navigational hinderance to channel traffic. Potential design alternatives did not encroach into the current channel width. Figure 1.3 depicts the current state of the breakwater.

## 1.2 Purpose of Study

At the request of the City of St. Clair Shores, the Ocean Engineering Laboratory (OEL) investigated the various parameters affecting the harbor entrance with the goal of providing suitable design options to alleviate the channel entrance problem. This report summarizes the findings of this investigation. The solution involves a comprehensive analysis of all factors affecting the harbor and harbor structures. Efforts were directed towards determining the best scenario for the future of Blossom Heath Harbor.

The purpose of this report is to document the feasible engineering alternatives and to provide preliminary cost estimates for the proposed designs. Towards these goals, the following tasks were performed:

- An onsite field investigation was conducted, consisting of precision nearshore hydrographic surveys.
- An aerial photo survey was acquired to accurately determine the current morphology of the harbor entrance.
- A detailed underwater survey of the existing harbor structure was conducted. This includes video and acoustic imagery obtained by Michigan's Remote Operated Vehicle for Education and Research, M-ROVER.
- The wind and wave climatology was analyzed to determine environmental characteristics necessary for input to numerical modeling efforts.
- Two numerical models were executed to fully investigate the effects of proposed harbor entrance alternatives.

•A harbor flushing analysis was performed to specify a mechanical pumping system to circulate and clarify the harbor water.

# 2. FIELD DATA COLLECTION

## 2.1. Wind and Wave Climatology of the Site

In order to fully understand the physical processes that affect the harbor entrance, it was first necessary to establish the wind and wave climate for the site. This data was obtained from the Ontario Ministry of Natural Resources (OMNR), utilizing their Emeryville site located in Lake St. Clair. The most recent period of record available was completed by OMNR in 1988 and spans the years 1971-1986. Wave heights and associated periods were evaluated for all compass directions incident upon the study site.

This wave climatology was used as input to the nearshore wave refraction and diffraction model and to the harbor resonance model. Table 1 shows the wave characteristics NNE through ENE approach directions and the number of hours these conditions have occurred during the period of record. These approach directions were chosen because they give the worst harbor conditions and occur 25% of the time.

Table 1. Wave Hindcast Data from NNE through ENE in Hours

| Wave Height (feet) | Period 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 6.56 | | | | | | 7 |
| 4.92 | | | | | 1244 | 180 |
| 3.28 | | | | 9146 | 5128 | |
| 1.64 | 176 | 2109 | 6779 | 4775 | | |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| | Period ( sec ) | | | | | |
| | | | | Total # of hours = | 29544 | |

## 2.2. Precision Nearshore Hydrographic Survey

The purpose of this survey was to establish the current detailed bathymetry within the harbor and near the entrance to create the input depth grid for the computational modeling. The survey system consists of an integrated dual digital acoustic depth sounder, plotter and GPS antenna along with a Differential GPS beacon receiver. The raw data strings were processed and depth/position pairs were plotted. The survey data collected extended from the shallow end of the public boat docks to a depth of 11 feet Low Water Datum (LWD). The bathymetry of the area is shown in Figure 2.1.

### 2.3 Remote Operated Vehicle Inspection

An underwater inspection of the existing sheet pile structure showed that the structure remains in good condition. The inspection was performed using M-ROVER (Figure 2.2). M- ROVER has a low light, high resolution, color video camera that recorded a clear, detailed picture of the harbor structure. M-ROVER is also equipped with a high resolution, scanning, imaging, color sonar that operates at 675 kHz and provides detailed measurements of the underwater. Both the video and sonar signals were recorded simultaneously on videotape for analysis. A copy of this video was provided to the USCG to assist in their dredging efforts to ensure that no loose tires remained in the channel.

### 2.4 Aerial Photographs

Aerial photographs were taken to illustrate the physical make-up of the site and to document the existing problems that occur during storm wave conditions. These photographs are used as illustrative tools throughout this report, and for identification of the materials of the different structures around the harbor entrance, walls, and boat docks. The materials information is a necessary input for the harbor resonance modeling (HARBD).

## 3. COMPUTATIONAL MODELING

### 3.1 Nearshore Wave Refraction and Diffraction Analysis

When deep water waves approach a coast, the waves undergo significant modifications due to the interaction of the wave motion with the nearshore bottom. Through this process the wave's height, length, phase speed and direction of travel change. In the simplest case, as a wave approaches a straight coastline with planar and parallel depth contours at an angle, the portion of the wave travelling in the shallowest water will move the slowest. This phenomena results in a bending of the wave crests such that they tend to become parallel to the bottom contours and shoreline. This is known as topographic refraction. Over a more complex nearshore bathymetry, the wave energy is concentrated over ridges and dispersed over depressions.

Wave diffraction is a phenomenon through which energy is transferred laterally along a wave crest. This phenomenon is most apparent when a regular train of waves is interrupted by a surface piercing barrier, such as a breakwater, jetty, or island. If this phenomenon did not occur, there would exist a perfectly calm area in the lee of a breakwater. Through the process of diffraction, wave energy moves along wave crests from a region of high wave energy to low wave energy thus "smoothing out" the effects of topographic refraction.

In order to determine the characteristics of the waves interacting with the nearshore bathymetry in the vicinity of Blossom Heath Harbor, the Regional Coastal Processes Wave model (RCPWAVE) was used. The model was developed by the US Army Corps of Engineers as part of the Regional Coastal Processes Numerical Modeling System to predict coastal processes around man-made structures. This model utilizes a detailed nearshore bathymetry grid and deep water wave conditions as input and outputs a wave height and direction grid.

To initiate the RCPWAVE modeling portion of this study, it was first necessary to establish the geometry and bathymetry of the study site. The coordinate system, datum, grid spacing, and nearshore bathymetry were defined by the Precision Nearshore Hydrographic Survey performed inside and outside of the harbor, as well as digital nautical charts. The nautical chart used contained bathymetric data from 1997. The depth units in the chart are feet and the Blossom Heath area is represented in Figure 1.2. The offshore wave climatology was derived from the OMNR database described in Section 2.1.

The grid was subdivided into two reaches to account for the shoal offshore of the harbor. The two grids, situated north and south of the entrance, have different sizes: 63 by 75 cells for the north, and 167 by 188 cells for the south grid. The numerical rectilinear grid cell size was 50 feet in the cross-shore and longshore directions. This grid spacing was dictated by the necessity of fully characterizing the wave field with at least 3 nodes per wavelength for the shortest analyzed wave. Both the north and the south grids had wave angles of approach ranging from -45° to 67.5° off normal. The angles of approach greater than -45° off normal were not necessary in this analysis because the harbor is sheltered by coastal structures to the south.

To ensure that the modeling approach taken was correct, the two output grids resulting from waves approaching at 90° (east) were inter-compared. The north grid did not include the complex shoal bathymetry and this comparison showed that waves from the east are not influenced greatly by the shoal.

The output from each incident wave direction was analyzed to determine the resultant significant wave height and wave energy in the study area. Based upon simple inspection of the bathymetric data, one would expect to see a concentration of wave energy, and thus an increase in wave height, over topographic ridges.

Under storm wave conditions approaching from the northeast, the results of the numerical wave refraction/diffraction analysis show that the wave energy remains relatively constant until the waves approach the harbor entrance. Wave heights build as they approach the vertical sheet wall lining the entrance area. Although the fetch is longest from the southeast quadrant, the orientation of the harbor diminishes the wave's impact on the harbor entrance. As a result, the harbor resonance analysis focuses on waves from the northeast/east directions. When the wave approaching directions are 45°, 67.5°, and 90°, there are high wave conditions produced both at the entrance and inside the harbor. Plots of the RCPWAVE output can be found in the Appendix.

## 3.2 Harbor Resonance Modeling

A harbor resonance model modified by Purdue University's Great Lakes Coastal Research Laboratory to account for transmission through boundaries, HARBD, was used to analyze the reflected and transmitted wave conditions near and inside the harbor. This model has been tested against field measurements for both small and large (commercial) harbors. Slightly modified versions of this program have been used for practical applications: Chang (1992) applied it to the Cargill dock in Burns International Harbor, Indiana; Appleton (1994) has applied it to Lake Macatawa, Michigan.

This model uses a finite element mesh as input and a conservation of energy approach. It includes the effects of wave refraction, diffraction and reflection, and it accounts for variable depths and boundary conditions. The outputs include a free surface elevation map and the amplification factor of the harbor.

The finite element mesh was generated by utilizing the mesh module of the Surface-water Modeling System (SMS). The location of the shoreline structures and the geometry of the harbor were obtained from the chart mentioned is section 3.1 of this report, and are important inputs into the model. The bathymetry of the area was obtained from the bathymetric chart and the 1999 precision nearshore hydrographic survey data. The depths were input as positive values at the nodes, which were chosen such that there are six nodes per wave length.

Once the depths values are assigned to the nodes, it was necessary to specify the boundary conditions. The aerial photography and site visitation (1999) were used to determine the type of material used for all the structures around the harbor, and for identifying any natural beach near the entrance channel. It is possible to assign transmission coefficients to materials providing protection to the entrance. Typical coefficients have values between 0.2 and 0.5, with 0.25 used in this case.

A grid of the current harbor configuration was run for a series of incident wave heights and periods, determined from the wave climatology presented in Section 2.1 of this report. The current harbor design was run for wave periods ranging from 2 to 6 seconds with 0.1 second increments for waves approaching from the same directions as those used in the nearshore wave refraction/diffraction modeling. It was found that waves approaching from the northeast produced the maximum wave height and energy conditions within the harbor and channel. This numerical result compares well with information provided by the City of St. Clair Shores and the USCG Station St. Clair Shores. Five data points were collected for each wave period and plotted to produce the wave energy spectrum. The data point locations can be found in Figure 3.1 and the wave energy spectrum is shown in Figure 3.2. An example of the model output for an incident wave with a period of 5.5 seconds is shown in Figure 3.3.

The wave height factor is the water surface elevation above or below mean water level divided by the incident wave height. Figure 3.4. shows the relative amplification factor for wave height, with respect to a constant reference wave height. The harbor entrance, the public docks, and the wall structures are affected by high amplification factors for wave periods in between 2.5 and 3 seconds, wave height amplification factors averaging values of 1.9 to 3.5.

### 3.3. Harbor Flow Analysis

A harbor flow analysis was conducted with the purpose of computing the required volume of water necessary to be replaced periodically so the quality of the water inside the harbor would be increased. Blossom Heath Harbor lacks natural flushing phenomena such as tides and/or river input, causing various pollutants to be concentrated inside the basin. It is the OEL recommendation in consultation with Prein&Newhof Engineers of Grand Rapids, Michigan, that a pump station be used to solve this problem.

The harbor flow analysis was based on the bathymetry of the harbor, which provided the total volume of water that would have to be flushed. The average depth inside the harbor is 4 ft, and the total volume of water is approximately 5 million gallons. Based on the fact that this water would have to be replaced every 2 days, a pump with at least 1,750 gallons per minute is necessary for this project. The pump type recommended by Prein&Newhof is a low-head, submersible pump with vortex suppressor, placed on a rail system with cables, and mounted against the concrete wall. The flow rate for this pump is 2,000 gallons per minute. The rail system provides easy accessibility to the pump for cleaning, maintenance and removal during winter ice conditions.

## 4. PROPOSED DESIGN ALTERNATIVES

### 4.1 Alternative Designs

Three alternative designs were developed and analyzed. Alternative design 1, see Figure 4.1, consists of adding rubblemound along part of the southern wall of the entrance channel. The width of the rubblemound would be approximately the same as the current floating tire breakwater design, about 10 feet. The slope would be approximately 1:1.5 for all considered designs. Alternative design 2, see Figure 4.2, consists of rubblemound along the entire southern wall and in front of the Coast Guard station. Alternative design 3, see Figure 4.3, consists of a rubblemound breakwater designed to shelter the harbor from northeasterly waves and another breakwater that extends perpendicular from the southern wall to absorb the wave energy from easterly waves. All three designs were configured to provide no more obstruction than currently exists through the entrance channel.

All three designs were generated and run for wave periods ranging from 2.5 through 5.5 seconds at 0.1 second increments for waves approaching from the northeast. The five data points defined in section 3.2 were collected, averaged, and then compared to the current design. The decrease in wave height magnitude factors from each alternative design are shown in Figure 4.4. Alternative designs 1 and 2 reduce the wave energy and resulting wave heights by 33%, while alternative design 3 decreases the wave energy and heights by about 73%.

An example of the modeling output for all three alternative designs is shown in Figure 4.5 and compared to the current design. For waves approaching from the east quadrant, the resultant wave action for each design are shown in Figure 4.6. Easterly wave conditions are prevalent approximately 10% of the time.

## 4.2 Conclusions from the Harbor Flow Analysis

Based on the preliminary calculations of the cost of materials and maintenance to provide fresh water circulation in the harbor and using the information provided by Prein and Newhoff Engineers of Grand Rapids, MI, we have made some conservative estimates.

| Item | Quantity | Unit Price | Amount |
|---|---|---|---|
| Intake Pipe (16") | 500 l. ft | $200 | $100,000 |
| Concrete Pump Station | 1 | $30,000 | $30,000 |
| Contingencies, Engineering Project Administration | 1 | $50,000 | $50,000 |
| Submersible Pump | 1 | $20,000 | $20,000 |
| Floating Mixer (Optional) | 1 | $15,000 | $15,000 |
| Total | | | **$215,000** |

## 4.3 Conclusions from the Alternative Harbor Model Designs

The following results were obtained from the analysis of model runs of the various harbor configurations proposed for Blossom Heath/USCG Station St. Clair Shores.

1. Alternative designs 1 and 2 have very similar results. Additional rubblemound along the southern wall and in front of the USCG station, produces a reduction in the wave energy.

2. Alternative designs 1 and 2 still remain vulnerable for incident waves from the east.

3. Alternative design 3 clearly dissipates the most wave energy for every incident wave angle and provides the best overall entrance and harbor conditions, by significantly reducing the wave energy (73%).

4. Roughly the cost estimates of material is $85,000 for design 1 $450,000 for design 3.

## ACKNOWLEDGMENTS

The authors of this report would like to thank the personnel from US Coast Guard Station, St. Clair Shores, the Group Detroit US Coast Guard for the aerial photographs, and the Prein&Newhof Engineering of Grand Rapids for the technical help provided with the pumping specifications and material costs.

## References


1. Chang, Y.S. "A Harbor Resonance Model with Reflecting, Absorbing, and Transmitting Boundaries", Ph.D. Thesis, August 1992, Purdue University.
2. Chen H.S., Mei C. C. "Oscillations and Wave Forces in an Offshore Harbor", Report No. 190, August 1974, Massachusetts Institute of Technology.
3. Wave Hindcast Database for lakes Erie and St. Clair, March 1988, Ontario Ministry of Natural Resources .

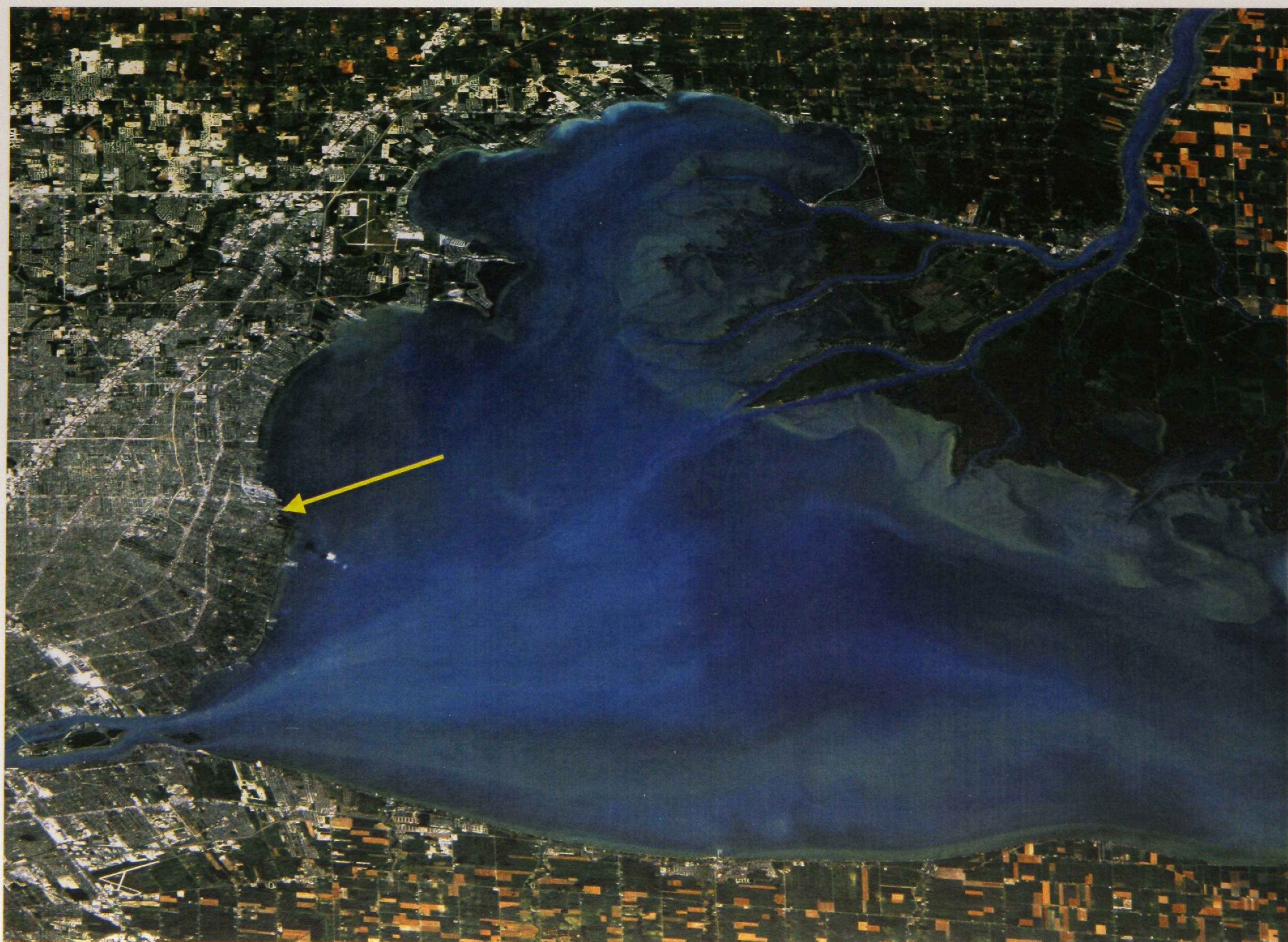


**Figure 1.1. Satellite Image of the Blossom Heath Area (1998)**

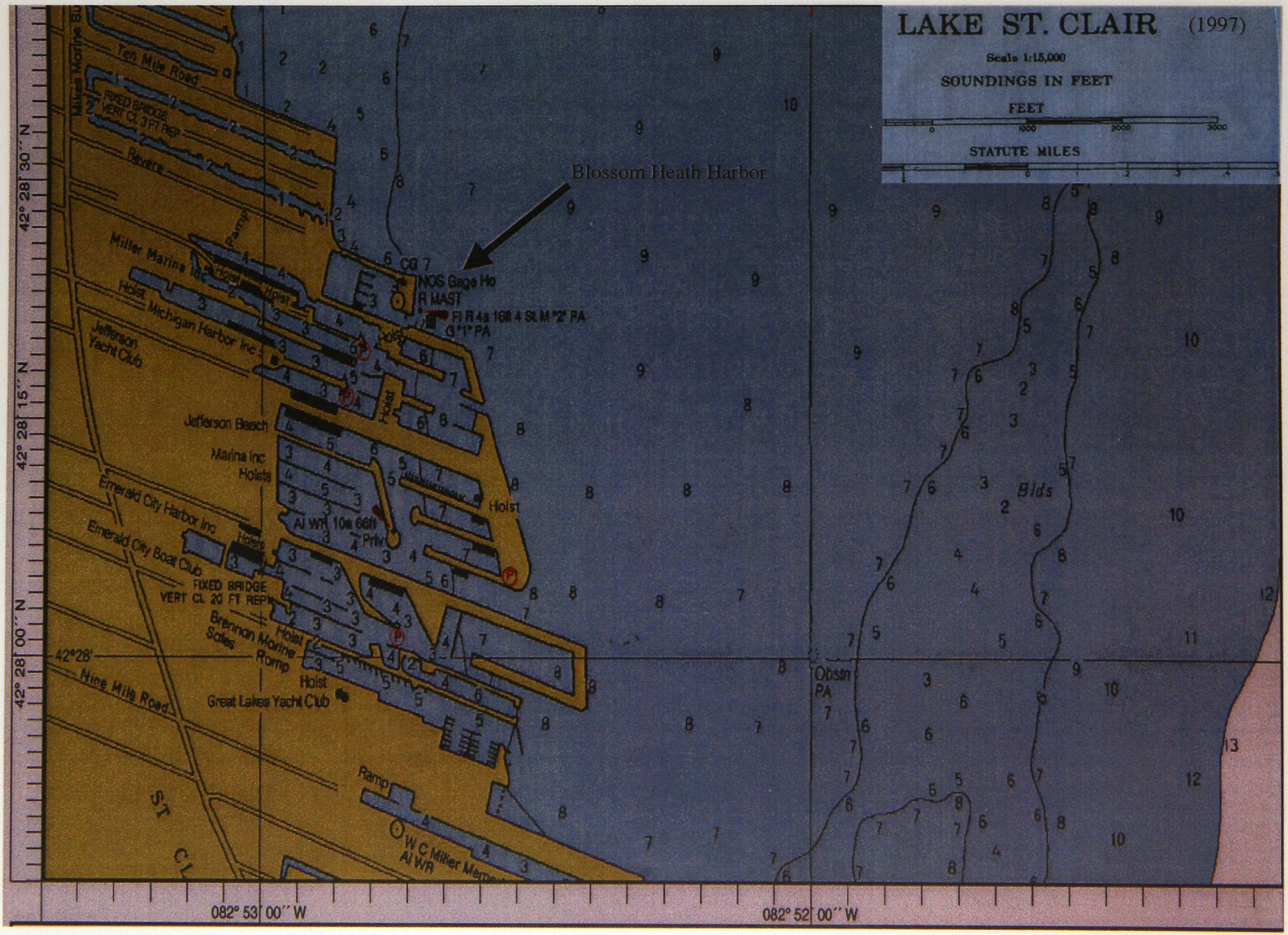



**Figure 1.2. Nautical Chart of Blossom Heath Area (1997)**

**Figure 1.3. Aerial Photo Showing the Current State of the Breakwater (1999)**

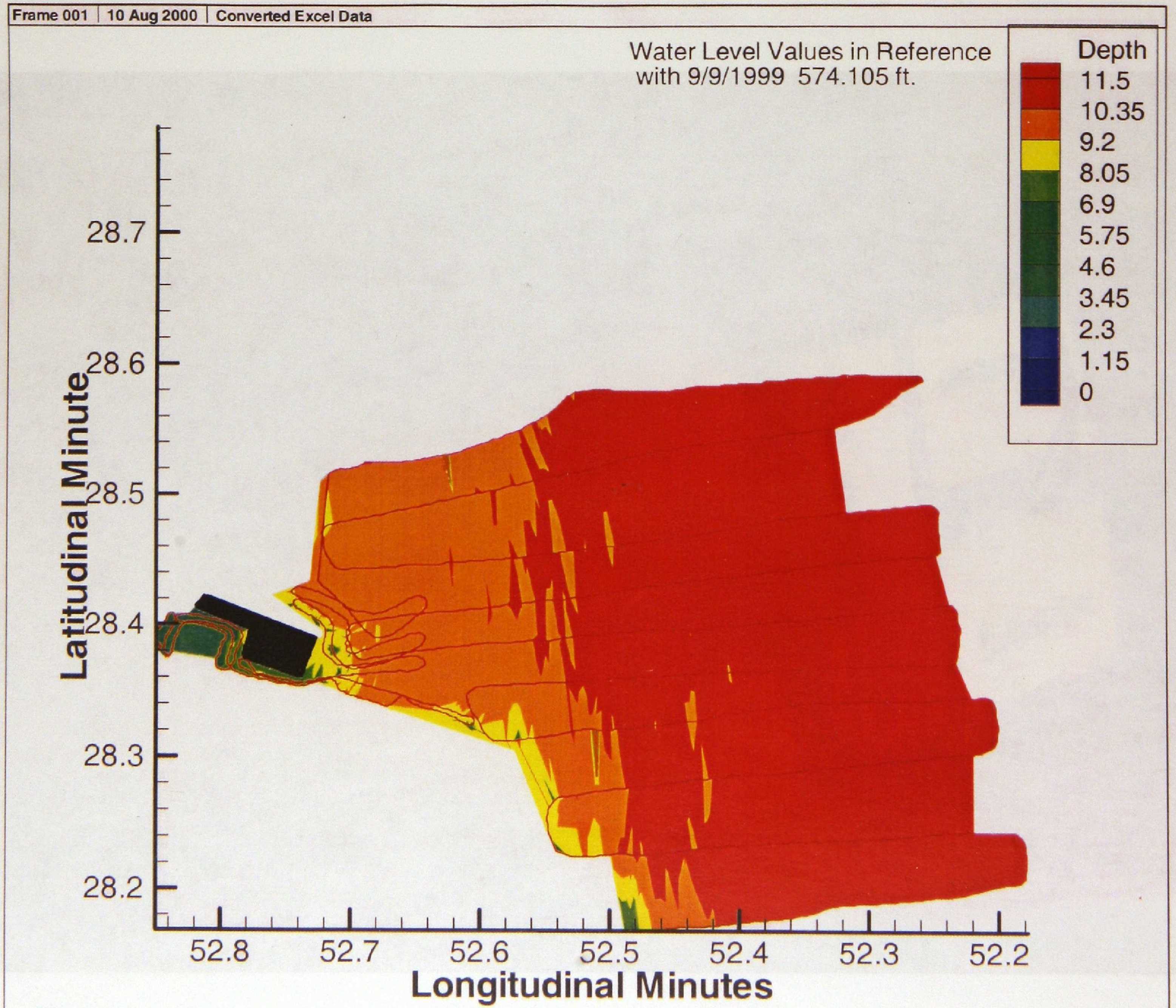



**Figure 2.1. Bathymetry of Blossom Heath Area**

Figure 2.2. M-ROVER Surveying the Entrance Channel

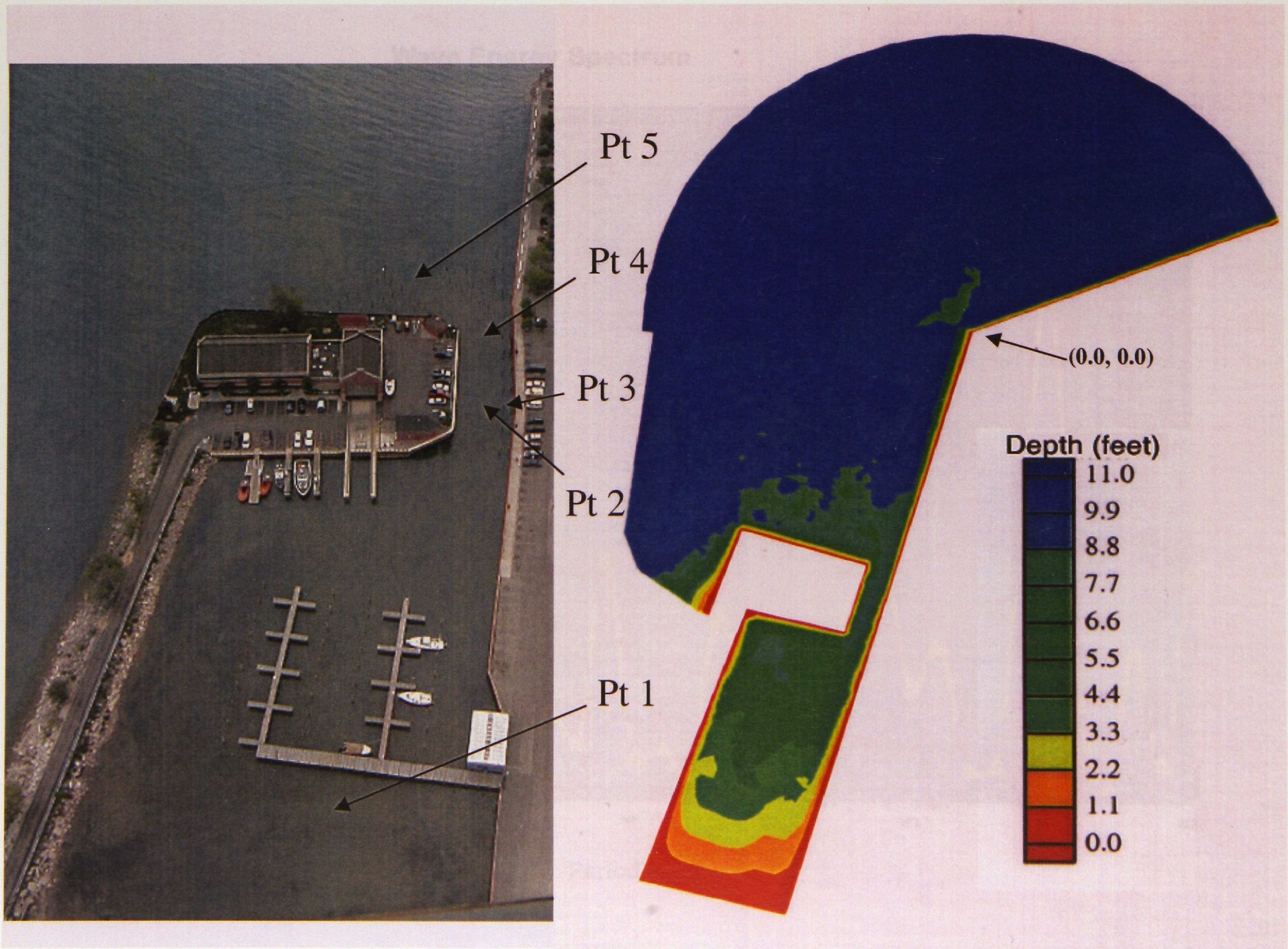



**Figure 3.1. Radiation Domain and the Data Points Chosen for Analysis**

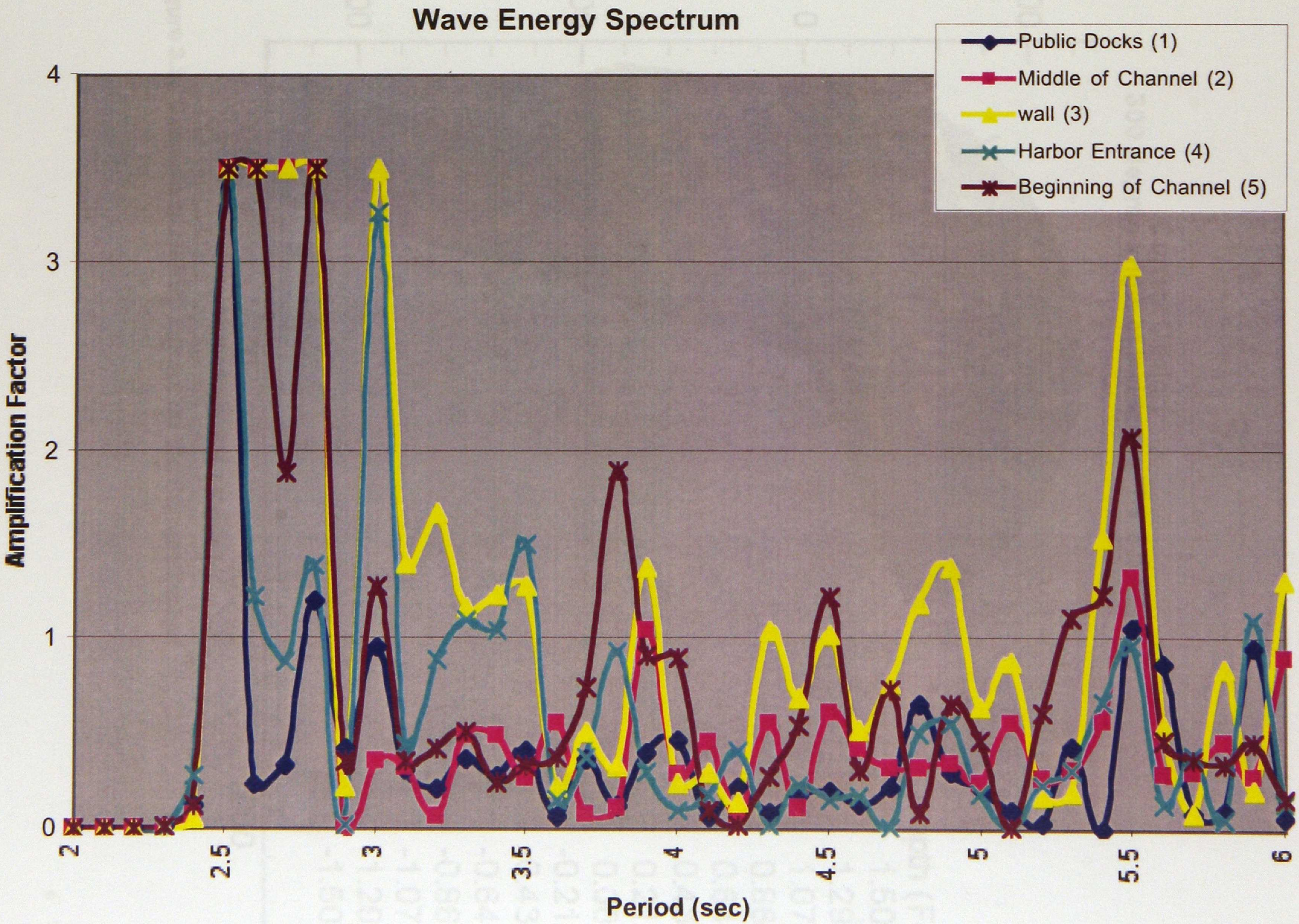



**Figure 3.2. Wave Energy Spectrum and Amplification Factors for the Current Harbor Design**

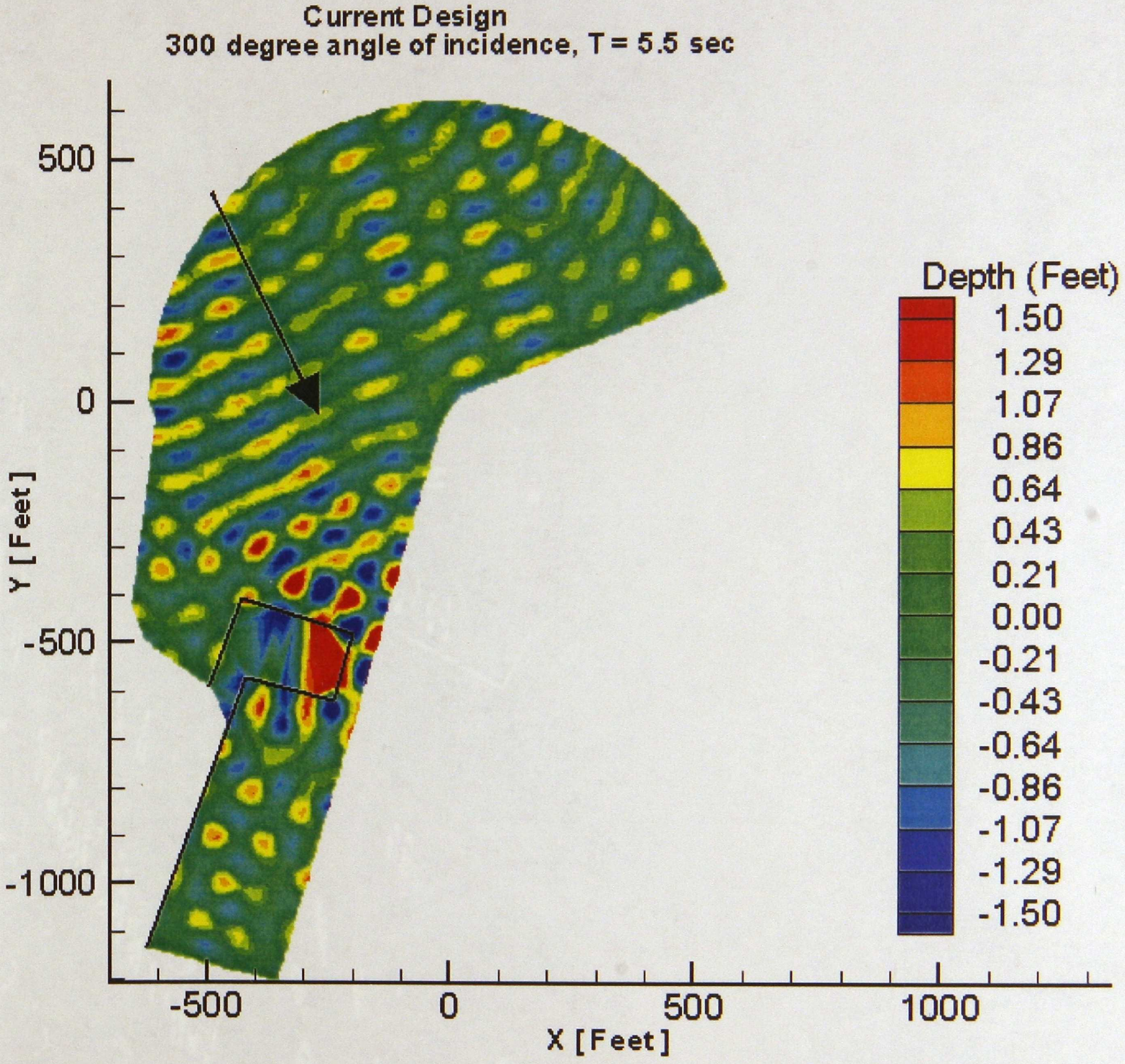



**Figure 3.3. Example of HARBD Output for the Current Design**

**Figure 4.1. Alternative Design 1 with Rubblemound Along Part of the Southern Wall.**

**Figure 4.2. Alternative Design 2 with Rubblemound Along the Entire Southern Wall.**

**Figure 4.3. Alternative Design 3 with Rubblemoumnd Breakwater**

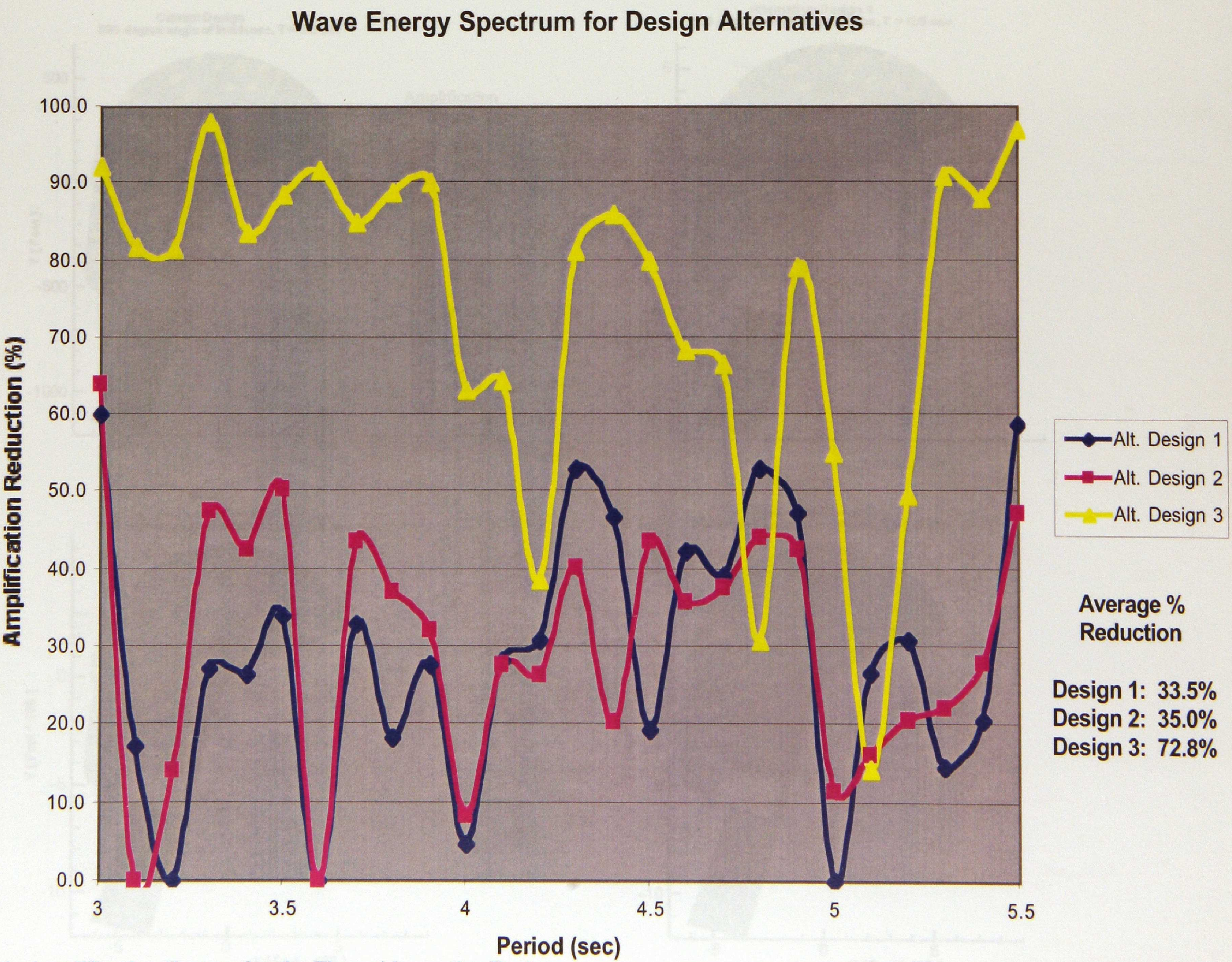



**Figure 4.4. Amplification Factors for the Three Alternative Designs**

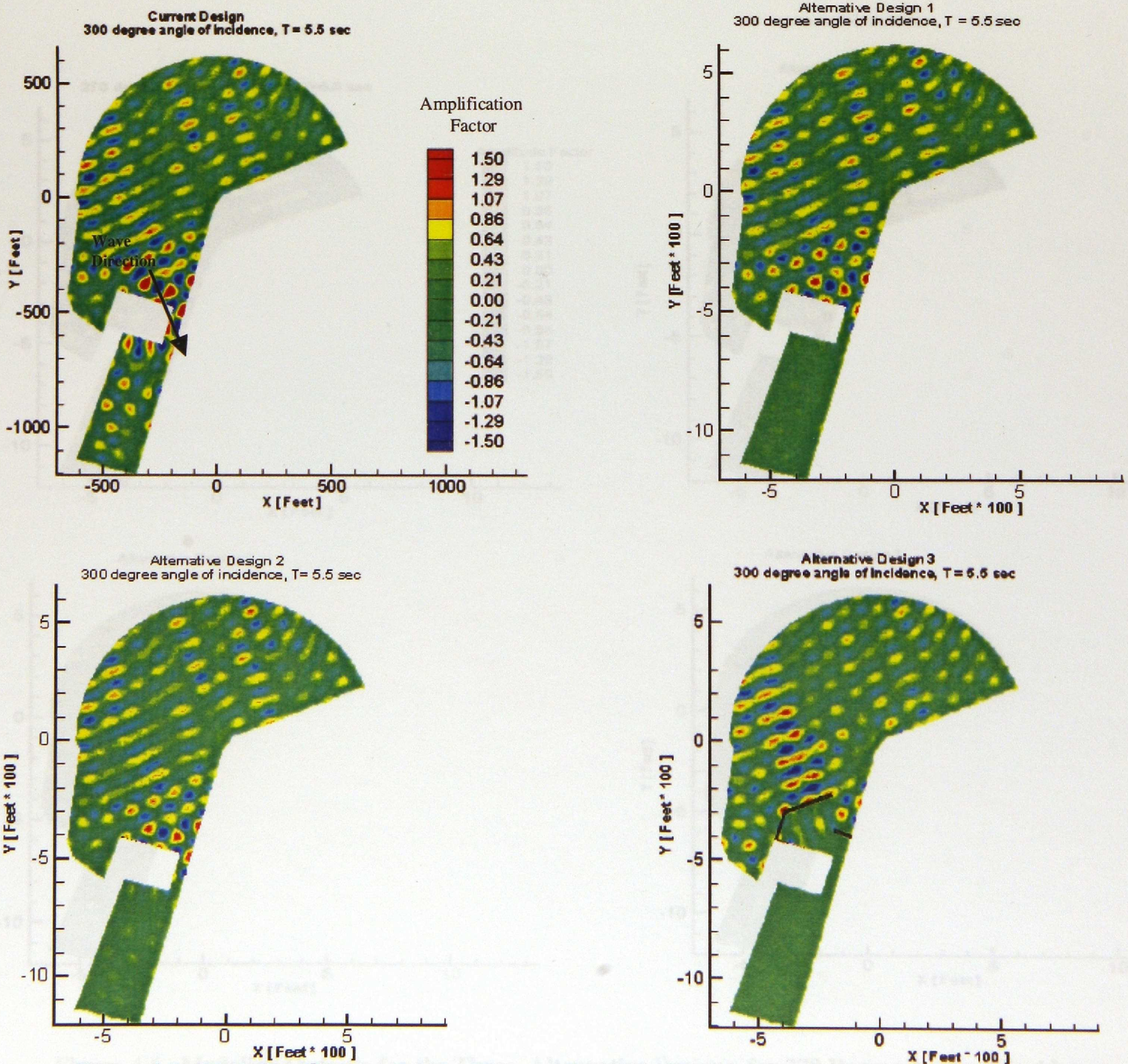



**Figure 4.5. Modeling Outputs for the Three Alternative Designs, for 300 Degree Angle of Incidence**

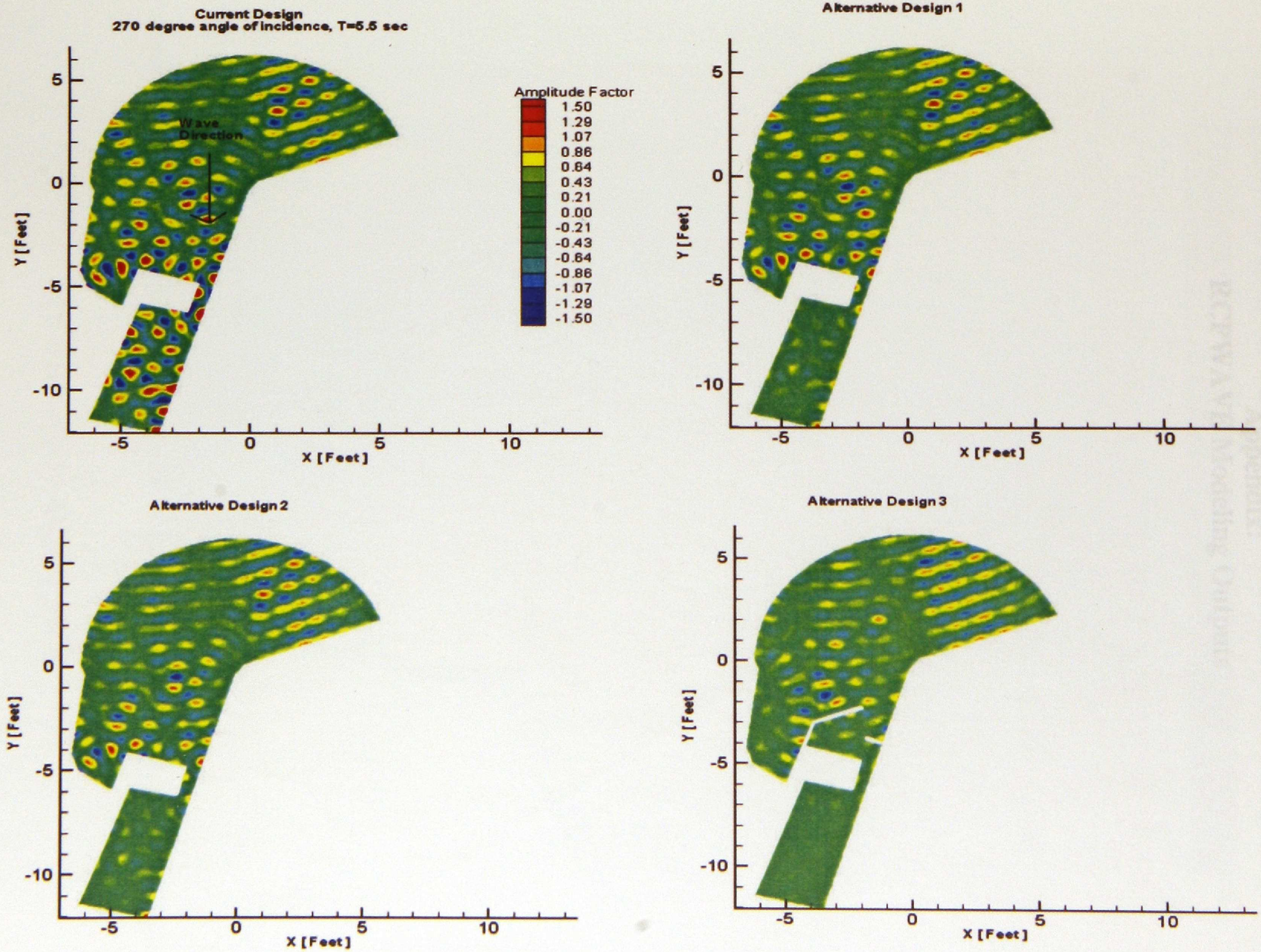
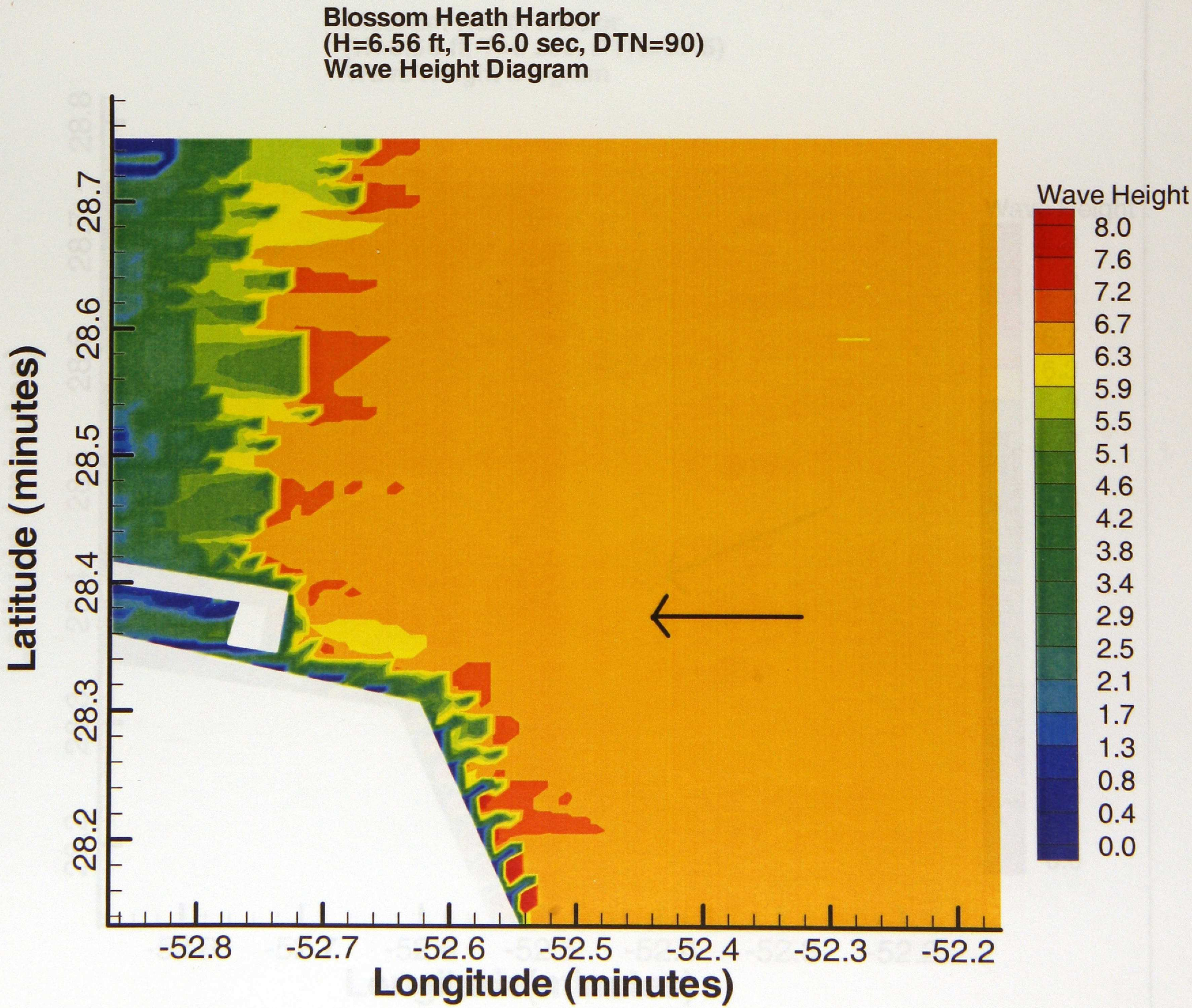



**Figure 4.6. Modeling Outputs for the Three Alternative Designs, for 270 Degree Angle of Incidence**

# Appendix:
# RCPWAVE Modeling Outputs


Blossom Heath Harbor
(H=6.56 ft, T=6.0 sec, DTN=90)
Wave Height Diagram
Latitude (minutes)
28.7
28.6
28.5
28.4
28.3
28.2
Longitude (minutes)
-52.8
-52.7
-52.6
-52.5
-52.4
-52.3
-52.2
Wave Height
8.0
7.6
7.2
6.7
6.3
5.9
5.5
5.1
4.6
4.2
3.8
3.4
2.9
2.5
2.1
1.7
1.3
0.8
0.4
0.0

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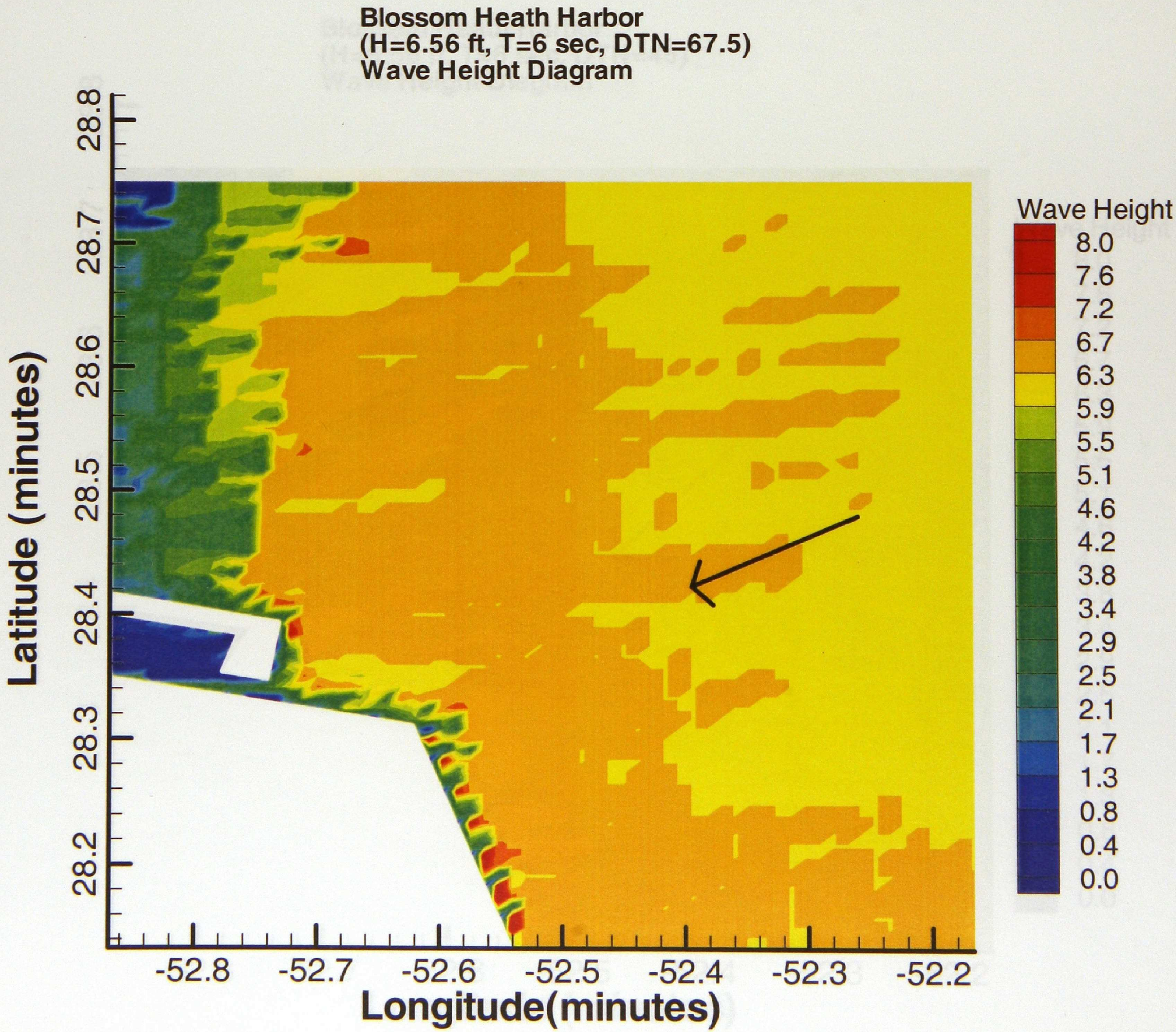

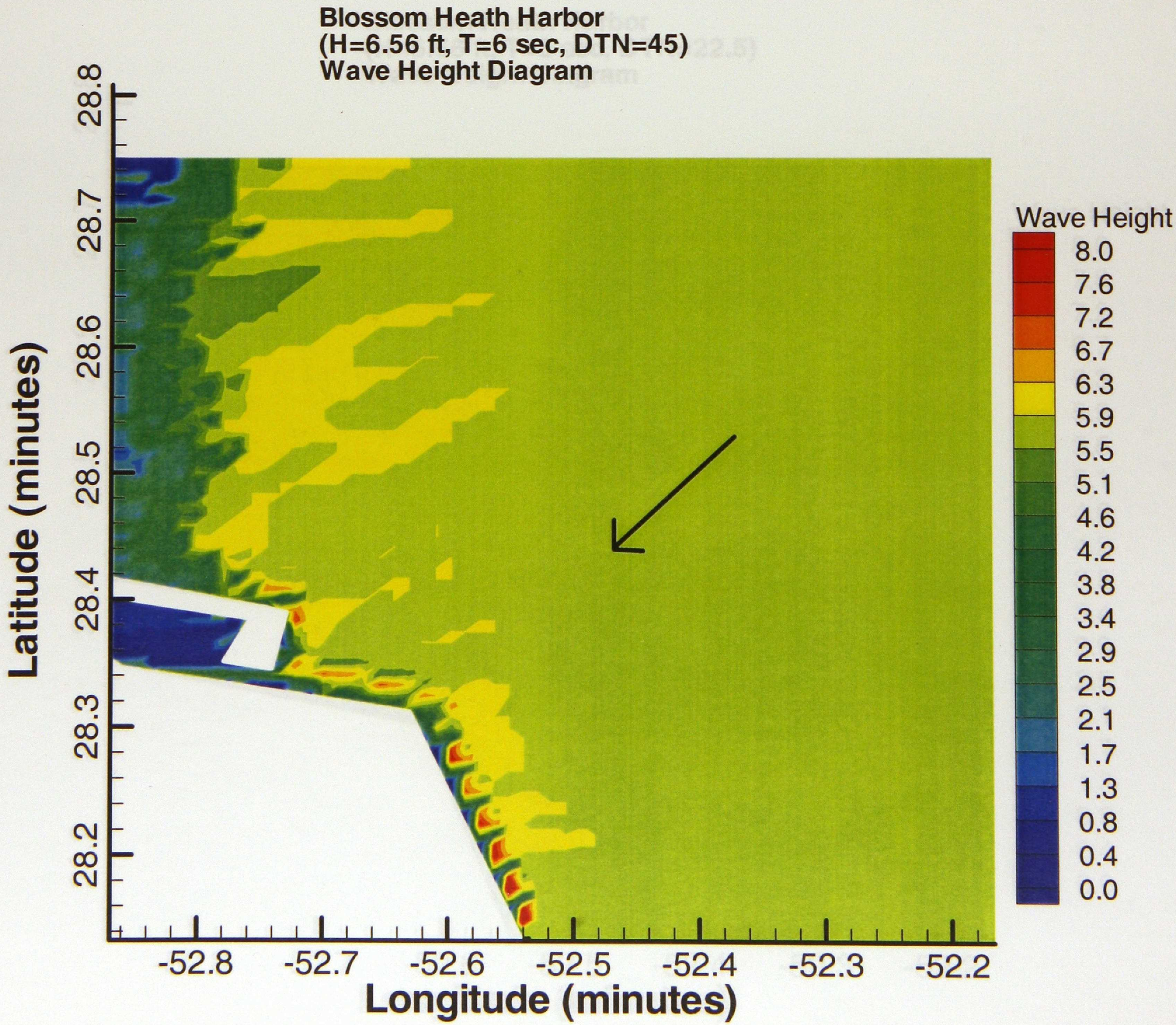

Blossom Heath Harbor
(H=6.56 ft, T=6 sec, DTN=45)
Wave Height Diagram
Latitude (minutes)
28.8
28.7
28.6
28.5
28.4
28.3
28.2
Longitude (minutes)
-52.8
-52.7
-52.6
-52.5
-52.4
-52.3
-52.2
Wave Height
8.0
7.6
7.2
6.7
6.3
5.9
5.5
5.1
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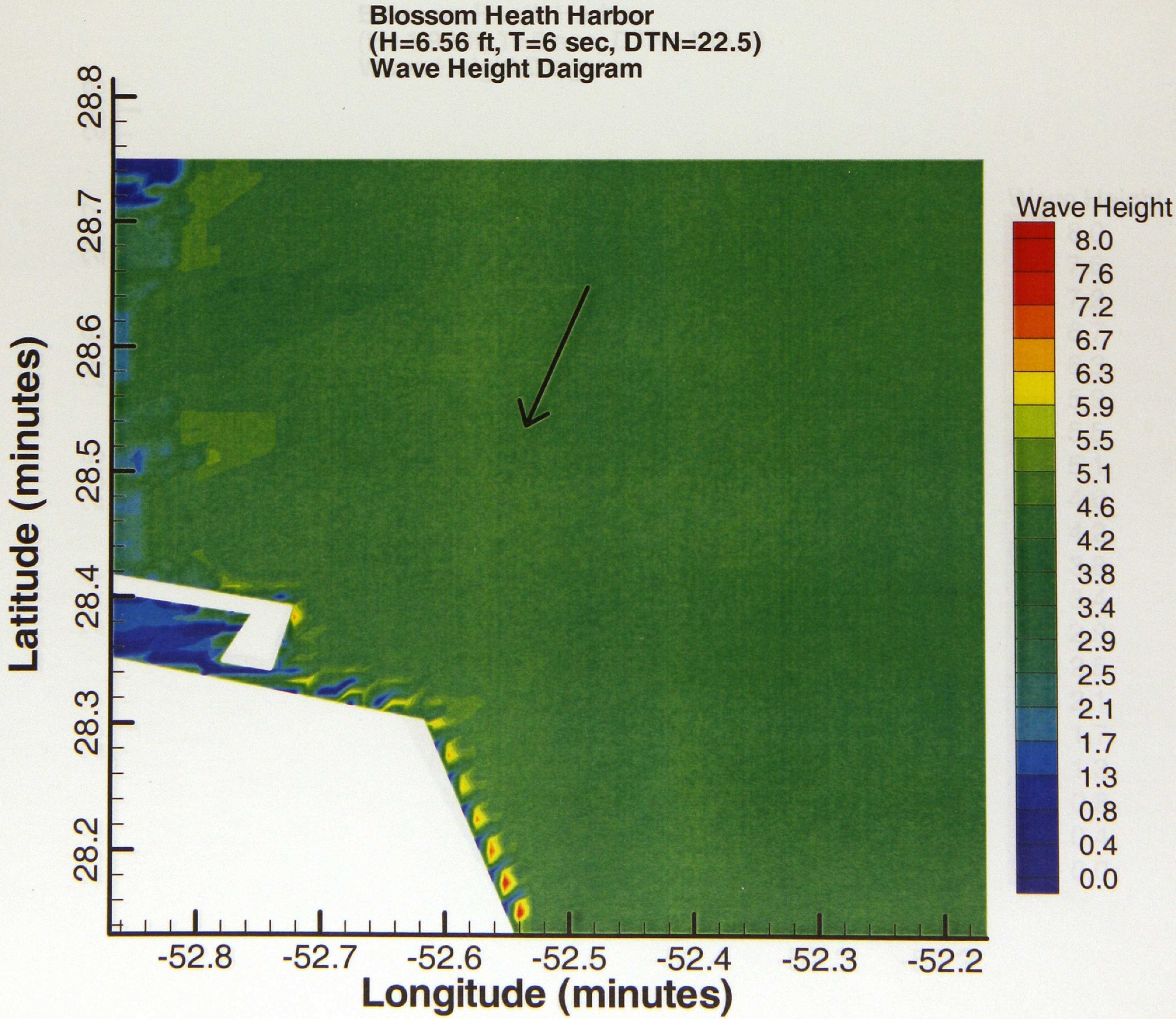
Blossom Heath Harbor
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Wave Height Daigram
Latitude (minutes)
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28.7
28.6
28.5
28.4
28.3
28.2
Longitude (minutes)
-52.8
-52.7
-52.6
-52.5
-52.4
-52.3
-52.2
Wave Height
8.0
7.6
7.2
6.7
6.3
5.9
5.5
5.1
4.6
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2.1
1.7
1.3
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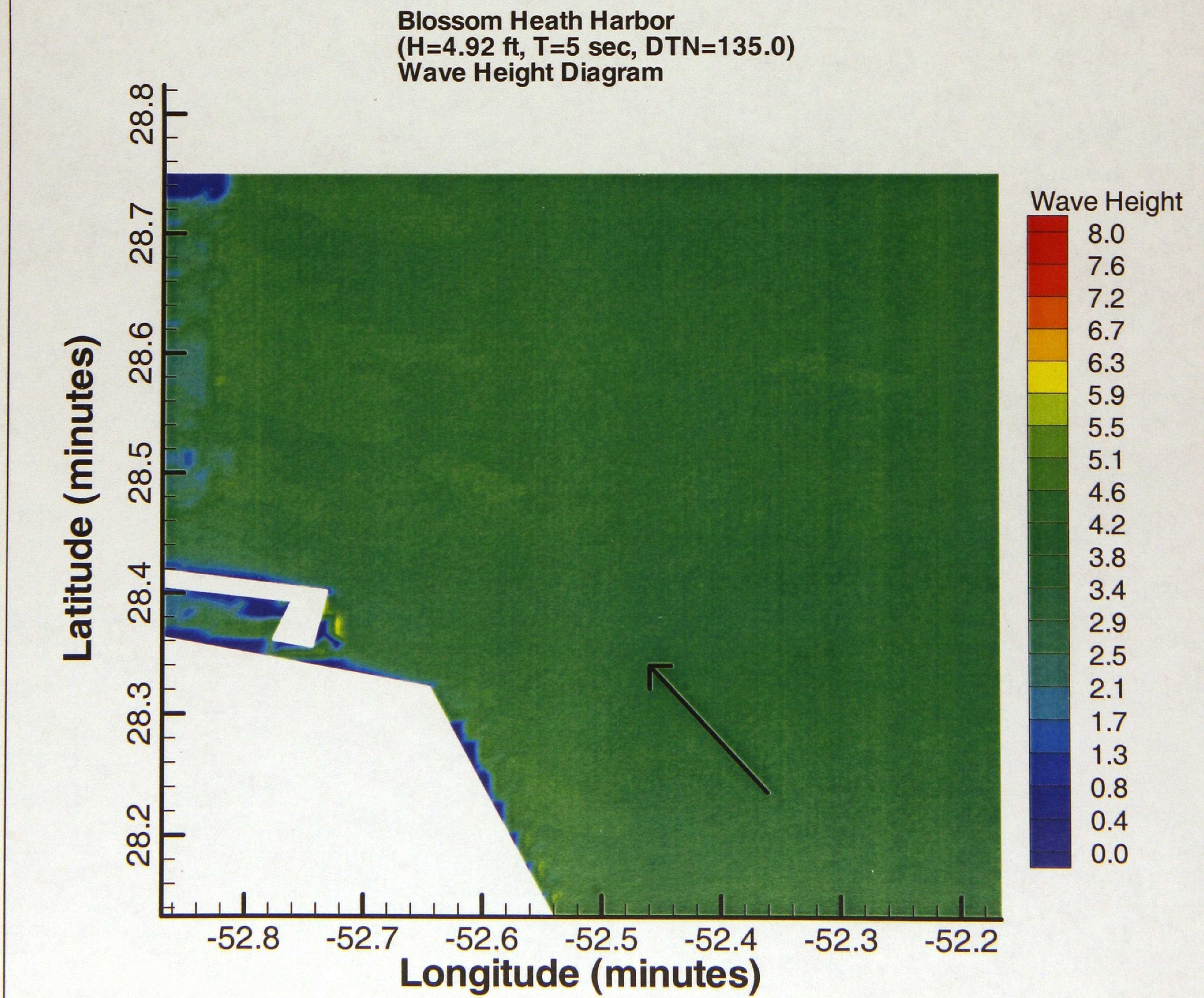
0.4
0.0


Blossom Heath Harbor
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Wave Height Diagram
Latitude (minutes)
28.8
28.7
28.6
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28.4
28.3
28.2
Longitude (minutes)
-52.8
-52.7
-52.6
-52.5
-52.4
-52.3
-52.2
Wave Height
8.0
7.6
7.2
6.7
6.3
5.9
5.5
5.1
4.6
4.2
3.8
3.4
2.9
2.5
2.1
1.7
1.3
0.8
0.4
0.0

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