FINAL MID-CHESAPEAKE BAY ISLAND ECOSYSTEM RESTORATION
INTEGRATED FEASIBILITY REPORT
& ENVIRONMENTAL IMPACT STATEMENT (EIS)

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ATTACHMENT I

LIFE-CYCLE ANALYSIS OF MID-BAY AND POPLAR ISLAND PROJECTS

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Life-Cycle Analysis of Mid Bay and Poplar Island Projects, Chesapeake Bay, Maryland

Jeffrey A. Melby, Edward F. Thompson, Mary A. Cialone, Jane M. Smith, Leon E. Borgman, Zeki Demirbilek, Jeffrey L. Hanson, and Lihwa Lin

December 2004

Coastal and Hydraulics Laboratory

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by Jeffrey A. Melby, Edward F. Thompson, Mary A. Cialone, Jane M. Smith, Leon E. Borgman, Zeki Demirbilek, Jeffrey L. Hanson, and Lihwa Lin

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Final report

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Preface

This report describes procedures and results of a life-cycle analysis study of coastal protection structures at Poplar, James, and Barren Islands. The study was performed in support of planning and design studies. The study was performed by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), for the U.S. Army Engineer District, Baltimore (NAB). The study was conducted during the period March 2004 through December 2004.

Ms. Karen Nook, NAB, was the study manager and point of contact for the Mid Bay studies, including James and Barren Islands. Mr. Greg Bass, NAB, was the study manager and point of contact for the Poplar Island study. Meetings at critical points in the study were the life-cycle analysis planning meeting and site visit on 25-26 August 2004, and the review meeting on 8 November 2004 at NAB.

The life-cycle investigation reported herein was conducted by Drs. Jeffrey A. Melby and Edward F. Thompson, both of the Coastal Harbors and Structures Branch (CHSB), CHL. Hydrodynamic modeling was conducted by Ms. Mary A. Cialone, of the Coastal Processes Branch (CPB), CHL, Dr. Zeki Demirbilek, CHSB, and Dr. Lihwa Lin, of the Coastal Engineering Branch, CHL. Wave modeling was conducted by Drs. Jane M. Smith and Jeffrey L. Hanson, CPB. The methodology and computer programs for Empirical Simulation Technique (EST) life-cycle simulation were developed by Dr. Leon E. Borgman of L. E. Borgman, Inc. The final report was edited by Drs. Melby and Thompson.

This study was performed under the general supervision of Mr. Thomas W. Richardson, Director, CHL. Direct supervision of this project was provided by Mr. Dennis G. Markle, Chief, Coastal Harbors and Structures Branch.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL James R. Rowan, EN, was Commander and Executive Director.

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1 Introduction

Background

A number of project studies for the Chesapeake Bay involving stone revetment design have been conducted over the past decade. The Poplar Island Habitat Restoration project has generated a particularly strong and visible need for design-related studies. Poplar Island is located 15 miles south-southeast of Annapolis, Maryland, along the east side of Chesapeake Bay (Figure 1). The island is a crescent-shaped enhanced habitat with stone revetment around much of its perimeter, about 2.5 miles long and 0.5 miles wide. Poplar Island embodies exposure to waves from all directions, with fetch distances ranging from less than one mile to twenty miles and more, depending on exposure direction. Poplar Island is also subject to tides and storm surges. The mean tide range is 1.2 feet. Extreme storm surges can reach much higher than the range of even extreme high astronomical tides, adding as much as six feet to the astronomical tide level.

The occurrence of extreme conditions at Chesapeake Bay island sites involves an interplay between high winds, elevated water levels, high waves, and shallow water depths. Revetment damage is typically caused by energetic waves directly moving stone on the slope or by high water levels allowing high or moderately high waves to overtop the structure and collapse the crest by undermining the landward side. Extreme water levels do not necessarily coincide with extreme wave heights attacking the various reaches of the island perimeter.

Optimized design of Poplar Island revetments presents a complex and difficult challenge. Methods used in past Chesapeake Bay revetment design studies are basically traditional approaches. Recent advances in numerical modeling technology have provided tools for significantly improved accuracy of wave and water level estimates. With present technology, the time variation of winds, waves, and water levels during historical storms can be hindcast based on available historical information.

Stone size prediction as well as stone damage development is traditionally done, as in the previous studies, using tools developed for design of coincident extreme wave and water level during a single storm. The traditional approach has several limitations. First, it requires a careful choice of design wave and water level combinations to be used. Second, it does not account for key life-cycle processes, as when the structure sustains a small amount of damage in a storm, and then, in its weakened state, is subjected to another or several more

damaging storms. Damage can accumulate over the life of the structure, especially in the interval between repair visits. Third, because the traditional approach does not deal with life-cycle processes, it does not lend itself to clear analysis of the tradeoff between initial construction and maintenance costs over the projected life of the structure, a key economic consideration. Finally, the traditional approach is rooted in historical storm information; it does not take into account the natural variability of future storm conditions.

The Coastal Engineering Manual (CEM) is now the current standard for coastal structure design within the U.S. Army Corps of Engineers (USACE). It includes recently updated methods for estimating wave runup and overtopping for design. For compliance with USACE standards, the CEM should be used as a basis cross-sectional design of the island dikes. This includes predicting life-cycle damage to both the armor layer and the toe. The most common technique presently used by the USACE in coastal studies to extend historical storms within a life cycle or risk analysis utilizes the Empirical Simulation Technique (EST) with historical waves and water levels. This method is superior to other techniques because it is based entirely on historical events and their analysis. Further, it does not presuppose any knowledge of correlation between various parameters that are usually nonlinearly related. Other techniques require that combined probability distributions be determined. Typically, the various parameters are related in a highly nonlinear manner and data do not exist to determine the correlations. Monte-Carlo simulation can produce unrealistic combinations of parameters.

Because of the limitations in traditional tools and the emergence of improved technology, the US Army Engineer District, Baltimore (NAB), requested the US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (CHL), to develop a state-of-the-art tool for analysis of life-cycle cost of these projects applied to Poplar Island. NAB also requested that CHL conduct a similar analysis of a planned island project at James Island, along the east side of Chesapeake Bay, 17 miles south of Poplar Island (Figure 1). A third island site in Chesapeake Bay, Barren Island, is under consideration for future protection/restoration efforts. Barren Island is 12 miles south-southeast of James Island, along the east side of Chesapeake Bay opposite the mouth of the Patuxent River (Figure 1). NAB requested that this island also be included in the analysis. James Island and Barren Island are collectively termed “Mid Bay” sites.

Study Approach

The study described in this report was performed by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), in support of the NAB design efforts at the three island sites: Poplar Island, James Island, and Barren Island. The approach consisted of the following components:

a. Identify historical tropical and extratropical storms needed to develop design conditions at Chesapeake Bay project sites.

b. Acquire wind fields for historical storms identified in *a*, to be used for water level modeling. Open-ocean winds for most storms were available from previous studies.

c. Adjust wind fields over Chesapeake Bay waters as needed to represent winds over the bay suitable for water level modeling.

d. Analyze existing historical data from regional anemometers in order to develop local winds over Chesapeake Bay fetches for wave analysis.

e. Compute historical storm water levels using the existing ADCIRC numerical model, updating the regional bathymetry and shoreline grid already developed for other NAB studies at Ocean City Inlet and Assateague Island.

f. Hindcast historical storm waves using model winds along with measured winds from several area anemometers. Compute historical offshore waves using relationships for wind-wave growth over irregular, restricted fetches.

g. Transform waves through shallow nearshore waters to shore using a spectral wave transformation model (STWAVE).

h. Compute responses for these historical events, such as runup, overtopping as a function of crest height, structure damage as a function of stone size, and required toe stone weight. Use techniques based on recommendations given in the CEM.

i. Recreate multiple life cycles of storms and project responses using the EST. Each life cycle represents a possible future condition, which is statistically consistent with historical storm forcing, response, and sequencing information. The EST simulation includes progressive revetment damage due to successive storms that may occur between maintenance opportunities. Realistic maintenance cycles are incorporated into the simulation.

j. Compute life-cycle damage and function for selected designs that appear to be favorable.

Candidate designs and design evaluation criteria, including environmental considerations, were defined in close coordination with NAB. Results are summarized based on analysis of mean and extreme structure responses in multiple life-cycle scenarios developed in *i*. The results will assist NAB in quantifying design construction cost vs. benefit trade-offs between initial construction and expected maintenance.

The historical storms selected for simulation include both winter storms (extratropical storms) and hurricanes (tropical storms). The storms chosen, the reasons for choosing them, and procedures for estimating storm wind and pressure fields are discussed in Chapter 2.

Storm wind and pressure fields over Chesapeake Bay provide the key meteorological forcing that can cause unusually high water levels during storms. To accurately simulate water levels due to the combined effect of historical storms and astronomical tides, the entire Chesapeake Bay must be modeled. Procedures and results from these hydrodynamic simulations of historical storms are presented in Chapter 3.

Storm winds also generate unusually high waves. Adaptation of winds to local wave growth around the study islands, wave generation, and wave transformation to island shores are described in Chapter 4.

The life-cycle simulation approach used in this study drew together some important recent advances in statistical procedures for hypothesizing future storm sequences and for predicting cumulative structural response to a succession of storms. The methodology is described in Chapters 5 and 6.

Life-cycle simulations were developed and summarized for each of the three study islands. Poplar Island results are presented in Chapter 7. Results for James and Barren Islands are given in Chapters 8 and 9.

Conclusions and recommendations are given in Chapter 10. This chapter is followed by references.

Figure 1. Location map of study area

2 Selection of Historical Tropical and Extratropical Storms

This chapter describes the process of selecting 95 historical tropical and extratropical storms for the Chesapeake Bay – Mid Bay and Poplar Island project. The hydrodynamic model ADCIRC (Luettich et al. 1992) was applied to the Chesapeake Bay area for each historical event, which is documented in Chapter 3. The simulations were performed for the 95 historical storms to report predicted water levels at the three island locations described in Chapter 1. Predicted water levels at the three islands were extracted for each of the storm simulations to be applied in the life cycle analysis. Predicted water level time series were extracted for each of the storm simulations to be applied in the wave modeling task.

The purpose of the simulations presented in Chapter 3 was to determine water levels under various storm conditions at the three island sites. Tasks accomplished to attain the goal included: 1) identifying historical tropical and extratropical storms that passed through the Chesapeake Bay region, 2) acquiring wind fields for historical storms identified as potential storms to simulate, 3) adjusting wind fields over land and over bay as needed to represent overland wind adjustments and over-bay wind adjustments, 4) analyzing existing historical data from regional anemometers to develop local winds over Chesapeake Bay, 5) developing a numerical finite element grid of Chesapeake Bay, including overland areas, 6) validating the hydrodynamic model ADCIRC to several historical storm events, 7) applying ADCIRC to the suite of historical storm events to compute storm water levels, and 8) extracting water levels at the three island sites. This chapter documents the completion of tasks 1-4.

Selection of Storms

Hurricanes. The North Atlantic Hurricane Track Database (1851-2003) was extracted from the internet web site (http://weather.unisys.com/hurricane) to determine the set of tropical storms that traversed the Chesapeake Bay region. Fifty-two hurricanes (Table 1) were selected from the database for simulation based upon the following criteria: storms with maximum wind speeds greater than 50 knots in the area between 75 and 79 deg W longitude and 36 and 39 deg N latitude.

Table 1
Selected Tropical Storms (Hurricanes)

Simulation	Year/Month	Name	Database Number
1	1856/Aug	None	31
2	1861/Sep	None	64
3	1861/Nov	None	67
4	1863/Sep	None	78
5	1874/Sep	None	156
6	1876/Sep	None	165
7	1877/Sep	None	172
8	1878/Oct	None	187
9	1879/Aug	None	190
10	1880/Sep	None	202
11	1881/Sep	None	213
12	1888/Oct	None	269
13	1889/Sep	None	277
14	1893/Jun	None	302
15	1893/Aug	None	307
16	1893/Sep	None	310
17	1893/Oct	None	312
18	1894/Sep	None	316
19	1894/Oct	None	317
20	1897/Oct	None	336
21	1899/Aug	None	347
22	1899/Oct	None	351
23	1904/Sep	None	384
24	1908/Jul	None	409
25	1923/Oct	None	492
26	1933/Aug	None	562
27	1933/Sep	None	567
28	1935/Aug	None	588
29	1936/Sep	None	605
30	1944/Jul	None	667
31	1944/Sep	None	671
32	1946/Jul	None	688
33	1953/Aug	Barbara	755
34	1954/Oct	Hazel	776
35	1955/Aug	Connie	780
36	1955/Aug	Diane	781
37	1955/Sep	Ione	787
38	1960/Jul	Brenda	830
39	1960/Aug	Donna	832
40	1967/Sep	Doria	892
41	1971/Aug	Doria	937
42	1981/Jun	Bret	1030
43	1983/Sep	Dean	1050
44	1985/Sep	Gloria	1070
45	1986/Aug	Charley	1077
46	1992/Sep	Danielle	1137
47	1996/Jul	Bertha	1175
48	1996/Aug	Fran	1179
49	1998/Aug	Bonnie	1196
50	1998/Aug	Earl	1199
51	1999/Sep	Floyd	1214
52	2003/Sep	Isabel	1264

Figure 2 shows storm tracks for the selected fifty-two hurricanes. The database contained the maximum wind speed, and minimum pressure as each storm tracked across the Atlantic Ocean and/or Gulf of Mexico. Wind and pressure fields were generated for a given track using the Planetary Boundary Layer (PBL) model (Cardone 1977). Adjustments for overland and overbay were made to the wind fields as described below. The wind and pressure fields were then applied in the ADCIRC model simulations for Chesapeake Bay to attain the response of the bay to each storm.

Northeasters. Forty-three northeasters (1954-2003) were identified in the Atmospheric Environmental Service of Canada (AES-40) wind fields (Swail et al. 2000) and in the reanalysis project database (Kalnay et al. 1996) by the U.S. National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) (Table 2). Pressure fields were obtained from NCEP/NCAR database. Storms were selected based upon the criteria of peak wind speeds greater than 20 m/sec (66 ft/s) or 10 m/sec (33 ft/s) with durations exceeding 3 days at the ocean entrance of the Chesapeake Bay. Figure 3 shows an example selecting northeasters based on time series of wind speed and direction extracted from AES-40 for 1999 at the bay entrance. Wind speeds above 10 m/sec (33 ft/s) were marked as black cross. Northeaster storms were identified for the wind speed with green circles and northwesters were identified for the wind speed with blue circles. Hurricane wind speed was identified with magenta circles. Adjustments for overland and overbay were made to the wind fields as described below. The wind and pressure fields were then applied in the ADCIRC model simulations for Chesapeake Bay to attain the response of the bay to each storm.

Adjustments to Wind and Water Levels

Water Level Data. NOAA historical water level data (1996-2003) for Chesapeake Bay was extracted from the internet web site (http://co-ops.nos.noaa.gov/data_res.html) to examine seasonal and daily water level variations, excluding daily tides. These variations were applied to the model results to account for the monthly mean variation of the water level.

Over-Land Wind Adjustment. AES-40, NCEP/NCAR and PBL model wind fields are generally accurate for the open coast and ocean applications. In the Chesapeake Bay and adjacent land area, the wind fields needed to be adjusted for over-bay and over-land effects. This was done using the equation

$$U_L = U_W/R_L \qquad (1)$$

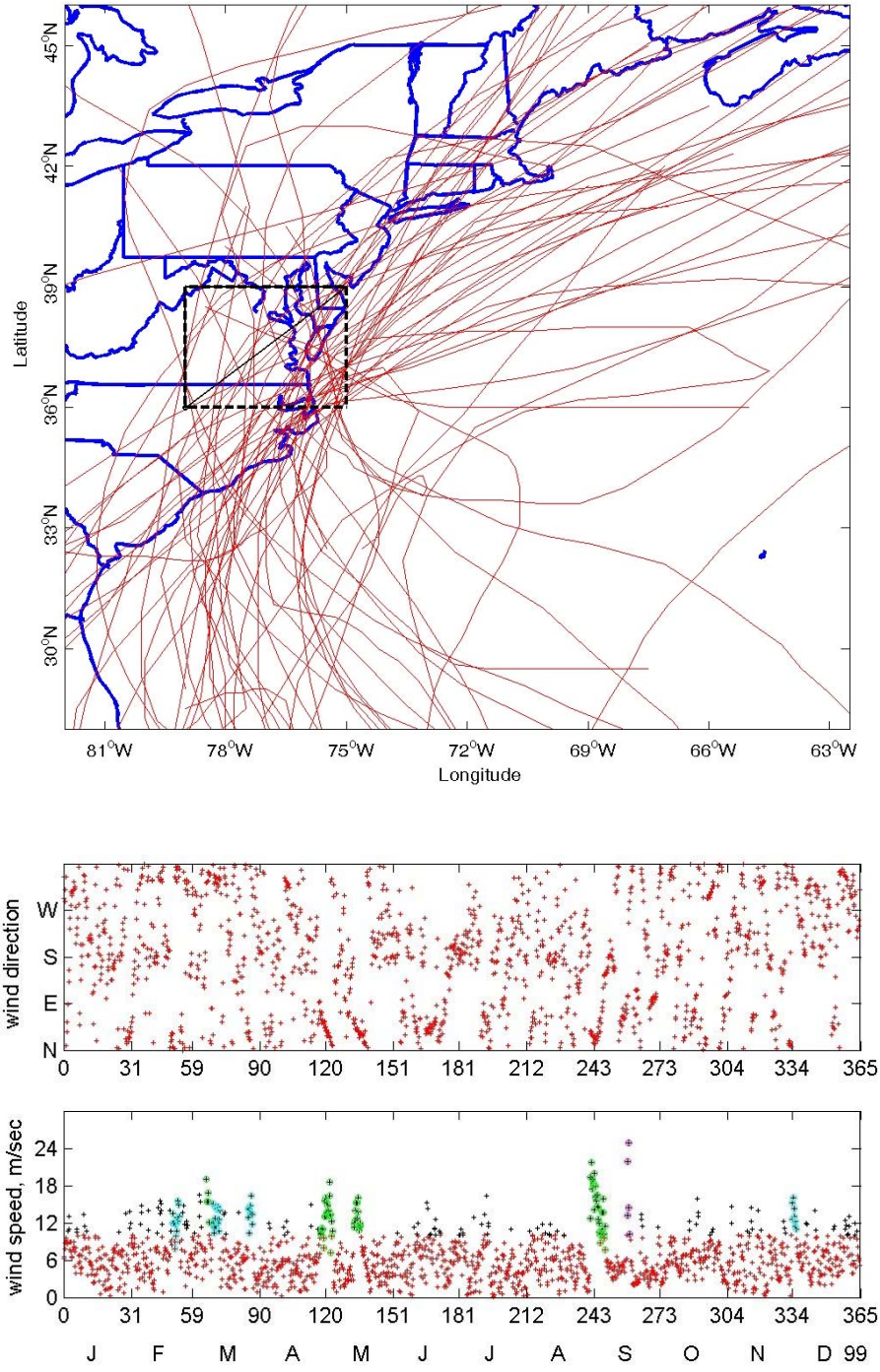
where U_L is the wind speed over land, U_W is the wind speed over water, and R_L is an adjustment factor and following procedures described in Part II, Coastal Engineering Manual, US Army Corps of Engineers (available from the internet web site at (http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=ARTICLES;104). Figure 3 shows an example comparing AES-40 winds with and without over-land adjustment with measured data at NOAA Station 8577330 (38^o 19’ 00” N, 76^o 27’ 12” W) for September 8-15, 2003, during the passage of a northeaster

system. The necessity of adjustment for the over-land effect to AES-40 winds is evident as compared to the measured data.

Table 2
Selected Extratropical Storms (Northeasters)

Simulation	Year/Month/Date/Time	Duration (day)	Mean Wind Speed m/sec (ft/sec)
1	1954/01/21/12	2.5	18.4 (60.4)
2	1956/10/16/06	3.5	11.7 (38.4)
3	1956/10/24/06	6.5	14.3 (46.9)
4	1957/10/02/06	4.0	13.7 (44.9)
5	1958/02/15/12	6.0	14.9 (48.9)
6	1958/10/19/12	3.0	16.7 (54.8)
7	1962/03/05/06	3.0	16.3 (53.5)
8	1962/11/26/00	9.5	14.5 (47.6)
9	1966/01/26/06	6.0	15.8 (51.8)
10	1969/01/19/18	3.0	12.5 (41.0)
11	1972/05/24/00	4.0	14.0 (45.9)
12	1972/10/04/06	4.5	13.0 (42.7)
13	1974/11/30/18	4.5	14.6 (47.9)
14	1975/06/28/18	3.5	14.8 (48.6)
15	1977/10/29/00	5.0	12.4 (40.7)
16	1978/04/26/00	2.5	14.7 (48.2)
17	1980/12/26/18	5.0	13.2 (43.3)
18	1981/08/19/00	4.5	12.3 (40.4)
19	1983/02/10/18	5.0	13.4 (44.0)
20	1884/03/28/12	3.0	15.8 (51.8)
21	1884/09/26/12	6.0	13.1 (43.0)
22	1884/10/10/12	4.5	14.8 (48.6)
23	1884/11/19/06	3.5	13.0 (42.7)
24	1985/10/28/12	9.0	13.6 (44.6)
25	1986/11/29/18	4.5	12.8 (42.0)
26	1987/02/15/00	3.5	12.8 (42.0)
27	1988/04/11/12	3.0	14.8 (48.6)
28	1989/03/07/06	4.0	13.6 (44.6)
29	1991/01/07/00	5.0	13.4 (44.0)
30	1991/04/18/00	3.5	14.4 (47.2)
31	1991/10/28/00	4.0	14.6 (47.9)
32	1991/11/08/00	2.5	18.2 (59.7)
33	1993/03/12/12	3.0	13.8 (45.3)
34	1994/10/12/00	4.5	13.1 (43.0)
35	1996/10/03/12	6.5	12.4 (40.7)
36	1997/06/01/00	7.0	12.0 (39.4)
37	1997/10/14/06	7.0	12.1 (39.7)
38	1998/05/10/12	4.5	12.2 (40.0)
39	1999/04/28/12	6.0	12.5 (41.0)
40	1999/08/29/12	8.5	14.2 (46.6)
41	2000/05/28/12	3.5	15.0 (49.2)
42	2003 /04/08/00	4.5	12.1 (39.7)
43	2003/09/08/06	4.5	13.9 (45.6)

Figure 2. Tracks of fifty-two hurricanes (1851-2003) and a rectangle window



(dash-line) used for the storm selection

Figure 3. Screened wind events for northeasters (green circle), northwesters (blue circle) and hurricane wind speed (magenta circle)

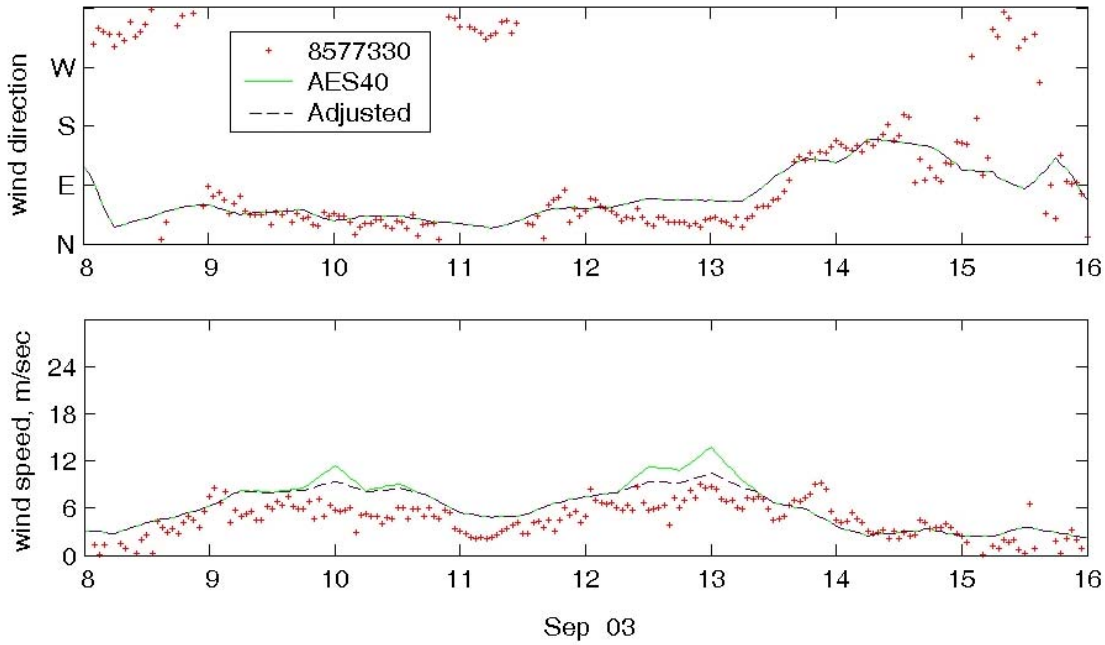


Figure 4. Comparison of AES-40 winds with (dash line) and without (solid line) over-land effect with measured data (cross) at NOAA Station 8577330 for September 8-15, 2003

3 Hydrodynamic Modeling of Historical Tropical and Extratropical Storms

This chapter describes numerical simulations of 95 historical tropical and extratropical storms for the Chesapeake Bay – Mid Bay and Poplar Island project. The hydrodynamic model ADCIRC (Luettich et al. 1992) was applied to the Chesapeake Bay area for each historical event. The simulations were performed for the 95 historical storms to report predicted water levels at the three island locations described in Chapter 1. Predicted water levels at the three islands were extracted for each of the storm simulations to be applied in the life cycle analysis. Predicted water level time series were extracted for each of the storm simulations to be applied in the wave modeling task.

The purpose of the simulations presented in this chapter was to determine water levels under various storm conditions at the three island sites. Tasks accomplished to attain the goal included: 1) identifying historical tropical and extratropical storms that passed through the Chesapeake Bay region, 2) acquiring wind fields for historical storms identified as potential storms to simulate, 3) adjusting wind fields over land and over bay as needed to represent overland wind adjustments and over-bay wind adjustments, 4) analyzing existing historical data from regional anemometers to develop local winds over Chesapeake Bay, 5) developing a numerical finite element grid of Chesapeake Bay, including overland areas, 6) validating the hydrodynamic model ADCIRC to several historical storm events, 7) applying ADCIRC to the suite of historical storm events to compute storm water levels, and 8) extracting water levels at the three island sites. This chapter documents the completion of tasks 5-8.

Numerical Model

ADCIRC is documented in technical reports and technical notes, as well as in the literature of study applications and engineering projects. A short description of the models is given here for broad understanding of the function of the models. For more details the reader is referred to the references provided.

ADCIRC

ADCIRC is a highly developed numerical model for solving the equations of motion for a moving fluid on a rotating earth (Luettich et al. 1992). It serves as the primary? Corps of Engineers' regional oceanographic and storm surge model and is certified by the Federal Emergency Management Agency. The equations are formulated with hydrostatic pressure and Boussinesq approximations and are discretized in space with the finite-element method and in time with the finite difference method. ADCIRC can be run either as a two-dimensional depth-integrated (2DDI) model or as a three-dimensional (3D) model. Water surface elevation is obtained from the solution of the depth-integrated continuity equation in the Generalized Wave-Continuity Equation (GWCE) form. Flow velocity is obtained from the solution of either the 2DDI or 3D momentum equations. All nonlinear terms are retained in these equations.

ADCIRC can be operated in either a Cartesian or a spherical coordinate system. ADCIRC boundary conditions include specified elevation (harmonic tidal constituents or time series), specified normal flow (harmonic tidal constituents or time series), zero normal flow, slip or no slip conditions for velocity, external barrier overflow out of the domain, internal barrier overflow between sections of the domain, surface stress (wind and/or wave radiation stress), atmospheric pressure, outward radiation of waves (Sommerfield condition). ADCIRC can be forced with elevation, normal flow, or surface stress boundary conditions, tidal potential, and earth load/self attraction tide. Recently, global-scale ADCIRC studies were completed on high-performance computers to provide accurate tidal constituents for the Atlantic Ocean coast, Gulf of Mexico coast, and Pacific Ocean coast of the United States to furnish reliable tidal constituents for project-scale simulations (Mukai et al. 2002; Spargo et al. 2004).

Numerical Grid Development

A regional scale ADCIRC grid with a rudimentary representation of Chesapeake Bay was developed through previous Coastal Inlets Research Program (CIRP) and Offshore and Coastal Technologies, Inc. (OCTI) studies (Figure 5). This grid was refined in Chesapeake Bay and far-field areas for the present study (Figure 6) using National Ocean Service (NOS) Digital Navigation Charts (DNC). In this hydrodynamic study, the existing-condition bathymetry was taken from a composite of Virginia Institute of Marine Science (VIMS), GEODAS. Periodic surveys conducted by Philadelphia District (NAD) were used to update the topography for the location of Poplar, James, and Barren Islands relative to the ADCIRC grid mesh. The numerical grid was developed for ADCIRC to represent present-day (2004) conditions. Detailed Chesapeake Bay coastline and bathymetric data were obtained from VIMS and incorporated into the refined ADCIRC grid (Figure 7). Chesapeake & Delaware Canal bathymetric data was obtained from NAD. Further grid development included the incorporation of overbank areas into the Chesapeake Bay tributaries to accurately predict storm surge in these relatively narrow branches of the bay (Figure 8). The ADCIRC grid was extended to include low land topography data to +10 m (33 ft), mean tide level, from USGS Digital EEM database GTOPO30 -- 30-sec arc resolution http://edcdaac.usgs.gov/gtopo30/gtopo30.asp. The grid was constructed with a minimum resolution of 50 m (164 ft) and a maximum cell

size of 500 m (1640 ft) in the open ocean. The ADCIRC grid generated in this process was applied to tidal current and storm surge simulations to calculate water level at the three island sites.

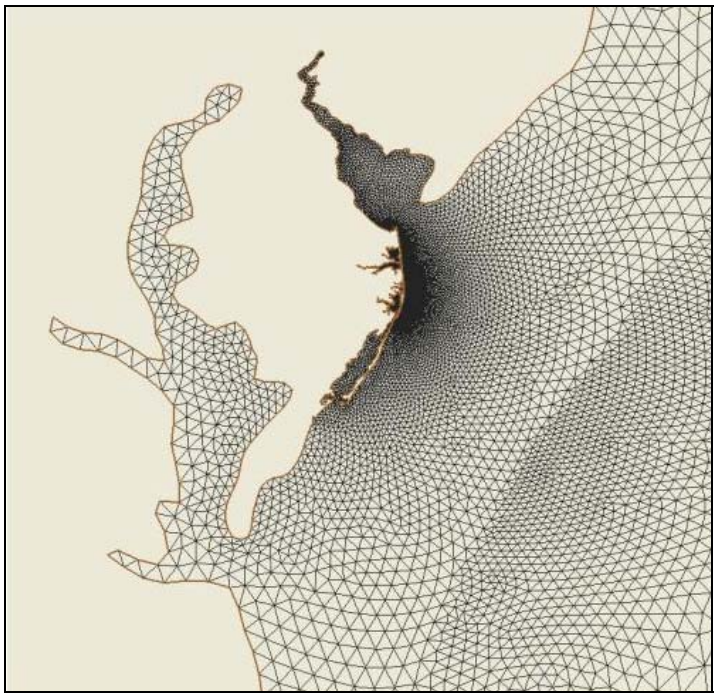


Figure 5. Portion of original ADCIRC grid resolution and shoreline

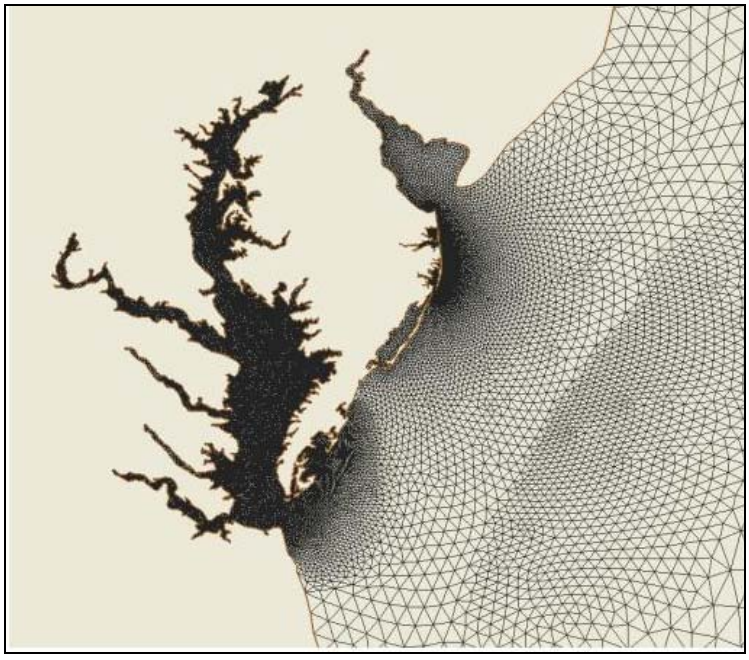


Figure 6. Portion revised ADCIRC grid resolution and shoreline

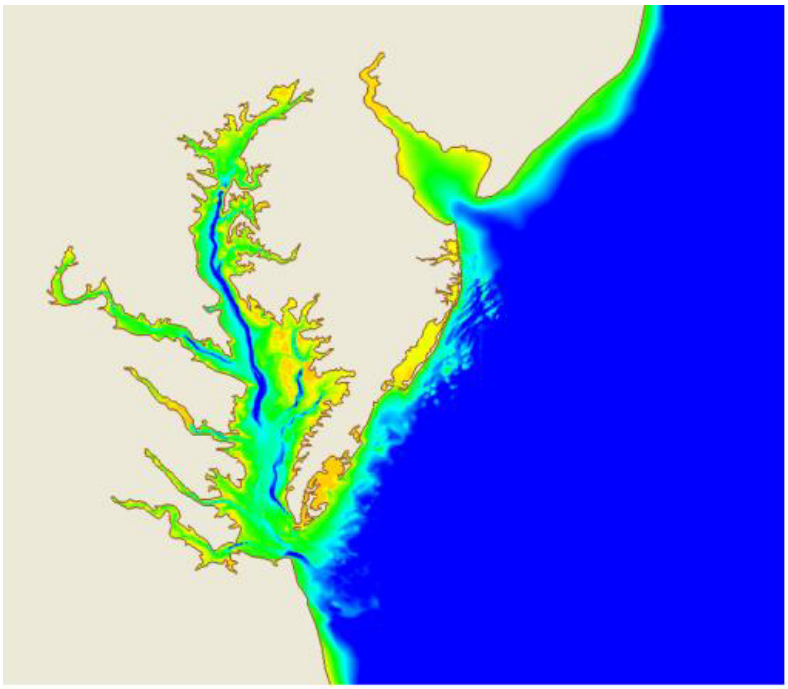
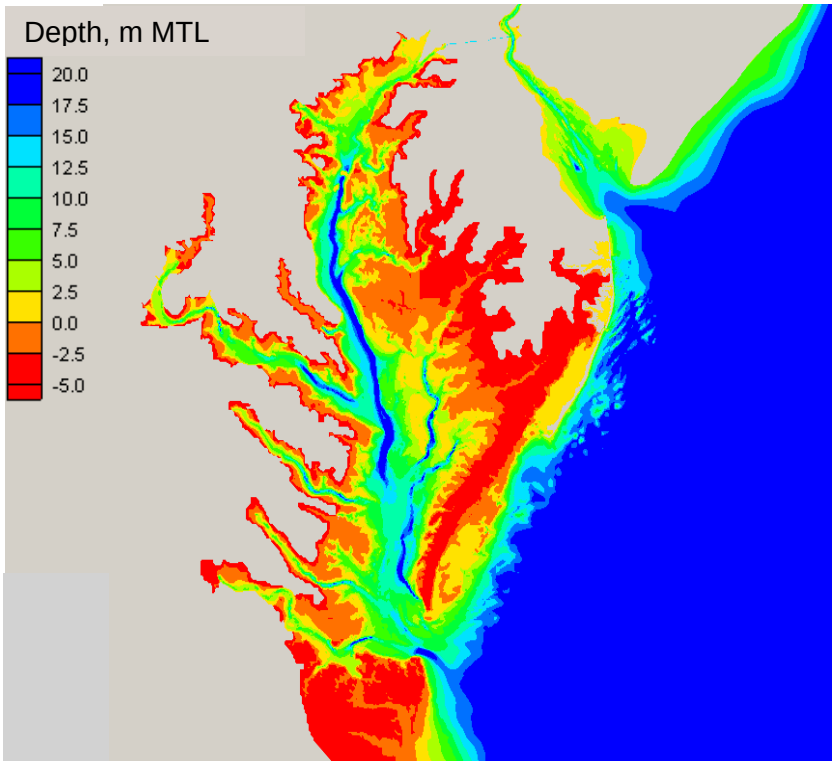


Figure 7. Portion of the revised ADCIRC grid bathymetry prior to grid extension

Figure 8. Portion of revised ADCIRC grid bathymetry with overbank extensions



Validation to Storms

NOAA historical water level data (1996-2003) for Chesapeake Bay was extracted from the internet web site (http://co-ops.nos.noaa.gov/data_res.html) to examine seasonal water level variations and to validate numerical model results. Figure 9, for instance, shows monthly mean water levels at NOAA Stations 8574680 (Baltimore, MD) and 8638863 (Bay Bridge, VA) for years 2002 and 2003. These figures clearly show seasonal variation of mean water in the bay.

Tropical Storms (Hurricanes)

The validation process for tropical storms (hurricanes) applying PBL wind and pressure fields involved comparison of water levels at twelve NOAA stations (Figure 11 and Table 3) to water levels produced by ADCIRC for two major hurricanes, Fran (1996) and Isabel (2003), and four moderate hurricanes, Bertha (1996), Bonnie (1998), Earl (1998), and Floyd (1999). Fran and Isabel approached the bay from the ocean with similar storm tracks nearly perpendicular to the coastline and made the landfall south of the bay. They continued in a northwest course to move further inland west of the bay. The passage of Bertha is similar to Floyd as both hurricanes approached and passed the bay paralleling or along the coastline east of the bay. Bonnie and Earl, on the other hand, followed a northeast track from land to ocean crossing the coastline south of the bay. Figure 10 shows storm tracks of these hurricanes. Hurricanes of similar track to Fran and Isabel can generate higher storm surge as the onshore wind traps more water along the coastline and in the bay.

Figures 12-13 show the measured and modeled water level time series at seven NOAA stations for Hurricane Fran. It is noted that an average water level increase of 0.1 m (0.3 ft) in the interval of March to November was added to model results to account for the seasonal variation. Model results generally agree well with the measured water levels. For instance, at Station 8574680 (Baltimore, MD) near the north end of the bay, both measured and modeled peak water levels are 1.3 m (4.3 ft). At Station 8638863 (Bay Bridge Tunnel, VA) close to the bay entrance, both measured and modeled peak water levels are 0.8 m (2.6 ft). Figures 14-15 show the measured and modeled water level time series also at seven stations for Hurricane Isabel. Model results again agree well with measured data. At Station 8574680 (Baltimore, MD), measured and modeled peak water levels are 2.2 (7.2 ft) and 2.3 m (7.5 ft), respectively. At Station 8638863 (Bay Bridge Tunnel, VA), both measured and modeled peak water levels are 1.9 m (6.2 ft). Tables 4-9 compare measured and modeled peak water levels for Hurricanes Bertha, Fran, Bonnie, Earl, Floyd and Isabel. For these hurricanes, the difference of predicted and measured peak water level, ranges between –0.31 to 0.46 m (-1.0 - 1.5 ft). The root-mean-square error of predicted peak water level versus measured data ranges between 0.07 to 0.2 m (0.23 – 0.7 ft). The bias of the predicted peak water level is between –0.1 and 0.31 m (-0.3 – 1.0 ft). Model water levels are generally more reliable for hurricanes of similar track to Fran and Isabel than those with storm track similar to Bertha and Bonnie, etc., as compared to the measured data.

Extratropical Storms (Northeasters)

The validation process for extratropical (northeaster) storm simulations is the same as for the tropical storms. Figure 16 shows two examples of comparisons

of model simulations and measurements for two northeasters. Note the measurements shown for September 2003 include a high storm surge on 19 September due to Hurricane Isabel. This event was simulated earlier in the study as part of the model validation for tropical storms. In these examples, an average water level increase of 0.1 m (0.3 ft) in the interval of March to November was added to model results to account for the seasonal variation. Model water level predictions for the extratropical storms generally agree well with the measured data. For instance, during the extratropical storm in mid-May 1998, at Station 8574680 (Baltimore, MD), the measured and modeled peak water levels are 0.76 and 0.64 m (2.5 and 2.1 ft), respectively. At Station 8638863 (Bay Bridge, VA), the measured and modeled peak water levels are 1.1 and 1.2 m (3.6 and 3.9 ft), respectively. During the extratropical storm around 10 September 2003, at Station 8574680 (Baltimore, MD) the measured and model water levels are 0.53 and 0.46 m (1.7 and 1.5 ft), respectively. At Station 8638863 (Bay Bridge, VA), both measured and modeled peak water levels are 1.0 m (3.1 ft).

The validated ADCIRC model was then applied to the suite of 52 hurricanes and 43 extratropical storms (presented in Chapter2) to compute water levels at Poplar, James, and Barren Islands to be applied in the wave modeling and life cycle analysis tasks.

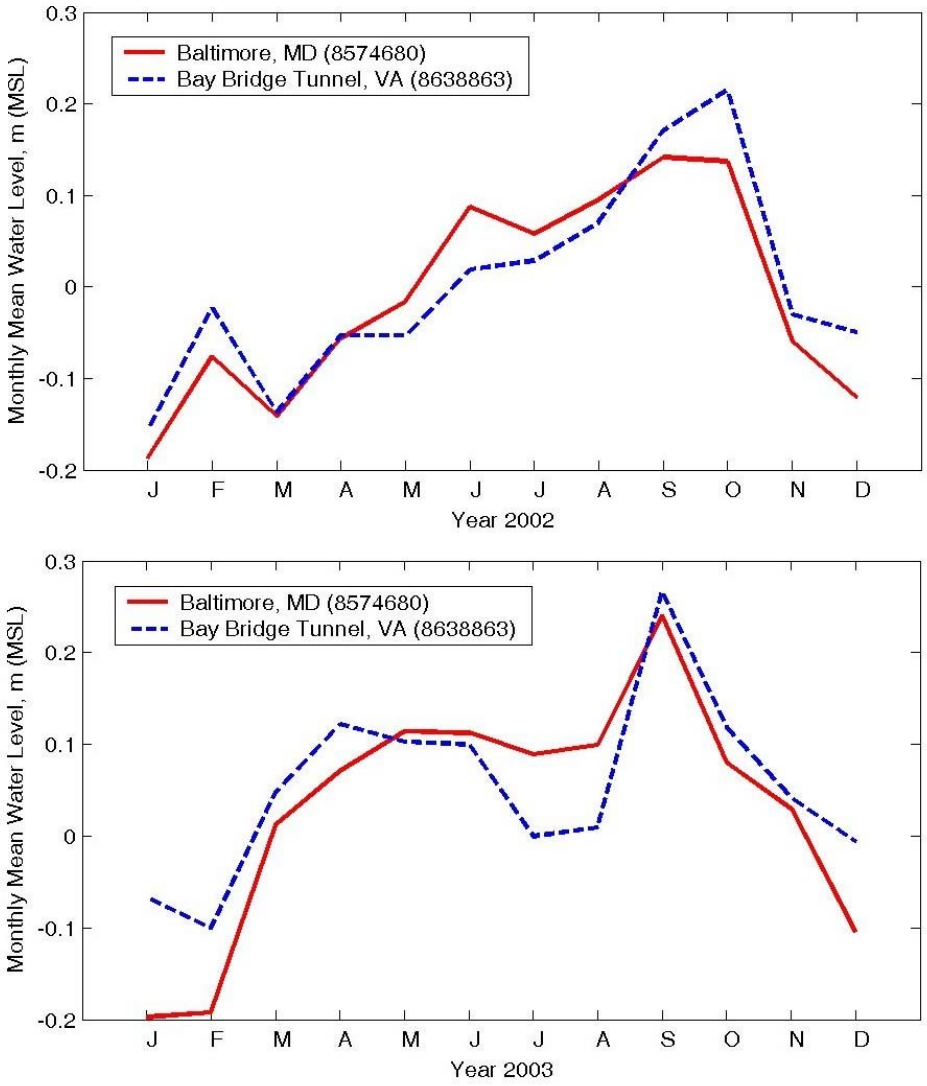


Figure 9. Monthly mean water levels at Stations 8574680 and 8638863 for 2002-2003

Table 3
NOAA Stations for wind/water level measurements (1996-2003), Chesapeake Bay and Delaware Bay

Station	Station Name	Coordinates
8551910	Reedy Pt, C&D Canal, DE	39° 33’ 30” N, 75° 34’ 26” W
8557380	Lewes, Ft. Miles, DE	38° 46’ 54” N, 75° 07’ 12” W
8571892	Cambridge, Choptank River, MD	38° 34’ 24” N, 76° 04’ 06” W
8573927	Chesapeake City, MD	39° 31’ 36” N, 75° 48’ 36” W
8574680	Baltimore, MD	38° 16’ 00” N, 76° 34’ 28” W
8575512	US Naval Academy, MD	38° 59’ 00” N, 76° 28’ 48” W
8577330	Solomons Is, MD	38° 19’ 00” N, 76° 27’ 12” W
8632200	Kiptopeke Beach, VA	37° 10’ 00” N, 75° 59’ 18” W
8635750	Lewisetta, Potomac River, VA	37° 59’ 48” N, 76° 27’ 48” W
8636580	Windmill Pt, VA	37° 36’ 42” N, 76° 16’ 30” W
8638610	Sewells Pt, VA	36° 56’ 48” N, 76° 19’ 48” W
8638863	Chesapeake Bay Bridge Tunnel, VA	36° 58’ 00” N, 76° 06’ 48” W

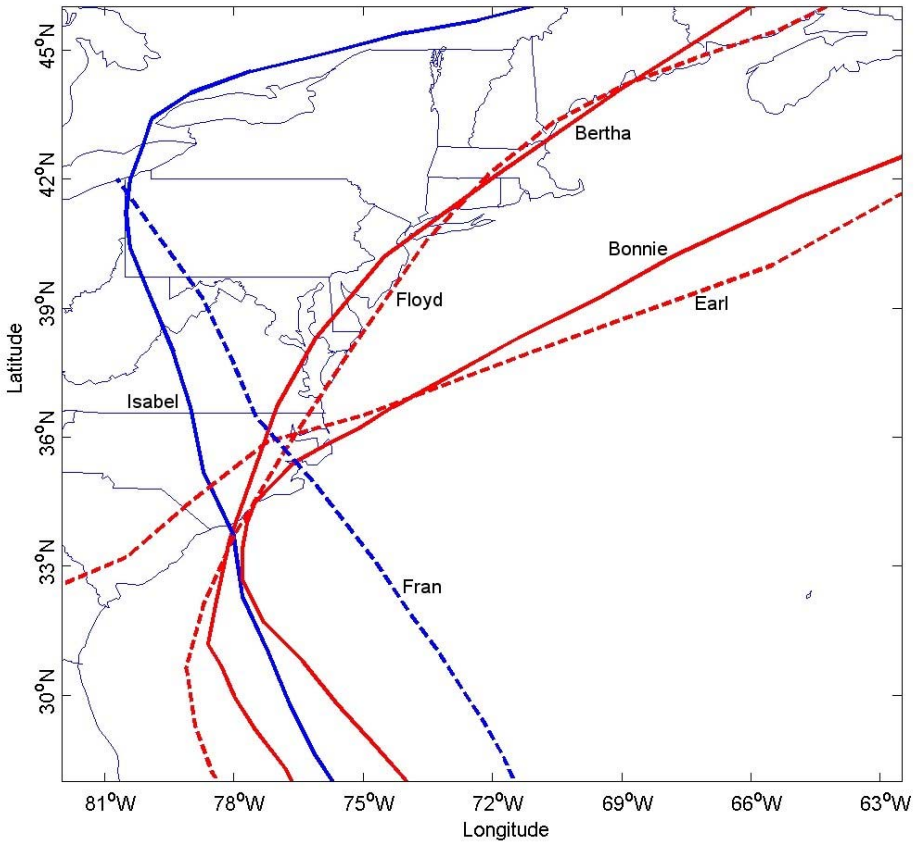


Figure 10. Storm tracks of Hurricanes Bertha, Bonnie, Earl, Floyd, Fran and Isabel

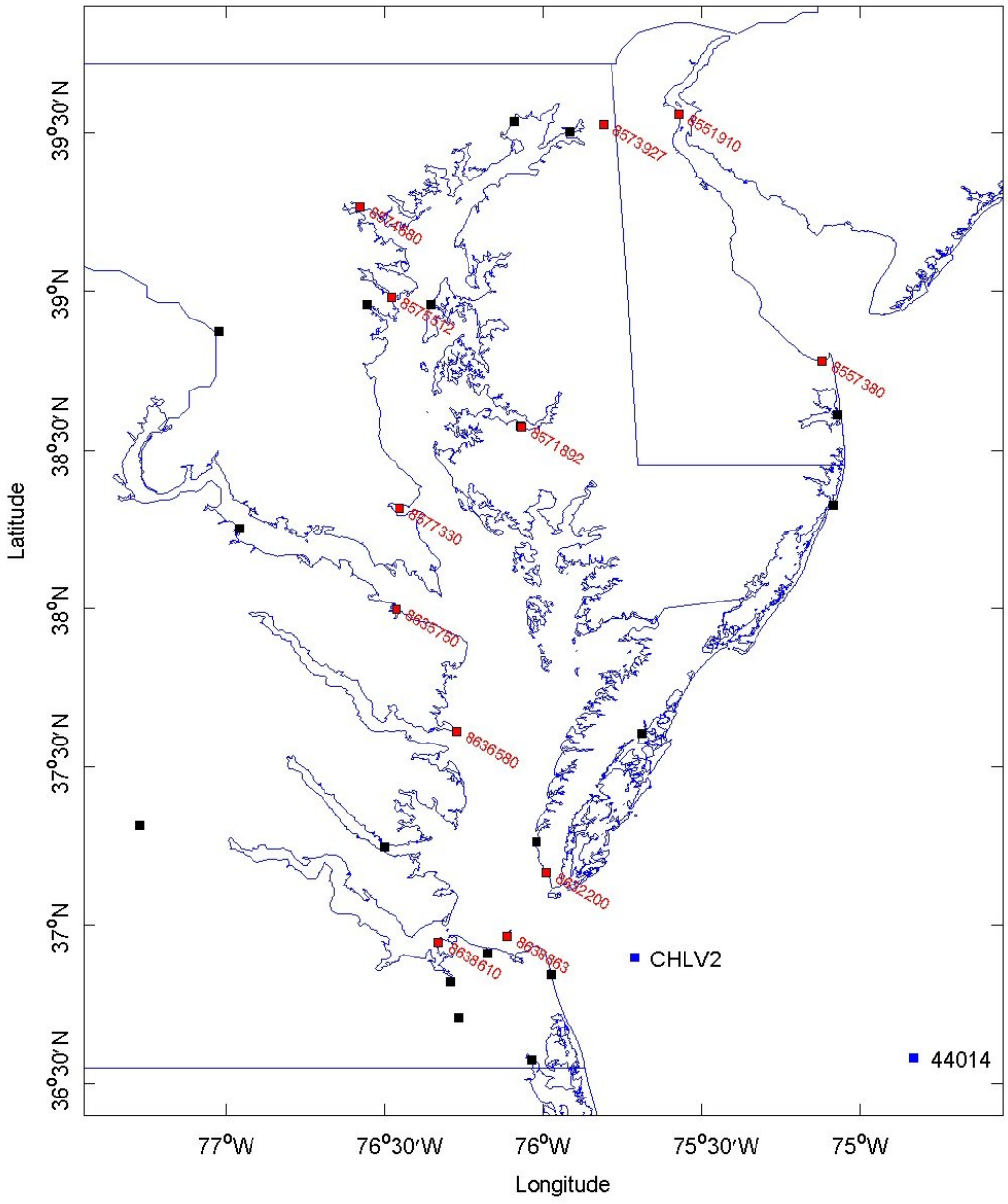


Figure 11. Wind/water level stations – active (red square), historical (blue square)

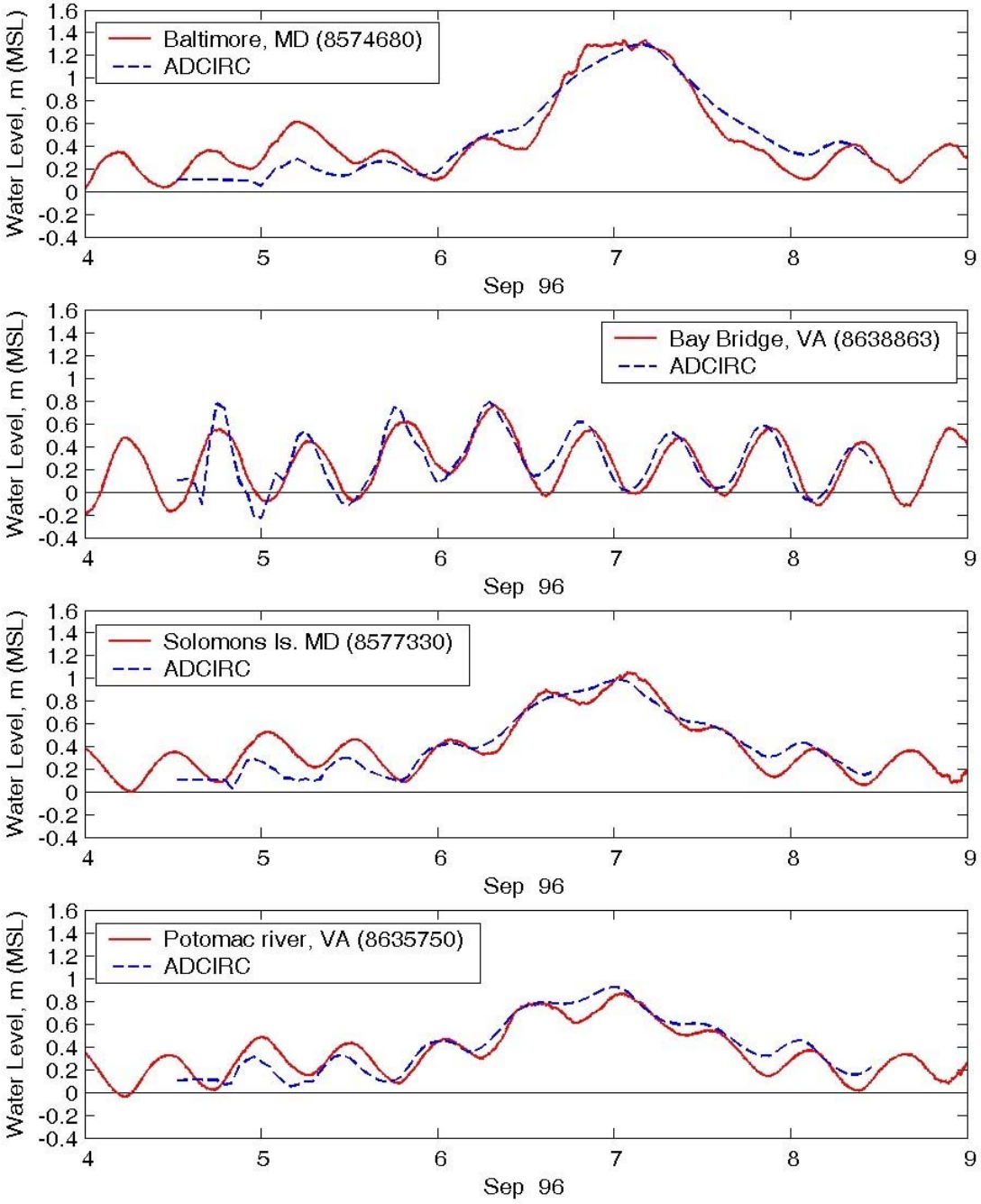


Figure 12. Measured and model water levels at Stations 8574680, 8638863, 8577300 and 8635750 for 4-9 Sep 96

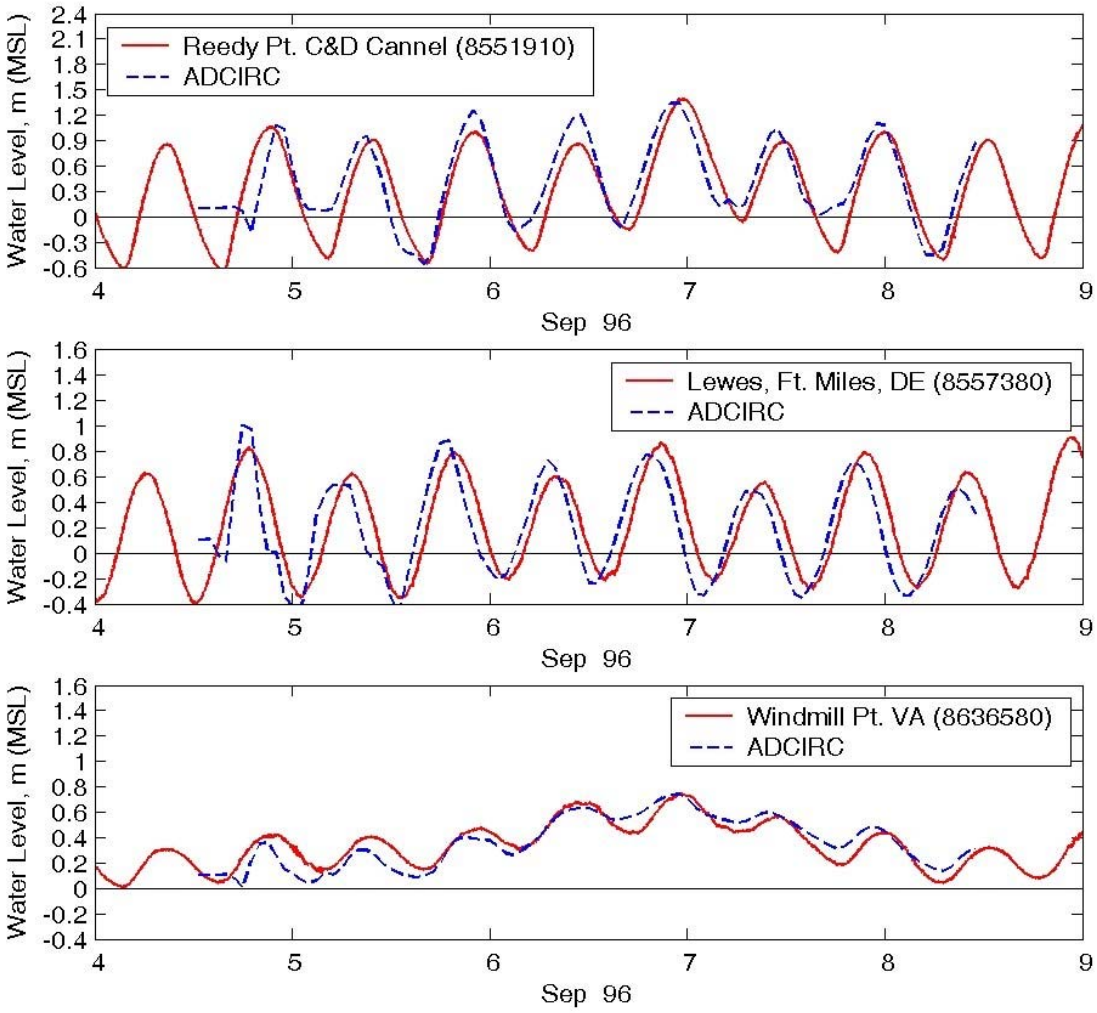


Figure 13. Measured and model water levels at Stations 8551910, 8557380, and 8636580 for 4-9 Sep 96

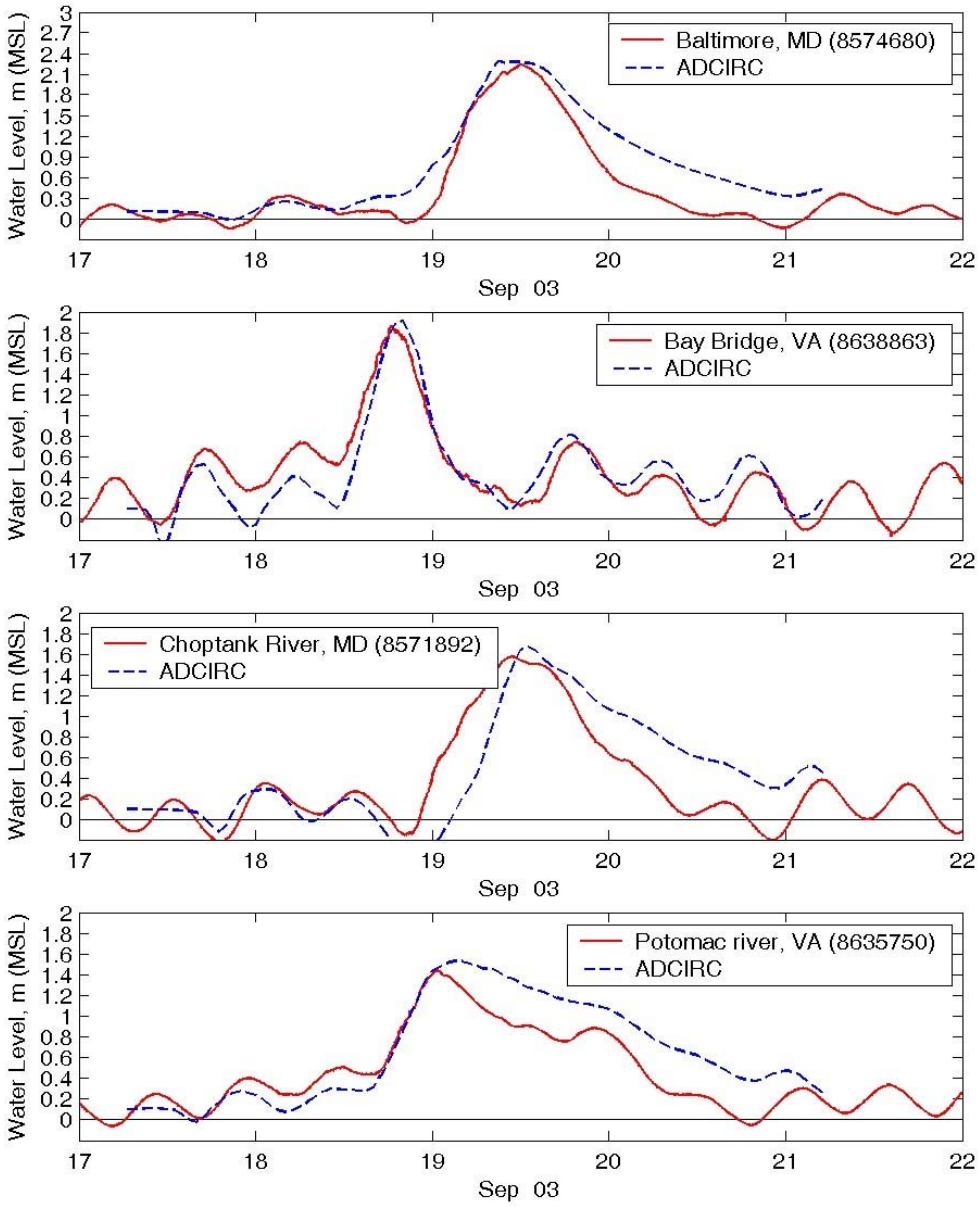


Figure 14. Measured and model water levels at Stations 8574680, 8638863, 8571892 and 8635750 for 17-22 Sep 03

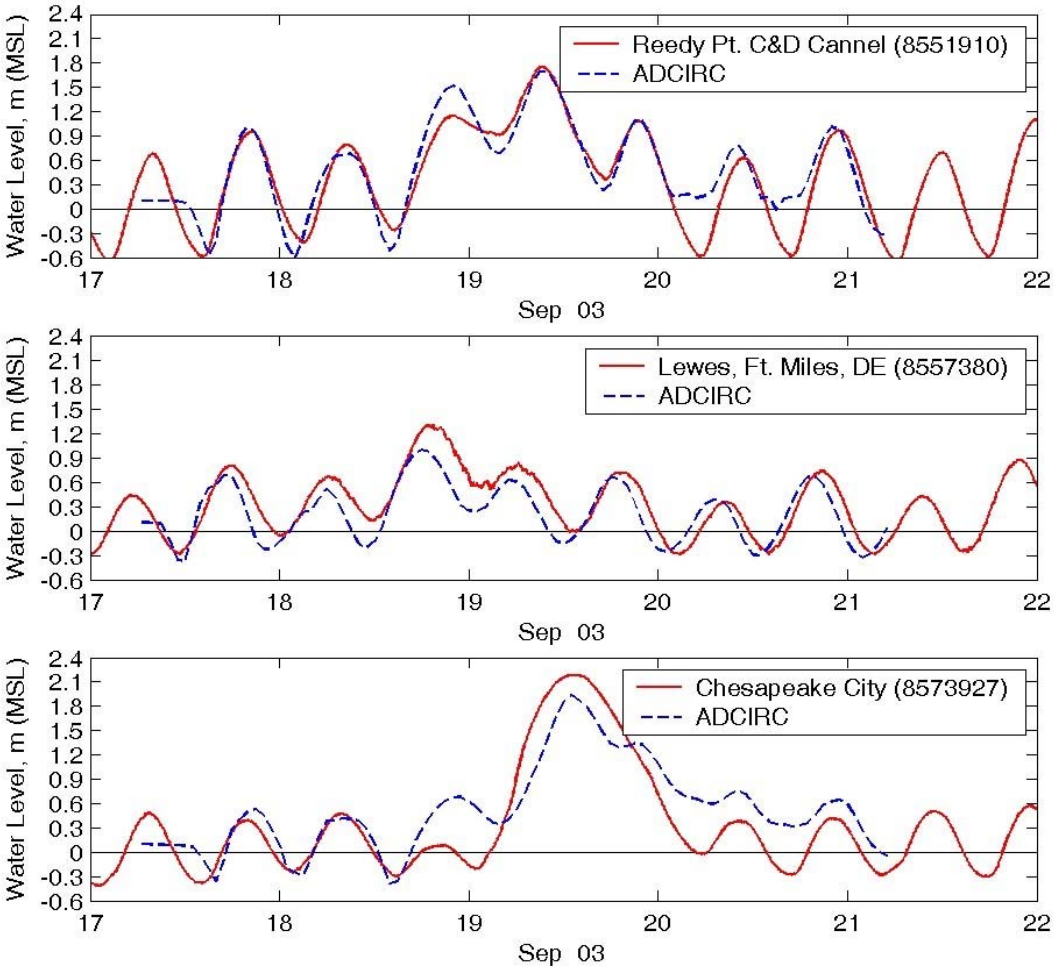


Figure 15. Measured and model water levels at Stations 8551910, 8557380, and 8573927 for 17-22 Sep 03

Table 4
Comparison of measured and predicted peak water levels during Hurricane Bertha (July 1996)

Station	Station name	Measured, m (ft)	Predicted, m (ft)	Predicted – Measured, m (ft)
8551910	Reedy Pt, C&D Canal, DE	1.33 (4.36)	1.37 (4.49)	0.04 (0.13)
8557380	Lewes, Ft. Miles, DE	0.84 (2.76)	0.89 (2.92)	0.05 (0.16)
8574680	Baltimore, MD	0.57 (1.87)	0.70 (2.30)	0.13 (0.43)
8575512	US Naval Academy, MD	0.55 (1.80)	0.78 (2.56)	0.23 (0.75)
8577330	Solomons Is, MD	0.64 (2.10)	0.90 (2.95)	0.26 (0.85)
8632200	Kiptopeke Beach, VA	0.59 (1.94)	0.54 (1.77)	-0.05 (-0.16)
8635750	Lewisetta, Potomac River, VA	0.60 (1.97)	0.83 (2.72)	0.23 (0.75)
8638610	Sewells Pt, VA	0.60 (1.97)	0.57 (1.87)	-0.03 (-0.10)
8638863	Chesapeake Bay Bridge Tunnel, VA	0.60 (1.97)	0.66 (2.17)	0.06 (0.20)

Root-mean-square error of predicted peak water level = 0.11 (m)
Bias = mean of (predicted – measured) = 0.10 (m)

Table 5
Comparison of measured and predicted peak water levels during Hurricane Fran (September 1996)

Station	Station name	Measured, m (ft)	Predicted, m (ft)	Predicted – Measured, m (ft)
8551910	Reedy Pt, C&D Canal, DE	1.39 (4.56)	1.34 (4.40)	-0.05 (-0.16)
8557380	Lewes, Ft. Miles, DE	0.86 (2.82)	1.00 (3.28)	0.14 (0.46)
8574680	Baltimore, MD	1.33 (4.36)	1.30 (4.27)	-0.03 (-0.10)
8577330	Solomons Is, MD	1.05 (3.44)	0.99 (3.25)	-0.06 (-0.20)
8635750	Lewisetta, Potomac River, VA	0.87 (2.85)	0.93 (3.05)	0.06 (0.20)
8636580	Windmill Pt, VA	0.74 (2.43)	0.74 (2.43)	0.00 (0.00)
8638863	Chesapeake Bay Bridge Tunnel, VA	0.76 (2.49)	0.79 (2.59)	0.03 (0.10)

Root-mean-square error of predicted peak water level = 0.07 (m)
Bias = mean of (predicted – measured) = 0.01 (m)

Table 6
Comparison of measured and predicted peak water levels during Hurricane Bonnie (August 1998)

Station	Station name	Measured, m (ft)	Predicted, m (ft)	Predicted – Measured, m (ft)
8551910	Reedy Pt, C&D Canal, DE	0.85 (2.79)	1.10 (3.61)	0.25 (0.82)
8557380	Lewes, Ft. Miles, DE	0.92 (3.02)	0.76 (2.49)	-0.16 (-0.52)
8571892	Cambridge, Choptank River, MD	0.60 (1.97)	0.62 (2.03)	0.02 (0.07)
8574680	Baltimore, MD	0.62 (2.03)	0.63 (2.07)	0.01 (0.03)
8577330	Solomons Is, MD	0.57 (1.87)	0.67 (2.20)	0.10 (0.33)
8635750	Lewisetta, Potomac River, VA	0.65 (2.13)	0.78 (2.56)	0.13 (0.43)
8636580	Windmill Pt, VA	0.75 (2.46)	0.81 (2.66)	0.06 (0.20)
8638863	Chesapeake Bay Bridge Tunnel, VA	1.23 (4.04)	1.02 (3.35)	-0.21 (-0.69)

Root-mean-square error of predicted peak water level = 0.14 (m)
Bias = mean of (predicted – measured) = 0.03 (m)

Table 7
Comparison of measured and predicted peak water levels during Hurricane Earl (September 1998)

Station	Station name	Measured, m (ft)	Predicted, m (ft)	Predicted – Measured, m (ft)
8551910	Reedy Pt, C&D Canal, DE	1.18 (3.87)	1.25 (4.10)	0.07 (0.23)
8557380	Lewes, Ft. Miles, DE	1.13 (3.71)	0.89 (2.92)	-0.24 (-0.79)
8571892	Cambridge, Choptank River, MD	0.64 (2.10)	0.54 (1.77)	-0.10 (-0.33)
8574680	Baltimore, MD	0.58 (1.90)	0.44 (1.44)	-0.14 (-0.46)
8577330	Solomons Is, MD	0.54 (1.77)	0.42 (1.38)	-0.12 (-0.39)
8635750	Lewisetta, Potomac River, VA	0.53 (1.74)	0.44 (1.44)	-0.09 (-0.30)
8636580	Windmill Pt, VA	0.51 (1.67)	0.45 (1.48)	-0.06 (-0.20)
8638863	Chesapeake Bay Bridge Tunnel, VA	0.81 (2.66)	0.72 (2.36)	-0.09 (-0.30)

Root-mean-square error of predicted peak water level = 0.08 (m)
Bias = mean of (predicted – measured) = -0.10 (m)

Table 8
Comparison of measured and predicted peak water levels during Hurricane Floyd (September 1999)

Station	Station name	Measured, m (ft)	Predicted, m (ft)	Predicted – Measured, m (ft)
8551910	Reedy Pt, C&D Canal, DE	1.31 (4.30)	1.56 (5.12)	0.25 (0.82)
8557380	Lewes, Ft. Miles, DE	1.27 (4.17)	1.40 (4.59)	0.13 (0.43)
8571892	Cambridge, Choptank River, MD	0.66 (2.17)	1.11 (3.64)	0.45 (1.48)
8574680	Baltimore, MD	0.62 (2.03)	1.06 (3.48)	0.44 (1.44)
8577330	Solomons Is, MD	0.65 (2.13)	1.11 (3.64)	0.46 (1.51)
8635750	Lewisetta, Potomac River, VA	0.85 (2.79)	1.26 (4.13)	0.41 (1.35)
8636580	Windmill Pt, VA	0.85 (2.79)	1.16 (3.81)	0.31 (1.02)
8638863	Chesapeake Bay Bridge Tunnel, VA	1.30 (4.27)	1.33 (4.36)	0.03 (0.10)
Root-mean-square error of predicted peak water level = 0.15 (m) Bias = mean of (predicted – measured) = 0.31 (m)				

Table 9
Comparison of measured and predicted peak water levels during Hurricane Isabel (September 2003)

Station	Station name	Measured, m (ft)	Predicted, m (ft)	Predicted – Measured, m (ft)
8551910	Reedy Pt, C&D Canal, DE	1.75 (5.74)	1.69 (5.54)	-0.06 (-0.20)
8557380	Lewes, Ft. Miles, DE	1.31 (4.30)	1.00 (3.28)	-0.31 (-1.02)
8571892	Cambridge, Choptank River, MD	1.58 (5.18)	1.68 (5.51)	0.10 (0.33)
8573927	Chesapeake City, MD	2.18 (7.15)	1.94 (6.36)	-0.26 (-0.85)
8574680	Baltimore, MD	2.24 (7.35)	2.28 (7.48)	0.04 (0.13)
8575512	US Naval Academy, MD	1.98 (6.50)	2.30 (7.55)	0.32 (1.05)
8577330	Solomons Is, MD	1.85 (6.07)	1.80 (5.91)	-0.05 (-0.16)
8632200	Kiptopeke Beach, VA	1.55 (5.09)	1.70 (5.58)	0.15 (0.49)
8635750	Lewisetta, Potomac River, VA	1.44 (4.72)	1.53 (5.02)	0.09 (0.30)
8636580	Windmill Pt, VA	1.48 (4.86)	1.30 (4.27)	-0.18 (-0.59)
8638610	Sewells Pt, VA	1.99 (6.53)	2.35 (7.71)	0.36 (1.18)
8638863	Chesapeake Bay Bridge Tunnel, VA	1.87 (6.14)	1.91 (6.27)	0.04 (0.13)
Root-mean-square error of predicted peak water level = 0.20 (m) Bias = mean of (predicted – measured) = 0.02 (m)				

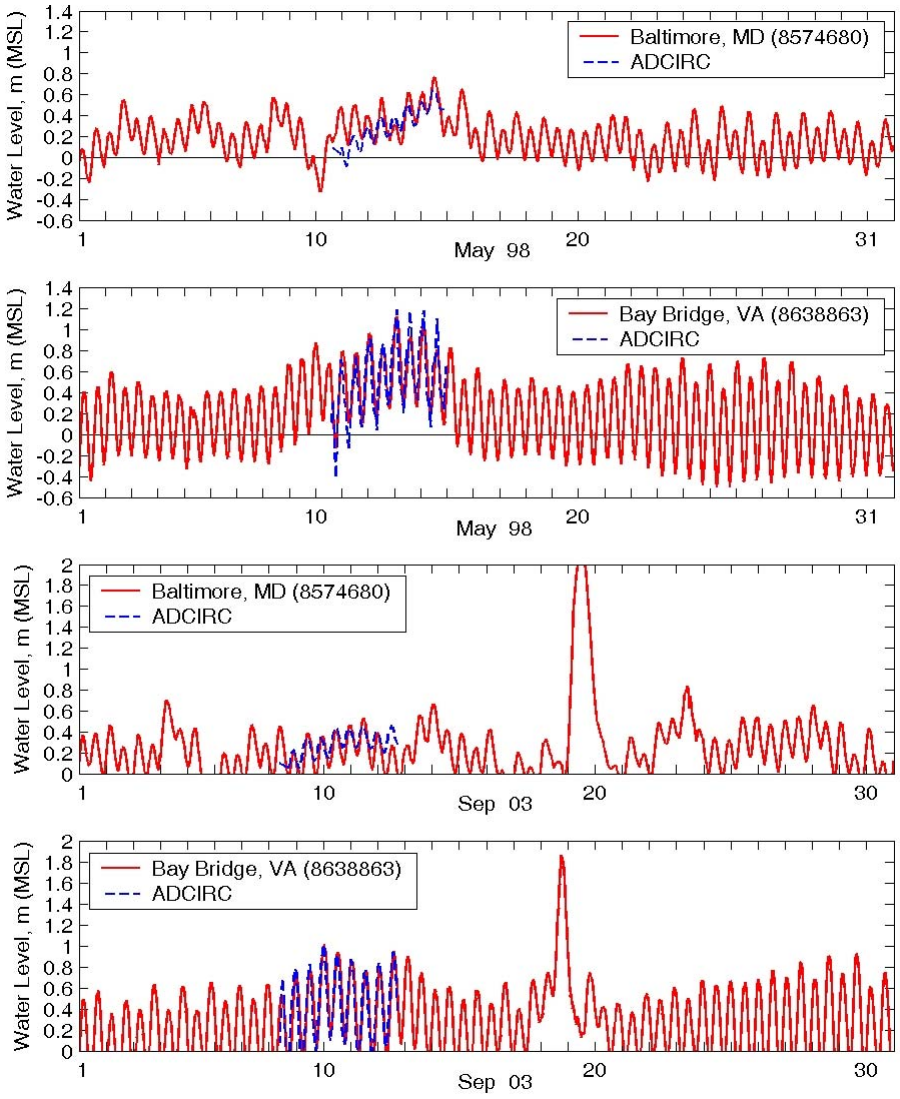


Figure 16. Measured and model water levels at Stations 8574680 and 8638863 for May 98 and Sep 03

Extraction of Maximum Water Level and Water Level Time Series at Poplar, Barren, and James Islands

The validated model was applied to the suite of storms presented in Chapter 2 (Tables 1 and 2). Maximum water levels were extracted at 24 locations around Barren Island, James Island and Poplar Island for use in the wave modeling and life cycle analysis tasks (Figures 17-19 and Tables 10-12). Maximum water levels for tropical storms are shown in Tables 13-15. For instance, water levels predicted at Poplar Island for 52 hurricanes ranged between 0.33 and 2.44 m (1.1 and 8.0 ft). For a given storm, water levels from one side of Poplar Island to the other side of Poplar Island vary by as much as 0.43 m (1.4 ft).

Maximum water levels for extratropical storms are shown in Tables 16-18. For instance, water levels at Poplar Island for these northeasters ranged between 0.19 and 0.98 m (0.6 and 3.2 ft). For a given storm, water levels from one side of Poplar Island to the other side of Poplar Island vary by as much as 0.05 m (0.2 ft).

Time series of water level were extracted at a location for wave estimates around each island. The coordinates of these points are (76.28^{o} W, 38.33^{o} N) for Barren Island, (76.37^{o} W, 38.52^{o} N) for James Island, and (76.4^{o} W, 38.77^{o} N) for Poplar Island. Details of wave modeling are presented in Chapter 4.

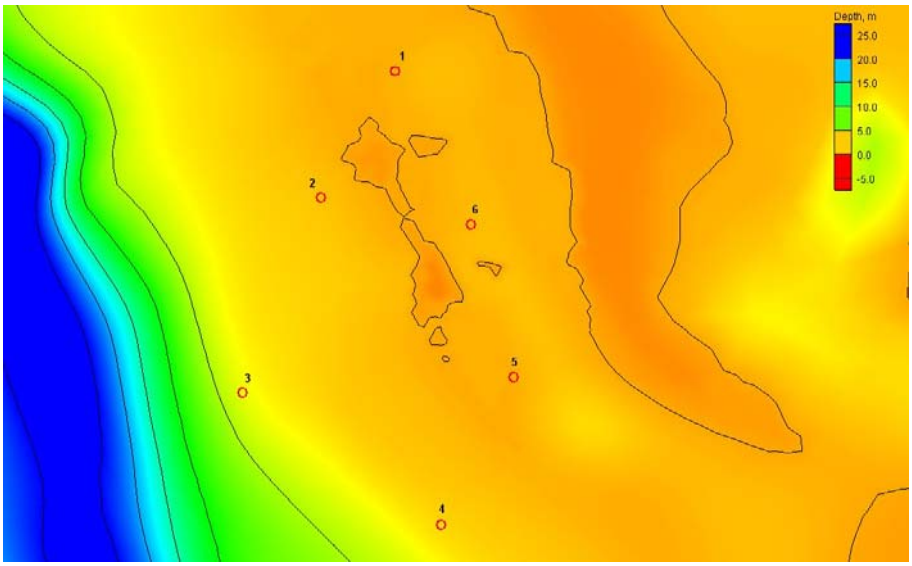


Figure 17. Save stations (red circle) around Barren Island

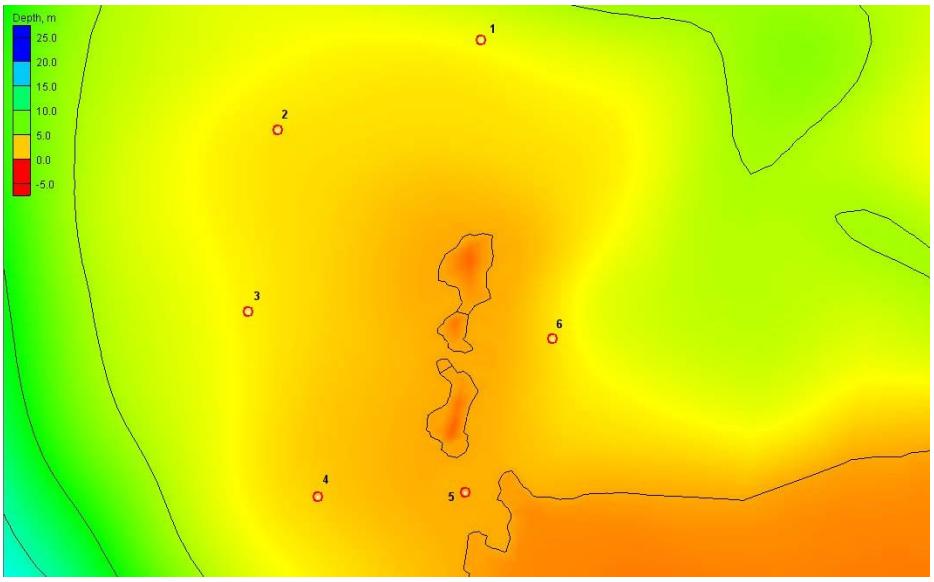


Figure 18. Save stations around James Island

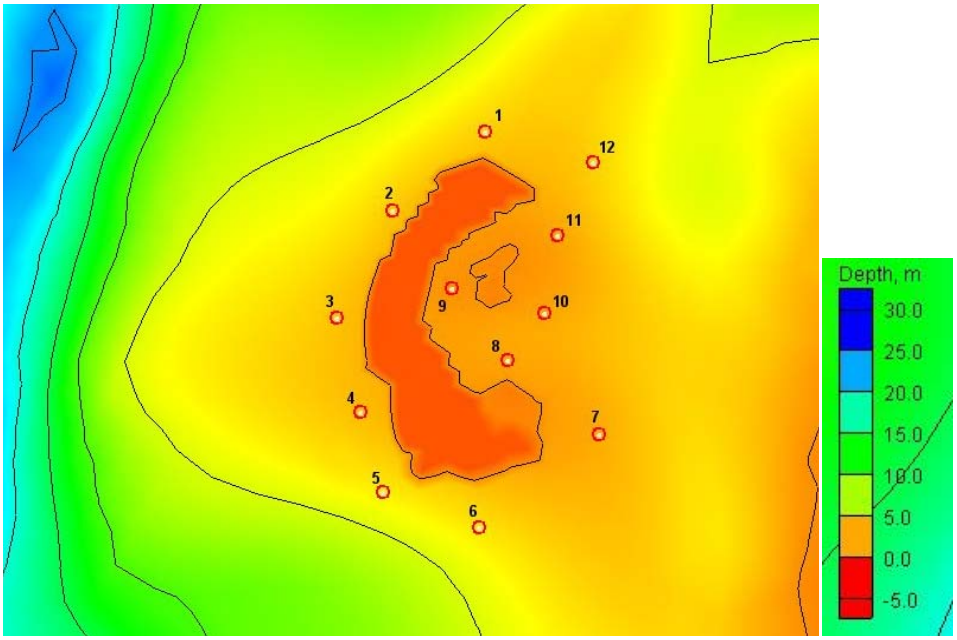


Figure 19. Twelve Poplar Island locations for saving simulated water levels

Table 10
Barren Island save location coordinates and depths

Station	Coordinates	Depth, m (ft), msl
1	38° 20' 29" N, 76° 15' 10" W	0.30 (0.98)
2	38° 19' 39" N, 76° 15' 40" W	0.82 (2.69)
3	38° 18' 20" N, 76° 16' 12" W	3.15 (10.33)
4	38° 17' 27" N, 76° 14' 52" W	1.37 (4.49)
5	38° 18' 26" N, 76° 14' 23" W	0.23 (0.75)
6	38° 19' 28" N, 76° 14' 40" W	0.57 (1.87)

Table 11
James Island save location coordinates and depths

Station	Coordinates	Depth, m (ft), msl
1	38° 32' 31" N, 76° 20' 13" W	2.75 (9.02)
2	38° 32' 01" N, 76° 21' 22" W	1.80 (5.91)
3	38° 30' 59" N, 76° 21' 32" W	2.15 (7.05)
4	38° 29' 56" N, 76° 21' 08" W	1.18 (3.87)
5	38° 29' 58" N, 76° 20' 18" W	0.25 (0.82)
6	38° 30' 50" N, 76° 19' 49" W	1.64 (5.38)

Table 12
Poplar Island save location coordinates and depths

Station No.	Coordinates	Depth, m (ft), msl
1	38° 46' 46" N, 76° 22' 28" W	2.17 (7.12)
2	38° 46' 27" N, 76° 23' 02" W	1.99 (6.53)
3	38° 45' 48" N, 76° 23' 23" W	1.75 (5.74)
4	38° 45' 13" N, 76° 23' 14" W	1.58 (5.18)
5	38° 44' 43" N, 76° 23' 06" W	3.30 (10.83)
6	38° 44' 30" N, 76° 22' 31" W	2.97 (9.74)
7	38° 45' 04" N, 76° 21' 46" W	0.97 (3.18)
8	38° 45' 32" N, 76° 22' 20" W	0.73 (2.40)
9	38° 45' 50" N, 76° 22' 42" W	0.36 (1.18)
10	38° 45' 49" N, 76° 22' 07" W	0.76 (2.49)
11	38° 46' 18" N, 76° 22' 02" W	0.74 (2.43)
12	38° 46' 45" N, 76° 21' 49" W	2.18 (7.15)

Table 13
Peak Water Levels at Barren Island for 52 Tropical Storms for ADCIRC Save Station Locations, m (ft), msl

Storm	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
1	0.445 (1.46)	0.491 (1.61)	0.514 (1.69)	0.506 (1.66)	0.471 (1.55)	0.456 (1.50)
2	0.910 (2.99)	0.890 (2.92)	0.875 (2.87)	0.878 (2.88)	0.896 (2.94)	0.903 (2.96)
3	0.504 (1.65)	0.513 (1.68)	0.526 (1.73)	0.532 (1.75)	0.516 (1.69)	0.508 (1.67)
4	0.580 (1.90)	0.560 (1.84)	0.550 (1.80)	0.564 (1.85)	0.581 (1.91)	0.576 (1.89)
5	1.197 (3.93)	1.078 (3.54)	1.015 (3.33)	1.046 (3.43)	1.138 (3.73)	1.165 (3.82)
6	1.221 (4.01)	1.140 (3.74)	1.095 (3.59)	1.110 (3.64)	1.169 (3.84)	1.166 (3.83)
7	1.135 (3.72)	1.085 (3.56)	1.052 (3.45)	1.081 (3.55)	1.123 (3.68)	1.117 (3.66)
8	1.711 (5.61)	1.607 (5.27)	1.541 (5.06)	1.569 (5.15)	1.652 (5.42)	1.664 (5.46)
9	0.721 (2.37)	0.719 (2.36)	0.721 (2.37)	0.735 (2.41)	0.734 (2.41)	0.731 (2.40)
10	0.494 (1.62)	0.516 (1.69)	0.525 (1.72)	0.522 (1.71)	0.506 (1.66)	0.496 (1.63)
11	0.662 (2.17)	0.684 (2.24)	0.696 (2.28)	0.693 (2.27)	0.676 (2.22)	0.666 (2.19)
12	0.531 (1.74)	0.529 (1.74)	0.526 (1.73)	0.536 (1.76)	0.541 (1.77)	0.536 (1.76)
13	0.561 (1.84)	0.568 (1.86)	0.574 (1.88)	0.575 (1.89)	0.567 (1.86)	0.555 (1.82)
14	0.444 (1.46)	0.456 (1.50)	0.460 (1.51)	0.462 (1.52)	0.454 (1.49)	0.444 (1.46)
15	0.945 (3.10)	0.892 (2.93)	0.851 (2.79)	0.837 (2.75)	0.894 (2.93)	0.920 (3.02)
16	0.880 (2.89)	0.835 (2.74)	0.806 (2.64)	0.804 (2.64)	0.841 (2.76)	0.853 (2.80)
17	0.389 (1.28)	0.411 (1.35)	0.426 (1.40)	0.416 (1.36)	0.403 (1.32)	0.395 (1.30)
18	0.484 (1.59)	0.512 (1.68)	0.527 (1.73)	0.523 (1.72)	0.498 (1.63)	0.486 (1.59)
19	0.555 (1.82)	0.556 (1.82)	0.557 (1.83)	0.561 (1.84)	0.558 (1.83)	0.561 (1.84)
20	0.424 (1.39)	0.423 (1.39)	0.422 (1.38)	0.430 (1.41)	0.431 (1.41)	0.426 (1.40)
21	0.851 (2.79)	0.900 (2.95)	0.933 (3.06)	0.918 (3.01)	0.877 (2.88)	0.857 (2.81)
22	1.193 (3.91)	1.040 (3.41)	1.002 (3.29)	0.993 (3.26)	1.120 (3.67)	1.147 (3.76)
23	1.369 (4.49)	1.342 (4.40)	1.317 (4.32)	1.330 (4.36)	1.344 (4.41)	1.346 (4.42)
24	0.474 (1.56)	0.499 (1.64)	0.513 (1.68)	0.513 (1.68)	0.493 (1.62)	0.482 (1.58)
25	0.339 (1.11)	0.336 (1.10)	0.348 (1.14)	0.340 (1.12)	0.342 (1.12)	0.338 (1.11)
26	1.312 (4.30)	1.281 (4.20)	1.278 (4.19)	1.280 (4.20)	1.290 (4.23)	1.286 (4.22)
27	0.710 (2.33)	0.733 (2.40)	0.747 (2.45)	0.744 (2.44)	0.719 (2.36)	0.714 (2.34)
28	0.426 (1.40)	0.420 (1.38)	0.418 (1.37)	0.426 (1.40)	0.427 (1.40)	0.426 (1.40)
29	0.318 (1.04)	0.481 (1.58)	0.555 (1.82)	0.518 (1.70)	0.406 (1.33)	0.352 (1.15)
30	1.058 (3.47)	1.001 (3.28)	0.960 (3.15)	0.978 (3.21)	1.035 (3.40)	1.042 (3.42)
31	0.630 (2.07)	0.626 (2.05)	0.627 (2.06)	0.644 (2.11)	0.647 (2.12)	0.639 (2.10)
32	0.353 (1.16)	0.359 (1.18)	0.364 (1.19)	0.373 (1.22)	0.368 (1.21)	0.359 (1.18)
33	0.455 (1.49)	0.482 (1.58)	0.495 (1.62)	0.492 (1.61)	0.473 (1.55)	0.458 (1.50)
34	1.506 (4.94)	1.430 (4.69)	1.400 (4.59)	1.379 (4.52)	1.439 (4.72)	1.438 (4.72)
35	1.263 (4.14)	1.224 (4.02)	1.212 (3.98)	1.238 (4.06)	1.288 (4.23)	1.278 (4.19)
36	0.676 (2.22)	0.631 (2.07)	0.609 (2.00)	0.626 (2.05)	0.662 (2.17)	0.656 (2.15)
37	0.750 (2.46)	0.774 (2.54)	0.790 (2.59)	0.784 (2.57)	0.764 (2.51)	0.755 (2.48)
38	0.692 (2.27)	0.672 (2.20)	0.660 (2.17)	0.670 (2.20)	0.690 (2.26)	0.693 (2.27)
39	0.741 (2.43)	0.746 (2.45)	0.751 (2.46)	0.765 (2.51)	0.758 (2.49)	0.757 (2.48)
40	0.403 (1.32)	0.402 (1.32)	0.399 (1.31)	0.402 (1.32)	0.404 (1.33)	0.403 (1.32)
41	0.795 (2.61)	0.785 (2.58)	0.778 (2.55)	0.784 (2.57)	0.789 (2.59)	0.799 (2.62)
42	0.369 (1.21)	0.378 (1.24)	0.389 (1.28)	0.393 (1.29)	0.373 (1.22)	0.367 (1.20)
43	0.333 (1.09)	0.335 (1.10)	0.336 (1.10)	0.344 (1.13)	0.342 (1.12)	0.336 (1.10)
44	0.813 (2.67)	0.788 (2.59)	0.800 (2.62)	0.812 (2.66)	0.824 (2.70)	0.820 (2.69)
45	0.450 (1.48)	0.500 (1.64)	0.525 (1.72)	0.515 (1.69)	0.474 (1.56)	0.452 (1.48)
46	0.394 (1.29)	0.398 (1.31)	0.399 (1.31)	0.405 (1.33)	0.403 (1.32)	0.398 (1.31)
47	1.036 (3.40)	1.014 (3.33)	0.998 (3.27)	1.004 (3.29)	1.029 (3.38)	1.030 (3.38)
48	0.993 (3.26)	0.978 (3.21)	0.968 (3.18)	0.968 (3.18)	0.980 (3.22)	0.982 (3.22)
49	0.716 (2.35)	0.740 (2.43)	0.756 (2.48)	0.753 (2.47)	0.731 (2.40)	0.720 (2.36)
50	0.461 (1.51)	0.449 (1.47)	0.443 (1.45)	0.453 (1.49)	0.460 (1.51)	0.458 (1.50)
51	1.082 (3.55)	1.078 (3.54)	1.078 (3.54)	1.096 (3.60)	1.102 (3.62)	1.095 (3.59)
52	1.672 (5.49)	1.627 (5.34)	1.612 (5.29)	1.611 (5.29)	1.635 (5.36)	1.641 (5.38)

Table 14
Peak Water Levels at James Island for 52 Tropical Storms for ADCIRC Save Station Locations, m (ft), msl

Storm	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
1	0.511 (1.68)	0.506 (1.66)	0.501 (1.64)	0.492 (1.61)	0.488 (1.60)	0.528 (1.73)
2	0.886 (2.91)	0.883 (2.90)	0.884 (2.90)	0.885 (2.90)	0.883 (2.90)	0.885 (2.90)
3	0.485 (1.59)	0.494 (1.62)	0.494 (1.62)	0.487 (1.60)	0.480 (1.57)	0.489 (1.60)
4	0.515 (1.69)	0.513 (1.68)	0.514 (1.69)	0.514 (1.69)	0.507 (1.66)	0.506 (1.66)
5	1.165 (3.82)	1.127 (3.70)	1.102 (3.62)	1.083 (3.55)	1.113 (3.65)	1.159 (3.80)
6	1.187 (3.89)	1.201 (3.94)	1.210 (3.97)	1.192 (3.91)	1.128 (3.70)	1.134 (3.72)
7	0.959 (3.15)	0.955 (3.13)	0.964 (3.16)	0.971 (3.19)	0.962 (3.16)	0.960 (3.15)
8	1.620 (5.31)	1.596 (5.24)	1.575 (5.17)	1.551 (5.09)	1.566 (5.14)	1.602 (5.26)
9	0.682 (2.24)	0.673 (2.21)	0.673 (2.21)	0.671 (2.20)	0.682 (2.24)	0.691 (2.27)
10	0.536 (1.76)	0.536 (1.76)	0.534 (1.75)	0.531 (1.74)	0.524 (1.72)	0.541 (1.77)
11	0.690 (2.26)	0.688 (2.26)	0.685 (2.25)	0.679 (2.23)	0.675 (2.21)	0.697 (2.29)
12	0.522 (1.71)	0.517 (1.70)	0.515 (1.69)	0.531 (1.74)	0.517 (1.70)	0.523 (1.72)
13	0.603 (1.98)	0.606 (1.99)	0.602 (1.98)	0.596 (1.96)	0.588 (1.93)	0.600 (1.97)
14	0.474 (1.56)	0.473 (1.55)	0.470 (1.54)	0.467 (1.53)	0.462 (1.52)	0.471 (1.55)
15	1.187 (3.89)	1.160 (3.81)	1.131 (3.71)	1.105 (3.63)	1.127 (3.70)	1.170 (3.84)
16	1.013 (3.32)	1.005 (3.30)	0.992 (3.25)	0.978 (3.21)	0.975 (3.20)	0.992 (3.25)
17	0.452 (1.48)	0.450 (1.48)	0.443 (1.45)	0.437 (1.43)	0.432 (1.42)	0.473 (1.55)
18	0.534 (1.75)	0.538 (1.77)	0.539 (1.77)	0.536 (1.76)	0.523 (1.72)	0.538 (1.77)
19	0.568 (1.86)	0.562 (1.84)	0.558 (1.83)	0.556 (1.82)	0.562 (1.84)	0.575 (1.89)
20	0.436 (1.43)	0.429 (1.41)	0.421 (1.38)	0.417 (1.37)	0.419 (1.37)	0.435 (1.43)
21	0.922 (3.02)	0.930 (3.05)	0.931 (3.05)	0.924 (3.03)	0.902 (2.96)	0.928 (3.04)
22	1.254 (4.11)	1.220 (4.00)	1.199 (3.93)	1.179 (3.87)	1.182 (3.88)	1.223 (4.01)
23	1.168 (3.83)	1.159 (3.80)	1.164 (3.82)	1.168 (3.83)	1.167 (3.83)	1.169 (3.84)
24	0.509 (1.67)	0.507 (1.66)	0.507 (1.66)	0.504 (1.65)	0.501 (1.64)	0.519 (1.70)
25	0.364 (1.19)	0.358 (1.17)	0.352 (1.15)	0.345 (1.13)	0.342 (1.12)	0.403 (1.32)
26	1.205 (3.95)	1.200 (3.94)	1.202 (3.94)	1.200 (3.94)	1.141 (3.74)	1.147 (3.76)
27	0.736 (2.41)	0.730 (2.40)	0.726 (2.38)	0.722 (2.37)	0.721 (2.37)	0.748 (2.45)
28	0.422 (1.38)	0.426 (1.40)	0.425 (1.39)	0.419 (1.37)	0.414 (1.36)	0.420 (1.38)
29	0.509 (1.67)	0.516 (1.69)	0.518 (1.70)	0.512 (1.68)	0.468 (1.54)	0.557 (1.83)
30	1.051 (3.45)	1.042 (3.42)	1.035 (3.40)	1.027 (3.37)	1.035 (3.40)	1.049 (3.44)
31	0.605 (1.98)	0.599 (1.97)	0.596 (1.96)	0.595 (1.95)	0.602 (1.98)	0.606 (1.99)
32	0.350 (1.15)	0.346 (1.14)	0.341 (1.12)	0.337 (1.11)	0.342 (1.12)	0.352 (1.15)
33	0.497 (1.63)	0.504 (1.65)	0.506 (1.66)	0.502 (1.65)	0.489 (1.60)	0.497 (1.63)
34	1.698 (5.57)	1.685 (5.53)	1.663 (5.46)	1.640 (5.38)	1.648 (5.41)	1.676 (5.50)
35	1.095 (3.59)	1.085 (3.56)	1.094 (3.59)	1.110 (3.64)	1.119 (3.67)	1.113 (3.65)
36	0.639 (2.10)	0.639 (2.10)	0.636 (2.09)	0.628 (2.06)	0.621 (2.04)	0.620 (2.03)
37	0.774 (2.54)	0.776 (2.55)	0.776 (2.55)	0.774 (2.54)	0.766 (2.51)	0.780 (2.56)
38	0.699 (2.29)	0.694 (2.28)	0.687 (2.25)	0.678 (2.22)	0.678 (2.22)	0.704 (2.31)
39	0.656 (2.15)	0.667 (2.19)	0.667 (2.19)	0.663 (2.18)	0.664 (2.18)	0.665 (2.18)
40	0.433 (1.42)	0.427 (1.40)	0.422 (1.38)	0.419 (1.37)	0.424 (1.39)	0.435 (1.43)
41	0.795 (2.61)	0.787 (2.58)	0.784 (2.57)	0.783 (2.57)	0.795 (2.61)	0.808 (2.65)
42	0.396 (1.30)	0.391 (1.28)	0.392 (1.29)	0.390 (1.28)	0.386 (1.27)	0.398 (1.31)
43	0.337 (1.11)	0.333 (1.09)	0.328 (1.08)	0.342 (1.12)	0.328 (1.08)	0.336 (1.10)
44	0.726 (2.38)	0.718 (2.36)	0.713 (2.34)	0.711 (2.33)	0.712 (2.34)	0.721 (2.37)
45	0.527 (1.73)	0.527 (1.73)	0.530 (1.74)	0.527 (1.73)	0.506 (1.66)	0.533 (1.75)
46	0.400 (1.31)	0.395 (1.30)	0.395 (1.30)	0.397 (1.30)	0.397 (1.30)	0.402 (1.32)
47	0.944 (3.10)	0.955 (3.13)	0.967 (3.17)	0.974 (3.20)	0.967 (3.17)	0.953 (3.13)
48	1.029 (3.38)	1.029 (3.38)	1.026 (3.37)	1.019 (3.34)	1.014 (3.33)	1.014 (3.33)
49	0.753 (2.47)	0.757 (2.48)	0.755 (2.48)	0.753 (2.47)	0.742 (2.43)	0.751 (2.46)
50	0.464 (1.52)	0.456 (1.50)	0.448 (1.47)	0.443 (1.45)	0.450 (1.48)	0.463 (1.52)
51	1.036 (3.40)	1.040 (3.41)	1.042 (3.42)	1.041 (3.42)	0.992 (3.25)	1.070 (3.51)
52	1.684 (5.52)	1.690 (5.54)	1.687 (5.53)	1.669 (5.48)	1.635 (5.36)	1.642 (5.39)

Table 15
Peak Water Levels at Poplar Island for 52 Tropical Storms for ADCIRC Save Station Locations, m (ft), msl

Storm	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
1	0.450 (1.48)	0.444 (1.46)	0.439 (1.44)	0.439 (1.44)	0.443 (1.45)	0.439 (1.44)
2	0.918 (3.01)	0.916 (3.01)	0.914 (3.00)	0.916 (3.01)	0.916 (3.01)	0.918 (3.01)
3	0.516 (1.69)	0.520 (1.71)	0.523 (1.72)	0.524 (1.72)	0.528 (1.73)	0.529 (1.74)
4	0.525 (1.72)	0.526 (1.73)	0.526 (1.73)	0.530 (1.74)	0.529 (1.74)	0.529 (1.74)
5	1.268 (4.16)	1.259 (4.13)	1.253 (4.11)	1.271 (4.17)	1.280 (4.20)	1.311 (4.30)
6	1.422 (4.67)	1.417 (4.65)	1.399 (4.59)	1.471 (4.83)	1.516 (4.97)	1.563 (5.13)
7	0.949 (3.11)	0.948 (3.11)	0.950 (3.12)	0.960 (3.15)	0.955 (3.13)	0.960 (3.15)
8	2.028 (6.65)	2.027 (6.65)	2.000 (6.56)	2.186 (7.17)	2.342 (7.68)	2.398 (7.87)
9	0.687 (2.25)	0.697 (2.29)	0.708 (2.32)	0.708 (2.32)	0.719 (2.36)	0.722 (2.37)
10	0.525 (1.72)	0.525 (1.72)	0.526 (1.73)	0.528 (1.73)	0.529 (1.74)	0.527 (1.73)
11	0.660 (2.17)	0.658 (2.16)	0.658 (2.16)	0.659 (2.16)	0.660 (2.17)	0.658 (2.16)
12	0.523 (1.72)	0.523 (1.72)	0.523 (1.72)	0.522 (1.71)	0.522 (1.71)	0.519 (1.70)
13	0.612 (2.01)	0.612 (2.01)	0.615 (2.02)	0.614 (2.01)	0.616 (2.02)	0.617 (2.02)
14	0.490 (1.61)	0.493 (1.62)	0.494 (1.62)	0.494 (1.62)	0.495 (1.62)	0.495 (1.62)
15	1.434 (4.70)	1.436 (4.71)	1.436 (4.71)	1.445 (4.74)	1.451 (4.76)	1.580 (5.18)
16	1.191 (3.91)	1.169 (3.84)	1.155 (3.79)	1.209 (3.97)	1.262 (4.14)	1.331 (4.37)
17	0.377 (1.24)	0.368 (1.21)	0.367 (1.20)	0.371 (1.22)	0.376 (1.23)	0.374 (1.23)
18	0.529 (1.74)	0.528 (1.73)	0.530 (1.74)	0.531 (1.74)	0.532 (1.75)	0.529 (1.74)
19	0.554 (1.82)	0.552 (1.81)	0.551 (1.81)	0.552 (1.81)	0.553 (1.81)	0.553 (1.81)
20	0.434 (1.42)	0.435 (1.43)	0.435 (1.43)	0.435 (1.43)	0.435 (1.43)	0.434 (1.42)
21	0.886 (2.91)	0.878 (2.88)	0.876 (2.87)	0.879 (2.88)	0.883 (2.90)	0.877 (2.88)
22	1.432 (4.70)	1.408 (4.62)	1.390 (4.56)	1.469 (4.82)	1.527 (5.01)	1.602 (5.26)
23	1.165 (3.82)	1.163 (3.82)	1.163 (3.82)	1.171 (3.84)	1.166 (3.83)	1.168 (3.83)
24	0.499 (1.64)	0.495 (1.62)	0.492 (1.61)	0.491 (1.61)	0.494 (1.62)	0.492 (1.61)
25	0.376 (1.23)	0.375 (1.23)	0.374 (1.23)	0.374 (1.23)	0.373 (1.22)	0.373 (1.22)
26	1.424 (4.67)	1.414 (4.64)	1.396 (4.58)	1.460 (4.79)	1.499 (4.92)	1.547 (5.08)
27	0.693 (2.27)	0.685 (2.25)	0.677 (2.22)	0.675 (2.21)	0.681 (2.23)	0.680 (2.23)
28	0.438 (1.44)	0.441 (1.45)	0.442 (1.45)	0.443 (1.45)	0.445 (1.46)	0.446 (1.46)
29	0.409 (1.34)	0.387 (1.27)	0.372 (1.22)	0.374 (1.23)	0.385 (1.26)	0.375 (1.23)
30	1.057 (3.47)	1.061 (3.48)	1.061 (3.48)	0.065 (0.21)	1.066 (3.50)	1.068 (3.50)
31	0.616 (2.02)	0.615 (2.02)	0.614 (2.01)	0.614 (2.01)	0.613 (2.01)	0.614 (2.01)
32	0.334 (1.10)	0.336 (1.10)	0.337 (1.11)	0.338 (1.11)	0.338 (1.11)	0.338 (1.11)
33	0.507 (1.66)	0.508 (1.67)	0.511 (1.68)	0.511 (1.68)	0.512 (1.68)	0.510 (1.67)
34	2.048 (6.72)	2.014 (6.61)	2.013 (6.60)	2.213 (7.26)	2.382 (7.81)	2.444 (8.02)
35	1.065 (3.49)	1.059 (3.47)	1.052 (3.45)	1.052 (3.45)	1.046 (3.43)	1.052 (3.45)
36	0.804 (2.64)	0.792 (2.60)	0.785 (2.58)	0.824 (2.70)	0.837 (2.75)	0.858 (2.81)
37	0.760 (2.49)	0.755 (2.48)	0.752 (2.47)	0.752 (2.47)	0.755 (2.48)	0.753 (2.47)
38	0.696 (2.28)	0.696 (2.28)	0.696 (2.28)	0.697 (2.29)	0.695 (2.28)	0.696 (2.28)
39	0.656 (2.15)	0.659 (2.16)	0.667 (2.19)	0.666 (2.19)	0.670 (2.20)	0.665 (2.18)
40	0.450 (1.48)	0.448 (1.47)	0.446 (1.46)	0.446 (1.46)	0.446 (1.46)	0.446 (1.46)
41	0.759 (2.49)	0.757 (2.48)	0.760 (2.49)	0.762 (2.50)	0.764 (2.51)	0.763 (2.50)
42	0.378 (1.24)	0.381 (1.25)	0.383 (1.26)	0.385 (1.26)	0.385 (1.26)	0.386 (1.27)
43	0.336 (1.10)	0.337 (1.11)	0.336 (1.10)	0.335 (1.10)	0.336 (1.10)	0.335 (1.10)
44	0.700 (2.30)	0.706 (2.32)	0.709 (2.33)	0.712 (2.34)	0.709 (2.33)	0.708 (2.32)
45	0.513 (1.68)	0.511 (1.68)	0.512 (1.68)	0.514 (1.69)	0.517 (1.70)	0.514 (1.69)
46	0.387 (1.27)	0.387 (1.27)	0.388 (1.27)	0.389 (1.28)	0.390 (1.28)	0.390 (1.28)
47	0.873 (2.86)	0.874 (2.87)	0.887 (2.91)	0.891 (2.92)	0.891 (2.92)	0.891 (2.92)
48	1.109 (3.64)	1.108 (3.64)	1.105 (3.63)	1.113 (3.65)	1.117 (3.66)	1.124 (3.69)
49	0.754 (2.47)	0.755 (2.48)	0.759 (2.49)	0.759 (2.49)	0.760 (2.49)	0.758 (2.49)
50	0.474 (1.56)	0.475 (1.56)	0.475 (1.56)	0.476 (1.56)	0.476 (1.56)	0.475 (1.56)
51	0.989 (3.24)	0.981 (3.22)	0.990 (3.25)	0.996 (3.27)	1.000 (3.28)	0.984 (3.23)
52	1.927 (6.32)	1.918 (6.29)	1.895 (6.22)	1.954 (6.41)	1.994 (6.54)	2.046 (6.71)

(Sheet 1 of 2)

Table 15 (Continued)
Peak Water Levels at Poplar Island for 52 Tropical Storms for ADCIRC Save Station Locations, m (ft), msl

Storm	Station 7	Station 8	Station 9	Station 10	Station 11	Station 12
1	0.429 (1.41)	0.475 (1.56)	0.476 (1.56)	0.458 (1.50)	0.457 (1.50)	0.454 (1.49)
2	0.916 (3.01)	0.915 (3.00)	0.916 (3.01)	0.919 (3.02)	0.921 (3.02)	0.922 (3.02)
3	0.519 (1.70)	0.531 (1.74)	0.545 (1.79)	0.524 (1.72)	0.522 (1.71)	0.519 (1.70)
4	0.523 (1.72)	0.519 (1.70)	0.548 (1.80)	0.521 (1.71)	0.523 (1.72)	0.525 (1.72)
5	1.265 (4.15)	1.239 (4.06)	1.238 (4.06)	1.258 (4.13)	1.266 (4.15)	1.276 (4.19)
6	1.433 (4.70)	1.442 (4.73)	1.488 (4.88)	1.450 (4.76)	1.438 (4.72)	1.429 (4.69)
7	0.962 (3.16)	0.952 (3.12)	0.941 (3.09)	0.962 (3.16)	0.967 (3.17)	0.969 (3.18)
8	2.169 (7.12)	2.103 (6.90)	2.198 (7.21)	2.138 (7.01)	2.112 (6.93)	2.046 (6.71)
9	0.701 (2.33)	0.767 (2.52)	0.827 (2.71)	0.737 (2.42)	0.728 (2.39)	0.701 (2.30)
10	0.519 (1.70)	0.523 (1.72)	0.529 (1.74)	0.520 (1.71)	0.522 (1.71)	0.524 (1.72)
11	0.655 (2.15)	0.672 (2.20)	0.676 (2.22)	0.667 (2.19)	0.667 (2.19)	0.665 (2.18)
12	0.510 (1.67)	0.503 (1.65)	0.499 (1.64)	0.506 (1.66)	0.513 (1.68)	0.519 (1.70)
13	0.615 (2.02)	0.625 (2.05)	0.631 (2.07)	0.620 (2.03)	0.618 (2.03)	0.615 (2.02)
14	0.487 (1.60)	0.490 (1.61)	0.497 (1.63)	0.488 (1.60)	0.487 (1.60)	0.487 (1.60)
15	1.420 (4.66)	1.405 (4.61)	1.405 (4.61)	1.419 (4.66)	1.429 (4.69)	1.438 (4.72)
16	1.184 (3.88)	1.177 (3.86)	1.210 (3.97)	1.190 (3.90)	1.187 (3.89)	1.191 (3.91)
17	0.359 (1.18)	0.463 (1.52)	0.483 (1.58)	0.423 (1.39)	0.413 (1.35)	0.394 (1.29)
18	0.520 (1.71)	0.538 (1.77)	0.546 (1.79)	0.531 (1.74)	0.531 (1.74)	0.530 (1.74)
19	0.552 (1.81)	0.556 (1.82)	0.551 (1.81)	0.552 (1.81)	0.554 (1.82)	0.556 (1.82)
20	0.426 (1.40)	0.417 (1.37)	0.413 (1.35)	0.421 (1.38)	0.426 (1.40)	0.431 (1.41)
21	0.870 (2.85)	0.913 (3.00)	0.929 (3.05)	9.898 (32.47)	0.893 (2.93)	0.887 (2.91)
22	1.428 (4.69)	1.404 (4.61)	1.459 (4.79)	1.434 (4.70)	1.426 (4.68)	1.438 (4.72)
23	1.179 (3.87)	1.169 (3.84)	1.163 (3.82)	1.178 (3.86)	1.182 (3.88)	1.183 (3.88)
24	0.488 (1.60)	0.506 (1.66)	0.504 (1.65)	0.500 (1.64)	0.501 (1.64)	0.501 (1.64)
25	0.367 (1.20)	0.379 (1.24)	0.404 (1.33)	0.365 (1.20)	0.370 (1.21)	0.374 (1.23)
26	1.430 (4.69)	1.432 (4.70)	1.480 (4.86)	1.439 (4.72)	1.421 (4.66)	1.407 (4.62)
27	0.679 (2.23)	0.707 (2.32)	0.705 (2.31)	0.698 (2.29)	0.696 (2.28)	0.695 (2.28)
28	0.439 (1.44)	0.446 (1.46)	0.454 (1.49)	0.442 (1.45)	0.441 (1.45)	0.438 (1.44)
29	0.363 (1.19)	0.503 (1.65)	0.529 (1.74)	0.454 (1.49)	0.442 (1.45)	0.421 (1.38)
30	1.056 (3.46)	1.053 (3.45)	1.054 (3.46)	1.053 (3.45)	1.052 (3.45)	1.054 (3.46)
31	0.619 (2.03)	0.616 (2.02)	0.613 (2.01)	0.618 (2.03)	0.618 (2.03)	0.619 (2.03)
32	0.336 (1.10)	0.341 (1.12)	0.345 (1.13)	0.338 (1.11)	0.335 (1.10)	0.334 (1.10)
33	0.502 (1.65)	0.523 (1.72)	0.534 (1.75)	0.514 (1.69)	0.512 (1.68)	0.509 (1.67)
34	2.177 (7.14)	2.123 (6.97)	2.251 (7.39)	2.156 (7.07)	2.118 (6.95)	2.059 (6.76)
35	1.039 (3.41)	1.031 (3.38)	1.038 (3.41)	1.047 (3.44)	1.057 (3.47)	1.068 (3.50)
36	0.781 (2.56)	0.752 (2.47)	0.774 (2.54)	0.780 (2.56)	0.787 (2.58)	0.801 (2.63)
37	0.751 (2.46)	0.775 (2.54)	0.779 (2.56)	0.767 (2.52)	0.765 (2.51)	0.763 (2.50)
38	0.691 (2.27)	0.686 (2.25)	0.695 (2.28)	0.691 (2.27)	0.694 (2.28)	0.697 (2.29)
39	0.661 (2.17)	0.717 (2.35)	0.754 (2.47)	0.693 (2.27)	0.684 (2.24)	0.668 (2.19)
40	0.448 (1.47)	0.449 (1.47)	0.449 (1.47)	0.450 (1.48)	0.450 (1.48)	0.450 (1.48)
41	0.761 (2.50)	0.767 (2.52)	0.766 (2.51)	0.764 (2.51)	0.763 (2.50)	0.762 (2.50)
42	0.383 (1.26)	0.381 (1.25)	0.380 (1.25)	0.381 (1.25)	0.382 (1.25)	0.382 (1.25)
43	0.331 (1.09)	0.329 (1.08)	0.326 (1.07)	0.330 (1.08)	0.333 (1.09)	0.335 (1.10)
44	0.685 (2.25)	0.673 (2.21)	0.755 (2.48)	0.681 (2.23)	0.689 (2.26)	0.695 (2.28)
45	0.505 (1.66)	0.536 (1.76)	0.548 (1.80)	0.524 (1.72)	0.521 (1.71)	0.516 (1.69)
46	0.385 (1.26)	0.380 (1.25)	0.376 (1.23)	0.382 (1.25)	0.386 (1.27)	0.388 (1.27)
47	0.897 (2.94)	0.883 (2.90)	0.928 (3.04)	0.891 (2.92)	0.891 (2.92)	0.888 (2.91)
48	1.105 (3.63)	1.107 (3.63)	1.118 (3.67)	1.108 (3.64)	1.106 (3.63)	1.106 (3.63)
49	0.752 (2.47)	0.765 (2.51)	0.774 (2.54)	0.760 (2.49)	0.759 (2.49)	0.757 (2.48)
50	0.464 (1.52)	0.452 (1.48)	0.450 (1.48)	0.459 (1.51)	0.465 (1.53)	0.471 (1.55)
51	0.968 (3.18)	1.083 (3.55)	1.120 (3.67)	1.038 (3.41)	1.022 (3.35)	1.003 (3.29)
52	1.946 (6.38)	1.965 (6.45)	2.012 (6.60)	1.966 (6.45)	1.943 (6.37)	1.915 (6.28)

Table 16
Peak Water Levels at Barren Island for 43 Northeaster Storms for ADCIRC Save Station Locations, m (ft), msl

Storm	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
1	0.376 (1.23)	0.395 (1.30)	0.401 (1.32)	0.403 (1.32)	0.387 (1.27)	0.384 (1.26)
2	0.445 (1.46)	0.457 (1.50)	0.468 (1.54)	0.470 (1.54)	0.458 (1.50)	0.452 (1.48)
3	0.898 (2.95)	0.908 (2.98)	0.910 (2.99)	0.912 (2.99)	0.905 (2.97)	0.900 (2.95)
4	0.384 (1.26)	0.471 (1.55)	0.494 (1.62)	0.488 (1.60)	0.433 (1.42)	0.424 (1.39)
5	0.372 (1.22)	0.346 (1.14)	0.329 (1.08)	0.335 (1.10)	0.355 (1.16)	0.376 (1.23)
6	0.860 (2.82)	0.884 (2.90)	0.894 (2.93)	0.892 (2.93)	0.874 (2.87)	0.864 (2.83)
7	0.591 (1.94)	0.635 (2.08)	0.650 (2.13)	0.645 (2.12)	0.615 (2.02)	0.610 (2.00)
8	0.759 (2.49)	0.796 (2.61)	0.813 (2.67)	0.808 (2.65)	0.783 (2.57)	0.769 (2.52)
9	0.265 (0.87)	0.273 (0.90)	0.282 (0.93)	0.278 (0.91)	0.239 (0.78)	0.249 (0.82)
10	0.453 (1.49)	0.486 (1.59)	0.499 (1.64)	0.499 (1.64)	0.479 (1.57)	0.467 (1.53)
11	0.711 (2.33)	0.740 (2.43)	0.753 (2.47)	0.748 (2.45)	0.729 (2.39)	0.718 (2.36)
12	0.688 (2.26)	0.697 (2.29)	0.704 (2.31)	0.708 (2.32)	0.699 (2.29)	0.691 (2.27)
13	0.891 (2.92)	0.854 (2.80)	0.833 (2.73)	0.850 (2.79)	0.879 (2.88)	0.881 (2.89)
14	0.343 (1.13)	0.384 (1.26)	0.393 (1.29)	0.392 (1.29)	0.366 (1.20)	0.361 (1.18)
15	0.608 (1.99)	0.633 (2.08)	0.642 (2.11)	0.639 (2.10)	0.622 (2.04)	0.613 (2.01)
16	0.594 (1.95)	0.621 (2.04)	0.634 (2.08)	0.636 (2.09)	0.615 (2.02)	0.603 (1.98)
17	0.518 (1.70)	0.541 (1.77)	0.550 (1.80)	0.546 (1.79)	0.530 (1.74)	0.521 (1.71)
18	0.586 (1.92)	0.593 (1.95)	0.593 (1.95)	0.594 (1.95)	0.590 (1.94)	0.586 (1.92)
19	0.529 (1.74)	0.546 (1.79)	0.553 (1.81)	0.551 (1.81)	0.538 (1.77)	0.533 (1.75)
20	0.861 (2.82)	0.832 (2.73)	0.815 (2.67)	0.823 (2.70)	0.843 (2.77)	0.860 (2.82)
21	0.560 (1.84)	0.592 (1.94)	0.605 (1.98)	0.597 (1.96)	0.579 (1.90)	0.569 (1.87)
22	0.461 (1.51)	0.512 (1.68)	0.528 (1.73)	0.526 (1.73)	0.486 (1.59)	0.483 (1.58)
23	0.255 (0.84)	0.321 (1.05)	0.335 (1.10)	0.337 (1.11)	0.310 (1.02)	0.291 (0.95)
24	0.892 (2.93)	0.907 (2.98)	0.915 (3.00)	0.914 (3.00)	0.896 (2.94)	0.889 (2.92)
25	0.892 (2.93)	0.902 (2.96)	0.906 (2.97)	0.910 (2.99)	0.903 (2.96)	0.892 (2.93)
26	0.299 (0.98)	0.322 (1.06)	0.324 (1.06)	0.327 (1.07)	0.317 (1.04)	0.311 (1.02)
27	0.512 (1.68)	0.546 (1.79)	0.559 (1.83)	0.559 (1.83)	0.537 (1.76)	0.524 (1.72)
28	0.552 (1.81)	0.589 (1.93)	0.602 (1.98)	0.603 (1.98)	0.577 (1.89)	0.568 (1.86)
29	0.465 (1.53)	0.476 (1.56)	0.482 (1.58)	0.484 (1.59)	0.468 (1.54)	0.470 (1.54)
30	0.585 (1.92)	0.594 (1.95)	0.594 (1.95)	0.594 (1.95)	0.588 (1.93)	0.587 (1.93)
31	0.407 (1.34)	0.426 (1.40)	0.436 (1.43)	0.447 (1.47)	0.431 (1.41)	0.418 (1.37)
32	0.314 (1.03)	0.374 (1.23)	0.390 (1.28)	0.386 (1.27)	0.354 (1.16)	0.338 (1.11)
33	0.749 (2.46)	0.733 (2.40)	0.725 (2.38)	0.735 (2.41)	0.749 (2.46)	0.751 (2.46)
34	0.432 (1.42)	0.453 (1.49)	0.457 (1.50)	0.459 (1.51)	0.447 (1.47)	0.438 (1.44)
35	0.564 (1.85)	0.560 (1.84)	0.562 (1.84)	0.566 (1.86)	0.560 (1.84)	0.567 (1.86)
36	0.554 (1.82)	0.556 (1.82)	0.567 (1.86)	0.568 (1.86)	0.552 (1.81)	0.549 (1.80)
37	0.420 (1.38)	0.425 (1.39)	0.428 (1.40)	0.432 (1.42)	0.423 (1.39)	0.424 (1.39)
38	0.690 (2.26)	0.698 (2.29)	0.700 (2.30)	0.705 (2.31)	0.698 (2.29)	0.694 (2.28)
39	0.460 (1.51)	0.487 (1.60)	0.498 (1.63)	0.497 (1.63)	0.472 (1.55)	0.469 (1.54)
40	0.662 (2.17)	0.658 (2.16)	0.653 (2.14)	0.660 (2.17)	0.662 (2.17)	0.659 (2.16)
41	0.588 (1.93)	0.593 (1.95)	0.595 (1.95)	0.599 (1.97)	0.597 (1.96)	0.593 (1.95)
42	0.606 (1.99)	0.698 (2.29)	0.702 (2.30)	0.705 (2.31)	0.698 (2.29)	0.691 (2.27)
43	0.490 (1.61)	0.506 (1.66)	0.514 (1.69)	0.513 (1.68)	0.499 (1.64)	0.494 (1.62)

Table 17
Peak Water Levels at James Island for 43 Northeaster Storms for ADCIRC Save Station Locations, m (ft), msl

Storm	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
1	0.423 (1.39)	0.420 (1.38)	0.417 (1.37)	0.414 (1.36)	0.418 (1.37)	0.431 (1.41)
2	0.469 (1.54)	0.466 (1.53)	0.466 (1.53)	0.463 (1.52)	0.459 (1.51)	0.479 (1.57)
3	0.919 (3.02)	0.918 (3.01)	0.915 (3.00)	0.911 (2.99)	0.909 (2.98)	0.919 (3.02)
4	0.485 (1.59)	0.479 (1.57)	0.476 (1.56)	0.474 (1.56)	0.482 (1.58)	0.510 (1.67)
5	0.367 (1.20)	0.353 (1.16)	0.344 (1.13)	0.339 (1.11)	0.367 (1.20)	0.382 (1.25)
6	0.887 (2.91)	0.891 (2.92)	0.891 (2.92)	0.888 (2.91)	0.878 (2.88)	0.887 (2.91)
7	0.646 (2.12)	0.640 (2.10)	0.638 (2.09)	0.633 (2.08)	0.637 (2.09)	0.664 (2.18)
8	0.798 (2.62)	0.798 (2.62)	0.797 (2.61)	0.794 (2.60)	0.784 (2.57)	0.805 (2.64)
9	0.278 (0.91)	0.264 (0.87)	0.259 (0.85)	0.256 (0.84)	0.284 (0.93)	0.303 (0.99)
10	0.514 (1.69)	0.507 (1.66)	0.505 (1.66)	0.501 (1.64)	0.498 (1.63)	0.526 (1.73)
11	0.752 (2.47)	0.750 (2.46)	0.747 (2.45)	0.742 (2.43)	0.735 (2.41)	0.756 (2.48)
12	0.710 (2.33)	0.707 (2.32)	0.703 (2.31)	0.697 (2.29)	0.697 (2.29)	0.714 (2.34)
13	0.885 (2.90)	0.871 (2.86)	0.864 (2.83)	0.857 (2.81)	0.860 (2.82)	0.876 (2.87)
14	0.409 (1.34)	0.401 (1.32)	0.396 (1.30)	0.393 (1.29)	0.396 (1.30)	0.419 (1.37)
15	0.660 (2.17)	0.659 (2.16)	0.657 (2.16)	0.654 (2.15)	0.647 (2.12)	0.664 (2.18)
16	0.636 (2.09)	0.630 (2.07)	0.629 (2.06)	0.627 (2.06)	0.627 (2.06)	0.649 (2.13)
17	0.565 (1.85)	0.565 (1.85)	0.562 (1.84)	0.557 (1.83)	0.551 (1.81)	0.569 (1.87)
18	0.622 (2.04)	0.618 (2.03)	0.614 (2.01)	0.608 (1.99)	0.609 (2.00)	0.624 (2.05)
19	0.565 (1.85)	0.562 (1.84)	0.558 (1.83)	0.554 (1.82)	0.549 (1.80)	0.571 (1.87)
20	0.865 (2.84)	0.849 (2.79)	0.841 (2.76)	0.837 (2.75)	0.867 (2.84)	0.883 (2.90)
21	0.627 (2.06)	0.619 (2.03)	0.612 (2.01)	0.605 (1.98)	0.605 (1.98)	0.641 (2.10)
22	0.524 (1.72)	0.512 (1.68)	0.511 (1.68)	0.510 (1.67)	0.514 (1.69)	0.541 (1.77)
23	0.325 (1.07)	0.315 (1.03)	0.306 (1.00)	0.300 (0.98)	0.315 (1.03)	0.336 (1.10)
24	0.934 (3.06)	0.937 (3.07)	0.934 (3.06)	0.932 (3.06)	0.923 (3.03)	0.929 (3.05)
25	0.916 (3.01)	0.913 (3.00)	0.912 (2.99)	0.909 (2.98)	0.906 (2.97)	0.912 (2.99)
26	0.355 (1.16)	0.351 (1.15)	0.346 (1.14)	0.341 (1.12)	0.348 (1.14)	0.362 (1.19)
27	0.567 (1.86)	0.564 (1.85)	0.562 (1.84)	0.558 (1.83)	0.557 (1.83)	0.576 (1.89)
28	0.606 (1.99)	0.603 (1.98)	0.601 (1.97)	0.597 (1.96)	0.599 (1.97)	0.622 (2.04)
29	0.493 (1.62)	0.486 (1.59)	0.483 (1.58)	0.481 (1.58)	0.489 (1.60)	0.503 (1.65)
30	0.627 (2.06)	0.621 (2.04)	0.613 (2.01)	0.606 (1.99)	0.606 (1.99)	0.630 (2.07)
31	0.447 (1.47)	0.442 (1.45)	0.438 (1.44)	0.434 (1.42)	0.439 (1.44)	0.453 (1.49)
32	0.393 (1.29)	0.389 (1.28)	0.386 (1.27)	0.383 (1.26)	0.382 (1.25)	0.405 (1.33)
33	0.739 (2.42)	0.729 (2.39)	0.723 (2.37)	0.719 (2.36)	0.737 (2.42)	0.749 (2.46)
34	0.486 (1.59)	0.480 (1.57)	0.477 (1.56)	0.474 (1.56)	0.473 (1.55)	0.492 (1.61)
35	0.568 (1.86)	0.568 (1.86)	0.566 (1.86)	0.561 (1.84)	0.562 (1.84)	0.574 (1.88)
36	0.594 (1.95)	0.588 (1.93)	0.580 (1.90)	0.575 (1.89)	0.578 (1.90)	0.596 (1.96)
37	0.414 (1.36)	0.408 (1.34)	0.404 (1.33)	0.401 (1.32)	0.411 (1.35)	0.423 (1.39)
38	0.719 (2.36)	0.711 (2.33)	0.705 (2.31)	0.704 (2.31)	0.706 (2.32)	0.725 (2.38)
39	0.521 (1.71)	0.511 (1.68)	0.509 (1.67)	0.505 (1.66)	0.505 (1.66)	0.534 (1.75)
40	0.676 (2.22)	0.673 (2.21)	0.669 (2.19)	0.664 (2.18)	0.665 (2.18)	0.671 (2.20)
41	0.615 (2.02)	0.607 (1.99)	0.604 (1.98)	0.603 (1.98)	0.606 (1.99)	0.616 (2.02)
42	0.716 (2.35)	0.710 (2.33)	0.709 (2.33)	0.707 (2.32)	0.707 (2.32)	0.725 (2.38)
43	0.531 (1.74)	0.526 (1.73)	0.522 (1.71)	0.516 (1.69)	0.516 (1.69)	0.540 (1.77)

Table 18
Peak Water Levels at Poplar Island for 43 Northeaster Storms for ADCIRC Save Station Locations, m (ft), msl

Storm	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
1	0.377 (1.24)	0.374 (1.23)	0.371 (1.22)	0.370 (1.21)	0.373 (1.22)	0.372 (1.22)
2	0.451 (1.48)	0.451 (1.48)	0.449 (1.47)	0.448 (1.47)	0.450 (1.48)	0.449 (1.47)
3	0.922 (3.02)	0.921 (3.02)	0.921 (3.02)	0.922 (3.02)	0.922 (3.02)	0.920 (3.02)
4	0.396 (1.30)	0.382 (1.25)	0.373 (1.22)	0.370 (1.21)	0.377 (1.24)	0.375 (1.23)
5	0.236 (0.77)	0.238 (0.78)	0.239 (0.78)	0.240 (0.79)	0.239 (0.78)	0.241 (0.79)
6	0.885 (2.90)	0.885 (2.90)	0.887 (2.91)	0.888 (2.91)	0.889 (2.92)	0.888 (2.91)
7	0.502 (1.65)	0.493 (1.62)	0.485 (1.59)	0.483 (1.58)	0.489 (1.60)	0.487 (1.60)
8	0.760 (2.49)	0.754 (2.47)	0.751 (2.46)	0.753 (2.47)	0.757 (2.48)	0.754 (2.47)
9	0.226 (0.74)	0.230 (0.75)	0.231 (0.76)	0.232 (0.76)	0.228 (0.75)	0.230 (0.75)
10	0.484 (1.59)	0.480 (1.57)	0.478 (1.57)	0.478 (1.57)	0.481 (1.58)	0.479 (1.57)
11	0.733 (2.40)	0.729 (2.39)	0.728 (2.39)	0.730 (2.40)	0.732 (2.40)	0.731 (2.40)
12	0.684 (2.24)	0.681 (2.23)	0.678 (2.22)	0.679 (2.23)	0.680 (2.23)	0.679 (2.23)
13	0.949 (3.11)	0.946 (3.10)	0.945 (3.10)	0.950 (3.12)	0.949 (3.11)	0.952 (3.12)
14	0.375 (1.23)	0.371 (1.22)	0.368 (1.21)	0.368 (1.21)	0.371 (1.22)	0.370 (1.21)
15	0.644 (2.11)	0.642 (2.11)	0.642 (2.11)	0.643 (2.11)	0.645 (2.12)	0.644 (2.11)
16	0.595 (1.95)	0.589 (1.93)	0.583 (1.91)	0.583 (1.91)	0.587 (1.93)	0.586 (1.92)
17	0.555 (1.82)	0.556 (1.82)	0.558 (1.83)	0.558 (1.83)	0.560 (1.84)	0.558 (1.83)
18	0.632 (2.07)	0.634 (2.08)	0.634 (2.08)	0.634 (2.08)	0.635 (2.08)	0.634 (2.08)
19	0.440 (1.44)	0.436 (1.43)	0.434 (1.42)	0.434 (1.42)	0.436 (1.43)	0.434 (1.42)
20	0.748 (2.45)	0.753 (2.47)	0.750 (2.46)	0.744 (2.44)	0.736 (2.41)	0.738 (2.42)
21	0.598 (1.96)	0.596 (1.96)	0.596 (1.96)	0.598 (1.96)	0.600 (1.97)	0.598 (1.96)
22	0.463 (1.52)	0.453 (1.49)	0.445 (1.46)	0.443 (1.45)	0.450 (1.48)	0.450 (1.48)
23	0.296 (0.97)	0.292 (0.96)	0.287 (0.94)	0.287 (0.94)	0.291 (0.95)	0.290 (0.95)
24	0.959 (3.15)	0.963 (3.16)	0.965 (3.17)	0.968 (3.18)	0.970 (3.18)	0.972 (3.19)
25	0.936 (3.07)	0.938 (3.08)	0.940 (3.08)	0.941 (3.09)	0.941 (3.09)	0.941 (3.09)
26	0.250 (0.82)	0.250 (0.82)	0.247 (0.81)	0.247 (0.81)	0.249 (0.82)	0.247 (0.81)
27	0.543 (1.78)	0.537 (1.76)	0.534 (1.75)	0.534 (1.75)	0.538 (1.77)	0.536 (1.76)
28	0.463 (1.52)	0.456 (1.50)	0.449 (1.47)	0.448 (1.47)	0.453 (1.49)	0.452 (1.48)
29	0.481 (1.58)	0.479 (1.57)	0.478 (1.57)	0.479 (1.57)	0.480 (1.57)	0.480 (1.57)
30	0.621 (2.04)	0.621 (2.04)	0.621 (2.04)	0.622 (2.04)	0.623 (2.04)	0.622 (2.04)
31	0.441 (1.45)	0.440 (1.44)	0.439 (1.44)	0.438 (1.44)	0.440 (1.44)	0.440 (1.44)
32	0.442 (1.45)	0.433 (1.42)	0.425 (1.39)	0.424 (1.39)	0.430 (1.41)	0.429 (1.41)
33	0.594 (1.95)	0.590 (1.94)	0.584 (1.92)	0.582 (1.91)	0.584 (1.92)	0.586 (1.92)
34	0.479 (1.57)	0.477 (1.56)	0.477 (1.56)	0.477 (1.56)	0.479 (1.57)	0.477 (1.56)
35	0.548 (1.80)	0.545 (1.79)	0.546 (1.79)	0.548 (1.80)	0.550 (1.80)	0.548 (1.80)
36	0.598 (1.96)	0.599 (1.97)	0.599 (1.97)	0.600 (1.97)	0.600 (1.97)	0.600 (1.97)
37	0.371 (1.22)	0.368 (1.21)	0.365 (1.20)	0.364 (1.19)	0.366 (1.20)	0.367 (1.20)
38	0.706 (2.32)	0.704 (2.31)	0.703 (2.31)	0.702 (2.30)	0.703 (2.31)	0.702 (2.30)
39	0.485 (1.59)	0.482 (1.58)	0.482 (1.58)	0.482 (1.58)	0.483 (1.58)	0.482 (1.58)
40	0.688 (2.26)	0.691 (2.27)	0.691 (2.27)	0.693 (2.27)	0.693 (2.27)	0.693 (2.27)
41	0.611 (2.00)	0.611 (2.00)	0.611 (2.00)	0.612 (2.01)	0.613 (2.01)	0.612 (2.01)
42	0.691 (2.27)	0.688 (2.26)	0.686 (2.25)	0.686 (2.25)	0.689 (2.26)	0.688 (2.26)
43	0.522 (1.71)	0.521 (1.71)	0.519 (1.70)	0.518 (1.70)	0.519 (1.70)	0.518 (1.70)

(Sheet 1 of 2)

Table 18 (Continued)
Peak Water Levels at Poplar Island for 43 Northeaster Storms for ADCIRC Save Station Locations, m (ft), msl

Storm	Station 7	Station 8	Station 9	Station 10	Station 11	Station 12
1	0.370 (1.21)	0.379 (1.24)	0.377 (1.24)	0.375 (1.23)	0.376 (1.23)	0.376 (1.23)
2	0.440 (1.44)	0.460 (1.51)	0.465 (1.53)	0.451 (1.48)	0.450 (1.48)	0.448 (1.47)
3	0.918 (3.01)	0.927 (3.04)	0.931 (3.05)	0.923 (3.03)	0.923 (3.03)	0.922 (3.02)
4	0.365 (1.20)	0.419 (1.37)	0.411 (1.35)	0.401 (1.32)	0.402 (1.32)	0.399 (1.31)
5	0.243 (0.80)	0.232 (0.76)	0.214 (0.70)	0.234 (0.77)	0.237 (0.78)	0.240 (0.79)
6	0.883 (2.90)	0.894 (2.93)	0.901 (2.96)	0.890 (2.92)	0.888 (2.91)	0.886 (2.91)
7	0.481 (1.58)	0.511 (1.68)	0.512 (1.68)	0.501 (1.64)	0.502 (1.65)	0.502 (1.65)
8	0.749 (2.46)	0.773 (2.54)	0.778 (2.55)	0.765 (2.51)	0.763 (2.50)	0.761 (2.50)
9	0.220 (0.72)	0.206 (0.68)	0.186 (0.61)	0.211 (0.69)	0.218 (0.72)	0.229 (0.75)
10	0.470 (1.54)	0.484 (1.59)	0.487 (1.60)	0.479 (1.57)	0.481 (1.58)	0.483 (1.58)
11	0.727 (2.39)	0.744 (2.44)	0.749 (2.46)	0.738 (2.42)	0.735 (2.41)	0.733 (2.40)
12	0.674 (2.21)	0.687 (2.25)	0.694 (2.28)	0.683 (2.24)	0.682 (2.24)	0.683 (2.24)
13	0.938 (3.08)	0.927 (3.04)	0.928 (3.04)	0.937 (3.07)	0.943 (3.09)	0.950 (3.12)
14	0.361 (1.18)	0.373 (1.22)	0.368 (1.21)	0.369 (1.21)	0.373 (1.22)	0.374 (1.23)
15	0.640 (2.10)	0.656 (2.15)	0.663 (2.18)	0.651 (2.14)	0.650 (2.13)	0.647 (2.12)
16	0.583 (1.91)	0.603 (1.98)	0.602 (1.98)	0.596 (1.96)	0.595 (1.95)	0.595 (1.95)
17	0.550 (1.80)	0.561 (1.84)	0.566 (1.86)	0.556 (1.82)	0.555 (1.82)	0.555 (1.82)
18	0.628 (2.06)	0.630 (2.07)	0.631 (2.07)	0.628 (2.06)	0.629 (2.06)	0.630 (2.07)
19	0.429 (1.41)	0.446 (1.46)	0.447 (1.47)	0.439 (1.44)	0.441 (1.45)	0.442 (1.45)
20	0.745 (2.44)	0.734 (2.41)	0.714 (2.34)	0.738 (2.42)	0.742 (2.43)	0.750 (2.46)
21	0.589 (1.93)	0.604 (1.98)	0.609 (2.00)	0.598 (1.96)	0.598 (1.96)	0.598 (1.96)
22	0.447 (1.47)	0.476 (1.56)	0.472 (1.55)	0.466 (1.53)	0.467 (1.53)	0.465 (1.53)
23	0.281 (0.92)	0.288 (0.94)	0.277 (0.91)	0.286 (0.94)	0.293 (0.96)	0.295 (0.97)
24	0.966 (3.17)	0.972 (3.19)	0.980 (3.22)	0.969 (3.18)	0.966 (3.17)	0.962 (3.16)
25	0.936 (3.07)	0.937 (3.07)	0.939 (3.08)	0.936 (3.07)	0.936 (3.07)	0.937 (3.07)
26	0.239 (0.78)	0.238 (0.78)	0.230 (0.75)	0.239 (0.78)	0.244 (0.80)	0.248 (0.81)
27	0.530 (1.74)	0.546 (1.79)	0.546 (1.79)	0.540 (1.77)	0.542 (1.78)	0.543 (1.78)
28	0.447 (1.47)	0.467 (1.53)	0.464 (1.52)	0.460 (1.51)	0.462 (1.52)	0.464 (1.52)
29	0.482 (1.58)	0.487 (1.60)	0.483 (1.58)	0.484 (1.59)	0.483 (1.58)	0.483 (1.58)
30	0.618 (2.03)	0.623 (2.04)	0.626 (2.05)	0.621 (2.04)	0.621 (2.04)	0.622 (2.04)
31	0.434 (1.42)	0.431 (1.41)	0.426 (1.40)	0.432 (1.42)	0.435 (1.43)	0.439 (1.44)
32	0.426 (1.40	0.458 (1.50)	0.456 (1.50)	0.447 (1.47)	0.447 (1.47)	0.445 (1.46)
33	0.587 (1.93)	0.585 (1.92)	0.572 (1.88)	0.586 (1.92)	0.590 (1.94)	0.595 (1.95)
34	0.469 (1.54)	0.474 (1.56)	0.473 (1.55)	0.472 (1.55)	0.475 (1.56)	0.478 (1.57)
35	0.542 (1.78)	0.569 (1.87)	0.578 (1.90)	0.559 (1.83)	0.556 (1.82)	0.553 (1.81)
36	0.592 (1.94)	0.588 (1.93)	0.590 (1.94)	0.589 (1.93)	0.591 (1.94)	0.594 (1.95)
37	0.363 (1.19)	0.369 (1.21)	0.365 (1.20)	0.365 (1.20)	0.368 (1.21)	0.371 (1.22)
38	0.698 (2.29)	0.702 (2.30)	0.701 (2.30)	0.700 (2.30)	0.702 (2.30)	0.705 (2.31)
39	0.475 (1.56)	0.487 (1.60)	0.485 (1.59)	0.481 (1.58)	0.484 (1.59)	0.485 (1.59)
40	0.680 (2.23)	0.677 (2.22)	0.681 (2.23)	0.679 (2.23)	0.682 (2.24)	0.684 (2.24)
41	0.606 (1.99)	0.605 (1.98)	0.605 (1.98)	0.605 (1.98)	0.607 (1.99)	0.601 (2.00)
42	0.685 (2.25)	0.695 (2.28)	0.695 (2.28)	0.691 (2.27)	0.691 (2.27)	0.691 (2.27)
43	0.511 (1.68)	0.512 (1.68)	0.511 (1.68)	0.511 (1.68)	0.515 (1.69)	0.519 (1.70)

(Sheet 2 of 2)

4 Wave Modeling[1]

Life-cycle analysis of the disposal island designs for Poplar, James, and Barren Islands requires wave parameters around each island for a variety of storm conditions. Past studies have estimated waves for the study sites based on straight-line fetch wave generation with no near-island transformation. Straight-line fetch methods can underestimate wave heights and provide inaccurate wave direction in long-narrow water bodies, such as Chesapeake Bay (Smith 1991). Larger waves may be generated by a component of the wind down the axis of the bay than in the direct wind direction. Neglecting wave transformation across shallow areas on boundaries of the bay, where the islands are located, can also lead to errors in local wave parameter distributions due to neglect of refraction, shoaling, and breaking processes.

The data processing and modeling steps required to convert wind and water level data into life cycle analysis inputs appears in Figure 20. Winds were carefully validated and, in the case of the AES-40 hindcast winds, adjusted to compensate for reduced over-water drag. Three steps were required for wave modeling to produce the life cycle inputs, including a restricted-fetch wave growth model (Smith 1991) in the Automated Coastal Engineering System (ACES), application of a parametric spectral shape in the Surface Water Modeling system (SMS), and the spectral transformation model STWAVE (Smith et al. 2001). This chapter presents a detailed description of this approach and is broken into four sections: winds for wave modeling, wave generation modeling, wave transformation modeling, model results, and summary.

Winds for Wave Modeling

Wind histories from the selected hurricane and northeast storm events were used to generate open-bay wave estimates for transformation to shoreline locations at each study island. Two types of wind fields were used for the circulation modeling discussed in Chapter 3. For Northeasters, winds fields were extracted from the AES-40 hindcast, and for hurricanes, winds fields were generated using the PBL model (details are provided in Chapter 2). For circulation modeling, the large-scale wind fields are generally of greatest importance, but for wave modeling in an enclosed area, the local winds are of greater significance.

[1] Written by Jeffrey Hanson and Jane McKee Smith

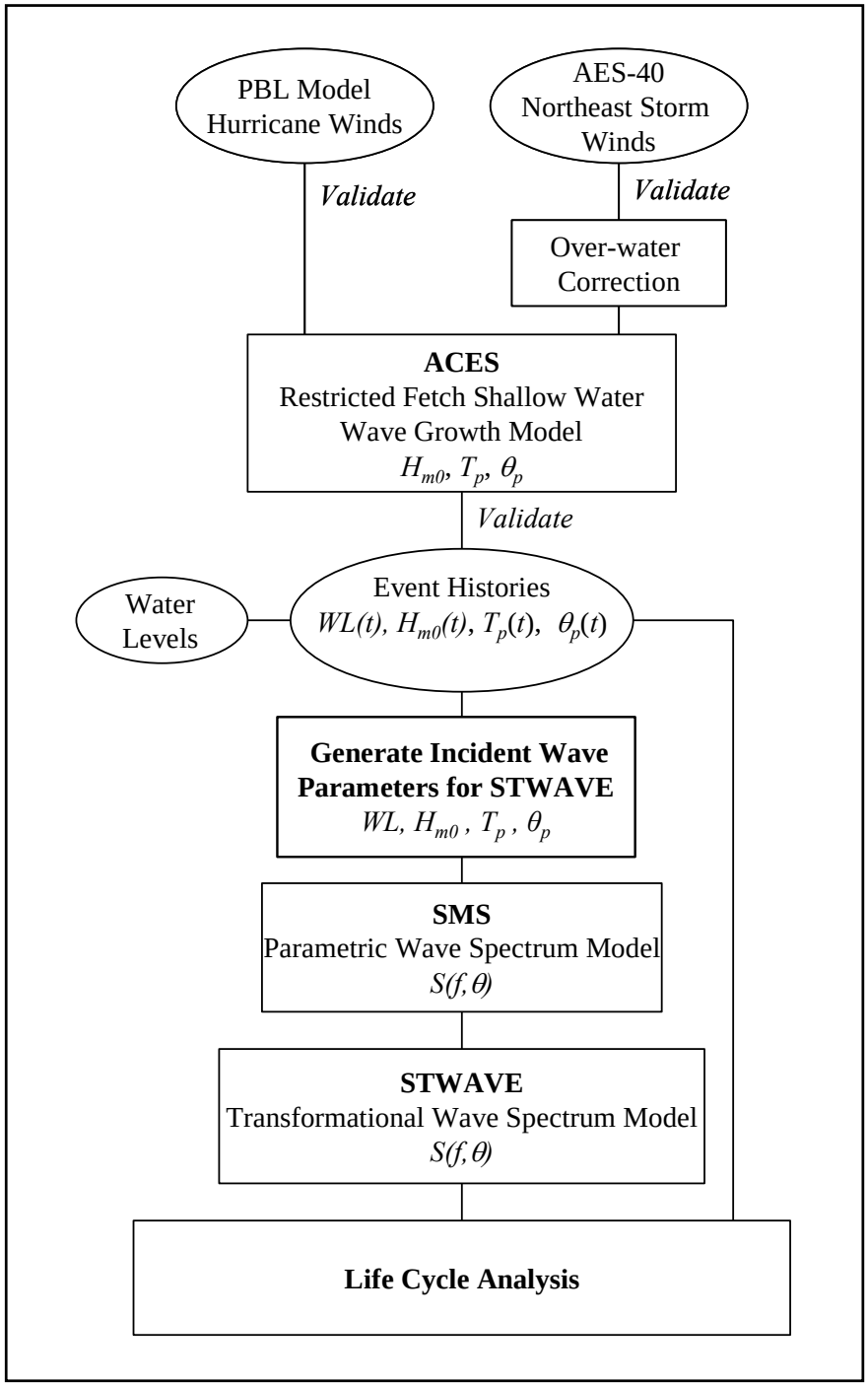


Figure 20. Wind and wave data processing flow chart.

As with any modeling study, validation of input winds is essential to ensure optimal model performance. Both the PBL and AES-40 winds were compared with measurements from observation stations maintained by the National Climatic Data Center (NCDC), National Data Buoy Center (NDBC), and the National Ocean Service (NOS). Locations of the most relevant stations and the three wind and wave prediction sites are provided in Figure 21. Also included is the location of an NOS Acoustic Doppler

Current Profiler (ADCP) deployment that was used to validate the wave estimates (see the following section). Most of the meteorological stations in Figure 21 are in partially- or fully-sheltered environments and not suitable for evaluation of wind forcing conditions in the open bay. The NDBC station at Thomas Point (TPLM2), located in an open bay setting at 38°53'54" N; 76°26'12" W, provides the best location to access wind fields for open-bay wave growth modeling. The longest meteorological time-series in the region is from the NCDC Baltimore-Washington International (BWI) Station. However, this station is several miles inland and is located 47.6 m (156 ft) above sea level in an open field.

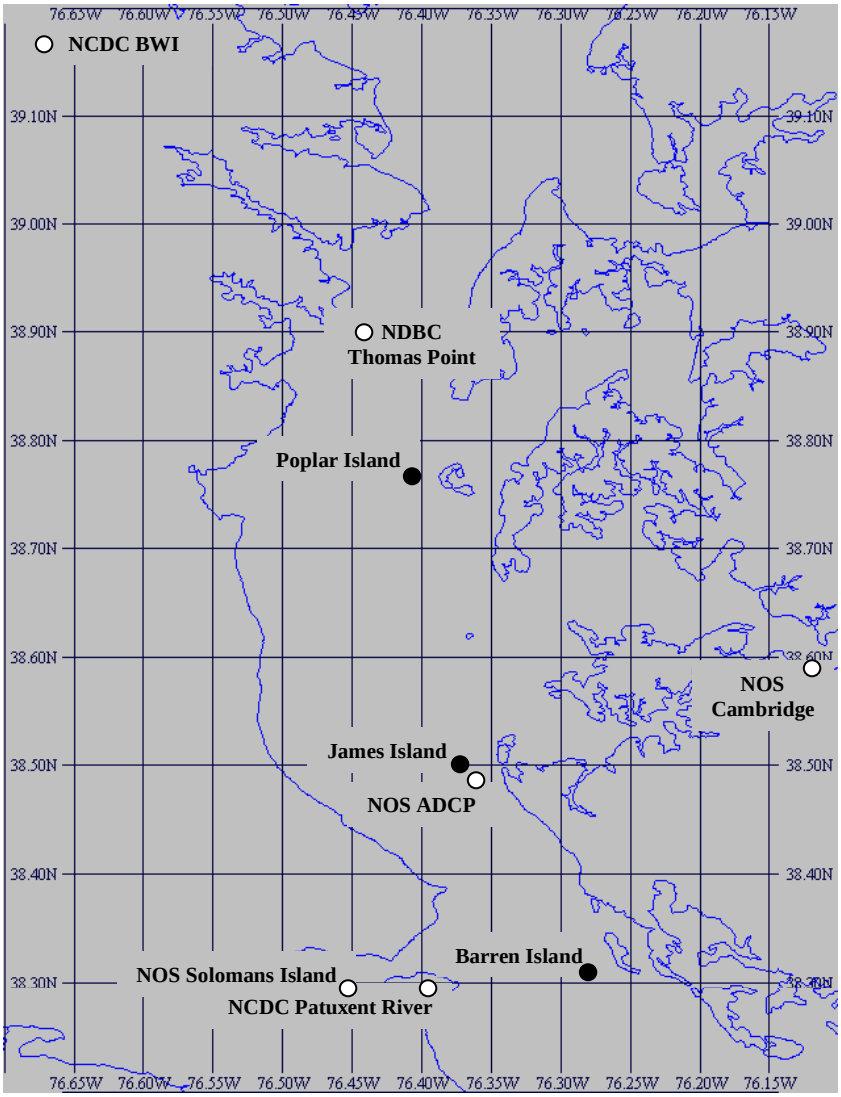
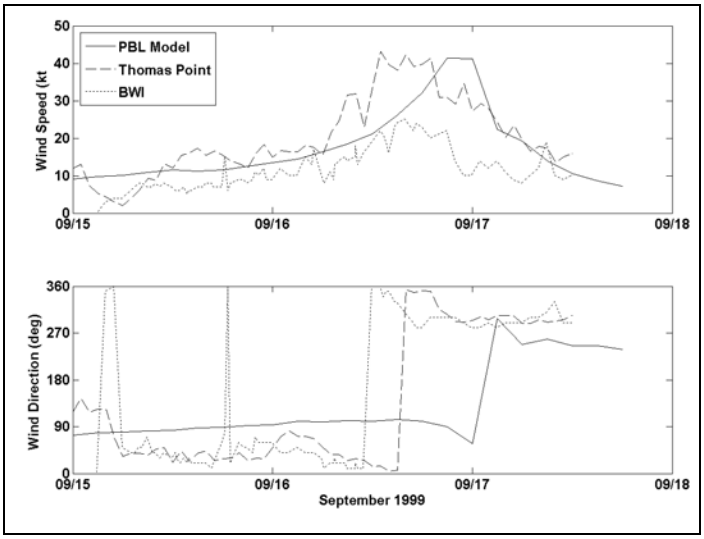


Figure 21. Locations of study islands and weather stations in Chesapeake Bay.

The agreement between wind hindcasts and station measurements was highly variable from storm to storm. Comparisons of PBL model, Thomas Point station, and BWI station wind speed and direction histories during two major hurricanes appear in Figure 22. PBL estimates represent the time and duration of Hurricane Isabel quite well (Figure 22a), although maximum wind speeds are overestimated by approximately 5.1

m/s (10 kt) and wind direction is off by approximately 45 deg. In contrast, the maximum wind speed and wind duration during Hurricane Floyd are matched very well by the PBL winds (Figure 22b), but with an 8-h offset in the time of storm passage and approximately 60 degree offset in wind direction. Wind speeds at the overland BWI station are significantly reduced in strength compared to the open-bay observations. This wind-sheltering trend was also evident at the other stations depicted on Figure 21. Surprisingly, winds from BWI were used in earlier studies to generate wave climatologies at the mid-bay island sites (Kelley et al. 2002; Moffatt & Nichol 2002a, 2002b). Figure 22 suggests the use of winds from a land-based or partially sheltered location for open-bay wave simulations will likely result in a significant underestimation of the actual wave climate.

a. Hurricane Isabel



b. Hurricane Floyd

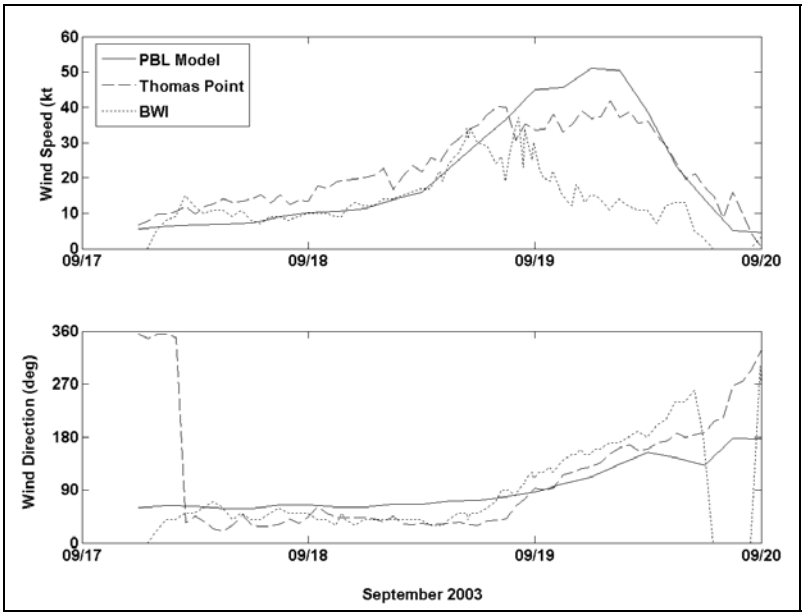


Figure 22. Comparison of PBL hurricane winds with observations. (Wind speeds given in kts, to convert use 0.5144 m/s/kt)

The AES-40 hindcast winds required an over-water adjustment to match northeast storm conditions in the open bay. Comparisons of AES-40 wind speed estimates to Thomas Point measurements during six major northeast storms appear in Figure 23. Hindcast winds show reasonable agreement with observed winds below approximately 8.2 m/s (16 kt). As wind speeds increase above 8.2 m/s (16 kt), hindcast winds depict a linearly increasing negative bias that results in hindcast wind speeds 30 % below the maximum observed winds. One possible explanation for this offset is that a coarse model resolution resulted in the application of a relatively high over-land drag coefficient to the bay region. This bias is removed from the AES-40 hindcast data with the following adjustment factor applied to winds ≥ 8.3 m/s (16.5 kt):

$$U_{10}(\text{adjusted}) = 2.62 \text{ kt} * U_{10}(\text{original}) - 25.33 \text{ kt} \qquad (2)$$

The results of applying Equation 2 to the six northeast storm events discussed above appear in Figure 24. A significant hindcast improvement is realized. A linear least-squares regression through the data results in a slope that is within 10% of unity and a squared regression coefficient of $r^2 = 0.91$. A comparison of the original and adjusted AES-40 winds to Thomas Point observations during two typical northeast storm events appears in Figure 25. The wind directions and adjusted speeds match the mesoscale (day-to-day) variability quite well.

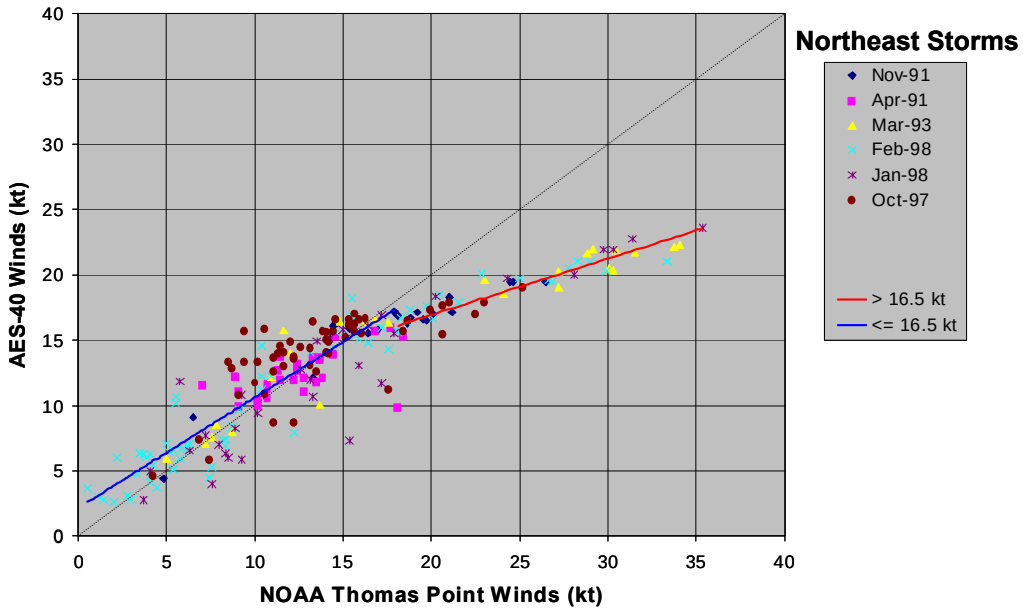


Figure 23. Scatter plot of AES-40 hindcast and Thomas Point station wind speeds during six major northeast storms. A linearly increasing negative hindcast bias is evident at wind speeds above 8.2 m/s (16 kt). (Wind speeds given in kts)

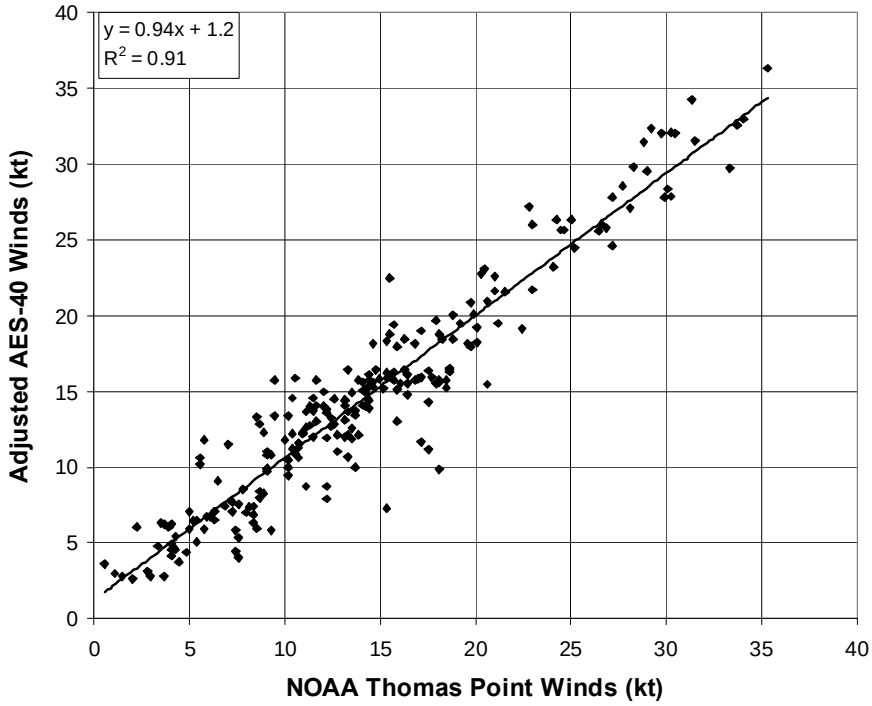


Figure 24. Scatter plot of adjusted AES-40 hindcast winds and Thomas Point measurements during six major northeast storms. Linear adjustment of winds greater than 8.3 m/s (16.5 kt) kt results in a reasonably good match between hindcast and observations. (Wind speeds given in kts)

Winds extracted from the PBL hurricane and adjusted AES-40 northeast storm hindcasts provide reasonable inputs for estimating wave growth in the open bay. Wind forcing histories were generated offshore of each island location in Table 19. The following section addresses the application of these winds to estimating the evolution of surface wave conditions during each hurricane and northeast storm.

Table 19
Offshore Wind and Wave Estimate Locations

Island	Latitude deg min sec	Longitude deg min sec	Approximate Water Depth m (ft)
Poplar	38 46 00 N	76 25 30 W	19.8 (65)
James	38 31 30 N	76 22 30 W	10.1 (33)
Barren W	38 20 00 N	76 17 30 W	15.2 (50)

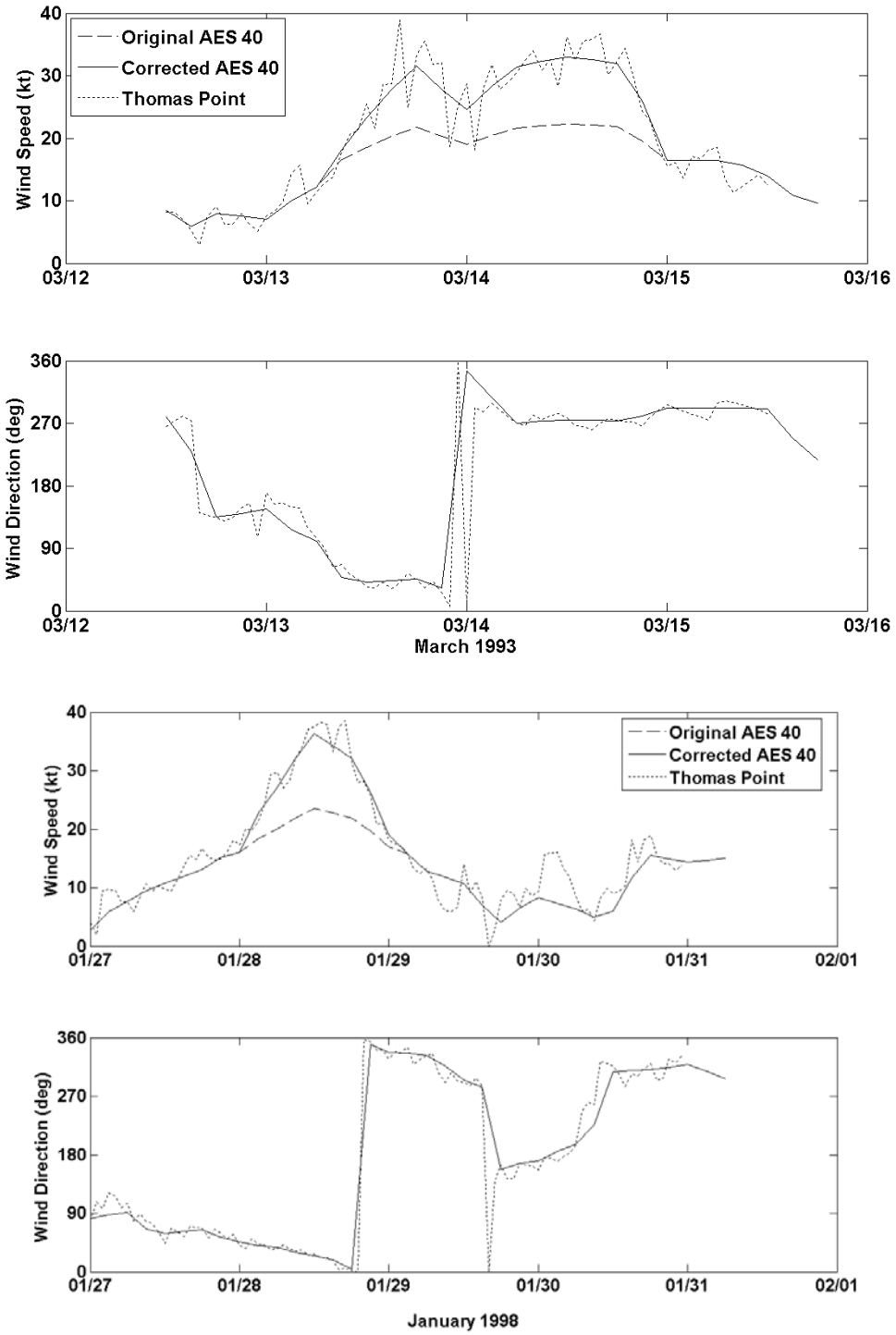


Figure 25. Evolution of original and adjusted AES-40 hindcast winds with observations during two northeast storms. (Wind speeds given in kts)

Wave Generation Modeling

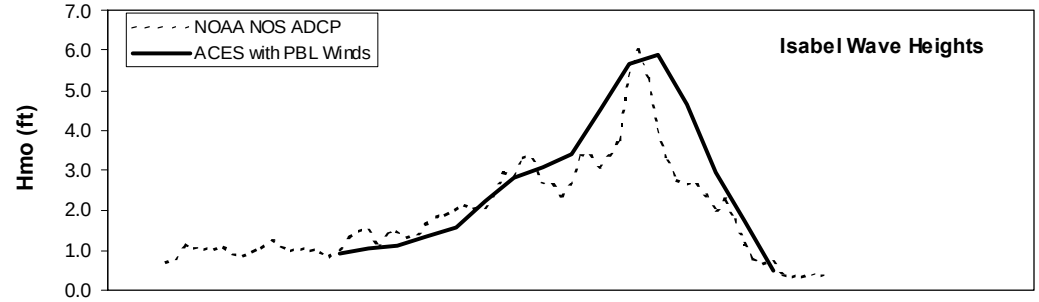
Hurricane and northeast storm wave height (H_{mo}), peak period (T_p) and mean direction (θ_m) estimates were calculated at the 'offshore' locations listed in Table 19 using the narrow-fetch methodology (Smith 1991) contained in ACES (Figure 20). At each site, fetch and average depth information at 10-deg directional increments were extracted from NOAA charts (U.S. Department of Commerce, Bathymetry of Chesapeake Bay, Plates 4 and 8). The resulting fetch and depth values for Poplar, James and Barren Islands appear in Table 20. These fetches were input into ACES, along with the wind speed and direction time history for each of the storms. ACES outputs wave height, peak period, and mean direction.

Although the measurement of fetch is straightforward, the estimation of average depth along a fetch is subjective given the intense bathymetric variability within the bay. Hence, wave measurements collected during Hurricane Isabel by NOAA/NOS[*] were used to calibrate the selection of average depth through optimizing the agreement between ACES wave estimates and measurements at the NOS ADCP site (Figure 21). The results of these comparisons appear in Figure 26. The wave height estimates (Figure 26a) capture the overall duration of the storm and the wave height of 1.8 m (6 ft) at the storm peak. However the duration of high waves around the storm peak are overestimated by several hours. The wave period estimates (Figure 26b) do not match the high variability of the observations but do capture a general trend of increasing periods up to approximately 5.5 s at the peak. Wave direction estimates (Figure 26c) show excellent agreement during the most intense part of the storm with waves coming from the south.

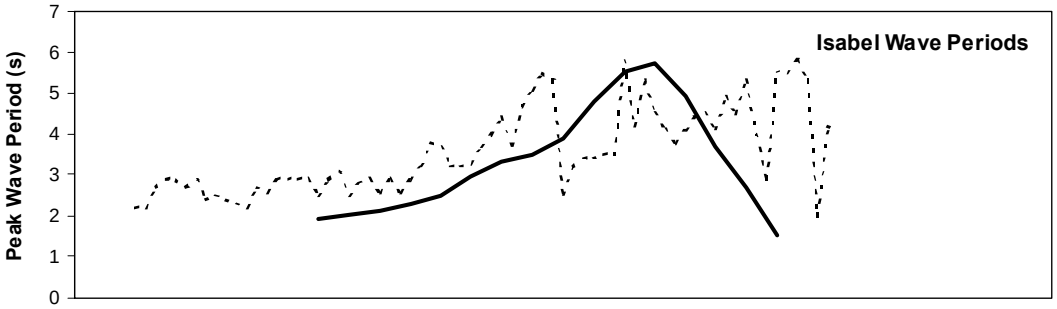
The hurricane and northeast storm water levels described in Chapter 3 were synthesized with the ACES H_{mo}, T_p and θ_m estimates to generate 3-hourly wave and water level history files for each offshore location in Table 19. To reduce the computational demand for numerically simulating the transformation of these waves to various shoreline locations, a series of look-up tables was generated to cover the range of possible conditions at each site. The use of these lookup tables with STWAVE is described in the following section.

[*] ADCP data courtesy of H.H. Shih, Ph. D., P.E., NOAA/NOS, Silver Spring, MD

a. Isabel Wave Heights.



b. Isabel Wave Periods



c. Isabel Wave Directions

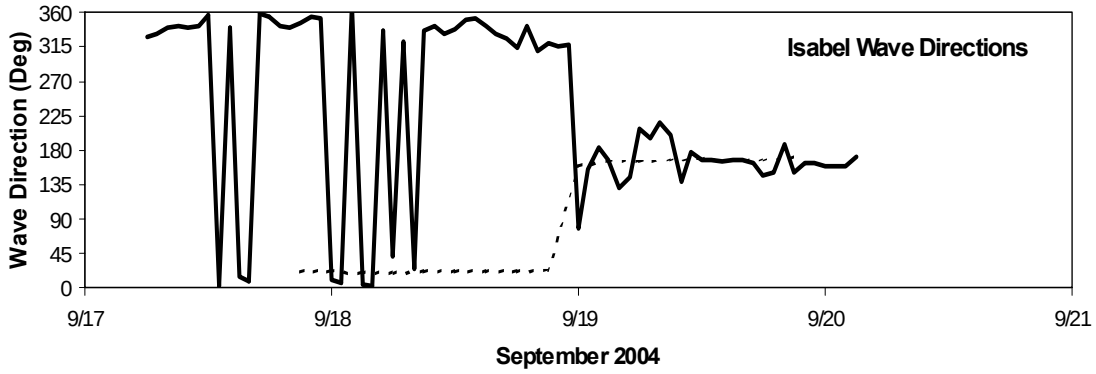


Figure 26. Comparison of NOAA NOS ADCP measurements with ACES wave estimates during Hurricane Isabel. PBL winds were used to drive the ACES estimates. Wave height given in ft).

Table 20
Fetch-Depth Table for ACES Wave Estimates

		Poplar Island		James Island		Barren Island	
Radial	Azimuth	Fetch km (mi)	Depth m (ft)	Fetch km (mi)	Depth m (ft)	Fetch km (mi)	Depth m (ft)
1	0	26 (16)	20 (66)	27 (17)	5 (16)	10 (6)	4 (13)
2	10	56 (35)	20 (66)	18 (11)	6 (20)	6 (4)	4 (13)
3	20	14 (9)	8 (26)	26 (16)	4 (13)	6 (3.5)	3 (10)
4	30	10 (6)	8 (26)	40 (25)	3 (10)	6 (3.5)	3 (10)
5	40	16 (10)	8 (26)	19 (12)	3 (10)	6 (3.5)	3 (10)
6	50	16 (10)	6 (20)	8 (5)	3 (10)	6 (3.5)	3 (10)
7	60	11 (7)	6 (20)	10 (6)	3 (10)	6 (3.5)	2 (7)
8	70	6 (4)	5 (16)	10 (6)	3 (10)	2 (1)	1 (3)
9	80	3 (2)	5 (16)	16 (10)	3 (10)	2 (1)	1 (3)
10	90	3 (2)	4 (13)	16 (10)	3 (10)	2 (1)	1 (3)
11	100	3 (2)	3 (10)	8 (5)	3 (10)	2 (1)	1 (3)
12	110	3 (2)	3 (10)	6 (4)	2 (7)	2 (1.5)	1 (3)
13	120	8 (5)	3 (10)	5 (3)	4 (13)	6 (4)	1 (3)
14	130	8 (5)	4 (13)	5 (3)	4 (13)	11 (7)	2 (7)
15	140	10 (6)	7 (23)	6 (4)	4 (13)	26 (16)	3 (10)
16	150	24 (15)	8 (26)	19 (12)	4 (13)	40 (25)	4 (13)
17	160	24 (15)	10 (33)	48 (30)	7 (23)	48 (30)	10 (33)
18	170	32 (20)	14 (46)	80 (50)	9 (30)	80 (50)	25 (82)
19	180	64 (40)	19 (62)	24 (15)	10 (33)	24 (15)	20 (66)
20	190	32 (20)	20 (66)	13 (8)	15 (49)	19 (12)	15 (49)
21	200	24 (15)	19 (62)	13 (8)	16 (52)	18 (11)	15 (49)
22	210	18 (11)	19 (62)	11 (7)	16 (52)	18 (11)	15 (49)
23	220	14 (9)	18 (59)	11 (7)	16 (52)	16 (10)	15 (49)
24	230	13 (8)	15 (49)	11 (7)	16 (52)	16 (10)	15 (49)
25	240	11 (7)	15 (49)	11 (7)	16 (52)	11 (7)	15 (49)
26	250	11 (7)	15 (49)	13 (8)	16 (52)	11 (7)	15 (49)
27	260	13 (8)	15 (49)	13 (8)	16 (52)	14 (9)	15 (49)
28	270	13 (8)	15 (49)	14 (9)	16 (52)	13 (8)	15 (49)
29	280	10 (6)	15 (49)	14 (9)	16 (52)	11 (7)	15 (49)
30	290	10 (6)	15 (49)	16 (10)	16 (52)	11 (7)	15 (49)
31	300	10 (6)	15 (49)	16 (10)	16 (52)	13 (8)	15 (49)
32	310	10 (6)	16 (52)	18 (11)	16 (52)	11 (7)	18 (59)
33	320	11 (7)	17 (56)	21 (13)	16 (52)	26 (16)	21 (69)
34	330	14 (9)	18 (59)	26 (16)	16 (52)	37 (23)	24 (79)
35	340	19 (12)	19 (62)	34 (21)	12 (39)	64 (40)	6 (20)
36	350	19 (12)	20 (66)	45 (28)	7 (23)	11 (7)	5 (16)

Wave Transformation Modeling

Numerical model simulations of wave transformation in Chesapeake Bay were required to provide the spatial and temporal variation of wave parameters around each of the three islands. This section describes the STWAVE model, model inputs, and sample model results. STWAVE was forced with directional wave spectra based on typical wave height, period, and direction combinations resultant from the wave generation modeling documented in the previous section. The simulations include representative tidal levels, which are required to simulate wave dissipation near the islands. The STWAVE simulations transformed waves resulting from northeasters and hurricanes in Chesapeake Bay.

STWAVE Model Description

The numerical model STWAVE (Smith, Sherlock, and Resio 2001) was used to transform waves to the project sites. STWAVE numerically solves the steady-state conservation of spectral action balance along backward-traced wave rays:

$$(C_{ga})_x \frac{\partial}{\partial x}\frac{C_a C_{ga}\cos(\mu-\alpha)E(f,\alpha)}{\omega_r} + (C_{ga})_y \frac{\partial}{\partial y}\frac{C_a C_{ga}\cos(\mu-\alpha)E(f,\alpha)}{\omega_r} = \sum\frac{S}{\omega_r} \qquad (3)$$

where

C_{ga} = absolute wave group celerity

x,y = spatial coordinates, subscripts indicate x and y components

C_a = absolute wave celerity

μ = current direction

α = propagation direction of spectral component

E = spectral energy density

f = frequency of spectral component

ω_r = relative angular frequency (frequency relative to the current)

S = energy source/sink terms

The source terms include wind input, nonlinear wave-wave interactions, dissipation within the wave field, and surf-zone breaking. The terms on the left-hand side of Equation 1 represent wave propagation (refraction and shoaling), and the source terms on the right-hand side of the equation represent energy growth or decay in the spectrum.

The assumptions made in STWAVE are as follows:

a. Mild bottom slope and negligible wave reflection.

b. Spatially homogeneous offshore wave conditions.

c. Steady waves, currents, and winds.

d. Linear refraction and shoaling.

e. Depth-uniform current.

f. Negligible bottom friction.

STWAVE is a half-plane model, meaning that only waves propagating toward the coast are represented. Waves reflected from the coast or waves generated by winds blowing offshore are neglected. Wave breaking in the surf zone limits the maximum wave height based on the local water depth and wave steepness:

$$H_{mo_{\max}} = 0.1L \tanh kd \tag{4}$$

where

H_{mo} = zero-moment wave height

L = wavelength

k = wave number

d = water depth

STWAVE is a finite-difference model and calculates wave spectra on a rectangular grid with square grid cells. The model outputs zero-moment wave height, peak wave period (T_p), and mean wave direction (α_m) at all grid points and two-dimensional spectra at selected grid points.

Wave Model Inputs

The inputs required to execute STWAVE are as follows:

a. Bathymetry grid (including shoreline position and grid size and resolution).

b. Incident frequency-direction wave spectrum on the offshore grid boundary.

c. Current field (optional).

d. Tide elevation, wind speed, and wind direction (optional).

Bathymetry grids. For each island several bathymetry grids were required to model the wave transformation. The same underlying bathymetry was used for each grid, but the grid orientation was changed so the input wave direction was less than 60 deg relative to the x-axis of the grid. The grid specifications for each island are given in Table 21. The grid origin is given in Maryland State Plane coordinates. The grid orientation is the orientation of the grid x-axis measured counter-clockwise from East (SMS default). The grid naming convention indicates the island and the approximate incident wave direction. The bathymetry for each grid is a compilation of the GEODAS data and survey data provided by the Baltimore Corps of Engineers District Office. Depths are relative to MLLW. Figures 27 to 29 show examples of the grids for each island.

Table 21
Bathymetry Grid Specifications

Grid	X origin, m (ft)	Y origin, m (ft)	Δx, m (ft)	Orientation, deg	X cells	Y cells
Poplar NW	446608 (1465250)	118192 (387770)	46 (150)	330	166	280
Poplar NE	455518 (1494480)	131405 (431120)	46 (150)	220	210	260
Poplar N	445307 (1460980)	128449 (421420)	46 (150)	290	292	202
Poplar S	457307 (1500350)	117318 (384900)	46 (150)	90	170	220
James W	452847 (1485720)	88200 (289370)	46 (150)	0	150	307
James S	457965 (1502510)	85778 (281425)	46 (150)	75	270	193
James NW	447222 (1467265)	101781 (333926)	46 (150)	287	280	230
James NE	454301 (1490490)	103882 (340820)	46 (150)	240	216	230
Barren NW	455502 (1494430)	73836 (242245)	46 (150)	337	245	182
Barren SE	466435 (1530300)	60408 (198190)	46 (150)	80	325	232
Barren W	463366 (1520230)	66962 (219690)	46 (150)	20	101	225

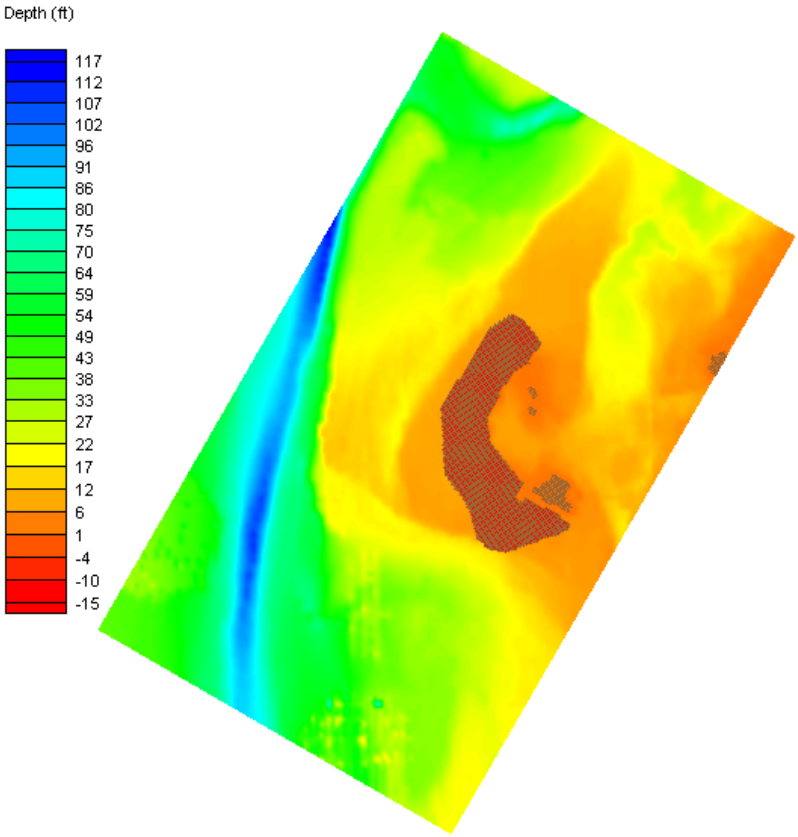


Figure 27. Poplar NW bathymetry grid (depths in feet mllw). Land is shown in brown. (To convert from ft to m use 0.3048 m/ft)

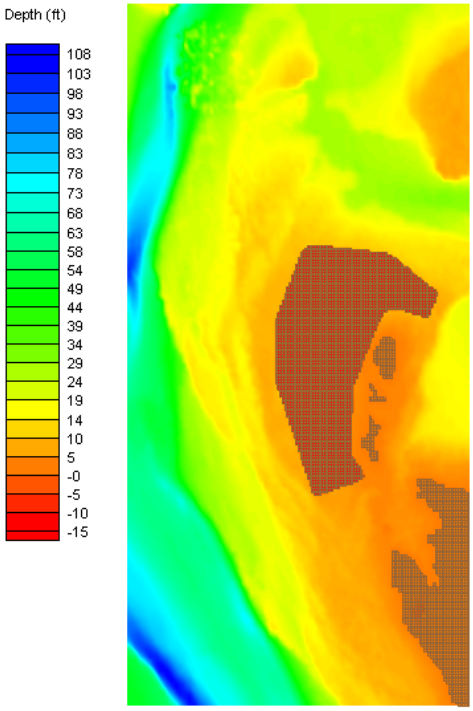


Figure 28. James W bathymetry grid (depths in feet mllw). Land is shown in brown.

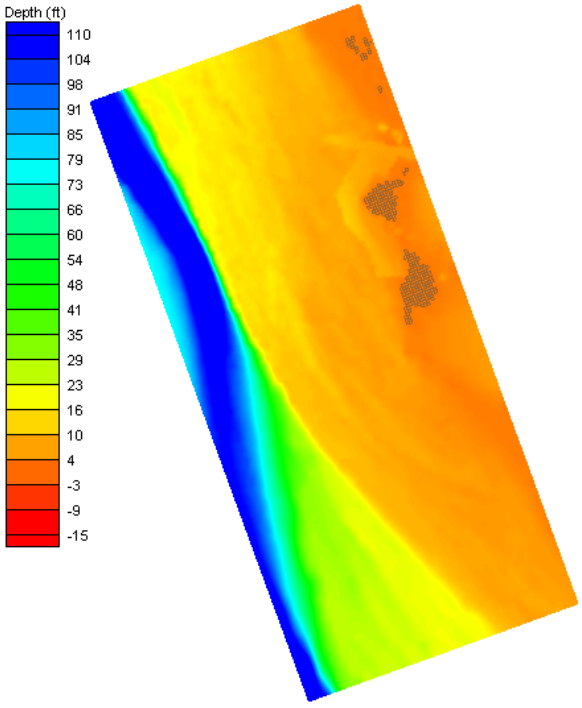


Figure 29. Barren W bathymetry grid (depths in feet mllw). Land is shown in brown.

Input wave spectra. Input wave spectra are required to drive STWAVE on the "offshore" grid boundary. The definition of "offshore" changes for each grid, and it is the boundary across which the waves are propagating. The wave generation model provides only wave height, peak wave period, and mean wave direction, so parametric spectral shapes are used to generate the input spectra. The wave energy is distributed in frequency using the TMA spectral shape with a spectral peakedness parameter of 3.3 (Bouws et al. 1984) and in direction using a $\cos^4(\alpha-\alpha_m)$ distribution, where α_m is the mean wave direction. The input spectra have 30 frequencies, starting with 0.04 Hz and incrementing by 0.01 Hz. The directional resolution is 5 deg. The wave parameters run for each grid are summarized in Table 22.

Water level. The range of water levels (combination of tide and storm surge) was determined by the circulation model simulations (Section 3). Water levels that occurred in the target storms in combination with the incident waves were modeled. The water levels run for each grid and associated wave conditions are given in Table 22. Water level is applied in STWAVE as constant water depth change over the grid.

Winds and currents. Wind and current effects were not included within the STWAVE domains.

Table 22
Waves and Water Levels Simulated in STWAVE

Grid	Depth Grid Boundary m (ft)	Grid Shore Normal deg	Wave Angle deg	Water Levels, m (ft) mllw	Wave Heights, m (ft)	Wave Periodsec.
Poplar NW	20 (66)	300	265, 335	0 (0), 0.3 (1), 0.6 (2), 0.9 (3)	0.6 (2), 1.2 (4)	3
Poplar NE	10 (33)	50	50	0 (0), 0.3 (1), 0.6 (2), 0.9 (3)	0.6 (2), 1.2 (4), 1.8 (6), 2.4 (8)	3, 5, 7
Poplar N	40 (131)	340	10	0 (0), 0.3 (1), 0.6 (2), 0.9 (3)	0.6 (2), 1.2 (4), 1.8 (6), 2.4 (8)	3, 5, 7
Poplar S	20 (66)	180	150, 180	0 (0), 0.3 (1), 0.6 (2), 0.9 (3), 1.2 (4), 1.5 (5), 1.8 (6), 2.1 (7)	0.6 (2), 1.2 (4), 1.8 (6), 2.4 (8)	3, 5, 7, 9
James W	30 (98)	270	270	0 (0), 0.3 (1), 0.6 (2), 0.9 (3)	0.6 (2), 1.2 (4), 1.8 (6), 2.4 (8)	3, 5
James S	30 (98)	195	30	0 (0), 0.3 (1), 0.6 (2), 0.9 (3), 1.2 (4), 1.5 (5)	0.6 (2), 1.2 (4), 1.8 (6), 2.4 (8)	3, 5, 7, 9
James NW	20 (66)	343	343	0 (0), 0.3 (1), 0.6 (2), 0.9 (3)	0.6 (2), 1.2 (4), 1.8 (6), 2.4 (8)	3, 5
James NE	10 (33)	30	30	0 (0), 0.3 (1), 0.6 (2), 0.9 (3)	0.6 (2), 1.2 (4), 1.8 (6), 2.4 (8)	3, 5
Barren NW	38 (125)	293	338	0 (0), 0.3 (1), 0.6 (2), 0.9 (3), 1.2 (4), 1.5 (5)	0.6 (2), 1.2 (4), 1.8 (6), 2.4 (8)	3, 5, 7
Barren SE	35 (115)	190	145, 167	0 (0), 0.3 (1), 0.6 (2), 0.9 (3), 1.2 (4), 1.5 (5)	0.6 (2), 1.2 (4), 1.8 (6), 2.4 (8)	3, 5, 7
Barren W	33 (108)	250	227, 262	0 (0), 0.3 (1), 0.6 (2), 0.9 (3)	0.6 (2), 1.2 (4)	3

Model Results

Some sample STWAVE results are shown is this section to illustrate the range of conditions simulated. The wave periods within Chesapeake Bay are relatively short, but periods as long as 9 sec were hindcast for extreme cases. Figure 30 shows the wave height and direction for two simulations on the Poplar South grid. The top panel is a period of 3 sec and the bottom panel is 9 sec, both for incident H = 1.8 m (6 ft), dir =180 deg, and water level = 0 m (0 ft). The longer period waves interact more strongly with the bottom, resulting in greater refraction (turning of the wave directions) and shoaling (increases in wave height in shallow depths). To the west of the proposed island, wave heights are approximately 0.3 m (1 ft) higher for the longer period wave in the shallow areas. The wave vectors also show more turning of the wave direction toward the island for the longer period wave.

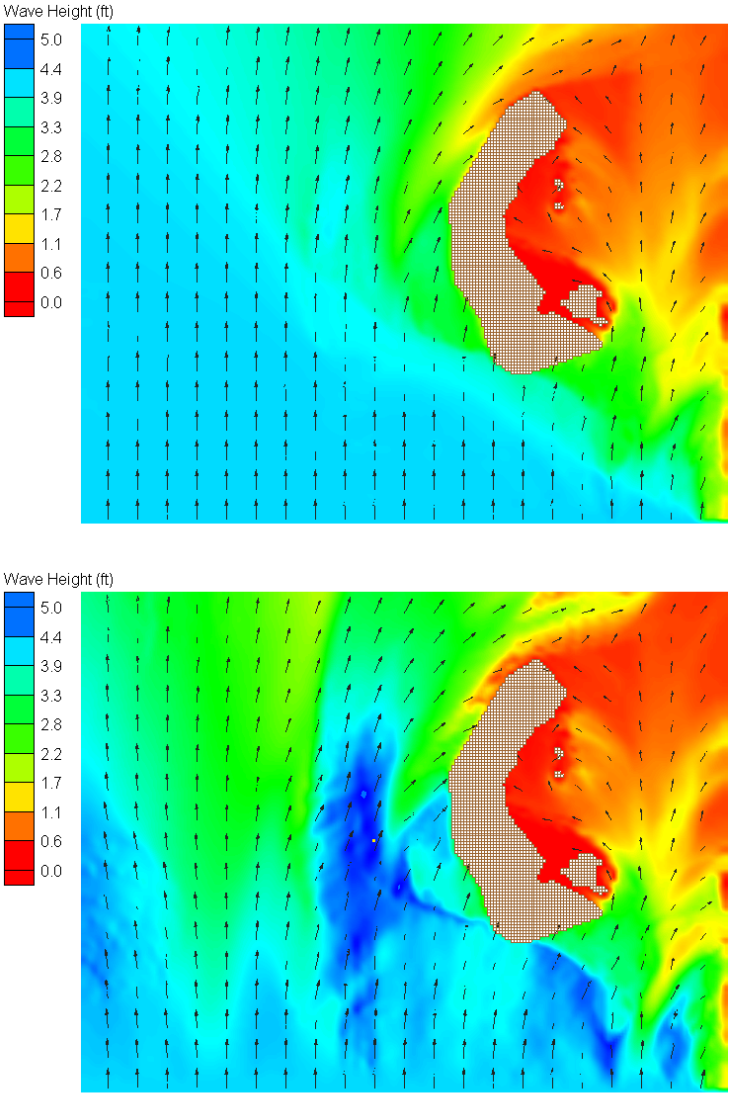


Figure 30. Poplar S grid wave height contours for incident waves H = 1.8 m (6 ft), T = 3 s (top) and 9 sec (bottom), dir = 180 deg, and water level = +2.1 m (7 ft) mllw.

Wave height is a key parameter for design of the island revetment because it is raised to a power. The incident wave height from the generation modeling may be altered significantly through transformation before reaching the islands and vary along an island. Figure 31 shows a simulation for James Island with waves from the west and incident wave heights of 0.6 m (2 ft) and 2.4 m (8 ft) and period of 5 sec. Near the island, the 0.6-m (2-ft) wave shoals to a height of approximately 0.67 m (2.2 ft) and the 2.4-m (8-ft) wave breaks and is dissipated to approximately 1.1 m (3.5 ft). If waves are depth-limited, then a larger offshore wave height may not translate to a larger nearshore wave height. Similarly, when the water depth around the island is increased due to storm surge and tide, larger waves may attack the island. Figure 32 shows results from Barren Island with waves from the west and a modest increase in water level from 0 to 1 m (0 to 3 ft) mllw (H = 1.2 m (4 ft), T = 3 sec). Wave heights near Barren increase from approximately 0.76 m (2.5 ft) (depth limited) to 1.2 m (4 ft) in some areas with the increase in water level.

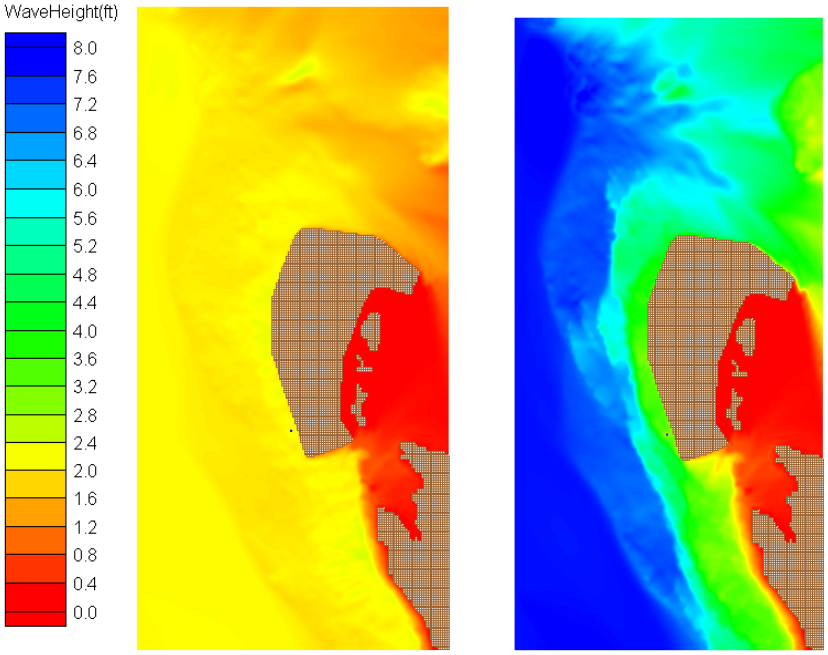


Figure 31. James W grid wave height contours for incident waves H = 0.61 m (2 ft) (left) and 2.4 m (8 ft) (right), T = 5 s, dir = 270 deg, and water level = 0 ft mllw.

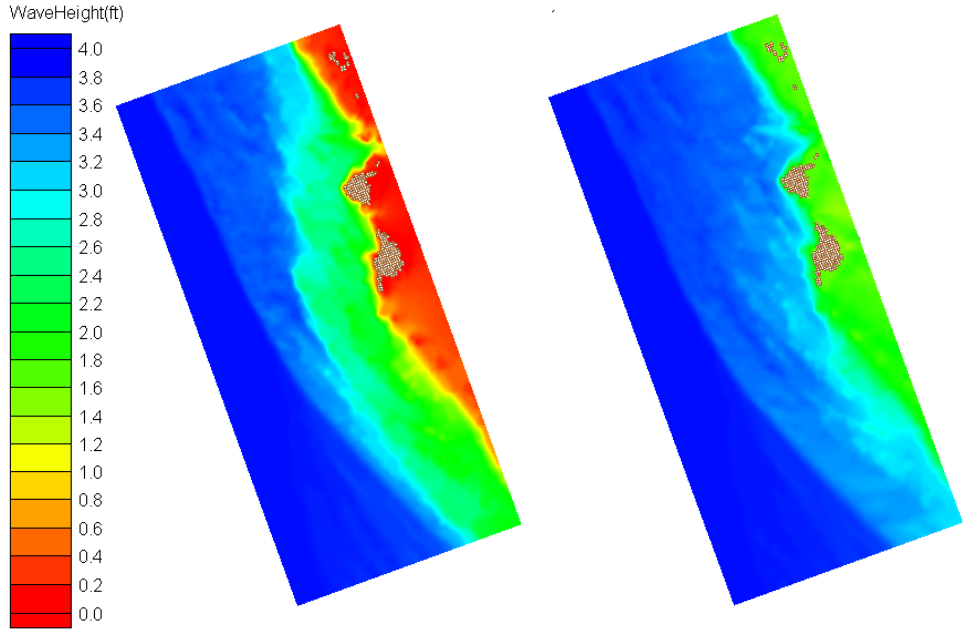


Figure 32. Barren W grid wave height contours for incident waves H = 1.2 m (4 ft), T = 3 s, dir = 262 deg, and water level = 0 ft mllw (left) and +1 m (3 ft) mllw (right).

Summary of Wave Results

Modeling of waves at Poplar, James, and Barren Islands required a three-step process: generation of wave parameters (height, period, and direction) using the narrow-fetch methodology with wind speed and direction, application of the TMA parametric spectral shape to estimate wave spectra from the wave parameters, and application of the STWAVE wave model to calculate the transformation of the waves over the complex nearshore bathymetry at each site. Accurate wind input is critical to wave modeling. Ideally, wind measurements would be used to drive the wave model, but open-water measurements were not available over sufficient years. Thus, hurricane winds were hindcast using the PBL model and northeast storm winds were extracted from the AES-40 hindcast (Chapter 2). Winds for wave modeling were validated with open-water measurements at the NDBC Thomas Point station. The PBL winds showed some lags in time, but generally gave good agreement in the peak parameters. The AES-40 winds underestimated high wind speeds (>8.5 m/s or >16.5 kt), and a correction factor was developed and applied. The narrow-fetch technology was validated for Chesapeake Bay using wave measurements from Hurricane Isabel. These measurements were used to calibrate the water depth input for the generation modeling. Wave generation was modeling with the narrow-fetch methodology in ACES. The model input includes radial fetch lengths (10-deg increments), and wind speed and direction time history. The output is a time history of wave heights, periods, and directions. The range of these storm wave parameters was wave height of 0.6 m – 2.4 m (2-8) ft and wave period of 3-9 s. The maximum values varied based on wave direction. Preferential wave directions for each island are noted in Table 22. These directions coincide with the longer fetches in the bay. Waves are generated along these fetches by the component of the wind in the fetch direction. For each island, the representative wave parameters and range of water levels (Chapter 3) were used to drive STWAVE. A parametric spectral wave shape was applied

to estimate wave spectra from the wave parameters. These spectra were input to STWAVE with the water levels. STWAVE calculates the wave shoaling, refraction, sheltering, and breaking to give the spatial distribution of wave height, period, and direction around each island. Because of the complex bathymetry and multiple wave angles, several model grids were required for each island (Table 21). Water level is a critical parameter in the transformation because of the shallow depths around the islands. For depth-limited conditions, the wave height varies linearly with water depth. Results from the STWAVE simulations were stored in lookup tables. These tables are a matrix of local wave parameters around each island that coincide to an input wave height, wave period, wave direction, and water level combination. With these tables, time histories of the 'offshore' storm waves can be converted to transformed nearshore wave parameters for application of the life-cycle analysis for design of island revetment.

5 Life-Cycle Simulation Methodology – Waves and Water Levels

This chapter describes the procedures used for life-cycle simulation of waves and water levels. Methods used to develop a 148-yr time history of historical storm events and return period wave and water levels at nearshore stations around Poplar Island are described in the first two sections. These methods are used to describe waves and water levels around James and Barren Islands and this is described in the following two sections. Procedures for creating future wave and water level life-cycle scenarios are described in the final section. These procedures were applied to create a large number of possible future 50-yr life-cycles which are statistically consistent with historical information. The methods used to optimize design of Poplar Island protective structures are presented in the next chapter.

Sequence of Historical Storms

The life-cycle simulation approach begins with a known wave and water level time history over a multi-year time period. Initially, the time history is based on historical data or hindcasts. In this study, the available time history consists only of storms, since the non-storm time periods are not a consideration for structure design. Also, the time period covered by tropical storms is 148 years (1856-2003), while the time period covered by northeasters is only 50 years (1954-2003). Northeasters are more common than tropical storms and are less likely than tropical storms to be atypically severe. The 50 year period of northeasters available in the hindcasts is expected to give a good representation of the range of northeasters affecting the project areas. To populate the early tropical storm years with northeasters, the northeasters were folded back as shown in Table 23. Care was taken to fold leap years back into leap years and similarly with non-leap years. Thus, a 148-year offshore time history of historical storm waves and water levels was created. The final time history contains 179 storms. The time history was padded with zeros in between storm events, so the final historical time history covered 148 years at 3-hr intervals. Cumulative Julian day was added, starting with 0.000 at 0000 hrs 1 Jan 1856 and accumulating through the 148 years. The FORTRAN program written to create this time history is called Poplar_make_timehist.f.

Table 23
Northeaster Years Matched to Early Tropical Storm Years

Tropical Storm Years	Matched Northeaster Years
1856 (leap year) -1857	2000 (leap year) - 2001
1858 – 1905	1954 – 2000 (leap year) & 2002 (nonleap year)
1906 – 1953	1954 – 2000 (leap year) & 2003 (nonleap year)

Time History of Storm Waves and Water Levels for Poplar Island

The next step is to transform the 148-yr offshore wave time history to selected points along the study area coast. For Poplar Island, sixteen points (Stations 1-16) were selected adjacent to shore for design analysis (Figure 33). Another 16 points (Stations 17-32) were selected further offshore from each of the points shown, approximately 300 m from shore, but these are not included in the figures. Finally, seven points (Stations 33-39) were selected adjacent to shore for the planned expansion of the north end of Poplar Island (Figure 34). Reference water depths (mllw) at the stations are given in Table 24. These depths are based on NAB's most recent survey data, which is more recent than the bathymetry used for water level and wave numerical model grids. The computer program that transforms the 148-yr offshore time history to nearshore design analysis stations is Poplar_timehist.f.

Table 24
Water Depths at Poplar Island Design Analysis Stations

Station	Depth, m (ft) mllw	Station	Depth, m (ft) mllw
1	1.40 (4.59)	21	5.49 (18.01)
2	1.83 (6.00)	22	2.44 (8.01)
3	3.05 (10.01)	23	2.44 (8.01)
4	4.45 (14.60)	24	2.65 (8.69)
5	2.74 (8.99)	25	3.05 (10.01)
6	2.29 (7.51)	26	2.90 (9.51)
7	2.59 (8.50)	27	3.05 (10.01)
8	2.29 (7.51)	28	3.66 (12.01)
9	2.44 (8.01)	29	3.81 (12.50)
10	2.13 (6.99)	30	2.90 (9.51)
11	2.29 (7.51)	31	2.59 (8.50)
12	3.05 (10.01)	32	1.98 (6.50)
13	3.05 (10.01)	33	3.35 (10.99)
14	2.74 (8.99)	34	3.50 (11.48)
15	2.44 (8.01)	35	3.35 (10.99)
16	2.13 (6.99)	36	3.05 (10.01)
17	1.52 (4.99)	37	3.05 (10.01)
18	1.83 (6.00)	38	2.44 (8.01)
19	5.00 (16.40)	39	1.68 (5.51)
20	5.28 (17.32)		

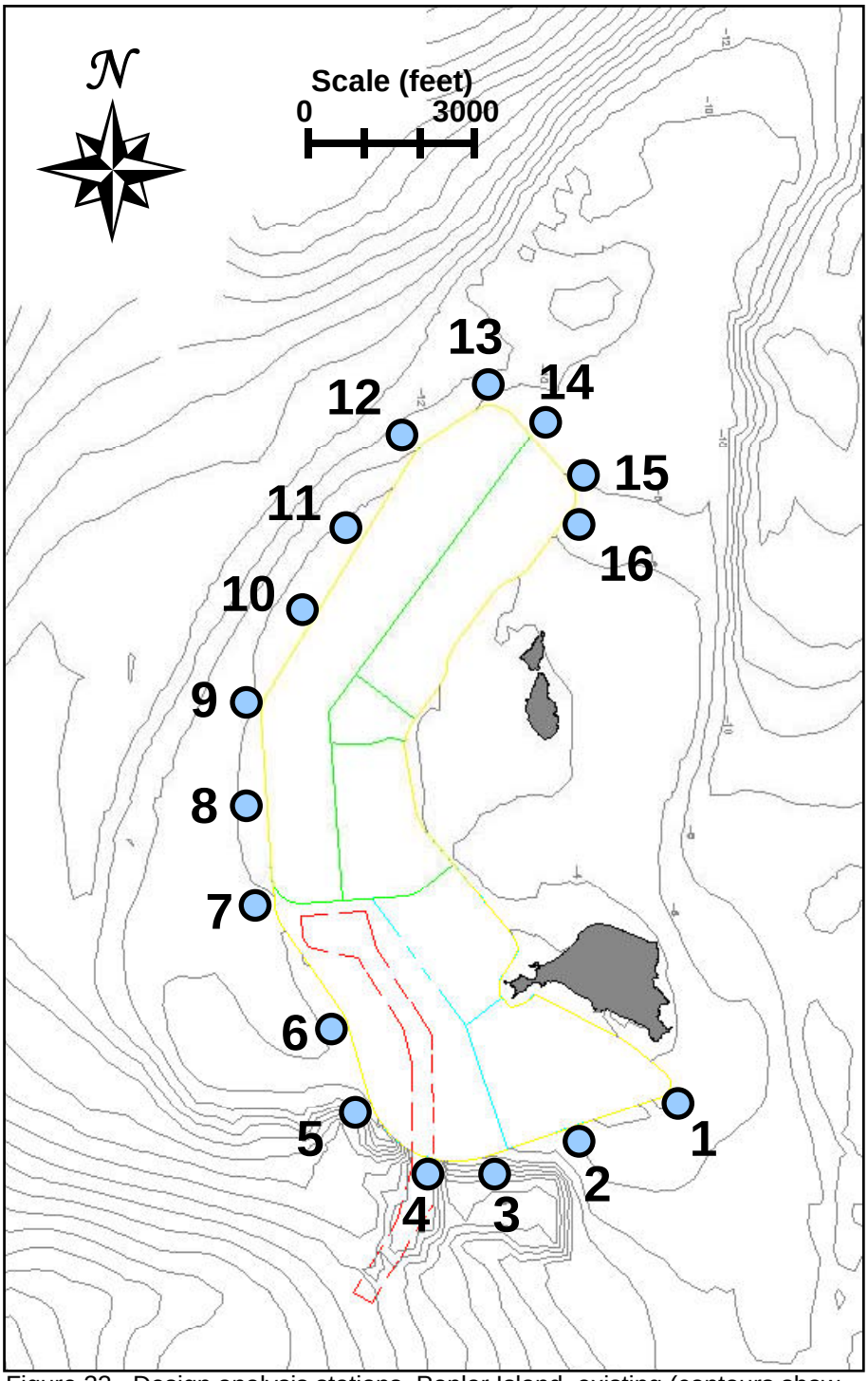


Figure 33. Design analysis stations, Poplar Island, existing (contours show bathymetry at 2-ft intervals)

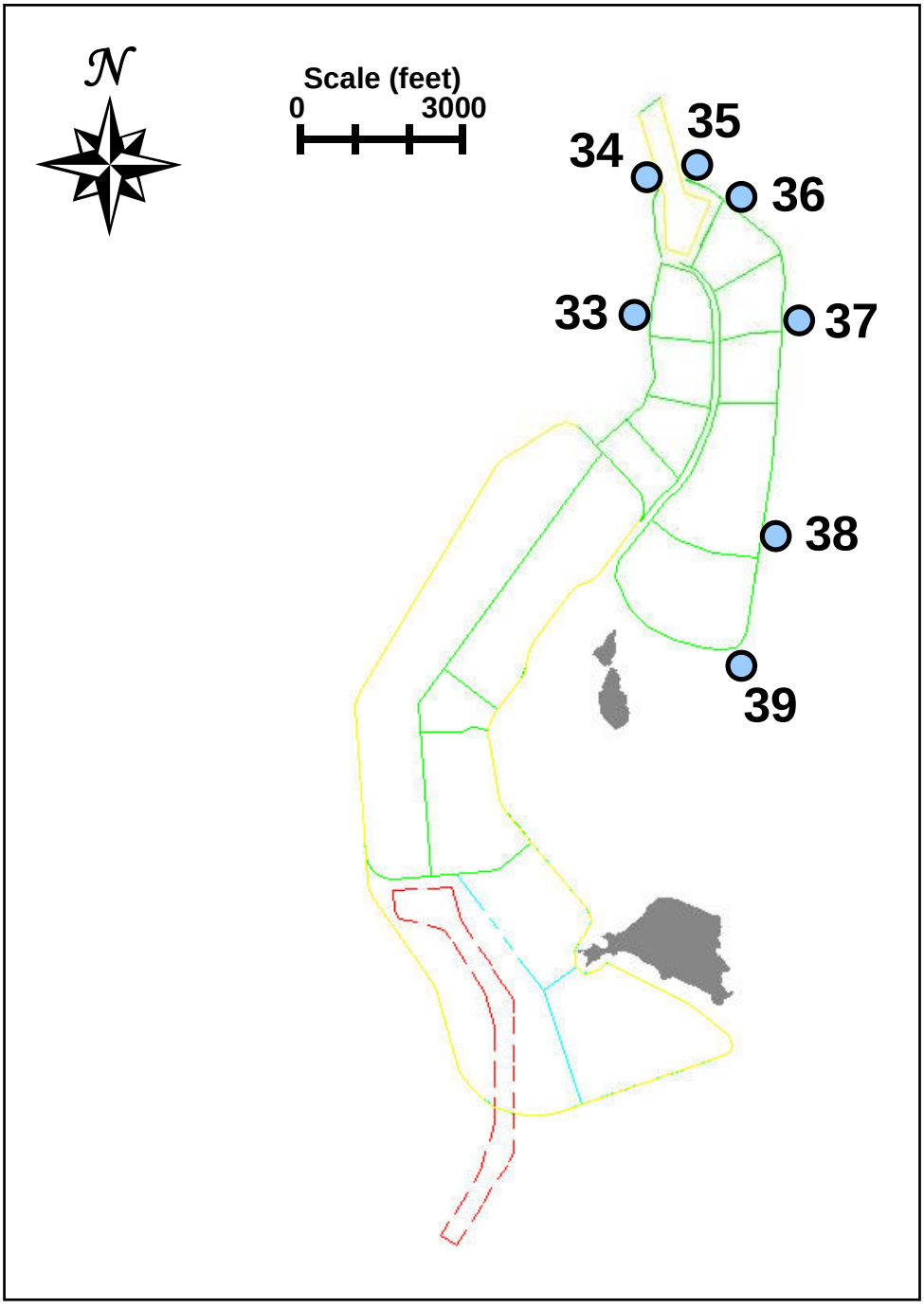


Figure 34. Design analysis stations, Poplar Island, planned expansion

The offshore wave and water level time history was transformed to the selected nearshore stations using lookup table information from the STWAVE runs discussed in Chapter 4. The lookup table provided a transformation factor to relate offshore and nearshore significant wave height and similar factors for wave period and direction. Factors from the STWAVE case that best matched the offshore wave case were used for period and direction. For significant wave height, the factor was interpolated from STWAVE cases that best matched the offshore significant height, direction, and water level and bracketed the offshore

wave period. Water level in the nearshore station time history was taken from the closest ADCIRC nearshore save station (Chapter 3) and converted from msl to mllw datum.

Since STWAVE was run only with the existing Poplar Island, waves extracted for stations around the proposed north expansion needed to be screened to account for sheltering effects of the expansion land mass. The screening was applied based on wave direction from STWAVE at each station. Directions accepted at each station are given in Table 25. For cases with directions outside the accepted range, significant height was reduced to 0.01 m (0.33 ft).

Table 25
Nearshore Wave Directions Accepted at Stations Around Planned Poplar Island Expansion

Station	Direction Range (deg azimuth, coming from)
33 and 34	220 through 350
35	290 through 110
36	320 through 120
37 and 38	20 through 170
39	60 through 180

Significant wave height in the STWAVE model runs is reduced to account for depth-limited spectral breaking when waves are high enough and propagate into shallow enough water. Many of the design analysis stations are in sufficiently shallow water to be affected by depth-limited breaking. Although STWAVE accounts for the process, application of a transformation factor to offshore significant wave height may occasionally produce a height at nearshore stations that exceeds the realistic depth-limited maximum. To safeguard against unreasonably high significant wave heights at shallow water stations, heights are constrained to be at most 0.6 times the local water depth, including astronomical tide and storm surge. The value 0.6 is considered appropriate since limiting significant height over water depth ratios from STWAVE results of design concern range from around 0.55 to 0.62, with most values in the range 0.55 to 0.58.

Maximum significant wave height by storm, needed to determine return period wave height values for structure design, is also extracted in Poplar_timehist.f along with corresponding peak period, wave direction, and water level. Separate output files are created for tropical storms only, northeasters only, and all storms together. For Station 2, these maximum values are shown for tropical storms and northeasters in Figures 35 and 36, respectively. Maximum values for Station 33, a west-facing station, are shown in Figures 37 and 38, maximum values for Station 36, a northeast-facing station, are shown in Figures 39 and 40, and maximum values for Station 39, a south-facing station, are shown in Figures 41 and 42. These values of maximum H_s for each storm as well as associated peak period, direction, and depth are tabulated for all stations of the northern extension of Poplar Island in Appendix A. Tables A1 – A7 summarize hurricanes for stations 33 – 39, respectively, and Tables A8 – A14 summarize extratropical storms for Poplar Island.

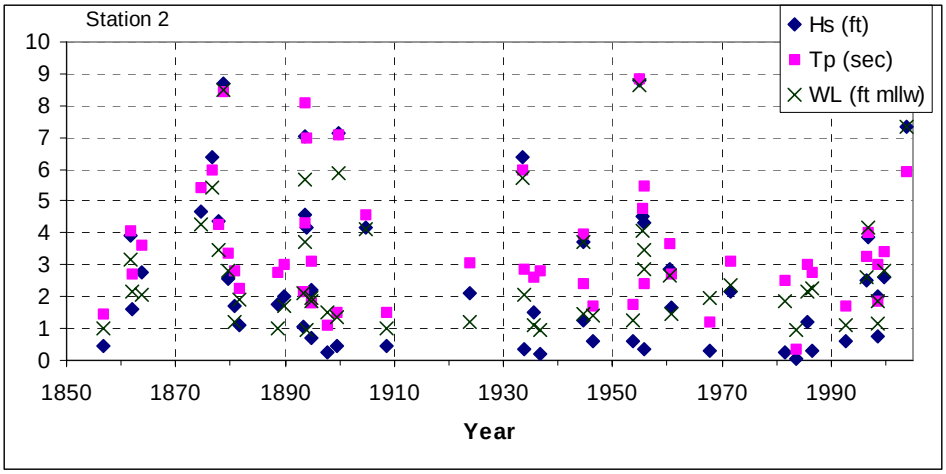


Figure 35. Maximum H_s and associated T_p , θ_p , and water level, Poplar Island, Station 2, tropical storms only

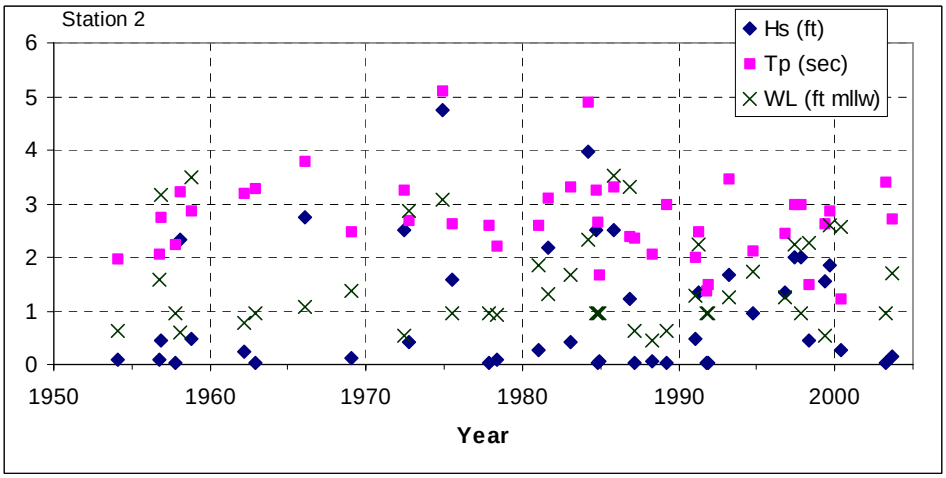


Figure 36. Maximum H_s and associated T_p , θ_p , and water level, Poplar Island, Station 2, northeasters only

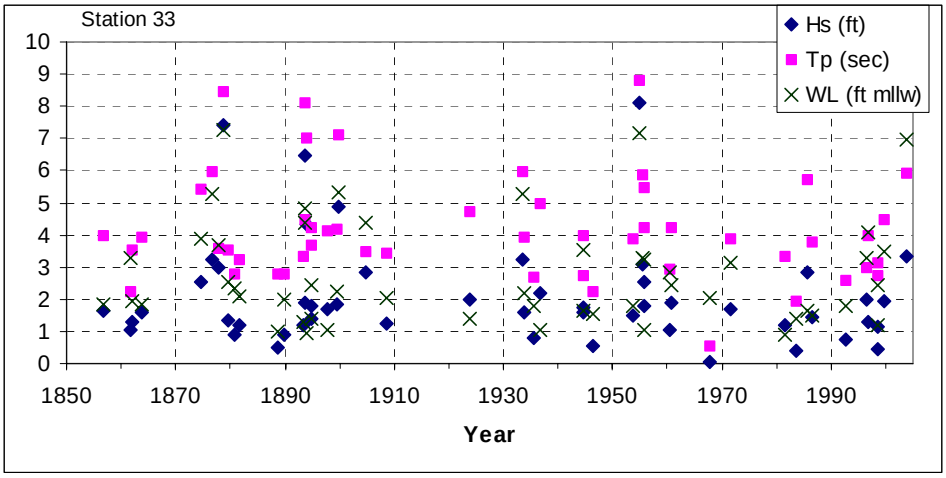


Figure 37. Maximum H_s and associated T_p , θ_p , and water level, Poplar Island, Station 33, tropical storms only

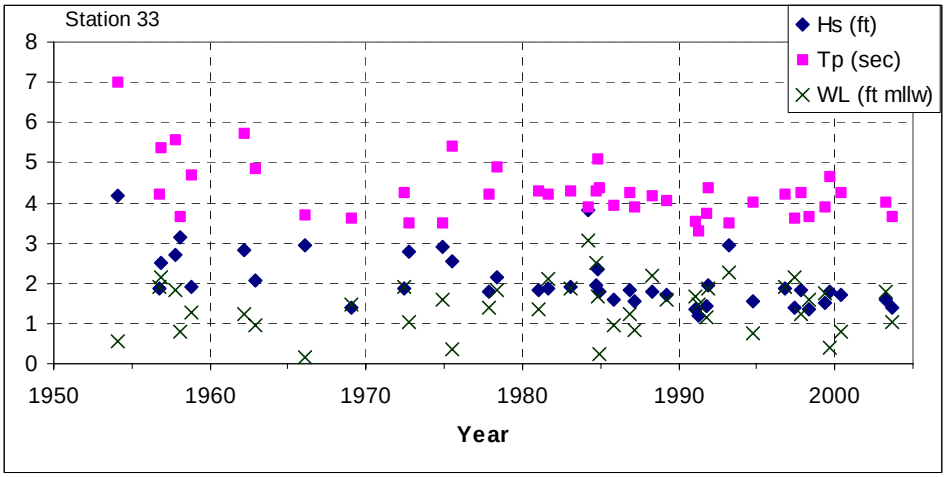


Figure 38. Maximum H_s and associated T_p , θ_p , and water level, Poplar Island, Station 33, northeasters only

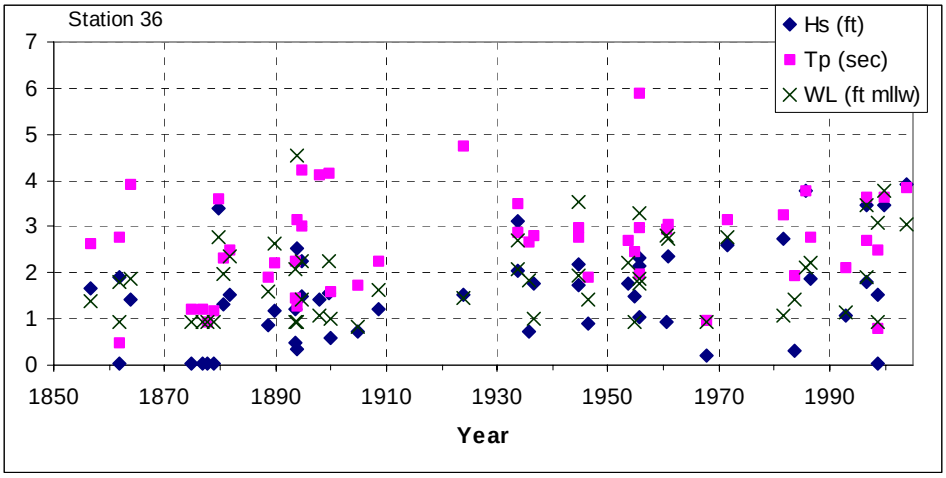


Figure 39. Maximum H_s and associated T_p , θ_p , and water level, Poplar Island, Station 36, tropical storms only

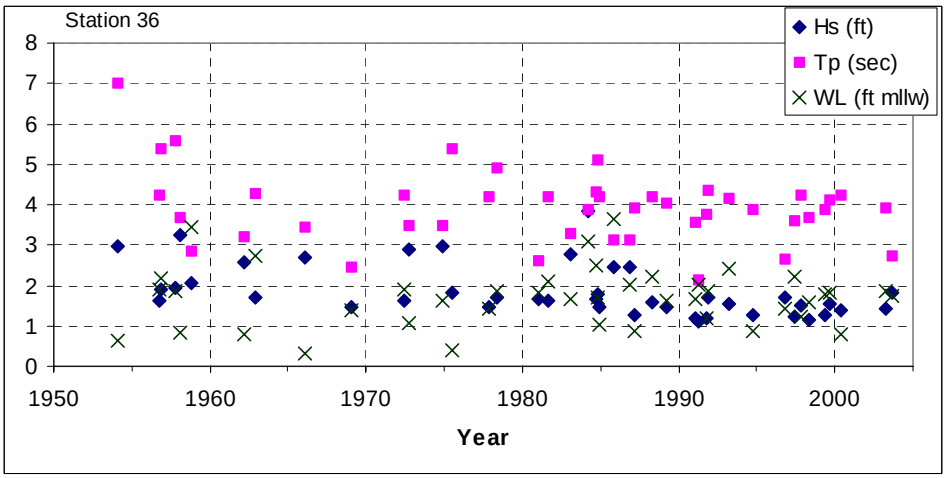


Figure 40. Maximum H_s and associated T_p , θ_p , and water level, Poplar Island, Station 36, northeasters only

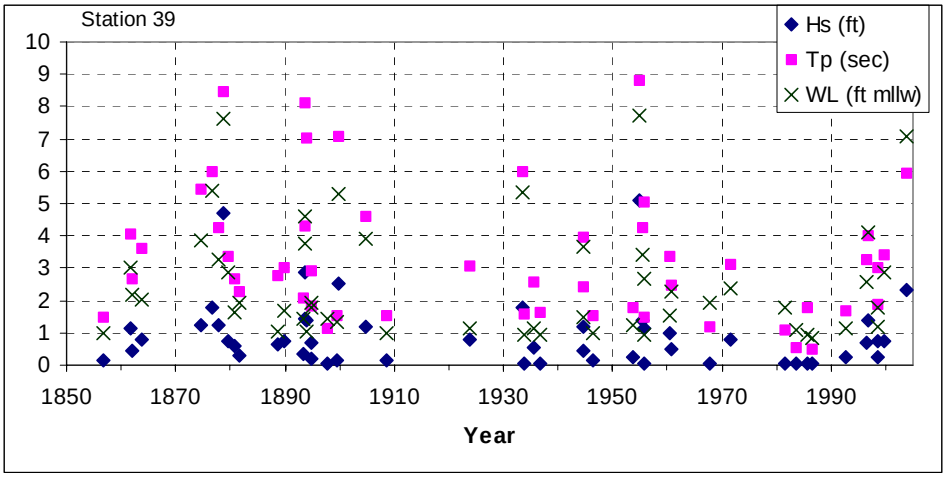


Figure 41. Maximum H_s and associated T_p , θ_p , and water level, Poplar Island, Station 39, tropical storms only

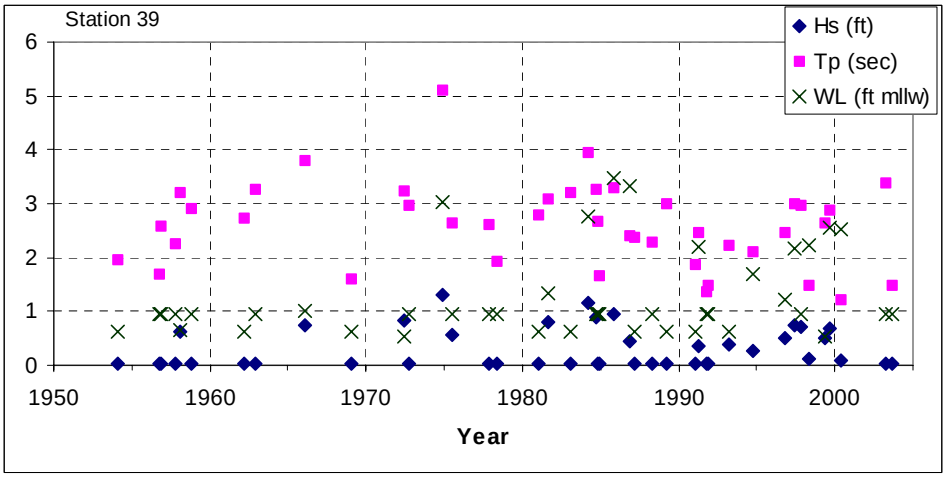


Figure 42. Maximum H_s and associated T_p , θ_p , and water level, Poplar Island, Station 39, northeasters only

Return Period Wave Parameters

Maximum H_s by storm at each station were subjected to extremal analysis using a modified version of the FORTRAN computer program that is the basis for the Extremal Significant Wave Height Analysis application in CEDAS/ACES. This program was used in preference to CEDAS/ACES so that multiple stations could be analyzed more easily and output information could be configured for convenient additional processing steps. As with CEDAS/ACES, the modified program follows the approach developed by Goda (1988). The modified program considers the same five candidate extremal distribution functions as in the CEDAS/ACES application and the distribution rejection and acceptance criteria proposed by Goda and Kobune (1990). In place of the CEDAS/ACES plot displays, the modified program produces a text file of plot

information for the five extremal distribution functions for convenient display using a commercial spreadsheet program.

Extremal analysis of significant wave heights was applied to all storms together and to hurricanes only. Generally, H_s values at return periods less than 30-50 years were dominated by northeasters and, for stations exposed to hurricane waves, those at the longer return periods were dominated by hurricanes. Analysis of all storms included 179 storms over the 148-yr time period. Analysis of hurricanes only included 52 storms over the 148-yr period. The best fitting extremal distribution was selected, based on the criteria of Goda and Kobune (1990) and a good visual fit to the return periods of concern for this project. Using the best-fit distribution, significant wave heights were determined for return periods of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, and 100 years. For hurricane-influenced stations where the best fit distribution for all storms underestimated H_s at the longest return periods, return period H_s was taken from the best-fit for hurricanes only for return periods dominated by hurricanes.

To estimate an appropriate peak wave period and water level (also needed for structure design) to accompany each return period significant wave height, the computer program return_period_Tp.f is run. Inputs include return period significant wave heights and 148-yr time history of waves and water levels at each station. The time history is screened to find all significant heights within a bin centered on the desired return period wave height. Bin widths considered are 0.2, 0.4, 0.6, 0.8, and 1.0 m (0.7, 1.3, 2.0, 2.6, 3.3 ft). For example, the 50-yr significant height at Poplar Island Station 2 is 2.24 m (7.34 ft). All cases in the 148-yr Station 2 time history with significant height in the range 2.14 – 2.34 m (0.2-m bin) (7.02 – 7.68 ft (0.7-ft bin)) were identified and their peak periods and water levels were averaged. The process was repeated for significant heights in the range 2.04 – 2.44 m (0.4-m bins) (6.69 – 8.01 ft (1.3-ft bin)), 1.94 – 2.54 m (0.6-m bins) (6.36 – 8.33 ft (2.0-ft bin)), 1.84 – 2.64 m (0.8-m bins) (6.04 – 8.66 ft (2.6-ft bin)), and 1.74 – 2.74 m (1.0-m bins) (5.71 – 8.99 ft (3.3-ft bin)). For each return period, a representative period and water level was chosen with consideration of bins that captured enough cases to form a meaningful average but not so many cases as to dilute the target severe events.

Time History of Storm Waves and Water Levels for James Island

The analysis of waves and water levels for James Island follows the same method used for Poplar. Figure 43 shows the STWAVE station locations around James Island. Table 26 lists design water depths for James Island. Maximum significant wave height by storm, needed to determine return period wave height values for structure design, was extracted along with corresponding peak period, wave direction, and water level. As for Poplar, separate output files were created for tropical storms only, northeasters only, and all storms together. For Station 3, a southwest-facing station, these maximum values are shown for tropical storms and northeasters in Figures 44 and 45, respectively. Maximum values for Station 8, a northwest-facing station, are shown in Figures 46 and 47, maximum values

for Station 11, a northeast-facing station, are shown in Figures 48 and 49. These values of maximum H_s for each storm as well as associated peak period, direction, and depth are tabulated for all stations of the northern extension of James Island in Appendix E. Tables E1 – E7 summarize hurricanes and Tables E8 – E14 summarize extratropical storms for select stations around James Island.

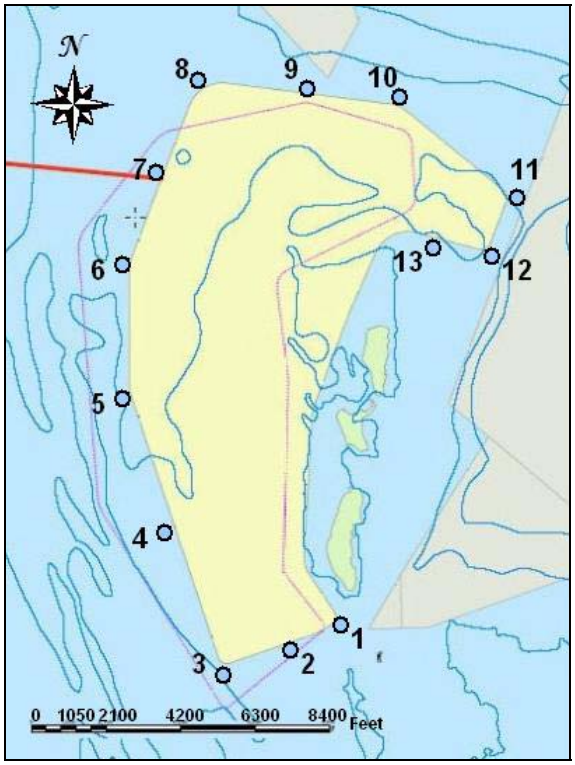


Figure 43. Design analysis stations, James Island

Table 26
Water Depths at James Island Design Analysis Stations

Station	Depth, m (ft) mllw	Station	Depth, m (ft) mllw
1	0.30 (0.98)	13	1.74 (5.71)
2	1.20 (3.94)	14	0.68 (2.23)
3	1.86 (6.10)	15	2.66 (8.73)
4	1.90 (6.23)	16	1.88 (6.17)
5	2.15 (7.05)	17	2.68 (8.79)
6	2.04 (6.69)	18	2.47 (8.10)
7	2.14 (7.02)	19	2.76 (9.06)
8	2.73 (8.96)	20	2.70 (8.86)
9	2.91 (9.55)	21	3.90 (12.80)
10	2.93 (9.61)	22	4.10 (13.45)
11	1.91 (6.27)	23	2.87 (9.42)
12	1.89 (6.20)		

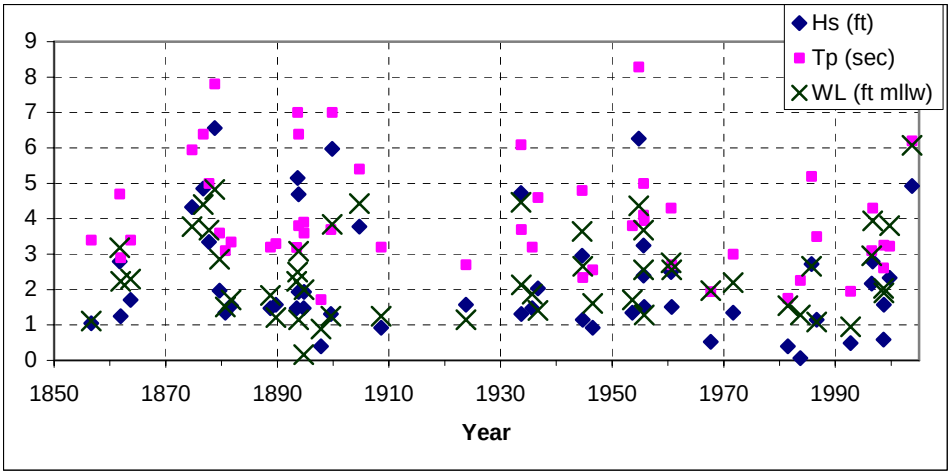


Figure 44. Maximum H_s and associated T_p , θ_p , and water level, James Island, Station 3, tropical storms only

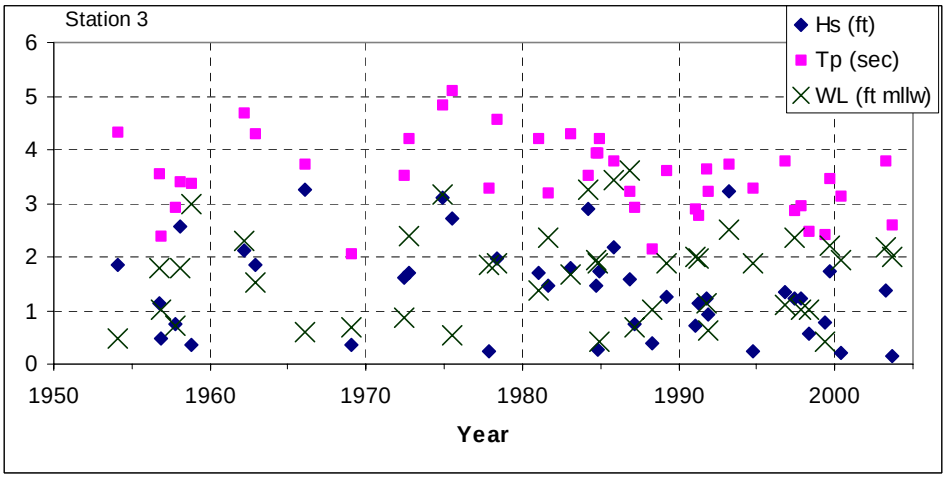


Figure 45. Maximum H_s and associated T_p , θ_p , and water level, James Island, Station 3, northeasters only

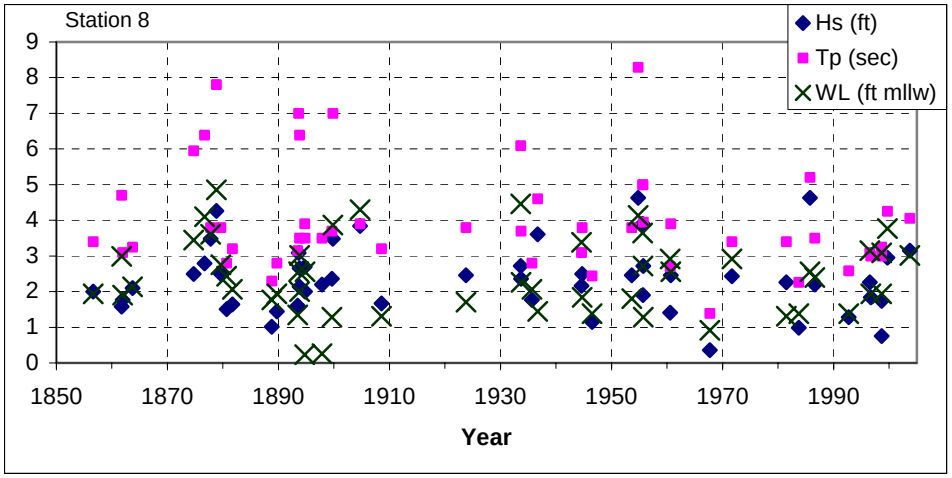


Figure 46. Maximum H_s and associated T_p , θ_p , and water level, James Island, Station 8, tropical storms only

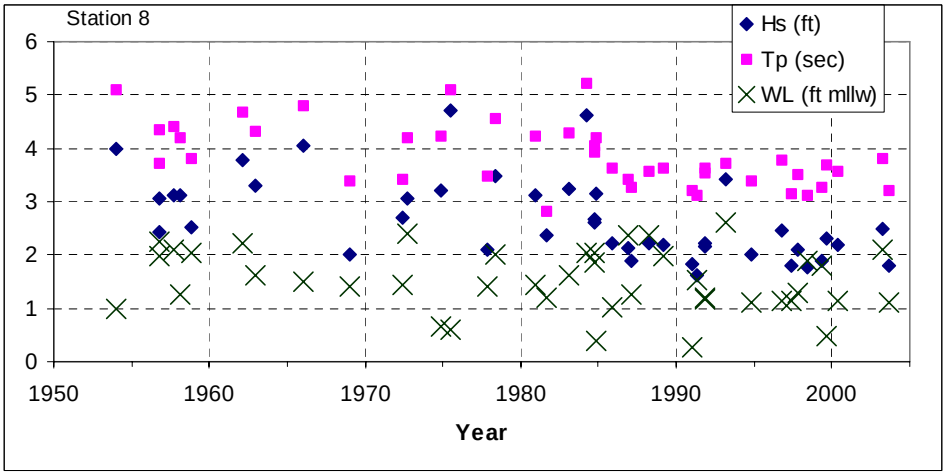


Figure 47. Maximum H_s and associated T_p , θ_p , and water level, James Island, Station 8, northeasters only

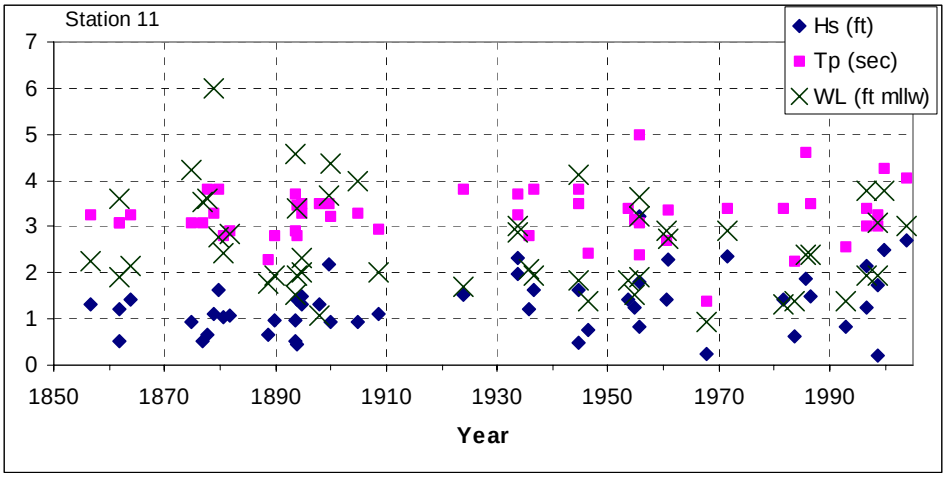


Figure 48. Maximum H_s and associated T_p , θ_p , and water level, James Island, Station 11, tropical storms only

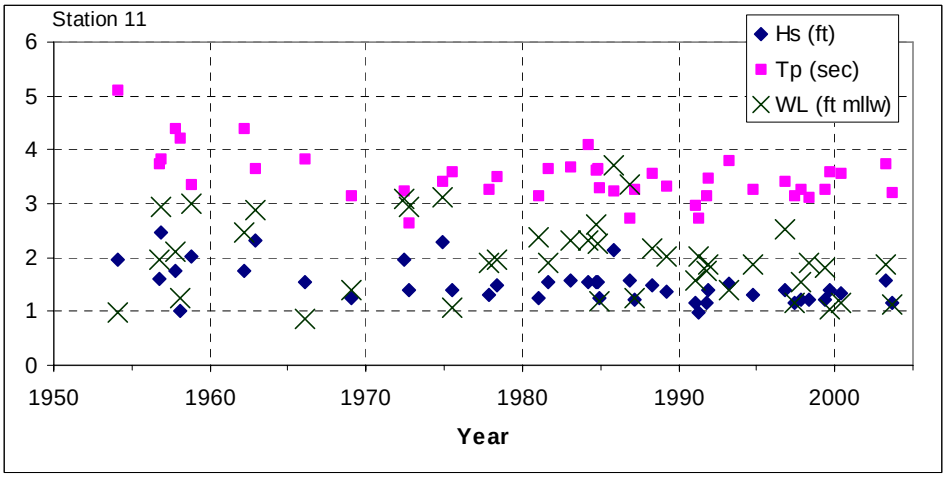


Figure 49. Maximum H_s and associated T_p , θ_p , and water level, James Island, Station 11, northeasters only

Time History of Storm Waves and Water Levels for Barren Island

The analysis of waves and water levels for Barren Island follows the same method used for Poplar and James. Figure 50 shows the STWAVE station locations around Barren Island. Table 27 lists design water depths for Barren Island. Maximum significant wave height by storm, needed to determine return period wave height values for structure design, was extracted along with corresponding peak period, wave direction, and water level. As for Poplar and James, separate output files were created for tropical storms only, northeasters only, and all storms together. For Station 3, a west-facing station at the center of the western leg of the structure, these maximum values are shown for tropical storms and northeasters in Figures 51 and 52, respectively. Maximum values for

Station 5, a northwest-facing station, are shown in Figures 53 and 54, maximum values for Station 6, a north-facing station near the northern end of the structure, are shown in Figures 55 and 56. These values of maximum H_s for each storm as well as associated peak period, direction, and depth are tabulated for all stations of the northern extension of Barren Island in Appendix I. Tables I1 – I6 summarize hurricanes and Tables I7 – I12 summarize extratropical storms for Barren Island.

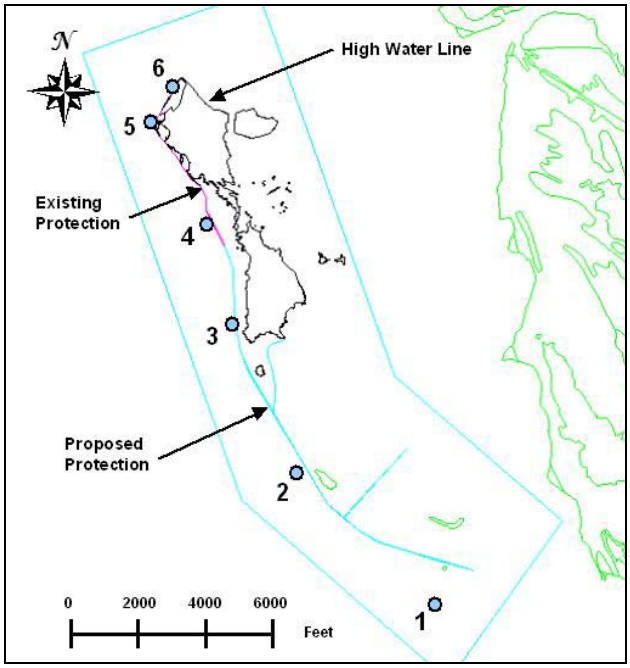


Figure 50. Design analysis stations, Barren Island

Table 27
Water Depths at Barren Island Design Analysis Stations

Station	Depth, m (ft) mllw
1	0.81 (2.66)
2	1.09 (3.58)
3	1.06 (3.48)
4	1.36 (4.46)
5	1.68 (5.51)
6	1.62 (5.31)
7	1.18 (3.87)
8	1.30 (4.27)
9	1.64 (5.38)
10	1.54 (5.05)
11	2.82 (9.25)
12	1.91 (6.27)

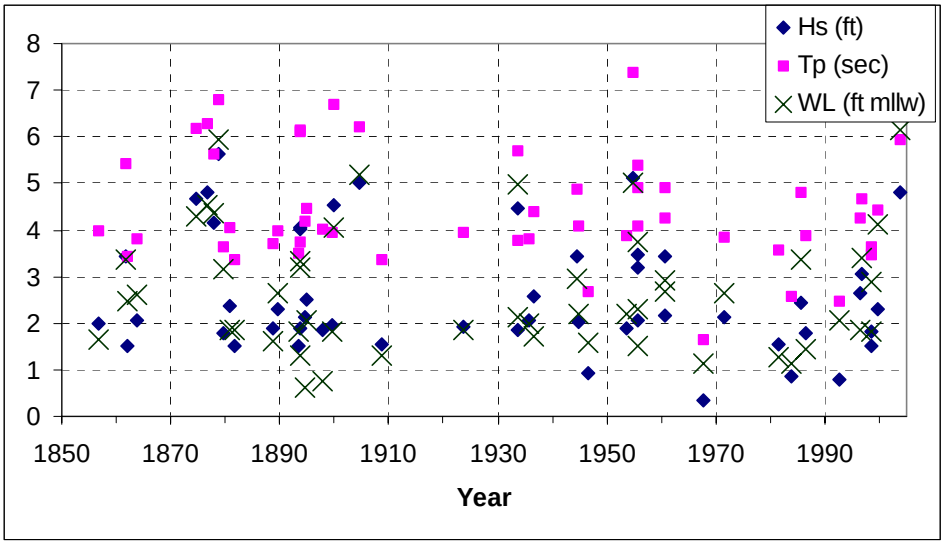


Figure 51. Maximum H_s and associated T_p , θ_p , and water level, Barren Island, Station 3, tropical storms only

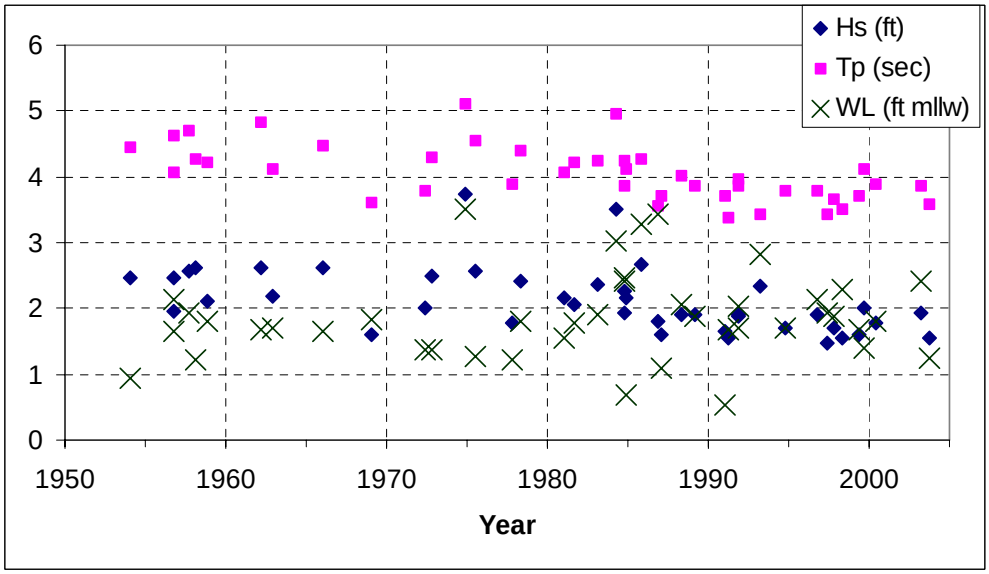


Figure 52. Maximum H_s and associated T_p , θ_p , and water level, Barren Island, Station 3, northeasters only

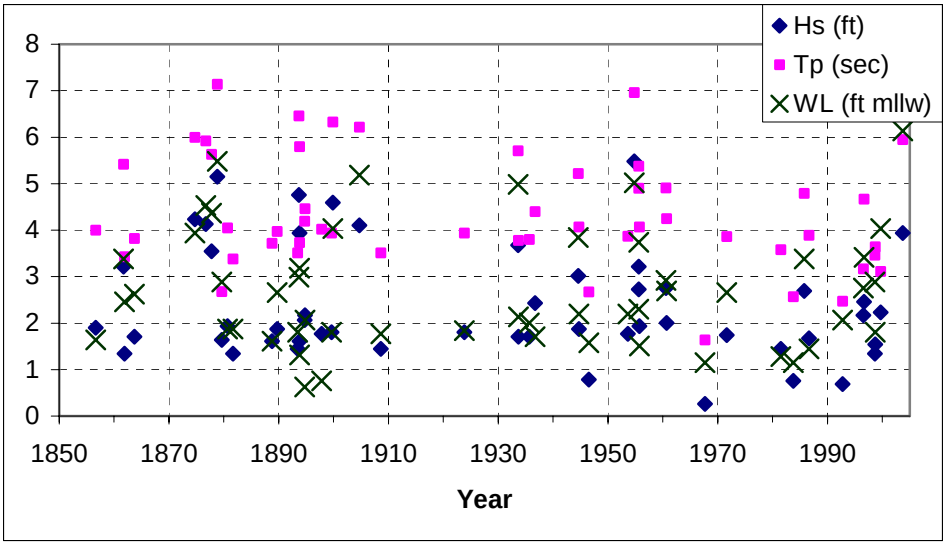


Figure 53. Maximum H_s and associated T_p , θ_p , and water level, Barren Island, Station 5, tropical storms only

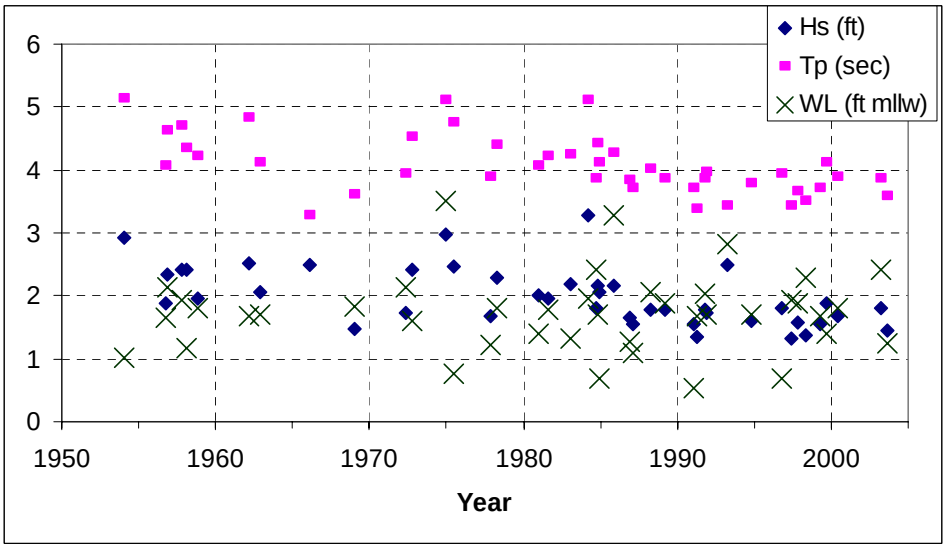


Figure 54. Maximum H_s and associated T_p , θ_p , and water level, Barren Island, Station 5, northeasters only

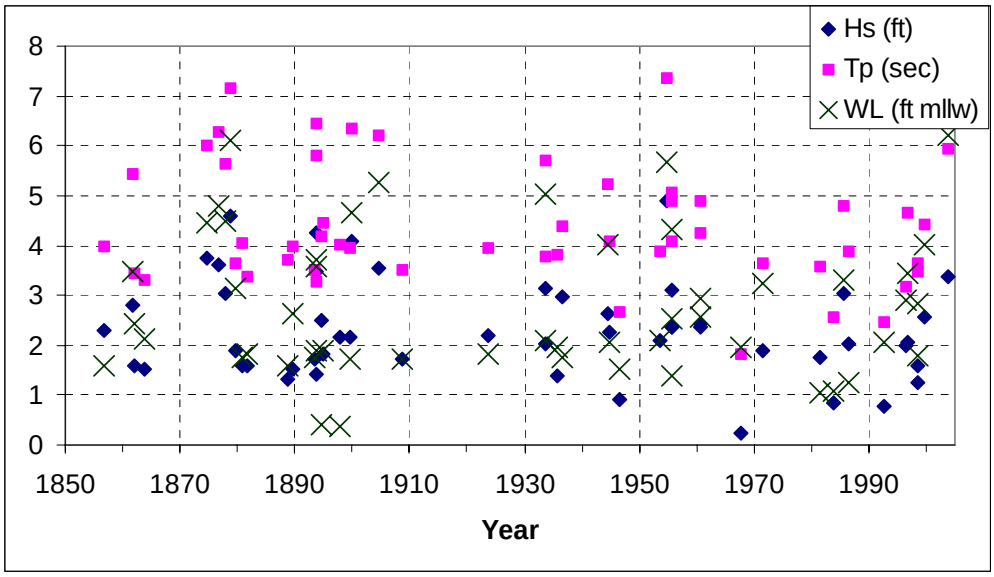


Figure 55. Maximum H_s and associated T_p , θ_p , and water level, Barren Island, Station 6, tropical storms only

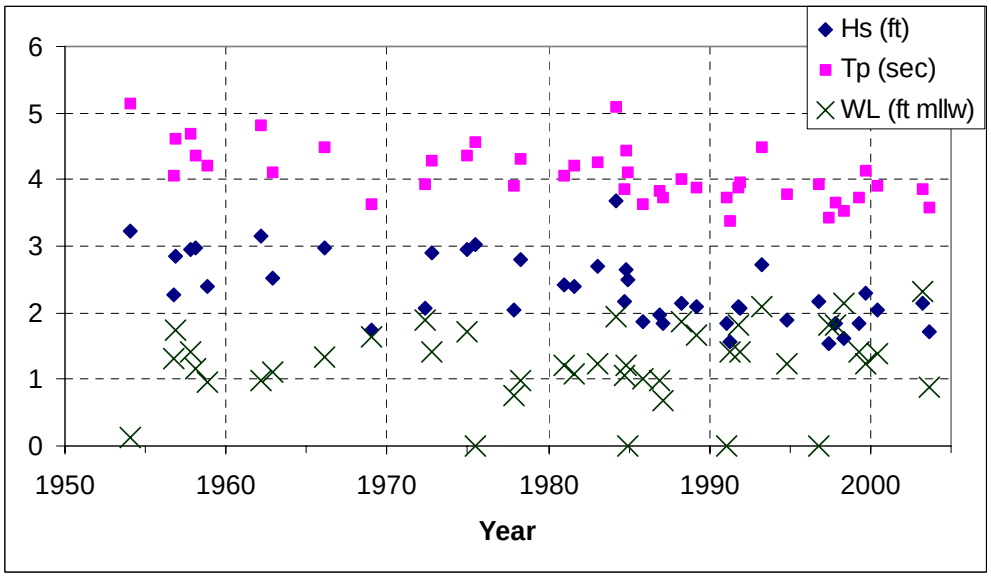


Figure 56. Maximum H_s and associated T_p , θ_p , and water level, Barren Island, Station 6, northeasters only

Simulation of Future Storm Sequences

Introduction

Simulation of future storm sequences is done with a multivariate time series Empirical Simulation Technique (EST) configured for life-cycle analysis. The EST computer program used in this study is a substantial extension and improvement of an earlier FORTRAN program described by Borgman and

Scheffner (1991). The present program was developed in conjunction with this study and a similar study at Neah Bay, WA (Melby and Thompson 2005). The updated program is written in the much more advanced and graphics-friendly software, Matlab, extends the method to treat more than three time series at multiple locations simultaneously, introduces a more uniform way to handle month-to-month transitions, and includes various improvements in the methodology which have been developed in the thirteen years since the writing of the earlier software. Although the new software version was developed specifically for this study and the Neah Bay study, it is expected to be easily adapted to other project applications.

Program Overview

The EST program consists of a suite of Matlab codes. The codes are organized into two parts:

(1) **analysis phase:** empirical data time series are transformed to equivalent multivariate pseudo-Gaussian time series and all the basic arrays needed for the simulation process are computed and stored for later use, and

(2) **simulation phase:** new pseudo-Gaussian time series are computed with frequency-domain (FFT) techniques, and then inversely transformed back to the empirical time series statistical structure.

These phases are illustrated in flowchart format in Figure 50. The components are discussed in additional detail in the following paragraphs.

Step 1: Data Preparation

The initial step is to convert the ASCII files of original wave and water level time series to Matlab data files in the *.mat format. The mat-files are highly compressed and can be easily read in subsequent programs.

The first step is to read the multiple files (one file per station) in ASCII format and organize the time series for all stations into a single large matrix.

The next step is to load arrays created by the previous program and break up the massive matrix into smaller matrices, one for each oceanic property (significant wave height, peak wave period, wave direction, and water level) at each station.

Step 2: Convert Empirical Time Series to Normal

The first intrinsic EST code unit computes empirical cumulative distribution functions and converts the empirical time series to psuedo-Gaussian time series. The basic tasks in this step are to (1) define the empirical cumulative distribution function (CDF) for each time series time step, (2) transform each data time series into an equivalent pseudo-Gaussian time series, and (3) save the inverse transform for use in the later simulation phase program. The logic and algorithms for each of these tasks are discussed below.

Step 2a – Compute Empirical CDF: The 148 years of data contain 366-day leap years embedded within the more normal 365-day years. The first step is to remove the February 29 data from the time series for special later treatment. The 148 years for the remaining days are all of length 365 and each year of each time series can be stacked into 148 columns of length 8*365 = 2,920. This number of rows for a year follows from the eight 3-hour increments in a day.

<need to update numbers to represent MidBay & Poplar study> The following scheme is used to assign a rank to the value in each row of the 2,920 by 33 matrix. Select H_s at location 5 on April 1, 0300 hours as an example for illustration purposes. There are already 33 values of H_s for April 1, 0300 hours in the row, one for each of the 33 years of data. It was decided to augment this row of values with the r days of values previous to and following the April 1, 0300 hours row. r is set to 10 days, although this choice is arbitrary and may be changed as required. The single row of H_s values at April 1, 0300 hours, together with the 10 days of H_s values on either side of the reference row gives a set of 33+2*10*8*33 = 5313 values of H_s. This set of 5313 values is ranked in order of increasing size.

Two computations are now done with this ranked set. First, an empirical CDF equal to rank/5314 is associated with each H_s, and a set of reference x values are interpolated for each fractile in a reference set Us of 61 fractiles. This is saved as the row corresponding to $\underline{H_s}$, April 1, 0300 hours in a 2920 by 61 matrix. This 2929 by 61 matrix will be extracted later in the simulation phase and used to interpolate back from the pseudo-Gaussian time series to the simulated empirical time series.

Step 2b – Convert to Pseudo-Gaussian Time Series: The second computation with the ranked set involves finding the ranks of the 33 H_s values in the April 1 0300 hour row within the 5313 ranked set. The ranks of the 33 values are used to map from the empirical time series over to the pseudo-Gaussian time series by the following procedure. Let the ranks be [r1, r2, r3, ..., r33] for the central reference row. An empirical CDF (within the total ranked set) can be determined as [r1, r2, r3, ..., r33] /5314. The Gaussian variable z determined with the Matlab command z = norminv (rj / 5314) defines the equivalent normal variate at that same fractile. The symbol, rj stands for any one of the [r1, r2, r3, ..., r33] ranks. The 33-column matrix is reshaped back into a single time series of length 33 years, except now the time series contains the Hs as mapped into the normal variate scale.

The same steps are required for the leap years special day of Feb. 29, and those fractile-transformed days have to be inserted back into the 33-year pseudo-Gaussian time series for H_s at location 5. This same process is completed for all 26 locations and all ocean properties (water level, H_s, T_p, cosine direction, and sine direction). The full set of all these pseudo-Gaussian time series is stored in the 33 year by 26 location matrices and stored in a single file. These time series are then available for cross-spectral analysis in the next step.

Step 3: Compute Cross-Spectra and Eigen Values

Step 3a - Cross-Spectral Estimation by Gaussian Smoothing: The cross-spectral analysis of the pseudo-Gaussian data time series proceeds through the following steps.

(1) The time series are transformed to the frequency domain to obtain the complex-valued Fourier coefficients .

(2) The cross-spectral estimates are obtained by smoothing the "raw" estimates.

(3) The co- and quad-spectral densities are extracted from the real and imaginary parts.

Step 3b - Statistics of the Real and Imaginary Parts of the FFT Coefficients: If the pseudo-Gaussian time series are approximated as being truly multivariate normal, then a number of consequences for the real and imaginary parts of their complex Fourier coefficients result. The most important result is that the coefficients are independent of each other for $0 < m < N/2$, and simply related by complex conjugation to the coefficients of negative frequencies in $N/2 \leq m < N$. The implication of this is that the Fourier coefficients for each frequency, $m = 1, 2, 3, \ldots, m_0$ can be created separately without destroying the cross-correlations of the time series being simulated. The intercorrelation at a given frequency integer, m, can be forced into the simulation through the covariance matrix for the real and imaginary parts of the Fourier coefficients for the various wave properties being simulated. The covariance matrix depends on the spectra and the co and quad cross-spectra.

Step 3c - Simulation of Correlated Vectors with Eigenvectors: A multivariate normal column vector, $\boldsymbol{V}$, with mean zero and covariance matrix, C, can be simulated from a vector of independent normal random numbers, $\boldsymbol{Z}$ (of same size as $\boldsymbol{V}$) , with the eigenvectors and eigenvalues of C. The columns of the orthogonal matrix G contain the eigenvectors, while L is a diagonal matrix whose elements on the diagonal are the corresponding eigenvalues. A simulation of $\boldsymbol{V}$ is given by

$$\boldsymbol{V} = \boldsymbol{G}\,\boldsymbol{L}^{1/2}\,\boldsymbol{Z} \qquad (5)$$

The Analysis phase of the Time Series EST concludes with the computation of the matrix $\boldsymbol{GL}^{1/2}$ from the covariance matrix for each m less than or equal to the cutoff, m_0.

Step 4: Synthesize Time Series

The synthesis phase of the time series EST has two steps. First the Pseudo-Gaussian time series for the wave properties are each simulated by using the ? matrices to generate the FFT coefficients and then by inverse Fourier transforming the coefficients back to time-domain. The second step is to use the empirical CDF to reverse transform the simulated pseudo-Gaussian time series back to the value scales of the original empirical data time series. The process is just the reversal of the steps in the analysis phase.

The user may wish to do a final smoothing of the time series with a selected bandwidth that may vary from one wave property to another. This post-smoothing can make the curves visually more comparable to the original input data, but also typically makes the CDF comparisons of simulations to data less in agreement.

Comparison of Simulation with Original Time Series

Chart comparisons of the simulated time series with the input data time series is a useful step for quality control.

Future Sea Level Rise

The EST life-cycle simulation can easily incorporate predicted sea level rise scenarios. First, life cycles are simulated based on historical wave and water levels, with no speculation about future sea level rise. Then, water levels during each simulated life-cycle can be increased incrementally during the life-cycle to follow the predicted trend for water level increase over the simulation time period.

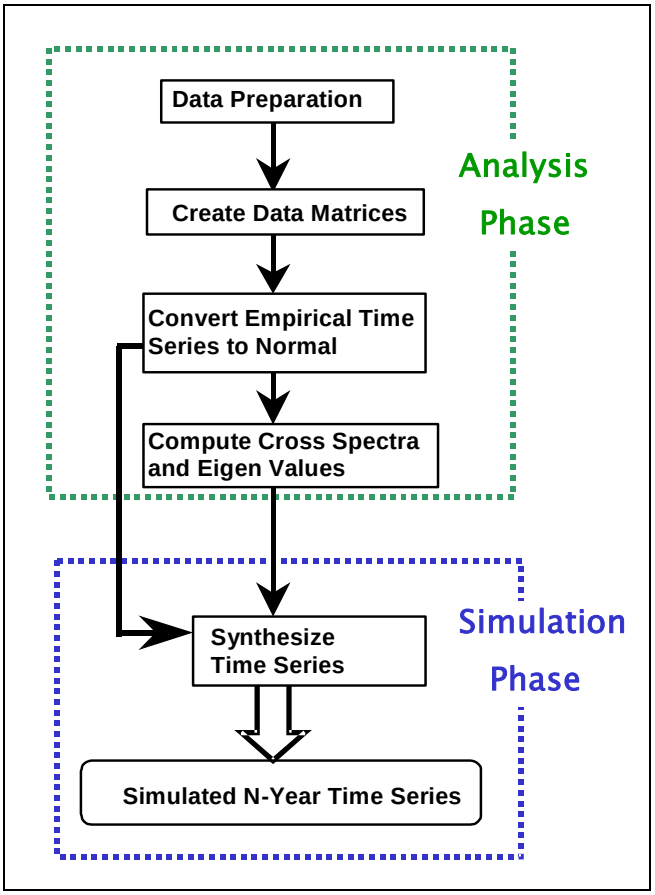


Figure 57. Flowchart of EST for life-cycle analysis

6 Life-Cycle Simulation Methodology – Structural Optimization

This chapter describes the procedures used for optimizing structure design within the framework of life-cycle simulation. Procedures are described in terms of optimizing protective structures at the three Islands: Poplar, James, and Barren. Methods discussed in the previous chapter were used to create suites of possible future 50-yr storm wave and water level life-cycles which are statistically consistent with historical information. Candidate structure designs were then subjected to storm wave and water level life cycles and the structure responses were analyzed. The optimization analysis contained herein has been developed using the latest rubble mound structure design guidance, presented in the CEM Part VI.

Overview

USACE planning policies and regulations for Civil Works water resource projects are stipulated in Engineer Regulation (ER) 1105-2-100 "Planning Guidance Notebook". The primary focus of this ER is to specify regulations required in planning projects that will produce the NED (National Economic Development) plan. The NED plan is the alternative plan with the greatest net economic benefit consistent with protecting the Nation's environment. Typically, the NED plan is the least expensive alternative over the structure economic lifetime, including first cost and maintenance costs.

Structural optimization for the Poplar Island dike was described in Maryland Port Administration (MPA) Contract report (1995). The methods for optimization contained herein are similar to those described in the MPA report. In this study, it is anticipated that the least coast dike structure cross section that prevents breaching during the economic life will provide the structure portion of the NED alternative. Therefore, the basic objective of the optimization scheme described herein is to minimize total amortized costs including maintenance and first costs with the constraint that breach failures over the economic life are to be avoided. This constraint is required to avoid large environmental costs such as sediment inundation of lobster beds or areas of sensitive submerged aquatic vegetation (SAV). First costs and maintenance costs vary depending on the design return period wave event. For shorter return period designs, the armor

will be smaller and the crest height lower. This design will cost less to construct but will produce higher maintenance costs and higher probability of breach failure. Designing for longer return periods produces a more reliable structure but costs more in up front costs. The optimal design will be a balance between first costs and maintenance costs while avoiding structural breaches.

Variables that are most influential in the optimization are the crest height, armor stone size and structure slope. Damage occurs primarily as a result of waves attacking and displacing armor stones and as a result of wave overtopping producing scour of the crest. Damage to the armor layer will progress in a predictable and continuous manner until the filter layers are exposed. At that point, the deterioration will accelerate until the structure is breached. There has been significant work recently on damage development as a result of armor stone displacement (Melby and Kobayashi 1998, 1999, 2000). However there has been little work on predicting the transition from significant damage to catastrophic breaching of the structure. Herein, we conservatively assume that the damage progresses very rapidly from exposure of the filter layers to breaching during one 3 hr increment. Damage to the crest due to overtopping is similar in that damage progresses slowly unless the overtopping exceeds a certain magnitude. At that point, the damage progresses very rapidly to a breached condition. Herein, it is assumed that, for an unarmored crest, the structure progresses from minor damage to breach within one time step of 3 hrs if the overtopping rate exceeds this value.

Structure foundation failure also influences the design. Foundation failure is not evaluated in this report. However, input to this analysis from the MPA report cited above and from the Baltimore District suggests that a seaward structure slope of 1V:3H or flatter would be optimal from a geotechnical point of view. The Baltimore District has also suggested that portions of the structure may be able to be built with a 1V:2.5H seaward slope. Therefore, for this optimization analysis, slopes of 1V:2.5H, 1V:3H, 1V:3.5H and 1V:4H were evaluated for economic optimization.

Analysis of candidate structure designs to determine an optimum design was done with a FORTRAN computer programs configured for this study. Within the programs, engineering response was computed primarily according to guidance published in the Coastal Engineering Manual (CEM). The engineering analysis was based on empirical equations given in the following sections. The step-by-step flow of the program is described in the final section of this chapter. The math models used for predicting engineering response of the structure are described in detail in the following sections.

Wave Runup and Overtopping

Wave Runup

Irregular wave runup on the structure is computed according to

$$\frac{R_{2\%}}{H_s} = 0.96\xi_{om} \qquad 1.0 < \xi_{om} \le 1.5 \tag{6}$$

$$\frac{R_{2\%}}{H_s} = 1.17\xi_{om}^{0.46} \qquad \xi_{om} > 1.5 \tag{7}$$

$$\xi_{om} = \frac{\tan\alpha}{\sqrt{s_{om}}} \qquad s_{om} = \frac{H_s}{L_{om}} \qquad L_{om} = \frac{gT_m^2}{2\pi} \tag{8}$$

where

$R_{2\%}$ = 2 percent probability of exceedance for wave runup height on the structure

H_s = significant wave height, H_{mo} in this case, where $H_{mo} = (mo)^{1/2}$ and mo is the zero moment of the incident wave spectrum

α = structure seaward slope

T_m = mean wave period

g = acceleration of gravity

tan α = structure slope from horizontal

L_{om} = deep water linear wave length based on the mean period

s_{om} = wave steepness based on the local wave height, deep water wave length, and mean period

ξ_{om} = Iribarren parameter based on the mean period

The CEM provides equations for determining irregular wave runup on a compound slope. The equations (9 - 17) are given in the following section. This technique is useful for determining the degree of runup on the upper slope of upland cells. Figure 58 shows a graphic idealization of a typical compound slope.

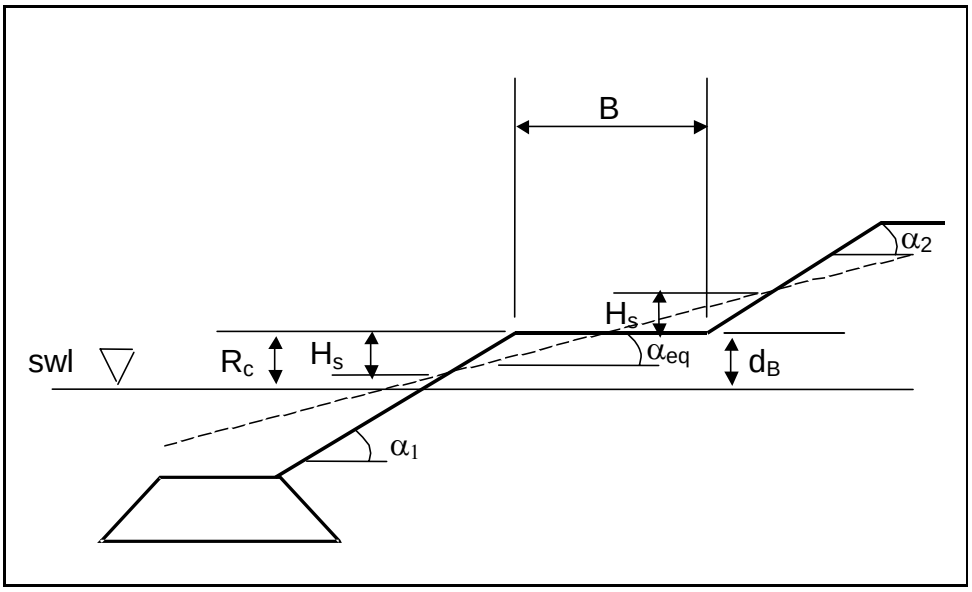


Figure 58. Definition sketch for runup on a compound slope

The runup relation for a compound slope is given by

$$\frac{R_{2\%}}{H_s} = \begin{cases} 1.5\xi_{eq}\gamma_r\gamma_h\gamma_\beta\gamma_b & for \quad 0.5 < \xi_{eq} \le 2 \\ 3.0\gamma_r\gamma_h\gamma_\beta & for \quad \xi_{eq} > 2 \end{cases} \tag{9}$$

where the equivalent Iribarren number is given by equations 10 – 17.

$$\xi_{eq} = \xi_{op}[1 - r_B(1 - r_{dB})] \qquad 0.6 \le \gamma_b \le 1.0 \tag{10}$$

$$r_B = 1 - \frac{\tan\alpha_{eq}}{\tan\alpha} \tag{11}$$

$$r_{dB} = 0.5\left(\frac{d_B}{H_s}\right)^2 \qquad 0 \le r_{dB} \le 1 \tag{12}$$

$$\xi_{op} = \frac{\tan\alpha_1}{\sqrt{s_{op}}} \tag{13}$$

$$s_{op} = \frac{H_s}{L_{op}} \qquad L_{op} = \frac{gT_p^2}{2\pi} \tag{14}$$

$$\tan\alpha_{eq} = \frac{2H_s}{B + H_s(\cot\alpha_1 + \cot\alpha_2)} \tag{15}$$

$$\tan\bar{\alpha} = \frac{2H_s}{(H_s - d_B)\cot\alpha_1 + (H_s + d_B)\cot\alpha_2} \qquad -H_s \le d_B \le H_s \tag{16}$$

$$\begin{aligned} \tan\bar{\alpha} &= \tan\alpha_1 \quad if\ d_B < -H_s \\ \tan\bar{\alpha} &= \tan\alpha_2 \quad if\ d_B > H_s \end{aligned} \tag{17}$$

where

T_p = wave period peak corresponding to the peak frequency of the energy density spectrum

R_c = dike crest freeboard

α_1 = lower structure slope

α_2 = upper structure slope

γ_r = roughness correction = 0.55 (for two layers of rock armor)

γ_b = influence of berm correction = 1.0 (for berm depth > $1.4H_s$)

γ_h = depth-limited correction = 1.0 (must assume Rayleigh distributed waves without measurements)

γ_β = wave direction and directional spreading correction = 1.0 (for mostly head-on waves)

L_{op} = Airy wave length based on the peak period

s_{op} = wave steepness based on the local wave height, deep water wave length, and peak period

ξ_{op} = Iribarren parameter based on the peak period

d_B = depth of berm crest, negative if the reference still water level is below the berm crest

If $d_B < -H_s\sqrt{2}$ then $R_{u2\%} = R_c$. If the structure is breached, then the runup is not computed.

Wave Overtopping

For an impermeable rough revetment, the volume rate of irregular wave overtopping per unit length of structure q is given by

$$\frac{q}{\sqrt{gH_s^3}}\sqrt{\frac{s_{op}}{\tan\alpha}} = 0.06\exp\left(-5.2\frac{R_c}{H_s}\frac{\sqrt{s_{op}}}{\tan\alpha}\frac{1}{\gamma_r\gamma_b\gamma_h\gamma_\beta}\right) \tag{18}$$

$$for \quad \xi_{op} < 2 \quad and \quad 0.3 < \frac{R_c}{H_s}\sqrt{\frac{s_{op}}{\tan\alpha}}\frac{1}{\gamma_r\gamma_b\gamma_h\gamma_\beta} < 2 \tag{19}$$

and

$$\frac{q}{\sqrt{gH_s^3}} = 0.2\exp\left(-2.6\frac{R_c}{H_s}\frac{1}{\gamma_r\gamma_b\gamma_h\gamma_\beta}\right) \tag{20}$$

$$for \quad \xi_{op} > 2$$

According to CEM Table VI-5-6, significant damage to a non-paved revetment crest will occur if $50 < q < 200$ liters/s/m ($4.0 < q < 16.1$ gal/s/ft). In this study a lower limit of $q = 0.05$ m^3/s/m (4.0 gal/s/ft) was used for non-paved revetment crests. For paved or lightly armored crests, the lower limit value used was $q = 0.2$ m^3/s/m (16.1 gal/s/ft). For heavily armored crests, it was assumed that the main armor extended up over crest. If the structure was breached, then the crest height was assumed to fall to the reference water level (mllw) and overtopping was computed for that crest height. The values of coefficients γ_r, γ_b, γ_h, γ_β were conservatively set as discussed in the preceding section.

Wave Overtopping Transmission

Barren Island includes a low-crested offshore structure as an alternative for the southern section. The primary functional criterion for design of this structure is overtopping transmission. Overtopping transmission $C_t = (H_{mo})_t/(H_{mo})_i$ was computed using the following relations

$$C_t = \left(0.031\frac{H_s}{D_{n50}} - 0.24\right)\frac{R_c}{D_{n50}} + b \qquad 0.60 \le C_t \le 0.15 \tag{21}$$

$$b = -2.6s_{op} - 0.05\frac{H_s}{D_{n50}} + 0.85 \tag{22}$$

where $(H_{mo})_t$ is the transmitted significant wave height and $(H_{mo})_i = H_s$ is the incident significant wave height. The freeboard R_c was computed for both overtopping calculations using the return period water levels listed in Tables J1 – J6.

Armor Stability

The Hudson Equation is well known and has been used for years to determine armor stability. The equation in stability number form is given by

$$N_s = \frac{H_s}{\Delta D_{n50}} = (K_D \cot \alpha)^{1/3} \tag{23}$$

where $\Delta = S_r - 1$, $S_r = \rho_r/\rho_w$ = specific gravity of stone, ρ_r = density of stone, ρ_w density of water, $D_{n50} = (V_{50})^{1/3}$ = nominal stone diameter, $V_{50} = M_{50}/\rho_r$ = median volume of armor stone, M_{50} = median mass, K_D = empirical coefficient and cot α = structure seaward slope. K_D takes into account all parameters not in the equation. The appropriate irregular wave height statistic has been discussed by many authors. Melby (2000) notes that recent guidance suggests H_s is reasonable if using K_D values published in the SPM. The Hudson equation design assumes damage based on eroded volume of $D\% = 0$ to 5.

Van der Meer proposed equations in the late 1980's that are based solely on irregular wave experiments and explicitly include more parameters. These relations were given as

For plunging waves where $\xi_{om} < \xi_{mc}$:

$$N_s = \frac{H_s}{\Delta D_{n50}} = 8.7P^{0.18}\left(\frac{S}{\sqrt{N_z}}\right)^{0.2} \xi_{om}^{-0.5} \tag{24}$$

For surging waves where $\xi_{om} > \xi_{mc}$:

$$N_s = \frac{H_s}{\Delta D_{n50}} = 1.4P^{-0.13}\left(\frac{S}{\sqrt{N_z}}\right)^{0.2} \sqrt{\cot \alpha}\,\xi_{om}^{P} \tag{25}$$

where

$$\xi_{mc} = [6.2P^{0.31}\sqrt{\tan \alpha}]^{\left(\frac{1}{P+0.5}\right)} \tag{26}$$

Here P = notional permeability, S = eroded area or damage, and N_z = storm duration/T_m. Damage levels given by S = 1 to 3 represent the start of damage and correspond to Hudson's D% = 0 to 5. For an impermeable dike, P = 0.1.

The wave height required in these equations is the significant H_s. Van der Meer suggested using the $H_{2\%}$ for application in shallow water. The stability equations for shallow water are identical except that the Rayleigh relation $H_{2\%} = 1.4H_s$ is substituted. The statistic $H_{2\%}$ must be determined from actual measured time series of water surface elevation in shallow water. If $H_{2\%}$ is determined from a synthetic distribution, as it was for this study, a Rayleigh distribution must be assumed. In this case, the equations using $H_{2\%}$ are identical to those based on H_s. Further, Equations 24 - 26 were developed from primarily intermediate depth lab tests and do not explicitely incorporate depth. Therefore, equations 24 - 26 are for primarily intermediate to deep-water applications and are not directly applicable to Poplar Island where waves are mostly depth-limited.

Melby and Hughes (2003) proposed stone stability equations specifically for both deep and shallow water applications. They derived stability equations based on the maximum momentum flux and fit to van der Meer's data. The fit was slightly better than that of equations 24 - 26. They noted that the equations were based on first principles and would therefore be applicable to a wider range of conditions. In the following, the background for the maximum wave momentum flux is given.

Assuming irrotational potential flow on a locally flat bottom in water depth h, the wave-averaged and depth-integrated radiation stress is given by

$$M = S_{xx} = \frac{1}{L}\int_0^L \int_{-h}^{\eta_x} (p_d + \rho_w u^2) dz dx \qquad (27)$$

where L is the wave length, η_x is the free surface location, p_d is the dynamic pressure, ρ_w is the fluid density, u is the velocity in the x-direction, x is the horizontal coordinate, and z is the vertical coordinate. The maximum depth-integrated wave momentum flux is given by

$$(M_F)_{\max} = \int_{-h}^{\eta_x} (p_d + \rho u^2) dx \qquad (28)$$

Using linear wave theory values for u and p_d yields

$$\left(\frac{(M_F)_{\max}}{\rho_w g h^2}\right)_{\max} = \frac{1}{2}\frac{H}{h}\frac{\tanh kh}{kh} + \frac{1}{8}\left(\frac{H}{h}\right)^2\left[1 + \frac{2kh}{\sinh 2kh}\right] \qquad (29)$$

where g is the acceleration of gravity, H is the wave height, and $k = 2\pi/L$ is the wave number. In Equation 29, the first term on the right hand side is the dynamic pressure term while the second is the velocity term. In general, the pressure term will dominate. For example, for low steepness waves, the velocity term will only contribute 5 percent to the maximum momentum flux. For waves in shallow water at the steepness limit, the velocity term will provide the maximum contribution, roughly 30 percent of the momentum flux. Equation 29 assumes waves to be periodic and sinusoidal. But in shallow water, waves are nonlinear with peaked crests and shallow troughs. The wave forces from these nonlinear waves can be very different from those resulting from linear waves. Equation 29 will under predict the momentum under the nonlinear wave crest.

The maximum wave momentum flux is highly nonlinear for nonlinear waves - steep waves in shallow water. This corresponds to the case where armor stability is at its minimum. It is desirable to develop a relation that can characterize the stability over the full range of water depths expected. Hughes (2004) approximated the non-linear wave momentum flux using a numerical Fourier solution. The resulting approximate relation was found to be

$$\left(\frac{M_F}{\rho_w g h^2}\right)_{\max} = A_0\left(\frac{h}{gT_m^2}\right)^{-A_1}$$

$$A_0 = 0.639\left(\frac{H_s}{h}\right)^{2.026} \qquad (30)$$

$$A_1 = 0.180\left(\frac{H_s}{h}\right)^{-0.391}$$

Use of a nonlinear approximation for momentum flux is important because stability is at its minimum when the incident wave is the most nonlinear.

Two stability equations resulted from the fit to data using Equation 30. The recommended equations for stability were

Plunging Waves

$$N_m = 5.0(S/N_z^{0.5})^{0.2} P^{0.18}\sqrt{\cot\theta} \qquad s_m \geq s_{mc} \qquad (31)$$

Surging Waves

$$N_m = 5.0(S / N_z^{0.5})^{0.2} P^{0.18} (\cot\theta)^{0.5-P} s_m^{-P/3} \qquad s_m < s_{mc} \qquad (32)$$

where

$$s_{mc} = -0.0035\cot\theta + 0.03316 \qquad (33)$$

and

$$N_m = \left(\frac{K_a[(M_F)_{\max} / \gamma_w h^2]}{(S_r - 1)} \right)^{1/2} \frac{h}{D_n} \qquad (34)$$

with $K_a = 1$.

Equations 31 and 32 are analogous to Equations 24 and 25 and Equation 34 with Equation 30 is analogous to Equation 23. It is clear that the wave forcing portion given by equations 30 – 35 provides a more rigorous prediction of the incident wave effect on stability. The inclusion of depth explicitly in Equation 34 through the maximum momentum flux is a significant improvement over Equation 24 - 25. The wave-structure interaction portion described by the right hand side of Equations 31 and 32 is similar to that given in the van der Meer equations. Equations 30 – 34 are used herein to predict zero-damage stone size for the toe layer as well as the armor layer for each return period wave condition at each station.

Accumulated Damage

Although relations 24 – 26 and 31 – 33 provide a way to predict damage on a structure, the damage is for constant wave conditions. The CEM provides equations to predict the normalized eroded cross sectional area as a function of time for varying wave and water level conditions. The normalized eroded area as a function of time is given as

$$\overline{S}(t) = \overline{S}(t_n) + a_p N_{mo}^{5} T_p^{-b} (t^b - t_n^b) \quad for \quad t_n \le t \le t_{n+1} \qquad (35)$$

where $\overline{S}(t_n) = A_e/D^2_{n50}$ is the mean damage at time t_n, A_e is the mean eroded cross sectional area, $N_{mo} = H_{mo}/\Delta D_{n50}$ is the stability number, and a_p and b are empirical parameters. A similar equation uses time domain wave parameters. The calibrated parameter values are $a_p = 0.022$ and $b = 0.25$. Note that S can be thought of as the number of stones displaced from a D_{n50}-wide cross section. The

standard deviation of S was given as a function of the mean $\overline{S}(t_n)$ by the relation $\sigma_S = 0.5\overline{S}^{0.65}$. This standard deviation describes the alongshore variability of damage. Also given were relations for maximum depth of erosion, minimum remaining cover depth, and length of the eroded hole. The maximum eroded depth is d_e, minimum remaining cover depth is d_c, and maximum eroded length is l_e. These three parameters are normalized to obtain $E = d_e/D_{n50}$, $C = d_c/D_{n50}$, and $L = l_e/D_{n50}$. Melby and Kobayashi (1998a) expressed the key profile parameters as a function of the mean damage as follows: $\overline{E} = 0.46\overline{S}^{0.5}$, $\overline{C} = C_o - 0.1\overline{S}$, $\overline{L} = 0.44\overline{S}^{0.5}$ where C_o is the initial armor layer thickness.

A modification to Equation 35 was introduced by Melby and Kobayashi (1999) to allow for non-zero initial damage values. The modified equation is

$$\begin{aligned} \overline{S}(t) &= 0.011\, N_s^5 (N_e + \delta N)^{0.25} \\ N_e &= \left(\frac{\overline{S}(t_n)}{0.011\, N_s^5} \right)^4 \\ \delta N &= (t - t_n)/T_m \qquad for \qquad t_n \le t \le t_{n+1} \end{aligned} \tag{36}$$

This equation is similar to Equation 35 but predicted damage is not dependent on the time that the simulation begins. Within this report, accumulated mean eroded area is predicted using Equation 36 if the zero damage condition is exceeded at any point in the time series. The mean plus one standard deviation of damage is used for design. The parameters E, C, and L are also predicted if the zero-damage level is exceeded.

Toe Stability

The toe berm for Poplar Island can be either emergent or submerged, depending on the water level, because the toe berm crest was built to +0.3 m (1 ft) mllw. Stability equations are given in the CEM for a submerged toe berm and for a low crested structure but not for a sometimes-emergent toe berm.

In the CEM, the low crested structure median stable weight W_{50} is determined using the following equations

$$\frac{h_c'}{h} = (2.1 + 0.1S)\exp(-0.14N_s^*) \tag{37}$$

$$N_s^* = -\left(\frac{1}{0.14}\right)\ln\left(\frac{h_c'}{h}\frac{1}{(2.1 + 0.1S)}\right) \tag{38}$$

$$W_{50} = \gamma_r D_{n50}^3 = \gamma_r \left(\frac{H_s s_p^{-1/3}}{\Delta N_s^*} \right) \tag{39}$$

$$s_p = \frac{H_s}{L_p} \qquad \Delta = S_r - 1 = \frac{\rho_r}{\rho_w} - 1 \tag{40}$$

where

h'_c = height of toe berm above bottom

h = water depth seaward of toe berm

N_s* = spectral stability number

L_p = wave length corresponding to peak spectral frequency at toe of structure

W_{50} = median stone weight

γ_r = stone specific weight

The stable toe berm stability number is given by

$$N_s = \left(0.24 \frac{h_b}{D_{n50}} + 1.6 \right) N_{od}^{0.15} \tag{41}$$

or, rearranging, the nominal diameter is given by

$$D_{n50} = 0.625 \frac{H_s}{\Delta N_{od}^{0.15}} - 0.15 h_b \tag{42}$$

where

N_{od} = 2 for acceptable damage

h_b = height of water surface above berm crest

= h - 1.0 ft - h_{MLLW}

Equations 41 - 42 are limited to the condition where $0.4 < h_b / h_s < 0.9$. Within this analysis, for structure crests closer to the water level, Equations 37 - 40 are used as they produce a more conservative stone size.

Low-crested Rubble Mound Breakwater Stability

As stated earlier, the southern extension to the Barren Island structure was proposed to be an offshore low-crested rubble mound breakwater. The stable weight for a traditional rubble mound structure was discussed earlier in the Chapter. Equations 31 – 34 assume a traditional two-stone thick armor layer and filter layers below the armor as well as a stable toe. These equations also assume little or no overtopping. The stable weights from Equations 31 – 34 were modified for the heavily overtopped low structure crest as required. The low crest stability modification suggested by the CEM in Table VI-5-24 was used. The modification reduces the stable armor weight by a small amount, the amount increasing as the crest approaches the still water level. The reduction is limited to emergent structures. The reduction relation is given by

$$f_i = \left(1.25 - 4.8 \frac{R_c}{H_s} \sqrt{\frac{s_{op}}{2\pi}} \right)^{-1} \qquad 0.8 \le f_i \le 1.0$$
$$0 < \frac{R_c}{H_s} \sqrt{\frac{s_{op}}{2\pi}} < 0.052 \tag{43}$$

and is applied to the nominal median diameter. So in the stability equations, D_{n50} is replaced by $f_i D_{n50}$. The equation above is limited to $R_c > 0$. For these calculations, if the structure crest was submerged for the given return period depth, the water level was lowered to the crest and the wave height reduced to the breaking limit according to the relation $H_b = 0.6h$, where h is the depth for the computation of stable weight. The breaker height index of 0.6 was appropriate for this site due to the shallow sloping bathymetry and range of wave periods. This value was used to limit all historical wave heights as discussed in Chapter 5.

As stated above, the calculations are for emergent structures only. This method results in a more conservative stone size than if a submerged armor weight stability equation was used and is reasonable considering that the water levels during storms will vary widely. For the condition where the water level is even with the structure crest, the reduction in D_{n50} was 20 percent. As the freeboard approached 2 - 3 ft, f_i approached 1.0, depending on the wave height and wave period.

Economic Present Worth

The relation to determine the present worth of first cost and future maintenance costs is

$$PW_m = C_m \left[\frac{1+i}{1+p} \right]^{N_m} \tag{44}$$

where

PW_m = present worth of cost C_m

C_m = cost m in today's dollars

i = inflation rate = 0.03

p = prime interest rate = 0.05375

N_m = number of years between today and date of cost C_m

Corps policy for determining the NED alternative dictates that the inflation rate is zero so that benefits are not inflated. However, this minimizes the importance of repairs in out years. For the Chesapeake Bay islands, infrequent hurricanes can cause significant damage including structure breaching. If these major repairs are required in the latter half of the economic life, they will have a negligible contribution to the total present worth cost if the inflation is assumed to be zero. Baltimore District engineers suggested that they would like to minimize the potential for these large breaches and associated repairs because a breach will result in sediment contamination of important ecological areas (e.g. Lobster beds and SAV areas). As such, it was determined that an inflation rate should be used in the simulations. The inflation rate was set at 0.03. Cleanup cost for sediment contamination is not incorporated in this analysis. However, it is expected that environmental cleanup would increase the repair costs for a breach significantly.

The total present worth PW_T is computed by simply summing all of the PW_m values.

$$PW_T = \sum_{m=1}^{N} PW_m \tag{45}$$

The present worth total cost can be annualized using the relation

$$A_T = PW_T \left[\frac{r(1+r)^N}{(1+r)^N - 1} \right] \tag{46}$$

where r = annualizing interest rate = 0.05375 and N = economic design life of structure = 50 years.

A cost relation was derived to account for the fact that structure length of constant cross section will typically be significantly longer than the repair length. The final total cost for a section of structure of constant cross section is given by

$$PW_T / L_s = \left[\sum FMC + \sum \frac{FFC}{L_s} \right] \left(\frac{1}{1+p} \right)^{lag} + \frac{L_r}{L_s} \sum \left[\left(RMC + \frac{RFC}{L_r} \right) \left(\frac{1}{1+p} \right)^{N_{mr}} \right] \quad (47)$$

where

L_s = Length of structure of constant cross section

L_r = Length of repair

lag = Time until initial construction

FMC = Initial construction material costs per unit length of structure (e.g. armor layer cost for initial construction)

FFC/L_s = Initial construction fixed costs per unit length of structure (e.g. mobilization cost)

RMC = Repair material costs per unit length of structure

RFC/L_r = Repair fixed costs per unit length of repair

Herein, PW_T was computed for several ratios of L_r/L_s. The length of sections between STWAVE stations on Poplar Island is roughly 244 - 1463 m (800 to 4000 ft). The repair length for breaches and associated repairs on Poplar Island from Hurricane Isabel was roughly 122 m (400 ft). Therefore, $L_r/L_s = 0.1 – 0.5$. It is assumed that other islands would be similar. For this study, L_r/L_s values used were 0.1, 0.3, and 0.5. A value of 0.3 was used for most calculations as an average. The present worth per unit structure length resulting from Equation 47 can be multiplied by L_s for each section to get total present worth cost for that section. Ranges for *FMC*, FFC/L_s, *RMC*, and RFC/L_r were developed based on the initial construction costs for Poplar Island and hurricane Isabel repair of the Phase II southern dike. The ranges are given in Table 29.

Structure Life-Cycle Analysis Program

The structure analysis process developed for this study is summarized in more detail in the following paragraphs. Chronological historical or simulated waves and water levels at the toe of the structure were placed in a file named *wavefile.txt*. Wave parameters were significant wave height and peak wave period, typically at 3 hr intervals. Water levels were referenced to some datum, in this study mllw. Given historical waves and water levels at the toe of the structure, the long-term distribution of maximum storm significant wave heights was determined. From that distribution, wave heights and corresponding wave periods and water levels were chosen for representative return periods ranging from 5 yrs to 100 yrs. The above wave and water level analysis were discussed

in more detail in Chapter 5. The structural analysis for each STWAVE station is as follows:

1) Assemble analysis constants, material descriptions, and material costs and update program input file *Damage-Input.txt*. There is a unique input file for each STWAVE station. The computed extremal wave height, wave period and water level for each return period are also placed in this input file. Table 28 lists input file parameters that were assigned constant values in the simulations. Table 29 lists input file parameters that varied among the simulations and gives the range of values simulated.

2) Program LC_COST_REV.EXE is run. This program reads *wavefile.txt* and *Damage-Input.txt*. The program computes a representative zero-damage cross-section for each return period wave condition. The fixed parameters used in this calculation that are read from *Damage-Input.txt* are stone density, crest height, depth relative to mllw, zero-damage levels for armor and toe, number of waves at mean period for zero-damage computation, structure permeability, structure slope and toe berm crest height. Values computed include:

a. Armor Weights. Primary median armor weight, W_{a50}, based on stability Equations 31 - 34 and toe median armor weight, W_{ta50}, based on stability Equations 37 - 42. For low-crested structure, armor size is modified according to Equation 43.

b. Filter layer and core material sizes. Filter layer median weight $W_{u50} = W_{a50}/10$ for primary armor. Filter layer median weight $W_{tu50} = W_{ta50}/10$ for toe armor. The bedding material was assumed to be quarry run material. The road surface was assumed to be graded gravel. The core of the dike structures was assumed to be sand.

c. Armor and filter layer thicknesses. The armor layer thickness was computed as $t_a = 2D_{n50}$ while the filter layer thickness was computed as $t_u = 2D_{u50}$ where $D_{u50} = (W_{u50}/\gamma_r)^{1/3}$

d. Cross sectional area of each material for the given cross section.

e. Initial cost of cross section. This cost was used for both initial cost and breach repair cost. Any sand fill is not included in this calculation.

3) For each return period and corresponding cross-sectional design, the program steps through the historical wave file computing zero-damage stability number and actual stability number based on Equations 31 - 34 at each time step. If the zero-damage stability number is exceeded, then damage is computed and accumulated using Equation 36. If damage exceeds either the minor damage or the breach damage limits, the repair flag is set and a time counter is started. The structure is repaired to its original condition if the mobilization time limits for minor repair or breach repair are exceeded, depending on the level of damage. At that point, all counters and damage levels are reset to zero. The damage limits as well as the repair time

limits are inputs in file *Damage_Input.txt*. Note that if minor damage is caused by a storm, greater damage or even a breach could result on the damaged structure before the repair mobilization time is completed. If a breach occurs on an already damaged structure, the repair counter is restarted as it is assumed that mobilization and funding for breach repair are significantly different than mobilization for minor repair.

4) Wave runup and wave overtopping are computed at each time step using Equations 6 - 20. If wave overtopping exceeds the predefined damage limits, then a breach of the section is assumed to occur. In this case, the time counter is started. The structure is repaired to its original condition if the time limits for breach repair are exceeded. If the structure is a low-crested, overtopping transmission is computed.

5) Present worth costs per unit length are computed for initial cost and for each repair that is instigated. Note that there is no cost associated with damage unless a repair occurs. Present worth costs are accumulated throughout the life cycle.

6) Output from the program includes summaries of all damage, overtopping and repair as well as overall summaries. An economic detail file of all repairs and an economic summary file are also output. A time history of damage, runup, and overtopping is written. Initial material volumes and material costs are also output for each return period cross section in summary files. Cumulative damage, repairs, and costs are also output at each event as they occur.

Table 28
Fixed Parameter Values

Parameter	Variable	Value
Permeability	P	0.1
Porosity	Por	0.38
Stone Specific Gravity	S_r	2.578
Stone Density	ρ_r	2.644 tonnes/m^3 (165 pcf)
Minor Repair Limit	S_M	8
Breach Repair Limit	S_B	18
Minor Repair Time Limit	-	180 days
Breach Repair Time Limit	–	120 days
Roughness Parameter	γ_b	0.55
Crest Width	B	7.62 m (25 ft)
Upper Structure Slope	α_2	1V:3H
Toe Berm Height	d_B	+0.305 m (1 ft) mllw
Toe Berm Seaward Slope	cot φ	2
Toe Berm Leeward Slope	cot β	1.5
Toe Berm Crest Width	-	$4D_{toe}$
Toe Armor Thickness	-	$2D_{toe}$
Allowable Main Armor Damage	S	1.0
Allowable Toe Damage	N_{od}	1.0
Number of Waves for Zero Damage	N_z	7000
Inflation or Escalation Rate	i	0.03 or 0.0
Interest Rate	R	0.05375
Economic Life	N	50 years
Armor Material Unit Cost	-	$56/tonne ($50.4/ton)
Filter Material Unit Cost	-	$39/tonne ($35.1/ton)
Bedding Material Unit Cost	-	$44/tonne ($39.6/ton)
Quarry-run Material Unit Cost	-	$44/tonne ($539.6/ton)
Geotechnical Material Unit Cost	-	$4.78/$m^2$ ($0.44/$ft^2$)
Lag Before Initial Construction	Lag	2

Table 29
Parameter Ranges

Parameter	Variable	Values
Overtopping Limit	q_{allow}	0.05, 0.20 m^3/s/m (4.0 gal/s/ft, 16.1 gal/s/ft)
Structure Crest Height	R_c	2.44, 2.59, 2.74, 2.90, 3.05, 3.20, 3.35 m (8.0, 8.5, 9.0, 9.5, 10.0, 10.5, 11.0 ft)
Fixed First Cost	FFC/L_s	$500/m, $1000/m ($152/ft, $305/ft)
Fixed Repair Cost	RFC/L_r	$2500/m, $1000/m ($762/ft, $305/ft)
Structure Slopes	Cot α	2.5, 3.0, 4.0
Ratio of repair length to section length	L_r/L_s	0.1, 0.3, 0.5

7 Life-Cycle Simulation Results, Poplar Island

This chapter describes the results produced for Poplar Island using life-cycle simulation of waves, water levels, and structure response. Wave and water level results are presented in the following section. Methods used to develop these results are discussed in Chapter 5. Structure response and optimization are presented in the second section of this chapter. The methodology used to optimize design of Poplar Island protective structures is given in Chapter 6. For this preliminary draft report, only the historical wave climate has been used to analyze the structure. The empirical simulation technique summarized in Chapter 5 has not been employed.

Waves and Water Levels

The extremal H_s for various return periods at each Poplar Island station are shown in Figure 59. The results are tabulated and plotted independently for each station in Appendix B in order to provide more background information. Stations with an open exposure toward the south experience the highest waves. These are also the stations most dominated by hurricanes. North- and east-facing stations along the north end of Poplar Island are less dominated by hurricanes. Return period H_s is relatively low at these stations and the difference in H_s between the shortest and longest return periods is relatively small. For example, of the stations around the proposed extension, three have some exposure toward the south. Stations 33 and 34 face west but are also open to the south-southwest. Station 39, on the relatively protected backside of the island, also has some exposure toward the south, though it is partially obstructed by Poplar and Coaches Islands. Return period H_s at stations 33 through 39 follow a smooth variation around the proposed expansion for return periods up to about 40 - 50 years. For longer return periods, the impact of hurricanes causes a noticeable increase in H_s at Stations 33, 34, and 39 relative to the other stations. Return period values of peak wave period and water level from this analysis are illustrated in Figures 53 and 54.

Tables B1 – B16 in Appendix B summarize extremal waves for Poplar Island Stations 1 – 16. Extremal waves for the north extension Poplar Island Stations 33 – 39 are summarized in Tables B17 – B23. Figures B1 – B7 in Appendix B illustrate the data in Tables B17 – B23 for the north extension.

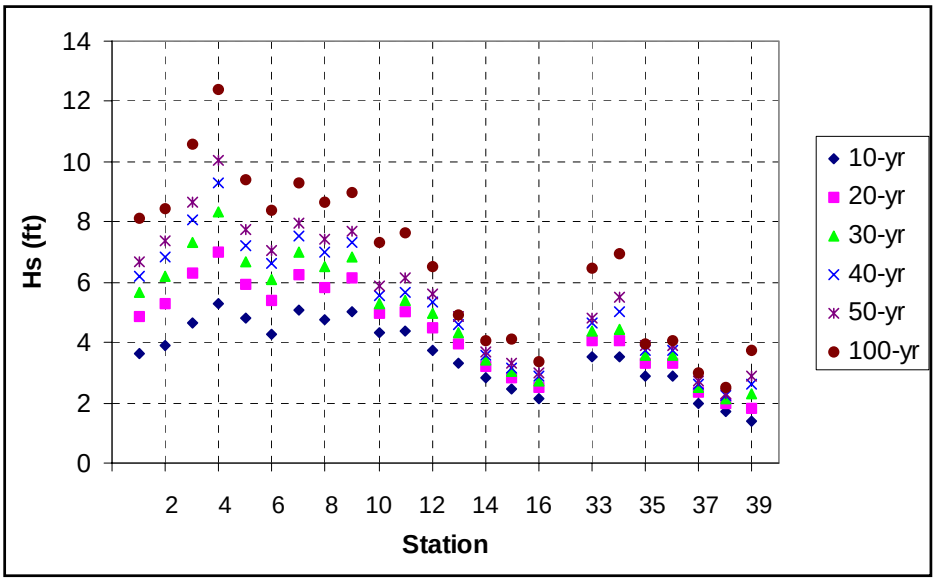


Figure 59. Return period H_s at nearshore stations, Poplar Island

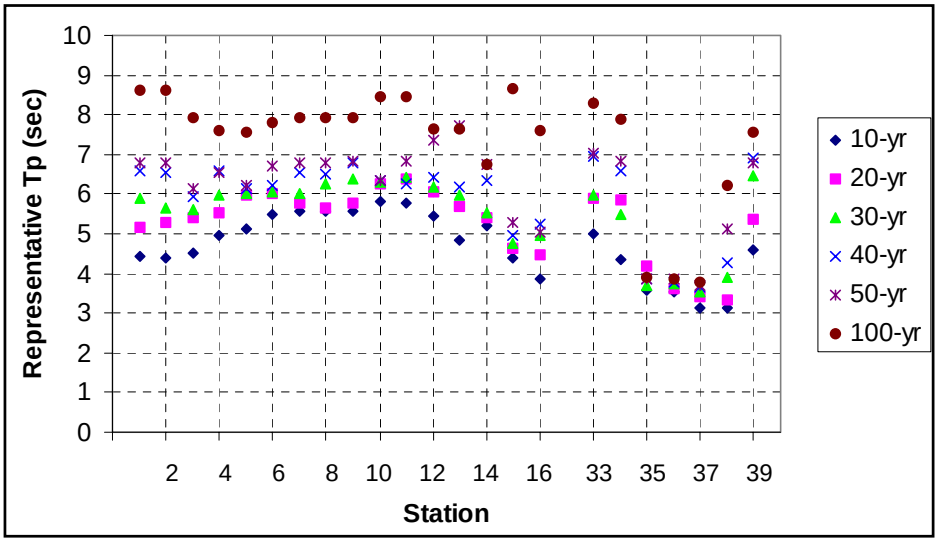


Figure 60. Return period T_p at nearshore stations, Poplar Island

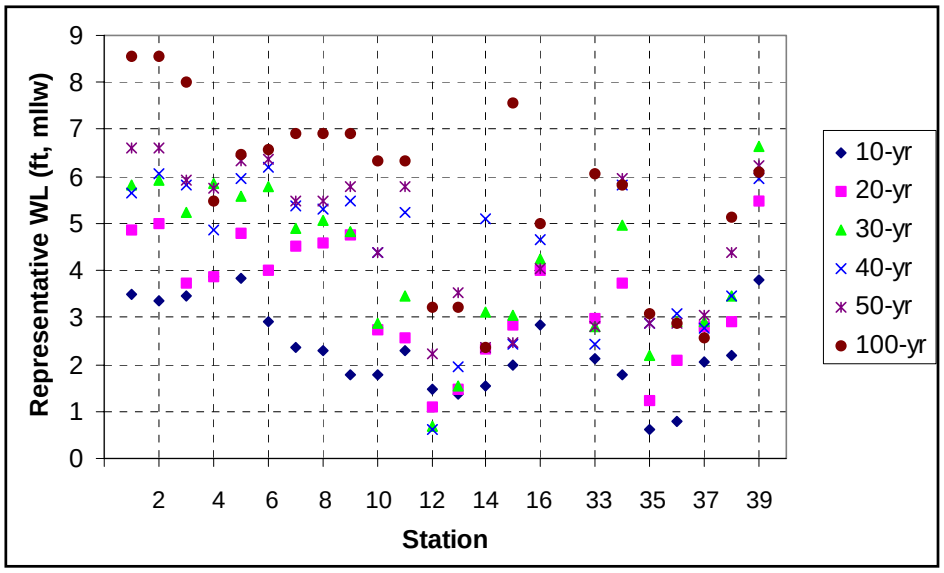


Figure 61. Return period water level at nearshore stations, Poplar Island

Extreme water levels were also analyzed for Poplar Island. The Fisher-Tippet Distribution was fit to the data. Table B24 lists extreme water level as a function of return period for northeaster storms for water level analysis Station 1 (see Figure 19). Table B25 lists extreme water level as a function of return period for hurricanes.

Structural Optimization for Least Cost

The structural optimization for Poplar Island for the historical wave climate is separated into two parts: optimization for least cost and optimization for fewest repairs. The computer program LC_COST_REV was used to analyze a large number of parametric permutations for each STWAVE station in order to determine the best alternative. All cross-sections had the general geometry of cross sections constructed for Phases I and II as shown in Figure 62. The layer thicknesses were assumed to be $2D_{a50}$ for armor, $2D_{u50}$ for filter layer, 0.3 m (1 ft) for bedding layer, 20 cm (8 inches) for rock roadway and $2D_{ta50}$ for toe armor. Here $D_{a50} = (V_{50})^{1/3} = (W_{50}/\gamma_r)^{1/3}$ is the nominal diameter of the armor corresponding to the 50 percent exceedance level on the weight distribution curve. Similarly, D_{u50} is the filter layer 50 percent exceedance nominal diameter and D_{ta50} is the toe armor 50 percent exceedance nominal diameter.

The filter layer thickness under the toe armor was determined by fixing the toe crest elevation at +0.3 m (1 ft) mllw and requiring the crest armor thickness to be $2D_{ta50}$. The filter layer was sized such that $W_u = W_a/10$. The bedding material was assumed to be crushed gravel sized material.

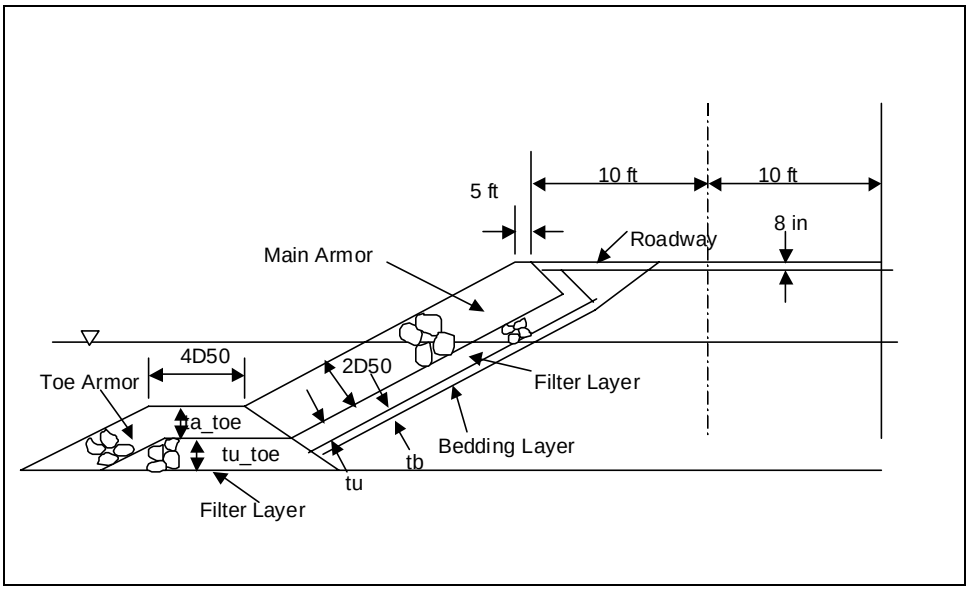


Figure 62. General revetment cross section

The fixed input parameters for the analysis were summarized in Table 28 and parameters that were varied were listed in Table 29 in Chapter 6. The depth relative to mllw and extremal wave parameters were unique for each station and were input for each run.

Overtopping limits of 0.05 m^3/s/m (4.0 gal/s/ft), corresponding to an unarmored crest, 0.2 m^3/s/m (16.1 gal/s/ft), corresponding to a paved crest, and 1000 m^3/s/m (80,519 gal/s/ft), corresponding to a heavily armored crest, were used in the optimization. Crest stability design guidance is very crude. The CEM and the CIRIA Rock Manual both contain equations for crest armor stability. However, the empirical equations provide nothing better than a crude estimate of the stable stone weight. All applicable equations and figures were investigated in order to determine stable crest armor requirements for Poplar Island. Although estimates of stable weight varied by a factor of 4 or more between the different methods, three of the methods agreed to within roughly 20 percent and the average estimated stone weights were within roughly 10 percent of the primary structure armor weight. Therefore, in this study, we have assumed that the *heavily armored* crest is armored with a single layer of main armor.

Crest Armoring

1. Unarmored – gravel on geotextile, overtopping limit = 0.05 m^3/s/m (4.0 gal/s/ft). Consequence of exceeding overtopping limit is structure breach.
2. Paved – Asphalt pavement, overtopping limit = 0.20 m^3/s/m (16.1 gal/s/ft). Consequence of exceeding overtopping limit is structure breach.

3. Heavily Armored – Single layer of main armor on filter layers, overtopping limit = 1000 m^3/s/m (80,519 gal/s/ft). Will never reach overtopping limit. Stone sized for 2 percent displacement by count for return period wave conditions.

Armor Stability

Figures and Tables in Appendix B show the significant wave height, peak period and depth as a function of return period from the extremal wave height analysis discussed previously. Each STWAVE station is shown on a separate plot. In general the wave heights are lower than reported in previous Poplar Island design reports. In Appendix C, Figures C1 – C8 show the stable main armor weight as a function of return period for each STWAVE station of the north extension of Poplar Island. In general the results for a seaward structure slope of cot α = 3.0 are shown. The results for cot α = 2.5 for station 1 are shown for comparison. The figures show results for the stability relations listed in Chapter 6: Melby and Hughes (2004), van der Meer (1988), and Hudson (1958). The Melby and Hughes and van der Meer relations agree very well as they are based on the same data set. The relative magnitude of the two methods alternates depending on a number of factors. The Hudson equation is not conservative for this analysis because it is consistently under-predicting the armor stone size. The Hudson and van der Meer equations do not include the effect of water depth. The van der Meer relations are primarily based on intermediate depth tests with only a few shallow water tests covering a very narrow range of breaking wave conditions. Therefore, they are not optimal for shallow water applications like Poplar Island. The Melby and Hughes relation is presumed to be more accurate than the other two equations because it includes water depth explicitly. Therefore, herein, the Melby and Hughes stability relations are used exclusively.

Figures D9 – D38 in Appendix D show present worth as a function of return period and illustrate the results of the structural optimization. The costs shown are per running meter (3.28 ft) of structure. These results were based on a value of inflation of 0.0. Figure D9 shows costs for 2 structure crest heights for Station 33: 2.44 m (8 ft) and 2.74 m (9 ft), mllw. Costs change dramatically between return periods of 5 years and 10 years. That is because there is a lot of damage and subsequent repair costs for the small armor stone corresponding to the 5-year return period. However, much of this damage is eliminated when the stone size is increased slightly. It can be seen that the repair costs are high for the lower crest height while the repair costs are near zero for the higher crest height for return periods greater than 10 years. Also, the repair costs are almost constant over the range of return periods greater than 5 years. The reason for this is that Hurricane Isabel is at the beginning of the time series. This hurricane causes breaching of the structure for the low crest height but not for the higher crest height. Further, the breaching occurs regardless of the armor stone size because it is caused by overtopping. Other hurricanes cause similar breaching but they are too far into the time series to result in significant present worth cost. The predominant effect of this one hurricane illustrates the need for the simulation analysis with many realizations of the historical storm climate.

Figure D16 shows present worth cost for a number of crest heights and the steepest slope for Station 33. The optimal crest height is R_c = 2.74 m (9 ft) for this section and occurs for a return period of 10 years. The remainder of the figures illustrate similar findings for different stations. Table 30 shows results of the cost minimization analysis for each station. Table 31 shows the stable main armor and toe armor sizes for the various stations. Several conclusions can be drawn from these results as follows:

1. For several stations, the costs are not dependent on the stone size past the minimum point of the cost curve. This is true of stations 35, 36, 37 and 38.
2. The crest armoring always was more costly than an unarmored crest.
3. The steepest allowable structure slope of cot a = 2.5 was always the least cost
4. The minimum cost return period steadily increases as one proceeds clockwise around the island from station 33 until station 38 where it decreases again.
5. The stable armor stone size decreases as one proceeds clockwise around the island from station 33.
6. The largest armor stone size is at station 33 and is 956 lbs.
7. The stable armor stone size decreases dramatically at station 37 to 333 lbs.
8. It appears that design can be reduced to 2 unique cross sections: Station 33 – 36 combined using Station 33 cross section and Stations 37 - 39 combined using Station 37 cross section.
9. Costs are nearly constant over the range of fixed costs used.
10. There is not a significant cost penalty for shallower structure slopes because the stone size decreases as the structure slope decreases and the number of failures resulting from overtopping also decrease.
11. There is not a significant cost penalty for higher crest heights because of the decrease in repair costs.
12. Including inflation and including some extraneous costs associated with failure, like cleanup, will change the relative costs. For more significant repair costs, the more reliable structures with larger stone sizes, armored crests, and higher crest heights will likely be more economical.

Table 30
Least Cost Analysis Results for the Historical Storm Time Series

Station	Overtopping Limit m3/s/m	Crest Height m	Slope cot α	Return Period yrs	Total Cost
33	0.05	2.74	2.5	10	$4200/m
	0.2	2.44	2.5	10	$4535/m
34	0.05	3.35	2.5	10	$4469/m
	0.2	2.59	2.5	10	$4729/m
35	0.05	2.44	2.5	25	$3827/m
	0.2	2.44	2.5	25	$4232/m
36	0.05	2.44	2.5	30	$3578/m
	0.2	2.44	2.5	35	$4009/m
37	0.05	2.44	2.5	30	$3280/m
	0.2	2.44	2.5	30	$3588/m
38	0.05	2.44	2.5	20	$2716/m
	0.2	2.44	2.5	20	$2917/m
39	0.05	2.59	2.5	10	$2144/m
	0.2	2.44	2.5	10	$2322/m

Table 31
Least Cost Analysis Cross Sections

Station	Overtopping Limit m3/s/m	Armor Mass in tonnes	Toe Armor Mass in tonnes	Armor Weight in lbs	Toe Armor Weight in lbs
33	0.05	0.43	1.04	956	2311
	0.2	0.43	1.04	956	2311
34	0.05	0.37	0.98	822	2178
	0.2	0.37	0.98	822	2178
35	0.05	0.31	0.91	689	2022
	0.2	0.31	0.91	689	2022
36	0.05	0.36	0.95	800	2111
	0.2	0.36	0.95	800	2111
37	0.05	0.15	0.74	333	1644
	0.2	0.15	0.74	333	1644
38	0.05	0.08	0.62	178	1378
	0.2	0.08	0.62	178	1378
39	0.05	0.05	0.56	111	1244
	0.2	0.05	0.56	111	1244

Structural Optimization for Minimum Repairs

A number of trials were run with program LC_COST_REV in order to define damage throughout the life of the structure. This analysis facilitates selecting the option with the most reliability. Inflation was included in this analysis. The input wave conditions were only the historical. The results are summarized in the following two sections.

Stability Failure

To isolate failure of the structure from stability, the crest elevation was set just high enough so that there would be no failures resulting from overtopping. The constant parameters for this analysis are listed in Table 32. The resulting stone sizes are listed in Table 33. The following section provides a brief summary of damage for each station.

Table 32
Fixed Parameter Values

Parameter	Variable	Value
Permeabilitv	P	0.1
Porosity	Por	0.38
Stone Specific Gravity	S_r	2.578
Stone Density	ρ_r	2.644 tonnes/m^3 (165 pcf)
Minor Repair Limit	S_M	8
Breach Repair Limit	S_B	18
Minor Repair Time Limit	-	180 days
Breach Repair Time Limit	–	120 days
Roughness Parameter	γ_b	0.55
Crest Width	B	7.62 m (25 ft)
Upper Structure Slope	α_2	1V:3H
Toe Berm Height	d_B	+0.305 m (1 ft) mllw
Toe Berm Seaward Slope	cot φ	2
Toe Berm Leeward Slope	cot β	1.5
Toe Berm Crest Width	-	$4D_{toe}$
Toe Armor Thickness	-	$2D_{toe}$
Allowable Main Armor Damage	S	1.0
Allowable Toe Damage	N_{od}	1.0
Number of Waves for Zero Damage	N_z	7000
Inflation or Escalation Rate	i	0.03
Interest Rate	R	0.05375
Economic Life	N	50 years
Armor Material Unit Cost	-	$56/tonne ($50.4/ton)
Filter Material Unit Cost	-	$39/tonne ($35.1/ton)
Bedding Material Unit Cost	-	$44/tonne ($39.6/ton)
Quarry-run Material Unit Cost	-	$44/tonne ($539.6/ton)
Geotechnical Material Unit Cost	-	$4.78/$m^2$ ($0.44/$ft^2$)
Lag Before Initial Construction	Lag	2
Fixed First Cost	FFC/L_s	$500/m ($152/ft)
Fixed Repair Cost	RFC/L_r	$2500/m ($762/ft)
Structure Slopes	Cot α	3.0
Ratio of repair length to section	L_r/L_s	0.3

Station 33 - Return period of 5 yr has 7 breaches resulting from stability. For 10-yr return period, the number of breaches drops to 3. For return periods of 15 yr, the number of breaches drops to 1 and there are no breaches for longer return periods.

Station 34 – Return period of 5 yr has 5 breaches resulting from stability. For 10 and 15 yr return periods, the number of breaches drops to 3. For return periods of 20 – 30 yr, the number of breaches drops to 2, for 35 yr, 1 breach, and there are no breaches for 40 yr return period and longer.

Station 35 – Return period of 5 yr has 6 breaches resulting from stability. No breaches for return periods longer than 5 yr.

Station 36 – Return period of 5 yr has 8 breaches resulting from stability. For return period of 10 yr, the number of breaches drops to 1 and there are no breaches for longer return periods.

Station 37 – Return period of 5 yr has 6 breaches resulting from stability. No breaches for return periods longer than 5 yr.

Station 38 – Return period of 5 yr has 5 breaches resulting from stability. For return periods of 10 and 15 yr, the number of breaches drops to 1 and there are no breaches for longer return periods.

Station 39 – Return period of 5 yr has 7 breaches resulting from stability. For 10 yr return period, the number of breaches drops to 4. For return period of 15 yr, the number of breaches drops to 3. For 20 – 25 yr, the number of breaches drops to 2, and there are no breaches for 30 yr return period and longer.

Table 34 and Figure 63 summarize the breaches resulting from instability. It is clear that there is little possibility for failure due to armor instability if the structure cross sections are designed for return periods of 35 or greater.

Table 33
Stable Stone Weights for all Stations and Several Return Periods for Poplar Island

Main Armor Stable Stone Weight Wa50 in lb

Station	Return Period				
	10 yr	20 yr	30 yr	40 yr	50 yr
33	718	1193	1422	1802	2020
34	622	1178	1387	2249	2849
35	318	518	560	653	713
36	313	453	567	642	724
37	113	180	229	267	287
38	76	120	164	202	264
39	71	164	324	473	578

Underlayer Stable Stone Weight Wu50 in lb

Station	Return Period				
	10 yr	20 yr	30 yr	40 yr	50 yr
33	72	119	142	180	202
34	62	118	139	225	285
35	32	52	56	65	71
36	31	45	57	64	72
37	11	18	23	27	29
38	8	12	16	20	26
39	7	16	32	47	58

Toe Armor Stable Stone Weight Wt50 in lb

Station	Return Period				
	10 yr	20 yr	30 yr	40 yr	50 yr
33	2318	2729	2876	3142	3244
34	2180	2707	2800	3276	3513
35	1758	2064	2051	2158	2209
36	1751	1938	2071	2147	2222
37	1291	1491	1602	1678	1718
38	1173	1349	1500	1602	1756
39	1227	1571	1929	2180	2309

Table 34
Number of Breaches due to Armor Instability as a function of return period for Historical Wave Conditions for Poplar Island

Station	Return Period										
	5	10	15	20	25	30	35	40	45	50	100
33	7	3	1	0	0	0	0	0	0	0	0
34	5	3	3	2	2	2	1	0	0	0	0
35	6	0	0	0	0	0	0	0	0	0	0
36	8	1	0	0	0	0	0	0	0	0	0
37	6	0	0	0	0	0	0	0	0	0	0
38	5	1	1	0	0	0	0	0	0	0	0
39	7	4	3	2	2	0	0	0	0	0	0

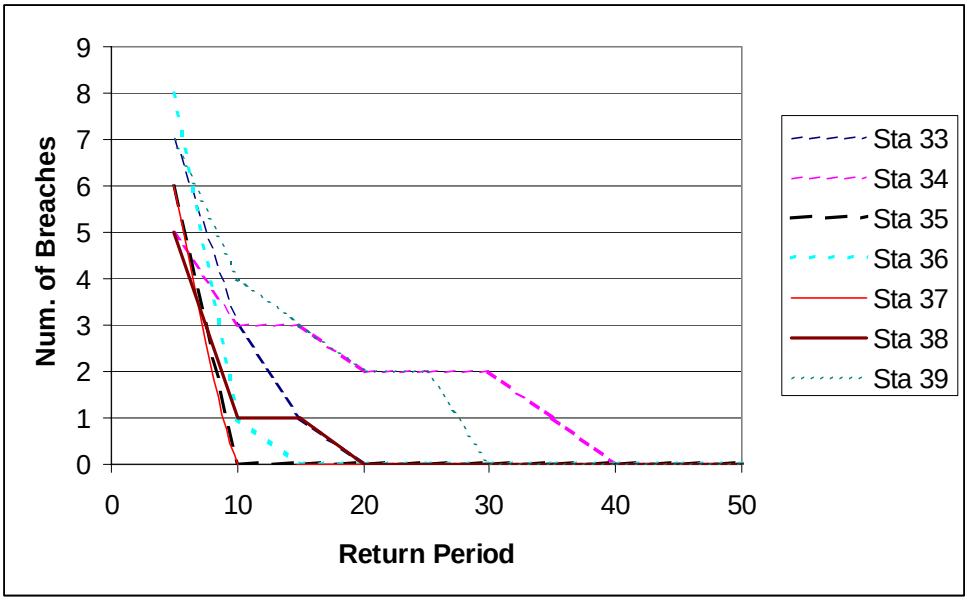


Figure 63. Number of breaches due to armor instability as a function of return period for historical wave conditions for Poplar Island

Overtopping Failure

Most breach failures are due to both instability and overtopping for low return periods and relatively low structure crest heights. However, as stated in the previous section, instability failures did not occur for return periods greater than 35 yrs. So, to isolate breach failures due to overtopping as a function of crest height, only return periods greater than 30 yrs were considered. The number of breaches due to overtopping as a function of return period was constant for these longer return periods. The constant parameters for this analysis are listed in Table 33.

For all stations, overtopping was analyzed for both paved crests and unarmored crest. Herein we assume that if crest armoring equivalent in size to the main structure armor is used, then there will be no damage due to overtopping. Breaches from overtopping are summarized in the following lists and in Tables 35 and 36.

Station 33

Heavily Armored Crest - No breaches resulting from overtopping

Paved Crest

For 8 – 11 ft crest height, 2 breaches occur for Hurricanes Isabel and Hazel

For crest heights of 11.5 ft or higher, no breaches occur

Unarmored Crest

For 8 ft crest height, 5 breaches occur

For 9 ft crest height, 3 breaches occur

For 10 – 13 ft crest height, 2 breaches occur for Hurricanes Isabel and Hazel

For crest heights of 14 ft or higher, no breaches occur

Hurricane Isabel was in 2003 and Hazel was in 1953. Other breaches occurred from 2 other extra tropical storms in mid-1950's and early 1960's.

Station 34

Heavily Armored Crest - No breaches resulting from overtopping

Paved Crest

For 8 ft crest height, 3 breaches occur

For 9 – 11.5 ft crest height, 2 breaches occur for Hurricanes Isabel and Hazel

For 12 ft crest height, 1 breach occurs

For crest heights of 13 ft or higher, 0 breaches occur

Unarmored Crest

For 8 - 9 ft crest height, 5 breaches occur

For 10 - 14 ft crest height, 2 breaches occur Hurricanes Isabel and Hazel

For crest heights of 15 ft or higher, no breaches occur

Station 35

Heavily Armored Crest - No breaches resulting from overtopping

Paved Crest - For 8 ft crest height or higher, no breaches occur

Unarmored Crest - For 8 ft crest height or higher, no breaches occur

Station 36

Heavily Armored Crest - No breaches resulting from overtopping

Paved Crest - For 8 ft crest height or higher, no breaches occur

Unarmored Crest - For 8 ft crest height or higher, no breaches occur

Station 37

Heavily Armored Crest - No breaches resulting from overtopping

Paved Crest - For 8 ft crest height or higher, no breaches occur

Unarmored Crest - For 8 ft crest height or higher, no breaches occur

Station 38

Heavily Armored Crest - No breaches resulting from overtopping

Paved Crest - For 8 ft crest height or higher, no breaches occur

Unarmored Crest

For 8 ft crest height, 2 breaches occur

For 9 ft crest height or higher, no breaches occur

Station 39

Heavily Armored Crest - No breaches resulting from overtopping

Paved Crest

For 8 – 9 ft crest height, 2 breaches occur

For 10 ft crest height or higher, 0 breaches occur

Unarmored Crest

For 8 ft crest height, 3 breaches occur

For 9 – 10.5 ft crest height, 2 breaches occur

For 11 ft crest height, 1 breach occurs

For crest heights of 11.5 ft or higher, 0 breaches occur

Table 35
Number of Breaches of Unarmored Crest due to Overtopping as a function of return period and Crest Height for Historical Wave Conditions for Poplar Island

Station	Crest Height in ft								
	8	9	10	11	12	13	14	15	16
33	5	3	2	2	2	2	0	0	0
34	5	5	2	2	2	2	2	0	0
35	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0
38	2	0	0	0	0	0	0	0	0
39	2	2	0	0	0	0	0	0	0

Table 36
Number of Breaches of Paved Crest due to Overtopping as a function of return period and Crest Height for Historical Wave Conditions for Poplar Island

Station	Crest Height in ft								
	8	9	10	11	12	13	14	15	16
33	2	2	2	2	0	0	0	0	0
34	3	2	2	2	1	0	0	0	0
35	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0
39	2	2	0	0	0	0	0	0	0

Summary and Recommendations

The recommended cross sections for this preliminary analysis are as follows:

8 Life-Cycle Simulation Results, James Island

This chapter describes the results produced for James Island using life-cycle simulation of waves, water levels, and structure response. Wave and water level results are presented in the following section. Methods used to develop these results are discussed in Chapter 5. Structure response and optimization are presented in the second section of this chapter. The methodology used to optimize design of protective structures is given in Chapter 6. For this preliminary draft report, only the historical wave climate has been used to analyze the structure. The empirical simulation technique summarized in Chapter 5 has not been employed.

Waves and Water Levels

The extremal H_s for various return periods at each station is shown in Figure 64. Stations with an open exposure toward the south experience the highest waves. These are also the stations most dominated by hurricanes. North- and east-facing stations (1, 9 – 13) are less dominated by hurricanes. Return period H_s is relatively low at these stations and the difference in H_s between the shortest and longest return periods is relatively small. Peak wave period and water level are shown as functions of return period for stations around James Island in Figures 65 and 66, respectively. Tables F1 – F13 in Appendix F summarize extremal waves for James Island Stations 1 – 13. Extreme water levels were also analyzed for James Island. The Fisher-Tippet distribution was fit to the data. Table F14 lists extreme water level as a function of return period for northeaster storms for water level analysis Station 3. Table F15 lists extreme water level as a function of return period for hurricanes.

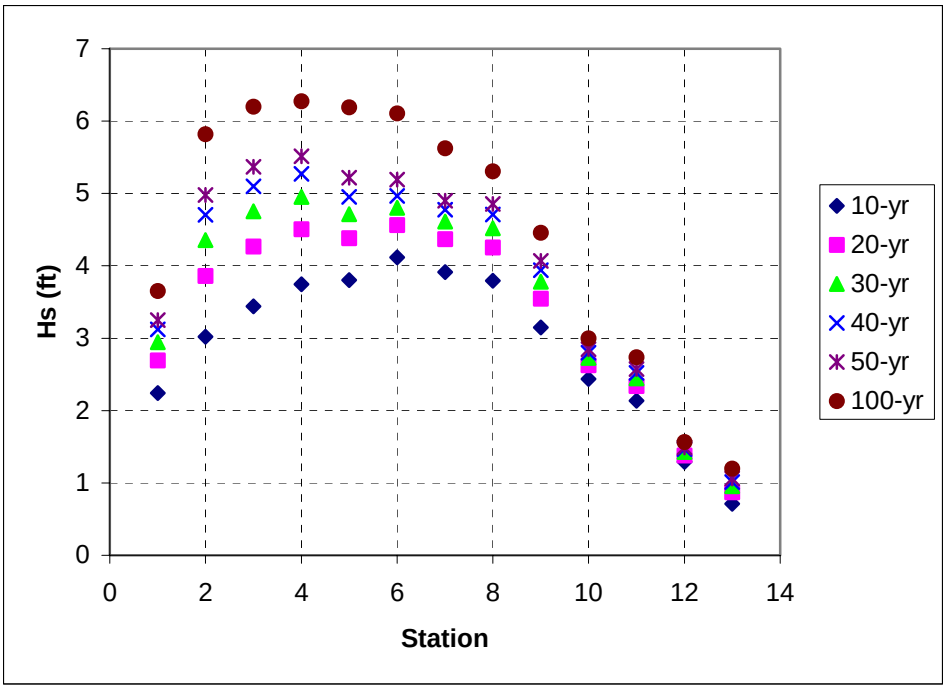


Figure 64. Return period H_s at nearshore stations, James Island

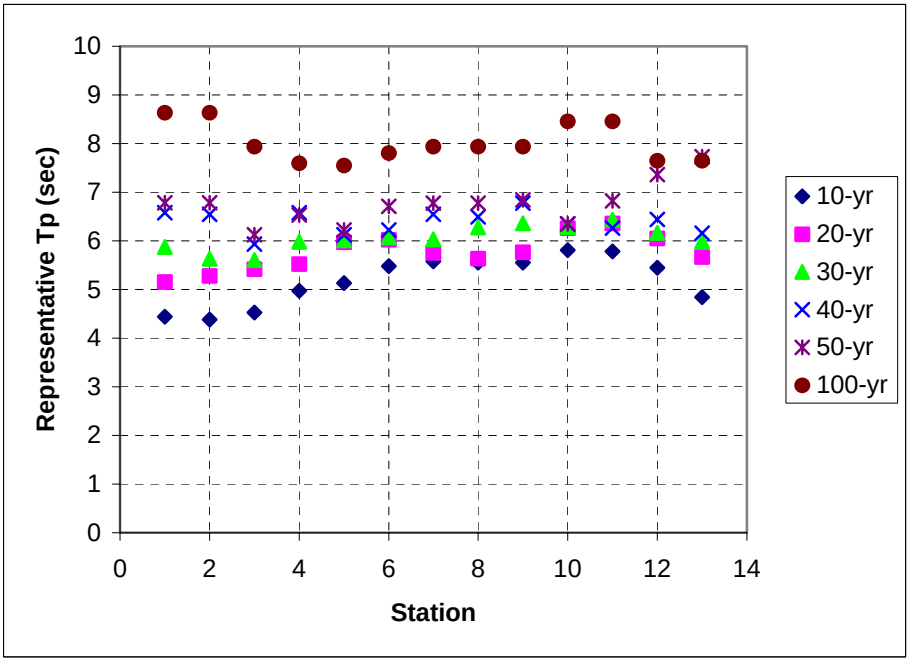


Figure 65. Return period T_p at nearshore stations, James Island

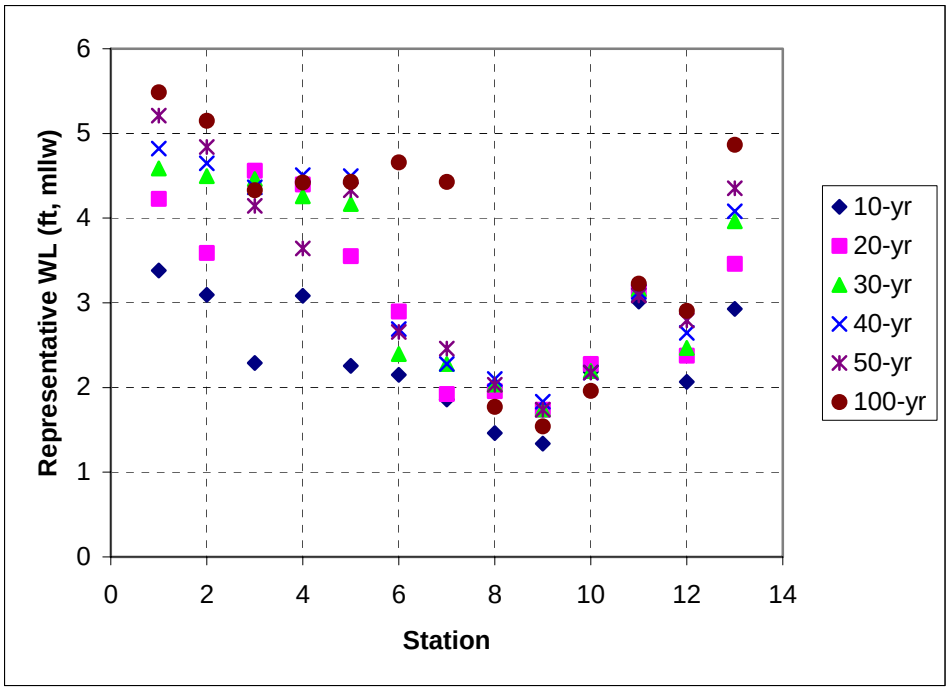


Figure 66. Return period water level at nearshore stations, James Island

Structural Optimization

The computer program LC_COST_REV was used to analyze a large number of parametric permutations for each STWAVE station in order to determine the least cost alternative. All cross-sections of the dike had the general geometry of the Poplar Island dike as shown in Figure 67. The layer thicknesses were assumed to be $2D_{a50}$ for armor, $2D_{u50}$ for filter layer, 1 ft for bedding layer, 8 inches for rock roadway and $2D_{ta50}$ for toe armor. Here $D_{a50} = (V_{50})^{1/3} = (W_{50}/\gamma_r)^{1/3}$ is the nominal diameter of the armor weight corresponding to the 50 percent exceedance level on the weight distribution curve. Similarly, D_{u50} is the filter layer 50 percent exceedance nominal diameter and D_{ta50} is the toe armor 50 percent exceedance nominal diameter.

The filter layer thickness under the toe armor was set by assuming that the toe crest elevation was at +1 ft MLLW and the crest armor thickness was $2D_{ta50}$. The filter layer was sized such that $W_u = W_a/10$. The bedding material was assumed to be crushed gravel sized material.

The fixed input parameters for the analysis were summarized in Table 28 and parameters that were varied were listed in Table 29 in Chapter 6. The depth relative to mllw and extremal wave parameters were unique for each station and were input for each run.

Overtopping limits of 0.05 $m^3/s/m$ (4.0 gal/s/ft), corresponding to an unarmored crest, 0.2 $m^3/s/m$ (16.1 gal/s/ft), corresponding to a paved crest, and 1000 $m^3/s/m$ (80,519 gal/s/ft), corresponding to a heavily armored crest, were used in the optimization. Crest stability design guidance for a heavily armored crest is crude. The CEM and the CIRIA Rock Manual both contain equations for

crest armor stability. However, the empirical equations provide nothing better than crude estimates of stable stone weight. All applicable equations and figures were investigated in order to determine stable crest armor requirements for James Island. Although estimates of stable weight varied by a factor of 4 or more between the different methods, three of the methods agreed to within roughly 20 percent and the average estimated stone weight was within roughly 10 percent of the primary or main structure armor weight. Therefore, in this study, we have assumed that the *heavily armored* crest is armored with a single layer of main armor. The crest armoring options are summarized as follows:

Crest Armoring

1. Unarmored – gravel on geotextile, overtopping limit = 0.05 m^3/s/m (4.0 gal/s/ft). Consequence of exceeding overtopping limit is structure breach.
2. Paved – Asphalt pavement, overtopping limit = 0.20 m^3/s/m (16.1 gal/s/ft). Consequence of exceeding overtopping limit is structure breach.
3. Heavily Armored – Single layer of main armor on filter layers, overtopping limit = 1000 m^3/s/m (80,519 gal/s/ft). Will never reach overtopping limit. Stone sized for 2 percent displacement by count for return period wave conditions.

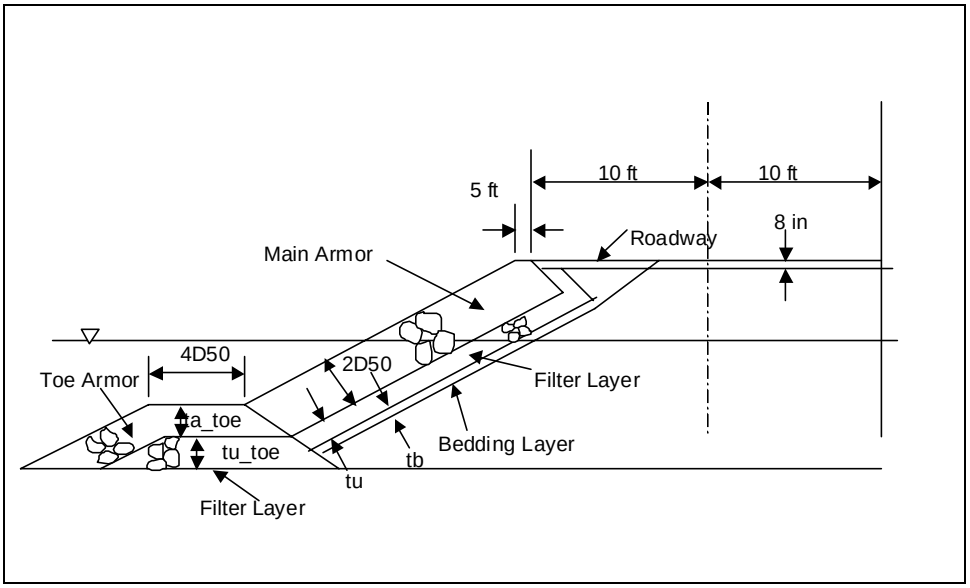


Figure 67. General revetment cross section

Armor Stability

Tables in Appendix F show the extremal wave height analysis discussed previously. Figures F1 – F13 show the significant wave height, peak period and depth relative to mllw as a function of return period for STWAVE stations 1 - 13. Tables G1 – G13 in Appendix G show the stable main armor weight, stable toe armor weight, and stable underlayer weight as a function of return period for

each STWAVE station of James Island. The stability relations of Melby and Hughes (2004), and toe stability relations of Chapter 6 were used to calculate these values.

A number of trials were run with program LC_COST_REV in order to define damage throughout the life of the structure. The input wave conditions were only the historical. The results are summarized in the following two sections.

To isolate failure of the structure from stability, the results for a heavily armored crest were used so that there would be no failures resulting from overtopping. The constant parameters for this analysis are listed in Table 37. The resulting stone sizes are listed in Appendix G. Table 38 summarizes the breaches resulting from instability. Table 39 summarizes the minor damage repairs resulting from instability. It is clear that there is no more than one failure or breach due to armor instability for all stations and all historical storms over 148 yrs if the structure cross-sections are designed for return periods of 30 yrs or greater. There is no more than one repair for return periods of 35 yrs or more. Table 40 summarizes the stable stone sizes for the 35 yr return period condition.

Table 37
Fixed Parameter Values

Parameter	Variable	Value
Permeabilitv	P	0.1
Porosity	Por	0.38
Stone Specific Gravity	S_r	2.578
Stone Density	ρ_r	2.644 tonnes/m^3 (165 pcf)
Minor Repair Limit	S_M	8
Breach Repair Limit	S_B	18
Minor Repair Time Limit	-	180 days
Breach Repair Time Limit	–	120 days
Roughness Parameter	γ_b	0.55
Crest Width	B	7.62 m (25 ft)
Upper Structure Slope	α_2	1V:3H
Toe Berm Height	d_B	+0.305 m (1 ft) mllw
Toe Berm Seaward Slope	cot φ	2
Toe Berm Leeward Slope	cot β	1.5
Toe Berm Crest Width	-	$4D_{toe}$
Toe Armor Thickness	-	$2D_{toe}$
Allowable Main Armor Damage	*S*	1.0
Allowable Toe Damage	N_{od}	1.0
Number of Waves for Zero Damage	N_z	7000
Inflation or Escalation Rate	*i*	0.03
Interest Rate	*R*	0.05375
Economic Life	*N*	50 years
Armor Material Unit Cost	-	$56/tonne ($50.4/ton)
Filter Material Unit Cost	-	$39/tonne ($35.1/ton)
Bedding Material Unit Cost	-	$44/tonne ($39.6/ton)
Quarry-run Material Unit Cost	-	$44/tonne ($539.6/ton)
Geotechnical Material Unit Cost	-	$4.78/$m^2$ ($0.44/$ft^2$)
Lag Before Initial Construction	Lag	2
Fixed First Cost	FFC/L_s	$500/m ($152/ft)
Fixed Repair Cost	RFC/L_r	$2500/m ($762/ft)
Structure Slopes	Cot α	3.0
Ratio of repair length to section	L_r/L_s	0.3

Table 38. Number of Breaches due to Armor Instability as a function of return period for Historical Wave Conditions for James Island

Station	Return Period										
	5	10	15	20	25	30	35	40	45	50	100
1	11	2	2	1	2	0	1	1	1	0	0
2	12	5	3	1	1	0	0	1	0	0	0
3	14	4	2	1	0	0	0	0	0	0	0
4	10	2	1	0	0	0	0	0	0	0	0
5	7	2	0	0	0	0	0	0	0	0	0
6	7	2	1	0	0	0	0	0	0	0	0
7	5	1	1	0	0	0	0	0	0	0	0
8	9	4	1	0	0	0	0	0	0	0	0
9	5	2	3	0	1	1	1	1	0	0	0
10	6	0	0	0	0	0	0	0	0	0	0
11	5	2	1	1	0	0	0	0	0	0	0
12	7	0	1	0	0	0	0	0	0	0	0
13	7	3	3	1	2	1	1	0	1	1	0

Table 39. Number of Repairs resulting from minor damage due to Armor Instability as a function of return period for Historical Wave Conditions for James Island

Station	Return Period										
	5	10	15	20	25	30	35	40	45	50	100
1	4	6	2	2	0	2	0	0	0	1	0
2	3	3	3	3	1	2	1	0	1	0	0
3	4	3	1	2	3	1	1	1	0	0	0
4	5	3	2	2	1	1	0	0	0	0	0
5	6	1	3	2	1	1	1	1	1	0	0
6	3	2	1	1	1	1	1	1	1	1	0
7	7	5	1	1	1	1	1	1	1	1	0
8	2	2	2	2	2	1	0	0	0	0	0
9	10	4	0	3	1	0	0	0	0	0	0
10	3	3	1	1	1	0	0	0	0	0	0
11	5	4	2	2	2	2	1	0	0	0	0
12	5	3	0	1	1	0	0	0	0	0	0
13	8	3	1	3	0	1	0	1	0	0	0

Table 40. Stone Sizes and Layer Thicknesses for 35-yr Return Period Wave Conditions

Station	Armor Weight W_{a50}, lb	Armor Layer Thickness t_a, ft	Filter Layer Weight W_{u50}, lb	Filter Layer Thickness t_u, ft	Toe Armor Weight $W_{a,toe}$, lb	Toe Armor Layer Thickness $t_{a,toe}$, ft
1	471	2.83	47	1.31	129	1.84
2	1402	4.07	140	1.89	1973	4.56
3	1849	4.46	185	2.07	3060	5.28
4	2069	4.63	207	2.15	3080	5.29
5	1853	4.47	185	2.07	3169	5.34
6	1642	4.29	164	1.99	3033	5.26
7	1502	4.17	150	1.94	2973	5.23
8	1416	4.08	142	1.90	2856	5.16
9	880	3.48	88	1.62	2471	4.91
10	373	2.62	37	1.21	1927	4.53
11	224	2.20	22	1.02	1653	4.30
12	64	1.46	6	0.68	1171	3.83
13	31	1.14	3	0.52	956	3.58

Overtopping

For low return period armor layer designs and relatively low structure crest heights most breach failures are a result of exceeding both instability and overtopping limits. However, instability failures primarily occur for lower return periods. So, to isolate the number of repairs required due to overtopping as a function of crest height, only return periods greater than 35 yrs were considered. The number of breaches due to overtopping as a function of return period was constant for return periods of 35 yrs or greater.

For all stations, overtopping for both paved crests and unarmored crest was analyzed. It was assumed that if the crest armoring was equivalent in size to the main structure armor, there was no damage due to overtopping. Tables 41 and 42 list the number of repairs resulting from overtopping damage throughout the entire historical time history. For an unarmored crest it appears that stations 2 – 7 can be grouped and Stations 9 – 13 can be grouped. Stations 1 and 8 appear to be transition areas. For Stations 2 – 7, the unarmored crest height required to avoid breach failures is 10 ft. Similarly, for Stations 9 – 13, the unarmored crest height required to avoid breach failures is 8 ft. For a paved crest, Table 42 indicates that an 8 or 9 ft crest height would be sufficient for Stations 2 – 7 while a 7 ft crest height would be sufficient for Stations 9 – 13. However, the least cost analysis showed the paved crest to have a slightly higher present worth total cost than the unarmored crest.

Table 41. Number of Breaches of Unarmored Crest due to Overtopping as a function of return period and Crest Height for Historical Wave Conditions for Poplar Island

Station	Crest Height in ft						
	6	7	8	9	10	11	12
1	4	3	0	0	0	0	0
2	9	5	3	2	0	0	0
3	9	6	4	3	0	0	0
4	9	6	3	3	0	0	0
5	8	6	3	2	0	0	0
6	6	4	3	2	0	0	0
7	6	3	3	1	0	0	0
8	3	3	0	0	0	0	0
9	0	0	0	0	0	0	0
10	2	0	0	0	0	0	0
11	3	0	0	0	0	0	0
12	3	0	0	0	0	0	0
13	3	0	0	0	0	0	0

Table 42
Number of Breaches of Paved Crest due to Overtopping as a function of return period and Crest Height for Historical Wave Conditions for Poplar Island

Station	Crest Height in ft						
	6	7	8	9	10	11	12
1	3	0	0	0	0	0	0
2	3	3	1	0	0	0	0
3	6	3	0	0	0	0	0
4	6	3	0	0	0	0	0
5	4	3	0	0	0	0	0
6	3	3	0	0	0	0	0
7	3	3	0	0	0	0	0
8	3	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	1	0	0	0	0	0	0
11	1	0	0	0	0	0	0
12	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0

An analysis of the compound slope shown in Figure 58 of Chapter 6 was conducted to determine the runup heights on the upland cells. In general, the largest storms did produce wave runup on the upper slope of the upland cells but runup height never exceeded 5 ft. This indicates that armoring would be required on the lower portion of the upland cell slope. However, the armoring need not be all that large. It is likely that 50 lb material would be sufficiently stable on this slope. The material would not need to exceed a height of 5 ft on the upland slope.

Summary and Recommendations

Given this preliminary analysis using only historical wave and water level conditions, the recommended cross sections for this preliminary analysis are as follows:

Geometry:

The suggested geometry is as per Figure 67 with the following structure parameters:

Stations 2 – 7: Unarmored Crest Height = 10 ft

Stations 9 – 13: Unarmored Crest Height = 8 ft

Stations 1 and 8 would be transition areas for crest height.

Structure slope: 1V:3H

Toe crest height: +1 ft mllw

Seaward toe slope: 1V:2H

Leeward Toe slope: 1V:1.5H

Toe crest width: $4D_{toe}$

The following armor sizes are recommended for this preliminary study given that only the historical wave conditions have been used:

Stations 2 – 9: W_{a50} = 2500 lb, W_{u50} = 250 lb, $W_{a,toe}$ = 3500 lb

Stations 1 and 10 – 12: W_{a50} = 500 lb, W_{u50} = 50 lb, $W_{a,toe}$ = 2000 lb

Station 13 and remainder of east side: W_{a50} = 50 lb, W_{u50} = 5 lb, $W_{a,toe}$ = 1000 lb

Recommend using 250 lb underlayer under 3500 lb and 2000 lb toe armor and 50 lb underlayer under 1000 lb toe armor for preliminary design. Recommend more scrutiny of the toe design in the next stage of design in order to develop a more optimal solution for the toe berm. In order to optimize design based on quarry yield, it will likely be necessary to either increase or decrease the number of stone classes.

9 Life-Cycle Simulation Results, Barren Island

This chapter describes the results produced for Barren Island using life-cycle simulation of waves, water levels, and structure response. Wave and water level results are presented in the following section. Methods used to develop these results are discussed in Chapter 5. Structure response and optimization are presented in the second section of this chapter. The methodology used to optimize design of protective structures is given in Chapter 6. For this preliminary draft report, only the historical wave climate has been used to analyze the structure. The empirical simulation technique summarized in Chapter 5 has not been employed.

Waves and Water Levels

The extremal H_s for various return periods at each station is shown in Figure 68. Peak wave period and water depth are shown as functions of return period for the six stations in Figures 68 and 70, respectively. The figures indicate that the exposure does not vary much for the six stations. However, stations 1 and 6 have slightly reduced exposure. Station 1 is in very shallow water and station 6 has some sheltering from the more severe southern exposure.

Tables J1 – J6 in Appendix J summarize extremal waves for Barren Island Stations 1 – 6. Figures J1 – J12 show wave height, wave period and water level as a function of return period for the 6 stations. Figures J2, J4, J6, J8, J10, and J12 show water level compared to crest freeboard heights of 2, 4, 6, and 8 ft as a function of return period. Extreme water levels were also analyzed for Barren Island. The Fisher-Tippet distribution was fit to the data. Table J7 lists extreme water level as a function of return period for northeaster storms for water level analysis Station 2. Table J8 lists extreme water level as a function of return period for hurricanes.

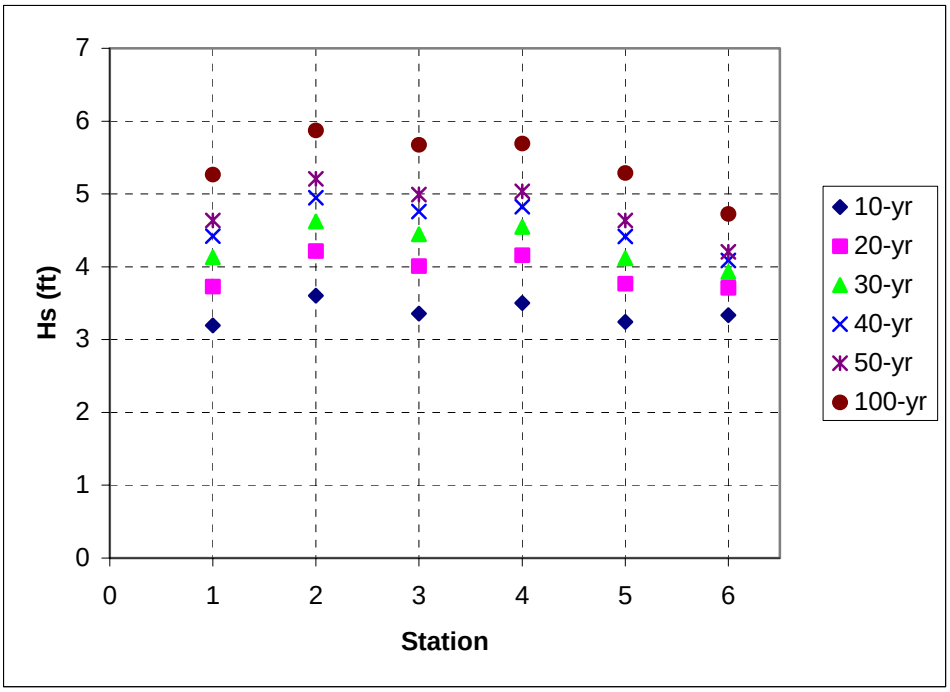


Figure 68. Return period H_s at nearshore stations, Barren Island

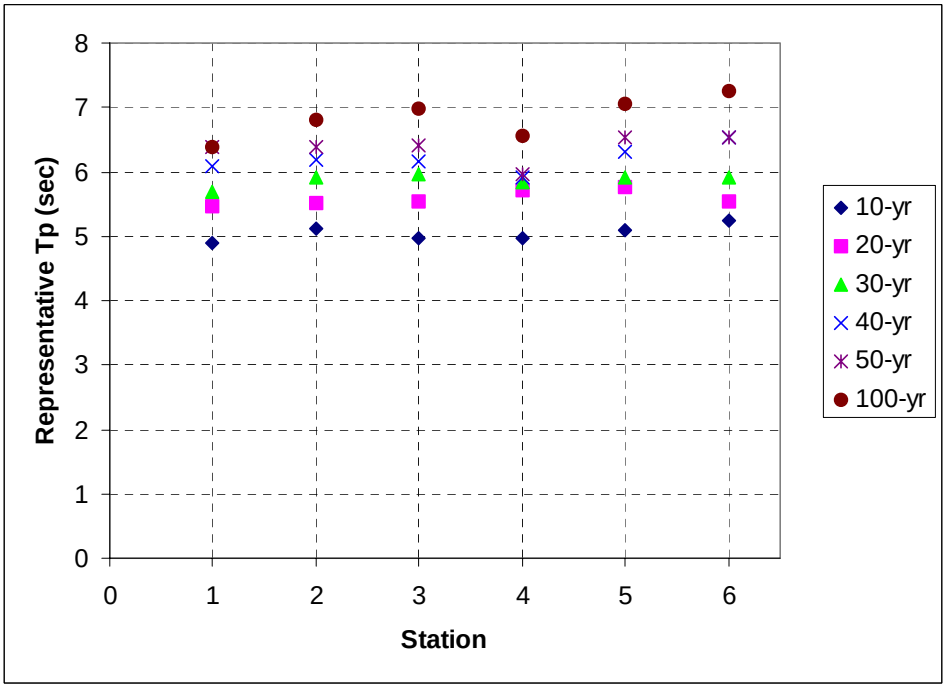


Figure 69. Return period T_p at nearshore stations, Barren Island

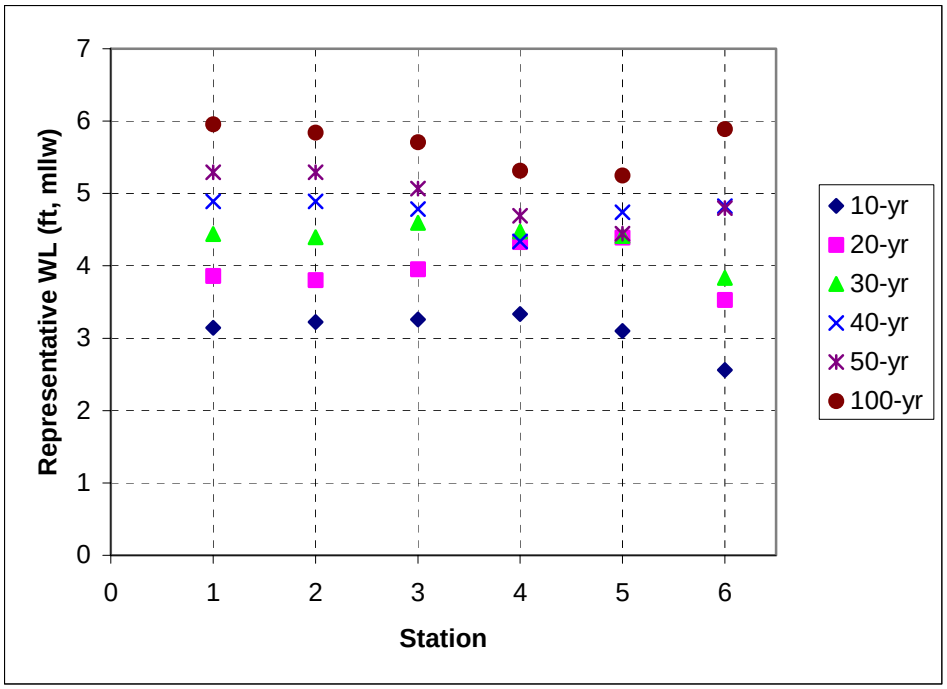


Figure 70. Return period water level at nearshore stations, Barren Island

Structural Optimization

Cross sections were analyzed as follows: 1. southern portion opposite stations 1 – 3 consists of the low-crested offshore breakwater shown in Figure 71, and 2. northern portion opposite stations 4 – 6 consists of the dike cross section shown in Figure 72. The simple section shown in Figure 71 consists of a multi-layer section with 2-stone thick armor and underlayers. The crest is three stones wide. The toe is two stones wide and a single stone high. The side slopes are 1V:1.5H. The entire structure is underlain by a geotextile fabric. The layer thicknesses were assumed to be $2D_{a50}$ for armor, $2D_{u50}$ for filter layer, D_{ta50} for toe armor. Here $D_{a50} = (V_{50})^{1/3} = (W_{50}/\gamma_r)^{1/3}$ is the nominal diameter of the armor weight corresponding to the 50 percent exceedance level on the weight distribution curve. Similarly, D_{u50} is the filter layer 50 percent exceedance nominal diameter and D_{ta50} is the toe armor 50 percent exceedance nominal diameter. The section shown in Figure 72 consists of the existing structure with a single layer overlay. The existing structure has a single layer of armor over a core. The existing tow is 2 stones wide by 1 stone high, similar to that described for Stations 1 – 3. The new toe is the same dimension and placed seaward of the existing toe. The side slopes are 1V:1.5H. The entire structure rests on a geotextile fabric. On the lee side, the structure has a filter layer to prevent leakage of the sand within the fill.

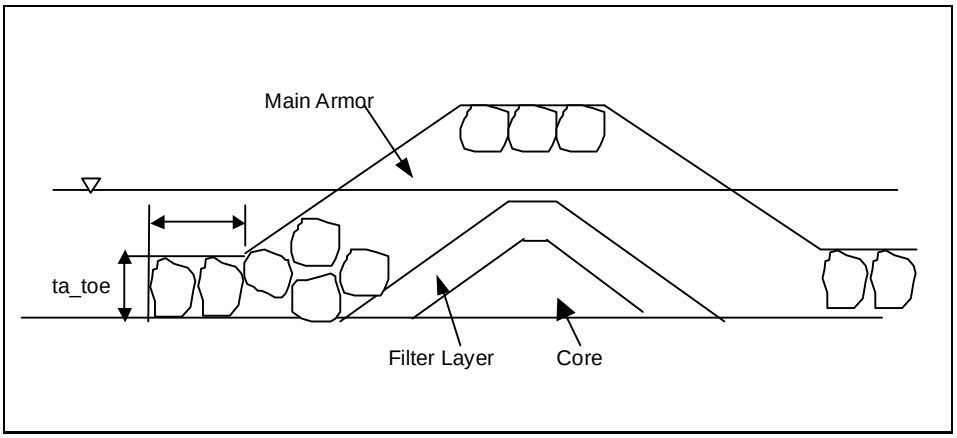


Figure 71. General cross section for stations 1, 2, and 3.

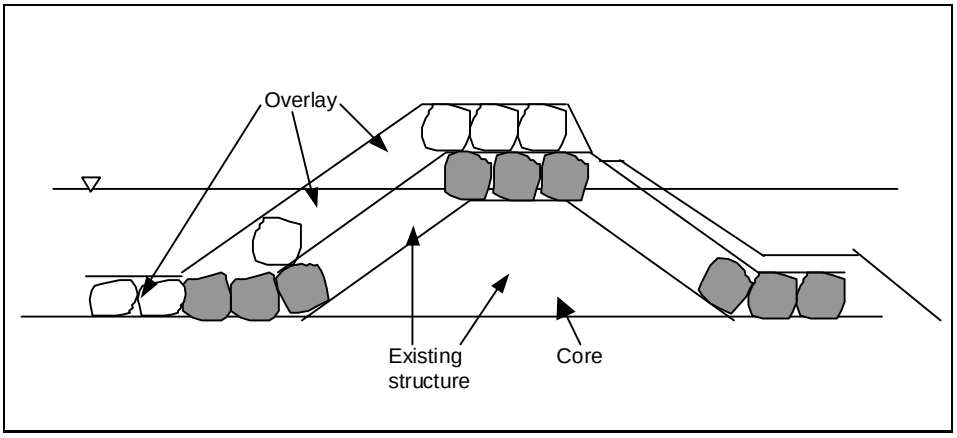


Figure 72. General cross section for stations 4, 5, and 6.

Armor Stability

Tables in Appendix J show the significant wave height, peak period and depth as a function of return period from the extremal wave height analysis discussed previously. Figures J1 – J6 show the significant wave height, peak period and depth relative to mllw as a function of return period from the extremal wave height analysis discussed previously. Each STWAVE station is shown on a separate plot.

Values used to calculate armor stability are as follows:

Zero damage level: $S = 1$ was assumed

Structure slope: 1V:1.5H was assumed for all sections

Specific Gravity: $S_r = 2.578$

Number of waves for zero damage level: $N_z = 7000$

Tables K1 – K24 in Appendix K show the stable armor weight and stable underlayer weight as a function of return period for each STWAVE station of Barren Island. For each station, crest freeboard heights of 2, 4, 6, and 8 ft are shown. The stability relations of Melby and Hughes (2004). Figures K1, K3, K5, K7, K9, and K11 show stable main armor weight as a function of return period for stations 1, 2, 3, 4, 5, and 6 respectively. Figures K2, K4, and K6 show wave transmission as a function of return period for stations 1, 2, and 3, respectively. The overtopping transmission is shown for crest freeboard heights of 2, 4, 6, and 8 ft. Figures K8, K10, and K12 show wave overtopping volume as a function of return period for stations 4, 5, and 8, respectively. The overtopping is shown for crest freeboard heights of 2, 4, 6, and 8 ft.

Summary of Results and Conclusions

Stations 1 – 3: Low-crested trapezoidal rubble mound breakwater structure for SAV protection as per Figure 71. In this case, a limiting wave height of H_s = 1 m (3 ft) was assumed for SAV protection. A crest height of 4 ft provides SAV protection limiting wave height up to just over the 30-year return period storm event. A crest height of 6 ft provides SAV protection for wave conditions exceeding the 50-year return period event. This result is based on an overtopping analysis of the structure and does not take into account wave transmission through the structure or diffraction through the gap between the mainland and the island. It also does not take into account local waves generated on the eastern side of the island. For a return period of 50 years and crest height of 4 ft, the main armor, underlayer, and toe armor weights are: W_{a50} = 1000 lb, W_{u50} = 100 lb, W_{ta50} = 1000 lb. For a return period of 50 years and crest height of 6 ft, the main armor, underlayer, and toe armor weights are: W_{a50} = 1600 lb, W_{u50} = 160 lb, W_{ta50} = 1600 lb.

Stations 4 – 6: Low-crested trapezoidal rubble mound breakwater structure to retain fill as per Figure 72. Considering the rubble mound structure only, the structure stone size to prevent breaching is given in Appendix K for each return period. The cross section shows main armor across the crest. Therefore, the stability of the crest is roughly the same as the primary armor. For a return period of 50 years and crest height of 4 ft, the main armor, underlayer, and toe armor weights are: W_{a50} = 1300 lb, W_{u50} = 130 lb, W_{ta50} = 1300 lb. For a return period of 50 years and crest height of 6 ft, the main armor, underlayer, and toe armor weights are: W_{a50} = 1600 lb, W_{u50} = 160 lb, W_{ta50} = 1600 lb.

These calculations will be refined in the life cycle analysis using the empirical simulation method.

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Appendix A: Maximum Significant Wave Height for Storm History for Poplar Island

Table A1
Maximum H_S by Storm, Poplar Island, Station 33, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/20	0.50 (1.64)	3.97	333.00	0.56 (1.84)	9
2	None	1861/09/28	0.32 (1.05)	2.23	273.96	1.00 (3.28)	6
3	None	1861/11/03	0.40 (1.31)	3.51	333.00	0.59 (1.94)	3
4	None	1863/09/19	0.49 (1.61)	3.93	333.00	0.56 (1.84)	3
5	None	1874/09/29	0.77 (2.53)	5.43	241.51	1.19 (3.90)	6
6	None	1876/09/18	0.99 (3.25)	5.97	241.65	1.61 (5.28)	12
7	None	1877/10/05	0.91 (2.99)	3.56	272.92	1.12 (3.67)	12
8	None	1878/10/23	2.26 (7.41)	8.45	243.64	2.22 (7.28)	15
9	None	1879/08/19	0.41 (1.35)	3.54	331.20	0.78 (2.56)	6
10	None	1880/09/10	0.27 (0.89)	2.79	335.81	0.71 (2.33)	0
11	None	1881/09/11	0.37 (1.21)	3.25	333.10	0.64 (2.10)	6
12	None	1888/10/12	0.15 (0.49)	2.78	221.43	0.30 (0.98)	0
13	None	1889/09/25	0.27 (0.89)	2.77	334.90	0.61 (2.00)	0
14	None	1893/06/17	0.37 (1.21)	3.33	333.00	0.40 (1.31)	6
15	None	1893/08/29	1.97 (6.46)	8.11	250.00	1.47 (4.82)	15
16	None	1893/10/14	0.58 (1.90)	4.50	328.89	1.34 (4.40)	6
17	None	1893/10/23	1.32 (4.33)	7.01	250.60	0.29 (0.95)	12
18	None	1894/09/29	0.55 (1.80)	4.22	327.00	0.42 (1.38)	24
19	None	1894/10/10	0.43 (1.41)	3.66	332.10	0.74 (2.43)	6
20	None	1897/10/25	0.52 (1.71)	4.11	327.00	0.32 (1.05)	12
21	None	1899/08/19	0.56 (1.84)	4.17	328.00	0.68 (2.23)	57
22	None	1899/11/01	1.48 (4.86)	7.09	246.62	1.62 (5.31)	9
23	None	1904/09/15	0.87 (2.85)	3.49	275.00	1.33 (4.36)	6
24	None	1908/08/01	0.38 (1.25)	3.42	333.00	0.62 (2.03)	12
25	None	1923/10/24	0.60 (1.97)	4.75	325.88	0.43 (1.41)	9
26	None	1933/08/24	0.99 (3.25)	5.98	240.30	1.61 (5.28)	24
27	None	1933/09/17	0.49 (1.61)	3.93	331.20	0.66 (2.17)	18
28	None	1935/09/06	0.25 (0.82)	2.68	335.81	0.55 (1.80)	0
29	None	1936/09/19	0.67 (2.20)	5.00	324.12	0.32 (1.05)	30
30	None	1944/08/03	0.53 (1.74)	2.76	331.99	1.08 (3.54)	6
31	None	1944/09/15	0.49 (1.61)	3.99	332.79	0.50 (1.64)	12
32	None	1946/07/07	0.16 (0.52)	2.26	333.00	0.47 (1.54)	0
33	Barbara	1953/08/14	0.46 (1.51)	3.89	331.00	0.54 (1.77)	12
34	Hazel	1954/10/16	2.47 (8.10)	8.82	243.64	2.19 (7.18)	12
35	Connie	1955/08/13	0.94 (3.08)	5.89	326.00	1.00 (3.28)	24
36	Diane	1955/08/18	0.78 (2.56)	5.48	249.00	0.99 (3.25)	18
37	Ione	1955/09/20	0.55 (1.80)	4.24	326.12	0.32 (1.05)	12
38	Brenda	1960/07/30	0.32 (1.05)	2.96	337.72	0.86 (2.82)	3
39	Donna	1960/09/12	0.57 (1.87)	4.24	329.77	0.75 (2.46)	9
40	Doria	1967/09/12	0.02 (0.07)	0.57	332.96	0.62 (2.03)	0
41	Doria	1971/08/28	0.51 (1.67)	3.89	333.10	0.95 (3.12)	3
42	Bret	1981/07/01	0.37 (1.21)	3.31	334.80	0.28 (0.92)	6
43	Dean	1983/09/30	0.12 (0.39)	1.95	333.90	0.43 (1.41)	0
44	Gloria	1985/09/27	0.86 (2.82)	5.73	323.12	0.50 (1.64)	9
45	Charley	1986/08/18	0.44 (1.44)	3.80	331.89	0.45 (1.48)	12
46	Danielle	1992/09/26	0.23 (0.75)	2.61	333.90	0.54 (1.77)	0
47	Bertha	1996/07/13	0.61 (2.00)	2.97	275.00	1.00 (3.28)	3
48	Fran	1996/09/07	0.40 (1.31)	4.00	229.12	1.25 (4.10)	3
49	Bonnie	1998/08/28	0.35 (1.15)	3.14	334.90	0.75 (2.46)	9
50	Earl	1998/09/05	0.14 (0.46)	2.74	221.43	0.36 (1.18)	0
51	Floyd	1999/09/17	0.59 (1.94)	4.49	329.89	1.06 (3.48)	9
52	Isabel	2003/09/19	1.01 (3.31)	5.92	228.13	2.12 (6.96)	15

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table A2
Maximum H_S by Storm, Poplar Island, Station 34, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/20	0.48 (1.57)	3.97	330.00	0.56 (1.84)	9
2	None	1861/09/28	0.34 (1.12)	4.08	247.25	0.92 (3.02)	6
3	None	1861/11/03	0.38 (1.25)	3.51	330.00	0.59 (1.94)	3
4	None	1863/09/19	0.47 (1.54)	3.93	330.00	0.56 (1.84)	6
5	None	1874/0929	0.92 (3.02)	5.43	242.49	1.19 (3.90)	12
6	None	1876/09/18	1.17 (3.84)	5.97	244.63	1.61 (5.28)	12
7	None	1877/10/05	0.89 (2.92)	3.56	272.92	1.12 (3.67)	12
8	None	1878/10/23	2.54 (8.33)	8.45	244.63	2.22 (7.28)	15
9	None	1879/08/19	0.39 (1.28)	3.54	328.22	0.78 (2.56)	6
10	None	1880/09/10	0.26 (0.85)	2.79	332.79	0.71 (2.33)	0
11	None	1881/09/11	0.35 (1.15)	3.25	330.11	0.64 (2.10)	3
12	None	1888/10/12	0.17 (0.56)	2.78	234.58	0.30 (0.98)	0
13	None	1889/09/25	0.26 (0.85)	2.77	331.89	0.61 (2.00)	0
14	None	1893/06/17	0.36 (1.18)	3.33	330.00	0.40 (1.31)	6
15	None	1893/08/29	2.06 (6.76)	8.11	250.00	1.47 (4.82)	18
16	None	1893/10/14	0.54 (1.77)	4.32	244.00	1.13 (3.71)	6
17	None	1893/10/23	1.14 (3.74)	6.61	249.61	0.29 (0.95)	15
18	None	1894/09/29	0.51 (1.67)	4.22	324.00	0.42 (1.38)	24
19	None	1894/10/10	0.41 (1.35)	3.66	329.11	0.74 (2.43)	6
20	None	1897/10/25	0.49 (1.61)	4.11	324.00	0.32 (1.05)	12
21	None	1899/08/19	0.53 (1.74)	4.17	326.00	0.68 (2.23)	57
22	None	1899/11/01	1.67 (5.48)	7.09	246.62	1.62 (5.31)	12
23	None	1904/09/15	0.84 (2.76)	3.49	275.00	1.33 (4.36)	9
24	None	1908/08/01	0.36 (1.18)	3.42	330.00	0.62 (2.03)	12
25	None	1923/10/24	0.52 (1.71)	4.75	322.87	0.43 (1.41)	9
26	None	1933/08/24	1.17 (3.84)	5.98	243.27	1.61 (5.28)	24
27	None	1933/09/17	0.47 (1.54)	3.93	328.22	0.66 (2.17)	18
28	None	1935/09/06	0.24 (0.79)	2.68	332.79	0.55 (1.80)	0
29	None	1936/09/19	0.59 (1.94)	5.00	321.13	0.32 (1.05)	30
30	None	1944/08/03	0.53 (1.74)	2.76	330.99	1.08 (3.54)	6
31	None	1944/09/15	0.46 (1.51)	3.99	329.77	0.50 (1.64)	9
32	None	1946/07/07	0.16 (0.52)	2.26	330.00	0.47 (1.54)	0
33	Barbara	1953/08/14	0.44 (1.44)	3.89	328.00	0.54 (1.77)	12
34	Hazel	1954/10/16	2.75 (9.02)	8.82	244.63	2.19 (7.18)	12
35	Connie	1955/08/13	0.81 (2.66)	5.89	323.00	1.00 (3.28)	27
36	Diane	1955/08/18	0.89 (2.92)	5.48	249.00	0.99 (3.25)	21
37	Ione	1955/09/20	0.51 (1.67)	4.24	323.12	0.32 (1.05)	12
38	Brenda	1960/07/30	0.33 (1.08)	3.66	226.20	0.79 (2.59)	6
39	Donna	1960/09/12	0.54 (1.77)	4.24	327.76	0.75 (2.46)	9
40	Doria	1967/09/12	0.02 (0.07)	0.57	332.96	0.62 (2.03)	0
41	Doria	1971/08/28	0.49 (1.61)	3.89	330.11	0.95 (3.12)	3
42	Bret	1981/07/01	0.35 (1.15)	3.31	331.78	0.28 (0.92)	6
43	Dean	1983/09/30	0.12 (0.39)	1.95	330.89	0.43 (1.41)	0
44	Gloria	1985/09/27	0.72 (2.36)	5.73	320.13	0.50 (1.64)	9
45	Charley	1986/08/18	0.42 (1.38)	3.80	328.89	0.45 (1.48)	12
46	Danielle	1992/09/26	0.22 (0.72)	2.61	330.89	0.54 (1.77)	0
47	Bertha	1996/07/13	0.59 (1.94)	2.97	275.00	1.00 (3.28)	3
48	Fran	1996/09/07	0.46 (1.51)	4.00	236.98	1.25 (4.10)	3
49	Bonnie	1998/08/28	0.33 (1.08)	3.08	332.90	0.91 (2.99)	9
50	Earl	1998/09/05	0.22 (0.72)	3.02	225.48	0.56 (1.84)	0
51	Floyd	1999/09/17	0.56 (1.84)	4.49	327.88	1.06 (3.48)	6
52	Isabel	2003/09/19	1.20 (3.94)	5.92	236.00	2.12 (6.96)	12

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table A3
Maximum H_S by Storm, Poplar Island, Station 35, Tropical Storms

Storm Number	Storm Name	Date	H_s, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/20	0.50 (1.64)	2.62	40.02	0.42 (1.38)	15
2	None	1861/09/26	0.01 (0.03)	0.48	229.12	0.29 (0.95)	0
3	None	1861/11/03	0.57 (1.87)	2.78	40.02	0.55 (1.80)	9
4	None	1863/09/19	0.44 (1.44)	3.93	330.00	0.57 (1.87)	3
5	None	1874/09/28	0.01 (0.03)	1.23	230.41	0.29 (0.95)	0
6	None	1876/09/17	0.01 (0.03)	1.21	227.82	0.29 (0.95)	0
7	None	1877/10/03	0.01 (0.03)	0.93	227.82	0.29 (0.95)	0
8	None	1878/10/22	0.01 (0.03)	1.17	229.12	0.29 (0.95)	0
9	None	1879/08/19	1.01 (3.31)	3.62	44.00	0.85 (2.79)	6
10	None	1880/09/09	0.39 (1.28)	2.33	45.95	0.60 (1.97)	3
11	None	1881/09/10	0.45 (1.48)	2.48	43.00	0.72 (2.36)	9
12	None	1888/10/12	0.26 (0.85)	1.90	41.98	0.49 (1.61)	0
13	None	1889/09/25	0.36 (1.18)	2.23	43.98	0.80 (2.62)	3
14	None	1893/06/17	0.37 (1.21)	2.26	43.98	0.63 (2.07)	6
15	None	1893/08/27	0.15 (0.49)	1.44	42.96	0.29 (0.95)	0
16	None	1893/10/14	0.75 (2.46)	3.14	45.01	1.38 (4.53)	6
17	None	1893/10/21	0.11 (0.36)	1.28	40.02	0.29 (0.95)	0
18	None	1894/09/29	0.47 (1.54)	4.22	326.00	0.43 (1.41)	24
19	None	1894/10/10	0.68 (2.23)	3.02	43.98	0.69 (2.26)	6
20	None	1897/10/25	0.45 (1.48)	4.11	326.00	0.33 (1.08)	9
21	None	1899/08/19	0.49 (1.61)	4.17	327.00	0.69 (2.26)	57
22	None	1899/10/31	0.17 (0.56)	1.58	43.93	0.31 (1.02)	0
23	None	1904/09/14	0.21 (0.69)	1.75	41.95	0.25 (0.82)	0
24	None	1908/08/01	0.37 (1.21)	2.26	40.02	0.50 (1.64)	15
25	None	1923/10/24	0.48 (1.57)	4.75	324.88	0.44 (1.44)	6
26	None	1933/08/24	0.92 (3.02)	3.49	44.00	0.82 (2.69)	15
27	None	1933/09/16	0.61 (2.00)	2.87	42.02	0.63 (2.07)	27
28	None	1935/09/06	0.23 (0.75)	2.68	332.79	0.56 (1.84)	0
29	None	1936/09/19	0.55 (1.80)	2.79	330.99	0.31 (1.02)	30
30	None	1944/08/03	0.53 (1.74)	2.76	331.99	1.08 (3.54)	3
31	None	1944/09/14	0.66 (2.17)	2.99	43.98	0.59 (1.94)	18
32	None	1946/07/07	0.27 (0.89)	1.92	41.00	0.43 (1.41)	0
33	Barbara	1953/08/14	0.53 (1.74)	2.69	42.02	0.68 (2.23)	21
34	Hazel	1954/10/15	0.44 (1.44)	2.46	43.93	0.28 (0.92)	6
35	Connie	1955/08/13	0.74 (2.43)	5.89	324.00	1.00 (3.28)	33
36	Diane	1955/08/17	0.31 (1.02)	1.99	44.97	0.57 (1.87)	3
37	Ione	1955/09/19	0.65 (2.13)	2.97	43.00	0.54 (1.77)	39
38	Brenda	1960/07/30	0.30 (0.98)	2.96	334.69	0.86 (2.82)	0
39	Donna	1960/09/12	0.70 (2.30)	3.04	48.97	0.83 (2.72)	9
40	Doria	1967/09/11	0.06 (0.20)	0.96	41.98	0.29 (0.95)	0
41	Doria	1971/08/28	0.77 (2.53)	3.17	47.98	0.84 (2.76)	9
42	Bret	1981/07/01	0.80 (2.62)	3.25	41.98	0.33 (1.08)	12
43	Dean	1983/09/30	0.11 (0.36)	1.95	330.89	0.43 (1.41)	0
44	Gloria	1985/09/27	1.10 (3.61)	3.77	41.02	0.64 (2.10)	24
45	Charley	1986/08/18	0.56 (1.84)	2.76	42.02	0.68 (2.23)	21
46	Danielle	1992/09/26	0.32 (1.05)	2.12	41.00	0.35 (1.15)	3
47	Bertha	1996/07/13	1.03 (3.38)	3.65	44.00	1.06 (3.48)	3
48	Fran	1996/09/06	0.54 (1.77)	2.70	45.95	0.58 (1.90)	15
49	Bonnie	1998/08/28	0.46 (1.51)	2.48	46.00	0.94 (3.08)	42
50	Earl	1998/09/02	0.01 (0.03)	0.78	233.00	0.29 (0.95)	0
51	Floyd	1999/09/16	1.03 (3.38)	3.64	45.97	1.15 (3.77)	6
52	Isabel	2003/09/19	1.15 (3.77)	3.83	45.97	0.93 (3.05)	9

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table A4
Maximum H_S by Storm, Poplar Island, Station 36, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/20	0.51 (1.67)	2.62	41.02	0.42 (1.38)	15
2	None	1861/09/26	0.01 (0.03)	0.48	226.17	0.29 (0.95)	0
3	None	1861/11/03	0.58 (1.90)	2.78	41.02	0.55 (1.80)	9
4	None	1863/09/19	0.43 (1.41)	3.93	329.00	0.57 (1.87)	3
5	None	1874/09/28	0.01 (0.03)	1.23	227.44	0.29 (0.95)	0
6	None	1876/09/17	0.01 (0.03)	1.21	224.89	0.29 (0.95)	0
7	None	1877/10/03	0.01 (0.03)	0.93	224.89	0.29 (0.95)	0
8	None	1878/10/22	0.01 (0.03)	1.17	226.17	0.29 (0.95)	0
9	None	1879/08/19	1.04 (3.41)	3.62	44.00	0.85 (2.79)	6
10	None	1880/09/09	0.40 (1.31)	2.33	46.96	0.60 (1.97)	3
11	None	1881/09/10	0.46 (1.51)	2.48	44.00	0.72 (2.36)	9
12	None	1888/10/12	0.26 (0.85)	1.90	42.98	0.49 (1.61)	0
13	None	1889/09/25	0.36 (1.18)	2.23	44.99	0.80 (2.62)	3
14	None	1893/06/17	0.37 (1.21)	2.26	44.99	0.63 (2.07)	6
15	None	1893/08/27	0.15 (0.49)	1.44	43.96	0.29 (0.95)	0
16	None	1893/10/14	0.77 (2.53)	3.14	45.01	1.38 (4.53)	6
17	None	1893/10/21	0.11 (0.36)	1.28	41.02	0.29 (0.95)	0
18	None	1894/09/29	0.45 (1.48)	4.22	326.00	0.43 (1.41)	24
19	None	1894/10/10	0.69 (2.26)	3.02	44.99	0.69 (2.26)	6
20	None	1897/10/25	0.43 (1.41)	4.11	326.00	0.33 (1.08)	9
21	None	1899/08/19	0.48 (1.57)	4.17	327.00	0.69 (2.26)	54
22	None	1899/10/31	0.18 (0.59)	1.58	44.94	0.31 (1.02)	0
23	None	1904/09/14	0.22 (0.72)	1.75	42.96	0.25 (0.82)	0
24	None	1908/08/01	0.37 (1.21)	2.26	41.02	0.50 (1.64)	15
25	None	1923/10/24	0.47 (1.54)	4.75	324.88	0.44 (1.44)	6
26	None	1933/08/24	0.95 (3.12)	3.49	44.00	0.82 (2.69)	12
27	None	1933/09/16	0.62 (2.03)	2.87	43.01	0.63 (2.07)	27
28	None	1935/09/06	0.22 (0.72)	2.68	331.78	0.56 (1.84)	0
29	None	1936/09/19	0.54 (1.77)	2.79	330.99	0.31 (1.02)	30
30	None	1944/08/03	0.53 (1.74)	2.76	331.99	1.08 (3.54)	3
31	None	1944/09/14	0.67 (2.20)	2.99	44.99	0.59 (1.94)	18
32	None	1946/07/07	0.27 (0.89)	1.92	42.00	0.43 (1.41)	0
33	Barbara	1953/08/14	0.54 (1.77)	2.69	43.01	0.68 (2.23)	24
34	Hazel	1954/10/15	0.45 (1.48)	2.46	44.94	0.28 (0.92)	6
35	Connie	1955/08/13	0.71 (2.33)	5.89	324.00	1.00 (3.28)	33
36	Diane	1955/08/17	0.32 (1.05)	1.99	45.97	0.57 (1.87)	3
37	Ione	1955/09/19	0.66 (2.17)	2.97	44.00	0.54 (1.77)	39
38	Brenda	1960/07/30	0.29 (0.95)	2.96	333.68	0.86 (2.82)	0
39	Donna	1960/09/12	0.72 (2.36)	3.04	48.97	0.83 (2.72)	9
40	Doria	1967/09/11	0.06 (0.20)	0.96	42.98	0.29 (0.95)	0
41	Doria	1971/08/28	0.79 (2.59)	3.17	47.98	0.84 (2.76)	9
42	Bret	1981/07/01	0.83 (2.72)	3.25	42.98	0.33 (1.08)	9
43	Dean	1983/09/30	0.10 (0.33)	1.95	329.89	0.43 (1.41)	0
44	Gloria	1985/09/27	1.15 (3.77)	3.77	41.02	0.64 (2.10)	24
45	Charley	1986/08/18	0.57 (1.87)	2.76	43.01	0.68 (2.23)	21
46	Danielle	1992/09/26	0.33 (1.08)	2.12	42.00	0.35 (1.15)	3
47	Bertha	1996/07/13	1.06 (3.48)	3.65	44.00	1.06 (3.48)	3
48	Fran	1996/09/06	0.55 (1.80)	2.70	46.96	0.58 (1.90)	15
49	Bonnie	1998/08/28	0.47 (1.54)	2.48	46.00	0.94 (3.08)	45
50	Earl	1998/09/02	0.01 (0.03)	0.78	230.00	0.29 (0.95)	0
51	Floyd	1999/09/16	1.06 (3.48)	3.64	45.97	1.15 (3.77)	6
52	Isabel	2003/09/19	1.19 (3.90)	3.83	45.97	0.93 (3.05)	9

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table A5
Maximum H_S by Storm, Poplar Island, Station 37, Tropical Storms

Storm Number	Storm Name	Date	H_s, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/20	0.39 (1.28)	2.62	45.01	0.42 (1.38)	15
2	None	1861/09/26	0.01 (0.03)	0.48	191.75	0.29 (0.95)	0
3	None	1861/11/03	0.44 (1.44)	2.78	45.01	0.55 (1.80)	6
4	None	1863/09/17	0.01 (0.03)	0.49	186.23	0.29 (0.95)	0
5	None	1874/09/28	0.01 (0.03)	1.23	192.83	0.29 (0.95)	0
6	None	1876/09/17	0.01 (0.03)	1.21	190.67	0.29 (0.95)	0
7	None	1877/10/03	0.01 (0.03)	0.93	190.67	0.29 (0.95)	0
8	None	1878/10/22	0.01 (0.03)	1.17	191.75	0.29 (0.95)	0
9	None	1879/08/19	0.79 (2.59)	3.62	45.00	0.85 (2.79)	3
10	None	1880/09/09	0.32 (1.05)	2.33	49.98	0.60 (1.97)	3
11	None	1881/09/10	0.36 (1.18)	2.48	47.00	0.72 (2.36)	24
12	None	1888/10/12	0.20 (0.66)	1.90	46.99	0.49 (1.61)	3
13	None	1889/09/25	0.29 (0.95)	2.23	47.99	0.80 (2.62)	3
14	None	1893/06/17	0.30 (0.98)	2.26	47.99	0.63 (2.07)	3
15	None	1893/08/27	0.11 (0.36)	1.44	47.98	0.29 (0.95)	0
16	None	1893/10/14	0.63 (2.07)	3.14	48.00	1.38 (4.53)	3
17	None	1893/10/21	0.08 (0.26)	1.28	45.01	0.29 (0.95)	0
18	None	1894/09/29	0.33 (1.08)	2.39	46.01	0.63 (2.07)	12
19	None	1894/10/10	0.55 (1.80)	3.02	47.99	0.69 (2.26)	3
20	None	1897/10/25	0.10 (0.33)	1.35	46.00	0.47 (1.54)	0
21	None	1899/08/17	0.27 (0.89)	2.20	46.00	0.45 (1.48)	21
22	None	1899/10/31	0.13 (0.43)	1.58	48.97	0.31 (1.02)	0
23	None	1904/09/14	0.16 (0.52)	1.71	47.98	0.35 (1.15)	3
24	None	1908/08/01	0.28 (0.92)	2.26	45.01	0.50 (1.64)	30
25	None	1923/10/22	0.04 (0.13)	0.95	45.01	0.37 (1.21)	0
26	None	1933/08/24	0.73 (2.39)	3.49	45.00	0.82 (2.69)	3
27	None	1933/09/16	0.49 (1.61)	2.87	46.01	0.63 (2.07)	12
28	None	1935/09/04	0.01 (0.03)	0.88	185.00	0.29 (0.95)	0
29	None	1936/09/17	0.01 (0.03)	1.65	337.91	0.29 (0.95)	0
30	None	1944/08/01	0.10 (0.33)	1.36	47.98	0.30 (0.98)	0
31	None	1944/09/14	0.53 (1.74)	2.99	47.99	0.59 (1.94)	27
32	None	1946/07/07	0.20 (0.66)	1.92	46.00	0.43 (1.41)	3
33	Barbara	1953/08/14	0.43 (1.41)	2.69	46.01	0.68 (2.23)	24
34	Hazel	1954/10/15	0.34 (1.12)	2.46	48.97	0.28 (0.92)	12
35	Connie	1955/08/12	0.50 (1.64)	2.97	45.01	0.44 (1.44)	36
36	Diane	1955/08/17	0.25 (0.82)	1.99	48.99	0.57 (1.87)	18
37	Ione	1955/09/19	0.52 (1.71)	2.97	47.00	0.54 (1.77)	33
38	Brenda	1960/07/28	0.01 (0.03)	0.54	195.00	0.29 (0.95)	0
39	Donna	1960/09/12	0.59 (1.94)	3.04	51.99	0.83 (2.72)	3
40	Doria	1967/09/11	0.04 (0.13)	0.96	46.99	0.29 (0.95)	0
41	Doria	1971/08/28	0.64 (2.10)	3.17	51.00	0.84 (2.76)	6
42	Bret	1981/07/01	0.61 (2.00)	3.25	46.99	0.33 (1.08)	6
43	Dean	1983/09/28	0.01 (0.03)	0.54	46.99	0.34 (1.12)	0
44	Gloria	1985/09/27	0.83 (2.72)	3.77	44.01	0.64 (2.10)	24
45	Charley	1986/08/18	0.45 (1.48)	2.76	46.01	0.68 (2.23)	12
46	Danielle	1992/09/26	0.25 (0.82)	2.12	46.00	0.35 (1.15)	12
47	Bertha	1996/07/13	0.81 (2.66)	3.65	45.00	1.06 (3.48)	3
48	Fran	1996/09/06	0.44 (1.44)	2.70	49.98	0.58 (1.90)	30
49	Bonnie	1998/08/28	0.39 (1.28)	2.48	49.00	0.94 (3.08)	54
50	Earl	1998/09/02	0.01 (0.03)	0.78	195.00	0.29 (0.95)	0
51	Floyd	1999/09/16	0.81 (2.66)	3.64	46.98	1.15 (3.77)	27
52	Isabel	2003/09/19	0.89 (2.92)	3.83	46.98	0.93 (3.05)	9

[1]Storm duration is the time during a storm when H_S > 0.15 m

Table A6
Maximum H_S by Storm, Poplar Island, Station 38, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/20	0.30 (0.98)	2.62	36.03	0.44 (1.44)	9
2	None	1861/09/28	0.16 (0.52)	4.08	143.89	0.92 (3.02)	6
3	None	1861/11/03	0.34 (1.12)	2.78	36.03	0.56 (1.84)	6
4	None	1863/09/19	0.13 (0.43)	3.04	148.00	0.71 (2.33)	0
5	None	1874/09/29	0.19 (0.62)	5.43	139.82	1.17 (3.84)	9
6	None	1876/09/18	0.28 (0.92)	5.97	144.19	1.63 (5.35)	15
7	None	1877/10/05	0.18 (0.59)	4.27	143.89	0.99 (3.25)	3
8	None	1878/10/23	0.74 (2.43)	8.45	141.21	2.30 (7.55)	21
9	None	1879/08/19	0.64 (2.10)	3.62	40.00	0.86 (2.82)	3
10	None	1880/09/09	0.26 (0.85)	2.33	44.94	0.60 (1.97)	3
11	None	1881/09/10	0.30 (0.98)	2.48	42.00	0.72 (2.36)	12
12	None	1888/10/12	0.15 (0.49)	1.90	37.97	0.49 (1.61)	0
13	None	1889/09/25	0.24 (0.79)	2.23	42.98	0.80 (2.62)	3
14	None	1893/06/17	0.24 (0.79)	2.26	42.98	0.63 (2.07)	3
15	None	1893/08/29	0.40 (1.31)	8.11	138.00	1.44 (4.72)	15
16	None	1893/10/14	0.55 (1.80)	3.14	47.00	1.38 (4.53)	9
17	None	1893/10/23	0.17 (0.56)	7.01	134.25	0.31 (1.02)	3
18	None	1894/09/29	0.27 (0.89)	2.39	41.02	0.63 (2.07)	6
19	None	1894/10/10	0.45 (1.48)	3.02	42.98	0.69 (2.26)	3
20	None	1897/10/25	0.08 (0.26)	1.35	37.00	0.47 (1.54)	0
21	None	1899/08/17	0.21 (0.69)	2.20	37.00	0.45 (1.48)	12
22	None	1899/11/01	0.37 (1.21)	7.09	140.22	1.61 (5.28)	12
23	None	1904/09/15	0.20 (0.66)	3.66	154.53	1.27 (4.17)	9
24	None	1908/08/01	0.23 (0.75)	2.20	41.02	0.64 (2.10)	21
25	None	1923/10/24	0.12 (0.39)	3.06	149.45	0.36 (1.18)	0
26	None	1933/08/24	0.59 (1.94)	3.49	40.00	0.85 (2.79)	15
27	None	1933/09/16	0.40 (1.31)	2.87	41.02	0.64 (2.10)	12
28	None	1935/09/06	0.08 (0.26)	2.59	143.73	0.33 (1.08)	0
29	None	1936/09/17	0.01 (0.03)	1.65	357.96	0.29 (0.95)	0
30	None	1944/08/03	0.19 (0.62)	3.98	145.83	1.10 (3.61)	9
31	None	1944/09/14	0.44 (1.44)	2.99	42.98	0.61 (2.00)	18
32	None	1946/07/07	0.16 (0.52)	1.92	37.00	0.43 (1.41)	3
33	Barbara	1953/08/14	0.35 (1.15)	2.69	41.02	0.68 (2.23)	18
34	Hazel	1954/10/16	0.79 (2.59)	8.82	141.21	2.30 (7.55)	27
35	Connie	1955/08/12	0.38 (1.25)	2.97	36.03	0.45 (1.48)	30
36	Diane	1955/08/17	0.21 (0.69)	1.99	43.96	0.56 (1.84)	27
37	Ione	1955/09/19	0.43 (1.41)	2.97	42.00	0.56 (1.84)	30
38	Brenda	1960/07/30	0.14 (0.46)	3.38	143.73	0.46 (1.51)	0
39	Donna	1960/09/12	0.52 (1.71)	3.04	50.99	0.84 (2.76)	3
40	Doria	1967/09/11	0.03 (0.10)	0.96	37.97	0.29 (0.95)	0
41	Doria	1971/08/28	0.56 (1.84)	3.17	49.99	0.85 (2.79)	6
42	Bret	1981/07/01	0.48 (1.57)	3.25	37.97	0.35 (1.15)	6
43	Dean	1983/09/28	0.01 (0.03)	0.54	37.97	0.34 (1.12)	0
44	Gloria	1985/09/27	0.67 (2.20)	3.77	37.03	0.69 (2.26)	24
45	Charley	1986/08/18	0.37 (1.21)	2.76	41.02	0.68 (2.23)	9
46	Danielle	1992/09/26	0.19 (0.62)	2.12	37.00	0.35 (1.15)	3
47	Bertha	1996/07/13	0.65 (2.13)	3.65	40.00	1.06 (3.48)	3
48	Fran	1996/09/06	0.36 (1.18)	2.70	44.94	0.60 (1.97)	30
49	Bonnie	1998/08/28	0.34 (1.12)	2.48	48.00	0.95 (3.12)	48
50	Earl	1998/09/05	0.12 (0.39)	3.02	149.64	0.55 (1.80)	0
51	Floyd	1999/09/16	0.65 (2.13)	3.64	41.95	1.18 (3.87)	9
52	Isabel	2003/09/19	0.72 (2.36)	3.83	41.95	0.97 (3.18)	24

[1]Storm duration is the time during a storm when H_S > 0.15 m

Table A7
Maximum H_S by Storm, Poplar Island, Station 39, Tropical Storms

Storm Number	Storm Name	Date	H_s, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/19	0.04 (0.13)	1.48	151.00	0.30 (0.98)	0
2	None	1861/09/28	0.34 (1.12)	4.08	152.00	0.92 (3.02)	18
3	None	1861/11/02	0.13 (0.43)	2.69	153.00	0.66 (2.17)	0
4	None	1863/09/19	0.24 (0.79)	3.61	153.85	0.62 (2.03)	9
5	None	1874/09/29	0.38 (1.25)	5.43	148.62	1.18 (3.87)	21
6	None	1876/09/18	0.55 (1.80)	5.97	153.14	1.64 (5.38)	24
7	None	1877/10/05	0.38 (1.25)	4.27	152.00	1.00 (3.28)	9
8	None	1878/10/23	1.44 (4.72)	8.45	152.15	2.33 (7.64)	27
9	None	1879/08/18	0.22 (0.72)	3.38	155.00	0.88 (2.89)	3
10	None	1880/09/09	0.18 (0.59)	2.67	147.34	0.50 (1.64)	3
11	None	1881/09/10	0.09 (0.30)	2.26	153.00	0.59 (1.94)	0
12	None	1888/10/12	0.19 (0.62)	2.78	150.66	0.31 (1.02)	12
13	None	1889/09/24	0.23 (0.75)	3.01	147.34	0.51 (1.67)	15
14	None	1893/06/17	0.10 (0.33)	2.08	144.03	0.44 (1.44)	0
15	None	1893/08/29	0.87 (2.85)	8.11	149.00	1.40 (4.59)	27
16	None	1893/10/14	0.44 (1.44)	4.32	149.00	1.14 (3.74)	9
17	None	1893/10/23	0.43 (1.41)	7.01	140.22	0.32 (1.05)	24
18	None	1894/09/28	0.06 (0.20)	1.81	154.02	0.55 (1.80)	0
19	None	1894/10/10	0.21 (0.69)	2.92	149.60	0.59 (1.94)	12
20	None	1897/10/24	0.02 (0.07)	1.12	152.00	0.44 (1.44)	0
21	None	1899/08/15	0.04 (0.13)	1.51	149.00	0.40 (1.31)	0
22	None	1899/11/01	0.77 (2.53)	7.09	151.16	1.62 (5.31)	18
23	None	1904/09/15	0.36 (1.18)	4.58	154.03	1.19 (3.90)	18
24	None	1908/07/30	0.04 (0.13)	1.51	149.00	0.30 (0.98)	0
25	None	1923/10/24	0.24 (0.79)	3.06	151.48	0.35 (1.15)	6
26	None	1933/08/24	0.55 (1.80)	5.98	152.29	1.63 (5.35)	15
27	None	1933/09/14	0.01 (0.03)	1.58	12.00	0.29 (0.95)	0
28	None	1935/09/06	0.17 (0.56)	2.59	145.69	0.34 (1.12)	6
29	None	1936/09/17	0.01 (0.03)	1.65	12.00	0.29 (0.95)	0
30	None	1944/08/03	0.36 (1.18)	3.98	150.69	1.11 (3.64)	15
31	None	1944/09/15	0.14 (0.46)	2.41	150.66	0.46 (1.51)	0
32	None	1946/07/05	0.05 (0.16)	1.55	144.86	0.30 (0.98)	0
33	Barbara	1953/08/15	0.07 (0.23)	1.77	151.48	0.38 (1.25)	0
34	Hazel	1954/10/16	1.56 (5.12)	8.82	152.15	2.35 (7.71)	21
35	Connie	1955/08/13	0.42 (1.38)	4.24	153.97	1.04 (3.41)	12
36	Diane	1955/08/19	0.34 (1.12)	5.04	147.82	0.82 (2.69)	27
37	Ione	1955/09/18	0.01 (0.03)	1.49	13.01	0.29 (0.95)	0
38	Brenda	1960/07/30	0.30 (0.98)	3.38	145.69	0.47 (1.54)	18
39	Donna	1960/09/13	0.15 (0.49)	2.49	155.55	0.70 (2.30)	0
40	Doria	1967/09/11	0.02 (0.07)	1.20	153.00	0.59 (1.94)	0
41	Doria	1971/08/28	0.24 (0.79)	3.10	153.85	0.72 (2.36)	9
42	Bret	1981/07/01	0.02 (0.07)	1.11	144.03	0.54 (1.77)	0
43	Dean	1983/09/28	0.01 (0.03)	0.54	31.95	0.33 (1.08)	0
44	Gloria	1985/09/25	0.01 (0.03)	1.76	12.00	0.29 (0.95)	0
45	Charley	1986/08/16	0.01 (0.03)	0.48	31.85	0.25 (0.82)	0
46	Danielle	1992/09/26	0.07 (0.23)	1.70	149.00	0.34 (1.12)	0
47	Bertha	1996/07/13	0.21 (0.69)	3.29	153.00	0.79 (2.59)	6
48	Fran	1996/09/07	0.42 (1.38)	4.00	149.47	1.25 (4.10)	27
49	Bonnie	1998/08/29	0.08 (0.26)	1.88	150.66	0.36 (1.18)	0
50	Earl	1998/09/05	0.23 (0.75)	3.02	154.70	0.55 (1.80)	15
51	Floyd	1999/09/16	0.23 (0.75)	3.40	155.00	0.88 (2.89)	9
52	Isabel	2003/09/19	0.71 (2.33)	5.92	154.38	2.16 (7.09)	18

[1]Storm duration is the time during a storm when H_S > 0.15 m

Table A8
Maximum H_S by Storm, Poplar Island, Station 33, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1954/01/23	1.27 (4.17)	7.00	321.13	0.17 (0.56)	48
2	1956/10/17	0.57 (1.87)	4.22	328.89	0.58 (1.90)	39
3	1956/10/28	0.77 (2.53)	5.39	325.00	0.65 (2.13)	108
4	1957/10/06	0.82 (2.69)	5.58	324.00	0.56 (1.84)	45
5	1958/02/17	0.96 (3.15)	3.68	331.97	0.24 (0.79)	123
6	1958/10/21	0.58 (1.90)	4.71	325.00	0.39 (1.28)	57
7	1962/03/08	0.86 (2.82)	5.74	323.12	0.38 (1.25)	63
8	1962/11/27	0.63 (2.07)	4.86	325.00	0.29 (0.95)	225
9	1966/01/31	0.90 (2.95)	3.69	276.95	0.05 (0.16)	108
10	1969/01/22	0.42 (1.38)	3.61	333.00	0.45 (1.48)	60
11	1972/05/26	0.57 (1.87)	4.25	328.00	0.58 (1.90)	72
12	1972/10/08	0.85 (2.79)	3.50	330.00	0.32 (1.05)	60
13	1974/12/04	0.88 (2.89)	3.50	332.96	0.48 (1.57)	72
14	1975/07/01	0.78 (2.56)	5.40	323.12	0.11 (0.36)	60
15	1977/10/30	0.54 (1.77)	4.20	327.00	0.42 (1.38)	84
16	1978/04/28	0.65 (2.13)	4.90	325.23	0.56 (1.84)	48
17	1980/12/30	0.56 (1.84)	4.30	325.23	0.41 (1.35)	93
18	1981/08/21	0.57 (1.87)	4.20	328.00	0.64 (2.10)	30
19	1983/02/12	0.58 (1.90)	4.30	328.89	0.57 (1.87)	87
20	1984/03/30	1.17 (3.84)	3.90	330.01	0.94 (3.08)	60
21	1984/09/30	0.60 (1.97)	4.30	328.00	0.76 (2.49)	135
22	1984/10/14	0.71 (2.33)	5.11	325.00	0.51 (1.67)	69
23	1984/11/21	0.54 (1.77)	4.36	324.24	0.07 (0.23)	75
24	1985/10/29	0.48 (1.57)	3.93	329.21	0.29 (0.95)	111
25	1986/12/01	0.56 (1.84)	4.27	327.00	0.38 (1.25)	57
26	1987/02/18	0.47 (1.54)	3.91	330.11	0.25 (0.82)	27
27	1988/04/14	0.55 (1.80)	4.18	328.00	0.67 (2.20)	54
28	1989/03/10	0.52 (1.71)	4.04	327.11	0.49 (1.61)	96
29	1991/01/09	0.41 (1.35)	3.55	333.00	0.51 (1.67)	57
30	1991/04/21	0.37 (1.21)	3.31	331.20	0.45 (1.48)	9
31	1991/10/31	0.44 (1.44)	3.76	329.21	0.35 (1.15)	45
32	1991/11/10	0.60 (1.97)	4.36	328.00	0.57 (1.87)	51
33	1993/03/15	0.90 (2.95)	3.52	277.04	0.69 (2.26)	51
34	1994/10/16	0.47 (1.54)	4.03	326.00	0.23 (0.75)	39
35	1996/10/09	0.57 (1.87)	4.21	327.11	0.58 (1.90)	84
36	1997/06/04	0.42 (1.38)	3.61	333.00	0.66 (2.17)	48
37	1997/10/16	0.56 (1.84)	4.25	326.12	0.38 (1.25)	117
38	1998/05/13	0.41 (1.35)	3.67	331.00	0.48 (1.57)	45
39	1999/05/03	0.46 (1.51)	3.90	331.00	0.53 (1.74)	42
40	1999/08/31	0.55 (1.80)	4.64	323.12	0.12 (0.39)	114
41	2000/05/30	0.52 (1.71)	4.24	326.00	0.24 (0.79)	33
42	2003/04/11	0.49 (1.61)	4.02	327.88	0.54 (1.77)	72
43	2003/09/10	0.42 (1.38)	3.68	331.00	0.32 (1.05)	15

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table A9
Maximum H_S by Storm, Poplar Island, Station 34, Extratropical Storms

Storm Number	Date	H_s, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1954/01/23	1.05 (3.44)	7.00	317.14	0.17 (0.56)	48
2	1956/10/17	0.54 (1.77)	4.22	326.88	0.58 (1.90)	39
3	1956/10/28	0.66 (2.17)	5.39	322.00	0.65 (2.13)	96
4	1957/10/06	0.69 (2.26)	5.58	321.00	0.56 (1.84)	45
5	1958/02/17	0.99 (3.25)	3.68	330.96	0.24 (0.79)	117
6	1958/10/21	0.52 (1.71)	4.26	324.88	0.54 (1.77)	54
7	1962/03/08	0.73 (2.39)	5.74	320.13	0.38 (1.25)	63
8	1962/11/29	0.57 (1.87)	4.26	327.88	0.84 (2.76)	225
9	1966/01/31	0.92 (3.02)	3.69	277.95	0.05 (0.16)	117
10	1969/01/22	0.40 (1.31)	3.61	330.00	0.45 (1.48)	54
11	1972/05/26	0.54 (1.77)	4.25	326.00	0.58 (1.90)	66
12	1972/10/08	0.88 (2.89)	3.50	329.00	0.32 (1.05)	51
13	1974/12/04	0.90 (2.95)	3.50	331.95	0.48 (1.57)	72
14	1975/07/01	0.65 (2.13)	5.40	319.14	0.11 (0.36)	60
15	1977/10/30	0.50 (1.64)	4.20	324.00	0.42 (1.38)	78
16	1978/04/28	0.58 (1.90)	4.90	322.25	0.56 (1.84)	48
17	1980/12/30	0.52 (1.71)	4.30	322.25	0.41 (1.35)	93
18	1981/08/21	0.54 (1.77)	4.20	326.00	0.64 (2.10)	30
19	1983/02/12	0.55 (1.80)	4.30	326.88	0.57 (1.87)	81
20	1984/03/30	1.18 (3.87)	3.90	329.01	0.94 (3.08)	60
21	1984/09/30	0.56 (1.84)	4.30	326.00	0.76 (2.49)	135
22	1984/10/14	0.61 (2.00)	5.11	322.00	0.51 (1.67)	66
23	1984/11/20	0.50 (1.64)	4.21	323.12	0.30 (0.98)	75
24	1985/10/29	0.45 (1.48)	3.93	326.23	0.29 (0.95)	108
25	1986/12/01	0.52 (1.71)	4.27	324.00	0.38 (1.25)	54
26	1987/02/18	0.44 (1.44)	3.91	327.11	0.25 (0.82)	24
27	1988/04/14	0.53 (1.74)	4.18	326.00	0.67 (2.20)	42
28	1989/03/10	0.50 (1.64)	4.04	325.12	0.49 (1.61)	93
29	1991/01/09	0.39 (1.28)	3.55	330.00	0.51 (1.67)	57
30	1991/04/21	0.35 (1.15)	3.31	328.22	0.45 (1.48)	9
31	1991/10/31	0.41 (1.35)	3.76	326.23	0.35 (1.15)	45
32	1991/11/10	0.57 (1.87)	4.36	326.00	0.57 (1.87)	48
33	1993/03/15	0.85 (2.79)	3.52	277.04	0.69 (2.26)	51
34	1994/10/15	0.44 (1.44)	3.88	328.00	0.26 (0.85)	39
35	1996/10/09	0.54 (1.77)	4.21	325.12	0.58 (1.90)	72
36	1997/06/04	0.40 (1.31)	3.61	330.00	0.66 (2.17)	48
37	1997/10/16	0.52 (1.71)	4.25	323.12	0.38 (1.25)	96
38	1998/05/13	0.39 (1.28)	3.67	328.00	0.48 (1.57)	45
39	1999/05/03	0.44 (1.44)	3.90	328.00	0.53 (1.74)	39
40	1999/09/01	0.52 (1.71)	4.13	326.00	0.56 (1.84)	111
41	2000/05/30	0.47 (1.54)	4.24	322.00	0.24 (0.79)	33
42	2003/04/12	0.46 (1.51)	3.91	329.11	0.56 (1.84)	66
43	2003/09/10	0.39 (1.28)	3.68	328.00	0.32 (1.05)	9

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table A10
Maximum H_S by Storm, Poplar Island, Station 35, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1954/01/23	0.94 (3.08)	7.00	320.13	0.19 (0.62)	45
2	1956/10/17	0.50 (1.64)	4.22	327.88	0.58 (1.90)	30
3	1956/10/28	0.60 (1.97)	5.39	323.00	0.66 (2.17)	108
4	1957/10/06	0.61 (2.00)	5.58	322.00	0.57 (1.87)	39
5	1958/02/17	1.00 (3.28)	3.68	331.97	0.25 (0.82)	54
6	1958/10/22	0.62 (2.03)	2.86	45.01	1.05 (3.44)	63
7	1962/03/06	0.77 (2.53)	3.19	41.00	0.24 (0.79)	72
8	1962/11/29	0.54 (1.77)	4.26	328.89	0.83 (2.72)	213
9	1966/01/28	0.87 (2.85)	3.46	331.97	0.10 (0.33)	69
10	1969/01/21	0.44 (1.44)	2.47	41.00	0.42 (1.38)	48
11	1972/05/26	0.51 (1.67)	4.25	327.00	0.58 (1.90)	60
12	1972/10/08	0.88 (2.89)	3.50	330.00	0.33 (1.08)	66
13	1974/12/04	0.91 (2.99)	3.50	332.96	0.49 (1.61)	42
14	1975/07/01	0.58 (1.90)	5.40	321.13	0.12 (0.39)	54
15	1977/10/30	0.46 (1.51)	4.20	326.00	0.43 (1.41)	72
16	1978/04/28	0.54 (1.77)	4.90	323.24	0.57 (1.87)	51
17	1980/12/29	0.50 (1.64)	2.60	42.02	0.55 (1.80)	93
18	1981/08/21	0.51 (1.67)	4.20	327.00	0.64 (2.10)	48
19	1983/02/12	0.83 (2.72)	3.30	43.00	0.51 (1.67)	93
20	1984/03/30	1.19 (3.90)	3.90	330.01	0.94 (3.08)	54
21	1984/09/30	0.53 (1.74)	4.30	327.00	0.76 (2.49)	126
22	1984/10/14	0.55 (1.80)	5.11	324.00	0.52 (1.71)	63
23	1984/11/20	0.46 (1.51)	4.21	325.12	0.31 (1.02)	63
24	1985/11/05	0.73 (2.39)	3.11	47.98	1.11 (3.64)	117
25	1986/12/01	0.73 (2.39)	3.12	43.00	0.61 (2.00)	42
26	1987/02/18	0.41 (1.35)	3.91	327.11	0.26 (0.85)	15
27	1988/04/14	0.49 (1.61)	4.18	327.00	0.67 (2.20)	36
28	1989/03/10	0.46 (1.51)	4.04	326.12	0.50 (1.64)	93
29	1991/01/09	0.36 (1.18)	3.55	330.00	0.51 (1.67)	45
30	1991/04/20	0.33 (1.08)	2.14	42.02	0.61 (2.00)	9
31	1991/10/31	0.38 (1.25)	3.76	326.23	0.36 (1.18)	24
32	1991/11/10	0.53 (1.74)	4.36	327.00	0.57 (1.87)	45
33	1993/03/14	0.49 (1.61)	4.14	325.23	0.74 (2.43)	21
34	1994/10/15	0.40 (1.31)	3.88	328.00	0.27 (0.89)	27
35	1996/10/09	0.51 (1.67)	2.65	41.00	0.44 (1.44)	69
36	1997/06/04	0.38 (1.25)	3.61	330.00	0.67 (2.20)	42
37	1997/10/16	0.48 (1.57)	4.25	325.12	0.38 (1.25)	75
38	1998/05/13	0.36 (1.18)	3.67	328.00	0.48 (1.57)	27
39	1999/05/03	0.40 (1.31)	3.90	328.00	0.54 (1.77)	27
40	1999/09/01	0.48 (1.57)	4.13	327.00	0.56 (1.84)	102
41	2000/05/30	0.43 (1.41)	4.24	324.00	0.24 (0.79)	27
42	2003/04/12	0.44 (1.44)	3.91	329.11	0.57 (1.87)	48
43	2003/09/12	0.54 (1.77)	2.72	40.02	0.53 (1.74)	9

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table A11
Maximum H_S by Storm, Poplar Island, Station 36, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1954/01/23	0.90 (2.95)	7.00	321.13	0.19 (0.62)	45
2	1956/10/17	0.49 (1.61)	4.22	327.88	0.58 (1.90)	33
3	1956/10/28	0.58 (1.90)	5.39	323.00	0.66 (2.17)	108
4	1957/10/06	0.59 (1.94)	5.58	323.00	0.57 (1.87)	39
5	1958/02/17	0.99 (3.25)	3.68	331.97	0.25 (0.82)	45
6	1958/10/22	0.63 (2.07)	2.86	45.01	1.05 (3.44)	60
7	1962/03/06	0.79 (2.59)	3.19	42.00	0.24 (0.79)	72
8	1962/11/29	0.52 (1.71)	4.26	328.89	0.83 (2.72)	201
9	1966/01/28	0.82 (2.69)	3.46	331.97	0.10 (0.33)	63
10	1969/01/21	0.45 (1.48)	2.47	42.00	0.42 (1.38)	42
11	1972/05/26	0.50 (1.64)	4.25	327.00	0.58 (1.90)	51
12	1972/10/08	0.88 (2.89)	3.50	330.00	0.33 (1.08)	63
13	1974/12/04	0.90 (2.95)	3.50	332.96	0.49 (1.61)	42
14	1975/07/01	0.56 (1.84)	5.40	321.13	0.12 (0.39)	48
15	1977/10/30	0.45 (1.48)	4.20	326.00	0.43 (1.41)	57
16	1978/04/28	0.52 (1.71)	4.90	323.24	0.57 (1.87)	48
17	1980/12/29	0.51 (1.67)	2.60	43.01	0.55 (1.80)	87
18	1981/08/21	0.50 (1.64)	4.20	327.00	0.64 (2.10)	48
19	1983/02/12	0.85 (2.79)	3.30	44.00	0.51 (1.67)	87
20	1984/03/30	1.17 (3.84)	3.90	330.01	0.94 (3.08)	51
21	1984/09/30	0.51 (1.67)	4.30	327.00	0.76 (2.49)	114
22	1984/10/14	0.54 (1.77)	5.11	324.00	0.52 (1.71)	57
23	1984/11/20	0.45 (1.48)	4.21	325.12	0.31 (1.02)	60
24	1985/11/05	0.75 (2.46)	3.11	47.98	1.11 (3.64)	105
25	1986/12/03	0.75 (2.46)	3.12	44.00	0.61 (2.00)	42
26	1987/02/18	0.39 (1.28)	3.91	327.11	0.26 (0.85)	15
27	1988/04/14	0.48 (1.57)	4.18	327.00	0.67 (2.20)	33
28	1989/03/10	0.45 (1.48)	4.04	326.12	0.50 (1.64)	84
29	1991/01/09	0.36 (1.18)	3.55	329.00	0.51 (1.67)	24
30	1991/04/20	0.34 (1.12)	2.14	43.01	0.61 (2.00)	9
31	1991/10/31	0.36 (1.18)	3.76	326.23	0.36 (1.18)	18
32	1991/11/10	0.52 (1.71)	4.36	327.00	0.57 (1.87)	36
33	1993/03/14	0.47 (1.54)	4.14	325.23	0.74 (2.43)	18
34	1994/10/15	0.39 (1.28)	3.88	328.00	0.27 (0.89)	21
35	1996/10/09	0.52 (1.71)	2.65	42.00	0.44 (1.44)	69
36	1997/06/04	0.37 (1.21)	3.61	329.00	0.67 (2.20)	39
37	1997/10/16	0.46 (1.51)	4.25	325.12	0.38 (1.25)	51
38	1998/05/13	0.35 (1.15)	3.67	328.00	0.48 (1.57)	21
39	1999/05/03	0.39 (1.28)	3.90	328.00	0.54 (1.77)	24
40	1999/09/01	0.47 (1.54)	4.13	327.00	0.56 (1.84)	102
41	2000/05/30	0.42 (1.38)	4.24	325.00	0.24 (0.79)	27
42	2003/04/12	0.43 (1.41)	3.91	328.11	0.57 (1.87)	45
43	2003/09/12	0.55 (1.80)	2.72	41.02	0.53 (1.74)	9

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table A12
Maximum H_S by Storm, Poplar Island, Station 37, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1954/01/22	0.01 (0.03)	1.96	337.00	0.19 (0.62)	0
2	1956/10/17	0.23 (0.75)	2.07	45.01	0.48 (1.57)	12
3	1956/10/27	0.47 (1.54)	2.75	48.00	0.95 (3.12)	15
4	1957/10/02	0.01 (0.03)	2.25	335.18	0.29 (0.95)	0
5	1958/02/16	0.01 (0.03)	2.10	339.73	0.19 (0.62)	0
6	1958/10/22	0.52 (1.71)	2.86	48.00	1.05 (3.44)	9
7	1962/03/06	0.59 (1.94)	3.19	46.00	0.24 (0.79)	9
8	1962/11/26	0.01 (0.03)	3.27	337.00	0.29 (0.95)	0
9	1966/01/30	0.31 (1.02)	2.40	48.97	-0.05 (-0.16)	3
10	1969/01/21	0.34 (1.12)	2.47	46.00	0.42 (1.38)	3
11	1972/05/24	0.01 (0.03)	3.37	339.73	0.29 (0.95)	0
12	1972/10/07	0.49 (1.61)	2.90	45.01	0.53 (1.74)	36
13	1974/12/02	0.70 (2.30)	3.40	45.99	1.00 (3.28)	12
14	1975/06/29	0.20 (0.66)	1.95	47.98	0.25 (0.82)	3
15	1977/10/29	0.01 (0.03)	2.60	337.00	0.29 (0.95)	0
16	1978/04/26	0.27 (0.89)	2.21	46.00	0.28 (0.92)	9
17	1980/12/29	0.41 (1.35)	2.60	46.01	0.55 (1.80)	12
18	1981/08/21	0.34 (1.12)	2.40	46.01	0.75 (2.46)	30
19	1983/02/12	0.65 (2.13)	3.30	47.00	0.51 (1.67)	24
20	1984/03/29	0.58 (1.90)	3.20	46.99	0.23 (0.75)	9
21	1984/09/27	0.01 (0.03)	3.26	199.33	0.29 (0.95)	0
22	1984/10/11	0.01 (0.03)	2.67	338.82	0.29 (0.95)	0
23	1984/11/19	0.15 (0.49)	1.67	46.00	0.29 (0.95)	0
24	1985/11/05	0.61 (2.00)	3.11	51.00	1.11 (3.64)	30
25	1986/12/03	0.58 (1.90)	3.12	47.00	0.61 (2.00)	9
26	1987/02/15	0.01 (0.03)	2.37	337.00	0.19 (0.62)	0
27	1988/04/12	0.23 (0.75)	2.07	45.01	0.14 (0.46)	3
28	1989/03/07	0.01 (0.03)	2.99	337.00	0.19 (0.62)	0
29	1991/01/07	0.01 (0.03)	1.86	336.09	0.19 (0.62)	0
30	1991/04/20	0.27 (0.89)	2.14	46.01	0.61 (2.00)	9
31	1991/10/28	0.01 (0.03)	1.36	337.91	0.29 (0.95)	0
32	1991/11/08	0.01 (0.03)	1.48	334.27	0.29 (0.95)	0
33	1993/03/13	0.01 (0.03)	1.61	288.34	0.19 (0.62)	0
34	1994/10/13	0.25 (0.82)	2.07	47.00	0.62 (2.03)	6
35	1996/10/09	0.39 (1.28)	2.65	46.00	0.44 (1.44)	21
36	1997/06/02	0.27 (0.89)	2.13	46.01	0.63 (2.07)	18
37	1997/10/14	0.01 (0.03)	2.98	192.83	0.29 (0.95)	0
38	1998/05/14	0.14 (0.46)	1.63	46.00	0.54 (1.77)	0
39	1999/05/02	0.20 (0.66)	1.90	46.99	0.46 (1.51)	6
40	1999/09/05	0.32 (1.05)	2.40	46.00	0.35 (1.15)	9
41	2000/05/29	0.17 (0.56)	1.78	47.98	0.29 (0.95)	9
42	2003/04/08	0.01 (0.03)	3.39	337.00	0.29 (0.95)	0
43	2003/09/12	0.42 (1.38)	2.72	45.01	0.53 (1.74)	3

[1]Storm duration is the time during a storm when H_S > 0.15 m

Table A13
Maximum H_S by Storm, Poplar Island, Station 38, Extratropical Storms

Storm Number	Date	H_s, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1954/01/22	0.01 (0.03)	1.96	346.03	0.19 (0.62)	0
2	1956/10/17	0.18 (0.59)	2.07	36.03	0.48 (1.57)	6
3	1956/10/27	0.41 (1.35)	2.75	47.00	0.96 (3.15)	15
4	1957/10/02	0.01 (0.03)	2.25	355.07	0.29 (0.95)	0
5	1958/02/16	0.09 (0.30)	3.21	155.04	0.19 (0.62)	0
6	1958/10/22	0.45 (1.48)	2.86	47.00	1.06 (3.48)	9
7	1962/03/06	0.46 (1.51)	3.19	37.00	0.25 (0.82)	9
8	1962/11/26	0.01 (0.03)	3.27	357.00	0.29 (0.95)	0
9	1966/01/30	0.24 (0.79)	2.40	35.88	-0.04 (-0.13)	3
10	1969/01/21	0.26 (0.85)	2.47	37.00	0.43 (1.41)	3
11	1972/05/25	0.11 (0.36)	3.25	136.89	0.15 (0.49)	0
12	1972/10/07	0.40 (1.31)	2.70	49.00	0.87 (2.85)	36
13	1974/12/02	0.56 (1.84)	3.40	40.98	1.00 (3.28)	24
14	1975/06/29	0.16 (0.52)	1.95	34.92	0.25 (0.82)	3
15	1977/10/29	0.01 (0.03)	2.60	357.00	0.29 (0.95)	0
16	1978/04/26	0.21 (0.69)	2.21	37.00	0.28 (0.92)	9
17	1980/12/29	0.33 (1.08)	2.60	41.02	0.55 (1.80)	12
18	1981/08/21	0.28 (0.92)	2.40	41.02	0.75 (2.46)	30
19	1983/02/12	0.54 (1.77)	3.30	42.00	0.51 (1.67)	24
20	1984/03/29	0.45 (1.48)	3.20	37.97	0.24 (0.79)	12
21	1984/09/27	0.13 (0.43)	3.26	150.27	0.29 (0.95)	0
22	1984/10/11	0.01 (0.03)	2.67	358.93	0.29 (0.95)	0
23	1984/11/19	0.11 (0.36)	1.67	37.00	0.29 (0.95)	0
24	1985/11/05	0.54 (1.77)	3.11	49.99	1.12 (3.67)	39
25	1986/12/03	0.48 (1.57)	3.12	42.00	0.62 (2.03)	9
26	1987/02/15	0.01 (0.03)	2.37	357.00	0.19 (0.62)	0
27	1988/04/12	0.18 (0.59)	2.07	32.04	0.15 (0.49)	3
28	1989/03/07	0.01 (0.03)	2.99	357.00	0.19 (0.62)	0
29	1991/01/07	0.01 (0.03)	1.86	356.04	0.19 (0.62)	0
30	1991/04/20	0.22 (0.72)	2.14	41.02	0.61 (2.00)	9
31	1991/10/28	0.01 (0.03)	1.36	357.96	0.29 (0.95)	0
32	1991/11/08	0.01 (0.03)	1.48	354.11	0.29 (0.95)	0
33	1993/03/13	0.06 (0.20)	2.23	144.55	0.19 (0.62)	0
34	1994/10/13	0.21 (0.69)	2.07	42.00	0.62 (2.03)	6
35	1996/10/09	0.30 (0.98)	2.65	37.00	0.44 (1.44)	21
36	1997/06/02	0.22 (0.72)	2.13	41.02	0.63 (2.07)	15
37	1997/10/14	0.11 (0.36)	2.98	145.37	0.29 (0.95)	0
38	1998/05/14	0.11 (0.36)	1.63	37.00	0.55 (1.80)	0
39	1999/05/02	0.15 (0.49)	1.90	37.97	0.46 (1.51)	0
40	1999/09/05	0.26 (0.85)	2.34	44.94	0.56 (1.84)	9
41	2000/05/29	0.13 (0.43)	1.78	38.94	0.29 (0.95)	0
42	2003/04/08	0.01 (0.03)	3.39	357.00	0.29 (0.95)	0
43	2003/09/12	0.32 (1.05)	2.72	36.03	0.53 (1.74)	3

[1]Storm duration is the time during a storm when H_S > 0.15 m

Table A14
Maximum H_S by Storm, Poplar Island, Station 39, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1954/01/22	0.01 (0.03)	1.96	359.07	0.19 (0.62)	0
2	1956/10/16	0.01 (0.03)	1.69	12.00	0.29 (0.95)	0
3	1956/10/24	0.01 (0.03)	2.58	10.00	0.29 (0.95)	0
4	1957/10/02	0.01 (0.03)	2.25	8.99	0.29 (0.95)	0
5	1958/02/16	0.19 (0.62)	3.21	152.00	0.20 (0.66)	6
6	1958/10/20	0.01 (0.03)	2.90	12.00	0.29 (0.95)	0
7	1962/03/05	0.01 (0.03)	2.74	10.00	0.19 (0.62)	0
8	1962/11/26	0.01 (0.03)	3.27	11.00	0.29 (0.95)	0
9	1966/01/31	0.23 (0.75)	3.80	153.14	0.31 (1.02)	15
10	1969/01/20	0.01 (0.03)	1.61	0.14	0.19 (0.62)	0
11	1972/05/25	0.25 (0.82)	3.25	141.78	0.16 (0.52)	6
12	1972/10/04	0.01 (0.03)	2.98	13.01	0.29 (0.95)	0
13	1974/12/02	0.40 (1.31)	5.10	150.00	0.92 (3.02)	33
14	1975/06/29	0.17 (0.56)	2.63	144.03	0.29 (0.95)	3
15	1977/10/29	0.01 (0.03)	2.60	11.00	0.29 (0.95)	0
16	1978/04/26	0.01 (0.03)	1.94	31.00	0.29 (0.95)	0
17	1980/12/27	0.01 (0.03)	2.80	10.00	0.19 (0.62)	0
18	1981/08/20	0.24 (0.79)	3.10	147.34	0.41 (1.35)	9
19	1983/02/11	0.01 (0.03)	3.20	10.00	0.19 (0.62)	0
20	1984/03/30	0.35 (1.15)	3.95	159.31	0.84 (2.76)	9
21	1984/09/27	0.27 (0.89)	3.26	152.31	0.29 (0.95)	3
22	1984/10/11	0.01 (0.03)	2.67	13.01	0.29 (0.95)	0
23	1984/11/19	0.01 (0.03)	1.67	31.00	0.29 (0.95)	0
24	1985/11/06	0.29 (0.95)	3.31	155.86	1.06 (3.48)	21
25	1986/12/03	0.14 (0.46)	2.40	152.42	1.01 (3.31)	0
26	1987/02/15	0.01 (0.03)	2.37	11.00	0.19 (0.62)	0
27	1988/04/12	0.01 (0.03)	2.28	8.99	0.29 (0.95)	0
28	1989/03/07	0.01 (0.03)	2.99	11.00	0.19 (0.62)	0
29	1991/01/07	0.01 (0.03)	1.86	10.00	0.19 (0.62)	0
30	1991/04/20	0.11 (0.36)	2.48	153.00	0.67 (2.20)	0
31	1991/10/28	0.01 (0.03)	1.36	12.00	0.29 (0.95)	0
32	1991/11/08	0.01 (0.03)	1.48	7.99	0.29 (0.95)	0
33	1993/03/13	0.12 (0.39)	2.23	146.52	0.19 (0.62)	0
34	1994/10/13	0.08 (0.26)	2.12	149.00	0.52 (1.71)	0
35	1996/10/09	0.15 (0.49)	2.46	150.66	0.37 (1.21)	0
36	1997/06/06	0.23 (0.75)	3.00	153.00	0.66 (2.17)	6
37	1997/10/14	0.22 (0.72)	2.98	147.34	0.29 (0.95)	9
38	1998/05/14	0.04 (0.13)	1.48	154.02	0.68 (2.23)	0
39	1999/04/29	0.15 (0.49)	2.63	145.00	0.16 (0.52)	0
40	1999/09/06	0.21 (0.69)	2.87	150.45	0.78 (2.56)	18
41	2000/05/31	0.03 (0.10)	1.21	153.00	0.77 (2.53)	0
42	2003/04/08	0.01 (0.03)	3.39	11.00	0.29 (0.95)	0
43	2003/09/08	0.01 (0.03)	1.50	10.00	0.29 (0.95)	0

[1]Storm duration is the time during a storm when H_S > 0.15 m

Appendix B: Extremal Wave and Water Level Analysis Results for Poplar Island

Table B1
Poplar Island Station 1 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.77 (2.53)	3.32	0.70 (2.30)
10	1.11 (3.64)	4.44	1.06 (3.48)
15	1.33 (4.36)	4.68	1.12 (3.67)
20	1.49 (4.89)	5.16	1.48 (4.86)
25	1.62 (5.31)	5.60	1.75 (5.74)
30	1.72 (5.64)	5.88	1.77 (5.81)
35	1.82 (5.97)	6.02	1.75 (5.74)
40	1.89 (6.20)	6.58	1.72 (5.64)
45	1.97 (6.46)	6.55	1.88 (6.17)
50	2.03 (6.66)	6.79	2.01 (6.59)
100	2.47 (8.10)	8.64	2.61 (8.56)

Table B2
Poplar Island Station 2 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.79 (2.59)	3.31	0.70 (2.30)
10	1.18 (3.87)	4.38	1.03 (3.38)
15	1.43 (4.69)	4.77	1.08 (3.54)
20	1.62 (5.31)	5.29	1.52 (4.99)
25	1.77 (5.81)	5.52	1.77 (5.81)
30	1.89 (6.20)	5.63	1.81 (5.94)
35	2.00 (6.56)	6.26	1.73 (5.68)
40	2.09 (6.86)	6.55	1.84 (6.04)
45	2.17 (7.12)	6.74	1.94 (6.36)
50	2.24 (7.35)	6.79	2.01 (6.59)
100	2.58 (8.46)	8.64	2.61 (8.56)

Table B3
Poplar Island Station 3 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.95 (3.12)	3.79	0.91 (2.99)
10	1.41 (4.63)	4.52	1.06 (3.48)
15	1.70 (5.58)	5.00	1.20 (3.94)
20	1.92 (6.30)	5.42	1.13 (3.71)
25	2.09 (6.86)	5.71	1.08 (3.54)
30	2.23 (7.32)	5.60	1.60 (5.25)
35	2.36 (7.74)	5.86	1.80 (5.91)
40	2.46 (8.07)	5.93	1.78 (5.84)
45	2.56 (8.40)	5.98	1.84 (6.04)
50	2.64 (8.66)	6.12	1.80 (5.91)
100	3.23 (10.60)	7.94	2.44 (8.01)

Table B4
Poplar Island Station 4 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	1.13 (3.71)	4.05	0.93 (3.05)
10	1.61 (5.28)	4.97	1.18 (3.87)
15	1.91 (6.27)	5.23	1.26 (4.13)
20	2.13 (6.99)	5.53	1.18 (3.87)
25	2.31 (7.58)	5.75	1.34 (4.40)
30	2.54 (8.33)	5.98	1.78 (5.84)
35	2.69 (8.83)	6.21	1.55 (5.09)
40	2.83 (9.28)	6.58	1.48 (4.86)
45	2.96 (9.71)	6.69	1.27 (4.17)
50	3.07 (10.07)	6.53	1.75 (5.74)
100	3.78 (12.40)	7.60	1.67 (5.48)

Table B5
Poplar Island Station 5 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	1.14 (3.74)	4.99	0.57 (1.87)
10	1.46 (4.79)	5.13	1.17 (3.84)
15	1.66 (5.45)	5.48	1.21 (3.97)
20	1.81 (5.94)	5.97	1.46 (4.79)
25	1.93 (6.33)	6.11	1.41 (4.63)
30	2.03 (6.66)	6.01	1.70 (5.58)
35	2.11 (6.92)	6.05	1.70 (5.58)
40	2.20 (7.22)	6.12	1.82 (5.97)
45	2.29 (7.51)	6.22	1.93 (6.33)
50	2.36 (7.74)	6.22	1.93 (6.33)
100	2.86 (9.38)	7.55	1.97 (6.46)

Table B6
Poplar Island Station 6 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.98 (3.22)	4.64	0.44 (1.44)
10	1.29 (4.23)	5.48	0.89 (2.92)
15	1.50 (4.92)	5.76	1.16 (3.81)
20	1.64 (5.38)	6.03	1.22 (4.00)
25	1.76 (5.77)	6.03	1.57 (5.15)
30	1.86 (6.10)	6.07	1.76 (5.77)
35	1.95 (6.40)	6.12	1.78 (5.84)
40	2.02 (6.63)	6.22	1.89 (6.20)
45	2.09 (6.86)	6.22	1.89 (6.20)
50	2.15 (7.05)	6.71	1.94 (6.36)
100	2.55 (8.37)	7.81	2.00 (6.56)

Table B7
Poplar Island Station 7 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	1.23 (4.04)	4.98	0.45 (1.48)
10	1.55 (5.09)	5.58	0.72 (2.36)
15	1.76 (5.77)	5.78	0.94 (3.08)
20	1.91 (6.27)	5.76	1.38 (4.53)
25	2.03 (6.66)	5.79	1.53 (5.02)
30	2.13 (6.99)	6.03	1.49 (4.89)
35	2.22 (7.28)	6.35	1.54 (5.05)
40	2.30 (7.55)	6.55	1.64 (5.38)
45	2.36 (7.74)	6.77	1.67 (5.48)
50	2.42 (7.94)	6.77	1.67 (5.48)
100	2.84 (9.32)	7.94	2.11 (6.92)

Table B8
Poplar Island Station 8 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	1.15 (3.77)	4.98	0.45 (1.48)
10	1.45 (4.76)	5.55	0.70 (2.30)
15	1.64 (5.38)	5.78	0.94 (3.08)
20	1.78 (5.84)	5.64	1.39 (4.56)
25	1.89 (6.20)	5.94	1.53 (5.02)
30	1.99 (6.53)	6.28	1.54 (5.05)
35	2.07 (6.79)	6.35	1.54 (5.05)
40	2.14 (7.02)	6.49	1.61 (5.28)
45	2.20 (7.22)	6.77	1.67 (5.48)
50	2.26 (7.41)	6.77	1.67 (5.48)
100	2.64 (8.66)	7.94	2.11 (6.92)

Table B9
Poplar Island Station 9 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	1.23 (4.04)	4.93	0.42 (1.38)
10	1.54 (5.05)	5.55	0.54 (1.77)
15	1.73 (5.68)	5.89	0.97 (3.18)
20	1.87 (6.14)	5.77	1.45 (4.76)
25	1.99 (6.53)	5.99	1.35 (4.43)
30	2.08 (6.82)	6.36	1.48 (4.86)
35	2.16 (7.09)	6.45	1.66 (5.45)
40	2.23 (7.32)	6.77	1.67 (5.48)
45	2.30 (7.55)	6.77	1.67 (5.48)
50	2.35 (7.71)	6.84	1.76 (5.77)
100	2.74 (8.99)	7.94	2.11 (6.92)

Table B10
Poplar Island Station 10 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	1.12 (3.67)	5.14	0.44 (1.44)
10	1.32 (4.33)	5.81	0.54 (1.77)
15	1.43 (4.69)	5.99	0.63 (2.07)
20	1.51 (4.95)	6.27	0.83 (2.72)
25	1.57 (5.15)	6.42	0.85 (2.79)
30	1.62 (5.31)	6.28	0.87 (2.85)
35	1.66 (5.45)	6.35	1.34 (4.40)
40	1.69 (5.54)	6.35	1.34 (4.40)
45	1.73 (5.68)	6.35	1.34 (4.40)
50	1.79 (5.87)	6.35	1.34 (4.40)
100	2.23 (7.32)	8.46	1.93 (6.33)

Table B11
Poplar Island Station 11 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	1.14 (3.74)	5.18	0.50 (1.64)
10	1.34 (4.40)	5.79	0.69 (2.26)
15	1.46 (4.79)	6.06	0.83 (2.72)
20	1.53 (5.02)	6.36	0.78 (2.56)
25	1.59 (5.22)	6.38	0.88 (2.89)
30	1.64 (5.38)	6.43	1.06 (3.48)
35	1.68 (5.51)	6.35	1.19 (3.90)
40	1.73 (5.68)	6.26	1.59 (5.22)
45	1.80 (5.91)	6.82	1.77 (5.81)
50	1.87 (6.14)	6.82	1.77 (5.81)
100	2.32 (7.61)	8.46	1.93 (6.33)

Table B12
Poplar Island Station 12 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.91 (2.99)	4.51	0.37 (1.21)
10	1.13 (3.71)	5.45	0.45 (1.48)
15	1.27 (4.17)	5.67	0.45 (1.48)
20	1.37 (4.49)	6.05	0.34 (1.12)
25	1.45 (4.76)	6.14	0.32 (1.05)
30	1.52 (4.99)	6.17	0.21 (0.69)
35	1.58 (5.18)	6.17	0.21 (0.69)
40	1.63 (5.35)	6.44	0.19 (0.62)
45	1.67 (5.48)	6.64	0.40 (1.31)
50	1.71 (5.61)	7.36	0.68 (2.23)
100	1.99 (6.53)	7.65	0.98 (3.22)

Table B13
Poplar Island Station 13 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.83 (2.72)	4.31	0.35 (1.15)
10	1.00 (3.28)	4.84	0.42 (1.38)
15	1.12 (3.67)	5.37	0.51 (1.67)
20	1.20 (3.94)	5.67	0.45 (1.48)
25	1.26 (4.13)	5.75	0.49 (1.61)
30	1.32 (4.33)	5.98	0.47 (1.54)
35	1.37 (4.49)	6.09	0.53 (1.74)
40	1.41 (4.63)	6.16	0.59 (1.94)
45	1.45 (4.76)	7.02	0.62 (2.03)
50	1.48 (4.86)	7.73	1.07 (3.51)
100	1.50 (4.92)	7.65	0.98 (3.22)

Table B14
Poplar Island Station 14 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.75 (2.46)	4.42	0.36 (1.18)
10	0.87 (2.85)	5.21	0.47 (1.54)
15	0.93 (3.05)	5.30	0.54 (1.77)
20	0.98 (3.22)	5.42	0.71 (2.33)
25	1.01 (3.31)	5.39	0.81 (2.66)
30	1.04 (3.41)	5.52	0.95 (3.12)
35	1.07 (3.51)	5.22	1.25 (4.10)
40	1.09 (3.58)	6.32	1.55 (5.09)
45	1.11 (3.64)	6.32	1.55 (5.09)
50	1.13 (3.71)	6.73	0.72 (2.36)
100	1.24 (4.07)	6.73	0.72 (2.36)

Table B15
Poplar Island Station 15 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.64 (2.10)	4.16	0.49 (1.61)
10	0.75 (2.46)	4.40	0.61 (2.00)
15	0.81 (2.66)	4.36	0.66 (2.17)
20	0.86 (2.82)	4.63	0.87 (2.85)
25	0.89 (2.92)	4.75	0.93 (3.05)
30	0.92 (3.02)	4.75	0.93 (3.05)
35	0.95 (3.12)	4.90	0.84 (2.76)
40	0.97 (3.18)	4.97	0.74 (2.43)
45	0.99 (3.25)	5.12	0.73 (2.40)
50	1.00 (3.28)	5.29	0.75 (2.46)
100	1.26 (4.13)	8.64	2.30 (7.55)

Table B16
Poplar Island Station 16 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.53 (1.74)	3.52	0.78 (2.56)
10	0.65 (2.13)	3.84	0.86 (2.82)
15	0.72 (2.36)	4.05	0.95 (3.12)
20	0.77 (2.53)	4.48	1.22 (4.00)
25	0.80 (2.62)	4.54	1.23 (4.04)
30	0.83 (2.72)	4.96	1.30 (4.27)
35	0.86 (2.82)	4.96	1.30 (4.27)
40	0.88 (2.89)	5.24	1.42 (4.66)
45	0.90 (2.95)	5.03	1.24 (4.07)
50	0.92 (3.02)	5.03	1.24 (4.07)
100	1.03 (3.38)	7.60	1.53 (5.02)

Table B17
Poplar Island Station 33 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.90 (2.95)	4.31	0.27 (0.89)
10	1.08 (3.54)	4.98	0.65 (2.13)
15	1.17 (3.84)	5.98	0.98 (3.22)
20	1.25 (4.10)	5.90	0.91 (2.99)
25	1.30 (4.27)	5.99	0.86 (2.82)
30	1.34 (4.40)	5.99	0.86 (2.82)
35	1.38 (4.53)	6.88	0.82 (2.69)
40	1.41 (4.63)	6.94	0.74 (2.43)
45	1.44 (4.72)	7.02	0.86 (2.82)
50	1.47 (4.82)	7.02	0.86 (2.82)
100	1.96 (6.43)	8.28	1.85 (6.07)

Table B18
Poplar Island Station 34 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.88 (2.89)	4.17	0.30 (0.98)
10	1.07 (3.51)	4.35	0.54 (1.77)
15	1.17 (3.84)	5.49	1.01 (3.31)
20	1.24 (4.07)	5.84	1.13 (3.71)
25	1.30 (4.27)	5.62	1.41 (4.63)
30	1.35 (4.43)	5.50	1.51 (4.95)
35	1.38 (4.53)	6.31	1.89 (6.20)
40	1.54 (5.05)	6.60	1.77 (5.81)
45	1.61 (5.28)	6.72	1.66 (5.45)
50	1.68 (5.51)	6.82	1.82 (5.97)
100	2.12 (6.96)	7.88	1.77 (5.81)

Table B19
Poplar Island Station 35 Extremal Wave Analysis Results

Return Period Years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.75 (2.46)	3.87	0.24 (0.79)
10	0.88 (2.89)	3.59	0.19 (0.62)
15	0.96 (3.15)	3.86	0.38 (1.25)
20	1.01 (3.31)	4.19	0.37 (1.21)
25	1.06 (3.48)	3.67	0.51 (1.67)
30	1.09 (3.58)	3.69	0.67 (2.20)
35	1.12 (3.67)	3.80	0.94 (3.08)
40	1.14 (3.74)	3.86	0.88 (2.89)
45	1.16 (3.81)	3.86	0.88 (2.89)
50	1.18 (3.87)	3.86	0.88 (2.89)
100	1.20 (3.94)	3.88	0.94 (3.08)

Table B20
Poplar Island Station 36 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.75 (2.46)	3.57	0.23 (0.75)
10	0.88 (2.89)	3.55	0.24 (0.79)
15	0.96 (3.15)	3.95	0.44 (1.44)
20	1.01 (3.31)	3.62	0.64 (2.10)
25	1.06 (3.48)	3.66	0.62 (2.03)
30	1.09 (3.58)	3.75	0.88 (2.89)
35	1.12 (3.67)	3.75	0.88 (2.89)
40	1.14 (3.74)	3.80	0.94 (3.08)
45	1.17 (3.84)	3.86	0.88 (2.89)
50	1.19 (3.90)	3.86	0.88 (2.89)
100	1.23 (4.04)	3.86	0.88 (2.89)

Table B21
Poplar Island Station 37 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.49 (1.61)	2.82	0.64 (2.10)
10	0.61 (2.00)	3.13	0.63 (2.07)
15	0.67 (2.20)	3.23	0.61 (2.00)
20	0.71 (2.33)	3.41	0.85 (2.79)
25	0.74 (2.43)	3.49	0.79 (2.59)
30	0.77 (2.53)	3.55	0.89 (2.92)
35	0.79 (2.59)	3.55	0.89 (2.92)
40	0.81 (2.66)	3.65	0.85 (2.79)
45	0.82 (2.69)	3.65	0.85 (2.79)
50	0.83 (2.72)	3.70	0.93 (3.05)
100	0.92 (3.02)	3.80	0.78 (2.56)

Table B22
Poplar Island Station 38 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.43 (1.41)	3.06	0.75 (2.46)
10	0.52 (1.71)	3.11	0.67 (2.20)
15	0.57 (1.87)	3.27	0.82 (2.69)
20	0.61 (2.00)	3.35	0.88 (2.89)
25	0.63 (2.07)	3.41	0.90 (2.95)
30	0.65 (2.13)	3.89	1.05 (3.44)
35	0.67 (2.20)	4.25	1.05 (3.44)
40	0.68 (2.23)	4.25	1.05 (3.44)
45	0.69 (2.26)	5.11	1.34 (4.40)
50	0.70 (2.30)	5.11	1.34 (4.40)
100	0.77 (2.53)	6.22	1.57 (5.15)

Table B23
Poplar Island Station 39 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.33 (1.08)	3.80	0.85 (2.79)
10	0.42 (1.38)	4.59	1.16 (3.81)
15	0.47 (1.54)	4.96	1.39 (4.56)
20	0.56 (1.84)	5.37	1.67 (5.48)
25	0.63 (2.07)	5.69	1.82 (5.97)
30	0.69 (2.26)	6.45	2.02 (6.63)
35	0.75 (2.46)	6.45	2.02 (6.63)
40	0.80 (2.62)	6.92	1.82 (5.97)
45	0.84 (2.76)	7.25	1.71 (5.61)
50	0.88 (2.89)	6.79	1.90 (6.23)
100	1.14 (3.74)	7.55	1.86 (6.10)

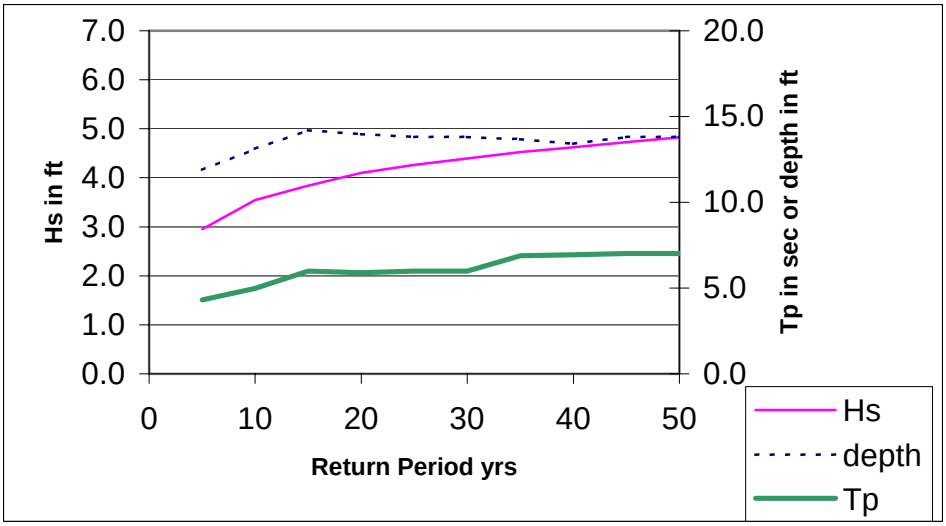

Figure B1. Significant wave height, peak wave period and total depth relative to MLLW as a function of return period from extremal wave height analysis of Station 33 wave data

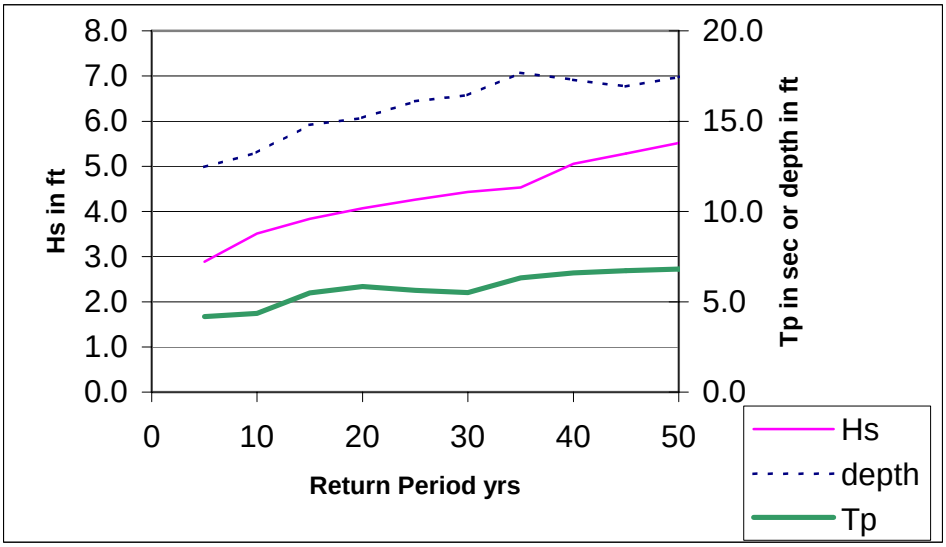

Figure B2. Significant wave height, peak wave period and total depth relative to MLLW as a function of return period from extremal wave height analysis of Station 34 wave data

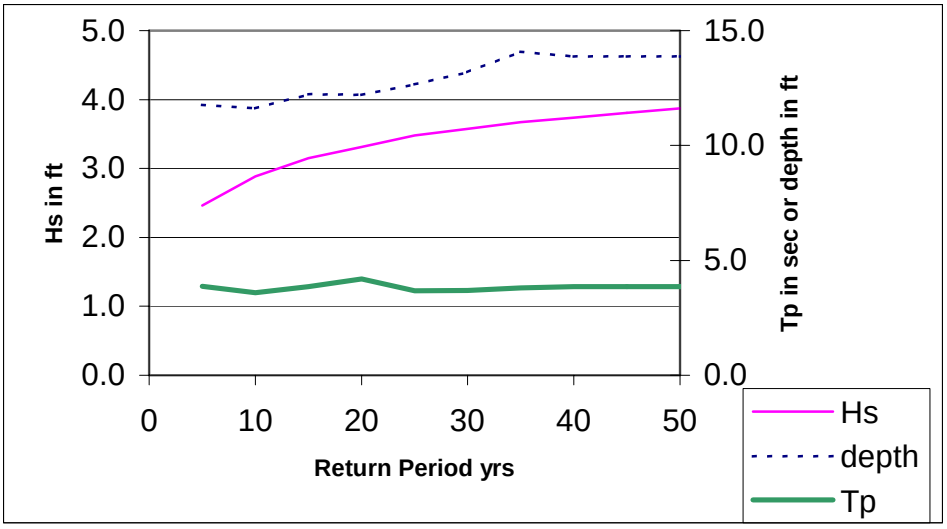

Figure B3. Significant wave height, peak wave period and total depth relative to MLLW as a function of return period from extremal wave height analysis of Station 35 wave data

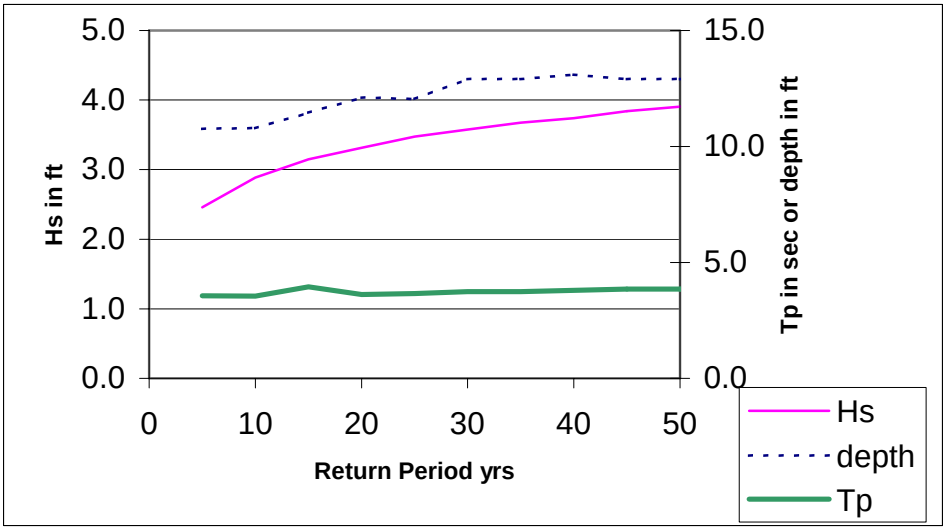

Figure B4. Significant wave height, peak wave period and total depth relative to MLLW as a function of return period from extremal wave height analysis of Station 36 wave data

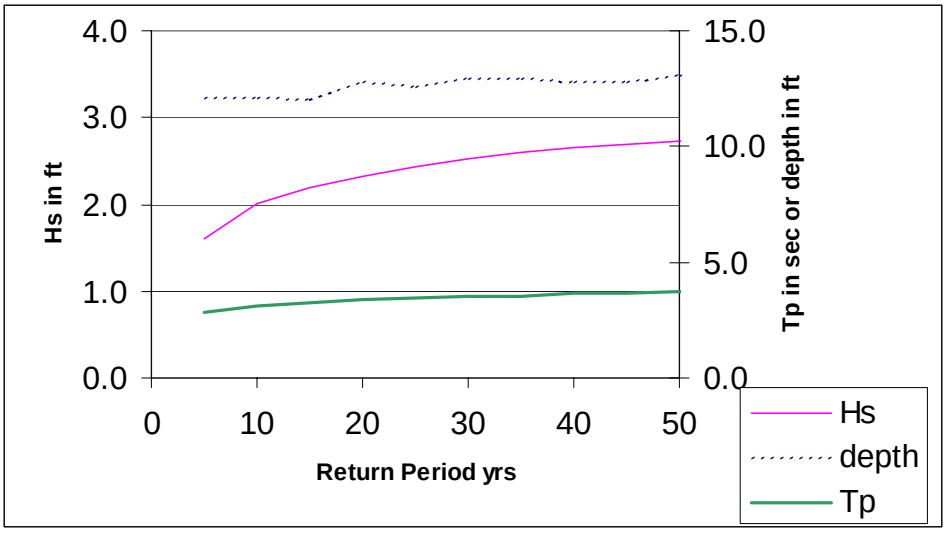

Figure B5. Significant wave height, peak wave period and total depth relative to MLLW as a function of return period from extremal wave height analysis of Station 37 wave data

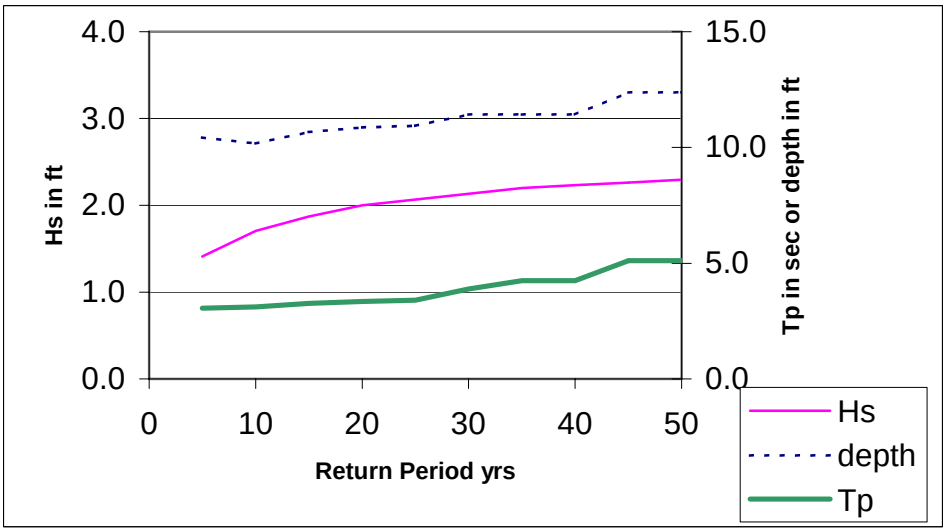

Figure B6. Significant wave height, peak wave period and total depth relative to MLLW as a function of return period from extremal wave height analysis of Station 38 wave data

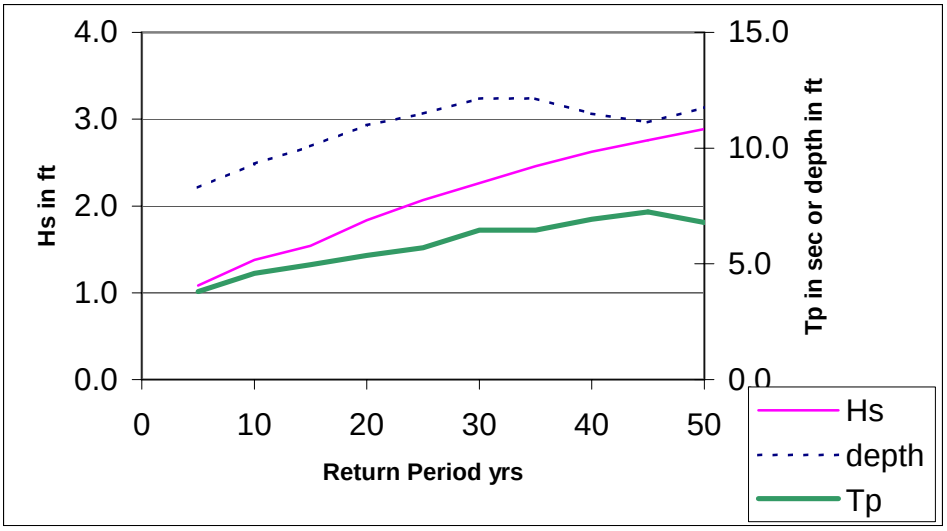

Figure B7. Significant wave height, peak wave period and total depth relative to MLLW as a function of return period from extremal wave height analysis of Station 39 wave data

Table B24
Extreme Water Levels for Historical Northeasters from Poplar Island Water Level Analysis Station 1 (Figure 19)

Return Period in yrs	Water Level Relative to mllw (ft)
2	1.62
5	2.21
10	2.6
25	3.1
50	3.46
100	3.83

Table B25
Extreme Water Levels for Historical Hurricanes from Poplar Island Water Level Analysis Station 1 (Figure 19)

Return Period in yrs	Water Level Relative to mllw (ft)
2	0.45
5	2.02
10	3.06
25	4.38
50	5.35
100	6.32

Appendix C: Armor Weight as a Function of Return Period for Poplar Island

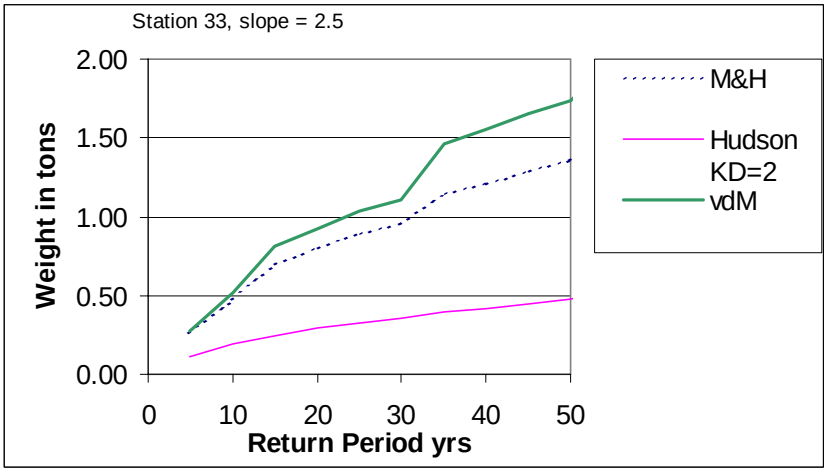

Figure C1. Armor weight as a function of return period for Poplar Station 33 with structure slope of 1V:2.5H using stability equations from Melby and Hughes, Hudson, and van der Meer

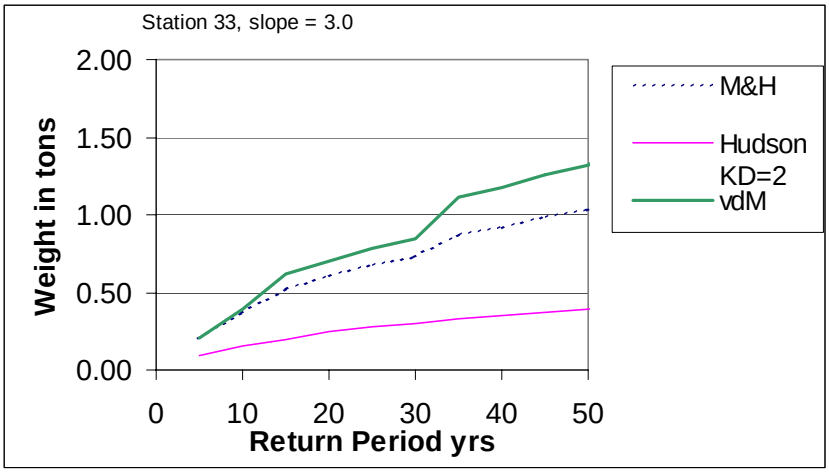

Figure C2. Armor weight as a function of return period for Poplar Station 33 with structure slope of 1V:3.0H using stability equations from Melby and Hughes, Hudson, and van der Meer

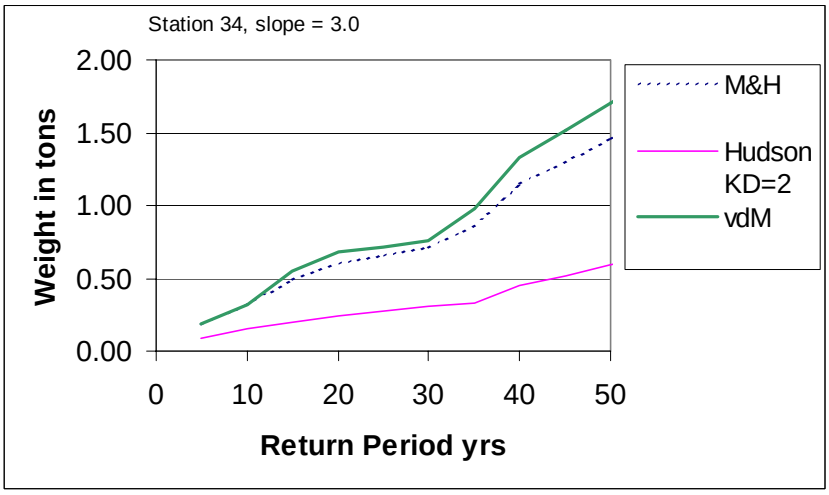

Figure C3. Armor weight as a function of return period for Poplar Station 34 with structure slope of 1V:3.0H using stability equations from Melby and Hughes, Hudson, and van der Meer

Figure C4. Armor weight as a function of return period for Poplar Station 35 with structure slope of 1V:3.0H using stability equations from Melby and Hughes, Hudson, and van der Meer

Figure C5. Armor weight as a function of return period for Poplar Station 36 with structure slope of 1V:3.0H using stability equations from Melby and Hughes, Hudson, and van der Meer

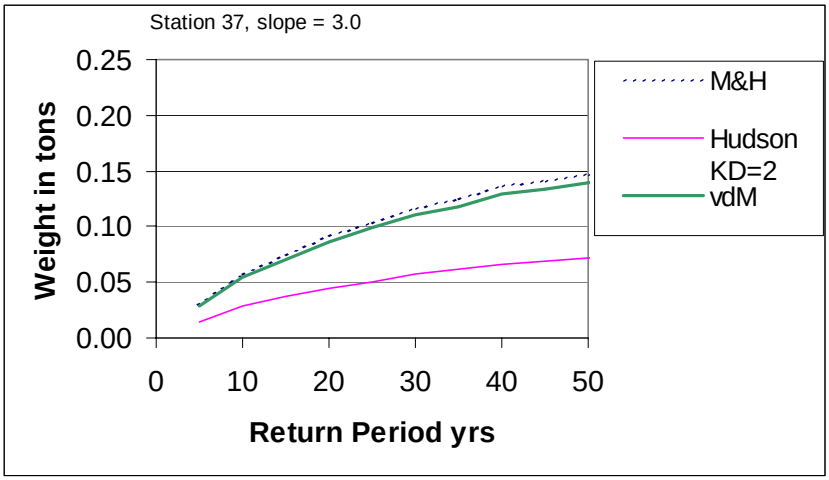

Figure C6. Armor weight as a function of return period for Poplar Station 37 with structure slope of 1V:3.0H using stability equations from Melby and Hughes, Hudson, and van der Meer

Figure C7. Armor weight as a function of return period for Poplar Station 38 with structure slope of 1V:3.0H using stability equations from Melby and Hughes, Hudson, and van der Meer

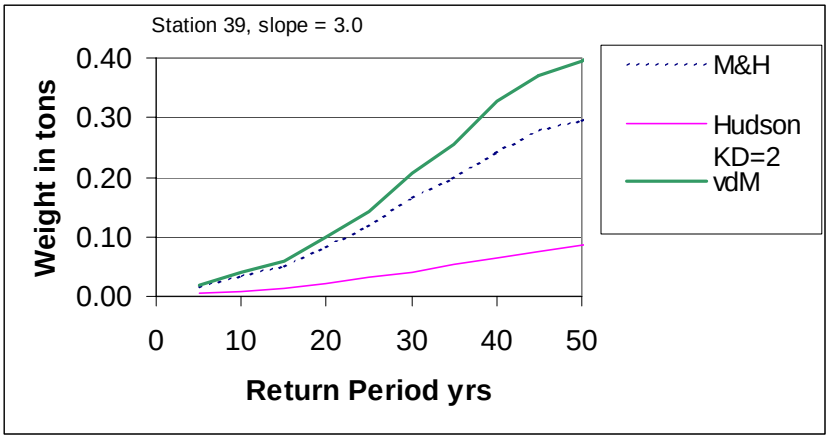

Figure C8. Armor weight as a function of return period for Poplar Station 39 with structure slope of 1V:3.0H using stability equations from Melby and Hughes, Hudson, and van der Meer

Appendix D: Simulation Results for Poplar Island

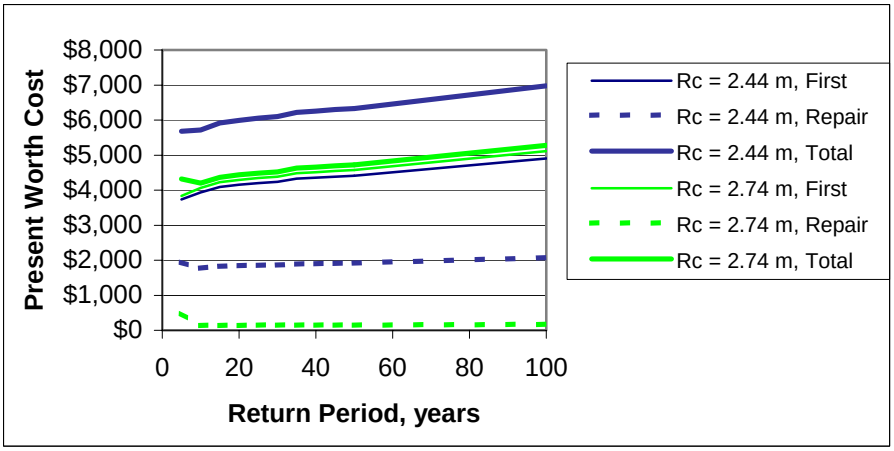

Figure D9. First cost, repair cost and total cost for Station 33 for structure slope cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest.

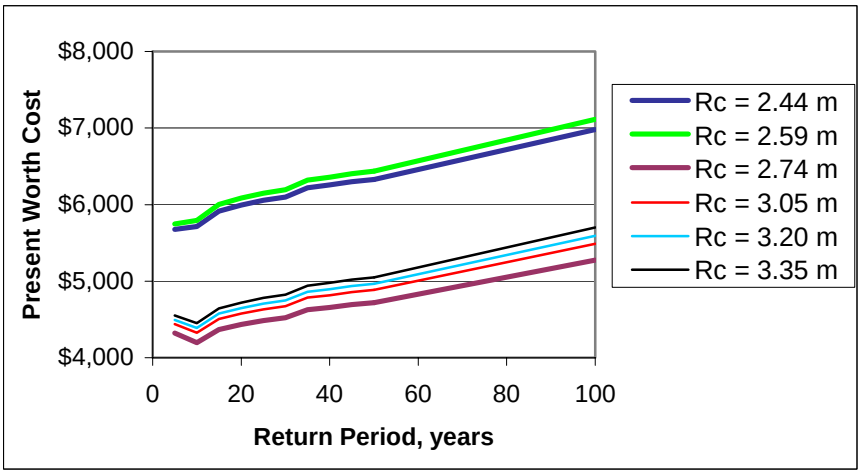

Figure D10. Total cost for Station 33 for structure slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

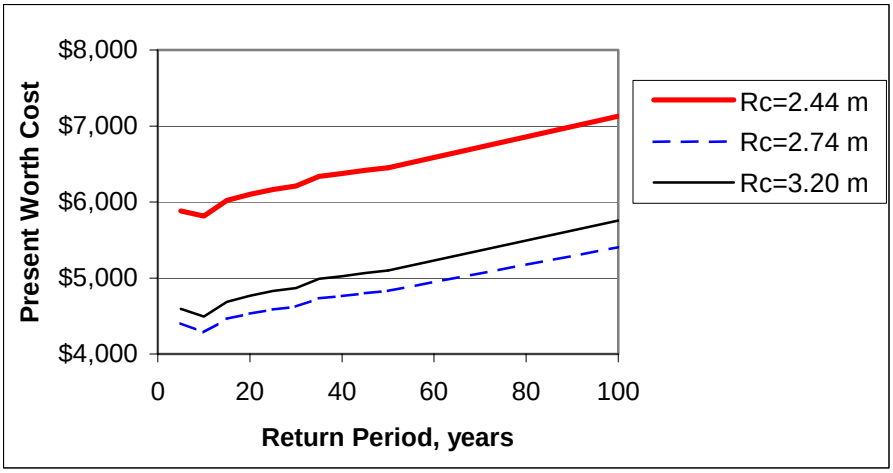

Figure D11. Total cost for Station 33 for structure slope of cot α = 3.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

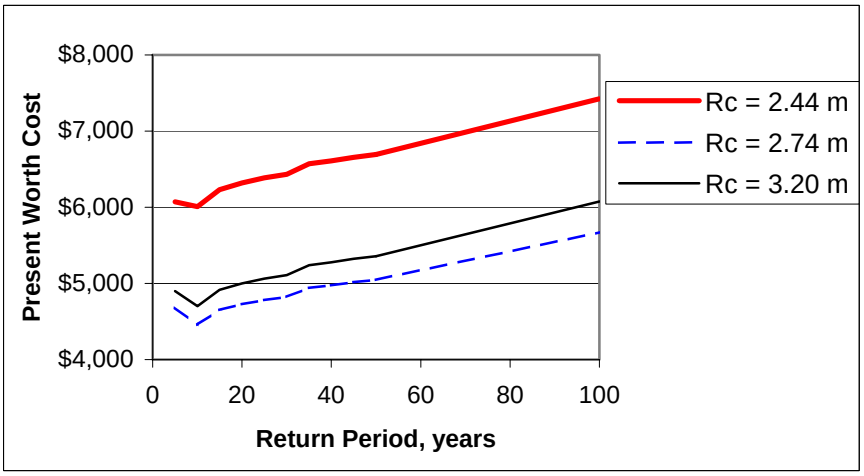

Figure D12. Total cost for Station 33 for structure slope of cot α = 4.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

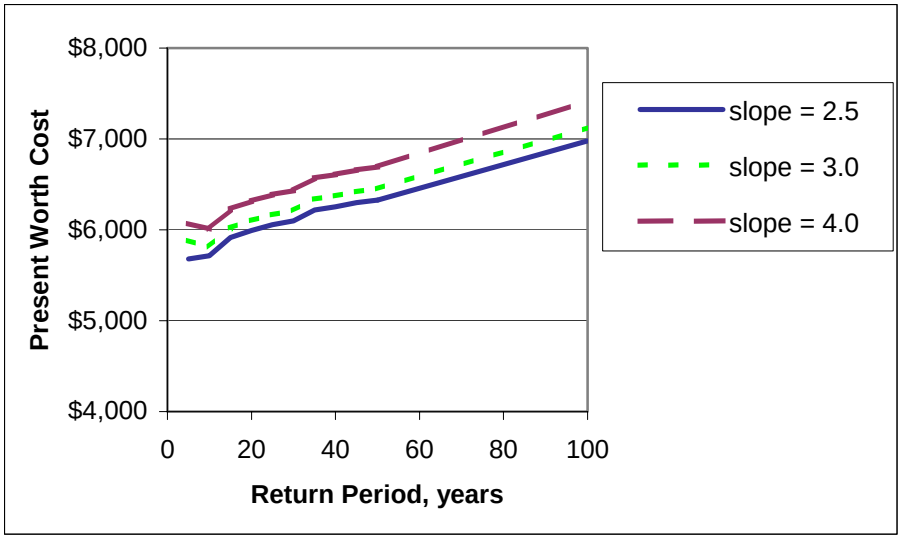

Figure D13. Total cost for Station 33 for structure slope of cot α = 2.5, crest height = 2.44 m, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

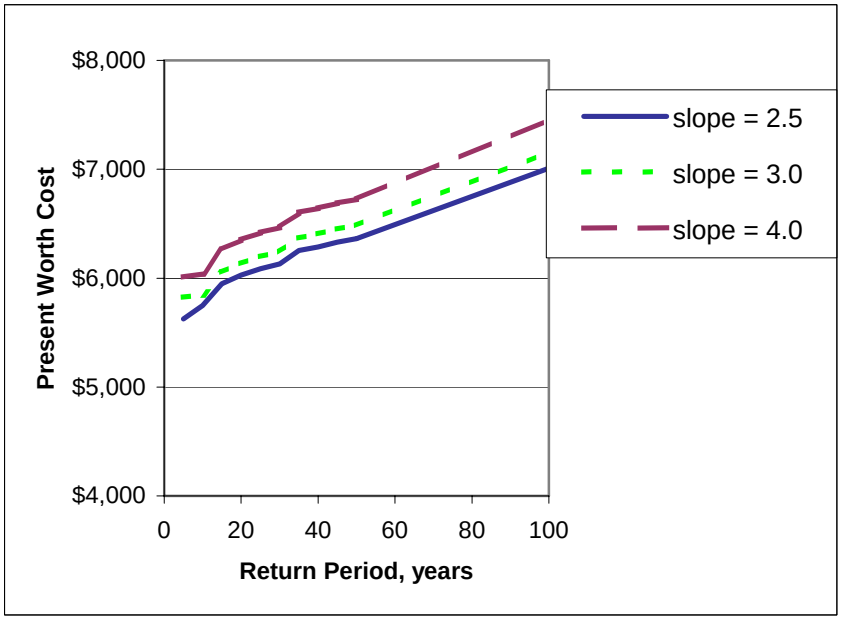

Figure D14. Total cost for Station 33 for structure slope of cot α = 2.5, crest height = 2.44 m, fixed first cost = $1000/m, fixed repair cost = $1000/m and unarmored crest

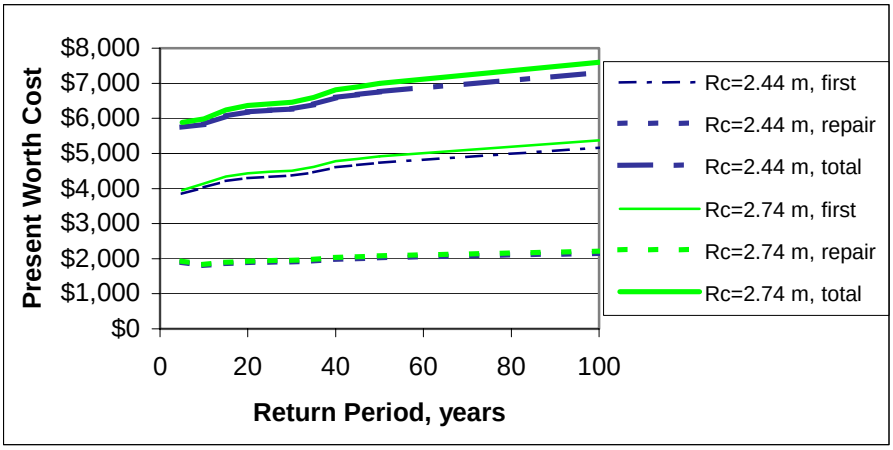

Figure D15. First cost, repair cost and total cost for Station 34 for slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

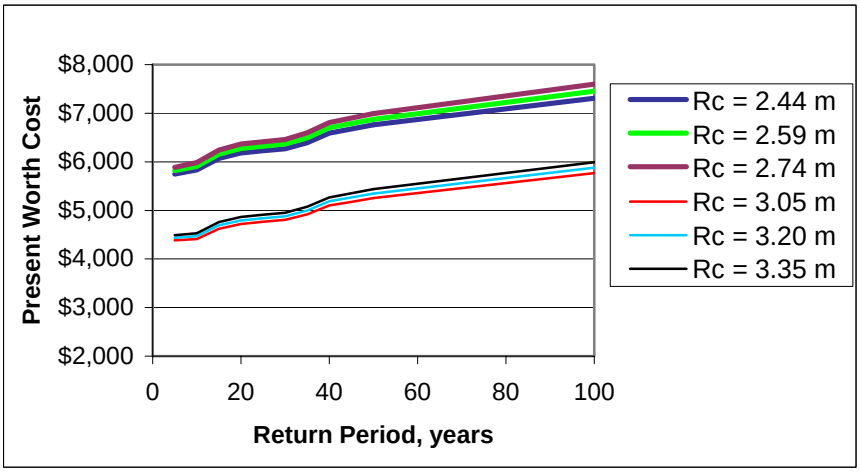

Figure D16. Total cost for Station 34 for structure slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

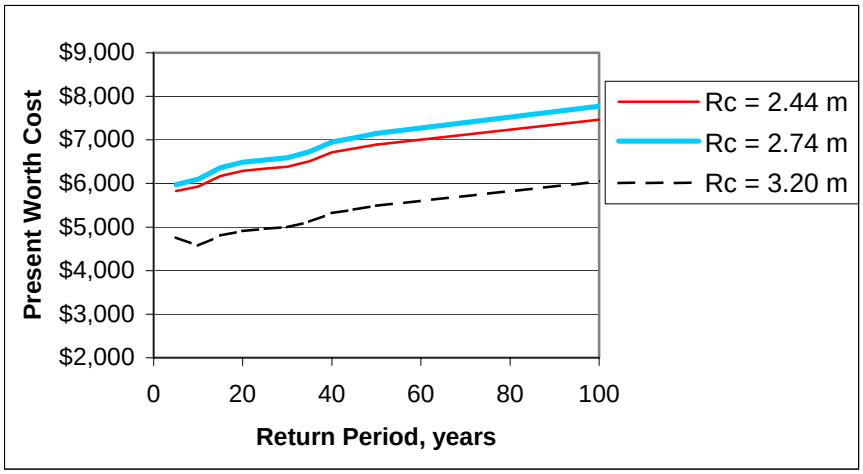

Figure D17. Total cost for Station 34 for structure slope of cot α = 3.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

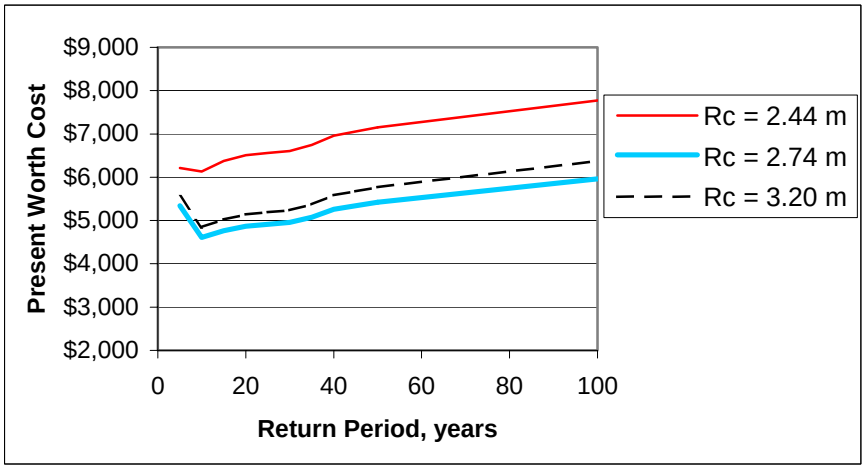

Figure D18. Total cost for Station 34 for structure slope of cot α = 4.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

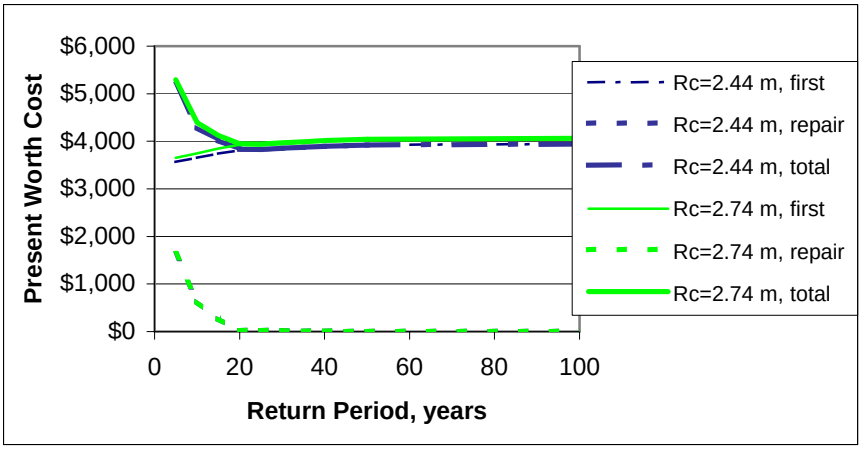

Figure D19. First cost, repair cost and total cost for Station 35 for slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

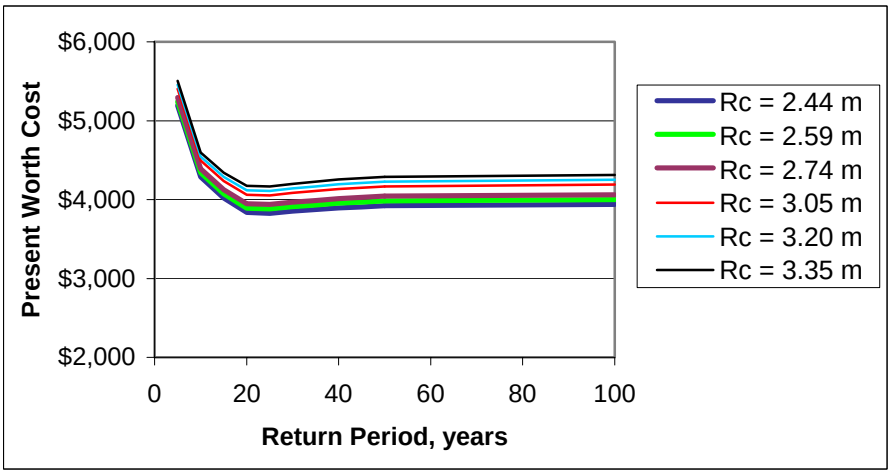

Figure D20. Total cost for Station 35 for structure slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

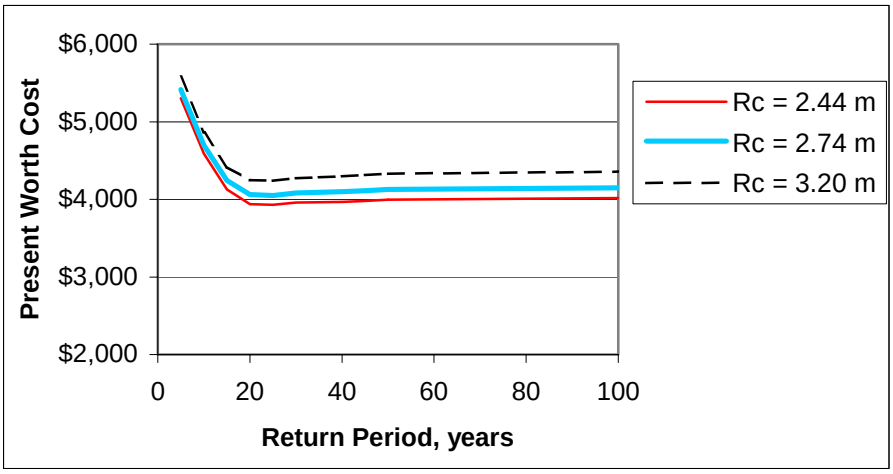

Figure D21. Total cost for Station 35 for structure slope of cot α = 3.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

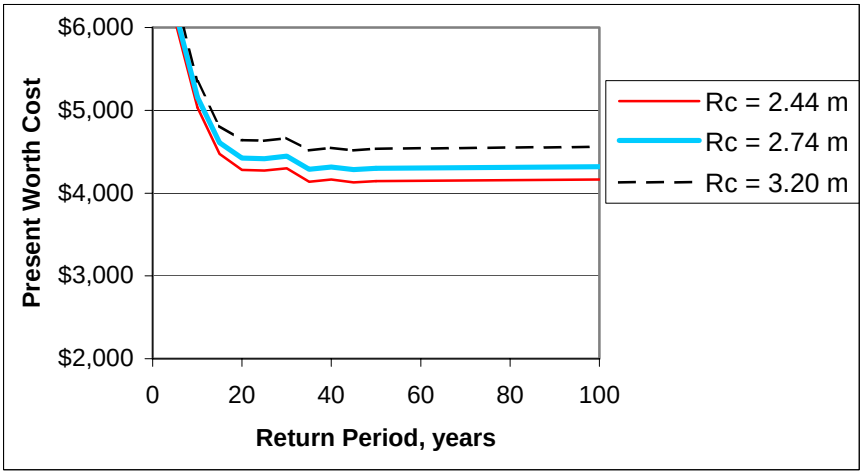

Figure D22. Total cost for Station 35 for structure slope of cot α = 4.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

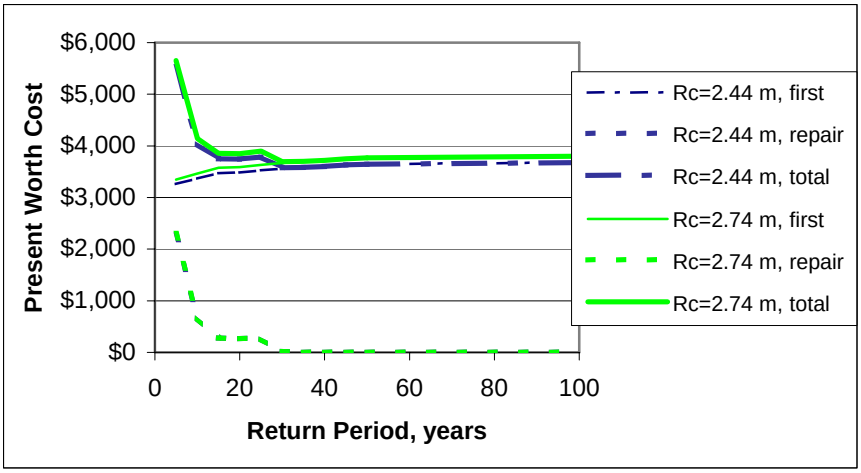

Figure D23. First cost, repair cost and total cost for Station 36 for slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

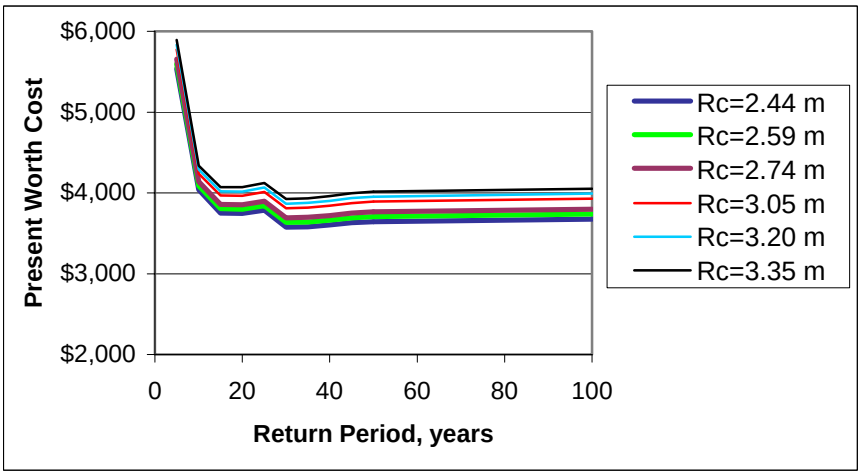

Figure D24. Total cost for Station 36 for structure slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

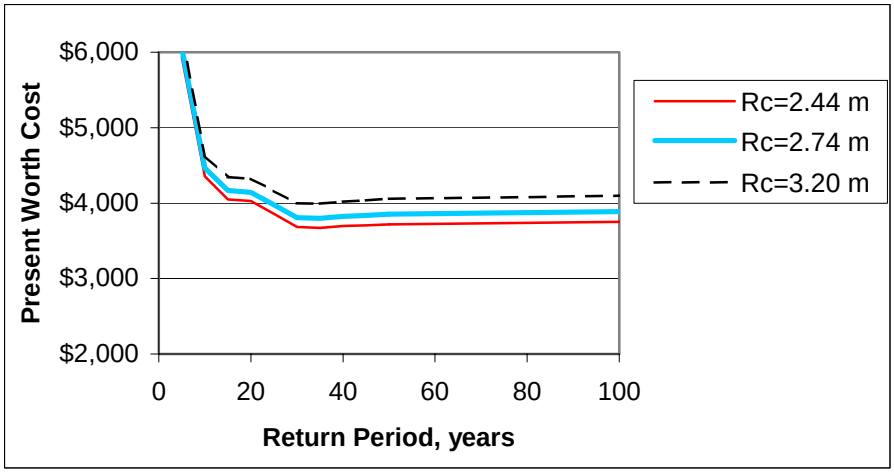

Figure D25. Total cost for Station 36 for structure slope of cot α = 3.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

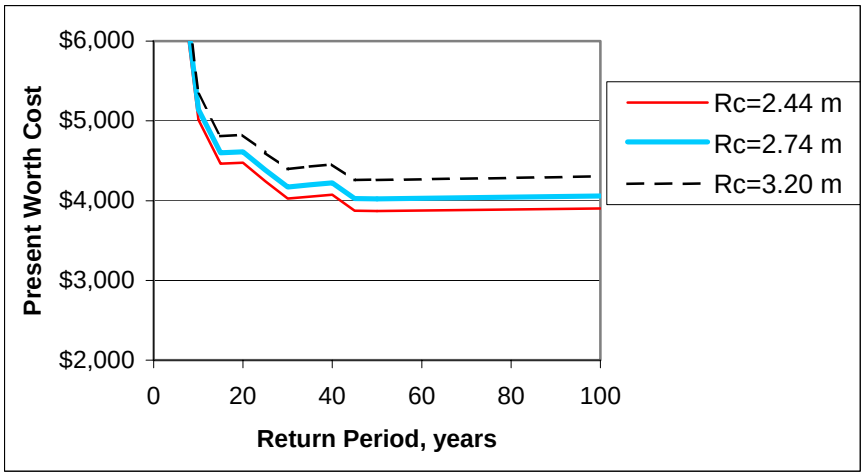

Figure D26. Total cost for Station 36 for structure slope of cot α = 4.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

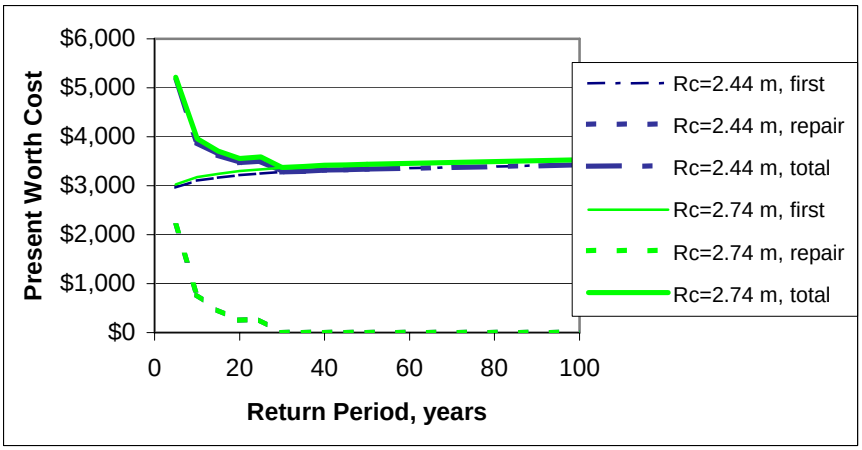

Figure D27. First cost, repair cost and total cost for Station 37 for slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest.

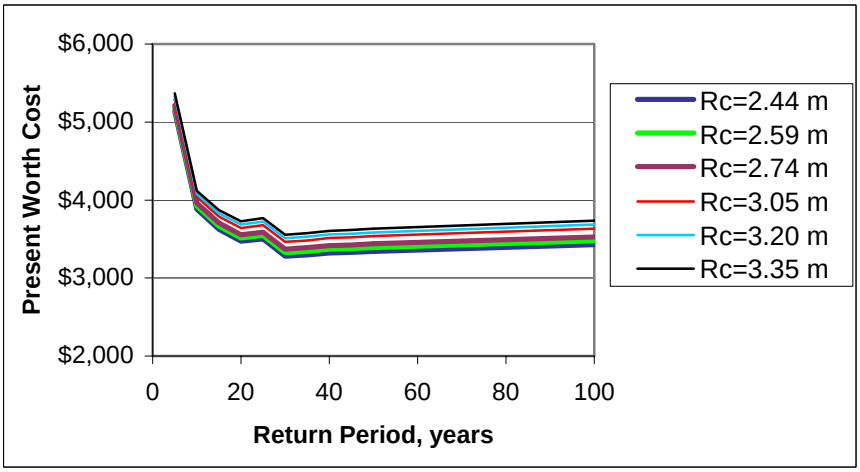

Figure D28. Total cost for Station 37 for structure slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

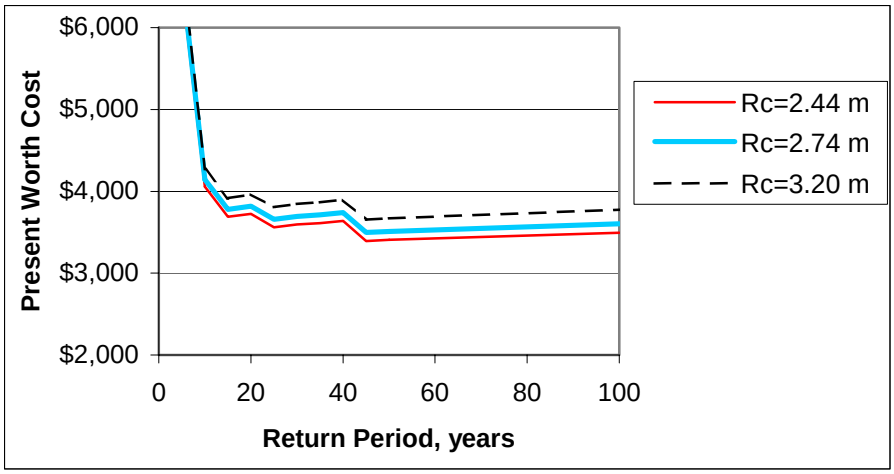

Figure D29. Total cost for Station 37 for structure slope of cot α = 3.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

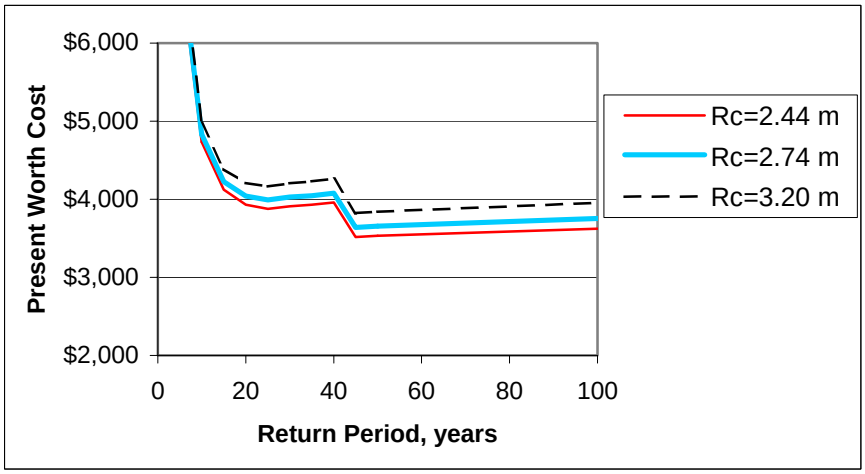

Figure D30. Total cost for Station 37 for structure slope of cot α = 4.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

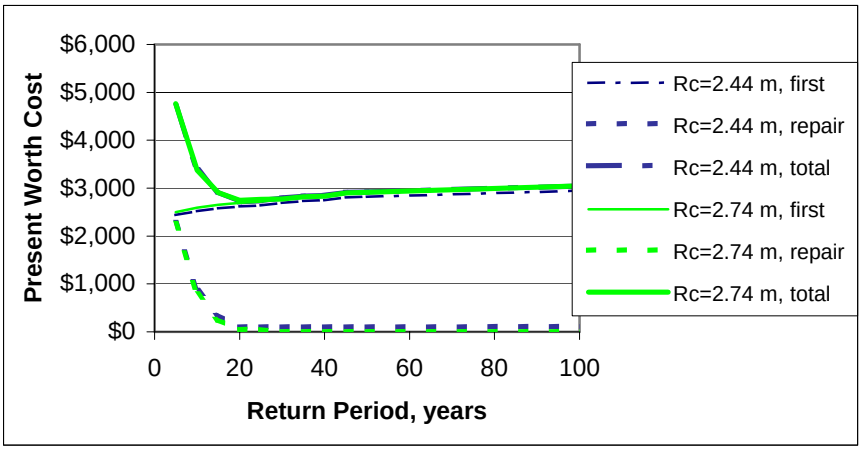

Figure D31. First cost, repair cost and total cost for Station 38 for slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

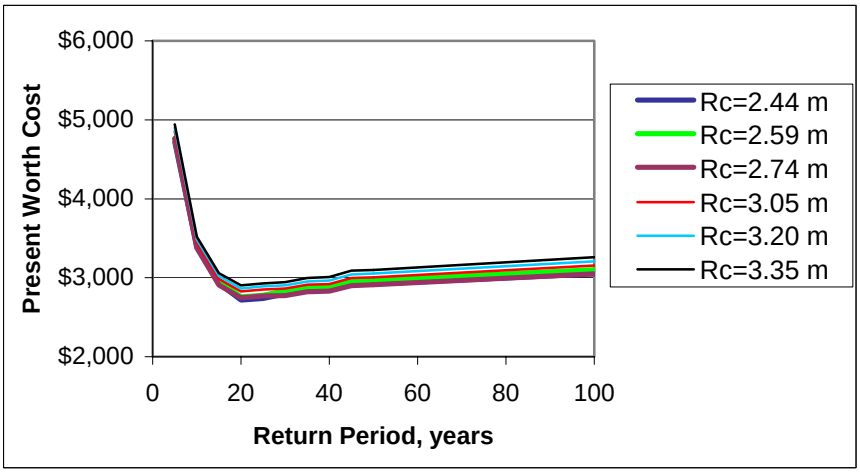

Figure D32. Total cost for Station 38 for structure slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

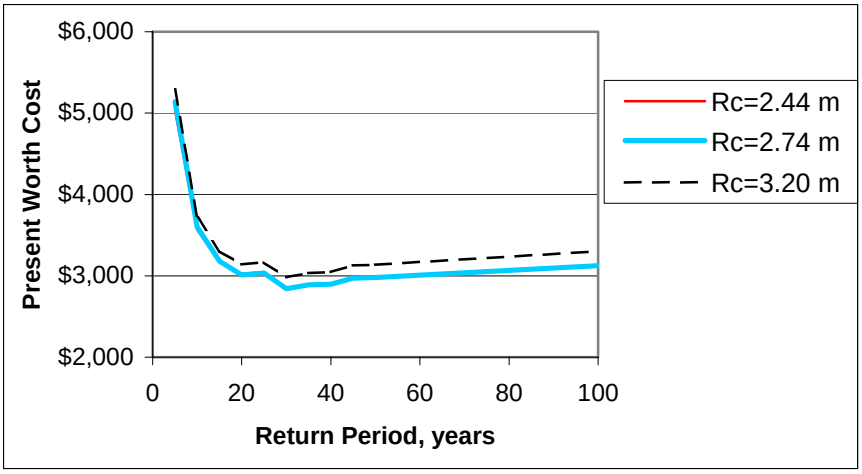

Figure D33. Total cost for Station 38 for structure slope of cot α = 3.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

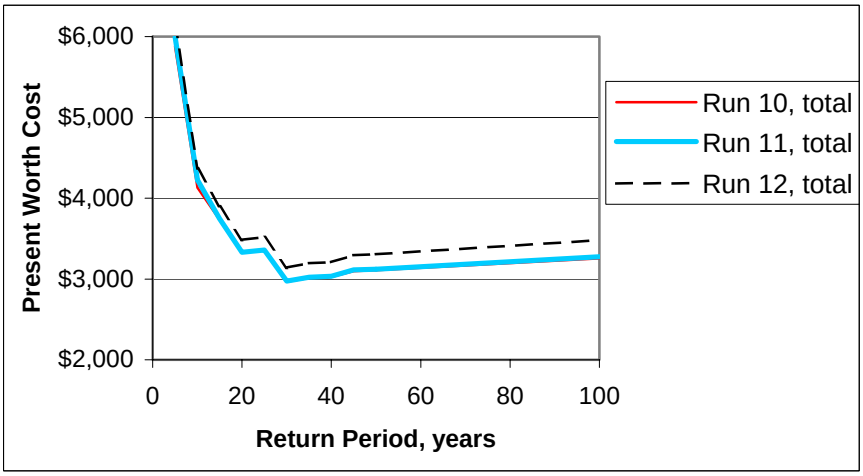

Figure D34. Total cost for Station 38 for structure slope of cot α = 4.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

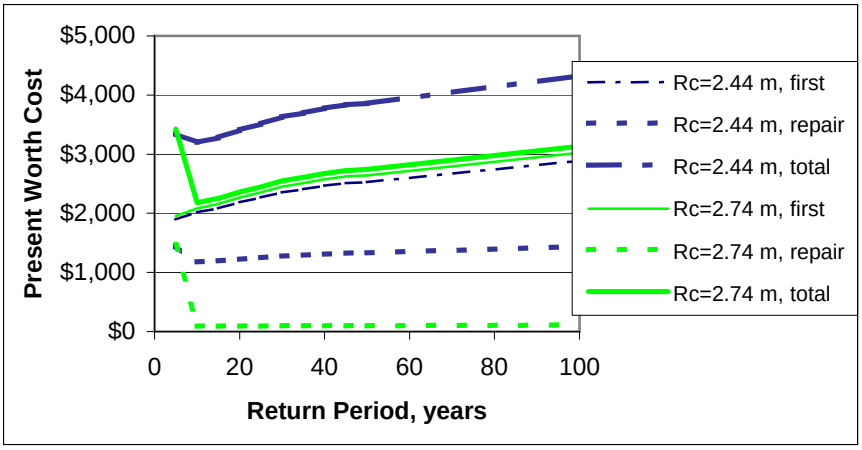

Figure D35. First cost, repair cost and total cost for Station 39 for slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

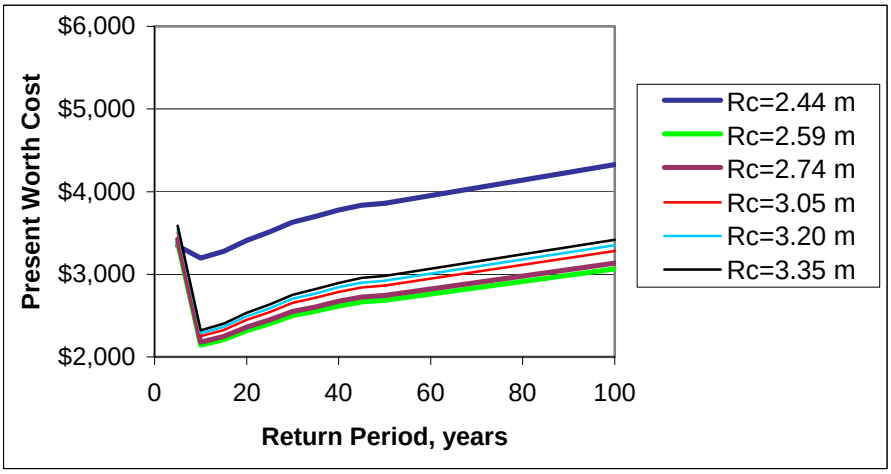

Figure D36. Total cost for Station 39 for structure slope of cot α = 2.5, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

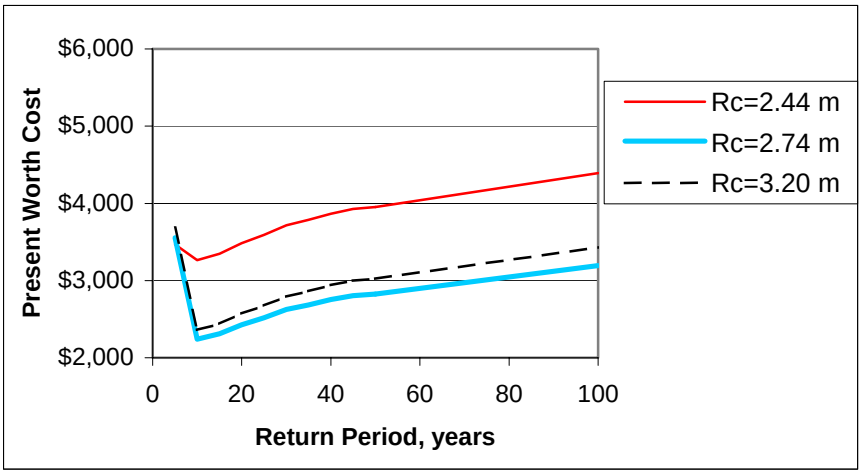

Figure D37. Total cost for Station 39 for structure slope of cot α = 3.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

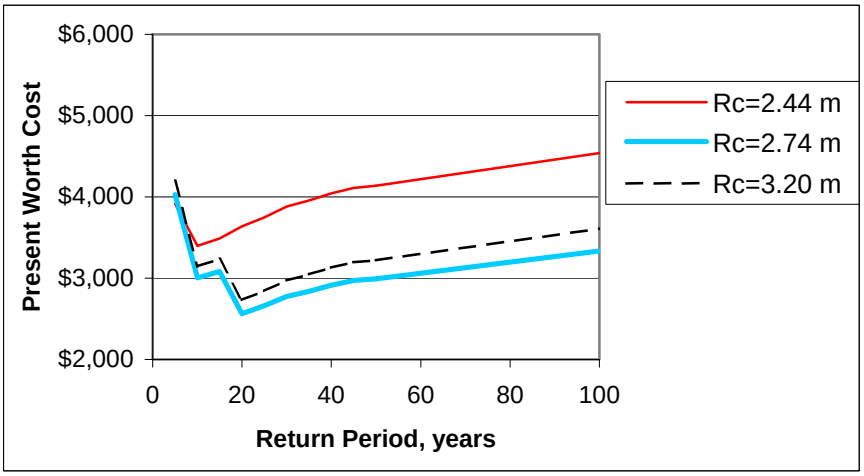

Figure D38. Total cost for Station 39 for structure slope of cot α = 4.0, fixed first cost = $500/m, fixed repair cost = $2500/m and unarmored crest

The following time series plots provide an illustration of the effect of storms on the life cycle analysis. The results are for a single station and for a single simulation using historical storms. The input conditions are as follows

Table D
Analysis Parameters for Times Series Simulation Plots

Value	Parameter
33	! Station
3.35	! h_MLLW
2.644	! SpecWt tonne/m^3
2.578	! Specific gravity
2.44	! CrestHt from MLLW
0.3048	! Toe ht from MLLW
0.05	! OT_limit m^3/s/m
2.5	! StrucSlope
7000	! NzZero
1	! SZero
0.1	! P
0.38	! Por
8	! S_Minor
18	! S_Breach
180	! Minor_Rule
120	! Breach_Rule
50	! EconLife, yrs
0.05375	! PrimeRate
0	! InflRate
0.05375	! AnnRate
56	! ArmorUnitCost
39	! FilterUnitCost $/tonne
44	! BedUnitCost
44	! QRUnitCost
4.78	! GeotUnitCost
500	! FixdFirstCost
2500	! FixdRepCost
0.3	! RepairLenFrac Lr/Ls
2	! lag

In particular, note that the structure slope is 1V:2.5H, crest ht is 2.4 m or 8 ft, unarmored crest, and there is no inflation.

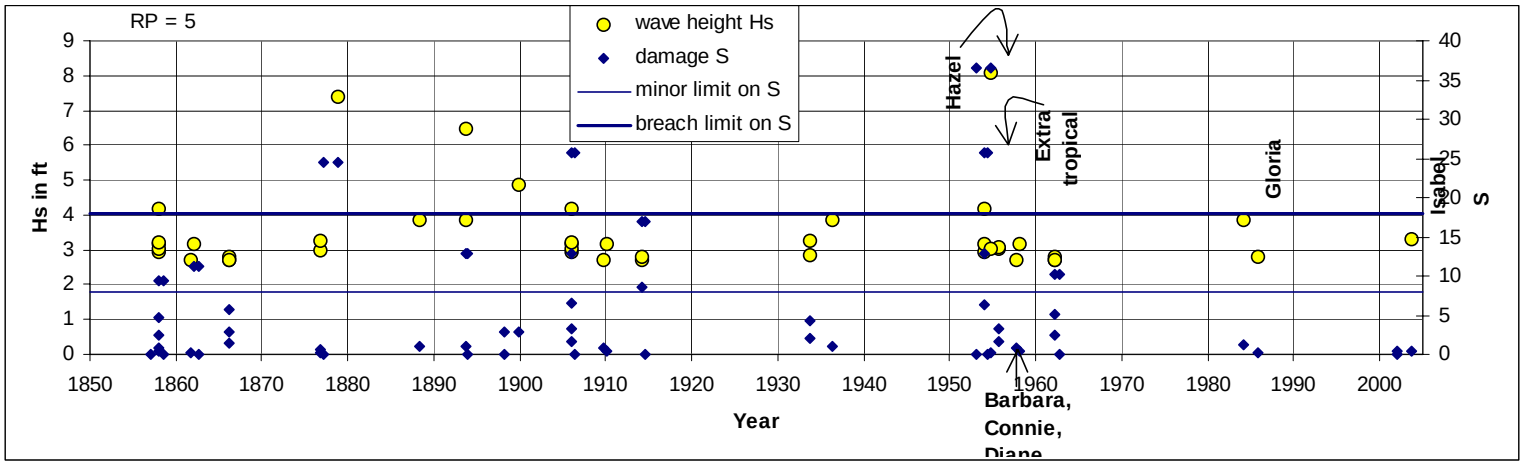

Figure 1. Maximum storm wave height Hs and armor damage S as a function of time for historical conditions for return period of 5 yr.

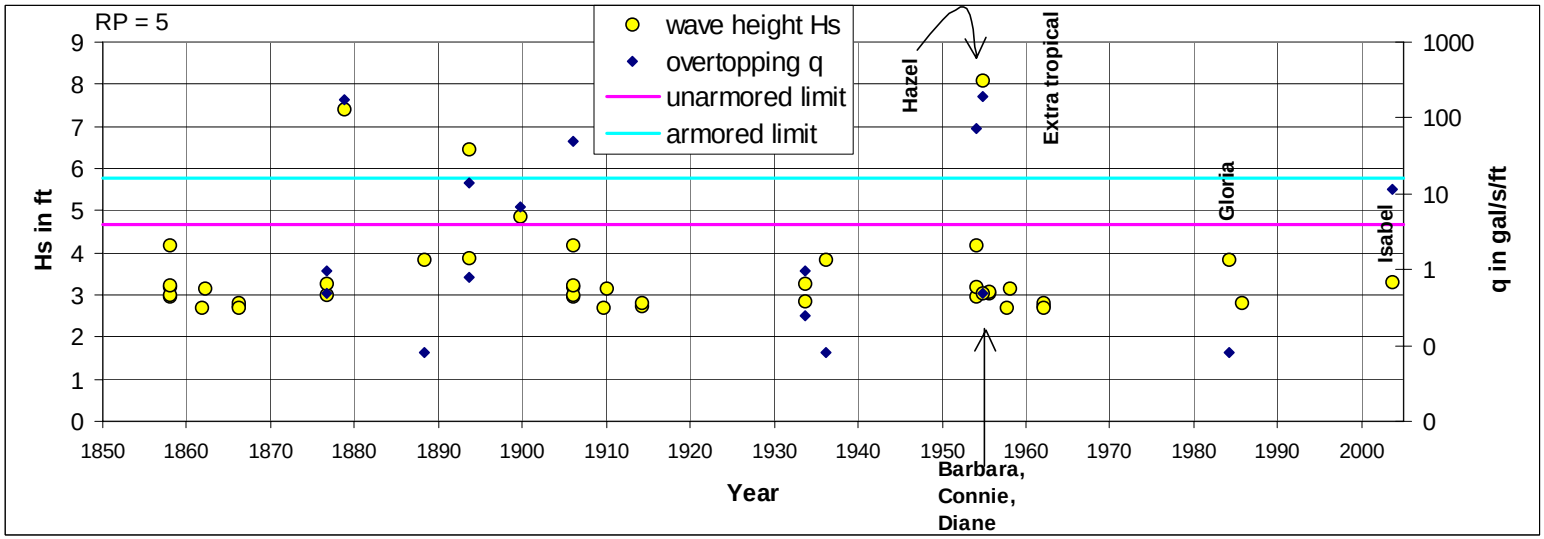

Figure 2. Maximum wave height Hs and overtopping rate q as a function of time for historical conditions for return period of 5 yr.

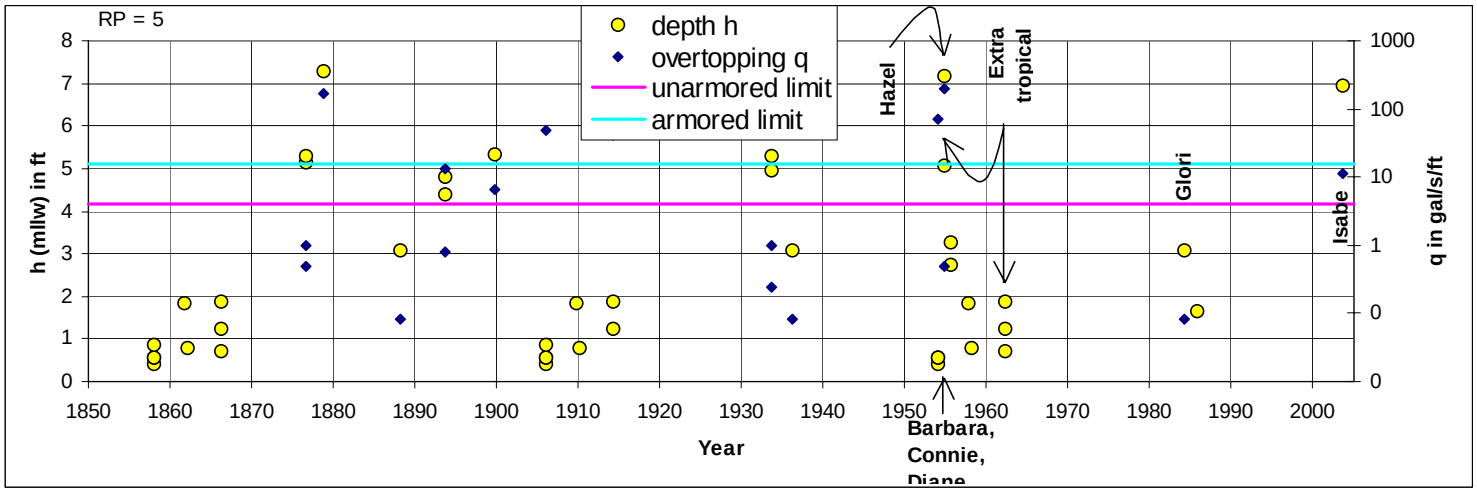

Figure 3. Maximum water depth from mllw and overtopping rate q vs time for historical conditions for return period of 5 yr.

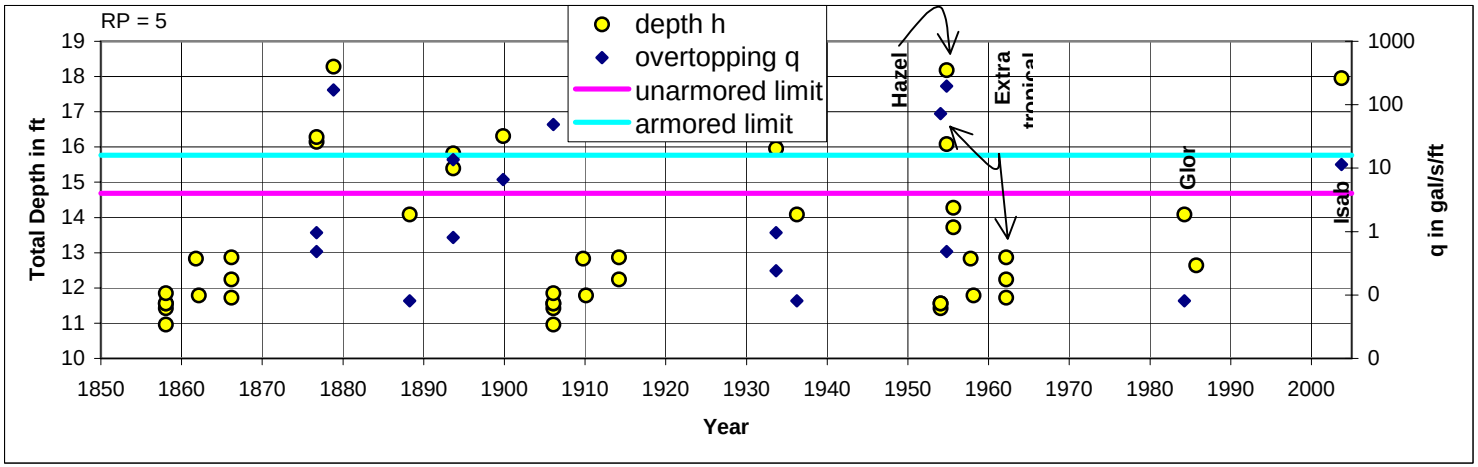

Figure 4. Maximum total water depth and overtopping rate q vs time for historical conditions for return period of 5 yr.

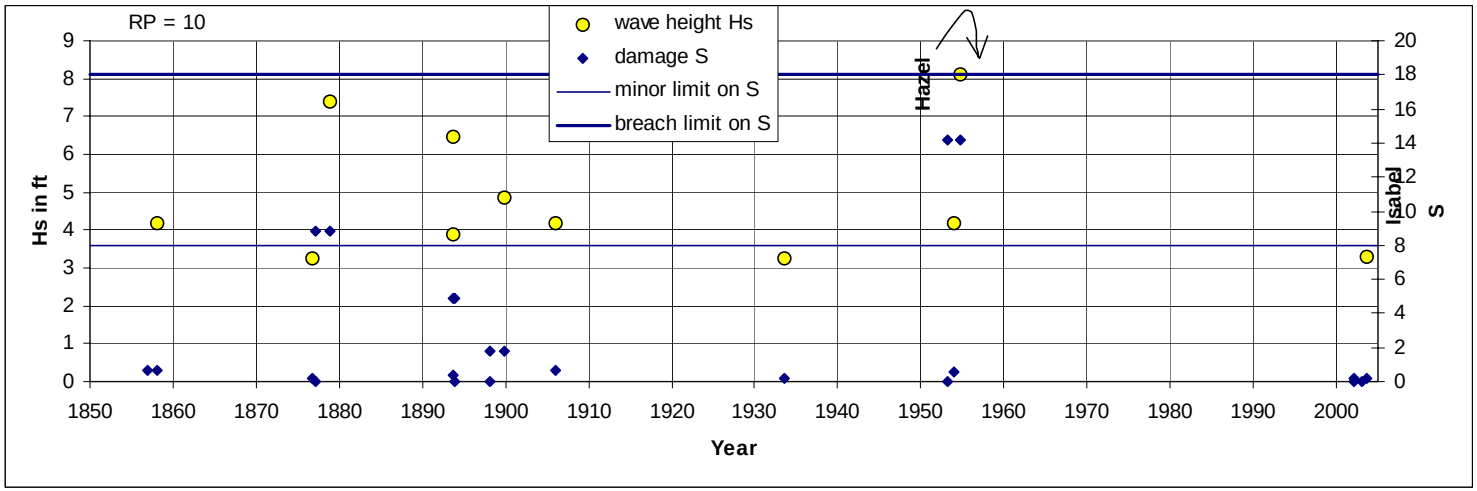

Figure 5. Same as Figure 1 but for return period of 10 yr.

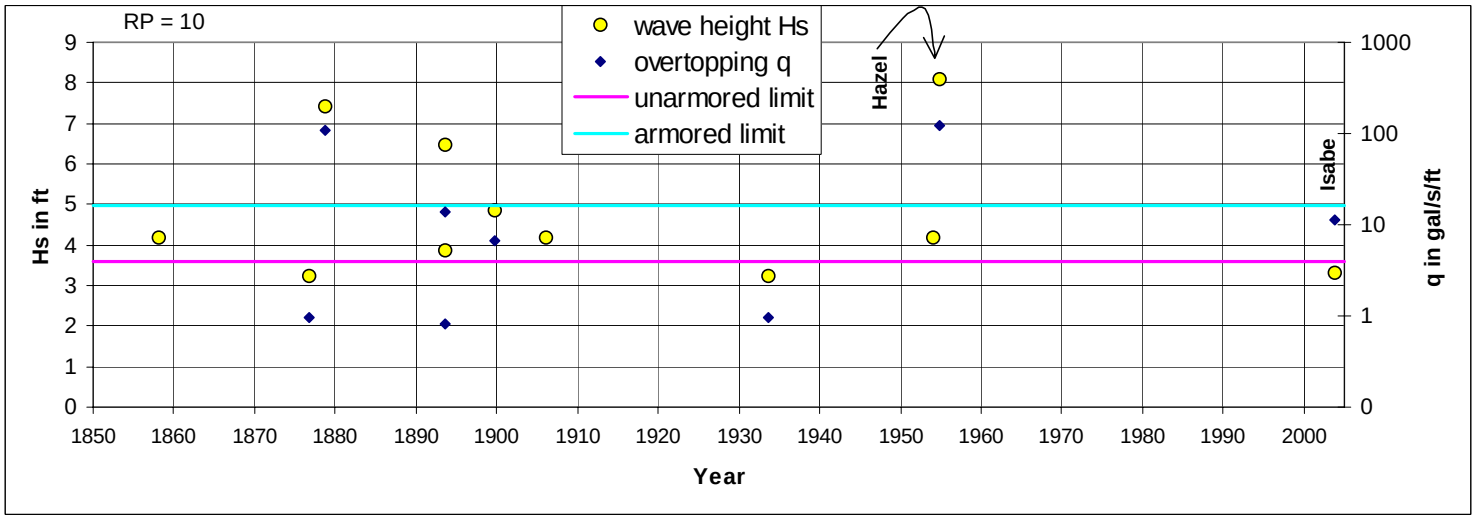

Figure 6. Same as Figure 2 but for return period of 10 yr.

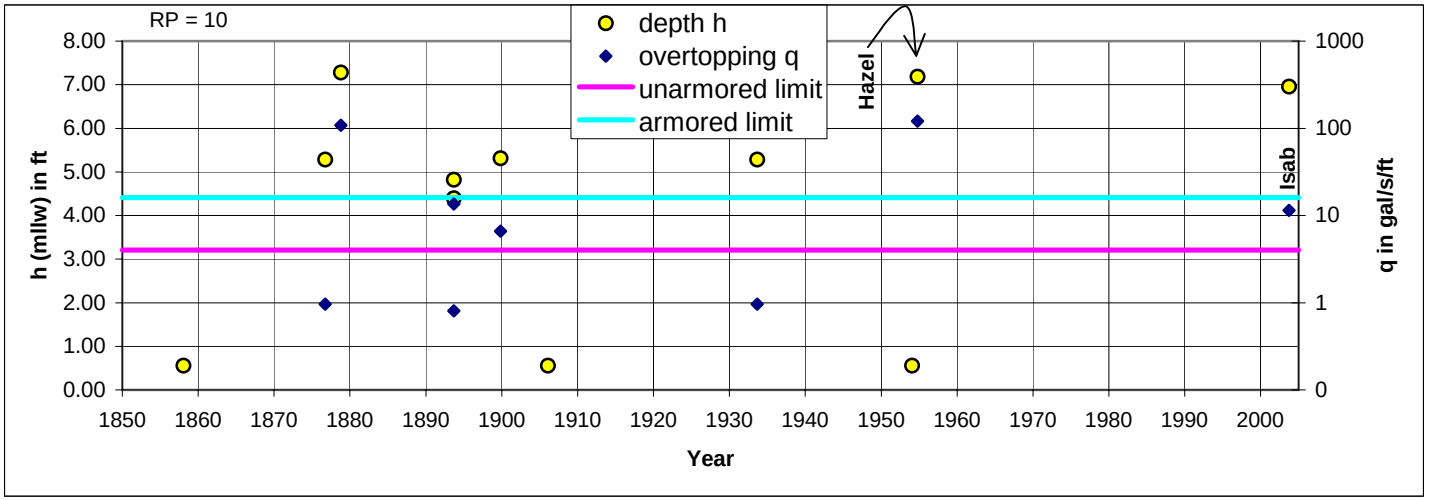

Figure 7. Same as Figure 3 but for return period of 10 yr.

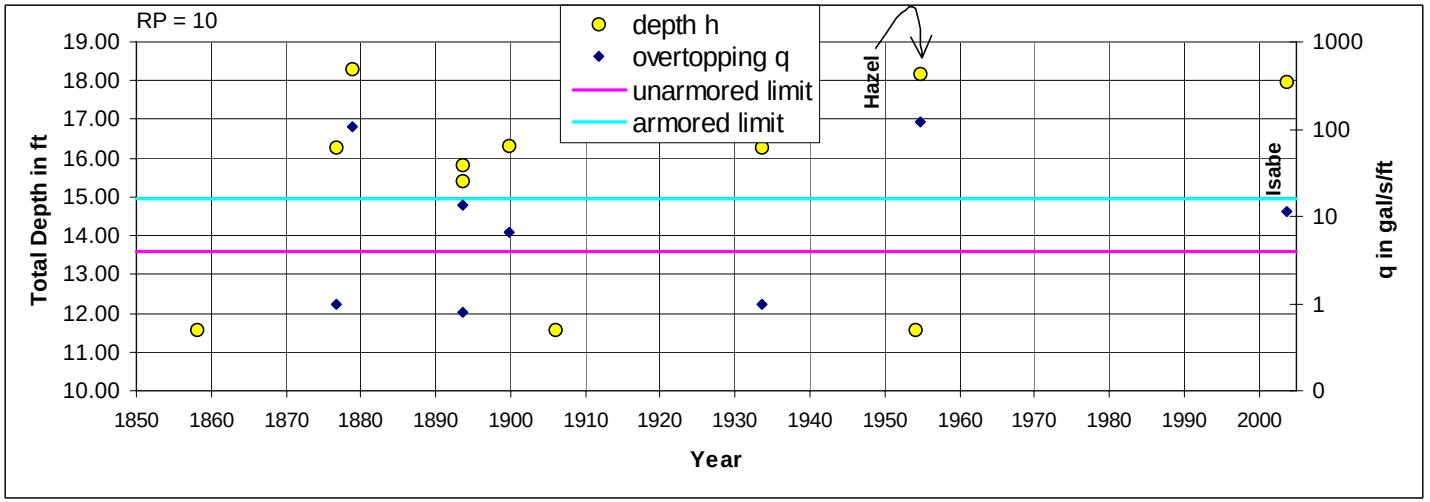

Figure 8. Same as Figure 4 but for return period of 10 yr.

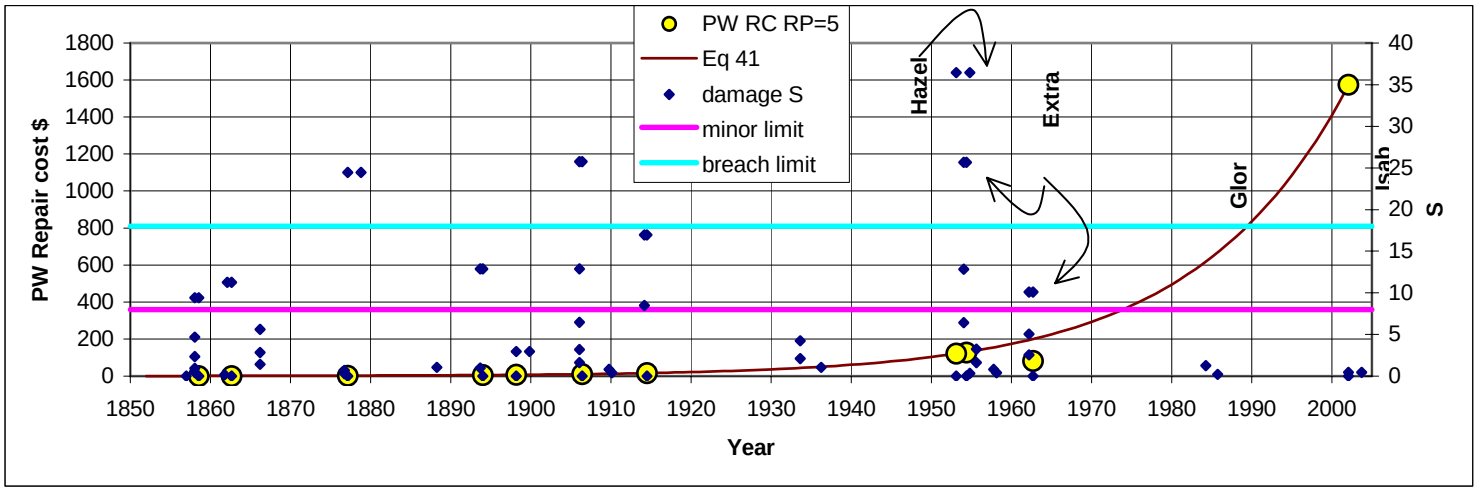

Figure 9. Present worth cost and damage vs time for return period of 5 yr

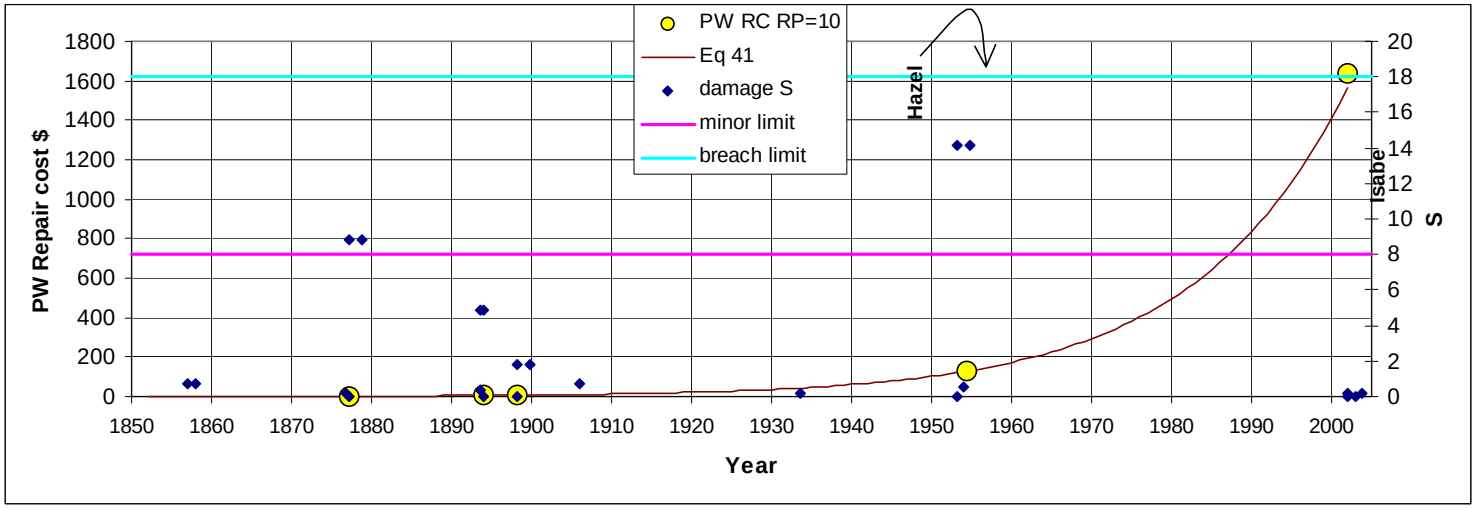

Figure 10. Figure 9. Present worth cost and damage vs time for return period of 10 yr

Appendix E: Maximum Significant Wave Height for Storm History for James Island

Table E1
Maximum H_S by Storm, James Island, Station 1, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/19	0.21 (0.69)	2.26	206.47	0.32 (1.05)	6
2	None	1861/09/28	0.57 (1.87)	4.70	209.72	0.97 (3.18)	30
3	None	1861/11/02	0.43 (1.41)	2.90	202.52	0.68 (2.23)	24
4	None	1863/09/19	0.60 (1.97)	3.40	211.21	0.70 (2.30)	21
5	None	1874/09/30	0.77 (2.53)	5.60	217.64	1.19 (3.90)	42
6	None	1876/09/18	0.88 (2.89)	6.39	217.31	1.34 (4.40)	54
7	None	1877/10/05	0.68 (2.23)	5.00	209.72	1.12 (3.67)	24
8	None	1878/10/23	1.10 (3.61)	5.50	213.49	1.54 (5.05)	39
9	None	1879/08/18	0.51 (1.67)	3.60	199.31	0.87 (2.85)	33
10	None	1880/09/09	0.41 (1.35)	3.10	207.73	0.46 (1.51)	21
11	None	1881/09/10	0.51 (1.67)	3.16	202.52	0.67 (2.20)	12
12	None	1888/10/12	0.51 (1.67)	3.20	205.00	0.56 (1.84)	33
13	None	1889/09/25	0.47 (1.54)	3.00	203.76	0.77 (2.53)	30
14	None	1893/06/17	0.52 (1.71)	3.19	202.52	0.68 (2.23)	21
15	None	1893/08/29	0.74 (2.43)	5.50	213.56	0.94 (3.08)	45
16	None	1893/10/14	0.76 (2.49)	5.00	213.04	1.16 (3.81)	39
17	None	1893/10/23	0.38 (1.25)	3.01	207.73	0.33 (1.08)	24
18	None	1894/09/28	0.39 (1.28)	2.75	201.27	0.66 (2.17)	36
19	None	1894/10/10	0.50 (1.64)	3.40	210.27	0.53 (1.74)	30
20	None	1897/10/24	0.12 (0.39)	1.72	206.47	0.27 (0.89)	0
21	None	1899/08/18	0.17 (0.56)	3.50	48.04	1.10 (3.61)	15
22	None	1899/11/01	0.96 (3.15)	4.50	213.27	1.38 (4.53)	33
23	None	1904/09/15	0.89 (2.92)	5.40	206.74	1.35 (4.43)	27
24	None	1908/08/01	0.07 (0.23)	2.96	46.90	0.57 (1.87)	0
25	None	1923/10/24	0.31 (1.02)	2.70	217.87	0.42 (1.38)	9
26	None	1933/08/24	0.87 (2.85)	6.09	219.93	1.36 (4.46)	18
27	None	1933/09/17	0.16 (0.52)	3.25	45.96	0.93 (3.05)	3
28	None	1935/09/06	0.51 (1.67)	3.20	205.00	0.57 (1.87)	18
29	None	1936/09/18	0.09 (0.30)	3.80	49.00	0.62 (2.03)	0
30	None	1944/08/03	0.70 (2.30)	4.60	211.27	0.87 (2.85)	42
31	None	1944/09/15	0.30 (0.98)	2.65	216.60	0.48 (1.57)	3
32	None	1946/07/07	0.28 (0.92)	2.56	207.73	0.49 (1.61)	12
33	Barbara	1953/08/15	0.20 (0.66)	2.19	216.60	0.45 (1.48)	3
34	Hazel	1954/10/16	0.98 (3.22)	8.29	222.98	1.33 (4.36)	21
35	Connie	1955/08/13	0.65 (2.13)	4.10	216.36	1.12 (3.67)	15
36	Diane	1955/08/19	0.56 (1.84)	4.30	219.45	0.64 (2.10)	33
37	Ione	1955/09/20	0.15 (0.49)	3.10	47.00	0.97 (3.18)	0
38	Brenda	1960/07/30	0.56 (1.84)	4.30	213.00	0.84 (2.76)	30
39	Donna	1960/09/12	0.49 (1.61)	3.10	202.52	0.71 (2.33)	39
40	Doria	1967/09/11	0.18 (0.59)	1.94	201.27	0.60 (1.97)	3
41	Doria	1971/08/28	0.46 (1.51)	3.00	211.21	0.67 (2.20)	27
42	Bret	1981/07/01	0.12 (0.39)	1.75	209.00	0.47 (1.54)	0
43	Dean	1983/09/30	0.03 (0.10)	2.26	46.00	0.39 (1.28)	0
44	Gloria	1985/09/27	0.25 (0.82)	3.10	237.00	0.85 (2.79)	3
45	Charley	1986/08/18	0.08 (0.26)	3.50	51.10	0.74 (2.43)	0
46	Danielle	1992/09/26	0.15 (0.49)	1.95	212.80	0.29 (0.95)	0
47	Bertha	1996/07/13	0.58 (1.90)	3.90	200.54	0.91 (2.99)	36
48	Fran	1996/09/07	0.88 (2.89)	4.30	208.25	1.20 (3.94)	45
49	Bonnie	1998/08/29	0.18 (0.59)	2.11	215.33	0.32 (1.05)	3
50	Earl	1998/09/04	0.53 (1.74)	3.25	206.24	0.58 (1.90)	33
51	Floyd	1999/09/16	0.60 (1.97)	3.40	202.52	0.71 (2.33)	24
52	Isabel	2003/09/19	1.04 (3.41)	5.22	209.75	1.83 (6.00)	18

[1]Storm duration is the time during a storm when H_S > 0.15 m

Table E2
Maximum H_S by Storm, James Island, Station 3, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/20	0.32 (1.05)	3.40	294.00	0.34 (1.12)	3
2	None	1861/09/28	0.85 (2.79)	4.70	210.72	0.97 (3.18)	21
3	None	1861/11/02	0.38 (1.25)	2.90	195.60	0.68 (2.23)	9
4	None	1863/09/19	0.52 (1.71)	3.40	204.00	0.70 (2.30)	9
5	None	1874/09/29	1.32 (4.33)	5.95	215.30	1.15 (3.77)	27
6	None	1876/09/18	1.48 (4.86)	6.39	220.33	1.34 (4.40)	33
7	None	1877/10/05	1.02 (3.35)	5.00	210.72	1.12 (3.67)	18
8	None	1878/10/23	2.00 (6.56)	7.81	219.93	1.47 (4.82)	36
9	None	1879/08/18	0.60 (1.97)	3.60	191.45	0.87 (2.85)	30
10	None	1880/09/09	0.41 (1.35)	3.10	200.78	0.46 (1.51)	9
11	None	1881/09/10	0.47 (1.54)	3.34	199.55	0.52 (1.71)	12
12	None	1888/10/12	0.45 (1.48)	3.20	198.00	0.56 (1.84)	18
13	None	1889/09/25	0.48 (1.57)	3.30	203.22	0.37 (1.21)	21
14	None	1893/06/17	0.45 (1.48)	3.19	195.60	0.68 (2.23)	6
15	None	1893/08/29	1.57 (5.15)	7.00	228.41	0.76 (2.49)	39
16	None	1893/10/14	1.43 (4.69)	6.39	225.02	0.94 (3.08)	27
17	None	1893/10/23	0.59 (1.94)	3.80	207.71	0.35 (1.15)	9
18	None	1894/09/30	0.45 (1.48)	3.90	292.00	0.05 (0.16)	24
19	None	1894/10/10	0.59 (1.94)	3.60	197.79	0.61 (2.00)	21
20	None	1897/10/24	0.12 (0.39)	1.72	199.55	0.27 (0.89)	0
21	None	1899/08/19	0.40 (1.31)	3.70	294.00	0.38 (1.25)	9
22	None	1899/11/01	1.82 (5.97)	7.00	224.31	1.17 (3.84)	33
23	None	1904/09/15	1.15 (3.77)	5.40	206.74	1.35 (4.43)	27
24	None	1908/08/01	0.28 (0.92)	3.20	294.00	0.38 (1.25)	0
25	None	1923/10/24	0.48 (1.57)	2.70	258.10	0.35 (1.15)	6
26	None	1933/08/24	1.44 (4.72)	6.09	222.98	1.36 (4.46)	15
27	None	1933/09/17	0.40 (1.31)	3.70	296.00	0.65 (2.13)	6
28	None	1935/09/06	0.45 (1.48)	3.20	198.00	0.57 (1.87)	9
29	None	1936/09/19	0.62 (2.03)	4.60	286.00	0.43 (1.41)	6
30	None	1944/08/03	0.90 (2.95)	4.80	213.28	1.11 (3.64)	33
31	None	1944/09/15	0.35 (1.15)	2.34	262.00	0.81 (2.66)	6
32	None	1946/07/07	0.28 (0.92)	2.56	200.78	0.49 (1.61)	0
33	Barbara	1953/08/15	0.41 (1.35)	3.80	294.00	0.52 (1.71)	3
34	Hazel	1954/10/16	1.91 (6.27)	8.29	226.04	1.33 (4.36)	21
35	Connie	1955/08/13	0.73 (2.39)	4.10	216.36	1.12 (3.67)	12
36	Diane	1955/08/18	0.99 (3.25)	5.00	221.24	0.78 (2.56)	30
37	Ione	1955/09/20	0.46 (1.51)	3.95	294.00	0.39 (1.28)	3
38	Brenda	1960/07/30	0.76 (2.49)	4.30	213.00	0.84 (2.76)	18
39	Donna	1960/09/13	0.46 (1.51)	2.70	266.85	0.78 (2.56)	18
40	Doria	1967/09/11	0.16 (0.52)	1.94	194.40	0.60 (1.97)	0
41	Doria	1971/08/28	0.41 (1.35)	3.00	204.00	0.67 (2.20)	18
42	Bret	1981/07/01	0.12 (0.39)	1.75	202.00	0.47 (1.54)	0
43	Dean	1983/09/30	0.02 (0.07)	2.26	320.00	0.39 (1.28)	0
44	Gloria	1985/09/27	0.83 (2.72)	5.20	287.00	0.81 (2.66)	6
45	Charley	1986/08/18	0.35 (1.15)	3.50	294.00	0.33 (1.08)	6
46	Danielle	1992/09/26	0.15 (0.49)	1.95	205.67	0.29 (0.95)	0
47	Bertha	1996/07/13	0.66 (2.17)	3.10	261.03	0.90 (2.95)	27
48	Fran	1996/09/07	0.85 (2.79)	4.30	209.26	1.20 (3.94)	27
49	Bonnie	1998/08/29	0.18 (0.59)	2.61	296.00	0.62 (2.03)	0
50	Earl	1998/09/04	0.48 (1.57)	3.25	199.20	0.58 (1.90)	12
51	Floyd	1999/09/17	0.71 (2.33)	3.23	279.47	1.16 (3.81)	24
52	Isabel	2003/09/19	1.50 (4.92)	6.20	218.62	1.85 (6.07)	18

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table E3
Maximum H_S by Storm, James Island, Station 5, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/20	0.56 (1.84)	3.40	311.00	0.34 (1.12)	15
2	None	1861/09/28	0.76 (2.49)	4.70	212.70	0.96 (3.15)	18
3	None	1861/11/03	0.41 (1.35)	2.90	313.00	0.67 (2.20)	12
4	None	1863/09/19	0.46 (1.51)	3.10	313.00	0.59 (1.94)	15
5	None	1874/09/29	1.19 (3.90)	5.95	215.30	1.14 (3.74)	24
6	None	1876/09/18	1.31 (4.30)	6.39	221.33	1.35 (4.43)	24
7	None	1877/10/05	1.09 (3.58)	3.80	263.02	1.02 (3.35)	15
8	None	1878/10/23	2.00 (6.56)	7.81	222.98	1.49 (4.89)	42
9	None	1879/08/19	0.58 (1.90)	3.45	313.00	0.86 (2.82)	27
10	None	1880/09/09	0.36 (1.18)	3.10	203.76	0.45 (1.48)	9
11	None	1881/09/11	0.48 (1.57)	3.20	313.00	0.60 (1.97)	18
12	None	1888/10/12	0.39 (1.28)	3.20	202.00	0.57 (1.87)	12
13	None	1889/09/25	0.42 (1.38)	3.30	206.24	0.37 (1.21)	15
14	None	1893/06/17	0.46 (1.51)	3.15	311.00	0.40 (1.31)	15
15	None	1893/08/29	1.49 (4.89)	7.00	229.43	0.77 (2.53)	30
16	None	1893/10/14	1.27 (4.17)	6.39	226.04	0.96 (3.15)	21
17	None	1893/10/23	0.53 (1.74)	3.80	208.73	0.35 (1.15)	15
18	None	1894/09/30	0.76 (2.49)	3.90	309.00	0.06 (0.20)	27
19	None	1894/10/10	0.59 (1.94)	3.50	313.00	0.77 (2.53)	21
20	None	1897/10/26	0.45 (1.48)	3.50	336.14	0.06 (0.20)	12
21	None	1899/08/19	0.68 (2.23)	3.70	311.00	0.38 (1.25)	63
22	None	1899/11/01	1.65 (5.41)	7.00	225.33	1.19 (3.90)	24
23	None	1904/09/15	1.20 (3.94)	3.90	267.01	1.23 (4.04)	24
24	None	1908/08/01	0.48 (1.57)	3.20	311.00	0.39 (1.28)	9
25	None	1923/10/24	0.53 (1.74)	2.70	266.01	0.34 (1.12)	12
26	None	1933/08/24	1.29 (4.23)	6.09	224.00	1.38 (4.53)	30
27	None	1933/09/17	0.69 (2.26)	3.70	313.00	0.66 (2.17)	24
28	None	1935/09/06	0.39 (1.28)	3.20	202.00	0.57 (1.87)	9
29	None	1936/09/19	1.00 (3.28)	4.60	299.00	0.43 (1.41)	33
30	None	1944/08/03	0.80 (2.62)	4.80	215.30	1.11 (3.64)	33
31	None	1944/09/15	0.49 (1.61)	3.80	338.87	0.57 (1.87)	18
32	None	1946/07/07	0.25 (0.82)	2.56	203.76	0.49 (1.61)	0
33	Barbara	1953/08/15	0.70 (2.30)	3.80	311.00	0.52 (1.71)	21
34	Hazel	1954/10/16	2.11 (6.92)	8.29	228.07	1.36 (4.46)	21
35	Connie	1955/08/13	0.82 (2.69)	5.00	336.00	1.16 (3.81)	33
36	Diane	1955/08/18	0.90 (2.95)	5.00	221.24	0.80 (2.62)	30
37	Ione	1955/09/20	0.78 (2.56)	3.95	311.00	0.39 (1.28)	21
38	Brenda	1960/07/30	0.67 (2.20)	4.30	216.00	0.84 (2.76)	12
39	Donna	1960/09/12	0.67 (2.20)	3.70	313.00	0.86 (2.82)	21
40	Doria	1967/09/11	0.14 (0.46)	1.94	198.33	0.61 (2.00)	0
41	Doria	1971/08/28	0.58 (1.90)	3.45	315.00	0.98 (3.22)	18
42	Bret	1981/07/01	0.46 (1.51)	3.40	24.53	0.46 (1.51)	9
43	Dean	1983/09/30	0.20 (0.66)	2.26	337.00	0.40 (1.31)	0
44	Gloria	1985/09/27	1.14 (3.74)	5.20	298.00	0.79 (2.59)	15
45	Charley	1986/08/18	0.60 (1.97)	3.50	311.00	0.33 (1.08)	15
46	Danielle	1992/09/26	0.25 (0.82)	2.58	338.73	0.45 (1.48)	0
47	Bertha	1996/07/13	0.71 (2.33)	3.10	268.00	0.91 (2.99)	15
48	Fran	1996/09/07	0.73 (2.39)	4.30	213.28	1.21 (3.97)	27
49	Bonnie	1998/08/29	0.32 (1.05)	2.61	313.00	0.62 (2.03)	3
50	Earl	1998/09/04	0.41 (1.35)	3.25	203.22	0.58 (1.90)	9
51	Floyd	1999/09/17	0.77 (2.53)	3.23	286.93	1.15 (3.77)	30
52	Isabel	2003/09/19	1.32 (4.33)	6.20	221.65	1.87 (6.14)	30

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table E4
Maximum H_S by Storm, James Island, Station 7, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/20	0.61 (2.00)	3.40	319.00	0.34 (1.12)	21
2	None	1861/09/28	0.58 (1.90)	4.70	229.60	0.96 (3.15)	6
3	None	1861/11/03	0.43 (1.41)	2.90	319.00	0.67 (2.20)	15
4	None	1863/09/19	0.49 (1.61)	3.10	319.00	0.59 (1.94)	6
5	None	1874/09/29	1.00 (3.28)	5.95	232.40	1.14 (3.74)	12
6	None	1876/09/18	1.09 (3.58)	6.39	234.41	1.35 (4.43)	15
7	None	1877/10/05	1.07 (3.51)	3.80	267.91	1.02 (3.35)	15
8	None	1878/10/23	1.70 (5.58)	7.81	236.22	1.49 (4.89)	24
9	None	1879/08/19	0.62 (2.03)	3.45	319.00	0.86 (2.82)	12
10	None	1880/09/10	0.30 (0.98)	2.80	350.00	0.73 (2.39)	0
11	None	1881/09/11	0.51 (1.67)	3.20	319.00	0.60 (1.97)	12
12	None	1888/10/12	0.22 (0.72)	3.20	221.00	0.57 (1.87)	0
13	None	1889/09/25	0.29 (0.95)	2.80	350.00	0.57 (1.87)	0
14	None	1893/06/17	0.50 (1.64)	3.15	319.00	0.40 (1.31)	15
15	None	1893/08/29	1.37 (4.49)	7.00	241.72	0.77 (2.53)	21
16	None	1893/10/14	1.09 (3.58)	6.39	239.27	0.96 (3.15)	12
17	None	1893/10/23	0.44 (1.44)	3.50	349.10	0.59 (1.94)	9
18	None	1894/09/30	0.84 (2.76)	3.90	319.00	0.06 (0.20)	30
19	None	1894/10/10	0.62 (2.03)	3.50	319.00	0.77 (2.53)	12
20	None	1897/10/26	0.51 (1.67)	3.50	346.11	0.06 (0.20)	12
21	None	1899/08/19	0.74 (2.43)	3.70	319.00	0.38 (1.25)	69
22	None	1899/11/01	1.43 (4.69)	7.00	238.65	1.19 (3.90)	12
23	None	1904/09/15	1.18 (3.87)	3.90	271.97	1.23 (4.04)	12
24	None	1908/08/01	0.52 (1.71)	3.20	319.00	0.39 (1.28)	15
25	None	1923/10/24	0.56 (1.84)	3.80	347.11	0.51 (1.67)	12
26	None	1933/08/24	1.05 (3.44)	6.09	237.24	1.38 (4.53)	27
27	None	1933/09/17	0.73 (2.39)	3.70	319.00	0.66 (2.17)	27
28	None	1935/09/06	0.35 (1.15)	2.80	40.26	0.64 (2.10)	6
29	None	1936/09/19	1.10 (3.61)	4.60	314.00	0.43 (1.41)	36
30	None	1944/08/03	0.67 (2.20)	3.10	293.28	0.97 (3.18)	21
31	None	1944/09/15	0.53 (1.74)	3.80	350.90	0.57 (1.87)	15
32	None	1946/07/07	0.25 (0.82)	2.24	319.00	0.47 (1.54)	0
33	Barbara	1953/08/15	0.77 (2.53)	3.80	319.00	0.52 (1.71)	21
34	Hazel	1954/10/16	1.93 (6.33)	8.29	240.29	1.36 (4.46)	21
35	Connie	1955/08/13	0.91 (2.99)	5.00	345.00	1.16 (3.81)	30
36	Diane	1955/08/18	0.77 (2.53)	5.00	238.65	0.80 (2.62)	21
37	Ione	1955/09/20	0.85 (2.79)	3.95	319.00	0.39 (1.28)	24
38	Brenda	1960/07/30	0.49 (1.61)	4.30	233.00	0.84 (2.76)	6
39	Donna	1960/09/12	0.71 (2.33)	3.70	319.00	0.86 (2.82)	12
40	Doria	1967/09/11	0.08 (0.26)	1.39	350.68	0.28 (0.92)	0
41	Doria	1971/08/28	0.61 (2.00)	3.45	320.00	0.98 (3.22)	9
42	Bret	1981/07/01	0.50 (1.64)	3.40	37.08	0.46 (1.51)	12
43	Dean	1983/09/30	0.21 (0.69)	2.26	348.00	0.40 (1.31)	0
44	Gloria	1985/09/27	1.26 (4.13)	5.20	312.00	0.79 (2.59)	18
45	Charley	1986/08/18	0.66 (2.17)	3.50	319.00	0.33 (1.08)	15
46	Danielle	1992/09/26	0.27 (0.89)	2.58	349.78	0.45 (1.48)	0
47	Bertha	1996/07/13	0.70 (2.30)	3.10	272.99	0.91 (2.99)	9
48	Fran	1996/09/06	0.50 (1.64)	4.35	232.40	1.13 (3.71)	21
49	Bonnie	1998/08/29	0.34 (1.12)	2.61	319.00	0.62 (2.03)	9
50	Earl	1998/09/04	0.24 (0.79)	3.25	222.34	0.58 (1.90)	0
51	Floyd	1999/09/17	0.76 (2.49)	3.23	292.27	1.15 (3.77)	15
52	Isabel	2003/09/19	1.05 (3.44)	6.20	234.81	1.87 (6.14)	27

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table E5
Maximum H_S by Storm, James Island, Station 9, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/20	0.54 (1.77)	3.25	20.97	0.69 (2.26)	18
2	None	1861/09/26	0.01 (0.03)	0.74	276.67	0.31 (1.02)	0
3	None	1861/11/03	0.50 (1.64)	3.10	21.95	0.58 (1.90)	12
4	None	1863/09/19	0.59 (1.94)	3.25	73.59	0.65 (2.13)	6
5	None	1874/09/28	0.01 (0.03)	1.47	278.33	0.31 (1.02)	0
6	None	1876/09/19	0.11 (0.36)	1.64	299.50	0.74 (2.43)	0
7	None	1877/10/05	0.71 (2.33)	3.80	296.27	1.10 (3.61)	6
8	None	1878/10/24	0.23 (0.75)	2.30	286.17	1.51 (4.95)	0
9	None	1879/08/19	0.66 (2.17)	3.80	21.95	0.84 (2.76)	6
10	None	1880/09/10	0.43 (1.41)	2.80	20.00	0.74 (2.43)	6
11	None	1881/09/10	0.46 (1.51)	2.90	20.00	0.87 (2.85)	15
12	None	1888/10/12	0.28 (0.92)	2.30	17.93	0.54 (1.77)	0
13	None	1889/09/25	0.42 (1.38)	2.80	20.00	0.59 (1.94)	6
14	None	1893/06/17	0.43 (1.41)	2.90	14.07	0.47 (1.54)	15
15	None	1893/08/27	0.18 (0.59)	1.80	69.03	0.32 (1.05)	0
16	None	1893/10/12	0.16 (0.52)	1.72	17.93	0.31 (1.02)	0
17	None	1893/10/23	0.58 (1.90)	3.45	21.95	0.59 (1.94)	6
18	None	1894/09/30	0.69 (2.26)	3.90	326.00	0.07 (0.23)	36
19	None	1894/10/10	0.54 (1.77)	3.30	22.92	0.71 (2.33)	6
20	None	1897/10/25	0.55 (1.80)	3.50	15.04	0.33 (1.08)	18
21	None	1899/08/18	0.65 (2.13)	3.50	24.98	1.12 (3.67)	78
22	None	1899/10/31	0.24 (0.79)	2.03	69.99	0.28 (0.92)	0
23	None	1904/09/15	0.79 (2.59)	3.90	300.76	1.31 (4.30)	3
24	None	1908/08/01	0.46 (1.51)	2.96	18.05	0.61 (2.00)	24
25	None	1923/10/24	0.63 (2.07)	3.80	15.04	0.52 (1.71)	15
26	None	1933/08/24	0.70 (2.30)	3.70	26.95	0.88 (2.89)	15
27	None	1933/09/17	0.61 (2.00)	3.70	323.00	0.69 (2.26)	45
28	None	1935/09/06	0.50 (1.64)	2.80	74.56	0.63 (2.07)	6
29	None	1936/09/19	0.94 (3.08)	4.60	330.00	0.44 (1.44)	39
30	None	1944/08/03	0.43 (1.41)	3.10	324.32	1.03 (3.38)	6
31	None	1944/09/15	0.66 (2.17)	3.80	20.97	0.56 (1.84)	18
32	None	1946/07/07	0.32 (1.05)	2.44	17.93	0.42 (1.38)	3
33	Barbara	1953/08/15	0.64 (2.10)	3.80	325.00	0.55 (1.80)	27
34	Hazel	1954/10/15	0.53 (1.74)	3.15	69.99	0.47 (1.54)	6
35	Connie	1955/08/13	0.96 (3.15)	5.00	15.00	1.11 (3.64)	33
36	Diane	1955/08/17	0.34 (1.12)	2.38	74.56	0.58 (1.90)	12
37	Ione	1955/09/20	0.71 (2.33)	3.95	325.00	0.39 (1.28)	45
38	Brenda	1960/07/30	0.42 (1.38)	2.70	24.00	0.89 (2.92)	3
39	Donna	1960/09/12	0.68 (2.23)	3.35	78.15	0.83 (2.72)	12
40	Doria	1967/09/11	0.10 (0.33)	1.39	18.89	0.28 (0.92)	0
41	Doria	1971/08/28	0.70 (2.30)	3.40	78.15	0.89 (2.92)	12
42	Bret	1981/07/01	0.59 (1.94)	3.40	69.03	0.40 (1.31)	24
43	Dean	1983/09/30	0.27 (0.89)	2.26	16.00	0.42 (1.38)	0
44	Gloria	1985/09/27	1.22 (4.00)	5.20	328.00	0.78 (2.56)	30
45	Charley	1986/08/18	0.61 (2.00)	3.50	21.95	0.73 (2.39)	18
46	Danielle	1992/09/26	0.35 (1.15)	2.58	17.93	0.42 (1.38)	6
47	Bertha	1996/07/13	0.63 (2.07)	3.40	26.95	1.15 (3.77)	6
48	Fran	1996/09/06	0.53 (1.74)	3.00	73.59	0.59 (1.94)	12
49	Bonnie	1998/08/28	0.52 (1.71)	3.00	24.00	0.94 (3.08)	60
50	Earl	1998/09/02	0.01 (0.03)	0.92	280.00	0.31 (1.02)	0
51	Floyd	1999/09/17	0.76 (2.49)	4.25	14.04	1.15 (3.77)	9
52	Isabel	2003/09/19	0.82 (2.69)	4.06	67.88	0.92 (3.02)	18

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table E6
Maximum H_S by Storm, James Island, Station 11, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/20	0.40 (1.31)	3.25	25.99	0.69 (2.26)	27
2	None	1861/09/28	0.16 (0.52)	3.10	155.45	1.10 (3.61)	3
3	None	1861/11/03	0.37 (1.21)	3.10	26.97	0.58 (1.90)	9
4	None	1863/09/19	0.43 (1.41)	3.25	79.29	0.65 (2.13)	6
5	None	1874/09/30	0.28 (0.92)	3.10	160.15	1.29 (4.23)	3
6	None	1876/09/18	0.16 (0.52)	3.10	153.64	1.08 (3.54)	3
7	None	1877/10/05	0.20 (0.66)	3.80	314.84	1.10 (3.61)	3
8	None	1878/10/24	0.34 (1.12)	3.30	158.45	1.83 (6.00)	12
9	None	1879/08/19	0.50 (1.64)	3.80	26.97	0.84 (2.76)	6
10	None	1880/09/10	0.32 (1.05)	2.80	25.00	0.74 (2.43)	6
11	None	1881/09/10	0.33 (1.08)	2.90	25.00	0.87 (2.85)	33
12	None	1888/10/12	0.20 (0.66)	2.30	24.96	0.54 (1.77)	3
13	None	1889/09/25	0.30 (0.98)	2.80	25.00	0.59 (1.94)	6
14	None	1893/06/17	0.30 (0.98)	2.90	21.04	0.47 (1.54)	15
15	None	1893/08/29	0.16 (0.52)	3.70	159.49	1.39 (4.56)	3
16	None	1893/10/14	0.14 (0.46)	2.80	152.73	1.03 (3.38)	0
17	None	1893/10/23	0.43 (1.41)	3.45	26.97	0.59 (1.94)	9
18	None	1894/09/29	0.45 (1.48)	3.50	24.01	0.61 (2.00)	39
19	None	1894/10/10	0.40 (1.31)	3.30	27.96	0.71 (2.33)	6
20	None	1897/10/25	0.40 (1.31)	3.50	22.02	0.33 (1.08)	21
21	None	1899/08/18	0.67 (2.20)	3.50	37.02	1.12 (3.67)	96
22	None	1899/11/01	0.28 (0.92)	3.23	156.49	1.33 (4.36)	12
23	None	1904/09/15	0.29 (0.95)	3.30	157.41	1.21 (3.97)	18
24	None	1908/08/01	0.34 (1.12)	2.96	23.03	0.61 (2.00)	45
25	None	1923/10/24	0.46 (1.51)	3.80	22.02	0.52 (1.71)	18
26	None	1933/08/24	0.71 (2.33)	3.70	39.05	0.88 (2.89)	18
27	None	1933/09/17	0.60 (1.97)	3.25	34.98	0.92 (3.02)	66
28	None	1935/09/06	0.37 (1.21)	2.80	80.28	0.63 (2.07)	6
29	None	1936/09/18	0.50 (1.64)	3.80	25.00	0.59 (1.94)	57
30	None	1944/08/03	0.15 (0.49)	3.50	155.78	1.26 (4.13)	0
31	None	1944/09/15	0.50 (1.64)	3.80	25.99	0.56 (1.84)	36
32	None	1946/07/07	0.23 (0.75)	2.44	24.96	0.42 (1.38)	12
33	Barbara	1953/08/14	0.43 (1.41)	3.40	25.00	0.56 (1.84)	39
34	Hazel	1954/10/15	0.38 (1.25)	3.15	77.99	0.47 (1.54)	30
35	Connie	1955/08/13	0.98 (3.22)	5.00	38.00	1.11 (3.64)	78
36	Diane	1955/08/17	0.25 (0.82)	2.38	80.28	0.58 (1.90)	39
37	Ione	1955/09/20	0.55 (1.80)	3.10	36.00	0.98 (3.22)	54
38	Brenda	1960/07/30	0.43 (1.41)	2.70	36.00	0.89 (2.92)	3
39	Donna	1960/09/12	0.70 (2.30)	3.35	91.85	0.83 (2.72)	9
40	Doria	1967/09/11	0.07 (0.23)	1.39	25.95	0.28 (0.92)	0
41	Doria	1971/08/28	0.72 (2.36)	3.40	91.85	0.89 (2.92)	12
42	Bret	1981/07/01	0.43 (1.41)	3.40	77.01	0.40 (1.31)	33
43	Dean	1983/09/30	0.19 (0.62)	2.26	23.00	0.42 (1.38)	6
44	Gloria	1985/09/27	0.57 (1.87)	4.60	26.99	0.73 (2.39)	57
45	Charley	1986/08/18	0.45 (1.48)	3.50	26.97	0.73 (2.39)	24
46	Danielle	1992/09/26	0.25 (0.82)	2.58	24.96	0.42 (1.38)	15
47	Bertha	1996/07/13	0.65 (2.13)	3.40	39.05	1.15 (3.77)	3
48	Fran	1996/09/06	0.38 (1.25)	3.00	79.29	0.59 (1.94)	42
49	Bonnie	1998/08/28	0.53 (1.74)	3.00	36.00	0.94 (3.08)	72
50	Earl	1998/09/04	0.06 (0.20)	3.25	151.92	0.59 (1.94)	0
51	Floyd	1999/09/17	0.76 (2.49)	4.25	36.98	1.15 (3.77)	33
52	Isabel	2003/09/19	0.82 (2.69)	4.06	94.13	0.92 (3.02)	42

[1]Storm duration is the time during a storm when H_S > 0.15 m

Table E7
Maximum H_S by Storm, James Island, Station 13, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	None	1856/08/19	0.04 (0.13)	2.26	187.70	0.31 (1.02)	0
2	None	1861/09/28	0.20 (0.66)	3.10	175.15	1.09 (3.58)	12
3	None	1861/11/02	0.14 (0.46)	2.90	198.56	0.66 (2.17)	0
4	None	1863/09/19	0.18 (0.59)	3.40	207.09	0.68 (2.23)	3
5	None	1874/09/30	0.28 (0.92)	3.10	159.09	1.29 (4.23)	12
6	None	1876/09/18	0.26 (0.85)	5.30	196.51	1.34 (4.40)	15
7	None	1877/10/05	0.19 (0.62)	5.00	203.76	1.00 (3.28)	3
8	None	1878/10/23	0.39 (1.28)	7.81	189.38	1.19 (3.90)	24
9	None	1879/08/18	0.16 (0.52)	3.60	188.51	0.80 (2.62)	3
10	None	1880/09/09	0.07 (0.23)	3.10	188.85	0.40 (1.31)	0
11	None	1881/09/10	0.16 (0.52)	3.16	198.56	0.70 (2.30)	3
12	None	1888/10/12	0.16 (0.52)	3.20	201.00	0.58 (1.90)	3
13	None	1889/09/25	0.15 (0.49)	3.00	199.78	0.76 (2.49)	0
14	None	1893/06/17	0.16 (0.52)	3.19	198.56	0.67 (2.20)	3
15	None	1893/08/29	0.23 (0.75)	3.70	179.30	1.38 (4.53)	12
16	None	1893/10/14	0.23 (0.75)	5.00	197.68	1.18 (3.87)	18
17	None	1893/10/24	0.07 (0.23)	3.10	192.30	0.32 (1.05)	0
18	None	1894/09/28	0.12 (0.39)	2.75	197.35	0.66 (2.17)	0
19	None	1894/10/10	0.11 (0.36)	3.60	200.78	0.55 (1.80)	0
20	None	1897/10/24	0.02 (0.07)	1.72	187.70	0.29 (0.95)	0
21	None	1899/08/18	0.10 (0.33)	3.50	17.97	1.13 (3.71)	0
22	None	1899/11/01	0.31 (1.02)	4.50	195.76	1.43 (4.69)	15
23	None	1904/09/15	0.30 (0.98)	3.30	156.36	1.21 (3.97)	12
24	None	1908/08/01	0.01 (0.03)	2.96	86.70	0.62 (2.03)	0
25	None	1923/10/24	0.05 (0.16)	2.70	198.06	0.40 (1.31)	0
26	None	1933/08/24	0.25 (0.82)	5.00	197.68	1.31 (4.30)	15
27	None	1933/09/17	0.09 (0.30)	3.25	16.03	0.94 (3.08)	0
28	None	1935/09/06	0.16 (0.52)	3.20	201.00	0.55 (1.80)	3
29	None	1936/09/18	0.01 (0.03)	3.80	89.00	0.61 (2.00)	0
30	None	1944/08/03	0.23 (0.75)	4.60	205.24	0.79 (2.59)	12
31	None	1944/09/15	0.05 (0.16)	2.65	196.91	0.47 (1.54)	0
32	None	1946/07/07	0.05 (0.16)	2.56	188.85	0.48 (1.57)	0
33	Barbara	1953/08/15	0.03 (0.10)	2.19	196.91	0.44 (1.44)	0
34	Hazel	1954/10/16	0.34 (1.12)	8.29	203.64	0.93 (3.05)	21
35	Connie	1955/08/14	0.21 (0.69)	3.20	173.10	1.00 (3.28)	9
36	Diane	1955/08/19	0.17 (0.56)	3.20	210.75	0.58 (1.90)	3
37	Ione	1955/09/20	0.08 (0.26)	3.10	17.00	0.99 (3.25)	0
38	Brenda	1960/07/30	0.13 (0.43)	4.30	205.00	0.79 (2.59)	0
39	Donna	1960/09/12	0.15 (0.49)	3.10	198.56	0.66 (2.17)	0
40	Doria	1967/09/11	0.06 (0.20)	1.94	197.35	0.62 (2.03)	0
41	Doria	1971/08/28	0.15 (0.49)	3.00	207.09	0.68 (2.23)	0
42	Bret	1981/07/01	0.02 (0.07)	1.75	190.00	0.51 (1.67)	0
43	Dean	1983/09/28	0.01 (0.03)	0.70	188.85	0.34 (1.12)	0
44	Gloria	1985/09/27	0.01 (0.03)	3.30	92.45	0.67 (2.20)	0
45	Charley	1986/08/18	0.01 (0.03)	3.30	90.15	0.66 (2.17)	0
46	Danielle	1992/09/26	0.03 (0.10)	1.95	193.45	0.30 (0.98)	0
47	Bertha	1996/07/13	0.18 (0.59)	3.90	189.67	0.79 (2.59)	6
48	Fran	1996/09/07	0.30 (0.98)	4.30	191.15	1.18 (3.87)	24
49	Bonnie	1998/08/28	0.08 (0.26)	3.00	17.00	0.94 (3.08)	0
50	Earl	1998/09/04	0.17 (0.56)	3.25	202.22	0.58 (1.90)	3
51	Floyd	1999/09/16	0.18 (0.59)	3.40	198.56	0.67 (2.20)	9
52	Isabel	2003/09/19	0.35 (1.15)	5.22	182.25	1.83 (6.00)	18

[1]Storm duration is the time during a storm when H_S > 0.15 m

Table E8
Maximum H_S by Storm, James Island, Station 1, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1945/01/23	0.07 (0.23)	5.10	47.90	0.24 (0.79)	0
2	1956/10/17	0.09 (0.30)	3.73	49.00	0.55 (1.80)	0
3	1956/10/28	0.19 (0.62)	3.83	45.96	0.86 (2.82)	12
4	1957/10/05	0.08 (0.26)	3.34	47.95	0.61 (2.00)	0
5	1958/02/15	0.38 (1.25)	3.28	207.73	0.34 (1.12)	15
6	1958/10/21	0.16 (0.52)	3.37	48.04	0.91 (2.99)	6
7	1962/03/08	0.09 (0.30)	3.79	46.90	0.84 (2.76)	0
8	1962/11/27	0.18 (0.59)	3.66	47.00	0.90 (2.95)	18
9	1966/01/30	0.39 (1.28)	3.15	221.67	0.35 (1.15)	30
10	1969/01/21	0.08 (0.26)	3.15	49.00	0.48 (1.57)	0
11	1972/05/24	0.32 (1.05)	2.77	210.27	0.43 (1.41)	6
12	1972/10/07	0.11 (0.36)	2.65	45.96	0.90 (2.95)	0
13	1974/12/02	0.79 (2.59)	4.43	216.36	1.07 (3.51)	48
14	1975/06/28	0.37 (1.21)	2.96	207.73	0.32 (1.05)	6
15	1977/10/29	0.08 (0.26)	3.27	47.95	0.56 (1.84)	0
16	1978/04/27	0.08 (0.26)	3.50	49.00	0.55 (1.80)	0
17	1980/12/29	0.08 (0.26)	3.14	49.00	0.72 (2.36)	0
18	1981/08/20	0.52 (1.71)	3.19	205.00	0.72 (2.36)	9
19	1983/02/11	0.09 (0.30)	3.69	49.00	0.67 (2.20)	0
20	1981/03/29	0.63 (2.07)	4.43	220.75	0.83 (2.72)	9
21	1984/09/26	0.36 (1.18)	3.25	219.13	0.31 (1.02)	3
22	1984/10/14	0.09 (0.30)	3.64	46.90	0.69 (2.26)	0
23	1984/11/19	0.17 (0.56)	2.01	205.20	0.31 (1.02)	3
24	1985/11/05	0.58 (1.90)	3.80	203.00	1.05 (3.44)	30
25	1986/12/02	0.49 (1.61)	3.21	201.77	1.10 (3.61)	18
26	1987/02/17	0.06 (0.20)	3.26	43.92	0.35 (1.15)	0
27	1988/04/13	0.08 (0.26)	3.56	49.00	0.67 (2.20)	0
28	1989/03/08	0.08 (0.26)	3.33	47.95	0.64 (2.10)	0
29	1991/01/08	0.07 (0.23)	2.97	47.95	0.49 (1.61)	0
30	1991/04/19	0.40 (1.31)	2.79	201.27	0.60 (1.97)	9
31	1991/10/31	0.07 (0.23)	2.93	45.85	0.56 (1.84)	0
32	1991/11/10	0.08 (0.26)	3.47	47.95	0.57 (1.87)	0
33	1993/03/14	0.35 (1.15)	3.73	252.99	0.76 (2.49)	27
34	1994/10/15	0.08 (0.26)	3.27	47.95	0.57 (1.87)	0
35	1996/10/09	0.33 (1.08)	2.78	216.60	0.35 (1.15)	3
36	1997/06/06	0.42 (1.38)	2.88	208.73	0.72 (2.36)	18
37	1997/10/14	0.36 (1.18)	2.97	211.53	0.31 (1.02)	12
38	1998/05/14	0.08 (0.26)	2.25	45.96	0.90 (2.95)	0
39	1999/04/29	0.20 (0.66)	2.18	210.27	0.35 (1.15)	3
40	1999/09/05	0.60 (1.97)	3.45	205.00	0.70 (2.30)	45
41	2000/05/30	0.07 (0.23)	3.13	46.90	0.59 (1.94)	0
42	2003/04/11	0.10 (0.33)	2.44	45.96	0.91 (2.99)	0
43	2003/09/09	0.06 (0.02)	2.60	49.00	0.61 (2.00)	0

[1]Storm duration is the time during a storm when H_S > 0.15 m

Table E9
Maximum H_S by Storm, James Island, Station 3, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1945/01/23	0.56 (1.84)	4.32	284.00	0.15 (0.49)	3
2	1956/10/18	0.35 (1.15)	3.54	294.00	0.55 (1.80)	3
3	1956/10/24	0.15 (0.49)	2.39	294.00	0.31 (1.02)	0
4	1957/10/03	0.23 (0.75)	2.92	292.00	0.22 (0.72)	0
5	1958/02/16	0.78 (2.56)	3.40	282.27	0.55 (1.80)	138
6	1958/10/21	0.11 (0.36)	3.37	349.89	0.91 (2.99)	0
7	1962/03/08	0.65 (2.13)	4.68	287.00	0.70 (2.30)	3
8	1962/12/05	0.56 (1.84)	4.31	286.00	0.46 (1.51)	6
9	1966/01/30	0.99 (3.25)	3.73	257.13	0.18 (0.59)	114
10	1969/01/19	0.11 (0.36)	2.05	294.00	0.21 (0.69)	0
11	1972/05/24	0.49 (1.61)	3.52	211.53	0.26 (0.85)	6
12	1972/10/07	0.52 (1.71)	4.21	287.00	0.73 (2.39)	27
13	1974/12/02	0.95 (3.12)	4.83	217.14	0.96 (3.15)	90
14	1975/06/30	0.83 (2.72)	5.09	284.00	0.16 (0.52)	9
15	1977/10/29	0.07 (0.23)	3.27	319.18	0.56 (1.84)	0
16	1978/04/28	0.60 (1.97)	4.56	287.00	0.57 (1.87)	15
17	1980/12/30	0.52 (1.71)	4.22	286.00	0.42 (1.38)	36
18	1981/08/20	0.45 (1.48)	3.19	198.00	0.72 (2.36)	9
19	1983/02/12	0.55 (1.80)	4.29	286.00	0.51 (1.67)	39
20	1981/03/29	0.88 (2.89)	3.52	244.53	0.99 (3.25)	51
21	1984/10/02	0.45 (1.48)	3.94	296.00	0.59 (1.94)	18
22	1984/10/14	0.08 (0.26)	3.93	318.36	0.57 (1.87)	0
23	1984/11/21	0.53 (1.74)	4.20	284.00	0.13 (0.43)	18
24	1985/11/05	0.66 (2.17)	3.80	195.00	1.05 (3.44)	39
25	1986/12/02	0.48 (1.57)	3.21	193.82	1.10 (3.61)	12
26	1987/02/16	0.23 (0.75)	2.93	292.00	0.21 (0.69)	0
27	1988/04/11	0.12 (0.39)	2.14	294.00	0.31 (1.02)	0
28	1989/03/10	0.38 (1.25)	3.62	296.00	0.57 (1.87)	9
29	1991/01/09	0.22 (0.72)	2.89	296.00	0.61 (2.00)	0
30	1991/04/19	0.35 (1.15)	2.79	194.40	0.60 (1.97)	9
31	1991/10/31	0.37 (1.21)	3.63	294.00	0.35 (1.15)	6
32	1991/11/09	0.28 (0.92)	3.21	294.00	0.19 (0.62)	0
33	1993/03/14	0.98 (3.22)	3.73	278.50	0.76 (2.49)	24
34	1994/10/15	0.07 (0.23)	3.27	319.18	0.57 (1.87)	0
35	1996/10/04	0.41 (1.35)	3.78	294.00	0.34 (1.12)	21
36	1997/06/06	0.37 (1.21)	2.88	201.60	0.72 (2.36)	6
37	1997/10/14	0.37 (1.21)	2.97	204.45	0.31 (1.02)	15
38	1998/05/10	0.17 (0.56)	2.49	294.00	0.31 (1.02)	0
39	1999/04/29	0.24 (0.79)	2.43	208.50	0.13 (0.43)	0
40	1999/09/05	0.53 (1.74)	3.47	195.60	0.67 (2.20)	42
41	2000/05/30	0.06 (0.20)	3.13	318.36	0.59 (1.94)	0
42	2003/04/11	0.42 (1.38)	3.80	296.00	0.66 (2.17)	12
43	2003/09/09	0.05 (0.16)	2.60	320.00	0.61 (2.00)	0

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table E10
Maximum H_S by Storm, James Island, Station 5, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1945/01/23	0.93 (3.05)	4.32	298.00	0.15 (0.49)	42
2	1956/10/18	0.61 (2.00)	3.54	311.00	0.56 (1.84)	33
3	1956/10/28	0.63 (2.07)	4.35	335.14	0.67 (2.20)	96
4	1957/10/05	0.65 (2.13)	4.41	335.14	0.62 (2.03)	42
5	1958/02/16	0.89 (2.92)	4.21	300.00	0.35 (1.15)	132
6	1958/10/20	0.51 (1.67)	3.89	337.13	0.50 (1.64)	54
7	1962/03/08	1.09 (3.58)	4.68	302.00	0.70 (2.30)	69
8	1962/12/05	0.94 (3.08)	4.31	300.00	0.47 (1.54)	183
9	1966/01/27	1.11 (3.64)	4.79	299.00	0.43 (1.41)	132
10	1969/01/21	0.41 (1.35)	3.39	337.00	0.46 (1.51)	51
11	1972/05/26	0.55 (1.80)	3.41	338.87	0.45 (1.48)	54
12	1972/10/07	0.89 (2.92)	4.21	302.00	0.73 (2.39)	36
13	1974/12/04	0.90 (2.95)	4.23	300.00	0.42 (1.38)	105
14	1975/06/30	1.11 (3.64)	5.09	295.00	0.17 (0.56)	51
15	1977/10/30	0.43 (1.41)	3.47	336.14	0.40 (1.31)	48
16	1978/04/28	1.01 (3.31)	4.56	302.00	0.58 (1.90)	48
17	1980/12/30	0.88 (2.89)	4.22	300.00	0.42 (1.38)	90
18	1981/08/20	0.48 (1.57)	2.83	336.14	0.40 (1.31)	36
19	1983/02/12	0.92 (3.02)	4.29	300.00	0.50 (1.64)	78
20	1981/03/30	1.25 (4.10)	5.02	299.00	0.49 (1.61)	69
21	1984/10/02	0.77 (2.53)	3.94	313.00	0.59 (1.94)	141
22	1984/10/14	0.56 (1.84)	4.04	333.28	0.54 (1.77)	57
23	1984/11/21	0.88 (2.89)	4.20	298.00	0.12 (0.39)	63
24	1985/10/28	0.64 (2.10)	3.64	311.00	0.31 (1.02)	129
25	1986/11/30	0.44 (1.44)	3.04	309.00	0.17 (0.56)	60
26	1987/02/16	0.41 (1.35)	2.93	309.00	0.21 (0.69)	30
27	1988/04/13	0.45 (1.48)	3.55	337.00	0.44 (1.44)	36
28	1989/03/10	0.65 (2.13)	3.62	313.00	0.58 (1.90)	84
29	1991/01/09	0.39 (1.28)	2.89	313.00	0.61 (2.00)	42
30	1991/04/21	0.46 (1.51)	3.15	313.00	0.62 (2.03)	6
31	1991/10/31	0.64 (2.10)	3.63	311.00	0.35 (1.15)	39
32	1991/11/09	0.49 (1.61)	3.21	311.00	0.18 (0.59)	54
33	1993/03/14	1.02 (3.35)	3.73	285.94	0.77 (2.53)	48
34	1994/10/15	0.41 (1.35)	3.40	336.14	0.38 (1.25)	18
35	1996/10/04	0.70 (2.30)	3.78	311.00	0.34 (1.12)	63
36	1997/06/04	0.37 (1.21)	3.14	337.00	0.37 (1.21)	27
37	1997/10/19	0.60 (1.97)	3.52	311.00	0.42 (1.38)	78
38	1998/05/12	0.33 (1.08)	3.13	337.13	0.60 (1.97)	18
39	1999/05/03	0.41 (1.35)	2.95	311.00	0.42 (1.38)	24
40	1999/08/30	0.48 (1.57)	3.70	335.27	0.14 (0.46)	126
41	2000/05/29	0.45 (1.48)	3.57	336.14	0.38 (1.25)	27
42	2003/04/12	0.73 (2.39)	3.80	313.00	0.65 (2.13)	51
43	2003/09/10	0.37 (1.21)	3.20	336.14	0.34 (1.12)	15

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table E11
Maximum H_S by Storm, James Island, Station 7, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1945/01/23	1.04 (3.41)	4.32	313.00	0.15 (0.49)	45
2	1956/10/18	0.66 (2.17)	3.54	319.00	0.56 (1.84)	36
3	1956/10/25	0.71 (2.33)	4.24	341.12	0.22 (0.72)	99
4	1957/10/05	0.73 (2.39)	4.41	343.12	0.62 (2.03)	48
5	1958/02/16	0.97 (3.18)	4.21	314.00	0.35 (1.15)	129
6	1958/10/20	0.58 (1.90)	3.89	349.10	0.50 (1.64)	60
7	1962/03/08	1.17 (3.84)	4.68	314.00	0.70 (2.30)	69
8	1962/12/05	1.03 (3.38)	4.31	314.00	0.47 (1.54)	201
9	1966/01/27	1.23 (4.04)	4.79	314.00	0.43 (1.41)	126
10	1969/01/21	0.44 (1.44)	3.39	348.00	0.46 (1.51)	57
11	1972/05/26	0.61 (2.00)	3.41	350.90	0.45 (1.48)	60
12	1972/10/07	0.95 (3.12)	4.21	314.00	0.73 (2.39)	42
13	1974/12/04	1.00 (3.28)	4.24	313.00	0.16 (0.52)	96
14	1975/06/30	1.28 (4.20)	5.09	312.00	0.17 (0.56)	51
15	1977/10/30	0.47 (1.54)	3.47	347.11	0.40 (1.31)	69
16	1978/04/28	1.08 (3.54)	4.56	314.00	0.58 (1.90)	48
17	1980/12/30	0.97 (3.18)	4.22	314.00	0.42 (1.38)	102
18	1981/08/21	0.51 (1.67)	3.60	347.11	0.40 (1.31)	30
19	1983/02/12	1.01 (3.31)	4.29	314.00	0.50 (1.64)	81
20	1981/03/30	1.39 (4.56)	5.02	314.00	0.49 (1.61)	69
21	1984/10/02	0.82 (2.69)	3.94	319.00	0.59 (1.94)	141
22	1984/10/14	0.63 (2.07)	4.04	341.24	0.54 (1.77)	57
23	1984/11/21	0.98 (3.22)	4.20	313.00	0.12 (0.39)	66
24	1985/10/28	0.70 (2.30)	3.64	319.00	0.31 (1.02)	129
25	1986/12/01	0.49 (1.61)	3.45	346.11	0.14 (0.46)	60
26	1987/02/16	0.44 (1.44)	2.93	319.00	0.21 (0.69)	30
27	1988/04/13	0.49 (1.61)	3.55	348.00	0.44 (1.44)	39
28	1989/03/10	0.69 (2.26)	3.62	319.00	0.58 (1.90)	84
29	1991/01/07	0.42 (1.38)	3.20	346.11	0.09 (0.30)	45
30	1991/04/21	0.50 (1.64)	3.13	319.00	0.46 (1.51)	6
31	1991/10/31	0.70 (2.30)	3.63	319.00	0.35 (1.15)	48
32	1991/11/09	0.53 (1.74)	3.21	319.00	0.18 (0.59)	54
33	1993/03/14	1.04 (3.41)	3.73	292.31	0.77 (2.53)	51
34	1994/10/15	0.44 (1.44)	3.40	347.11	0.38 (1.25)	18
35	1996/10/04	0.77 (2.53)	3.78	319.00	0.34 (1.12)	72
36	1997/06/04	0.39 (1.28)	3.14	348.00	0.37 (1.21)	24
37	1997/10/19	0.66 (2.17)	3.52	319.00	0.42 (1.38)	84
38	1998/05/12	0.35 (1.15)	3.13	349.10	0.60 (1.97)	21
39	1999/05/03	0.45 (1.48)	2.95	319.00	0.42 (1.38)	27
40	1999/08/30	0.54 (1.77)	3.70	345.22	0.14 (0.46)	96
41	2000/05/29	0.49 (1.61)	3.57	347.11	0.38 (1.25)	27
42	2003/04/12	0.77 (2.53)	3.80	319.00	0.65 (2.13)	51
43	2003/09/10	0.40 (1.31)	3.20	347.11	0.34 (1.12)	15

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table E12
Maximum H_S by Storm, James Island, Station 9, Extratropical Storms

Storm Number	Date	H_s, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1945/01/23	0.86 (2.82)	4.32	332.00	0.12 (0.39)	51
2	1956/10/17	0.65 (2.13)	3.73	20.00	0.60 (1.97)	51
3	1956/10/28	0.74 (2.43)	4.35	12.04	0.69 (2.26)	147
4	1957/10/05	0.75 (2.46)	4.41	12.04	0.64 (2.10)	54
5	1958/02/16	0.81 (2.66)	4.21	330.00	0.38 (1.25)	126
6	1958/10/21	0.67 (2.20)	3.80	19.03	0.62 (2.03)	72
7	1962/03/08	1.01 (3.31)	4.68	329.00	0.68 (2.23)	75
8	1962/12/05	0.86 (2.82)	4.31	330.00	0.49 (1.61)	228
9	1966/01/27	1.06 (3.48)	4.79	330.00	0.46 (1.51)	132
10	1969/01/21	0.53 (1.74)	3.39	16.00	0.43 (1.41)	63
11	1972/05/26	0.66 (2.17)	3.41	11.95	0.44 (1.44)	75
12	1972/10/07	0.81 (2.66)	4.21	329.00	0.73 (2.39)	105
13	1974/12/04	0.83 (2.72)	4.23	330.00	0.45 (1.48)	66
14	1975/06/30	1.22 (4.00)	5.09	331.00	0.18 (0.59)	66
15	1977/10/30	0.55 (1.80)	3.47	15.04	0.43 (1.41)	117
16	1978/04/28	0.93 (3.05)	4.56	329.00	0.61 (2.00)	51
17	1980/12/30	0.81 (2.66)	4.22	330.00	0.44 (1.44)	111
18	1981/08/20	0.65 (2.13)	2.83	15.04	0.37 (1.21)	57
19	1983/02/12	0.85 (2.79)	4.29	330.00	0.49 (1.61)	120
20	1981/03/30	1.22 (4.00)	5.23	328.00	0.62 (2.03)	66
21	1984/10/02	0.69 (2.26)	3.94	323.00	0.62 (2.03)	138
22	1984/10/14	0.64 (2.10)	3.93	11.09	0.57 (1.87)	99
23	1984/11/21	0.80 (2.62)	4.20	332.00	0.12 (0.39)	78
24	1985/11/05	0.64 (2.10)	3.25	78.15	1.13 (3.71)	153
25	1986/12/02	0.59 (1.94)	3.41	20.00	0.72 (2.36)	69
26	1987/02/17	0.51 (1.67)	3.26	14.07	0.38 (1.25)	48
27	1988/04/13	0.60 (1.97)	3.56	20.00	0.66 (2.17)	60
28	1989/03/10	0.58 (1.90)	3.62	323.00	0.60 (1.97)	96
29	1991/01/08	0.48 (1.57)	2.97	19.03	0.48 (1.57)	78
30	1991/04/21	0.41 (1.35)	2.73	19.03	0.62 (2.03)	24
31	1991/10/31	0.58 (1.90)	3.63	325.00	0.36 (1.18)	66
32	1991/11/10	0.58 (1.90)	3.47	19.03	0.57 (1.87)	51
33	1993/03/14	0.70 (2.30)	3.73	323.14	0.80 (2.62)	51
34	1994/10/15	0.54 (1.77)	3.27	19.03	0.57 (1.87)	90
35	1996/10/04	0.63 (2.07)	3.78	325.00	0.35 (1.15)	144
36	1997/06/04	0.49 (1.61)	3.14	16.00	0.35 (1.15)	90
37	1997/10/19	0.54 (1.77)	3.52	325.00	0.39 (1.28)	129
38	1998/05/12	0.50 (1.64)	3.13	19.03	0.58 (1.90)	69
39	1999/05/02	0.51 (1.67)	3.27	15.04	0.55 (1.80)	81
40	1999/08/30	0.59 (1.94)	3.60	15.04	0.32 (1.05)	144
41	2000/05/30	0.57 (1.87)	3.56	16.00	0.39 (1.28)	54
42	2003/04/12	0.65 (2.13)	3.80	323.00	0.64 (2.10)	96
43	2003/09/10	0.49 (1.61)	3.20	15.04	0.34 (1.12)	66

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table E13
Maximum H_S by Storm, James Island, Station 11, Extratropical Storms

Storm Number	Date	H_s, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1945/01/23	0.60 (1.97)	5.10	23.03	0.30 (0.98)	54
2	1956/10/17	0.49 (1.61)	3.73	25.00	0.60 (1.97)	69
3	1956/10/28	0.75 (2.46)	3.83	34.98	0.90 (2.95)	153
4	1957/10/05	0.53 (1.74)	4.41	25.01	0.64 (2.10)	66
5	1958/02/16	0.31 (1.02)	4.21	341.00	0.38 (1.25)	123
6	1958/10/21	0.62 (2.03)	3.37	37.02	0.91 (2.99)	72
7	1962/03/07	0.53 (1.74)	4.41	24.02	0.75 (2.46)	84
8	1962/11/27	0.71 (2.33)	3.66	36.00	0.88 (2.89)	228
9	1966/01/27	0.47 (1.54)	3.82	22.02	0.26 (0.85)	132
10	1969/01/21	0.38 (1.25)	3.15	25.00	0.43 (1.41)	66
11	1972/05/27	0.60 (1.97)	3.24	36.00	0.94 (3.08)	87
12	1972/10/07	0.43 (1.41)	2.65	34.98	0.90 (2.95)	108
13	1974/12/02	0.70 (2.30)	3.41	91.85	0.95 (3.12)	60
14	1975/06/30	0.43 (1.41)	3.59	21.04	0.33 (1.08)	75
15	1977/10/29	0.40 (1.31)	3.27	24.01	0.58 (1.90)	120
16	1978/04/27	0.45 (1.48)	3.50	25.00	0.60 (1.97)	60
17	1980/12/29	0.38 (1.25)	3.14	25.00	0.72 (2.36)	117
18	1981/08/20	0.47 (1.54)	3.66	24.01	0.58 (1.90)	93
19	1983/02/11	0.48 (1.57)	3.69	25.00	0.71 (2.33)	120
20	1981/03/29	0.47 (1.54)	4.11	26.99	0.71 (2.33)	66
21	1984/09/30	0.47 (1.54)	3.63	24.01	0.80 (2.62)	135
22	1984/10/14	0.47 (1.54)	3.64	23.03	0.69 (2.26)	108
23	1984/11/20	0.38 (1.25)	3.31	21.04	0.36 (1.18)	75
24	1985/11/05	0.65 (2.13)	3.25	91.85	1.13 (3.71)	177
25	1986/12/02	0.48 (1.57)	2.73	91.85	1.02 (3.35)	72
26	1987/02/17	0.37 (1.21)	3.26	21.04	0.38 (1.25)	48
27	1988/04/13	0.45 (1.48)	3.56	25.00	0.66 (2.17)	63
28	1989/03/08	0.42 (1.38)	3.33	24.01	0.62 (2.03)	96
29	1991/01/08	0.35 (1.15)	2.97	24.01	0.48 (1.57)	78
30	1991/04/21	0.30 (0.98)	2.73	24.01	0.62 (2.03)	66
31	1991/10/31	0.35 (1.15)	3.15	20.05	0.53 (1.74)	54
32	1991/11/10	0.43 (1.41)	3.47	24.01	0.57 (1.87)	45
33	1993/03/13	0.46 (1.51)	3.81	23.00	0.43 (1.41)	39
34	1994/10/15	0.40 (1.31)	3.27	24.01	0.57 (1.87)	108
35	1996/10/08	0.43 (1.41)	3.42	26.97	0.77 (2.53)	141
36	1997/06/04	0.35 (1.15)	3.14	23.00	0.35 (1.15)	105
37	1997/10/16	0.37 (1.21)	3.26	21.04	0.47 (1.54)	117
38	1998/05/12	0.37 (1.21)	3.13	24.01	0.58 (1.90)	90
39	1999/05/02	0.37 (1.21)	3.27	22.02	0.55 (1.80)	93
40	1999/08/30	0.43 (1.41)	3.60	22.02	0.32 (1.05)	144
41	2000/05/29	0.41 (1.35)	3.57	22.02	0.35 (1.15)	66
42	2003/04/10	0.48 (1.57)	3.75	25.99	0.57 (1.87)	105
43	2003/09/10	0.35 (1.15)	3.20	22.02	0.34 (1.12)	96

[1]Storm duration is the time during a storm when H_S > 0.15 m

Table E14
Maximum H_S by Storm, James Island, Station 13, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw	Duration, hr[1]
1	1945/01/23	0.01 (0.03)	2.36	86.70	0.53 (1.74)	0
2	1956/10/17	0.01 (0.03)	3.35	90.15	0.69 (2.26)	0
3	1956/10/28	0.11 (0.36)	3.83	16.03	0.92 (3.02)	0
4	1957/10/05	0.01 (0.03)	3.34	87.85	0.62 (2.03)	0
5	1958/02/15	0.08 (0.26)	3.28	188.85	0.35 (1.15)	0
6	1958/10/21	0.09 (0.30)	3.37	17.97	0.92 (3.02)	0
7	1962/03/06	0.01 (0.03)	3.05	87.85	0.80 (2.62)	0
8	1962/11/27	0.10 (0.33)	3.66	17.00	0.89 (2.92)	0
9	1966/01/30	0.07 (0.23)	3.15	201.52	0.35 (1.15)	0
10	1969/01/21	0.01 (0.03)	3.15	89.00	0.43 (1.41)	0
11	1972/05/27	0.09 (0.30)	3.24	17.00	0.95 (3.12)	0
12	1972/10/07	0.06 (0.20)	2.65	16.03	0.90 (2.95)	0
13	1974/12/02	0.23 (0.75)	4.43	210.18	1.09 (3.58)	21
14	1975/06/28	0.07 (0.23)	2.96	188.85	0.32 (1.05)	0
15	1977/11/01	0.01 (0.03)	2.99	90.15	0.58 (1.90)	0
16	1978/04/26	0.01 (0.03)	3.40	89.00	0.68 (2.23)	0
17	1980/12/29	0.01 (0.03)	3.14	89.00	0.72 (2.36)	0
18	1981/08/20	0.16 (0.52)	3.19	201.00	0.71 (2.33)	3
19	1983/02/15	0.01 (0.03)	3.05	86.70	0.62 (2.03)	0
20	1981/03/29	0.15 (0.49)	4.43	212.45	0.81 (2.66)	0
21	1984/09/26	0.08 (0.26)	3.25	199.21	0.31 (1.02)	0
22	1984/10/14	0.01 (0.03)	3.64	86.70	0.70 (2.30)	0
23	1984/11/19	0.03 (0.10)	2.01	186.55	0.31 (1.02)	0
24	1985/11/05	0.23 (0.75)	3.35	173.10	0.96 (3.15)	12
25	1986/12/02	0.21 (0.69)	3.21	167.98	1.12 (3.67)	6
26	1987/02/15	0.01 (0.03)	2.02	81.86	0.31 (1.02)	0
27	1988/04/13	0.01 (0.03)	3.24	90.15	0.62 (2.03)	0
28	1989/03/09	0.01 (0.03)	3.14	85.55	0.80 (2.62)	0
29	1991/01/08	0.01 (0.03)	2.97	87.85	0.49 (1.61)	0
30	1991/04/19	0.13 (0.43)	2.79	197.35	0.58 (1.90)	0
31	1991/10/31	0.01 (0.03)	2.93	85.55	0.61 (2.00)	0
32	1991/11/09	0.01 (0.03)	3.12	86.70	0.56 (1.84)	0
33	1993/03/14	0.07 (0.23)	3.42	0.00	0.94 (3.08)	0
34	1994/10/15	0.01 (0.03)	3.27	87.85	0.58 (1.90)	0
35	1996/10/09	0.06 (0.20)	2.78	196.91	0.35 (1.15)	0
36	1997/06/06	0.13 (0.43)	2.88	204.65	0.71 (2.33)	0
37	1997/10/14	0.07 (0.23)	2.97	192.30	0.31 (1.02)	0
38	1998/05/14	0.05 (0.16)	2.25	16.03	0.94 (3.08)	0
39	1999/04/29	0.03 (0.10)	2.18	191.15	0.31 (1.02)	0
40	1999/09/05	0.19 (0.62)	3.47	198.56	0.70 (2.30)	12
41	2000/05/31	0.01 (0.03)	1.08	204.65	0.80 (2.62)	0
42	2003/04/11	0.06 (0.20)	2.44	16.03	0.94 (3.08)	0
43	2003/09/09	0.01 (0.03)	2.60	89.00	0.65 (2.13)	0

[1]Storm duration is the time during a storm when H_S > 0.15 m

Appendix F: Extremal Wave and Water Level Analysis Results for James Island

Table F1
James Island Station 1 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.53 (1.74)	3.32	0.83 (2.72)
10	0.68 (2.23)	4.44	1.03 (3.38)
15	0.76 (2.49)	4.68	1.14 (3.74)
20	0.82 (2.69)	5.16	1.29 (4.23)
25	0.86 (2.82)	5.60	1.35 (4.43)
30	0.90 (2.95)	5.88	1.40 (4.59)
35	0.93 (3.05)	6.02	1.41 (4.63)
40	0.95 (3.12)	6.58	1.47 (4.82)
45	0.97 (3.18)	6.55	1.47 (4.82)
50	0.99 (3.25)	6.79	1.59 (5.22)
100	1.11 (3.64)	8.64	1.67 (5.48)

Table F2
James Island Station 2 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.66 (2.17)	3.31	0.80 (2.62)
10	0.92 (3.02)	4.38	0.94 (3.08)
15	1.07 (3.51)	4.77	1.06 (3.48)
20	1.18 (3.87)	5.29	1.09 (3.58)
25	1.26 (4.13)	5.52	1.19 (3.90)
30	1.33 (4.36)	5.63	1.37 (4.49)
35	1.38 (4.53)	6.26	1.50 (4.92)
40	1.43 (4.69)	6.55	1.42 (4.66)
45	1.48 (4.86)	6.74	1.43 (4.69)
50	1.52 (4.99)	6.79	1.48 (4.86)
100	1.77 (5.81)	8.64	1.57 (5.15)

Table F3
James Island Station 3 Extremal Wave Analysis Results

Return Period Years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.79 (2.59)	3.79	0.52 (1.71)
10	1.05 (3.44)	4.52	0.70 (2.30)
15	1.20 (3.94)	5.00	1.36 (4.46)
20	1.30 (4.27)	5.42	1.39 (4.56)
25	1.38 (4.53)	5.71	1.27 (4.17)
30	1.45 (4.76)	5.60	1.36 (4.46)
35	1.50 (4.92)	5.86	1.27 (4.17)
40	1.55 (5.09)	5.93	1.33 (4.36)
45	1.60 (5.25)	5.98	1.41 (4.63)
50	1.64 (5.38)	6.12	1.26 (4.13)
100	1.89 (6.20)	7.94	1.32 (4.33)

Table F4
James Island Station 4 Extremal Wave Analysis Results

Return Period Years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.91 (2.99)	4.05	0.49 (1.61)
10	1.14 (3.74)	4.97	0.94 (3.08)
15	1.28 (4.20)	5.23	1.10 (3.61)
20	1.37 (4.49)	5.53	1.34 (4.40)
25	1.45 (4.76)	5.75	1.37 (4.49)
30	1.51 (4.95)	5.98	1.30 (4.27)
35	1.56 (5.12)	6.21	1.33 (4.36)
40	1.61 (5.28)	6.58	1.37 (4.49)
45	1.64 (5.38)	6.69	1.11 (3.64)
50	1.68 (5.51)	6.53	1.11 (3.64)
100	1.91 (6.27)	7.60	1.35 (4.43)

Table F5
James Island Station 5 Extremal Wave Analysis Results

Return Period Years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.98 (3.22)	4.99	0.53 (1.74)
10	1.16 (3.81)	5.13	0.69 (2.26)
15	1.26 (4.13)	5.48	1.04 (3.41)
20	1.34 (4.40)	5.97	1.08 (3.54)
25	1.39 (4.56)	6.11	1.34 (4.40)
30	1.44 (4.72)	6.01	1.27 (4.17)
35	1.48 (4.86)	6.05	1.33 (4.36)
40	1.51 (4.95)	6.12	1.37 (4.49)
45	1.55 (5.09)	6.22	1.11 (3.64)
50	1.59 (5.22)	6.22	1.32 (4.33)
100	1.89 (6.20)	7.55	1.35 (4.43)

Table F6
James Island Station 6 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	1.10 (3.61)	4.64	0.48 (1.57)
10	1.25 (4.10)	5.48	0.65 (2.13)
15	1.34 (4.40)	5.76	0.78 (2.56)
20	1.39 (4.56)	6.03	0.88 (2.89)
25	1.43 (4.69)	6.03	0.77 (2.53)
30	1.46 (4.79)	6.07	0.73 (2.40)
35	1.49 (4.89)	6.12	0.90 (2.95)
40	1.51 (4.95)	6.22	0.82 (2.69)
45	1.54 (5.05)	6.22	0.82 (2.69)
50	1.58 (5.18)	6.71	0.81 (2.66)
100	1.86 (6.10)	7.81	1.42 (4.66)

Table F7
James Island Station 7 Extremal Wave Analysis Results

Return Period Years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	1.03 (3.38)	4.98	0.45 (1.48)
10	1.19 (3.90)	5.58	0.57 (1.87)
15	1.28 (4.20)	5.78	0.57 (1.87)
20	1.33 (4.36)	5.76	0.59 (1.94)
25	1.37 (4.49)	5.79	0.59 (1.94)
30	1.41 (4.63)	6.03	0.69 (2.26)
35	1.43 (4.69)	6.35	0.69 (2.26)
40	1.46 (4.79)	6.55	0.69 (2.26)
45	1.48 (4.86)	6.77	0.68 (2.23)
50	1.49 (4.89)	6.77	0.75 (2.46)
100	1.71 (5.61)	7.94	1.35 (4.43)

Table F8
James Island Station 8 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	1.01 (3.31)	4.98	0.39 (1.28)
10	1.16 (3.81)	5.55	0.45 (1.48)
15	1.24 (4.07)	5.78	0.60 (1.97)
20	1.30 (4.27)	5.64	0.60 (1.97)
25	1.34 (4.40)	5.94	0.67 (2.20)
30	1.38 (4.53)	6.28	0.62 (2.03)
35	1.41 (4.63)	6.35	0.54 (1.77)
40	1.43 (4.69)	6.49	0.64 (2.10)
45	1.46 (4.79)	6.77	0.67 (2.20)
50	1.48 (4.86)	6.77	0.62 (2.03)
100	1.62 (5.31)	7.94	0.54 (1.77)

Table F9
James Island Station 9 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.83 (2.72)	4.93	0.39 (1.28)
10	0.96 (3.15)	5.55	0.41 (1.35)
15	1.03 (3.38)	5.89	0.54 (1.77)
20	1.08 (3.54)	5.77	0.53 (1.74)
25	1.12 (3.67)	5.99	0.52 (1.71)
30	1.15 (3.77)	6.36	0.53 (1.74)
35	1.18 (3.87)	6.45	0.56 (1.84)
40	1.20 (3.94)	6.77	0.56 (1.84)
45	1.22 (4.00)	6.77	0.53 (1.74)
50	1.24 (4.07)	6.84	0.53 (1.74)
100	1.36 (4.46)	7.94	0.47 (1.54)

Table F10
James Island Station 10 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.68 (2.23)	5.14	0.62 (2.03)
10	0.74 (2.43)	5.81	0.67 (2.20)
15	0.78 (2.56)	5.99	0.70 (2.30)
20	0.80 (2.62)	6.27	0.69 (2.26)
25	0.82 (2.69)	6.42	0.68 (2.23)
30	0.83 (2.72)	6.28	0.67 (2.20)
35	0.84 (2.76)	6.35	0.66 (2.17)
40	0.85 (2.79)	6.35	0.66 (2.17)
45	0.86 (2.82)	6.35	0.66 (2.17)
50	0.87 (2.85)	6.35	0.66 (2.17)
100	0.91 (2.99)	8.46	0.60 (1.97)

Table F11
James Island Station 11 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.58 (1.90)	5.18	0.79 (2.59)
10	0.65 (2.13)	5.79	0.92 (3.02)
15	0.69 (2.26)	6.06	0.93 (3.05)
20	0.71 (2.33)	6.36	0.96 (3.15)
25	0.73 (2.40)	6.38	0.96 (3.15)
30	0.75 (2.46)	6.43	0.96 (3.15)
35	0.76 (2.49)	6.35	0.95 (3.12)
40	0.77 (2.53)	6.26	0.95 (3.12)
45	0.78 (2.56)	6.82	0.95 (3.12)
50	0.79 (2.59)	6.82	0.94 (3.08)
100	0.83 (2.72)	8.46	0.98 (3.22)

Table F12
James Island Station 12 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.36 (1.18)	4.51	0.59 (1.94)
10	0.39 (1.28)	5.45	0.63 (2.07)
15	0.41 (1.35)	5.67	0.66 (2.17)
20	0.42 (1.38)	6.05	0.72 (2.36)
25	0.43 (1.41)	6.14	0.72 (2.36)
30	0.44 (1.44)	6.17	0.75 (2.46)
35	0.44 (1.44)	6.17	0.81 (2.66)
40	0.45 (1.48)	6.44	0.81 (2.66)
45	0.45 (1.48)	6.64	0.85 (2.79)
50	0.45 (1.48)	7.36	0.85 (2.79)
100	0.48 (1.57)	7.65	0.89 (2.92)

Table F13
James Island Station 13 Extremal Wave Analysis Results

Return Period years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.17 (0.56)	4.31	0.80 (2.62)
10	0.22 (0.72)	4.84	0.89 (2.92)
15	0.25 (0.82)	5.37	0.99 (3.25)
20	0.26 (0.85)	5.67	1.05 (3.44)
25	0.28 (0.92)	5.75	1.10 (3.61)
30	0.29 (0.95)	5.98	1.21 (3.97)
35	0.30 (0.98)	6.09	1.24 (4.07)
40	0.31 (1.02)	6.16	1.24 (4.07)
45	0.32 (1.05)	7.02	1.31 (4.30)
50	0.32 (1.05)	7.73	1.33 (4.36)
100	0.37 (1.21)	7.65	1.48 (4.86)

Table F14
Extreme Water Levels for Historical Northeasters from James Island Water Level Analysis Station 3 (Figure 18)

Return Period in yrs	Water Level Relative to mllw (ft)
2	1.72
5	2.26
10	2.62
25	3.07
50	3.4
100	3.73

Table F15
Extreme Water Levels for Historical Hurricanes from James Island Water Level Analysis Station 3 (Figure 18)

Return Period in yrs	Water Level Relative to mllw (ft)
2	0.77
5	2.01
10	2.82
25	3.86
50	4.62
100	5.38

Appendix G: Armor Weight as a Function of Return Period for James Island

Table G1
Armor Weight as a Function of Return Period for Station 1 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	0.778	78	0.361	8	1.677	782
10	1.024	178	0.476	18	1.706	827
15	1.145	249	0.531	25	1.719	847
20	1.237	316	0.574	31	0.846	100
25	1.293	358	0.600	35	0.873	111
30	1.375	433	0.640	43	0.899	120
35	1.414	471	0.656	47	0.919	129
40	1.444	500	0.669	50	0.932	136
45	1.483	542	0.689	54	0.945	140
50	1.529	596	0.712	59	0.958	147
100	1.677	784	0.778	78	1.040	187

Table G2
Armor Weight as a Function of Return Period for Station 2 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	0.965	149	0.449	15	2.126	1600
10	1.345	404	0.623	40	2.352	2162
15	1.568	642	0.728	64	2.313	2053
20	1.745	884	0.810	88	2.303	2033
25	1.854	1062	0.863	105	2.290	1996
30	1.946	1224	0.902	121	2.274	1956
35	2.034	1402	0.945	139	2.280	1973
40	2.123	1591	0.988	158	2.293	2007
45	2.195	1760	1.020	174	2.297	2013
50	2.277	1964	1.056	195	2.310	2047
100	2.592	2893	1.204	287	2.303	2036

Table G3
Armor Weight as a Function of Return Period for Station 3 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	1.161	260	0.538	26	2.198	1764
10	1.486	547	0.689	54	2.352	2167
15	1.785	949	0.830	94	2.497	2591
20	1.936	1207	0.899	120	2.559	2789
25	2.064	1462	0.958	145	2.618	2982
30	2.169	1696	1.007	168	2.654	3116
35	2.231	1849	1.037	183	2.641	3060
40	2.300	2027	1.070	201	2.625	3009
45	2.369	2216	1.102	220	2.612	2964
50	2.418	2356	1.122	233	2.605	2944
100	2.808	3682	1.306	365	2.602	2936

Table G4
Armor Weight as a Function of Return Period for Station 4 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	1.316	380	0.610	38	2.277	1964
10	1.680	791	0.781	78	2.454	2460
15	1.880	1104	0.873	109	2.536	2713
20	2.067	1473	0.961	146	2.618	2987
25	2.172	1707	1.010	169	2.654	3116
30	2.247	1891	1.043	187	2.661	3133
35	2.316	2069	1.076	205	2.644	3080
40	2.388	2271	1.109	225	2.635	3044
45	2.428	2378	1.129	236	2.635	3044
50	2.474	2520	1.148	250	2.625	3007
100	2.838	3798	1.319	376	2.618	2987

Table G5
Armor Weight as a Function of Return Period for Station 5 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	1.414	471	0.656	47	2.316	2064
10	1.690	804	0.784	80	2.448	2442
15	1.870	1089	0.869	108	2.526	2684
20	2.001	1331	0.928	132	2.582	2860
25	2.123	1591	0.988	158	2.631	3036
30	2.195	1758	1.020	174	2.661	3136
35	2.234	1853	1.037	184	2.671	3169
40	2.277	1967	1.060	195	2.687	3224
45	2.333	2113	1.083	209	2.713	3324
50	2.369	2216	1.102	220	2.717	3333
100	2.831	3769	1.316	374	2.736	3411

Table G6
Armor Weight as a Function of Return Period for Station 6 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	1.555	624	0.722	62	2.382	2247
10	1.804	978	0.837	97	2.500	2600
15	1.929	1196	0.896	119	2.549	2756
20	1.998	1324	0.928	131	2.572	2833
25	2.044	1422	0.948	141	2.592	2900
30	2.106	1553	0.978	154	2.621	3002
35	2.146	1642	0.997	163	2.631	3033
40	2.156	1669	1.001	165	2.635	3042
45	2.192	1753	1.017	174	2.648	3082
50	2.270	1944	1.053	193	2.680	3204
100	2.818	3729	1.309	370	2.703	3291

Table G7
Armor Weight as a Function of Return Period for Station 7 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	1.470	529	0.682	52	2.343	2136
10	1.722	849	0.801	84	2.461	2484
15	1.834	1029	0.853	102	2.507	2624
20	1.909	1158	0.886	115	2.539	2727
25	1.969	1267	0.915	126	2.566	2804
30	2.057	1451	0.955	144	2.605	2944
35	2.083	1502	0.968	149	2.615	2973
40	2.116	1580	0.984	157	2.628	3016
45	2.116	1576	0.981	156	2.618	2987
50	2.126	1596	0.988	158	2.618	2987
100	2.612	2962	1.214	294	2.782	3584

Table G8
Armor Weight as a Function of Return Period for Station 8 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	1.450	507	0.673	50	2.316	2069
10	1.667	771	0.774	76	2.418	2356
15	1.795	962	0.833	95	2.477	2524
20	1.886	1113	0.876	110	2.516	2647
25	1.969	1267	0.915	126	2.552	2769
30	2.028	1387	0.942	137	2.579	2853
35	2.041	1416	0.948	140	2.579	2856
40	2.064	1460	0.958	145	2.585	2869
45	2.110	1562	0.981	155	2.602	2933
50	2.146	1644	0.997	163	2.618	2989
100	2.287	1993	1.063	198	2.661	3131

Table G9
Armor Weight as a Function of Return Period for Station 9 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	1.243	320	0.577	32	2.221	1820
10	1.430	487	0.663	48	2.316	2067
15	1.532	600	0.712	59	2.365	2202
20	1.594	676	0.741	67	2.392	2278
25	1.650	747	0.768	74	2.418	2349
30	1.696	813	0.787	81	2.438	2416
35	1.742	880	0.810	87	2.457	2471
40	1.765	916	0.820	91	2.467	2500
45	1.781	940	0.827	93	2.470	2511
50	1.804	978	0.840	97	2.480	2538
100	1.959	1249	0.909	124	2.539	2729

Table G10
Armor Weight as a Function of Return Period for Station 10 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	1.030	182	0.479	18	2.093	1527
10	1.129	240	0.525	24	2.156	1669
15	1.194	282	0.554	28	2.192	1756
20	1.227	307	0.571	30	2.215	1802
25	1.253	329	0.584	33	2.228	1840
30	1.289	356	0.597	35	2.251	1896
35	1.309	373	0.607	37	2.264	1927
40	1.322	384	0.614	38	2.267	1942
45	1.335	396	0.620	39	2.274	1958
50	1.345	407	0.627	40	2.280	1973
100	1.411	467	0.656	46	2.313	2062

Table G11
Armor Weight as a Function of Return Period for Station 11 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	0.879	113	0.410	11	2.018	1367
10	0.958	147	0.443	15	2.060	1458
15	1.007	169	0.469	17	2.093	1522
20	1.027	180	0.476	18	2.103	1544
25	1.056	198	0.492	20	2.123	1589
30	1.083	211	0.502	21	2.136	1622
35	1.102	224	0.512	22	2.149	1653
40	1.115	231	0.518	23	2.156	1669
45	1.129	240	0.525	24	2.162	1684
50	1.145	251	0.531	25	2.175	1709
100	1.214	298	0.564	30	2.215	1811

Table G12
Armor Weight as a Function of Return Period for Station 12 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	0.600	36	0.279	**4**	1.808	984
10	0.646	44	0.299	**4**	1.850	1053
15	0.676	51	0.315	**5**	1.877	1098
20	0.696	56	0.322	**6**	1.893	1127
25	0.709	60	0.328	**6**	1.903	1144
30	0.728	64	0.338	**6**	1.916	1171
35	0.728	64	0.338	**6**	1.916	1171
40	0.738	67	0.344	**7**	1.926	1189
45	0.745	69	0.344	**7**	1.929	1198
50	0.745	69	0.344	**7**	1.929	1198
100	0.797	84	0.371	**8**	1.972	1273

Table G13
Armor Weight as a Function of Return Period for Station 13 at James Island

Return Period years	Armor Nominal Diameter D_{n50} in ft	Armor Weight $W_{a,50}$ in lb	Filter Layer Nominal Diameter D_{u50} in ft	Filter Layer Weight W_{u50} in lb	Toe Armor Nominal Diameter $D_{toe,50}$ in ft	Toe Armor Weight $W_{toe,50}$ in ft
5	0.335	7	0.154	1	1.526	591
10	0.417	11	0.194	1	1.634	724
15	0.472	18	0.220	2	1.693	809
20	0.495	20	0.230	2	1.719	847
25	0.528	24	0.246	2	1.752	896
30	0.551	29	0.256	3	1.775	933
35	0.568	31	0.262	3	1.791	956
40	0.581	33	0.269	3	1.804	978
45	0.607	38	0.282	4	1.827	1013
50	0.617	40	0.285	4	1.837	1029
100	0.692	56	0.322	6	1.900	1142

Appendix I: Maximum Significant Wave Height for Storm History for Barren Island

Table I1
Maximum H_S by Storm, Barren Island, Station 1, Tropical Storms

Storm Number	Storm Name	Date	H_s, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	None	1856/08/20	0.47 (1.54)	4.00	254	0.48 (1.57)
2	None	1861/09/26	0.95 (3.12)	4.79	218	0.96 (3.15)
3	None	1861/11/03	0.52 (1.71)	3.22	204	0.38 (1.25)
4	None	1863/09/19	0.69 (2.26)	3.82	210	0.80 (2.62)
5	None	1874/09/28	1.26 (4.13)	6.19	215	1.29 (4.23)
6	None	1876/09/17	1.30 (4.27)	6.28	215	1.35 (4.43)
7	None	1877/10/03	1.18 (3.87)	5.63	210	1.32 (4.33)
8	None	1878/10/22	1.56 (5.12)	6.80	212	1.78 (5.84)
9	None	1879/08/19	0.50 (1.64)	2.68	250	0.87 (2.85)
10	None	1880/09/09	0.81 (2.66)	4.05	207	0.59 (1.94)
11	None	1881/09/10	0.46 (1.51)	3.38	274	0.55 (1.80)
12	None	1888/10/12	0.57 (1.87)	3.48	204	0.62 (2.03)
13	None	1889/09/25	0.77 (2.53)	3.97	202	0.81 (2.66)
14	None	1893/06/17	0.49 (1.61)	3.22	202	0.65 (2.13)
15	None	1893/08/27	1.08 (3.54)	5.75	218	1.08 (3.54)
16	None	1893/10/14	1.05 (3.44)	6.15	219	0.94 (3.08)
17	None	1893/10/21	0.54 (1.77)	3.73	210	0.40 (1.31)
18	None	1894/09/29	0.49 (1.61)	4.01	260	0.61 (2.00)
19	None	1894/10/10	0.67 (2.20)	4.46	210	0.65 (2.13)
20	None	1897/10/25	0.46 (1.51)	3.46	274	0.46 (1.51)
21	None	1899/08/19	0.52 (1.71)	3.99	274	0.93 (3.05)
22	None	1899/10/31	1.22 (4.00)	5.03	214	1.22 (4.00)
23	None	1904/09/14	1.43 (4.69)	6.22	211	1.57 (5.15)
24	None	1908/08/01	0.47 (1.54)	3.38	272	0.39 (1.28)
25	None	1923/10/24	0.58 (1.90)	3.42	213	0.52 (1.71)
26	None	1933/08/24	1.37 (4.49)	5.71	205	1.52 (4.99)
27	None	1933/09/16	0.47 (1.54)	3.78	268	0.64 (2.10)
28	None	1935/09/06	0.69 (2.26)	3.80	202	0.62 (2.03)
29	None	1936/09/19	0.63 (2.07)	4.54	261	0.61 (2.00)
30	None	1944/08/03	1.00 (3.28)	4.89	211	0.90 (2.95)
31	None	1944/09/14	0.52 (1.71)	4.07	263	0.70 (2.30)
32	None	1946/07/07	0.28 (0.92)	2.43	204	0.35 (1.15)
33	Barbara	1953/08/14	0.48 (1.57)	3.87	269	0.67 (2.20)
34	Hazel	1954/10/15	1.38 (4.53)	7.37	217	1.48 (4.86)
35	Connie	1955/08/13	0.93 (3.05)	5.38	221	1.13 (3.71)
36	Diane	1955/08/17	0.87 (2.85)	4.25	218	0.64 (2.10)
37	Ione	1955/09/19	0.49 (1.61)	4.07	254	0.47 (1.54)
38	Brenda	1960/07/30	1.00 (3.28)	4.91	208	0.88 (2.89)
39	Donna	1960/09/12	0.55 (1.80)	4.25	262	0.84 (2.76)
40	Doria	1967/09/11	0.12 (0.39)	1.64	204	0.34 (1.12)
41	Doria	1971/08/28	0.71 (2.33)	3.86	211	0.80 (2.62)
42	Bret	1981/07/01	0.41 (1.35)	3.25	277	0.61 (2.00)
43	Dean	1983/09/30	0.26 (0.85)	2.57	276	0.33 (1.08)
44	Gloria	1985/09/27	0.66 (2.17)	3.03	249	1.04 (3.41)
45	Charley	1986/08/18	0.42 (1.38)	3.89	267	0.45 (1.48)
46	Danielle	1992/09/26	0.24 (0.79)	2.47	276	0.63 (2.07)
47	Bertha	1996/07/13	0.85 (2.79)	4.26	207	0.60 (1.97)
48	Fran	1996/09/06	0.92 (3.02)	4.33	208	1.21 (3.97)
49	Bonnie	1998/08/28	0.46 (1.51)	3.46	280	0.88 (2.89)
50	Earl	1998/09/02	0.55 (1.80)	3.34	212	0.40 (1.31)
51	Floyd	1999/09/16	0.69 (2.26)	3.11	251	1.23 (4.04)
52	Isabel	2003/09/19	1.51 (4.95)	5.95	207	1.85 (6.07)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table I2
Maximum H_S by Storm, Barren Island, Station 2, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	None	1856/08/20	0.59 (1.94)	4.00	278	0.48 (1.57)
2	None	1861/09/26	1.07 (3.51)	4.79	226	0.96 (3.15)
3	None	1861/11/03	0.50 (1.64)	3.22	212	0.38 (1.25)
4	None	1863/09/19	0.70 (2.30)	3.82	216	0.80 (2.62)
5	None	1874/09/28	1.43 (4.69)	6.19	222	1.29 (4.23)
6	None	1876/09/17	1.46 (4.79)	6.28	222	1.35 (4.43)
7	None	1877/10/03	1.31 (4.30)	5.63	216	1.32 (4.33)
8	None	1878/10/22	1.72 (5.64)	6.80	218	1.78 (5.84)
9	None	1879/08/19	0.52 (1.71)	2.68	261	0.87 (2.85)
10	None	1880/09/09	0.82 (2.69)	4.05	217	0.59 (1.94)
11	None	1881/09/10	0.44 (1.44)	3.38	285	0.55 (1.80)
12	None	1888/10/12	0.65 (2.13)	3.72	212	0.47 (1.54)
13	None	1889/09/25	0.78 (2.56)	3.97	208	0.81 (2.66)
14	None	1893/06/17	0.49 (1.61)	3.22	207	0.65 (2.13)
15	None	1893/08/27	1.23 (4.04)	5.75	226	1.08 (3.54)
16	None	1893/10/14	1.22 (4.00)	6.15	228	0.94 (3.08)
17	None	1893/10/21	0.65 (2.13)	3.73	217	0.40 (1.31)
18	None	1894/09/29	0.61 (2.00)	4.19	277	0.19 (0.62)
19	None	1894/10/10	0.78 (2.56)	4.46	218	0.65 (2.13)
20	None	1897/10/25	0.56 (1.84)	4.02	279	0.23 (0.75)
21	None	1899/08/19	0.58 (1.90)	3.94	285	0.55 (1.80)
22	None	1899/10/31	1.38 (4.53)	5.86	214	1.21 (3.97)
23	None	1904/09/14	1.59 (5.22)	6.22	217	1.57 (5.15)
24	None	1908/08/01	0.44 (1.44)	3.38	284	0.39 (1.28)
25	None	1923/10/24	0.58 (1.90)	2.77	236	0.40 (1.31)
26	None	1933/08/24	1.49 (4.89)	5.71	210	1.52 (4.99)
27	None	1933/09/16	0.54 (1.77)	3.78	284	0.64 (2.10)
28	None	1935/09/06	0.70 (2.30)	3.80	208	0.62 (2.03)
29	None	1936/09/19	0.77 (2.53)	4.40	276	0.53 (1.74)
30	None	1944/08/03	1.14 (3.74)	4.89	218	0.90 (2.95)
31	None	1944/09/14	0.60 (1.97)	4.07	284	0.70 (2.30)
32	None	1946/07/07	0.27 (0.89)	2.43	212	0.35 (1.15)
33	Barbara	1953/08/14	0.56 (1.84)	3.87	285	0.67 (2.20)
34	Hazel	1954/10/15	1.54 (5.05)	7.37	224	1.48 (4.86)
35	Connie	1955/08/13	1.07 (3.51)	5.38	229	1.13 (3.71)
36	Diane	1955/08/17	0.99 (3.25)	4.90	226	0.67 (2.20)
37	Ione	1955/09/19	0.61 (2.00)	4.07	278	0.47 (1.54)
38	Brenda	1960/07/30	1.14 (3.74)	4.91	215	0.88 (2.89)
39	Donna	1960/09/12	0.64 (2.10)	4.25	283	0.84 (2.76)
40	Doria	1967/09/11	0.11 (0.36)	1.64	212	0.34 (1.12)
41	Doria	1971/08/28	0.72 (2.36)	3.86	217	0.80 (2.62)
42	Bret	1981/07/01	0.45 (1.48)	3.58	287	0.39 (1.28)
43	Dean	1983/09/30	0.25 (0.82)	2.57	288	0.33 (1.08)
44	Gloria	1985/09/27	0.71 (2.33)	4.79	277	1.05 (3.44)
45	Charley	1986/08/18	0.53 (1.74)	3.89	286	0.45 (1.48)
46	Danielle	1992/09/26	0.23 (0.75)	2.47	287	0.63 (2.07)
47	Bertha	1996/07/13	0.92 (3.02)	4.26	217	0.60 (1.97)
48	Fran	1996/09/06	1.01 (3.31)	4.67	215	1.04 (3.41)
49	Bonnie	1998/08/28	0.43 (1.41)	3.46	289	0.88 (2.89)
50	Earl	1998/09/02	0.61 (2.00)	3.64	215	0.54 (1.77)
51	Floyd	1999/09/16	0.72 (2.36)	3.11	262	1.23 (4.04)
52	Isabel	2003/09/19	1.63 (5.35)	5.95	211	1.85 (6.07)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table I3
Maximum H_S by Storm, Barren Island, Station 3, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	None	1856/08/20	0.61 (2.00)	4.00	288	0.50 (1.64)
2	None	1861/09/26	1.05 (3.44)	5.42	220	1.03 (3.38)
3	None	1861/11/03	0.46 (1.51)	3.43	296	0.75 (2.46)
4	None	1863/09/19	0.63 (2.07)	3.82	220	0.80 (2.62)
5	None	1874/09/28	1.42 (4.66)	6.19	226	1.31 (4.30)
6	None	1876/09/17	1.47 (4.82)	6.28	226	1.38 (4.53)
7	None	1877/10/03	1.27 (4.17)	5.63	220	1.33 (4.36)
8	None	1878/10/22	1.72 (5.64)	6.80	221	1.81 (5.94)
9	None	1879/08/19	0.54 (1.77)	3.65	293	0.96 (3.15)
10	None	1880/09/09	0.72 (2.36)	4.05	221	0.57 (1.87)
11	None	1881/09/10	0.46 (1.51)	3.38	295	0.57 (1.87)
12	None	1888/10/12	0.58 (1.90)	3.72	217	0.49 (1.61)
13	None	1889/09/25	0.70 (2.30)	3.97	212	0.81 (2.66)
14	None	1893/06/17	0.46 (1.51)	3.51	293	0.55 (1.80)
15	None	1893/08/27	1.24 (4.07)	6.10	232	1.01 (3.31)
16	None	1893/10/14	1.22 (4.00)	6.15	232	0.97 (3.18)
17	None	1893/10/21	0.58 (1.90)	3.73	222	0.40 (1.31)
18	None	1894/09/29	0.65 (2.13)	4.19	287	0.19 (0.62)
19	None	1894/10/10	0.76 (2.49)	4.46	223	0.63 (2.07)
20	None	1897/10/25	0.57 (1.87)	4.02	289	0.23 (0.75)
21	None	1899/08/19	0.60 (1.97)	3.94	294	0.55 (1.80)
22	None	1899/10/31	1.38 (4.53)	6.70	234	1.23 (4.04)
23	None	1904/09/14	1.53 (5.02)	6.22	220	1.58 (5.18)
24	None	1908/08/01	0.47 (1.54)	3.38	294	0.40 (1.31)
25	None	1923/10/24	0.59 (1.94)	3.94	293	0.56 (1.84)
26	None	1933/08/24	1.36 (4.46)	5.71	213	1.52 (4.99)
27	None	1933/09/16	0.57 (1.87)	3.78	293	0.65 (2.13)
28	None	1935/09/06	0.63 (2.07)	3.80	212	0.61 (2.00)
29	None	1936/09/19	0.78 (2.56)	4.40	286	0.52 (1.71)
30	None	1944/08/03	1.05 (3.44)	4.89	222	0.90 (2.95)
31	None	1944/09/14	0.62 (2.03)	4.07	294	0.67 (2.20)
32	None	1946/07/07	0.28 (0.92)	2.67	297	0.48 (1.57)
33	Barbara	1953/08/14	0.58 (1.90)	3.87	294	0.67 (2.20)
34	Hazel	1954/10/15	1.56 (5.12)	7.37	228	1.53 (5.02)
35	Connie	1955/08/13	1.06 (3.48)	5.38	233	1.14 (3.74)
36	Diane	1955/08/17	0.97 (3.18)	4.90	231	0.70 (2.30)
37	Ione	1955/09/19	0.63 (2.07)	4.07	288	0.46 (1.51)
38	Brenda	1960/07/30	1.05 (3.44)	4.91	219	0.89 (2.92)
39	Donna	1960/09/12	0.66 (2.17)	4.25	293	0.82 (2.69)
40	Doria	1967/09/11	0.10 (0.33)	1.64	216	0.35 (1.15)
41	Doria	1971/08/28	0.65 (2.13)	3.86	221	0.81 (2.66)
42	Bret	1981/07/01	0.47 (1.54)	3.58	296	0.39 (1.28)
43	Dean	1983/09/30	0.26 (0.85)	2.57	298	0.35 (1.15)
44	Gloria	1985/09/27	0.74 (2.43)	4.79	286	1.03 (3.38)
45	Charley	1986/08/18	0.54 (1.77)	3.89	295	0.44 (1.44)
46	Danielle	1992/09/26	0.24 (0.79)	2.47	297	0.63 (2.07)
47	Bertha	1996/07/13	0.81 (2.66)	4.26	221	0.57 (1.87)
48	Fran	1996/09/06	0.93 (3.05)	4.67	219	1.04 (3.41)
49	Bonnie	1998/08/28	0.46 (1.51)	3.46	299	0.88 (2.89)
50	Earl	1998/09/02	0.55 (1.80)	3.64	220	0.55 (1.80)
51	Floyd	1999/09/16	0.70 (2.30)	4.43	292	1.26 (4.13)
52	Isabel	2003/09/19	1.47 (4.82)	5.95	214	1.87 (6.14)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table I4
Maximum H_S by Storm, Barren Island, Station 4, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	None	1856/08/20	0.51 (1.67)	4.00	278	0.50 (1.64)
2	None	1861/09/26	1.10 (3.61)	5.42	215	1.03 (3.38)
3	None	1861/11/03	0.47 (1.54)	3.22	209	0.36 (1.18)
4	None	1863/09/19	0.64 (2.10)	3.82	214	0.80 (2.62)
5	None	1874/09/28	1.50 (4.92)	6.00	230	1.20 (3.94)
6	None	1876/09/17	1.51 (4.95)	5.92	222	1.38 (4.53)
7	None	1877/10/03	1.27 (4.17)	5.63	215	1.33 (4.36)
8	None	1878/10/22	1.82 (5.97)	6.74	224	1.67 (5.48)
9	None	1879/08/19	0.52 (1.71)	2.68	261	0.88 (2.89)
10	None	1880/09/09	0.73 (2.40)	4.05	215	0.57 (1.87)
11	None	1881/09/10	0.37 (1.21)	3.38	282	0.57 (1.87)
12	None	1888/10/12	0.60 (1.97)	3.72	209	0.49 (1.61)
13	None	1889/09/25	0.71 (2.33)	3.97	206	0.81 (2.66)
14	None	1893/06/17	0.46 (1.51)	3.22	205	0.63 (2.07)
15	None	1893/08/27	1.37 (4.49)	5.75	226	1.01 (3.31)
16	None	1893/10/14	1.39 (4.56)	5.80	226	0.97 (3.18)
17	None	1893/10/21	0.60 (1.97)	3.73	214	0.40 (1.31)
18	None	1894/09/29	0.54 (1.77)	4.19	277	0.19 (0.62)
19	None	1894/10/10	0.79 (2.59)	4.46	216	0.63 (2.07)
20	None	1897/10/25	0.48 (1.57)	4.02	279	0.23 (0.75)
21	None	1899/08/19	0.49 (1.61)	3.94	283	0.55 (1.80)
22	None	1899/10/31	1.56 (5.12)	6.33	228	1.23 (4.04)
23	None	1904/09/14	1.51 (4.95)	5.87	217	1.58 (5.18)
24	None	1908/08/01	0.38 (1.25)	3.51	282	0.54 (1.77)
25	None	1923/10/24	0.57 (1.87)	2.77	237	0.40 (1.31)
26	None	1933/08/24	1.35 (4.43)	5.71	209	1.52 (4.99)
27	None	1933/09/16	0.46 (1.51)	3.78	282	0.65 (2.13)
28	None	1935/09/06	0.64 (2.10)	3.80	206	0.61 (2.00)
29	None	1936/09/19	0.67 (2.20)	4.40	276	0.52 (1.71)
30	None	1944/08/03	1.05 (3.44)	4.89	216	0.90 (2.95)
31	None	1944/09/14	0.51 (1.67)	4.07	283	0.67 (2.20)
32	None	1946/07/07	0.26 (0.85)	2.43	209	0.35 (1.15)
33	Barbara	1953/08/14	0.48 (1.57)	3.87	283	0.67 (2.20)
34	Hazel	1954/10/15	1.74 (5.71)	6.96	224	1.53 (5.02)
35	Connie	1955/08/13	1.10 (3.61)	5.38	228	1.14 (3.74)
36	Diane	1955/08/17	1.02 (3.35)	4.90	224	0.70 (2.30)
37	Ione	1955/09/19	0.52 (1.71)	4.07	278	0.46 (1.51)
38	Brenda	1960/07/30	1.06 (3.48)	4.91	213	0.89 (2.92)
39	Donna	1960/09/12	0.55 (1.80)	3.56	208	0.39 (1.28)
40	Doria	1967/09/11	0.11 (0.36)	1.64	209	0.35 (1.15)
41	Doria	1971/08/28	0.66 (2.17)	3.86	215	0.81 (2.66)
42	Bret	1981/07/01	0.38 (1.25)	3.58	285	0.39 (1.28)
43	Dean	1983/09/30	0.20 (0.66)	2.57	285	0.35 (1.15)
44	Gloria	1985/09/27	0.68 (2.23)	3.03	260	1.03 (3.38)
45	Charley	1986/08/18	0.45 (1.48)	3.89	284	0.44 (1.44)
46	Danielle	1992/09/26	0.19 (0.62)	2.15	214	0.30 (0.98)
47	Bertha	1996/07/13	0.82 (2.69)	4.26	215	0.57 (1.87)
48	Fran	1996/09/06	0.93 (3.05)	4.67	213	1.04 (3.41)
49	Bonnie	1998/08/28	0.37 (1.21)	3.46	287	0.88 (2.89)
50	Earl	1998/09/02	0.57 (1.87)	3.64	212	0.55 (1.80)
51	Floyd	1999/09/16	0.72 (2.36)	3.11	262	1.23 (4.04)
52	Isabel	2003/09/19	1.45 (4.76)	5.95	210	1.87 (6.14)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table I5
Maximum H_S by Storm, Barren Island, Station 5, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	None	1856/08/20	0.58 (1.90)	4.00	287	0.50 (1.64)
2	None	1861/09/26	0.98 (3.22)	5.42	220	1.03 (3.38)
3	None	1861/11/03	0.41 (1.35)	3.43	293	0.75 (2.46)
4	None	1863/09/19	0.52 (1.71)	3.82	220	0.80 (2.62)
5	None	1874/09/28	1.29 (4.23)	6.00	237	1.20 (3.94)
6	None	1876/09/17	1.26 (4.13)	5.92	227	1.38 (4.53)
7	None	1877/10/03	1.08 (3.54)	5.63	221	1.33 (4.36)
8	None	1878/10/22	1.57 (5.15)	7.14	229	1.67 (5.48)
9	None	1879/08/19	0.50 (1.64)	2.68	260	0.88 (2.89)
10	None	1880/09/09	0.59 (1.94)	4.05	222	0.57 (1.87)
11	None	1881/09/10	0.41 (1.35)	3.38	292	0.57 (1.87)
12	None	1888/10/12	0.49 (1.61)	3.72	217	0.49 (1.61)
13	None	1889/09/25	0.57 (1.87)	3.97	212	0.81 (2.66)
14	None	1893/06/17	0.44 (1.44)	3.51	293	0.55 (1.80)
15	None	1893/08/27	1.45 (4.76)	6.46	238	0.91 (2.99)
16	None	1893/10/14	1.20 (3.94)	5.80	232	0.97 (3.18)
17	None	1893/10/21	0.49 (1.61)	3.73	222	0.40 (1.31)
18	None	1894/09/29	0.63 (2.07)	4.19	287	0.19 (0.62)
19	None	1894/10/10	0.66 (2.17)	4.46	223	0.63 (2.07)
20	None	1897/10/25	0.54 (1.77)	4.02	288	0.23 (0.75)
21	None	1899/08/19	0.55 (1.80)	3.94	293	0.55 (1.80)
22	None	1899/10/31	1.40 (4.59)	6.33	234	1.23 (4.04)
23	None	1904/09/14	1.25 (4.10)	6.22	222	1.58 (5.18)
24	None	1908/08/01	0.44 (1.44)	3.51	293	0.54 (1.77)
25	None	1923/10/24	0.55 (1.80)	3.94	293	0.56 (1.84)
26	None	1933/08/24	1.12 (3.67)	5.71	215	1.52 (4.99)
27	None	1933/09/16	0.52 (1.71)	3.78	292	0.65 (2.13)
28	None	1935/09/06	0.52 (1.71)	3.80	212	0.61 (2.00)
29	None	1936/09/19	0.74 (2.43)	4.40	285	0.52 (1.71)
30	None	1944/08/03	0.92 (3.02)	5.22	225	1.17 (3.84)
31	None	1944/09/14	0.57 (1.87)	4.07	291	0.67 (2.20)
32	None	1946/07/07	0.24 (0.79)	2.67	295	0.48 (1.57)
33	Barbara	1953/08/14	0.54 (1.77)	3.87	293	0.67 (2.20)
34	Hazel	1954/10/15	1.67 (5.48)	6.96	229	1.53 (5.02)
35	Connie	1955/08/13	0.98 (3.22)	5.38	233	1.14 (3.74)
36	Diane	1955/08/17	0.83 (2.72)	4.90	231	0.70 (2.30)
37	Ione	1955/09/19	0.59 (1.94)	4.07	287	0.46 (1.51)
38	Brenda	1960/07/30	0.84 (2.76)	4.91	220	0.89 (2.92)
39	Donna	1960/09/12	0.61 (2.00)	4.25	290	0.82 (2.69)
40	Doria	1967/09/11	0.08 (0.26)	1.64	217	0.35 (1.15)
41	Doria	1971/08/28	0.53 (1.74)	3.86	221	0.81 (2.66)
42	Bret	1981/07/01	0.44 (1.44)	3.58	296	0.39 (1.28)
43	Dean	1983/09/30	0.23 (0.75)	2.57	296	0.35 (1.15)
44	Gloria	1985/09/27	0.82 (2.69)	4.79	286	1.03 (3.38)
45	Charley	1986/08/18	0.51 (1.67)	3.89	295	0.44 (1.44)
46	Danielle	1992/09/26	0.21 (0.69)	2.47	294	0.63 (2.07)
47	Bertha	1996/07/13	0.66 (2.17)	3.17	238	0.84 (2.76)
48	Fran	1996/09/06	0.75 (2.46)	4.67	220	1.04 (3.41)
49	Bonnie	1998/08/28	0.41 (1.35)	3.46	296	0.88 (2.89)
50	Earl	1998/09/02	0.47 (1.54)	3.64	220	0.55 (1.80)
51	Floyd	1999/09/16	0.68 (2.23)	3.11	261	1.23 (4.04)
52	Isabel	2003/09/19	1.20 (3.94)	5.95	216	1.87 (6.14)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table I6
Maximum H_S by Storm, Barren Island, Station 6, Tropical Storms

Storm Number	Storm Name	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	None	1856/08/20	0.70 (2.30)	4.00	290	0.48 (1.57)
2	None	1861/09/26	0.85 (2.79)	5.42	224	1.06 (3.48)
3	None	1861/11/03	0.48 (1.57)	3.43	295	0.74 (2.43)
4	None	1863/09/19	0.46 (1.51)	3.30	291	0.65 (2.13)
5	None	1874/09/28	1.14 (3.74)	6.00	240	1.36 (4.46)
6	None	1876/09/17	1.10 (3.61)	6.28	230	1.46 (4.79)
7	None	1877/10/03	0.93 (3.05)	5.63	224	1.37 (4.49)
8	None	1878/10/22	1.40 (4.59)	7.14	231	1.86 (6.10)
9	None	1879/08/19	0.58 (1.90)	3.65	292	0.96 (3.15)
10	None	1880/09/09	0.48 (1.57)	4.05	225	0.53 (1.74)
11	None	1881/09/10	0.48 (1.57)	3.38	294	0.56 (1.84)
12	None	1888/10/12	0.40 (1.31)	3.72	222	0.48 (1.57)
13	None	1889/09/25	0.46 (1.51)	3.97	217	0.80 (2.62)
14	None	1893/06/17	0.52 (1.71)	3.51	294	0.54 (1.77)
15	None	1893/08/27	1.30 (4.27)	6.46	241	1.13 (3.71)
16	None	1893/10/14	1.06 (3.48)	5.80	235	1.09 (3.58)
17	None	1893/10/21	0.43 (1.41)	3.26	295	0.58 (1.90)
18	None	1894/09/29	0.76 (2.49)	4.19	290	0.12 (0.39)
19	None	1894/10/10	0.56 (1.84)	4.46	226	0.58 (1.90)
20	None	1897/10/25	0.66 (2.17)	4.02	291	0.11 (0.36)
21	None	1899/08/19	0.66 (2.17)	3.94	295	0.52 (1.71)
22	None	1899/10/31	1.25 (4.10)	6.33	237	1.42 (4.66)
23	None	1904/09/14	1.08 (3.54)	6.22	224	1.61 (5.28)
24	None	1908/08/01	0.52 (1.71)	3.51	294	0.52 (1.71)
25	None	1923/10/24	0.67 (2.20)	3.94	294	0.56 (1.84)
26	None	1933/08/24	0.96 (3.15)	5.71	218	1.53 (5.02)
27	None	1933/09/16	0.62 (2.03)	3.78	294	0.64 (2.10)
28	None	1935/09/06	0.42 (1.38)	3.80	217	0.60 (1.97)
29	None	1936/09/19	0.91 (2.99)	4.40	288	0.53 (1.74)
30	None	1944/08/03	0.80 (2.62)	5.22	229	1.22 (4.00)
31	None	1944/09/14	0.69 (2.26)	4.07	295	0.63 (2.07)
32	None	1946/07/07	0.28 (0.92)	2.67	296	0.46 (1.51)
33	Barbara	1953/08/14	0.64 (2.10)	3.87	295	0.64 (2.10)
34	Hazel	1954/10/15	1.49 (4.89)	7.37	232	1.73 (5.68)
35	Connie	1955/08/13	0.95 (3.12)	5.06	292	1.32 (4.33)
36	Diane	1955/08/17	0.72 (2.36)	4.90	235	0.77 (2.53)
37	Ione	1955/09/19	0.72 (2.36)	4.07	290	0.42 (1.38)
38	Brenda	1960/07/30	0.72 (2.36)	4.91	224	0.90 (2.95)
39	Donna	1960/09/12	0.74 (2.43)	4.25	294	0.78 (2.56)
40	Doria	1967/09/11	0.07 (0.23)	1.81	198	0.60 (1.97)
41	Doria	1971/08/28	0.58 (1.90)	3.65	292	0.99 (3.25)
42	Bret	1981/07/01	0.53 (1.74)	3.58	297	0.32 (1.05)
43	Dean	1983/09/30	0.26 (0.85)	2.57	297	0.33 (1.08)
44	Gloria	1985/09/27	0.93 (3.05)	4.79	288	1.01 (3.31)
45	Charley	1986/08/18	0.62 (2.03)	3.89	296	0.38 (1.25)
46	Danielle	1992/09/26	0.24 (0.79)	2.47	296	0.63 (2.07)
47	Bertha	1996/07/13	0.61 (2.00)	3.17	242	0.88 (2.89)
48	Fran	1996/09/06	0.63 (2.07)	4.67	224	1.05 (3.44)
49	Bonnie	1998/08/28	0.48 (1.57)	3.46	298	0.86 (2.82)
50	Earl	1998/09/02	0.38 (1.25)	3.64	225	0.55 (1.80)
51	Floyd	1999/09/16	0.78 (2.56)	4.43	292	1.22 (4.00)
52	Isabel	2003/09/19	1.03 (3.38)	5.95	219	1.89 (6.20)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table I7
Maximum H_S by Storm, Barren Island, Station 1, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	1954/01/23	0.59 (1.94)	4.46	254	0.32 (1.05)
2	1956/10/17	0.47 (1.54)	4.06	257	0.50 (1.64)
3	1956/10/28	0.64 (2.10)	4.62	260	0.65 (2.13)
4	1957/10/06	0.66 (2.17)	4.70	260	0.59 (1.94)
5	1958/02/17	0.72 (2.36)	4.26	211	0.38 (1.25)
6	1958/10/21	0.54 (1.77)	4.22	260	0.56 (1.84)
7	1962/03/08	0.67 (2.20)	4.74	260	0.67 (2.20)
8	1962/11/27	0.53 (1.74)	4.02	266	1.04 (3.41)
9	1966/01/31	0.68 (2.23)	4.48	258	0.52 (1.71)
10	1969/01/22	0.47 (1.54)	3.46	273	0.11 (0.36)
11	1972/05/26	0.56 (1.84)	3.78	209	0.43 (1.41)
12	1972/10/08	0.61 (2.00)	4.22	257	0.81 (2.66)
13	1974/12/04	1.10 (3.61)	5.10	216	1.07 (3.51)
14	1975/07/01	0.61 (2.00)	4.56	254	0.42 (1.38)
15	1977/10/30	0.47 (1.54)	3.51	274	0.50 (1.64)
16	1978/04/28	0.63 (2.07)	4.41	259	0.54 (1.77)
17	1980/12/30	0.55 (1.80)	4.06	258	0.48 (1.57)
18	1981/08/21	0.56 (1.84)	3.43	205	0.63 (2.07)
19	1983/02/12	0.61 (2.00)	4.25	258	0.59 (1.94)
20	1984/03/30	1.02 (3.35)	4.95	217	0.92 (3.02)
21	1984/09/30	0.49 (1.61)	3.86	268	0.73 (2.39)
22	1984/10/14	0.58 (1.90)	4.24	259	0.77 (2.53)
23	1984/11/21	0.49 (1.61)	4.07	254	0.28 (0.92)
24	1985/10/29	0.91 (2.99)	4.27	206	0.99 (3.25)
25	1986/12/01	0.61 (2.00)	3.56	199	1.03 (3.38)
26	1987/02/18	0.47 (1.54)	3.51	274	0.26 (0.85)
27	1988/04/14	0.49 (1.61)	4.01	260	0.62 (2.03)
28	1989/03/10	0.48 (1.57)	3.87	269	0.56 (1.84)
29	1991/01/09	0.46 (1.51)	3.38	274	0.66 (2.17)
30	1991/04/21	0.47 (1.54)	3.38	272	0.52 (1.71)
31	1991/10/31	0.48 (1.57)	3.87	269	0.64 (2.10)
32	1991/11/10	0.48 (1.57)	3.96	270	0.55 (1.80)
33	1993/03/15	0.68 (2.23)	3.05	250	0.82 (2.69)
34	1994/10/16	0.47 (1.54)	3.52	274	0.42 (1.38)
35	1996/10/09	0.48 (1.57)	3.79	265	0.64 (2.10)
36	1997/06/04	0.45 (1.48)	3.44	276	0.58 (1.90)
37	1997/10/16	0.47 (1.54)	3.40	271	0.46 (1.51)
38	1998/05/13	0.47 (1.54)	3.52	276	0.71 (2.33)
39	1999/05/03	0.47 (1.54)	3.51	274	0.46 (1.51)
40	1999/08/31	0.66 (2.17)	3.72	202	0.60 (1.97)
41	2000/05/30	0.48 (1.57)	3.53	275	0.55 (1.80)
42	2003/04/11	0.49 (1.61)	3.86	268	0.76 (2.49)
43	2003/09/10	0.43 (1.41)	3.32	275	0.44 (1.44)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table I8
Maximum H_S by Storm, Barren Island, Station 2, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	1954/01/23	0.74 (2.43)	4.46	278	0.32 (1.05)
2	1956/10/17	0.58 (1.90)	4.06	281	0.50 (1.64)
3	1956/10/28	0.75 (2.46)	4.62	281	0.65 (2.13)
4	1957/10/06	0.78 (2.56)	4.70	281	0.59 (1.94)
5	1958/02/17	0.88 (2.89)	4.26	221	0.38 (1.25)
6	1958/10/21	0.63 (2.07)	4.22	281	0.56 (1.84)
7	1962/03/08	0.80 (2.62)	4.82	279	0.52 (1.71)
8	1962/11/27	0.65 (2.13)	4.12	277	0.54 (1.77)
9	1966/01/31	0.81 (2.66)	4.17	233	0.27 (0.89)
10	1969/01/22	0.47 (1.54)	3.62	289	0.59 (1.94)
11	1972/05/26	0.68 (2.23)	3.78	216	0.43 (1.41)
12	1972/10/08	0.74 (2.43)	4.29	275	0.43 (1.41)
13	1974/12/04	1.25 (4.10)	5.10	223	1.07 (3.51)
14	1975/07/01	0.77 (2.53)	4.56	278	0.42 (1.38)
15	1977/10/30	0.53 (1.74)	3.90	285	0.37 (1.21)
16	1978/04/28	0.73 (2.39)	4.41	280	0.54 (1.77)
17	1980/12/30	0.64 (2.10)	4.06	279	0.48 (1.57)
18	1981/08/21	0.62 (2.03)	4.22	279	0.57 (1.87)
19	1983/02/12	0.71 (2.33)	4.25	279	0.59 (1.94)
20	1984/03/30	1.17 (3.84)	4.95	224	0.92 (3.02)
21	1984/09/30	0.57 (1.87)	3.86	284	0.73 (2.39)
22	1984/10/14	0.68 (2.23)	4.24	280	0.77 (2.53)
23	1984/11/21	0.62 (2.03)	4.12	276	0.23 (0.75)
24	1985/10/29	0.90 (2.95)	4.27	214	0.99 (3.25)
25	1986/12/01	0.60 (1.97)	3.56	203	1.03 (3.38)
26	1987/02/18	0.47 (1.54)	3.72	285	0.33 (1.08)
27	1988/04/14	0.56 (1.84)	4.01	281	0.62 (2.03)
28	1989/03/10	0.56 (1.84)	3.87	285	0.56 (1.84)
29	1991/01/09	0.48 (1.57)	3.72	286	0.18 (0.59)
30	1991/04/21	0.44 (1.44)	3.38	284	0.52 (1.71)
31	1991/10/31	0.56 (1.84)	3.87	285	0.64 (2.10)
32	1991/11/10	0.55 (1.80)	3.96	287	0.55 (1.80)
33	1993/03/15	0.70 (2.30)	3.05	264	0.82 (2.69)
34	1994/10/16	0.50 (1.64)	3.78	286	0.55 (1.80)
35	1996/10/09	0.56 (1.84)	3.79	281	0.64 (2.10)
36	1997/06/04	0.43 (1.41)	3.44	287	0.58 (1.90)
37	1997/10/16	0.49 (1.61)	3.66	285	0.60 (1.97)
38	1998/05/13	0.45 (1.48)	3.52	288	0.71 (2.33)
39	1999/05/03	0.47 (1.54)	3.72	285	0.51 (1.67)
40	1999/08/31	0.67 (2.20)	3.72	208	0.60 (1.97)
41	2000/05/30	0.53 (1.74)	3.90	285	0.58 (1.90)
42	2003/04/11	0.57 (1.87)	3.86	284	0.76 (2.49)
43	2003/09/10	0.44 (1.44)	3.59	286	0.40 (1.31)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table I9
Maximum H_S by Storm, Barren Island, Station 3, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	1954/01/23	0.75 (2.46)	4.46	288	0.29 (0.95)
2	1956/10/17	0.60 (1.97)	4.06	291	0.50 (1.64)
3	1956/10/28	0.75 (2.46)	4.62	292	0.65 (2.13)
4	1957/10/06	0.78 (2.56)	4.70	292	0.59 (1.94)
5	1958/02/17	0.80 (2.62)	4.26	224	0.37 (1.21)
6	1958/10/21	0.64 (2.10)	4.22	292	0.55 (1.80)
7	1962/03/08	0.80 (2.62)	4.82	289	0.51 (1.67)
8	1962/11/27	0.67 (2.20)	4.12	287	0.52 (1.71)
9	1966/01/31	0.80 (2.62)	4.48	289	0.50 (1.64)
10	1969/01/22	0.49 (1.61)	3.62	298	0.56 (1.84)
11	1972/05/26	0.61 (2.00)	3.78	221	0.42 (1.38)
12	1972/10/08	0.76 (2.49)	4.29	284	0.42 (1.38)
13	1974/12/04	1.14 (3.74)	5.10	227	1.07 (3.51)
14	1975/07/01	0.78 (2.56)	4.56	288	0.39 (1.28)
15	1977/10/30	0.54 (1.77)	3.90	294	0.37 (1.21)
16	1978/04/28	0.74 (2.43)	4.41	290	0.55 (1.80)
17	1980/12/30	0.66 (2.17)	4.06	289	0.47 (1.54)
18	1981/08/21	0.63 (2.07)	4.22	290	0.54 (1.77)
19	1983/02/12	0.72 (2.36)	4.25	289	0.58 (1.90)
20	1984/03/30	1.07 (3.51)	4.95	228	0.92 (3.02)
21	1984/09/30	0.59 (1.94)	3.86	293	0.74 (2.43)
22	1984/10/14	0.69 (2.26)	4.24	290	0.75 (2.46)
23	1984/11/21	0.66 (2.17)	4.12	286	0.21 (0.69)
24	1985/10/29	0.81 (2.66)	4.27	218	1.00 (3.28)
25	1986/12/01	0.55 (1.80)	3.56	206	1.05 (3.44)
26	1987/02/18	0.49 (1.61)	3.72	294	0.33 (1.08)
27	1988/04/14	0.58 (1.90)	4.01	292	0.63 (2.07)
28	1989/03/10	0.58 (1.90)	3.87	294	0.57 (1.87)
29	1991/01/09	0.50 (1.64)	3.72	295	0.16 (0.52)
30	1991/04/21	0.47 (1.54)	3.38	294	0.51 (1.67)
31	1991/10/31	0.58 (1.90)	3.87	294	0.62 (2.03)
32	1991/11/10	0.57 (1.87)	3.96	296	0.52 (1.71)
33	1993/03/15	0.71 (2.33)	3.44	263	0.86 (2.82)
34	1994/10/16	0.52 (1.71)	3.78	295	0.52 (1.71)
35	1996/10/09	0.58 (1.90)	3.79	290	0.65 (2.13)
36	1997/06/04	0.45 (1.48)	3.44	297	0.59 (1.94)
37	1997/10/16	0.52 (1.71)	3.66	294	0.57 (1.87)
38	1998/05/13	0.47 (1.54)	3.52	298	0.70 (2.30)
39	1999/05/03	0.49 (1.61)	3.72	294	0.51 (1.67)
40	1999/08/31	0.61 (2.00)	4.13	289	0.43 (1.41)
41	2000/05/30	0.54 (1.77)	3.90	294	0.55 (1.80)
42	2003/04/11	0.59 (1.94)	3.86	293	0.74 (2.43)
43	2003/09/10	0.47 (1.54)	3.59	295	0.38 (1.25)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table I10
Maximum H_S by Storm, Barren Island, Station 4, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	1954/01/23	0.70 (2.30)	4.82	279	0.13 (0.43)
2	1956/10/17	0.50 (1.64)	4.06	281	0.50 (1.64)
3	1956/10/28	0.65 (2.13)	4.62	280	0.65 (2.13)
4	1957/10/06	0.67 (2.20)	4.70	280	0.59 (1.94)
5	1958/02/17	0.81 (2.66)	4.26	217	0.37 (1.21)
6	1958/10/21	0.54 (1.77)	4.22	280	0.55 (1.80)
7	1962/03/08	0.70 (2.30)	4.82	279	0.51 (1.67)
8	1962/11/27	0.56 (1.84)	4.12	277	0.52 (1.71)
9	1966/01/31	0.77 (2.53)	4.17	229	0.27 (0.89)
10	1969/01/22	0.40 (1.31)	3.62	287	0.56 (1.84)
11	1972/05/26	0.62 (2.03)	3.78	213	0.42 (1.38)
12	1972/10/08	0.64 (2.10)	4.29	275	0.42 (1.38)
13	1974/12/04	1.15 (3.77)	5.10	221	1.07 (3.51)
14	1975/07/01	0.67 (2.20)	4.56	278	0.39 (1.28)
15	1977/10/30	0.45 (1.48)	3.90	283	0.37 (1.21)
16	1978/04/28	0.63 (2.07)	4.41	279	0.55 (1.80)
17	1980/12/30	0.55 (1.80)	4.06	278	0.47 (1.54)
18	1981/08/21	0.53 (1.74)	4.22	279	0.54 (1.77)
19	1983/02/12	0.60 (1.97)	4.25	278	0.58 (1.90)
20	1984/03/30	1.08 (3.54)	4.95	222	0.92 (3.02)
21	1984/09/30	0.52 (1.71)	3.48	219	0.34 (1.12)
22	1984/10/14	0.59 (1.94)	4.43	279	0.52 (1.71)
23	1984/11/21	0.55 (1.80)	4.12	276	0.21 (0.69)
24	1985/10/29	0.81 (2.66)	4.27	213	1.00 (3.28)
25	1986/12/01	0.56 (1.84)	3.56	202	1.05 (3.44)
26	1987/02/18	0.41 (1.35)	3.72	283	0.33 (1.08)
27	1988/04/14	0.48 (1.57)	4.01	280	0.63 (2.07)
28	1989/03/10	0.48 (1.57)	3.87	283	0.57 (1.87)
29	1991/01/09	0.41 (1.35)	3.72	283	0.16 (0.52)
30	1991/04/21	0.37 (1.21)	3.38	281	0.51 (1.67)
31	1991/10/31	0.48 (1.57)	3.87	283	0.62 (2.03)
32	1991/11/10	0.47 (1.54)	3.96	285	0.52 (1.71)
33	1993/03/15	0.71 (2.33)	3.44	262	0.86 (2.82)
34	1994/10/16	0.42 (1.38)	3.78	283	0.52 (1.71)
35	1996/10/09	0.48 (1.57)	3.79	279	0.65 (2.13)
36	1997/06/04	0.38 (1.25)	2.97	209	0.78 (2.56)
37	1997/10/16	0.42 (1.38)	3.66	283	0.57 (1.87)
38	1998/05/13	0.38 (1.25)	3.52	285	0.70 (2.30)
39	1999/05/03	0.41 (1.35)	3.72	283	0.51 (1.67)
40	1999/08/31	0.61 (2.00)	3.72	206	0.59 (1.94)
41	2000/05/30	0.45 (1.48)	3.90	283	0.55 (1.80)
42	2003/04/11	0.48 (1.57)	3.86	282	0.74 (2.43)
43	2003/09/10	0.38 (1.25)	3.59	283	0.38 (1.25)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table I11
Maximum H_S by Storm, Barren Island, Station 5, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	1954/01/23	0.89 (2.92)	5.14	286	0.31 (1.02)
2	1956/10/17	0.57 (1.87)	4.06	290	0.50 (1.64)
3	1956/10/28	0.71 (2.33)	4.62	289	0.65 (2.13)
4	1957/10/06	0.74 (2.43)	4.70	289	0.59 (1.94)
5	1958/02/17	0.74 (2.43)	4.35	283	0.36 (1.18)
6	1958/10/21	0.60 (1.97)	4.22	289	0.55 (1.80)
7	1962/03/08	0.77 (2.53)	4.82	288	0.51 (1.67)
8	1962/11/27	0.63 (2.07)	4.12	286	0.52 (1.71)
9	1966/01/31	0.76 (2.49)	3.29	261	-0.17 (-0.56)
10	1969/01/22	0.45 (1.48)	3.62	297	0.56 (1.84)
11	1972/05/26	0.53 (1.74)	3.94	295	0.65 (2.13)
12	1972/10/08	0.74 (2.43)	4.53	282	0.49 (1.61)
13	1974/12/04	0.91 (2.99)	5.10	228	1.07 (3.51)
14	1975/07/01	0.75 (2.46)	4.75	286	0.23 (0.75)
15	1977/10/30	0.51 (1.67)	3.90	294	0.37 (1.21)
16	1978/04/28	0.70 (2.30)	4.41	287	0.55 (1.80)
17	1980/12/30	0.61 (2.00)	4.06	286	0.43 (1.41)
18	1981/08/21	0.60 (1.97)	4.22	289	0.54 (1.77)
19	1983/02/12	0.67 (2.20)	4.25	286	0.40 (1.31)
20	1984/03/30	1.00 (3.28)	5.10	283	0.60 (1.97)
21	1984/09/30	0.55 (1.80)	3.86	292	0.74 (2.43)
22	1984/10/14	0.66 (2.17)	4.43	288	0.52 (1.71)
23	1984/11/21	0.63 (2.07)	4.12	286	0.21 (0.69)
24	1985/10/29	0.66 (2.17)	4.27	220	1.00 (3.28)
25	1986/12/01	0.50 (1.64)	3.84	295	0.39 (1.28)
26	1987/02/18	0.47 (1.54)	3.72	294	0.33 (1.08)
27	1988/04/14	0.54 (1.77)	4.01	289	0.63 (2.07)
28	1989/03/10	0.54 (1.77)	3.87	293	0.57 (1.87)
29	1991/01/09	0.47 (1.54)	3.72	295	0.16 (0.52)
30	1991/04/21	0.41 (1.35)	3.38	292	0.51 (1.67)
31	1991/10/31	0.54 (1.77)	3.87	293	0.62 (2.03)
32	1991/11/10	0.53 (1.74)	3.96	295	0.52 (1.71)
33	1993/03/15	0.76 (2.49)	3.44	261	0.86 (2.82)
34	1994/10/16	0.49 (1.61)	3.78	295	0.52 (1.71)
35	1996/10/09	0.55 (1.80)	3.94	292	0.21 (0.69)
36	1997/06/04	0.40 (1.31)	3.44	294	0.59 (1.94)
37	1997/10/16	0.48 (1.57)	3.66	293	0.57 (1.87)
38	1998/05/13	0.42 (1.38)	3.52	295	0.70 (2.30)
39	1999/05/03	0.47 (1.54)	3.72	294	0.51 (1.67)
40	1999/08/31	0.57 (1.87)	4.13	288	0.43 (1.41)
41	2000/05/30	0.51 (1.67)	3.90	294	0.55 (1.80)
42	2003/04/11	0.55 (1.80)	3.86	292	0.74 (2.43)
43	2003/09/10	0.44 (1.44)	3.59	295	0.38 (1.25)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Table I12
Maximum H_S by Storm, Barren Island, Station 6, Extratropical Storms

Storm Number	Date	H_S, m (ft)	T_p, sec	θ_p, deg az.	Water Level, m (ft) mllw
1	1954/01/23	0.98 (3.22)	5.14	287	0.04 (0.13)
2	1956/10/17	0.69 (2.26)	4.06	293	0.40 (1.31)
3	1956/10/28	0.87 (2.85)	4.62	293	0.53 (1.74)
4	1957/10/06	0.90 (2.95)	4.70	293	0.43 (1.41)
5	1958/02/17	0.91 (2.99)	4.35	286	0.35 (1.15)
6	1958/10/21	0.73 (2.39)	4.22	292	0.29 (0.95)
7	1962/03/08	0.96 (3.15)	4.82	291	0.30 (0.98)
8	1962/11/27	0.77 (2.53)	4.12	289	0.34 (1.12)
9	1966/01/31	0.91 (2.99)	4.48	290	0.41 (1.35)
10	1969/01/22	0.53 (1.74)	3.62	299	0.50 (1.64)
11	1972/05/26	0.63 (2.07)	3.94	297	0.58 (1.90)
12	1972/10/08	0.88 (2.89)	4.29	286	0.43 (1.41)
13	1974/12/04	0.90 (2.95)	4.35	287	0.52 (1.71)
14	1975/07/01	0.92 (3.02)	4.56	290	0.00 (0.00)
15	1977/10/30	0.62 (2.03)	3.90	295	0.23 (0.75)
16	1978/04/28	0.85 (2.79)	4.31	289	0.30 (0.98)
17	1980/12/30	0.74 (2.43)	4.06	289	0.37 (1.21)
18	1981/08/21	0.73 (2.39)	4.22	292	0.33 (1.08)
19	1983/02/12	0.82 (2.69)	4.25	289	0.38 (1.25)
20	1984/03/30	1.12 (3.67)	5.10	285	0.59 (1.94)
21	1984/09/30	0.66 (2.17)	3.86	293	0.32 (1.05)
22	1984/10/14	0.81 (2.66)	4.43	291	0.37 (1.21)
23	1984/11/21	0.76 (2.49)	4.12	289	0.00 (0.00)
24	1985/10/29	0.57 (1.87)	3.63	293	0.31 (1.02)
25	1986/12/01	0.60 (1.97)	3.84	296	0.30 (0.98)
26	1987/02/18	0.56 (1.84)	3.72	295	0.21 (0.69)
27	1988/04/14	0.65 (2.13)	4.01	293	0.57 (1.87)
28	1989/03/10	0.64 (2.10)	3.87	295	0.51 (1.67)
29	1991/01/09	0.56 (1.84)	3.72	296	0.00 (0.00)
30	1991/04/21	0.48 (1.57)	3.38	293	0.43 (1.41)
31	1991/10/31	0.64 (2.10)	3.87	295	0.55 (1.80)
32	1991/11/10	0.63 (2.07)	3.96	297	0.43 (1.41)
33	1993/03/15	0.83 (2.72)	4.49	283	0.64 (2.10)
34	1994/10/16	0.58 (1.90)	3.78	296	0.38 (1.25)
35	1996/10/09	0.66 (2.17)	3.94	294	0.00 (0.00)
36	1997/06/04	0.47 (1.54)	3.44	296	0.55 (1.80)
37	1997/10/16	0.56 (1.84)	3.66	295	0.55 (1.80)
38	1998/05/13	0.49 (1.61)	3.52	297	0.65 (2.13)
39	1999/05/03	0.56 (1.84)	3.72	295	0.43 (1.41)
40	1999/08/31	0.70 (2.30)	4.13	291	0.38 (1.25)
41	2000/05/30	0.62 (2.03)	3.90	295	0.42 (1.38)
42	2003/04/11	0.65 (2.13)	3.86	294	0.71 (2.33)
43	2003/09/10	0.52 (1.71)	3.59	296	0.27 (0.89)

[1]Storm duration is the time during a storm when H_S > 0.3 m

Appendix J: Extremal Wave and Water Level Analysis Results for Barren Island

Table J1
Barren Island Station 1 Extremal Wave Analysis Results

Return Period Years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.81 (2.66)	4.29	0.85 (2.79)
10	0.97 (3.18)	4.89	0.96 (3.15)
15	1.07 (3.51)	5.26	1.01 (3.31)
20	1.14 (3.74)	5.47	1.18 (3.87)
25	1.20 (3.94)	5.66	1.35 (4.43)
30	1.26 (4.13)	5.70	1.35 (4.43)
35	1.31 (4.30)	5.90	1.45 (4.76)
40	1.35 (4.43)	6.08	1.49 (4.89)
45	1.38 (4.53)	6.30	1.53 (5.02)
50	1.41 (4.63)	6.38	1.61 (5.28)
100	1.61 (5.28)	6.38	1.82 (5.97)

Table J2
Barren Island Station 2 Extremal Wave Analysis Results

Return Period Years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.91 (2.99)	4.37	0.80 (2.62)
10	1.10 (3.61)	5.11	0.98 (3.22)
15	1.21 (3.97)	5.23	1.06 (3.48)
20	1.29 (4.23)	5.52	1.16 (3.81)
25	1.35 (4.43)	5.55	1.27 (4.17)
30	1.41 (4.63)	5.90	1.34 (4.40)
35	1.46 (4.79)	6.16	1.45 (4.76)
40	1.51 (4.95)	6.20	1.49 (4.89)
45	1.55 (5.09)	6.34	1.56 (5.12)
50	1.59 (5.22)	6.38	1.61 (5.28)
100	1.79 (5.87)	6.80	1.78 (5.84)

Table J3
Barren Island Station 3 Extremal Wave Analysis Results

Return Period Years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.84 (2.76)	4.47	0.65 (2.13)
10	1.02 (3.35)	4.97	0.99 (3.25)
15	1.14 (3.74)	5.26	1.10 (3.61)
20	1.22 (4.00)	5.55	1.20 (3.94)
25	1.29 (4.23)	5.88	1.33 (4.36)
30	1.36 (4.46)	5.97	1.40 (4.59)
35	1.41 (4.63)	6.10	1.44 (4.72)
40	1.45 (4.76)	6.15	1.46 (4.79)
45	1.49 (4.89)	6.39	1.51 (4.95)
50	1.52 (4.99)	6.42	1.54 (5.05)
100	1.73 (5.68)	6.97	1.74 (5.71)

Table J4
Barren Island Station 4 Extremal Wave Analysis Results

Return Period Years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.87 (2.85)	4.34	0.76 (2.49)
10	1.07 (3.51)	4.98	1.02 (3.35)
15	1.18 (3.87)	5.30	1.15 (3.77)
20	1.27 (4.17)	5.72	1.32 (4.33)
25	1.33 (4.36)	5.79	1.25 (4.10)
30	1.39 (4.56)	5.85	1.36 (4.46)
35	1.43 (4.69)	5.89	1.35 (4.43)
40	1.47 (4.82)	5.91	1.32 (4.33)
45	1.50 (4.92)	5.96	1.43 (4.69)
50	1.53 (5.02)	5.96	1.43 (4.69)
100	1.74 (5.71)	6.57	1.62 (5.31)

Table J5
Barren Island Station 5 Extremal Wave Analysis Results

Return Period Years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.83 (2.72)	4.59	0.54 (1.77)
10	0.99 (3.25)	5.10	0.95 (3.12)
15	1.08 (3.54)	5.42	1.15 (3.77)
20	1.15 (3.77)	5.76	1.34 (4.40)
25	1.20 (3.94)	5.86	1.33 (4.36)
30	1.25 (4.10)	5.91	1.35 (4.43)
35	1.30 (4.27)	6.09	1.37 (4.49)
40	1.35 (4.43)	6.30	1.45 (4.76)
45	1.38 (4.53)	6.42	1.32 (4.33)
50	1.41 (4.63)	6.53	1.36 (4.46)
100	1.61 (5.28)	7.05	1.60 (5.25)

Table J6
Barren Island Station 6 Extremal Wave Analysis Results

Return Period Years	Significant Wave Height Hs, m (ft)	Peak Wave Period Tp, sec	Water Level MLLW, m (ft)
5	0.90 (2.95)	4.48	0.30 (0.98)
10	1.02 (3.35)	5.25	0.78 (2.56)
15	1.08 (3.54)	5.49	1.04 (3.41)
20	1.13 (3.71)	5.53	1.08 (3.54)
25	1.17 (3.84)	5.77	1.16 (3.81)
30	1.20 (3.94)	5.90	1.17 (3.84)
35	1.22 (4.00)	6.42	1.45 (4.76)
40	1.25 (4.10)	6.53	1.47 (4.82)
45	1.26 (4.13)	6.53	1.47 (4.82)
50	1.28 (4.20)	6.53	1.46 (4.79)
100	1.44 (4.72)	7.26	1.80 (5.91)

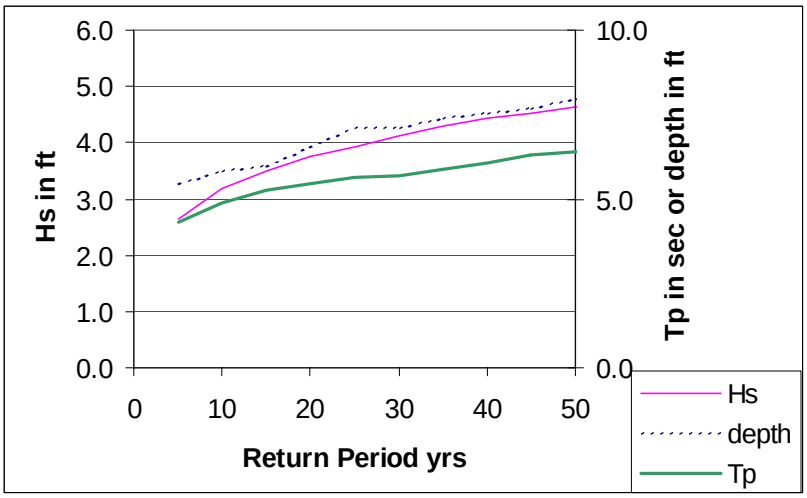

Figure J1. Barren Island Station 1 significant wave height, peak period, and depth (mllw) plotted as a function of return period

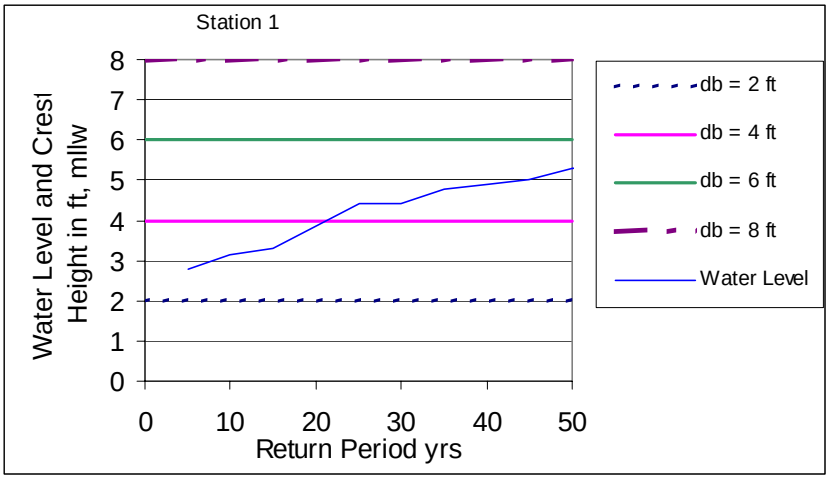

Figure J2. Barren Island Station 1 water level and crest height as a function of return period

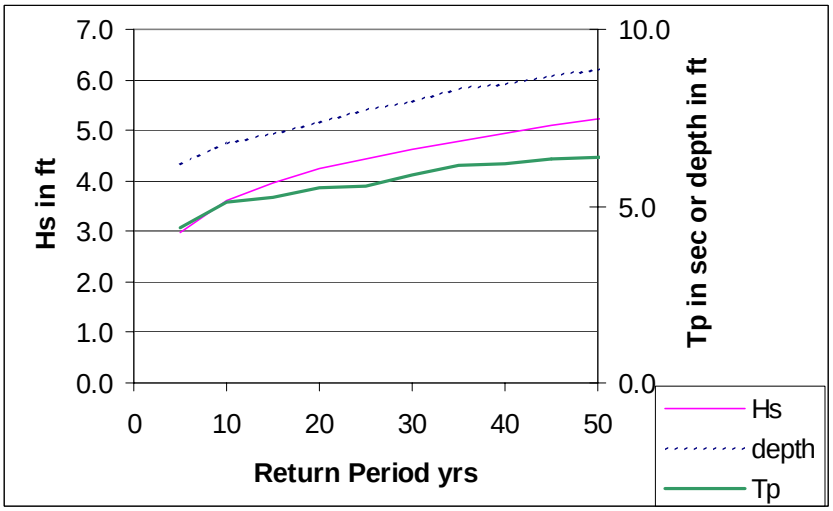

Figure J3. Barren Island Station 2 significant wave height, peak period, and depth (mllw) plotted as a function of return period

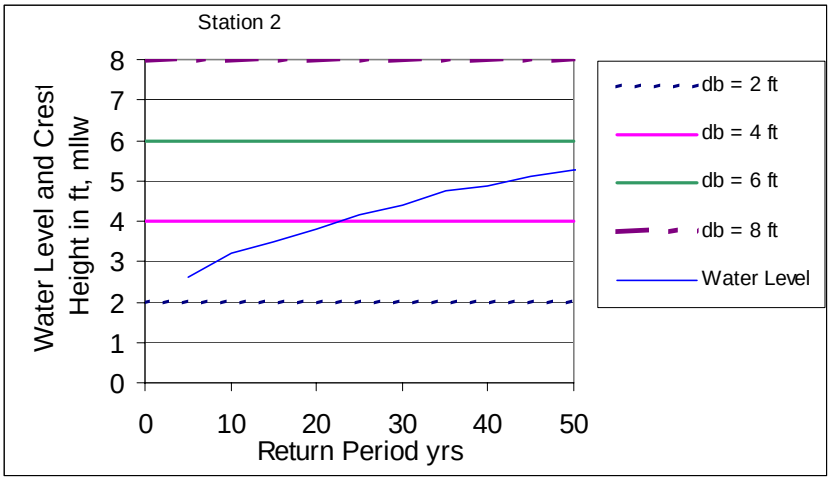

Figure J4. Barren Island Station 2 water level and crest height as a function of return period

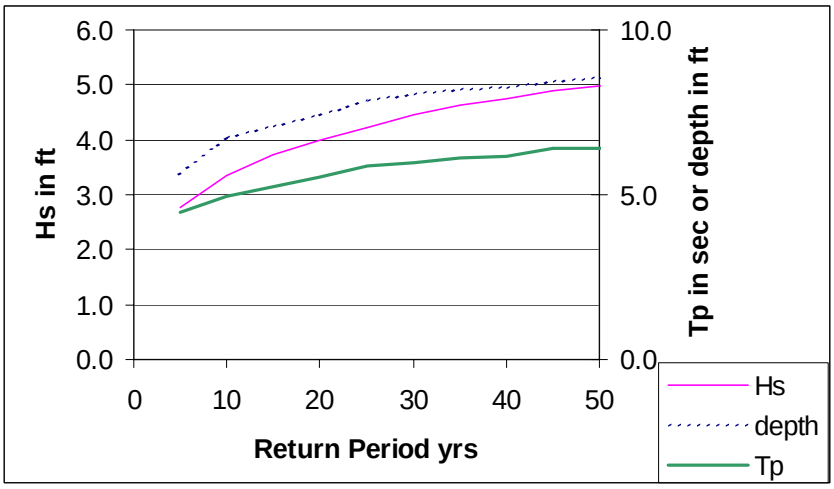

Figure J5. Barren Island Station 3 significant wave height, peak period, and depth (mllw) plotted as a function of return period

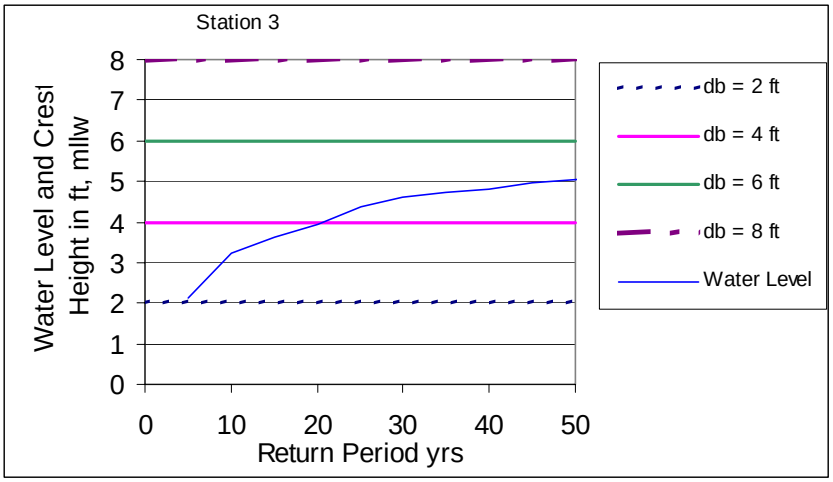

Figure J6. Barren Island Station 3 water level and crest height as a function of return period

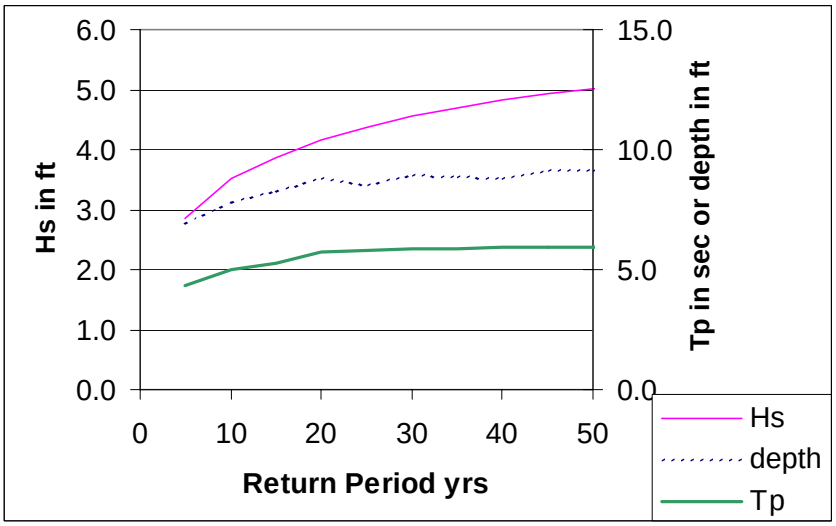

Figure J7. Barren Island Station 4 significant wave height, peak period, and depth (mllw) plotted as a function of return period

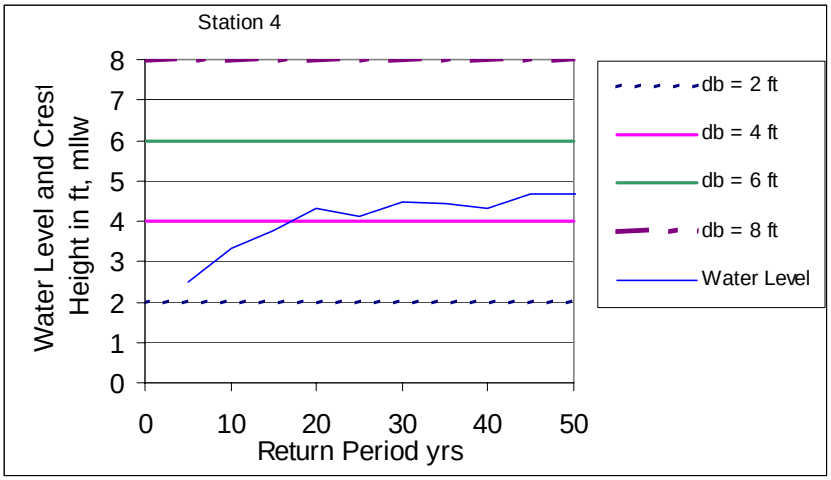

Figure J8. Barren Island Station 4 water level and crest height as a function of return period

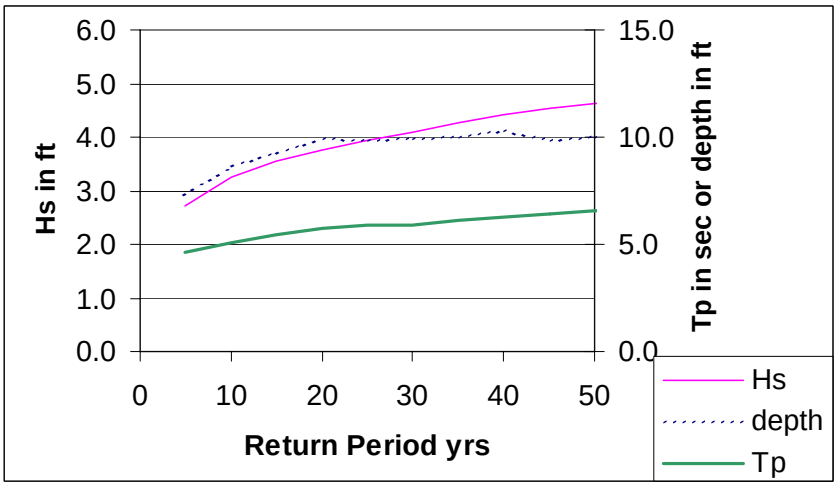

Figure J9. Barren Island Station 5 significant wave height, peak period, and depth (mllw) plotted as a function of return period

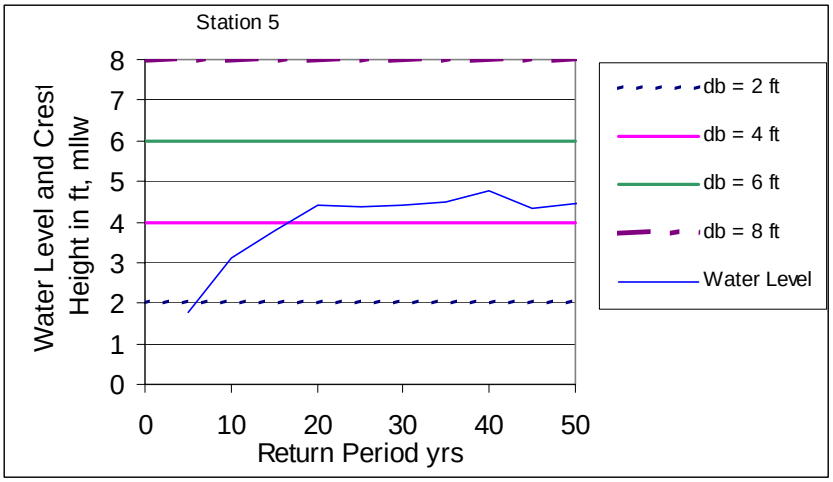

Figure J10. Barren Island Station 5 water level and crest height as a function of return period

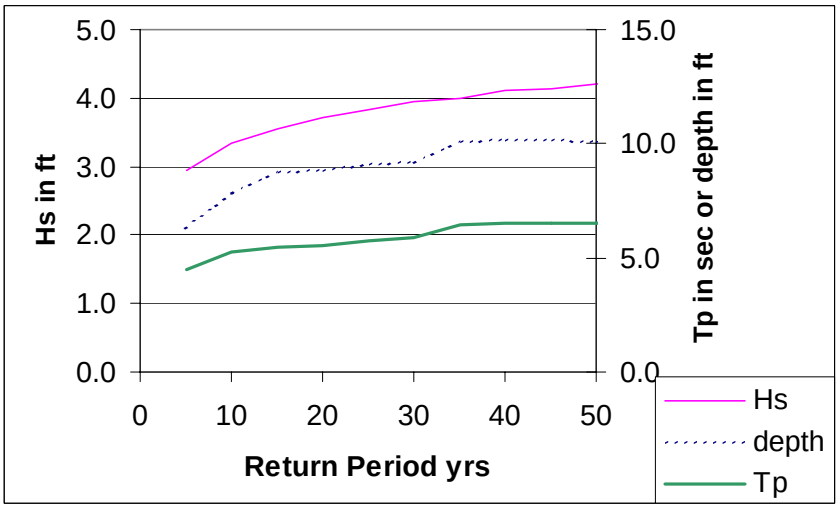

Figure J11. Barren Island Station 6 significant wave height, peak period, and depth (mllw) plotted as a function of return period

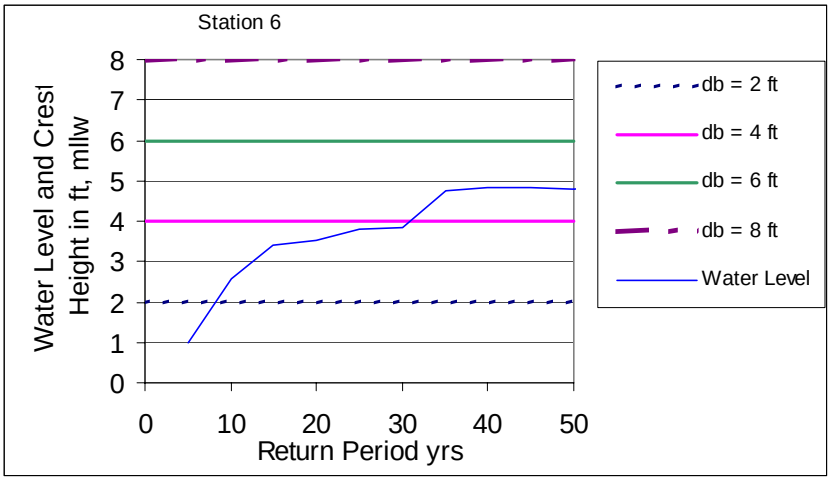

Figure J12. Barren Island Station 6 water level and crest height as a function of return period

Table J7
Extreme Water Levels for Historical Extra-Tropical Storms from Barren Island Water Level Analysis Station 2 (Figure 17)

Return Period in yrs	Water Level Relative to mllw in meters (ft)
2	0.52 (1.69)
5	0.68 (2.23)
10	0.79 (2.58)
25	0.92 (3.03)
50	1.02 (3.36)
100	1.12 (3.69)

Table J8
Extreme Water Levels for Historical Hurricanes from Barren Island Water Level Analysis Station 2 (Figure 17)

Return Period in yrs	Water Level Relative to mllw in meters (ft)
2	0.24 (0.78)
5	0.61 (1.99)
10	0.85 (2.79)
25	1.16 (3.80)
50	1.39 (4.55)
100	1.62 (5.30)

Appendix K: Armor Weight and Transmitted Hs as a Function of Return Period for Barren Island

Table K1
Armor Weight as a Function of Return Period for Station 1 Crest Height of 2 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.66	4.66	0.0	180	18
10	2.79	4.66	0.0	222	22
15	2.79	4.66	0.0	233	23
20	2.79	4.66	0.0	239	24
25	2.79	4.66	0.0	245	25
30	2.79	4.66	0.0	246	25
35	2.79	4.66	0.0	252	25
40	2.79	4.66	0.0	257	26
45	2.79	4.66	0.0	263	26
50	2.79	4.66	0.0	265	27
100	2.79	4.66	0.0	265	27

Table K2
Armor Weight as a Function of Return Period for Station 1 Crest Height of 4 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.66	5.45	1.2	270	27
10	3.18	5.81	0.9	393	39
15	3.51	5.97	0.7	498	50
20	3.74	6.53	0.1	540	54
25	3.94	6.66	0.0	613	61
30	3.99	6.66	0.0	638	64
35	3.99	6.66	0.0	653	65
40	3.99	6.66	0.0	666	67
45	3.99	6.66	0.0	682	68
50	3.99	6.66	0.0	688	69
100	3.99	6.66	0.0	688	69

Table K3
Armor Weight as a Function of Return Period for Station 1 Crest Height of 6 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.66	5.45	3.2	363	36
10	3.18	5.81	2.9	626	63
15	3.51	5.97	2.7	794	79
20	3.74	6.53	2.1	817	82
25	3.94	7.09	1.6	838	84
30	4.13	7.09	1.6	939	94
35	4.30	7.41	1.2	991	99
40	4.43	7.55	1.1	1058	106
45	4.53	7.68	1.0	1114	111
50	4.63	7.94	0.7	1142	114
100	5.18	8.63	0.0	1380	138

Table K4
Armor Weight as a Function of Return Period for Station 1 Crest Height of 8 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.66	5.45	5.2	363	36
10	3.18	5.81	4.9	626	63
15	3.51	5.97	4.7	841	84
20	3.74	6.53	4.1	1028	103
25	3.94	7.09	3.6	1215	122
30	4.13	7.09	3.6	1375	138
35	4.30	7.41	3.2	1448	145
40	4.43	7.55	3.1	1513	151
45	4.53	7.68	3.0	1560	156
50	4.63	7.94	2.7	1578	158
100	5.18	8.63	2.0	1846	185

Table K5
Armor Weight as a Function of Return Period for Station 2 Crest Height of 2 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.99	5.58	0.0	252	25
10	3.35	5.58	0.0	370	37
15	3.35	5.58	0.0	376	38
20	3.35	5.58	0.0	389	39
25	3.35	5.58	0.0	391	39
30	3.35	5.58	0.0	407	41
35	3.35	5.58	0.0	418	42
40	3.35	5.58	0.0	420	42
45	3.35	5.58	0.0	427	43
50	3.35	5.58	0.0	428	43
100	3.35	5.58	0.0	447	45

Table K6
Armor Weight as a Function of Return Period for Station 2 Crest Height of 4 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.99	6.20	1.4	381	38
10	3.61	6.79	0.8	550	55
15	3.97	7.05	0.5	667	67
20	4.23	7.38	0.2	762	76
25	4.43	7.58	0.0	831	83
30	4.55	7.58	0.0	922	92
35	4.55	7.58	0.0	949	95
40	4.55	7.58	0.0	953	95
45	4.55	7.58	0.0	967	97
50	4.55	7.58	0.0	971	97
100	4.55	7.58	0.0	1013	101

Table K7
Armor Weight as a Function of Return Period for Station 2 Crest Height of 6 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.99	6.20	3.4	501	50
10	3.61	6.79	2.8	888	89
15	3.97	7.05	2.5	1028	103
20	4.23	7.38	2.2	1121	112
25	4.43	7.74	1.8	1169	117
30	4.63	7.97	1.6	1273	127
35	4.79	8.33	1.2	1336	134
40	4.95	8.46	1.1	1426	143
45	5.09	8.69	0.9	1491	149
50	5.22	8.86	0.7	1559	156
100	5.65	9.42	0.2	1846	185

Table K8
Armor Weight as a Function of Return Period for Station 2 Crest Height of 8 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.99	6.20	5.4	501	50
10	3.61	6.79	4.8	907	91
15	3.97	7.05	4.5	1174	117
20	4.23	7.38	4.2	1438	144
25	4.43	7.74	3.8	1630	163
30	4.63	7.97	3.6	1847	185
35	4.79	8.33	3.2	1877	188
40	4.95	8.46	3.1	1981	198
45	5.09	8.69	2.9	2037	204
50	5.22	8.86	2.7	2111	211
100	5.65	9.42	2.2	2391	239

Table K9
Armor Weight as a Function of Return Period for Station 3 Crest Height of 2 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.76	5.48	0.0	209	21
10	3.29	5.48	0.0	346	35
15	3.29	5.48	0.0	360	36
20	3.29	5.48	0.0	373	37
25	3.29	5.48	0.0	387	39
30	3.29	5.48	0.0	391	39
35	3.29	5.48	0.0	396	40
40	3.29	5.48	0.0	399	40
45	3.29	5.48	0.0	409	41
50	3.29	5.48	0.0	410	41
100	3.29	5.48	0.0	433	43

Table K10
Armor Weight as a Function of Return Period for Station 3 Crest Height of 4 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.76	5.61	1.9	368	37
10	3.35	6.73	0.8	449	45
15	3.74	7.09	0.4	565	57
20	4.00	7.41	0.1	653	65
25	4.23	7.48	0.0	770	77
30	4.46	7.48	0.0	885	89
35	4.49	7.48	0.0	910	91
40	4.49	7.48	0.0	915	92
45	4.49	7.48	0.0	939	94
50	4.49	7.48	0.0	942	94
100	4.49	7.48	0.0	994	99

Table K11
Armor Weight as a Function of Return Period for Station 3 Crest Height of 6 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.76	5.61	3.9	411	41
10	3.35	6.73	2.8	738	74
15	3.74	7.09	2.4	878	88
20	4.00	7.41	2.1	966	97
25	4.23	7.84	1.6	1039	104
30	4.46	8.07	1.4	1140	114
35	4.63	8.20	1.3	1228	123
40	4.76	8.27	1.2	1305	131
45	4.89	8.43	1.0	1388	139
50	4.99	8.53	0.9	1441	144
100	5.51	9.19	0.3	1785	179

Table K12
Armor Weight as a Function of Return Period for Station 3 Crest Height of 8 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.76	5.61	5.9	411	41
10	3.35	6.73	4.8	738	74
15	3.74	7.09	4.4	1019	102
20	4.00	7.41	4.1	1260	126
25	4.23	7.84	3.6	1521	152
30	4.46	8.07	3.4	1651	165
35	4.63	8.20	3.3	1745	175
40	4.76	8.27	3.2	1835	184
45	4.89	8.43	3.0	1909	191
50	4.99	8.53	2.9	1969	197
100	5.51	9.19	2.3	2311	231

Table K13
Armor Weight as a Function of Return Period for Station 4 Crest Height of 2 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.85	6.46	0.0	231	23
10	3.51	6.46	0.0	422	42
15	3.87	6.46	0.0	560	56
20	3.88	6.46	0.0	591	59
25	3.88	6.46	0.0	596	60
30	3.88	6.46	0.0	600	60
35	3.88	6.46	0.0	602	60
40	3.88	6.46	0.0	604	60
45	3.88	6.46	0.0	607	61
50	3.88	6.46	0.0	607	61
100	3.88	6.46	0.0	647	65

Table K14
Armor Weight as a Function of Return Period for Station 4 Crest Height of 4 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.85	6.96	1.5	366	37
10	3.51	7.81	0.7	507	51
15	3.87	8.23	0.2	615	62
20	4.17	8.46	0.0	748	75
25	4.36	8.46	0.0	844	84
30	4.56	8.46	0.0	946	95
35	4.69	8.46	0.0	1019	102
40	4.82	8.46	0.0	1093	109
45	4.92	8.46	0.0	1155	116
50	5.02	8.46	0.0	1213	121
100	5.08	8.46	0.0	1330	133

Table K15
Armor Weight as a Function of Return Period for Station 4 Crest Height of 6 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.85	6.96	3.5	456	46
10	3.51	7.81	2.7	833	83
15	3.87	8.23	2.2	940	94
20	4.17	8.79	1.7	1023	102
25	4.36	8.56	1.9	1185	118
30	4.56	8.92	1.5	1243	124
35	4.69	8.89	1.6	1337	134
40	4.82	8.79	1.7	1448	145
45	4.92	9.15	1.3	1446	145
50	5.02	9.15	1.3	1514	151
100	5.71	9.78	0.7	2002	200

Table K16
Armor Weight as a Function of Return Period for Station 4 Crest Height of 8 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.85	6.96	5.5	456	46
10	3.51	7.81	4.7	856	86
15	3.87	8.23	4.2	1150	115
20	4.17	8.79	3.7	1472	147
25	4.36	8.56	3.9	1652	165
30	4.56	8.92	3.5	1812	181
35	4.69	8.89	3.6	1934	193
40	4.82	8.79	3.7	2084	208
45	4.92	9.15	3.3	2049	205
50	5.02	9.15	3.3	2138	214
100	5.71	9.78	2.7	2646	265

Table K17
Armor Weight as a Function of Return Period for Station 5 Crest Height of 2 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.72	7.28	0.2	234	23
10	3.25	7.51	0.0	367	37
15	3.54	7.51	0.0	473	47
20	3.77	7.51	0.0	575	58
25	3.94	7.51	0.0	645	65
30	4.10	7.51	0.0	717	72
35	4.27	7.51	0.0	805	81
40	4.43	7.51	0.0	902	90
45	4.51	7.51	0.0	953	95
50	4.51	7.51	0.0	964	96
100	4.51	7.51	0.0	1014	101

Table K18
Armor Weight as a Function of Return Period for Station 5 Crest Height of 4 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.72	7.28	2.2	428	43
10	3.25	8.63	0.9	462	46
15	3.54	9.28	0.2	519	52
20	3.77	9.51	0.0	607	61
25	3.94	9.51	0.0	681	68
30	4.10	9.51	0.0	756	76
35	4.27	9.51	0.0	850	85
40	4.43	9.51	0.0	954	95
45	4.53	9.51	0.0	1019	102
50	4.63	9.51	0.0	1087	109
100	5.28	9.51	0.0	1578	158

Table K19
Armor Weight as a Function of Return Period for Station 5 Crest Height of 6 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.72	7.28	4.2	429	43
10	3.25	8.63	2.9	737	74
15	3.54	9.28	2.2	800	80
20	3.77	9.91	1.6	832	83
25	3.94	9.88	1.6	927	93
30	4.10	9.94	1.6	1009	101
35	4.27	10.01	1.5	1107	111
40	4.43	10.27	1.2	1182	118
45	4.53	9.84	1.7	1331	133
50	4.63	9.97	1.5	1384	148
100	5.28	10.76	0.8	1789	179

Table K20
Armor Weight as a Function of Return Period for Station 5 Crest Height of 8 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.72	7.28	6.2	429	43
10	3.25	8.63	4.9	737	74
15	3.54	9.28	4.2	968	97
20	3.77	9.91	3.6	1196	120
25	3.94	9.88	3.6	1341	134
30	4.10	9.94	3.6	1491	149
35	4.27	10.01	3.5	1609	161
40	4.43	10.27	3.2	1670	167
45	4.53	9.84	3.7	1876	188
50	4.63	9.97	3.5	1925	193
100	5.28	10.76	2.8	2345	235

Table K21
Armor Weight as a Function of Return Period for Station 6 Crest Height of 2 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.95	6.30	1.0	338	34
10	3.35	7.31	0.0	400	40
15	3.54	7.31	0.0	475	48
20	3.71	7.31	0.0	533	53
25	3.84	7.31	0.0	597	60
30	3.94	7.31	0.0	644	64
35	4.00	7.31	0.0	711	71
40	4.10	7.31	0.0	762	76
45	4.13	7.31	0.0	777	78
50	4.20	7.31	0.0	807	81
100	4.39	7.31	0.0	963	96

Table K22
Armor Weight as a Function of Return Period for Station 6 Crest Height of 4 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.95	6.30	3.0	498	50
10	3.35	7.87	1.4	561	56
15	3.54	8.73	0.6	556	56
20	3.71	8.86	0.5	607	61
25	3.84	9.12	0.2	650	65
30	3.94	9.15	0.2	698	70
35	4.00	9.31	0.0	755	76
40	4.10	9.31	0.0	811	81
45	4.13	9.31	0.0	826	83
50	4.20	9.31	0.0	858	86
100	4.72	9.31	0.0	1226	123

Table K23
Armor Weight as a Function of Return Period for Station 6 Crest Height of 6 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.95	6.30	5.0	498	50
10	3.35	7.87	3.4	795	80
15	3.54	8.73	2.6	862	86
20	3.71	8.86	2.5	924	92
25	3.84	9.12	2.2	958	96
30	3.94	9.15	2.2	1013	101
35	4.00	10.07	1.2	944	94
40	4.10	10.14	1.2	997	100
45	4.13	10.14	1.2	1016	102
50	4.20	10.10	1.2	1058	106
100	4.72	11.22	0.1	1303	130

Table K24
Armor Weight as a Function of Return Period for Station 6 Crest Height of 8 ft at Barren Island

Return Period years	Significant Wave Height Hs, ft	Water Depth, h, ft	Freeboard, Rc, ft	Armor Stone Weight, lb	Underlayer Stone Weight, lb
5	2.95	6.30	7.0	498	50
10	3.35	7.87	5.4	795	80
15	3.54	8.73	4.6	965	97
20	3.71	8.86	4.5	1085	109
25	3.84	9.12	4.2	1226	123
30	3.94	9.15	4.2	1326	133
35	4.00	10.07	3.2	1351	135
40	4.10	10.14	3.2	1410	141
45	4.13	10.14	3.2	1433	143
50	4.20	10.10	3.2	1489	149
100	4.72	11.22	2.1	1707	171

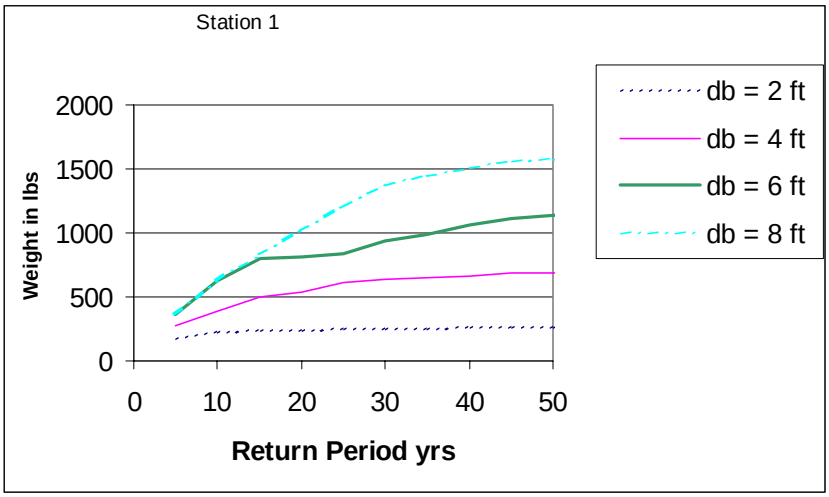

Figure K1. Barren Island Station 1 stable armor weight for various crest heights as a function of return period

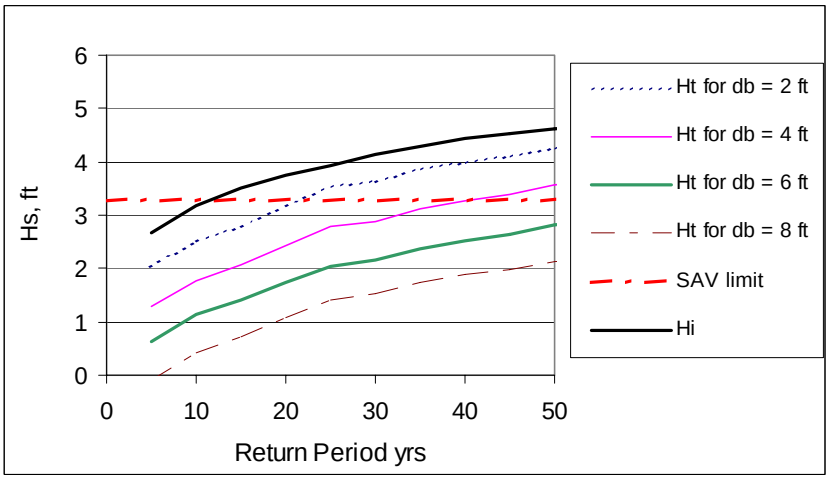

Figure K2. Barren Island Station 1 incident and transmitted significant wave height for various crest heights as a function of return period. A rough estimate of the limiting wave height for submerged aquatic vegetation is also shown.

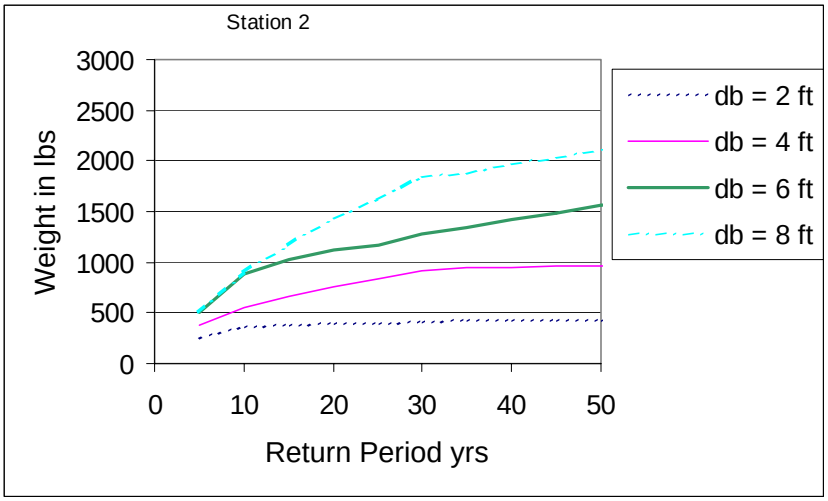

Figure K3. Barren Island Station 2 stable armor weight for various crest heights as a function of return period

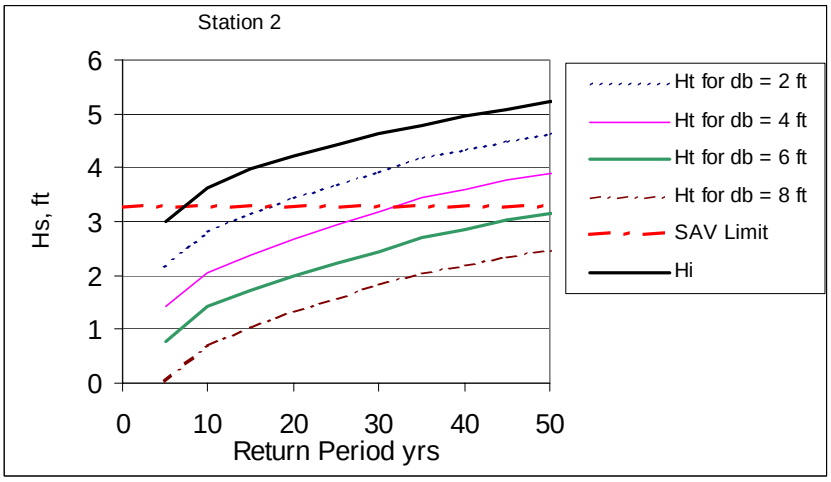

Figure K4. Barren Island Station 2 incident and transmitted significant wave height for various crest heights as a function of return period. A rough estimate of the limiting wave height for submerged aquatic vegetation is also shown.

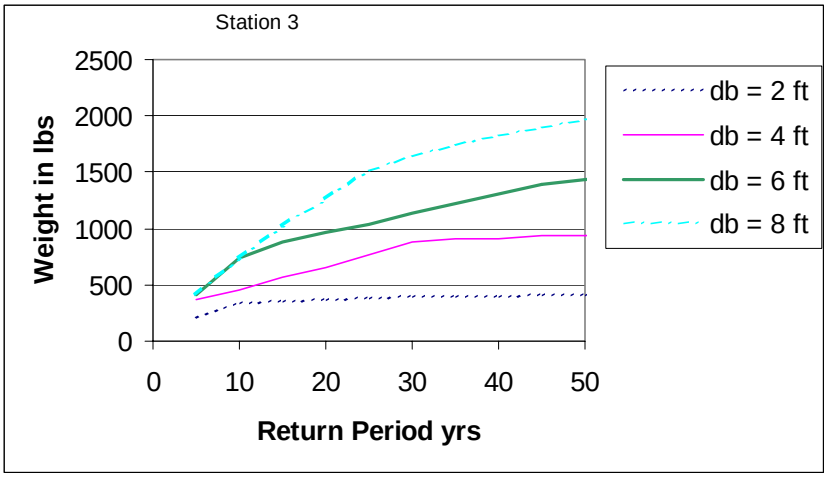

Figure K5. Barren Island Station 3 stable armor weight for various crest heights as a function of return period

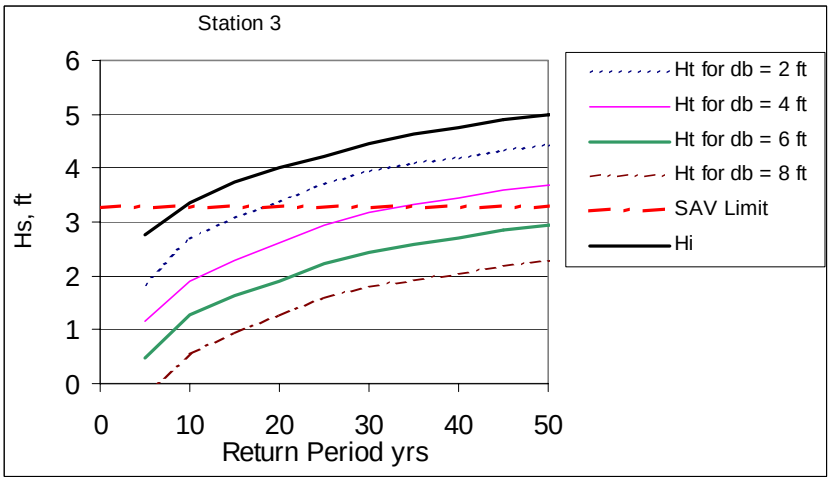

Figure K6. Barren Island Station 3 incident and transmitted significant wave height for various crest heights as a function of return period. A rough estimate of the limiting wave height for submerged aquatic vegetation is also shown.

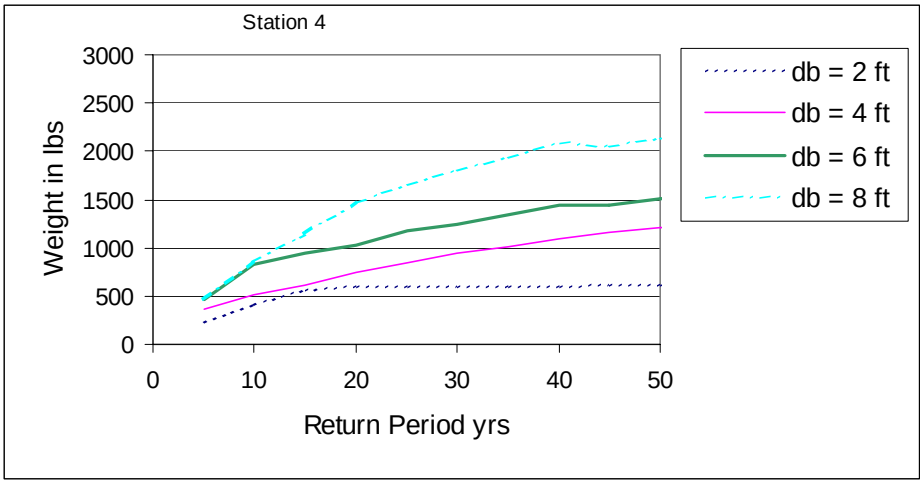

Figure K7. Barren Island Station 4 stable armor weight for various crest heights as a function of return period

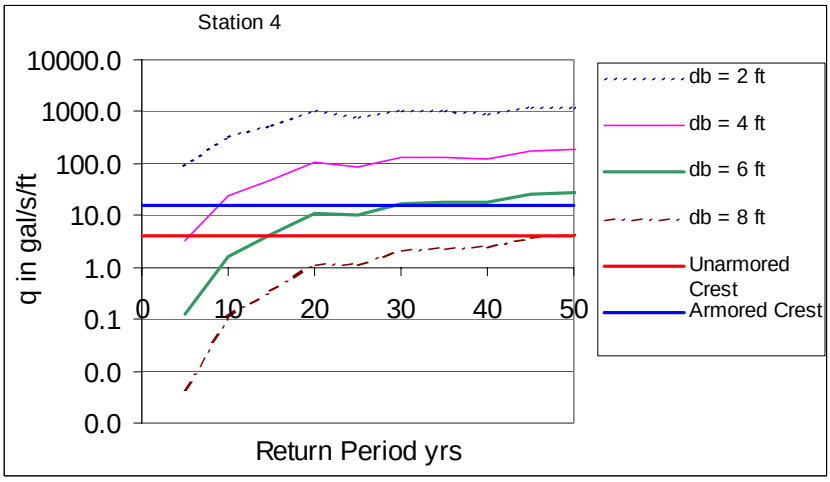

Figure K8. Barren Island Station 4 wave transmission for various crest heights as a function of return period. A rough estimate of the limiting wave height for submerged aquatic vegetation is also shown.

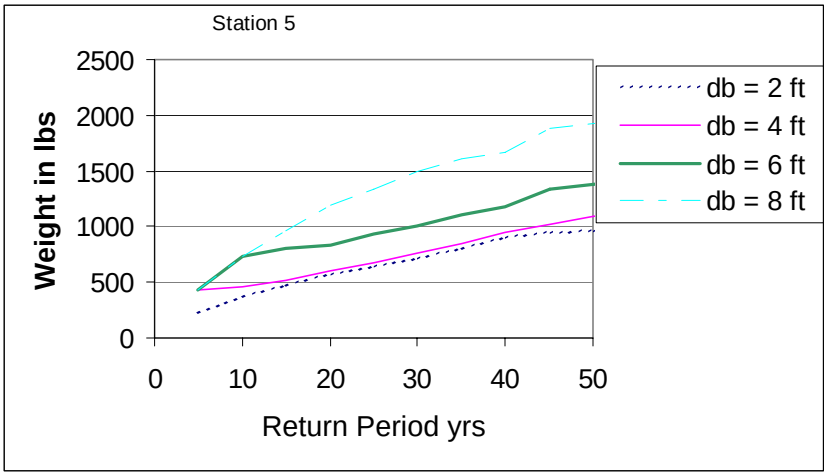

Figure K9. Barren Island Station 5 stable armor weight for various crest heights as a function of return period

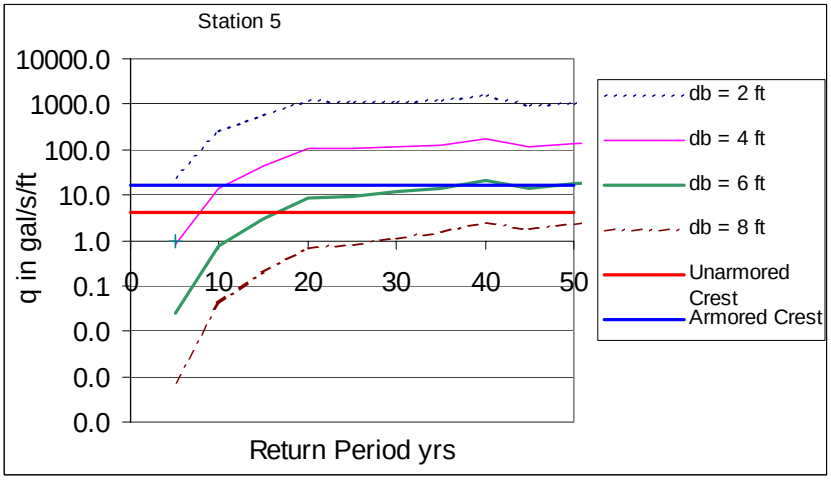

Figure K10. Barren Island Station 5 wave transmission for various crest heights as a function of return period. A rough estimate of the limiting wave height for submerged aquatic vegetation is also shown.

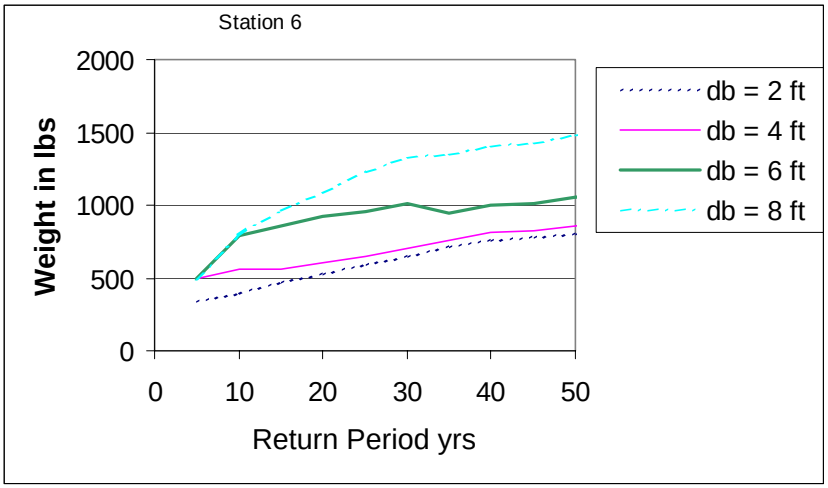

Figure K11. Barren Island Station 6 stable armor weight for various crest heights as a function of return period

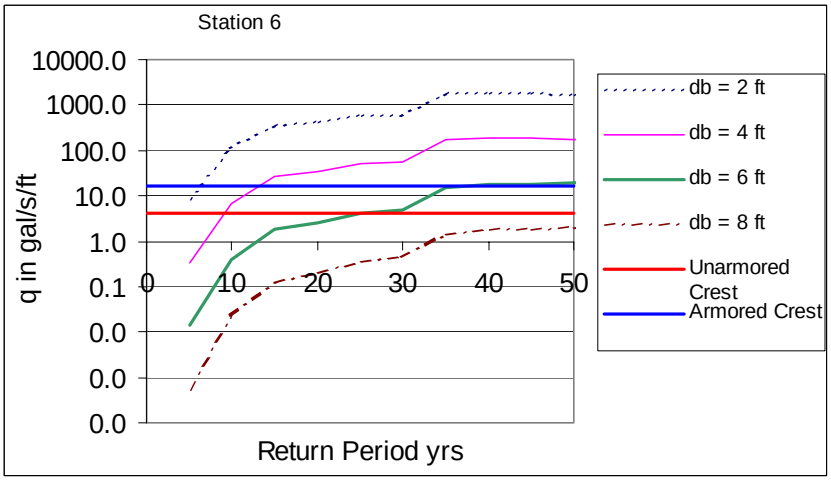

Figure K12. Barren Island Station 6 wave transmission for various crest heights as a function of return period. A rough estimate of the limiting wave height for submerged aquatic vegetation is also shown.

ATTACHMENT J

TIDE GAUGING RESULTS FOR JAMES ISLAND

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Tide Gauging Results
James Island, Chesapeake Bay, Maryland

Offshore & Coastal Technologies, Incorporated

February 14, 2005

Field Deployment

Two tide gauges were deployed in the James Island region of the Chesapeake Bay, Maryland, during December 2004 to early February 2005. The gauges were subsurface absolute pressure-based, temperature-corrected devices with internal batteries and memory. They were secured to the seafloor using ground anchors to measure water level time histories. Although the scope of work for the project only required one gauge, two were deployed for redundancy and to maximize the likelihood of gauge recovery.

The gauges were mounted horizontally to a steel angle that was welded to a 2-cm diameter steel screw anchor which vertically penetrated the seafloor 1.3 meters. After the mounts were secured to the seafloor, the gauges were approximately 6 inches above the seafloor at locations that were about 15 meters from the beach in a water depth of about 1.5m MLLW. The locations of the gauges were selected based on a visual inspection of the island to determine a location where the island and surrounding shoreline is relatively stable, not overwashed, and not susceptible to scour by waves and/or ice. Both gauges were, in fact, recovered with complete data sets.

The locations were:

Gauge 1385: 38 degrees 31.166 minutes N, 76 degrees 20.076 minutes W
Gauge 1386: 38 degrees 31.137 minutes N, 76 degrees 20.095 minutes W

The time histories of pressure were collected at a sample interval of 180 seconds from December 18, 2004, to February 9, 2005. Upon both deployment and retrieval, the locations of the gauges were verified with differential GPS, and the elevations of the pressure ports and actual water levels were surveyed relative to monument James4 (Geometrics, 2004). James4 is located on the south end of the northern James Island. Characteristics of James4 are reported by Geometrics (2004) as follows:

Latitude	38 deg 31 min 06.24759 sec N
Longitude	76 deg 20 min 07.20581 sec W
Elevation	0.51m (NAVD88)
Elevation accuracy	0.0171m

Analysis

The gauges were deployed for a total of 40 days. Sometime during the deployment, the mount for gauge 1386 was hit by an object that caused damage to the mount and a change in elevation of the gauge by 2.5 cm. For this reason, the data set from the other gauge,

gauge 1385, was selected for analysis. The time history from the gauge was reviewed to determine a 29-day time period when storm effects were minimized. The period from December 24, 2004 to January 22, 2005 was selected. Because the Chesapeake Bay is very responsive to storms and fronts, especially those with a strong northerly or southerly components that blow water out of or into the bay, it is difficult to find a period dominated entirely by astronomical tide. The selected time period included two minor weather events, but was preceded and followed by more major events that fortuitously were outside of the selected lunar cycle.

The time history was analyzed to identify the twice-daily high and low tides, which then provided the tidal datums relative to the mean tide level. Based upon the direct field verification of the sensor reading of the water level above the pressure port upon deployment and again upon retrieval, the time history was related to NAVD88.

Results

The following table provides the tidal datums relative to NAVD88. The table also presents an extrapolation to the latest 19-year epoch based on an identical analysis of the same lunar cycle versus the long term statistics from the Baltimore NOS gauge:

Table 1. Tidal datums* based on 29-day time history and extended to a 19-year epoch (m)

	Ref MTL (29-day)	Ref NAVD88 (29-day)	Ref NAVD88 (19-yr est**)
MHHW (m)	0.253	0.268	0.269
MHW (m)	0.192	0.207	0.202
MTL (m)	0.000	0.014	-0.001
MLW (m)	-0.197	-0.183	-0.194
MLLW (m)	-0.259	-0.245	-0.244

*estimated uncertainty is the sum of 0.002m (measurements)+0.0171 (Geometrics) = 0.0173m
** based on Baltimore

Based on the finding that MLLW is 0.244m below NAVD88, and using the elevations for monuments as reported by Geometrics (2004), the MLLW elevations* of the three existing control stations are as follows:

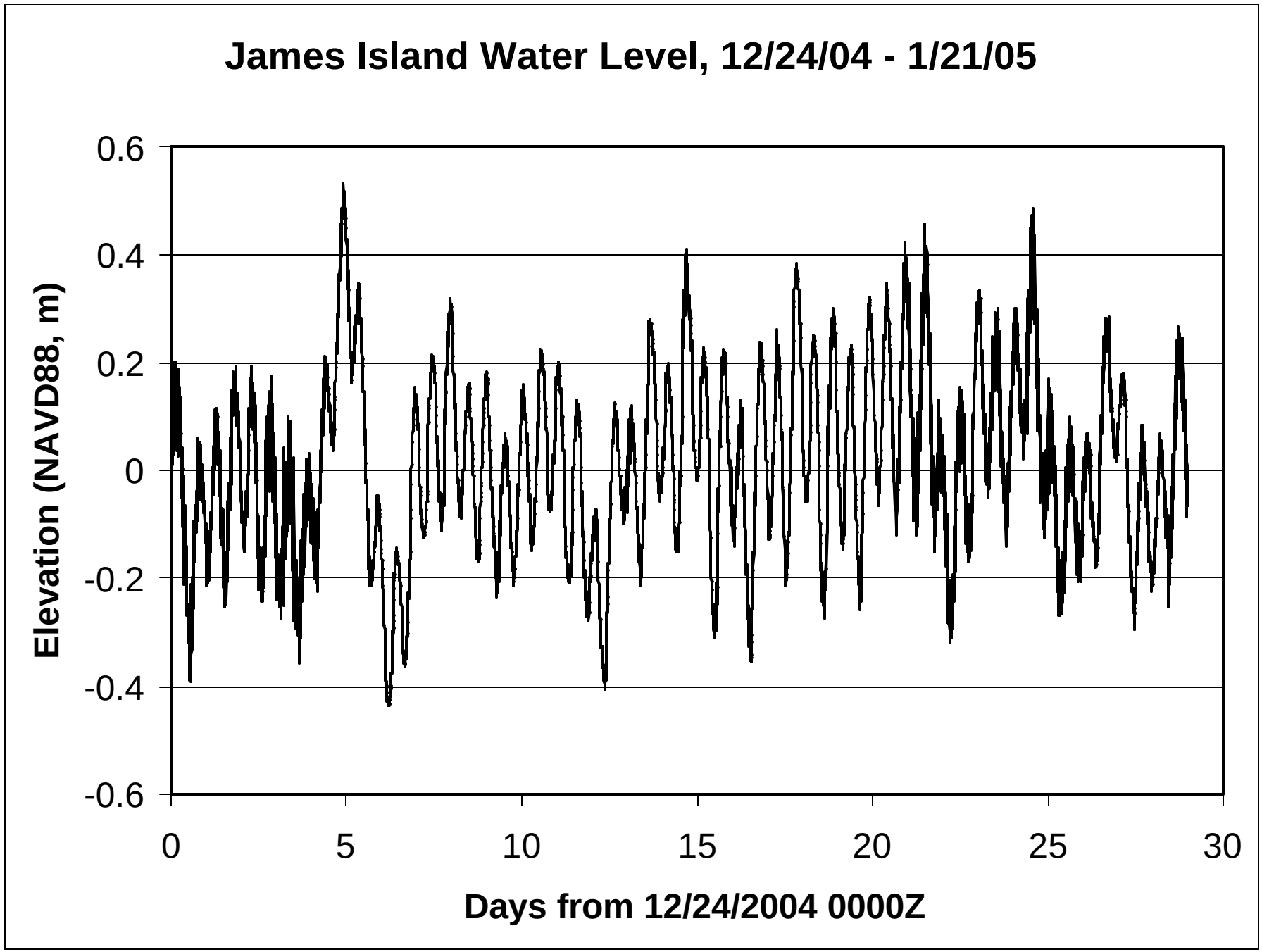
James1 0.74m NAVD88 + 0.244 = 0.98m MLLW [3.22ft MLLW]
James3 1.03m NAVD88 + 0.244 = 1.27m MLLW [4.17ft MLLW]
James4 0.51m NAVD88 + 0.244 = 0.75m MLLW [2.46ft MLLW]

*estimated uncertainty in James4 is the sum of 0.002m (measurements)+0.0171 (Geometrics) ~ 0.02m. For James1 and James3, additional uncertainty due to Geometrics inaccuracies would need to be applied.

The location of tide gauge 1385 in Maryland State Plane Coordinates (m, NAD83) was:

N 94873.1m E 458026.8

Appendix A: Gauge Time History Plot


James Island Water Level, 12/24/04 - 1/21/05
Elevation (NAVD88, m)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
5
10
15
20
25
30
Days from 12/24/2004 0000Z

Appendix B. Photographs

Figure 1. Location of Gauge 1385

Figure 2. View of location of Gauge 1385 from James4. Gauge 1385 was located adjacent to the peninula on the east side of the island beyond the tree stump in the water. Gauge 1386 was located near the tree stump in the water.

Figure 3. Deployment of Gauge 1386.

ATTACHMENT K

TIDAL BENCHMARK INFORMATION FOR BARREN ISLAND

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Station ID: **8571579** **PUBLICATION DATE:** **01/27/2005**
Name: **BARREN ISLAND, CHESAPEAKE BAY MARYLAND**
NOAA Chart: **12261** **Latitude:** **38° 20.5' N**
USGS Quad: **BARREN ISLAND** **Longitude:** **76° 15.9' W**

To reach the tidal bench marks on Barren Island (which is approximately 35 km (22 mi) SW of Cambridge and about a 10-minute boat ride from the fishing creek at a small boat dock at Tyler Cove) from the boat dock near Honga, go WSW by boat following a narrow channel until the bay waters are entered. Continue westerly until the last bouy light, then make a wide turn south (sunken obstructions near Barren Island) for approximately 1.3 km (0.8 mi) passing the NW corner of the island. Continue 0.3 km (0.2 mi) south along the west side of the island, then turn east and proceed with caution to the island.

T I D A L B E N C H M A R K S

PRIMARY BENCH MARK STAMPING: **1579 B 2001**
DESIGNATION: 857 1579 B TIDAL

MONUMENTATION: Flange-encased Rod VM#: 16625
AGENCY: National Ocean Service (NOS) PID#: AJ8224
SETTING CLASSIFICATION: Stainless steel rod in sleeve

The primary bench mark is a flange encased rod located on Barren Island north along the beach on the west side of the island, 0.08 km (0.05 mi) east of bench mark 1579 C 2001, 13.56 m (44.5 ft) east of the center of a Y junction, 3.26 m (10.7 ft) NE of the centerline of a truck trail, and 0.9 m (2.9 ft) WSW of a fiberglass carsonite witness post. The datum point is set 1 cm (0.03 ft) above ground, being the top of a stainless steel rod driven 53.6 M (176 ft) to refusal, in a sleeve extending to a depth of 1.2 m (3.9 ft), and encased in a 5-inch logo cap. Note: The sleeve depth does not meet the specifications for a Class A mark.

Station ID: 8571579 **PUBLICATION DATE:** 01/27/2005
Name: BARREN ISLAND, CHESAPEAKE BAY MARYLAND
NOAA Chart: 12261 **Latitude:** 38° 20.5' N
USGS Quad: BARREN ISLAND **Longitude:** 76° 15.9' W

T I D A L B E N C H M A R K S

BENCH MARK STAMPING: **1579 A 2001**
DESIGNATION: 857 1579 A TIDAL

MONUMENTATION: Flange-encased Rod VM#: 16624
AGENCY: National Ocean Service (NOS) PID#: AJ8223
SETTING CLASSIFICATION: Stainless steel rod in sleeve

The bench mark is a flange encased rod located on the NW corner of Barren Island where the east-west wooden sea wall turns SE, 0.2 km (0.1 mi) NW of bench mark 1579 B 2001, 0.2 km (0.1 mi) westerly of bench mark 33B1 1, 29.57 m (97 ft) SW where the joint for the east-west and SE sea walls meet, 17.07 m (56.0 ft) south of the north edge of Barren Island which edge is south of a wooden sea wall, 3.05 m (10.0 ft) south of the centerline inside curve in a truck trail (abandoned runway), and 0.76 m (2.5 ft) north of a carsonite witness post. The datum point is set 7 cm (0.2 ft) above ground, being the top of a stainless steel rod driven 30.5 m (100.1 ft) to refusal, in a sleeve extending to a depth of 1.2 m (3.9 ft), and encased in a 5-inch logo cap. Note: The sleeve depth does not meet the specifications for a Class A mark.

BENCH MARK STAMPING: **1579 C 2001**
DESIGNATION: 857 1579 C TIDAL

MONUMENTATION: Flange-encased Rod VM#: 16626
AGENCY: National Ocean Service (NOS) PID#: AJ8225
SETTING CLASSIFICATION: Stainless steel rod in sleeve

The bench mark is a flange encased rod located on Barren Island north along the beach on the west side of the island, 0.13 km (0.08 mi) west of bench mark 1579 B 2001, 0.08 km (0.05 mi) easterly of bench mark 33B1 3, 8.87 m (29.1 ft) NW of the centerline of the truck trail, 8.60 m (28.2 ft) east of a lone pine tree, and 0.64 m (2.1 ft) SE of a fiberglass carsonite witness post. The datum point is set 2 cm (0.07 ft) above ground, being the top of a stainless steel rod driven 24.4 m (80.1 ft) to refusal, in a sleeve extending to a depth of 1.2 m (3.9 ft), and encased in a 5-inch logo cap. Note: The sleeve depth does not meet the specifications for a Class A mark.

Station ID: 8571579 **PUBLICATION DATE: 01/27/2005**
Name: BARREN ISLAND, CHESAPEAKE BAY MARYLAND
NOAA Chart: 12261 **Latitude: 38° 20.5' N**
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T I D A L B E N C H M A R K S

BENCH MARK STAMPING: 1579 D 2001
DESIGNATION: 857 1579 D TIDAL

MONUMENTATION: Flange-encased Rod VM#: 16627
AGENCY: National Ocean Service (NOS) PID#: AJ8226
SETTING CLASSIFICATION: Stainless steel rod in sleeve

The bench mark is a flange encased rod located on Barren Island north along the beach on the west side of the island, 0.2 km (0.1 mi) north of bench mark 33B1 2, 0.2 km (0.1 mi) SE of bench mark 33B1 3, 12.41 m (40.7 ft) south of a pine tree at the edge of the tree line, and 0.52 m (1.7 ft) WSW of a fiberglass carsonite witness post. The datum point is set 9 cm (0.3 ft) above ground, being the top of a stainless steel rod driven 24.2 m (79.4 ft) to refusal, in a sleeve extending to a depth of 1.2 m (3.9 ft), and encased in a 5-inch logo cap. Note: The sleeve depth does not meet the specifications for a Class A mark.

BENCH MARK STAMPING: 1579 E 2001
DESIGNATION: 857 1579 E TIDAL

MONUMENTATION: Flange-encased Rod VM#: 16628
AGENCY: National Ocean Service (NOS) PID#: AJ8227
SETTING CLASSIFICATION: Stainless steel rod in sleeve

The bench mark is a flange encased rod located on Barren Island southeasterly along the west bank to the mark on the left in a sandy area, between the beach and marsh land, 0.2 km (0.1 mi) north of bench mark 33B1 1, 0.2 km (0.1 mi) SE of bench mark 1579 D 2001, 4.33 m (14.2 ft) NW of a small PVC pipe, and 0.76 m (2.5 ft) SW of a fiberglass carsonite witness post. The datum point is set 20 cm (0.7 ft) above ground, being the top of a flange encased rod driven 30.5 m (100.1 ft) to refusal, in a sleeve extending to a depth of 1.2 m (3.9 ft), and encased in a 5-inch logo cap. Note: The sleeve depth does not meet the specifications for a Class A mark.

Station ID: 8571579 **PUBLICATION DATE: 01/27/2005**
Name: BARREN ISLAND, CHESAPEAKE BAY MARYLAND
NOAA Chart: 12261 **Latitude: 38° 20.5' N**
USGS Quad: BARREN ISLAND **Longitude: 76° 15.9' W**

T I D A L B E N C H M A R K S

BENCH MARK STAMPING: BARREN 3 1993
DESIGNATION: BARREN 3

MONUMENTATION: Survey disk VM#: 16629
AGENCY: US Army Corps Of Engineers (USE) PID#: AJ8228
SETTING CLASSIFICATION: Concrete Post

The bench mark is a disk set in a prefabricated concrete post located near the NE corner of Barren Island, 0.3 km (0.2 mi) east along the beach from bench mark 857 1579 A TIDAL, 20.42 m (67.0 ft) SW of a sign bearing the words "CRAB LINE", 16.46 m (54.0 ft) SE of the edge of the beach, 0.52 m (1.7 ft) north of a fiberglass carsonite witness post, and 0.17 m (0.6 ft) above ground.

BENCH MARK STAMPING:
DESIGNATION: 33B1 1

MONUMENTATION: See descriptive text VM#: 16630
AGENCY: US Army Corps Of Engineers (USE) PID#: AJ8230
SETTING CLASSIFICATION: Steel rebar with yellow cap

The bench mark is an unknown length of steel rebar with a yellow cap located along the south edge of the west bank of Barren Island, just north of where the island splits due to a slough, 0.6 km (0.4 mi) south of bench mark 33B1 3, 0.3 km (0.2 mi) SE from bench mark 33B1 2, 0.2 km (0.1 mi) south of bench mark 1579 E 2001, 1.55 m (5.1 ft) west of a fiberglass carsonite witness post, and 0.70 m (2.3 ft) west of a fiberglass carsonite witness post.

Station ID: **8571579** **PUBLICATION DATE:** **01/27/2005**
Name: **BARREN ISLAND, CHESAPEAKE BAY MARYLAND**
NOAA Chart: **12261** **Latitude:** **38° 20.5' N**
USGS Quad: **BARREN ISLAND** **Longitude:** **76° 15.9' W**

T I D A L B E N C H M A R K S

BENCH MARK STAMPING:
DESIGNATION: 33B1 2

MONUMENTATION: See descriptive text VM#: 16631
AGENCY: US Army Corps Of Engineers (USE) PID#: AJ8229
SETTING CLASSIFICATION: Steel rebar with yellow cap

The bench mark is an unknown length of steel rebar with a yellow cap located on Barren Island near the boat landing area, 0.16 km (0.1 mi) south of bench mark 857 1579 D TIDAL, 0.16 km (0.1 mi) NW of bench mark 857 1579 E TIDAL, 14.08 m (46.2 ft) NE of the west edge of the bank, 0.73 m (2.4 ft) WSW of a fiberglass carsonite witness post, 0.70 m (2.3 ft) NE of a fiberglass carsonite witness post, and 0.11 m (0.4 ft) above ground.

Station ID: 8571579 **PUBLICATION DATE: 01/27/2005**
Name: BARREN ISLAND, CHESAPEAKE BAY MARYLAND
NOAA Chart: 12261 **Latitude: 38° 20.5' N**
USGS Quad: BARREN ISLAND **Longitude: 76° 15.9' W**

T I D A L D A T U M S

Tidal datums at BARREN ISLAND, CHESAPEAKE BAY based on:

LENGTH OF SERIES:	15 MONTHS
TIME PERIOD:	January 2002 - March 2003
TIDAL EPOCH:	1983-2001
CONTROL TIDE STATION:	8577330 SOLOMONS ISLAND, PATUXENT RIVER

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

HIGHEST OBSERVED WATER LEVEL (03/21/2003)	= 0.952
MEAN HIGHER HIGH WATER (MHHW)	= 0.472
MEAN HIGH WATER (MHW)	= 0.420
NORTH AMERICAN VERTICAL DATUM-1988 (NAVD)	= 0.370
MEAN SEA LEVEL (MSL)	= 0.240
MEAN TIDE LEVEL (MTL)	= 0.234
MEAN LOW WATER (MLW)	= 0.047
MEAN LOWER LOW WATER (MLLW)	= 0.000
LOWEST OBSERVED WATER LEVEL (01/24/2003)	= -0.592

National Geodetic Vertical Datum (NGVD 29)

Bench Mark Elevation Information In METERS above:

Stamping or Designation	MLLW	MHW
1579 B 2001	1.166	0.746
1579 A 2001	1.163	0.743
1579 C 2001	0.934	0.514
1579 D 2001	1.069	0.649
1579 E 2001	1.060	0.640
BARREN 3 1993	0.933	0.513
33B1 1	0.887	0.467
33B1 2	0.874	0.454

Station ID: 8571579 **PUBLICATION DATE:** 01/27/2005
Name: BARREN ISLAND, CHESAPEAKE BAY MARYLAND
NOAA Chart: 12261 **Latitude:** 38° 20.5' N
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D E F I N I T I O N S

Mean Sea Level (MSL) is a tidal datum determined over a 19-year National Tidal Datum Epoch. It pertains to local mean sea level and should not be confused with the fixed datums of North American Vertical Datum of 1988 (NAVD 88).

NGVD 29 is a fixed datum adopted as a national standard geodetic reference for heights but is now considered superseded. NGVD 29 is sometimes referred to as Sea Level Datum of 1929 or as Mean Sea Level on some early issues of Geological Survey Topographic Quads. NGVD 29 was originally derived from a general adjustment of the first-order leveling networks of the U.S. and Canada after holding mean sea level observed at 26 long term tide stations as fixed. Numerous local and wide-spread adjustments have been made since establishment in 1929. Bench mark elevations relative to NGVD 29 are available from the National Geodetic Survey (NGS) data base via the World Wide Web at National Geodetic Survey.

NAVD 88 is a fixed datum derived from a simultaneous, least squares, minimum constraint adjustment of Canadian/Mexican/United States leveling observations. Local mean sea level observed at Father Point/Rimouski, Canada was held fixed as the single initial constraint. NAVD 88 replaces NGVD 29 as the national standard geodetic reference for heights. Bench mark elevations relative to NAVD 88 are available from NGS through the World Wide Web at National Geodetic Survey.

NGVD 29 and NAVD 88 are fixed geodetic datums whose elevation relationships to local MSL and other tidal datums may not be consistent from one location to another.

The Vertical Mark Number (VM#) and PID# shown on the bench mark sheet are unique identifiers for bench marks in the tidal and geodetic databases, respectively. Each bench mark in either database has a single, unique VM# and/or PID# assigned. Where both VM# and PID# are indicated, both tidal and geodetic elevations are available for the bench mark listed.

The NAVD 88 elevation is shown on the Elevations of Tidal Datums Table Referred to MLLW only when two or more of the bench marks listed have NAVD 88 elevations. The NAVD 88 elevation relationship shown in the table is derived from an average of several bench mark elevations relative to tide station datum. As a result of this averaging, NAVD 88 bench mark elevations computed indirectly from the tidal datums elevation table may differ slightly from NAVD 88 elevations listed for each bench mark in the NGS database.

QUANTITY ESTIMATES

1. James Island. The following sections provide a description of the calculation methods used and the assumptions made for each of the estimated quantities for the recommended plan at James Island.

1.1. Dredging. Dredging volumes were calculated for three components of the recommended plan: the access channel, unsuitable foundation excavation, and borrow material sites within the upland cells. See Table 1.1. Dredging volumes for the access channel were calculated by developing two triangulated irregular network (TIN) surface models. The first TIN surface model was developed from available bathymetric data and represented the existing seafloor. The second TIN surface model represented the proposed surface of the access channel. Using Geographic Information System (GIS) software, a cut/fill analysis was performed using the two TIN surface models in order to calculate the volume of dredging required for the proposed access channel. For the dredging volume associated with the excavation of unsuitable foundation material, it was assumed that a 500' long, 200' wide, and 13.5' deep section of existing material under the proposed perimeter dike footprint would require removal. For the volume associated with the borrow sites within the upland cells, a third TIN surface model was created that represented the surficial sand thickness for the area under the proposed upland portion of the recommended plan. An analysis of this surface model was performed to calculate the total volume of sand borrow to be dredged within the upland area. Excluded from this analysis were the area under and within 100' of the perimeter and interior dike footprints and the access channel footprint.

1.2. Fill Material. Fill volumes were calculated for each component of the recommended plan, including material required for the replacement of unsuitable foundation material and the construction of perimeter, interior, and separator dikes. See Table 1.2. For the replacement of unsuitable material volume, it was assumed that approximately 500 linear feet of upland perimeter dike footprint would have to be replaced with suitable foundation material prior to dike construction. The calculated volume of backfill required was based on the amount of material needed to fill a void 500' in length, 200' in width, and 13.5' in depth. The average end area method was used to calculate volume quantities for all perimeter, interior, and separator dike reaches. A TIN surface model was developed from available bathymetric data for the entire site using Autodesk's Land Desktop software. For all perimeter dikes and the separator dike, cross-sections were developed along the proposed alignment at 500' intervals. These cross-sections were then used in the average end area volume calculation. Average seafloor elevations for the upland and wetland portions of the recommended plan were used to develop typical cross-sections for the interior dikes, as interior dike alignments were not developed for this study. These typical cross-sections, along with assumed dike lengths, were used in the average end area volume calculation. It was estimated that the upland portion of the project would require approximately 12,000 linear feet of interior dikes, while the wetland portion would require approximately 75,000 linear feet of interior dikes.

1.3. Dike Stone. The perimeter dikes require multiple layers of stone. Volumes were calculated for each of the stone sizes required to construct the various dike reaches for the recommended plan. See Table 1.3. No stone work is required for the upland interior dikes, wetland interior dikes, or the separator dike. The average end area method was used to calculate stone volume quantities for all perimeter dike reaches. Average seafloor elevations along the upland and wetland perimeter dikes were used to develop typical cross-sections for each dike reach. These typical cross-sections, along with dike lengths, were used in the average end area volume calculation. The stone volumes were then converted to weights by using the conversion factor of 1.5tons/cubic yard. The area of required geotextile was calculated for each dike reach by measuring the length of geotextile using the typical cross sections developed for stone quantity calculations.

1.4. Erosion Control. Based on experience gained from the Poplar Island Environmental Restoration Project (PIERP), erosion control measures are required on all unprotected slopes due to the potential impacts of wave action and surface runoff. Two types of erosion control measures are required for this project: one for unprotected slopes within the expected tide range (Type 1) and one for unprotected slopes above the expected tide range (Type 2). The quantities for both types of erosion control measures are shown in Table 1.4. It was assumed that the inside of all perimeter dikes, all upland interior dikes, approximately 40,000' of wetland interior dikes, and the separator dike will require erosion control measures. Quantities were calculated by multiplying the width of the erosion control required by the length of the dike reach.

1.5. Roadways. Stabilized roadways will be required for the operation and maintenance of the project. Quantity estimates for these roadways are included in Table 1.5. It was assumed that all perimeter dikes, all upland interior dikes, approximately 40,000' of wetland interior dikes, and the separator dike will require stabilized roadways. Quantities were calculated by multiplying the length of roadway by the width of stone and geotextile.

1.6. Miscellaneous. Quantity estimates for all other features that are part of the recommended plan are included in Table 1.6. With respect to the number of spillways required, it was assumed that the uplands will be divided into four quadrants by interior dikes, and each cell will require a spillway that will discharge directly to the bay. For the wetland cells, it was assumed that five spillways discharging directly to the bay will be required. In addition to these nine perimeter dike spillways, it was estimated that an additional ten interior dike spillways will be required.

Table 1-1. James Island Dredging Quantities.

Dredging	Length (ft)	Quantity	Unit
Access Channel	12,720	2,710,000	CY
Unsuitable Foundation Excavation	500	50,000	CY
Borrow Within Upland Cells	-	13,220,000	CY
Total		**15,980,000**	**CY**

Table 1-2. James Island Fill Material Quantities.

Fill Material	Length (ft)	Quantity	Unit
Unsuitable Foundation Backfill	500	50,000	CY
Upland Perimeter Dike Station 0+00 to 125+00	12,500	1,879,000	CY
Upland Perimeter Dike Station 125+00 to 207+16	8,216	1,162,000	CY
Wetland Perimeter Dike Station 207+16 to 300+00	9,284	220,000	CY
Wetland Perimeter Dike Station 300+00 to 452+35	15,235	536,000	CY
Upland Interior Dike	12,000	1,667,000	CY
Wetland Interior Dike	75,000	2,174,000	CY
Upland/Wetland Separator Dike	6,234	913,000	CY
Total		**8,601,000**	**CY**

Table 1-3. James Island Dike Stone Quantities.

Dike Stone	Length (ft)	Quantity	Unit
Upland Perimeter Dike Station 0+00 to 125+00	12,500		
Armor Stone (2500lb)		108,150	TONS
Underlayer Stone (250lb)		73,950	TONS
Bedding Stone		33,750	TONS
Toe Armor Stone (3500lb)		126,150	TONS
Toe Underlayer Stone (250lb)		129,600	TONS
Geotextile		177,800	SY
Upland Perimeter Dike Station 125+00 to 207+16	8,216		
Armor Stone (500lb)		31,350	TONS
Underlayer Stone (50lb)		15,300	TONS
Bedding Stone		13,350	TONS
Toe Armor Stone (1000lb)		39,750	TONS
Toe Underlayer Stone (50lb)		58,500	TONS
Geotextile		97,400	SY
Wetland Perimeter Dike Station 207+16 to 300+00	9,284		
Armor Stone (500lb)		35,550	TONS
Underlayer Stone (50lb)		17,250	TONS
Bedding Stone		15,000	TONS
Toe Armor Stone (1000lb)		39,300	TONS
Toe Underlayer Stone (50lb)		43,500	TONS
Geotextile		126,600	SY
Wetland Perimeter Dike Station 300+00 to 452+35	15,235		
Armor Stone (2500lb)		131,700	TONS
Underlayer Stone (250lb)		90,150	TONS
Bedding Stone		41,100	TONS
Toe Armor Stone (3500lb)		133,350	TONS
Toe Underlayer Stone (250lb)		88,950	TONS
Geotextile		172,900	SY

Table 1-4. James Island Erosion Control Quantities.

Erosion Control	Length (ft)	Quantity	Unit
Perimeter Dike Station 0+00 to 452+35	45,235		
Erosion Control Type 1		283,000	SY
Erosion Control Type 2		71,000	SY
Upland Interior Dike	12,000		
Erosion Control Type 1		160,000	SY
Erosion Control Type 2		36,000	SY
Wetland Interior Dike	40,000		
Erosion Control Type 1		71,500	SY
Erosion Control Type 2		120,000	SY
Upland/Wetland Separator Dike	6,234		
Erosion Control Type 1		83,200	SY
Erosion Control Type 2		30,000	SY

Table 1-5. James Island Roadway Quantities.

Roadways	Length (ft)	Quantity	Unit
Upland Perimeter Dike Station 0+00 to 207+16	20,716		
8" Crushed Stone		53,000	SY
Geotextile		60,000	SY
Wetland Perimeter Dike Station 207+16 to 452+35	24,519		
8" Crushed Stone		63,000	SY
Geotextile		71,000	SY
Upland Interior Dike	12,000		
8" Crushed Stone		31,000	SY
Geotextile		35,000	SY
Wetland Interior Dike	40,000		
8" Crushed Stone		102,300	SY
Geotextile		115,600	SY
Upland/Wetland Separator Dike	6,234		
8" Crushed Stone		16,000	SY
Geotextile		18,100	SY

Table 1-6. James Island Miscellaneous Quantities.

Miscellaneous	Quantity	Unit
Perimeter Dike Spillways	9	EACH
Interior Dike Spillways	10	EACH
Culvert Control Structures	2	EACH
Operation Facilities	1	EACH
Off-Loading Area	1	EACH
Personnel Pier	1	EACH

2. Barren Island. This section provides a description of the calculation methods used and the assumptions made for each of the estimated quantities for the recommended plan at Barren Island.

The proposed modification of the existing sill will require the addition of stone, and the near shore sill and the south breakwater will require multiple layers of stone. Volumes were calculated for each of the stone sizes required to construct the various dike reaches for the recommended plan. See Table 2. The average end area method was used to calculate stone volume quantities for sill and breakwater reaches. Average seafloor elevations along the proposed alignment were used to develop typical cross-sections for each reach. These typical cross-sections, along with section lengths, were used in the average end area volume calculation. The stone volumes were then converted to weights by using the conversion factor of 1.5tons/cubic yard. The area of required geotextile was calculated for each section by measuring the length of geotextile using the typical cross sections developed for stone quantity calculations.

Table 2. Barren Island Dike Stone Quantities.

Dike Stone	Length (ft)	Quantity	Unit
Modification of Existing Sill	4,900		
Armor Stone (1300lb)		11,250	TONS
Geotextile		5,900	SY
Near-Shore Sill (by component)	9,760		
Western Protection:	4,620		
Armor Stone (1300lb)		29,700	TONS
Intermediate Stone (130lb)		7,200	TONS
Core Stone		2,850	TONS
Bedding Stone		4,400	TONS
Geotextile		31,850	SY
Containment Sill:	1,300		
Armor Stone (1300lb)		8,400	TONS
Intermediate Stone (130lb)		2,100	TONS
Core Stone		900	TONS
Bedding Stone		1,250	TONS
Geotextile		9,000	SY
Northern Protection:	3,840		
Armor Stone (1300lb)		21,600	TONS
Intermediate Stone (130lb)		4,350	TONS
Core Stone		900	TONS
Bedding Stone		3,650	TONS
Geotextile		26,500	SY
South Breakwater	8,200		
Armor Stone (1300lb)		66,000	TONS
Intermediate Stone (130lb)		18,900	TONS
Core Stone		15,000	TONS
Geotextile		45,600	SY

ATTACHMENT M

COST ESTIMATE AND COST RISK ANALYSIS

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Cost Engineering

1. General. The following methodology was used in the preparation of Draft Feasibility Study Cost Estimate for James Island Site, Mid-Bay Island Project, Chesapeake Bay, Maryland dated April 2008.

a. The estimate is in accordance with the guidance contained in ER 1110-2-1302, Civil Works Cost Engineering.

b. The estimate is presented in the standard Work Breakdown Structure.

c. The price level for the estimate is 1 October 2007.

d. Construction costs developed by Cost Engineering Branch are based on input/quantities from Civil Engineering Section, Civil Works Branch (see Engineering Appendix). Unit costs for were developed using the M-II estimating software containing the 2006 Unit Price Book, the Corps of Engineers Dredge Estimating Program and from historical data from the Poplar Island Environmental Restoration Project Baseline Estimate. The estimate is documented with notes to explain the assumed construction methods, crews, productivity, and other specific information.

e. PPMD provided costs for Construction Management.

f. PPMD provided costs for the Planning, Engineering and Design.

g. PPMD provided the escalation factors.

h. Base Plan for Mechanical Maintenance Dredging includes Pooles Island for NAP channels and Deep Trough for NAB channels. For estimating purposes, the weighted averaged distance from a central location of NAP channels to Pooles Island and a central location of NAB channels to Deep Trough is used for computing the Base Plan Maintenance Dredging cost. The same method of calculation is used for computing Maintenance Dredging to James Island.

i. Recommendations from the Value Engineering analysis will be considered by the project team during the pre-construction engineering and design phase. Cost impacts of these recommendations are not reflected herein.

2. Estimate Scope. The estimate reflects the cost for constructing:

- 853 Acres of Upland Placement sites.
- 980 Acres of Wetland Placement Sites.

3. Contingency. To protect against the risk of potential cost increases, Cost Risk Analysis is performed based on risks associated with main groups of cost items namely, dredging, stone dike construction, and site management, to determine an appropriate contingency that represents 75% confident level of the project cost estimate.

Navigation, Ports & Harbor Cost Items

The uncertainty associated with the dike construction are average. The preliminary designs for the dikes are based on designs that were used for the Poplar Island Project. The final detailed design, however, will reduce the uncertainty of these cost items even farther. After Cost Risk Analysis (CRA) is completed, a contingency of 20 percent (representing 75% confidence level) is considered reasonable. Also, at 75% confidence level, Cost Risk Analysis for O&M results in 18% Contingency.

Planning Engineering and Design Cost Items

The uncertainties associated with the construction management are moderate. After Cost Risk Analysis (CRA) is completed, a contingency of 20 percent (representing 75% confidence level) is considered reasonable.

Construction Management Cost Items

The uncertainties associated with the construction management are moderate. After Cost Risk Analysis (CRA) is completed, a contingency of 20 percent (representing 75% confidence level) is considered reasonable.

Cost Engineering

1. General. The following methodology was used in the preparation of Feasibility Study Cost Estimate for the Barren Island Site, Mid-Bay Island Project, Chesapeake Bay, Maryland dated April 2008.

a. The estimate is in accordance with the guidance contained in ER 1110-2-1302, Civil Works Cost Engineering.

b. The estimate is presented in the standard Work Breakdown Structure.

c. The price level for the estimate is 1 October 2007.

d. Construction costs developed by Cost Engineering Branch are based on input/quantities from Civil Engineering Section, Civil Works Branch (see Engineering Appendix). Unit costs for were developed using the M-II estimating software containing the 2006 Unit Price Book. Dredged material from the C&D Canal approach channel and the Chesapeake Bay approach channel to the Port of Baltimore in MD and the Federal navigation channels in the Honga River will supply the backfill for future wetland restoration. If primary source is from the Honga River, the wetlands will need to be created in several increments, as the quantity of maintenance dredged material will likely not be enough to create the wetlands all at once. The estimate is documented with notes to explain the assumed construction methods, crews, productivity, and other specific information.

e. PPMD provided costs for Construction Management.

f. Civil Works Design Management Section provided costs for the Planning, Engineering and Design.

g. PPMD provided the future escalation factors based on the Office of Management and Budget (OMB) dated 20 Feb 08.

h. Recommendations from the Value Engineering analysis will be considered by the project team during the pre-construction engineering and design phase. Cost impacts of these recommendations are not reflected herein.

2. Estimate Scope. The estimate reflects the cost for:

- Modifications of 4,900 feet of existing sill.
- Constructing 11,035 feet of near-shore sill.
- Construction of 3,530 feet of breakwaters

3. Contingency. To protect against the risk of potential cost increases, Cost Risk Analysis is performed based on risks associated with main groups of cost items namely, dredging, stone dike construction, and site management, to determine an appropriate contingency that represents 75% confident level of the project cost estimate.

Navigation, Ports & Harbor Cost Items

The uncertainty associated with the sill and breakwater construction, are average. The quantities and alignments for the sill and breakwaters are based on preliminary designs. The final detailed design, however, will reduce the uncertainty of these cost items even farther. After Cost Risk Analysis (CRA) is completed, a contingency of 20 percent (representing 75% confidence level) is considered reasonable. Also, at 75% confidence level, Cost Risk Analysis for O&M results in 18% Contingency and 12% for Wetland Planting for Barren Island.

Planning Engineering and Design Cost Items

The uncertainties associated with the construction management are moderate. After Cost Risk Analysis (CRA) is completed, a contingency of 20 percent (representing 75% confidence level) is considered reasonable.

Construction Management Cost Items

The uncertainties associated with the construction management are moderate. After Cost Risk Analysis (CRA) is completed, a contingency of 20 percent (representing 75% confidence level) is considered reasonable.

Date Prepare.. 3/2009

TOTAL PROJECT COST SUMMARY
ALL CONTRACTS
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2008 EFFECTIVE PRICING LEVEL: 01 OCT 07			FULLY FUNDED ESTIMATE FY 2060		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	1,178,749	235,750	20%	1,414,499	1,178,749	235,750	1,414,499	2,042,694	408,539	2,451,233
	TOTAL CONSTRUCTION COST	***1,178,749***	***235,750***	***20%***	***1,414,499***	***1,178,749***	***235,750***	***1,414,499***	***2,042,694***	***408,539***	***2,451,233***
30	PLANNING, ENGINEERING AND DESIGN	47,084	9,417	20%	56,501	47,084	9,417	56,501	154,034	30,807	184,841
31	CONSTRUCTION MANAGEMENT	21,842	4,368	20%	26,210	21,842	4,368	26,210	64,938	12,988	77,926
	TOTAL PROJECT COSTS	***1,247,675***	***249,535***	***20%***	***1,497,210***	***1,247,675***	***249,535***	***1,497,210***	***2,261,667***	***452,333***	***2,714,000***
	O&M										
12	NAVIGATION, PORTS & HARBORS	**19,907**	**3,583**	**18%**	**23,490**	**19,907**	**3,583**	**23,490**	**36,994**	**6,659**	**43,653**

DISTRICT APPROVED:

ACTING CHIEF, ESTIMATING AND SPECIFICATIONS SECTION

CHIEF, REAL ESTATE DIVISION

CHIEF, PLANNING DIVISION

CHIEF, CIVIL PROGRAMS BRANCH

CHIEF, ENGINEERING DIVISION

CHIEF, OPERATIONS DIVISION

CHIEF, PROGRAMS MANAGEMENT BRANCH

PROJECT MANAGER

DDE (PM)

DIVISION APPROVED:

CHIEF, COST ENGINEERING _____

DIRECTOR REALESTATE _____

CHIEF, PROGRAMS MANAGEMENT _____

DIRECTOR OF PPMD _____

APPROVED DATE: _____

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY12
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2012 EFFECTIVE PRICING LEVEL: 01 OCT 2011			FULLY FUNDED ESTIMATE FY 2012		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
30	PLANNING, ENGINEERING AND DESIGN	781	156	20%	937	942	188	1,131	942	188	1,131
	TOTAL PROJECT COSTS	***781***	***156***	***20%***	***937***	***942***	***188***	***1,131***	***942***	***188***	***1,131***

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY13
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2013 EFFECTIVE PRICING LEVEL: 01 OCT 2012			FULLY FUNDED ESTIMATE FY 2013		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
30	PLANNING, ENGINEERING AND DESIGN	708	142	20%	849	887	177	1,064	887	177	1,064
	TOTAL PROJECT COSTS	***708***	***142***	***20%***	***849***	***887***	***177***	***1,064***	***887***	***177***	***1,064***

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY14
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY — PREPARED BY : CENAB-EN-DT , LUAN NGO
LOCATION : JAMES ISLAND, MD — P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2014 EFFECTIVE PRICING LEVEL: 01 OCT 2013			FULLY FUNDED ESTIMATE FY 2014		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	78,754	15,751	20%	94,505	91,512	18,302	109,815	91,512	18,302	109,815
	TOTAL CONSTRUCTION COST	***78,754***	***15,751***	***20%***	***94,505***	***91,512***	***18,302***	***109,815***	***91,512***	***18,302***	***109,815***
30	PLANNING, ENGINEERING AND DESIGN	210	42	20%	252	274	55	328	274	55	328
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	623	125	748	623	125	748
	TOTAL PROJECT COSTS	***79,443***	***15,889***	***20%***	***95,331***	***92,409***	***18,482***	***110,891***	***92,409***	***18,482***	***110,891***

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY15
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2015 EFFECTIVE PRICING LEVEL: 01 OCT 2014			FULLY FUNDED ESTIMATE FY 2015		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	119,085	23,817	20%	142,902	141,115	28,223	169,338	141,115	28,223	169,338
	TOTAL CONSTRUCTION COST	***119,085***	***23,817***	***20%***	***142,902***	***141,115***	***28,223***	***169,338***	***141,115***	***28,223***	***169,338***
30	PLANNING, ENGINEERING AND DESIGN	210	42	20%	252	284	57	341	284	57	341
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	647	129	777	647	129	777
	TOTAL PROJECT COSTS	***119,773***	***23,955***	***20%***	***143,728***	***142,047***	***28,409***	***170,456***	***142,047***	***28,409***	***170,456***

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY16
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2016 EFFECTIVE PRICING LEVEL: 01 OCT 2015			FULLY FUNDED ESTIMATE FY 2016		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	78,143	15,629	20%	93,772	94,475	18,895	113,370	94,475	18,895	113,370
	TOTAL CONSTRUCTION COST	***78,143***	***15,629***	***20%***	***93,772***	***94,475***	***18,895***	***113,370***	***94,475***	***18,895***	***113,370***
30	PLANNING, ENGINEERING AND DESIGN	210	42	20%	252	295	59	355	295	59	355
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	673	135	807	673	135	807
	TOTAL PROJECT COSTS	***78,832***	***15,766***	***20%***	***94,598***	***95,443***	***19,089***	***114,532***	***95,443***	***19,089***	***114,532***

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY17
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2017 EFFECTIVE PRICING LEVEL: 01 OCT 2016			FULLY FUNDED ESTIMATE FY 2017		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	37,968	7,594	20%	45,562	46,815	9,363	56,178	46,815	9,363	56,178
	TOTAL CONSTRUCTION COST	***37,968***	***7,594***	***20%***	***45,562***	***46,815***	***9,363***	***56,178***	***46,815***	***9,363***	***56,178***
30	PLANNING, ENGINEERING AND DESIGN	210	42	20%	252	307	61	368	307	61	368
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	699	140	839	699	140	839
	TOTAL PROJECT COSTS	***38,657***	***7,731***	***20%***	***46,388***	***47,821***	***9,564***	***57,385***	***47,821***	***9,564***	***57,385***

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY18
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2018 EFFECTIVE PRICING LEVEL: 01 OCT 2017			FULLY FUNDED ESTIMATE FY 2018		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	25,606	5,121	20%	30,727	32,213	6,443	38,655	32,213	6,443	38,655
	TOTAL CONSTRUCTION COST	***25,606***	***5,121***	***20%***	***30,727***	***32,213***	***6,443***	***38,655***	***32,213***	***6,443***	***38,655***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	1,858	372	2,229	1,858	372	2,229
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	727	145	872	727	145	872
	TOTAL PROJECT COSTS	***27,308***	***5,462***	***20%***	***32,769***	***34,797***	***6,959***	***41,757***	***34,797***	***6,959***	***41,757***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$424	$76	18.0%	$500	$533	$96	$629	$533	$96	$629

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY19
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2019 EFFECTIVE PRICING LEVEL: 01 OCT 2018			FULLY FUNDED ESTIMATE FY 2019		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	1,958	392	20%	2,350	2,513	503	3,015	2,513	503	3,015
	TOTAL CONSTRUCTION COST	***1,958***	***392***	***20%***	***2,350***	***2,513***	***503***	***3,015***	***2,513***	***503***	***3,015***
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	755	151	907	755	151	907
	TOTAL PROJECT COSTS	***2,437***	***487***	***20%***	***2,924***	***3,268***	***654***	***3,922***	***3,268***	***654***	***3,922***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$424	$76	18.0%	$500	$544	$98	$641	$544	$98	$641

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY20
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2020 EFFECTIVE PRICING LEVEL: 01 OCT 2019			FULLY FUNDED ESTIMATE FY 2020		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	25,697	5,139	20%	30,837	33,638	6,728	40,365	33,638	6,728	40,365
	TOTAL CONSTRUCTION COST	***25,697***	***5,139***	***20%***	***30,837***	***33,638***	***6,728***	***40,365***	***33,638***	***6,728***	***40,365***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	2,009	402	2,411	2,009	402	2,411
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	786	157	943	786	157	943
	TOTAL PROJECT COSTS	***27,399***	***5,480***	***20%***	***32,878***	***36,433***	***7,287***	***43,720***	***36,433***	***7,287***	***43,720***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$424	$76	18.0%	$500	$555	$100	$654	$555	$100	$654

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY21
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2021 EFFECTIVE PRICING LEVEL: 01 OCT 2020			FULLY FUNDED ESTIMATE FY 2021		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	2,050	410	20%	2,460	2,736	547	3,284	2,736	547	3,284
	TOTAL CONSTRUCTION COST	***2,050***	***410***	***20%***	***2,460***	***2,736***	***547***	***3,284***	***2,736***	***547***	***3,284***
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	819	164	982	819	164	982
	TOTAL PROJECT COSTS	***2,528***	***506***	***20%***	***3,034***	***3,555***	***711***	***4,266***	***3,555***	***711***	***4,266***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$424	$76	18.0%	$500	$566	$102	$667	$566	$102	$667

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY22
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2022 EFFECTIVE PRICING LEVEL: 01 OCT 2021			FULLY FUNDED ESTIMATE FY 2022		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	25,775	5,155	20%	30,930	35,105	7,021	42,126	35,105	7,021	42,126
	TOTAL CONSTRUCTION COST	***25,775***	***5,155***	***20%***	***30,930***	***35,105***	***7,021***	***42,126***	***35,105***	***7,021***	***42,126***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	2,178	436	2,614	2,178	436	2,614
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	852	170	1,023	852	170	1,023
	TOTAL PROJECT COSTS	***27,476***	***5,495***	***20%***	***32,971***	***38,135***	***7,627***	***45,763***	***38,135***	***7,627***	***45,763***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$587	$106	18.0%	$692	$783	$141	$924	$783	$141	$924

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY23
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2023 EFFECTIVE PRICING LEVEL: 01 OCT 2022			FULLY FUNDED ESTIMATE FY 2023		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	2,127	425	20%	2,553	2,955	591	3,546	2,955	591	3,546
	TOTAL CONSTRUCTION COST	***2,127***	***425***	***20%***	***2,553***	***2,955***	***591***	***3,546***	***2,955***	***591***	***3,546***
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	887	177	1,064	887	177	1,064
	TOTAL PROJECT COSTS	***2,606***	***521***	***20%***	***3,127***	***3,842***	***768***	***4,610***	***3,842***	***768***	***4,610***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$567	$102	18.0%	$669	$788	$142	$930	$788	$142	$930

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY24
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2024 EFFECTIVE PRICING LEVEL: 01 OCT 2023			FULLY FUNDED ESTIMATE FY 2024		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	1,789	358	20%	2,147	2,536	507	3,043	2,536	507	3,043
	TOTAL CONSTRUCTION COST	***1,789***	***358***	***20%***	***2,147***	***2,536***	***507***	***3,043***	***2,536***	***507***	***3,043***
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	924	185	1,109	924	185	1,109
	TOTAL PROJECT COSTS	***2,268***	***454***	***20%***	***2,721***	***3,460***	***692***	***4,152***	***3,460***	***692***	***4,152***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$567	$102	18.0%	$669	$804	$145	$949	$804	$145	$949

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY25
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2025 EFFECTIVE PRICING LEVEL: 01 OCT 2024			FULLY FUNDED ESTIMATE FY 2025		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	1,621	324	20%	1,945	2,342	468	2,810	2,342	468	2,810
	TOTAL CONSTRUCTION COST	***1,621***	***324***	***20%***	***1,945***	***2,342***	***468***	***2,810***	***2,342***	***468***	***2,810***
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	964	193	1,157	964	193	1,157
	TOTAL PROJECT COSTS	***2,099***	***420***	***20%***	***2,519***	***3,306***	***661***	***3,967***	***3,306***	***661***	***3,967***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$567	$102	18.0%	$669	$820	$148	$967	$820	$148	$967

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY26
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2026 EFFECTIVE PRICING LEVEL: 01 OCT 2025			FULLY FUNDED ESTIMATE FY 2026		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	1,621	324	20%	1,945	2,389	478	2,867	2,389	478	2,867
	TOTAL CONSTRUCTION COST	***1,621***	***324***	***20%***	***1,945***	***2,389***	***478***	***2,867***	***2,389***	***478***	***2,867***
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	995	199	1,194	995	199	1,194
	TOTAL PROJECT COSTS	***2,099***	***420***	***20%***	***2,519***	***3,384***	***677***	***4,061***	***3,384***	***677***	***4,061***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$567	$102	18.0%	$669	$836	$151	$987	$836	$151	$987

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY27
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2027 EFFECTIVE PRICING LEVEL: 01 OCT 2026			FULLY FUNDED ESTIMATE FY 2027		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	22,262	4,452	20%	26,715	33,460	6,692	40,152	33,460	6,692	40,152
	TOTAL CONSTRUCTION COST	***22,262***	***4,452***	***20%***	***26,715***	***33,460***	***6,692***	***40,152***	***33,460***	***6,692***	***40,152***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	2,619	524	3,142	2,619	524	3,142
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,024	205	1,229	1,024	205	1,229
	TOTAL PROJECT COSTS	***23,964***	***4,793***	***20%***	***28,757***	***37,103***	***7,421***	***44,524***	***37,103***	***7,421***	***44,524***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$567	$102	18.0%	$669	$853	$153	$1,006	$853	$153	$1,006

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY28
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2028 EFFECTIVE PRICING LEVEL: 01 OCT 2027			FULLY FUNDED ESTIMATE FY 2028		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	26,010	5,202	20%	31,212	39,899	7,980	47,879	39,899	7,980	47,879
	TOTAL CONSTRUCTION COST	***26,010***	***5,202***	***20%***	***31,212***	***39,899***	***7,980***	***47,879***	***39,899***	***7,980***	***47,879***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	2,694	539	3,233	2,694	539	3,233
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,054	211	1,265	1,054	211	1,265
	TOTAL PROJECT COSTS	***27,711***	***5,542***	***20%***	***33,253***	***43,647***	***8,729***	***52,377***	***43,647***	***8,729***	***52,377***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$587	$106	18.0%	$692	$900	$162	$1,062	$900	$162	$1,062

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY29
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2029 EFFECTIVE PRICING LEVEL: 01 OCT 2028			FULLY FUNDED ESTIMATE FY 2029		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	28,532	5,706	20%	34,238	44,624	8,925	53,549	44,624	8,925	53,549
	TOTAL CONSTRUCTION COST	***28,532***	***5,706***	***20%***	***34,238***	***44,624***	***8,925***	***53,549***	***44,624***	***8,925***	***53,549***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	2,773	555	3,327	2,773	555	3,327
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,085	217	1,302	1,085	217	1,302
	TOTAL PROJECT COSTS	***30,233***	***6,047***	***20%***	***36,280***	***48,481***	***9,696***	***58,178***	***48,481***	***9,696***	***58,178***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$977	$176	18.0%	$1,153	$1,528	$275	$1,804	$1,528	$275	$1,804

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY30
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2030 EFFECTIVE PRICING LEVEL: 01 OCT 2029			FULLY FUNDED ESTIMATE FY 2030		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	28,860	5,772	20%	34,632	46,047	9,209	55,256	46,047	9,209	55,256
	TOTAL CONSTRUCTION COST	***28,860***	***5,772***	***20%***	***34,632***	***46,047***	***9,209***	***55,256***	***46,047***	***9,209***	***55,256***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	2,890	578	3,468	2,890	578	3,468
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,116	223	1,339	1,116	223	1,339
	TOTAL PROJECT COSTS	***30,578***	***6,116***	***20%***	***36,693***	***50,053***	***10,011***	***60,063***	***50,053***	***10,011***	***60,063***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$404	$73	18.0%	$477	$645	$116	$761	$645	$116	$761

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY31
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2031 EFFECTIVE PRICING LEVEL: 01 OCT 2030			FULLY FUNDED ESTIMATE FY 2031		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	28,860	5,772	20%	34,632	46,967	9,393	56,361	46,967	9,393	56,361
	TOTAL CONSTRUCTION COST	***28,860***	***5,772***	***20%***	***34,632***	***46,967***	***9,393***	***56,361***	***46,967***	***9,393***	***56,361***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	2,974	595	3,569	2,974	595	3,569
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,148	230	1,378	1,148	230	1,378
	TOTAL PROJECT COSTS	***30,578***	***6,116***	***20%***	***36,693***	***51,089***	***10,218***	***61,307***	***51,089***	***10,218***	***61,307***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$404	$73	18.0%	$477	$657	$118	$776	$657	$118	$776

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY32
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2032 EFFECTIVE PRICING LEVEL: 01 OCT 2031			FULLY FUNDED ESTIMATE FY 2032		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	28,860	5,772	20%	34,632	47,908	9,582	57,490	47,908	9,582	57,490
	TOTAL CONSTRUCTION COST	***28,860***	***5,772***	***20%***	***34,632***	***47,908***	***9,582***	***57,490***	***47,908***	***9,582***	***57,490***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	3,060	612	3,672	3,060	612	3,672
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,182	236	1,418	1,182	236	1,418
	TOTAL PROJECT COSTS	***30,578***	***6,116***	***20%***	***36,693***	***52,150***	***10,430***	***62,580***	***52,150***	***10,430***	***62,580***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$411	$74	18.0%	$485	$683	$123	$806	$683	$123	$806

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY33
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2033 EFFECTIVE PRICING LEVEL: 01 OCT 2032			FULLY FUNDED ESTIMATE FY 2033		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	28,860	5,772	20%	34,632	48,866	9,773	58,640	48,866	9,773	58,640
	TOTAL CONSTRUCTION COST	***28,860***	***5,772***	***20%***	***34,632***	***48,866***	***9,773***	***58,640***	***48,866***	***9,773***	***58,640***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	3,149	630	3,779	3,149	630	3,779
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,216	243	1,459	1,216	243	1,459
	TOTAL PROJECT COSTS	***30,578***	***6,116***	***20%***	***36,693***	***53,231***	***10,646***	***63,877***	***53,231***	***10,646***	***63,877***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$567	$102	18.0%	$669	$955	$172	$1,127	$955	$172	$1,127

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY34
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2034 EFFECTIVE PRICING LEVEL: 01 OCT 2033			FULLY FUNDED ESTIMATE FY 2034		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	28,860	5,772	20%	34,632	49,842	9,968	59,810	49,842	9,968	59,810
	TOTAL CONSTRUCTION COST	***28,860***	***5,772***	***20%***	***34,632***	***49,842***	***9,968***	***59,810***	***49,842***	***9,968***	***59,810***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	3,240	648	3,888	3,240	648	3,888
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,251	250	1,501	1,251	250	1,501
	TOTAL PROJECT COSTS	***30,578***	***6,116***	***20%***	***36,693***	***54,333***	***10,867***	***65,200***	***54,333***	***10,867***	***65,200***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$625	$113	18.0%	$738	$1,080	$194	$1,275	$1,080	$194	$1,275

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY35
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2035 EFFECTIVE PRICING LEVEL: 01 OCT 2034			FULLY FUNDED ESTIMATE FY 2035		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	28,822	5,764	20%	34,587	50,773	10,155	60,928	50,773	10,155	60,928
	TOTAL CONSTRUCTION COST	***28,822***	***5,764***	***20%***	***34,587***	***50,773***	***10,155***	***60,928***	***50,773***	***10,155***	***60,928***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	3,334	667	4,001	3,334	667	4,001
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,287	257	1,545	1,287	257	1,545
	TOTAL PROJECT COSTS	***30,540***	***6,108***	***20%***	***36,647***	***55,395***	***11,079***	***66,473***	***55,395***	***11,079***	***66,473***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$594	$107	18.0%	$701	$1,047	$188	$1,235	$1,047	$188	$1,235

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY36
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2036 EFFECTIVE PRICING LEVEL: 01 OCT 2035			FULLY FUNDED ESTIMATE FY 2036		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	26,063	5,213	20%	31,275	46,830	9,366	56,196	46,830	9,366	56,196
	TOTAL CONSTRUCTION COST	***26,063***	***5,213***	***20%***	***31,275***	***46,830***	***9,366***	***56,196***	***46,830***	***9,366***	***56,196***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	3,431	686	4,117	3,431	686	4,117
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,325	265	1,590	1,325	265	1,590
	TOTAL PROJECT COSTS	***27,780***	***5,556***	***20%***	***33,336***	***51,585***	***10,317***	***61,902***	***51,585***	***10,317***	***61,902***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$613	$110	18.0%	$724	$1,102	$198	$1,300	$1,102	$198	$1,300

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY37
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2037 EFFECTIVE PRICING LEVEL: 01 OCT 2036			FULLY FUNDED ESTIMATE FY 2037		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	26,484	5,297	20%	31,781	48,540	9,708	58,248	48,540	9,708	58,248
	TOTAL CONSTRUCTION COST	***26,484***	***5,297***	***20%***	***31,781***	***48,540***	***9,708***	***58,248***	***48,540***	***9,708***	***58,248***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	3,530	706	4,236	3,530	706	4,236
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,363	273	1,636	1,363	273	1,636
	TOTAL PROJECT COSTS	***28,202***	***5,640***	***20%***	***33,842***	***53,434***	***10,687***	***64,120***	***53,434***	***10,687***	***64,120***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$1,011	$182	18.0%	$1,193	$1,853	$334	$2,187	$1,853	$334	$2,187

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY38
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2038 EFFECTIVE PRICING LEVEL: 01 OCT 2037			FULLY FUNDED ESTIMATE FY 2038		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	26,522	5,304	20%	31,827	49,581	9,916	59,497	49,581	9,916	59,497
	TOTAL CONSTRUCTION COST	***26,522***	***5,304***	***20%***	***31,827***	***49,581***	***9,916***	***59,497***	***49,581***	***9,916***	***59,497***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	3,633	727	4,359	3,633	727	4,359
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,403	281	1,683	1,403	281	1,683
	TOTAL PROJECT COSTS	***28,240***	***5,648***	***20%***	***33,888***	***54,616***	***10,923***	***65,540***	***54,616***	***10,923***	***65,540***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$594	$107	18.0%	$701	$1,110	$200	$1,310	$1,110	$200	$1,310

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY39
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2039 EFFECTIVE PRICING LEVEL: 01 OCT 2038			FULLY FUNDED ESTIMATE FY 2039		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	29,253	5,851	20%	35,104	55,780	11,156	66,936	55,780	11,156	66,936
	TOTAL CONSTRUCTION COST	***29,253***	***5,851***	***20%***	***35,104***	***55,780***	***11,156***	***66,936***	***55,780***	***11,156***	***66,936***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	3,738	748	4,486	3,738	748	4,486
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,443	289	1,732	1,443	289	1,732
	TOTAL PROJECT COSTS	***30,971***	***6,194***	***20%***	***37,165***	***60,962***	***12,192***	***73,154***	***60,962***	***12,192***	***73,154***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$587	$106	18.0%	$692	$1,119	$201	$1,320	$1,119	$201	$1,320

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY40
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2040 EFFECTIVE PRICING LEVEL: 01 OCT 2039			FULLY FUNDED ESTIMATE FY 2040		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	29,162	5,832	20%	34,994	56,717	11,343	68,060	56,717	11,343	68,060
	TOTAL CONSTRUCTION COST	***29,162***	***5,832***	***20%***	***34,994***	***56,717***	***11,343***	***68,060***	***56,717***	***11,343***	***68,060***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	3,846	769	4,616	3,846	769	4,616
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,485	297	1,782	1,485	297	1,782
	TOTAL PROJECT COSTS	***30,879***	***6,176***	***20%***	***37,055***	***62,049***	***12,410***	***74,458***	***62,049***	***12,410***	***74,458***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$474	$85	18.0%	$560	$923	$166	$1,089	$923	$166	$1,089

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY41
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2041 EFFECTIVE PRICING LEVEL: 01 OCT 2040			FULLY FUNDED ESTIMATE FY 2041		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	29,057	5,811	20%	34,868	57,642	11,528	69,171	57,642	11,528	69,171
	TOTAL CONSTRUCTION COST	***29,057***	***5,811***	***20%***	***34,868***	***57,642***	***11,528***	***69,171***	***57,642***	***11,528***	***69,171***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	3,958	792	4,750	3,958	792	4,750
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,528	306	1,834	1,528	306	1,834
	TOTAL PROJECT COSTS	***30,774***	***6,155***	***20%***	***36,929***	***63,129***	***12,626***	***75,754***	***63,129***	***12,626***	***75,754***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$373	$67	18.0%	$440	$739	$133	$872	$739	$133	$872

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY42
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2042 EFFECTIVE PRICING LEVEL: 01 OCT 2041			FULLY FUNDED ESTIMATE FY 2042		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	28,979	5,796	20%	34,775	58,639	11,728	70,367	58,639	11,728	70,367
	TOTAL CONSTRUCTION COST	***28,979***	***5,796***	***20%***	***34,775***	***58,639***	***11,728***	***70,367***	***58,639***	***11,728***	***70,367***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	4,073	815	4,887	4,073	815	4,887
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,573	315	1,887	1,573	315	1,887
	TOTAL PROJECT COSTS	***30,697***	***6,139***	***20%***	***36,836***	***64,284***	***12,857***	***77,141***	***64,284***	***12,857***	***77,141***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$373	$67	18.0%	$440	$754	$136	$890	$754	$136	$890

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY43
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2043 EFFECTIVE PRICING LEVEL: 01 OCT 2042			FULLY FUNDED ESTIMATE FY 2043		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	28,888	5,778	20%	34,665	59,624	11,925	71,549	59,624	11,925	71,549
	TOTAL CONSTRUCTION COST	***28,888***	***5,778***	***20%***	***34,665***	***59,624***	***11,925***	***71,549***	***59,624***	***11,925***	***71,549***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	4,191	838	5,029	4,191	838	5,029
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,618	324	1,942	1,618	324	1,942
	TOTAL PROJECT COSTS	***30,605***	***6,121***	***20%***	***36,726***	***65,433***	***13,087***	***78,520***	***65,433***	***13,087***	***78,520***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$349	$63	18.0%	$412	$720	$130	$850	$720	$130	$850

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY44
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2044 EFFECTIVE PRICING LEVEL: 01 OCT 2043			FULLY FUNDED ESTIMATE FY 2044		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	28,796	5,759	20%	34,556	60,625	12,125	72,750	60,625	12,125	72,750
	TOTAL CONSTRUCTION COST	***28,796***	***5,759***	***20%***	***34,556***	***60,625***	***12,125***	***72,750***	***60,625***	***12,125***	***72,750***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	4,312	862	5,175	4,312	862	5,175
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,665	333	1,998	1,665	333	1,998
	TOTAL PROJECT COSTS	***30,514***	***6,103***	***20%***	***36,617***	***66,603***	***13,321***	***79,923***	***66,603***	***13,321***	***79,923***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$426	$77	18.0%	$503	$897	$162	$1,059	$897	$162	$1,059

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY45
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2045 EFFECTIVE PRICING LEVEL: 01 OCT 2044			FULLY FUNDED ESTIMATE FY 2045		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	28,796	5,759	20%	34,556	61,837	12,367	74,205	61,837	12,367	74,205
	TOTAL CONSTRUCTION COST	***28,796***	***5,759***	***20%***	***34,556***	***61,837***	***12,367***	***74,205***	***61,837***	***12,367***	***74,205***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	4,437	887	5,325	4,437	887	5,325
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,713	343	2,056	1,713	343	2,056
	TOTAL PROJECT COSTS	***30,514***	***6,103***	***20%***	***36,617***	***67,988***	***13,598***	***81,586***	***67,988***	***13,598***	***81,586***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$868	$156	18.0%	$1,024	$1,863	$335	$2,199	$1,863	$335	$2,199

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY46
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2046 EFFECTIVE PRICING LEVEL: 01 OCT 2045			FULLY FUNDED ESTIMATE FY 2046		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	25,844	5,169	20%	31,013	56,607	11,321	67,928	56,607	11,321	67,928
	TOTAL CONSTRUCTION COST	***25,844***	***5,169***	***20%***	***31,013***	***56,607***	***11,321***	***67,928***	***56,607***	***11,321***	***67,928***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	4,566	913	5,479	4,566	913	5,479
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,763	353	2,116	1,763	353	2,116
	TOTAL PROJECT COSTS	***27,562***	***5,512***	***20%***	***33,074***	***62,936***	***12,587***	***75,523***	***62,936***	***12,587***	***75,523***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$407	$73	18.0%	$480	$892	$160	$1,052	$892	$160	$1,052

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY47
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2047 EFFECTIVE PRICING LEVEL: 01 OCT 2046			FULLY FUNDED ESTIMATE FY 2047		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	25,844	5,169	20%	31,013	57,739	11,548	69,287	57,739	11,548	69,287
	TOTAL CONSTRUCTION COST	***25,844***	***5,169***	***20%***	***31,013***	***57,739***	***11,548***	***69,287***	***57,739***	***11,548***	***69,287***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	4,699	940	5,638	4,699	940	5,638
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,814	363	2,177	1,814	363	2,177
	TOTAL PROJECT COSTS	***27,562***	***5,512***	***20%***	***33,074***	***64,252***	***12,850***	***77,102***	***64,252***	***12,850***	***77,102***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$407	$73	18.0%	$480	$909	$164	$1,073	$909	$164	$1,073

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY48
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2048 EFFECTIVE PRICING LEVEL: 01 OCT 2047			FULLY FUNDED ESTIMATE FY 2048		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	25,844	5,169	20%	31,013	58,894	11,779	70,673	58,894	11,779	70,673
	TOTAL CONSTRUCTION COST	***25,844***	***5,169***	***20%***	***31,013***	***58,894***	***11,779***	***70,673***	***58,894***	***11,779***	***70,673***
30	PLANNING, ENGINEERING AND DESIGN	1,239	248	20%	1,487	4,835	967	5,802	4,835	967	5,802
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,867	373	2,240	1,867	373	2,240
	TOTAL PROJECT COSTS	***27,562***	***5,512***	***20%***	***33,074***	***65,596***	***13,119***	***78,715***	***65,596***	***13,119***	***78,715***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$332	$60	18.0%	$391	$756	$136	$892	$756	$136	$892

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY49
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2049 EFFECTIVE PRICING LEVEL: 01 OCT 2048			FULLY FUNDED ESTIMATE FY 2049		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	25,514	5,103	20%	30,617	59,306	11,861	71,167	59,306	11,861	71,167
	TOTAL CONSTRUCTION COST	***25,514***	***5,103***	***20%***	***30,617***	***59,306***	***11,861***	***71,167***	***59,306***	***11,861***	***71,167***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	4,911	982	5,893	4,911	982	5,893
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,921	384	2,305	1,921	384	2,305
	TOTAL PROJECT COSTS	***27,216***	***5,443***	***20%***	***32,659***	***66,138***	***13,228***	***79,365***	***66,138***	***13,228***	***79,365***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$288	$52	18.0%	$340	$669	$120	$790	$669	$120	$790

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY50
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2050 EFFECTIVE PRICING LEVEL: 01 OCT 2049			FULLY FUNDED ESTIMATE FY 2050		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	25,514	5,103	20%	30,617	60,492	12,098	72,591	60,492	12,098	72,591
	TOTAL CONSTRUCTION COST	***25,514***	***5,103***	***20%***	***30,617***	***60,492***	***12,098***	***72,591***	***60,492***	***12,098***	***72,591***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	5,053	1,011	6,064	5,053	1,011	6,064
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	1,977	395	2,372	1,977	395	2,372
	TOTAL PROJECT COSTS	***27,216***	***5,443***	***20%***	***32,659***	***67,522***	***13,504***	***81,027***	***67,522***	***13,504***	***81,027***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$288	$52	18.0%	$340	$683	$123	$806	$683	$123	$806

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY51
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2051 EFFECTIVE PRICING LEVEL: 01 OCT 2050			FULLY FUNDED ESTIMATE FY 2051		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	25,514	5,103	20%	30,617	61,702	12,340	74,042	61,702	12,340	74,042
	TOTAL CONSTRUCTION COST	***25,514***	***5,103***	***20%***	***30,617***	***61,702***	***12,340***	***74,042***	***61,702***	***12,340***	***74,042***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	5,200	1,040	6,240	5,200	1,040	6,240
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	2,034	407	2,441	2,034	407	2,441
	TOTAL PROJECT COSTS	***27,216***	***5,443***	***20%***	***32,659***	***68,935***	***13,787***	***82,723***	***68,935***	***13,787***	***82,723***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$230	$41	18.0%	$271	$556	$100	$656	$556	$100	$656

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY52
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2052 EFFECTIVE PRICING LEVEL: 01 OCT 2051			FULLY FUNDED ESTIMATE FY 2052		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	25,514	5,103	20%	30,617	62,934	12,587	75,521	62,934	12,587	75,521
	TOTAL CONSTRUCTION COST	***25,514***	***5,103***	***20%***	***30,617***	***62,934***	***12,587***	***75,521***	***62,934***	***12,587***	***75,521***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	5,351	1,070	6,421	5,351	1,070	6,421
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	2,093	419	2,512	2,093	419	2,512
	TOTAL PROJECT COSTS	***27,216***	***5,443***	***20%***	***32,659***	***70,378***	***14,076***	***84,453***	***70,378***	***14,076***	***84,453***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$249	$45	18.0%	$294	$615	$111	$725	$615	$111	$725

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY53
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2053 EFFECTIVE PRICING LEVEL: 01 OCT 2052			FULLY FUNDED ESTIMATE FY 2053		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	23,616	4,723	20%	28,339	59,418	11,884	71,301	59,418	11,884	71,301
	TOTAL CONSTRUCTION COST	***23,616***	***4,723***	***20%***	***28,339***	***59,418***	***11,884***	***71,301***	***59,418***	***11,884***	***71,301***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	5,506	1,101	6,607	5,506	1,101	6,607
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	2,154	431	2,585	2,154	431	2,585
	TOTAL PROJECT COSTS	***25,317***	***5,063***	***20%***	***30,381***	***67,077***	***13,415***	***80,493***	***67,077***	***13,415***	***80,493***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$691	$124	18.0%	$815	$1,738	$313	$2,051	$1,738	$313	$2,051

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY54
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY — PREPARED BY : CENAB-EN-DT , LUAN NGO
LOCATION : JAMES ISLAND, MD — P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2054 EFFECTIVE PRICING LEVEL: 01 OCT 2053			FULLY FUNDED ESTIMATE FY 2054		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	3,694	739	20%	4,433	9,480	1,896	11,376	9,480	1,896	11,376
	TOTAL CONSTRUCTION COST	***3,694***	***739***	***20%***	***4,433***	***9,480***	***1,896***	***11,376***	***9,480***	***1,896***	***11,376***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	5,665	1,133	6,798	5,665	1,133	6,798
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	2,216	443	2,659	2,216	443	2,659
	TOTAL PROJECT COSTS	***5,396***	***1,079***	***20%***	***6,475***	***17,362***	***3,472***	***20,834***	***17,362***	***3,472***	***20,834***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$230	$41	18.0%	$271	$590	$106	$696	$590	$106	$696

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY55
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY — PREPARED BY : CENAB-EN-DT , LUAN NGO
LOCATION : JAMES ISLAND, MD — P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2055 EFFECTIVE PRICING LEVEL: 01 OCT 2054			FULLY FUNDED ESTIMATE FY 2055		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	3,694	739	20%	4,433	9,670	1,934	11,603	9,670	1,934	11,603
	TOTAL CONSTRUCTION COST	***3,694***	***739***	***20%***	***4,433***	***9,670***	***1,934***	***11,603***	***9,670***	***1,934***	***11,603***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	5,830	1,166	6,996	5,830	1,166	6,996
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	2,281	456	2,737	2,281	456	2,737
	TOTAL PROJECT COSTS	***5,396***	***1,079***	***20%***	***6,475***	***17,780***	***3,556***	***21,336***	***17,780***	***3,556***	***21,336***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$230	$41	18.0%	$271	$602	$108	$710	$602	$108	$710

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY56
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2056 EFFECTIVE PRICING LEVEL: 01 OCT 2055			FULLY FUNDED ESTIMATE FY 2056		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	16,521	3,304	20%	19,825	44,111	8,822	52,933	44,111	8,822	52,933
	TOTAL CONSTRUCTION COST	***16,521***	***3,304***	***20%***	***19,825***	***44,111***	***8,822***	***52,933***	***44,111***	***8,822***	***52,933***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	5,999	1,200	7,199	5,999	1,200	7,199
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	2,347	469	2,816	2,347	469	2,816
	TOTAL PROJECT COSTS	***18,222***	***3,644***	***20%***	***21,867***	***52,456***	***10,491***	***62,947***	***52,456***	***10,491***	***62,947***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$280	$50	18.0%	$331	$748	$135	$883	$748	$135	$883

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY57
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2057 EFFECTIVE PRICING LEVEL: 01 OCT 2056			FULLY FUNDED ESTIMATE FY 2057		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	16,521	3,304	20%	19,825	44,993	8,999	53,991	44,993	8,999	53,991
	TOTAL CONSTRUCTION COST	***16,521***	***3,304***	***20%***	***19,825***	***44,993***	***8,999***	***53,991***	***44,993***	***8,999***	***53,991***
30	PLANNING, ENGINEERING AND DESIGN	1,223	245	20%	1,468	6,173	1,235	7,407	6,173	1,235	7,407
31	CONSTRUCTION MANAGEMENT	478	96	20%	574	2,415	483	2,898	2,415	483	2,898
	TOTAL PROJECT COSTS	***18,222***	***3,644***	***20%***	***21,867***	***53,580***	***10,716***	***64,296***	***53,580***	***10,716***	***64,296***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$230	$41	18.0%	$271	$626	$113	$739	$626	$113	$739

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY58
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2058 EFFECTIVE PRICING LEVEL: 01 OCT 2057			FULLY FUNDED ESTIMATE FY 2058		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	330	66	20%	396	917	183	1,100	917	183	1,100
	TOTAL CONSTRUCTION COST	***330***	***66***	***20%***	***396***	***917***	***183***	***1,100***	***917***	***183***	***1,100***
30	PLANNING, ENGINEERING AND DESIGN	956	191	20%	1,147	4,965	993	5,958	4,965	993	5,958
31	CONSTRUCTION MANAGEMENT	263	53	20%	316	1,368	274	1,642	1,368	274	1,642
	TOTAL PROJECT COSTS	***1,549***	***310***	***20%***	***1,859***	***7,250***	***1,450***	***8,700***	***7,250***	***1,450***	***8,700***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$230	$41	18.0%	$271	$639	$115	$753	$639	$115	$753

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY59
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2059 EFFECTIVE PRICING LEVEL: 01 OCT 2058			FULLY FUNDED ESTIMATE FY 2059		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	330	66	20%	396	935	187	1,122	935	187	1,122
	TOTAL CONSTRUCTION COST	***330***	***66***	***20%***	***396***	***935***	***187***	***1,122***	***935***	***187***	***1,122***
30	PLANNING, ENGINEERING AND DESIGN	956	191	20%	1,147	5,109	1,022	6,131	5,109	1,022	6,131
31	CONSTRUCTION MANAGEMENT	263	53	20%	316	1,408	282	1,690	1,408	282	1,690
	TOTAL PROJECT COSTS	***1,549***	***310***	***20%***	***1,859***	***7,452***	***1,490***	***8,942***	***7,452***	***1,490***	***8,942***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$230	$41	18.0%	$271	$651	$117	$768	$651	$117	$768

Date Prepared: 2/5/2009

TOTAL PROJECT COST SUMMARY
FY60
THIS ESTIMATE IS BASED ON THE DRAFT FEASIBILITY STUDY, DATED MAR 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : JAMES ISLAND, MD

PREPARED BY : CENAB-EN-DT , LUAN NGO
P.O.C.: DANIEL DURSKI, ACTING CHIEF, ESTIMATING AND SPECS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MII ESTIMATE 03 MAR 08 EFFECTIVE PRICING LEVEL 01 OCT 07				AUTHORIZ./BUDGET YEAR: 2060 EFFECTIVE PRICING LEVEL: 01 OCT 2059			FULLY FUNDED ESTIMATE FY 2060		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORT, & HARBORS	330	66	20%	396	954	191	1,144	954	191	1,144
	TOTAL CONSTRUCTION COST	***330***	***66***	***20%***	***396***	***954***	***191***	***1,144***	***954***	***191***	***1,144***
30	PLANNING, ENGINEERING AND DESIGN	956	191	20%	1,147	5,257	1,051	6,308	5,257	1,051	6,308
31	CONSTRUCTION MANAGEMENT	263	53	20%	316	1,449	290	1,739	1,449	290	1,739
	TOTAL PROJECT COSTS	***1,549***	***310***	***20%***	***1,859***	***7,659***	***1,532***	***9,191***	***7,659***	***1,532***	***9,191***
	O&M										
12	NAVIGATION, PORTS & HARBORS	$230	$41	18.0%	$271	$664	$120	$784	$664	$120	$784

TOTAL PROJECT COST SUMMARY
ALL CONTRACTS
THIS ESTIMATE IS BASED ON THE FEASIBILITY STUDY, DATED MARCH 2008

PROJECT: MID-BAY ISLAND STUDY
LOCATION : BARREN ISLAND, MARYLAND

PREPARED BY : CENAB-EN-DT LUAN NGO
P.O.C.: DANIEL DURSKI, CHIEF, ESTIMATING & SPECIFICATIONS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MCACES ESTIMATE 3 MAR 08 EFFECTIVE PRICING LEVEL 1OCT 07				AUTHORIZ /BUDGET YEAR FY 08 EFFECTIVE PRICING LEVEL: 1 OCT 07			FULLY FUNDED ESTIMATE		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORTS & HARBORS	35,306	6,694	19%	42,000	35,306	6,694	42,000	38,429	7,276	45,705
	TOTAL CONSTRUCTION COST	**35,306**	**6,694**	**19%**	**42,000**	**35,306**	**6,694**	**42,000**	**38,429**	**7,276**	**45,705**
01	LAND AND DAMAGES	$58	$12	20.0%	$69	58	12	69	$66	$13	$79
30	PLANNING, ENGINEERING AND DESIGN	466	93	20%	560	466	93	560	517	103	620
31	CONSTRUCTION MANAGEMENT	953	191	20%	1,144	953	191	1,144	1,087	217	1,304
	TOTAL PROJECT COSTS	**36,783**	**6,989**	**19%**	**43,773**	**36,783**	**6,989**	**43,773**	**40,098**	**7,609**	**47,708**
	O&M										
12	NAVIGATION, PORTS & HARBORS	139	25	18%	164	139	25	164	155	28	183

DISTRICT APPROVED:

_____ ACTING CHIEF, ESTIMATING AND SPECIFICATIONS SECTION

_____ CHIEF, REAL ESTATE DIVISION

_____ CHIEF, PLANNING DIVISION

_____ CHIEF, CIVIL PROJECT MANAGEMENT BRANCH

_____ CHIEF, ENGINEERING DIVISION

_____ 5/20/08 CHIEF, OPERATIONS DIVISION

_____ CHIEF, PROGRAMS MANAGEMENT BRANCH

_____ PROJECT MANAGER

_____ DDE (PM)

DIVISION APPROVED:

CHIEF, COST ENGINEERING _____

DIRECTOR REALESTATE _____

CHIEF, PROGRAMS MANAGEMENT _____

DIRECTOR OF PPMD _____

APPROVED DATE: _____

TOTAL PROJECT COST SUMMARIES

FY - 09

THIS ESTIMATE IS BASED ON THE FEASIBILITY STUDY, DATED MARCH 2008

PROJECT: MID-BAY ISLAND STUDY — PREPARED BY : CENAB-EN-DT LUAN NGO

LOCATION : BARREN ISLAND, MARYLAND — P.O.C.: DANIEL DURSKI, CHIEF, ESTIMATING & SPECIFICATIONS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MCACES ESTIMATE 3 MAR 08 EFFECTIVE PRICING LEVEL 1OCT 07				AUTHORIZ./BUDGET YEAR FY-09 EFFECTIVE PRICING LEVEL: 1 Oct 08			FULLY FUNDED ESTIMATE		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORTS & HARBORS	$0	$0	0.0%	$0	$0	$0	$0	$0	$0	$0
	TOTAL CONSTRUCTION COST	$0	$0	0.0%	$0	$0	$0	$0	$0	$0	$0
01	LAND AND DAMAGES	$13	$3	20.0%	$15	$14	$3	$17	$14	$3	$17
30	PLANNING, ENGINEERING AND DESIGN	$235	$47	20.0%	$282	$253	$51	$304	$253	$51	$304
31	CONSTRUCTION MANAGEMENT	$0	$0	0.0%	$0	$0	$0	$0	$0	$0	$0
	TOTAL PROJECT COSTS	$248	$50	20.0%	$298	$267	$53	$321	$267	$53	$321

TOTAL PROJECT COST SUMMARIES

FY - 10

THIS ESTIMATE IS BASED ON THE FEASIBILITY STUDY, DATED MARCH 2008

PROJECT: MID-BAY ISLAND STUDY — PREPARED BY : CENAB-EN-DT LUAN NGO

LOCATION : BARREN ISLAND, MARYLAND — P.O.C.: DANIEL DURSKI, CHIEF, ESTIMATING & SPECIFICATIONS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MCACES ESTIMATE 3 MAR 08 EFFECTIVE PRICING LEVEL 1OCT 07				AUTHORIZ./BUDGET YEAR FY-10 EFFECTIVE PRICING LEVEL: 1 OCT 09			FULLY FUNDED ESTIMATE		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORTS & HARBORS	$15,102	$3,020	20.0%	$18,123	$16,205	$3,241	$19,446	$16,205	$3,241	$19,446
	TOTAL CONSTRUCTION COST	$15,102	$3,020	20.0%	$18,123	$16,205	$3,241	$19,446	$16,205	$3,241	$19,446
01	LAND AND DAMAGES	$18	$4	20.0%	$22	$20	$4	$24	$20	$4	$24
30	PLANNING, ENGINEERING AND DESIGN	$115	$23	20.0%	$139	$129	$26	$155	$129	$26	$155
31	CONSTRUCTION MANAGEMENT	$478	$96	20.0%	$574	$535	$107	$642	$535	$107	$642
	TOTAL PROJECT COSTS	$15,714	$3,143	20.0%	$18,857	$16,889	$3,378	$20,267	$16,889	$3,378	$20,267

TOTAL PROJECT COST SUMMARIES

FY - 11

THIS ESTIMATE IS BASED ON THE FEASIBILITY STUDY, DATED MARCH 2008

PROJECT: MID-BAY ISLAND STUDY — PREPARED BY : CENAB-EN-DT LUAN NGO

LOCATION : BARREN ISLAND, MARYLAND — P.O.C.: DANIEL DURSKI, CHIEF, ESTIMATING & SPECIFICATIONS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MCACES ESTIMATE 3 MAR 08 EFFECTIVE PRICING LEVEL 1OCT 07				AUTHORIZ./BUDGET YEAR FY-11 EFFECTIVE PRICING LEVEL: 1 OCT 10			FULLY FUNDED ESTIMATE		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORTS & HARBORS	$15,614	$3,123	20.0%	$18,736	$17,097	$3,419	$20,516	$17,097	$3,419	$20,516
	TOTAL CONSTRUCTION COST	$15,614	$3,123	20.0%	$18,736	$17,097	$3,419	$20,516	$17,097	$3,419	$20,516
01	LAND AND DAMAGES	$18	$4	20.0%	$22	$21	$4	$25	$21	$4	$25
30	PLANNING, ENGINEERING AND DESIGN	$115	$23	20.0%	$139	$134	$27	$161	$134	$27	$161
31	CONSTRUCTION MANAGEMENT	$475	$95	20.0%	$570	$551	$110	$662	$551	$110	$662
	TOTAL PROJECT COSTS	$16,222	$3,244	20.0%	$19,466	$17,804	$3,561	$21,364	$17,804	$3,561	$21,364

TOTAL PROJECT COST SUMMARIES

FY - 12

THIS ESTIMATE IS BASED ON THE FEASIBILITY STUDY, DATED MARCH 2008

PROJECT: MID-BAY ISLAND STUDY (WETLAND PLANTING) PREPARED BY : CENAB-EN-DT LUAN NGO

LOCATION : BARREN ISLAND, MARYLAND P.O.C.: DANIEL DURSKI, CHIEF, ESTIMATING & SPECIFICATIONS SECTION

ACCOUNT NUMBER	ITEM DESCRIPTION	CURRENT MCACES ESTIMATE 3 MAR 08 EFFECTIVE PRICING LEVEL 1OCT 07				AUTHORIZ./BUDGET YEAR FY-12 EFFECTIVE PRICING LEVEL: 1 OCT 11			FULLY FUNDED ESTIMATE		
		COST ($K)	CNTG ($K)	CNTG %	TOTAL ($K)	COST ($K)	CNTG ($K)	TOTAL ($K)	COST ($K)	CNTG ($K)	FULL ($K)
12	NAVIGATION, PORTS & HARBORS	$4,590	$551	12.0%	$5,141	$5,127	$615	$5,742	$5,127	$615	$5,742
	TOTAL CONSTRUCTION COST	$4,590	$551	12.0%	$5,141	$5,127	$615	$5,742	$5,127	$615	$5,742
01	LAND AND DAMAGES	$9	$2	20.0%	$11	$11	$2	$13	$11	$2	$13
	TOTAL PROJECT COSTS	$4,599	$553	12.0%	$5,152	$5,138	$617	$5,755	$5,138	$617	$5,755
	O&M										
12	NAVIGATION, PORTS & HARBORS	$139	$25	18.0%	$164	$155	$28	$183	$155	$28	$183

ITR CERTIFICATION for COST ESTIMATE

Formal ITR for Project Baselines Requiring Congressional Funding:

As of 29 April 2008, Walla Walla District, Cost Engineering Center of Expertise (Cx) for Civil Works Projects, certifies the Total Project Cost approximating $2,806,482,000 for the James Island & Barren Island Project as part of the Mid-Chesapeake Bay Island Ecosystem Restoration Project located in Chesapeake Bay, Maryland, developed and presented by Baltimore District. The Walla Walla Cost Cx and independent ITR reviewer (Mr. Wally Brassfield) have provided an adequate Independent Technical Review (ITR) of the Total Project Cost baseline, studying the project scope, report, cost estimates, schedules, escalation and contingencies in accordance with ER 1110-2-1150 Engineering and Design for Civil Works Projects and ER 1110-2-1302 Civil Works Cost Engineering.

1 May 2008

James Neubauer, PE, CCE, PM1
ITR Cost Engineering Lead for:

Kim Callan, PE ,CCE, PM1
CH, Cost Engineering Branch
Walla Walla District

James Island & Barren Island
Cost Risk Analysis Report
9 April 2008

1. Purpose and Scope

The primary purpose of the Cost and Schedule Risk Analysis (CSRA) described in this report is to quantify contingencies for the James Island & Barren Island Project (JBIP) as part of the Mid-Chesapeake Bay Island Ecosystem Restoration Project located in Chesapeake Bay, Maryland.

The scope of this report is to identify project cost estimate contingencies and is based on probabilistic risk analysis methods. The results are intended to provide project leadership with contingency information for scheduling, budgeting, and project control purposes, as well as to provide tools to support decision making and risk management as the project progresses through planning and implementation. To fully recognize its benefits, CSRA should be considered as an ongoing process conducted concurrent to, and iteratively with, other important project processes such as scope and execution plan development, resource planning, procurement planning, cost estimating, budgeting and scheduling.

The CSRA is a requirement only for the portion of the project that is currently federally-authorized (as described further in Section 2); however, federal risks are probably better understood within the context, objectives and constraints of the project in its entirety. Therefore, the scope of the CSRA includes the complete Project and results are provided for both federal and non-federal project scopes.

In addition to broadly defined risk analysis standards and recommended practices, the CSRA was performed to meet the requirements and recommendations of the following documents and sources:

- Cost and Schedule Risk Analysis Process guidance prepared by the U.S. Army Corps of Engineers (USACE), dated August 2007.
- Application of Cost Risk Analysis Methods to Develop Contingencies for Civil Works Total Project Costs
- Memorandum from Major General Don T. Riley (US Army Director of Civil Works), dated July 3, 2007.
- Application of Cost Risk Analysis Methods to Develop Contingencies for Civil Works Total Project Costs
- Engineering and Construction bulletin issued by James C. Dalton, P.E. (Chief, Engineering and Construction, Directorate of Civil Works), dated September 10, 2007.
- Project-specific, independent technical review comments, suggestions and recommendations provided by Walla Walla District personnel.

2. Risk Analysis Process

The risk analysis process used for the JBIP Project is intended to determine the probability of various cost outcomes and quantify the required contingency needed in the cost estimate to achieve any desired level of confidence.

In simple terms, contingency is an amount added to an estimate (cost or schedule) to allow for items, conditions or events for which the occurrence or impact is uncertain and that experience suggests will likely result in additional costs being incurred or additional time being required. The amount of contingency included in project control plans depends, at least in part, on the project leadership's willingness to accept risk. The less risk that project leadership is willing to accept that the project will overrun its budget or schedule, the more contingency that it should include in the control plans. The risk of overrun is expressed, in a probabilistic context, using confidence levels.

USACE guidance focuses on the eighty-percent level of confidence (P80) and, accordingly, the risk analysis for the JBIP Project generally highlights that particular level in reporting results. It should be noted that use of P80 as a decision criteria is a risk adverse approach (whereas the use of P50 would be a risk neutral approach, and use of levels less than fifty-percent would be risk-seeking).

The risk analysis process uses Monte Carlo techniques to determine probabilities and contingency. The Monte Carlo techniques are facilitated computationally by a commercially available risk analysis software package (Crystal Ball) that is an add-in to Microsoft Excel. The specific use of the Crystal Ball software is identified as a USACE requirement in the September 10, 2007 engineering and construction bulletin listed in Section 1. Because Crystal Ball is an Excel add-in, both the cost estimate and schedule were recreated in Excel format from their native MII (MCACES 2nd Generation) formats. The level of detail recreated in the Excel-format cost estimate and schedule is sufficient for CSRA purposes, but generally less than that of the native formats. It is important to note that no contingency was included in the cost estimate so that the estimate costs represent the most likely outcomes without subjective adjustments for perceived risks.

The primary steps, in functional terms, of the risk analysis process are described in the following subsections. Risk analysis results are provided in Section 4.

2.1 Identify and Assess Risk Factors

Risk factors are events and conditions that may influence or drive uncertainty in project performance. They may be inherent characteristics or conditions of the project, or external influences, events, or conditions such as weather or economic conditions. Risk factors may have either favorable or unfavorable impacts on project cost and schedule.

Checklists or historical databases of common risk factors are sometimes used to facilitate risk factor identification. However, key risk factors are often unique to a project and not readily derivable from historical information. Therefore, input from the entire project team about its risk perceptions is generally obtained using creative processes such as brainstorming or other facilitated risk assessment

meetings. In practice, a combination of professional judgment from the project team and empirical data from similar projects is desirable.

Project team meetings were held for the formal purposes of identifying and assessing JBIP Project risk factors. Meeting attendance included capable and qualified representatives from multiple project team disciplines and functions, including project management, technical management, finance, design engineering, cost engineering and estimating, scheduling and risk analysis. Meetings focused primarily on risk factor identification using brainstorming techniques, but also included some facilitated discussions based on risk factors common to projects of similar scope and risk factor assessment and quantification. It was facilitated using a consensus-building approach.

Results of the risk identification meetings are summarized in the risk register tables provided within this document (Appendix A).

2.2 Quantify Risk Factor Impacts

An effective CSRA process requires a clear understanding of each key risk factor and its potential impact to project cost and schedule. Moreover, risk factors should be carefully and thoughtfully defined in mathematical terms to avoid interactions and dependencies that may prove difficult for the project team to understand or estimate. For these cognitive reasons, as well as computational efficiency, risk factors used in probabilistic risk analysis should be modeled as independent random variables to the extent possible.

The quantitative impacts of JBIP Project risk factors on project plans were analyzed using a combination of professional judgment, empirical data and analytical techniques. Risk factor impacts were quantified using probability distributions (density functions), both as a tool to help project team members visualize the uncertainty of risk factor impacts, and because risk factors are entered into the Crystal Ball software in the form of probability density functions.

Similar to the identification and assessment process, risk factor quantification involved multiple project team disciplines and functions, including project management, technical management, finance, design engineering, cost engineering and estimating, scheduling and risk analysis. However, the quantification process relied more extensively on collaboration between technical management, cost engineering, scheduling and risk analysis team members with lesser inputs from other functions and disciplines.
The project team used an iterative, consensus-building approach to estimate the following elements of each risk factor:

- Maximum possible value for the risk factor
- Minimum possible value for the risk factor
- Most likely value (the statistical mode), if applicable
- Nature of the probability density function used to approximate risk factor uncertainty

For this CSRA, risk factors are defined in mathematical terms to literally function as factors (i.e., a number multiplied by an estimated cost or schedule duration to form a product) in the Monte Carlo simulations used to quantify contingency. Accordingly, the risk factors are generally expressed in the form of a percentage with a statistical mode equal to 100%. This approach is favorable conceptually because it results in the most likely value of an estimated cost or schedule duration being preserved in probabilistic terms when it is multiplied by the risk factor (e.g., a deterministic most likely cost in the MII estimate multiplied by a risk factor with a mode of 100% yields a probability distribution of costs with a mode equal to the most likely cost).

Model data are presented in Appendix B and Model parameters called assumption distribution charts are included in Appendix C.

Upon completion of the risk analysis, sensitivity charts (or Tornado Charts) are developed to depicts key cost drivers that have a high probability of occurrence. These key drivers are shown in Appendix D.

2.3 Analyze Contingency

Contingency was analyzed using the Crystal Ball software as an add-in to the Microsoft Excel format of the cost estimate and schedule. Monte Carlo simulations were performed by applying the risk factors (quantified as probability density functions) to the appropriate estimated cost and schedule elements identified by the project team.

For the cost estimate, the total project contingency was calculated as the difference between the P80 cost forecast and the most likely cost. The total project contingency was then allocated on a feature-specific level based on the dollar-weighed relative risk of each feature as quantified by Monte Carlo simulation. Standard deviation was used as the feature-specific measure of risk for contingency allocation purposes. This approach results in a relatively larger portion of total project contingency being allocated to features with relatively higher estimated cost uncertainty.

3. Risk Analysis Results

The results of the JBIP Project CSRA are provided in the following sections.

3.1 Risk Register

A risk register is a tool commonly used in project planning and risk analysis. The JBIP Project risk register (Appendix A) reflects the results of risk factor identification and assessment, risk factor quantification, and contingency analysis.

It is important to note that the risk register can be an effective tool for managing identified risks throughout the project lifecycle. As such, it is recommended that the risk register be updated as the JBIP Project progresses through planning and implementation.

Recommended uses of the risk register going forward include:

- Documenting risk mitigation strategies being pursued in response to the identified risks and their assessment in terms of probability and impact.
- Providing project sponsors, stakeholders and leadership/management with a documented framework from which risk status can be reported in the context of project controls.
- Communicating risk management issues to stakeholders.
- Providing a mechanism for eliciting risk analysis feedback and project control input from stakeholders.
- Identifying risk transfer, elimination or mitigation actions required for implementation of risk management plans.

3.2 Summary of Cost Contingency

Project cost contingency for James Island & Barren Island was quantified as 25% of total estimated costs based on P80. Table 1 provides the implied, overall project cost contingencies calculated for various levels of confidence. Figure 1 presents the Table 1 data in a graphical format.

James Island & Barren Estimate

Contingency Analysis

Most Likely Cost Estimate	$ 1,274,820,564
Confidence Level	**Value**	**Contingency**
0%	715,026,991	-43.9%
5%	1,046,100,604	-17.9%
10%	1,097,320,418	-13.9%
15%	1,133,395,091	-11.1%
20%	1,163,051,509	-8.8%
25%	1,189,709,415	-6.7%
30%	1,214,961,240	-4.7%
35%	1,240,082,290	-2.7%
40%	1,265,252,533	-0.8%
45%	1,291,542,073	1.3%
50%	1,319,371,426	3.5%
55%	1,350,885,978	6.0%
60%	1,386,484,218	8.8%
65%	1,428,093,742	12.0%
70%	1,475,469,583	15.7%
75%	1,528,913,524	19.9%
80%	1,588,549,304	24.6%
85%	1,657,269,166	30.0%
90%	1,737,416,674	36.3%
95%	1,846,764,183	44.9%
100%	2,452,548,644	92.4%

Table 1

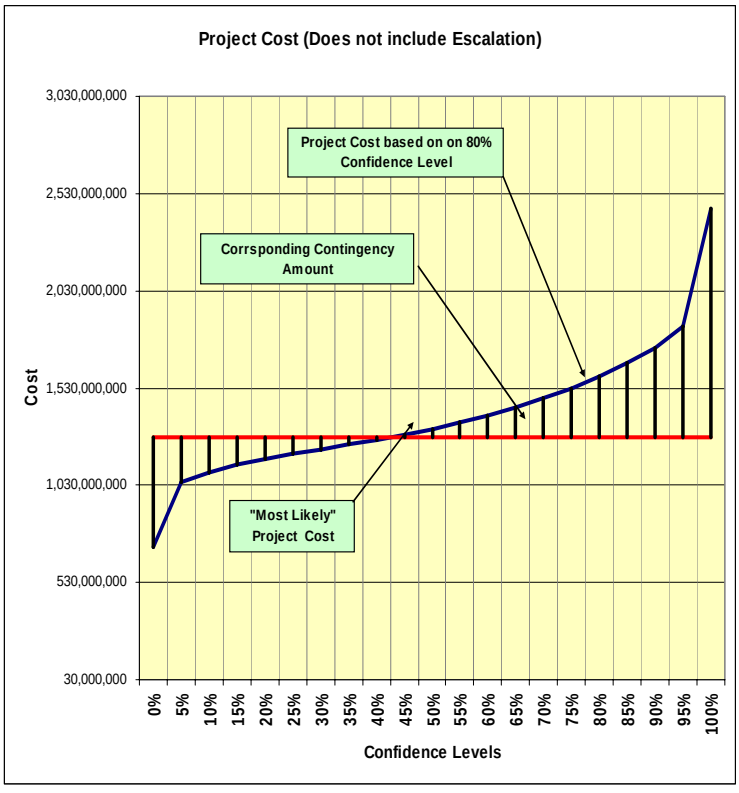


Figure A

Project cost contingency for O&M was quantified as 19% of total estimated costs based on P80. Table 2 provides the implied, overall project cost contingencies calculated for various levels of confidence.

O&M
Contingency Analysis

Confidence Level		Value		Contingency
0%		19,989,993		0.0%
5%		21,095,471		5.5%
10%		21,490,290		7.5%
15%		21,845,048		9.3%
20%		22,169,766		10.9%
25%		22,489,255		12.5%
30%		22,837,597		14.2%
35%		23,225,476		16.2%
40%		23,691,659		18.5%
45%		24,338,632		21.8%
50%		27,310,013		36.6%
55%		22,674,786		13.4%
60%		22,847,153		14.3%
65%		23,020,814		15.2%
70%		23,198,407		16.1%
75%		23,420,700		17.2%
80%		23,656,497		18.3%
85%		23,945,908		19.8%
90%		24,281,115		21.5%
95%		24,797,594		24.1%
100%		27,357,349		36.9%

Table 2

Project cost contingency for Wetland Development was quantified as 13% of total estimated costs based on P80. Table 3 provides the implied, overall project cost contingencies calculated for various levels of confidence.

Wetlands
Contingency Analysis

Confidence Level		Value		Contingency
0%		4,574,477		-0.3%
5%		4,632,388		0.9%
10%		4,660,097		1.5%
15%		4,687,061		2.1%
20%		4,714,046		2.7%
25%		4,742,825		3.3%
30%		4,773,147		4.0%
35%		4,805,132		4.7%
40%		4,835,369		5.3%
45%		4,869,492		6.1%
50%		4,904,125		6.8%
55%		4,940,671		7.6%
60%		4,980,000		8.5%
65%		5,019,977		9.4%
70%		5,064,724		10.3%
75%		5,113,379		11.4%
80%		5,166,038		12.5%
85%		5,224,636		13.8%
90%		5,295,739		15.4%
95%		5,388,906		17.4%
100%		5,652,791		23.2%

Table 3

Additional forecast for various cost components are shown in Appendix E

Appendix A – Risk Registers

Risk Register

Risk Level

Likelihood of Occurrence						
	Very Likely	Low	Moderate	High	High	High
	Likely	Low	Moderate	High	High	High
	Unlikely	Low	Low	Moderate	Moderate	High
	Very Unlikely	Low	Low	Low	Low	High
		Negligible	Marginal	Significant	Critical	Crisis

FOR DIKE CONSTRUCTION CONSIDERATION

Impact or Consequences of Occurrence

Risk No.	Risk Event	Likelihood	Impact	Risk Level	Notes
1	Bidding Climate - Saturated Local Market	Very Unlikely	Critical	Low	Although there definitely won't be a saturated local market, but usually at least 1 bidder will show up. So, the risk is considered low, knowing the cost is usually high.
2	Volatile Real Estate Values	Na	Na	Na	No real estate acquisitions for this project
3	Scope Definition	Unlikely	Marginal	Low	Change in the design will likely not change quantities significantly
4	Scope Growth/Reduction	Unlikely	Marginal	Low	Change in the design will likely not change quantities significantly
5	Weather	Unlikely	Marginal	Low	Type of construction not necessarily weather dependent
6	Schedule Constraints	Unlikely	Marginal	Low	There are known environmental windows that are well defined and accounted for in the contract schedules
7	Labor Availability/Pricing	Likely	Marginal	Moderate	Skilled labor pool in the lower Eastern Shore could be problematic due to low population
8	Equipment Availability/Pricing	Unlikely	Marginal	Low	It is expected that contractors will be well-equipped for this type of project since one similar (Poplar Island) is currently in construction.
9	Material Availability/Pricing	Likely	Significant	High	The possible shortage of material (namely armor stone) supply due to the size of the stone and large quantity required may result in high dollars of dike construction.
10	Fuel Prices	Likely	Significant	High	It is anticipated that fuel prices will be fluctuate from time to time and it will impact dike construction costs depending on when the project will be built.
11	Potential savings due to innovation, streamlining, and gains in effeciency	Na	Na	Na	
12	Acquisition Plan	Likely	Negligible	Low	No matter what type of acquistion is planned, the bidding history for this type of project seems to indicate that an environment of about 1 or 2 bidders will likely occur. Therefore, the dike construction cost is already expected to be high due to known historical

Risk Register

Risk Level

Likelihood of Occurrence						
Very Likely	Low	Moderate	High	High	High	FOR DREDGING CONSIDERATION
Likely	Low	Moderate	High	High	High	
Unlikely	Low	Low	Moderate	Moderate	High	
Very Unlikely	Low	Low	Low	Low	High	
	Negligible	Marginal	Significant	Critical	Crisis	

Impact or Consequences of Occurrence

Risk No.	Risk Event	Likelihood	Impact	Risk Level	Notes
1	Bidding Climate - Saturated Local Market	Very Unlikely	Critical	Low	Although there definitely won't be a saturated local market, but usually at least 1 bidder will show up. So, the risk is considered low, knowing the cost is usually high.
2	Volatile Real Estate Values	Na	Na	Na	
3	Scope Definition	Unlikely	Negligible	Low	Amount of average annual dredging is very predictable
4	Scope Growth/Reduction	Unlikely	Negligible	Low	Amount of average annual dredging is very predictable
5	Weather	Very Unlikely	Marginal	Low	Dredging is not a weather dependent activity.
6	Schedule Constraints	Unlikely	Marginal	Low	There are known environmental windows that are well defined and accounted for in the contract schedules
7	Labor Availability/Pricing	Unlikely	Marginal	Low	
8	Equipment Availability/Pricing	Unlikely	Marginal	Low	It is expected that contractors will be well-equipped for this type of project since one similar (Poplar Island) is currently in construction.
9	Material Availability/Pricing	Very Unlikely	Negligible	Low	Dredging cost does not include material costs.
10	Fuel Prices	Likely	Significant	High	It is anticipated that fuel prices will be fluctuate from time to time and it will impact dike construction costs depending on when the project will be built.
11	Potential savings due to innovation, streamlining, and gains in effeciency	Na	Na	Na	
12	Acquisition Plan	Likely	Negligible	Low	No matter what type of acquisition is planned, the bidding history for dredging in this type of project seems to indicate that an environment of about 1 or 2 bidders will likely occur. Therefore, the dredging cost is already expected to be high.
13					

Risk Register

Risk Level

Likelihood of Occurrence						
	Very Likely	Low	Moderate	High	High	High
	Likely	Low	Moderate	High	High	High
	Unlikely	Low	Low	Moderate	Moderate	High
	Very Unlikely	Low	Low	Low	Low	High
		Negligible	Marginal	Significant	Critical	Crisis

FOR SITE MANAGEMENT CONSIDERATION

Impact or Consequences of Occurrence

Risk No.	Risk Event	Likelihood	Impact	Risk Level	Notes
1	Bidding Climate - Saturated Local Market	very unlikely	critical	low	Although there definitely won't be a saturated local market, but usually at least 1 bidder will show up. So, the risk is considered low, knowing the cost is usually high.
2	Volatile Real Estate Values	NA	NA	NA	
3	Scope Definition	likely	significant	HIGH	Site management cost may largely be impacted because of scope change.
4	Scope Growth/Reduction	likely	significant	HIGH	same as scope definition
5	Weather	very unlikely	marginal	low	Site development not weather sensitive over the long duration of the project.
6	Schedule Constraints	unlikely	marginal	low	
7	Labor Availability/Pricing	unlikely	marginal	low	Labor availability may be fluctuate from time to time but there is usually a contract on-board to take care of site management items.
8	Equipment Availability/Pricing	unlikely	marginal	low	It is expected that contractors will be well-equipped for this type of project since one similar (Poplar Island) is currently in construction.
9	Material Availability/Pricing	unlikely	negligible	low	Material pricing could marginally impact site management cost but because site management is more of labor and equipment effort than material impact.
10	Fuel Prices	likely	significant	HIGH	It is anticipated that fuel prices will be fluctuate from time to time and it will impact site management costs depending on when the project will be built.
11	Potential savings due to innovation, streamlining, and gains in effeciency	likely	significant	HIGH	Primarily associated with habitat development. Costs could swing either way.
12	Acquisition Plan	likely	negligible	low	No matter what type of acquisistion is planned, the bidding history for this type of project seems to indicate that an environment of about 1 or 2 bidders will likely occur. Therefore, the site management cost is already expected to be high.
13	Site Management	likely	negligible	low	Includes crust mgmt, grading, etc. are well defined and predictable.

Risk Register

Risk Level

Likelihood of Occurrence						
	Very Likely	Low	Moderate	High	High	High
	Likely	Low	Moderate	High	High	High
	Unlikely	Low	Low	Moderate	Moderate	High
	Very Unlikely	Low	Low	Low	Low	High
		Negligible	Marginal	Significant	Critical	Crisis

FOR O&M CONSIDERATION

Impact or Consequences of Occurrence

Risk No.	Risk Event	Likelihood	Impact	Risk Level	Notes
1	Bidding Climate - Saturated Local Market	Very Unlikely	Critical	Low	Although there definitely won't be a saturated local market, but usually at least 1 bidder will show up. So, the risk is considered low, knowing the cost is usually high.
2	Volatile Real Estate Values	Na	Na	Na	No real estate acquisitions for this project
3	Scope Definition	Unlikely	Marginal	Low	Change in the design will likely not change quantities significantly
4	Scope Growth/Reduction	Unlikely	Marginal	Low	Change in the design will likely not change quantities significantly
5	Weather	Unlikely	Marginal	Low	Type of construction not necessarily weather dependent
6	Schedule Constraints	Unlikely	Marginal	Low	There are known environmental windows that are well defined and accounted for in the contract schedules
7	Labor Availability/Pricing	Likely	Marginal	Moderate	Skilled labor pool in the lower Eastern Shore could be problematic due to low population
8	Equipment Availability/Pricing	Unlikely	Marginal	Low	It is expected that contractors will be well-equipped for this type of project since one similar (Poplar Island) is currently in construction.
9	Material Availability/Pricing	Likely	Significant	High	The possible shortage of material (namely armor stone) supply due to the size of the stone and large quantity required may result in high dollars of O&M
10	Fuel Prices	Likely	Significant	High	It is anticipated that fuel prices will be fluctuate from time to time and it will impact O&M costs depending on when the project will be built.
11	Potential savings due to innovation, streamlining, and gains in effeciency	Na	Na	Na	
12	Acquisition Plan	Likely	Negligible	Low	No matter what type of acquistion is planned, the bidding history for this type of project seems to indicate that an environment of about 1 or 2 bidders will likely occur. Therefore, the dike construction cost is already expected to be high due to known historical

Risk Register

Risk Level

Likelihood of Occurrence						
Very Likely	Low	Moderate	High	High	High	**For Barren Island Wetland Planting**
Likely	Low	Moderate	High	High	High	
Unlikely	Low	Low	Moderate	Moderate	High	
Very Unlikely	Low	Low	Low	Low	High	
	Negligible	Marginal	Significant	Critical	Crisis	

Impact or Consequences of Occurrence

Risk No.	Risk Event	Likelihood	Impact	Risk Level	Notes
1	Bidding Climate - Saturated Local Market	Very Unlikely	Critical	Low	Historical cost show consistency in Wetland planting costs, no matter what bidding climate it is.
2	Volatile Real Estate Values	Na	Na	Na	No real estate acquisitions for this project
3	Scope Definition	Unlikely	Marginal	Low	Change in the design will likely not change quantities significantly
4	Scope Growth/Reduction	Unlikely	Marginal	Low	Change in the design will likely not change quantities significantly
5	Weather	Unlikely	Marginal	Low	Type of construction not necessarily weather dependent
6	Schedule Constraints	Unlikely	Marginal	Low	There are known environmental windows that are well defined and accounted for in the contract schedules
7	Labor Availability/Pricing	Unlikely	Marginal	Low	It is unlikely that skilled labors for wetland planting will become unavailable.
8	Equipment Availability/Pricing	Unlikely	Marginal	Low	It is expected that contractors will be well-equipped for this type of project since one similar (Poplar Island) is currently in construction.
9	Material Availability/Pricing	Unlikely	Marginal	Low	It is unlikely to expect shortage of wetland plants.
10	Fuel Prices	Likely	Significant	High	It is anticipated that fuel prices will be fluctuate from time to time and it will impact O&M costs depending on when the project will be built.
11	Potential savings due to innovation, streamlining, and gains in effeciency	Na	Na	Na	
12	Acquisition Plan	Likely	Negligible	Low	No matter what type of acquistion is planned, the bidding history for this type of project seems to be consistent and steady.

Appendix B – Model Backup

CRYSTAL BALL ANALYSIS **BARREN ISLAND**

Barren Island Risk Analysis **$ -**

FUEL (Fuel Changes)

	LOW	BASELINE	HIGH
	33,696,483.09	33980864.69	34597024.81
Difference in Fuel Project Cost	-284,381.60	0	616,160.12
gas	$3.05 /gal	$3.25 /gal	$4.00 /gal
diesel off-road	$2.90 /gal	$3.20 /gal	$3.85 /gal
diesel on-road	$3.40 /gal	$3.60 /gal	$4.25 /gal

STONE MATERIAL (Matl only)

	Low	Baseline	High
	27,895,395.69	32135288.05	36555885.31
Difference in Stone Cost	-4,239,892.36	0	4,420,597.26
stones			*(will be a mixture of Arundel's and others)*
1300 lbs	$45.00 /ton	$45.00 /ton	$60.00 /ton
130 lbs	$25.00 /ton	$25.00 /ton	$50.00 /ton
Core Stone	$23.00 /ton	$23.00 /ton	$36.00 /ton
			39,017,622.07

FY 17

	Low		Baseline		High	
South Breakwater						
Armor Stone 1300 lbs	39550	ton	65,910.00	ton	72,501.00	ton
Intermediate Stone 130 lbs	11300	ton	18,900.00	ton	20,790.00	ton
Core Stone	9000	ton	14,970.00	ton	16,467.00	ton
	Decreased by 40% due to spacing of the breakwaters				Increase by 5% due to lost stones during placement	

CRYSTAL BALL ANALYSIS **JAMES ISLAND**
SITE MANAGEMENT

	LOW	BASELINE	HIGH
	1,256,016,434.05	1,259,542,827.90	1,267,691,890.36
FUEL	-3,526,393.85	$ -	8,149,062.46
gas	$3.05 /gal	$3.25 /gal	$4.00 /gal
diesel on-road	$3.40 /gal	$3.60 /gal	$4.25 /gal
diesel off-road	$2.90 /gal	$3.20 /gal	$3.85 /gal
	HIGH	BASELINE	LOW

	Low	Baseline	High
STONE MATERIAL (Matl only)	1,259,542,827.90	1,259,542,827.90	1,294,630,514.63
	0.00	$ -	35,087,686.73
MATERIAL			
stones			
2500-3500 lbs	$45.00 /ton	$45.00 /ton	$60.00 /ton
500-1000 lbs	$35.00 /ton	$35.00 /ton	$50.00 /ton
50-250 lbs	$25.00 /ton	$25.00 /ton	$50.00 /ton
Bedding Stone	$23.00 /ton	$23.00 /ton	$36.00 /ton
			revised unloading to $8/ton
	0% stone prices from VA Quarries		85% stone prices from VA Quarries
	100% stone prices from MD Quarries		15% stone prices from MD Quarries

	Quantity	UOM	DirectCost	DirectCost
Disposal Site Management	1	EA		
Environmmental Monitoring	1	EA	20% increase	no change
USFW Monitoring	1	EA		
NOAA	1	EA		
USGS	1	EA		
APHIS	1	EA		
Terrapins	1	EA		
Monitoring S & A	1	EA		
Site Management and Operations	1	EA		
Monitoring	1	EA	no change	no change
Treatment - pH Neutralization	1	EA		
Environmental Support	1	EA		
Laboratory Services	1	EA		
Laboratory Supplies	1	EA		
Misc. Repairs/Serv of Lab Equip	1	EA		
Site Operations	1	EA		
Project Management	1	EA	50% increase	25% decrease
Engineering and Technical Support	1	EA		
H & S Support	1	EA		
Travel / Non-Heavy Equipment Operator	1	EA		
Electric	1	EA	no change	no change
Insurance	1	EA		
Inflow Operations	1	EA	50% increase	25% decrease
Miscellaneous Dike Maintenance - Equipment	1	EA		
24 Hour Inflow Inspection	1	EA		
Miscellaneous Dike Maintenance - Labor	1	EA		
Communications	1	EA		
Radio	1	EA	no change	no change

Postal / Courier	1 EA		
Telephone	1 EA		
Miscellaneous Technical & Spec Fees	**1 EA**		
Instruction/Training	1 EA		
Engineer/Geotec Consultant	1 EA		
Contract Services	**1 EA**		
Trash Removal	1 EA	no change	no change
Water	1 EA		
Miscellaneous	1 EA		
Septic	1 EA		
Supplies & Materials	**1 EA**		
Stone, Sand, Etc.	1 EA	no change	no change
Photo Supplies	1 EA		
Office	1 EA		
Building & Household	1 EA		
Safety	1 EA		
Miscellaneous Supplies and Materials	1 EA		
Uniforms	1 EA		
Security	1 EA		
Small Tools	1 EA		
Construction Materials	1 EA		
Transportation Expenses	**1 EA**	50% increase	25% decrease
LAUNCH,20.25',TRANSPORTR,3500# (Stand-by)	500 HR	750	375
Boat Captain	2,000.00 HR	3000	1500
Deckhand	2,000.00 HR	3000	1500
LAUNCH,20.25',TRANSPORTR,3500#	1,500.00 HR	2250	1125
Additional on-site personnel	**1 EA**		
Biologist	2,080.00 HR	3120	1560
Environmental Coordinator	2,080.00 HR	3120	1560
Crust Management (quantities vary depending on the year)	**1 EA**		
Install Perimeter Trench	**1 EA**		
HYD EXCAV, CRWLR, 60,700 LBS 1.75 CY BKT, 23.25'DIG D, 34.5'R	339 HR		
Equip. Operators, Medium	678 HR		
Equip. Operators, Oilers	170 HR		
TRK,HWY, 8,800GVW,4X4, 3/4T-PKUP	848 HR		
Pontoon Long Reach Excavator	339 HR		
Cut Interior Drainage Trenches	**1 EA**		
Equip. Operators, Medium	1,614.00 HR		
Pontoon Long Reach Excavator	1,614.00 HR		
Equip. Operators, Oilers	403 HR		

Maintain trenches, sumps and bleeder channels	**1 EA**		
TRK,HWY, 8,800GVW,4X4, 3/4T-PKUP	2,296.00 HR		
Pontoon Long Reach Excavator	844 HR		
HYD EXCAV, CRWLR, 60,700 LBS 1.75 CY BKT, 23.25'DIG D, 34.5'R	993 HR		
Equip. Operators, Medium	1,837.00 HR		
Equip. Operators, Oilers	459 HR		
Miscellaneous Dike Maintenance	**1 EA**		
Equipment, Materials, Etc.	1 EA		
Labor	1 EA		
Habitat Development (Note: Grading cell W-1C (40 acres), grade cell W-3B (28 acres), and plant cell W-1A (35 acres))	**1 EA**	100% increase	25% decrease
Excavate trench, mdm soil, 4'-6' D, 1/2 CY excavator	24,200.00 CY		
Grade site with 75 HP dozer	24,200.00 CY		
Wetland planting in cell W-3 and W-4	60 ACR		
Outlet Structure	**1 EA**		
Mob and Demob including technical support	2 EA	no change	no change
Turbidity curtain, materials and installation	2 EA		
Temporary sand cofferdam	2 EA		
Remove cofferdam	2 EA		
Remove armor stone	2 EA		
Excavation of material to -1.5 ft.	2 EA		
Backfill and compaction	2 EA		
Replace armor stone	2 EA		
Remove excess material from site.	2 EA		
Driscoplex HDPE pipe	2 EA		
Installation of new pipe	2 EA		
Roadway geotextile	2 EA		
Pipe boot	2 EA		
Pipe boot skirt	2 EA		
Slope armor	2 EA		
Crushed stone roadway removal	2 EA		
Culvert Disposal	2 EA		

Crust Management

FY18, 19, 43

Install Perimeter Trench

		low est.	hi est.
Hydraulic Excavator	339 hr	254	509
Equipment op, med	678 hr	509	1017
Equipment, oiler	170 hr	128	255
Truck Hwy	848 hr	636	1272
Pontoon	339 hr	254	509

Cut Interior Drainage Trenches

		low est.	hi est.
Equipment op, med	1614 hr	1211	1816
Pontoon	1614 hr	1211	1816
Equipment, oiler	403 hr	302	453

Maintain trenches, sumps and bleeder channels

		low est.	hi est.
Truck Hwy	2296 hr	1722	3444
Pontoon	844 hr	633	1266
Hydraulic Excavator	993 hr	745	1490
Equipment op, med	1837 hr	1378	2756
Equipment, oiler	459 hr	344	689

FY20, 21, 42

Install Perimeter Trench

		low est.	hi est.
Hydraulic Excavator	463	347	695
Equipment op, med	925	694	1388
Equipment, oiler	231	173	347
Truck Hwy	1156	867	1734
Pontoon	463	347	695

Cut Interior Drainage Trenches

		low est.	hi est.
Equipment op, med	1841	1381	2071
Pontoon	1841	1381	2071
Equipment, oiler	460	345	518

Maintain trenches, sumps and bleeder channels

		low est.	hi est.
Truck Hwy	2620	1965	3930
Pontoon	963	722	1445
Hydraulic Excavator	1133	850	1700
Equipment op, med	2096	1572	3144
Equipment, oiler	524	393	786

FY22, 23, 41

Install Perimeter Trench

		low est.	hi est.
Hydraulic Excavator	586	440	879
Equipment op, med	1172	879	1758
Equipment, oiler	293	220	440
Truck Hwy	1465	1099	2198
Pontoon	339	254	509

Cut Interior Drainage Trenches

		low est.	hi est.
Equipment op, med	2069	1552	2328
Pontoon	2069	1552	2328
Equipment, oiler	517	388	582

Maintain trenches, sumps and bleeder channels

		low est.	hi est.
Truck Hwy	2944	2208	4416
Pontoon	1082	812	1623
Hydraulic Excavator	1273	955	1910
Equipment op, med	2355	1766	3533
Equipment, oiler	589	442	884

FY24

Install Perimeter Trench

		low est.	hi est.
Hydraulic Excavator	293 hr	220	440
Equipment op, med	586 hr	440	879
Equipment, oiler	146 hr	110	219
Truck Hwy	732 hr	549	1098
Pontoon	170 hr	128	255

Cut Interior Drainage Trenches

		low est.	hi est.
Equipment op, med	1034 hr	776	1163
Pontoon	1034 hr	776	1163
Equipment, oiler	258 hr	194	290

Maintain trenches, sumps and bleeder channels

		low est.	hi est.
Truck Hwy	1472 hr	1104	2208
Pontoon	541 hr	406	812
Hydraulic Excavator	636 hr	477	954
Equipment op, med	1178 hr	884	1767
Equipment, oiler	294 hr	221	441

FY25, 26

Install Perimeter Trench

		low est.	hi est.
Hydraulic Excavator	147	110	221
Equipment op, med	293	220	440
Equipment, oiler	73	55	110
Truck Hwy	366	275	549
Pontoon	85	64	128

Cut Interior Drainage Trenches

		low est.	hi est.
Equipment op, med	517	388	582
Pontoon	517	388	582
Equipment, oiler	129	97	145

Maintain trenches, sumps and bleeder channels

		low est.	hi est.
Truck Hwy	736	552	1104
Pontoon	270	203	405
Hydraulic Excavator	318	239	477
Equipment op, med	589	442	884
Equipment, oiler	147	110	221

FY27-34, 40

Install Perimeter Trench

		low est.	hi est.
Hydraulic Excavator	710	533	1065
Equipment op, med	1419	1064	2129
Equipment, oiler	355	266	533
Truck Hwy	1774	1331	2661
Pontoon	710	533	1065

Cut Interior Drainage Trenches

		low est.	hi est.
Equipment op, med	2296	1722	2583
Pontoon	2296	1722	2583
Equipment, oiler	574	431	646

Maintain trenches, sumps and bleeder channels

		low est.	hi est.
Truck Hwy	3268	2451	4902
Pontoon	1201	901	1802
Hydraulic Excavator	1413	1060	2120
Equipment op, med	2614	1961	3921
Equipment, oiler	654	491	981

FY35, 39

Install Perimeter Trench

		low est.	hi est.
Hydraulic Excavator	883 hr	662	1325
Equipment op, med	1666 hr	1250	2499
Equipment, oiler	417 hr	313	626
Truck Hwy	2083 hr	1562	3125
Pontoon	883 hr	662	1325

FY36, 38

Install Perimeter Trench

		low est.	hi est.
Hydraulic Excavator	957	718	1436
Equipment op, med	1913	1435	2870
Equipment, oiler	478	359	717
Truck Hwy	2391	1793	3587
Pontoon	957	718	1436

Cut Interior Drainage Trenches

			low est.	hi est.
Equipment op, med	2524	hr	1893	2840
Pontoon	2524	hr	1893	2840
Equipment, oiler	631	hr	473	710

Maintain trenches, sumps and bleeder channels

			low est.	hi est.
Truck Hwy	3591	hr	2693	5387
Pontoon	1320	hr	990	1980
Hydraulic Excavator	1553	hr	1165	2330
Equipment op, med	2873	hr	2155	4310
Equipment, oiler	718	hr	539	1077

FY37

Install Perimeter Trench

		low est.	hi est.
Hydraulic Excavator	1080	810	1620
Equipment op, med	2160	1620	3240
Equipment, oiler	540	405	810
Truck Hwy	2700	2025	4050
Pontoon	1080	810	1620

Cut Interior Drainage Trenches

		low est.	hi est.
Equipment op, med	2979	2234	3351
Pontoon	2979	2234	3351
Equipment, oiler	745	559	838

Maintain trenches, sumps and bleeder channels

		low est.	hi est.
Truck Hwy	4239	3179	6359
Pontoon	1558	1169	2337
Hydraulic Excavator	1833	1375	2750
Equipment op, med	3391	2543	5087
Equipment, oiler	848	636	1272

Cut Interior Drainage Trenches

			low est.	hi est.
Equipment op, med	2751		2063	3095
Pontoon	2751		2063	3095
Equipment, oiler	688		516	774

Maintain trenches, sumps and bleeder channels

			low est.	hi est.
Truck Hwy	3915		2936	5873
Pontoon	1439		1079	2159
Hydraulic Excavator	1693		1270	2540
Equipment op, med	3132		2349	4698
Equipment, oiler	783		587	1175

FY44-55

Install Perimeter Trench

			low est.	hi est.
Hydraulic Excavator	216	hr	162	324
Equipment op, med	431	hr	323	647
Equipment, oiler	108	hr	81	162
Truck Hwy	539	hr	404	809
Pontoon	216	hr	162	324

Cut Interior Drainage Trenches

			low est.	hi est.
Equipment op, med	1386	hr	1040	1559
Pontoon	1386	hr	1040	1559
Equipment, oiler	347	hr	260	390

Maintain trenches, sumps and bleeder channels

			low est.	hi est.
Truck Hwy	1973	hr	1480	2960
Pontoon	725	hr	544	1088
Hydraulic Excavator	853	hr	640	1280
Equipment op, med	1578	hr	1184	2367
Equipment, oiler	395	hr	296	593

HABITAT DEVELOPMENT

	FY28-34, 38-45		low est.	hi est.	FY54	low est.
Excavate trench, mdm soil, 4'-6' D, 1/2 CY excavator	24200	CY	18150	48400	341,200	255900
Grade site with 75 HP dozer	24200	CY	18150	48400	341,200	255900

ADAPTIVE MANAGEMENT

	FY30-48, 60		low est.	hi est.
Environmental Monitoring	160	HR	120	240
TRK,HWY, 8,800GVW,4X4, 3/4T-PKUP	500	HR	375	750
Pontoon Long Reach Excavator	500	HR	375	750
HYD EXCAV, CRWLR, 60,700 LBS 1.75 CY BKT, 23.25'DIG D, 34.5'R	500	HR	375	750
Equip. Operators, Medium	1000	HR	750	1500
Equip. Operators, Oilers	500	HR	375	750
Wetland planting in cells	6	ACR		9

James Estimate

Model Backup $ 1,240,839,699

Description	Qty	Low	ML	High
10" Galvanized deck cleat	15	$ 813	$ 813	$ 1,625
2" x 6" wood joist, framing	1560	$ 747	$ 747	$ 1,494
2" x 8" wood joist, framing	2220	$ 1,132	$ 1,132	$ 2,265
24 Hour Inflow Inspection	114	$ 4,226,250	$ 5,586,000	$ 9,297,750
250 lb underlayer stone (2% Waste and Loss)	9858	$ 158,765	$ 158,757	$ 460,579
250 lb underlayer toe stone (2% Waste and Loss)	13149	$ 211,768	$ 211,756	$ 580,076
4' x 4" wood, column framing	384	$ 400	$ 400	$ 801
50 lb toe underlayer stone (2% Waste and Loss)	6123	$ 88,285	$ 88,280	$ 246,394
50 lb underlayer stone (2% Waste and Loss)	1968	$ 28,376	$ 28,374	$ 79,194
A/E Services	113	$ 7,400,000	$ 7,400,000	$ 15,200,000
Access Channel	1500	$ 50,000	$ 50,000	$ 100,000
Adaptive Managegment	10560	$ 352,000	$ 352,000	$ 704,000
Anchor bolts, threaded both ends, 1/2" diameter x 7" long, includes 2 nuts	1260	$ 2,544	$ 2,544	$ 5,087
APHIS Techicians	2204	$ 547,200	$ 547,200	$ 971,200
Armor 2500 lb (5% Waste and Loss)	35979	$ 1,009,190	$ 1,009,136	$ 2,131,415
Armor 500 lb (2% Waste and Loss)	4029	$ 185,523	$ 185,514	$ 398,604
Backfill and compaction	84	$ 785,400	$ 785,400	$ 1,570,800
Bedding Stone (2% Waste and Loss)	6213	$ 82,309	$ 82,305	$ 202,154
Biologist	257920	$ 1,459,894	$ 1,879,571	$ 2,932,523
Boat Captain	248000	$ 2,795,600	$ 3,663,200	$ 5,591,200
Box culvert, precast concrete, 12' - 0" x 12' - 0" I.D., excludes excavation and backfill	4800	$ 1,393,556	$ 1,393,482	$ 2,787,021
Building & Household	114	$ 62,700	$ 62,700	$ 75,900
CBFO Admin Support	114	$ 570,000	$ 570,000	$ 999,000
CENAB Environmental Specialist, GS-12	19456	$ 668,800	$ 668,800	$ 1,172,160
CENAB Environmental Specialist, GS-9	24320	$ 494,000	$ 494,000	$ 865,800
CENAB Planning Division, Civilworks Branch Overhead	114	$ 273,600	$ 273,600	$ 402,380
Civil Engineering Section	39700	$ 1,210,860	$ 1,210,860	$ 2,481,240
Construction Materials	114	$ 380,000	$ 380,000	$ 460,000
Contract Administration	104	$ 238,000	$ 238,000	$ 490,000
Cost Estimating	18080	$ 568,320	$ 568,320	$ 1,152,000
Crew	9096	$ 3,501,999	$ 3,501,813	$ 7,003,770
Crew Boat	4422	$ 4,826,639	$ 4,826,383	$ 9,652,965
Crushed stone roadway removal	84	$ 123,200	$ 123,200	$ 246,400
Culvert Disposal	84	$ 224,000	$ 224,000	$ 448,000
Cut handrails and install 6" x 6" end posts	120	$ 604	$ 604	$ 1,207
Deckhand	248000	$ 2,480,080	$ 3,249,760	$ 4,960,160
Design, fabricate and install a 30' x 30' floating pier. Quote from Marina Ventures Inc. Includes 4 steel piles	2700	$ 52,646	$ 52,643	$ 105,288
pier. Quote from Marina Ventures Inc.	360	$ 3,917	$ 3,917	$ 7,834
Draftsman	9280	$ 228,000	$ 228,000	$ 468,000
Dredging	15980000		$ 38,352,000	
Drilling and Lab	3000	$ 100,000	$ 100,000	$ 200,000
Driscoplex HDPE pipe	84	$ 3,500,000	$ 3,500,000	$ 7,000,000
Electric	114	$ 1,520,000	$ 1,520,000	$ 2,000,000
Electrical Section	1500	$ 50,000	$ 50,000	$ 100,000
Engineer/Geotec Consultant	114	$ 205,200	$ 205,200	$ 248,400
Engineering and Technical Support	114	$ 457,239	$ 570,570	$ 1,053,699
Engineering Division	113	$ 18,500,000	$ 18,500,000	$ 38,000,000
Engineering Management	74640	$ 2,297,360	$ 2,297,360	$ 4,718,800
Environmental - PL	113	$ 4,440,000	$ 4,440,000	$ 9,120,000
Environmental Coordinator	257920	$ 1,332,469	$ 1,745,994	$ 2,664,938
Environmental Monitoring	10920	$ 277,200	$ 360,000	$ 567,600
Environmental Support	114	$ 1,330,000	$ 1,330,000	$ 1,715,000
Equip. Operators, Medium	591700	$ 6,405,715	$ 8,483,303	$ 11,261,082
Equip. Operators, Oilers	165041	$ 1,648,103	$ 2,183,946	$ 2,941,051
Equipment, Materials, etc.	114	$ 1,483,500	$ 1,960,800	$ 3,379,800
Erosion control type 1	2154204	$ 2,860,119	$ 2,859,968	$ 5,737,748
Erosion control type 2	894750	$ 3,237,154	$ 3,236,982	$ 6,486,879
Excavate trench, mdm soil, 4'-6' D, 1/2 CY excavator	3920250	$ 1,323,689	$ 1,764,918	$ 4,853,525
Excavation and loading	25803000	$ 43,082,811	$ 43,080,528	$ 86,162,829
Excavation and loading fill	1950	$ 3,256	$ 3,256	$ 6,512

James Estimate

Model Backup $ 1,240,839,699

Description	Qty	Low	ML	High
Excavation of material to -1.5 ft.	84	$ 480,480	$ 480,480	$ 960,960
Fish and Wildlife Biologist GS-12	228	$ 5,700,000	$ 5,700,000	$ 9,990,000
Geotechnical Branch	57300	$ 2,216,040	$ 2,216,040	$ 4,545,360
Geotextile	6399	$ 7,385	$ 7,384	$ 14,769
Grade site with 75 HP dozer	3920250	$ 2,874,751	$ 3,833,002	$ 10,540,755
GRADER, MOTOR, ARTICULATED, 6X4, 12' BLADE W/ 17 TEETH SCARIFIERS	72	$ 1,361	$ 1,361	$ 2,723
H&S Support	114	$ 329,195	$ 410,780	$ 758,685
Haul armor to island	719553	$ 3,409,878	$ 3,409,697	$ 5,789,228
Haul bedding to island	311202	$ 1,474,750	$ 1,474,672	$ 2,627,875
Haul stone to island	1216353	$ 5,764,156	$ 5,763,850	$ 10,326,170
Haul underlayer stone to island	1551603	$ 7,352,866	$ 7,352,477	$ 12,766,176
Hauling	25979868	$ 33,578,965	$ 33,577,185	$ 67,155,753
Hauling Armor on the island	920253	$ 3,686,496	$ 3,686,301	$ 6,501,796
Hauling bedding on the island	311202	$ 2,493,325	$ 2,493,193	$ 4,442,887
Hauling fill	1950	$ 2,505	$ 2,505	$ 5,010
Hauling roadway material	540	$ 1,311	$ 1,311	$ 2,623
Hauling underlayer stone on the island	589953	$ 2,363,328	$ 2,363,203	$ 4,130,963
HYD EXCAV, CRWLR, 60,700 LBS 1.75 CY BKT, 23.25'DIG D, 34.5'R	213530	$ 4,072,262	$ 5,387,370	$ 7,722,875
6.50CY, 3-TINE/ 4-TINE (ADD 37.5 TON HYDRAULIC EXCAVATOR)	144	$ 518	$ 518	$ 1,037
DIGGING DEPTH	144	$ 5,265	$ 5,265	$ 10,529
Hydrology and Hydraulic Section	10780	$ 361,080	$ 361,080	$ 738,480
Installation of new pipe	84	$ 591,360	$ 591,360	$ 1,182,720
Instruction/Training	114	$ 83,600	$ 83,600	$ 101,200
Insurance	114	$ 91,200	$ 91,200	$ 120,000
Joist & beam hangers, galvanized, 16 gauge, for 3" x 10" to 3" x 14" joist	15	$ 40	$ 40	$ 80
Labor	114	$ 175,375	$ 231,800	$ 399,550
Laboratory Services	114	$ 1,938,000	$ 1,938,000	$ 2,499,000
Laboratory Supplies	114	$ 380,000	$ 380,000	$ 490,000
Ladder, steel, 24" W	9	$ 3,572	$ 3,572	$ 7,144
56,000 GVW TRUCK)	72	$ 2,978	$ 2,978	$ 5,955
Larger Spillway	27	$ 6,998,608	$ 6,998,237	$ 14,062,812
LAUNCH,20.25',TRANSPORTR,3500#	186000	$ 2,856,510	$ 3,743,013	$ 6,101,217
LAUNCH,20.25',TRANSPORTR,3500# (Stand-by)	62000	$ 38,213	$ 49,954	$ 76,616
Light load armor stone	437178	$ 1,950,789	$ 1,950,685	$ 3,901,393
Light load underlayer stone	439428	$ 1,960,829	$ 1,960,725	$ 3,921,492
Loading	176868	$ 3,062,901	$ 3,103,081	$ 7,698,941
Loading Bedding Stone	311202	$ 1,040,590	$ 1,138,085	$ 1,854,240
Loading roadway material	540	$ 9,351	$ 9,474	$ 23,506
Lumber Treatment, water borne preservative, .40 CCA	12	$ 625	$ 625	$ 1,250
Main Dike Geotextile	1394688	$ 1,387,128	$ 1,387,055	$ 2,779,106
Maintenance Dredging	95,162,925.00		$ 1,272,328,307	
Maintenance Dredging (Base Plan)	95,162,925.00		$ (651,866,036)	
MARINE EQUIPMENT, FLAT-DECK CARGO BARGE, 120 FT LENGTH, 45 FT BEAM, 7.00 FT DEPTH, 800 TON	132	$ 406	$ 406	$ 812
9.00 FT DEPTH, 1,100 TON	240	$ 1,303	$ 1,303	$ 2,605
HP, TOW BOAT	240	$ 21,577	$ 21,575	$ 43,152
Mechanical Section	1500	$ 50,000	$ 50,000	$ 100,000
Miscellaneous	114	$ 380,000	$ 380,000	$ 460,000
Miscellaneous Dike Maintenance - Equipment	114	$ 1,293,750	$ 1,710,000	$ 2,846,250
Miscellaneous Dike Maintenance - Labor	114	$ 146,625	$ 193,800	$ 322,575
Miscellaneous fasteners	18	$ 1,013	$ 1,013	$ 2,026
Miscellaneous Repairs/Service of Lab Equipment	114	$ 342,000	$ 342,000	$ 441,000
Miscellaneous Supplies and Materials	114	$ 205,200	$ 205,200	$ 248,400
Mob and Demob including technical support	84	$ 1,400,000	$ 1,400,000	$ 2,800,000
Mobilization and Demobilization	30		$ 107,762,106	
Mobilization and Demobilization (Base Plan)	30		$ (31,128,189)	
Mobilization and Demobilization of dredge	2		$ 2,498,291	
New Operations and Vehicle Storage and Maintenance Building	3	$ 4,335,384	$ 4,335,198	$ 8,670,488
NOAA equipment	114	$ 193,800	$ 193,800	$ 339,660
NOAA personnel travel and lodging	11970	$ 650,370	$ 650,370	$ 1,141,455
NOAA supplies (containers, chemicals, etc.)	114	$ 129,200	$ 129,200	$ 226,440

James Estimate

Model Backup $ 1,240,839,699

Description	Qty	Low	ML	High
NOAA technical personnels	1368	$ 3,648,000	$ 3,648,000	$ 6,393,600
Office	114	$ 41,800	$ 41,800	$ 50,600
Office administrative type work	32376	$ 478,440	$ 478,440	$ 978,480
Operations Division (S&A)	143	$ 11,280,000	$ 11,280,000	$ 23,040,000
Operations Facility	6000	$ 200,000	$ 200,000	$ 400,000
Permanent	30	$ 2,311,542	$ 2,311,420	$ 4,645,173
Personnel Pier/Unloading Dock	4500	$ 150,000	$ 150,000	$ 300,000
Photo Supplies	114	$ 11,400	$ 11,400	$ 13,800
Piles, pile, wood, treated, friction or end bearing, 12 lb. creosote/C.F., 12" butts, 7" points, 40 - 49' long, ASTM class B, excludes mobilization or demobilization	1440	$ 31,364	$ 31,363	$ 62,727
Pipe boot	84	$ 49,000	$ 49,000	$ 98,000
Pipe boot skirt	84	$ 43,120	$ 43,120	$ 86,240
Placement	25803000	$ 33,560,485	$ 33,558,706	$ 67,118,793
Placement of fill	1950	$ 2,536	$ 2,536	$ 5,072
Placing	795900	$ 662,516	$ 662,481	$ 1,324,989
Placing 250 lb underlayer stone	492303	$ 7,840,037	$ 7,839,622	$ 22,845,869
Placing 250 lb underlayer toe stone	655650	$ 10,559,391	$ 10,558,831	$ 28,906,277
Placing 50 lb underlayer stone	97650	$ 1,407,974	$ 1,407,900	$ 3,929,511
Placing 50 lb underlayer toe stone	306000	$ 4,448,805	$ 4,448,569	$ 12,387,111
Placing Armor 2500 lb	719553	$ 20,183,042	$ 20,181,972	$ 42,626,311
Placing Armor 500 lb	200700	$ 9,241,637	$ 9,241,147	$ 19,856,011
Placing Bedding Stone	311202	$ 4,122,765	$ 4,122,546	$ 10,121,317
Placing roadway material	1650	$ 1,373	$ 1,373	$ 2,747
Placing Toe Armor 1000 lb	237150	$ 6,229,608	$ 6,229,277	$ 14,081,564
Placing Toe Armor 3500 lb	778503	$ 20,163,906	$ 20,162,837	$ 42,677,224
Planning Division	4640	$ 199,120	$ 199,120	$ 408,720
Planting in 1/2 of upland cell	1704	$ 12,390,334	$ 16,519,569	$ 41,704,708
Pontoon Long Reach Excavator	374770	$ 5,688,705	$ 7,525,372	$ 9,508,998
Postal / Courier	114	$ 22,800	$ 22,800	$ 27,600
Power & Communications	3000	$ 100,000	$ 100,000	$ 200,000
Preconstruction Conference	4288	$ 168,960	$ 168,960	$ 345,600
Program Management	595	$ 19,500	$ 19,500	$ 40,000
Program Management - PPMD	113	$ 4,440,000	$ 4,440,000	$ 9,120,000
Project Management	127086	$ 4,172,486	$ 4,759,217	$ 9,018,355
Quality assurance work	539600	$ 7,974,000	$ 7,974,000	$ 16,308,000
Radio	114	$ 13,680	$ 13,680	$ 16,560
Recreation	3000	$ 100,000	$ 100,000	$ 200,000
Remove armor stone	84	$ 112,000	$ 112,000	$ 224,000
Remove cofferdam	84	$ 1,124,200	$ 1,124,200	$ 2,248,400
Remove excess material from site.	84	$ 72,800	$ 72,800	$ 145,600
Replace armor stone	84	$ 112,000	$ 112,000	$ 224,000
Roadway Geotextile	1079184	$ 1,123,651	$ 1,123,594	$ 2,250,187
WIDE, 3X2, SOIL COMPACTOR	72	$ 1,713	$ 1,713	$ 3,426
Safety	114	$ 152,000	$ 152,000	$ 184,000
Safety inspection work	16188	$ 239,220	$ 239,220	$ 489,240
Security	114	$ 24,700	$ 24,700	$ 29,900
Septic	114	$ 152,000	$ 152,000	$ 184,000
Sheet piling, steel, 27 psf, 25' excavation, left in place, excludes wales	231	$ 182,650	$ 182,641	$ 365,289
Single 3" x 10" wood beam, heavy mill timber framing	10740	$ 14,828	$ 14,827	$ 29,656
Single 3" x 12" wood beam, heavy mill timber framing	1530	$ 2,112	$ 2,112	$ 4,225
Single 3" x 8" wood beam, heavy mill timber framing	600	$ 828	$ 828	$ 1,657
Single 4" x 10" wood beam, heavy mill timber framing	1290	$ 1,781	$ 1,781	$ 3,562
Single 4" x 12" wood beam, heavy mill timber framing	96	$ 133	$ 133	$ 265
Slope armor	84	$ 61,600	$ 61,600	$ 123,200
Small Tools	114	$ 76,000	$ 76,000	$ 92,000
Stone, Sand, Etc.	114	$ 380,000	$ 380,000	$ 460,000
Submitial review	16188	$ 239,220	$ 239,220	$ 489,240
Support clerical/management work	80940	$ 1,461,900	$ 1,461,900	$ 2,989,800
Surveying Section	37800	$ 1,178,000	$ 1,178,000	$ 2,413,000
Technical Section - Prep Documents	4640	$ 145,920	$ 145,920	$ 299,520
Telephone	114	$ 91,200	$ 91,200	$ 110,400

James Estimate

Model Backup $ 1,240,839,699

Description	Qty	Low	ML	High
Temporary sand cofferdam	84	$ 879,200	$ 879,200	$ 1,758,400
Toe Armor 1000 lb (5% Waste, Loss, and Damge)	11859	$ 311,520	$ 311,503	$ 704,167
Toe Armor 3500 lb (5% Waste, Loss, and Damage)	38928	$ 1,008,269	$ 1,008,216	$ 2,134,053
Toe Dike Geotextile	2054748	$ 2,371,212	$ 2,371,087	$ 4,215,539
(W/UNIVERSAL BLADE)	72	$ 2,008	$ 2,008	$ 4,016
Trash Removal	114	$ 57,000	$ 57,000	$ 69,000
Travel/Non-Heavy Equipment Operator	114	$ 182,860	$ 228,000	$ 421,480
Treatment, pH neutralization	114	$ 2,090,000	$ 2,090,000	$ 2,695,000
TRK,HWY, 8,800GVW,4X4, 3/4T-PKUP	458305	$ 1,469,378	$ 1,945,973	$ 2,890,514
TRUCK OPTION, FLATBED, 8' X 12' (2.4M X 3.7M) (ADD 25,000 GVW TRUCK)	72	$ 20	$ 20	$ 40
TRUCK, HWY 25,000 (11,340KG)GVW, 4X2, 2 AXLE, (ADD ACCESSORIES)	72	$ 949	$ 949	$ 1,958
TRUCK, OFF-HIGHWAY, RIGID FRAME, 145 CY, 205 TON, 4X4, REAR DUMP	216	$ 39,160	$ 39,158	$ 78,318
REAR DUMP	72	$ 3,257	$ 3,257	$ 6,514
Turbidity curtain, materials and installation	84	$ 504,000	$ 504,000	$ 1,008,000
Uniforms	114	$ 49,400	$ 49,400	$ 59,800
University of Ohio field assistants	141056	$ 440,800	$ 440,800	$ 772,560
University of Ohio Overhead	114	$ 239,400	$ 239,400	$ 419,580
University of Ohio personnel travel and lodging	114	$ 335,920	$ 335,920	$ 588,820
University of Ohio professor/researcher	19456	$ 340,480	$ 340,480	$ 596,736
University of Ohio research supplies	114	$ 78,128	$ 78,128	$ 138,176
Unloading Armor Stone	200700	$ 440,407	$ 733,972	$ 1,069,518
Unloading Stone	719553	$ 1,578,953	$ 2,631,450	$ 3,829,597
Unloading Underlayer Stone	589953	$ 1,294,565	$ 2,157,494	$ 3,140,776
Upland Development	1704	$ 12,390,334	$ 16,519,569	$ 41,704,708
USFW Office/Field Supplies, Maintenance, Fuel, and Travel	228	$ 668,800	$ 668,800	$ 1,172,388
USFW Overhead	114	$ 1,231,200	$ 1,231,200	$ 2,157,840
USGS Interns	31160	$ 428,032	$ 428,032	$ 751,520
USGS Overhead	114	$ 195,700	$ 195,700	$ 343,370
USGS principle researcher, GS-14	15580	$ 559,360	$ 559,360	$ 982,100
Washers, 2" x 2" x 1/8"	960	$ 136	$ 136	$ 272
Water	114	$ 57,000	$ 57,000	$ 69,000
Wetland planting in cell W-1 and W-2	240	$ 1,350,000	$ 1,800,000	$ 4,950,000
Wetland planting in cell W-11 and W-12	240	$ 1,350,000	$ 1,800,000	$ 4,950,000
Wetland planting in cell W-13 and W-14	240	$ 1,350,000	$ 1,800,000	$ 4,950,000
Wetland planting in cell W-15 and W-16	280	$ 1,575,000	$ 2,100,000	$ 5,775,000
Wetland planting in cell W-17 and W-18	280	$ 1,575,000	$ 2,100,000	$ 5,775,000
Wetland planting in cell W-19 and W-20	280	$ 1,575,000	$ 2,100,000	$ 5,775,000
Wetland planting in cell W-21 and W-22	280	$ 1,575,000	$ 2,100,000	$ 5,775,000
Wetland planting in cell W-23 and W-24	280	$ 1,575,000	$ 2,100,000	$ 5,775,000
Wetland planting in cell W-25 and W-26	280	$ 1,575,000	$ 2,100,000	$ 5,775,000
Wetland planting in cell W-27 and W-28	280	$ 2,100,000	$ 2,100,000	$ 6,300,000
Wetland planting in cell W-3 and W-4	240	$ 1,350,000	$ 1,800,000	$ 4,950,000
Wetland planting in cell W-5 and W-6	240	$ 1,350,000	$ 1,800,000	$ 4,950,000
Wetland planting in cell W-7 and W-8	240	$ 1,350,000	$ 1,800,000	$ 4,950,000
Wetland planting in cell W-9 and W-10	240	$ 1,350,000	$ 1,800,000	$ 4,950,000
Wetland planting in cells	351	$ 2,835,000	$ 3,780,000	$ 5,805,000
Wetland Tital Guts	4500	$ 150,000	$ 150,000	$ 300,000

CRYSTAL BALL ANALYSIS **O&M (for both James Island and Barren Island)**

FUEL (Fuel Changes)

	LOW	BASELINE	HIGH
Barren	137,703.19	139,210.61	142,476.70
James	19,738,046.50	$ 19,928,960	20,351,222.27
	19,875,749.69	20,068,170.99	20,493,698.97
Difference in Fuel Project Cost	-192,421.30	$ -	425,527.98

Risk Basis

gas	$3.05 /gal	$3.25 /gal	$4.00 /gal
diesel off-road	$2.90 /gal	$3.20 /gal	$3.85 /gal
diesel on-road	$3.40 /gal	$3.60 /gal	$4.25 /gal

STONE MATERIAL (Matl only)

	Low	Baseline	High
Barren	139,210.61	139,210.61	155,566.50
James	19,928,960.38	$ 19,928,960	21,338,927.48
	20,068,170.99	20,068,170.99	21,494,493.98
Difference in Stone Cost	0.00	$ -	1,426,322.99

Risk Basis

stones			
2500-3500 lbs	$45.00 /ton	$45.00 /ton	$60.00 /ton
500-1000 lbs	$35.00 /ton	$35.00 /ton	$50.00 /ton
50-250 lbs	$25.00 /ton	$25.00 /ton	$50.00 /ton
1300 lbs	$45.00 /ton	$45.00 /ton	$60.00 /ton
130 lbs	$25.00 /ton	$25.00 /ton	$50.00 /ton
Core Stone	$23.00 /ton	$23.00 /ton	$36.00 /ton
Bedding Stone	$23.00 /ton	$23.00 /ton	$36.00 /ton

85% stone prices from VA Quarries	0% stone prices from VA Quarries	0% stone prices from VA Quarries	revised unloading to $8/ton
15% stone prices from MD Quarries	100% stone prices from MD Quarries	100% stone prices from MD Quarries	

Overall Market Conditions

Allowance for 15% over IGE w/ Profit			1.15
		20,068,170.99	23,078,396.64
Difference		0	3,010,225.65
		0	

Total Project Summary -O&M $ 20,068,171

O&M
Contingency Analysis

Confidence Level		Value		Contingency
0%		19,989,993		0.0%
5%		21,095,471		5.5%
10%		21,490,290		7.5%
15%		21,845,048		9.3%
20%		22,169,766		10.9%
25%		22,489,255		12.5%
30%		22,837,597		14.2%
35%		23,225,476		16.2%
40%		23,691,659		18.5%
45%		24,338,632		21.8%
50%		27,310,013		36.6%
55%		22,674,786		13.4%
60%		22,847,153		14.3%
65%		23,020,814		15.2%
70%		23,198,407		16.1%
75%		23,420,700		17.2%
80%		23,656,497		18.3%
85%		23,945,908		19.8%
90%		24,281,115		21.5%
95%		24,797,594		24.1%
100%		27,357,349		36.9%

CRYSTAL BALL ANALYSIS **Wetland Planting for Barren Island**

FUEL (Fuel Changes)

	LOW	BASELINE	HIGH
Barren	4,573,965.67	4,590,118.63	4,625,116.72
	4,573,965.67	4,590,118.63	4,625,116.72
Difference in Fuel Project Cost	-16,152.96	$ -	34,998.09

Risk Basis

gas	$3.05 /gal	$3.25 /gal	$4.00 /gal
diesel off-road	$2.90 /gal	$3.20 /gal	$3.85 /gal
diesel on-road	$3.40 /gal	$3.60 /gal	$4.25 /gal

Overall Market Conditions

Allowance for 15% over IGE w/ Profit		1.15
	4,590,118.63	5,278,636.42
	0	688,517.79
	0	

Total Project Summary -Wetland Planting 4,590,118.63

Wetlands
Contingency Analysis

Confidence Level		Value		Contingency
0%		4,574,477		-0.3%
5%		4,632,388		0.9%
10%		4,660,097		1.5%
15%		4,687,061		2.1%
20%		4,714,046		2.7%
25%		4,742,825		3.3%
30%		4,773,147		4.0%
35%		4,805,132		4.7%
40%		4,835,369		5.3%
45%		4,869,492		6.1%
50%		4,904,125		6.8%
55%		4,940,671		7.6%
60%		4,980,000		8.5%
65%		5,019,977		9.4%
70%		5,064,724		10.3%
75%		5,113,379		11.4%
80%		5,166,038		12.5%
85%		5,224,636		13.8%
90%		5,295,739		15.4%
95%		5,388,906		17.4%
100%		5,652,791		23.2%

Appendix C – Assumption Charts

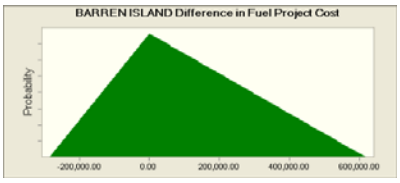
Assumptions

Worksheet: [Cost Model.xls]Barren Island

Assumption: BARREN ISLAND Difference in Fuel Project Cost **Cell: D9**

Triangular distribution with parameters:

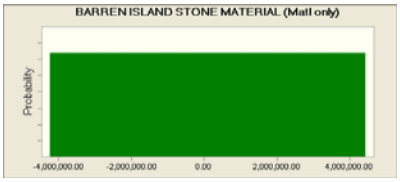
Minimum	-284,381.60	(=B9)
Likeliest	0.00	
Maximum	616,160.12	(=G9)



Assumption: BARREN ISLAND STONE MATERIAL (Matl only) **Cell: D19**

Uniform distribution with parameters:

Minimum	-4,239,892.36	(=B19)
Maximum	4,420,597.26	(=G19)



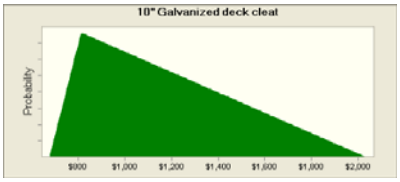
Worksheet: [Cost Model.xls]James

Assumption: 10" Galvanized deck cleat **Cell: D5**

Triangular distribution with parameters:

10%	$813	(=C5)
Likeliest	$813	(=D5)
90%	$1,625	(=E5)

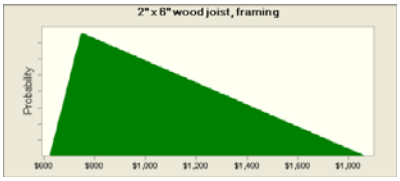
Assumption: 10" Galvanized deck cleat (cont'd) **Cell: D5**



Assumption: 2" x 6" wood joist, framing **Cell: D6**

Triangular distribution with parameters:

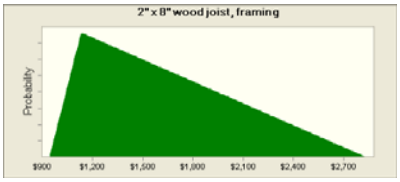
10%	$747	(=C6)
Likeliest	$747	(=D6)
90%	$1,494	(=E6)



Assumption: 2" x 8" wood joist, framing **Cell: D7**

Triangular distribution with parameters:

10%	$1,132	(=C7)
Likeliest	$1,132	(=D7)
90%	$2,265	(=E7)

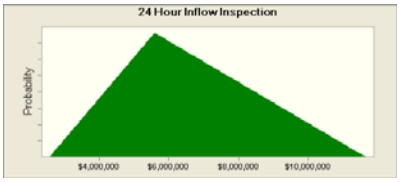


Assumption: 24 Hour Inflow Inspection **Cell: D8**

Triangular distribution with parameters:

10%	$4,226,250	(=C8)
Likeliest	$5,586,000	(=D8)
90%	$9,297,750	(=E8)

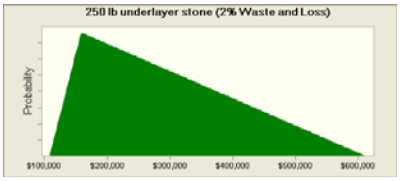
Assumption: 24 Hour Inflow Inspection (cont'd) **Cell: D8**



Assumption: 250 lb underlayer stone (2% Waste and Loss) **Cell: D9**

Triangular distribution with parameters:

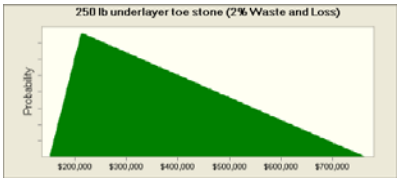
10%	$158,765	(=C9)
Likeliest	$158,757	(=D9)
90%	$460,579	(=E9)



Assumption: 250 lb underlayer toe stone (2% Waste and Loss) **Cell: D10**

Triangular distribution with parameters:

10%	$211,768	(=C10)
Likeliest	$211,756	(=D10)
90%	$580,076	(=E10)

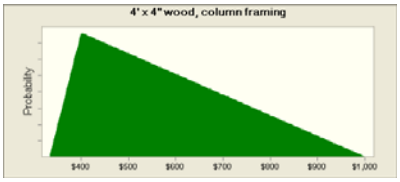


Assumption: 4' x 4" wood, column framing **Cell: D11**

Triangular distribution with parameters:

10%	$400	(=C11)
Likeliest	$400	(=D11)
90%	$801	(=E11)

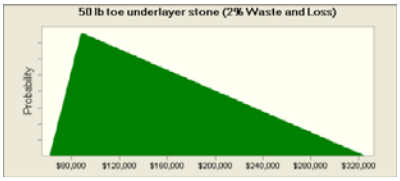
Assumption: 4' x 4" wood, column framing (cont'd) **Cell: D11**



Assumption: 50 lb toe underlayer stone (2% Waste and Loss) **Cell: D12**

Triangular distribution with parameters:

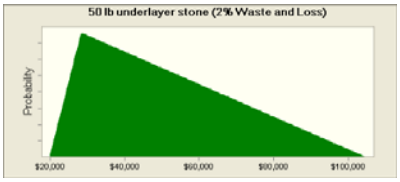
10%	$88,285	(=C12)
Likeliest	$88,280	(=D12)
90%	$246,394	(=E12)



Assumption: 50 lb underlayer stone (2% Waste and Loss) **Cell: D13**

Triangular distribution with parameters:

10%	$28,376	(=C13)
Likeliest	$28,374	(=D13)
90%	$79,194	(=E13)

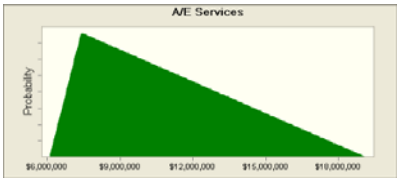


Assumption: A/E Services **Cell: D14**

Triangular distribution with parameters:

10%	$7,400,000	(=C14)
Likeliest	$7,400,000	(=D14)
90%	$15,200,000	(=E14)

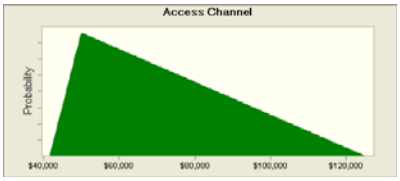
Assumption: A/E Services (cont'd) **Cell: D14**



Assumption: Access Channel **Cell: D15**

Triangular distribution with parameters:

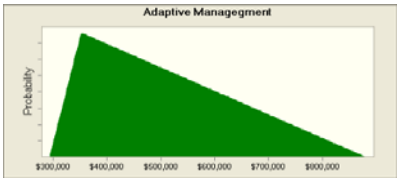
10%	$50,000	(=C15)
Likeliest	$50,000	(=D15)
90%	$100,000	(=E15)



Assumption: Adaptive Managegment **Cell: D16**

Triangular distribution with parameters:

10%	$352,000	(=C16)
Likeliest	$352,000	(=D16)
90%	$704,000	(=E16)

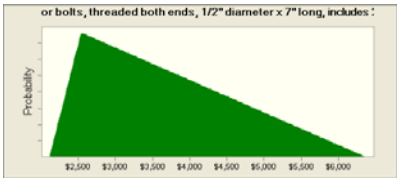


Assumption: Anchor bolts, threaded both ends, 1/2" diameter x 7" long, includes 2 nuts **Cell: D17**

Triangular distribution with parameters:

10%	$2,544	(=C17)
Likeliest	$2,544	(=D17)
90%	$5,087	(=E17)

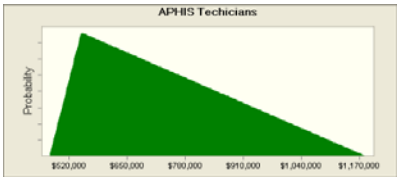
Assumption: Anchor bolts, threaded both ends, 1/2" diameter x 7" long, includes 2 nuts (cont'd **Cell: D17**



Assumption: APHIS Techicians **Cell: D18**

Triangular distribution with parameters:

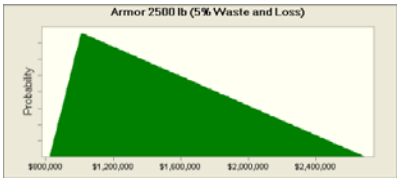
10%	$547,200	(=C18)
Likeliest	$547,200	(=D18)
90%	$971,200	(=E18)



Assumption: Armor 2500 lb (5% Waste and Loss) **Cell: D19**

Triangular distribution with parameters:

10%	$1,009,190	(=C19)
Likeliest	$1,009,136	(=D19)
90%	$2,131,415	(=E19)

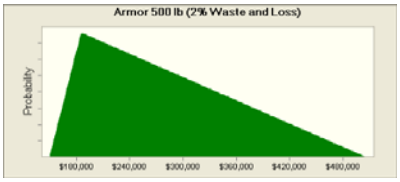


Assumption: Armor 500 lb (2% Waste and Loss) **Cell: D20**

Triangular distribution with parameters:

10%	$185,523	(=C20)
Likeliest	$185,514	(=D20)
90%	$398,604	(=E20)

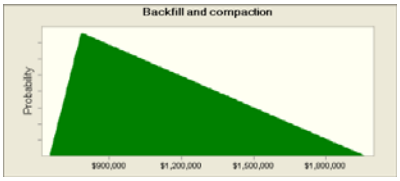
Assumption: Armor 500 lb (2% Waste and Loss) (cont'd) **Cell: D20**



Assumption: Backfill and compaction **Cell: D21**

Triangular distribution with parameters:

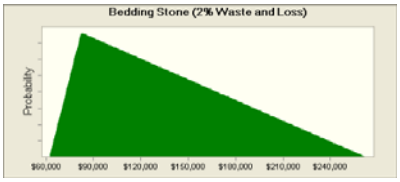
10%	$785,400	(=C21)
Likeliest	$785,400	(=D21)
90%	$1,570,800	(=E21)



Assumption: Bedding Stone (2% Waste and Loss) **Cell: D22**

Triangular distribution with parameters:

10%	$82,309	(=C22)
Likeliest	$82,305	(=D22)
90%	$202,154	(=E22)

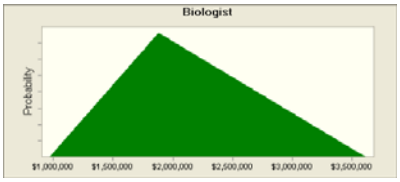


Assumption: Biologist **Cell: D23**

Triangular distribution with parameters:

10%	$1,459,894	(=C23)
Likeliest	$1,879,571	(=D23)
90%	$2,932,523	(=E23)

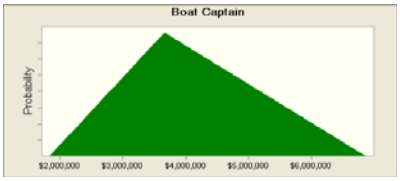
Assumption: Biologist (cont'd) **Cell: D23**



Assumption: Boat Captain **Cell: D24**

Triangular distribution with parameters:

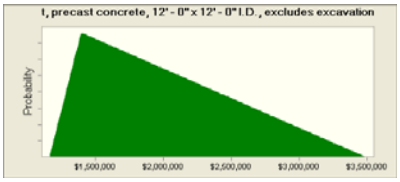
10%	$2,795,600	(=C24)
Likeliest	$3,663,200	(=D24)
90%	$5,591,200	(=E24)



Assumption: Box culvert, precast concrete, 12' - 0" x 12' - 0" I.D., excludes excavation and load **Cell: D25**

Triangular distribution with parameters:

10%	$1,393,556	(=C25)
Likeliest	$1,393,482	(=D25)
90%	$2,787,021	(=E25)

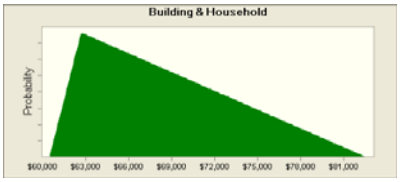


Assumption: Building & Household **Cell: D26**

Triangular distribution with parameters:

10%	$62,700	(=C26)
Likeliest	$62,700	(=D26)
90%	$75,900	(=E26)

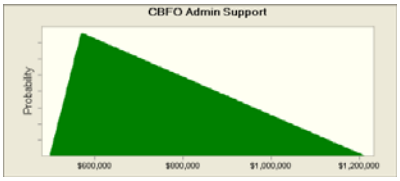
Assumption: Building & Household (cont'd) **Cell: D26**



Assumption: CBFO Admin Support **Cell: D27**

Triangular distribution with parameters:

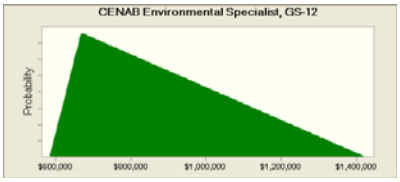
10%	$570,000	(=C27)
Likeliest	$570,000	(=D27)
90%	$999,000	(=E27)



Assumption: CENAB Environmental Specialist, GS-12 **Cell: D28**

Triangular distribution with parameters:

10%	$668,800	(=C28)
Likeliest	$668,800	(=D28)
90%	$1,172,160	(=E28)

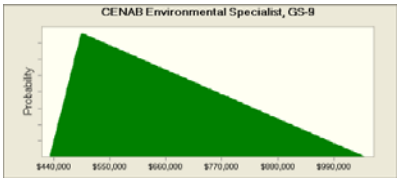


Assumption: CENAB Environmental Specialist, GS-9 **Cell: D29**

Triangular distribution with parameters:

10%	$494,000	(=C29)
Likeliest	$494,000	(=D29)
90%	$865,800	(=E29)

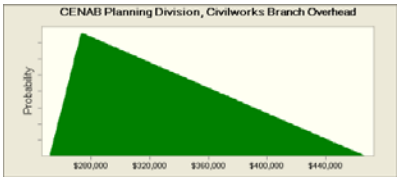
Assumption: CENAB Environmental Specialist, GS-9 (cont'd) **Cell: D29**



Assumption: CENAB Planning Division, Civilworks Branch Overhead **Cell: D30**

Triangular distribution with parameters:

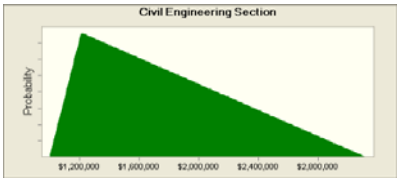
10%	$273,600	(=C30)
Likeliest	$273,600	(=D30)
90%	$402,380	(=E30)



Assumption: Civil Engineering Section **Cell: D31**

Triangular distribution with parameters:

10%	$1,210,860	(=C31)
Likeliest	$1,210,860	(=D31)
90%	$2,481,240	(=E31)

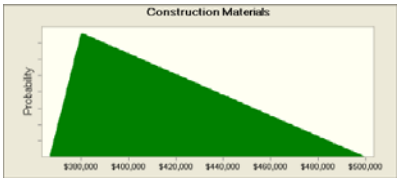


Assumption: Construction Materials **Cell: D32**

Triangular distribution with parameters:

10%	$380,000	(=C32)
Likeliest	$380,000	(=D32)
90%	$460,000	(=E32)

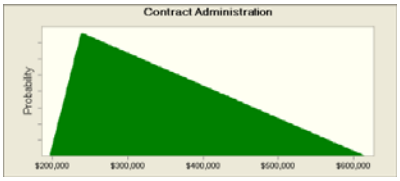
Assumption: Construction Materials (cont'd) **Cell: D32**



Assumption: Contract Administration **Cell: D33**

Triangular distribution with parameters:

10%	$238,000	(=C33)
Likeliest	$238,000	(=D33)
90%	$490,000	(=E33)



Assumption: Cost Estimating **Cell: D34**

Triangular distribution with parameters:

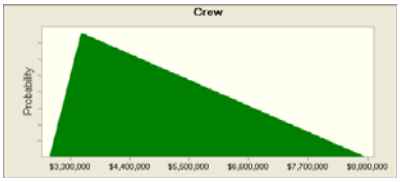
10%	$568,320	(=C34)
Likeliest	$568,320	(=D34)
90%	$1,152,000	(=E34)

Assumption: Crew **Cell: D35**

Triangular distribution with parameters:

10%	$3,501,999	(=C35)
Likeliest	$3,501,813	(=D35)
90%	$7,003,770	(=E35)

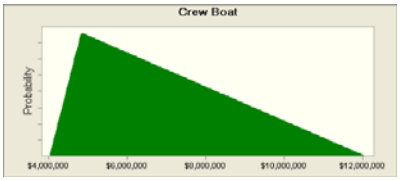
Assumption: Crew (cont'd) **Cell: D35**



Assumption: Crew Boat **Cell: D36**

Triangular distribution with parameters:

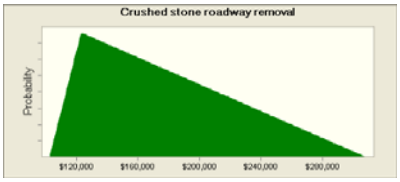
10%	$4,826,639	(=C36)
Likeliest	$4,826,383	(=D36)
90%	$9,652,965	(=E36)



Assumption: Crushed stone roadway removal **Cell: D37**

Triangular distribution with parameters:

10%	$123,200	(=C37)
Likeliest	$123,200	(=D37)
90%	$246,400	(=E37)

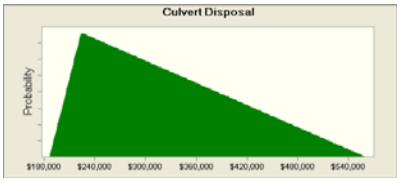


Assumption: Culvert Disposal **Cell: D38**

Triangular distribution with parameters:

10%	$224,000	(=C38)
Likeliest	$224,000	(=D38)
90%	$448,000	(=E38)

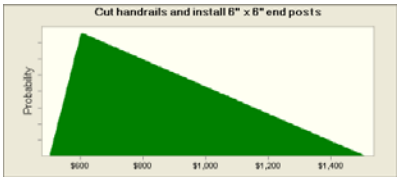
Assumption: Culvert Disposal (cont'd) **Cell: D38**



Assumption: Cut handrails and install 6" x 6" end posts **Cell: D39**

Triangular distribution with parameters:

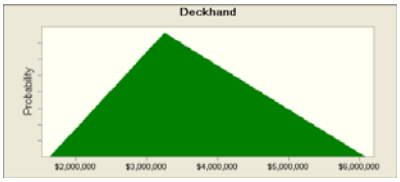
10%	$604	(=C39)
Likeliest	$604	(=D39)
90%	$1,207	(=E39)



Assumption: Deckhand **Cell: D40**

Triangular distribution with parameters:

10%	$2,480,080	(=C40)
Likeliest	$3,249,760	(=D40)
90%	$4,960,160	(=E40)

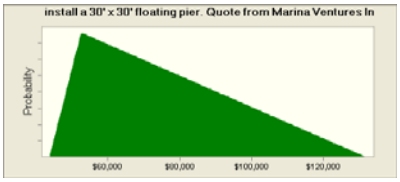


Assumption: Design, fabricate and install a 30' x 30' floating pier. Quote from Marina Ventures II **Cell: D41**

Triangular distribution with parameters:

10%	$52,646	(=C41)
Likeliest	$52,643	(=D41)
90%	$105,288	(=E41)

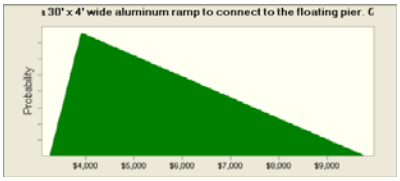
Assumption: Design, fabricate and install a 30' x 30' floating pier. Quote from Marina Ventures In **Cell: D41**



Assumption: Design, fabricate and install a 30' x 4' wide aluminum ramp to connect to the floati **Cell: D42**

Triangular distribution with parameters:

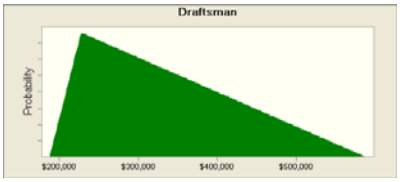
10%	$3,917	(=C42)
Likeliest	$3,917	(=D42)
90%	$7,834	(=E42)



Assumption: Draftsman **Cell: D43**

Triangular distribution with parameters:

10%	$228,000	(=C43)
Likeliest	$228,000	(=D43)
90%	$468,000	(=E43)

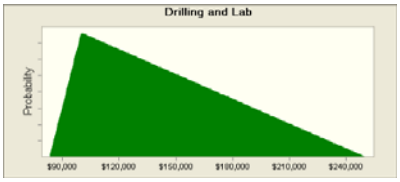


Assumption: Drilling and Lab **Cell: D45**

Triangular distribution with parameters:

10%	$100,000	(=C45)
Likeliest	$100,000	(=D45)
90%	$200,000	(=E45)

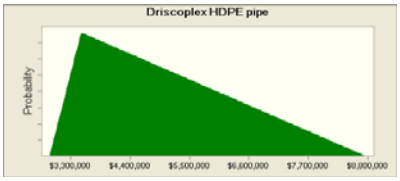
Assumption: Drilling and Lab (cont'd) **Cell: D45**



Assumption: Driscoplex HDPE pipe **Cell: D46**

Triangular distribution with parameters:

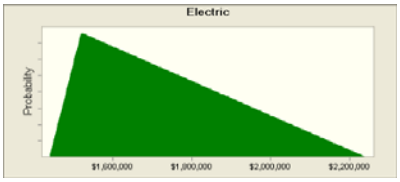
10%	$3,500,000	(=C46)
Likeliest	$3,500,000	(=D46)
90%	$7,000,000	(=E46)



Assumption: Electric **Cell: D47**

Triangular distribution with parameters:

10%	$1,520,000	(=C47)
Likeliest	$1,520,000	(=D47)
90%	$2,000,000	(=E47)

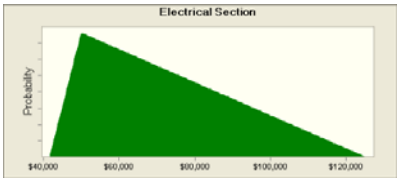


Assumption: Electrical Section **Cell: D48**

Triangular distribution with parameters:

10%	$50,000	(=C48)
Likeliest	$50,000	(=D48)
90%	$100,000	(=E48)

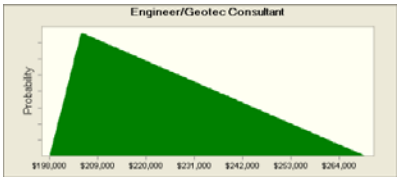
Assumption: Electrical Section (cont'd) **Cell: D48**



Assumption: Engineer/Geotec Consultant **Cell: D49**

Triangular distribution with parameters:

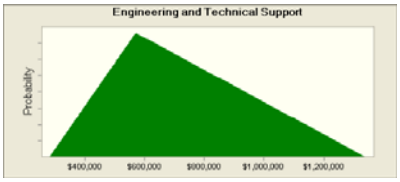
10%	$205,200	(=C49)
Likeliest	$205,200	(=D49)
90%	$248,400	(=E49)



Assumption: Engineering and Technical Support **Cell: D50**

Triangular distribution with parameters:

10%	$457,239	(=C50)
Likeliest	$570,570	(=D50)
90%	$1,053,699	(=E50)

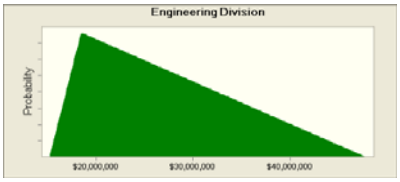


Assumption: Engineering Division **Cell: D51**

Triangular distribution with parameters:

10%	$18,500,000	(=C51)
Likeliest	$18,500,000	(=D51)
90%	$38,000,000	(=E51)

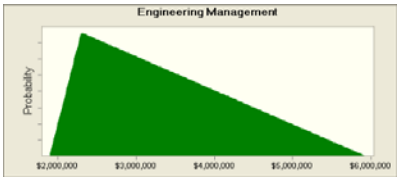
Assumption: Engineering Division (cont'd) **Cell: D51**



Assumption: Engineering Management **Cell: D52**

Triangular distribution with parameters:

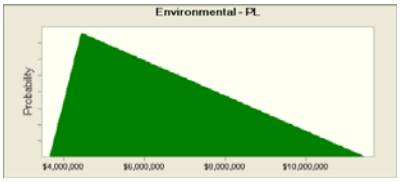
10%	$2,297,360	(=C52)
Likeliest	$2,297,360	(=D52)
90%	$4,718,800	(=E52)



Assumption: Environmental - PL **Cell: D53**

Triangular distribution with parameters:

10%	$4,440,000	(=C53)
Likeliest	$4,440,000	(=D53)
90%	$9,120,000	(=E53)

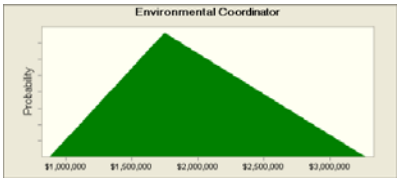


Assumption: Environmental Coordinator **Cell: D54**

Triangular distribution with parameters:

10%	$1,332,469	(=C54)
Likeliest	$1,745,994	(=D54)
90%	$2,664,938	(=E54)

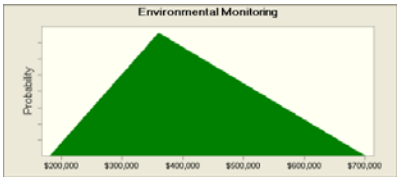
Assumption: Environmental Coordinator (cont'd) **Cell: D54**



Assumption: Environmental Monitoring **Cell: D55**

Triangular distribution with parameters:

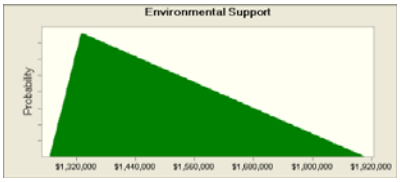
10%	$277,200	(=C55)
Likeliest	$360,000	(=D55)
90%	$567,600	(=E55)



Assumption: Environmental Support **Cell: D56**

Triangular distribution with parameters:

10%	$1,330,000	(=C56)
Likeliest	$1,330,000	(=D56)
90%	$1,715,000	(=E56)

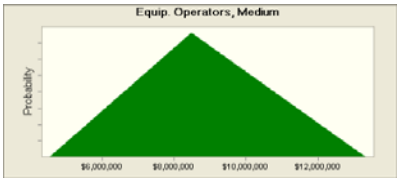


Assumption: Equip. Operators, Medium **Cell: D57**

Triangular distribution with parameters:

10%	$6,405,715	(=C57)
Likeliest	$8,483,303	(=D57)
90%	$11,261,082	(=E57)

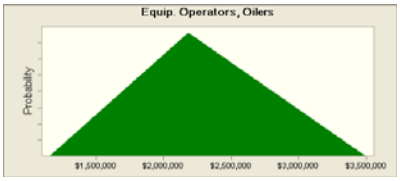
Assumption: Equip. Operators, Medium (cont'd) **Cell: D57**



Assumption: Equip. Operators, Oilers **Cell: D58**

Triangular distribution with parameters:

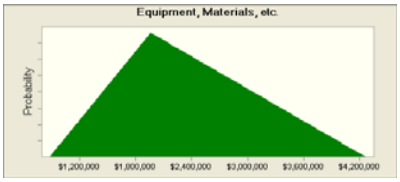
10%	$1,648,103	(=C58)
Likeliest	$2,183,946	(=D58)
90%	$2,941,051	(=E58)



Assumption: Equipment, Materials, etc. **Cell: D59**

Triangular distribution with parameters:

10%	$1,483,500	(=C59)
Likeliest	$1,960,800	(=D59)
90%	$3,379,800	(=E59)

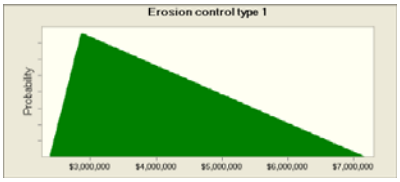


Assumption: Erosion control type 1 **Cell: D60**

Triangular distribution with parameters:

10%	$2,860,119	(=C60)
Likeliest	$2,859,968	(=D60)
90%	$5,737,748	(=E60)

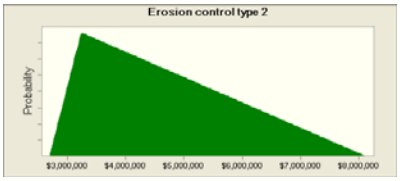
Assumption: Erosion control type 1 (cont'd) **Cell: D60**



Assumption: Erosion control type 2 **Cell: D61**

Triangular distribution with parameters:

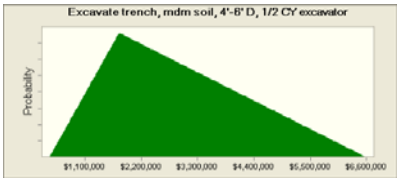
10%	$3,237,154	(=C61)
Likeliest	$3,236,982	(=D61)
90%	$6,486,879	(=E61)



Assumption: Excavate trench, mdm soil, 4'-6' D, 1/2 CY excavator **Cell: D62**

Triangular distribution with parameters:

10%	$1,323,689	(=C62)
Likeliest	$1,764,918	(=D62)
90%	$4,853,525	(=E62)

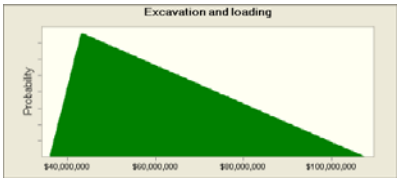


Assumption: Excavation and loading **Cell: D63**

Triangular distribution with parameters:

10%	$43,082,811	(=C63)
Likeliest	$43,080,528	(=D63)
90%	$86,162,829	(=E63)

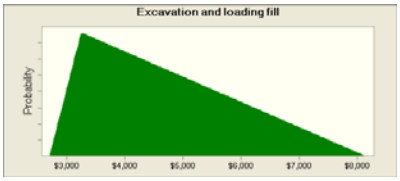
Assumption: Excavation and loading (cont'd) **Cell: D63**



Assumption: Excavation and loading fill **Cell: D64**

Triangular distribution with parameters:

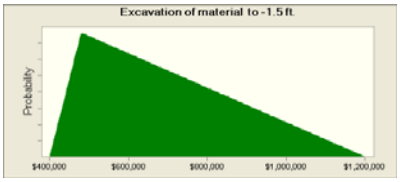
10%	$3,256	(=C64)
Likeliest	$3,256	(=D64)
90%	$6,512	(=E64)



Assumption: Excavation of material to -1.5 ft. **Cell: D65**

Triangular distribution with parameters:

10%	$480,480	(=C65)
Likeliest	$480,480	(=D65)
90%	$960,960	(=E65)

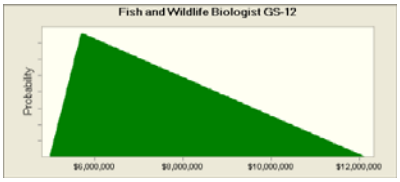


Assumption: Fish and Wildlife Biologist GS-12 **Cell: D66**

Triangular distribution with parameters:

10%	$5,700,000	(=C66)
Likeliest	$5,700,000	(=D66)
90%	$9,990,000	(=E66)

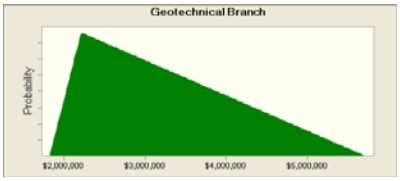
Assumption: Fish and Wildlife Biologist GS-12 (cont'd) **Cell: D66**



Assumption: Geotechnical Branch **Cell: D67**

Triangular distribution with parameters:

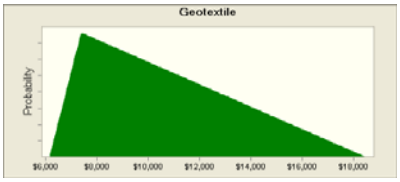
10%	$2,216,040	(=C67)
Likeliest	$2,216,040	(=D67)
90%	$4,545,360	(=E67)



Assumption: Geotextile **Cell: D68**

Triangular distribution with parameters:

10%	$7,385	(=C68)
Likeliest	$7,384	(=D68)
90%	$14,769	(=E68)

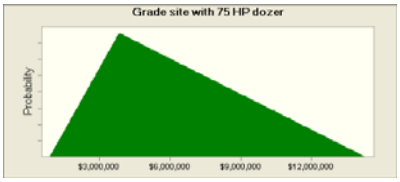


Assumption: Grade site with 75 HP dozer **Cell: D69**

Triangular distribution with parameters:

10%	$2,874,751	(=C69)
Likeliest	$3,833,002	(=D69)
90%	$10,540,755	(=E69)

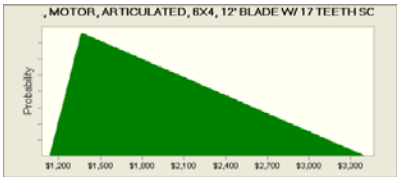
Assumption: Grade site with 75 HP dozer (cont'd) **Cell: D69**



Assumption: GRADER, MOTOR, ARTICULATED, 6X4, 12' BLADE W/ 17 TEETH SCARIFIERS **Cell: D70**

Triangular distribution with parameters:

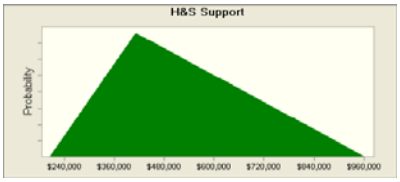
10%	$1,361	(=C70)
Likeliest	$1,361	(=D70)
90%	$2,723	(=E70)



Assumption: H&S Support **Cell: D71**

Triangular distribution with parameters:

10%	$329,195	(=C71)
Likeliest	$410,780	(=D71)
90%	$758,685	(=E71)

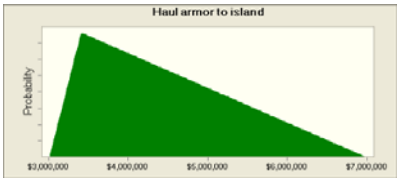


Assumption: Haul armor to island **Cell: D72**

Triangular distribution with parameters:

10%	$3,409,878	(=C72)
Likeliest	$3,409,697	(=D72)
90%	$5,789,228	(=E72)

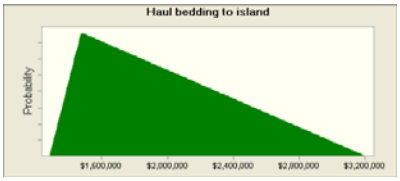
Assumption: Haul armor to island (cont'd) **Cell: D72**



Assumption: Haul bedding to island **Cell: D73**

Triangular distribution with parameters:

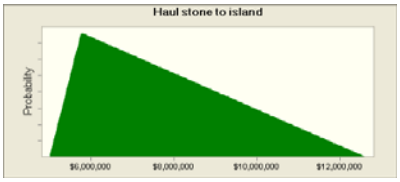
10%	$1,474,750	(=C73)
Likeliest	$1,474,672	(=D73)
90%	$2,627,875	(=E73)



Assumption: Haul stone to island **Cell: D74**

Triangular distribution with parameters:

10%	$5,764,156	(=C74)
Likeliest	$5,763,850	(=D74)
90%	$10,326,170	(=E74)

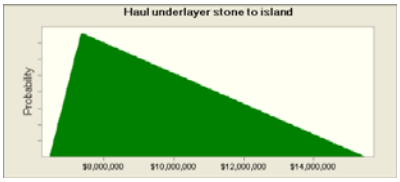


Assumption: Haul underlayer stone to island **Cell: D75**

Triangular distribution with parameters:

10%	$7,352,866	(=C75)
Likeliest	$7,352,477	(=D75)
90%	$12,766,176	(=E75)

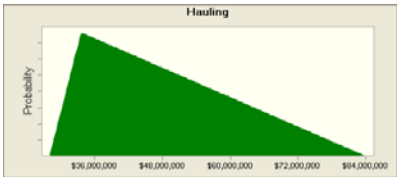
Assumption: Haul underlayer stone to island (cont'd) **Cell: D75**



Assumption: Hauling **Cell: D76**

Triangular distribution with parameters:

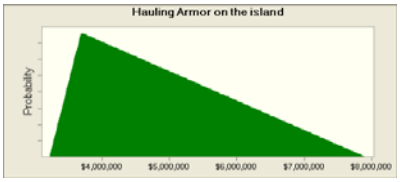
10%	$33,578,965	(=C76)
Likeliest	$33,577,185	(=D76)
90%	$67,155,753	(=E76)



Assumption: Hauling Armor on the island **Cell: D77**

Triangular distribution with parameters:

10%	$3,686,496	(=C77)
Likeliest	$3,686,301	(=D77)
90%	$6,501,796	(=E77)

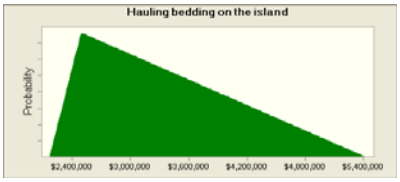


Assumption: Hauling bedding on the island **Cell: D78**

Triangular distribution with parameters:

10%	$2,493,325	(=C78)
Likeliest	$2,493,193	(=D78)
90%	$4,442,887	(=E78)

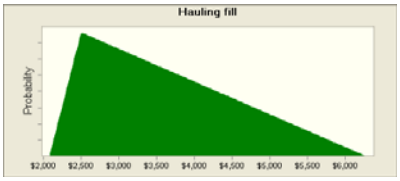
Assumption: Hauling bedding on the island (cont'd) **Cell: D78**



Assumption: Hauling fill **Cell: D79**

Triangular distribution with parameters:

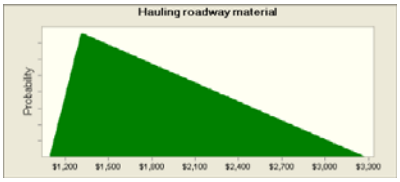
10%	$2,505	(=C79)
Likeliest	$2,505	(=D79)
90%	$5,010	(=E79)



Assumption: Hauling roadway material **Cell: D80**

Triangular distribution with parameters:

10%	$1,311	(=C80)
Likeliest	$1,311	(=D80)
90%	$2,623	(=E80)

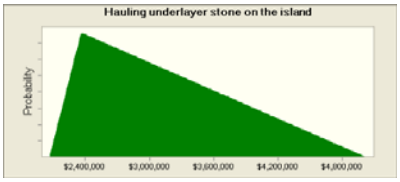


Assumption: Hauling underlayer stone on the island **Cell: D81**

Triangular distribution with parameters:

10%	$2,363,328	(=C81)
Likeliest	$2,363,203	(=D81)
90%	$4,130,963	(=E81)

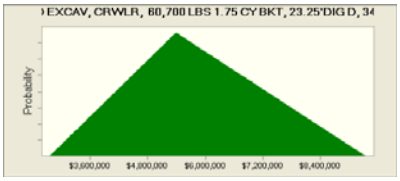
Assumption: Hauling underlayer stone on the island (cont'd) **Cell: D81**



Assumption: HYD EXCAV, CRWLR, 60,700 LBS 1.75 CY BKT, 23.25'DIG D, 34.5'R **Cell: D82**

Triangular distribution with parameters:

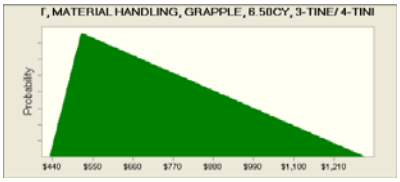
10%	$4,072,262	(=C82)
Likeliest	$5,387,370	(=D82)
90%	$7,722,875	(=E82)



Assumption: HYDRAULIC EXCAVATOR, ATTACHMENT, MATERIAL HANDLING, GRAPPLE, 8.5t **Cell: D83**

Triangular distribution with parameters:

10%	$518	(=C83)
Likeliest	$518	(=D83)
90%	$1,037	(=E83)

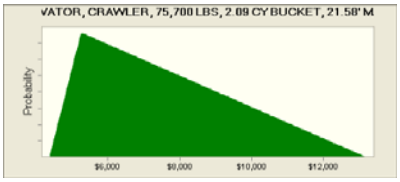


Assumption: HYDRAULIC EXCAVATOR, CRAWLER, 75,700 LBS, 2.09 CY BUCKET, 21.58' MAX **Cell: D84**

Triangular distribution with parameters:

10%	$5,265	(=C84)
Likeliest	$5,265	(=D84)
90%	$10,529	(=E84)

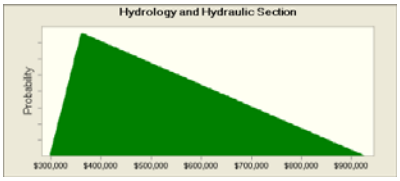
Assumption: HYDRAULIC EXCAVATOR, CRAWLER, 75,700 LBS, 2.09 CY BUCKET, 21.58' MAX **Cell: D84**



Assumption: Hydrology and Hydraulic Section **Cell: D85**

Triangular distribution with parameters:

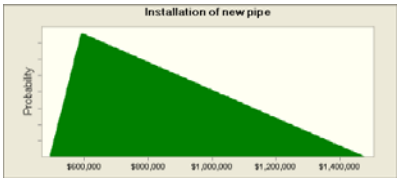
10%	$361,080	(=C85)
Likeliest	$361,080	(=D85)
90%	$738,480	(=E85)



Assumption: Installation of new pipe **Cell: D86**

Triangular distribution with parameters:

10%	$591,360	(=C86)
Likeliest	$591,360	(=D86)
90%	$1,182,720	(=E86)

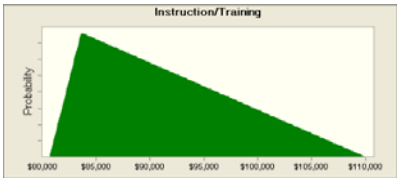


Assumption: Instruction/Training **Cell: D87**

Triangular distribution with parameters:

10%	$83,600	(=C87)
Likeliest	$83,600	(=D87)
90%	$101,200	(=E87)

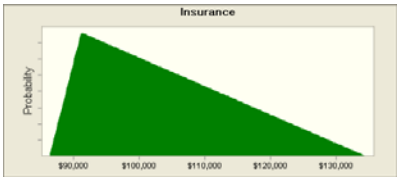
Assumption: Instruction/Training (cont'd) **Cell: D87**



Assumption: Insurance **Cell: D88**

Triangular distribution with parameters:

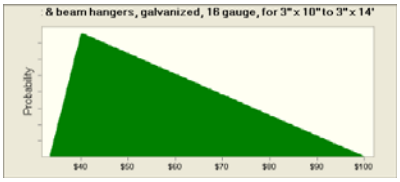
10%	$91,200	(=C88)
Likeliest	$91,200	(=D88)
90%	$120,000	(=E88)



Assumption: Joist & beam hangers, galvanized, 16 gauge, for 3" x 10" to 3" x 14" joist **Cell: D89**

Triangular distribution with parameters:

10%	$40	(=C89)
Likeliest	$40	(=D89)
90%	$80	(=E89)

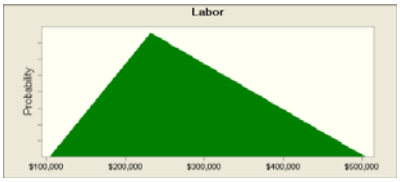


Assumption: Labor **Cell: D90**

Triangular distribution with parameters:

10%	$175,375	(=C90)
Likeliest	$231,800	(=D90)
90%	$399,550	(=E90)

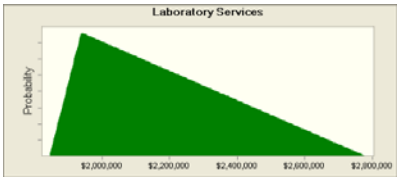
Assumption: Labor (cont'd) **Cell: D90**



Assumption: Laboratory Services **Cell: D91**

Triangular distribution with parameters:

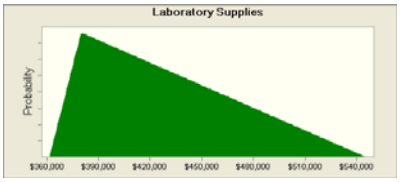
10%	$1,938,000	(=C91)
Likeliest	$1,938,000	(=D91)
90%	$2,499,000	(=E91)



Assumption: Laboratory Supplies **Cell: D92**

Triangular distribution with parameters:

10%	$380,000	(=C92)
Likeliest	$380,000	(=D92)
90%	$490,000	(=E92)

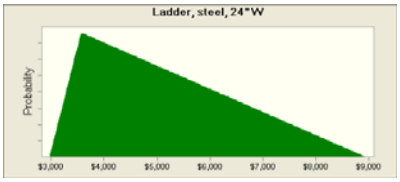


Assumption: Ladder, steel, 24" W **Cell: D93**

Triangular distribution with parameters:

10%	$3,572	(=C93)
Likeliest	$3,572	(=D93)
90%	$7,144	(=E93)

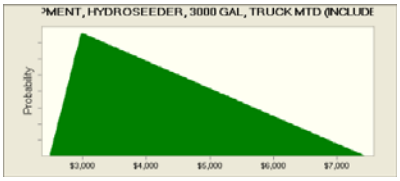
Assumption: Ladder, steel, 24" W (cont'd) **Cell: D93**



Assumption: LANDSCAPING EQUIPMENT, HYDROSEEDER, 3000 GAL, TRUCK MTD (INCLUDES **Cell: D94**

Triangular distribution with parameters:

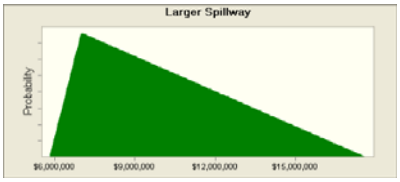
10%	$2,978	(=C94)
Likeliest	$2,978	(=D94)
90%	$5,955	(=E94)



Assumption: Larger Spillway **Cell: D95**

Triangular distribution with parameters:

10%	$6,998,608	(=C95)
Likeliest	$6,998,237	(=D95)
90%	$14,062,812	(=E95)

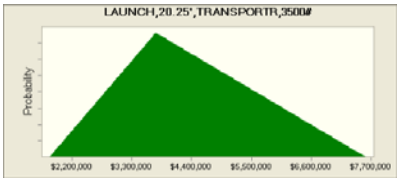


Assumption: LAUNCH,20.25',TRANSPORTR,3500# **Cell: D96**

Triangular distribution with parameters:

10%	$2,856,510	(=C96)
Likeliest	$3,743,013	(=D96)
90%	$6,101,217	(=E96)

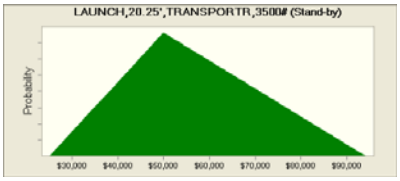
Assumption: LAUNCH,20.25',TRANSPORTR,3500# (cont'd) **Cell: D96**



Assumption: LAUNCH,20.25',TRANSPORTR,3500# (Stand-by) **Cell: D97**

Triangular distribution with parameters:

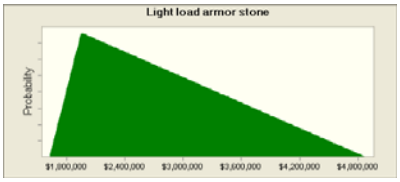
10%	$38,213	(=C97)
Likeliest	$49,954	(=D97)
90%	$76,616	(=E97)



Assumption: Light load armor stone **Cell: D98**

Triangular distribution with parameters:

10%	$1,950,789	(=C98)
Likeliest	$1,950,685	(=D98)
90%	$3,901,393	(=E98)

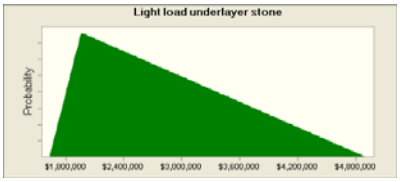


Assumption: Light load underlayer stone **Cell: D99**

Triangular distribution with parameters:

10%	$1,960,829	(=C99)
Likeliest	$1,960,725	(=D99)
90%	$3,921,492	(=E99)

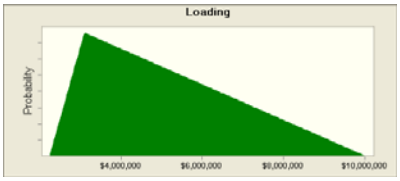
Assumption: Light load underlayer stone (cont'd) **Cell: D99**



Assumption: Loading **Cell: D100**

Triangular distribution with parameters:

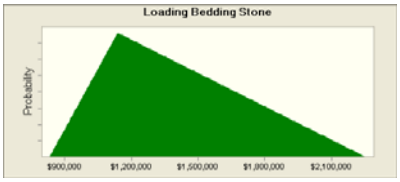
10%	$3,062,901	(=C100)
Likeliest	$3,103,081	(=D100)
90%	$7,698,941	(=E100)



Assumption: Loading Bedding Stone **Cell: D101**

Triangular distribution with parameters:

10%	$1,040,590	(=C101)
Likeliest	$1,138,085	(=D101)
90%	$1,854,240	(=E101)

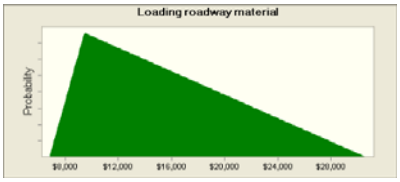


Assumption: Loading roadway material **Cell: D102**

Triangular distribution with parameters:

10%	$9,351	(=C102)
Likeliest	$9,474	(=D102)
90%	$23,506	(=E102)

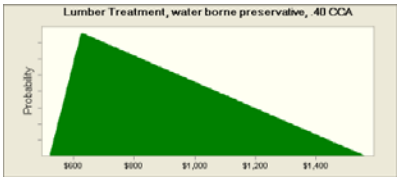
Assumption: Loading roadway material (cont'd) **Cell: D102**



Assumption: Lumber Treatment, water borne preservative, .40 CCA **Cell: D103**

Triangular distribution with parameters:

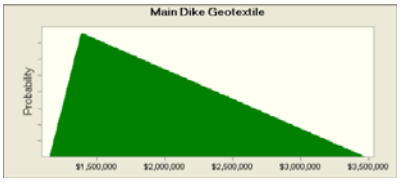
10%	$625	(=C103)
Likeliest	$625	(=D103)
90%	$1,250	(=E103)



Assumption: Main Dike Geotextile **Cell: D104**

Triangular distribution with parameters:

10%	$1,387,128	(=C104)
Likeliest	$1,387,055	(=D104)
90%	$2,779,106	(=E104)

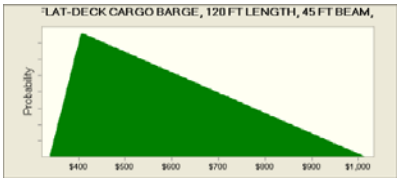


Assumption: MARINE EQUIPMENT, FLAT-DECK CARGO BARGE, 120 FT LENGTH, 45 FT BEAM **Cell: D107**

Triangular distribution with parameters:

10%	$406	(=C107)
Likeliest	$406	(=D107)
90%	$812	(=E107)

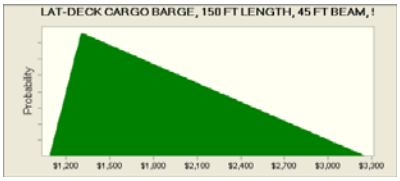
Assumption: MARINE EQUIPMENT, FLAT-DECK CARGO BARGE, 120 FT LENGTH, 45 FT BEAM **Cell: D107**



Assumption: MARINE EQUIPMENT, FLAT-DECK CARGO BARGE, 150 FT LENGTH, 45 FT BEAM **Cell: D108**

Triangular distribution with parameters:

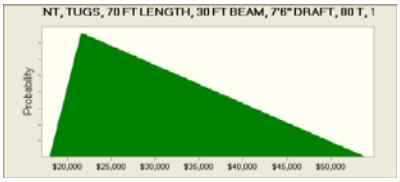
10%	$1,303	(=C108)
Likeliest	$1,303	(=D108)
90%	$2,605	(=E108)



Assumption: MARINE EQUIPMENT, TUGS, 70 FT LENGTH, 30 FT BEAM, 7'6" DRAFT, 80 T, 1350 **Cell: D109**

Triangular distribution with parameters:

10%	$21,577	(=C109)
Likeliest	$21,575	(=D109)
90%	$43,152	(=E109)

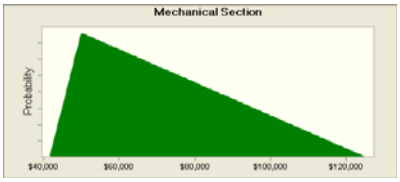


Assumption: Mechanical Section **Cell: D110**

Triangular distribution with parameters:

10%	$50,000	(=C110)
Likeliest	$50,000	(=D110)
90%	$100,000	(=E110)

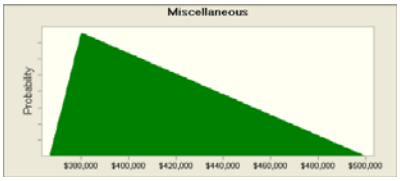
Assumption: Mechanical Section (cont'd) **Cell: D110**



Assumption: Miscellaneous **Cell: D111**

Triangular distribution with parameters:

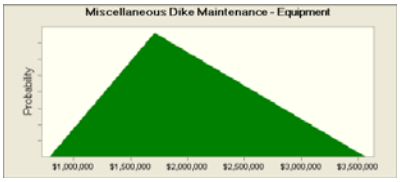
10%	$380,000	(=C111)
Likeliest	$380,000	(=D111)
90%	$460,000	(=E111)



Assumption: Miscellaneous Dike Maintenance - Equipment **Cell: D112**

Triangular distribution with parameters:

10%	$1,293,750	(=C112)
Likeliest	$1,710,000	(=D112)
90%	$2,846,250	(=E112)

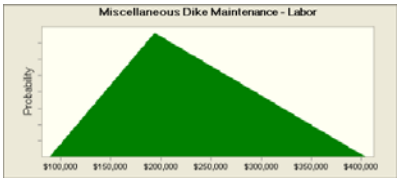


Assumption: Miscellaneous Dike Maintenance - Labor **Cell: D113**

Triangular distribution with parameters:

10%	$146,625	(=C113)
Likeliest	$193,800	(=D113)
90%	$322,575	(=E113)

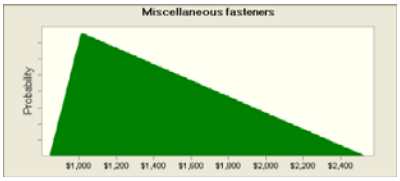
Assumption: Miscellaneous Dike Maintenance - Labor (cont'd) **Cell: D113**



Assumption: Miscellaneous fasteners **Cell: D114**

Triangular distribution with parameters:

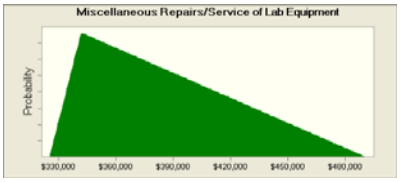
10%	$1,013	(=C114)
Likeliest	$1,013	(=D114)
90%	$2,026	(=E114)



Assumption: Miscellaneous Repairs/Service of Lab Equipment **Cell: D115**

Triangular distribution with parameters:

10%	$342,000	(=C115)
Likeliest	$342,000	(=D115)
90%	$441,000	(=E115)

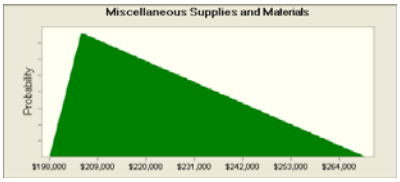


Assumption: Miscellaneous Supplies and Materials **Cell: D116**

Triangular distribution with parameters:

10%	$205,200	(=C116)
Likeliest	$205,200	(=D116)
90%	$248,400	(=E116)

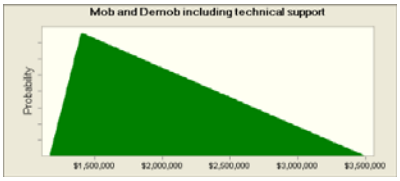
Assumption: Miscellaneous Supplies and Materials (cont'd) **Cell: D116**



Assumption: Mob and Demob including technical support **Cell: D117**

Triangular distribution with parameters:

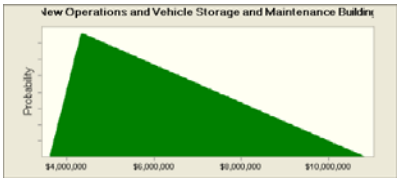
10%	$1,400,000	(=C117)
Likeliest	$1,400,000	(=D117)
90%	$2,800,000	(=E117)



Assumption: New Operations and Vehicle Storage and Maintenance Building **Cell: D121**

Triangular distribution with parameters:

10%	$4,335,384	(=C121)
Likeliest	$4,335,198	(=D121)
90%	$8,670,488	(=E121)

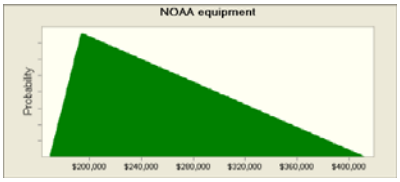


Assumption: NOAA equipment **Cell: D122**

Triangular distribution with parameters:

10%	$193,800	(=C122)
Likeliest	$193,800	(=D122)
90%	$339,660	(=E122)

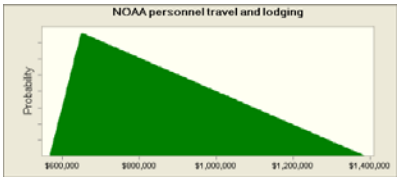
Assumption: NOAA equipment (cont'd) **Cell: D122**



Assumption: NOAA personnel travel and lodging **Cell: D123**

Triangular distribution with parameters:

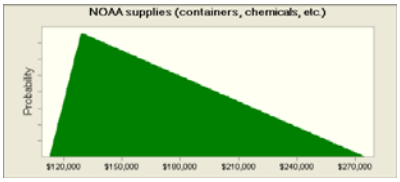
10%	$650,370	(=C123)
Likeliest	$650,370	(=D123)
90%	$1,141,455	(=E123)



Assumption: NOAA supplies (containers, chemicals, etc.) **Cell: D124**

Triangular distribution with parameters:

10%	$129,200	(=C124)
Likeliest	$129,200	(=D124)
90%	$226,440	(=E124)

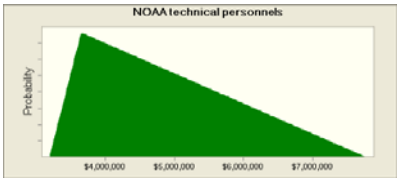


Assumption: NOAA technical personnels **Cell: D125**

Triangular distribution with parameters:

10%	$3,648,000	(=C125)
Likeliest	$3,648,000	(=D125)
90%	$6,393,600	(=E125)

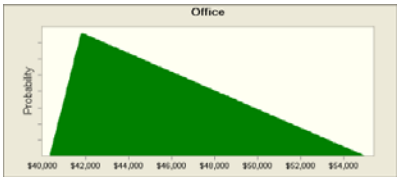
Assumption: NOAA technical personnels (cont'd) **Cell: D125**



Assumption: Office **Cell: D126**

Triangular distribution with parameters:

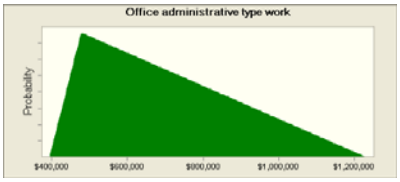
10%	$41,800	(=C126)
Likeliest	$41,800	(=D126)
90%	$50,600	(=E126)



Assumption: Office administrative type work **Cell: D127**

Triangular distribution with parameters:

10%	$478,440	(=C127)
Likeliest	$478,440	(=D127)
90%	$978,480	(=E127)

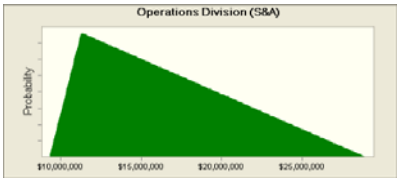


Assumption: Operations Division (S&A) **Cell: D128**

Triangular distribution with parameters:

10%	$11,280,000	(=C128)
Likeliest	$11,280,000	(=D128)
90%	$23,040,000	(=E128)

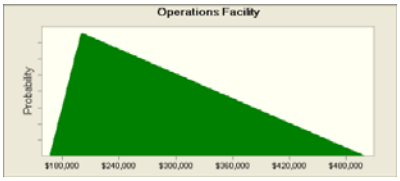
Assumption: Operations Division (S&A) (cont'd) **Cell: D128**



Assumption: Operations Facility **Cell: D129**

Triangular distribution with parameters:

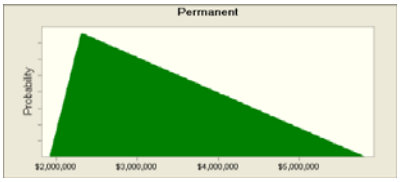
10%	$200,000	(=C129)
Likeliest	$200,000	(=D129)
90%	$400,000	(=E129)



Assumption: Permanent **Cell: D130**

Triangular distribution with parameters:

10%	$2,311,542	(=C130)
Likeliest	$2,311,420	(=D130)
90%	$4,645,173	(=E130)

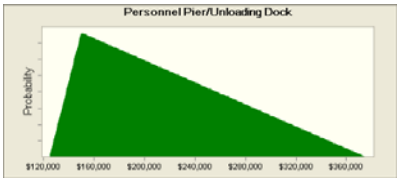


Assumption: Personnel Pier/Unloading Dock **Cell: D131**

Triangular distribution with parameters:

10%	$150,000	(=C131)
Likeliest	$150,000	(=D131)
90%	$300,000	(=E131)

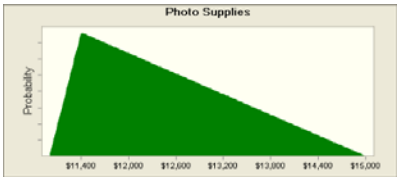
Assumption: Personnel Pier/Unloading Dock (cont'd) **Cell: D131**



Assumption: Photo Supplies **Cell: D132**

Triangular distribution with parameters:

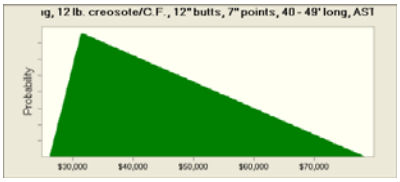
10%	$11,400	(=C132)
Likeliest	$11,400	(=D132)
90%	$13,800	(=E132)



Assumption: Piles, pile, wood, treated, friction or end bearing, 12 lb. creosote/C.F., 12" butts, 7" Cell: D133

Triangular distribution with parameters:

10%	$31,364	(=C133)
Likeliest	$31,363	(=D133)
90%	$62,727	(=E133)

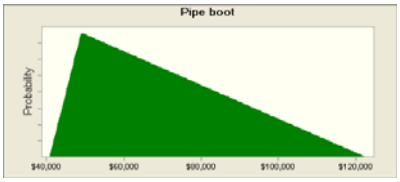


Assumption: Pipe boot **Cell: D134**

Triangular distribution with parameters:

10%	$49,000	(=C134)
Likeliest	$49,000	(=D134)
90%	$98,000	(=E134)

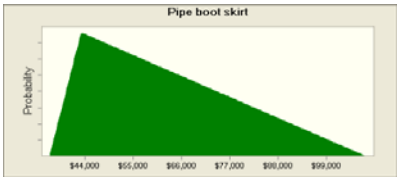
Assumption: Pipe boot (cont'd) **Cell: D134**



Assumption: Pipe boot skirt **Cell: D135**

Triangular distribution with parameters:

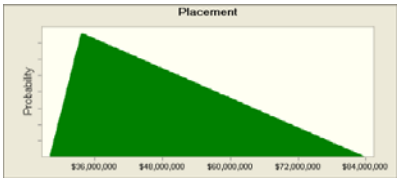
10%	$43,120	(=C135)
Likeliest	$43,120	(=D135)
90%	$86,240	(=E135)



Assumption: Placement **Cell: D136**

Triangular distribution with parameters:

10%	$33,560,485	(=C136)
Likeliest	$33,558,706	(=D136)
90%	$67,118,793	(=E136)

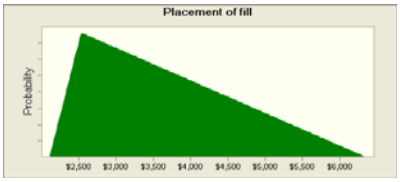


Assumption: Placement of fill **Cell: D137**

Triangular distribution with parameters:

10%	$2,536	(=C137)
Likeliest	$2,536	(=D137)
90%	$5,072	(=E137)

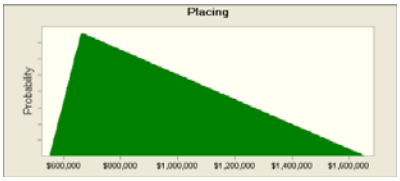
Assumption: Placement of fill (cont'd) **Cell: D137**



Assumption: Placing **Cell: D138**

Triangular distribution with parameters:

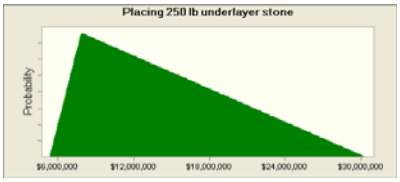
10%	$662,516	(=C138)
Likeliest	$662,481	(=D138)
90%	$1,324,989	(=E138)



Assumption: Placing 250 lb underlayer stone **Cell: D139**

Triangular distribution with parameters:

10%	$7,840,037	(=C139)
Likeliest	$7,839,622	(=D139)
90%	$22,845,869	(=E139)

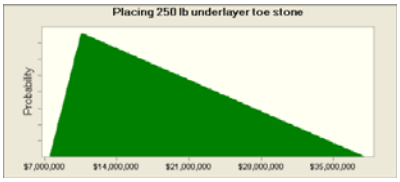


Assumption: Placing 250 lb underlayer toe stone **Cell: D140**

Triangular distribution with parameters:

10%	$10,559,391	(=C140)
Likeliest	$10,558,831	(=D140)
90%	$28,906,277	(=E140)

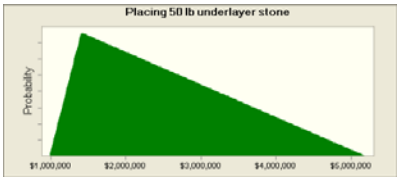
Assumption: Placing 250 lb underlayer toe stone (cont'd) **Cell: D140**



Assumption: Placing 50 lb underlayer stone **Cell: D141**

Triangular distribution with parameters:

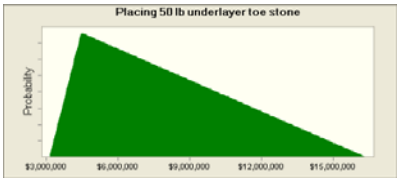
10%	$1,407,974	(=C141)
Likeliest	$1,407,900	(=D141)
90%	$3,929,511	(=E141)



Assumption: Placing 50 lb underlayer toe stone **Cell: D142**

Triangular distribution with parameters:

10%	$4,448,805	(=C142)
Likeliest	$4,448,569	(=D142)
90%	$12,387,111	(=E142)

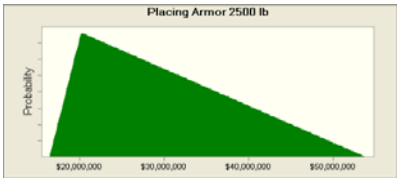


Assumption: Placing Armor 2500 lb **Cell: D143**

Triangular distribution with parameters:

10%	$20,183,042	(=C143)
Likeliest	$20,181,972	(=D143)
90%	$42,626,311	(=E143)

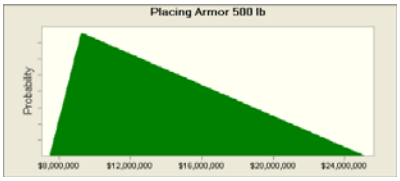
Assumption: Placing Armor 2500 lb (cont'd) **Cell: D143**



Assumption: Placing Armor 500 lb **Cell: D144**

Triangular distribution with parameters:

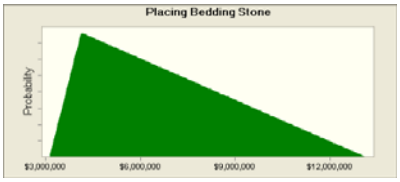
10%	$9,241,637	(=C144)
Likeliest	$9,241,147	(=D144)
90%	$19,856,011	(=E144)



Assumption: Placing Bedding Stone **Cell: D145**

Triangular distribution with parameters:

10%	$4,122,765	(=C145)
Likeliest	$4,122,546	(=D145)
90%	$10,121,317	(=E145)

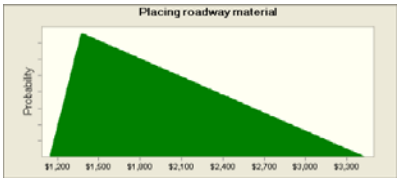


Assumption: Placing roadway material **Cell: D146**

Triangular distribution with parameters:

10%	$1,373	(=C146)
Likeliest	$1,373	(=D146)
90%	$2,747	(=E146)

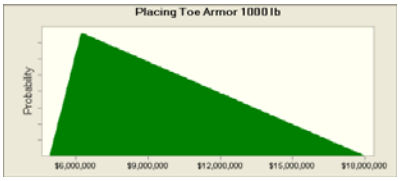
Assumption: Placing roadway material (cont'd) **Cell: D146**



Assumption: Placing Toe Armor 1000 lb **Cell: D147**

Triangular distribution with parameters:

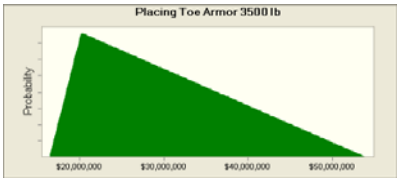
10%	$6,229,608	(=C147)
Likeliest	$6,229,277	(=D147)
90%	$14,081,564	(=E147)



Assumption: Placing Toe Armor 3500 lb **Cell: D148**

Triangular distribution with parameters:

10%	$20,163,906	(=C148)
Likeliest	$20,162,837	(=D148)
90%	$42,677,224	(=E148)

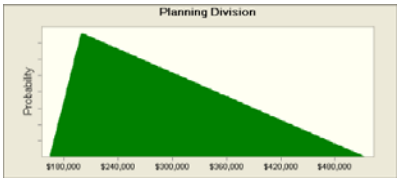


Assumption: Planning Division **Cell: D149**

Triangular distribution with parameters:

10%	$199,120	(=C149)
Likeliest	$199,120	(=D149)
90%	$408,720	(=E149)

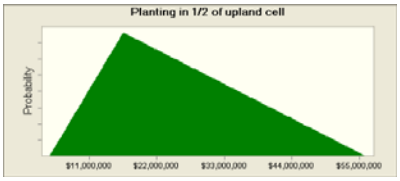
Assumption: Planning Division (cont'd) **Cell: D149**



Assumption: Planting in 1/2 of upland cell **Cell: D150**

Triangular distribution with parameters:

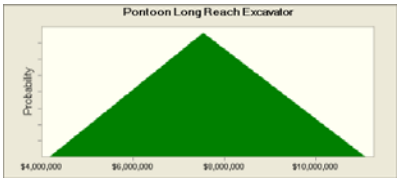
10%	$12,390,334	(=C150)
Likeliest	$16,519,569	(=D150)
90%	$41,704,708	(=E150)



Assumption: Pontoon Long Reach Excavator **Cell: D151**

Triangular distribution with parameters:

10%	$5,688,705	(=C151)
Likeliest	$7,525,372	(=D151)
90%	$9,508,998	(=E151)

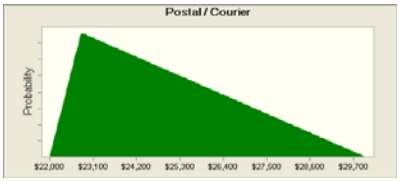


Assumption: Postal / Courier **Cell: D152**

Triangular distribution with parameters:

10%	$22,800	(=C152)
Likeliest	$22,800	(=D152)
90%	$27,600	(=E152)

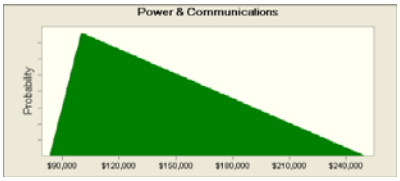
Assumption: Postal / Courier (cont'd) **Cell: D152**



Assumption: Power & Communications **Cell: D153**

Triangular distribution with parameters:

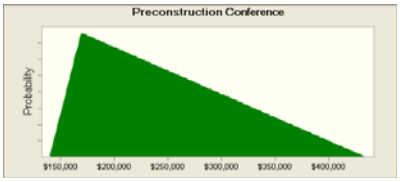
10%	$100,000	(=C153)
Likeliest	$100,000	(=D153)
90%	$200,000	(=E153)



Assumption: Preconstruction Conference **Cell: D154**

Triangular distribution with parameters:

10%	$168,960	(=C154)
Likeliest	$168,960	(=D154)
90%	$345,600	(=E154)

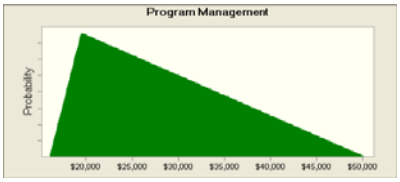


Assumption: Program Management **Cell: D155**

Triangular distribution with parameters:

10%	$19,500	(=C155)
Likeliest	$19,500	(=D155)
90%	$40,000	(=E155)

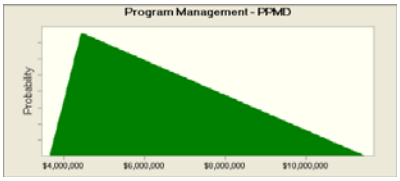
Assumption: Program Management (cont'd) **Cell: D155**



Assumption: Program Management - PPMD **Cell: D156**

Triangular distribution with parameters:

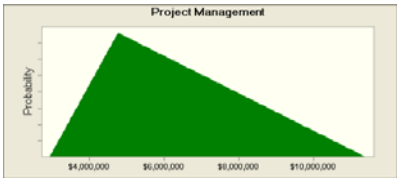
10%	$4,440,000	(=C156)
Likeliest	$4,440,000	(=D156)
90%	$9,120,000	(=E156)



Assumption: Project Management **Cell: D157**

Triangular distribution with parameters:

10%	$4,172,486	(=C157)
Likeliest	$4,759,217	(=D157)
90%	$9,018,355	(=E157)



Assumption: Quality assurance work **Cell: D158**

Triangular distribution with parameters:

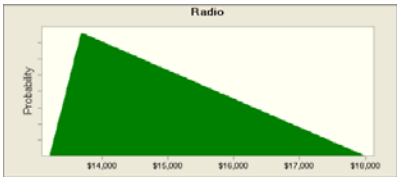
10%	$7,974,000	(=C158)
Likeliest	$7,974,000	(=D158)
90%	$16,308,000	(=E158)

Assumption: Quality assurance work (cont'd) **Cell: D158**

Assumption: Radio **Cell: D159**

Triangular distribution with parameters:

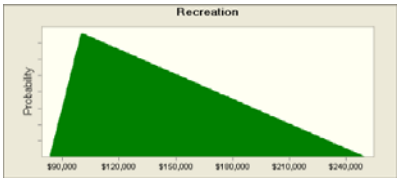
10%	$13,680	(=C159)
Likeliest	$13,680	(=D159)
90%	$16,560	(=E159)



Assumption: Recreation **Cell: D160**

Triangular distribution with parameters:

10%	$100,000	(=C160)
Likeliest	$100,000	(=D160)
90%	$200,000	(=E160)



Assumption: Remove armor stone **Cell: D161**

Triangular distribution with parameters:

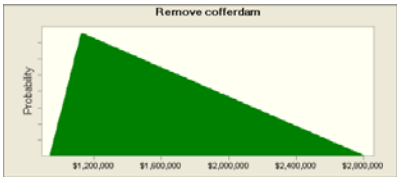
10%	$112,000	(=C161)
Likeliest	$112,000	(=D161)
90%	$224,000	(=E161)

Assumption: Remove armor stone (cont'd) **Cell: D161**

Assumption: Remove cofferdam **Cell: D162**

Triangular distribution with parameters:

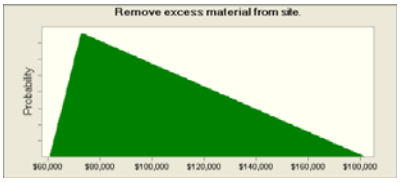
10%	$1,124,200	(=C162)
Likeliest	$1,124,200	(=D162)
90%	$2,248,400	(=E162)



Assumption: Remove excess material from site. **Cell: D163**

Triangular distribution with parameters:

10%	$72,800	(=C163)
Likeliest	$72,800	(=D163)
90%	$145,600	(=E163)



Assumption: Replace armor stone **Cell: D164**

Triangular distribution with parameters:

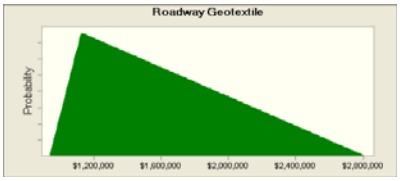
10%	$112,000	(=C164)
Likeliest	$112,000	(=D164)
90%	$224,000	(=E164)

Assumption: Replace armor stone (cont'd) **Cell: D164**

Assumption: Roadway Geotextile **Cell: D165**

Triangular distribution with parameters:

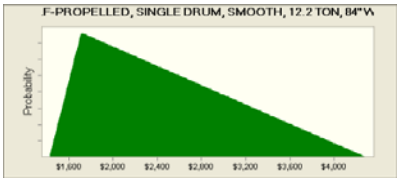
10%	$1,123,651	(=C165)
Likeliest	$1,123,594	(=D165)
90%	$2,250,187	(=E165)



Assumption: ROLLER, VIBRATORY, SELF-PROPELLED, SINGLE DRUM, SMOOTH, 12.2 TON, 84" W **Cell: D166**

Triangular distribution with parameters:

10%	$1,713	(=C166)
Likeliest	$1,713	(=D166)
90%	$3,426	(=E166)

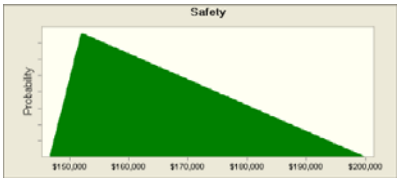


Assumption: Safety **Cell: D167**

Triangular distribution with parameters:

10%	$152,000	(=C167)
Likeliest	$152,000	(=D167)
90%	$184,000	(=E167)

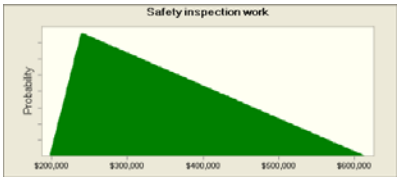
Assumption: Safety (cont'd) **Cell: D167**



Assumption: Safety inspection work **Cell: D168**

Triangular distribution with parameters:

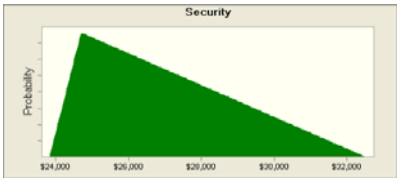
10%	$239,220	(=C168)
Likeliest	$239,220	(=D168)
90%	$489,240	(=E168)



Assumption: Security **Cell: D169**

Triangular distribution with parameters:

10%	$24,700	(=C169)
Likeliest	$24,700	(=D169)
90%	$29,900	(=E169)

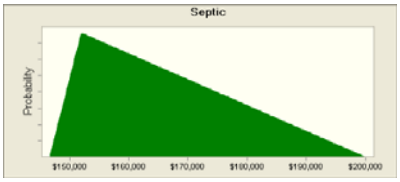


Assumption: Septic **Cell: D170**

Triangular distribution with parameters:

10%	$152,000	(=C170)
Likeliest	$152,000	(=D170)
90%	$184,000	(=E170)

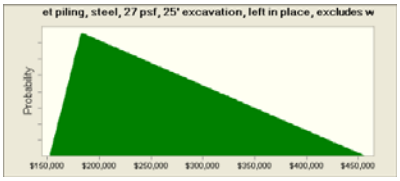
Assumption: Septic (cont'd) **Cell: D170**



Assumption: Sheet piling, steel, 27 psf, 25' excavation, left in place, excludes wales **Cell: D171**

Triangular distribution with parameters:

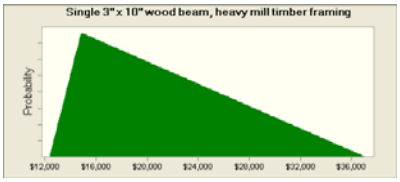
10%	$182,650	(=C171)
Likeliest	$182,641	(=D171)
90%	$365,289	(=E171)



Assumption: Single 3" x 10" wood beam, heavy mill timber framing **Cell: D172**

Triangular distribution with parameters:

10%	$14,828	(=C172)
Likeliest	$14,827	(=D172)
90%	$29,656	(=E172)

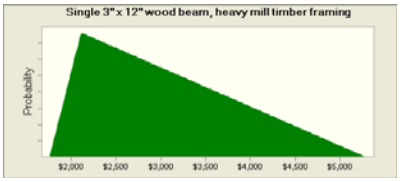


Assumption: Single 3" x 12" wood beam, heavy mill timber framing **Cell: D173**

Triangular distribution with parameters:

10%	$2,112	(=C173)
Likeliest	$2,112	(=D173)
90%	$4,225	(=E173)

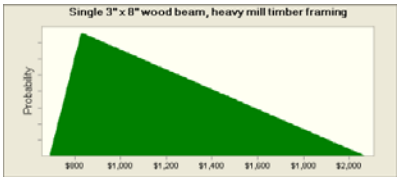
Assumption: Single 3" x 12" wood beam, heavy mill timber framing (cont'd) **Cell: D173**



Assumption: Single 3" x 8" wood beam, heavy mill timber framing **Cell: D174**

Triangular distribution with parameters:

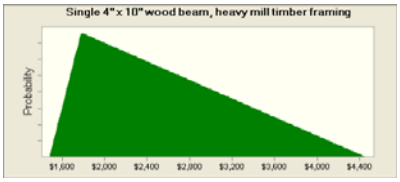
10%	$828	(=C174)
Likeliest	$828	(=D174)
90%	$1,657	(=E174)



Assumption: Single 4" x 10" wood beam, heavy mill timber framing **Cell: D175**

Triangular distribution with parameters:

10%	$1,781	(=C175)
Likeliest	$1,781	(=D175)
90%	$3,562	(=E175)

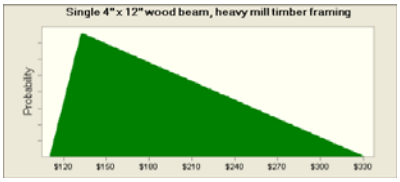


Assumption: Single 4" x 12" wood beam, heavy mill timber framing **Cell: D176**

Triangular distribution with parameters:

10%	$133	(=C176)
Likeliest	$133	(=D176)
90%	$265	(=E176)

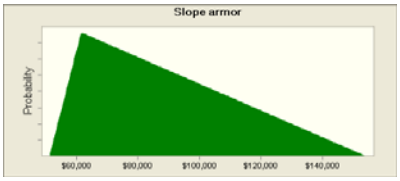
Assumption: Single 4" x 12" wood beam, heavy mill timber framing (cont'd) **Cell: D176**



Assumption: Slope armor **Cell: D177**

Triangular distribution with parameters:

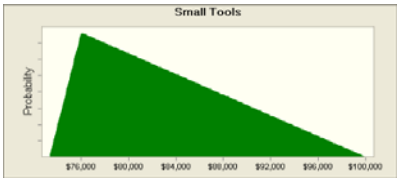
10%	$61,600	(=C177)
Likeliest	$61,600	(=D177)
90%	$123,200	(=E177)



Assumption: Small Tools **Cell: D178**

Triangular distribution with parameters:

10%	$76,000	(=C178)
Likeliest	$76,000	(=D178)
90%	$92,000	(=E178)

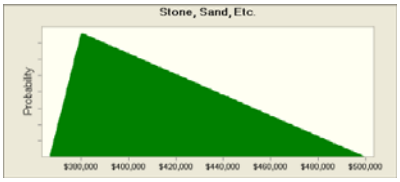


Assumption: Stone, Sand, Etc. **Cell: D179**

Triangular distribution with parameters:

10%	$380,000	(=C179)
Likeliest	$380,000	(=D179)
90%	$460,000	(=E179)

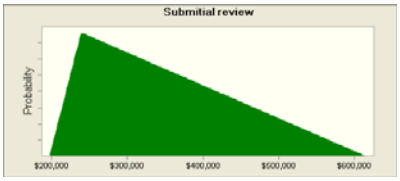
Assumption: Stone, Sand, Etc. (cont'd) **Cell: D179**



Assumption: Submitial review **Cell: D180**

Triangular distribution with parameters:

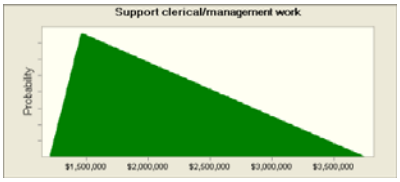
10%	$239,220	(=C180)
Likeliest	$239,220	(=D180)
90%	$489,240	(=E180)



Assumption: Support clerical/management work **Cell: D181**

Triangular distribution with parameters:

10%	$1,461,900	(=C181)
Likeliest	$1,461,900	(=D181)
90%	$2,989,800	(=E181)

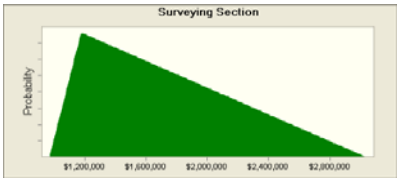


Assumption: Surveying Section **Cell: D182**

Triangular distribution with parameters:

10%	$1,178,000	(=C182)
Likeliest	$1,178,000	(=D182)
90%	$2,413,000	(=E182)

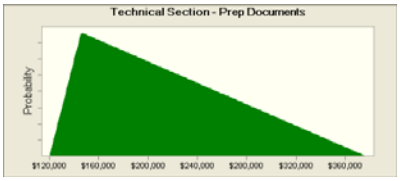
Assumption: Surveying Section (cont'd) **Cell: D182**



Assumption: Technical Section - Prep Documents **Cell: D183**

Triangular distribution with parameters:

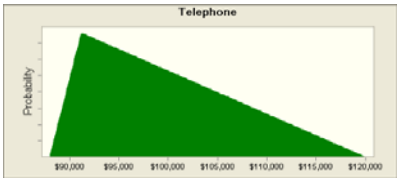
10%	$145,920	(=C183)
Likeliest	$145,920	(=D183)
90%	$299,520	(=E183)



Assumption: Telephone **Cell: D184**

Triangular distribution with parameters:

10%	$91,200	(=C184)
Likeliest	$91,200	(=D184)
90%	$110,400	(=E184)

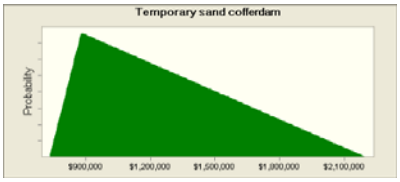


Assumption: Temporary sand cofferdam **Cell: D185**

Triangular distribution with parameters:

10%	$879,200	(=C185)
Likeliest	$879,200	(=D185)
90%	$1,758,400	(=E185)

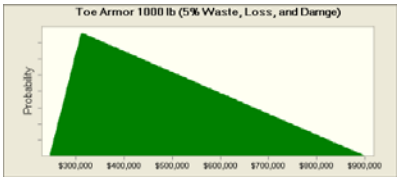
Assumption: Temporary sand cofferdam (cont'd) **Cell: D185**



Assumption: Toe Armor 1000 lb (5% Waste, Loss, and Damge) **Cell: D186**

Triangular distribution with parameters:

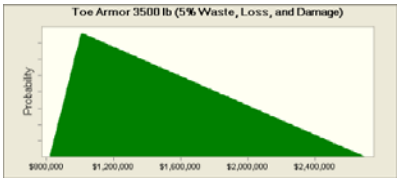
10%	$311,520	(=C186)
Likeliest	$311,503	(=D186)
90%	$704,167	(=E186)



Assumption: Toe Armor 3500 lb (5% Waste, Loss, and Damage) **Cell: D187**

Triangular distribution with parameters:

10%	$1,008,269	(=C187)
Likeliest	$1,008,216	(=D187)
90%	$2,134,053	(=E187)

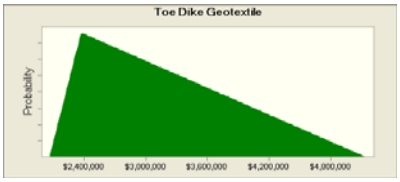


Assumption: Toe Dike Geotextile **Cell: D188**

Triangular distribution with parameters:

10%	$2,371,212	(=C188)
Likeliest	$2,371,087	(=D188)
90%	$4,215,539	(=E188)

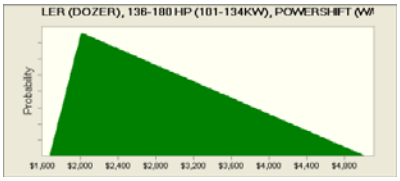
Assumption: Toe Dike Geotextile (cont'd) **Cell: D188**



Assumption: TRACTOR, CRAWLER (DOZER), 136-180 HP (101-134KW), POWERSHIFT (W/ UNIV **Cell: D189**

Triangular distribution with parameters:

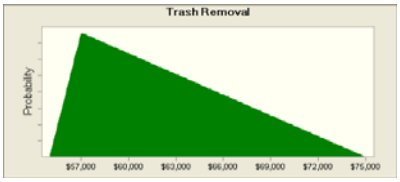
10%	$2,008	(=C189)
Likeliest	$2,008	(=D189)
90%	$4,016	(=E189)



Assumption: Trash Removal **Cell: D190**

Triangular distribution with parameters:

10%	$57,000	(=C190)
Likeliest	$57,000	(=D190)
90%	$69,000	(=E190)

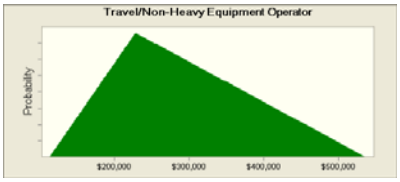


Assumption: Travel/Non-Heavy Equipment Operator **Cell: D191**

Triangular distribution with parameters:

10%	$182,860	(=C191)
Likeliest	$228,000	(=D191)
90%	$421,480	(=E191)

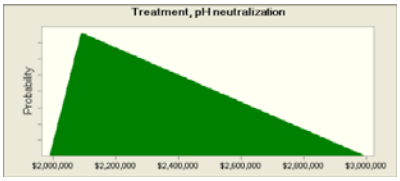
Assumption: Travel/Non-Heavy Equipment Operator (cont'd) **Cell: D191**



Assumption: Treatment, pH neutralization **Cell: D192**

Triangular distribution with parameters:

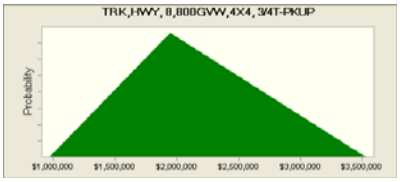
10%	$2,090,000	(=C192)
Likeliest	$2,090,000	(=D192)
90%	$2,695,000	(=E192)



Assumption: TRK,HWY, 8,800GVW,4X4, 3/4T-PKUP **Cell: D193**

Triangular distribution with parameters:

10%	$1,469,378	(=C193)
Likeliest	$1,945,973	(=D193)
90%	$2,890,514	(=E193)

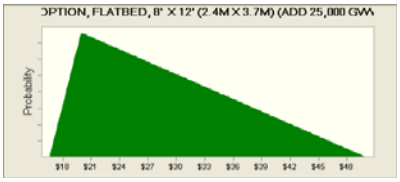


Assumption: TRUCK OPTION, FLATBED, 8' X 12' (2.4M X 3.7M) (ADD 25,000 GVW TRUCK) **Cell: D194**

Triangular distribution with parameters:

10%	$20	(=C194)
Likeliest	$20	(=D194)
90%	$40	(=E194)

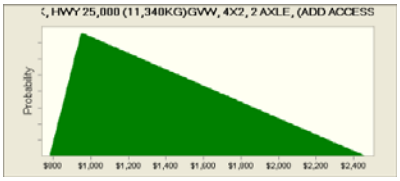
Assumption: TRUCK OPTION, FLATBED, 8' X 12' (2.4M X 3.7M) (ADD 25,000 GVW TRUCK) Cell: D194



Assumption: TRUCK, HWY 25,000 (11,340KG)GVW, 4X2, 2 AXLE, (ADD ACCESSORIES) Cell: D195

Triangular distribution with parameters:

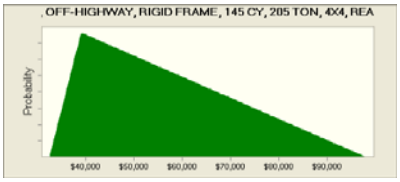
10%	$949	(=C195)
Likeliest	$949	(=D195)
90%	$1,958	(=E195)



Assumption: TRUCK, OFF-HIGHWAY, RIGID FRAME, 145 CY, 205 TON, 4X4, REAR DUMP Cell: D196

Triangular distribution with parameters:

10%	$39,160	(=C196)
Likeliest	$39,158	(=D196)
90%	$78,318	(=E196)

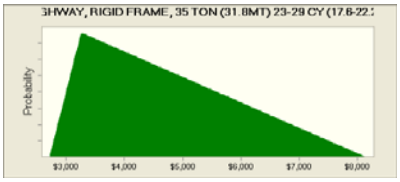


Assumption: TRUCK, OFF-HIGHWAY, RIGID FRAME, 35 TON (31.8MT) 23-29 CY (17.6-22.2M3) IR Cell: D197

Triangular distribution with parameters:

10%	$3,257	(=C197)
Likeliest	$3,257	(=D197)
90%	$6,514	(=E197)

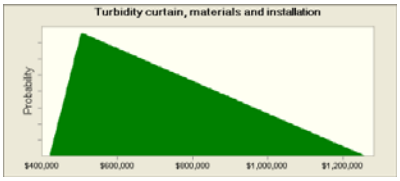
Assumption: TRUCK, OFF-HIGHWAY, RIGID FRAME, 35 TON (31.8MT) 23-29 CY (17.6-22.2M3) IR **Cell: D197**



Assumption: Turbidity curtain, materials and installation **Cell: D198**

Triangular distribution with parameters:

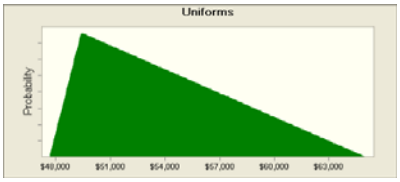
10%	$504,000	(=C198)
Likeliest	$504,000	(=D198)
90%	$1,008,000	(=E198)



Assumption: Uniforms **Cell: D199**

Triangular distribution with parameters:

10%	$49,400	(=C199)
Likeliest	$49,400	(=D199)
90%	$59,800	(=E199)

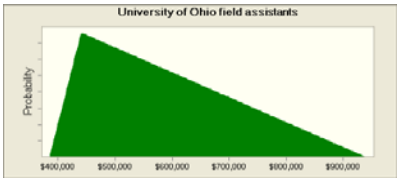


Assumption: University of Ohio field assistants **Cell: D200**

Triangular distribution with parameters:

10%	$440,800	(=C200)
Likeliest	$440,800	(=D200)
90%	$772,560	(=E200)

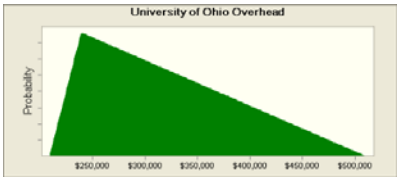
Assumption: University of Ohio field assistants (cont'd) **Cell: D200**



Assumption: University of Ohio Overhead **Cell: D201**

Triangular distribution with parameters:

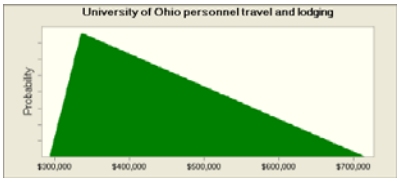
10%	$239,400	(=C201)
Likeliest	$239,400	(=D201)
90%	$419,580	(=E201)



Assumption: University of Ohio personnel travel and lodging **Cell: D202**

Triangular distribution with parameters:

10%	$335,920	(=C202)
Likeliest	$335,920	(=D202)
90%	$588,820	(=E202)

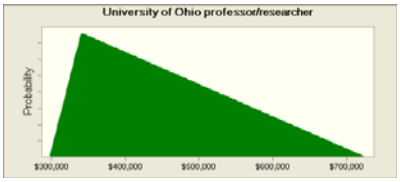


Assumption: University of Ohio professor/researcher **Cell: D203**

Triangular distribution with parameters:

10%	$340,480	(=C203)
Likeliest	$340,480	(=D203)
90%	$596,736	(=E203)

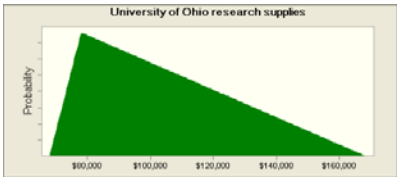
Assumption: University of Ohio professor/researcher (cont'd) **Cell: D203**



Assumption: University of Ohio research supplies **Cell: D204**

Triangular distribution with parameters:

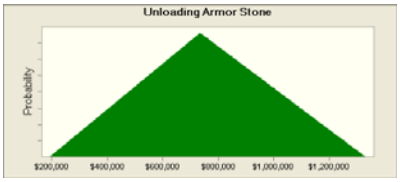
10%	$78,128	(=C204)
Likeliest	$78,128	(=D204)
90%	$138,176	(=E204)



Assumption: Unloading Armor Stone **Cell: D205**

Triangular distribution with parameters:

10%	$440,407	(=C205)
Likeliest	$733,972	(=D205)
90%	$1,069,518	(=E205)

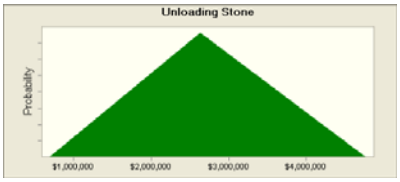


Assumption: Unloading Stone **Cell: D206**

Triangular distribution with parameters:

10%	$1,578,953	(=C206)
Likeliest	$2,631,450	(=D206)
90%	$3,829,597	(=E206)

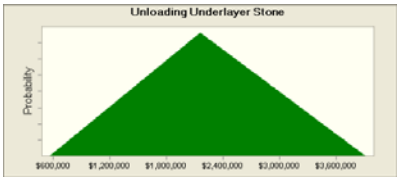
Assumption: Unloading Stone (cont'd) **Cell: D206**



Assumption: Unloading Underlayer Stone **Cell: D207**

Triangular distribution with parameters:

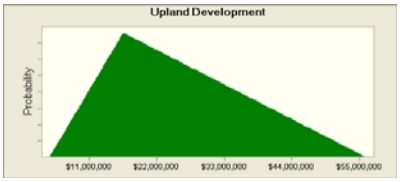
10%	$1,294,565	(=C207)
Likeliest	$2,157,494	(=D207)
90%	$3,140,776	(=E207)



Assumption: Upland Development **Cell: D208**

Triangular distribution with parameters:

10%	$12,390,334	(=C208)
Likeliest	$16,519,569	(=D208)
90%	$41,704,708	(=E208)

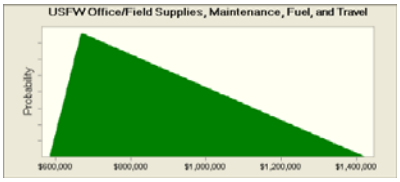


Assumption: USFW Office/Field Supplies, Maintenance, Fuel, and Travel **Cell: D209**

Triangular distribution with parameters:

10%	$668,800	(=C209)
Likeliest	$668,800	(=D209)
90%	$1,172,388	(=E209)

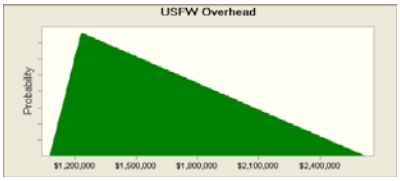
Assumption: USFW Office/Field Supplies, Maintenance, Fuel, and Travel (cont'd) **Cell: D209**



Assumption: USFW Overhead **Cell: D210**

Triangular distribution with parameters:

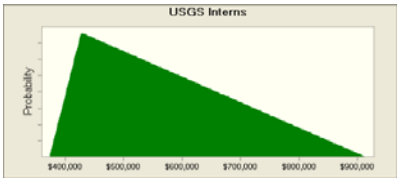
10%	$1,231,200	(=C210)
Likeliest	$1,231,200	(=D210)
90%	$2,157,840	(=E210)



Assumption: USGS Interns **Cell: D211**

Triangular distribution with parameters:

10%	$428,032	(=C211)
Likeliest	$428,032	(=D211)
90%	$751,520	(=E211)

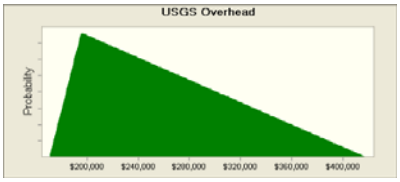


Assumption: USGS Overhead **Cell: D212**

Triangular distribution with parameters:

10%	$195,700	(=C212)
Likeliest	$195,700	(=D212)
90%	$343,370	(=E212)

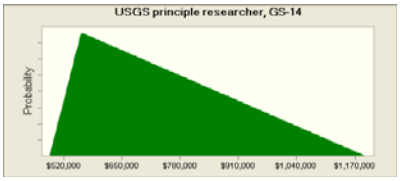
Assumption: USGS Overhead (cont'd) **Cell: D212**



Assumption: USGS principle researcher, GS-14 **Cell: D213**

Triangular distribution with parameters:

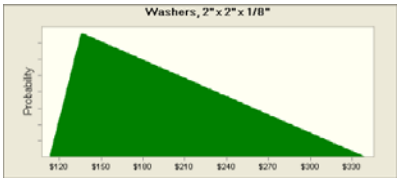
10%	$559,360	(=C213)
Likeliest	$559,360	(=D213)
90%	$982,100	(=E213)



Assumption: Washers, 2" x 2" x 1/8" **Cell: D214**

Triangular distribution with parameters:

10%	$136	(=C214)
Likeliest	$136	(=D214)
90%	$272	(=E214)

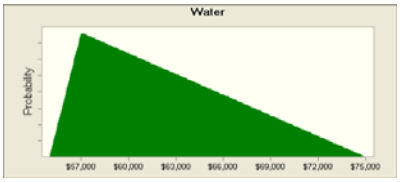


Assumption: Water **Cell: D215**

Triangular distribution with parameters:

10%	$57,000	(=C215)
Likeliest	$57,000	(=D215)
90%	$69,000	(=E215)

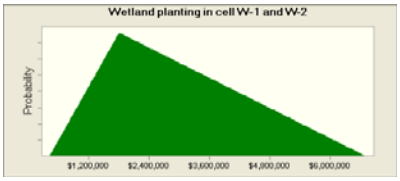
Assumption: Water (cont'd) **Cell: D215**



Assumption: Wetland planting in cell W-1 and W-2 **Cell: D216**

Triangular distribution with parameters:

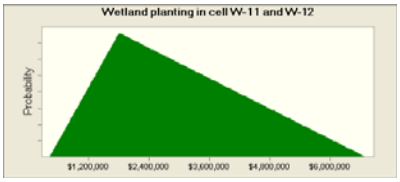
10%	$1,350,000	(=C216)
Likeliest	$1,800,000	(=D216)
90%	$4,950,000	(=E216)



Assumption: Wetland planting in cell W-11 and W-12 **Cell: D217**

Triangular distribution with parameters:

10%	$1,350,000	(=C217)
Likeliest	$1,800,000	(=D217)
90%	$4,950,000	(=E217)

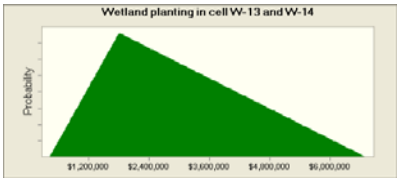


Assumption: Wetland planting in cell W-13 and W-14 **Cell: D218**

Triangular distribution with parameters:

10%	$1,350,000	(=C218)
Likeliest	$1,800,000	(=D218)
90%	$4,950,000	(=E218)

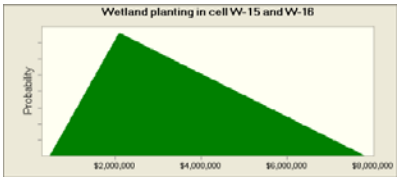
Assumption: Wetland planting in cell W-13 and W-14 (cont'd) **Cell: D218**



Assumption: Wetland planting in cell W-15 and W-16 **Cell: D219**

Triangular distribution with parameters:

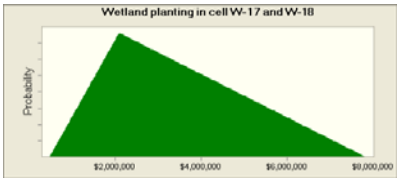
10%	$1,575,000	(=C219)
Likeliest	$2,100,000	(=D219)
90%	$5,775,000	(=E219)



Assumption: Wetland planting in cell W-17 and W-18 **Cell: D220**

Triangular distribution with parameters:

10%	$1,575,000	(=C220)
Likeliest	$2,100,000	(=D220)
90%	$5,775,000	(=E220)

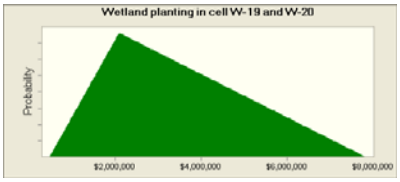


Assumption: Wetland planting in cell W-19 and W-20 **Cell: D221**

Triangular distribution with parameters:

10%	$1,575,000	(=C221)
Likeliest	$2,100,000	(=D221)
90%	$5,775,000	(=E221)

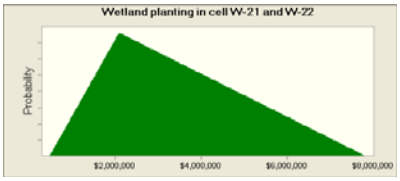
Assumption: Wetland planting in cell W-19 and W-20 (cont'd) **Cell: D221**



Assumption: Wetland planting in cell W-21 and W-22 **Cell: D222**

Triangular distribution with parameters:

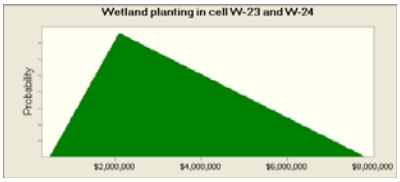
10%	$1,575,000	(=C222)
Likeliest	$2,100,000	(=D222)
90%	$5,775,000	(=E222)



Assumption: Wetland planting in cell W-23 and W-24 **Cell: D223**

Triangular distribution with parameters:

10%	$1,575,000	(=C223)
Likeliest	$2,100,000	(=D223)
90%	$5,775,000	(=E223)

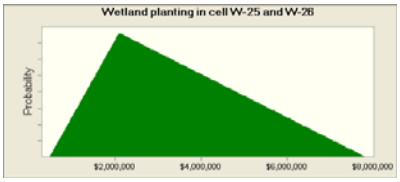


Assumption: Wetland planting in cell W-25 and W-26 **Cell: D224**

Triangular distribution with parameters:

10%	$1,575,000	(=C224)
Likeliest	$2,100,000	(=D224)
90%	$5,775,000	(=E224)

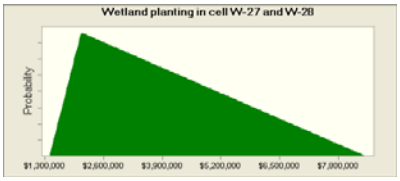
Assumption: Wetland planting in cell W-25 and W-26 (cont'd) **Cell: D224**



Assumption: Wetland planting in cell W-27 and W-28 **Cell: D225**

Triangular distribution with parameters:

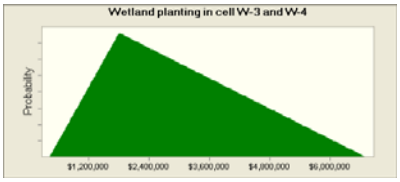
10%	$2,100,000	(=C225)
Likeliest	$2,100,000	(=D225)
90%	$6,300,000	(=E225)



Assumption: Wetland planting in cell W-3 and W-4 **Cell: D226**

Triangular distribution with parameters:

10%	$1,350,000	(=C226)
Likeliest	$1,800,000	(=D226)
90%	$4,950,000	(=E226)

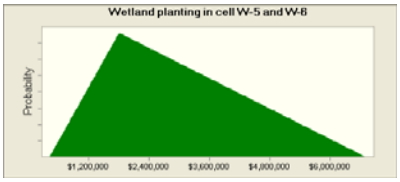


Assumption: Wetland planting in cell W-5 and W-6 **Cell: D227**

Triangular distribution with parameters:

10%	$1,350,000	(=C227)
Likeliest	$1,800,000	(=D227)
90%	$4,950,000	(=E227)

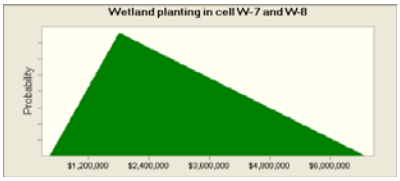
Assumption: Wetland planting in cell W-5 and W-6 (cont'd) **Cell: D227**



Assumption: Wetland planting in cell W-7 and W-8 **Cell: D228**

Triangular distribution with parameters:

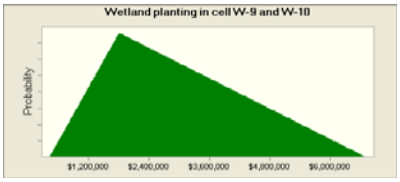
10%	$1,350,000	(=C228)
Likeliest	$1,800,000	(=D228)
90%	$4,950,000	(=E228)



Assumption: Wetland planting in cell W-9 and W-10 **Cell: D229**

Triangular distribution with parameters:

10%	$1,350,000	(=C229)
Likeliest	$1,800,000	(=D229)
90%	$4,950,000	(=E229)

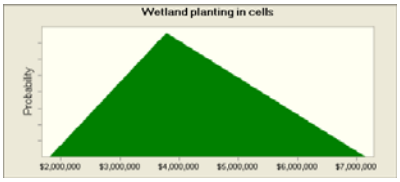


Assumption: Wetland planting in cells **Cell: D230**

Triangular distribution with parameters:

10%	$2,835,000	(=C230)
Likeliest	$3,780,000	(=D230)
90%	$5,805,000	(=E230)

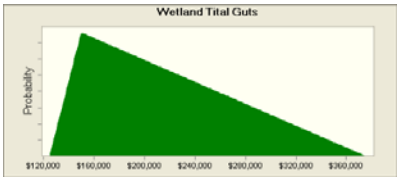
Assumption: Wetland planting in cells (cont'd) **Cell: D230**



Assumption: Wetland Tital Guts **Cell: D231**

Triangular distribution with parameters:

10%	$150,000	(=C231)
Likeliest	$150,000	(=D231)
90%	$300,000	(=E231)

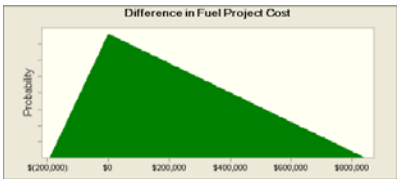


Worksheet: [Cost Model.xls]O&M Model

Assumption: Difference in Fuel Project Cost **Cell: D10**

Triangular distribution with parameters:

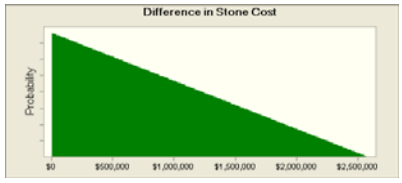
Minimum	$(192,421)	(=B10)
Likeliest	$0	(=D10)
80%	$425,528	(=F10)



Assumption: Difference in Stone Cost **Cell: D24**

Triangular distribution with parameters:

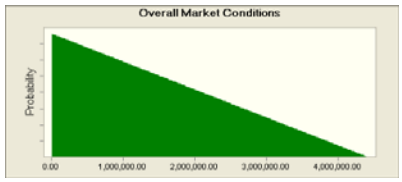
Minimum	$0	(=B24)
Likeliest	$0	(=D24)
80%	$1,426,323	(=F24)



Assumption: Overall Market Conditions **Cell: D44**

Triangular distribution with parameters:

Minimum	0.00	(=D43)
Likeliest	0.00	(=D43)
90%	3,010,225.65	(=F43)

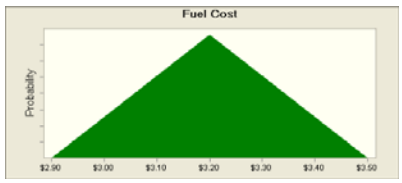


Worksheet: [Cost Model.xls]Risk Model

Assumption: Fuel Cost **Cell: E20**

Triangular distribution with parameters:

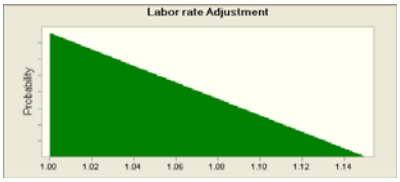
Minimum	$2.90	(=F20)
Likeliest	$3.20	(=E20)
Maximum	$3.50	(=G20)



Assumption: Labor rate Adjustment **Cell: E21**

Triangular distribution with parameters:

Minimum	1.00	(=F21)
Likeliest	1.00	(=E21)
Maximum	1.15	(=G21)

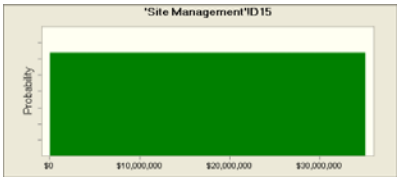


Worksheet: [Cost Model.xls]Site Management

Assumption: D15 **Cell: D15**

Uniform distribution with parameters:

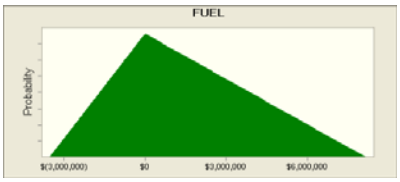
Minimum	$0	(=B15)
Maximum	$35,087,687	(=G15)



Assumption: FUEL **Cell: D6**

Triangular distribution with parameters:

Minimum	$(3,526,394)	(=B6)
Likeliest	$0	(=D6)
Maximum	$8,149,062	(=G6)

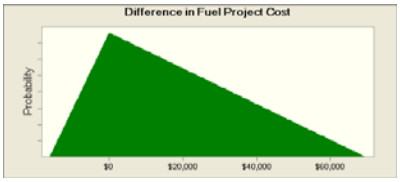


Worksheet: [Cost Model.xls]Wetlands Model

Assumption: Difference in Fuel Project Cost **Cell: D9**

Triangular distribution with parameters:

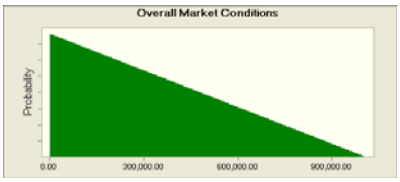
Minimum	$(16,153)	(=B9)
Likeliest	$0	(=D9)
80%	$34,998	(=F9)



Assumption: Overall Market Conditions **Cell: D22**

Triangular distribution with parameters:

Minimum	0.00	(=D21)
Likeliest	0.00	(=D21)
90%	688,517.79	(=F21)

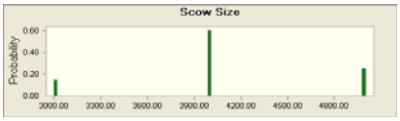


Worksheet: [Maintenance dredging to Deep Trough-12-19-07-Risk model (version 1).xls]DB_E

Assumption: Scow Size **Cell: EA7**

Custom distribution with parameters:

Value	Probability
3000	15.00
4000	60.00
5000	25.00

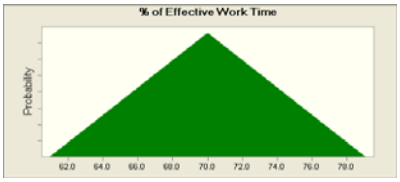


Worksheet: [Maintenance dredging to Deep Trough-12-19-07-Risk model (version 1).xls]Exc Input

Assumption: % of Effective Work Time **Cell: D62**

Triangular distribution with parameters:

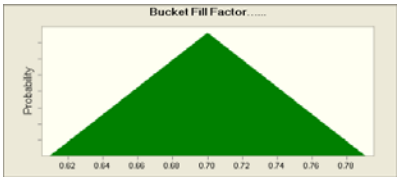
10%	65.0	(=K62)
Likeliest	70.0	(=D62)
90%	75.0	(=L62)



Assumption: Bucket Fill Factor..... **Cell: D46**

Triangular distribution with parameters:

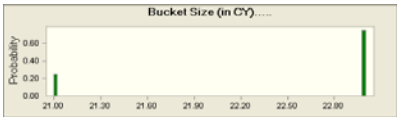
10%	0.65	(=K46)
Likeliest	0.7	(=D46)
90%	0.75	(=L46)



Assumption: Bucket Size (in CY)..... **Cell: D45**

Custom distribution with parameters:

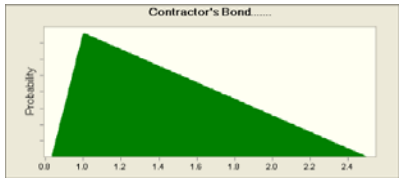
Value	Probability
21	0.25
23	0.75



Assumption: Contractor's Bond..... **Cell: D22**

Triangular distribution with parameters:

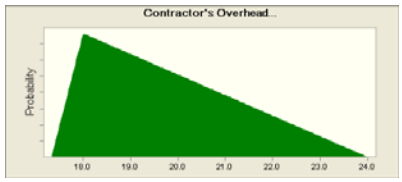
10%	1.0	(=K22)
Likeliest	1.0	(=D22)
90%	2.0	(=L22)



Assumption: Contractor's Overhead... **Cell: D19**

Triangular distribution with parameters:

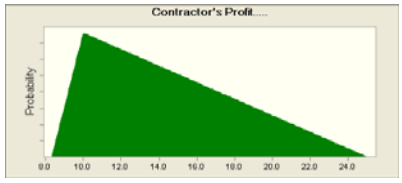
10%	18.0	(=K19)
Likeliest	18.0	(=D19)
90%	22.0	(=L19)



Assumption: Contractor's Profit..... **Cell: D20**

Triangular distribution with parameters:

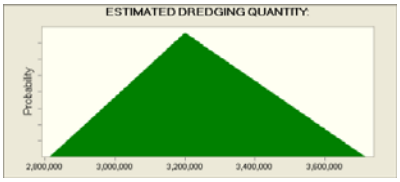
10%	10.0	(=K20)
Likeliest	10.0	(=D20)
90%	20.0	(=L20)



Assumption: ESTIMATED DREDGING QUANTITY: **Cell: D30**

Triangular distribution with parameters:

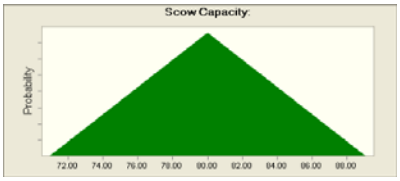
10%	3,000,000	(=K30)
Likeliest	3,200,000	(=D30)
90%	3,500,000	(=L30)



Assumption: Scow Capacity: **Cell: D79**

Triangular distribution with parameters:

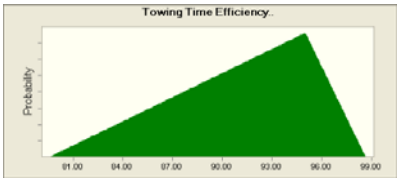
10%	75	(=K79)
Likeliest	80	(=D79)
90%	85	(=L79)



Assumption: Towing Time Efficiency.. **Cell: D74**

Triangular distribution with parameters:

10%	85	(=K74)
Likeliest	95	(=D74)
90%	96	(=L74)



Worksheet: [Maintenance dredging to James Island With 5000cy scows-12-19-07-Risk Model (versio

Assumption: Dump Scow Size **Cell: EA7**

Custom distribution with parameters:

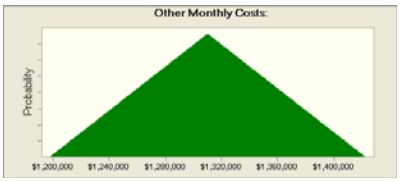
Value	Probability
4000	0.60
5000	0.40

Worksheet: [Maintenance dredging to James Island With 5000cy scows-12-19-07-Risk Model (versio

Assumption: Other Monthly Costs: **Cell: D105**

Triangular distribution with parameters:

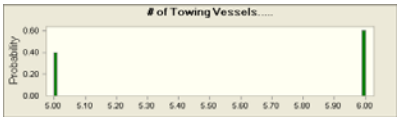
10%	$1,247,925	(=K105)
Likeliest	$1,310,044	(=D105)
90%	$1,372,192	(=L105)



Assumption: # of Towing Vessels..... **Cell: D87**

Custom distribution with parameters:

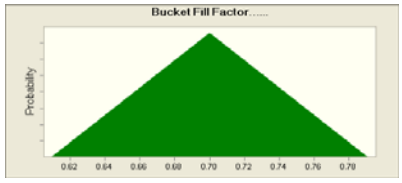
Value	Probability
5	40.00
6	60.00



Assumption: Bucket Fill Factor..... **Cell: D46**

Triangular distribution with parameters:

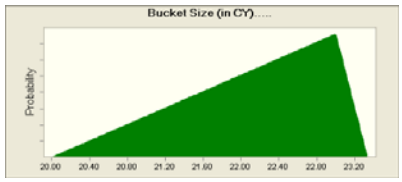
10%	0.65	(=K46)
Likeliest	0.7	(=D46)
90%	0.75	(=L46)



Assumption: Bucket Size (in CY)..... **Cell: D45**

Triangular distribution with parameters:

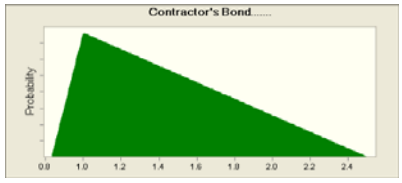
10%	21	(=K45)
Likeliest	23	(=D45)
90%	23	(=L45)



Assumption: Contractor's Bond..... **Cell: D22**

Triangular distribution with parameters:

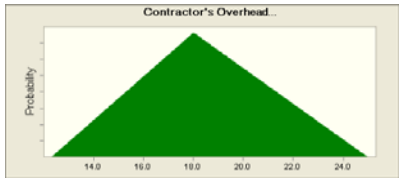
10%	1.0	(=K22)
Likeliest	1.0	(=D22)
90%	2.0	(=L22)



Assumption: Contractor's Overhead... **Cell: D19**

Triangular distribution with parameters:

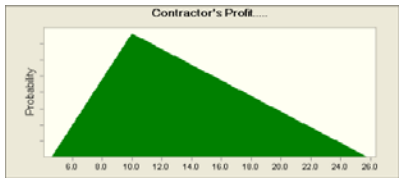
10%	15.0	(=K19)
Likeliest	18.0	(=D19)
90%	22.0	(=L19)



Assumption: Contractor's Profit..... **Cell: D20**

Triangular distribution with parameters:

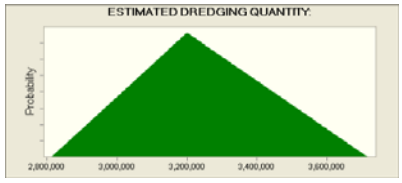
10%	8.0	(=K20)
Likeliest	10.0	(=D20)
90%	20.0	(=L20)



Assumption: ESTIMATED DREDGING QUANTITY: **Cell: D30**

Triangular distribution with parameters:

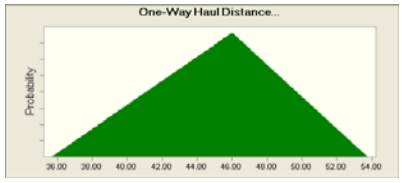
10%	3,000,000	(=K30)
Likeliest	3,200,000	(=D30)
90%	3,500,000	(=L30)



Assumption: One-Way Haul Distance... **Cell: D69**

Triangular distribution with parameters:

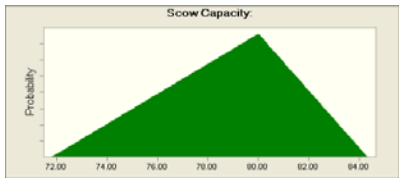
10%	40	(=K69)
Likeliest	46	(=D69)
90%	50	(=L69)



Assumption: Scow Capacity: **Cell: D79**

Triangular distribution with parameters:

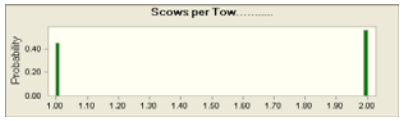
10%	75	(=K79)
Likeliest	80	(=D79)
90%	82	(=L79)



Assumption: Scows per Tow..... **Cell: D88**

Custom distribution with parameters:

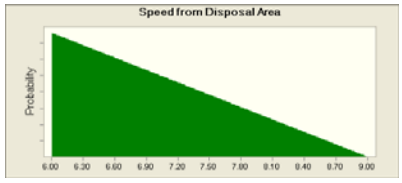
Value	Probability
1	1.00
2	1.25



Assumption: Speed from Disposal Area **Cell: D71**

Triangular distribution with parameters:

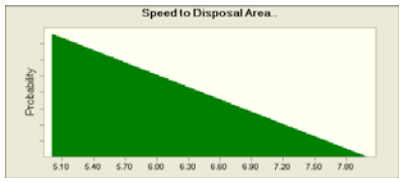
Minimum	6	(=K71)
Likeliest	6	(=D71)
Maximum	9	(=L71)



Assumption: Speed to Disposal Area.. **Cell: D70**

Triangular distribution with parameters:

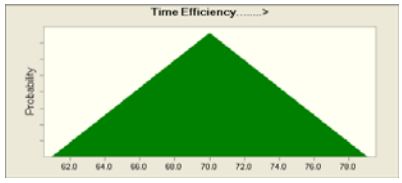
Minimum	5	(=K70)
Likeliest	5	(=D70)
Maximum	8	(=L70)



Assumption: Time Efficiency.....> **Cell: D62**

Triangular distribution with parameters:

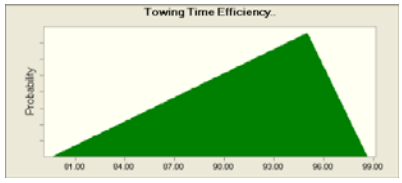
10%	65.0	(=K62)
Likeliest	70.0	(=D62)
90%	75.0	(=L62)



Assumption: Towing Time Efficiency.. **Cell: D74**

Triangular distribution with parameters:

10%	85	(=K74)
Likeliest	95	(=D74)
90%	96	(=L74)

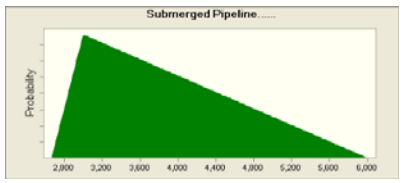


Worksheet: [Sand excavation for construction-12-11-07-Risk Model (version 1).xls]Exc Input

Assumption: Submerged Pipeline..... **Cell: D55**

Triangular distribution with parameters:

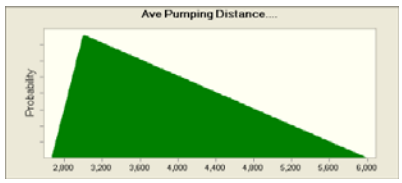
10%	3,000	(=K55)
Likeliest	3,000	(=D55)
90%	5,000	(=L55)



Assumption: Ave Pumping Distance.... **Cell: D59**

Triangular distribution with parameters:

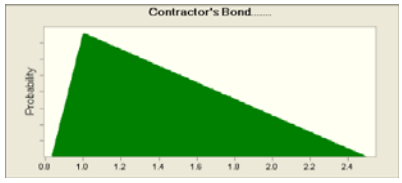
10%	3,000	(=K59)
Likeliest	3,000	(=D59)
90%	5,000	(=L59)



Assumption: Contractor's Bond..... **Cell: D22**

Triangular distribution with parameters:

10%	1.0	(=K22)
Likeliest	1.0	(=D22)
90%	2.0	(=L22)



Assumption: Contractor's Overhead... **Cell: D19**

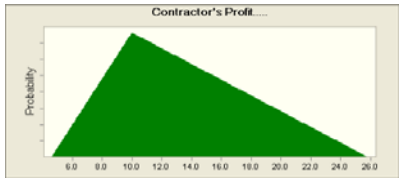
Triangular distribution with parameters:

10%	15.0	(=K19)
Likeliest	18.0	(=D19)
90%	22.0	(=L19)

Assumption: Contractor's Profit..... **Cell: D20**

Triangular distribution with parameters:

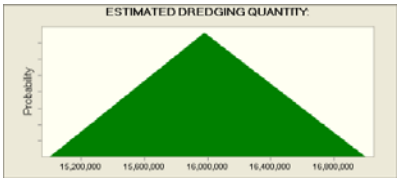
10%	8.0	(=K20)
Likeliest	10.0	(=D20)
90%	20.0	(=L20)



Assumption: ESTIMATED DREDGING QUANTITY: **Cell: D30**

Triangular distribution with parameters:

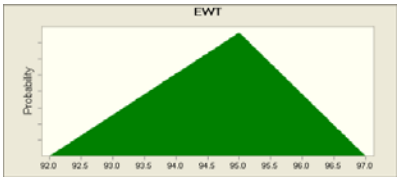
Minimum	15,000,000	(=K30)
Likeliest	15,980,000	(=D30)
Maximum	17,000,000	(=L30)



Assumption: EWT **Cell: B74**

Triangular distribution with parameters:

Minimum	92.0	(=K74)
Likeliest	95.0	(=B74)
Maximum	97.0	(=L74)

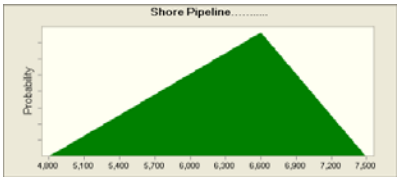


Worksheet: [UNLOADER James Island-12-19-07-Risk Model (version 1).xls]Exc Input

Assumption: Shore Pipeline..... **Cell: D56**

Triangular distribution with parameters:

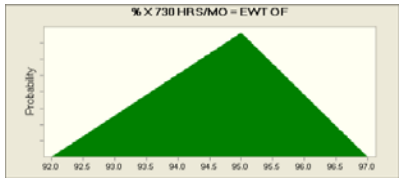
10%	5,500	(=K56)
Likeliest	6,600	(=D56)
90%	7,000	(=L56)



Assumption: % X 730 HRS/MO = EWT OF **Cell: B74**

Triangular distribution with parameters:

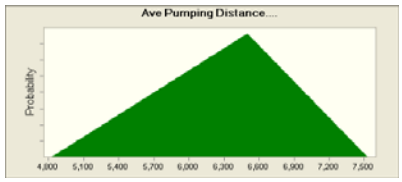
Minimum	92.0	(=$K$74)
Likeliest	95.0	
Maximum	97.0	(=$L$74)



Assumption: Ave Pumping Distance.... **Cell: D59**

Triangular distribution with parameters:

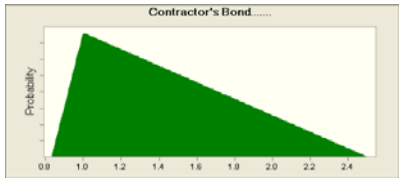
10%	5,500	(=K59)
Likeliest	6,500	(=D59)
90%	7,000	(=L59)



Assumption: Contractor's Bond..... **Cell: D22**

Triangular distribution with parameters:

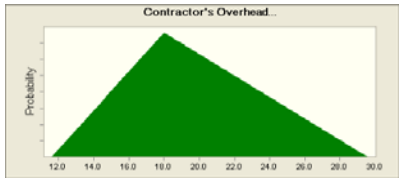
10%	1.0	(=K22)
Likeliest	1.0	(=D22)
90%	2.0	(=L22)



Assumption: Contractor's Overhead... **Cell: D19**

Triangular distribution with parameters:

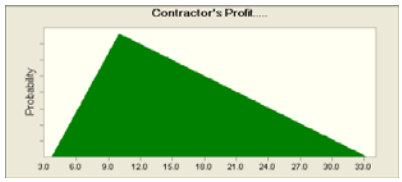
10%	15.0	(=K19)
Likeliest	18.0	(=D19)
90%	25.0	(=L19)



Assumption: Contractor's Profit..... **Cell: D20**

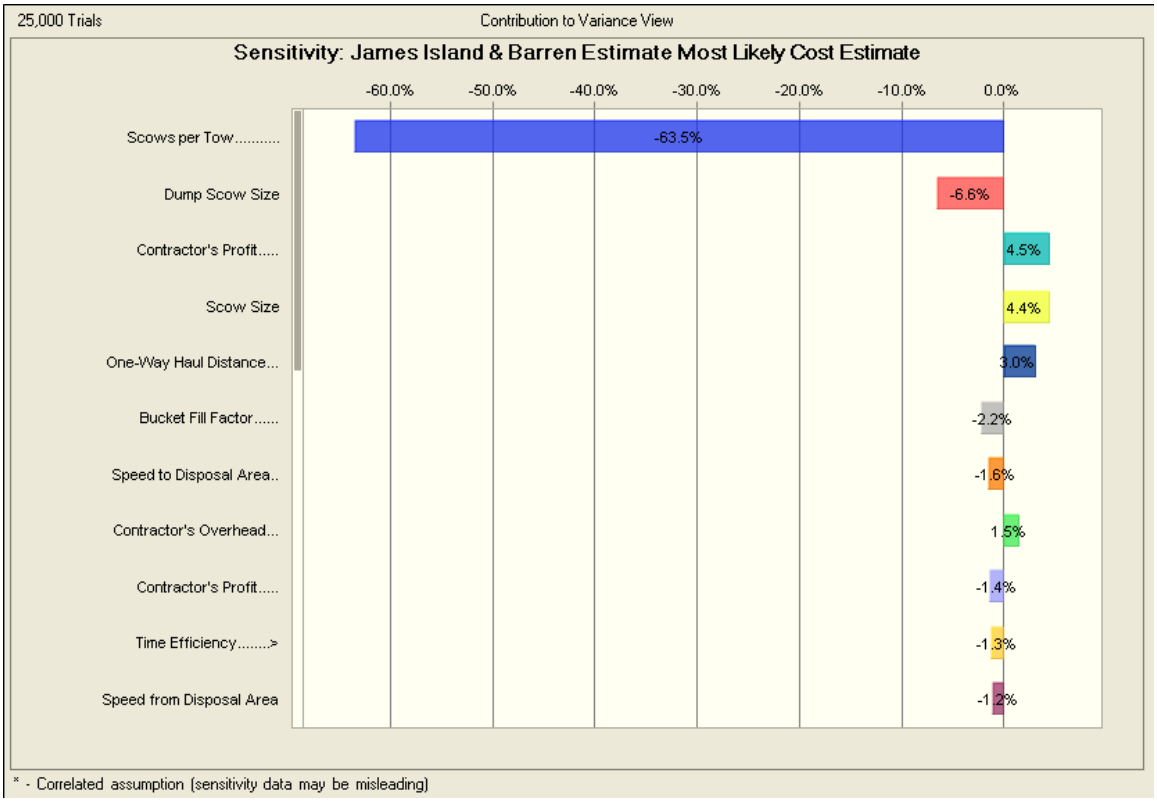
Triangular distribution with parameters:

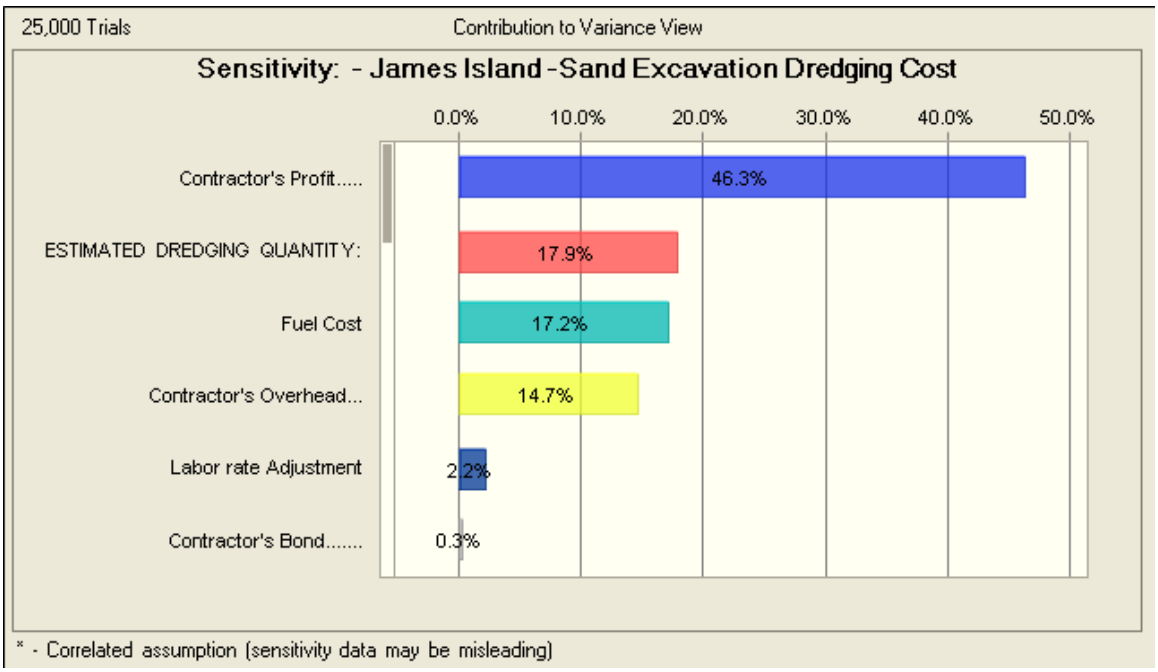
10%	8.0	(=K20)
Likeliest	10.0	(=D20)
90%	25.0	(=L20)

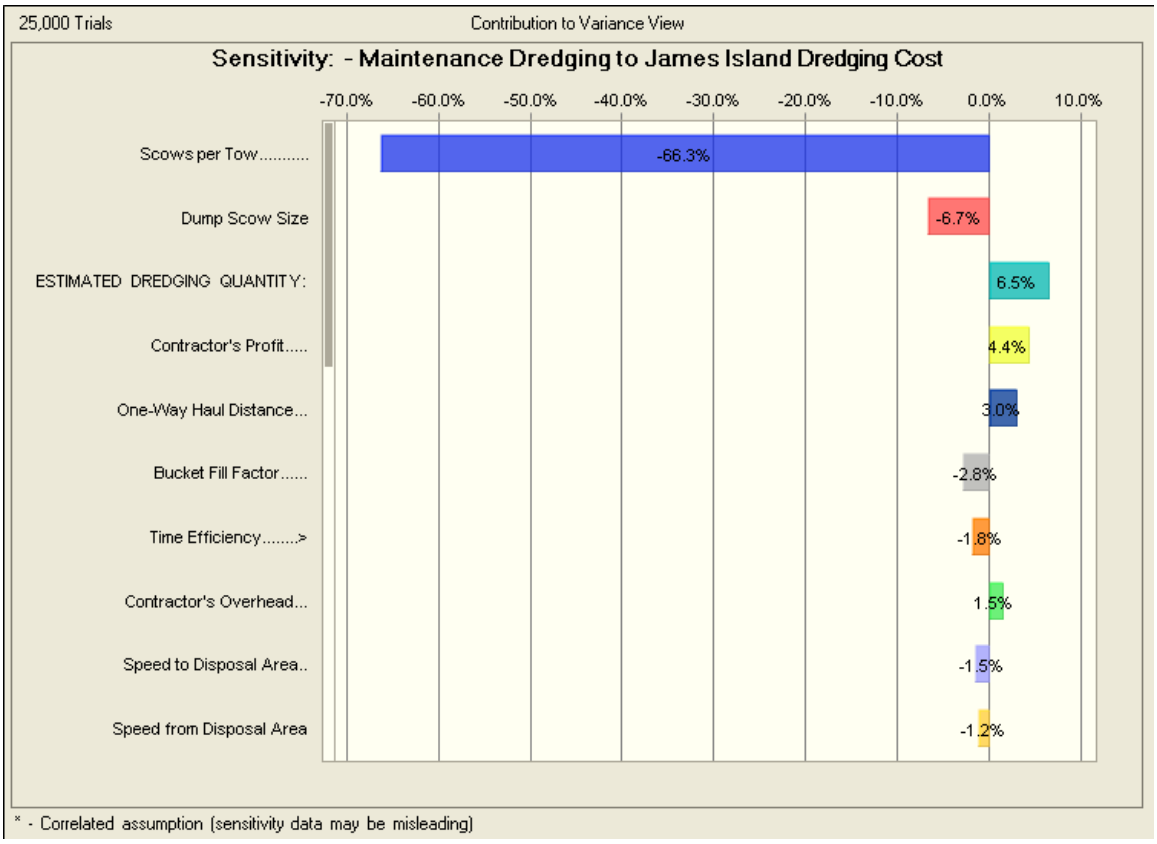


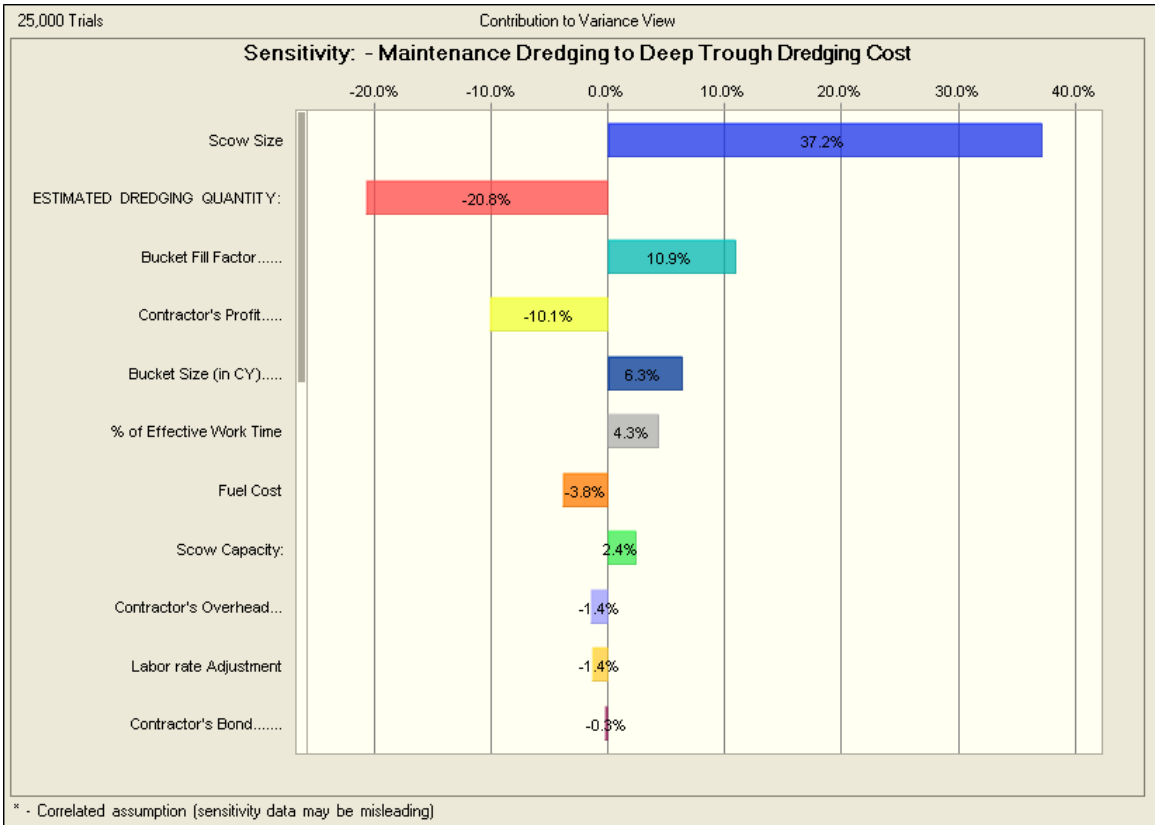
End of Assumptions

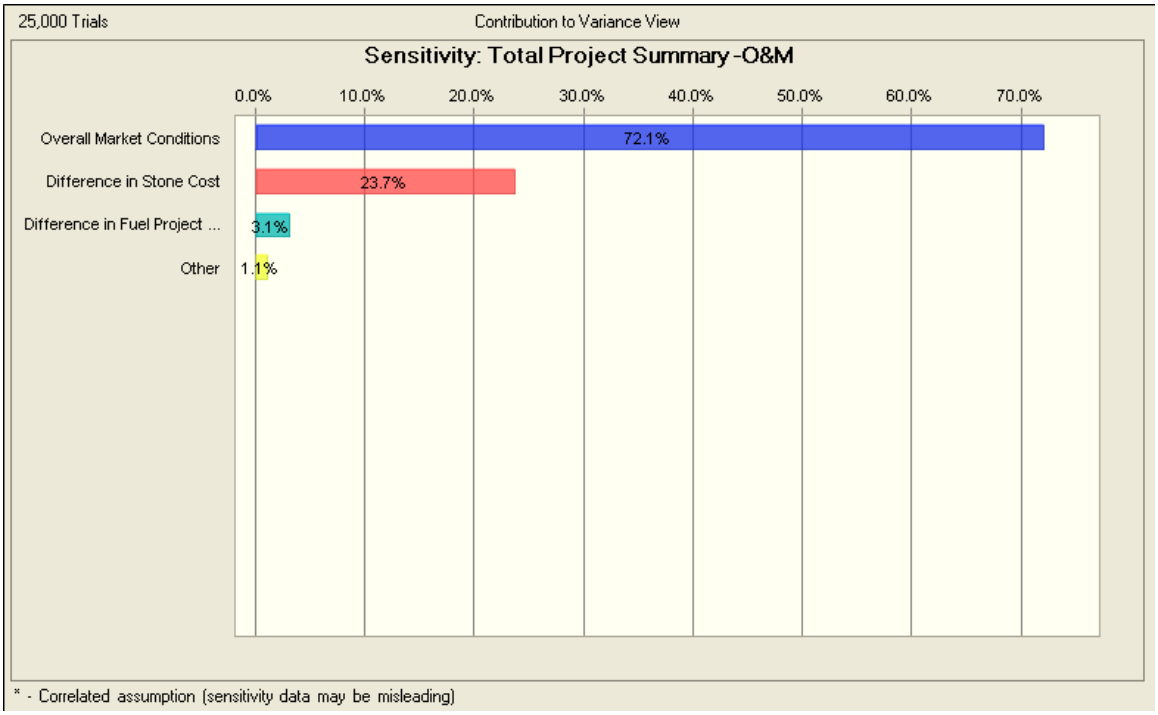
Appendix D – Sensitivity Charts

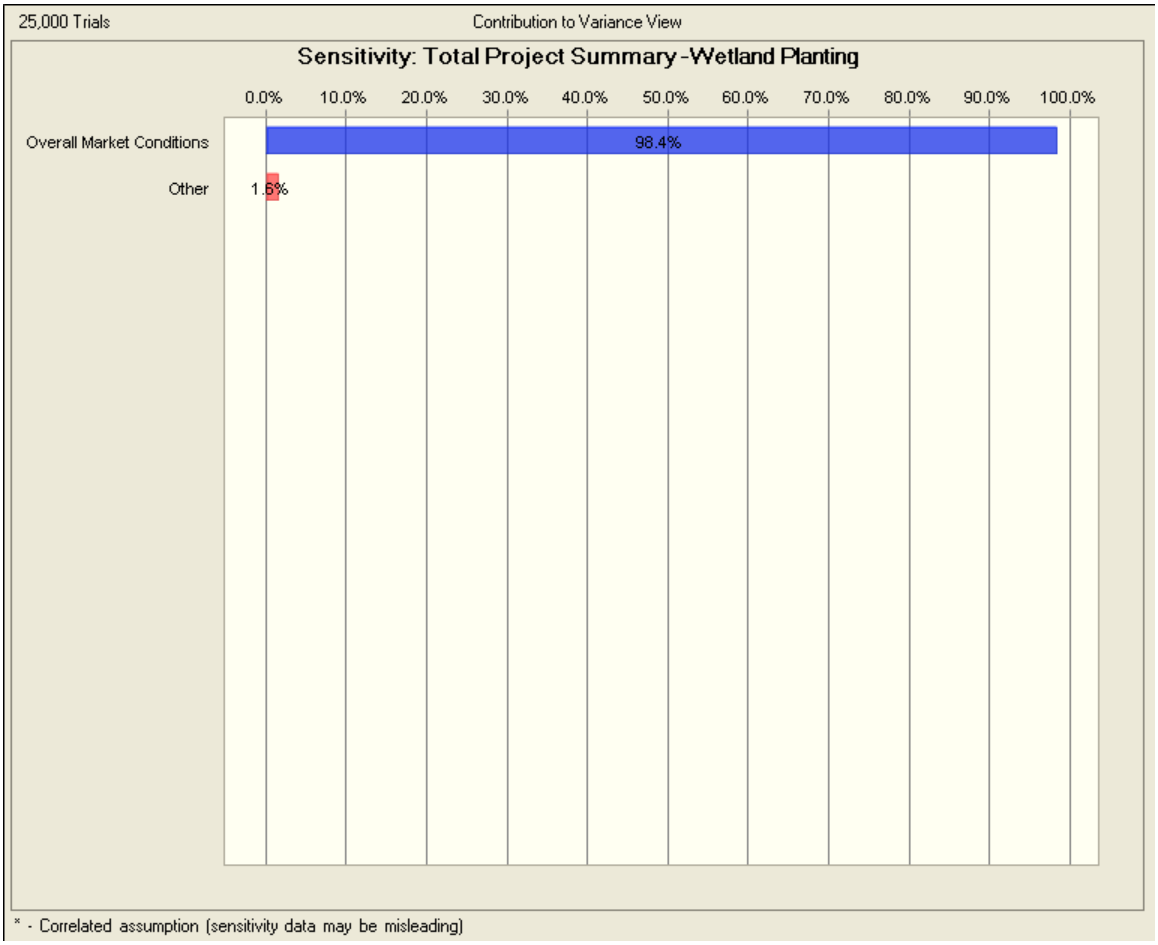

25,000 Trials
Contribution to Variance View
Sensitivity: James Island & Barren Estimate Most Likely Cost Estimate
-60.0%
-50.0%
-40.0%
-30.0%
-20.0%
-10.0%
0.0%
Scows per Tow.....
Dump Scow Size
Contractor's Profit.....
Scow Size
One-Way Haul Distance...
Bucket Fill Factor.....
Speed to Disposal Area..
Contractor's Overhead...
Contractor's Profit.....
Time Efficiency.....>
Speed from Disposal Area
-63.5%
-6.6%
4.5%
4.4%
3.0%
-2.2%
-1.6%
1.5%
-1.4%
-1.3%
-1.2%
* - Correlated assumption (sensitivity data may be misleading)


25,000 Trials
Contribution to Variance View
Sensitivity: - James Island -Sand Excavation Dredging Cost
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
Contractor's Profit.....
ESTIMATED DREDGING QUANTITY:
Fuel Cost
Contractor's Overhead...
Labor rate Adjustment
Contractor's Bond.....
46.3%
17.9%
17.2%
14.7%
2.2%
0.3%
* - Correlated assumption (sensitivity data may be misleading)


25,000 Trials
Contribution to Variance View
Sensitivity: - Maintenance Dredging to James Island Dredging Cost
-70.0%
-60.0%
-50.0%
-40.0%
-30.0%
-20.0%
-10.0%
0.0%
10.0%
Scows per Tow.....
Dump Scow Size
ESTIMATED DREDGING QUANTITY:
Contractor's Profit.....
One-Way Haul Distance...
Bucket Fill Factor.....
Time Efficiency.....>
Contractor's Overhead...
Speed to Disposal Area..
Speed from Disposal Area
-66.3%
-6.7%
6.5%
4.4%
3.0%
-2.8%
-1.8%
1.5%
-1.5%
-1.2%
* - Correlated assumption (sensitivity data may be misleading)


25,000 Trials
Contribution to Variance View
Sensitivity: - Maintenance Dredging to Deep Trough Dredging Cost
-20.0%
-10.0%
0.0%
10.0%
20.0%
30.0%
40.0%
Scow Size
ESTIMATED DREDGING QUANTITY:
Bucket Fill Factor.....
Contractor's Profit.....
Bucket Size (in CY).....
% of Effective Work Time
Fuel Cost
Scow Capacity:
Contractor's Overhead...
Labor rate Adjustment
Contractor's Bond.....
37.2%
-20.8%
10.9%
-10.1%
6.3%
4.3%
-3.8%
2.4%
-1.4%
-1.4%
-0.3%
* - Correlated assumption (sensitivity data may be misleading)


25,000 Trials
Contribution to Variance View
Sensitivity: Total Project Summary -O&M
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
Overall Market Conditions
72.1%
Difference in Stone Cost
23.7%
Difference in Fuel Project ...
3.1%
Other
1.1%
* - Correlated assumption (sensitivity data may be misleading)


25,000 Trials
Contribution to Variance View
Sensitivity: Total Project Summary -Wetland Planting
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%
Overall Market Conditions
98.4%
Other
1.6%
* - Correlated assumption (sensitivity data may be misleading)

Appendix E – Forecast

Forecasts

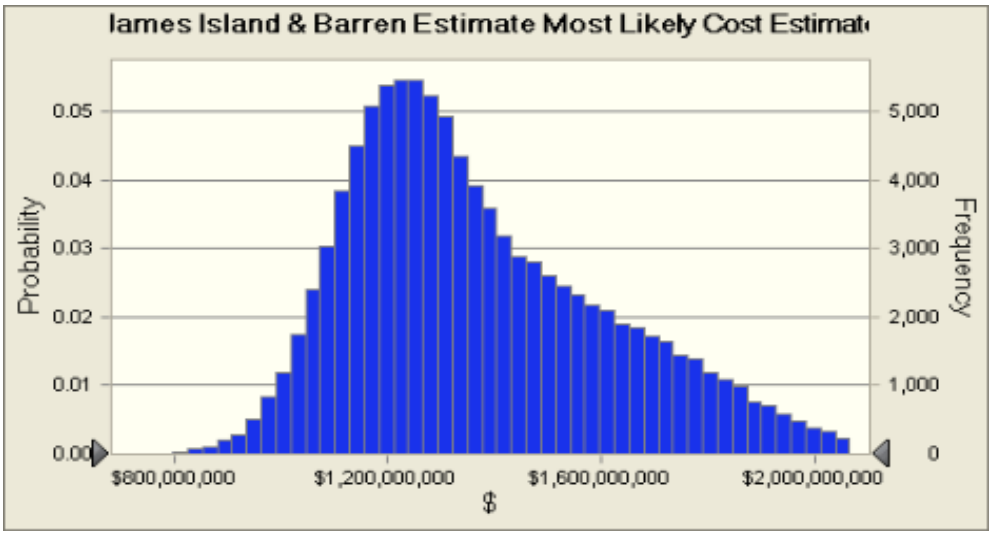
Forecast: James Island & Barren Estimate Most Likely Cost Estimate

Summary:

Entire range is from $715,026,991 to $2,452,548,644

Base case is $1,274,820,564

After 100,000 trials, the std. error of the mean is $782,342



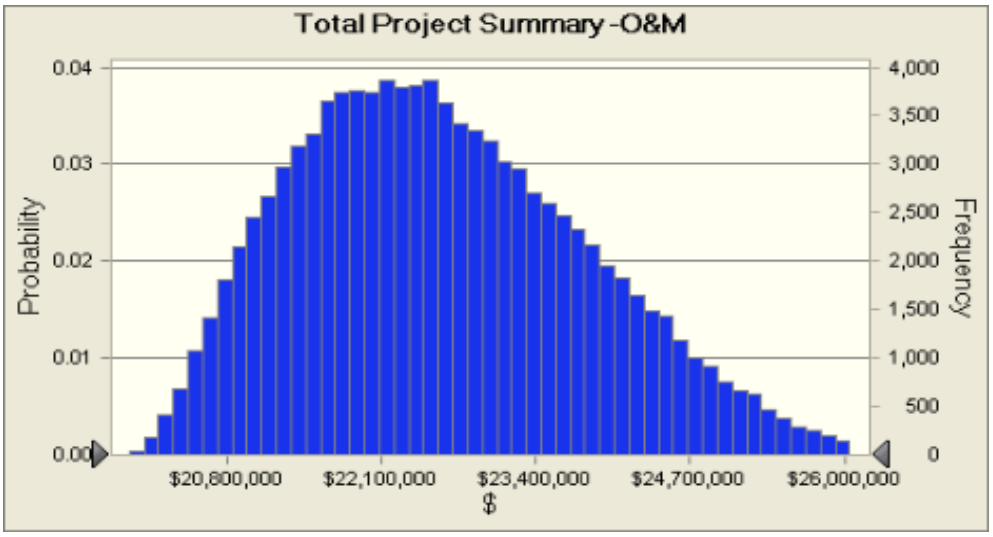
Forecast: James Island & Barren Estimate Most Likely Cost Estimate (cont'd)

Percentiles:	Forecast values
0%	$715,026,991
5%	$1,046,100,604
10%	$1,097,320,418
15%	$1,133,395,091
20%	$1,163,051,509
25%	$1,189,709,415
30%	$1,214,961,240
35%	$1,240,082,290
40%	$1,265,252,533
45%	$1,291,542,073
50%	$1,319,371,426
55%	$1,350,885,978
60%	$1,386,484,218
65%	$1,428,093,742
70%	$1,475,469,583
75%	$1,528,913,524
80%	$1,588,549,304
85%	$1,657,269,166
90%	$1,737,416,674
95%	$1,846,764,183
100%	$2,452,548,644

Forecast: Total Project Summary -O&M

Summary:
Entire range is from $19,977,903 to $27,230,791
Base case is $20,068,171
After 100,000 trials, the std. error of the mean is $3,873

Forecast: Total Project Summary -O&M (cont'd)

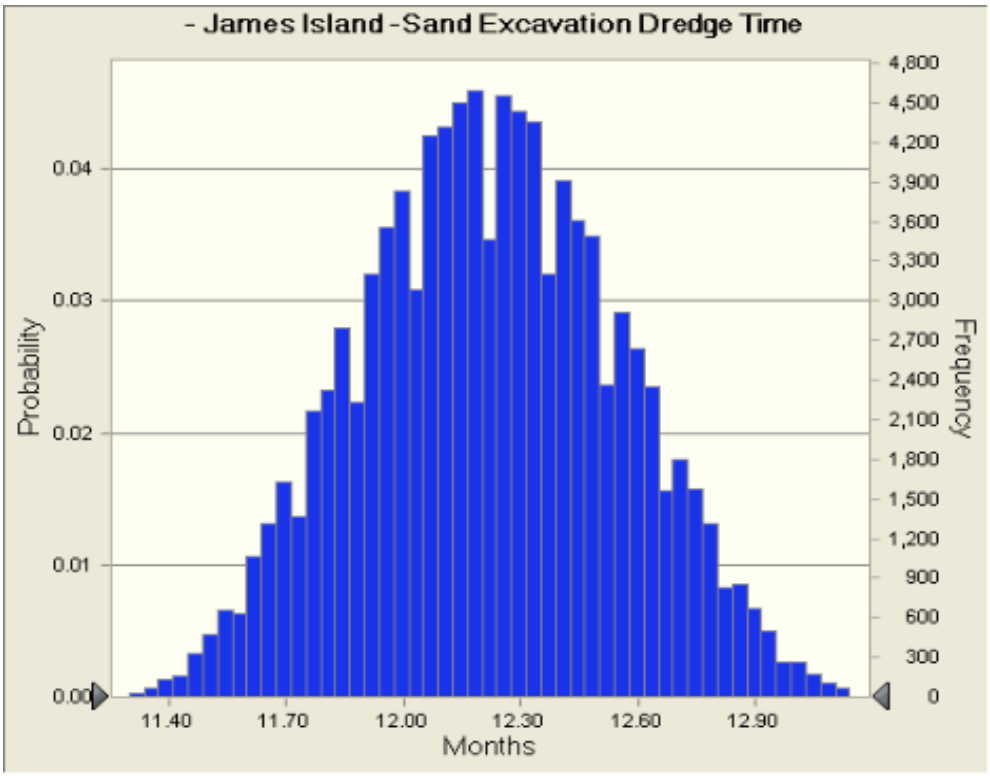


Percentiles:	Forecast values
0%	$19,977,903
5%	$20,807,635
10%	$21,083,245
15%	$21,303,423
20%	$21,501,869
25%	$21,677,381
30%	$21,844,821
35%	$22,008,869
40%	$22,172,748
45%	$22,334,125
50%	$22,496,289
55%	$22,660,665
60%	$22,839,863
65%	$23,025,653
70%	$23,225,950
75%	$23,448,586
80%	$23,693,691
85%	$23,971,089
90%	$24,321,669
95%	$24,806,958
100%	$27,230,791

Forecast: - James Island -Sand Excavation Dredge Time

Summary:
Entire range is from 11.27 to 13.27
Base case is 12.16
After 100,000 trials, the std. error of the mean is 0.00

Forecast: - James Island -Sand Excavation Dredge Time (cont'd)



Forecast: - James Island -Sand Excavation Dredge Time (cont'd)

Percentiles:	Forecast values
0%	11.27
5%	11.68
10%	11.78
15%	11.86
20%	11.93
25%	11.98
30%	12.03
35%	12.08
40%	12.13
45%	12.17
50%	12.22
55%	12.26
60%	12.30
65%	12.35
70%	12.40
75%	12.45
80%	12.51
85%	12.58
90%	12.66
95%	12.77
100%	13.27

Forecast: - James Island -Sand Excavation Dredging Cost

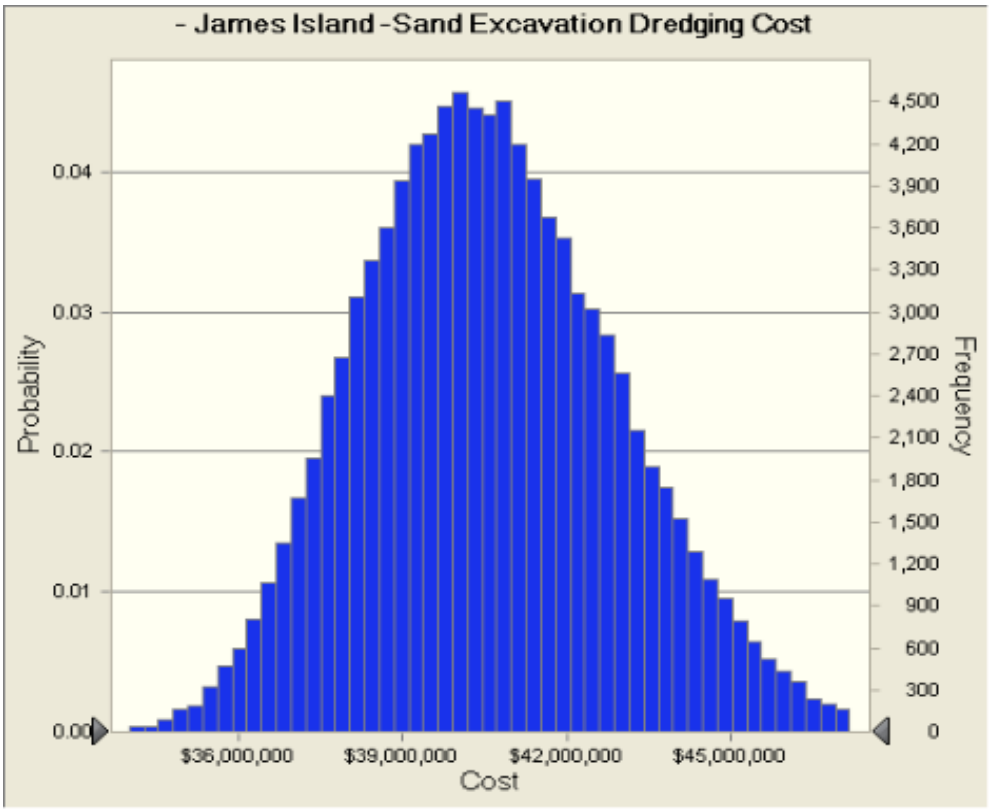
Summary:

Entire range is from $33,059,223 to $50,218,978

Base case is $38,352,000

After 100,000 trials, the std. error of the mean is $7,430

Forecast: - James Island -Sand Excavation Dredging Cost (cont'd)



Forecast: - James Island -Sand Excavation Dredging Cost (cont'd)

Percentiles:	Forecast values
0%	$33,059,223
5%	$36,932,553
10%	$37,640,769
15%	$38,136,768
20%	$38,545,213
25%	$38,913,646
30%	$39,247,780
35%	$39,560,246
40%	$39,866,888
45%	$40,161,526
50%	$40,462,304
55%	$40,763,940
60%	$41,066,715
65%	$41,399,598
70%	$41,754,632
75%	$42,140,817
80%	$42,583,986
85%	$43,072,696
90%	$43,722,741
95%	$44,671,223
100%	$50,218,978

Forecast: - James Island -Sand Excavation Max Pay Qty

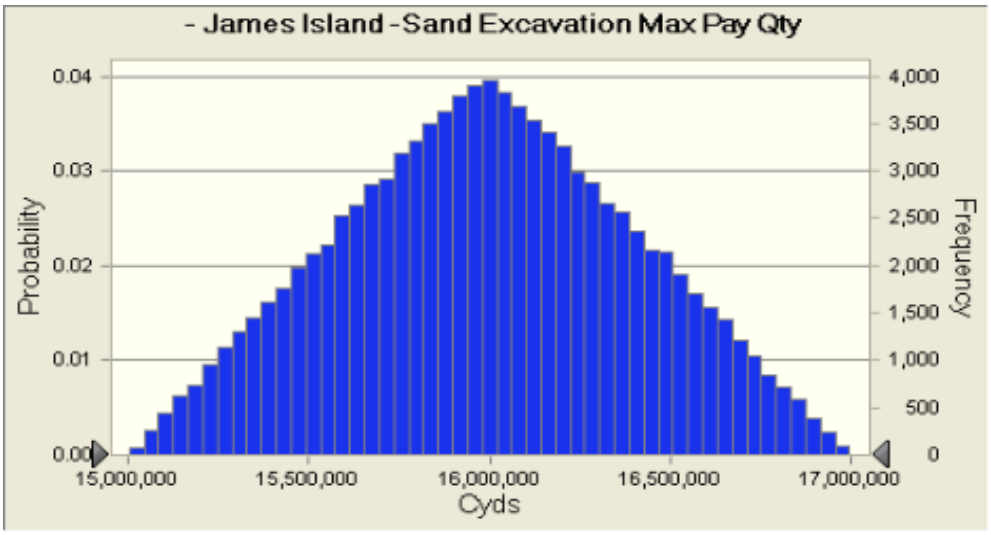
Summary:

Entire range is from 15,001,375 to 16,998,252

Base case is 15,980,000

After 100,000 trials, the std. error of the mean is 1,290

Forecast: - James Island -Sand Excavation Max Pay Qty (cont'd)



Percentiles:	Forecast values
0%	15,001,375
5%	15,311,153
10%	15,442,461
15%	15,542,199
20%	15,626,810
25%	15,698,891
30%	15,767,000
35%	15,827,545
40%	15,885,033
45%	15,938,953
50%	15,990,906
55%	16,043,298
60%	16,098,147
65%	16,155,649
70%	16,216,956
75%	16,285,746
80%	16,361,471
85%	16,446,638
90%	16,546,252
95%	16,676,647
100%	16,998,252

Forecast: - James Island -Sand Excavation Unit Cost

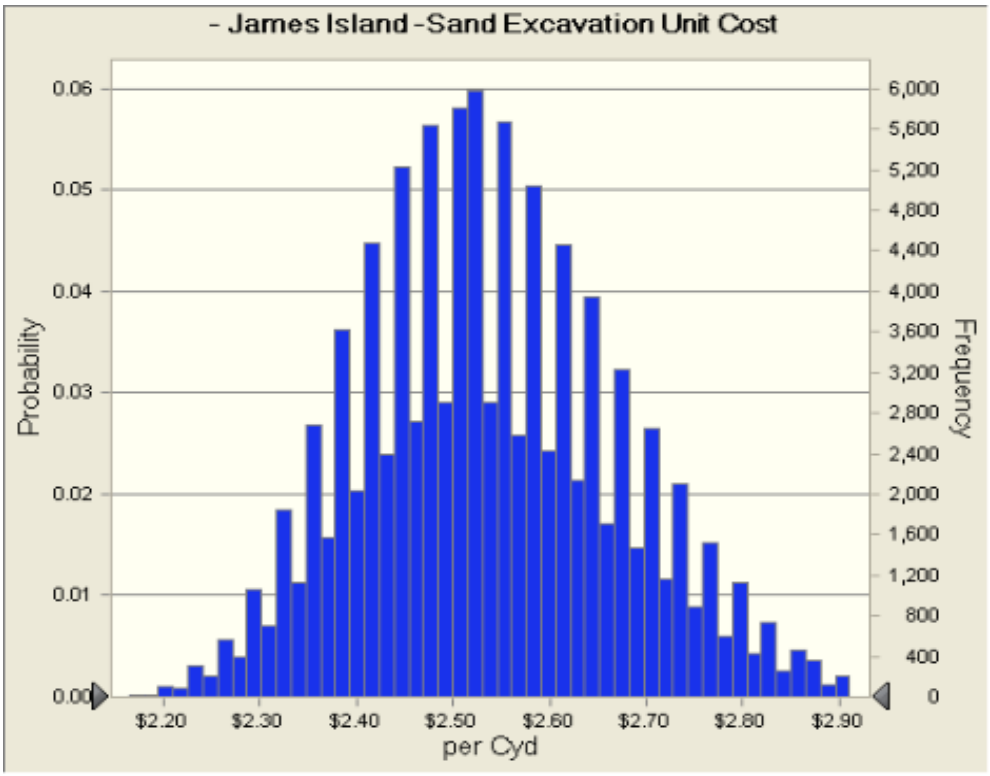
Summary:

Entire range is from $2.12 to $3.09

Base case is $2.40

After 100,000 trials, the std. error of the mean is $0.00

Forecast: - James Island -Sand Excavation Unit Cost (cont'd)



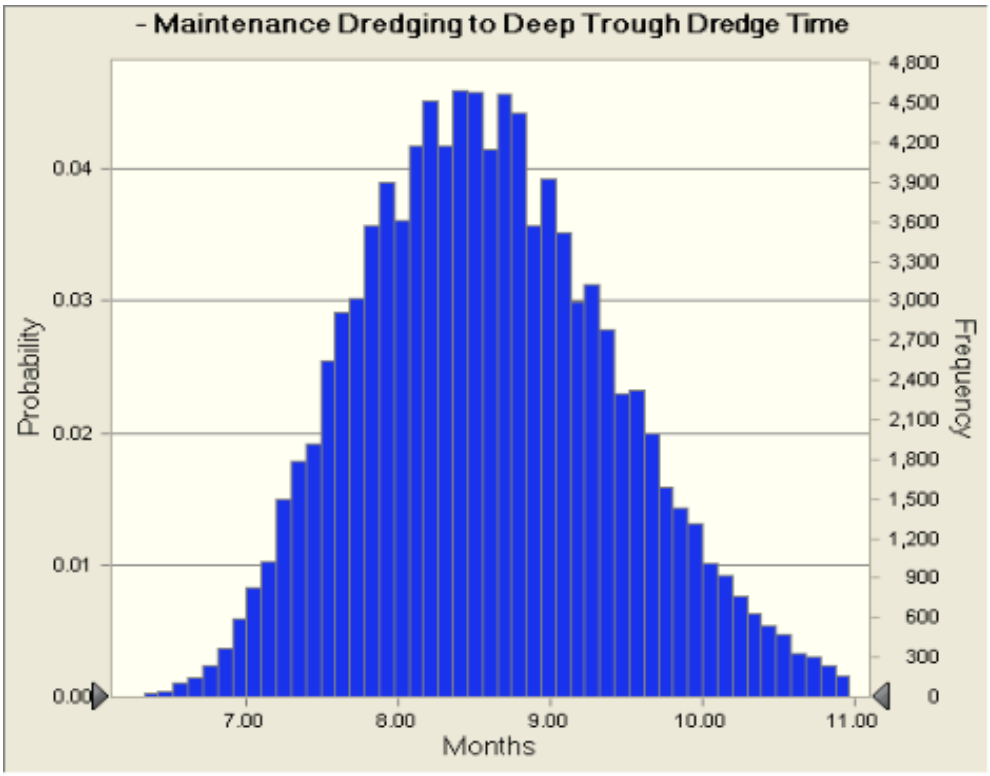
Forecast: - James Island -Sand Excavation Unit Cost (cont'd)

Percentiles:	Forecast values
0%	$2.12
5%	$2.33
10%	$2.37
15%	$2.40
20%	$2.42
25%	$2.44
30%	$2.46
35%	$2.48
40%	$2.50
45%	$2.51
50%	$2.53
55%	$2.55
60%	$2.56
65%	$2.58
70%	$2.60
75%	$2.63
80%	$2.65
85%	$2.68
90%	$2.72
95%	$2.77
100%	$3.09

Forecast: - Maintenance Dredging to Deep Trough Dredge Time

Summary:
Entire range is from 6.21 to 12.58
Base case is 8.14
After 100,000 trials, the std. error of the mean is 0.00

Forecast: - Maintenance Dredging to Deep Trough Dredge Time (cont'd)



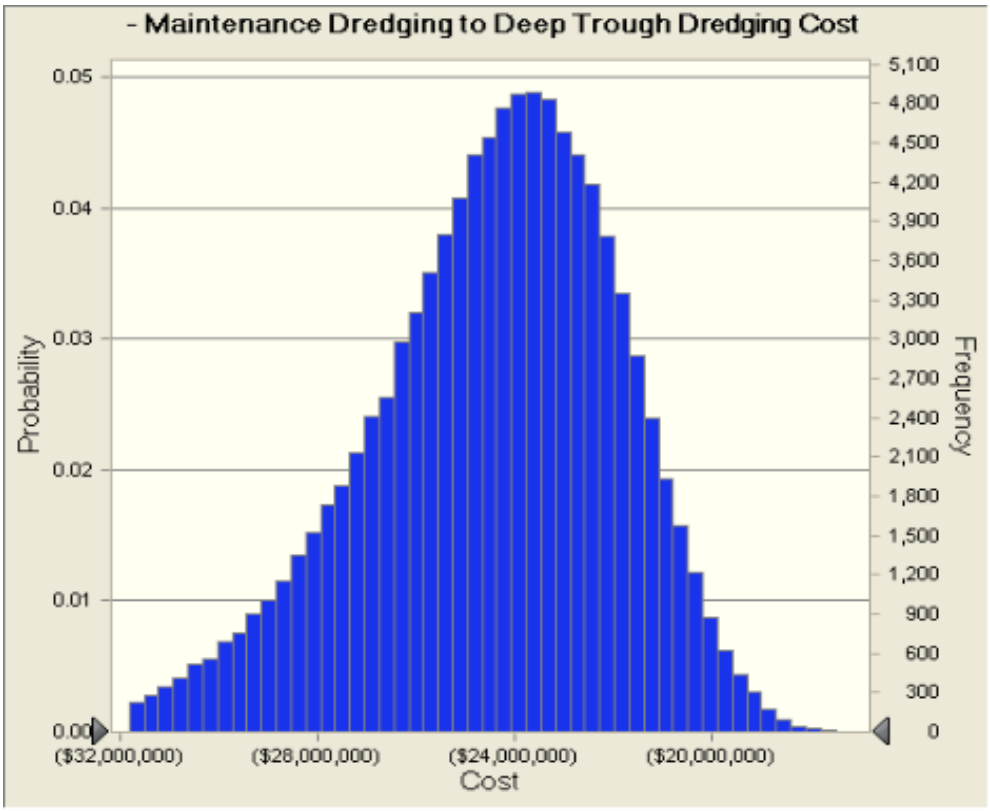
Forecast: - Maintenance Dredging to Deep Trough Dredge Time (cont'd)

Percentiles:	Forecast values
0%	6.21
5%	7.30
10%	7.54
15%	7.72
20%	7.86
25%	7.99
30%	8.11
35%	8.23
40%	8.33
45%	8.44
50%	8.55
55%	8.66
60%	8.77
65%	8.89
70%	9.01
75%	9.16
80%	9.31
85%	9.49
90%	9.73
95%	10.08
100%	12.58

Forecast: - Maintenance Dredging to Deep Trough Dredging Cost

Summary:
Entire range is from ($37,326,765) to ($16,830,164)
Base case is ($21,920,000)
After 100,000 trials, the std. error of the mean is $8,242

Forecast: - Maintenance Dredging to Deep Trough Dredging Cost (cont'd)



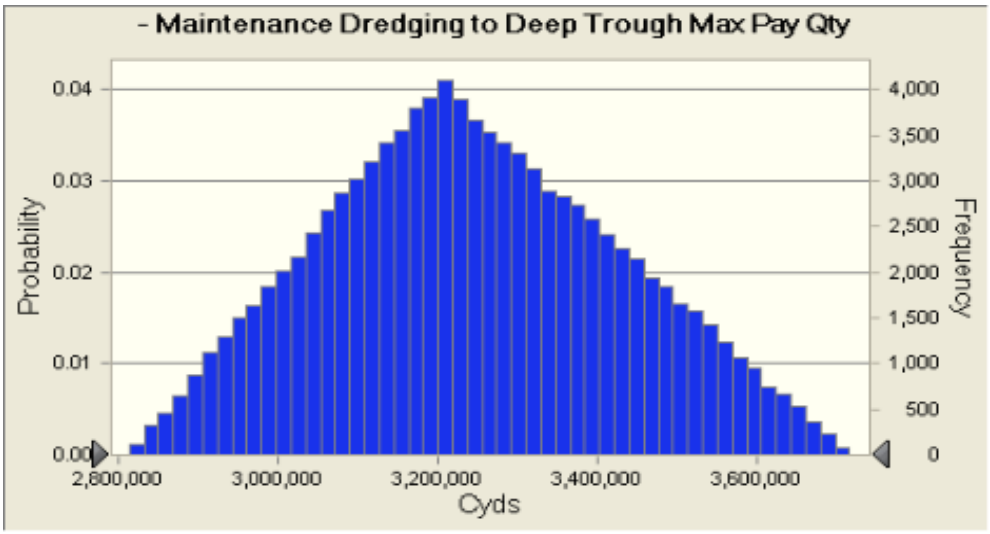
Forecast: - Maintenance Dredging to Deep Trough Dredging Cost (cont'd)

Percentiles:	Forecast values
0%	($37,326,765)
5%	($29,321,019)
10%	($28,060,172)
15%	($27,240,338)
20%	($26,606,890)
25%	($26,089,326)
30%	($25,642,610)
35%	($25,248,512)
40%	($24,888,231)
45%	($24,552,041)
50%	($24,232,161)
55%	($23,923,120)
60%	($23,623,248)
65%	($23,309,759)
70%	($22,996,541)
75%	($22,658,773)
80%	($22,311,433)
85%	($21,908,256)
90%	($21,426,664)
95%	($20,733,399)
100%	($16,830,164)

Forecast: - Maintenance Dredging to Deep Trough Max Pay Qty

Summary:
Entire range is from 2,813,622 to 3,715,441
Base case is 3,200,000
After 100,000 trials, the std. error of the mean is 584

Forecast: - Maintenance Dredging to Deep Trough Max Pay Qty (cont'd)



Percentiles:	Forecast values
0%	2,813,622
5%	2,944,660
10%	2,999,571
15%	3,042,326
20%	3,077,077
25%	3,108,196
30%	3,136,471
35%	3,162,581
40%	3,186,634
45%	3,209,354
50%	3,233,006
55%	3,257,863
60%	3,284,051
65%	3,311,813
70%	3,341,982
75%	3,375,128
80%	3,410,612
85%	3,451,421
90%	3,499,399
95%	3,561,632
100%	3,715,441

Forecast: - Maintenance Dredging to Deep Trough Unit Cost

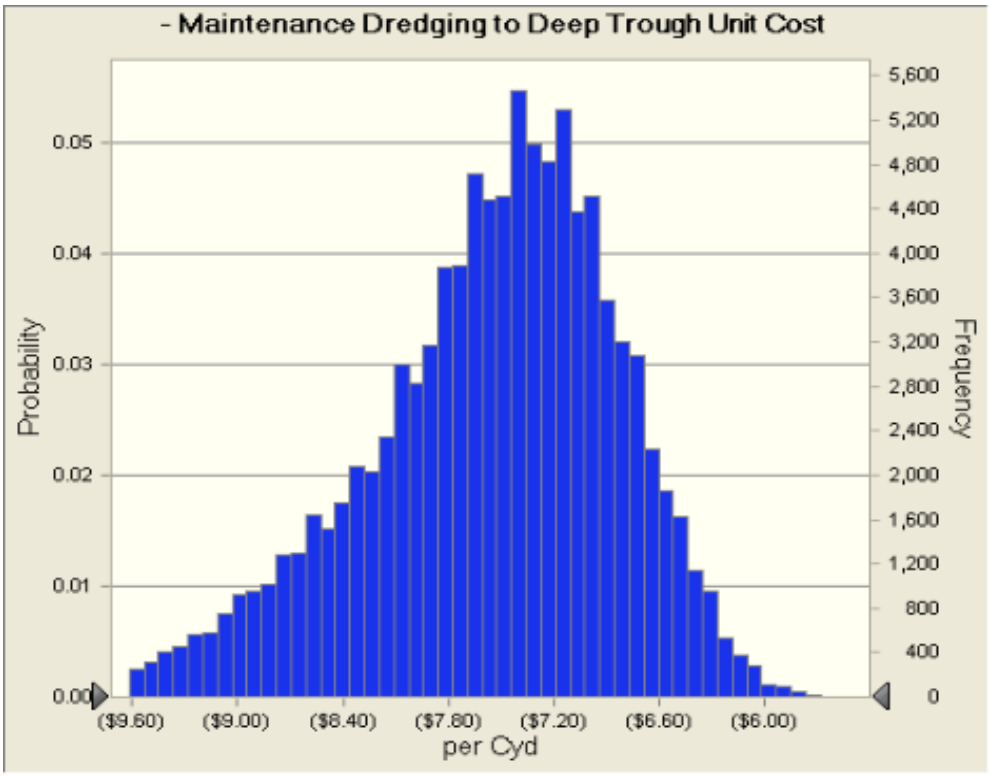
Summary:

Entire range is from ($11.30) to ($5.45)

Base case is ($6.85)

After 100,000 trials, the std. error of the mean is $0.00

Forecast: - Maintenance Dredging to Deep Trough Unit Cost (cont'd)



Forecast: - Maintenance Dredging to Deep Trough Unit Cost (cont'd)

Percentiles:	Forecast values
0%	($11.30)
5%	($8.95)
10%	($8.59)
15%	($8.34)
20%	($8.15)
25%	($7.99)
30%	($7.86)
35%	($7.75)
40%	($7.65)
45%	($7.56)
50%	($7.47)
55%	($7.39)
60%	($7.30)
65%	($7.22)
70%	($7.14)
75%	($7.05)
80%	($6.95)
85%	($6.84)
90%	($6.71)
95%	($6.52)
100%	($5.45)

Forecast: - Maintenance Dredging to James Island Dredge Time

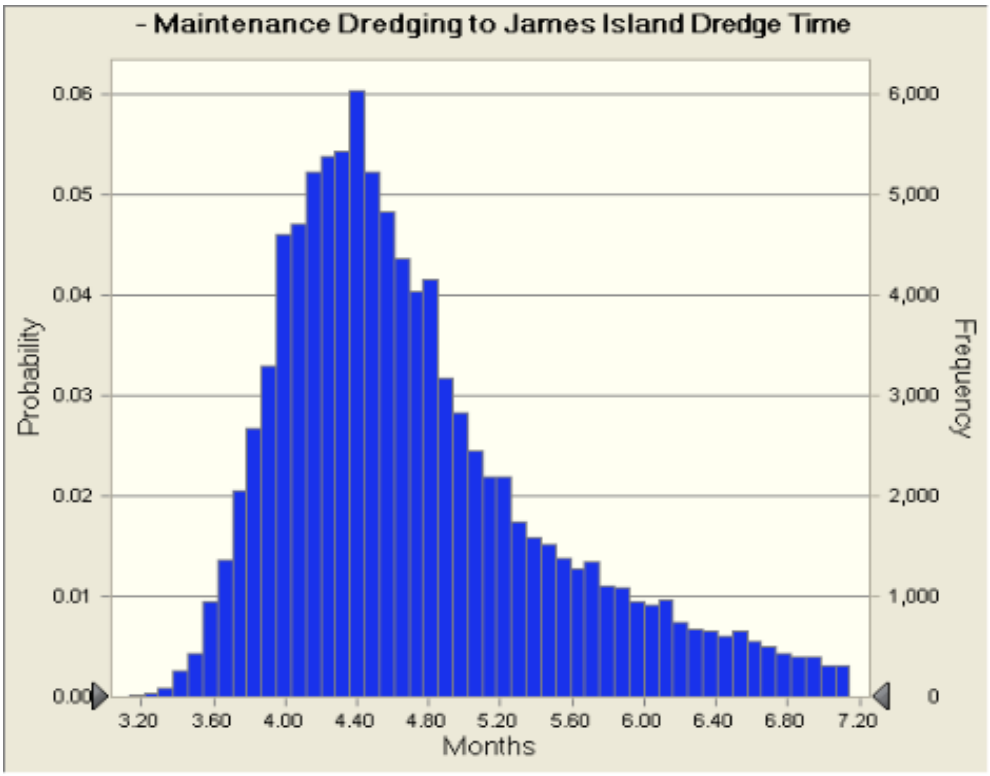
Summary:

Entire range is from 3.13 to 9.75

Base case is 4.66

After 100,000 trials, the std. error of the mean is 0.00

Forecast: - Maintenance Dredging to James Island Dredge Time (cont'd)



Forecast: - Maintenance Dredging to James Island Dredge Time (cont'd)

Percentiles:	Forecast values
0%	3.13
5%	3.78
10%	3.92
15%	4.02
20%	4.11
25%	4.18
30%	4.26
35%	4.33
40%	4.41
45%	4.48
50%	4.56
55%	4.65
60%	4.74
65%	4.85
70%	4.98
75%	5.14
80%	5.36
85%	5.63
90%	5.99
95%	6.54
100%	9.75

Forecast: - Maintenance Dredging to James Island Dredging Cost

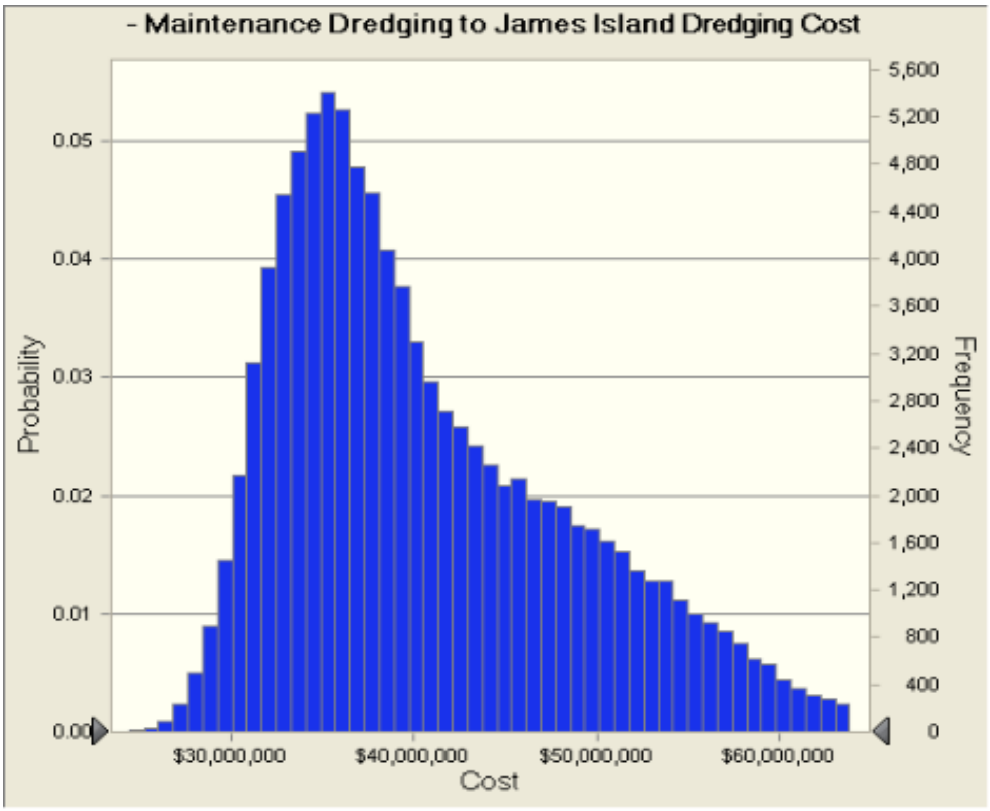
Summary:

Entire range is from $24,389,608 to $81,260,548

Base case is $42,784,000

After 100,000 trials, the std. error of the mean is $26,035

Forecast: - Maintenance Dredging to James Island Dredging Cost (cont'd)



Forecast: - Maintenance Dredging to James Island Dredging Cost (cont'd)

Percentiles:	Forecast values
0%	$24,389,608
5%	$30,729,244
10%	$31,962,496
15%	$32,928,208
20%	$33,760,944
25%	$34,547,403
30%	$35,296,099
35%	$36,046,904
40%	$36,845,269
45%	$37,712,717
50%	$38,662,910
55%	$39,719,629
60%	$40,987,241
65%	$42,455,296
70%	$44,126,941
75%	$45,996,471
80%	$48,049,985
85%	$50,360,895
90%	$53,142,665
95%	$56,888,265
100%	$81,260,548

Forecast: - Maintenance Dredging to James Island Max Pay Qty

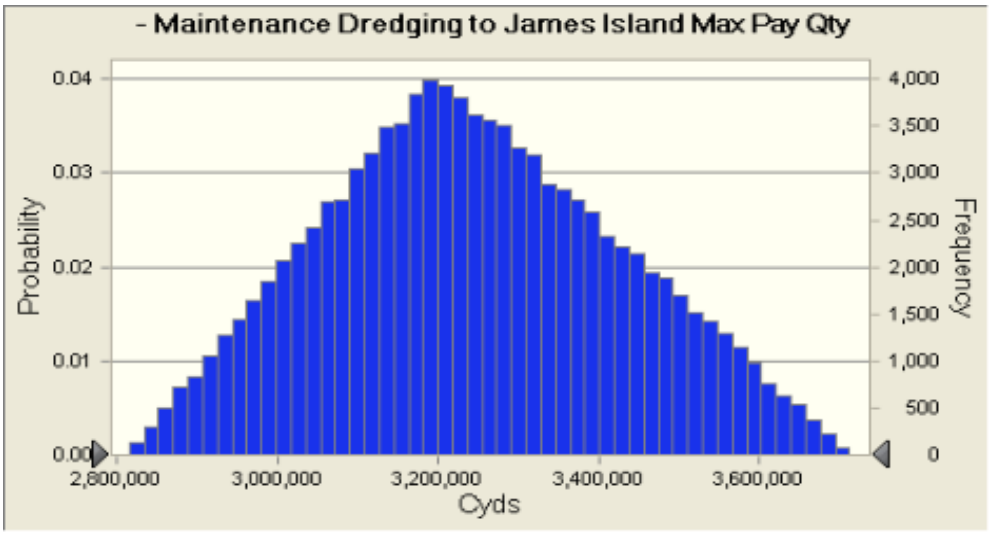
Summary:

Entire range is from 2,814,279 to 3,713,150

Base case is 3,200,000

After 100,000 trials, the std. error of the mean is 584

Forecast: - Maintenance Dredging to James Island Max Pay Qty (cont'd)

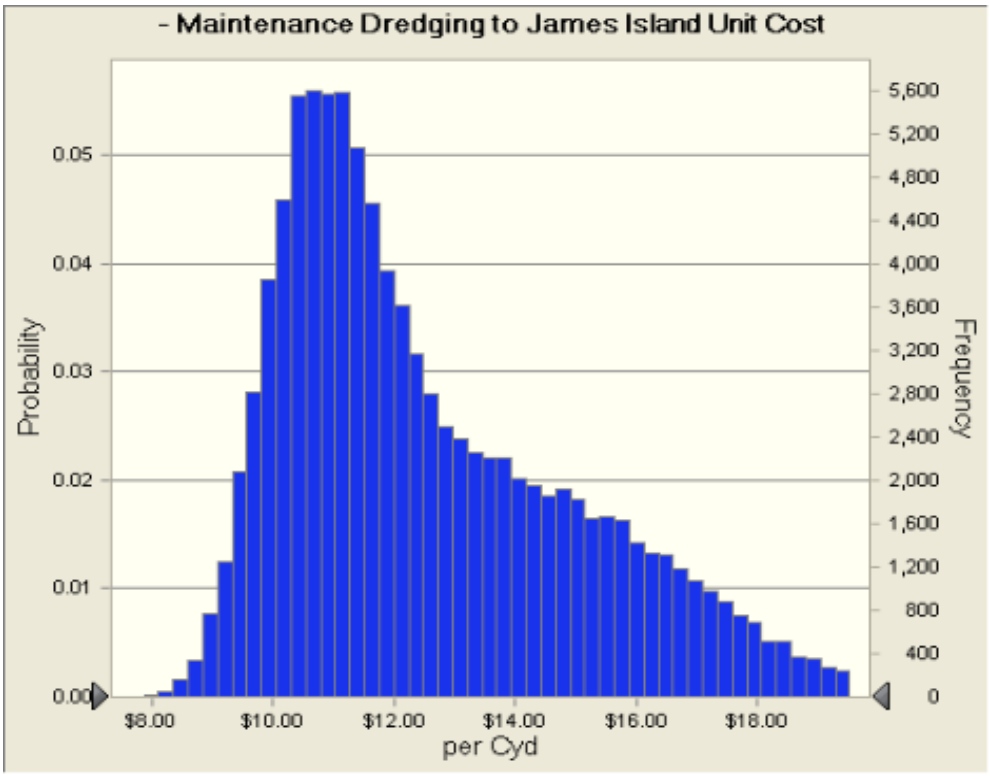


Percentiles:	Forecast values
0%	2,814,279
5%	2,945,281
10%	3,000,078
15%	3,041,434
20%	3,076,798
25%	3,108,205
30%	3,136,015
35%	3,161,998
40%	3,186,109
45%	3,208,634
50%	3,232,792
55%	3,257,980
60%	3,284,006
65%	3,311,409
70%	3,341,651
75%	3,374,234
80%	3,410,125
85%	3,451,452
90%	3,499,427
95%	3,562,400
100%	3,713,150

Forecast: - Maintenance Dredging to James Island Unit Cost

Summary:
Entire range is from $7.63 to $24.09
Base case is $13.37
After 100,000 trials, the std. error of the mean is $0.01

Forecast: - Maintenance Dredging to James Island Unit Cost (cont'd)



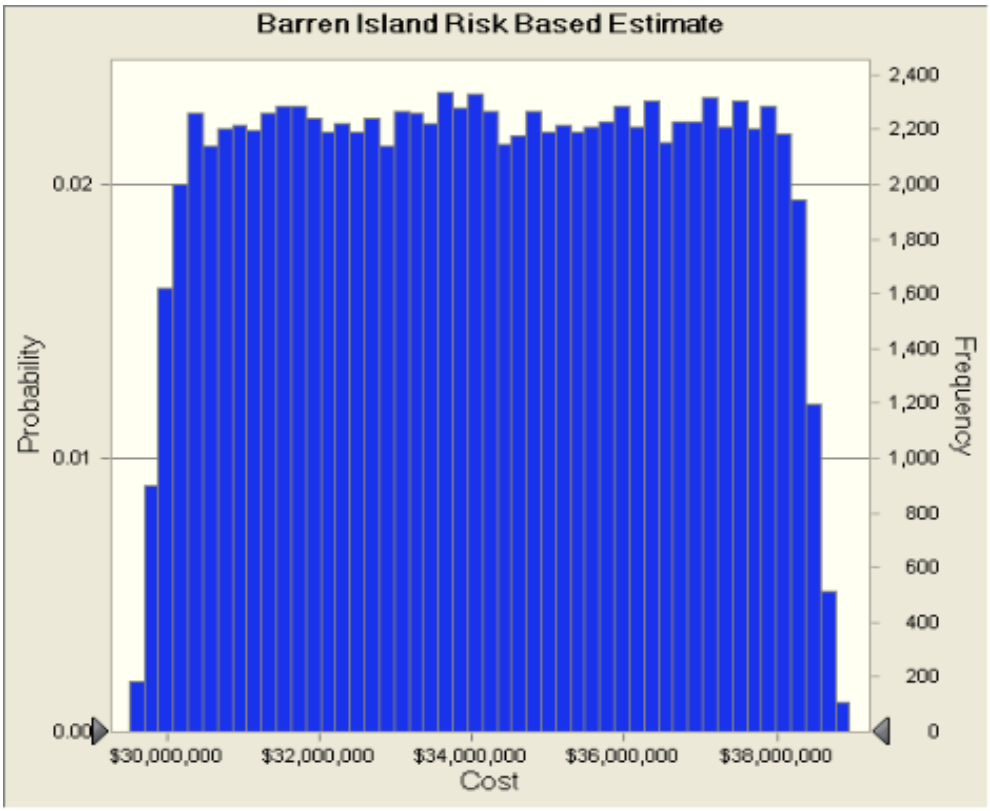
Forecast: - Maintenance Dredging to James Island Unit Cost (cont'd)

Percentiles:	Forecast values
0%	$7.63
5%	$9.61
10%	$9.98
15%	$10.25
20%	$10.48
25%	$10.70
30%	$10.91
35%	$11.13
40%	$11.36
45%	$11.61
50%	$11.88
55%	$12.22
60%	$12.61
65%	$13.08
70%	$13.62
75%	$14.20
80%	$14.83
85%	$15.52
90%	$16.34
95%	$17.43
100%	$24.09

Forecast: Barren Island Risk Based Estimate

Summary:
Entire range is from $29,493,753 to $38,956,919
Base case is $33,980,865
After 100,000 trials, the std. error of the mean is $7,916

Forecast: Barren Island Risk Based Estimate (cont'd)



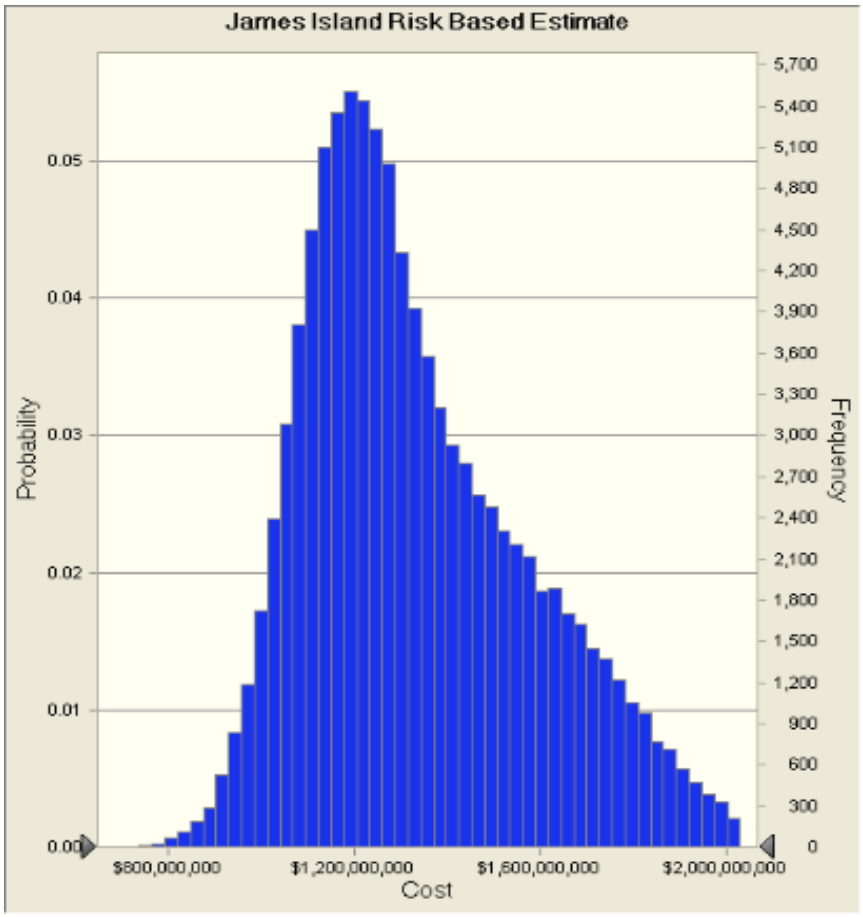
Forecast: Barren Island Risk Based Estimate (cont'd)

Percentiles:	Forecast values
0%	$29,493,753
5%	$30,291,589
10%	$30,729,464
15%	$31,171,377
20%	$31,595,517
25%	$32,021,853
30%	$32,459,015
35%	$32,899,348
40%	$33,332,445
45%	$33,753,576
50%	$34,175,403
55%	$34,616,292
60%	$35,050,574
65%	$35,488,309
70%	$35,924,260
75%	$36,352,138
80%	$36,788,704
85%	$37,213,693
90%	$37,644,268
95%	$38,072,851
100%	$38,956,919

Forecast: James Island Risk Based Estimate

Summary:
Entire range is from $680,841,678 to $2,415,294,353
Base case is $1,240,839,699
After 100,000 trials, the std. error of the mean is $782,269

Forecast: James Island Risk Based Estimate (cont'd)



Forecast: James Island Risk Based Estimate (cont'd)

Percentiles:	Forecast values
0%	$680,841,678
5%	$1,012,106,719
10%	$1,063,253,386
15%	$1,099,198,357
20%	$1,128,815,780
25%	$1,155,508,755
30%	$1,180,717,725
35%	$1,206,029,577
40%	$1,231,316,449
45%	$1,257,474,964
50%	$1,285,069,935
55%	$1,316,685,946
60%	$1,352,504,591
65%	$1,393,996,807
70%	$1,441,395,805
75%	$1,494,437,715
80%	$1,554,197,815
85%	$1,622,983,152
90%	$1,703,001,176
95%	$1,812,759,086
100%	$2,415,294,353

Forecast: Project Cost

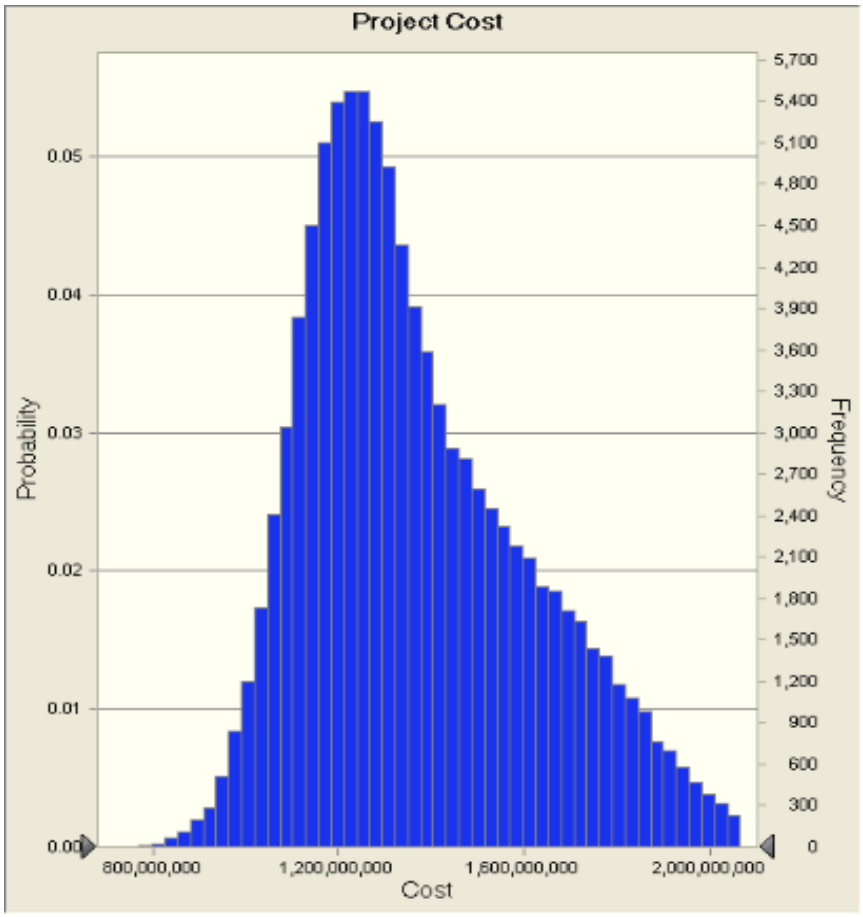
Summary:

Entire range is from 715,026,991 to 2,452,548,644

Base case is 1,274,820,564

After 100,000 trials, the std. error of the mean is 782,342

Forecast: Project Cost (cont'd)



Forecast: Project Cost (cont'd)

Percentiles:	Forecast values
0%	715,026,991
5%	1,046,100,604
10%	1,097,320,418
15%	1,133,395,091
20%	1,163,051,509
25%	1,189,709,415
30%	1,214,961,240
35%	1,240,082,290
40%	1,265,252,533
45%	1,291,542,073
50%	1,319,371,426
55%	1,350,885,978
60%	1,386,484,218
65%	1,428,093,742
70%	1,475,469,583
75%	1,528,913,524
80%	1,588,549,304
85%	1,657,269,166
90%	1,737,416,674
95%	1,846,764,183
100%	2,452,548,644

Forecast: Various Mob & Demob Hydrulic Unloader - Maintenance Dredging

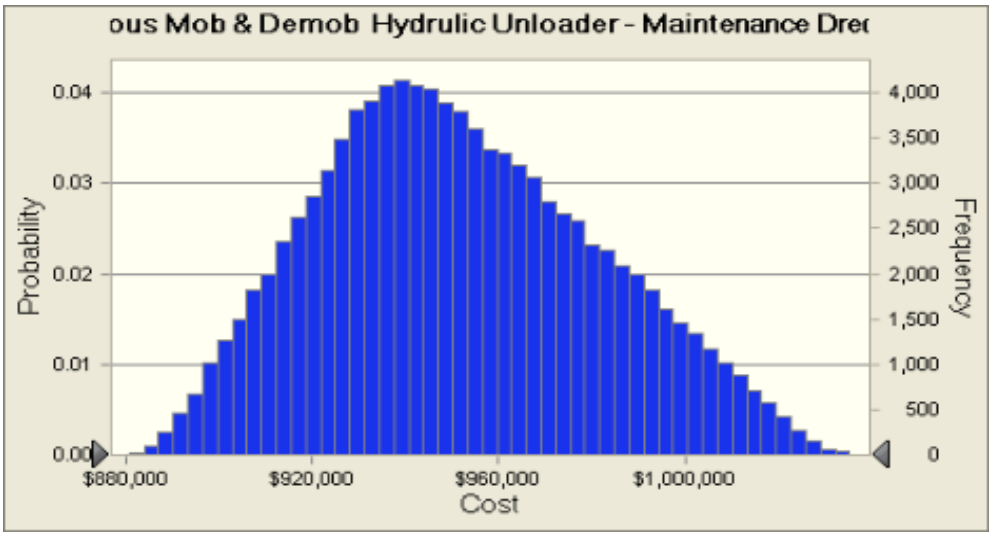
Summary:

Entire range is from $880,755 to $1,044,018

Base case is $932,668

After 100,000 trials, the std. error of the mean is $95

Forecast: Various Mob & Demob Hydrulic Unloader - Maintenance Dredging (cont'd)



Percentiles:	Forecast values
0%	$880,755
5%	$905,461
10%	$913,524
15%	$919,645
20%	$924,848
25%	$929,315
30%	$933,362
35%	$937,240
40%	$941,058
45%	$944,934
50%	$948,914
55%	$953,046
60%	$957,442
65%	$962,233
70%	$967,148
75%	$972,669
80%	$978,723
85%	$985,634
90%	$993,739
95%	$1,004,517
100%	$1,044,018

Forecast: Various Mob & Demob James Island -Sand Excavation

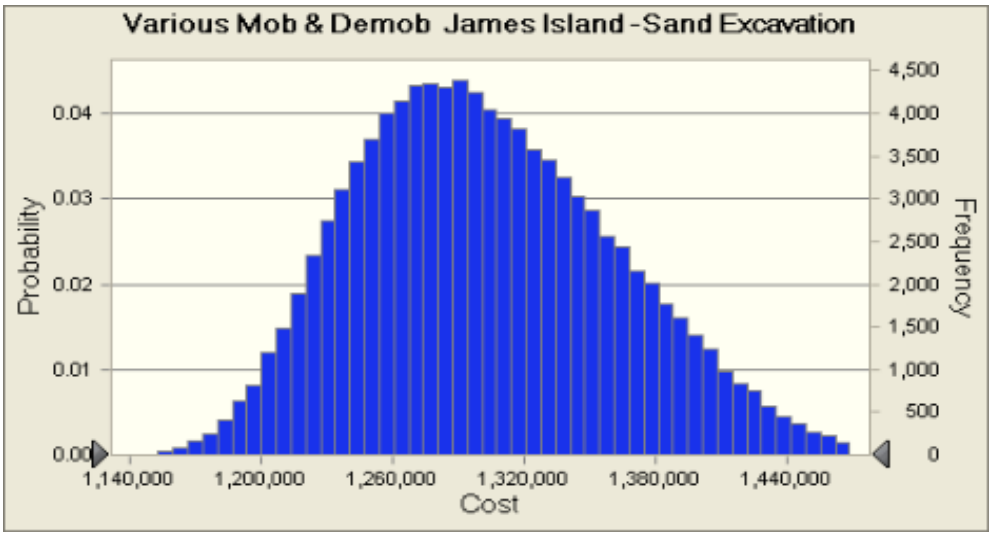
Summary:

Entire range is from 1,139,594 to 1,523,392

Base case is 1,249,146

After 100,000 trials, the std. error of the mean is 187

Forecast: Various Mob & Demob James Island -Sand Excavation (cont'd)

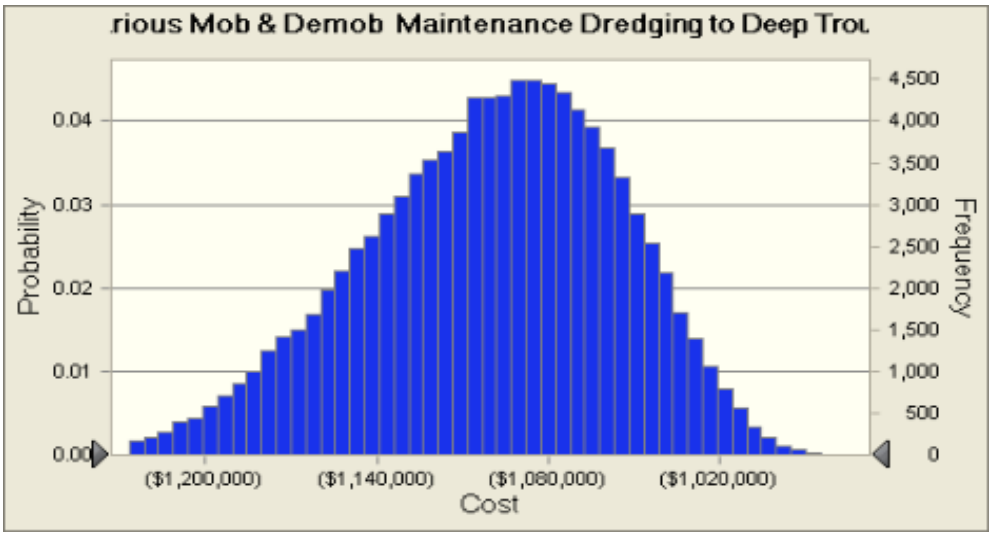


Percentiles:	Forecast values
0%	1,139,594
5%	1,213,235
10%	1,228,729
15%	1,239,951
20%	1,249,608
25%	1,258,317
30%	1,266,430
35%	1,274,170
40%	1,281,866
45%	1,289,650
50%	1,297,411
55%	1,305,546
60%	1,314,036
65%	1,322,950
70%	1,332,571
75%	1,342,859
80%	1,354,285
85%	1,367,739
90%	1,384,059
95%	1,406,984
100%	1,523,392

Forecast: Various Mob & Demob Maintenance Dredging to Deep Trough

Summary:
Entire range is from ($1,295,245) to ($973,616)
Base case is ($1,037,606)
After 100,000 trials, the std. error of the mean is $142

Forecast: Various Mob & Demob Maintenance Dredging to Deep Trough (cont'd)



Percentiles:	Forecast values
0%	($1,295,245)
5%	($1,180,551)
10%	($1,162,335)
15%	($1,149,595)
20%	($1,139,443)
25%	($1,130,698)
30%	($1,123,027)
35%	($1,115,775)
40%	($1,109,063)
45%	($1,102,992)
50%	($1,097,002)
55%	($1,091,027)
60%	($1,085,311)
65%	($1,079,594)
70%	($1,073,787)
75%	($1,067,535)
80%	($1,060,928)
85%	($1,053,712)
90%	($1,044,774)
95%	($1,032,717)
100%	($973,616)

Forecast: Various Mob & Demob Maintenance Dredging to James Island

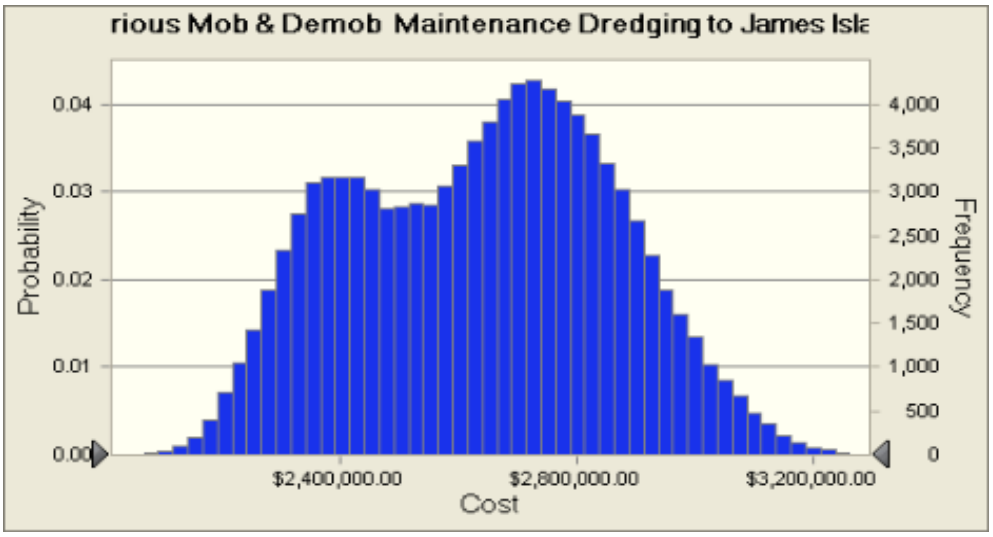
Summary:

Entire range is from $2,043,342.33 to $3,332,941.96

Base case is $2,659,402.37

After 100,000 trials, the std. error of the mean is $704.21

Forecast: Various Mob & Demob Maintenance Dredging to James Island (cont'd)

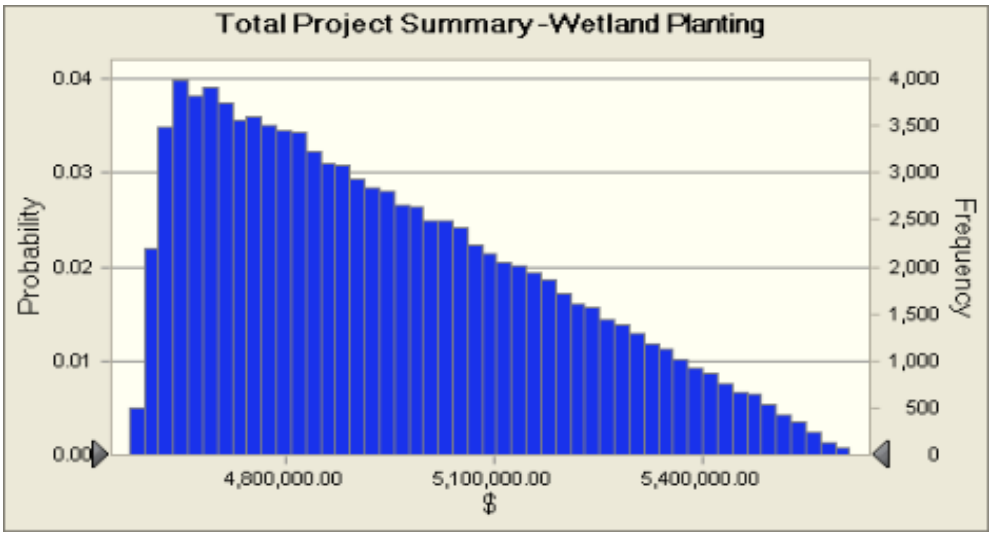


Percentiles:	Forecast values
0%	$2,043,342.33
5%	$2,281,560.69
10%	$2,333,790.08
15%	$2,374,368.56
20%	$2,413,355.67
25%	$2,453,166.42
30%	$2,496,721.60
35%	$2,540,069.83
40%	$2,583,019.45
45%	$2,620,326.98
50%	$2,654,531.35
55%	$2,685,712.57
60%	$2,715,042.78
65%	$2,744,136.02
70%	$2,774,520.78
75%	$2,805,664.46
80%	$2,839,187.55
85%	$2,877,418.31
90%	$2,924,961.59
95%	$2,992,114.22
100%	$3,332,941.96

Forecast: Total Project Summary -Wetland Planting

Summary:
Entire range is from 4,575,414.87 to 5,645,147.59
Base case is 4,590,118.63
After 100,000 trials, the std. error of the mean is 754.85

Forecast: Total Project Summary -Wetland Planting (cont'd)



Percentiles:	Forecast values
0%	4,575,414.87
5%	4,632,234.66
10%	4,659,151.96
15%	4,686,678.54
20%	4,714,174.20
25%	4,743,603.00
30%	4,773,075.48
35%	4,803,515.43
40%	4,834,863.10
45%	4,868,328.62
50%	4,902,805.74
55%	4,940,452.15
60%	4,978,876.76
65%	5,020,286.53
70%	5,063,313.64
75%	5,112,201.51
80%	5,165,223.02
85%	5,226,596.12
90%	5,298,387.61
95%	5,393,684.65
100%	5,645,147.59

End of Forecasts

ATTACHMENT N

HTRW

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US Army Corps of Engineers ®
Baltimore District

PHASE I
ENVIRONMENTAL SITE ASSESSMENT

BARREN ISLAND

DORCHESTER COUNTY
MARYLAND

Prepared by:

Engineering Division – HTRW Branch
U.S. ARMY ENGINEERING DISTRICT, BALTIMORE
10 South Howard Street
Baltimore MD 21201

MARCH 2004

PHASE I
ENVIRONMENTAL SITE ASSESSMENT

BARREN ISLAND

DORCHESTER COUNTY
MARYLAND

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1. SUMMARY

Barren Island is located in Dorchester County, Maryland (38:20:06 N latitude; 76:15:40 W longitude). The island is separated by Tar Bay from the Hooper Islands to the east, and bordered by the Chesapeake Bay to the west. The mouth of the Patuxent River lies across the bay, several miles west of Barren Island. A detailed survey in 1991 showed Barren Island to be 176.75 acres in size, a 78% reduction since historical mapping of the island in 1848. The Western shore of the island looses approximately 2.4 to 3.4 acres per year.

Barren Island is primarily forested with high and low salt marshes, eroding wooded banks lined with submerged snags, and sandy beach. Natural habitats include upland forest, high and low salt-water marsh, coves, and sandy beach. Submerged aquatic vegetation is found to the south and east of Barren Island. The island is federally owned and managed by the U.S. Fish and Wildlife Service as a satellite refuge to the Blackwater National Wildlife Refuge. Though currently uninhabited, Barren Island has a long history of human habitation beginning in pre-colonial times with native Americans. Colonial settlers farmed and fished the island as evidenced by a colonial-era cemetery located on the western-central shore of the island, which is eroding into the Chesapeake Bay. There are six archeological sites on or near Barren Island. As late as 1905 U.S.G.S. maps recorded the presence of 13 buildings on the island, about the same time as the last family is believed to have left. Barren Island was used as a hunting lodge, complete with airstrip, in the 1930s, and was last in private hands in 1991.

The Maryland Port Administration (MPA) Dredged Materials Management Program (DMMP) has identified Barren Island as a potential site for island habitat restoration through the beneficial use of dredged material. Several alignments are under consideration for the construction of dikes that will shelter the West Side of the island and be backfilled with dredged material for the purpose of restoring the extensive upland and wetland habitat lost through erosion.

As a result of being identified as a potential habitat restoration project, reconnaissance level studies of Barren Island were initiated in the spring of 2001. Since that time studies have included: subsurface geotechnical; coastal engineering; hydrodynamic and sedimentation modeling; dredging and site engineering; and existing environmental conditions. Thus far these studies support the restoration of Barren Island.

Environmental studies thus far have centered on the biota of Barren Island. Limited investigation into potential Comprehensive Environmental Response Compensation and Liability Act (CERCLA) liability showed that the closest site undergoing CERCLA activity is across the Chesapeake Bay at the Patuxent River Naval Air Station. With other studies supporting the Barren Island habitat restoration project progressing, the United States Army Corps of Engineers (USACE) decided

that it would be prudent to further investigate the past uses and environmental history of Barren Island using the methodology prescribed in ASTM E-1527, *Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process*. This report, prepared by the U.S. Army Engineering District, Baltimore, Engineering Division, Hazardous, Toxic, and Radioactive Waste (HTRW) Branch, covers the findings of the Phase I Site Assessment performed during the summer of 2003.

The purpose of the ASTM E-1527 Phase I process is to identify, to the extent feasible, recognized environmental conditions in connection with a property. It consists of four components:

Records Review – A search of publicly available records and databases has turned up no environmental issues involving Barren Island.

Site Reconnaissance – Barren Island has been, and continues to be, the site of environmental reconnaissance by biologists who are surveying the seasonal changes in flora and fauna. Personnel from Roy F. Weston, Inc. visited the site in October of 2001 for the purpose of assessing environmental conditions. As part of that effort inquiry was made regarding archaeological resources. None of the planned habitat restoration project will negatively impact known archeological resources on the island. No conditions were noted that would indicate the presence of environmental issues (Ref. 2). These conclusions are based on the observations reported by others as HTRW personnel did not have the opportunity to visit the site.

Interviews – The site visit report by Roy F. Weston Inc. provides a discussion of interviews conducted associated with their visit. No additional interviews were performed as a part of this investigation. No environmental consequences are suspected as a result of those interviews.

Report - The report that follows provides details of the data sources searched and other information collected during the course of this Phase I investigation.

2. SITE DESCRIPTION

Barren Island is located in Dorchester County Maryland (38:20:06 N latitude; 76:15:40 W longitude) about one mile due west, across Tar Bay, of Upper Hooper Island. The western shore of Barren Island lies on the Chesapeake Bay, with the mouth of the Patuxent River at the same latitude about three miles to the west. Over the past 325 years Barren Island has lost approximately 450 acres through natural erosion. Its current size is approximately 177 acres (1991 survey). The current rate of erosion is reducing the landmass of Barren Island by 2.4 to 3.4 acres per year.

Barren Island's highest shoreline elevation is approximately six feet above sea level. Natural habitats include forested uplands, wet meadows, submerged aquatic

vegetation, tidal marshes, coves, and sandy beach. Surrounding waters are generally shallow. The island can be divided into three sections. The north end includes low salt marsh, high salt marsh, sandy beaches, mud flats and eroding woodlands. The woodland area is present toward the center of the north end. The middle section of the island is approximately 50 yards long and consists of marsh that is not accessible because of shallow water and dense submerged aquatic vegetation. The south portion of the island contains high and low salt marsh areas to the southwest and a large forested area abutting Tar Bay to the east with a one to three foot eroded bank present in places. The island is home to multiple species of birds, including Bald Eagles, deer, raccoon and other small animals.

Native Americans once utilized the island in pre-colonial times as evidenced by the presence of arrowheads and shell midden piles. In colonial times Barren Island was used for both residential and agricultural purposes, with the last resident family believed to have left in approximately 1900. In the 1930s the land was privately owned and used as a hunt club. Ruins of a hunting lodge, boathouse, and a grass airstrip remain on the northern section of the island today. The southern remnant of the island shows no signs of human habitation, though a colonial cemetery is located on the southwest side of the island and is eroding into the Chesapeake Bay. Otherwise there are no buildings, roads, or bridges. There is no bridge connection between Barren Island and Hooper Island. There are no water wells, or sewage systems on the island. Access is limited as the island is part of the Blackwater Wildlife refuge and may be entered by permit only. There are no adjoining properties, only the waters of the Chesapeake Bay to the west and Tar Bay to the east.

3. USER PROVIDED INFORMATION

Title records show that the property is owned by The United States of America, and administered by the U.S. Fish and Wildlife Service.

There are no environmental liens or other use limitations noted in the deeds.

The property is used as a wildlife preserve. It has not been intensely cultivated for well over 50 years, and is uninhabited.

4. RECORDS REVIEW

Records from the data base sources noted below were reviewed in an effort to identify any interface between environmental regulatory authorities and this property. No such interface has been uncovered. (Ref. 1)

FEDERAL

NPL	National Priority List
Proposed NPL	Proposed National Priority List Sites
CERCLIS	Comprehensive Environmental Response,

	Compensation, and Liability Information System
CERC-NFRAP	CERCLIS No Further Remedial Action Planned
CORRACTS	Corrective Action Report
RCRIS-TSD	Resource Conservation and Recovery Information System – Treatment Storage and Disposal
RCRIS-LQG	Resource Conservation and Recovery Information System – Large Quantity Generators
RCRIS-SQG	Resource Conservation and Recovery Information System- Small Quantity Generators.

STATE

SHWS	Notice of Potential Hazardous Waste Sites
SWF/LF	Permitted Solid Waste Disposal Facilities/Landfill
UST	Registered Underground Storage Tank List
VCP	Voluntary Cleanup Program Applicants/Participants
SWRCY	Recycling Directory
OCPCASES	Oil Control Program Cases

OTHER FEDERAL

CONSENT	Superfund (CERCLA) Consent Decrees
ROD	Records Of Decision
Delisted NPL	National Priority List Deletions
FINDS	Facility Index System/Facility Identification Initiative Program Summary Report
HMIRS	Hazardous Materials Information Reporting System
MLTS	Material Licensing Tracking System
MINES	Mines Master Index File
NPL Liens	Federal Superfund Liens
PADS	PCB Activity Database System
DOD	Department of Defense Sites
RAATS	RCRA Administrative Action Tracking System
TRIS	Toxic Chemical Release Inventory System
TSCA	Toxic Substances Control Act
SSTS	Section 7 Tracking Systems
FTTS	FIFRA/ TSCA Tracking System - FIFRA (Federal Insecticide, Fungicide, & Rodenticide Act)/TSCA (Toxic Substances Control Act)

OTHER STATE OR LOCAL

Historical LUST	Leaking Underground Storage Tanks
AST	Permitted Aboveground Storage Tanks
Historical UST	Historical UST Registered Database

EDR PROPRIETARY HISTORICAL DATABASES

Coal Gas Former Manufactured Gas (Coal Gas) Sites

BROWNFIELDS DATABASES

VCP Voluntary Cleanup Program Applicants/Participants

SURROUNDING SITES: SEARCH RESULTS

Surrounding sites were not identified. This is an island surrounded by water.

PHYSICAL SETTING

Records reviewed include aerial photographs taken on May 11, 1964, provided by the Maryland Geological Survey, and three historical topographical maps. One map is of the 15 minute series dated 1905. The other two maps are both 7.5-Minute Series, one from 1942, and the other from 1974. The 1905 map shows thirteen buildings on the island. The newer maps show no buildings, but do show a short road and airstrip.

The island is in a FEMA Flood zone and contains wetlands listed in the National Wetland Inventory.

The geologic setting, according to P.G. Schruben, R.E. Arndt and W.J. Bawiec, Geology of the Conterminous U.S. at 1:2,500,000 Scale - a digital representation of the 1974 P.B. King and H.M. Beikman Map, USGS Digital Data Series DDS – 11 (1994) follows (Ref. 1):

Rock Stratigraphic Unit

Era:	Cenozoic
System:	Quaternary
Series:	Pleistocene
Code:	Qp (decoded above as Era, System, & Series) (ref. 1)

Geologic Age Identification

Category: Stratified Sequence (ref. 1)

Soil Classification

Soil Component Name: WESTBROOK

Soil Surface Texture: Mucky-peat

Hydrologic group:	Class D – very slow infiltration. Soils are clayey, have a high water table, or are shallow to an impervious layer (Ref. 1)
Soil Drainage Class:	Very Poorly. Soils are wet to the surface most of the time. Depth to water table is less than one foot, or is ponded
Hydric Status	Soil meets the requirements for a hydric soil.
Corrosion Potential –Uncoated steel:	High
Other soils in area:	silt loam sand

Water Wells

There are no water wells on Barren Island registered with USGS, Federal Reporting Data System - Public Water Systems, or the Maryland State database. There are no public water systems (systems that serve at least 25 people, for at least 60 days annually) within a mile of Barren Island. (Ref. 1)

HISTORICAL USE INFORMATION

Maryland Environmental Services (MES) requested a literature search at the Maryland Historic Trust in an effort to determine if there are any sites of historical or archaeological significance on Barren Island. No sites were identified that are expected to be impacted by the proposed project. The island has seen human habitation since pre-colonial days as evidenced by arrowheads and midden piles. Until about 1900 full time residents inhabited the island. There is a colonial-era cemetery on the western shore of the island that is eroding into the Chesapeake Bay. By the 1930s Barren Island was used as a hunting club, a use still evident in the ruins of the lodge, a boathouse, bulkheads, and a grass aircraft landing strip. Since 1991 the property has been a part of the Blackwater Wildlife Refuge under the stewardship of the U.S. Fish and Wildlife Service. Several projects to enhance wildlife habitat (e.g., planting bay grasses), prevent further erosion, and restore already eroded parts of the island have taken place on the island since 1991.

5. SITE RECONNAISSANCE

Barren Island and its surrounding waters have been the subject of reconnaissance efforts by various state and federal agencies and their contractors since the summer of 2001. The results of the various studies have been documented in reports prepared during 2001, 2002, and 2003, and consolidated into one report, prepared by Weston Solutions, Inc., published in August of 2002 (Ref. 2). Given the intense

reconnaissance of Barren Island by biologists and other environmental professionals, no additional site visit was deemed necessary to document current conditions on the island. This Phase I investigation report, prepared during the summer of 2003, references observations made by others and reported in reference 2 in lieu of an independent HTRW on-site inspection.

6. INTERVIEWS

No additional interviews were performed as a part of this Phase I investigation. Information gained as the result of site reconnaissance performed during 2001, 2002, and 2003 is deemed adequate for the purposes of this report for several reasons.

- There is no evidence that there has ever been industrial activity on the island.
- Releases due to accidents involving hazardous materials or leaky tanks are unlikely, as evidence shows the island has not been inhabited, and has been protected as a wildlife refuge past twelve years. Above ground gasoline tanks were removed by the U.S. Fish and Wildlife Service in the 1990s. (ref. 2)
- Information in the archives of the U.S. Fish and Wildlife Service provide a history of this island..

7. FINDINGS

This is an island site that has not seen full time human habitation for over 100 years. The need to cross shallow, snag-filled waters to access the site makes it an unlikely place to illicitly dump hazardous waste. All evidence points to an absence of even part-time human habitation on Barren Island for many years as the only dwelling, a hunting lodge, is in ruins. Above ground gasoline tanks were removed from the lodge area by the U.S. Fish and Wildlife Service shortly after they took over stewardship of the island as part of the Blackwater Wildlife Refuge in 1991. No hazardous materials have been stored on the Island since. The remains of a boat house, bulkhead, a grass landing strip and a colonial cemetery are all that remains to show that the island was ever used by humans. Since 1991 the only human intervention on the island has been to perform projects that enhance wildlife habitat, retard erosion, or restore already eroded areas of the island.

Data base searches show that regulated hazardous materials or hazardous wastes and underground storage tanks are located miles away from Barren Island, so it is unlikely that any of these activities would impact the island. The closest CERCLA site is across Chesapeake Bay at the Patuxent River Naval Air Station. Databases show no reported releases of hazardous materials in the area.

Historic aerial photographs from 1964 show no suspicious activity on the island and topographic maps from 1942 show that buildings shown on a 1905 map have disappeared.

8. CONCLUSIONS

Barren Island was inhabited in pre-colonial times. The evidence suggests that as many as 13 building were situated on the island at one time. By 1942 these buildings had disappeared. A hunting club existed on the island in the 1930s, but its buildings have also fallen to ruin. Gasoline storage tanks associated with the hunting lodge were removed by the current owner of the island, the U.S. Government, in the 1990s. There were never any underground storage tanks on the island.

Because of its location and topography, Barren Island is a poor candidate for midnight waste dumpers. It would be easier to dump into the Chesapeake Bay than to cart illicit waste onto Barren Island. The many environmental investigators who have combed the island during the past three years have found no evidence of dumping. Similarly, there have been no reports of distressed vegetation on the island.

Research of the many government-maintained databases (see Section 4) indicates that there have been no reported releases of hazardous materials or petroleum close to Barren Island. There are no permitted hazardous waste treatment, storage or disposal facilities near the island and the closest CERCLA site is on the western shore of the Chesapeake Bay, several miles away, at the Patuxent River Naval Air Station. It is highly unlikely that any of these activities could have any effect on Barren Island.

In conclusion, there is no reason to suspect that Barren Island contains hazardous waste, hazardous materials or substances that will in any way influence the proposed Island restoration project.

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1. Report: *EDR Radius Map with GeoCheck,* Environmental Data Resources, Inc., 3530 Post Road, Southport, CT 06890, June 25, 2003.
2. Report:: *Final Consolidated Report, Reconnaissance of the Proposed Environmental Restoration Project Near Barren Island, Dorchester County, Maryland*, Weston Solutions, Inc, August 2002.
3. Photograph: Maryland Geological Survey, Barren Island, May 11, 1964, digital B&W aerial image.
4. Photographs: Provided by Maryland Environmental Services, Barren Island site visit, September 27, 2001, digital color images.

US Army Corps of Engineers ®
Baltimore District

PHASE I
ENVIRONMENTAL SITE ASSESSMENT

JAMES ISLAND
LITTLE CHOPTANK RIVER
DORCHESTER COUNTY
MARYLAND

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SEPTEMBER 2003

PHASE I
ENVIRONMENTAL SITE ASSESSMENT

JAMES ISLAND
LITTLE CHOPTANK RIVER
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1. SUMMARY

James Island is located in Dorchester County Maryland (38:31:01 N latitude; 76:20:24 W longitude) at the confluence of the Little Choptank River and the Chesapeake Bay. In 1847 James Island was estimated to be 976 acres in size. Through the years natural erosion has reduced its size to approximately 92 acres (1994 estimate) and left it divided into three segments, the northern, middle, and southern segment. The northern and middle segments are connected by a sand spit and the southern segment is separated from the north and middle by shallow open water.

James Island is primarily forested with fringe marshes and eroding wooded banks lined with submerged snags. The shoreline elevations range from 5 to 10 feet above sea level on its northwestern shores and decrease to the south. Natural habitats include forested uplands, wet meadows, submerged aquatic vegetation, tidal marshes, coves, and some sandy beach. Surrounding waters are generally shallow and contain natural oyster bars. The island is used for recreational hunting and fishing and is currently uninhabited, though the southern remnant of the island shows signs of human habitation in the form of an old brick foundation and possible chimney from a dwelling.

The Maryland Port Administration (MPA) Dredged Materials Management Program (DMMP) has identified James Island as a potential site for island habitat restoration through the beneficial use of dredged material. Other interested parties, including the Dorchester County Resource Preservation and Development Corporation, a non-profit organization, and the private land owners of James Island recognize the benefits of stabilizing and protecting James Island from future erosion while restoring both upland and wetland habitat. Not only would James Island be the beneficiary of a stable shore line and increased land area, including wetlands, but other waterfront property on the Little Choptank river would receive continued protection that would be absent if James Island were to fully erode away.

As a result of being identified as a potential habitat restoration project, reconnaissance level studies of James Island were initiated in the spring of 2001. Since that time studies have included: subsurface geotechnical; coastal engineering; hydrodynamic and sedimentation modeling; dredging and site engineering; and existing environmental conditions. Thus far these studies support the restoration of James Island.

Environmental studies thus far have centered on the biota of James Island. Limited investigation into potential Comprehensive Environmental Response Compensation and Liability Act (CERCLA) liability showed that the closest site undergoing CERCLA activity is in Cambridge, Maryland, some 15 miles to the northeast. With other studies supporting the James Island habitat restoration project progressing, the United States Army Corps of Engineers (USACE) decided that it

would be prudent to further investigate the past uses and environmental history of James Island using the methodology prescribed in ASTM E-1527, *Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process*. This report covers the findings of the Phase I Site Assessment performed during the summer of 2003.

The purpose of the ASTM-1527 Phase I process is to identify, to the extent feasible, recognized environmental conditions in connection with a property. It consists of four components:

Records Review – A search of publicly available records and data bases has turned up no environmental issues involving James Island.

Site Reconnaissance – James Island has been, and continues to be, the site of environmental reconnaissance by biologists who are surveying the seasonal changes in flora and fauna. Others have surveyed the island for archaeological purposes. Except for some old ruins on the south side of the south segment, there is no sign of human habitation on the island.

Interviews – Other than anecdotal information reported by EA Engineering, Inc. (Reference 2), no additional interviews were performed as a part of this investigation. Reference 2 reports no industrial or agricultural uses that suggest possible environmental consequences.

Report - The report that follows provides details of the data sources searched and other information collected during the course of this Phase I investigation.

2. SITE DESCRIPTION

James Island is located in Dorchester County Maryland (38:31:01 N latitude; 76:20:24 W longitude) at the confluence of the Little Choptank River and the Chesapeake Bay. The mouth of the Little Choptank River discharges into the Chesapeake Bay in a northerly direction with James Island forming the western land mass of the mouth. The Chesapeake Bay lies to the north and west of James Island and the Little Choptank to the east. Through the years what was a 976 acre island (1847 estimate) has been reduced through natural erosion to approximately 92 acres (1994 estimate). The historic rate of erosion has reduced the landmass of James Island by 6 acres per year and left it divided into three segments, the northern, middle, and southern segment. The northern and middle segments are connected by a sand spit and the southern segment is separated from the north and middle by shallow open water. Taylors Island is approximately .6 mile south of the southern segment of James Island.

James Island is primarily forested with fringe marshes and eroding wooded banks lined with submerged snags. The highest shoreline elevation is approximately 10 feet

above sea level on its northwestern shores and decreases to the south. Natural habitats include forested uplands, wet meadows, submerged aquatic vegetation, tidal marshes, coves, and some sandy beach. Surrounding waters are generally shallow and contain natural oyster bars. The island is home to multiple species of birds, including a nest of Bald Eagles.

The island was once utilized for both residential and agricultural purposes during the 19th century. The southern remnant of the island shows signs of human habitation in the form of a brick foundation and possible chimney from a dwelling. During site visits, glass, brick, and pottery shards were found along the beaches. The Maryland Historical Trust records show four archeological sites located along the eastern shores of the island. Additionally, a shell midden has been observed on the southern remnant of the island. In June of 2001 two duck blinds in good repair were observed on or near James Island, one on the eastern side of the central remnant, the other in waters east of the sand spit connecting the central and northern remnant. Otherwise there are no buildings, roads, or bridges. There is no bridge connection between James Island and Taylor's Island. There are no water wells, or sewage systems on the island. Although the island is used for hunting, access is limited due to snags in the surrounding shallow waters. There are no adjoining properties, only the waters of the Chesapeake Bay and Little Choptank River.

3. USER PROVIDED INFORMATION

Title records show that the property is owned by two entities:

- Richard and Eleanor Bernstein who purchased the "North" Island of the chain in January, 1996. Acreage was estimated at 165.53 acres based on a 1941 survey. It is separated from the lower and middle island by Long Cove (Deed 330/753, Land Records of Dorchester County).

- Paul Nassetta & Leland Phillips who purchased the "South" Island in March of 1976. Acreage was estimated at 199.53 acres based on a 1941 survey, though it was acknowledged that natural tidal action had divided the property into 2 parcels since that survey (Deed 197/93, Land Records of Dorchester County).

There are no environmental liens or other use limitations noted in the deeds.

The owners and their guests have used the property for hunting, fishing, and other recreational purposes. It has not been intensely cultivated for over 50 years, and is uninhabited.

This Phase I environmental site assessment is being performed by the United States Army Corps of Engineers, not the owners, as a means of consolidating all known information regarding the possible presence of hazardous, toxic, or radioactive waste (HTRW) that may be present on James Island and its surrounding waters.

4. RECORDS REVIEW

Records from the data base sources noted below were reviewed in an effort to identify any interface between environmental regulatory authorities and this property. No such interface has been uncovered. (Ref. 1)

FEDERAL

NPL	National Priority List
Proposed NPL	Proposed National Priority List Sites
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CERC-NFRAP	CERCLIS No Further Remedial Action Planned
CORRACTS	Corrective Action Report
RCRIS-TSD	Resource Conservation and Recovery Information System – Treatment Storage and Disposal
RCRIS-LQG	Resource Conservation and Recovery Information System – Large Quantity Generators
RCRIS-SQG	Resource Conservation and Recovery Information System- Small Quantity Generators.

STATE

SHWS	Notice of Potential Hazardous Waste Sites
SWF/LF	Permitted Solid Waste Disposal Facilities/Landfill
UST	Registered Underground Storage Tank List
VCP	Voluntary Cleanup Program Applicants/Participants
SWRCY	Recycling Directory
OCPCASES	Oil Control Program Cases

OTHER FEDERAL

CONSENT	Superfund (CERCLA) Consent Decrees
ROD	Records Of Decision
Delisted NPL	National Priority List Deletions
FINDS	Facility Index System/Facility Identification Initiative Program Summary Report
HMIRS	Hazardous Materials Information Reporting System
MLTS	Material Licensing Tracking System
MINES	Mines Master Index File
NPL Liens	Federal Superfund Liens
PADS	PCB Activity Database System
DOD	Department of Defense Sites
RAATS	RCRA Administrative Action Tracking System
TRIS	Toxic Chemical Release Inventory System
TSCA	Toxic Substances Control Act

SSTS	Section 7 Tracking Systems
FTTS	FIFRA/ TSCA Tracking System - FIFRA (Federal Insecticide, Fungicide, & Rodenticide Act)/TSCA (Toxic Substances Control Act)

OTHER STATE OR LOCAL

Historical LUST	Leaking Underground Storage Tanks
AST	Permitted Aboveground Storage Tanks
Historical UST	Historical UST Registered Database

EDR PROPRIETARY HISTORICAL DATABASES

Coal Gas	Former Manufactured Gas (Coal Gas) Sites

BROWNFIELDS DATABASES

VCP Voluntary Cleanup Program Applicants/Participants

SURROUNDING SITES: SEARCH RESULTS

Surrounding sites were not identified. This is an island surrounded by water.

PHYSICAL SETTING

Records reviewed include aerial photographs taken on May 11, 1964, provided by the Maryland Geological Survey, and an historical topographical map, 30 x 60 Minute Series, from 1983. Neither source shows evidence o human presence on the island. The island shown in the 1964 photograph consists of two,instead of three segments. The island appears low, and consists of groves of trees, wetlands, and beaches.

The geologic setting, according to P.G. Schruben, R.E. Arndt and W.J. Bawiec, Geology of the Conterminous U.S. at 1:2,500,000 Scale - a digital representation of the 1974 P.B. King and H.M. Beikman Map, USGS Digital Data Series DDS – 11 (1994) follows (Ref. 1):

Rock Stratigraphic Unit

Era:	Cenoxonic
System:	Quaternary
Series:	Pleistocene
Code:	Qp (decoded above as Era, System, & Series) (ref. 1)

Geologic Age Identification

Category: Stratified Sequence (ref. 1)

Soil Classification

Soils classification on James Island is not reported by the U.S. Department of Agriculture. (Ref. 1)

Water Wells

There are no water wells on James Island registered with USGS, Federal FRDS PWS, or the Maryland State database. There are no public water systems (systems that serve at least 25 people, for at least 60 days annually) within a mile of James Island. (Ref. 1)

HISTORICAL USE INFORMATION

Maryland Environmental Services (MES) conducted a literature search at the Maryland Historic Trust in an effort to uncover historic uses of James Island. There are four recorded archeological sites along the eastern shore of the three island remnants. There are no standing structures on James Island, but there are ruins of a brick foundation and possible chimney on the southern remnant. The southern remnant also shows evidence of a shell midden along the northeastern shore and pieces of brick and pottery were discovered along the southeastern shore. The northern and middle remnants of James Island showed no evidence of historic or archeological resources that would suggest uses other than agriculture, hunting, and fishing.

5. SITE RECONNAISSANCE

James Island and its surrounding waters have been the subject of reconnaissance efforts by various state and federal agencies and their contractors since the summer of 2001. The results of the various studies have been documented in reports prepared during 2001, 2002, and 2003, and consolidated into one report, prepared by EA Engineering, Science, & Technology, Inc., published in April of 2003 (Ref 2). Given the intense reconnaissance of James Island by biologists and other environmental professionals, no additional site visit was deemed necessary to document current conditions on the island. This Phase I investigation report, prepared during the summer of 2003, references observations made by others and reported in that April 2003 document.

6. INTERVIEWS

No additional interviews were performed as a part of this Phase I investigation. Information gained as the result of site reconnaissance performed during 2001, 2002, and 2003 is deemed adequate for the purposes of this report for several reasons.

- There is no evidence that there has ever been industrial activity on the island.
- Releases due to accidents involving hazardous materials or leaky tanks are unlikely, as evidence shows the island has not been inhabited in modern times.
- The owners of James Island are aware of the intense reconnaissance of the island over the past three years, and have requested that they be contacted through their lawyer. Photographic evidence shows that there is no sign of homes, roads, or agricultural activity in 1964, 12 years prior to purchase by the oldest of the two owner entities, and we believe they can add little to the body of knowledge already gathered regarding HTRW disposal or releases. To avoid the generation of legal fees for the owners, no contact was attempted.
- Informal interviews produced some anecdotal information reported in Reference 2, though names, places, and dates are not specifically recorded. That information indicates that the island was used for hunting and fishing in the 1930's.

7. FINDINGS

This is an island site that has not had ties to land for well over 100 years. The need to cross shallow, snag-filled waters to access the site makes it an unlikely place to illicitly dump HTRW. All evidence points to an absence of human habitation on James Island for many years as the only dwelling found is very old and is in ruins. Broken pottery and glass on the beach and two duck blinds, are the only signs of any human activity on the island.

Database searches show that regulated hazardous materials or hazardous wastes and underground storage tanks are located miles away from James Island, so it is unlikely that any of these activities would impact the island. The closest CERCLA site is 15 miles away from James Island in Cambridge MD. Databases show no reported releases of hazardous materials in the area.

Historic aerial photographs show no evidence of human habitation on James Island in 1964, when James was much larger than now, and divided into only two segments. Topographic maps from1983 show a three-segment island with no homes or roads noted.

8. CONCLUSIONS

James Island was at one time inhabited. The evidence suggests that habitation dates to a time when roads were poor or did not exist on the eastern shore of Maryland and most inhabitants farmed and fished to survive. In time, James Island was abandoned as residents moved on to an easier life ashore where there was better transportation and electrification. The one-time residence fell into disrepair and crumbled. Agriculture ceased on James Island, and it became a property owned by non-residents used for hunting and fishing. There is no evidence that the ruined dwelling ever had an underground storage tank for heating oil for central heat or electricity.

Because of its location and topography, James Island is a poor candidate for midnight dumpers of wastes. It would be easier to dump into the Chesapeake Bay than to cart illicit waste through the shallow snag-filled waters surrounding James Island and dump them ashore. No evidence of dumping has been found by the many environmental investigators who have combed the island during the past three years. Similarly, there have been no reports of distressed vegetation on the island.

Research of the many government-maintained databases (see Section 4) indicates that there have been no reported releases of hazardous materials or petroleum close to James Island. There are no permitted hazardous waste treatment, storage or disposal facilities near the island and the closest CERCLA site is 15 miles away, in Cambridge MD. It is highly unlikely that any of these activities could have any effect on James Island.

In conclusion, there is no reason to suspect that James Island contains HTRW that will in any way influence the proposed Island restoration project.

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1. Report: *EDR Radius Map with GeoCheck,* Environmental Data Resources, Inc., 3530 Post Road, Southport, CT 06890, June 25, 2003.
2. Report:: *Final James Island Beneficial Use of Dredged Material, Consolidated Reconnaissance Report*, EA Engineering, Science and Technology, Inc. April 2003.
3. Photograph: Maryland Geological Survey, James Island, May 11, 1964, digital B&W aerial image.
4. Photograph: Maryland Environmental Services, James Island, April 2000, digital color image.
5. Photographs: Maryland Environmental services, James Island, June 26, 2001, thirty digital color images of James Island from water and shore.

ERDC/CHL TR-06-10

Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Mid-Bay Islands Hydrodynamics and Sedimentation Modeling Study, Chesapeake Bay

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Jane M. Smith, and Oner Yucel
Edited by Nicholas C. Kraus

August 2006

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Final report

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ABSTRACT: James Island and Barren Island, in Maryland waters, are among the few remaining eastern shore islands in mid-Chesapeake Bay. Both islands are eroding at a rapid rate due to wave and storm action, as well as to relative sea level rise. These two islands are considered as potential candidate restoration sites as a beneficial use of clean dredged material from the Baltimore Harbor and Channels Federal Navigation Project. The island restoration project requires the construction of protective dikes to contain the dredged material. The restoration work should provide efficient protection to the existing islands, shelter sandy beaches and the shoreline from severe erosion, and improve water quality and surrounding environment for submerged aquatic vegetation. This report describes establishment and operation of a suite of numerical modes to evaluate alternative designs as an initial study for restoration and modification of James Island and Barren Island. The predicted wave climate along the mainland shore was also estimated for the alternatives. Both typical and storm hydrodynamic conditions were assessed. In support of the numerical modeling, sediment samples were taken and bathymetric surveys made in key areas, together with assemblage of relevant data sets such as aerial photographs of the shoreline, wind, and presence and vulnerability of submerged aquatic vegetation. Data from the modeling and other data sets assembled and collected were compiled on a DVD.

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Preface

This report was produced for the U.S. Army Corps of Engineers, Baltimore District (NAB), and Maryland Port Administration (MPA) under contract with the Maryland Environmental Service. Work was performed by Andrews, Miller & Associates, Inc. (AMA), Blasland, Bouck & Lee, Inc. (BBL), and the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). Ms. Karen Nook Riches, civil engineer, was the NAB Point of Contact and lead technical review for NAB; and Mr. Scott Johnson and Ms. Stacey S. Blersh were the NAB Project Manager and Study Manager, respectively, of the Mid-Chesapeake Bay Island Ecosystem Restoration Feasibility Study. Dr. Stephen E. Storms was the MPA Project Manager and technical reviewer. Ms. Stephanie E. Lindley, Environmental Specialist, and Ms. Karen A. Cushman, Project Manager, were the MES Project Managers and technical reviewers. Dr. Nicholas C. Kraus, Senior Scientist Group, CHL, was the ERDC Project Manager and technical editor of this report.

Chapters 1, 2, 4, and 5 of this report were prepared by Dr. Lihwa Lin, research physical scientist, CHL, Coastal Engineering Branch (CEB), and Dr. Kraus. Chapter 3 was prepared by Dr. Jane M. Smith and Ms. Ann R. Sherlock, research hydraulic engineers, CHL, Coastal Processes Branch. Appendix A was prepared by Mr. Walter J. Dinicola, senior project engineer; Dr. Ram K. Mohan, Vice President; Mr. Mathew R. Henderson, senior engineer; and Mr. Mark Reemts, engineer in training, BBL; and by Mr. Edward T. Fulford, President, and Dr. Oner Yucel, senior coastal engineer, AMA. Appendix B was prepared by the aforementioned staff of BBL. Appendix C was prepared by the aforementioned staff of AMA. Ms. J. Holley Messing, CEB, completed word processing and formatting.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
knots (international)	0.5144444	meters per second
miles (U.S. statute)	1.609347	kilometers
square feet	0.09290304	square meters
square miles	2,589,998	square meters

1 Introduction

James Island and Barren Island, located in the state of Maryland waters, are among the few remaining eastern shore islands in the mid-Chesapeake Bay. Both islands are eroding at a rapid rate due to wave and storm action, as well as to relative sea level rise that has occurred in the last century. These two islands are considered potential candidate restoration sites as a beneficial use of clean dredged material from the Baltimore Harbor and Channels Federal Navigation Project. The island restoration project requires the construction of protective dikes to contain the dredged material. The restoration work should provide efficient protection to the existing islands, shelter sandy beaches and the shoreline from severe erosion, and improve water quality and the surrounding environment for submerged aquatic vegetation (SAV).

The state of Maryland and the U.S. Army Engineer District, Baltimore (hereafter, Baltimore District), are undertaking studies to determine the technical, economic, and environmental feasibility of protecting, restoring, and creating aquatic intertidal wetland and upland habitat for fish and wildlife at Mid-Chesapeake Bay islands as a beneficial use of clean sediments dredged from the Baltimore Harbor and Channels Federal Navigation Project. James Island and Barren Island are among 105 islands identified under the Dredged Material Management Plan.

This report describes establishment and operation of a suite of numerical models to evaluate alternative designs as a reconnaissance or initial study for restoration and modification of James Island and Barren Island. In addition to evaluation and optimization of design of the islands, the predicted wave climate on the mainland shore was also estimated for the various alternatives considered, as well as changes in conditions at SAV areas, and increased sedimentation in a Federal channel and a private waterman navigation channel located in the study areas. Both normal bay hydrodynamic conditions and storm conditions were assessed. Sediment sampling and bathymetry surveys in key areas of the study were conducted, together with assemblage of relevant data sets such as aerial photographs of the shoreline, wind, and presence and vulnerability of SAV.

Background

Chesapeake Bay is one of the most productive marine ecosystems and the largest estuary in the United States, extending more than 150 miles from its seaward end at the Atlantic Ocean to the bayward end at the entrance to the

Chesapeake and Delaware (C&D) Canal (Figure 1). It serves as a nursery ground for many commercially and noncommercially important species. The bay and its tributaries have a surface area of approximately 4,500 square miles.[1] Water depths in the bay average 20 ft with a maximum depth reaching 175 ft (Schubel and Pritchard 1987). The drainage area of the bay is approximately 64,000 square miles. Fresh water enters the bay from more than 150 major rivers and streams at approximately 80,000 cu ft/sec. Ocean tides enter the bay through the Atlantic Ocean entrance and C&D Canal. The mean range of tides in the bay varies from approximately 1 ft on the western shore to 3 ft at the Atlantic Ocean entrance and in the C&D Canal.

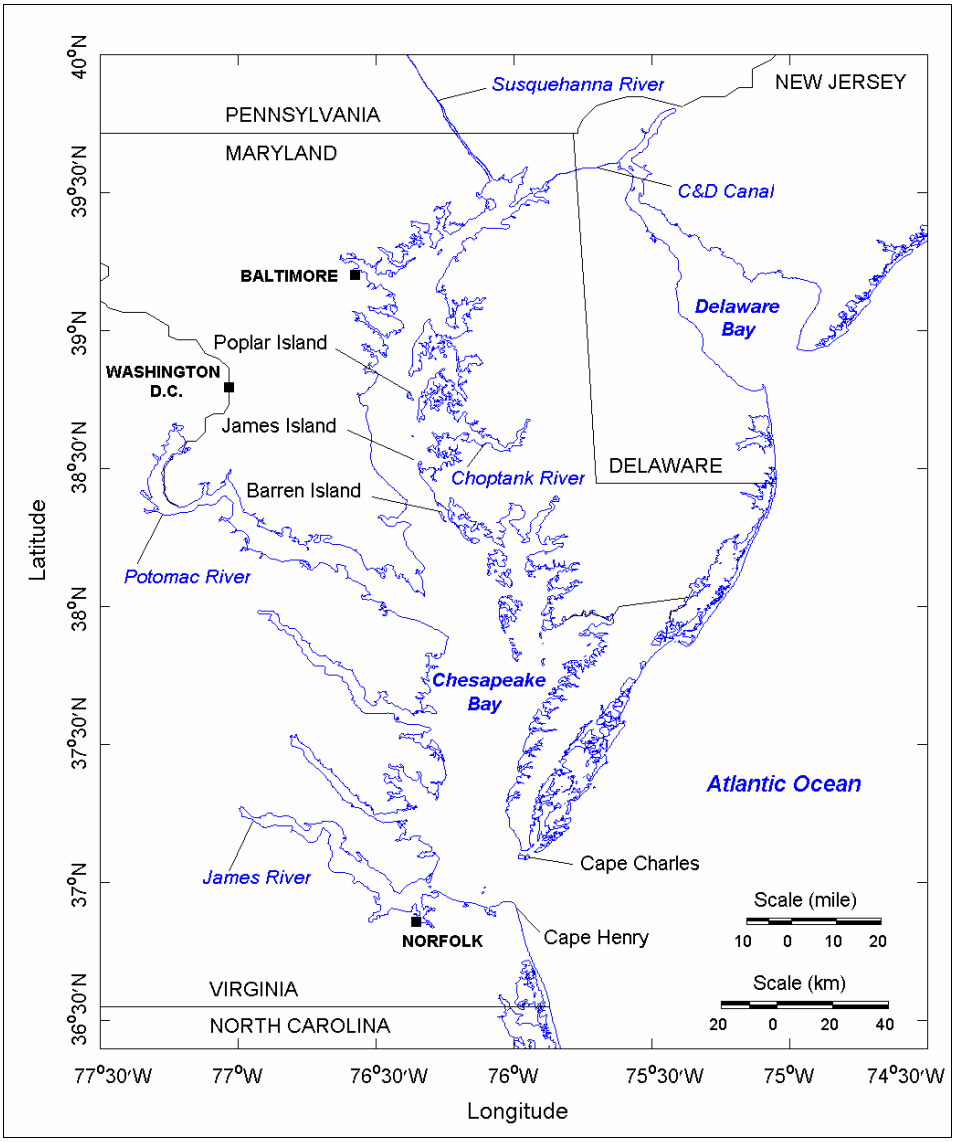

Figure 1. Chesapeake Bay map

[1] A table of conversion factors from non-SI units to SI units of measurement can be found on page xii.

In the last century, rising sea level and frequent flooding have caused extensive erosion to many islands in the bay. According to the National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), the bay water level has been rising more than 3 mm/year on average for a total of about 1 ft during the last 100 years. As a result, many islands are disappearing, the low-lying land along the bay is turning into open water, and other stretches are flooding. An accelerated sea level rise could eliminate most of the bay's marshes and beaches. The loss of these habitats would be harmful to birds, fish, oysters, and other aquatic life and wildlife.

To address the threat of losing more marsh, beaches and islands, a coalition of Federal, state and nongovernmental agencies has initiated studies and programs to restore critical wetlands and streams and important fisheries habitat throughout the bay. For example, the Poplar Island Environmental Restoration Project, launched in 1998, is a $427 million restoration project that involves placing material dredged from shipping channels to the previously rapidly vanishing Poplar Island. The island is located 15 miles south-southeast of Annapolis, MD, along the east side of Chesapeake Bay (Figure 2). Use of this dredged material for island and beach restoration is considered beneficial because of the need for sediment as a resource. In Chesapeake Bay, there are eight major ports (Cape Charles, Norfolk, Newport News, Hopewell, Richmond, and Alexandria in Virginia; and Baltimore and Cambridge in Maryland) and a long ship channel extending from the Atlantic Ocean entrance to the C&D Canal, with many local channels leading to major ports. Channels approaching these ports require more than 15 million cu yd of maintenance dredging annually. Most dredged sediments are clean silt and sand suitable for the beneficial use in island and wetland restoration projects.

Baltimore is the chief port on the upper portion of Chesapeake Bay. Channels serving the port require removal of about 3.2 million cu yd/year of dredged material. The placement of dredged material is a continuous and challenging task for the port. As a joint effort, the Maryland Port Administration (MPA) and the Baltimore District have conducted the Poplar Island Environmental Restoration Project (Melby et al. 2005) to reconstruct the island to its approximate size in 1847 using uncontaminated sediment dredged from Baltimore Harbor and approaching channels. Based on the projected capacity of all placement sites in the bay, it would be advantageous to develop additional sites by year 2010.

Chesapeake Bay is typically divided into three regions; Upper Bay, from the Susquehanna River to the Chesapeake Bay Bridge, MD; Mid Bay from the Chesapeake Bay Bridge, MD, to the mouth of the Potomac River; and Lower Bay, from the Potomac River to the Atlantic Ocean. The division of the bay into three zones is not completely arbitrary, but is aligned with the character of the land, rivers, and the Bay waters of each region. Mid Bay includes the eastern half of the Chesapeake Bay from the Chester River to the Maryland-Virginia state line. The salinity of the water in the Mid Bay is transitional and subjected to a great fluctuation between the fresher Upper Bay and salty Lower Bay.

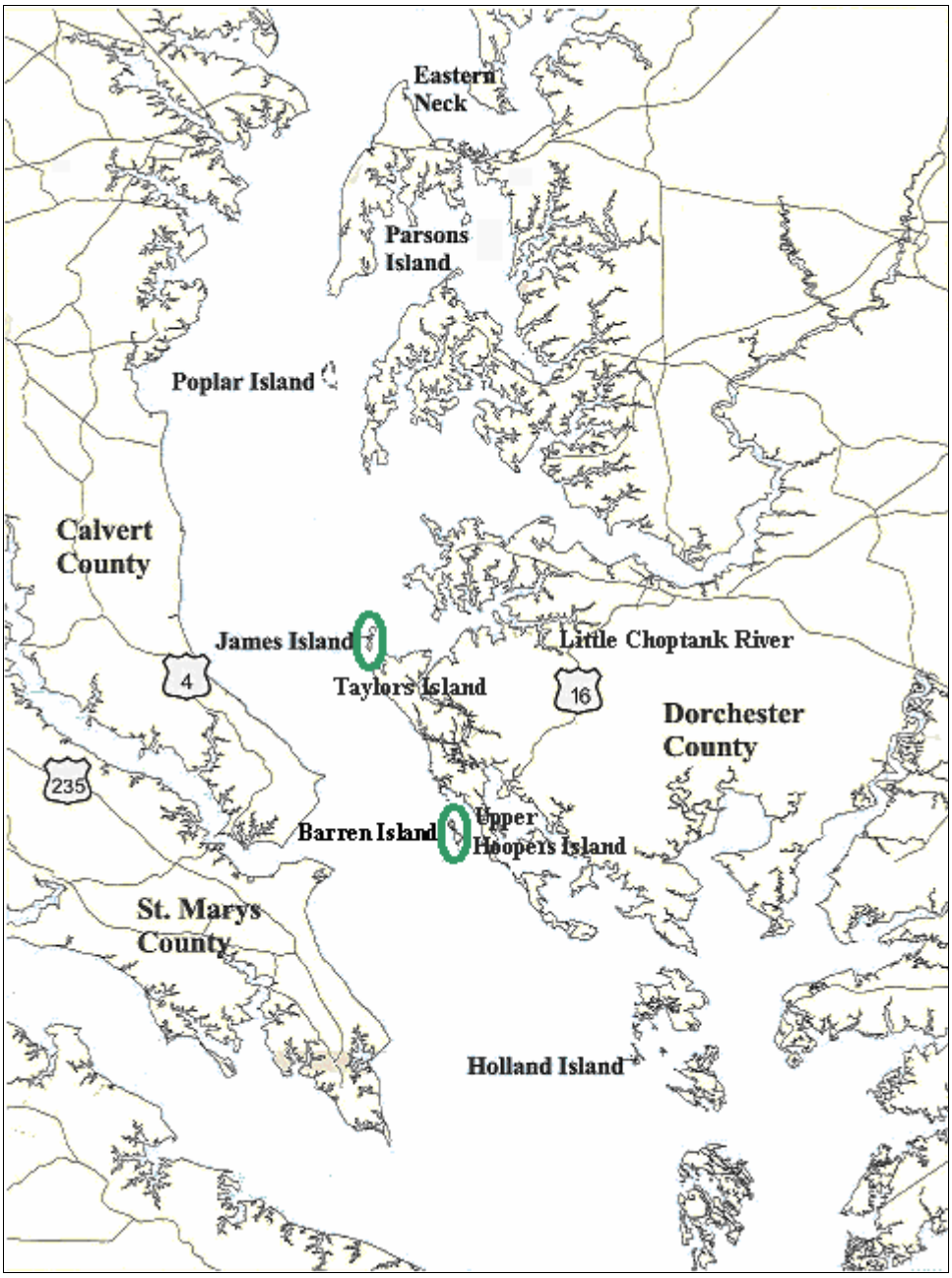

Figure 2. Location map of study area

Water circulation in Mid Bay is controlled by the tide, as well as by wind and waves either from Upper Bay or from Lower Bay. High water level, strong currents, and large waves occur more often in the Mid Bay as a result of frequent subtropical storms (northeasters) and tropical events (tropical storms, hurricanes). Therefore, vanishing marshes, beaches, and wetlands are a natural outcome for islands without adequate protection in the Mid Bay. Among these islands that are in danger of disappearing, Poplar Island is already under a restoration project. James Island and Barren Island are now considered as potential restoration sites. James Island is located in Mid Bay at the mouth of the Little Choptank River,

approximately 17 miles south of Poplar Island (Figure 2). Barren Island is located south and west of Taylors Island and Upper Hoopers Island, approximately 12 miles south-southeast of James Island (Figure 2). The emergent area and volume of these two islands have been rapidly decreasing in the last decade, and the islands may soon disappear if no protection efforts are taken.

Study Approach

The MPA and the Baltimore District are co-sponsoring studies of the technical, economic, and environmental feasibility of protecting, restoring, and creating aquatic intertidal wetland and upland habitat for fish and wildlife at Mid-Chesapeake Bay islands as a beneficial use of clean sediment dredged from the Baltimore Harbor and Channels Federal Navigation Project. James Island and Barren Island are among those identified as potential restoration sites after the Poplar Island Expansion. The study described in this report was performed by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), and consultants to MES, under contract to MPA [Andrews, Miller & Associates, Inc. (AMA), and Blasland, Bouck & Lee, Inc. (BBL)] to evaluate a number of alternative alignments at James Island and Barren Island restoration sites.

This study had the following goals, with emphasis on storms that would produce the maximum change in physical environmental conditions at the sites:

a. Perform wave modeling for James Island and Barren Island.

b. Perform circulation modeling in combination with wave modeling for James Island to establish preliminary tidal gut configurations.

c. Perform circulation modeling in combination with wave modeling for Barren Island to assess alternatives for protecting the islands and providing flushing within them.

d. Investigate sediment transport patterns at and around James Island and Barren Island, including sediment shoaling at neighboring navigation channels.

e. Evaluate engineering merits of environmental impacts of alternative island alignments.

Alternative designs and information for restoration and modification of James Island and Barren Island were defined in close coordination with MPA and the Baltimore District. Operation of wave, circulation, and sediment transport models was conducted for normal tides and four representative extra-tropical and tropical storms. Results from numerical models were analyzed for preliminary evaluation of alternative designs and their impacts on the mainland shoreline, adjacent Federal and private navigation channels, and environmental resources including SAV, oyster bars, and nursery grounds.

For the present study, alternative design of islands considered and storms chosen are discussed in Chapter 2. The wave modeling techniques for James Island and Barren Island are presented in Chapter 3. The circulation model and sediment transport calculation method are described in Chapter 4. The

evaluation and optimization of alternatives based on model results in addition to conclusions and recommendations are given in Chapter 5. This chapter is followed by the references.

This report contains three appendices. Appendix A documents data acquired in this study and the baseline monitoring conducted. Appendices B and C describe additional numerical simulations of hydrodynamics and sediment transport identified as the study progressed and made apart from those covered in the main text of the report for James Island and Barren Island, respectively. Data sets acquired from literature review and physical monitoring, as well as information generated as part of the numerical modeling, were assembled and delivered on DVD media to the sponsors as part of this study.

2 Island Restoration and Design Conditions

James Island and Barren Island are considered as two primary sites in Mid-Chesapeake Bay for wetland and upland restoration by placement of clean sediment dredged from Baltimore Harbor and Channels Federal Navigation Project. Both islands, serving as home to a large wildlife population, are presently eroding at a rapid rate, attributed to storm action and relative sea level rise in the last century (Cronin 2005).

Since the mid-19th century, James Island has diminished from more than 1,300 acres to about 550 acres by the late 1990s.[2] At present, James Island exists as a group of three small islands with a total surface area of 72 acres above mean tide level (mtl). The continuing erosion has threatened to destroy wetlands and valuable bay grass habitat that the island protects. Barren Island probably had an area of nearly 1,000 acres in the mid 1600s and now is less than 200 acres above mtl.[3] Barren Island has been undergoing an initial protection project with the placement of geotubes and dikes along with dredged sediment along its north end for shoreline protection and wetland recreation (http://restoration.noaa.gov/htmls/cwc_case.html).

Island Restoration

Present study efforts for restoration of James Island and Barren Island mainly concern (a) restoration of the island upland and wetland habitat through beneficial use of dredged material, (b) formulation of plans to address problems related to protecting island habitat, wetlands, and SAV, and (c) recommendation of cost-effective solutions for implementation of the project to restore island ecosystem habitat and address dredged material management options. Placement of dredged material at the James Island and Barren Island sites is intended to recreate wetlands and uplands and restore habitats that have been declining for a wide range of species. The sediment removed annually from the approach channels to Baltimore Harbor, approximately 3.2 million cu yd/year, is the main source of material intended for the island restoration. Because James Island is geographically closer to the channels, it is more economical to place the dredged material at James Island than at Barren Island. For Barren Island restoration and

[2] From the World Wide Web: www.bayjournal.com/article.cfm?article=1093.
[3] From the World Wide Web: www.bayjournal.com/article.cfm?article=1116.

protection, it appears more feasible to access material dredged locally from the nearby Honga River Channel.

James Island Alternatives

Alternative alignments for protecting, restoring, and creating wetlands at James Island and Barren Island were investigated in a feasibility study developed concurrently with the present study. For James Island, wetland and upland development of approximately 1,800 acres located west of the existing island was proposed based on the use of clean dredged material from Chesapeake Bay approach channels and environmental benefits from creating and protecting island habitat, the existing island, and SAV. The alignment layout is bounded by James Island to the east, deep water to the west, a natural oyster bar to the north, and a local navigation channel to the south.

The uplands (approximately 932 acres) are located on the northern side, and the wetlands (approximately 1,400 acres) are located on the southern side. The total baseline perimeter dike is 45,235 ft long. The designed upland development should prevent flooding under typical water-level (nonstorm) conditions while effectively flushing the wetlands through primary tidal channels. The design wetland elevation is +1.5 ft mean lower low water (mllw). The dike elevation along the upland perimeter is +25 ft mllw. The wetland dike elevation is +10 ft mllw along western and southern sides, +8 ft mllw along eastern sides, and +6 ft mllw for the interior dike along primary tidal channels.

Six James Island alternatives with three primary tidal channel configurations and two different channel widths were investigated in the present study (Table 1). The primary tidal channel is connected to the bay at the east side of the wetland for maximum protection of the channel. All of these alternatives have a turning basin in the upland southwestern corner with an access channel connecting to the main navigation channel. An unmarked channel used by local watermen exists between the existing James Island and Taylors Island (cf. Appendix A). The alignments of these alternatives are shown in Figure 3.

Table 1
James Island Alternatives

Alternative	Description
JI-1	150-ft-wide y-shaped primary channel.
JI-2	150-ft-wide fork-shaped primary channel.
JI-3	150-ft-wide y-shaped primary channel and a 4-acre bird island at the south channel opening to the bay. The channel around the bird island is 75 ft wide.
JI-4	300-ft-wide y-shaped primary channel.
JI-5	150-ft-wide c-shaped primary channel.
JI-6	300-ft-wide c-shaped primary channel and a 4-acre bird island at the south channel opening to the bay. The channel around the bird island is 150 ft wide.

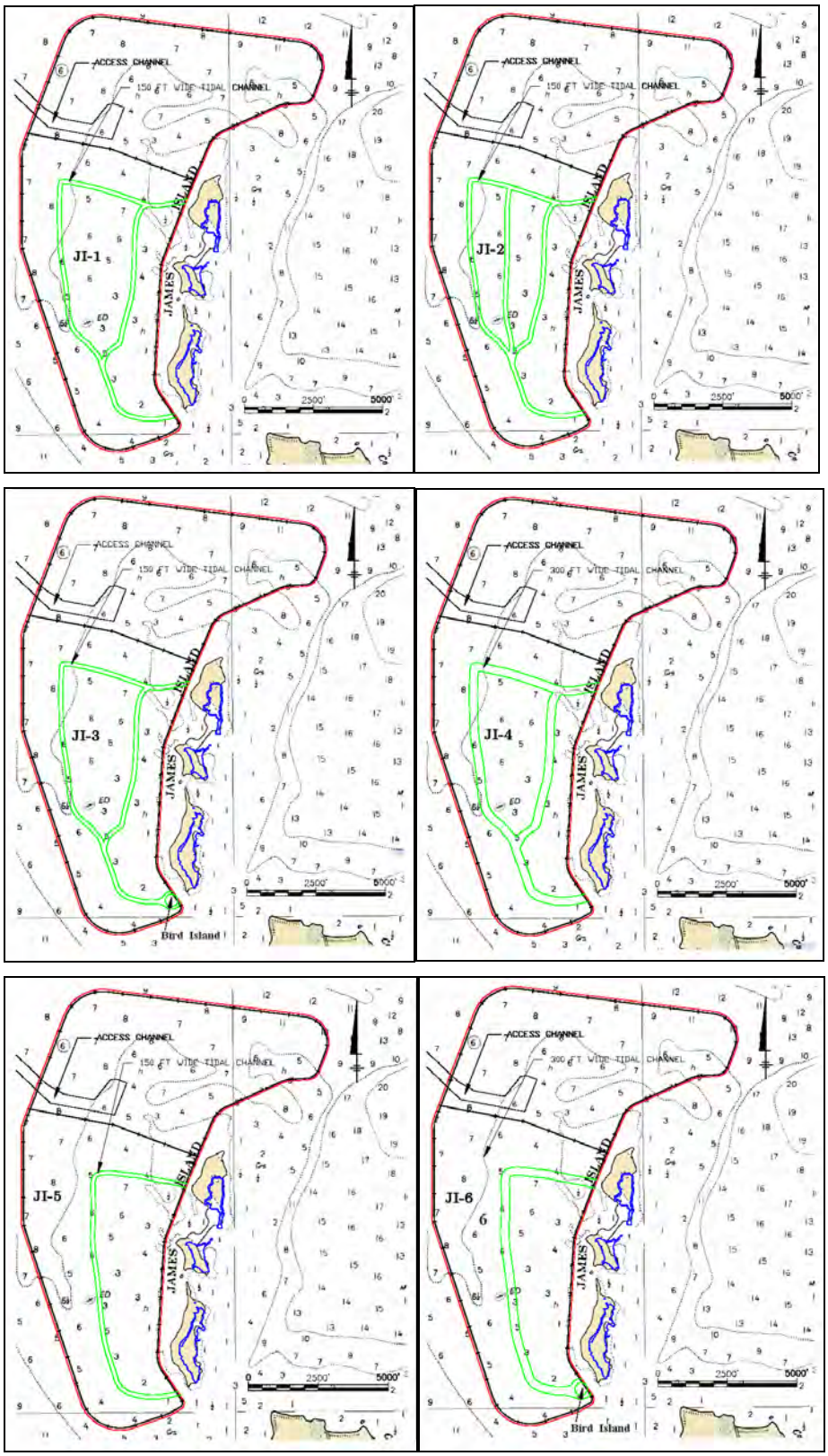

Figure 3. James Island Alts JI-1 through JI-6

Barren Island Alternatives

The proposed Barren Island project emphasizes protection of the existing island and SAV east and south of the island through construction of breakwaters and raising the existing shore protection structure. The design for the protection of the existing island includes a new northern breakwater/sill at +4 ft mllw (3,840 ft), a raised existing northwestern breakwater at +4 ft mllw (4,900 ft), and a new western breakwater at +4 ft mllw (5,915 ft).

The design for additional protection of SAV includes a new southern breakwater that extends southeastward from the island into the bay. The restoration should not increase sediment shoaling in the Honga River Channel that is located to the north and northeast of Barren Island. Six alternatives with four south breakwater configurations and two different south breakwater crest elevations are investigated in the present study (Table 2, Figure 4).

Table 2
Barren Island Alternatives

Alternative	Description
BI-1	8,166-ft-long south breakwater at +6 ft mllw.
BI-2	5,915-ft-long south breakwater at +6 ft mllw.
BI-3	8,166-ft-long south breakwater at +4 ft mllw.
BI-4	5,915-ft-long south breakwater at +4 ft mllw.
BI-5	8,166-ft-long south breakwater at +4 ft mllw with 400-ft segments and 200-ft gaps.
BI-6	8,166-ft-long south breakwater at +4 ft mllw with 500-ft segments and 100-ft gaps.

Normal Tide and Large Storm Conditions

The primary source of the tide in Chesapeake Bay is the progression of the ocean tide through the southern entrance from the Atlantic Ocean. A secondary source is through the C&D Canal from the ocean tide that progresses through Delaware Bay. The characteristics of the actual tide that takes place in the bay depend on the width, depth, and configuration of the estuarine basins and tributaries. The tide in the bay is unusual because one complete wavelength of a semidiurnal tide almost matches the length of the long axis of the bay. That is, when one high tide is reaching the northern end of the bay, the next high tide is just entering the bay near the Chesapeake Bay Bridge Tunnel.

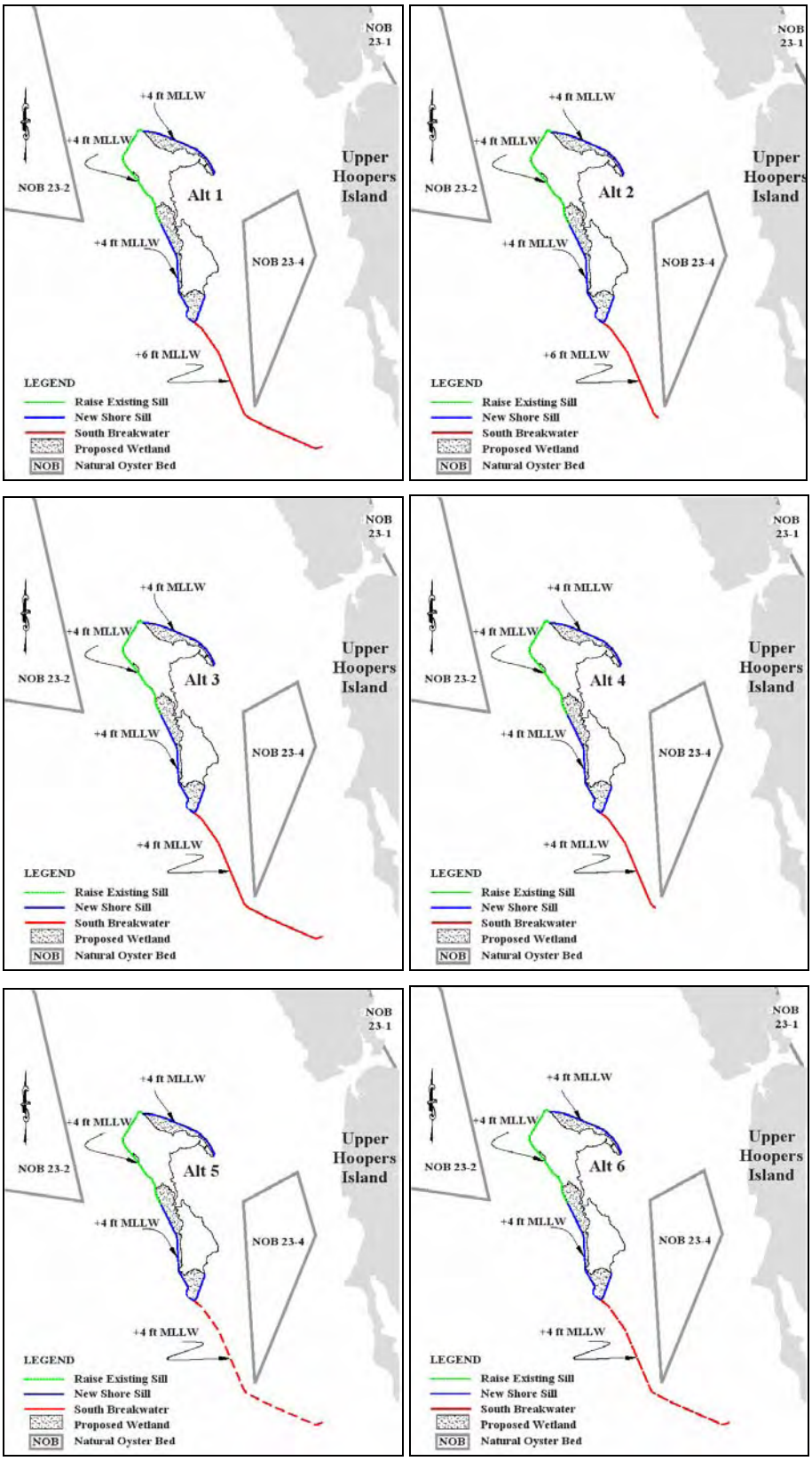

Figure 4. Barren Island Alts BI-1 through BI-6

Water level fluctuations in Chesapeake Bay are dominated by the semidiurnal tide. The mean range of tide (the elevation difference between mean high water and mean low water) in the bay varies from 2.8 ft at the Atlantic Ocean entrance, gradually decreasing to 1 ft near Annapolis, MD, in Mid Bay, and then increasing to nearly 2 ft near Chesapeake City, MD, at the northern end of the bay. The ranges of tide in the tributaries on the western and eastern sides of the bay show significant increases proceeding up the rivers. For example, in the Potomac River, the range of tide near the entrance is just about 1 ft, whereas the range of tide at Washington, DC, is just over 2.6 ft.

Water level in Chesapeake Bay is susceptible to strength and duration of wind speed and direction, barometric pressure changes, and runoff. Higher water level can be produced by changing wind direction to the orientation of the basin during a meteorological event. For example, a local squall line may cause significant change in local water level for a short duration, whereas a large-scale storm can alter the water level in the entire bay for several days. In Chesapeake Bay, relatively frequent meteorological patterns are also seen to significantly alter the water level. A moderate seasonal variation in water level, higher in the summer and lower in the winter, is usually observed in the bay. Therefore, non-astronomical factors, such as the configuration of the shoreline, local bathymetry, and meteorological influences all contribute in altering the water level.

For the island restoration project, it is essential to investigate both normal tide and large meteorological influences for the identified alternatives. In the meteorological case, two strong historical hurricanes, the 1954 Hazel and 2003 Isabel, and two moderate northeasters that occurred in March 1984 and March 1993, were selected for this investigation after examination of many storms. Hurricane Hazel and Hurricane Isabel are categorized as those of a 100-year event that can cause extreme high water levels in the bay. On the other hand, the March 1984 and March 1993 northeasters represent spring and winter moderate storms often seen on a yearly basis. Table 3 presents calculated maximum water levels at James and Barren Islands, respectively, from these four storms (Melby et al. 2005). For Hurricane Hazel and Hurricane Isabel, the calculated maximum water level at James Island and Barren Island ranges from 5 to 5.6 ft, mtl. For the March 1984 and March 1993 northeasters [referred to as NE20 and NE33, respectively, as identified by Melby et al. (2005)], the maximum water level at the two islands range from 2.5 to 2.9 ft mtl, much smaller than water levels associated with strong hurricanes.

Table 3
Peak Water Levels[1] at James Island and Barren Island, ft (mtl)

Storm	James Island	Barren Island
Hurricane Hazel, 1954	5.6	5.0
Hurricane Isabel, 2003	5.5	5.5
Northeaster, March 1984 (NE20)	2.9	2.8
Northeaster, March 1993 (NE33)	2.5	2.5

[1] Calculated maximum water level at existing island.

3 Wave Transformation

In a previous study, wave generation and transformation were modeled to supply information for design of shore protection for the proposed James Island and Barren Island projects (Melby et al. 2005). In the present study, additional wave transformation modeling was performed to assess impacts of the island designs on adjacent shorelines and provide wave input to calculate circulation and sediment transport. This chapter describes the wave transformation model STWAVE, model inputs and outputs, and model results.

Wave Transformation Modeling

Numerical model simulations of wave transformation in Chesapeake Bay were required to provide the relative difference in wave parameters in the local region and at the shoreline for the existing James Island and Barren Island configurations, the planned island alternatives, and estimated future conditions if projects are not constructed. This section describes the STWAVE model, model inputs, and sample model results. STWAVE was forced with directional wave spectra based on typical wave height, period, and direction combinations. The simulations include representative wave and tidal levels, and simulation of two hurricanes (Hazel and Isabel) and two northeasters (NE20 and NE33) summarized in Table 3.

STWAVE model description

The numerical model STWAVE (Smith et al. 2001) was used to transform waves to the project sites. STWAVE numerically solves the steady-state conservation of spectral action balance along backward-traced wave rays:

$$(C_{ga})_x \frac{\partial}{\partial x}\frac{C_a C_{ga}\cos(\mu-\alpha)E(f,\alpha)}{\omega_r} + (C_{ga})_y \frac{\partial}{\partial y}\frac{C_a C_{ga}\cos(\mu-\alpha)E(f,\alpha)}{\omega_r} = \sum\frac{S}{\omega_r} \quad (1)$$

where

C_{ga} = absolute wave group celerity

x,y = spatial coordinates; subscripts indicate x and y components

C_a = absolute wave celerity

μ = current direction

α = propagation direction of spectral component

E = spectral energy density

f = frequency of spectral component

ω_r = relative angular frequency (frequency relative to the current)

S = energy source/sink terms

The source terms include wind input, nonlinear wave-wave interactions, dissipation within the wave field, and surf-zone breaking. The terms on the left-hand side of Equation 1 represent wave propagation (refraction and shoaling), and the source terms on the right-hand side of the equation represent energy growth or decay in the spectrum.

The assumptions made in STWAVE are as follows:

a. Mild bottom slope and negligible wave reflection.

b. Spatially homogeneous offshore wave conditions.

c. Steady waves, currents, and winds.

d. Linear refraction and shoaling.

e. Depth-uniform current.

f. Negligible bottom friction.

STWAVE is a half-plane model, meaning that only waves propagating toward the coast are represented. Waves reflected from the coast or waves generated by winds blowing offshore are neglected. Wave breaking in the surf zone limits the maximum wave height based on the local water depth and wave steepness:

$$H_{m0_{\max}} = 0.1L \tanh kd \qquad (2)$$

where

H_{m0} = zero-moment wave height

L = wavelength

k = wave number

d = water depth

STWAVE is a finite-difference model and calculates wave spectra on a rectangular grid with square grid cells. The model outputs zero-moment wave height, peak wave period (T_p), and mean wave direction (α_m) at all grid points and two-dimensional (2-D) spectra at selected grid points.

Wave model inputs

The inputs required to execute STWAVE are as follows:

a. Bathymetry grid (including shoreline position and grid size and resolution).

b. Incident frequency-direction wave spectrum on the offshore grid boundary.

c. Current field (optional).

d. Tide elevation, wind speed, and wind direction (optional).

Bathymetry grids. The James Island and Barren Island model grids from the previous study were extended to include the full shoreline section of interest. The same underlying bathymetry was used for each grid, but the grid orientation was changed so the input wave direction was less than 60 deg relative to the x-axis of the grid. The grid specifications are given in Table 4. The grid origin is given in MD State Plane coordinates. The grid orientation is the orientation of the grid x-axis measured counterclockwise from East (Surface-water Modeling System (SMS) interface default). The grid naming convention indicates the approximate incident wave direction. The bathymetry for each grid was interpolated from the ADCIRC bathymetry grid, so the models are consistent. Depths are relative to mtl. Each grid was developed for the existing island configuration and then modified for the island alternatives. The James NE and S grids are the same grids with the origin redefined (rotated 180 deg), and the James NW and W grids are the same grids with the origin redefined (rotated 270 deg). Alts BI-5 and BI-6 required finer grid spacing to resolve the segmented breakwaters. Alts BI-5 and BI-6 grids have the same origin and cover the same domain as the base grid (150-ft resolution), but have higher resolution (50 and 25 ft, respectively).

Table 4
Bathymetry Grid Specifications

Grid	X Origin ft	Y Origin ft	Δx ft	Orientation deg	X Cells	Y Cells
James NE	1,486,470.71	343,645.08	150	255	373	268
James NW	1,467,265.00	333,926.00	150	287	373	328
James S	1,510,820.00	279,197.00	150	75	373	268
James W	1,483,623.20	280,420.75	150	17	328	373
Barren NW	1,494,430.00	242,245.00	150	337	295	211
Barren NW Alt BI-5	1,494,430.00	242,245.00	50	337	885	633
Barren NW Alt BI-6	1,494,430.00	242,245.00	25	337	1,770	1,266
Barren W	1,520,230.00	219,690.00	150	20	145	285
Barren W Alt BI-5	1,520,230.00	219,690.00	50	20	435	855
Barren W Alt BI-6	1,520,230.00	219,690.00	25	20	870	1,710
Barren SE	1,531,110.00	202,800.00	150	80	411	232
Barren SE Alt BI-5	1,531,110.00	202,800.00	50	80	1,233	696
Barren SE Alt BI-6	1,531,110.00	202,800.00	25	80	2,466	1,392

Input wave spectra and water levels. Input wave spectra are required to drive STWAVE on the offshore grid boundary. The definition of offshore changes for each grid, and it is the boundary across which the waves are propagating. Parametric spectral shapes are used to generate the input spectral. The wave energy is distributed in frequency using the TMA spectral shape with a spectral peakedness parameter of 3.3 (Bouws et al. 1985) and in direction using a $\cos^4(\alpha-\alpha_m)$ distribution, where α_m is the mean wave direction. The input spectra have 25 frequencies, starting with 0.05 Hz and incrementing by 0.02 Hz. The directional resolution is 5 deg. The wave parameters run to investigate shoreline impacts for each grid are summarized in Table 5 for James Island and Table 6 for Barren Island. These wave and water level parameters were chosen in coordination with the Baltimore District and are representative of the conditions generated in the previous study (Melby et al. 2005). These parameters do not represent specific storms, but cover the range of conditions. The 1.6-ft, 3-sec waves run without surge for each island and direction are typical conditions. The higher waves and surges represent moderate and strong storm conditions. Statistical analysis on return periods was not performed. Note that the largest waves are produced from hurricanes (generally from the south) and northeasters (producing waves out of the northwest because of the alignment of the bay).

The water depths at the grid input boundary are approximately 60 ft for James NE and S, 100 ft for James NW, and 45 ft for James W. The water depths at the grid input boundary are approximately 100 ft for Barren NW and W and 60 ft for Barren SE. Additionally, Hurricanes Hazel (October 1954) and Isabel (September 2003) and Northeasters 20 (March 1984) and 33 (March 1993) were simulated. These storm waves were used to drive wave-induced currents and sediment transport as discussed in Chapter 4. They were also consulted to investigate SAV survivability (Appendix C).

Table 5
Waves and Water Levels Simulated in STWAVE for James Island

Grid	Grid Shore Normal, deg	Wave Angle, deg	Water Level, ft (mtl)	Wave Height, ft	Wave Period, sec
James NE	15	30	2	5.0	5
			2	3.0	4
			0	1.6	3
James S	195	170	5	10.0	7
			4	7.0	6
			2	3.0	4
			0	1.6	3
James W	253	270	3	4.0	4
			0	1.6	3
James NW	343	343	2	7.0	5
			2	4.0	4
			0	1.6	3

Table 6
Waves and Water Levels Simulated in STWAVE for Barren Island

Grid	Grid Shore Normal, deg	Wave Angles, deg	Water Level, ft (mtl)	Wave Height, ft	Wave Period, sec
Barren NW	293	340	3	6.5	5
			2	3.0	4
			0	1.6	3
Barren SE	190	170	5	14.0	7
			4	10.0	6
			3	6.0	5
			2	3.0	4
			0	1.6	3
Barren W	250	260	3	3.0	3
			0	1.6	3

Winds and currents. Local wind and currents were not included within the STWAVE domains.

Wave diffraction. STWAVE includes simplified, phase-averaged wave diffraction that allows wave energy to spread behind structures (Smith et al. 2001). Wave energy is also spread behind structures through the directional distribution of wave energy included in the model.

Wave transmission. STWAVE does not include the process of wave transmission through rubble-mound structures, but transmission is significant for the low-crested breakwaters under consideration for the southern end of Barren Island. Wave transmission for Hurricane Hazel and Hurricane Isabel was estimated by reference to guidance from the *Coastal Engineering Manual* (Headquarters, U.S. Army Corps of Engineers (HQUSACE) 2002) (Figure II-7-19) based on transformed wave heights at the toe of the structure and estimates of freeboard (crest elevation above the mean water level), including the surge calculated from the ADCIRC simulations. Then, the structure crest elevation was modified in STWAVE to simulate transmission (lowering the modeled crest elevation allows more wave energy to pass over the structure at elevated water levels, representing the transmission over and through the structure in storms). Figures 5 and 6 show comparisons of transmission for Hurricane Isabel for Alt BI-1 with a crest elevation of +6 ft mllw (+5.2 ft mtl) and Alt BI-3 with a +4 ft mllw (+3.2 ft mtl), respectively. Reducing the crest elevation in the model to an elevation of +2 ft mtl provides the closest comparison to transmission results predicted by the *Coastal Engineering Manual* for the actual +5.2 ft crest elevation (Alt BI-1). For the +3.2 ft crest elevation, the optimal crest reduction was found to be +1 ft mtl. Thus, the crest elevations of the southern breakwater were modified to represent transmission in all Barren Island simulations.

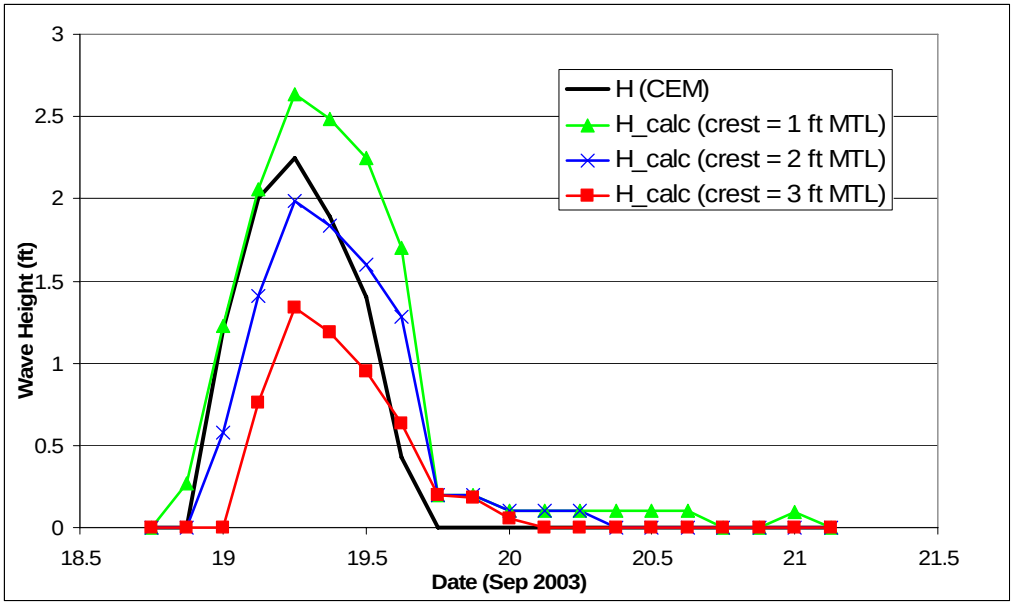

Figure 5. Wave transmission simulations for Hurricane Isabel for breakwater crest elevation of 5.2 ft mtl (6 ft mllw)

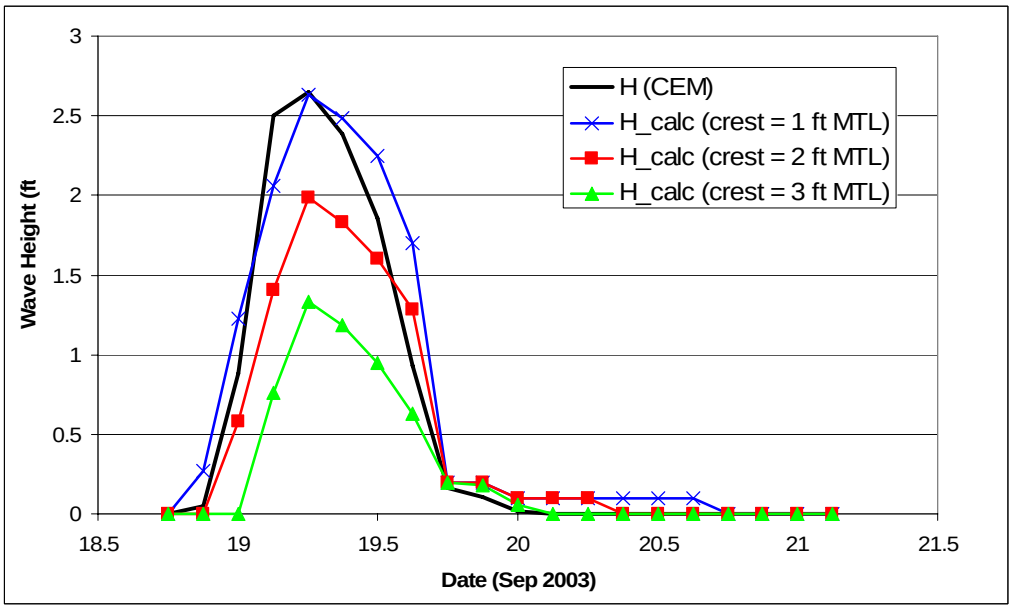

Figure 6. Wave transmission simulations for Hurricane Isabel for breakwater crest elevation of 3.2 ft mtl (4 ft mllw)

Wave Model Results for Shoreline Impacts

Model results to evaluate shoreline impacts are presented in two formats. First, color contour plots of the wave height differences are presented. These plots show the wave heights for selected alternative minus the existing condition, so negative values indicate a reduction in wave height. Blue indicates no difference and red indicates the maximum difference. Note that the scales vary from figure to figure. Land is represented in brown. Figures are provided for the maximum wave condition for each grid orientation in Tables 3 and 4. The lower wave conditions produced similar patterns. Next, plots of the wave height for the existing condition, all alternatives, and an estimate of the future condition without the projects are provided for points along the shoreline. These points are in a water depth of approximately 7 ft away from the islands, and 3-4 ft in the shallow areas in the lee of the islands. The locations of these points are shown as red squares in wave height difference figures. The first point (Point 1) is the most northerly point on each grid and the last point (Point 20) is the most southerly point. The future without-project bathymetries were estimated as erosion of the islands to the surrounding bathymetry elevation.

James Island

All the James Island alternatives have the same external island planform and, therefore, produce the same wave transformation. Figures 7-10 show the wave height differences between the alternatives and the existing condition for the maximum incident wave height for each of the four incident wave directions (northeast, south, west, and northwest grids) and Figures 11-14 show the height differences between the future no-project and the existing conditions for the same wave conditions.

As expected, the maximum differences occur in the lee of the island (relative to the wave direction). James Island is relatively far from the shore, so the impact of the proposed island alternative on the shoreline is relatively small. Figures 15-18 show the alongshore distribution of the wave height for the existing condition, future without-project, and Alts JI-1 through JI-6 (3-7-ft water depth). The island reduces the maximum wave height near the shore by as much as 2 ft. No increases in wave height along the shoreline occurred due to implementation of the alternatives. The future without-project wave heights near the shore are similar to the existing condition, with small increases in height over limited areas.

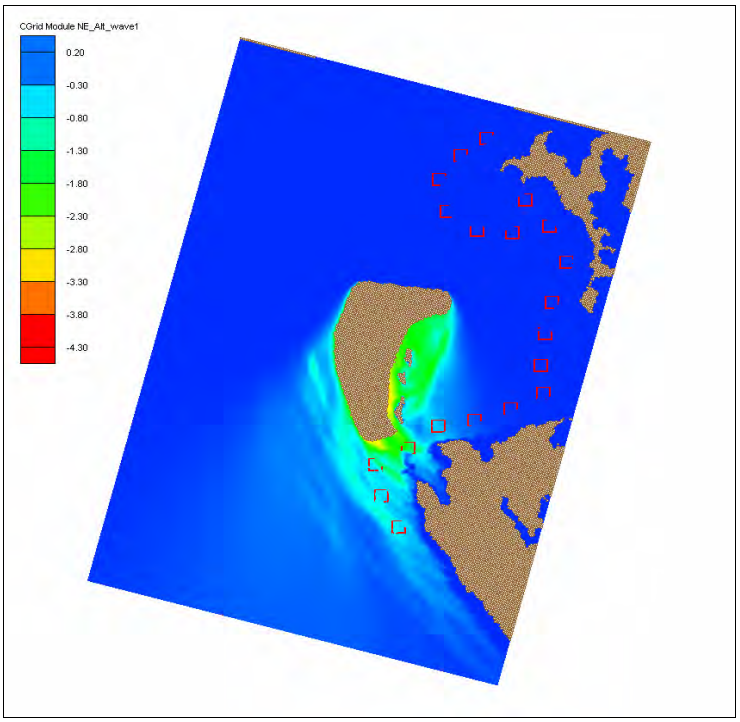

Figure 7. Wave height difference in feet (Alt – existing). Northeast grid, H = 5.0 ft, T = 5 sec, water level = 2 ft (mtl), wave direction = 30 deg

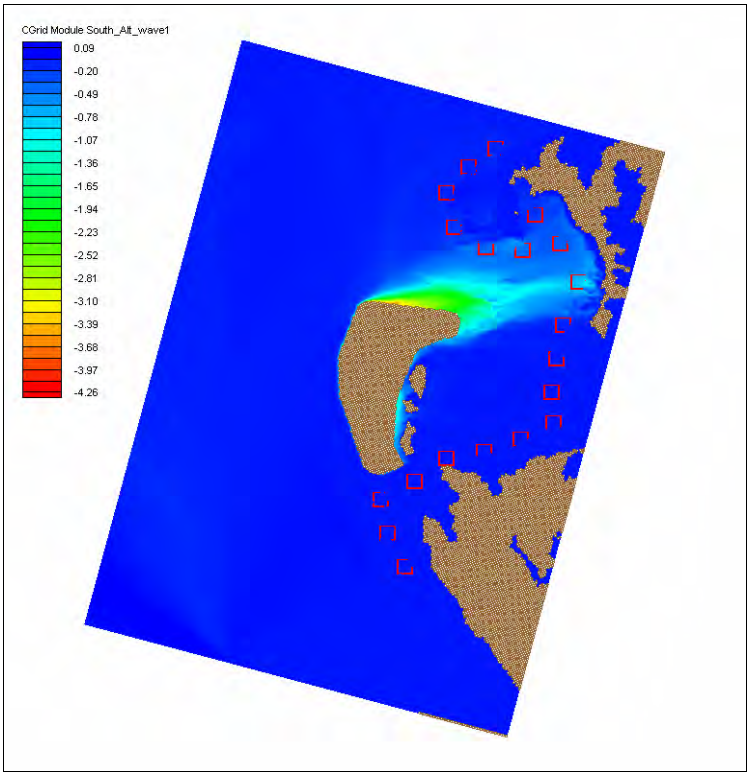

Figure 8. Wave height difference in feet (Alt – existing). South grid, H = 10 ft, T = 7 sec, water level = 5 ft (mtl), wave direction = 170 deg

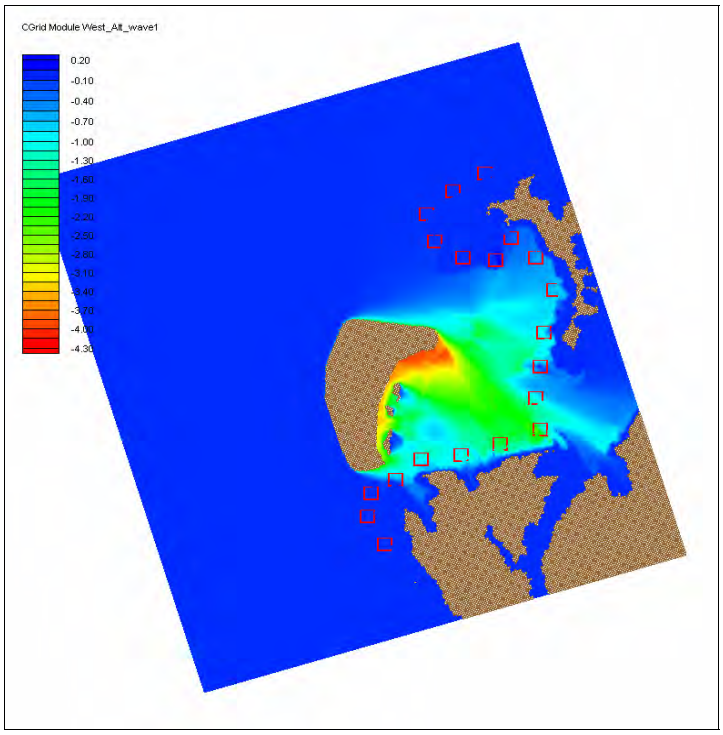

Figure 9. Wave height difference in feet (Alt – existing). West grid, H = 4 ft, T = 4 sec, water level = 4 ft (mtl), wave direction = 270 deg

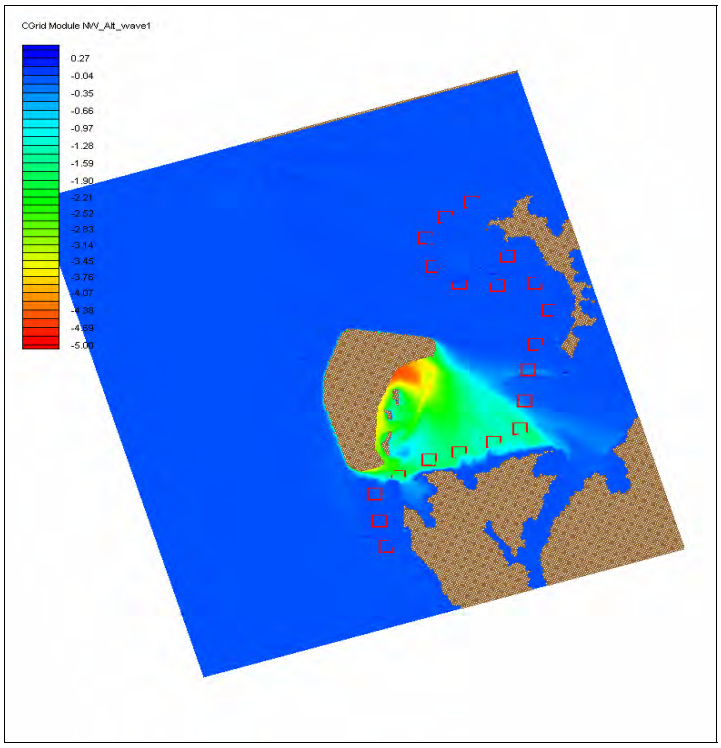

Figure 10. Wave height difference in feet (Alt – existing). Northwest grid, H = 7 ft, T = 5 sec, water level = 2 ft (mtl), wave direction = 343 deg

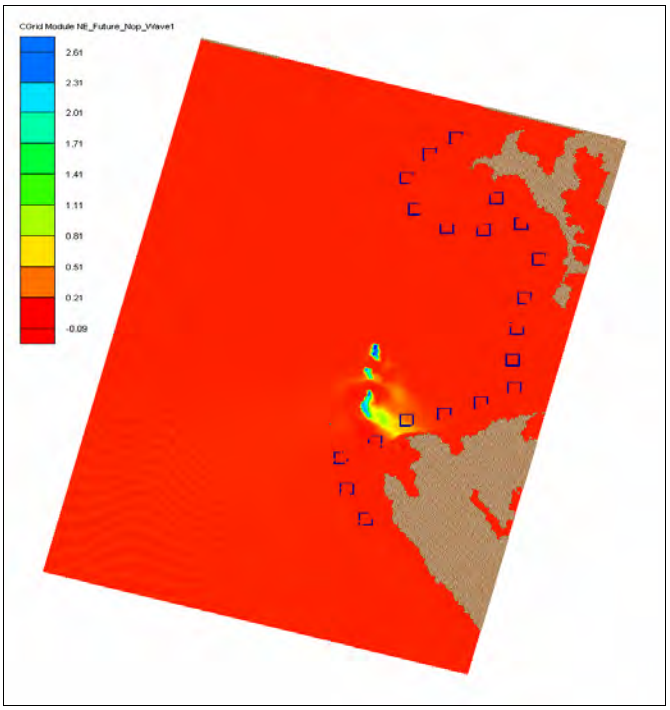

Figure 11. Wave height difference in feet (future without-project – existing). Northeast grid, H = 5 ft, T = 5 sec, water level = 2 ft (mtl), wave direction = 30 deg

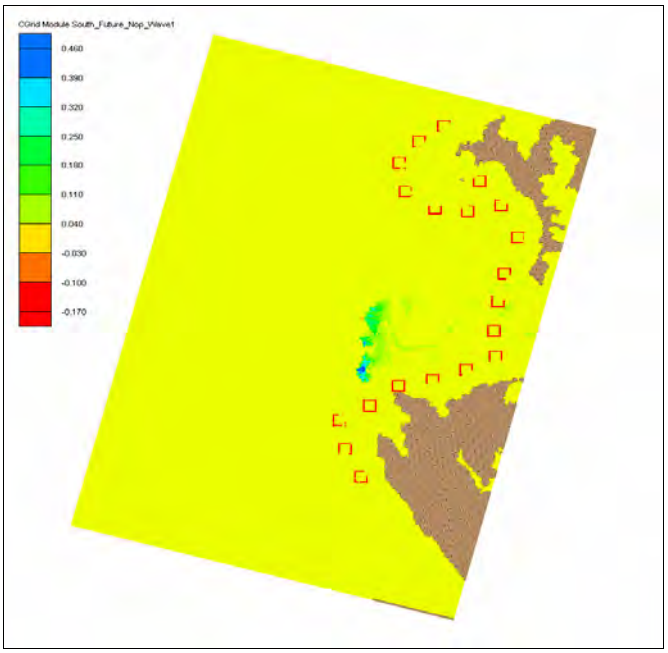

Figure 12. Wave height difference in feet (future without-project – existing). South grid, H = 10 ft, T = 7 sec, water level = 5 ft (mtl), wave direction = 170 deg

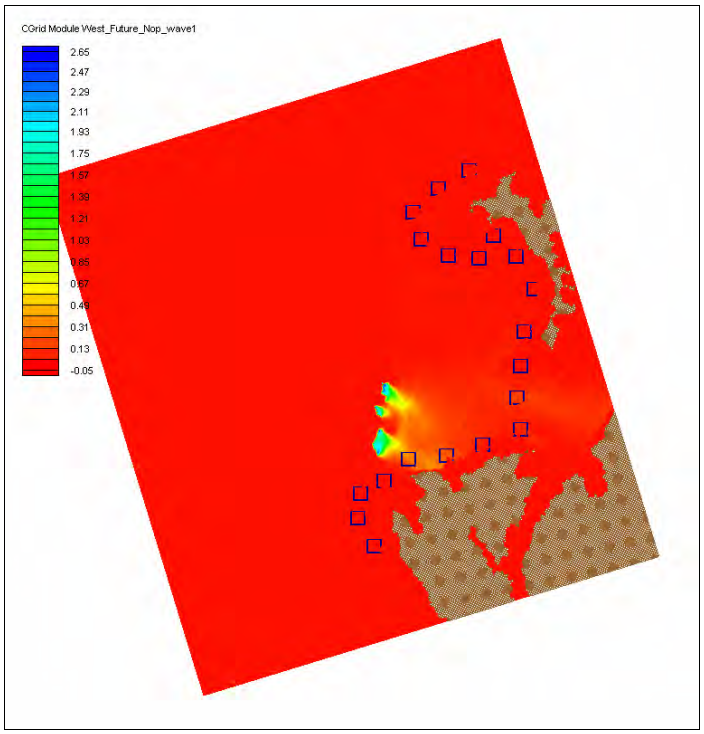

Figure 13. Wave height difference in feet (future without-project – existing). West grid, H = 4 ft, T = 4 sec, water level = 3 ft (mtl), wave direction = 270 deg

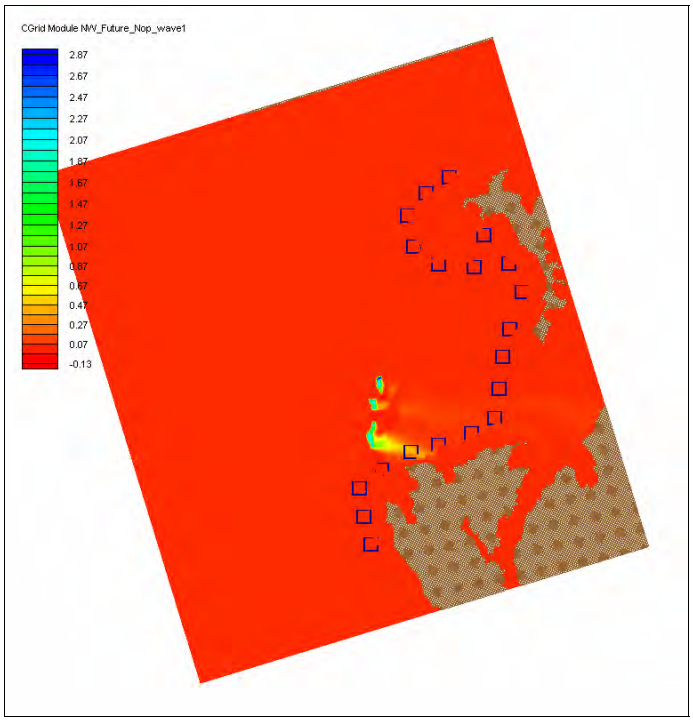

Figure 14. Wave height difference in feet (future without-project – existing). Northwest grid, H = 7 ft, T = 5 sec, water level = 2 ft (mtl), wave direction = 343 deg

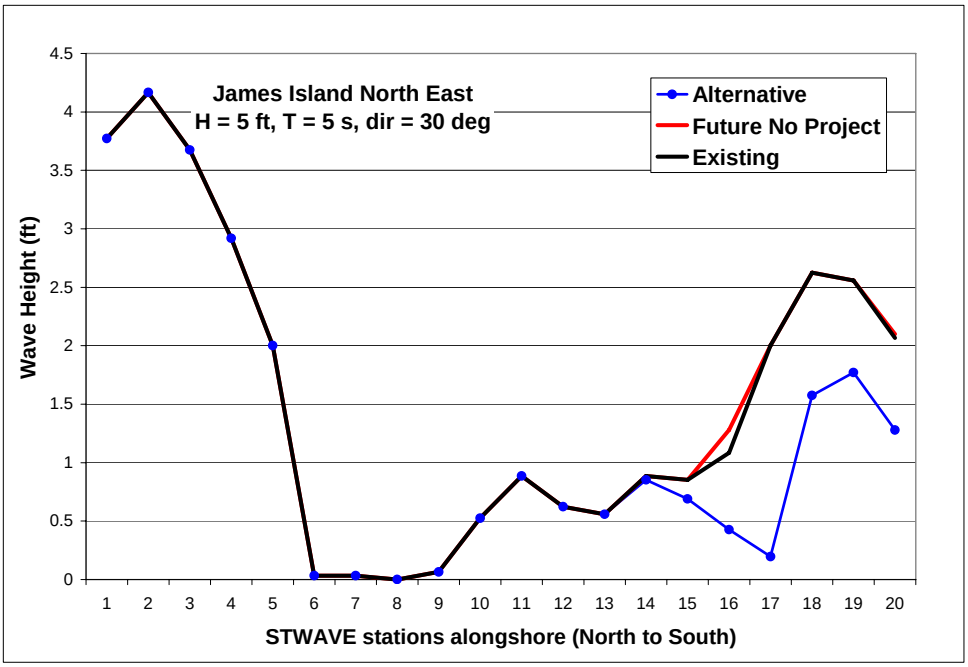

Figure 15. Alongshore wave height variation for James Island existing condition, future without-project, and alternative. Northeast grid, H = 5 ft, T = 5 sec, water level = 2 ft (mtl), wave direction = 30 deg

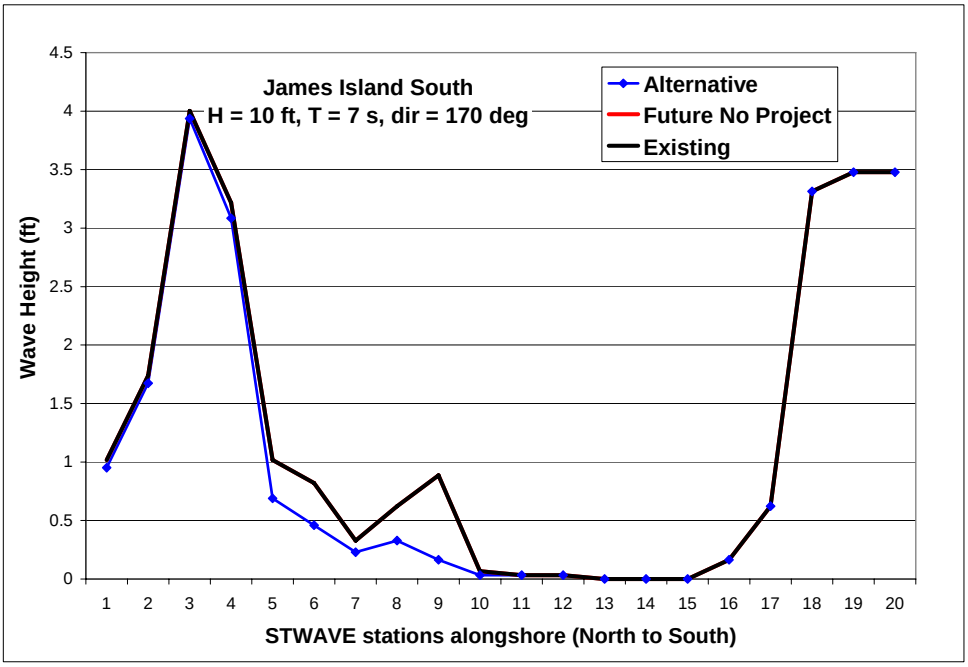

Figure 16. Alongshore wave height variation for James Island existing condition, future without-project, and alternative. South grid, H = 10 ft, T = 7 sec, water level = 5 ft (mtl), wave direction = 170 deg

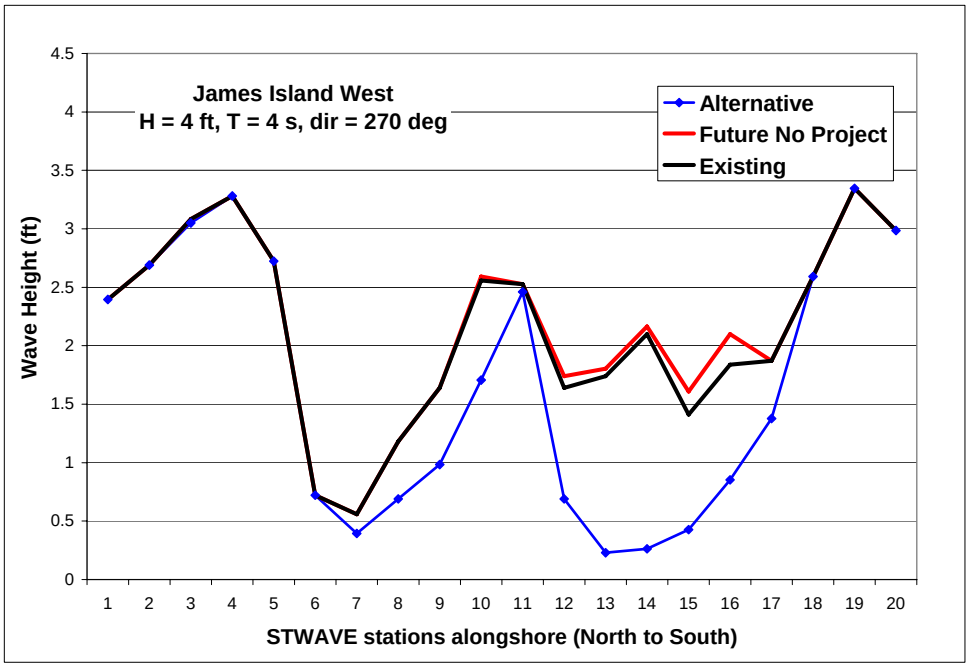

Figure 17. Alongshore wave height variation for James Island existing condition, future without-project, and alternative. West grid, H = 4 ft, T = 4 sec, water level = 3 ft (mtl), wave direction = 270 deg

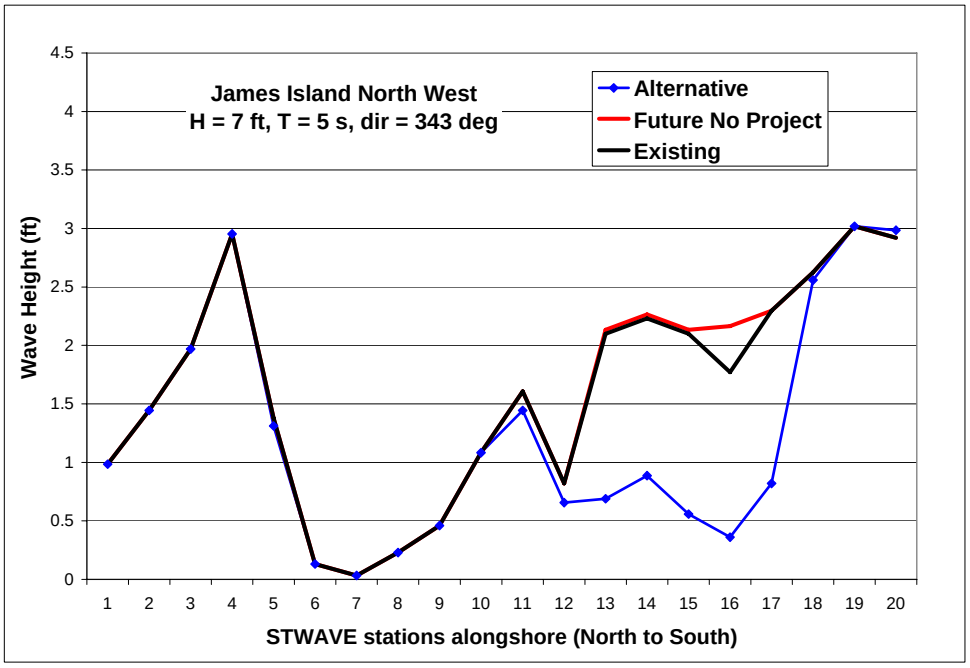

Figure 18. Alongshore wave height variation for James Island existing condition, future without-project, and alternative. Northwest grid, H = 7 ft, T = 5 sec, water level = 2 ft (mtl), wave direction = 343 deg

Barren Island

Alts BI-1 though BI-6 required modifications to the bathymetry grid and independent simulations. Figures 19-21 show the wave height differences between Alt BI-1 and the existing condition for the maximum incident wave height for each of the three incident wave directions (northwest, southeast, and west, grids) and Figures 22-24 show the wave height differences between the future without-project and existing conditions for the same wave conditions. As expected, the maximum differences occur in the lee of the south breakwater. Barren Island is relatively close to shore compared to James Island, so the impact of the proposed island alternative on the shoreline is greater. Figures 25-27 show the alongshore distribution of the wave height for the existing condition, future without-project, and Alts BI-1 though BI-6 (3-7-ft water depth). The alternatives reduce the maximum wave height near the shore by up to 4 ft. No increases in wave height along the shoreline occurred due to implementation of the alternatives.

The future without-project wave heights near the shoreline are significantly different than the existing condition. Wave heights at the shore could increase up to 3 ft if the island degrades, thus posing a significant risk by increasing shoreline erosion and potential destruction of SAV habitat. Alt BI-1 provides the greatest reduction in wave height at the shoreline because it has the greatest length and highest crest elevation (+6 ft mllw). Alt BI-3 provides the next highest protection (crest elevation of +4 ft mllw), followed by Alts BI-5 and BI-6 (segmented breakwaters) and Alts BI-2 and BI-4 (crest elevations of +6 and +4 ft mllw, but shorter breakwater length). Alt BI-5 has a crest elevation of +4 ft mllw and 200 ft breakwater gaps, and Alt BI-6 has a +4 ft mllw crest with 100-ft gaps. These two alternatives provide approximately the same wave reduction at the shoreline.

Summary

Modifications to wave transformation due to the James Island and Barren Island alternatives were modeled for two hurricanes, two northeasters, and representative wave conditions with the wave model STWAVE. The James Island alternatives expand the footprint of the island and reduce the wave height in the lee of the island by 1-2 ft. The future without-project condition increases the wave height at the shoreline slightly. Barren Island alternatives include six breakwater extensions to the south of the island. Alt BI-1 and Alt BI-3 reduce the wave height 2-3 ft at the shoreline in the lee of the island (greater reduction for Alt BI-1 with the greater breakwater crest height). Alts BI-2 and BI-4 (shorter overall breakwater length) provide approximately 0.5 ft less reduction in wave height than Alts BI-1 and BI-3 and the reduction is over a smaller region. Alts BI-5 and BI-6 are segmented breakwaters. They provide approximately 0.5 ft less reduction in wave height than Alts BI-1 and BI-3, but over a similar region. The future without-project condition results in a 2-4-ft increase in wave height at the shoreline, thus having the potential to adversely impact SAV habitats, as well as the shoreline. None of the alternatives considered for James Island and Barren Island increased the wave height at the shore.

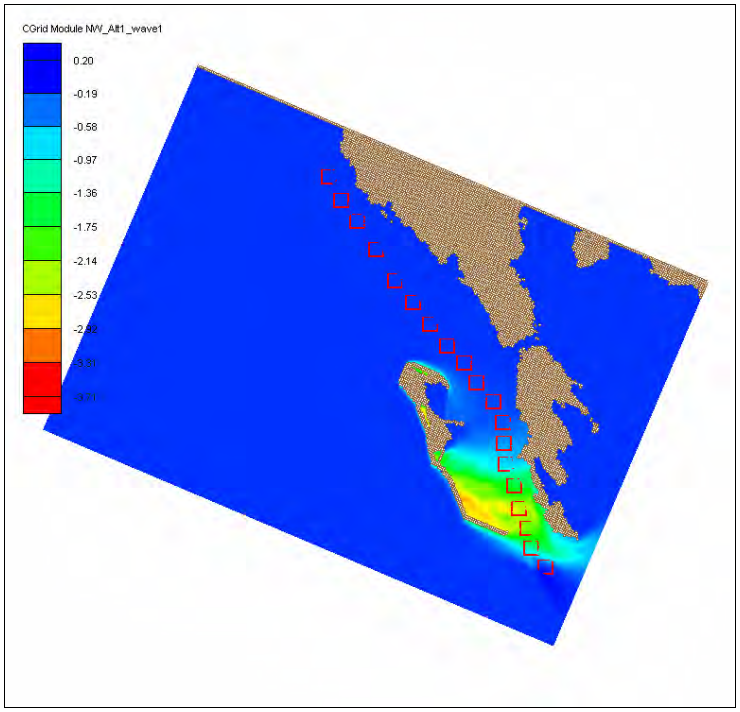

Figure 19. Wave height difference in feet (Alt BI-1 – existing). Northwest grid, H = 6.5 ft, T = 5 sec, water level = 3 ft (mtl), wave direction = 330 deg

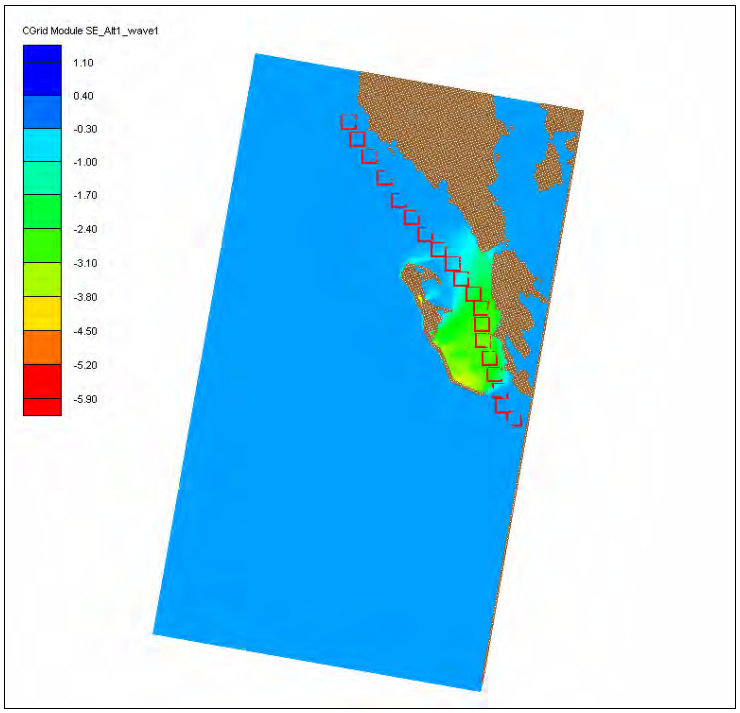

Figure 20. Wave height difference in feet (Alt BI-1 – existing). Southeast grid, H = 14 ft, T = 7 sec, water level = 5 ft (mtl), wave direction = 170 deg

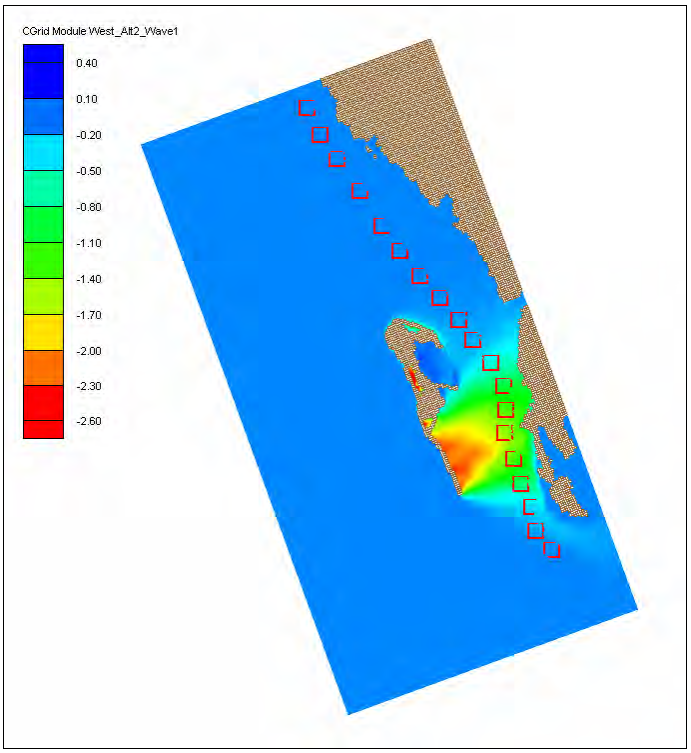

Figure 21. Wave height difference in feet (Alt BI-2 – existing). West grid, H = 3 ft, T = 3 sec, water level = 3 ft (mtl), wave direction = 260 deg

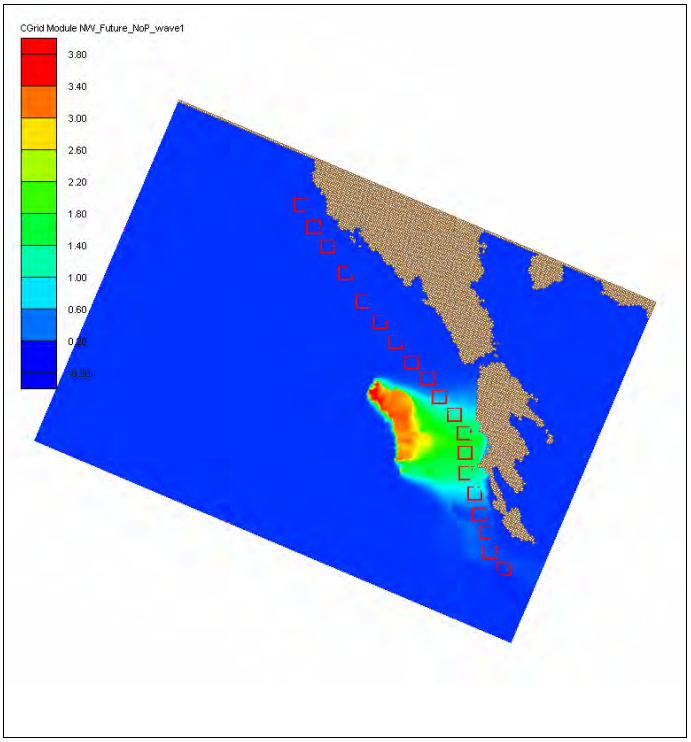

Figure 22. Wave height difference in feet (future without-project – existing). Northwest grid, H = 6.5 ft, T = 5 sec, water level = 3 ft (mtl), wave direction = 340 deg

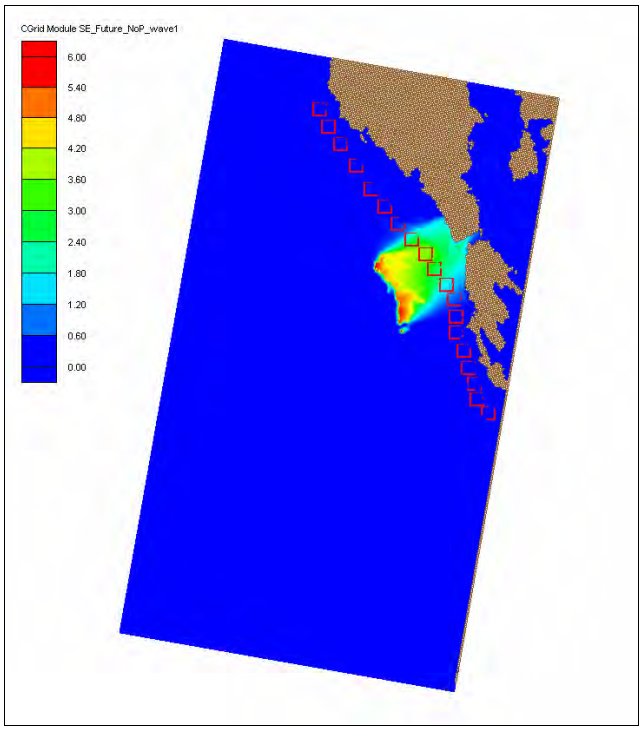

Figure 23. Wave height difference in feet (future without-project – existing). Southeast grid, H = 14 ft, T = 7 sec, water level = 5 ft (mtl), wave direction = 170 deg

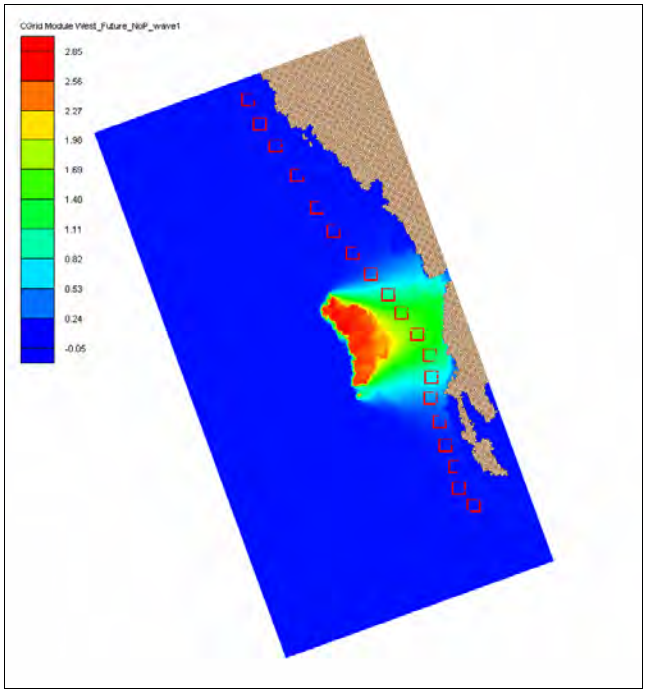

Figure 24. Wave height difference in feet (future without-project – existing). West grid, H = 3 ft, T = 3 sec, water level = 3 ft (mtl), wave direction = 260 deg

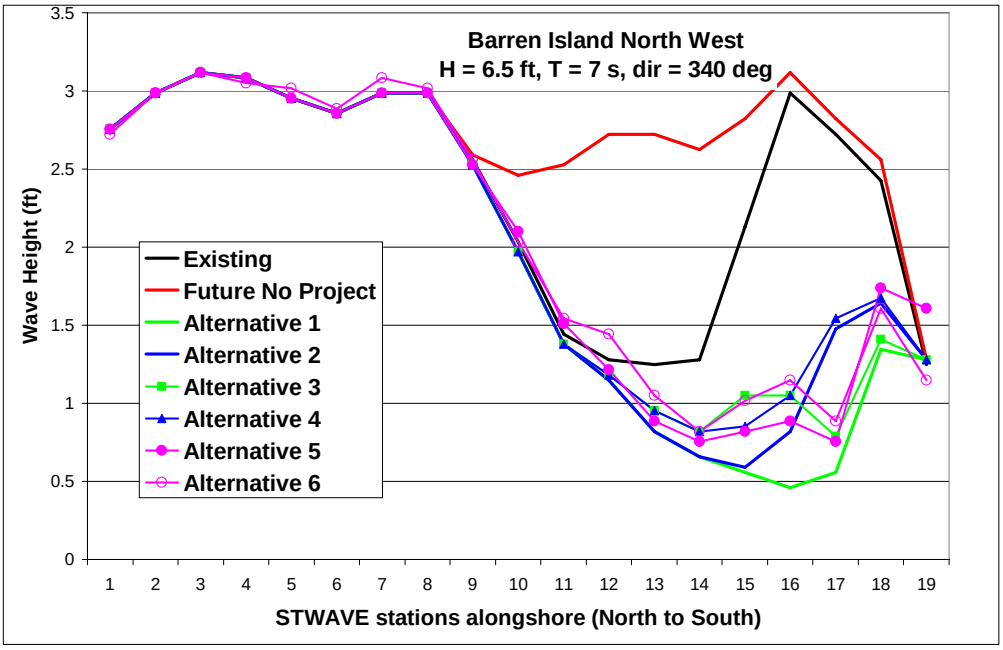

Figure 25. Alongshore wave height variation for Barren Island existing condition, future without-project, and Alt BI-1 through BI-6. Northwest grid, H = 6.5 ft, T = 5 sec, water level = 3 ft (mtl), wave direction = 340 deg

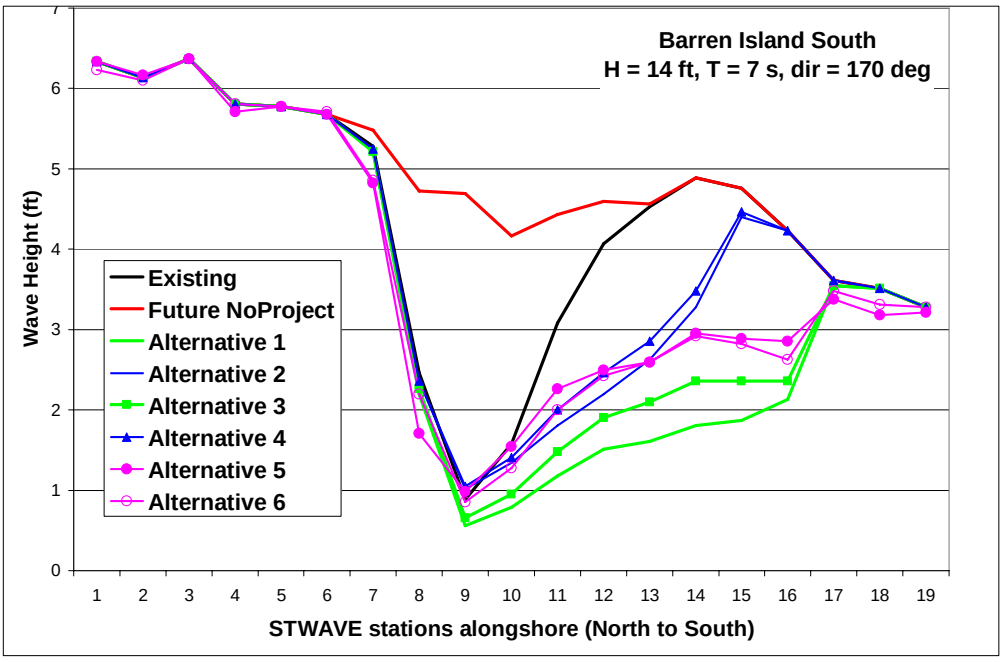

Figure 26. Alongshore wave height variation for Barren Island existing condition, future without-project, and Alt BI-1 through BI-6. Southeast grid, H = 14 ft, T = 7 sec, water level = 5 ft (mtl), wave direction = 170 deg

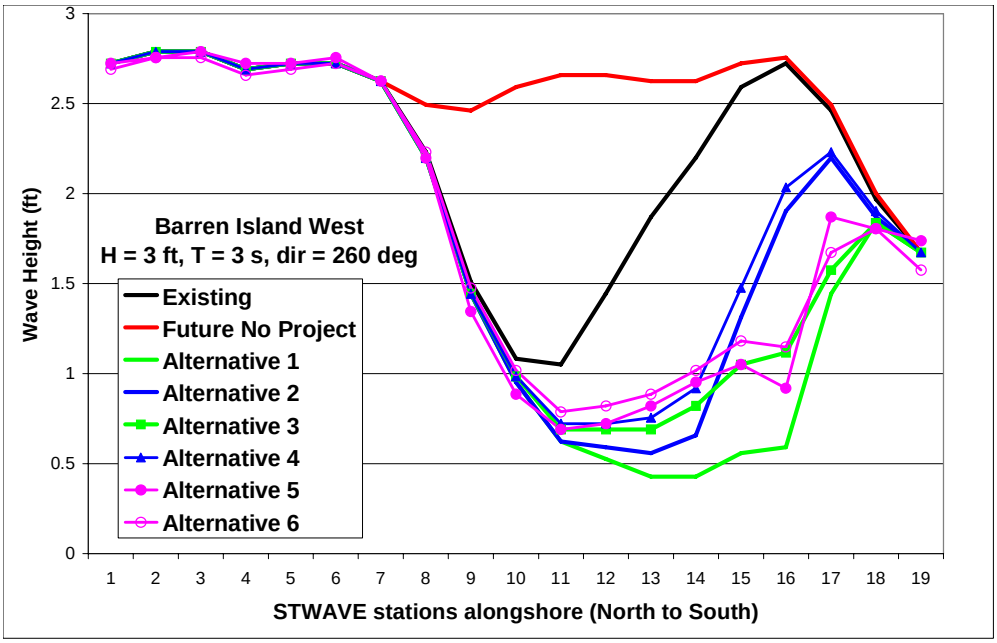

Figure 27. Alongshore wave height variation for Barren Island existing condition, future without-project, and Alt BI-1 through BI-6. West grid, H = 3 ft, T = 3 sec, water level = 3 ft (mtl), wave direction = 260 deg

4 Hydrodynamic and Sediment Transport Models

Hydrodynamic modeling and sediment transport modeling were conducted to investigate the environmental impact of alternative island alignments. The hydrodynamic modeling determines the influences of alternatives on water level and current velocity in the vicinity of islands, and the sediment modeling predicts the accretion and erosion of bay bottom in the surrounding area. The model used for the hydrodynamic calculation is a depth-integrated, 2-D finite element circulation model ADCIRC (Luettich et al. 1992), and the sediment transport model is based on the Van Rijn method (1984a, 1984b, 1984c), implemented in an advection-diffusion approach.

Hydrodynamic Modeling

The hydrodynamic model ADCIRC solves the equations of motion for a moving fluid on a rotating earth. It serves as the USACE regional oceanographic and storm surge model as certified by the Federal Emergency Management Agency for storm surge modeling. The model is formulated with hydrostatic pressure and Boussinesq approximations on a finite-element mesh. ADCIRC can be run either as a 2-D depth-integrated model or as a three-dimensional (3-D) model. Water-surface elevation is calculated from the depth-integrated continuity equation in the Generalized Wave-Continuity Equation form. Velocity is calculated from either the 2DDI or 3-D momentum equations. All nonlinear terms are retained in these equations. The model can be forced with water-surface elevation, normal flow, tidal potential at the mesh boundary, and water-surface stresses generated by winds, waves, and atmospheric pressures.

A regional scale ADCIRC mesh developed in the previous Mid-Bay Poplar Island project (Melby et al. 2005) was adopted in the present study. This mesh was refined in James Island and Barren Island areas using recent hydrographic survey data (June 2005) provided by AMA (Appendix A). The mesh also includes low land topography data to +10 m, mean tide level, from U.S. Geologic Survey Global 30 Arc-Second Elevation Data Set (http://www1.gsi.go.jp/geowww/globalmap-gsi/gtopo30/README.html). The numerical mesh was developed for ADCIRC to represent present-day (2005) conditions. The mesh has a minimum resolution of 20 m around the James Island and Barren Island area and a maximum cell size of 500 m in the open ocean. Figures 28 and 29

show the regional mesh and local scale bathymetry grid for James Island and Barren Island areas, respectively.

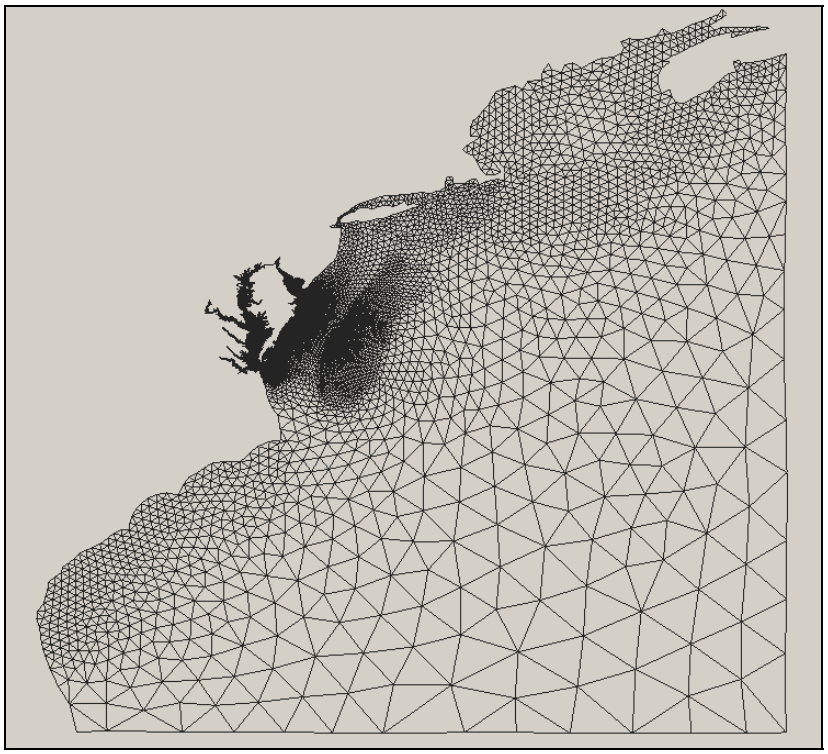

Figure 28. Regional ADCIRC mesh resolution and shoreline

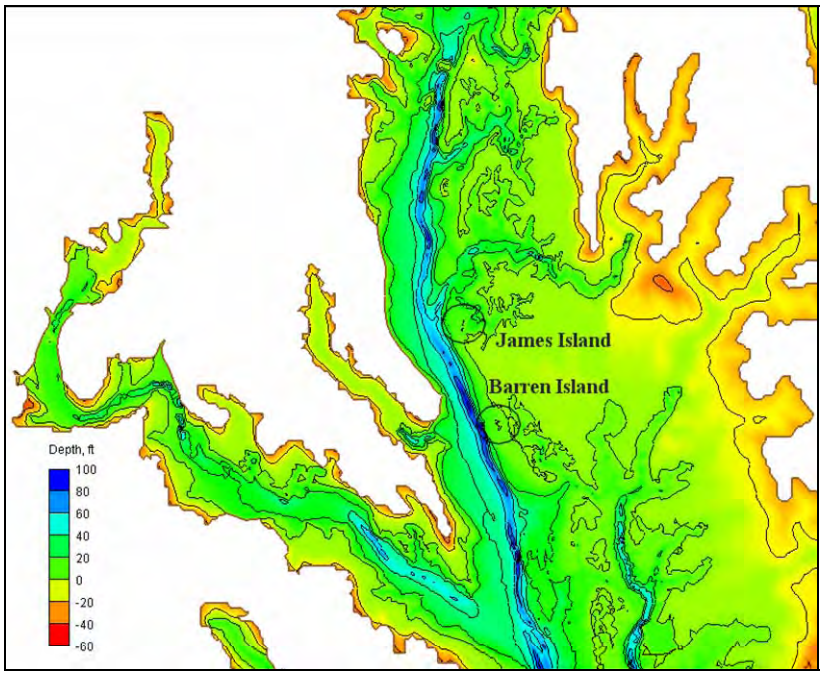

Figure 29. Mid-Bay ADCIRC mesh bathymetry with overbank extensions

Hydrodynamic simulations were conducted for the existing island condition, each of the alternative island alignments, and the future without-project condition. The future without-project condition assumes that both James Island and Barren Island disappear completely as a result of natural erosion under severe storms that occur frequently in the bay. Both islands were removed in the numerical mesh and replaced by water depth interpolated linearly from the surrounding bed. Figure 30 shows the local scale mesh bathymetry at James Island and Barren Island for the existing islands and future without-project conditions. The volume difference between the existing and the future without-project condition is 0.64 million cu yd at James Island and 1.13 million cu yd at Barren Island (Figure 31).

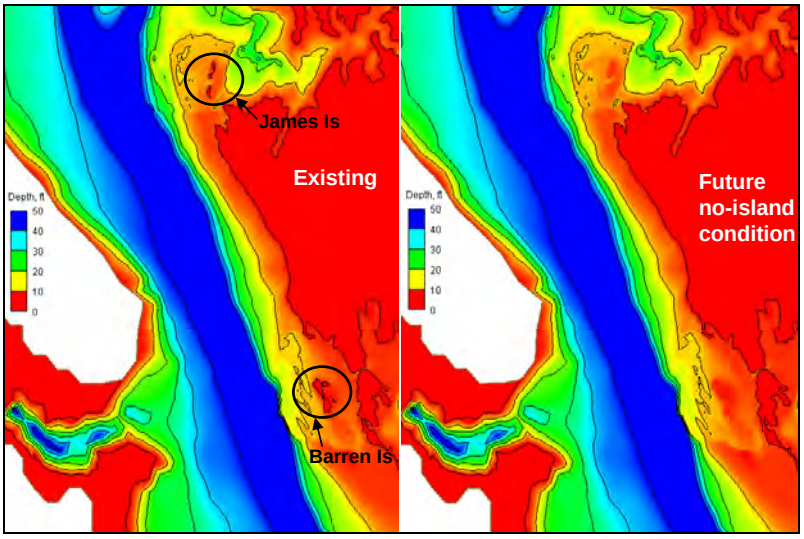

Figure 30. Local mesh bathymetry for existing and future without-project conditions

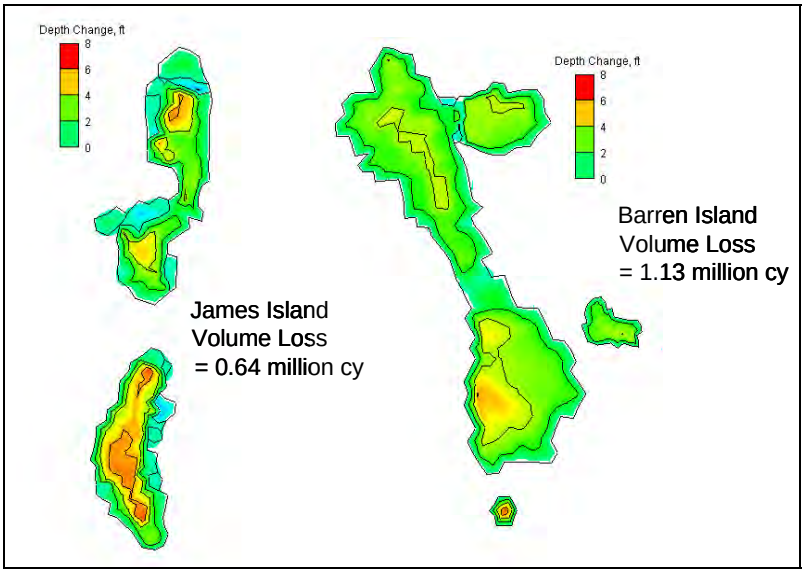

Figure 31. Volume difference for existing and future without-project conditions

Model simulation cases included a normal tide and four historical storms. The normal tide case covers a 2-week period of 1-15 January 2005. During this 2-week period, the wind was light over the bay as observed at several NOAA meteorological stations in the Mid-Bay area (Figure 32). Figure 33 shows measured wind speed and direction at sta 8571892 (Cambridge, Choptank River, MD) and sta 8577330 (Solomons Island, MD). The water level data collected at these NOAA stations is also available for the same period. Figure 34 shows measured water levels at sta 8571892 and 8577330. These wind and water level data show that the water level is affectively responsive to the change in wind direction, especially at locations near the shore and in the shallow tributaries.

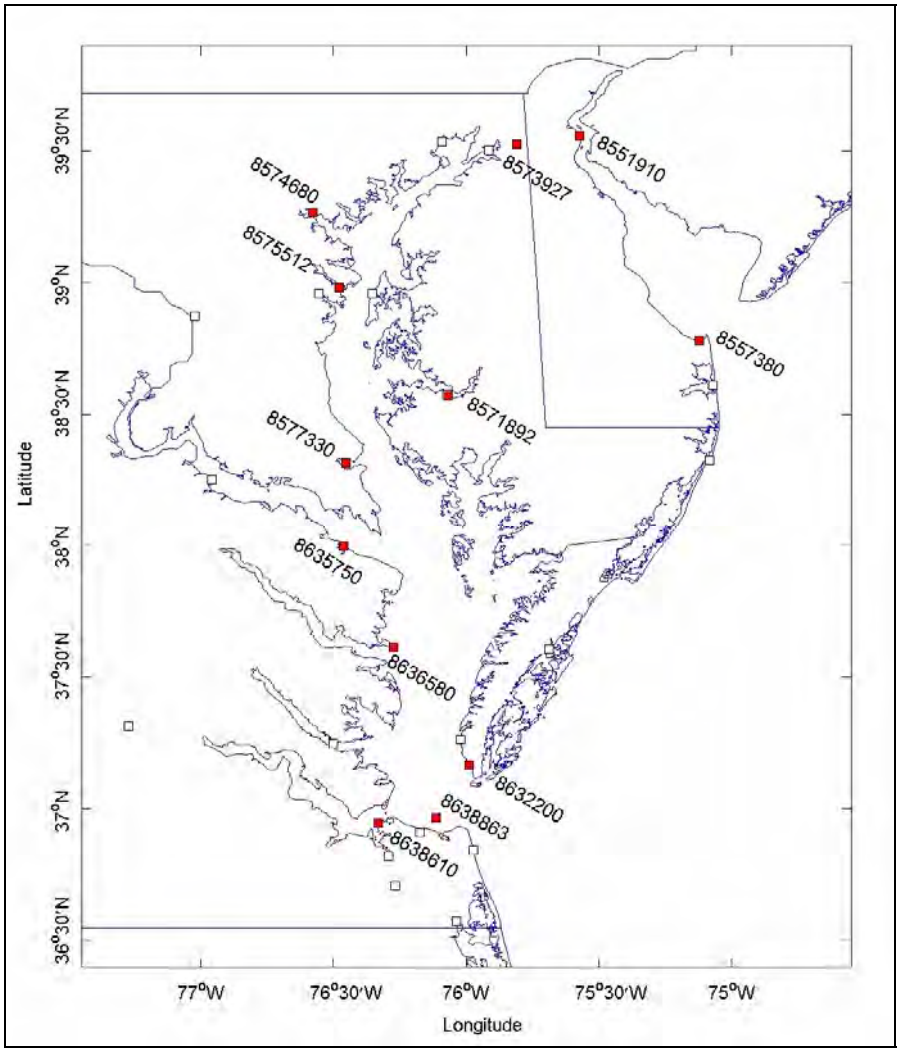

Figure 32. NOAA meteorological stations

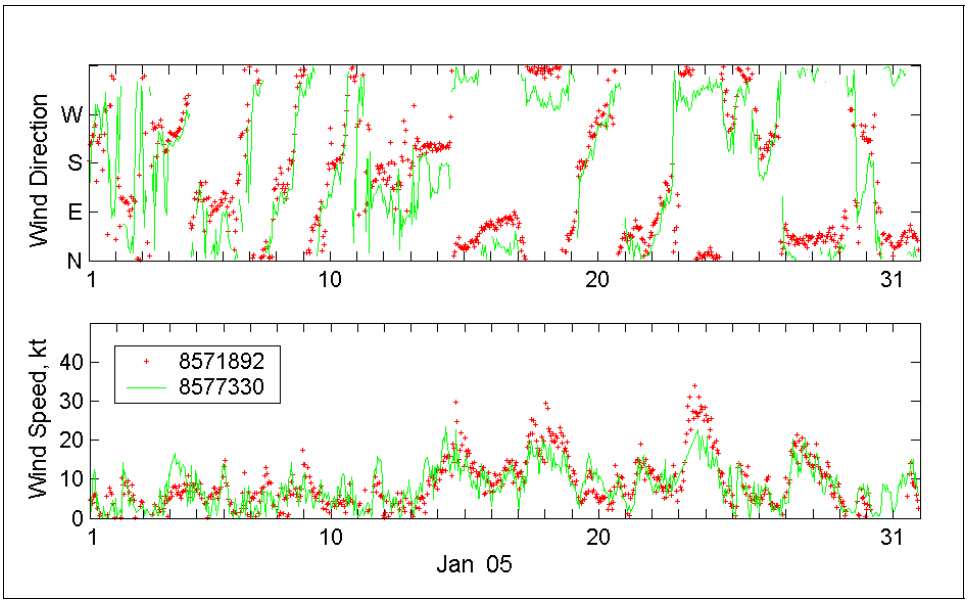

Figure 33. Measured wind speed and direction at sta 8571892 and 8577330

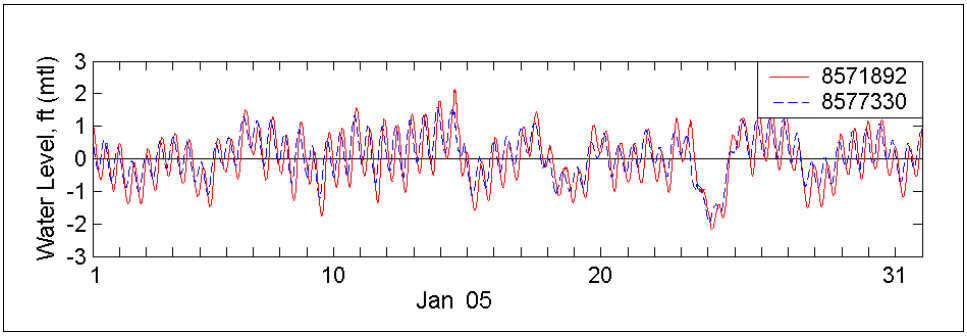

Figure 34. Measured water level at sta 8571892 and 8577330

The simulation for the normal tide case was conducted only for existing islands and for Alts JI-1 and BI-1 to demonstrate the rather weak tidal current condition in the vicinity of islands. The time-step in ADCIRC was 1 sec for the existing condition, and 0.25 sec for the Alt 1 simulation. Figure 35 compares calculated and measured water levels at James Island under the normal tide condition. The calculated water level compares well to the measurments. Figures 36 and 37 show corresponding maximum current conditions in the vicinity of existing James Island and Barren Island, respectively. For the existing condition, the current magnitude is small, with the maximum speed at 0.9 ft/sec in both island locations. Figures 38 and 39 show corresponding maximum current fields for Alts JI-1 and BI-1, respectively. For Alt JI-1, the strongest current, approximately 1.5 ft/sec, is calculated at the southeast corner of the alternative island alignment near the tidal channel entrance. In the tidal channel, the calculated maximum current speed is around 0.9 ft/sec. For Alt BI-1, the largest current magnitude, approximately 1.5 ft/sec, is seen at the northeast corner of the existing island.

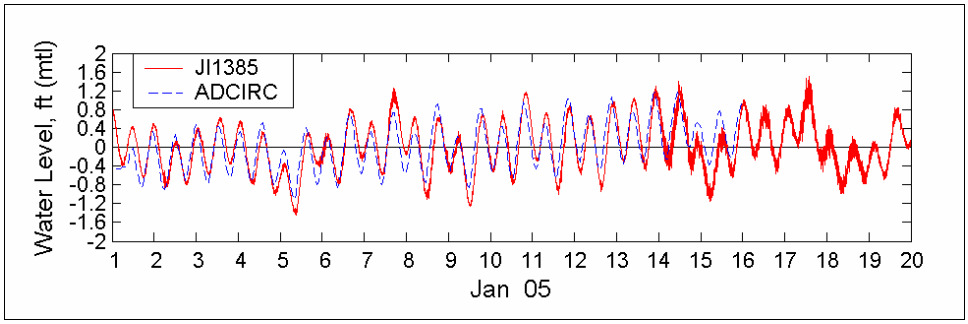

Figure 35. Measured and calculated water levels at James Island at Gauge JI1385

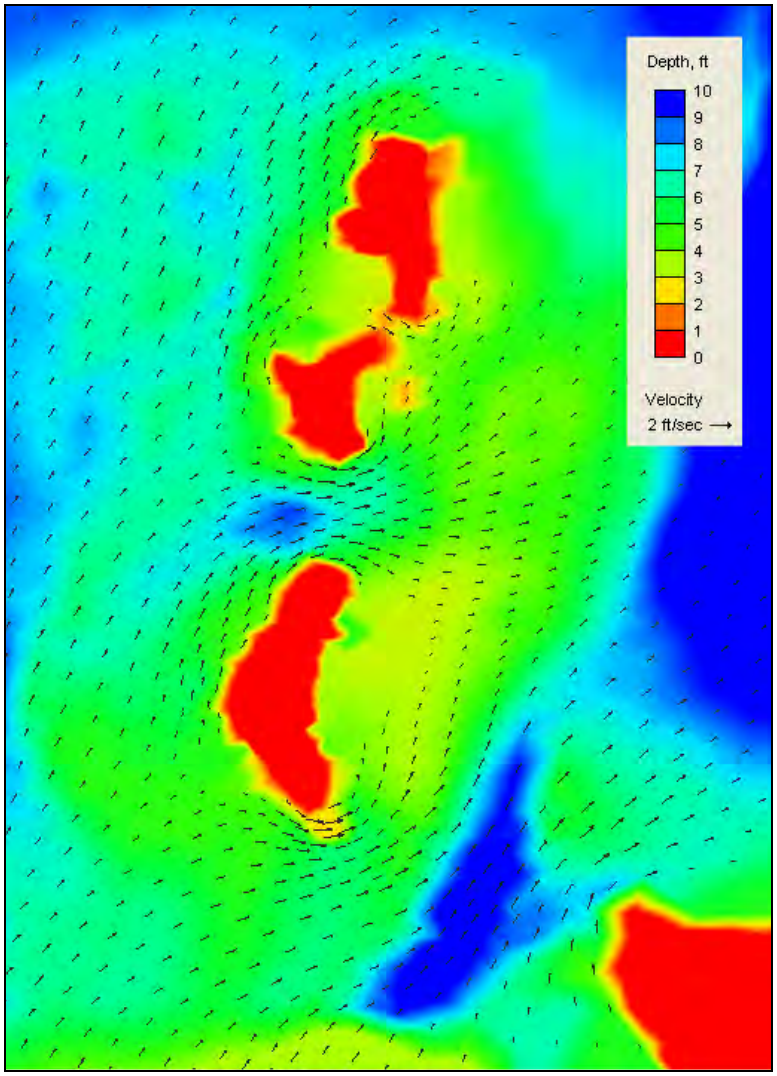

Figure 36. Calculated maximum current fields at James Island under normal tide condition

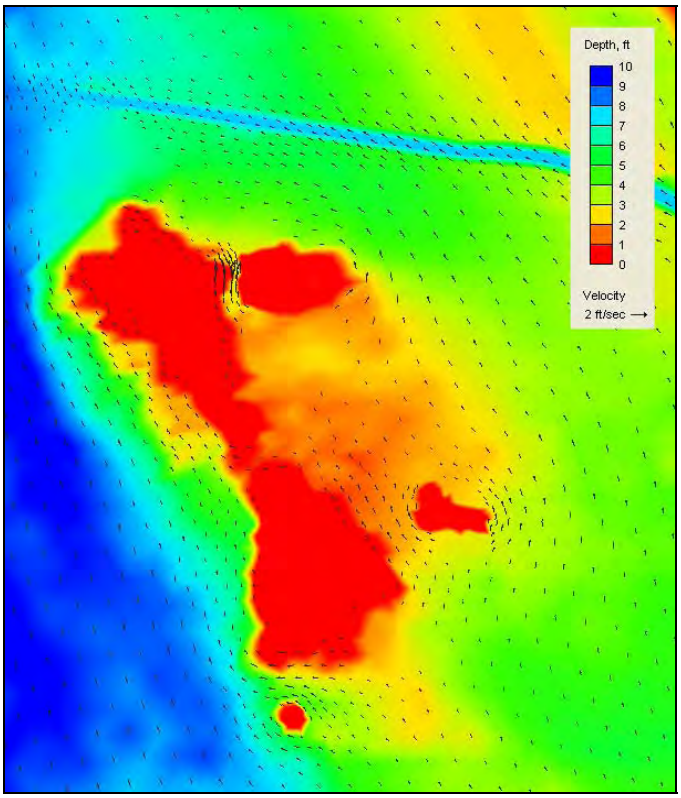

Figure 37. Calculated maximum current field at Barren Island under normal tide condition

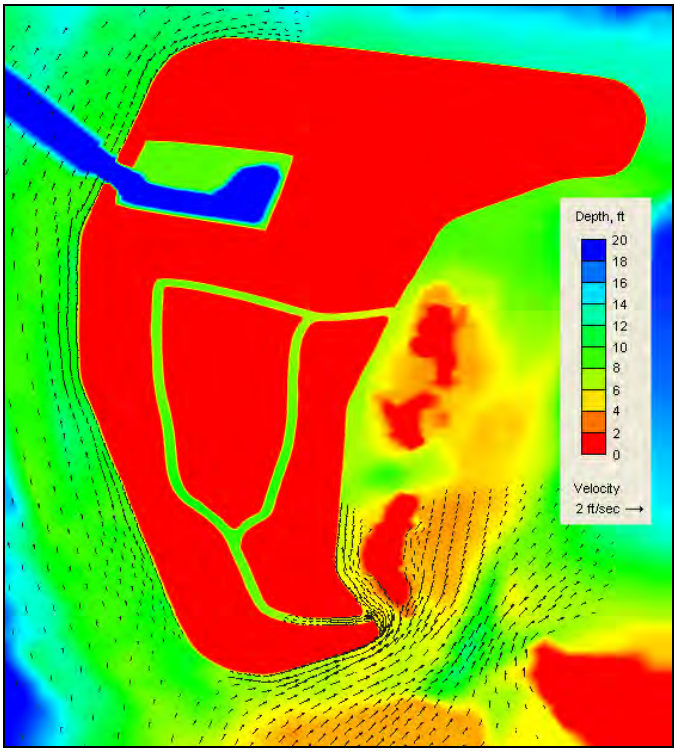

Figure 38. Calculated maximum current field at Alt JI-1 under normal tide condition

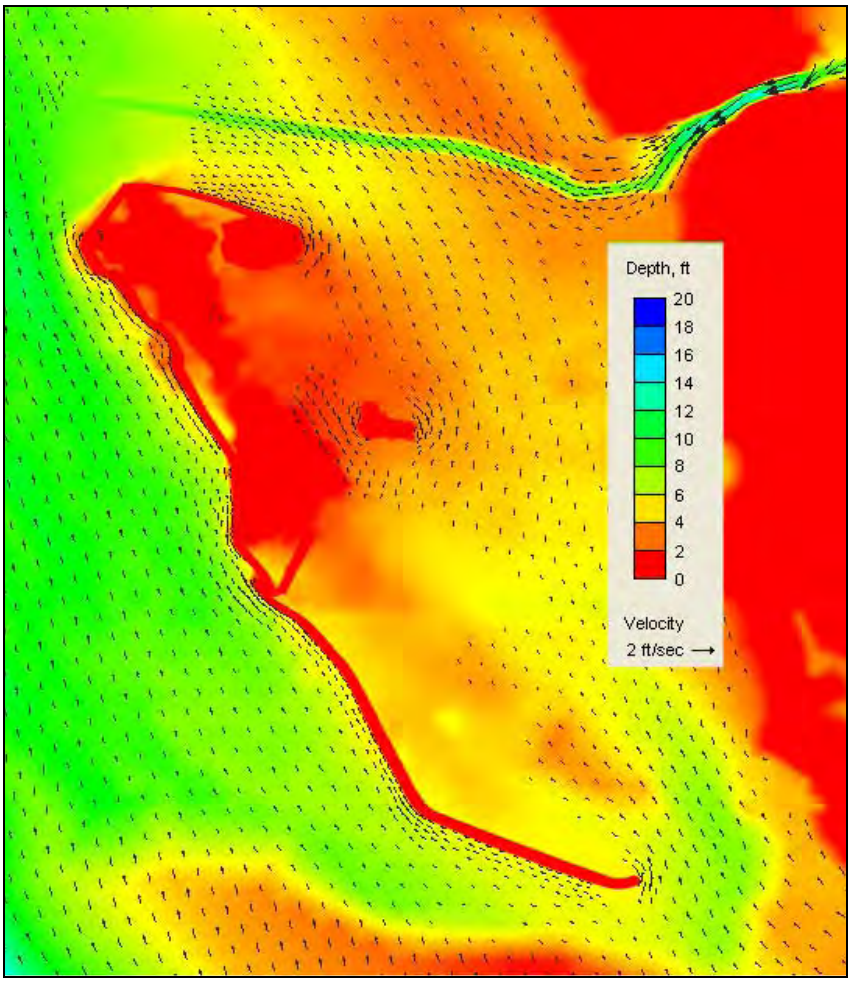

Figure 39. Calculated maximum current field at Alt BI-1 under normal tide condition

Four historical storms were selected for the hydrodynamics and sediment transport modeling. These four storms include two strong hurricanes, 1954 Hazel and 2003 Isabel, and two moderate northeasters, March 1984 and March 1993. For these hurricanes and northeast storms, both surface wind and pressure fields developed from the previous Mid-Chesapeake Bay and Poplar Island study (Melby et al. 2005) were input, together with the surface wave forcing and tidal potentials at the ocean boundary, to the hydrodynamic model. Figure 40 shows an example of the surface wind and pressure field during Hurricane Isabel. The surface wind-wave forcing was also included as input to the hydrodynamic and sediment transport models. Wave field and wave-induced surface shear stress information were precalculated by STWAVE in local areas covering James Island and Barren Island for individual storms and for each alternative island alignment. Figure 41 compares calculated current fields during the maximum water level for Hurricane Isabel at James Island (existing condition) with and without wave forcing. With wave forcing, the change in current magnitude and direction was significant around the island perimeter. Therefore, wave forcing was applied together with the surface wind and pressure input to the ADCIRC model in the present study.

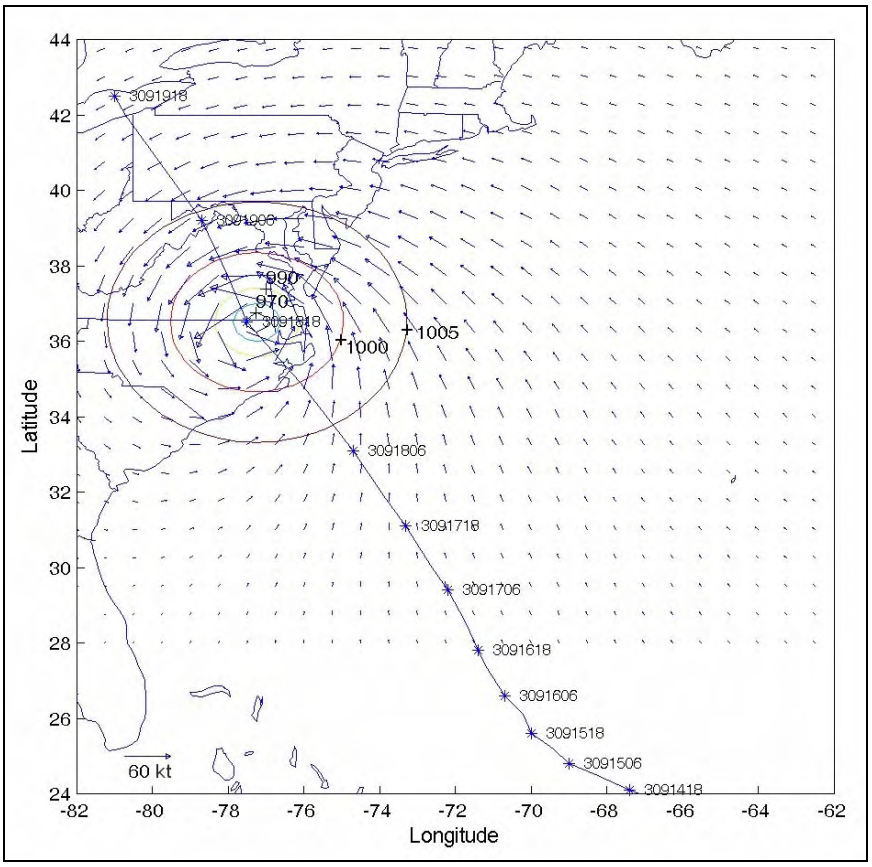

Figure 40. Hurricane Isabel (2003) storm track, wind field (knot), and pressure field (mb) at 1800 GMT, 18 September

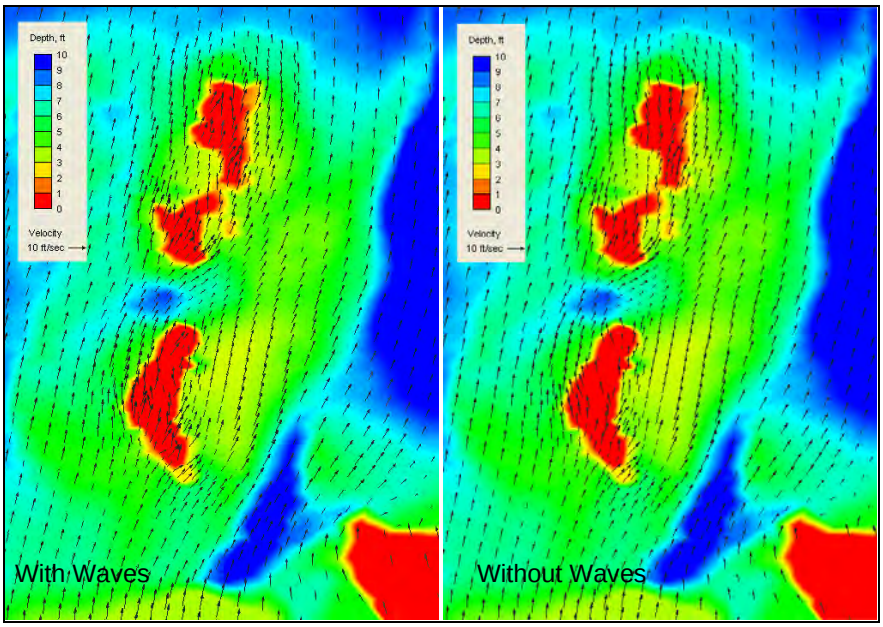

Figure 41. Maximum current fields at James Island during Hurricane Hazel with and without wave forcing condition

Figures 42 and 43 show the calculated water level comparison at the east and west sides of James Island and Barren Island (existing condition) during Hurricane Hazel and Hurricane Isabel. The high water level calculated at James Island and Barren Island during Hurricane Hazel and Hurricane Isabel reaches almost 6 ft mtl. The maximum water level at James Island during these two hurricanes is about the same at the east and west sides of the island, indicating that the storm water can circulate more freely around the island. On the other hand, the maximum wave level at the west side of Barren Island is higher than the east side, indicating that some storm water can be trapped between the island and the neighbored Taylors Island and Upper Hoopers Island to the east. For both the Hurricane Hazel and Hurricane Isabel simulations, the calculated peak water level on the east side of Barren Island is about 5 percent higher than on the west side as a result of strong winds and large waves impounding storm water from the south and southwest. For the northeasters, storm water impoundment to the east of Barren Island is insignificant because the strong wind and large waves originate mainly from either the north or the northwest.

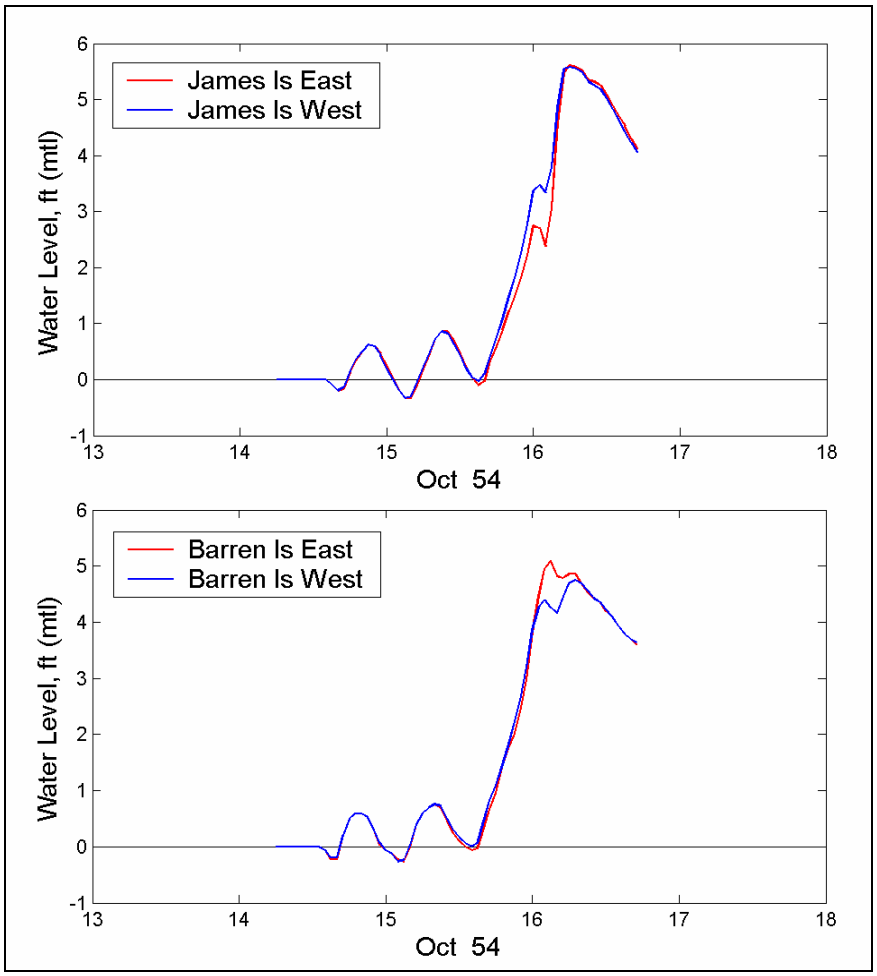

Figure 42. Water level comparison during Hurricane Hazel

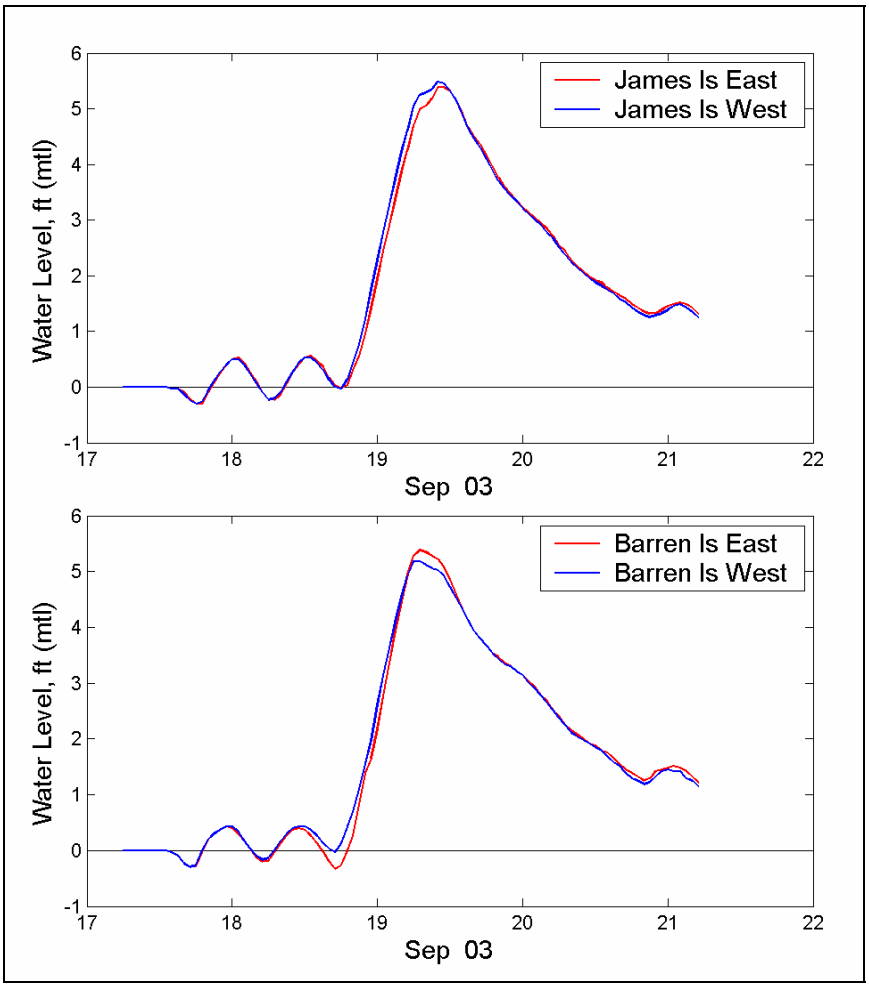

Figure 43. Water level comparison during Hurricane Isabel

Sediment Transport Model

Sediment in Chesapeake Bay can be moved by the current, or by waves, or by both a current and waves acting together. The sediment is transported by the basic processes of entrainment, transportation, and deposition. Entrainment occurs as a result of the bottom friction exerted on the bay bed by currents and waves. Sediment transport can take place by grains moving along the bed or away from the bed into suspension. The former is known as bed-load transport, and the latter is suspended-load transport. Bed-load transport is usually the dominant mode for weak flows and large grains (coarser than 2 mm), whereas suspended-load transport is dominant for strong and turbulent flows and smaller grains (finer than about 0.2 mm). In a typical marine or estuarine area, sediment transport likely involves mixed bed load and suspended load. Deposition of sediment occurs if grains come to rest in bed-load transport, or by settling out of suspension. Depending on the difference in transport rates at which sediment is entering or leaving the area, net accretion or erosion of the bed can occur, and these processes were represented in the modeling.

In the present study, a sediment model was applied to predict the pattern of accretion and erosion in the study area. The sediment transport rate calculated in the model is valid for the sand range (0.062 to 2 mm) through the transport formulas, including bed load and suspended load, developed by Van Rijn (1993). The sediment transport rate is a vector quantity over the 2-D bed plane and is defined as the change of sediment volume per unit time passing though a water column of unit width perpendicular to the flow direction. The transport rate is calculated through introduction of bed shear stresses induced by currents and waves exerted on the bottom sediment.

The hydrodynamic forcing (water level, current, and waves) for the sediment transport model was precalculated. The sediment transport simulation then employed the same finite element mesh as the ADCIRC model. Sediment fluxes were calculated at each element face to determine the sediment quantity transported in and out of each element, based on the transport direction and magnitude.

The sediment transport simulation for the Mid-Bay project involved non-erodible levee structures (armored with rock post-construction). In the situation of a storm condition, all or portions of these structures can be overtopped by high water depending on the height of the levee and the predicted surge level. For elements representing these structures, sediment deposition was permitted, but erosion was only allowed if there had been previous deposition. This procedure prevents unphysical erosion below the original levee elevation for the non-erodible structural condition. Erosion of the interior 6-ft sand dikes was not permitted.

Each sediment transport simulation requires an initial bathymetry, grain size information, and hydrodynamic forcing (water level, current, and waves). The sediment transport model can support multiple grain sizes. However, for the screening level analysis completed in the present study, a single grain size of 0.2 mm representing the average sediment size the James Island and Barren Island was specified. Figures 44 and 45 demonstrate calculated sediment accretion and bed erosion patterns at James Island and Barren Island, respectively, under Hurricane Hazel. Erosion appears on the surface and along the perimeter of James Island and Barren Island as a result of inundation of these two islands during the peak surge condition.

Figures 46 and 47 show sediment accretion and erosion patterns for Alt JI-3 during Hurricane Hazel and NE20. Sediment accretion and erosion appear to be more significant along the bay side levee of Alt JI-5 under the stronger Hurricane Hazel than NE20. It is noted that the pattern of accretion and erosion reverses on the north and south sides of the access channel for Hurricane Hazel and NE20 indicating opposite sand transport directions across the access channel during these two storms. Figures 48 and 49 show calculated sediment accretion and erosion for Alt BI-5 during Hurricane Hazel and NE20. There is more accretion and erosion at shore protection structures and breakwaters where stronger wave-current and wave-structure interactions occur. Bed erosion is significant at the south breakwater, where the current is strong surrounding segmented breakwater elements. Sediment transport simulations for Barren Islands Alts BI-1 through BI-6 generally show less sediment accretion or erosion along the Honga River Channel, especially between Taylors Island and Upper Hoopers Island. This trend is opposite to the future without-project condition, where the erosion

becomes significant along the bay side shoreline and Honga River Channel because Barren Island does not exist to provide the protection to Taylors Island and Upper Hoopers Island.

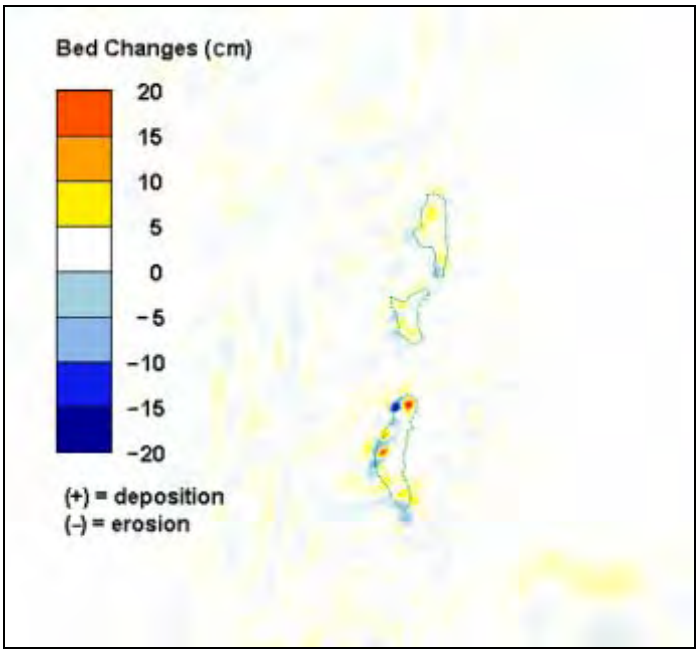

Figure 44. Bed change at James Island from Hurricane Hazel

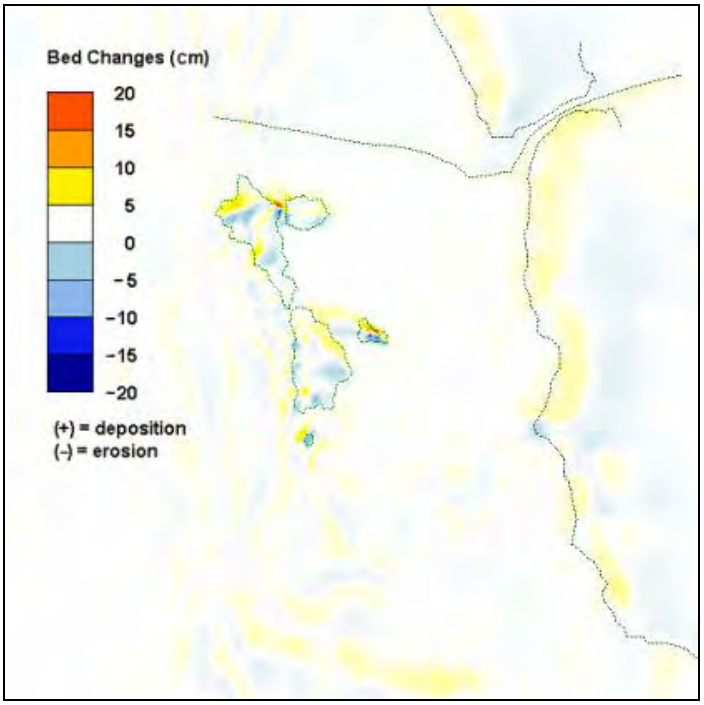

Figure 45. Bed change at Barren Island from Hurricane Hazel

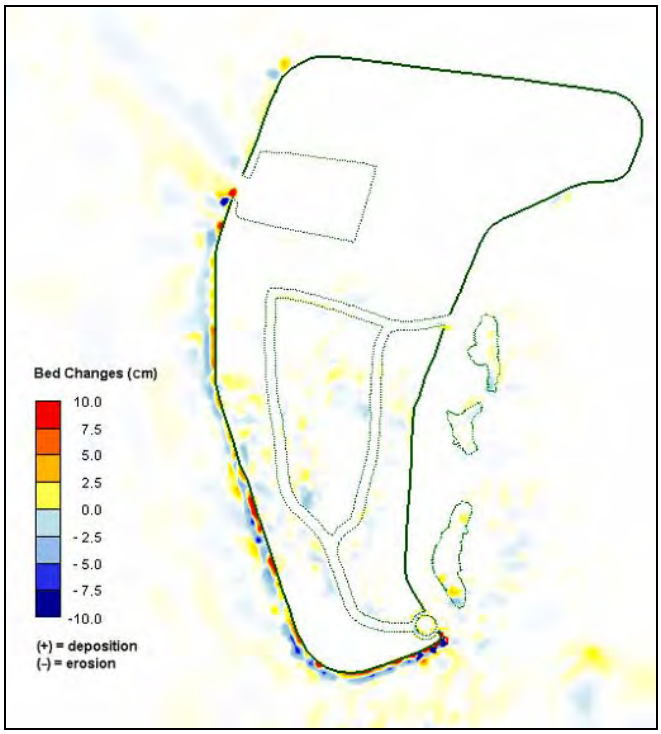

Figure 46. Bed change at James Island, Alt JI-3, from Hurricane Hazel

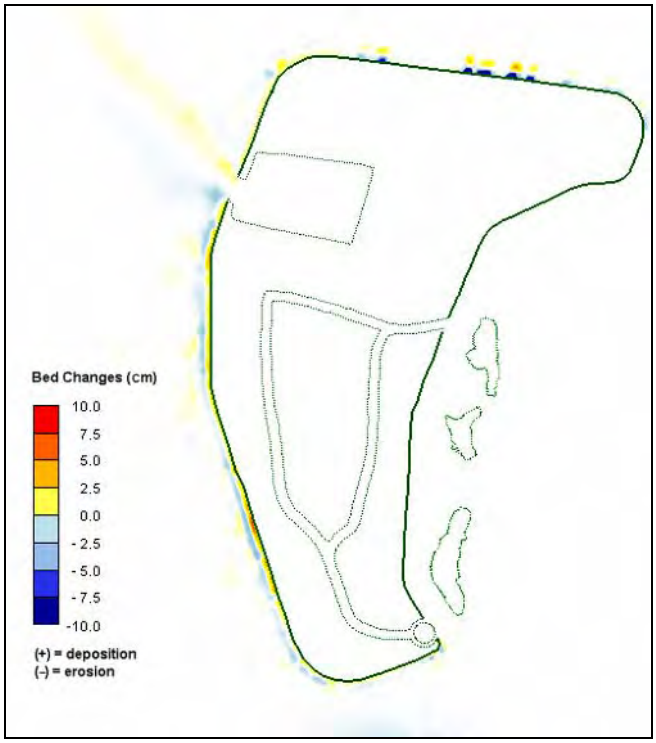

Figure 47. Bed changes at James Island, Alt JI-3, from NE20

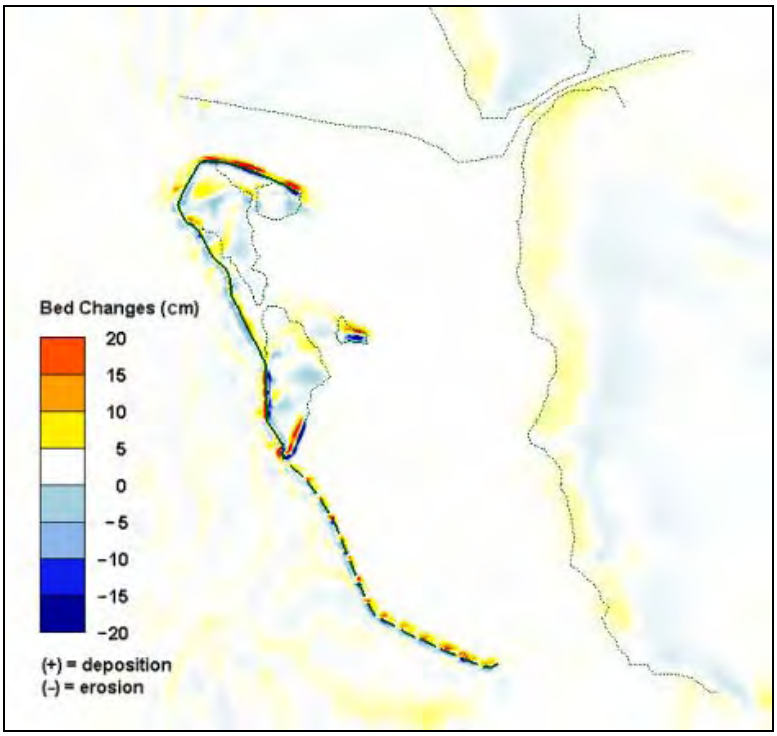

Figure 48. Bed change at Barren Island, Alt BI-5, from Hurricane Hazel

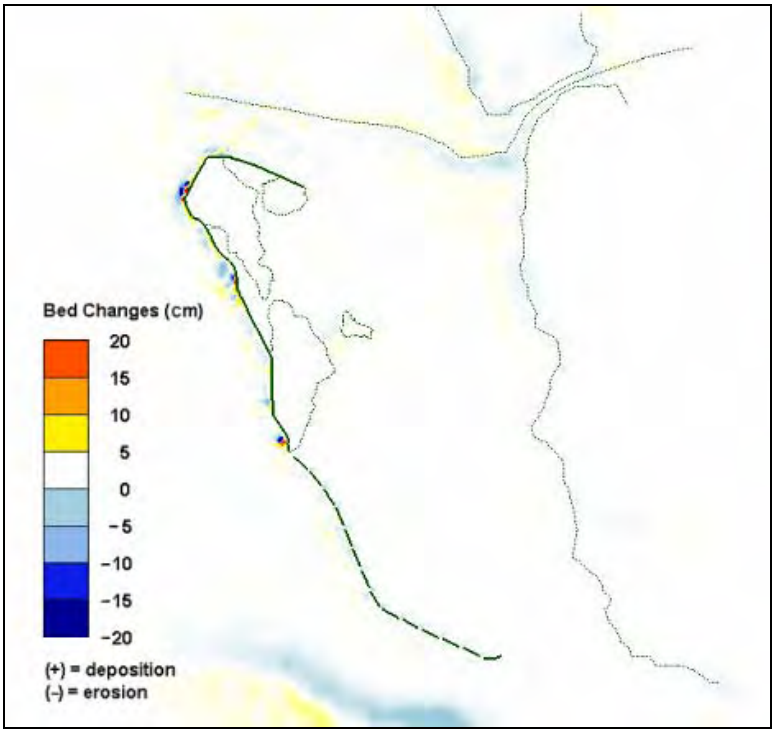

Figure 49. Bed change at Barren Island, Alt BI-5, from NE20

5 Evaluation of Alternatives

Evaluation of the James Island and Barren Island alternatives encompasses diverse subjects such as physical processes for assessing environmental impacts, engineering design, construction cost, recreational use, and other aspects such as real estate and cultural benefits. In the present study, components of the evaluation address waves, hydrodynamics (circulation and sediment transport) in support of engineering and environmental studies. The hydrodynamics and sediment transport were evaluated for a normal tide condition and four historical storms (Table 3) consisting of two strong (100+ year compatible) hurricanes (1954 Hazel and 2003 Isabel) and two moderate northeasters (NE20 and NE33).

The evaluation covers analysis of the existing island condition and future without-project condition, assuming that the existing James Island and Barren Island will erode completely if island restoration does not take place. Results from wave, hydrodynamic, and sediment transport simulations are compared to evaluate conditions for the engineering alternatives with respect to the adjacent islands, including sediment erosion in tidal guts and sediment shoaling in local channels.

Response to Waves

Chapter 3 describes numerical modeling of wave transformation for the James Island and Barren Island alternatives, existing condition, and future without-project condition. The wave results were examined to evaluate the nearshore (close to shore) wave climate associated with the individual alternatives. The nearshore waves were evaluated for a range of characteristic conditions. Additionally, two hurricanes (Hazel and Isabel) and two northeaster storms were simulated. Wave model results were input to drive the circulation and sediment transport models described in Chapter 4. The storm simulation results are available to specialists such as ecologists for assessing survivability of SAV in the areas sheltered by different alternatives.

James Island alternatives expanded the footprint of the island and reduced the wave height in the lee of the island by 1-2 ft. The future without-project condition (submerged island) increased the wave height at the shoreline slightly. The Barren Island alternatives include six breakwater extensions to the south of the island. Alts BI-1 and BI-3 reduced the wave height 2-3 ft at the shoreline in the lee of the island (greater reduction for Alt BI-1 with the greater breakwater crest height). Alts BI-2 and BI-4 (shorter overall breakwater length) provided approximately 0.5 ft less reduction in wave height than Alts BI-1 and BI-3, and

the reduction was over a smaller region. Alts BI-5 and BI-6 pertain to segmented breakwaters. They provided approximately 0.5 ft less reduction in wave height than Alts BI-1 and BI-3, but over a similar region. Increasing the length and crest elevation of the Barren Island breakwaters reduced wave energy in their lee. The future without-project condition increased the nearshore wave height 2-4 ft for Barren Island, thus potentially increasing shore erosion. None of the alternatives considered for James Island and Barren Island increased the nearshore wave height.

Current Velocity Comparison

The current velocity calculated from the hydrodynamic model allows evaluation and comparison of the individual alternatives. The current velocity was evaluated at key locations selected to identify conditions that might alter water quality and be a concern to environmental resources such as oyster beds and SAV. Tables 7 and 8 present easting and northing coordinates (MD State Plane) of the identified key locations at James Island and Barren Island, respectively. Among the locations selected for James Island, Points 1 and 12 are located in the local navigation channel. Points 5 and 8 represent the tidal gut entrance locations. Points 7 and 9 are located in the tidal gut channel. Points 2 and 3 are located in the neighboring oyster bed ground. Point 4 is located in the SAV area.

For Barren Island, Points 2 to 8, and 10 are located in the SAV area, and Points 9, 11, and 13 are located in the oyster bed. Points 14 and 15 are located in the north island cut (northward-most tidal gut). Points 16 and 17 are located in the up-wave side and lee side, respectively, of the south breakwater. Point 1 is located in the south local channel, and Point 12 is located in the Honga River Channel at the Tar Bay entrance. Figures 50 and 51 show the comparison location points for James Island and Barren Island, respectively (Alts JI-6 and BI-6 serve as the background bottom topography).

The response of the current field to the presence of each alternative was investigated for both normal tide and storm conditions. The normal tide simulation covered the 2-week period 1-15 January 2005. The simulation was conducted only for the existing island configuration and for Alts JI-1 and BI-1 to investigate sedimentation patterns (erosion and deposition) in a typical, frequent weak current. The calculation results were analyzed for the first 12-day period of the simulation because the wind was relatively weak in this period and became stronger afterward. Tables 9 and 10 present the maximum current velocity values from the normal tide analysis at comparison points for both islands and Alts JI-1 and Alt BI-1, respectively. These tables show that the current velocity is not strong and similar for the existing condition and Alt 1 for both islands, with a maximum speed of 2.1 ft/sec at the southeast corner of Alt JI-1 (Point 13) and 2 ft/sec at the north island cut of Alt BI-1 (Point 15). The stronger current at the southeast corner of Alt JI-1 occurs because of the sharp turning angle of the current between the south tidal gut outlet and open bay. The stronger current at the north island cut of Alt BI-1 occurs because of the increase in water surface gradient during high tide at the narrow cut. The calculated current velocity is similar in magnitude to the results from two previous numerical model studies by Moffatt & Nichol Engineers (2002, 2004) that investigated the current field

under normal tide for James Island and Barren Island for several different alternative alignments.

Table 7
James Island Save Locations

Location	Easting, ft	Northing, ft
1	1,503,685.827	304,923.294
2	1,508,416.896	312,049.5079
3	1,500,881.824	320,596.2927
4	1,502,676.969	309,755.1837
5	1,501,389.862	304,992.7822
6	1,498,119.882	303,393.7336
7	1,498,537.27	306,209.4816
8	1,501,737.73	312,605.6759
9	1,498,258.99	313,127.0997
10	1,495,058.53	313,439.9606
11	1,495,291.995	316,450.1312
12	1,500,916.47	303,225.9514
13	1,501,402.231	304,382.5459
14	1,501,761.549	305,303.0184
15	1,500,937.008	304,818.5696
16	1,500,618.438	305,018.0446

Table 8
Barren Island Save Locations

Location	Easting, ft	Northing, ft
1	1,531,352.428	234,510.8596
2	1,529,207.874	236,213.9108
3	1,528,176.575	237,928.248
4	1,527,378.707	239,325.689
5	1,526,812.041	244,400.853
6	1,533,207.316	236,718.0774
7	1,532,177.756	238,192.6837
8	1,530,727.526	240,194.1273
9	1,529,799.77	241,406.0367
10	1,529,077.986	244,985.1706
11	1,529,299.049	240,747.769
12	1,531,982.612	248,266.0761
13	1,518,821.522	250,722.4409
14	1,524,838.583	246,663.3858
15	1,524,906.168	246,087.5984
16	1,527,136.155	237,959.3176
17	1,527,016.076	237,691.601

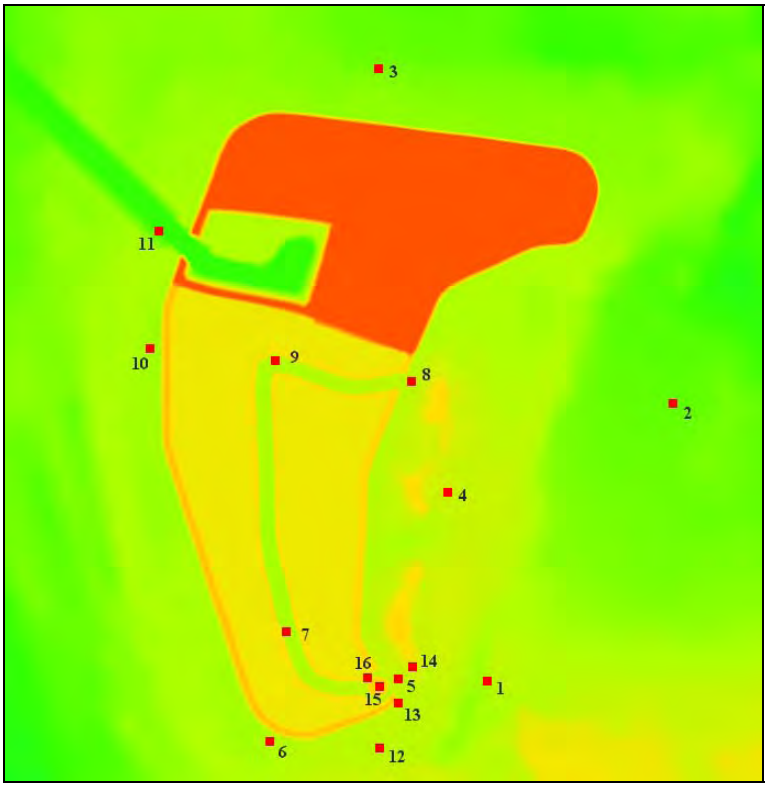

Figure 50. James Island comparison locations (JI-6)

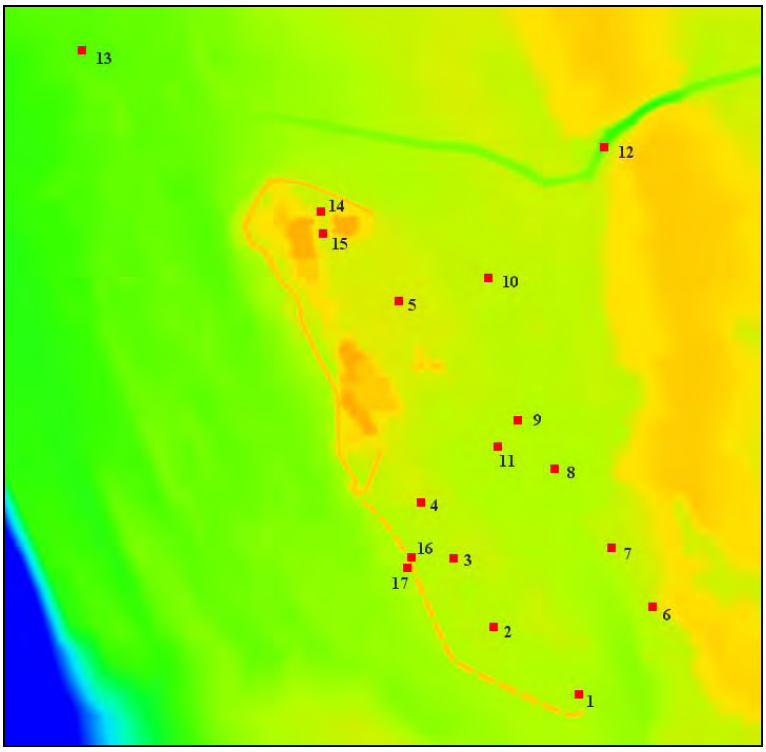

Figure 51. Barren Island comparison locations (BI-6)

Table 9
Calculated Maximum Current Speed (ft/sec) at James Island Under Normal Tide Condition

Location	Existing	Alt JI-1
1	1.97	1.94
2	0.36	0.20
3	0.82	0.59
4	1.08	0.79
5	1.28	1.28
6	1.34	0.66
7	1.28	0.52
8	1.71	0.88
9	1.41	0.20
10	1.38	1.57
11	0.95	0.49
12	1.11	1.80
13	1.18	2.13
14	0.00	0.00
15	0.92	0.72
16	0.79	0.00

NOTE: A '0' velocity indicates the 'no-current' (dry) condition.

Table 10
Calculated Maximum Current Speed (ft/sec) at Barren Island Under Normal Tide Condition

Location	Existing	Alt BI-1
1	1.15	1.15
2	1.08	0.69
3	0.98	0.75
4	0.85	0.69
5	0.92	0.89
6	1.15	1.18
7	0.98	0.98
8	0.98	0.89
9	0.95	0.92
10	1.15	1.15
11	0.62	0.56
12	1.90	1.87
13	0.82	0.82
14	0.85	0.82
15	0.92	2.03
16	0.56	0.10
17	0.56	0.23

Table 11
Calculated Maximum Current Speed (ft/sec) at James Island During Hurricane Hazel

Location	Existing	Future	JI-1	JI-2	JI-3	JI-4	JI-5	JI-6
1	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31
2	1.41	1.41	1.67	1.71	1.61	2.00	1.90	1.97
3	3.28	0.98	1.25	1.21	1.18	1.67	1.71	1.48
4	3.48	3.51	3.38	3.38	3.38	3.38	3.38	3.38
5	3.28	3.31	3.31	3.35	3.35	3.31	3.31	3.35
6	3.31	3.28	3.28	3.28	3.28	3.28	3.28	3.28
7	3.28	3.28	2.59	3.28	3.25	3.28	3.28	2.82
8	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31
9	3.28	3.28	1.67	1.97	1.90	1.80	0.59	0.75
10	3.28	3.28	3.28	3.28	3.28	3.28	3.28	3.28
11	3.28	3.28	2.43	2.46	2.40	3.02	3.02	3.02
12	3.31	3.31	3.31	3.28	3.28	3.28	3.31	3.31
13	3.31	3.31	3.48	3.44	3.54	3.51	3.58	3.51
14	6.14	6.40	4.10	4.13	3.94	5.61	5.51	5.58
15	3.31	3.31	3.31	3.31	0.00	3.31	3.28	0.00
16	3.31	3.35	0.03	0.07	3.35	1.28	1.21	3.31

Note: A ‘0’ velocity magnitude indicates the ‘no-current’ (dry) condition.

Table 12
Calculated Maximum Current Speed (ft/sec) at James Island During Hurricane Isabel

Location	Existing	Future	JI-1	JI-2	JI-3	JI-4	JI-5	JI-6
1	2.69	2.66	3.25	3.28	3.28	3.28	3.28	3.28
2	1.02	1.18	1.18	1.18	1.15	1.18	1.18	1.18
3	1.74	1.71	0.98	0.89	0.89	0.75	0.75	0.75
4	3.15	2.92	2.49	2.49	2.53	2.49	2.49	2.49
5	1.84	2.49	3.51	3.25	3.31	3.25	3.25	3.02
6	2.79	2.92	2.66	2.17	2.53	2.17	2.17	2.17
7	2.82	2.89	2.30	2.20	1.90	1.08	0.82	0.66
8	2.82	2.66	3.35	2.00	3.41	1.77	1.87	1.80
9	2.69	2.69	2.00	0.82	1.87	1.21	0.75	0.62
10	2.76	2.79	3.28	3.28	3.28	3.28	3.28	3.28
11	2.59	2.59	1.54	1.61	1.54	1.61	1.61	1.61
12	2.53	2.66	3.02	3.22	3.12	3.22	3.18	3.22
13	2.30	2.56	3.31	3.31	3.31	3.31	3.31	3.31
14	4.00	3.05	3.87	3.54	3.54	3.51	3.48	3.51
15	2.23	2.66	3.31	1.94	0.00	1.71	2.17	0.00
16	2.36	2.76	0.43	0.10	3.35	0.07	0.07	2.46

Note: A ‘0’ velocity magnitude indicates the ‘no-current’ (dry) condition.

Table 13
Calculated Maximum Current Speed (ft/sec) at James Island During NE20

Location	Existing	Future	JI-1	JI-2	JI-3	JI-4	JI-5	JI-6
1	1.48	1.35	1.51	1.67	1.51	1.51	1.51	1.51
2	0.36	0.52	0.36	0.36	0.39	0.36	0.36	0.36
3	1.08	1.02	0.82	0.85	0.82	0.82	0.82	0.82
4	1.18	1.41	0.92	0.92	0.92	0.92	0.92	0.92
5	1.31	1.35	1.48	1.61	1.44	1.44	1.48	1.44
6	1.48	1.51	1.25	1.38	1.25	1.25	1.25	1.25
7	1.64	1.38	0.66	0.75	0.49	0.59	0.59	0.46
8	1.51	2.03	1.21	1.21	1.15	1.25	1.21	1.21
9	1.48	1.57	0.26	0.16	0.16	0.20	0.56	0.36
10	1.48	1.41	1.97	2.00	1.97	1.97	1.97	1.97
11	1.41	1.38	0.62	0.62	0.62	0.62	0.62	0.62
12	1.18	1.57	1.90	2.13	1.90	1.90	1.90	1.90
13	1.12	1.28	2.43	2.43	2.40	2.46	2.43	2.40
14	0.00	1.67	0.00	0.00	0.00	0.00	0.00	0.00
15	1.35	1.74	0.85	0.95	0.00	0.92	0.75	0.00
16	1.44	1.84	0.00	0.00	1.18	0.00	0.00	0.95

Note: A '0' velocity magnitude indicates the 'no-current' (dry) condition.

Table 14
Calculated Maximum Current Speed (ft/sec) at James Island During NE33

Location	Existing	Future	JI-1	JI-2	JI-3	JI-4	JI-5	JI-6
1	1.61	1.74	1.61	1.61	1.84	1.57	1.61	1.61
2	0.30	0.39	0.26	0.26	0.30	0.26	0.26	0.26
3	0.82	1.21	0.56	0.56	0.56	0.56	0.56	0.56
4	1.35	1.54	0.62	0.62	0.62	0.62	0.62	0.62
5	1.51	0.95	1.44	1.44	1.44	1.41	1.41	1.41
6	0.98	1.02	1.48	1.48	1.51	1.51	1.48	1.51
7	0.95	1.02	0.62	0.66	0.49	0.59	0.56	0.46
8	1.57	1.25	0.72	0.72	0.69	0.75	0.72	0.66
9	1.31	1.25	0.26	0.16	0.20	0.23	0.52	0.36
10	1.21	1.21	1.12	1.12	1.08	1.12	1.12	1.12
11	1.18	1.12	0.49	0.49	0.52	0.49	0.49	0.49
12	1.44	1.21	1.90	1.90	1.94	1.94	1.90	1.90
13	1.35	1.21	2.10	2.10	2.53	2.00	2.10	1.80
14	0.00	1.64	0.00	0.00	0.00	0.00	0.00	0.00
15	1.21	1.05	0.89	0.95	0.00	0.98	0.79	0.00
16	1.18	1.08	0.00	0.00	1.25	0.00	0.00	1.02

Note: A '0' velocity magnitude indicates the 'no-current' (dry) condition.

Table 15
Calculated Maximum Current Speed (ft/sec) at Barren Island During Hurricane Hazel

Location	Existing	Future	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6
1	3.31	3.31	3.25	3.28	3.28	3.28	3.31	3.22
2	3.31	3.31	3.18	3.28	2.95	3.28	3.31	2.33
3	3.31	3.31	3.28	3.31	3.28	3.31	3.31	2.49
4	3.31	3.31	3.28	3.28	3.25	3.31	3.28	3.31
5	3.35	3.02	3.31	3.31	3.31	3.35	3.35	3.35
6	3.44	3.48	3.41	3.41	3.41	3.44	3.44	3.38
7	3.31	3.31	3.48	3.28	3.28	3.31	3.31	3.31
8	3.31	3.31	3.28	3.28	3.28	3.28	3.31	3.28
9	3.28	3.31	3.31	3.28	3.28	3.31	3.28	3.31
10	3.31	3.31	3.28	3.28	3.31	3.31	3.28	3.31
11	3.31	3.31	3.31	3.28	3.28	3.31	3.28	3.28
12	3.28	3.28	3.28	3.28	3.28	3.28	3.28	3.28
13	3.28	3.28	3.28	3.28	3.28	3.28	3.28	3.28
14	3.97	3.44	3.90	3.94	3.71	3.87	3.87	3.87
15	3.51	3.35	3.48	3.44	3.41	3.38	3.51	3.48
16	3.31	3.28	0.59	0.59	3.64	3.87	3.97	7.09
17	3.31	3.28	1.25	1.25	3.74	3.81	5.64	7.87

Table 16
Calculated Maximum Current Speed (ft/sec) at Barren Island During Hurricane Isabel

Location	Existing	Future	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6
1	3.28	3.28	2.99	3.12	3.28	3.22	2.72	2.82
2	3.28	3.28	1.90	2.43	2.76	2.89	2.89	1.84
3	3.15	3.28	2.36	2.62	2.72	2.66	2.72	1.97
4	2.82	3.22	2.46	2.53	2.49	2.43	2.46	3.28
5	3.28	3.28	3.02	2.95	3.15	2.89	2.89	3.08
6	3.15	3.22	3.15	3.02	3.05	3.08	2.72	2.72
7	3.22	3.28	3.15	2.99	3.15	3.12	3.05	2.99
8	2.89	3.22	2.79	2.79	2.85	2.79	2.72	2.56
9	2.69	2.99	2.69	2.72	2.72	2.69	2.66	2.62
10	2.95	2.99	3.08	3.18	3.05	3.08	3.12	3.28
11	2.62	3.02	2.56	2.62	2.59	2.56	2.56	2.46
12	3.28	3.28	3.28	3.28	3.28	3.31	3.28	3.28
13	2.79	2.89	2.82	2.82	2.79	2.79	2.76	2.72
14	3.61	3.25	3.44	3.48	3.44	3.48	3.51	3.54
15	3.38	3.15	3.81	3.38	3.51	3.38	3.38	3.41
16	3.08	3.22	1.97	0.49	2.89	2.82	3.15	7.35
17	3.08	3.18	1.35	1.25	3.28	3.28	5.25	6.76

Table 17
Calculated Maximum Current Speed (ft/sec) at Barren Island During NE20

Location	Existing	Future	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6
1	1.12	1.12	1.94	1.05	1.84	1.18	1.28	1.38
2	1.28	1.21	1.08	1.05	1.02	1.41	1.08	1.05
3	1.44	1.31	1.12	0.98	1.05	1.28	1.18	1.21
4	1.74	1.25	0.92	0.75	0.82	0.95	1.35	1.31
5	1.05	1.31	0.82	0.95	0.82	0.92	1.02	1.02
6	2.07	1.25	1.41	1.51	1.35	1.51	1.35	1.51
7	1.38	1.41	1.31	1.08	1.28	1.48	1.38	1.44
8	1.61	1.35	1.28	1.18	1.21	1.51	1.48	1.48
9	1.90	1.57	1.51	1.21	1.51	1.71	1.84	1.80
10	1.35	1.05	1.12	1.35	1.12	1.25	1.25	1.28
11	1.71	1.41	1.35	1.12	1.35	1.54	1.61	1.61
12	3.28	3.12	3.31	2.72	3.28	3.31	3.28	3.28
13	1.12	1.18	1.12	1.18	1.12	1.15	1.18	1.15
14	1.67	1.28	0.33	0.33	0.33	0.26	0.30	0.30
15	1.80	1.21	0.16	0.39	0.20	0.23	0.36	0.23
16	1.28	1.15	0.16	0.13	0.16	0.20	0.33	0.16
17	1.31	1.12	0.95	0.95	1.12	1.12	1.02	0.52

Table 18
Calculated Maximum Current Speed (ft/sec) at Barren Island During NE33

Location	Existing	Future	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6
1	0.66	0.82	2.33	0.82	0.98	0.82	1.05	1.41
2	0.89	1.41	1.28	1.41	0.49	1.48	1.31	1.41
3	1.15	2.03	1.21	1.12	0.46	1.15	1.64	1.67
4	1.38	2.43	0.79	0.75	0.39	0.79	1.84	1.67
5	0.52	1.54	0.89	0.46	0.52	0.49	0.62	0.75
6	1.35	0.72	0.89	0.92	0.69	0.92	0.79	0.98
7	0.95	1.18	1.25	1.35	0.52	1.31	1.18	1.48
8	1.35	2.40	1.41	1.02	0.59	1.05	2.07	2.10
9	1.94	2.10	1.21	1.51	0.56	1.54	1.54	1.61
10	1.54	1.54	1.38	1.38	0.69	1.38	1.38	1.28
11	1.64	2.07	1.02	1.28	0.52	1.31	1.61	1.57
12	3.31	3.28	3.28	3.28	2.89	3.28	3.28	3.28
13	0.85	0.92	0.92	0.85	0.82	0.89	0.95	0.95
14	0.79	1.35	0.46	0.23	0.30	0.43	0.23	0.23
15	1.15	1.21	1.90	0.26	0.43	1.84	0.33	0.43
16	0.95	1.71	0.20	0.16	0.10	0.20	0.49	0.26
17	0.98	1.57	0.49	0.49	0.56	0.56	0.75	0.36

For the simulated storms, the calculated maximum current velocity has a much greater magnitude for the hurricanes (Hazel and Isabel) as compared to the northeasters (NE20 and NE33) and the normal tide condition, for both the existing condition and the alternative configurations. The calculated maximum current velocity from the two northeasters is similar to that of the the normal tide condition at the SAV and oyster bed areas. Tables 11 to 18 present the maximum current velocity at comparison locations for the storms and the individual James Island and Barren Island alternatives.

James Island

For the James Island alternative evaluation, the maximum current velocity was overall strong during Hurricanes Hazel and Isabel (large hurricanes) in the existing condition, the future without-project condition, and for all six alternatives, because the low-lying island area was partially or completely submerged under the peak storm surge. In the case of Hurricanes Hazel and Isabel for all alternatives, the current velocity was stronger at the tidal gut south channel (Point 7) than at the north channel (Point 9) because more water entered the lower wetland through the south tidal gut. For the northeasters NE20 and NE33, the current velocity was stronger at the tidal gut north channel (Point 9) than the south channel (Point 7) because more water flowed into the wetland through the north tidal gut. The current velocity during these northeasters was weak in the tidal gut (Points 7 and 9) as compared to the existing island condition. The current magnitude in the existing condition was similar to the future without-project condition for both hurricanes and northeasters.

With a bird island present at the tidal gut south entrance (Alts JI-3 and JI-6), the maximum current velocity weakened in the tidal gut south channel (Point 7) because of increased friction. However, the current velocity was stronger at the narrower channel around the bird island (Point 16). On the other hand, the current velocity also became stronger in the local channel (Points 1 and 12) for all six alternatives other than the existing island condition because of the narrower water exchange area between James and Taylors Islands for the local channel.

The behavior of the individual alternatives with respect to the velocity is summarized as follows:

Alt JI-1. The maximum current velocity can become strong at the tidal gut channel and entrance area (Points 5, 7, 8, 9, 14, and 15) in a hurricane with high storm surge (e.g., Hurricane Isabel). The current velocity was generally stronger in the local channel (Points 1 and 12), with the current magnitude similar to other alternatives, as compared to the existing island condition. A strong current also occurred at the southeast corner of the island alternative because of the sharp turning angle of the flow between the south tidal gut outlet and open bay. In the case of a northeaster, the current at all key locations overall was not strong, similar to the current magnitude in other alternatives.

Alt JI-2. The maximum current velocity was similar to that in Alt JI-1. The maximum current can also become stronger at the tidal gut channel and entrance area (Points 5, 7, 8, 9, 14 and 15) in a hurricane (e.g., Hurricane Hazel).

Alt JI-3. The maximum current velocity was similar to that in Alts JI-1 and JI-2. However, with a bird island present in the tidal gut south entrance, the maximum current was stronger around the bird island (Point 16) in a hurricane with high storm surges (e.g., Hurricane Hazel). In contrast, the current in the tidal gut (Points 7 and 9) was generally weaker than for the other alternatives in a northeaster because of increased friction at the bird island periphery.

Alt JI-4. The maximum current velocity was similar to that in Alt JI-1. However, the current in the south end of the existing island (Point 14) can become strong in a hurricane (e.g., Hurricane Hazel). The current velocity was reduced in the tidal gut and at the north entrance (Points 7, 8, and 9) as a result of wider channel section.

Alt JI-5. The maximum current velocity was similar to that in Alt JI-4. Because the c-shaped tidal gut cross section is smaller (150 ft wide) and the current velocity in the channel similar to that of Alt JI-4, the flow discharge in the tidal gut was the weakest among all six alternatives.

Alt JI-6. The maximum current velocity was similar to that in Alt JI-3. The current velocity at the tidal gut and around the bird island (Points 7, 8, 9, and 16) was weaker than that in Alt JI-3 because of the wider channel section. The current in the south end of the existing island (Point 14) can become strong in a hurricane (e.g., Hurricane Hazel).

Barren Island

For the Barren Island alternatives, the calculated maximum current velocity was strong during Hurricane Hazel and Hurricane Isabel, because the existing island and alternatives were either partially or completely submerged under the peak storm surge. The current velocity in the existing island case was similar to the future without-project condition. The current velocity can become strong at the low-crested south breakwater (Points 16 and 17), especially in a hurricane. The effect of the individual alternatives on the current velocity is summarized as follows.

Alt BI-1. The maximum current velocity was similar to that in the existing island condition. However, the current magnitude was reduced significantly at the high-crested south breakwater (Points 16 and 17), especially in a northeaster storm. The current can become strong at the tip of south breakwater (Point 1) during a northeaster because of the sharp turning of the current flow.

Alt BI-2. The maximum current velocity was similar to that in Alt BI-1. However, the current flow becomes weaker south of the short south breakwater (Point 1) in the northeaster.

Alt BI-3. The maximum current velocity was similar to that in Alt BI-1. However, the current flow is stronger at the low-crested south breakwater (Points 16 and 17).

Alt BI-4. The maximum current velocity was similar to that in Alt BI-2. However, the current flow is stronger at the low-crested short south breakwater (Points 16 and 17).

Alt BI-5. The maximum current velocity was similar to that in Alt BI-3. However, the current flow was strong at the segmented south breakwater (Points 16 and 17) during the hurricanes.

Alt BI-6. The maximum current velocity was similar to that in Alt BI-4. However, the current flow becomes strong at the segmented short south breakwater (Points 16 and 17) during the hurricanes.

Sedimentation

Sedimentation is evaluated as the change of the bottom elevation surrounding the island and at the tidal guts and navigation channels. Results from the sediment transport simulations are evaluated at the same location as in the current velocity comparison. The evaluation results are presented only for the storms because the calculated bottom elevation change was negligibly small under the normal tide condition as compared to the storms. In the case of the normal tide, locally generated wind waves are small and, therefore, sediment movement is insignificant under the weak tidal current.

The sediment transport simulation shows that the bottom elevation change is greater for hurricanes as compared to northeasters. Bottom erosion will take place in areas with strong currents and gradients in the current, whereas sediment shoaling occurs next to erosion areas where the current is diminished. Tables 19 through 26 present the calculated bottom elevation change (positive values denote accretion and negative values denote erosion) at locations selected for the evaluation of James Island and Barren Island alternatives (Figures 40 and 41).

Table 19
Calculated Bed Elevation Change (cm) at James Island During Hurricane Hazel

Location	Existing	Future	JI-1	JI-2	JI-3	JI-4	JI-5	JI-6
1	-0.10	-0.10	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.10	0.20	0.00	0.00	0.00	0.00	0.00	0.00
4	-0.40	-1.00	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
5	-0.10	0.00	0.60	0.50	0.60	0.40	0.60	0.50
6	0.20	0.20	0.50	0.50	0.60	0.60	0.60	0.70
7	0.30	0.30	-0.10	-0.20	-0.10	0.00	0.00	0.00
8	0.20	0.00	0.10	0.10	0.10	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	0.00
10	0.00	0.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
11	-0.10	-0.10	0.10	0.10	0.10	0.10	0.10	0.10
12	0.00	0.00	-0.10	-0.10	-0.10	0.00	-0.10	0.00
13	-0.10	0.00	-10.60	-10.40	-10.50	-11.50	-11.50	-10.90
14	-4.80	-2.20	-6.80	-4.30	-2.00	-7.90	-7.90	-7.50
15	0.20	0.10	0.10	0.00	0.00	-0.20	-0.20	0.00
16	-0.40	-0.40	0.00	0.00	-1.20	0.20	0.20	-0.30

NOTE: Positive values denote accretion, and negative values denote erosion.

Table 20
Calculated Bed Elevation Change (cm) at James Island During Hurricane Isabel

Location	Existing	Future	JI-1	JI-2	JI-3	JI-4	JI-5	JI-6
1	0.00	0.10	-0.10	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	-0.20	-0.40	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	-0.20	0.20	0.40	0.20	0.40	0.50	0.30
6	-0.10	-0.10	0.10	0.00	0.00	0.00	-0.10	0.00
7	0.10	0.10	0.00	-0.10	-0.20	0.00	0.00	0.00
8	0.00	0.30	-0.10	0.00	-0.10	0.00	0.00	0.00
9	0.10	0.10	0.00	-0.10	0.00	0.00	0.00	0.00
10	0.00	0.00	0.20	0.30	0.30	0.30	0.20	0.30
11	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10
12	0.10	0.10	-0.20	-0.20	-0.10	-0.20	-0.20	-0.20
13	0.20	0.30	-9.95	-9.52	-9.53	-9.45	-9.65	-9.35
14	-3.50	0.50	-3.20	-1.80	-2.50	-1.80	-1.80	-1.80
15	0.10	0.10	0.00	0.10	0.00	0.00	0.20	0.00
16	-0.20	-0.20	-0.10	0.00	-5.30	0.00	0.00	0.10

NOTE: Positive values denote accretion, and negative values denote erosion.

Table 21
Calculated Bed Elevation Change (cm) at James Island During NE20

Location	Existing	Future	JI-1	JI-2	JI-3	JI-4	JI-5	JI-6
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.10	0.90	0.00	0.00	0.00	0.00	0.00	0.00
5	0.10	0.20	0.00	0.00	0.00	0.00	0.00	0.00
6	0.10	0.20	0.10	0.10	0.10	0.10	0.10	0.10
7	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	-0.20	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.10	-0.60	-0.60	-0.60	-0.60	-0.60	-0.60
11	0.00	-0.10	0.10	0.10	0.10	0.10	0.10	0.10
12	0.00	0.00	-0.10	-0.10	0.00	0.00	-0.10	-0.10
13	0.00	-0.10	-3.30	-3.40	-3.20	-3.30	-3.30	-3.10
14	-0.50	-2.00	0.10	0.10	0.10	0.10	0.10	0.10
15	0.00	-0.10	0.00	0.00	0.00	0.00	0.00	0.00
16	0.10	-0.20	0.00	0.00	0.00	0.00	0.00	0.00

NOTE: Positive values denote accretion, and negative values denote erosion.

Table 22
Calculated Bed Elevation Change (cm) at James Island During NE33

Location	Existing	Future	JI-1	JI-2	JI-3	JI-4	JI-5	JI-6
1	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20
14	-0.10	-0.50	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NOTE: Positive values denote accretion, and negative values denote erosion.

Table 23
Calculated Bed Elevation Change (cm) at Barren Island During Hurricane Hazel

Location	Existing	Future	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6
1	-0.10	-0.10	0.00	0.00	0.10	0.00	0.00	0.00
2	0.20	0.10	0.00	0.40	0.00	0.10	0.00	0.00
3	0.10	0.00	0.00	0.00	0.00	0.00	0.20	0.00
4	-0.10	-0.10	0.00	0.00	0.00	0.00	-0.10	0.00
5	0.00	-0.20	0.00	0.00	0.00	0.00	0.00	0.00
6	0.10	0.10	0.20	-0.10	0.20	0.10	0.20	0.30
7	0.20	0.20	0.00	0.30	0.00	0.20	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
9	-0.10	0.30	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	-0.30	0.00	0.00	0.00	0.00	0.10	0.00
11	0.00	-0.40	0.00	0.00	0.00	0.00	-0.10	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	-0.10	0.00
14	15.30	-0.90	1.20	1.10	1.00	1.40	8.50	8.30
15	0.60	-0.10	0.20	0.40	0.00	0.00	-2.90	-0.60
16	0.20	0.20	-0.10	-0.10	1.00	0.50	20.10	8.00
17	0.00	-0.10	1.10	0.70	-1.20	-0.10	-15.70	-32.70

NOTE: Positive values denote accretion, and negative values denote erosion.

Table 24
Calculated Bed Elevation Change (cm) at Barren Island During Hurricane Isabel

Location	Existing	Future	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6
1	-0.20	-0.10	0.00	0.10	0.10	0.10	0.00	0.00
2	0.30	0.30	0.00	0.20	0.00	0.10	-0.10	0.00
3	-0.20	-0.20	0.00	0.00	0.00	0.00	0.00	0.10
4	-0.20	-0.30	0.00	0.00	0.00	-0.10	0.00	-0.20
5	0.00	0.20	0.30	0.00	0.10	0.00	0.00	0.00
6	0.20	0.20	0.20	0.30	0.20	0.20	0.30	0.40
7	0.30	0.30	0.00	0.20	0.00	-0.10	-0.10	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.10	0.20	0.00	0.00	0.00	0.00	0.00	0.00
11	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00
12	-0.10	-0.30	-0.20	-0.10	-0.20	-0.10	-0.10	-0.10
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	58.50	-1.90	-3.40	1.30	0.00	0.90	3.70	4.20
15	1.80	0.70	9.00	0.60	2.80	-0.20	-3.30	-1.40
16	-0.30	-0.40	-0.10	0.00	-3.40	-2.30	23.00	32.60
17	-0.20	-0.30	0.70	1.10	4.70	2.00	-17.00	-42.40

NOTE: Positive values denote accretion, and negative values denote erosion.

Table 25
Calculated Bed Elevation Change (cm) at Barren Island During NE20

Location	Existing	Future	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6
1	-0.10	0.00	-0.10	-0.10	-0.10	-0.10	0.00	0.00
2	-0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.10
4	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	-0.10	0.00	0.00	0.00	0.00
6	-0.20	0.00	0.00	-0.10	0.00	-0.10	0.00	0.00
7	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	-0.10	0.00	-0.20	-0.20	-0.20	-0.20	-0.40	-0.30
13	-0.10	0.00	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
14	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.20	0.00	0.00	0.00	0.00	0.00	0.90	0.90
17	0.00	0.00	0.20	0.20	0.30	0.30	1.20	-0.10

NOTE: Positive values denote accretion, and negative values denote erosion.

Table 26
Calculated Bed Elevation Change (cm) at Barren Island During NE33

Location	Existing	Future	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	-0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00
4	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	-0.10	-0.50	-0.20	-0.10	-0.10	-0.20	-0.10	-0.10
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40
17	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.10

NOTE: Positive values denote accretion, and negative values denote erosion.

James Island

For the James Island alternatives, the greatest bed erosion occurred at the southeast corner of the alternative island (Point 13) and at the southern end of the existing island (Point 14). There was sediment accretion and erosion along the east and south sides of the alternative island (Points 6 and 10). Mild sediment shoaling also occurred in the access channel (Point 11). The evaluation of sedimentation for the individual James Island alternative is summarized as follows:

Alt JI-1. Sediment erosion was significant at the southeast corner of the alternative island (Point 13) as a result of the strong current (and gradient) in the area. The southern end of the existing island (Point 14) can erode extensively in a hurricane (e.g., Hurricane Hazel). There was mild erosion in the local channel (Points 1 and 12) corresponding to the increased current velocity at the channel.

Alt JI-2. The bottom change pattern was similar to that in Alt JI-1. The erosion at the southern end of the existing island was not as severe as in Alt JI-1 under a hurricane.

Alt JI-3. The bed change pattern was similar to that in Alt JI-1. However, more erosion can occur in the south tidal gut around the bird island under a hurricane.

Alt JI-4. The bed change pattern was similar to that in Alt JI-1. The sedimentation was smaller in the tidal gut and at the north entrance (Points 7, 8, and 9) than in Alt JI-1.

Alt JI-5. The bed change pattern was similar to that in Alt JI-4.

Alt JI-6. The bed change pattern was similar to that in Alts JI-4 and JI-5.

Barren Island

For the Barren Island alternatives, the strongest sediment shoaling appeared at the north island tidal channel cut (Points 14 and 15) as a result of sediment being eroded from the existing island and carried by the current to the channel. For the existing island, sediment shoaling at the north island tidal channel cut can be strong in a hurricane (e.g., Hurricane Isabel). The greatest erosion occurred at the up-wave side of the low-crest south breakwater (Points 16 and 17) for the hurricanes. Evaluation of sedimentation for the individual Barren Island alternative is summarized as follows:

Alt BI-1. Sedimentation in the lee side (sheltered area) of the island (Points 1 to 12) was overall minor. Sediment shoaling in the north island tidal channel cut (Points 14 and 15) was much smaller than in the existing island condition. There was mild sediment shoaling at the high-crest south breakwater (Points 16 and 17) as a result of the weaker current at the breakwater.

Alt BI-2. The sedimentation pattern was similar to that in Alt BI-1. However, some sediment deposition occurred east of the short south breakwater (Points 2, 6, and 7).

Alt BI-3. Bottom change was similar to that in Alt BI-1. However, both sediment accretion and erosion were more significant at the low-crested south breakwater (Points 16 and 17).

Alt BI-4. Bottom change was similar to that in Alt BI-3. However, both sediment accretion and erosion at the short and low-crest south breakwater (Points 16 and 17) were not as significant as in Alt BI-3.

Alt BI-5. Bottom change was similar to that in Alt BI-3. However, both sediment shoaling and erosion can become more significant in the north island tidal cut channel (Points 14 and 15) in a hurricane (e.g., Hurricane Hazel). More sediment deposition and erosion appeared at the segmented south breakwater (Points 16 and 17).

Alt BI-6. Bottom change was similar to that in Alt BI-5. However, both sediment deposition and erosion were more significant at the segmented short south breakwater than in Alt BI-5.

Summary

Results from wave, hydrodynamic, and sediment transport numerical simulation models were analyzed to evaluate the performance of James Island and Barren Island plan view alternatives from engineering assessments. For the James Island alternatives, the wave height reduction was found to be approximately 1-2 ft on the lee of the island, as compared to the existing configuration and future without-project condition, for four severe storms. With respect to current velocity and sediment transport, no major performance differences were found among the alternatives (Alts JI-1 to JI-6). In the absence

of protective structures (such as riprap dikes), significant erosion can occur at the southeast corner of the alternative island and at the south end of the existing island in a hurricane. If a bird island is present at the tidal gut south entrance, erosion under a hurricane was predicted to be greater at the bird island (Point 16) for a narrow tidal channel (Alt JI-3) as compared to a wider tidal channel (Alt JI-6).

Bed erosion of as much as 10 to 20 cm was calculated to occur in the local channel (Points 1 and 12) for all alternatives in a hurricane because of the increased gradients in current velocity. Similarly, channel erosion of 10 to 20 cm can occur at the narrower tidal gut in a hurricane for Alts JI-1 to JI-3 because of increased current magnitude. For all alternative configurations, accretion of 20 to 60 cm was calculated to occur at the tidal gut south entrance (Point 5) under a hurricane as a result of scour of the tidal gut channel and erosion at the south end of the existing island, as well as erosion at the southeast corner of the island alternative. Sediment accumulation at the tidal gut south entrance can be minimized by reducing the erosion at the south end of the existing island and southeast corner of the island alternative with protective structures.

For the Barren Island alternatives, Alts BI-1 and BI-3 have a longer south breakwater and provide the greatest wave height reduction, reaching 2-3 ft in the lee of the island for the four storms evaluated. The future without-project condition results in a 2-4 ft increase in wave height at the mainland nearshore. With respect to current velocity and sediment transport, no significant performance differences were found among the existing configuration and alternatives (Alts BI-1 to BI-6) at locations distant from the site (Points 6 to 13). The influence of the alternatives is localized in the area at and near the south breakwater (Points 1 to 5).

For the four storm conditions, the maximum current velocity at the Honga River Tar Bay entrance (Point 12) was always strong, approximately 3.3 ft/sec, regardless of the existing configuration or future without-project or the island alternatives. As a result, the Honga River Tar Bay entrance usually experiences bed erosion of 10 to 50 cm during severe storms. The predicted erosion is slightly greater for the future with-project condition than for the existing configuration and the alternatives. Alts BI-3 and BI-4, with a low-crest south breakwater, are likely to induce relatively greater current velocities during storms, causing potentially significant temporary erosion at the breakwaters. Segmented breakwaters (Alts BI-5 and BI-6) can create a similar condition with strong current around the segmented breakwater element, causing either sediment deposition or erosion at the structures, depending on the direction of the current. The strong current at the north island cut (Points 14 and 15) in a hurricane can also cause extensive bed erosion or accretion at various locations along and near this cut.

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Appendix A
Data Acquisition and Baseline Monitoring

This chapter summarizes coastal engineering data gathered as part of the Coastal Monitoring and Modeling Support task undertaken by Blasland, Bouck & Lee, Inc. (BBL), and Andrews, Miller & Associates, Inc. (AMA), at James Island and Barren Island. Collected information encompassed pre-existing data and preliminary investigations to develop baseline monitoring for the regions surrounding James Island and Barren Island. This work was undertaken by the Maryland Port Administration (MPA) and the U.S. Army Corps of Engineers, Baltimore District (hereafter, Baltimore District), through the Maryland Environmental Service (MES).

Data Acquisition

Existing data assembled to support the coastal modeling effort included:

a. Sediment type within the vicinity of James Island and Barren Island.

b. Wind data.

c. Review of dredging frequency of nearby navigational (Federal) channels, as well as estimated shoaling rates of the channels (based on available hydrographic surveys).

d. Available hydrographic surveys.

e. Aerial photography.

Data collection and monitoring information assembled for the coastal modeling tasks included:

a. Thirty sediment grab samples collected at each island at the time of the bathymetric surveys. Sediment grain size distributions (GSDs) and characteristics were determined for each sample using standard sieve and hydrometer analyses.

b. Identification of locations and characteristics of navigational channels, and calculation of associated historical shoaling rates.

c. Hydrographic surveys conducted at James Island and Barren Island.

d. High spatial resolution aerial imagery obtained for both islands.

e. Historical shoreline position data developed for the island shorelines and mainland shorelines east of James Island and Barren Island using available historical aerial photography and the latest high spatial resolution imagery.

Existing Data Assessment

Sediment type at James Island and Barren Island

E2CR, Inc. completed a geotechnical investigation for both James Island and Barren Island over the winter of 2001 as part of a reconnaissance study conducted by the MPA (E2CR 2002a, 2002b)[1]. The geotechnical studies involved several aspects including a field investigation with cone penetrometer tests (CPT), borings, and laboratory testing for determination of sediment characteristics. Twenty-two borings and four CPTs were made around James Island (Figure A1), extending between 27.5 and 70 ft below water level and 18 borings were made in the vicinity of Barren Island (Figure A2), extending between 35 and 70 ft.

A feasibility study was conducted by the U.S. Army Corps of Engineers (USACE) to further evaluate the potential for James Island and Barren Island to undergo restoration activities (USACE 2005). Sixty-two borings in the vicinity of James Island (Figure A1) and an additional 27 borings around Barren Island (Figure A2) were collected by the USACE to investigate the subsurface conditions along proposed dike and channel alignments. These borings were collected during the summer of 2004. Additional sampling involved collection of undisturbed samples of clay and silt for laboratory testing, which included triaxial strength testing, unconfined compression testing, and consolidation testing. On-site testing included grain size analysis, Atterberg Limits, and water contents.

1 References cited in this appendix are contained in the reference section of the main text of this report.

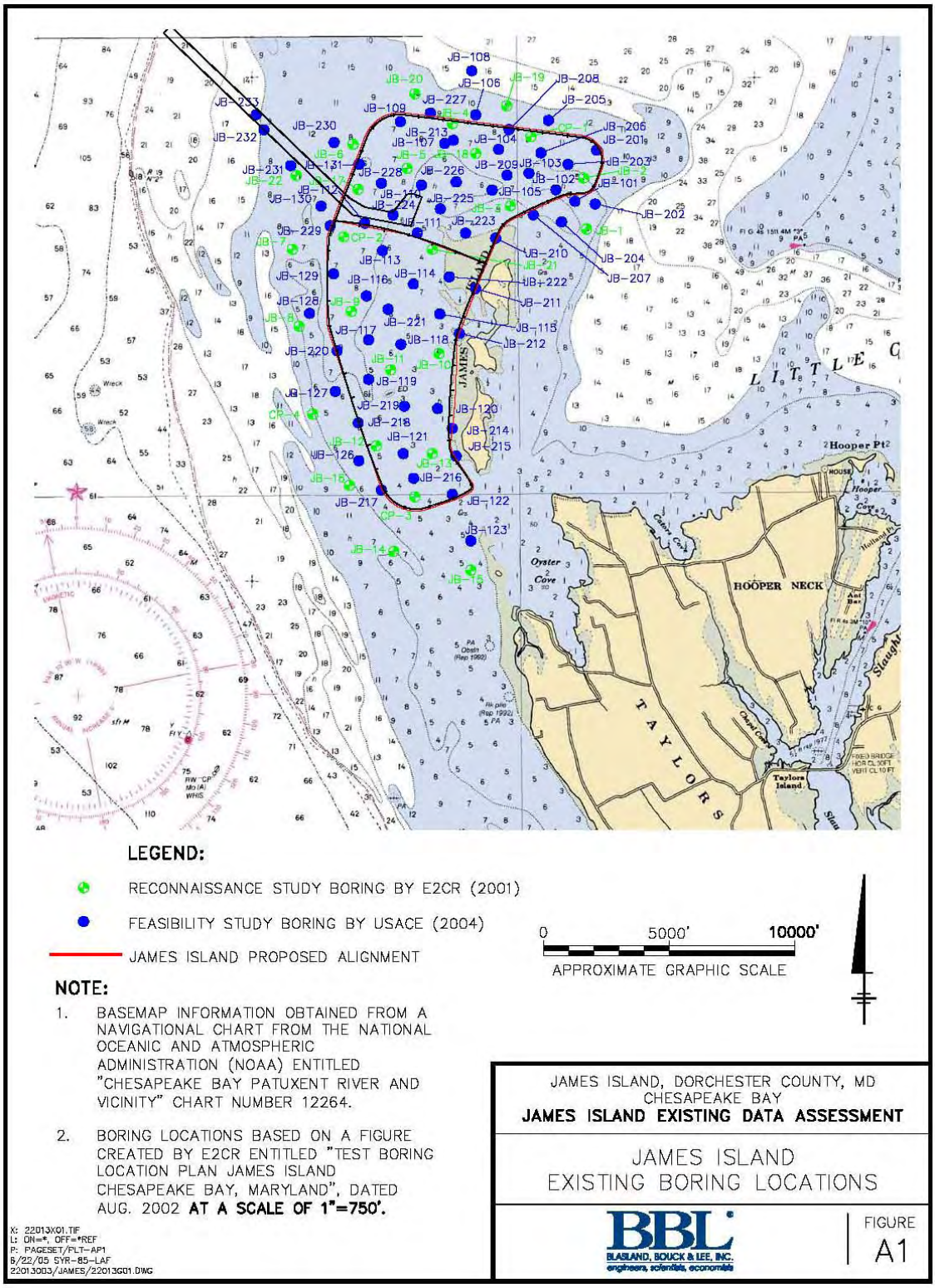

Figure A1. James Island existing boring locations

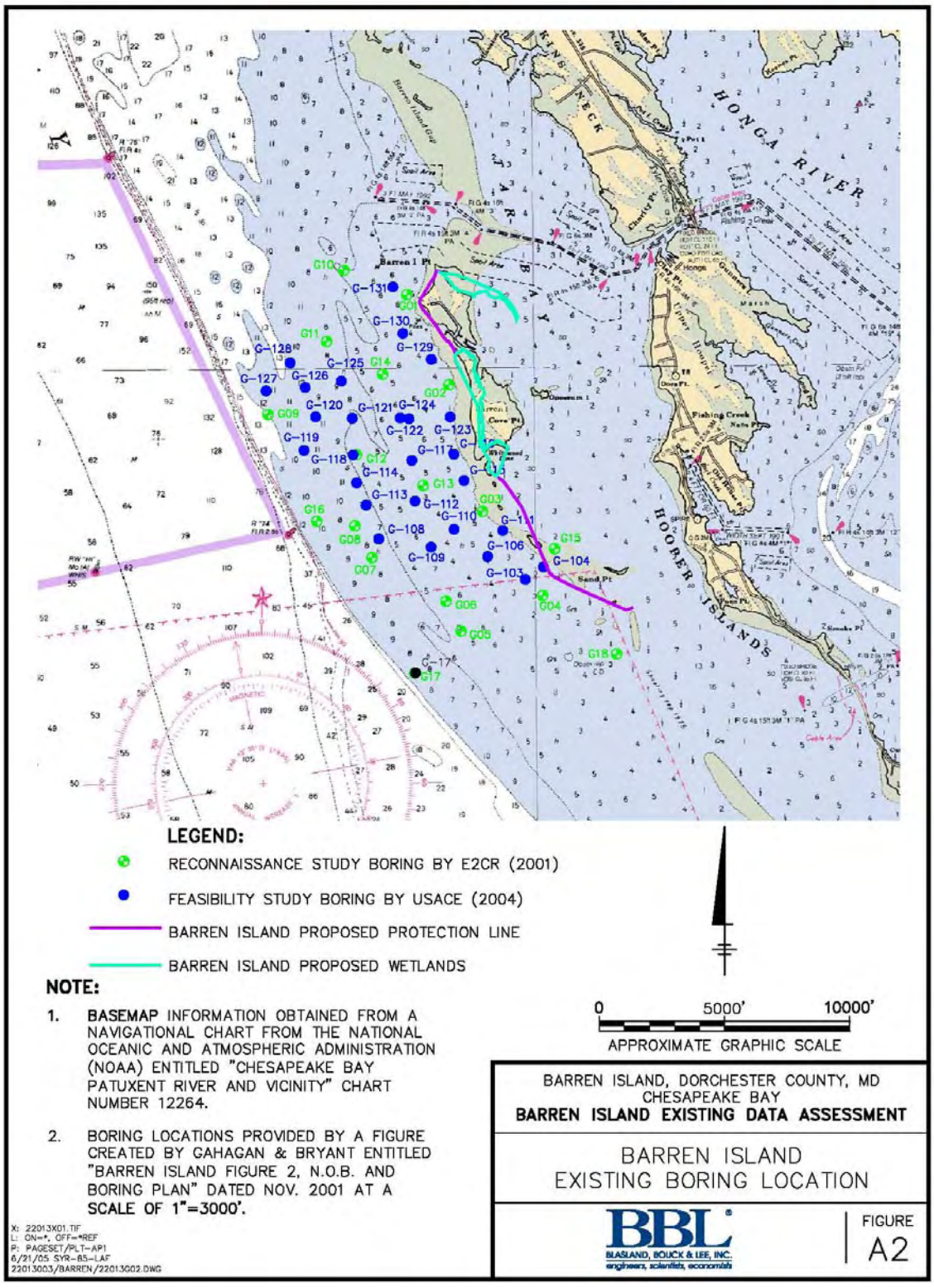

Figure A2. Barren Island existing boring locations

Tables A1 and A2 list information on the borings collected as part of the Reconnaissance and Feasibility Studies at James Island and Barren Island. Each table lists boring ID, location coordinates (X, Y) in Maryland State Plane, North American Datum 1983 (NAD83) (ft), the phase of study from when the boring was conducted, and the organization that collected the samples.

Table A1
Existing Borings - James Island

Boring ID	X Coordinate	Y Coordinate	Study Phase	Performed By
CP-1	1,503,547.73	318,451.27	RECON (2001)	E2CR
CP-2	1,496,094.74	314,458.80	RECON (2001)	E2CR
CP-3	1,498,937.64	304,093.73	RECON (2001)	E2CR
CP-4	1,494,865.38	307,395.20	RECON (2001)	E2CR
JB-1	1,505,768.86	314,771.88	RECON (2001)	E2CR
JB-2	1,505,653.61	316,806.50	RECON (2001)	E2CR
JB-3	1,502,733.88	315,693.22	RECON (2001)	E2CR
JB-4	1,500,426.62	318,975.34	RECON (2001)	E2CR
JB-5	1,498,623.21	317,190.39	RECON (2001)	E2CR
JB-6	1,496,471.83	318,150.12	RECON (2001)	E2CR
JB-7	1,494,051.53	313,965.71	RECON (2001)	E2CR
JB-8	1,494,320.46	310,894.58	RECON (2001)	E2CR
JB-9	1,496,404.59	311,488.89	RECON (2001)	E2CR
JB-10	1,499,890.99	309,807.78	RECON (2001)	E2CR
JB-11	1,497,970.12	309,155.17	RECON (2001)	E2CR
JB-12	1,497,393.85	306,122.43	RECON (2001)	E2CR
JB-13	1,499,622.07	305,815.31	RECON (2001)	E2CR
JB-14	1,498,085.37	301,911.52	RECON (2001)	E2CR
JB-15	1,501,158.77	301,170.23	RECON (2001)	E2CR
JB-16	1,496,322.51	304,550.34	RECON (2001)	E2CR
JB-17	1,496,665.92	316,358.37	RECON (2001)	E2CR
JB-18	1,501,354.38	317,787.88	RECON (2001)	E2CR
JB-19	1,502,580.77	319,690.26	RECON (2001)	E2CR
JB-20	1,498,938.22	320,165.86	RECON (2001)	E2CR
JB-21	1,499,629.15	313,959.74	RECON (2001)	E2CR
JB-22	1,494,210.62	316,907.99	RECON (2001)	E2CR
JB-101	1,505,302.92	315,875.03	FEASIBILITY (2004)	USACE
JB-102	1,504,544.64	316,334.80	FEASIBILITY (2004)	USACE
JB-103	1,503,475.02	316,994.63	FEASIBILITY (2004)	USACE
JB-104	1,502,268.25	317,946.89	FEASIBILITY (2004)	USACE
JB-105	1,502,009.86	316,326.38	FEASIBILITY (2004)	USACE
JB-106	1,501,352.45	319,326.19	FEASIBILITY (2004)	USACE
JB-107	1,500,121.21	318,184.27	FEASIBILITY (2004)	USACE
JB-108	1,501,196.79	321,075.21	FEASIBILITY (2004)	USACE
JB-109	1,498,351.10	319,051.73	FEASIBILITY (2004)	USACE
JB-110	1,499,195.47	316,528.65	FEASIBILITY (2004)	USACE
JB-111	1,499,034.34	314,615.49	FEASIBILITY (2004)	USACE
JB-112	1,496,933.66	315,005.21	FEASIBILITY (2004)	USACE
JB-113	1,497,640.74	313,907.53	FEASIBILITY (2004)	USACE
JB-114	1,498,874.04	312,580.94	FEASIBILITY (2004)	USACE
JB-115	1,499,923.73	311,384.60	FEASIBILITY (2004)	USACE
JB-116	1,497,002.00	312,105.00	FEASIBILITY (2004)	USACE

(Continued)

Table A1 (Concluded)

Boring ID	X Coordinate	Y Coordinate	Study Phase	Performed By
JB-117	1,497,089.00	310,349.00	FEASIBILITY (2004)	USACE
JB-118	1,498,374.64	310,169.67	FEASIBILITY (2004)	USACE
JB-119	1,497,088.98	308,774.60	FEASIBILITY (2004)	USACE
JB-120	1,499,839.55	307,610.57	FEASIBILITY (2004)	USACE
JB-121	1,498,469.29	305,810.17	FEASIBILITY (2004)	USACE
JB-122	1,500,420.56	304,195.40	FEASIBILITY (2004)	USACE
JB-123	1,501,157.41	302,339.30	FEASIBILITY (2004)	USACE
JB-126	1,496,698.53	305,534.58	FEASIBILITY (2004)	USACE
JB-127	1,495,764.92	308,299.91	FEASIBILITY (2004)	USACE
JB-128	1,494,733.74	311,408.54	FEASIBILITY (2004)	USACE
JB-129	1,495,692.30	312,983.30	FEASIBILITY (2004)	USACE
JB-130	1,495,196.58	315,680.91	FEASIBILITY (2004)	USACE
JB-131	1,496,710.41	317,360.76	FEASIBILITY (2004)	USACE
JB-201	1,506,169.82	317,914.86	FEASIBILITY (2004)	USACE
JB-202	1,506,114.23	315,769.76	FEASIBILITY (2004)	USACE
JB-203	1,505,037.75	317,350.08	FEASIBILITY (2004)	USACE
JB-204	1,504,776.58	315,051.71	FEASIBILITY (2004)	USACE
JB-205	1,504,254.11	319,104.57	FEASIBILITY (2004)	USACE
JB-206	1,503,953.76	317,807.45	FEASIBILITY (2004)	USACE
JB-207	1,503,646.08	315,336.79	FEASIBILITY (2004)	USACE
JB-208	1,502,683.59	318,738.99	FEASIBILITY (2004)	USACE
JB-209	1,502,601.52	316,917.44	FEASIBILITY (2004)	USACE
JB-210	1,502,150.97	314,405.28	FEASIBILITY (2004)	USACE
JB-211	1,501,346.99	312,396.39	FEASIBILITY (2004)	USACE
JB-212	1,500,708.18	310,611.29	FEASIBILITY (2004)	USACE
JB-213	1,500,461.97	318,308.12	FEASIBILITY (2004)	USACE
JB-214	1,500,417.52	306,825.65	FEASIBILITY (2004)	USACE
JB-215	1,500,576.56	305,713.99	FEASIBILITY (2004)	USACE
JB-216	1,498,881.69	304,831.82	FEASIBILITY (2004)	USACE
JB-217	1,497,597.14	304,367.44	FEASIBILITY (2004)	USACE
JB-218	1,496,671.99	307,041.74	FEASIBILITY (2004)	USACE
JB-219	1,498,511.45	307,702.24	FEASIBILITY (2004)	USACE
JB-220	1,495,833.03	309,919.01	FEASIBILITY (2004)	USACE
JB-221	1,497,863.95	311,572.22	FEASIBILITY (2004)	USACE
JB-222	1,500,302.52	312,864.33	FEASIBILITY (2004)	USACE
JB-223	1,500,949.54	314,609.02	FEASIBILITY (2004)	USACE
JB-224	1,498,059.71	315,336.92	FEASIBILITY (2004)	USACE
JB-225	1,499,949.27	315,572.99	FEASIBILITY (2004)	USACE
JB-226	1,500,577.22	316,649.85	FEASIBILITY (2004)	USACE
JB-227	1,499,548.39	319,394.13	FEASIBILITY (2004)	USACE
JB-228	1,497,597.81	316,598.19	FEASIBILITY (2004)	USACE
JB-229	1,495,559.61	314,904.49	FEASIBILITY (2004)	USACE
JB-230	1,495,711.12	318,223.74	FEASIBILITY (2004)	USACE
JB-231	1,493,985.41	317,301.20	FEASIBILITY (2004)	USACE
JB-232	1,492,918.73	318,730.33	FEASIBILITY (2004)	USACE
JB-233	1,492,612.62	319,335.20	FEASIBILITY (2004)	USACE

Table A2
Existing Borings - Barren Island

Boring ID	X	Y	Study Phase	Performed By
G-1	1,522,379.54	246,553.30	RECON (2001)	E2CR
G-2	1,524,057.91	242,955.25	RECON (2001)	E2CR
G-3	1,525,389.96	237,897.72	RECON (2001)	E2CR
G-4	1,527,803.88	234,536.55	RECON (2001)	E2CR
G-5	1,524,539.00	233,144.18	RECON (2001)	E2CR
G-6	1,523,941.32	234,304.76	RECON (2001)	E2CR
G-7	1,520,981.28	236,047.34	RECON (2001)	E2CR
G-8	1,520,306.49	237,310.57	RECON (2001)	E2CR
G-9	1,516,828.51	241,768.80	RECON (2001)	E2CR
G-10	1,519,862.00	247,534.75	RECON (2001)	E2CR
G-11	1,519,172.22	244,688.60	RECON (2001)	E2CR
G-12	1,520,360.39	240,157.76	RECON (2001)	E2CR
G-13	1,523,028.88	238,928.70	RECON (2001)	E2CR
G-14	1,521,405.78	243,377.04	RECON (2001)	E2CR
G-15	1,528,281.10	236,403.93	RECON (2001)	E2CR
G-16	1,518,774.71	237,498.76	RECON (2001)	E2CR
G-17	1,522,725.63	231,436.06	RECON (2001)	E2CR
G-18	1,530,731.35	232,187.48	RECON (2001)	E2CR
G-103	1,527,109.94	235,174.26	FEASIBILITY (2004)	USACE
G-104	1,527,831.17	235,675.89	FEASIBILITY (2004)	USACE
G-106	1,525,603.91	236,092.66	FEASIBILITY (2004)	USACE
G-108	1,521,254.28	236,796.11	FEASIBILITY (2004)	USACE
G-109	1,523,345.18	236,468.91	FEASIBILITY (2004)	USACE
G-110	1,524,264.06	237,174.36	FEASIBILITY (2004)	USACE
G-111	1,526,209.19	237,129.48	FEASIBILITY (2004)	USACE
G-112	1,522,700.75	238,304.92	FEASIBILITY (2004)	USACE
G-113	1,520,749.43	238,137.57	FEASIBILITY (2004)	USACE
G-114	1,520,367.71	239,034.90	FEASIBILITY (2004)	USACE
G-115	1,524,662.66	239,130.06	FEASIBILITY (2004)	USACE
G-116	1,524,255.68	240,178.88	FEASIBILITY (2004)	USACE
G-117	1,522,576.11	239,932.66	FEASIBILITY (2004)	USACE
G-118	1,520,231.29	240,156.74	FEASIBILITY (2004)	USACE
G-119	1,518,269.42	240,333.45	FEASIBILITY (2004)	USACE
G-120	1,518,729.06	241,672.43	FEASIBILITY (2004)	USACE
G-121	1,520,195.82	241,613.22	FEASIBILITY (2004)	USACE
G-122	1,522,459.20	241,590.82	FEASIBILITY (2004)	USACE
G-123	1,524,108.19	241,664.80	FEASIBILITY (2004)	USACE
G-124	1,522,108.26	241,628.47	FEASIBILITY (2004)	USACE
G-125	1,519,761.63	243,107.01	FEASIBILITY (2004)	USACE
G-126	1,518,313.44	242,842.66	FEASIBILITY (2004)	USACE
G-127	1,516,752.64	242,709.04	FEASIBILITY (2004)	USACE
G-128	1,517,716.02	243,829.38	FEASIBILITY (2004)	USACE
G-129	1,523,348.45	243,975.33	FEASIBILITY (2004)	USACE
G-130	1,522,216.64	245,008.22	FEASIBILITY (2004)	USACE
G-131	1,521,819.31	246,866.46	FEASIBILITY (2004)	USACE

Chesapeake Bay wind data

Wind data were collected from a variety of locations throughout Chesapeake Bay for comparison to and possible input to the models. Locations at Baltimore-Washington International Airport (BWI), Thomas Point, a buoy in the Mid-Bay region between James Island and Barren Island, and a temporary National Oceanic and Atmospheric Administration (NOAA) station set up on Barren Island, allowed good coverage of the region of interest surrounding James Island and Barren Island. Wind data from BWI were collected by Weston Solutions, Inc., for 1951 through 1982 for extremal analysis (Weston Solutions, Inc. 2002). Thomas Point is a NOAA National Data Buoy Center (NDBC) location, sta TPLM2. Wind data were collected for 7 years (January 1993 through the end of 2000). The Mid-Bay buoy is operated by the Chesapeake Bay Observing System (CBOS); data were collected from June 1995 to July 2003. The station on Barren Island was a temporary NOAA station (ID No. 8571579). This station was installed in December 2001 and recorded wind speed from January 2002 through most of April 2003. Patuxent Naval Air Station wind data were evaluated through other conceptual design projects, but were not analyzed here due the completeness of the BWI wind data set that was ultimately used. Figure A3 shows the location of each wind station relative to James Island and Barren Island.

Wind information for BWI Airport was analyzed to determine yearly extreme wind speeds from 1951 through 1982 (Table A3). Wind roses were generated using the data gathered from the other three wind stations. Data were plotted at 10-deg intervals, displaying average wind speed frequency over the duration of each station's recorded data interval. Figures A4 through A6 show the wind rose diagram for each of these stations.

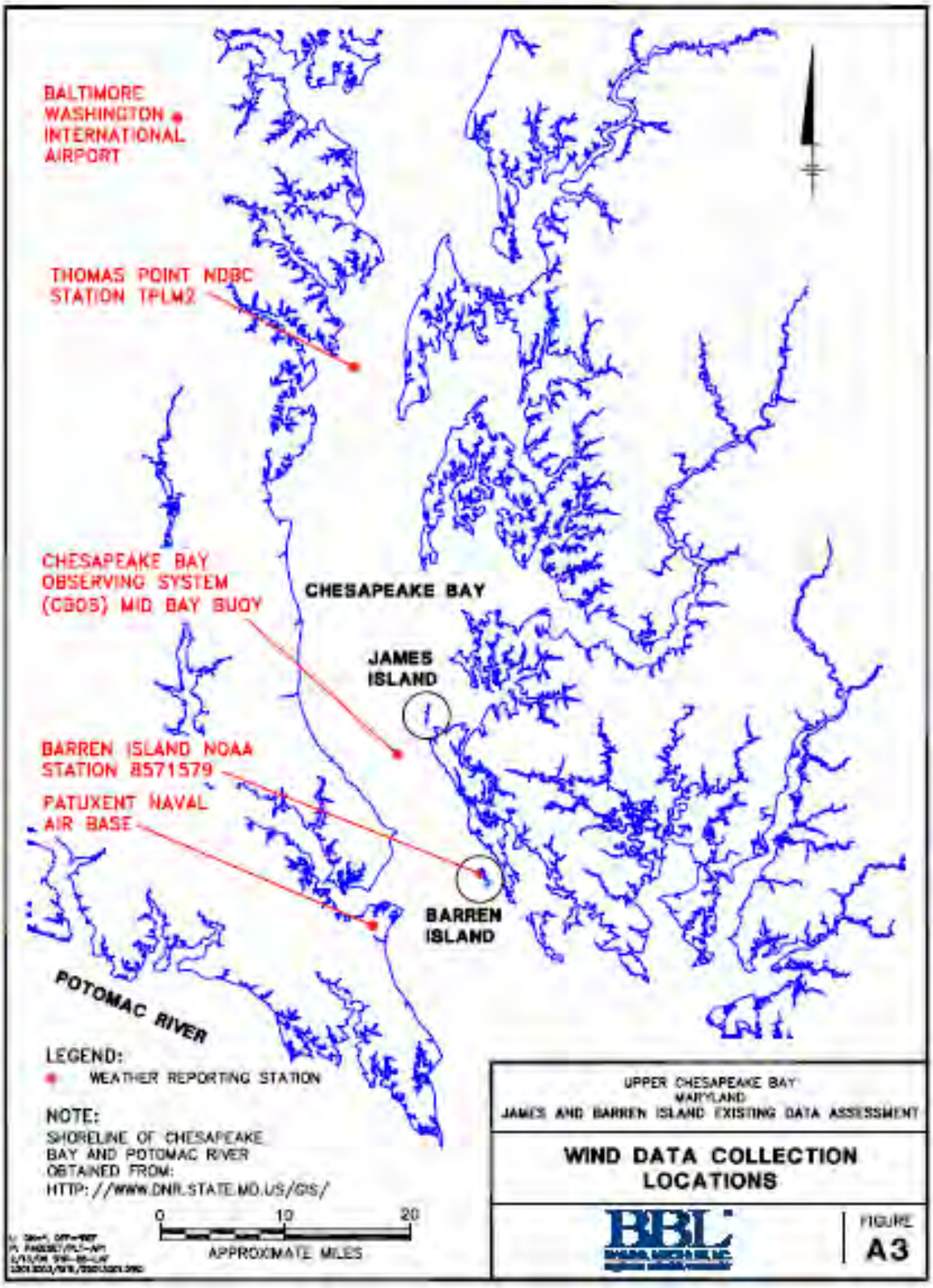

Figure A3. Wind data collection locations

Table A3
BWI Airport Annual Extreme Wind Speed (Weston Solutions, Inc. 2002)

Year	N	NE	E	SE	S	SW	W	NW
				Wind Direction				
1951	24	41	27	34	39	29	42	46
1952	66	25	47	66	41	66	46	43
1953	20	28	22	27	34	39	47	43
1954	31	27	22	60	28	39	57	44
1955	21	43	29	28	43	53	40	43
1956	29	34	25	24	28	34	56	40
1957	29	53	35	33	33	30	46	46
1958	30	52	25	33	37	43	40	43
1959	28	26	20	27	23	38	46	43
1960	26	38	28	27	25	35	40	53
1961	45	28	28	29	24	70	41	54
1962	56	41	28	17	25	36	42	61
1963	38	32	18	34	25	28	44	60
1964	34	31	23	24	47	23	48	61
1965	36	26	28	34	36	54	44	44
1966	32	25	29	24	47	43	50	48
1967	30	29	25	39	27	46	53	43
1968	45	30	36	26	19	45	48	50
1969	28	21	20	34	26	45	45	53
1970	28	28	18	21	39	34	48	60
1971	31	45	26	18	21	41	39	58
1972	28	25	35	26	20	41	41	41
1973	40	26	26	38	26	35	49	33
1974	32	23	46	29	33	33	45	41
1975	40	26	21	24	25	38	54	45
1976	31	18	20	28	32	28	45	54
1977	32	31	19	28	26	25	49	48
1978	39	28	36	28	19	52	33	45
1979	32	25	27	36	32	32	45	47
1980	33	27	18	32	20	32	45	50
1981	24	24	19	26	23	28	41	42
1982	31	20	23	23	29	34	40	48

NOTE: Data adjusted to 10-m (32.8 ft) elevation.

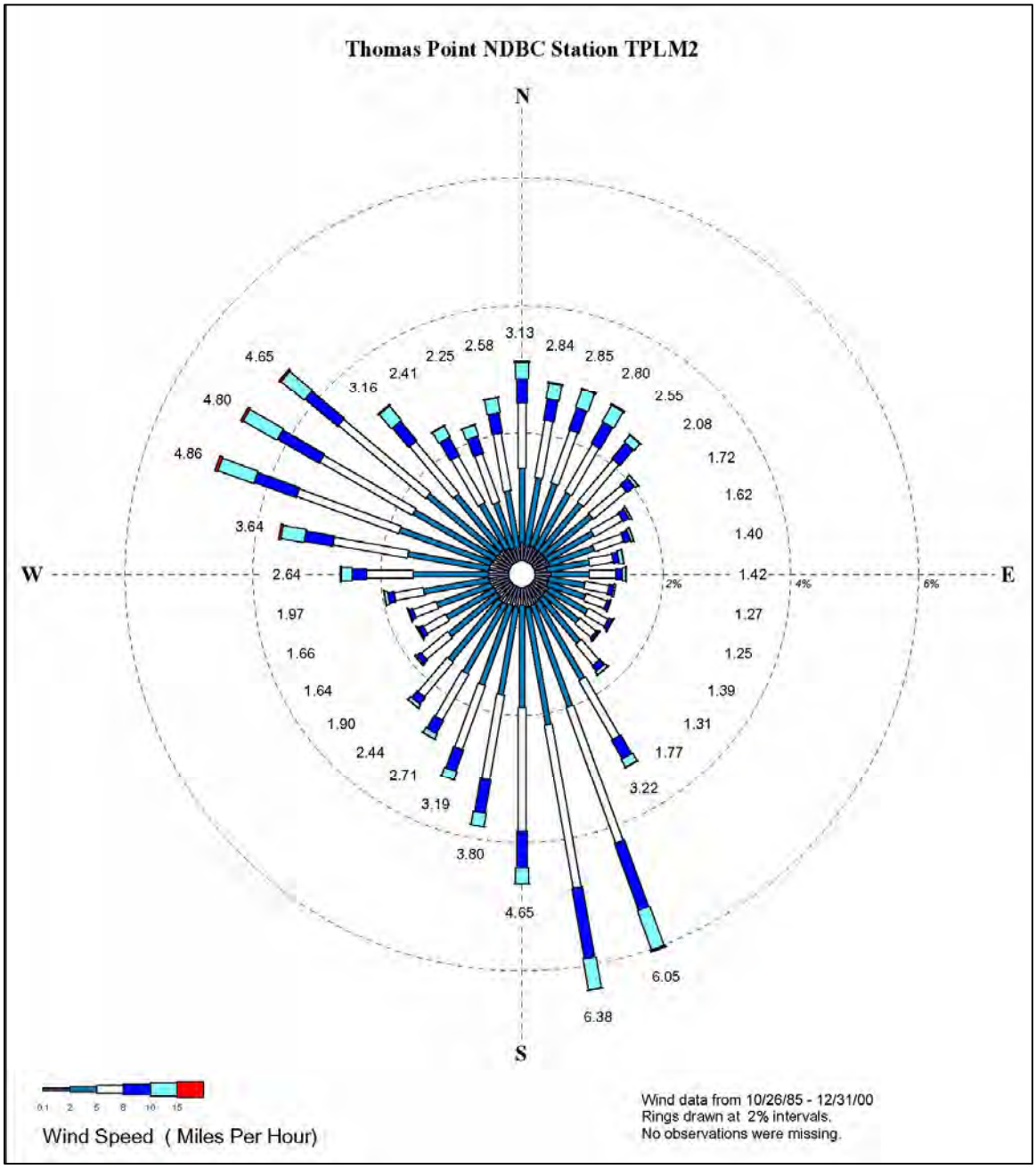

Figure A4. Thomas Point NDBC station wind rose

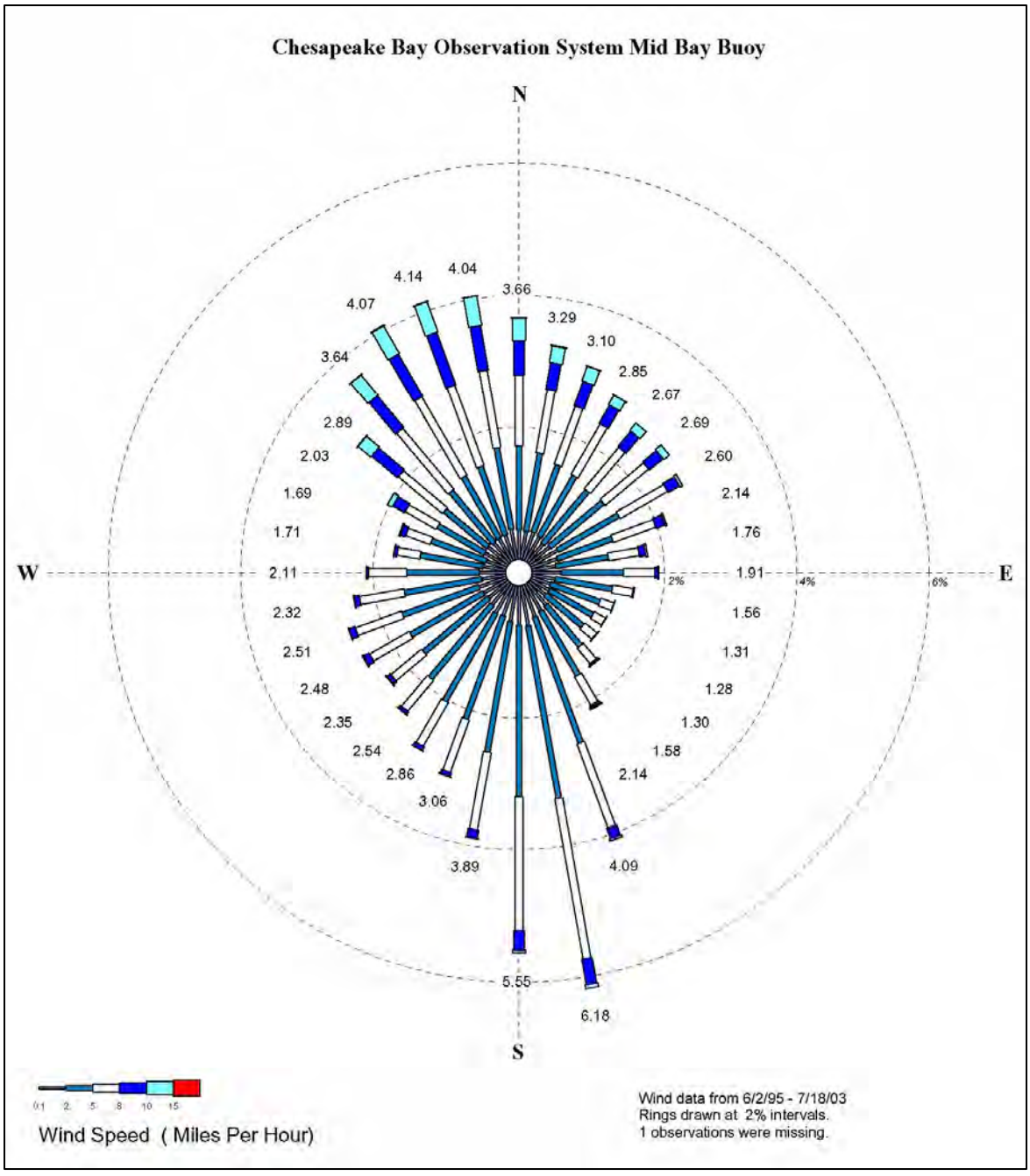

Figure A5. CBOS buoy wind rose

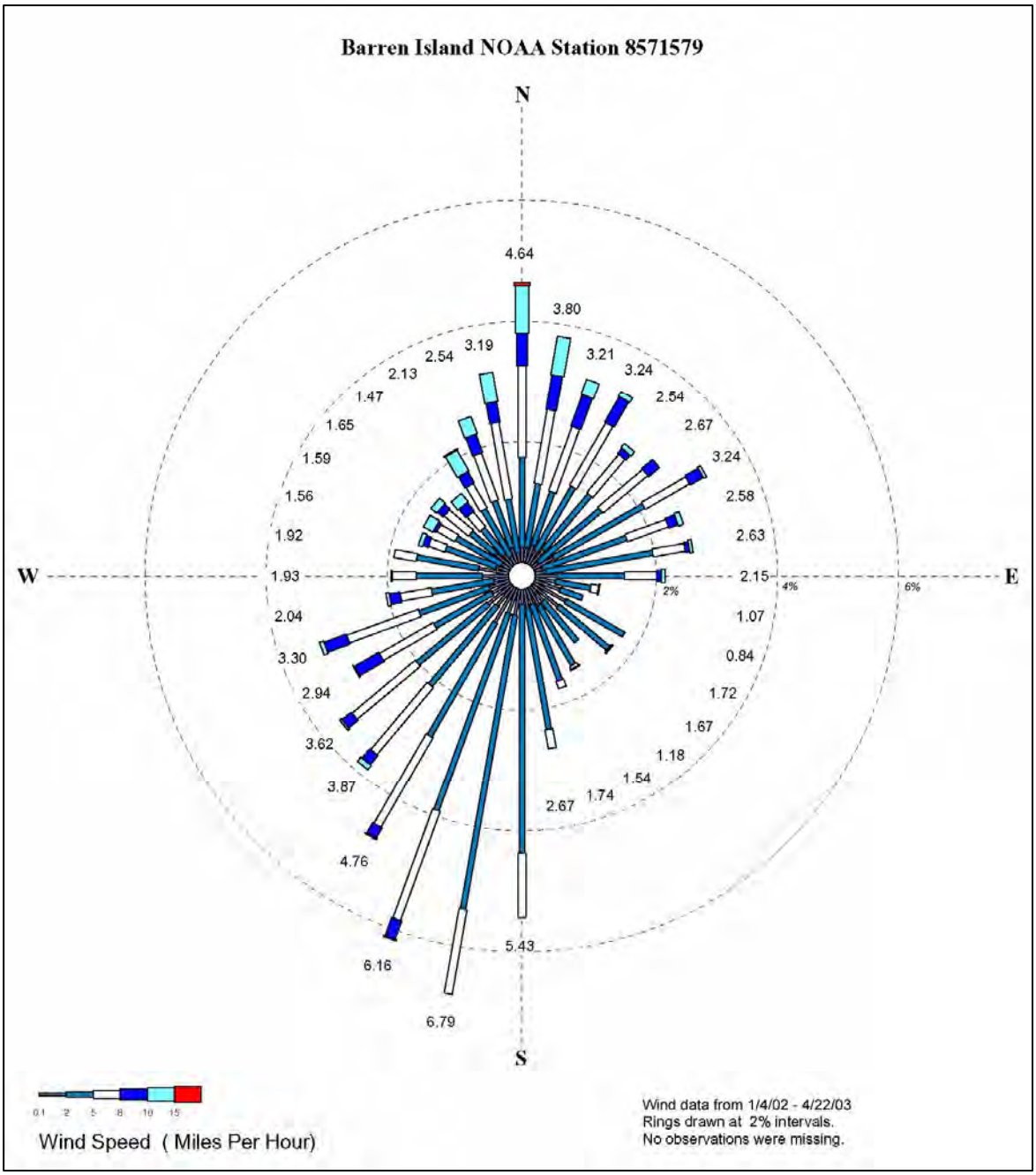

Figure A6. Barren Island NOAA station wind rose

Existing hydrographic surveys

Hydrographic survey data sets available for the James Island and Barren Island areas are as follows:

a. National Ocean Service (NOS) Digital Elevation Models and corresponding navigational charts for the Chesapeake Bay. Vertical and horizontal data are referenced to mean lower low water (mllw) based on the 1960 to 1978 tidal epoch and the Marylalnd State Plane, NAD83, respectively.

b. Hydrographic survey of Barren Island, MD, performed by Ocean Surveys, Inc., of Old Saybrook, CT, on 6-9 February and 20-23 February 2005. Vertical and horizontal data are referenced to mllw based on the 1960 to 1978 tidal epoch and the Maryland State Plane, NAD83, respectively.

c. Hydrographic survey of James Island, MD, performed by Ocean Surveys, Inc., on 8-12 January 2005. Vertical data are referenced to North American Vertical Datum 1988 (NAVD88). Horizontal data are referenced to the Maryland State Plane.

Aerial photography

An investigation of the available aerial photography for the James Island and Barren Island areas identified yearly aerial photographs from 1987 to 2004 that were obtained by the Virginia Institute of Marine Science (VIMS) in Gloucester, VA. These photographs were obtained as a part of the submerged aquatic vegetation monitoring program conducted by VIMS. The photographs provide an excellent source of shoreline data, as they are high resolution and were obtained as close as possible to mean low water. Digital copies of the photographs are available as a 12.5-micron resolution scan written to a CD-ROM at a cost of $335.00 for each year from the following vendor:

Air Photographics, Inc.
2115 Kelly Island Road
Martinsburg, WA 25401
1-800-624-8993

For the Mid-Bay Island study, digital photographs of James Island and Barren Island were obtained from Air Photographics, Inc., for 1989, 1999, and 2004. Additional aerial photographs were made available from the U.S. Army Engineer District, Baltimore, for March 2004 and January 2005.

Baseline Coastal Monitoring

Sediment sampling

Chesapeake Environmental Management (CEM) was subcontracted by BBL to collect grab samples in the vicinity of James Island and Barren Island to determine the composition of surficial sediments. Thirty samples were collected

in July 2005 at each island location. Locations of grab sample collection are shown on Figures A7 and A8.

These sediment samples, in conjunction with the existing boring samples and laboratory tests collected and run by E2CR and the Baltimore District, were analyzed to classify the top 6 in. of sediment in the regions around James Island and Barren Island. This information was used to generate Thiessen polygon maps of the sediment types in each area based on the spatial location of samples. Figures A9 and A10 show the surficial sediment types, as classified in the Unified Soil Classification System (USCS). Tables A4 and A5 provide individual sample and boring details in regards to the sediment type, USCS classification, and median grain size, D_{50}, if applicable to the individual sample. Tables A4 and A5 combine the results of the E2CR, Baltimore District, and CEM sampling for comparison. Additional details from the grab sample testing results are contained in Table A6: bulk density, percentages of different sediment sizes, and other sediment classifications are included.

In the vicinity of James Island, the typical median grain size was found to be 0.28 mm, whereas sediments near Barren Island showed a smaller median size of 0.23 mm. Both regions contained a majority of poorly graded sands and silty sands/sand-silt mixtures.

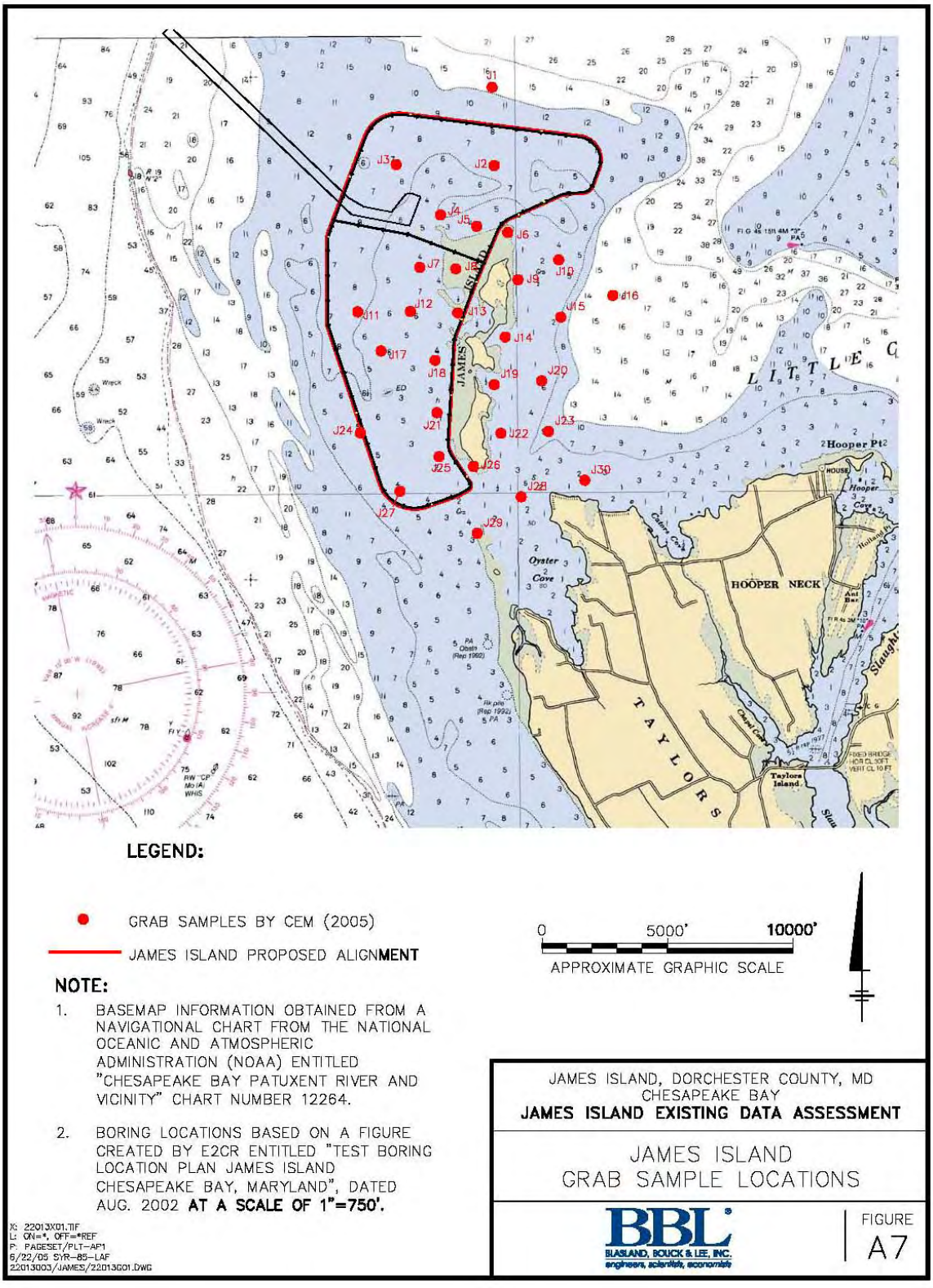

Figure A7. James Island grab sample locations

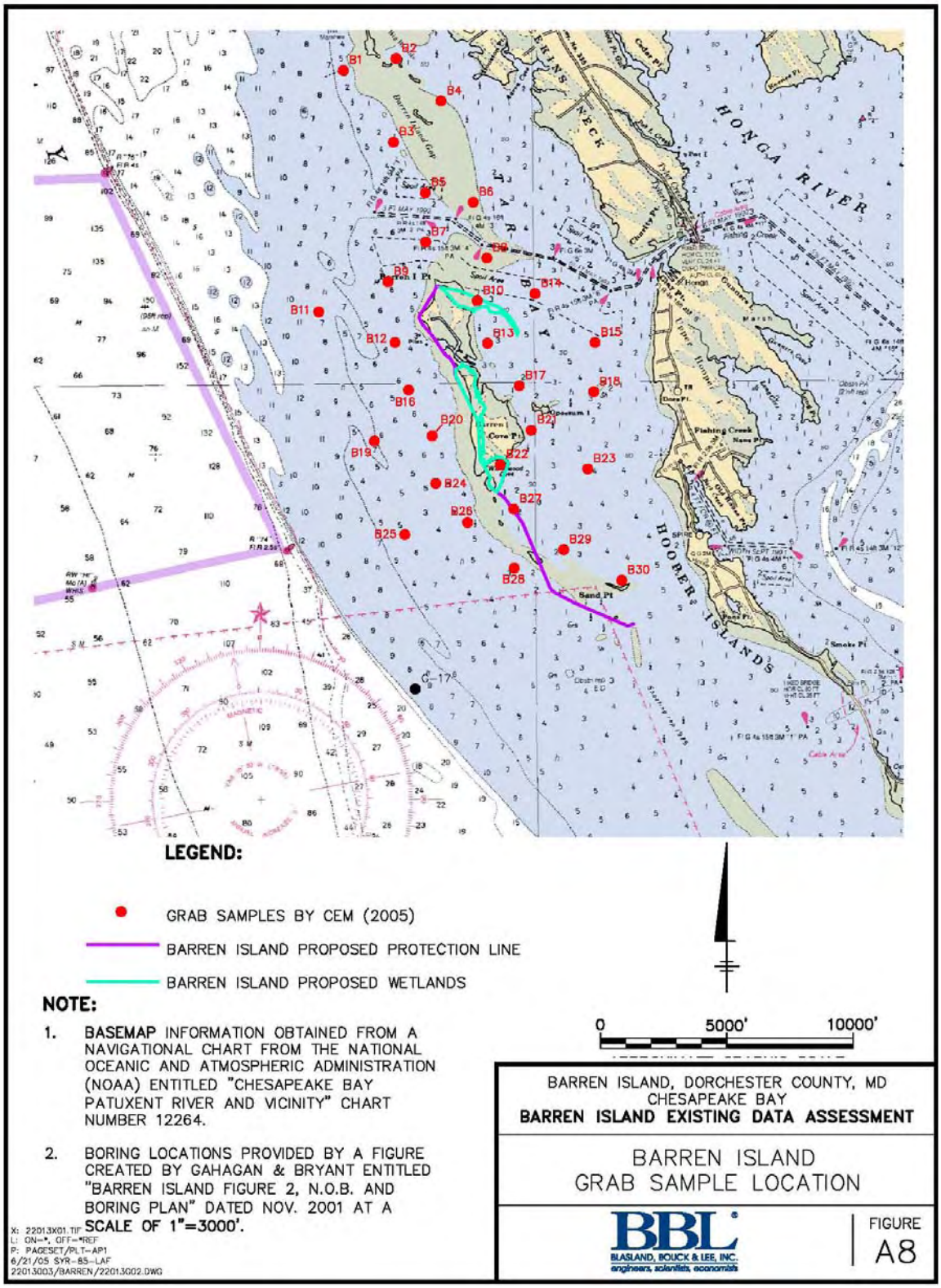

Figure A8. Barren Island grab sample locations

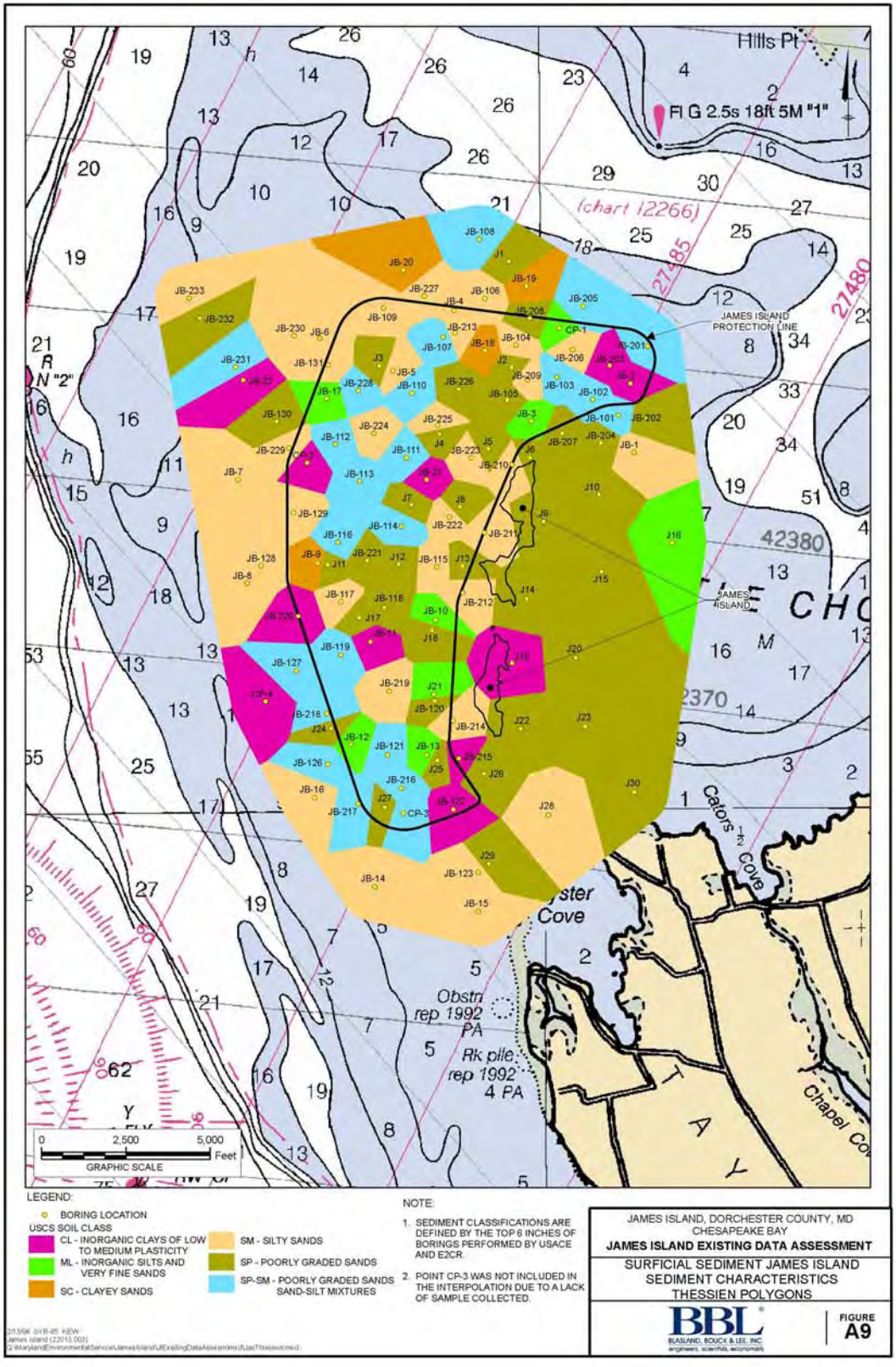

Figure A9. James Island sediment classification (USCS)

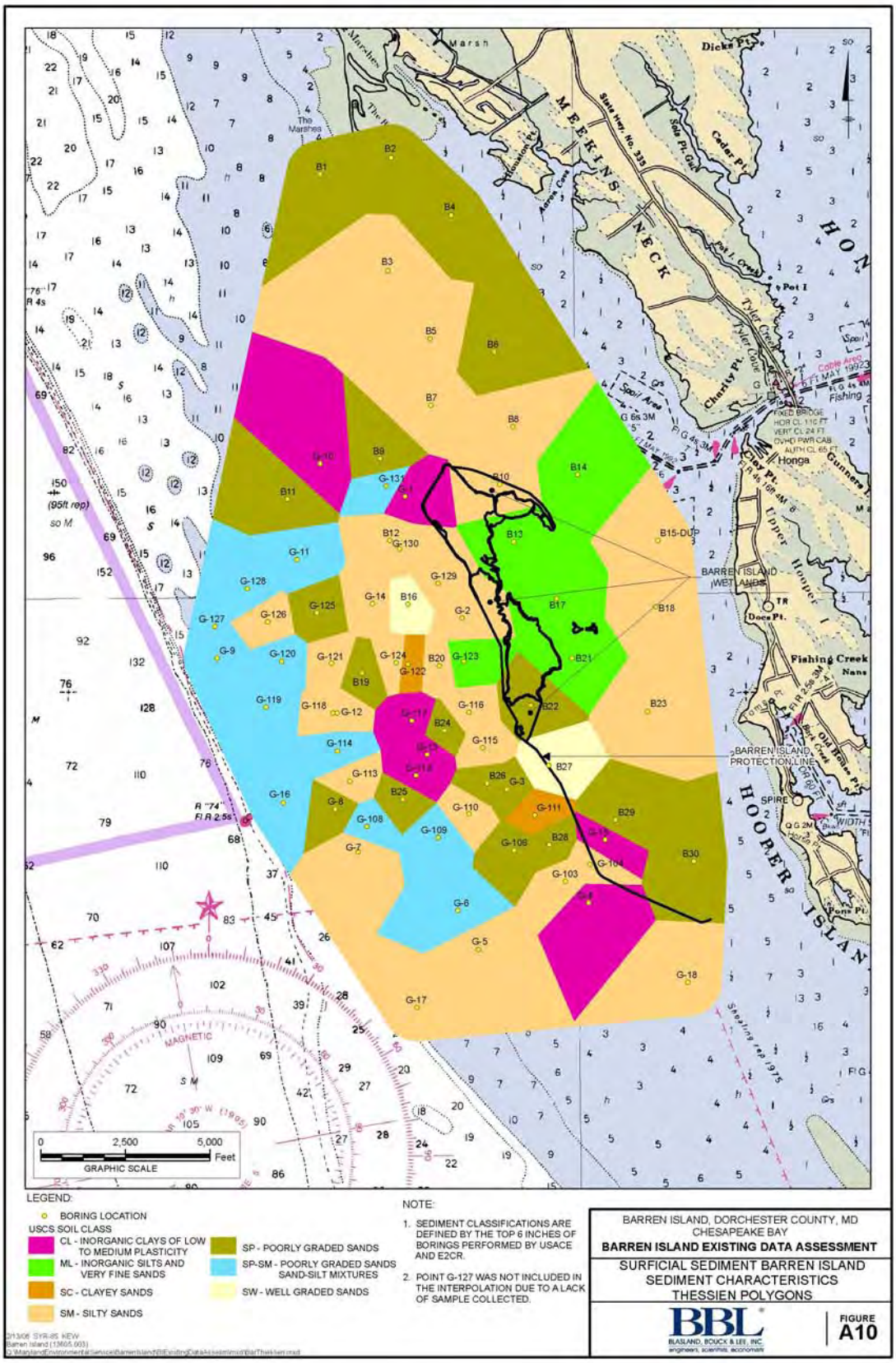

Figure A10. Barren Island sediment classification (USCS)

Table A4
James Island Sample Classification Log

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
JB-11	1,497,970.12	309,155.17	RECON (2001)	E2CR	Greenish gray, moist, sandy clay (CL)	CL		
CP-4	1,494,865.38	307,395.20	RECON (2001)	E2CR	Greenish gray, moist, silty clay	CL		
CP-2	1,496,094.74	314,458.80	RECON (2001)	E2CR	Gray, moist, sandy clay	CL		
JB-21	1,499,629.15	313,959.74	RECON (2001)	E2CR	Dark gray, moist, silty clay	CL		
JB-22	1,494,210.62	316,907.99	RECON (2001)	E2CR	Dark gray, moist, fine to med. sand, trace silty and shell frags	CL		
JB-2	1,505,653.61	316,806.50	RECON (2001)	E2CR	Greenish gray, moist, silty clay, little sand, trace shell frags (CL)	CL		
JB-12	1,497,393.85	306,122.43	RECON (2001)	E2CR	Dark gray, moist, silty fine sand, trace shell frags	ML		
JB-10	1,499,890.99	309,807.78	RECON (2001)	E2CR	Dark gray, moist, silty sand, trace shell frags	ML		
JB-13	1,499,622.07	305,815.31	RECON (2001)	E2CR	Brownish gray, moist, fine to med. sand, little silty, trace shell frags	ML		
JB-17	1,496,665.92	316,358.37	RECON (2001)	E2CR	Dark gray fine to med. sand, trace silt and shell frags	ML		
JB-3	1,502,733.88	315,693.22	RECON (2001)	E2CR	Orange brown, moist, silty fine sand, trace shell frags	ML		
CP-1	1,503,547.73	318,451.27	RECON (2001)	E2CR	Gray silty sand	ML		
JB-9	1,496,404.59	311,488.89	RECON (2001)	E2CR	Light green, moist, clayey sand, trace gravel (SC)	SC		
JB-20	1,498,938.22	320,165.86	RECON (2001)	E2CR	Brownish gray, moist, silty sand with a 6-in. layer of silty clay, trace shell frags on the top	SC		
JB-19	1,502,580.77	319,690.26	RECON (2001)	E2CR	Dark gray, moist, silty fine to med. sand, with a layer of orange brown, silty fine to med. sand at the bottom	SC		
JB-18	1,501,354.38	317,787.88	RECON (2001)	E2CR	Dark gray, moist, fine to med. sand, trace silt and shell frags	SC		
JB-14	1,498,085.37	301,911.52	RECON (2001)	E2CR	Dark gray, moist, fine sand, trace silt and shell frags	SM		
JB-15	1,501,158.77	301,170.23	RECON (2001)	E2CR	Dark gray, moist, fine to med. sand, trace silt	SM		
JB-16	1,496,322.51	304,550.34	RECON (2001)	E2CR	Dark brownish gray, moist, fine sand, trace shell frags and silt (SM)	SM		

(Sheet 1 of 7)

Table A4 (Continued)

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
JB-8	1,494,320.46	310,894.58	RECON (2001)	E2CR	Dark gray, moist, silty fine to med. sand, trace shell frags (SM)	SM		
JB-7	1,494,051.53	313,965.71	RECON (2001)	E2CR	Dark gray, moist, fine to med. sand, trace silty, little shell frags (SM)	SM		
JB-1	1,505,768.86	314,771.88	RECON (2001)	E2CR	Dark reddish gray, moist, silty fine sand, trace shell (SM)	SM		
JB-6	1,496,471.83	318,150.12	RECON (2001)	E2CR	Dark gray, moist, fine sand, trace silty and shell frags (SM)	SM		
JB-5	1,498,623.21	317,190.39	RECON (2001)	E2CR	Dark gray, moist, fine sand, trace silty and shell frags (SM)	SM		
JB-4	1,500,426.62	318,975.34	RECON (2001)	E2CR	Dark gray, moist, fine to med. sand, trace shell frags (SM)	SM		
CP-3	1,498,937.64	304,093.73	RECON (2001)	E2CR	NA			
JB-122	1,500,420.56	304,195.40	FEASIBILITY (2004)	USACE	Very moist, olive brown, soft, lean clay, w/sand and shells (CL) PPR 0.0'-1.5': 2.5, 1.0, 1.0	CL		
JB-203	1,505,037.75	317,350.08	FEASIBILITY (2004)	USACE	Wet, dark gray, very soft lean clay (CL)	CL		
JB-215	1,500,576.56	305,713.99	FEASIBILITY (2004)	USACE	Wet, dark gray, soft lean clay (CL)	CL		
JB-220	1,495,833.03	309,919.01	FEASIBILITY (2004)	USACE	Wet, light olive gray, soft sandy lean clay w/shells (CL)	CL		
JB-120	1,499,839.55	307,610.57	FEASIBILITY (2004)	USACE	Wet, olive brown and yellowish brown, sandy silt w/trace shells (ML)	ML		
JB-104	1,502,268.25	317,946.89	FEASIBILITY (2004)	USACE	Wet, olive brown and gray, silty fine sand w/shells (SM)	SM	0.18	Measured at top 6 in.
JB-106	1,501,352.45	319,326.19	FEASIBILITY (2004)	USACE	Wet, olive gray, silty fine sand w/shells (SM)	SM	0.2	Measured at top 6 in.
JB-109	1,498,351.10	319,051.73	FEASIBILITY (2004)	USACE	Wet, olive gray, silty fine-med. sand w/shells (SM)	SM		
JB-115	1,499,923.73	311,384.60	FEASIBILITY (2004)	USACE	Wet, dark gray, silty very fine sand w/trace of shells (SM)	SM		
JB-117	1,497,089.00	310,349.00	FEASIBILITY (2004)	USACE	Wet, very dark gray, silty fine sand w/shells (SM)	SM		
JB-123	1,501,157.41	302,339.30	FEASIBILITY (2004)	USACE	Wet, dark gray, silty fine sand w/trace shells (SM)	SM		

Table A4 (Continued)

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
JB-128	1,494,733.74	311,408.54	FEASIBILITY (2004)	USACE	Wet, very dark gray, poorly graded silty fine sand w/shells (SM)	SM	0.2	Measured at top 6 in.
JB-129	1,495,692.30	312,983.30	FEASIBILITY (2004)	USACE	Wet, dark gray, silty fine sand w/shells (SM)	SM		
JB-131	1,496,710.41	317,360.76	FEASIBILITY (2004)	USACE	Wet, olive gray and yellowish brown, silty fine sand w/shells (SM)	SM	0.18	Measured at top 6 in.
JB-206	1,503,953.76	317,807.45	FEASIBILITY (2004)	USACE	Wet, gray, silty fine sand w/trace shells (SM)	SM		
JB-209	1,502,601.52	316,917.44	FEASIBILITY (2004)	USACE	Wet, dark gray, silty fine sand w/shells (SM)	SM		
JB-210	1,502,150.97	314,405.28	FEASIBILITY (2004)	USACE	Wet, light brownish gray, silty fine sand w/trace shells (SM)	SM		
JB-211	1,501,346.99	312,396.39	FEASIBILITY (2004)	USACE	Wet, light olive brown silty fine sand (SM)	SM		
JB-212	1,500,708.18	310,611.29	FEASIBILITY (2004)	USACE	Wet, gray, silty fine sand (SM)	SM		
JB-213	1,500,461.97	318,308.12	FEASIBILITY (2004)	USACE	Wet, black, silty fine sand w/shells (SM)	SM		
JB-214	1,500,417.52	306,825.65	FEASIBILITY (2004)	USACE	Wet, light olive brown, silty very fine sand (SM)	SM		
JB-219	1,498,511.45	307,702.24	FEASIBILITY (2004)	USACE	Wet, dark gray and yellowish brown, silty fine sand w/shells (SM)	SM		
JB-222	1,500,302.52	312,864.33	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded med. silty sand w/shells (SM)	SM	0.21	Measured at top 6 in.
JB-223	1,500,949.54	314,609.02	FEASIBILITY (2004)	USACE	Wet, dark grayish brown, silty fine sand w/shells (SM)	SM		
JB-224	1,498,059.71	315,336.92	FEASIBILITY (2004)	USACE	Wet, yellowish brown and black, silty fine sand w/shells (SM)	SM		
JB-225	1,499,949.27	315,572.99	FEASIBILITY (2004)	USACE	Wet, black and olive brown, silty fine sand w/shells (SM)	SM		
JB-229	1,495,559.61	314,904.49	FEASIBILITY (2004)	USACE	Wet, light yellowish brown, silty med. to fine sand w/trace of gravel and shell frags (SM)	SM		
JB-230	1,495,711.12	318,223.74	FEASIBILITY (2004)	USACE	Wet, dark gray, silty med. to fine sand w/shells (SM)	SM		
JB-233	1,492,612.62	319,335.20	FEASIBILITY (2004)	USACE	Moist, dark gray, silty med. to fine sand w/shells (SM)	SM		

(Sheet 3 of 7)

Table A4 (Continued)

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
JB-227	1,499,548.39	319,394.13	FEASIBILITY (2004)	USACE	Wet, gray, silty med. to fine sand w/trace of shell frags (SM/SP-SM)	SM		
JB-105	1,502,009.86	316,326.38	FEASIBILITY (2004)	USACE	Wet, light yellowish brown, poorly graded fine sand (SP)	SP	0.28	Measured at top 6 in.
JB-118	1,498,374.64	310,169.67	FEASIBILITY (2004)	USACE	Moist, olive brown, poorly graded sand w/silt and shells (SP)	SP	0.3	Measured at top 6 in.
JB-130	1,495,196.58	315,680.91	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded, fine sand w/shells (SP)	SP	0.28	Measured at top 6 in.
JB-202	1,506,114.23	315,769.76	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded fine sand w/trace shells (SP)	SP	0.19	Measured at top 6 in.
JB-204	1,504,776.58	315,051.71	FEASIBILITY (2004)	USACE	Wet, very dark gray, poorly graded fine sand w/shells (SP)	SP		
JB-207	1,503,646.08	315,336.79	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded fine-med. sand w/shells (SP)	SP		
JB-208	1,502,683.59	318,738.99	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded fine sand w/trace shells (SP)	SP		
JB-221	1,497,863.95	311,572.22	FEASIBILITY (2004)	USACE	Wet, black, poorly graded fine sand w/shells (SP)	SP		
JB-226	1,500,577.22	316,649.85	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded fine sand w/shells (SP)	SP		
JB-232	1,492,918.73	318,730.33	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded sand w/silt and shells (SP)	SP	0.26	Measured at top 6 in.
JB-101	1,505,302.92	315,875.03	FEASIBILITY (2004)	USACE	Wet, gray, poorly graded fine sand w/silt and trace shell frags (SP-SM)	SP-SM	0.16	Measured at top 6 in.
JB-102	1,504,544.64	316,334.80	FEASIBILITY (2004)	USACE	Wet, gray, poorly graded fine sand w/silt and trace shell frags (SP-SM)	SP-SM		
JB-103	1,503,475.02	316,994.63	FEASIBILITY (2004)	USACE	Wet, gray, poorly graded fine sand w/trace shell frags (SP-SM)	SP-SM	0.18	Measured at top 6 in.
JB-107	1,500,121.21	318,184.27	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded med. sand w/silt and shells (SP-SM)	SP-SM		
JB-108	1,501,196.79	321,075.21	FEASIBILITY (2004)	USACE	Wet, light gray, poorly graded fine sand w/silt and shells (SP-SM)	SP-SM	0.21	Measured at top 6 in.
JB-110	1,499,195.47	316,528.65	FEASIBILITY (2004)	USACE	Wet, very dark gray, poorly graded fine sand w/silt and shells (SP-SM)	SP-SM		
JB-111	1,499,034.34	314,615.49	FEASIBILITY (2004)	USACE	Wet, light olive brown and black, poorly graded fine sand w/silt and shells (SP-SM)	SP-SM	0.25	Measured at top 6 in.

Table A4 (Continued)

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
JB-112	1,496,933.66	315,005.21	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded, fine sand w/silt and shells (SP-SM)	SP-SM	0.2	Measured at top 6 in.
JB-113	1,497,640.74	313,907.53	FEASIBILITY (2004)	USACE	Wet, light olive brown, poorly graded fine sand w/silt and shells (SP-SM)	SP-SM	0.21	Measured at top 6 in.
JB-114	1,498,874.04	312,580.94	FEASIBILITY (2004)	USACE	Wet, gray, poorly graded fine sand w/silt and shells (SP-SM)	SP-SM	0.18	Measured at top 6 in.
JB-116	1,497,002.00	312,105.00	FEASIBILITY (2004)	USACE	Wet, very dark gray, poorly graded, med. sand w/silt and shells (SP-SM)	SP-SM		
JB-119	1,497,088.98	308,774.60	FEASIBILITY (2004)	USACE	Wet, olive brown, poorly graded sand w/trace shells frags (SP-SM)	SP-SM		
JB-121	1,498,469.29	305,810.17	FEASIBILITY (2004)	USACE	Wet, light olive brown, poorly graded, fine sand w/silt (SP-SM)	SP-SM		
JB-126	1,496,698.53	305,534.58	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded, med. sand w/silt and shells (SP-SM)	SP-SM		
JB-127	1,495,764.92	308,299.91	FEASIBILITY (2004)	USACE	Wet, grayish brown, poorly graded, med. sand w/silt and shells (SP-SM)	SP-SM		
JB-201	1,506,169.82	317,914.86	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded fine sand w/silt and shells (SP-SM)	SP-SM		
JB-205	1,504,254.11	319,104.57	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded fine sand w/silt and shells (SP-SM)	SP-SM		
JB-216	1,498,881.69	304,831.82	FEASIBILITY (2004)	USACE	Wet, very dark gray, poorly graded fine sand w/silt and shells (SP-SM)	SP-SM	0.25	Measured at top 6 in.
JB-217	1,497,597.14	304,367.44	FEASIBILITY (2004)	USACE	Wet, black, poorly graded fine sand w/silt and shells (SP-SM)	SP-SM		
JB-218	1,496,671.99	307,041.74	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded fine sand w/silt and shells (SP-SM)	SP-SM	0.29	Measured at top 6 in.
JB-231	1,493,985.41	317,301.20	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded sand w/silt and shells (SP-SM)	SP-SM		
JB-228	1,497,597.81	316,598.19	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded med. to fine sand w/trace of silt and shell frags (SP-SM/SP)	SP-SM		
J19	1,502,147.53	308,535.70	Modeling Analysis (2005)	CEM	Clayey-silt	CL	0.02	Grab samples
J16	1,506,885.37	312,097.15	Modeling Analysis (2005)	CEM	Sandy-silt	ML	0.03	Grab samples
J28	1,503,224.82	304,039.72	Modeling Analysis (2005)	CEM	Silty-sand	SM	0.08	Grab samples

Table A4 (Continued)

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
J1	1,502,061.17	320,419.86	Modeling Analysis (2005)	CEM	Sand	SP	0.38	Grab samples
J2	1,502,145.90	317,288.43	Modeling Analysis (2005)	CEM	Sand	SP	0.36	Grab samples
J3	1,498,231.49	317,327.04	Modeling Analysis (2005)	CEM	Sand	SP	0.36	Grab samples
J4	1,500,005.18	315,312.39	Modeling Analysis (2005)	CEM	Sand	SP	0.36	Grab samples
J5	1,501,448.31	314,867.56	Modeling Analysis (2005)	CEM	Sand	SP	0.37	Grab samples
J6	1,502,689.81	314,615.58	Modeling Analysis (2005)	CEM	Sand	SP	0.37	Grab samples
J7	1,499,176.25	313,218.41	Modeling Analysis (2005)	CEM	Sand	SP	0.38	Grab samples
J8	1,500,611.90	313,161.96	Modeling Analysis (2005)	CEM	Sand	SP	0.39	Grab samples
J9	1,503,094.60	312,724.73	Modeling Analysis (2005)	CEM	Sand	SP	0.35	Grab samples
J10	1,504,724.30	313,519.70	Modeling Analysis (2005)	CEM	Sand	SP	0.31	Grab samples
J10-DUP	1,504,724.30	313,519.70	Modeling Analysis (2005)	CEM	Sand	SP	0.32	Grab samples
J11	1,496,704.53	311,440.59	Modeling Analysis (2005)	CEM	Sand	SP	0.37	Grab samples
J11-DUP	1,496,704.53	311,440.59	Modeling Analysis (2005)	CEM	Sand	SP	0.37	Grab samples
J12	1,498,797.84	311,455.45	Modeling Analysis (2005)	CEM	Sand	SP	0.37	Grab samples
J13	1,500,686.58	311,402.24	Modeling Analysis (2005)	CEM	Sand	SP	0.36	Grab samples
J14	1,502,586.78	310,432.69	Modeling Analysis (2005)	CEM	Sand	SP	0.36	Grab samples
J15	1,504,803.14	311,231.94	Modeling Analysis (2005)	CEM	Sand	SP	0.34	Grab samples
J17	1,497,631.21	309,875.06	Modeling Analysis (2005)	CEM	Sand	SP	0.38	Grab samples

Table A4 (Concluded)

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
J18	1,499,789.42	309,501.99	Modeling Analysis (2005)	CEM	Sand	SP	0.35	Grab samples
J20	1,504,039.79	308,683.06	Modeling Analysis (2005)	CEM	Sand	SP	0.33	Grab samples
J20-DUP	1,504,039.79	308,683.06	Modeling Analysis (2005)	CEM	Sand	SP	0.33	Grab samples
J21	1,499,866.44	307,408.44	Modeling Analysis (2005)	CEM	Sand	SP	0.31	Grab samples
J21-DUP	1,499,866.44	307,408.44	Modeling Analysis (2005)	CEM	Sand	SP	0.33	Grab samples
J22	1,502,419.27	306,583.18	Modeling Analysis (2005)	CEM	Sand	SP	0.18	Grab samples
J23	1,504,316.98	306,657.76	Modeling Analysis (2005)	CEM	Sand	SP	0.15	Grab samples
J24	1,496,805.45	306,603.63	Modeling Analysis (2005)	CEM	Sand	SP	0.37	Grab samples
J24-DUP	1,496,805.45	306,603.63	Modeling Analysis (2005)	CEM	Sand	SP	0.37	Grab samples
J25	1,499,945.85	305,648.75	Modeling Analysis (2005)	CEM	Sand	SP	0.34	Grab samples
J26	1,501,322.29	305,264.13	Modeling Analysis (2005)	CEM	Sand	SP	0.33	Grab samples
J27	1,498,386.49	304,265.81	Modeling Analysis (2005)	CEM	Sand	SP	0.35	Grab samples
J29	1,501,470.45	302,588.40	Modeling Analysis (2005)	CEM	Sand	SP	0.30	Grab samples
J30	1,505,767.03	304,707.89	Modeling Analysis (2005)	CEM	Sand	SP	0.32	Grab samples
J30-DUP	1,505,767.03	304,707.89	Modeling Analysis (2005)	CEM	Sand	SP	0.34	Grab samples

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Table A5
Barren Island Sample Classification Log

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
G-1	1,522,379.54	246,553.30	RECON (2001)	E2CR	Dark grey, wet, fine sandy clay (CL)	CL		
G-2	1,524,057.91	242,955.25	RECON (2001)	E2CR	Light brown, silty fine to coarse sand (SM)	SM		
G-3	1,525,389.96	237,897.72	RECON (2001)	E2CR	Medium to light gray, wet, silty fine to coarse sand, trace fine gravel (SP)	SP		
G-4	1,527,803.88	234,536.55	RECON (2001)	E2CR	Brownish gray, wet, fine sandy clay, trace shell frags (CL)	CL		
G-5	1,524,539.00	233,144.18	RECON (2001)	E2CR	Dark grey, wet, silty fine sand (SM)	SM		
G-6	1,523,941.32	234,304.76	RECON (2001)	E2CR	Brownish gray to orange brown, wet silty fine to med. sand, trace shell frags (SP-SM)	SP-SM		
G-7	1,520,981.28	236,047.34	RECON (2001)	E2CR	Brownish to greenish gray, wet, silty fine sand (SM)	SM	0.178	Measured at top 2 ft; overlying classification is the same
G-8	1,520,306.49	237,310.57	RECON (2001)	E2CR	Dark gray, wet, fine to med. sand (SP)	SP	0.274	Measured at top 2 ft; overlying classification is the same
G-9	1,516,828.51	241,768.80	RECON (2001)	E2CR	Medium gray, fine sand, trace silt and mica (SP-SM)	SP-SM		
G-10	1,519,862.00	247,534.75	RECON (2001)	E2CR	Black to orange brown and gray, fine sandy clay, with fine sand (CL)	CL		
G-12	1,520,360.39	240,157.76	RECON (2001)	E2CR	Dark gray, wet, silty fine sand (SM)	SM		
G-13	1,523,028.88	238,928.70	RECON (2001)	E2CR	Medium gray, wet to moist, silty clay, trace fine sand with occasional lenses of clayey sand (CL)	CL		
G-14	1,521,405.78	243,377.04	RECON (2001)	E2CR	Greenish brown, silty fine sand, trace shell frags (SM)	SM		
G-15	1,528,281.10	236,403.93	RECON (2001)	E2CR	Brownish gray, wet, fine sandy clay, trace shell frags (CL)	CL		

(Sheet 1 of 5)

Table A5 (Continued)

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
G-16	1,518,774.71	237,498.76	RECON (2001)	E2CR	Medium gray, wet, fine sand, trace silt (with layers of fine to med. sand) (SP-SM)	SP-SM	0.255	Measured at top 2 ft; overlying classification is the same
G-17	1,522,725.63	231,436.06	RECON (2001)	E2CR	Dark gray and brown, wet, silty fine sand (SM)	SM		
G-18	1,530,731.35	232,187.48	RECON (2001)	E2CR	Dark gray and brown, wet, silty fine sand (SC-SM)	SM		
G-103	1,527,109.94	235,174.26	FEASIBILITY (2004)	USACE	Wet, dark, gray, silty med.-fine sand w/trace of shell frags (SM)	SM	0.15	Measured at top 6 in.
G-104	1,527,831.17	235,675.89	FEASIBILITY (2004)	USACE	Wet, grayish brown, silty fine sand w/trace of shell frags (SM)	SM	0.16	Measured at top 6 in.
G-106	1,525,603.91	236,092.66	FEASIBILITY (2004)	USACE	Wet, grayish brown, poorly graded coarse to med. sand (SP)	SP		
G-108	1,521,254.28	236,796.11	FEASIBILITY (2004)	USACE	Wet, dark, gray, poorly graded sand w/silt and trace of shell frags (SP-SM)	SP-SM	0.18	Measured at top 6 in.
G-109	1,523,345.18	236,468.91	FEASIBILITY (2004)	USACE	Wet, dark, gray, poorly graded sand w/silt and trace of shell frags (SP-SM)	SP-SM		
G-11	1,519,172.22	244,688.60	FEASIBILITY (2004)	E2CR	Dark gray, silty fine to med. sand, trace shell frags (SP-SM)	SP-SM		
G-110	1,524,264.06	237,174.36	FEASIBILITY (2004)	USACE	Wet dark, gray and yellowish brown silty sand w/trace of shell frags (SM)	SM	0.16	Measured at top 6 in.
G-111	1,526,209.19	237,129.48	FEASIBILITY (2004)	USACE	Wet, grayish brown, silty, med. to coarse sand (SC)	SC		
G-112	1,522,700.75	238,304.92	FEASIBILITY (2004)	USACE	Moist, gray, soft lean clay w/sand (CL)	CL		
G-113	1,520,749.43	238,137.57	FEASIBILITY (2004)	USACE	Wet, dark, gray, poorly graded, silty, fine to med. sand (SM)	SM		
G-114	1,520,367.71	239,034.90	FEASIBILITY (2004)	USACE	Wet, dark, gray, poorly graded, fine sand w/silt and trace of shell frags (SP-SM)	SP-SM	0.18	Measured at top 6 in.
G-115	1,524,662.66	239,130.06	FEASIBILITY (2004)	USACE	Wet, light olive brown silty fine sand (SM)	SM		
G-116	1,524,255.68	240,178.88	FEASIBILITY (2004)	USACE	Wet, light olive brown, silty, very fine sand (SM)	SM		
G-117	1,522,576.11	239,932.66	FEASIBILITY (2004)	USACE	Very moist, yellowish brown and gray, soft lean clay (CL)	CL		

Table A5 (Continued)

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
G-118	1,520,231.29	240,156.74	FEASIBILITY (2004)	USACE	Wet, grayish brown, silty fine sand (SM)	SM	0.16	Measured at top 6 in.
G-119	1,518,269.42	240,333.45	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded, fine sand w/silt (SP-SM)	SP-SM	0.16	Measured at top 6 in.
G-120	1,518,729.06	241,672.43	FEASIBILITY (2004)	USACE	Wet, dark gray, poorly graded, fine sand w/silt (SP-SM)	SP-SM	0.2	Measured at top 6 in.
G-121	1,520,195.82	241,613.22	FEASIBILITY (2004)	USACE	Wet, very dark, gray, silty, fine sand (SM)	SM	0.16	Measured at top 6 in.
G-122	1,522,459.20	241,590.82	FEASIBILITY (2004)	USACE	Wet, black, clayey, fine sand (SC)	SC		
G-123	1,524,108.19	241,664.80	FEASIBILITY (2004)	USACE	Wet, very dark, gray, sandy silt(ML)	ML	0.07	Measured at top 6 in.
G-124	1,522,108.26	241,628.47	FEASIBILITY (2004)	USACE	Very moist, gray, silty, fine sand (SM)	SM		
G-125	1,519,761.63	243,107.01	FEASIBILITY (2004)	USACE	Wet, dark Grayish brown, poorly graded, fine sand w/silt (SP)	SP	0.2	Measured at top 6 in.
G-126	1,518,313.44	242,842.66	FEASIBILITY (2004)	USACE	Wet, grayish brown, poorly graded, fine silty sand (SM)	SM		
G-127	1,516,752.64	242,709.04	FEASIBILITY (2004)	USACE	Mostly empty jar with trace of sand			
G-128	1,517,716.02	243,829.38	FEASIBILITY (2004)	USACE	Wet, dark, gray, poorly graded, med. sand w/silt (SP-SM)	SP-SM	0.18	Measured at top 6 in.
G-129	1,523,348.45	243,975.33	FEASIBILITY (2004)	USACE	Wet, olive gray, silty, fine sand (SM)	SM	0.12	Measured at top 6 in.
G-130	1,522,216.64	245,008.22	FEASIBILITY (2004)	USACE	Wet, olive, silty, fine sand (SM)	SM	0.12	Measured at top 6 in.
G-131	1,521,819.31	246,866.46	FEASIBILITY (2004)	USACE	Wet, olive brown and gray, poorly graded, fine sand w/silt (SP-SM)	SP-SM		
B1	1,519,870.53	256,105.45	Modeling Analysis (2005)	CEM	Sand	SP	0.33	Grab samples
B2	1,521,959.79	256,583.40	Modeling Analysis (2005)	CEM	Sand	SP	0.31	Grab samples
B2-DUP	1,521,959.79	256,583.40	Modeling Analysis (2005)	CEM	Sand	SP	0.31	Grab samples
B3	1,521,857.50	253,244.16	Modeling Analysis (2005)	CEM	Clayey-silt	SM	0.013	Grab samples

(Sheet 3 of 5)

Table A5 (Continued)

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
B4	1,523,741.56	254,892.10	Modeling Analysis (2005)	CEM	Sand	SP	0.13	Grab samples
B4-DUP	1,523,741.56	254,892.10	Modeling Analysis (2005)	CEM	Sand	SP	0.13	Grab samples
B5	1,523,116.35	251,226.94	Modeling Analysis (2005)	CEM	Silty-sand	SM	0.11	Grab samples
B6	1,525,016.96	250,847.77	Modeling Analysis (2005)	CEM	Sand	SP	0.16	Grab samples
B7	1,523,132.19	249,260.43	Modeling Analysis (2005)	CEM	Silty-sand	SM	0.19	Grab samples
B8	1,525,556.05	248,624.52	Modeling Analysis (2005)	CEM	Silty-sand	SM	0.057	Grab samples
B9	1,521,639.15	247,676.36	Modeling Analysis (2005)	CEM	Sand	SP	0.32	Grab samples
B10	1,525,177.92	246,921.88	Modeling Analysis (2005)	CEM	Sandy-silt	SM	0.043	Grab samples
B10-DUP	1,525,177.92	246,921.88	Modeling Analysis (2005)	CEM	Silty-sand	SM	0.045	Grab samples
B11	1,518,899.94	246,477.05	Modeling Analysis (2005)	CEM	Sand	SP	0.38	Grab samples
B12	1,521,921.43	245,256.75	Modeling Analysis (2005)	CEM	Silty-sand	SM	0.14	Grab samples
B13	1,525,583.78	245,219.55	Modeling Analysis (2005)	CEM	Sandy-silt	ML	0.02	Grab samples
B14	1,527,470.24	247,201.62	Modeling Analysis (2005)	CEM	Sandy-silt	ML	0.017	Grab samples
B15	1,529,843.15	245,254.58	Modeling Analysis (2005)	CEM	Silty-sand	SM	0.06	Grab samples
B15-DUP	1,529,843.15	245,254.58	Modeling Analysis (2005)	CEM	Sandy-silt	ML	0.053	Grab samples
B16	1,522,457.74	243,361.18	Modeling Analysis (2005)	CEM	Sand	SW	0.38	Grab samples
B17	1,526,845.40	243,530.29	Modeling Analysis (2005)	CEM	Silty-sand	ML	0.019	Grab samples
B18	1,529,792.50	243,293.60	Modeling Analysis (2005)	CEM	Silt	SM	0.082	Grab samples

Table A5 (Concluded)

Sample ID	X Coordinate	Y Coordinate	Study Phase	Company	Top 6-in. Classification	USCS Classification	D_{50} (mm)	Grain Size Description
B19	1,521,101.82	241,323.00	Modeling Analysis (2005)	CEM	Silty-sand	SP	0.33	Grab samples
B20	1,523,390.43	241,535.58	Modeling Analysis (2005)	CEM	Sand	SM	0.13	Grab samples
B21	1,527,314.12	241,761.74	Modeling Analysis (2005)	CEM	Silty-sand	ML	0.024	Grab samples
B22	1,526,087.02	240,379.90	Modeling Analysis (2005)	CEM	Sandy-silt	SP	0.17	Grab samples
B22-DUP	1,526,087.02	240,379.90	Modeling Analysis (2005)	CEM	Sand	SP	0.18	Grab samples
B23	1,529,555.09	240,214.20	Modeling Analysis (2005)	CEM	Sand	SM	0.081	Grab samples
B24	1,523,534.84	239,636.88	Modeling Analysis (2005)	CEM	Silty-sand	SP	0.38	Grab samples
B25	1,522,307.91	237,599.68	Modeling Analysis (2005)	CEM	Sand	SP	0.34	Grab samples
B26	1,524,795.55	238,074.99	Modeling Analysis (2005)	CEM	Sand	SP	0.35	Grab samples
B27	1,526,622.68	238,611.88	Modeling Analysis (2005)	CEM	Sand	SW	0.32	Grab samples
B28	1,526,641.95	236,256.93	Modeling Analysis (2005)	CEM	Sand	SP	0.29	Grab samples
B29	1,528,601.42	236,995.35	Modeling Analysis (2005)	CEM	Sand	SP	0.3	Grab samples
B30	1,530,902.35	235,770.13	Modeling Analysis (2005)	CEM	Sand	SP	0.93	Grab samples

(Sheet 5 of 5)

Table A6
CEM Sample Sediment Characterization

Sample ID	Percent H20	Bulk Density	Percent Gravel	Percent Sand	Percent Silt	Percent Clay	SHEP CLASS	PEJRUP CLASS	WGHT LOSS	Percent Total	Soil Classification
B1	23.78	1.93	0.00	94.57	4.02	1.41	Sand	A,III	6.11	100.00	SP
B2	20.43	2.01	0.00	95.98	3.79	0.25	Sand	A,IV	4.73	100.02	SP
B2 DUP	18.34	2.07	0.00	96.05	2.68	1.27	Sand	A,III	1.86	100.00	SP
B3	36.73	1.67	0.00	13.45	65.53	21.02	Clayey-silt	C,III	9.73	100.00	SM
B4	21.51	1.99	0.00	86.47	11.58	1.96	Sand	B,IV	3.63	100.01	SP
B4 DUP	21.23	1.99	0.00	85.35	12.05	2.59	Sand	B,IV	2.60	99.99	SP
B5	27.19	1.85	0.43	59.53	32.78	7.26	Silty-sand	B,IV	7.33	100.00	SM
B6	27.87	1.84	0.00	80.33	16.41	2.76	Sand	B,IV	4.86	99.50	SP
B7	24.39	1.92	0.00	71.71	21.72	6.87	Silty-sand	B,III	2.09	100.30	SM
B8	32.04	1.76	0.00	48.37	42.35	9.27	Silty-sand	C,IV	8.22	99.99	SM
B9	17.57	2.09	0.00	90.84	7.40	1.76	Sand	A,IV	2.93	100.00	SP
B10	27.91	1.84	0.00	43.83	44.96	11.20	Sandy-silt	C,IV	7.33	99.99	SM
B10 DUP	26.63	1.87	0.00	44.72	43.66	11.62	Silty-sand	C,III	5.88	100.00	SM
B11	18.35	2.07	1.28	94.06	3.93	0.73	Sand	A,IV	10.07	100.00	SP
B12	27.65	1.94	0.27	61.88	31.74	6.11	Silty-sand	B,IV	6.57	100.00	SM
B13	35.09	1.70	0.00	23.16	64.76	12.08	Sandy-silt	C,IV	7.44	100.00	ML
B14	31.82	1.76	0.00	16.67	70.21	13.12	Sandy-silt	C,IV	6.53	100.00	ML
B15	30.95	1.78	0.00	49.57	45.31	5.12	Silty-sand	C,IV	6.09	100.00	SM
B15 DUP	25.67	1.89	0.00	47.00	47.01	5.99	Sandy-silt	C,IV	5.69	100.00	ML
B16	17.75	2.08	14.14	70.40	13.68	1.80	Sand	B,IV	2.59	100.02	SW
B16 DUP	18.00	2.08	9.65	64.13	22.08	4.14	Silty-sand	B,IV	3.75	100.00	SM
B17	29.14	1.81	0.00	17.79	76.14	7.08	Silt	C,IV	5.47	101.01	ML
B18	21.58	1.98	0.00	59.66	34.90	5.43	Silty-sand	B,IV	5.73	99.99	SM
B19	21.25	1.99	0.00	93.99	4.57	1.44	Sand	A,III	2.96	100.00	SP
B20	24.72	1.91	0.00	69.70	25.51	4.80	Silty-sand	B,IV	3.91	100.01	SM
B21	30.90	1.75	0.00	27.05	63.43	9.52	Sandy-silt	C,IV	5.86	100.00	ML
B22	26.37	1.87	0.00	91.23	7.28	1.50	Sand	A,IV	2.56	100.01	SP
B22 DUP	23.60	1.94	0.00	89.91	8.06	2.04	Sand	B,III	2.07	100.01	SP
B23	27.93	1.84	0.00	61.01	99.47	5.52	Silty-sand	B,IV	5.76	166.00	SM
B24	21.16	1.99	0.79	90.20	7.95	1.06	Sand	A,IV	1.43	100.00	SP
B25	18.63	2.06	0.00	94.39	3.97	1.64	Sand	A,III	2.13	100.00	SP
B26	17.51	2.09	0.00	93.61	5.24	1.14	Sand	A,IV	1.04	99.99	SP
B27	22.39	1.96	1.76	74.26	19.16	4.83	Sand	B,III	1.80	100.01	SW
B28	18.09	2.07	0.00	84.71	12.79	2.49	Sand	B,IV	2.92	99.99	SP
B29	17.82	2.08	0.99	89.43	7.82	1.76	Sand	A,IV	3.10	100.00	SP
B30	18.12	2.07	0.80	98.21	0.84	0.14	Sand	A,IV	5.44	99.99	SP
B30 DUP	18.65	2.06	0.34	97.19	1.85	0.62	Sand	A,III	2.23	100.00	SP
J1	16.76	2.11	2.28	96.84	0.26	0.63	Sand	A,II	2.24	100.01	SP
J2	18.27	2.07	0.00	98.86	0.33	0.81	Sand	A,II	12.30	100.00	SP
J3	16.70	2.11	0.00	99.34	0.28	0.38	Sand	A,II	6.69	100.00	SP

(Continued)

Table A6 (Concluded)

Sample ID	Percent H20	Bulk Density	Percent Gravel	Percent Sand	Percent Silt	Percent Clay	SHEP CLASS	PEJRUP CLASS	WGHT LOSS	Percent Total	Soil Classification
J4	18.54	2.06	0.00	98.85	0.38	0.77	Sand	A,II	11.26	100.00	SP
J5	18.85	2.12	0.00	98.78	0.64	0.58	Sand	A,III	9.78	100.00	SP
J6	17.10	2.10	0.00	98.78	0.46	0.75	Sand	A,II	6.06	99.99	SP
J7	17.37	2.09	0.46	98.78	0.28	0.47	Sand	A,II	2.93	99.99	SP
J8	15.92	2.14	0.54	98.68	0.33	0.47	Sand	A,II	4.84	100.02	SP
J9	19.08	2.05	0.00	96.40	2.71	0.89	Sand	A,III	3.68	100.00	SP
J10	20.93	2.00	0.00	89.05	9.22	1.73	Sand	B,IV	4.43	100.00	SP
J10 DUP	21.19	1.99	0.00	93.88	5.67	0.45	Sand	A,IV	4.17	100.00	SP
J11	20.09	2.02	0.10	99.06	0.37	0.48	Sand	A,II	1.38	100.01	SP
J11 DUP	29.95	1.93	0.00	99.36	0.21	0.49	Sand	A,II	3.97	100.06	SP
J12	17.83	2.08	0.00	98.69	0.60	0.51	Sand	A,III	5.57	99.80	SP
J13	15.14	2.16	0.00	98.15	1.44	0.41	Sand	A,III	2.79	100.00	SP
J14	18.04	2.08	0.39	81.86	14.73	3.02	Sand	B,IV	4.82	100.00	SP
J15	19.89	2.09	0.00	98.00	1.27	0.74	Sand	A,III	1.78	100.01	SP
J16	36.25	1.68	0.00	34.37	55.41	10.22	Sandy-silt	C,IV	4.97	100.00	ML
J17	16.56	2.12	0.41	98.67	0.73	0.30	Sand	A,III	5.36	100.11	SP
J18	20.31	2.02	0.00	92.81	7.08	0.11	Sand	A,IV	6.24	100.00	SP
J19	41.37	1.59	0.00	14.72	70.29	14.99	Clayey-silt	C,IV	7.16	100.00	CL
J20	21.61	1.99	0.00	95.34	3.94	0.72	Sand	A,IV	4.22	100.00	SP
J20 DUP	20.90	2.00	0.00	94.86	4.46	0.68	Sand	A,IV	4.29	100.00	SP
J21	20.71	2.01	0.00	87.79	11.25	0.96	Sand	B,IV	4.15	100.00	SP
J21 DUP	22.25	1.97	0.00	93.75	5.28	0.99	Sand	A,IV	4.69	100.02	SP
J22	22.34	1.97	0.00	96.20	3.08	0.72	Sand	A,IV	3.54	100.00	SP
J23	21.96	1.87	0.00	80.10	16.59	3.32	Sand	B,IV	5.26	100.01	SP
J24	19.61	2.03	0.00	98.84	1.08	0.08	Sand	A,IV	6.81	100.00	SP
J24 DUP	19.80	2.03	0.00	98.80	0.51	0.70	Sand	A,II	5.48	100.01	SP
J25	19.25	2.04	0.00	97.68	2.14	0.18	Sand	A,IV	9.10	100.00	SP
J26	18.71	2.06	0.00	95.05	4.02	0.93	Sand	A,IV	3.70	100.00	SP
J27	19.35	2.04	0.00	97.98	1.87	0.16	Sand	A,IV	5.28	100.01	SP
J28	35.87	1.68	0.00	53.46	34.35	12.19	Silty-sand	B,III	7.35	100.00	SM
J29	19.66	2.03	0.00	96.90	2.72	0.38	Sand	A,IV	4.99	100.00	SP
J30	25.64	1.89	0.00	81.38	13.73	4.89	Sand	B,III	4.88	100.00	SP
J30 DUP	20.70	2.01	0.00	88.34	8.80	2.86	Sand	B,III	4.46	100.00	SP

Navigational channels

Two channels were identified within the vicinity of James Island and Barren Island. The Honga River Channel, located near Barren Island, is a Federal navigational channel maintained by the Baltimore District. The channel's original alignment still appears on NOAA navigational charts, although it was straightened to its new alignment in 2003, as shown in Figure A11.

A second channel was identified after discussions with local watermen in the area. This private channel is located south of James Island, between the southern-most island and the mainland of Taylors Island. Although not marked on charts and not maintained, this channel is self-sustaining and used by local watermen heading out to the bay. To better identify the location of this channel, a field visit took place on 10 August 2005 to trace the path of the local channel. A local waterman was chartered to travel through the channel so that Global Positioning System (GPS) coordinates could be obtained. The resulting alignment, with outbound and inbound paths highlighted, is shown in Figure A12.

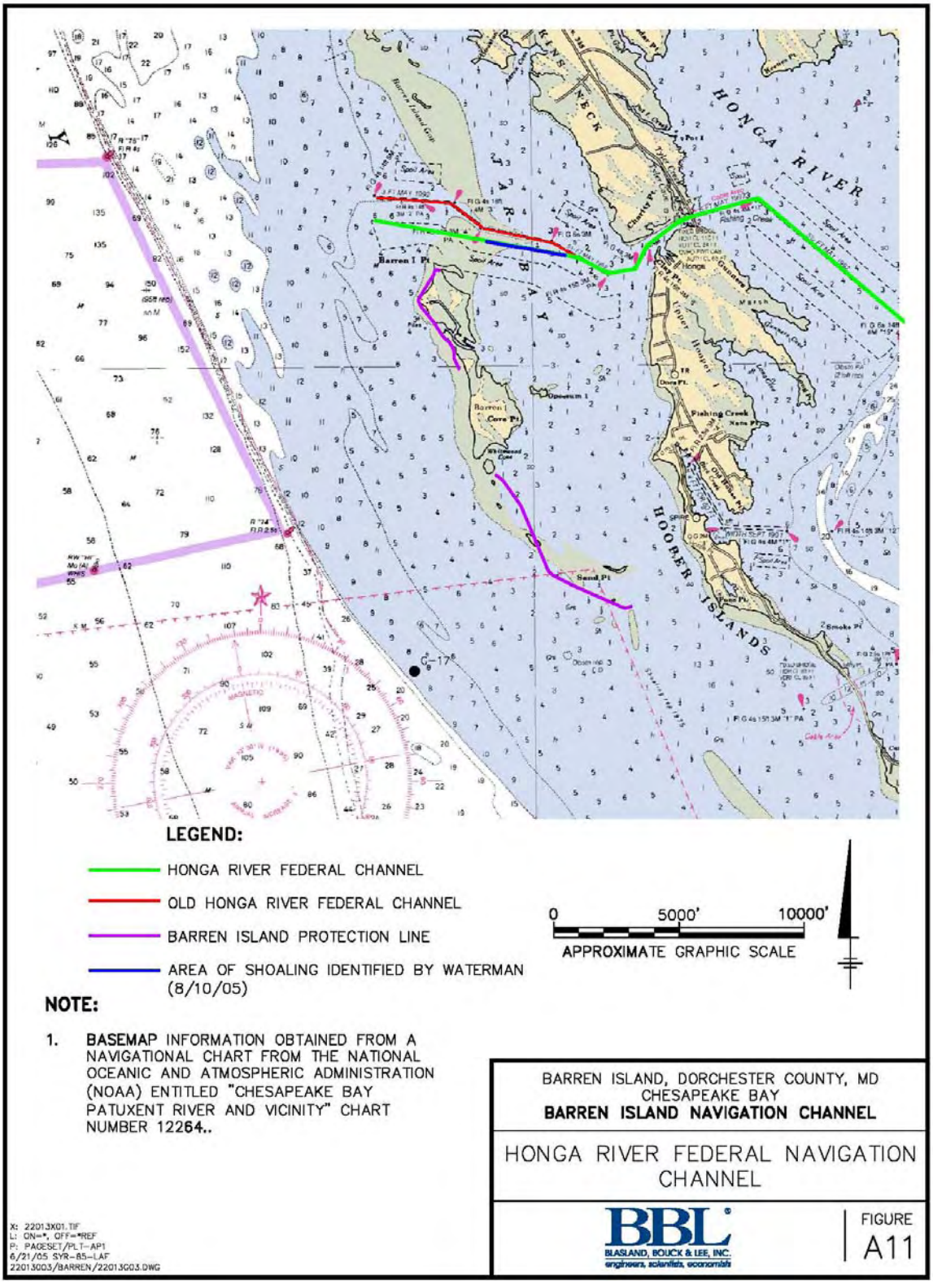

Figure A11. Honga River Federal Navigation Channel

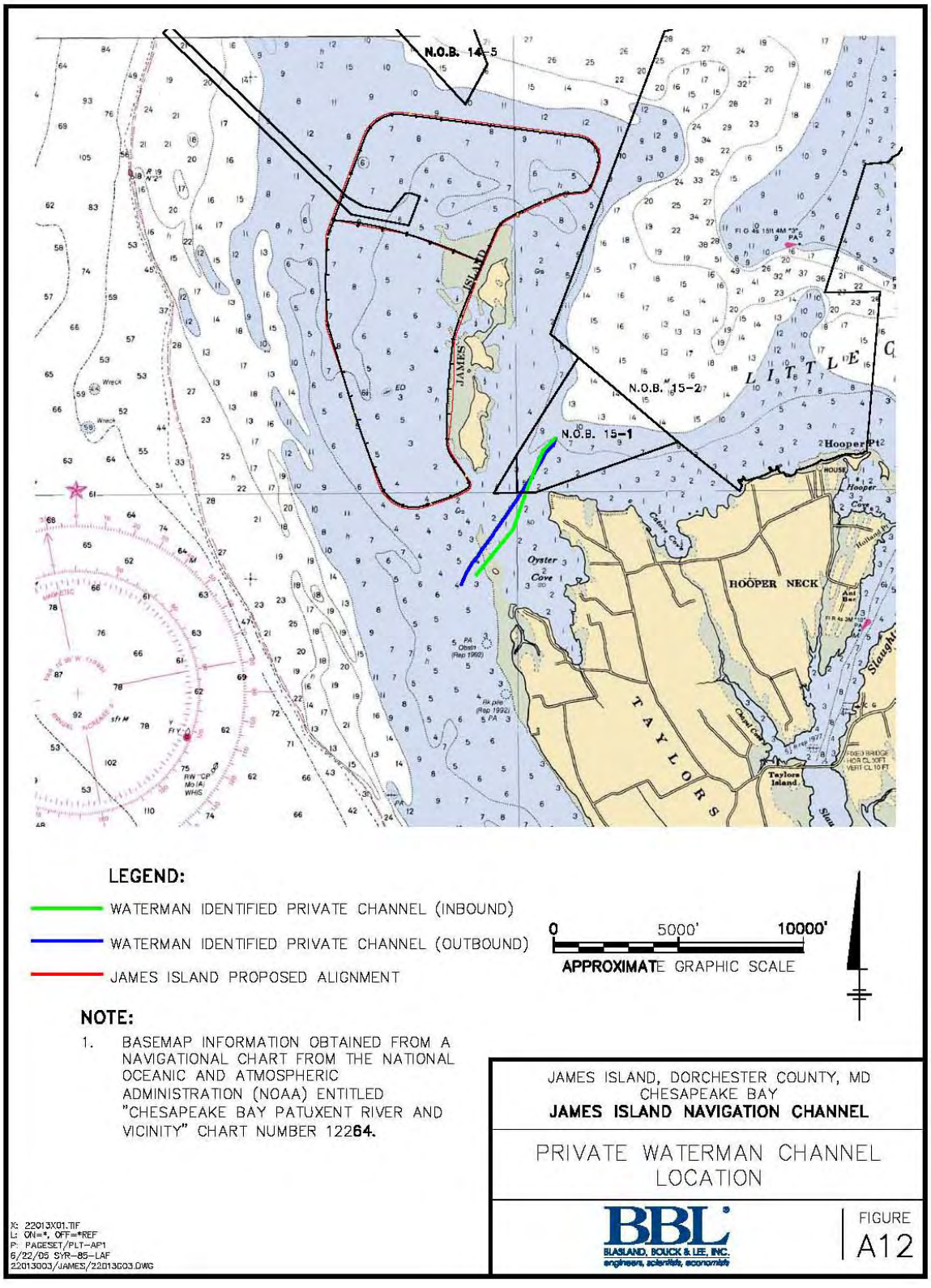

Figure A12. James Island private watermen channel

Shoaling

A shoaling analysis was performed for the Honga River Federal Navigational Channel, located near Barren Island. Data used for the shoaling study were provided by the Baltimore District on 22 August 2005 via electronic copy. Data were in three different formats: MicroStation files, AutoCAD files, and Easting, Northing, and Depth (x, y, z) files. The survey data were read into Terramodel to develop a three-dimensional (3-D) model of the survey data [Triangular Irregular Network (TIN)]. Two consecutive before-dredging or condition surveys were brought into Terramodel to determine a time line of shoaling over the given difference in time. Based on the average channel area and the volume of shoaled material, an average thickness of shoaling was then calculated.

Some data received were not applicable to the shoaling study due to contractor defaults, resulting in incomplete data sets. These periods of time were neglected from the analysis to provide the most accurate shoaling rates during periods of known change. The first analysis characterized the shoaling over the entire extent of the Honga River Channel, as seen in Figure A13 with old and current channel alignments. Table A7 follows with volume calculations done with Terramodel and shoaling rate calculations based on the amount of time passed between surveys. Surveys were taken approximately every year, with ranges of time from one-third of a year to 2.5 to 3.0 years between some surveys. Shoaling was somewhat variable, with an average of approximately 530,000 cu yd of material filling the channel, giving an average infill rate of 0.8 ft/year over the entire length of channel.

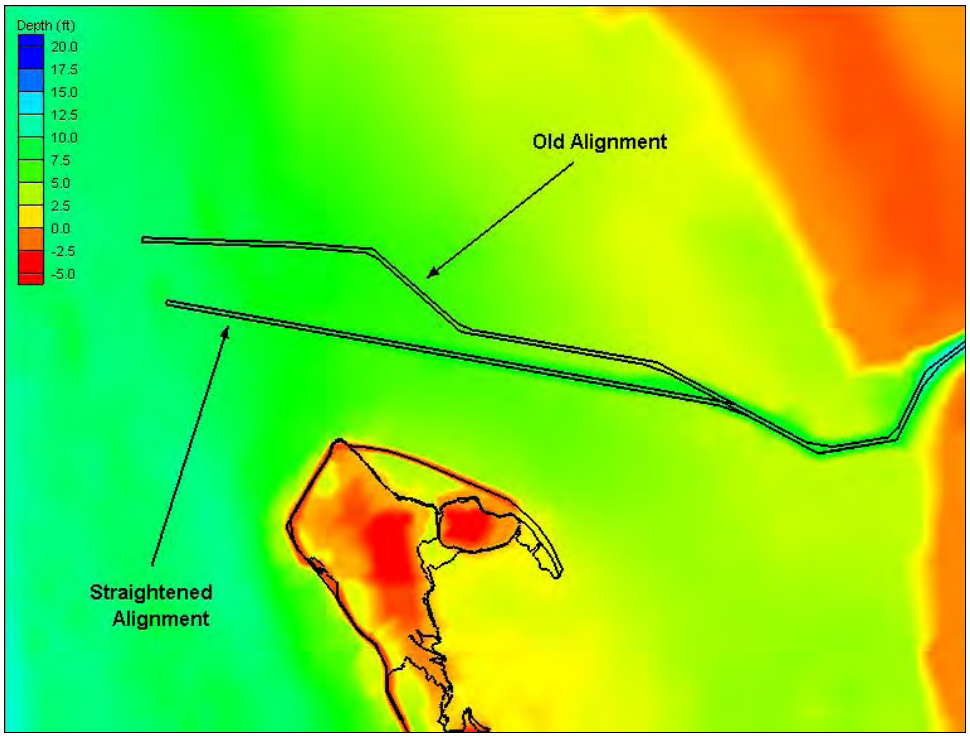

Figure A13. Honga River channel alignments

Table A7
Honga River Shoaling Analysis

Scenario	Year	Month	Day	Survey Type	Days Between Surveys	Dredging Event	Channel Area (sq ft)	Volume (cu yd)	Volume (cu ft)	Average Shoaling (ft)	Average Shoaling (ft/year)
1	1992	May	27	Condition surveys	751	No	656,238	22,604	610,308	0.93	0.45
	1994	Jun	17	Maintenance dredging							
2	1994	Jun	17	Maintenance dredging	369	No	650,245	39,748	1,073,196	1.65	1.63
	1995	Jun	21	Before dredge							
3	1996	Nov	25	After dredge	303	Yes	750,828	47,318	1,277,586	1.70	2.05
	1997	Sep	24	Condition surveys							
4	1997	Sep	24	Condition surveys	357	No	924,199	21,764	587,628	0.64	0.65
	1998	Sep	16	Before dredge							
5	1998	Sep	16	Before dredge	265	No	773,085	21,219	572,913	0.74	1.02
	1999	Jun	8	Before dredge							
6	1999	Jun	8	Before dredge	127	No	772,471	1,970	53,190	0.07	0.20
	1999	Oct	13	Before dredge							
7	1999	Oct	13	Before dredge	149	No	802,035	12,003	324,081	0.40	0.99
	2000	Mar	10	Before dredge							
8	2000	Mar	10	Before dredge	171	Yes	923,929	2,572	69,444	0.08	0.16
	2000	Aug	28	Maintenance dredging							
9	2000	Sep	27	After dredge	960	Yes	272,921	8,194	221,238	0.81	0.31
	2003	May	15	Maintenance dredging							
				Averages:	***384***		***725,106***	***19,710***	***532,176***	***0.708***	***0.829***

Notes:

1) Scenario 1 and 2 the survey type – maintenance dredge was an event where the contractor defaulted and no dredging occurred.

2) Scenarios 4, 5, 6, and 7 the survey type – before dredge was an event where several surveys where conducted in anticipation of dredging events that did not occur.

A secondary shoaling analysis was performed to more closely observe the shoaling in specific regions of the Honga River Channel, as noted during the field visit and predictions from hydrodynamic modeling performed by the U.S. Army Engineer Research and Development Center (ERDC). Two sections of the channel were studied separate from the rest of the channel for increased understanding of shoaling rates in the different portions of the channel. The two sections chosen for the detailed study are shown in Figure A14. Section 1 was noted to be in an area of high sediment movement from ERDC's modeling results (Chapter 4), whereas Section 2 was chosen due to shoaling noted in the region during the field visit. Section 2 is from the previous unstraightened alignment. Results are displayed in Tables A8 and A9 for Sections 1 and 2, respectively.

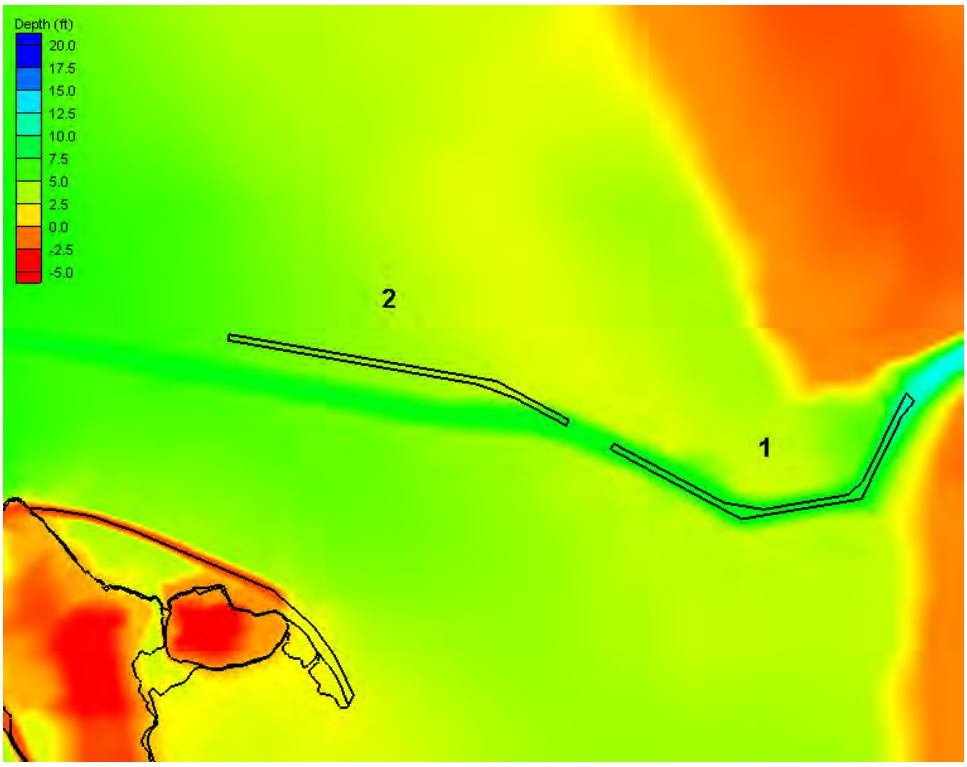

Figure A14. Honga River channel, selected shoaling study sections

Table A8
Honga River Section 1 Shoaling Analysis

Scenario	Year	Month	Day	Survey Type	Days Between Surveys	Dredging Event	Channel Area (sq ft)	Area 1 Volume (cu yd)	Area 1 Volume (cu ft)	Average Shoaling (ft)	Average Shoaling (ft/year)
1	1992	May	27	Condition surveys	751	No	136,374	3,528	95,256	0.70	0.34
	1994	Jun	17	Maintenance dredging							
2	1994	Jun	17	Maintenance dredging	369	No	161,043	19,412	524,121	3.25	3.22
	1995	Jun	21	Before dredge							
3	1996	Nov	25	After dredge	303	Yes	226,193	13,004	351,097	1.55	1.87
	1997	Sep	24	Condition surveys							
4	1997	Sep	24	Condition surveys	357	No	229,377	7,335	198,037	0.86	0.88
	1998	Sep	16	Before dredge							
5	1998	Sep	16	Before dredge	265	No	225,265	11,621	313,759	1.39	1.92
	1999	Jun	8	Before dredge							
6	1999	Jun	8	Before dredge	127	No	225,265	1,178	31,795	0.14	0.41
	1999	Oct	13	Before dredge							
7	1999	Oct	13	Before dredge	149	No	229,377	5,469	147,652	0.64	1.58
	2000	Mar	10	Before dredge							
8	2000	Mar	10	Before dredge	171	Yes	229,376	1,375	37,125	0.16	0.35
	2000	Aug	28	Maintenance dredging							
9	2000	Sep	27	After dredge	960	Yes	218,331	7,442	200,934	0.92	0.35
	2003	May	15	Maintenance dredging							
				Averages:	***384***		***208,956***	***7,818***	***211,086***	***1.070***	***1.212***

Notes:

1) Scenario 1 and 2 the survey type – maintenance dredge was an event where the contractor defaulted and no dredging occurred.

2) Scenarios 4, 5, 6, and 7 the survey type – before dredge was an event where several surveys where conducted in anticipation of dredging events that did not occur.

Table A9
Honga River Section 2 Shoaling Analysis

Scenario	Year	Month	Day	Survey Type	Days Between Surveys	Dredging Event	Channel Area (sq ft)	Area 1 Volume (cu yd)	Area 1 Volume (cu ft)	Average Shoaling (ft)	Average Shoaling (ft/year)
1	1992	May	27	Condition surveys	751	No	198,803	9,110	245,970	1.24	0.60
	1994	Jun	17	Maintenance dredging							
2	1994	Jun	17	Maintenance dredging	369	No	198,804	16,065	433,755	2.18	2.16
	1995	Jun	21	Before dredge							
3	1996	Nov	25	After dredge	303	Yes	130,104	21,074	569,001	4.37	5.27
	1997	Sep	24	Condition surveys							
4	1997	Sep	24	Condition surveys	357	No	198,809	6,637	179,210	0.90	0.92
	1998	Sep	16	Before dredge							
5	1998	Sep	16	Before dredge	265	No	198,809	2,576	69,549	0.35	0.48
	1999	Jun	8	Before dredge							
6	1999	Jun	8	Before dredge	127	No	198,809	392	10,589	0.05	0.15
	1999	Oct	13	Before dredge							
7	1999	Oct	13	Before dredge	149	No	198,809	1,465	39,542	0.20	0.49
	2000	Mar	10	Before dredge							
8	2000	Mar	10	Before dredge	171	Yes	198,809	399	10,773	0.05	0.12
	2000	Aug	28	Maintenance dredging							
9	2000	Sep	27	After dredge	960	Yes	Comparison Not Possible Due to Channel Realignment				
	2003	May	15	Maintenance dredging							
				Averages:	***384***		***190,219***	***7,215***	***194,799***	***1.169***	***1.273***

Notes:

1) Scenario 1 and 2 the survey type – maintenance dredge was an event where the contractor defaulted and no dredging occurred.

2) Scenarios 4, 5, 6, and 7 the survey type – before dredge was an event where several surveys where conducted in anticipation of dredging events that did not occur.

Hydrographic survey

Hydrographic surveys were conducted at James Island and Barren Island on 15-30 June 2005 by Hydro Data, Inc. The survey areas are shown in Figure A15 for both sites.

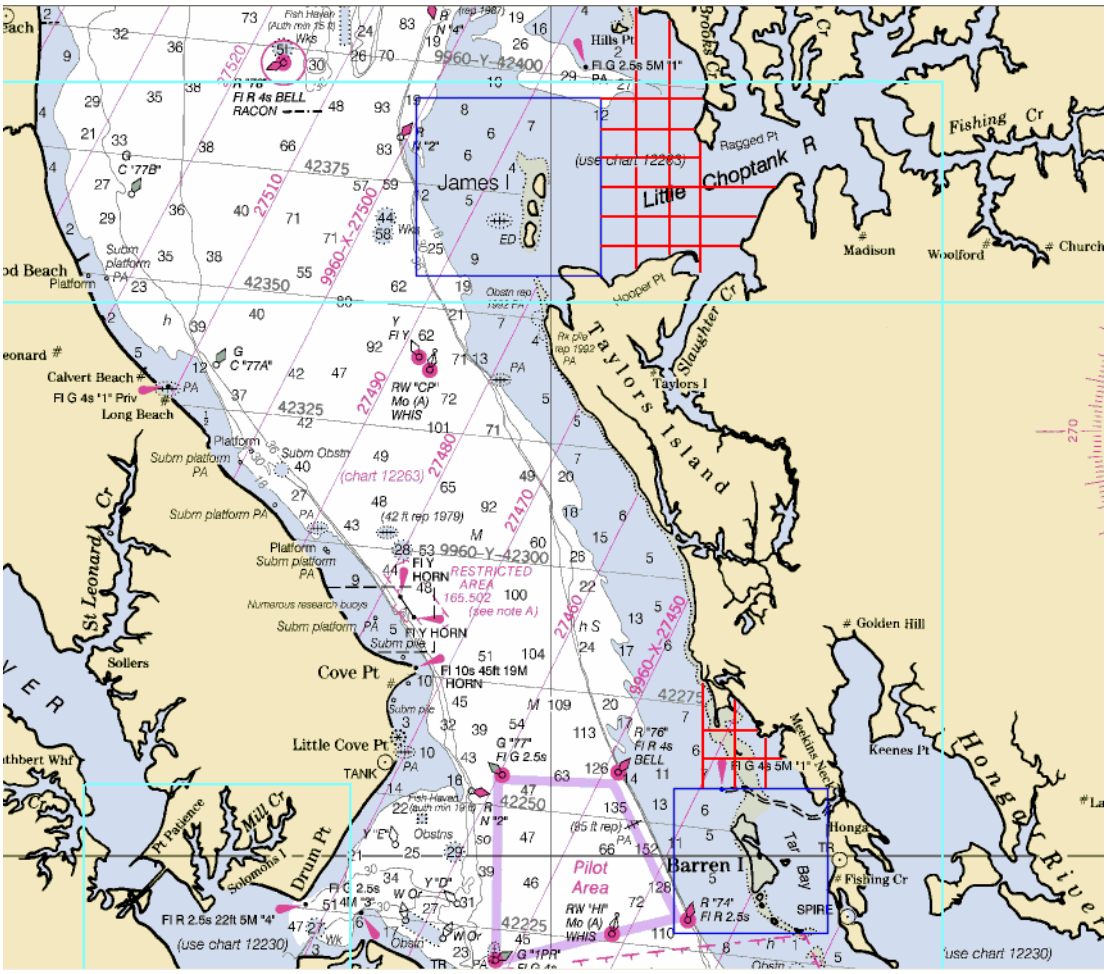

Figure A15. James Island and Barren Island hydrographic survey area, June 2005

Figure A15 shows two blue rectangles for the survey areas. The rectangle is 3 by 3 miles for James Island and 2.5 by 2.5 miles for Barren Island. The interval of survey transect lines (east to west) is every 400 ft in the rectangle. The red lines are additional transects (half mile between lines) outside the rectangle areas. Data points were collected at a rate of 18/sec, resulting in a data point every 2-4 ft.

Vertical and horizontal data are referenced to mllw based on the 1960 to 1978 tidal epoch and the Maryland State Plane, NAD83, respectively.

Historical shoreline position

Historical shoreline position data were developed for the island shorelines and mainland shorelines east of James Island and Barren Island. Available historical shoreline position data developed by the Maryland Department of Natural Resources (MDNR) and available historical aerial photography were combined with high spatial resolution imagery obtained as a part of this study. The high spatial resolution imagery was obtained following establishment of four aerial photography targets in each of the study areas and referencing the targets to the Maryland State Plane coordinate system as shown in Figure A16 and Figure A17 for James Island and Barren Island, respectively.

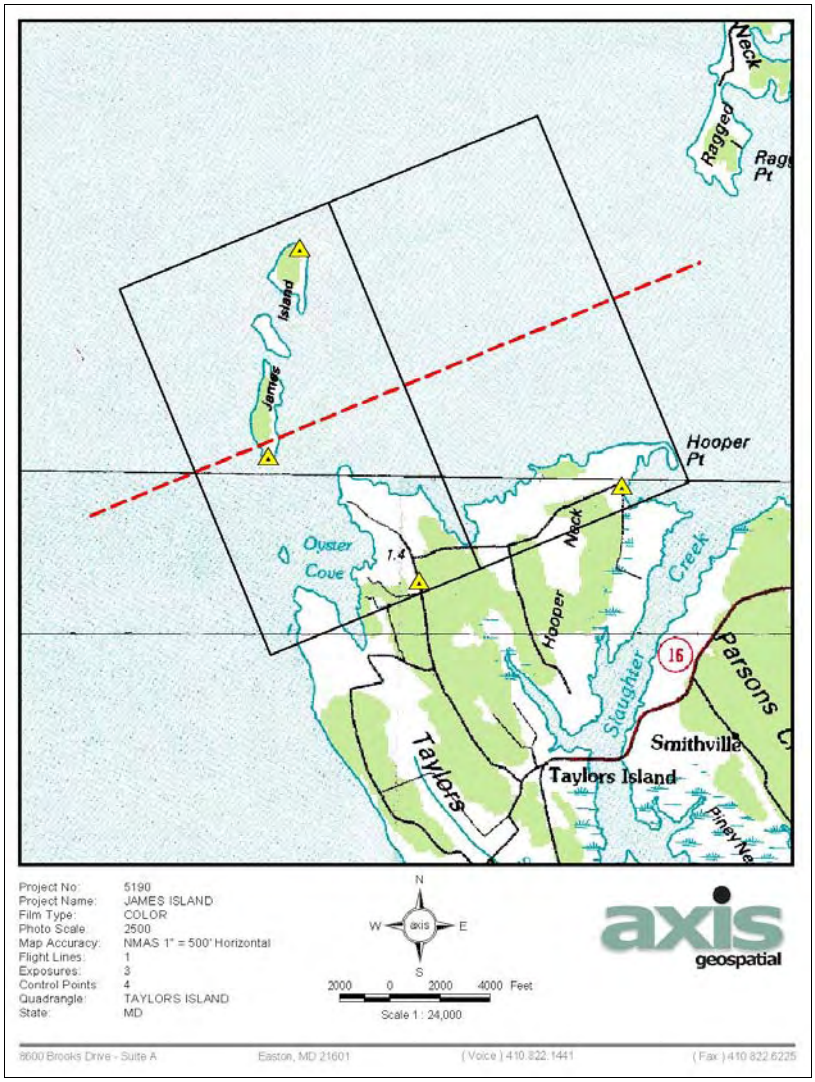

Figure A16. James Island aerial photograph coverage, 24 July 2005

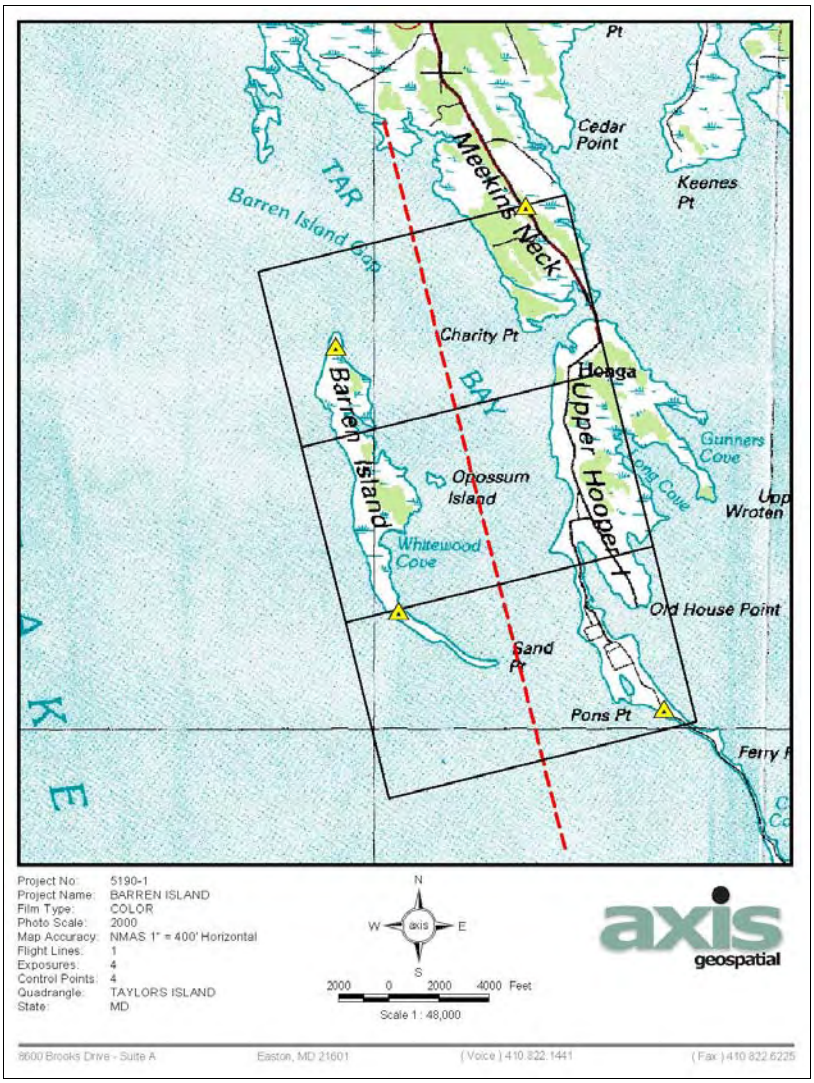

Figure A17. Barren Island aerial photograph coverage, 24 July 2005

Color infrared (CIR) film is the preferred film for shoreline mapping projects and was used for the imagery to allow best determination of shoreline location. The geo-referenced imagery was taken on 24 July 2005, at mean low water by Axis Geospatial of Easton, MD, to show the tonal differences in the exposed beach face. Stereo compilation was completed for 1 in. = 400 ft planimetrics and maps produced as AutoCAD files on CDROM. The digital ortho-processing was for 2-ft pixel CIR digital ortho Imagery in TIFF/TFW format on CDROM.

A shoreline position map was developed to determine shoreline change rates and to identify critical erosion areas, as well as be available to compare pre- and post-construction conditions to evaluate construction impacts. The shoreline position map was initially developed by overlaying three digital shorelines of the study area available from the MDNR. These shorelines were 1848, 1942, and 1994, and were georeferenced to the Maryland State Plane Grid Coordinate system.

Digital aerial photographs for 1989, 1999, and 2004 were then imported into AutoCAD Land Development Desktop along with the available 1848, 1942, and 1994 shorelines and digital planimetrics from the MDNR. Each digital photograph was registered and rectified by rotating and scaling to match the prominent features in the field. This procedure was followed for each year to result in registered and rectified tiled photographs attached to the AutoCAD coordinate drawing file.

Each of the sets of registered and rectified aerial photographs was inspected and analyzed to identify and map the mean high water (mhw) contour. This procedure consisted of locating the mhw contour based on the changes in beach sand tone, which typically denotes the mhw contour. Following this procedure, a continuous mhw contour for each of the aerial photography sets was overlaid on the earlier shorelines provided by the MDNR. The same procedure was followed with the July 2005 digital aerial photograph. The mhw contours for each of the years are shown in Figures A18 to A25.

Shoreline changes corresponding to each study area reach are also shown in Figures A18 to A25 for the following time periods:

a. 1848 – 1942.

b. 1942 – 1989.

c. 1989 – 1994.

d. 1994 – 1999.

e. 1999 – 2004.

f. 2004 – 2005.

Shoreline change was measured at 500-ft intervals along the baselines established for each shoreline reach. Measured annual shoreline change for each time period for each study area reach is shown in the figures. Table A10 summarizes the average annual shoreline change for each study area reach for the various time periods analyzed. Tables A11 to A16 compile the shoreline change rates along the shoreline reaches for each year for each of the time periods.

Potential sources of error in the development of the shoreline change rates include:

a. Limited prominent features in the field available for registering and rectifying each digital photograph.

b. Subjectivity of locating the mhw contour based on changes in beach sand tone.

c. Subjectivity of tracing of the continuous mhw contour for each of the aerial photography sets.

Given these potential sources of error, the estimated error in measuring the differences between two shorelines of different dates is estimated to be +/-30 ft.

Analysis of the data in Table A10 indicates a continuous trend of annual shoreline erosion for the various shoreline reaches with cycles of increasing and decreasing annual erosion rates throughout the time periods analyzed. As expected, the highest erosion rates occur along the most exposed shorelines, including those of James Island, Taylors Island, and Barren Island.

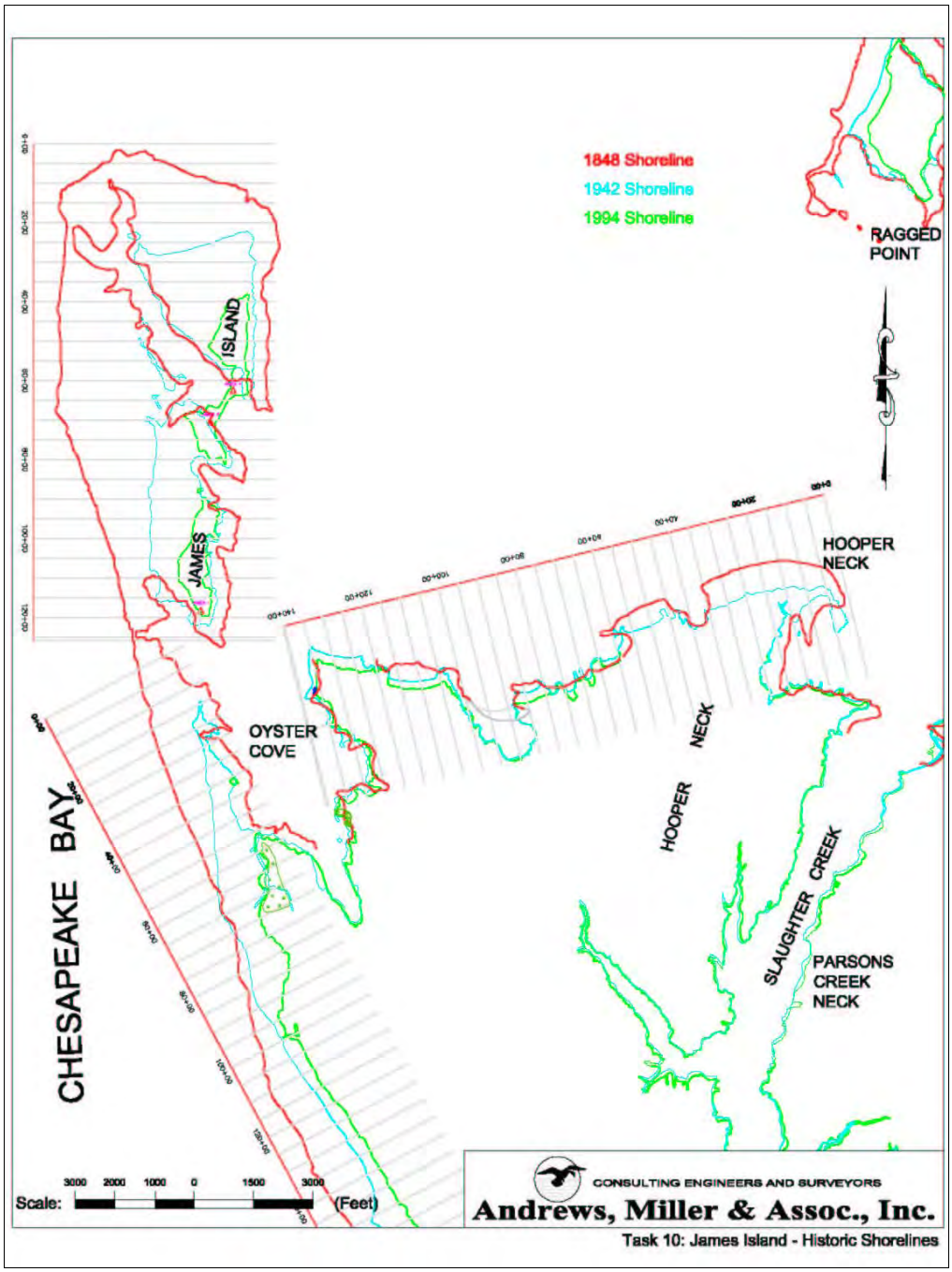

Figure A18. James Island shoreline position baselines

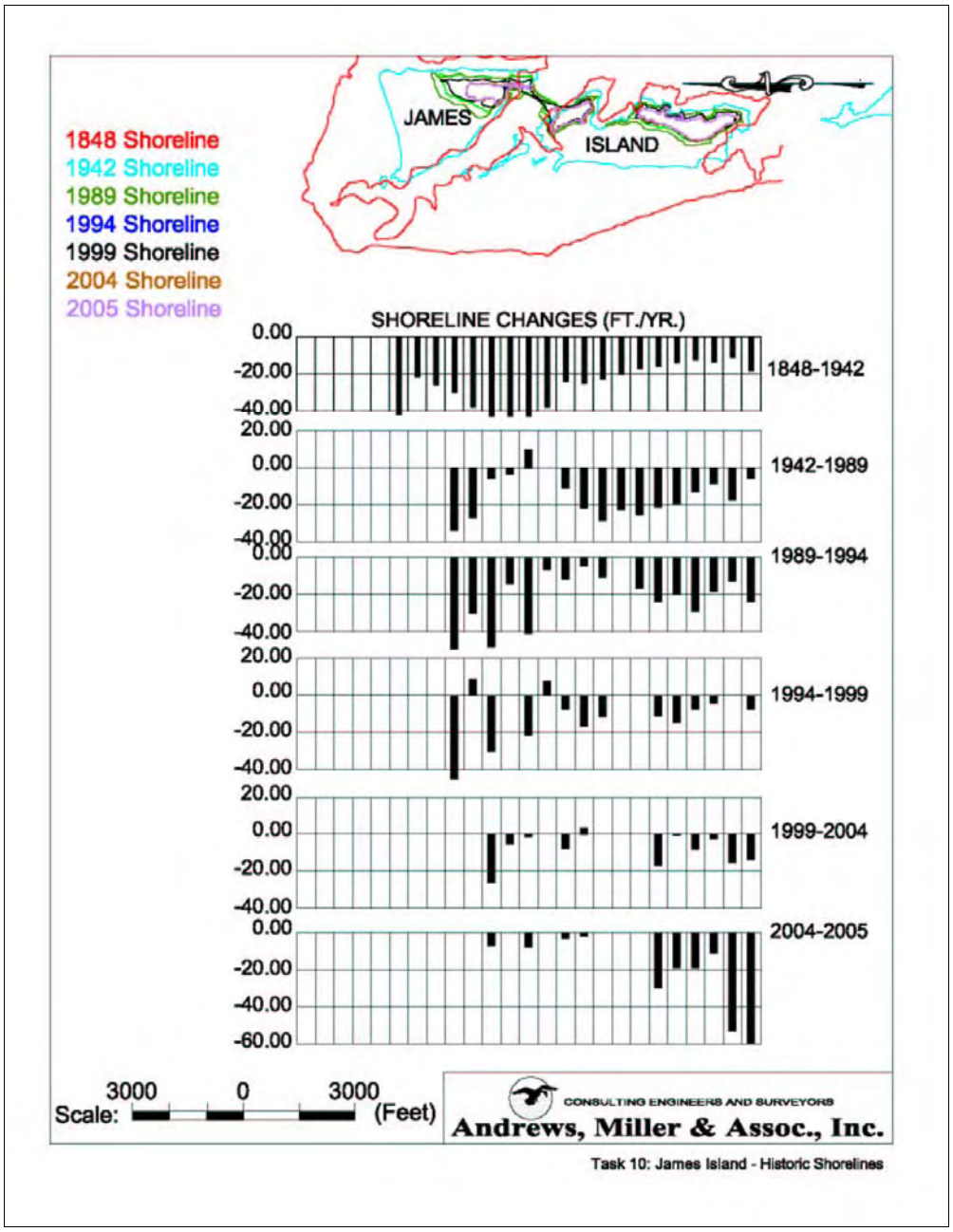

Figure A19. James Island shoreline position and change

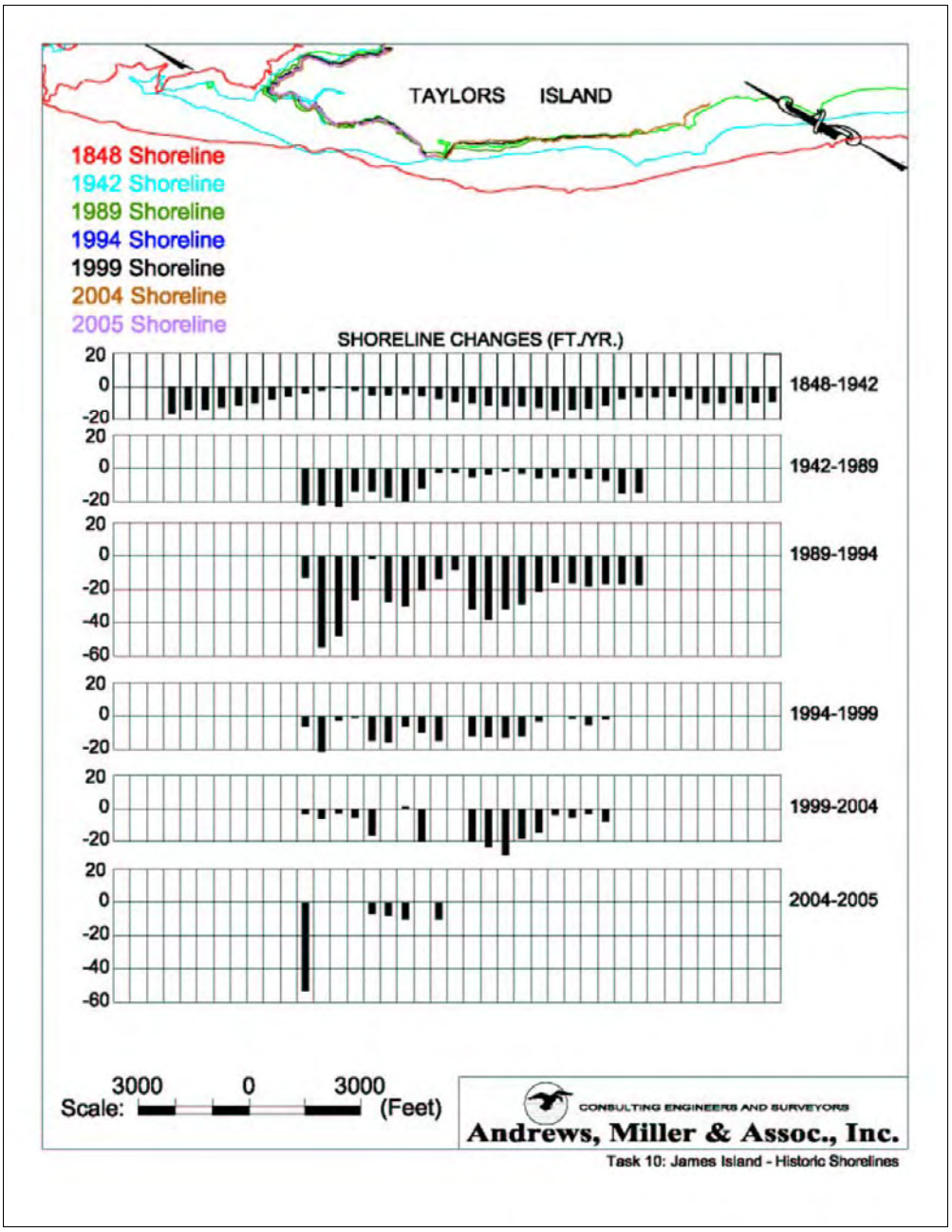

Figure A20. Taylors Island shoreline position and change

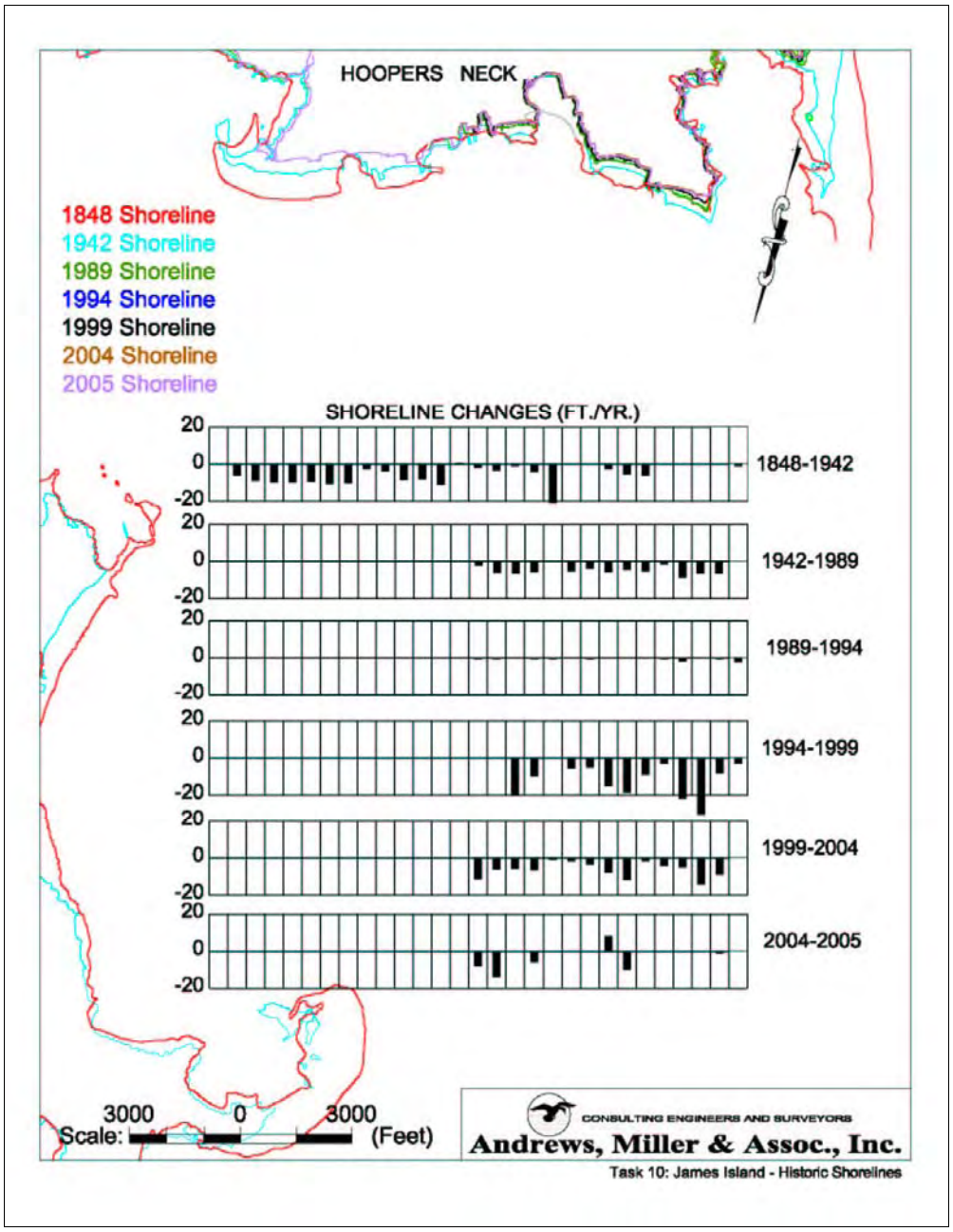

Figure A21. Hoopers Neck shoreline position and change

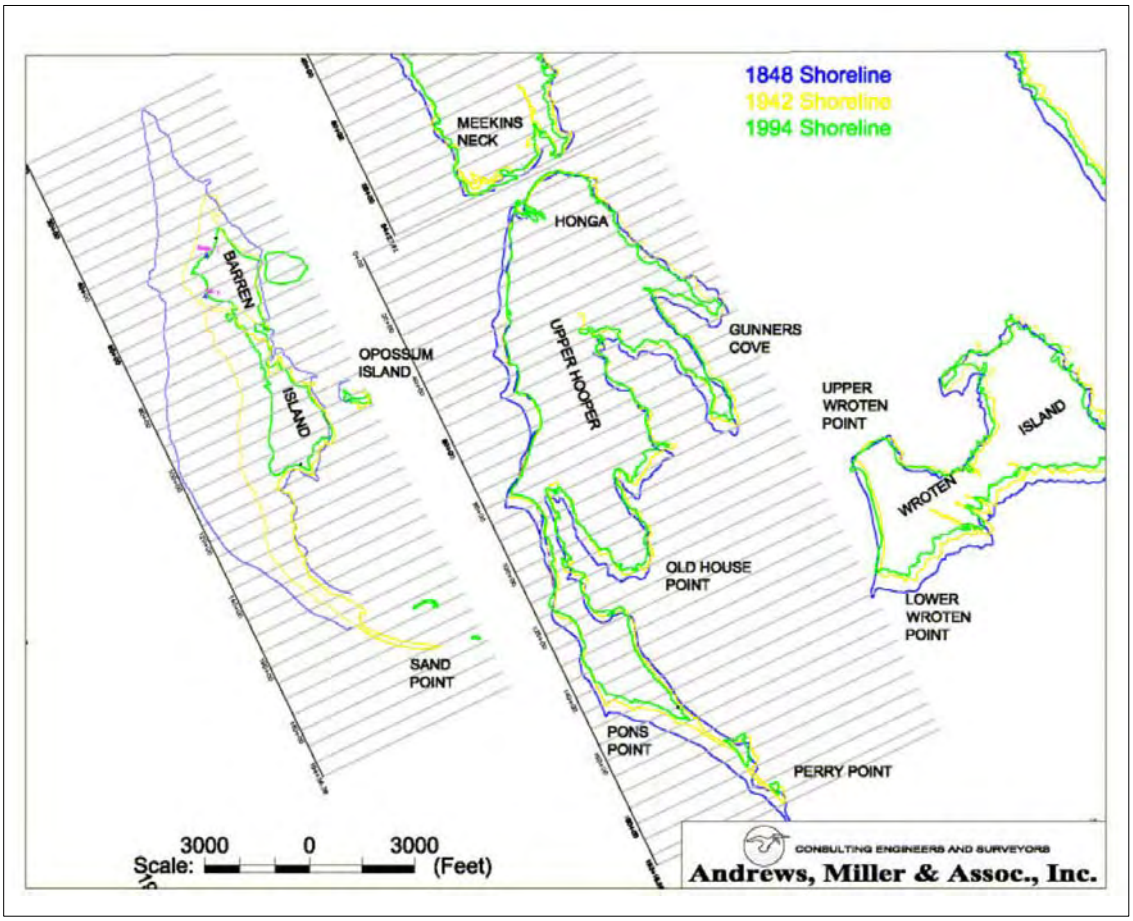

Figure A22. Barren Island shoreline position baselines

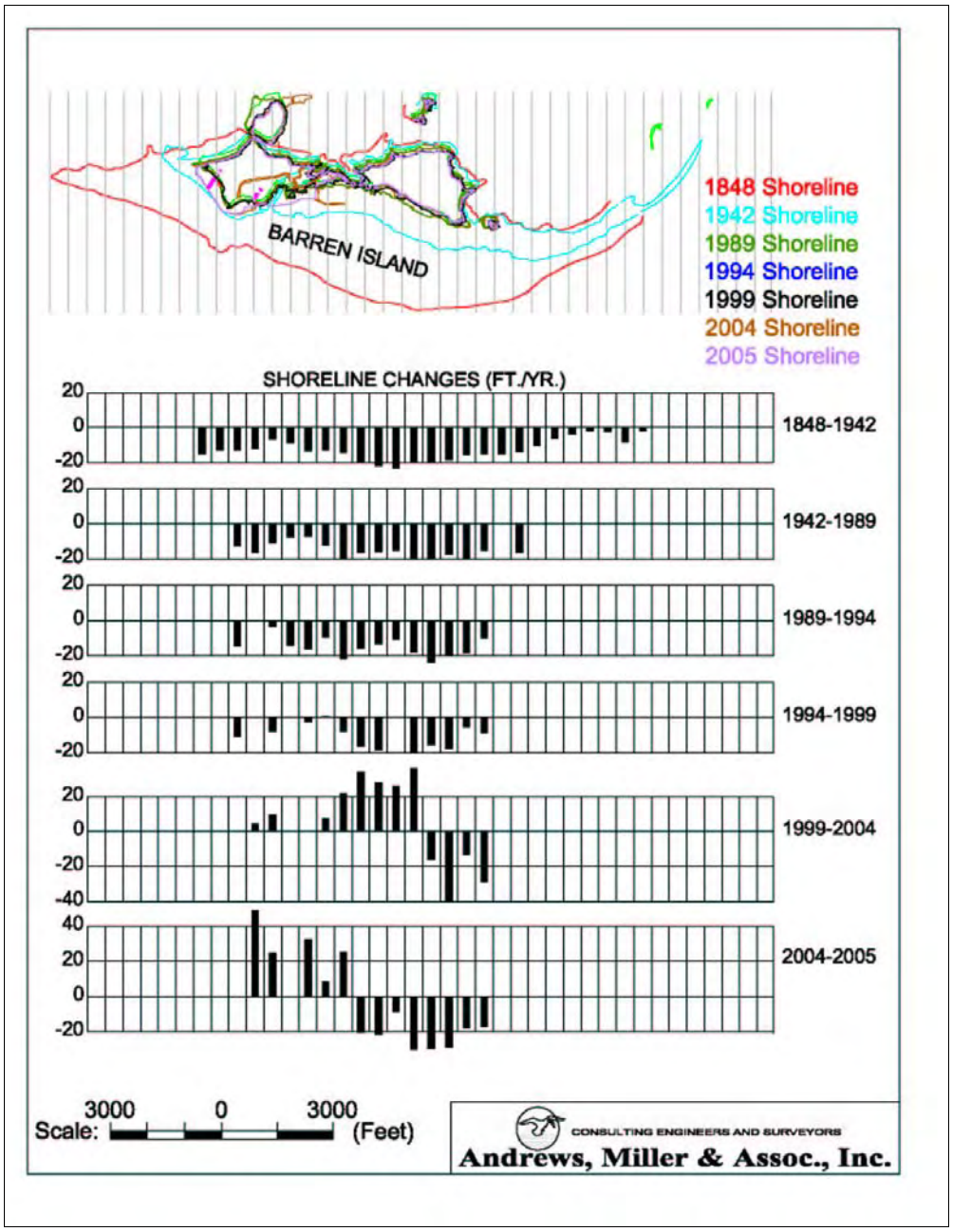

Figure A23. Barren Island shoreline position and change

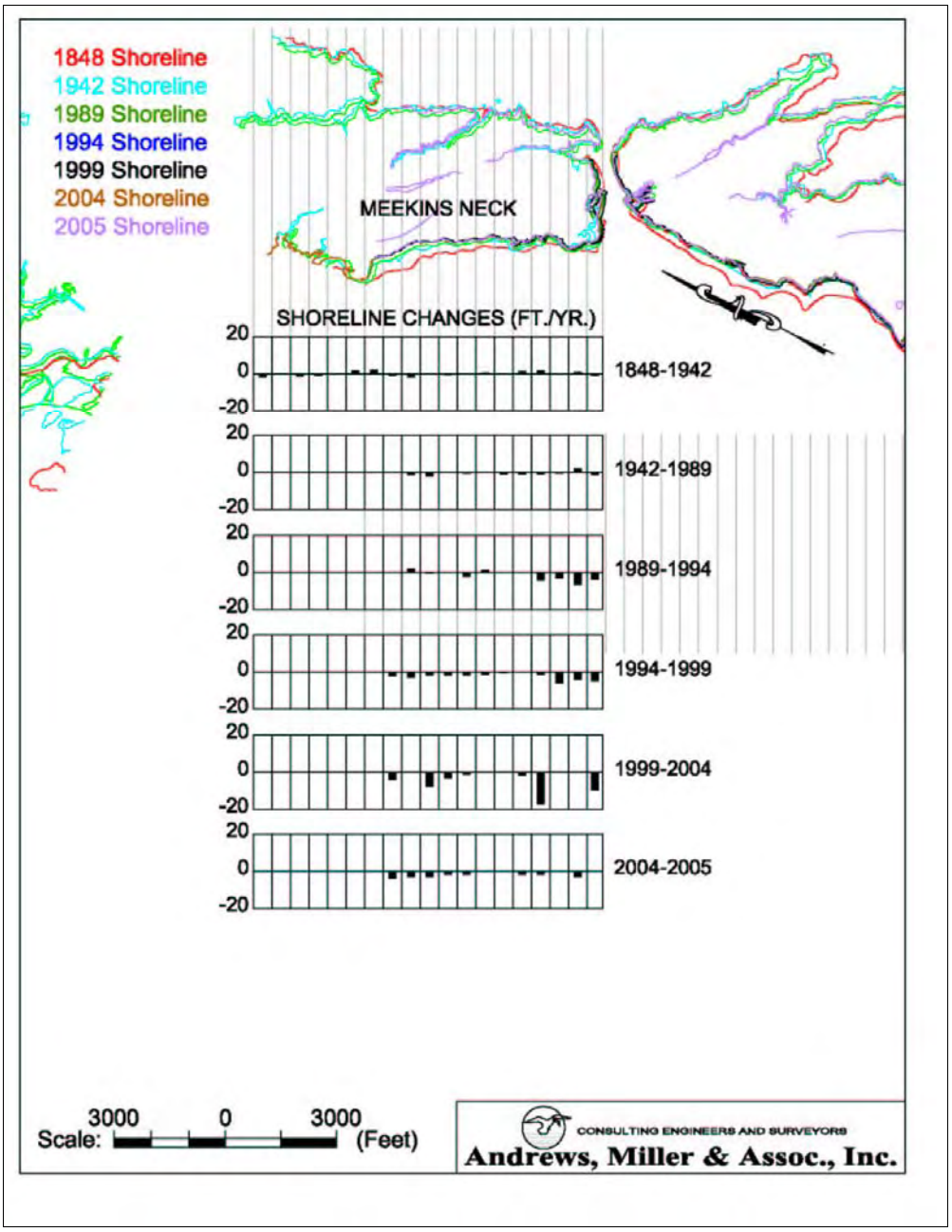

Figure A24. Meekins Neck shoreline position and change

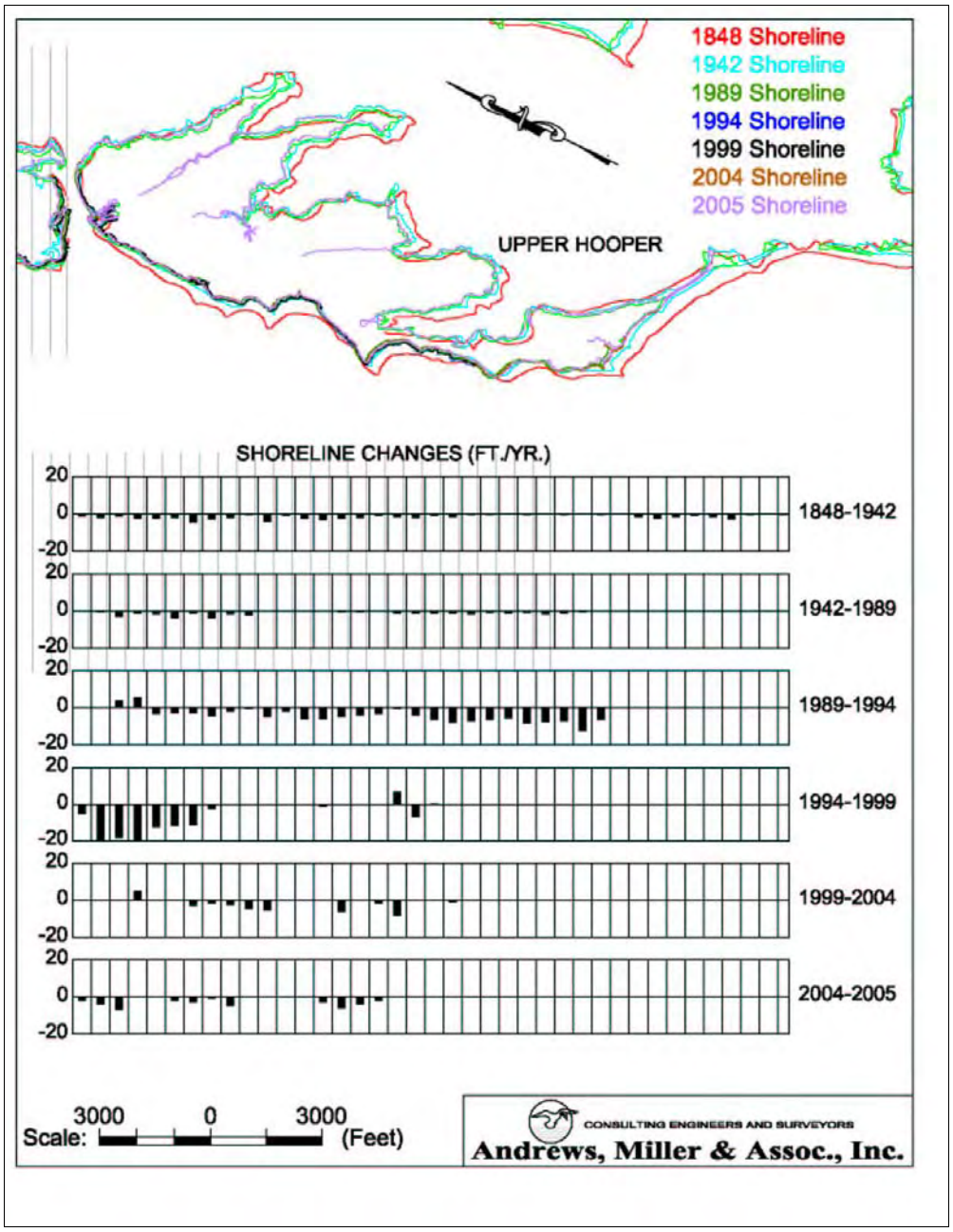

Figure A25. Upper Hoopers shoreline position and change

Table A10
Summary of Average Annual Shoreline Change for Various Time Periods (ft/year)

	1848 - 1942	1942 - 1989	1989 - 1994	1994 - 1999	1999 - 2004	2004 - 2005
James Island	-25	-14.3	-21.3	-10.6	-6.3	-14.1
Taylors Island	-8.8	-10.3	-23.4	-6.7	-8.5	-10.4
Hooper Neck	-5.9	-4.6	-0.6	-11.4	-6.5	-2.2
Barren Island	-12.3	-14.3	-31.4	-8.9	-0.2	-7.13
Meekins Neck	0	-0.4	-0.9	-2.2	-4	-1.8
Upper Hooper	-1.3	-1.3	-4.1	-5.2	-1.7	-2.3

Table A11
James Island Shoreline Change (ft)

Station Number	1848 - 1942		1942 - 1989		1989 - 1994		1994 - 1999		1999 - 2004		2004 - 2005	
	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year
0+00	1848 SL only											
5+00	1848 SL only											
10+00	1848 SL only											
15+00	1848 SL only											
20+00	1848 SL only											
25+00	-3,999	-42.54										
30+00	-2,048	-21.79										
35+00	-2,452	-26.09										
40+00	-2,851	-30.33	-1,585	-33.72	-247	-49.40	-225	-45.00				
45+00	-3,597	-38.27	-1,263	-26.87	-150	-30.00	-45	-9.00				
50+00	-4,062	-43.21	-263	-5.60	-240	-48.00	-151	-30.20	-131	-26.20	-7	-7.00
55+00	-4,095	-43.56	-150	-3.19	-71	-14.20		0.00	-26	-5.20	0	0.00
60+00	-4,094	-43.55	471	10.02	-205	-41.00	-108	-21.60	-7	-1.40	-8	-8.00
65+00	-3,584	-38.13	0	0.00	-32	-6.40	38	7.60		0.00	0	0.00
70+00	-2,275	-24.20	-512	-10.89	-59	-11.80	-38	-7.60	-39	-7.80	-3	-3.00
75+00	-2,381	-25.33	-1,023	-21.77	-23	-4.60	-83	-16.60	18	3.60	-2	-2.00
80+00	-2,154	-22.91	-1,337	-28.45	-53	-10.60	-58	-11.60		0.00		0.00
85+00	-1,894	-20.15	-1,056	-22.47		0.00		0.00		0.00		0.00
90+00	-1,648	-17.53	-1,184	-25.19	-82	-16.40		0.00		0.00		0.00
95+00	-1,513	-16.10	-996	-21.19	-119	-23.80	-55	-11.00	-85	-17.00	-30	-30.00
100+00	-1,319	-14.03	-928	-19.74	-99	-19.80	-74	-14.80	-3	-0.60	-19	-19.00
105+00	-1,167	-12.41	-598	-12.72	-145	-29.00	-38	-7.60	-40	-8.00	-19	-19.00
110+00	-1,297	-13.80	-393	-8.36	-91	-18.20	-22	-4.40	-12	-2.40	-11	-11.00
115+00	-1,072	-11.40	-813	-17.30	-62	-12.40	0	0.00	-76	-15.20	-53	-53.00
120+00	-1,736	-18.47	-268	-5.70	-118	-23.60	-38	-7.60	-69	-13.80	-60	-60.00
125+00	-182	-1.94	-199	-4.23	-120	-24.00		0.00		0.00		0.00
125+90												

Table A12
Taylors Island Shoreline Change (ft)

Station Number	1848 - 1942		1942 - 1989		1989 - 1994		1994 - 1999		1999 - 2004		2004 - 2005	
	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year
0+00	1848 SL only											
5+00	1848 SL only											
10+00	1848 SL only											
15+00	-1,550	-16.49										
20+00	-1,261	-13.41										
25+00	-1,262	-13.43										
30+00	-1,147	-12.20										
35+00	-1,060	-11.28										
40+00	-900	-9.57										
45+00	-700	-7.45										
50+00	-533	-5.67										
55+00	-382	-4.06	-1,005	-21.38	-63	-12.60	-30	-6.00	-16	-3.20	-53	-53.00
60+00	-216	-2.30	-1,023	-21.77	-272	-54.40	-107	-21.40	-31	-6.20	0	0.00
65+00	-24	-0.26	-1,072	-22.81	-239	-47.80	14	2.80	13	2.60	0	0.00
70+00	-223	-2.37	-637	-13.55	-131	-26.20	5	1.00	-25	-5.00	0	0.00
75+00	-475	-5.05	-626	-13.32	-7	-1.40	-73	-14.60	-81	-16.20	-7	-7.00
80+00	-471	-5.01	-806	-17.15	-136	-27.20	-78	-15.60	0	0.00	-8	-8.00
85+00	-402	-4.28	-900	-19.15	-148	-29.60	-32	-6.40	8	1.60	-10	-10.00
90+00	-492	-5.23	-557	-11.85	-100	-20.00	-48	-9.60	-97	-19.40	0	0.00
95+00	-694	-7.38	-106	-2.26	-87	-17.40	-73	-14.60	0	0.00	-16	-16.00
100+00	-829	-8.82	-111	-2.36	-41	-8.20	0	0.00	0	0.00		
105+00	-925	-9.84	-231	-4.91	-159	-31.80	-81	-16.20	-97	-19.40		
110+00	-1,056	-11.23	-154	-3.28	-188	-37.60	-63	-12.60	-117	-23.40		
115+00	-1,082	-11.51	-77	-1.64	-159	-31.80	-64	-12.80	-139	-27.80		
120+00	-1,055	-11.22	-141	-3.00	-143	-28.60	-60	-12.00	-91	-18.20		
125+00	-1,136	-12.09	-260	-5.53	-105	-21.00	15	3.00	-73	-14.60		
130+00	-1,312	-13.96	-244	-5.19	-78	-15.60	0	0.00	17	3.40		
135+00	-1,295	-13.78	-247	-5.26	-80	-16.00	6	1.20	-26	-5.20		
140+00	-1,215	-12.93	-285	-6.06	-89	-17.80	27	5.40	-14	-2.80		
145+00	-1,064	-11.32	-333	-7.09	-82	-16.40	8	1.60	-40	-8.00		
150+00	-671	-7.14	-687	-14.62	-62	-12.40	0	0.00				
155+00	-594	-6.32	-669	-14.23	-85	-17.00	0	0.00				
160+00	-585	-6.22										
165+00	-565	-6.01										
170+00	-641	-6.82										
175+00	-930	-9.89										

Table A13
Hoopers Neck Shoreline Change (ft)

Station Number	1848 - 1942		1942 - 1989		1989 - 1994		1994 - 1999		1999 - 2004		2004 - 2005	
	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year
0+00												
5+00	-574	-6.11										
10+00	-832	-8.85										
15+00	-896	-9.53										
20+00	-919	-9.78										
25+00	-885	-9.41										
30+00	-981	-10.44										
35+00	-945	-10.05										
40+00	-219	-2.33										
45+00	-328	-3.49										
50+00	-780	-8.30										
55+00	-747	-7.95										
60+00	-1,037	-11.03										
65+00	69	0.73										
70+00	-149	-1.59	-103	-2.19	-31	-0.66		0.00	-58	-11.60	-8	-8.00
75+00	-297	-3.16	-289	-6.15	-24	-0.51	0	0.00	-31	-6.20	-14	-14.00
80+00	-75	-0.80	-308	-6.55	-11	-0.23	-96	-19.20	-30	-6.00	0	0.00
85+00	-401	-4.27	-257	-5.47	-35	-0.74	-49	-9.80	-34	-6.80	-6	-6.00
90+00	-1,975	-21.01	-8	-0.17	-35	-0.74	0	0.00	-6	-1.20	0	0.00
95+00	0	0.00	-244	-5.19	-10	-0.21	-27	-5.40	-10	-2.00	0	0.00
100+00	0	0.00	-164	-3.49	-34	-0.72	-25	-5.00	-17	-3.40	0	0.00
105+00	-242	-2.57	-260	-5.53	8	0.17	-75	-15.00	-40	-8.00	8	8.00
110+00	-508	-5.40	-216	-4.60	-13	-0.28	-92	-18.40	-60	-12.00	-10	-10.00
115+00	-552	-5.87	-244	-5.19	0	0.00	-44	-8.80	-9	-1.80	0	0.00
120+00	-16	-0.17	-57	-1.21	-39	-0.83	-14	-2.80	-21	-4.20	0	0.00
125+00	0	0.00	-400	-8.51	-79	-1.68	-109	-21.80	-25	-5.00	0	0.00
130+00	0	0.00	-318	-6.77	0	0.00	-152	-30.40	-71	-14.20	0	0.00
135+00	0	0.00	-317	-6.74	-28	-0.60	-41	-8.20	-46	-9.20	-1	-1.00
140+00	-76	-0.81	-41	-0.87	-11	-2.20	-14	-2.80	0	0.00	0	0.00

Table A14
Barren Island Shoreline Change (ft)

Station Number	1848 - 1942		1942 - 1989		1989 - 1994		1994 - 1999		1999 - 2004		2004 - 2005	
	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year
0+00	1848 SL only											
5+00	1848 SL only											
10+00	1848 SL only											
15+00	1848 SL only											
20+00	1848 SL only											
25+00	1848 SL only											
30+00	-1,490	-15.85										
35+00	-1,245	-13.24										
40+00	-1,228	-13.06	-604	-12.85	-740	-148.00	-56	-11.20				
45+00	-1,146	-12.19	-777	-16.53	0	0.00	0	0.00	21	4.20	4.9	4.90
50+00	-653	-6.95	-516	-10.98	-18	-3.60	-41	-8.20	49	9.80	2.5	2.50
55+00	-830	-8.83	-367	-7.81	-710	-142.00	0	0.00	0	0.00	0	0.00
60+00	-1,301	-13.84	-338	-7.19	-82	-16.40	-14	-2.80	0	0.00	32.6	32.60
65+00	-1,251	-13.31	-573	-12.19	-47	-9.40	4	0.80	38	7.60	8.7	8.70
70+00	-1,346	-14.32	-915	-19.47	-108	-21.60	-41	-8.20	109	21.80	25.6	25.60
75+00	-1,857	-19.76	-782	-16.64	-80	-16.00	-83	-16.60	171	34.20	-20.5	-20.50
80+00	-2,057	-21.88	-754	-16.04	-66	-13.20	-94	-18.80	142	28.40	-21.7	-21.70
85+00	-2,181	-23.20	-706	-15.02	-55	-11.00	0	0.00	131	26.20	-8.5	-8.50
90+00	-1,827	-19.44	-935	-19.89	-89	-17.80	-98	-19.60	-182	-36.40	-30	-30.00
95+00	-1,826	-19.43	-923	-19.64	-120	-24.00	-78	-15.60	-82	-16.40	-29.7	-29.70
100+00	-1,752	-18.64	-819	-17.43	-100	-20.00	-90	-18.00	-198	-39.60	-28.8	-28.80
105+00	-1,477	-15.71	-937	-19.94	-92	-18.40	-29	-5.80	-68	-13.60	-17.8	-17.80
110+00	-1,451	-15.44	-709	-15.09	-46	-9.20	-44	-8.80	-144	-28.80	-17.1	-17.10
115+00	-1,428	-15.19		0.0								
120+00	-1,305	-13.88	-775	-16.49								
125+00	-1,006	-10.70										
130+00	-629	-6.69										
135+00	-361	-3.84										
140+00	-205	-2.18										
145+00	-250	-2.66										
150+00	-816	-8.68										
155+00	-197	-2.10										
160+00	-25	-0.27										
165+00	1942 SL only	0.00										
170+00	1942 SL only	0.00										
175+00	1942 SL only	0.00										
180+00		0.00										
185+00		0.00										

Table A15
Meekins Neck Shoreline Change (ft)

Station Number	1848 - 1942		1942 -1989		1989 - 1994		1994 - 1999		1999 - 2004		2004 - 2005	
	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year
0+00	-190	-2.02										
5+00	-47	-0.50										
10+00	-137	-1.46										
15+00	-123	-1.31										
20+00	13	0.14										
25+00	167	1.78										
30+00	200	2.13										
35+00	-107	-1.14	-17	-0.36	0	0.00	-10	-2.00	-21	-4.20	-4	-4.00
40+00	-172	-1.83	-53	-1.13	10	2.00	-15	-3.00	0	0.00	-3	-3.00
45+00	-44	-0.47	-107	-2.28	-3	-0.60	-8	-1.60	-36	-7.20	-3	-3.00
50+00	-86	-0.91	5	0.11	0	0.00	-9	-1.80	-16	-3.20	-2	-2.00
55+00	-12	-0.13	-30	-0.64	-12	-2.40	-9	-1.80	-6	-1.20	-2	-2.00
60+00	44	0.47	0	0.00	6	1.20	-6	-1.20	0	0.00	0	0.00
65+00	-26	-0.28	-46	-0.98	0	0.00	-3	-0.60	0	0.00	0	0.00
70+00	127	1.35	-45	-0.96	0	0.00	0	0.00	-9	-1.80	-2	-2.00
75+00	153	1.63	-35	-0.74	-21	-4.20	-7	-1.40	-67	-13.40	-2	-2.00
80+00	-29	-0.31	24	0.51	-16	-3.20	-30	-6.00	0	0.00	0	0.00
85+00	70	0.74	100	2.13	-33	-6.60	-21	-4.20	0	0.00	-3	-3.00
90+00	94	1.00	-54	-1.15	20	4.00	-25	-5.00	-48	-9.60	0	0.00
94+28	95	1.01	27	0.57	0	0.00	-1	-0.20	-55	-11.00	-3	-3.00

Table A16
Upper Hoopers Shoreline Change (ft)

Station Number	1848 - 1942		1942 - 1989		1989 - 1994		1994 - 1999		1999 - 2004		2004 - 2005	
	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year	Total Diff.	Per Year
0+00	-101	-1.07	-19	-0.40	0	0.00	-26	-5.20	0	0.00	-2	-2.00
5+00	-183	-1.95	-31	-0.66	-1	-0.20	-101	-20.20	0	0.00	-4	-4.00
10+00	-109	-1.16	-146	-3.11	20	4.00	-92	-18.40	0	0.00	-7	-7.00
15+00	-220	-2.34	-78	-1.66	27	5.40	-102	-20.40	25	5.00	0	0.00
20+00	-218	-2.32	-89	-1.89	-17	-3.40	-64	-12.80	0	0.00	0	0.00
25+00	-194	-2.06	-174	-3.70	-14	-2.80	-60	-12.00	-1	-0.20	-2	-2.00
30+00	-412	-4.38	-60	-1.28	-14	-2.80	-57	-11.40	-15	-3.00	-3	-3.00
35+00	-254	-2.70	-174	-3.70	-22	-4.40	-11	-2.20	-9	-1.80	-1	-1.00
40+00	-177	-1.88	-82	-1.74	-10	-2.00	0	0.00	-13	-2.60	-5	-5.00
45+00	52	0.55	-116	-2.47	-3	-0.60	0	0.00	-24	-4.80	0	0.00
50+00	-369	-3.93	0	0.00	-24	-4.80	0	0.00	-28	-5.60	0	0.00
55+00	80	0.85	0	0.00	-11	-2.20	0	0.00	0	0.00	0	0.00
60+00	-244	-2.60	0	0.00	-30	-6.00	0	0.00	0	0.00	0	0.00
65+00	-285	-3.03	0	0.00	-30	-6.00	-5	-1.00	0	0.00	-3	-3.00
70+00	-232	-2.47	-29	-0.62	-24	-4.80	-2	-0.40	-31	-6.20	-6	-6.00
75+00	-203	-2.16	-29	-0.62	-21	-4.20	0	0.00	0	0.00	-4	-4.00
80+00	63	0.67	0	0.00	-16	-3.20	0	0.00	-9	-1.80	-2	-2.00
85+00	-155	-1.65	-71	-1.51	-3	-0.60	35	7.00	-41	-8.20	0	0.00
90+00	-189	-2.01	-63	-1.34	-21	-4.20	-33	-6.60	0	0.00	0	0.00
95+00	-73	-0.78	-68	-1.45	-32	-6.40	2	0.40	0	0.00	0	0.00
100+00	-136	-1.45	-74	-1.57	-41	-8.20	0	0.00	-5	-1.00	0	0.00
105+00	-53	-0.56	-82	-1.74	-36	-7.20			0	0.00	0	0.00
110+00	-55	-0.59	-53	-1.13	-33	-6.60						
115+00	18	0.19	-76	-1.62	-28	-5.60						
120+00	-52	-0.55	-52	-1.11	-42	-8.40						
125+00	-9	-0.10	-94	-2.00	-39	-7.80						
130+00	-42	-0.45	-75	-1.60	-36	-7.20						
135+00	-6	-0.06	-33	-0.70	-62	-12.40						
140+00	35	0.37	22	0.47	-32	-6.40						
145+00	16	0.17	0	0.00								
150+00	-150	-1.60										
155+00	-211	-2.24										
160+00	-139	-1.48										
165+00	-87	-0.93										
170+00	-170	-1.81										
175+00	-279	-2.97										
180+00	-42	-0.45										
185+00	-2	-0.02										

Appendix B
Evaluation of Additional James Island Alternatives

To support the screening-level evaluation of potential candidate restoration sites, Blasland, Bouck, & Lee, Inc. (BBL) assisted the U.S. Army Engineer Research and Development Center (ERDC) in the hydrodynamic modeling efforts for the Mid-Bay Island Restoration Project. As part of this coordinated effort, BBL conducted a hydrodynamic analysis for an additional three primary channel alignment alternatives to the James Island design. These additional alignments were selected by ERDC; U.S. Army Engineer District, Baltimore; Maryland Environmental Service (MES); and Maryland Port Administration (MPA) after a review of the initial model simulations, James Island Alts 1-6, as described in Chapter 1 of the main text of this report. These alternatives, combined with additional breakwater alignments analysis for the Barren Island alternatives modeled by Andrews, Miller & Associates, Inc. (AMA), were proposed to complete the investigative activities towards island restoration in the Mid-Bay region. This appendix describes the model development activities and results for these three alternatives.

James Island Alternatives

In addition to the six alignments described in Chapter 1, three primary channel alignments (Alts JI-7, JI-8, and JI-9; Figure B1) that are similar to the first six alignments (with some variations) were added to examine conditions concerning interior tidal gut configurations. The objectives of the analysis of the three additional alternatives were:

a. Perform circulation modeling in combination with wave modeling for James Island to establish appropriate tidal gut configurations.

b. Investigate sediment transport patterns in and around James Island, including sediment shoaling at neighboring navigation channels.

c. Evaluate engineering merits and environmental impacts of alternative island alignments.

Screening of channel width effects, as well as the possibility of westward-facing channel entrances, was deemed sufficiently important to initiate additional

model simulations. The following three alignments were simulated to better define the impacts of typical conditions on each tidal gut configuration.

Alt JI-7. 150-ft wide "flipped y-shaped" primary channel – tidal gut entrances face westward.

Alt JI-8. 75-ft wide "y-shaped" primary channel.

Alt JI-9. 75-ft wide "c-shaped" primary channel.

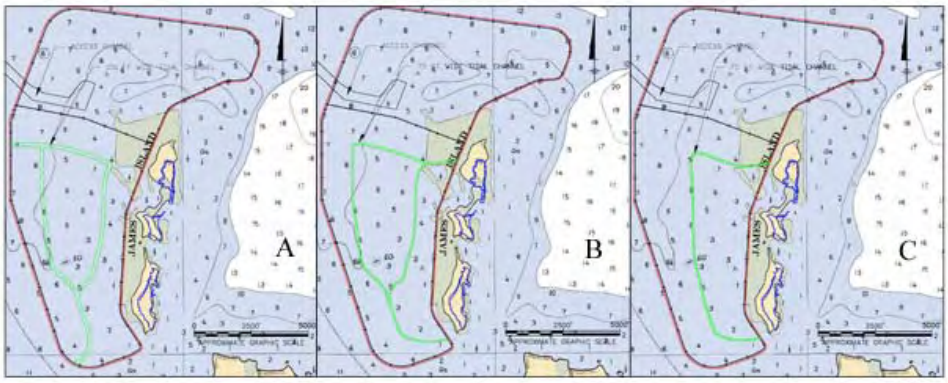

Figure B1. James Island alignment Alts 7, 8, and 9 (A, B, and C, respectively)

Suggestions by ecologists working with the Mid-Bay Island project led to the question of the natural system response to the primary channel entrances facing the open bay instead of the protected leeward side of the proposed James Island alignment. Additional concerns were expressed as the tidal channel flow exits toward the existing islands, potentially creating an increase in erosion in the existing islands and sedimentation at the tidal gut inlets.

The first additional configuration, Alt JI-7, was developed to test the potential hydrological effects of a westward-facing outlet system as a possible new design consideration. Alt JI-7 is a split "y" configuration similar to Alt JI-1 with primary channel outlets opening directly to Chesapeake Bay, rather than eastern-facing channel openings as seen in Alt JI-1.

Further comparisons with existing natural systems within Chesapeake Bay led to questions concerning the ability of different channel widths to properly flush and inundate the wetland system. To test the effectiveness of various channel widths, Alts JI-8 and JI-9 were established for comparison with the existing 150- and 300-ft channel widths. Alts JI-8 and JI-9 are configurations similar to Alts JI-1 and JI-5, respectively, with smaller 75-ft primary channels instead of 150- or 300-ft channel widths found in the other alternatives.

Wave Transformation

Additional simulations of the wave transformation effects were not conducted for James Island Alts JI7-JI9. Chapter 3 of the main text of this report describes the results of STWAVE wave transformation modeling performed for James

Island Alts J1-J6. The three additional primary channel alternatives evaluated by BBL did not alter the footprint of the island, but only the width and alignment of the interior channels. Therefore, overall effects on the wave transformation in the nearby region would be minimal compared to the six alternatives studied by ERDC. Although there would be slight differences in the bathymetry outside of the island footprint for the Alt JI-7 alternative (the alternative with the westward-facing channel openings), these differences were not considered sufficiently significant to warrant additional wave transformation modeling for this screening-level evaluation.

Hydrodynamic and Sediment Transport Modeling

The ERDC Inlet Modeling System (IMS) (Militello et al. 2004) was operated by BBL to evaluate the impacts to velocities and sediment transport patterns from the three James Island alternatives. The IMS is an integrated modeling system for calculating hydrodynamics and sediment transport for coastal projects at time scales of a tidal cycle, through a series of storms, to several years. Hydrodynamics were evaluated with two specific models, ADCIRC and M2D, and sediment transport patterns were evaluated with only M2D. Model pre- and post-processing was done with the Surface-water Modeling System, Version 9.0 beta. This section describes the model, the model inputs, and boundary conditions.

Hydrodynamic modeling with ADCIRC

Chapter 4 of the report describes the ADCIRC model, as well as the development of the regional scale ADCIRC Chesapeake Bay model for the project. BBL modified the ADCIRC model mesh developed by ERDC to evaluate the hydrodynamics for the Alt JI-8 and JI-9 alternatives. The ERDC model mesh was modified to represent the geometry and elevations for each alternative. The ADCIRC meshes for Alts JI-1 and JI-5 were redefined within the regions of the interior channels, increasing the resolution to accurately represent the 75-ft channels of Alts JI-8 and JI-9. Figure B2 illustrates the increased resolution in the channel areas to refine the channel to 75 ft.

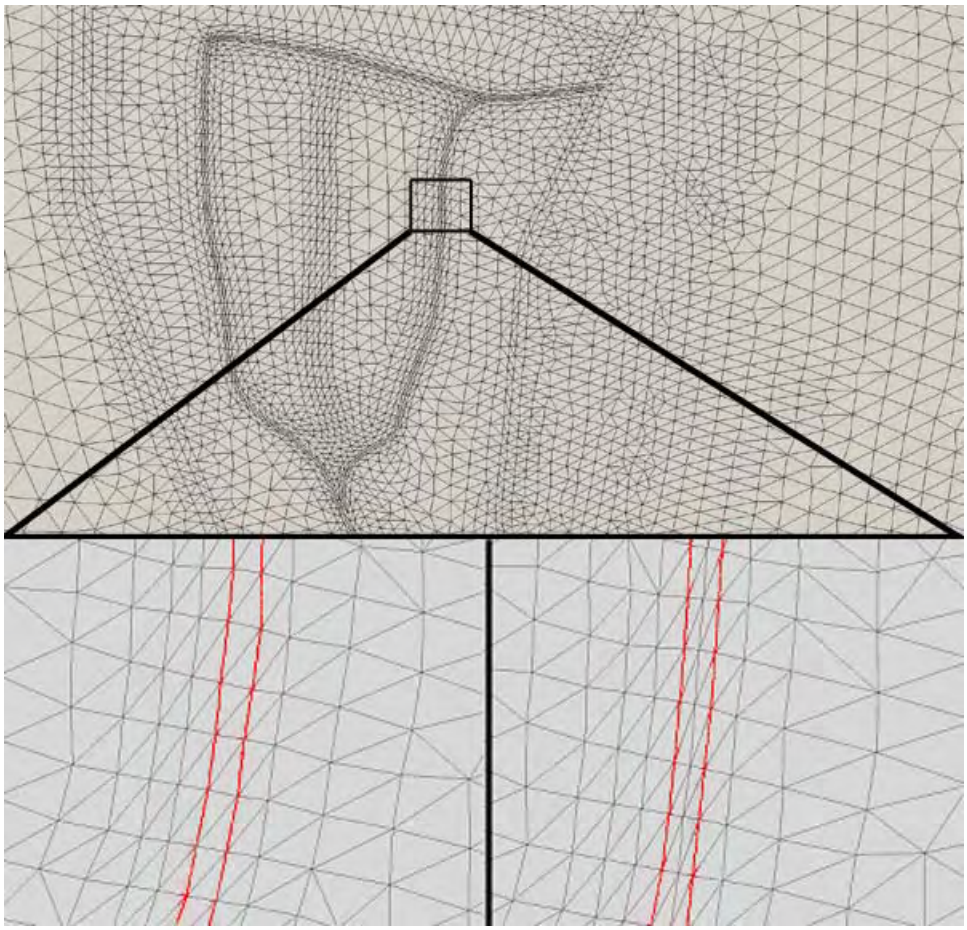

Figure B2. Example ADCIRC grid refinement in channel – bottom left is ERDC original grid, bottom right is BBL grid with increased resolution in channel area (same region highlighted in red)

Using the modified meshes for Alts JI-8 and JI-9, the spring tide was simulated with the ADCIRC model to allow for evaluation of velocities and water-surface elevations under tidal conditions. To determine the effects of varied channel widths, normal daily hydrological conditions were applied to Alts JI-8 and JI-9 for comparison to 150- and 300-ft channel widths. For each alternative, a normal tidal cycle was simulated over spring tide conditions, providing the largest range of water-level conditions within a full neap-spring tidal cycle. To allow for comparison with the other alternatives, the spring tide was chosen from the 2-week time span 1-15 January 2005 (simulated by ERDC). Figure B3 shows the predicted water level for the James Island region over the neap and spring tides modeled by ERDC; the period of modeling used for Alts JI-8 and JI-9 is highlighted in red, extending from 8-12 January 2005.

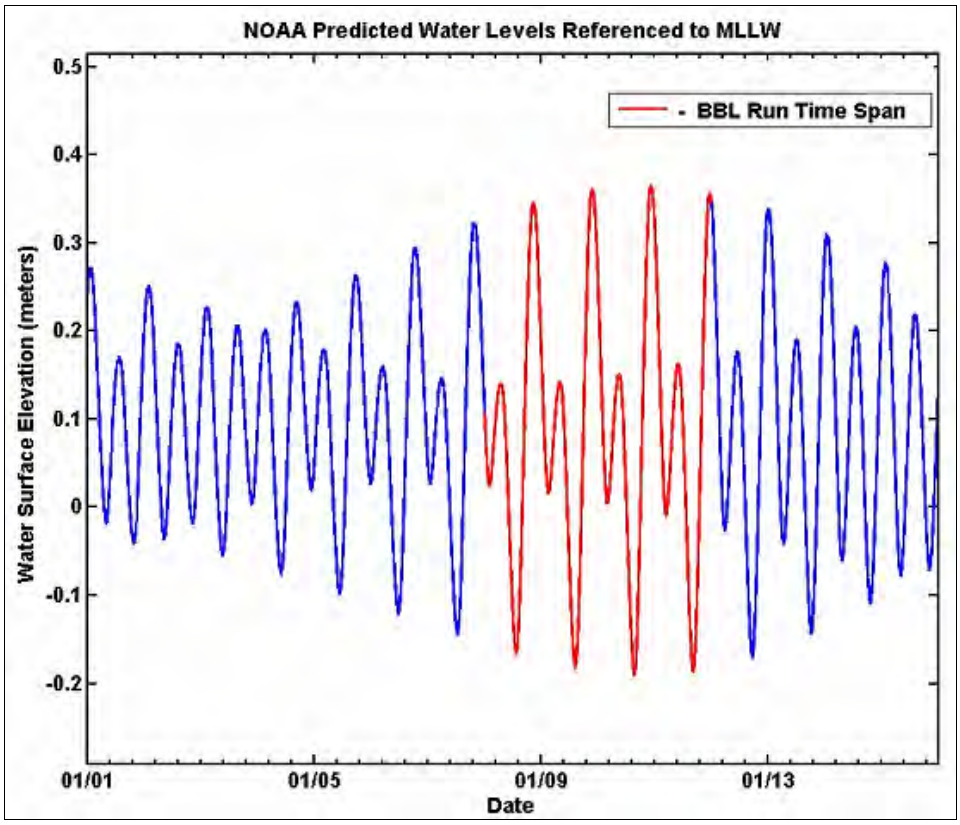

Figure B3. Predicted tidal ranges during 1-15 January in the James Island region. Red highlight indicates the time span of Alt JI-8 and JI-9 tidal conditions

Tidal circulation modeled in Alts JI-8 and JI-9 showed weak velocities in the region surrounding James Island. The private watermen channel to the southeast, between the island and the mainland, had the greatest velocity, resulting in maximum currents of 0.5 ft/sec. Interior velocities through the tidal guts for both alternatives showed an overall reduction in velocity, with velocities peaking at 0.2 to 0.3 ft/sec. Velocity differences between the two alternatives were minor, with slightly stronger currents through the southern portion of the channel in Alt JI-8, approximately 0.2 ft/sec faster than that exiting Alt JI-9. Maximum current velocity fields are shown in Figures B4 and B5.

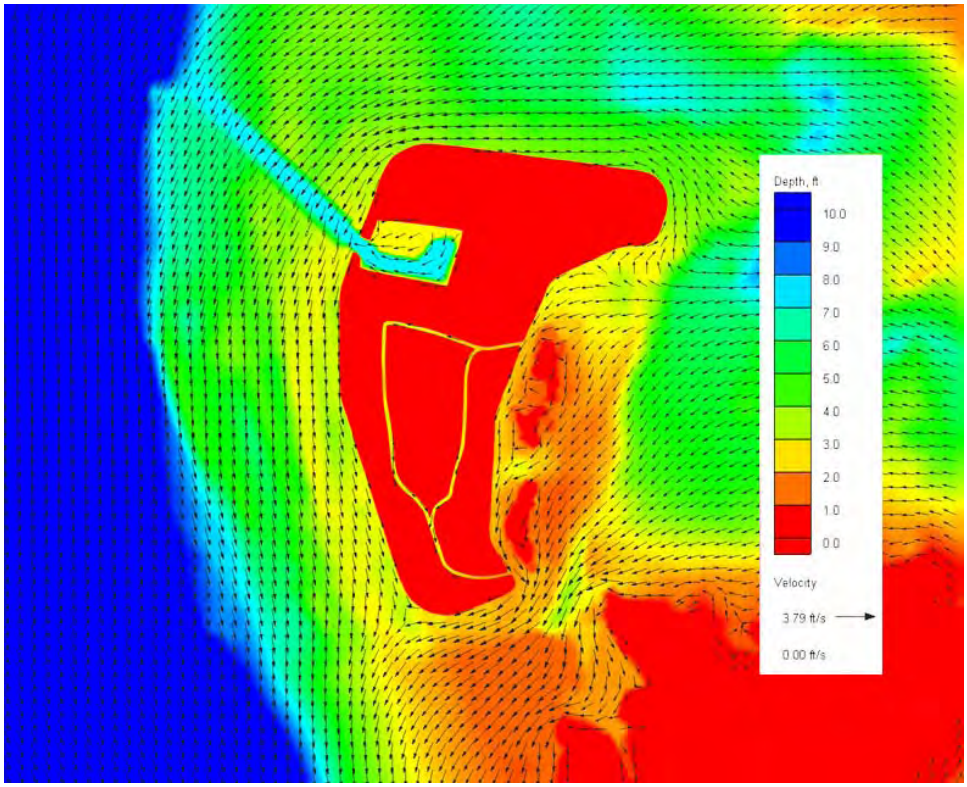

Figure B4. Alt JI-8 maximum current field, normal tide

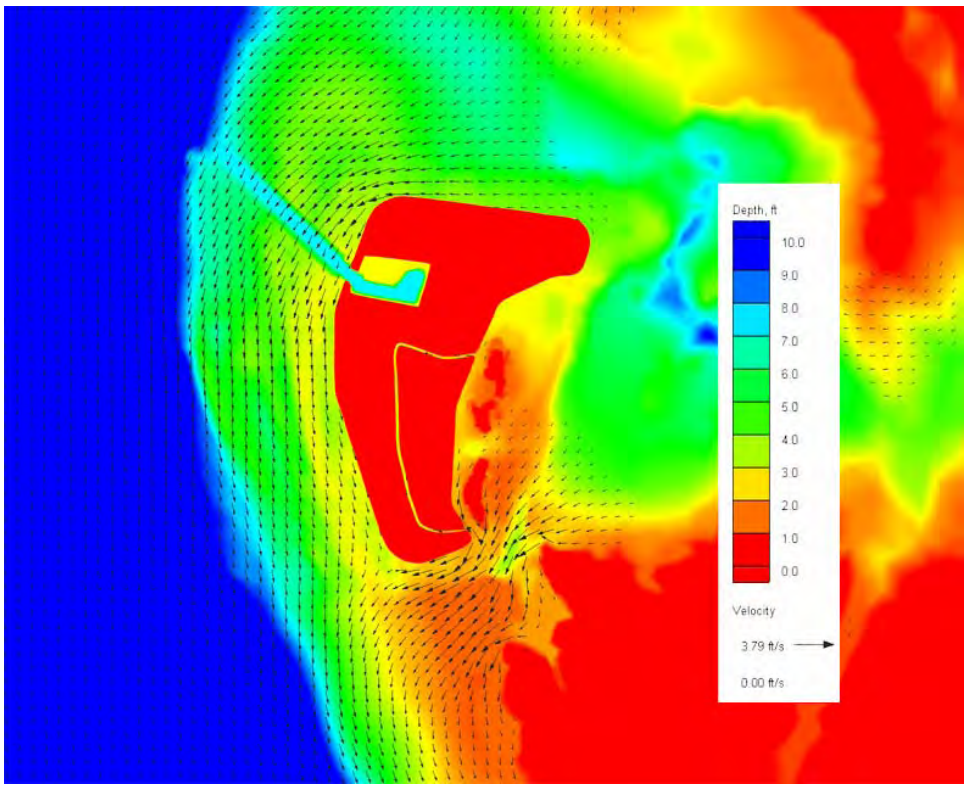

Figure B5. Alt JI-9 maximum current field, normal tide

Hydrodynamic and sediment transport modeling with M2D

The M2D model was operated to evaluate impacts to the hydrodynamics and sediment transport patterns during an extreme event for Alt JI-7. M2D is a finite-difference, two-dimensional (2-D), depth-integrated hydrological model that solves continuity and momentum equations of fluids in motion. M2D can also be coupled with wave radiation stresses provided by STWAVE to resolve changing wave conditions and their effects on local circulation. M2D was operated to simulate the effects of a northeaster (NE33) on Alt JI-7, taking advantage of the model's capabilities with wave stress coupling and sedimentation to determine storm effects on circulation and sedimentation within the westward-facing channels of Alt JI-7 (Militello et al. 2004).

Hydrodynamics

The M2D model grid was created in the SMS utilizing bathymetry data provided by ERDC, as well as data collected as part of a survey of James Island and Barren Island completed by AMA in June of 2005. Bathymetry data were interpolated into M2D using the SMS preprocessor, developing a model grid with a resolution of 20 ft in the regions of interest at the mouths and bends within the interior channel system. Land regions in excess of +4 ft elevation (model datum was developed for mean sea level) were flagged as inactive land cells because overtopping and flooding in these areas was not anticipated during the northeaster (NE). Inactive regions include portions of the mainland as well as the dike and upland systems of the island design. The M2D model grid used for the simulations is presented on Figure B6. Note that the inactive grid cells are shown with brown in A and with red in B.

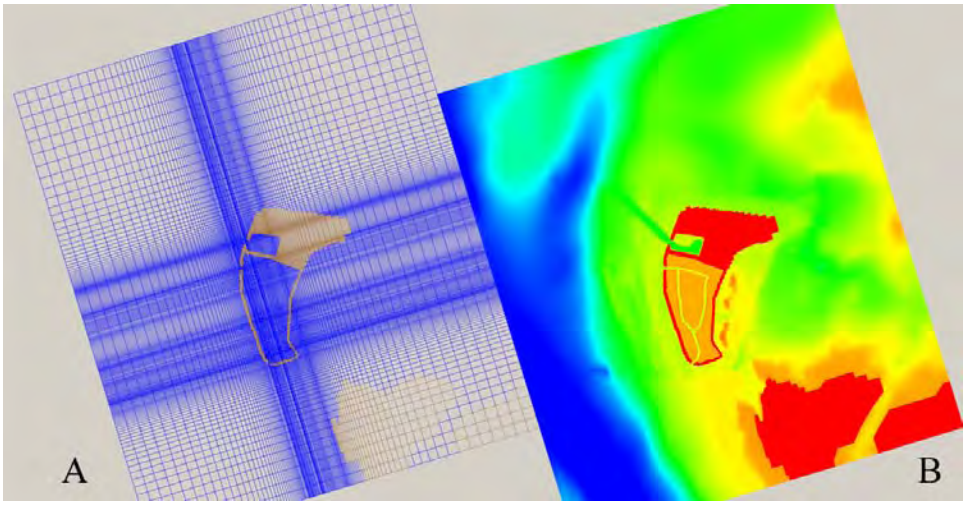

Figure B6. Alt JI-7 M2D model grid – grid cell structure visable on left in A, bathymetric view on right in B

Potential impacts of velocities at the entrances of the channel systems, as well as the potential modifications for deposition or erosion of sediments within each of the channels for the James Island alternatives, were subjects of concern for the westward-facing system. To evaluate these potential impacts, a simulation of the most commonly occurring large storm event in the Chesapeake Bay region, a northeaster, was performed. Discussions with ERDC concerning the range of historical northeaster storms, previously studied in the ERDC report by Melby et al. (2005) on the life cycle analysis of the Mid-Bay Island designs, led to the decision to force the system with a historical northeaster from 1993, identified as NE33 in Melby et al. (2005). NE33 was one of strongest historical northeasters recorded, with wind and wave effects to the north-northeast providing the most direct forcings on the westward-facing channel system. Wind files representing NE33 conditions were created from wind data provided to BBL by ERDC.

Current velocities as a result of NE33 forcing are as expected, with an overall increase in water velocity compared to normal tide. Velocities within the tidal guts are weaker as compared to those around the exterior of the island, showing maximum velocity of approximately 1.6 ft/sec. Flows outside the island are directed north and up the bay, impacting the southern channel entrance with greater effect than the northern channel entrance. Water is forced in the southern entrance and is then diverted through the two sides of the channel before exiting through the northern channel. The western interior channel receives the majority of water flow, showing increased velocities compared to the other north-south channel to the east of the island. Flow in the exterior region is altered due to the footprint of the proposed James Island alignment, creating a slight increase in flow off the southern tip of the island. Velocities through the channel between the island and the mainland are increased, resulting in the greatest velocities in the model off the tip of the island, approaching 2.7 ft/sec. The maximum current velocity field is shown in Figure B7.

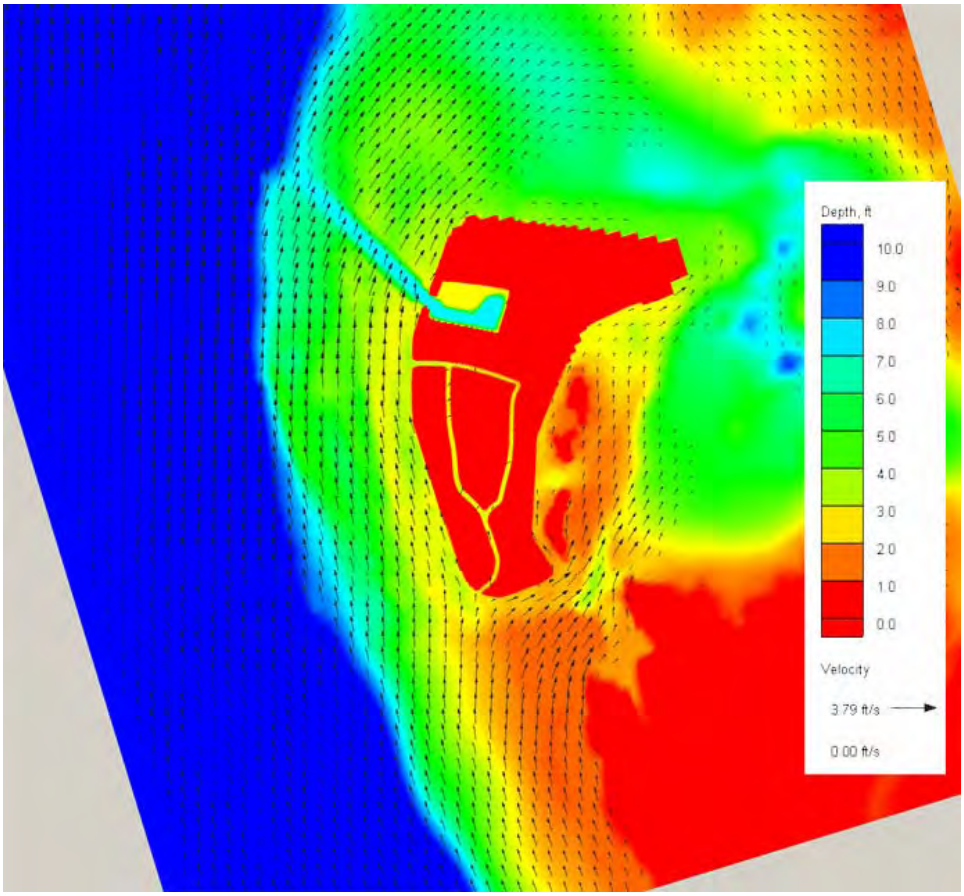

Figure B7. Alt JI-7 maximum current field, NE33

Sedimentation

A sedimentation analysis was performed for Alt JI-7 using M2D. Westward-facing channel mouths raised concerns over potential channel filling during storms. To evaluate conditions, sediment transport was enabled in the M2D model run to test northeaster effects on sediment deposition patterns. No suspended sediment forcing was included as a boundary condition, though bed-load transport was permitted across the boundary. Simulation was specified to determine sedimentation patterns throughout the James Island region as a result of the Alt JI-7 footprint. A 0.2-mm median diameter sand was specified to represent the sediment in the James Island region. Results of NE33 on sedimentation are shown in Figure B8, with the majority of material erosion or accretion from 1 to 2 cm, with maximum values exceeding 8 cm located close to the proposed access channel. Material deposition within the northern channel mouth was negligible, and the southern mouth shows approximately 1 cm of accretion. Note that maximum values of deposition and erosion occurred within regions of limitations in M2D that may affect the actual deposition pattern and rate. Theses limitations are described in the subsequent paragraph.

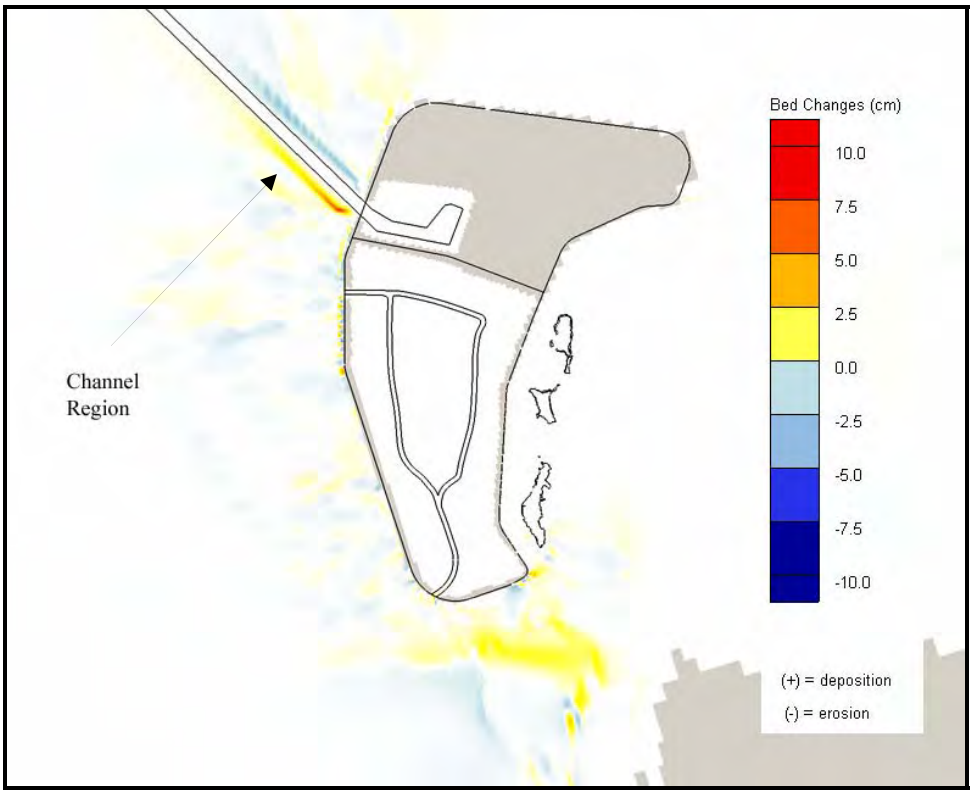

Figure B8. Alt JI-7 M2D sedimentation results

As described by ERDC as part of project training provided at the Mid-Bay Modeling Study Workshop, held 9-11 August 2005 in Baltimore, MD, this total-load version of M2D code (which allows most rapid simulations to be run) does not account for infilling of deep channels, as noted in the channel region indicated in Figure B8. Thus, the navigation channel leading to the turning basin within the upland part of the James Island alignment is not properly filled in, and no accretion is calculated within that channel toe. Sediment is calculated as removed from one channel side and deposited on the other, as noted in the figure with the north side of the channel eroding and depositing on the southern side of the channel. As a result, interpretation of sedimentation results must be made with care, observing patterns of deposition over the area surrounding James Island to determine regions of relative deposition or erosion.

Evaluation of Alternatives

For comparison, key locations established by ERDC were used to save data on maximum current speed and erosion/accretion in the modeled region of James Island. Table B1 lists the location of Points 1-16 in Maryland State Plane NAV83 Easting and Northing feet. Points 1-16 were chosen to provide an understanding of conditions surrounding the island, with additional detail in areas of concern at the tidal gut entrances, around the existing islands and within the interior of the island in the channel system. The key locations are shown in Figure B9.

Table B1
James Island Model Run Save Locations

Location	Easting, ft	Northing, ft
1	1,503,685.827	304,923.294
2	1,508,416.896	312,049.5079
3	1,500,881.824	320,596.2927
4	1,502,676.969	309,755.1837
5	1,501,389.862	304,992.7822
6	1,498,119.882	303,393.7336
7	1,498,537.27	306,209.4816
8	1,501,737.73	312,605.6759
9	1,498,258.99	313,127.0997
10	1,495,058.53	313,439.9606
11	1,495,291.995	316,450.1312
12	1,500,916.47	303,225.9514
13	1,501,402.231	304,382.5459
14	1,501,761.549	305,303.0184
15	1,500,937.008	304,818.5696
16	1,500,618.438	305,018.0446

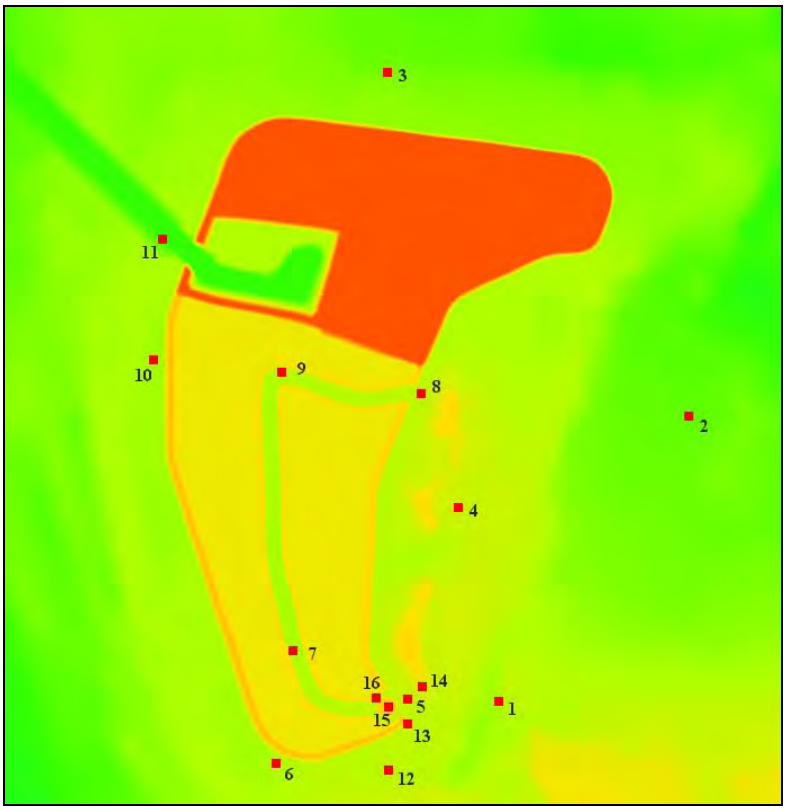

Figure B9. James Island key locations

Current Velocity Comparison

The behavior of the current for each alternative was as expected, with reasonable velocities for conditions in the nearby regions. Velocities were shown to have increased in the channel region to the southeast of the tip of James Island as a result of a narrower channel through which flow is diverted by the presence of the island. Velocity increases in other regions surrounding the island were slight, with no excessive changes as a result of the presence of the island. Table B2 presents the calculated maximum current speed at each of the 16 save key locations for each alternative modeled. Additional notes on individual configurations are as follows:

Alt JI-7. During NE33, current velocities within the mouths of the westward facing tidal guts were slightly greater than velocities in the mouths of the eastward-facing channel entrances in JI-8 and JI-9. Velocities quickly dissipated within the primary channel, showing only a 0.2-ft/sec increase over that of normal tidal velocities.

Alt JI-8. Similar to conditions found in JI-9; the only noticeable difference is a slight increase in velocity at the interior data collection locations, Points 7 and 9. Velocities differed by less than 0.1-ft/sec throughout the tidal gut.

Alt JI-9. Similar in comparison to JI-8; slight differences in velocities within the tidal gut, seen at Points 7 and 9, with a reduced channel velocity in comparison to that of JI-8.

Table B2
Calculated Maximum Current Speed (m/sec) at James Island

Location	JI-7 - (NE33)	JI-8 - (Tide)	JI-9 - (Tide)
1	0.79	0.47	0.48
2	0.14	0.04	0.04
3	0.24	0.16	0.17
4	0.37	0.09	0.10
5	0.52	0.33	0.35
6	0.27	0.17	0.17
7	0.39	0.14	0.03
8	0.31	0.08	0.08
9	0.12	0.06	0.00
10	0.67	0.30	0.32
11	0.45	0.15	0.16
12	0.82	0.55	0.57
13	0.77	0.52	0.54
14	0.18	0.00	0.00
15	0.00	0.25	0.23
16	0.00	0.00	0.00

NOTE: A '0' velocity magnitude indicates the 'no-current' (dry) condition.

Sedimentation

Sedimentation was only calculated for Alt JI-7, modeled in M2D. Sediment transport was calculated over the span of time of the northeaster, determining typical conditions for the frequent strong storms that impact the Chesapeake region. Table B3 presents the bed elevation change at each of the 16 key locations for each alternative scenario modeled.

Alt JI-7. Small pockets of greater deposition or erosion are visible, although no excessive movement of material appeared to occur. Sedimentation patterns do not appear to show a tendency to deposit or erode material at channel entrances or along channel lengths.

Alt JI-8. Sedimentation was not calculated within the ADCIRC model for Alt JI-8.

Alt JI-9. Sedimentation was not calculated within the ADCIRC model for Alt JI-9.

Table B3
Calculated Bed Elevation Change (cm) at James Island

Location	JI-7 - (NE33)	JI-8 - (Tide)	JI-9 - (Tide)
1	2.38	N/A	N/A
2	5.68	N/A	N/A
3	4.81	N/A	N/A
4	1.00	N/A	N/A
5	1.40	N/A	N/A
6	2.31	N/A	N/A
7	2.15	N/A	N/A
8	1.73	N/A	N/A
9	1.57	N/A	N/A
10	3.16	N/A	N/A
11	7.46	N/A	N/A
12	1.66	N/A	N/A
13	1.63	N/A	N/A
14	-0.54	N/A	N/A
15	-0.77	N/A	N/A
16	-0.73	N/A	N/A

NOTE: Positive values indicate accretion, negative values indicate erosion.

Summary

In summary, modeling of the three additional alternatives determined the feasibility and performance of a westward-facing tidal gut configuration, as well as the probable effects of varying channel width. Results from the Alt JI-7 test conditions under a strong northeaster did not show adverse hydrodynamic or sedimentation impacts. Deposition patterns did not suggest a tendency to deposit or erode material at the entrances to the tidal guts – the primary concern of such an arrangement. Storm effects were seen to be reduced in the interior regions of the island, placing only a small section at risk of the increased current and wave effects, compared to the eastward-facing equivalents. Results from Alts JI-8 and JI-9 configurations show little difference in velocities in comparison to the similar Alts JI-1, JI-4, JI-5, and JI-6 configurations. The difference in channel width at this scale does not seem to significantly impact the channel velocities of each design. Additional testing would be required to verify the volumetric flow capacities of each design and determine the appropriate flow to flush the system.

Appendix C
Evaluation of Additional Barren Island Alternatives

During preparation of the "Mid-Chesapeake Bay Island Ecosystem Restoration Integrated Feasibility Report and Environmental Impact Statement," the functional performance of the proposed breakwater south of the existing Barren Island was evaluated in terms of its capability to reduce wave heights to levels tolerable for submerged aquatic vegetation (SAV). An overtopping analysis was performed to determine the crest elevation for the breakwater structure required to reduce wave heights. Crest heights of 2, 4, 6, and 8 ft were evaluated. Available literature on SAV indicated that the tolerable wave height for SAV ranges from 0-2 m (0-6.6 ft) with an average of 1 m (3.3 ft). The preliminary results for the overtopping analysis indicate that a crest height of +4 ft mean lower low water (mllw) would provide SAV protection to the limiting tolerable wave height of 3.3 ft for just over a 30-year return period storm. A structure of +6 ft mllw would reduce wave height to tolerable levels for up to a 50-year return period event. These preliminary results were based solely on an analysis of overtopping, which is considered to be the dominant factor controlling the transmitted wave for submerged structures, as well as local waves generated on the eastern side of the project.

To further evaluate the performance of the southern breakwater alternatives, a preliminary investigation of wave transmission through the proposed structures and gaps in proposed segmented structures was conducted. Six alternative designs, Alts BI-1 through BI-6, for restoration and modification of Barren Island were defined in close coordination with the Maryland Port Administration (MPA) and the U.S. Army Engineer District, Baltimore. Numerical models were then applied by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), and the results analyzed for preliminary evaluation of alternative designs and their impacts on the mainland shoreline, adjacent Federal and private navigation channels, and neighboring SAV.

Study Approach

ERDC-CHL conducted the numerical modeling and evaluation of six alternative alignments at the Barren Island restoration site (see main text of this report). Their study had the following goals, with emphasis on storm conditions that would produce the maximum change in physical environmental conditions at the sites:

a. Perform wave modeling for Barren Island.

b. Perform circulation modeling in combination with wave modeling for Barren Island to assess alternatives.

c. Investigate sediment transport patterns at and around Barren Island, including sediment shoaling at neighboring navigation channels.

d. Evaluate engineering merits on environmental impacts of alternative island alignments.

Andrews, Miller & Associates, Inc. (AMA) reviewed the results of the modeling conducted by ERDC with the objective of developing two additional alternatives and then conducting circulation and wave modeling for those alternatives for comparison with Alts BI-1 through BI-6. Of particular interest is an evaluation of the proposed breakwater south of the existing island in terms of the capability to reduce wave heights and tidal currents to levels tolerable for survivability of SAV.

Evaluation of Barren Island Alts BI-1 to BI-6

The proposed Barren Island restoration emphasizes protection of the existing island and SAV east and south of the island though the construction of new breakwaters and raising of the existing shore protection structure. The design for the protection of the existing island includes a new northern breakwater or sill at + 4 ft mllw (3,840 ft long), a raised existing northwestern breakwater at +4 ft mllw (4,900 ft long), and a new western breakwater at +4 ft mllw (5,915 ft long).

The design for additional protection of SAV includes a new southern breakwater that extends southeastward from the Island into the bay. The restoration is expected to provide improved sheltering to the Honga River Channel that is located to the north and northeast of Barren Island. Six alternatives with four southern breakwater configurations and two different southern breakwater crest elevations were investigated by ERDC in the present study (Table C1).

This chapter focuses on an evaluation of the proposed breakwater south of the existing island for each alternative in terms of the capability to reduce wave heights and tidal currents to levels tolerable for SAV.

Table C1 Barren Island Alternatives	
Alternative	**Description**
BI-1	8,166-ft-long south breakwater at +6 ft mllw.
BI-2	5,915-ft-long south breakwater at +6 ft mllw.
BI-3	8,166-ft-long south breakwater at +4 ft mllw.
BI-4	5,915-ft-long south breakwater at +4 ft mllw.
BI-5	8,166-ft-long south breakwater at +4 ft mllw with 400-ft segments and 200-ft gaps.
BI-6	8,166-ft-long south breakwater at +6 ft mllw with 500-ft segments and 100-ft gaps.

SAV History at Barren Island

SAV has been present in the Barren Island area, particularly east of the island between the island and the mainland. There has been considerable fluctuation in the areal extent of the SAV in recent years, as shown in Figure C1. The data in Figure C1 were provided by the Virginia Institute of Marine Science (VIMS) from their annual SAV surveys in which they map the area of SAV by U.S. Geological Survey quadrangle map. Comparison of Figures C2 to C4 shows the most recent fluctuation in SAV in the Barren Island area with the greatest area of higher density SAV occurring in 2002 and the least area in 2004.

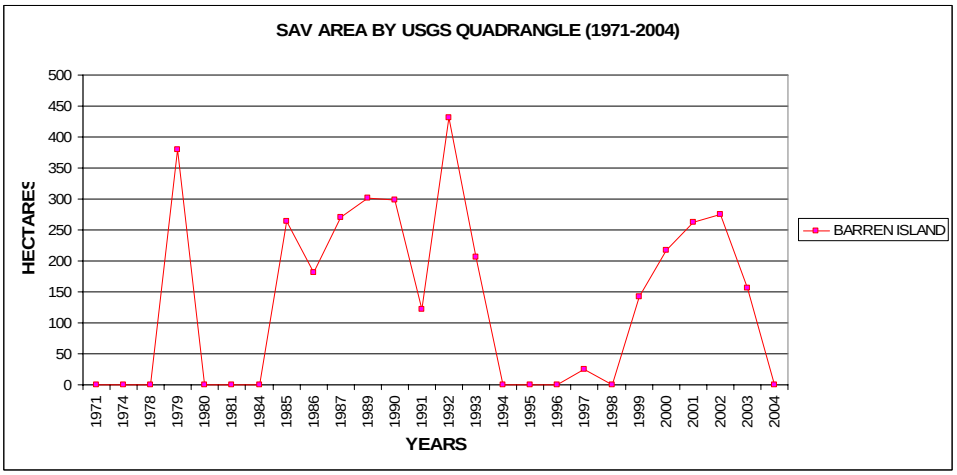

Figure C1. Estimated Barren Island SAV areal extent 1971–2004

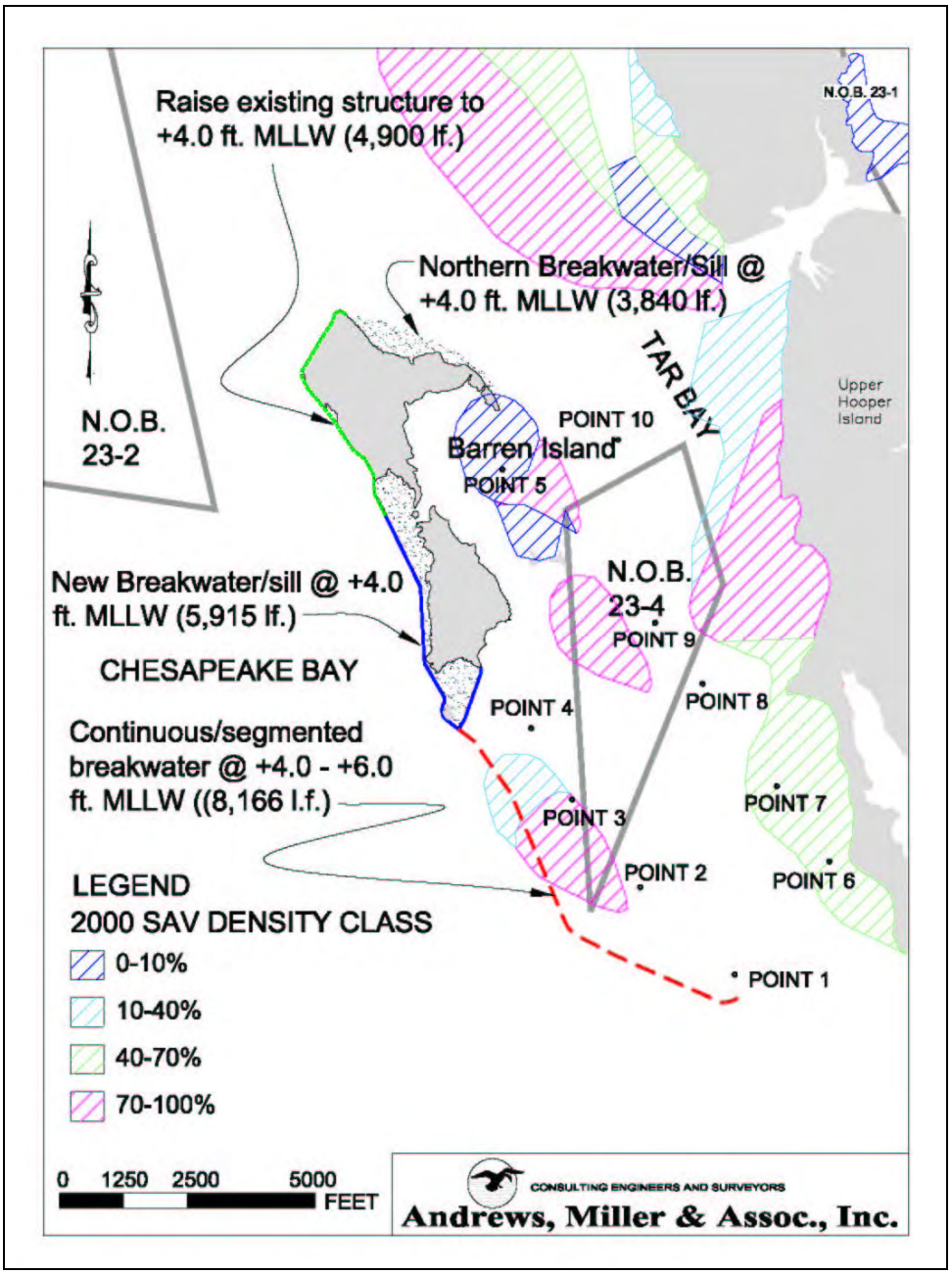

Figure C2. Barren Island SAV in 2000 (VIMS)

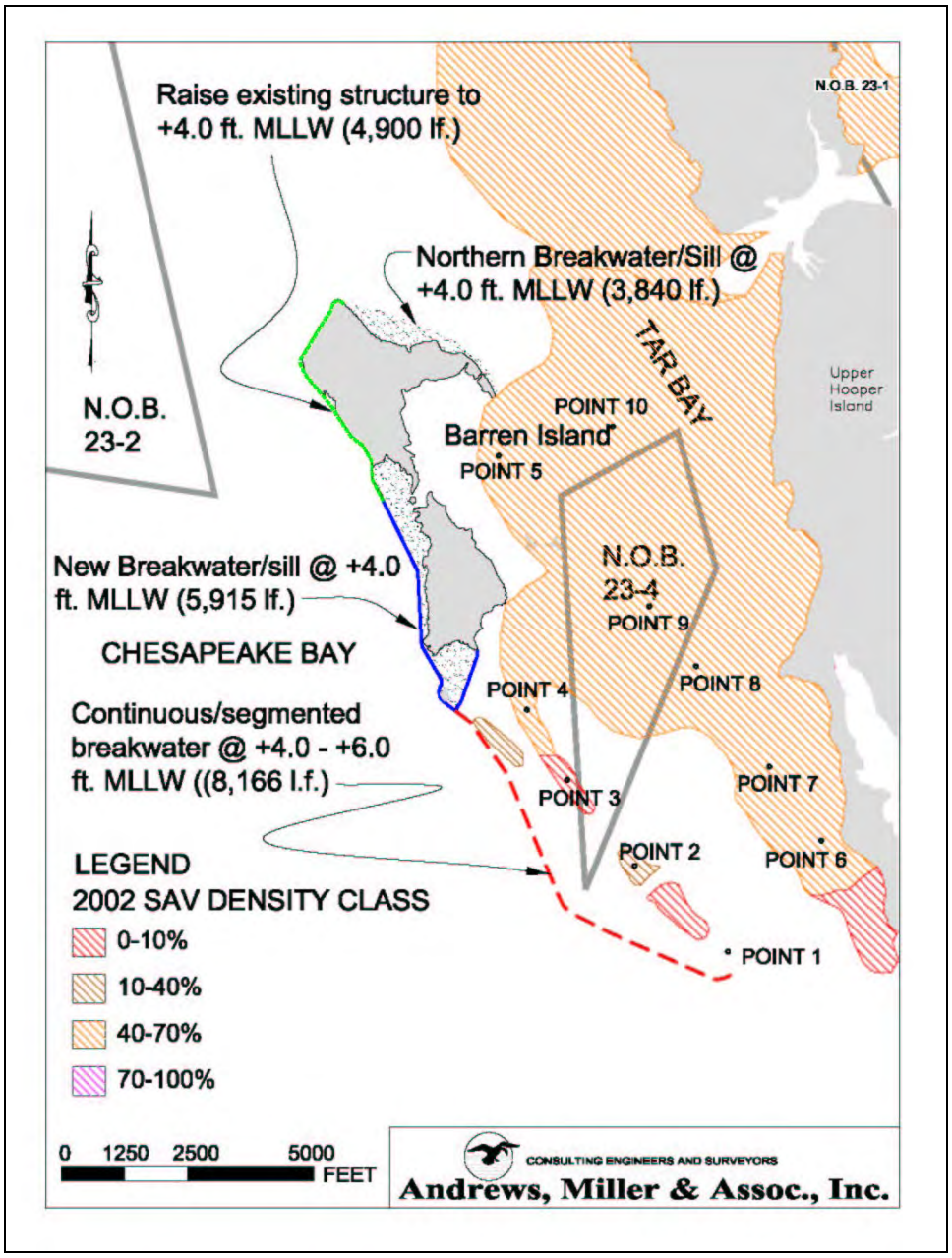

Figure C3. Barren Island SAV in 2002 (VIMS)

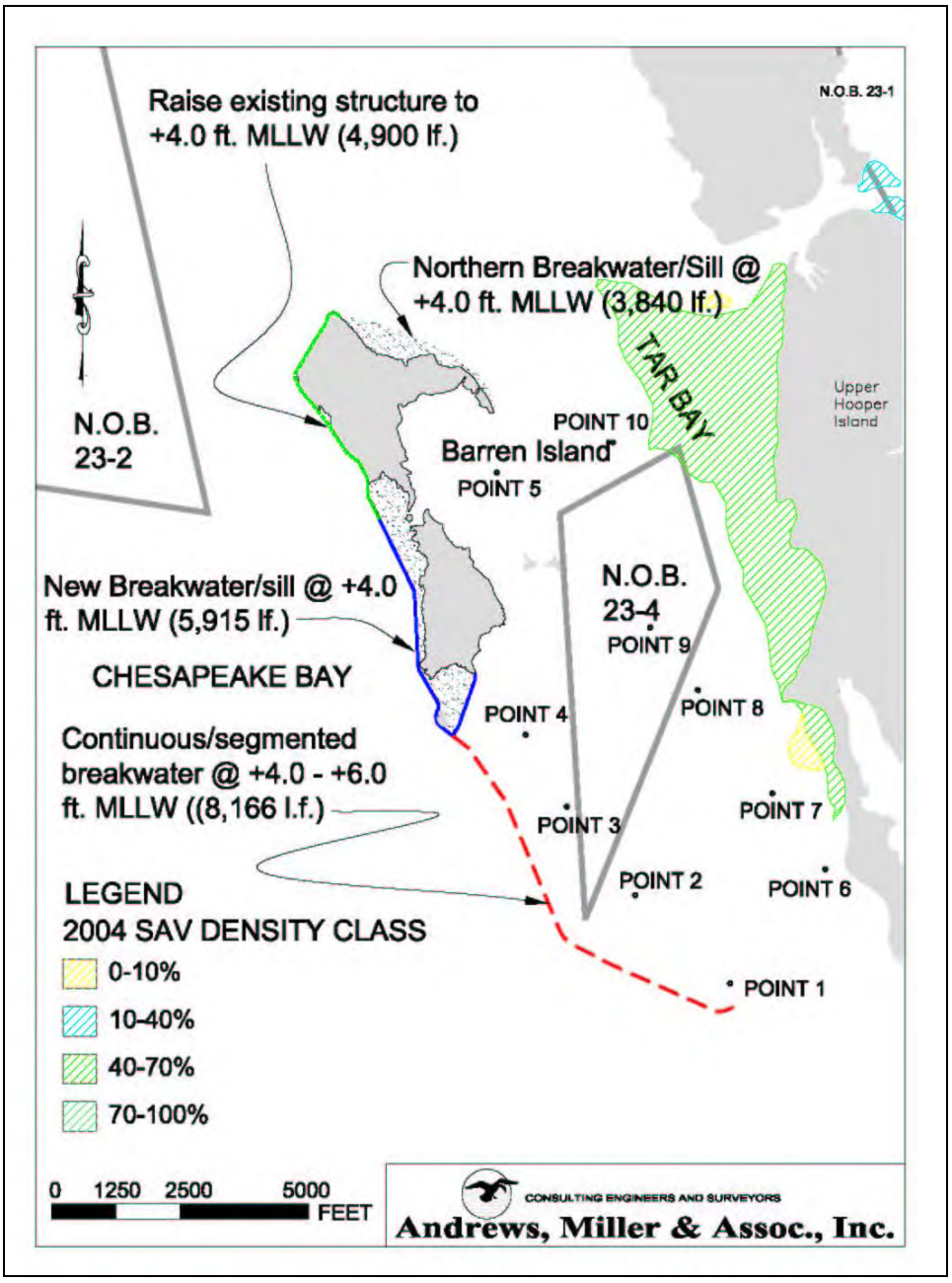

Figure C4. Barren Island SAV in 2004 (VIMS)

SAV Tolerance

One of the objectives of the Barren Island project is to enhance the conditions for SAV survivability east of the island. Research has indicated that SAV is affected by a number of environmental factors. Perhaps one of the most important parameters to SAV success is the provision of an area that limits the amount of tidal current velocity, wave height, and sedimentation to tolerable levels. These factors are discussed next. Quantitative data on the tolerable levels of these parameters are limited, and only general guidelines exist. Selected guidelines are discussed in the following paragraphs.

Literature search

A literature search was conducted to find available guidelines for the hydrodynamic threshold for SAV tolerance in Chesapeake Bay to wave energy and tidal current velocity. The most pertinent information is presented here.

A discussion of parameters, other than the established SAV light requirements, addressed waves, currents, tides, sediment organic content, grain size and contaminants and their influence on the presence or absence of SAV in a certain area (Chesapeake Bay Program 2000)[1].

Excerpts from this discussion (Chesapeake Bay Program 2000) are as follows:

> **"Current Velocity SAV Habitat Requirements**. From the positive and negative effects of the reduced current velocities found in SAV beds, it can be concluded that these plants could benefit from intermediate current velocities (Boeger 1992; Koch and Gust 1999; Merrell 1996; Koch 1999). Extremely low water flows could increase the blade diffusion boundary layer thickness as well as the accumulation of organic matter in the sediment leading to carbon starvation or death due to high phytotoxin concentrations in the sediment, respectively. In contrast, extremely high water flow has the potential to 1) increase drag above a critical value where erosion of the sediment and plants occurs, 2) reduce light availability through resuspension of sediment and self-shading and 3) decrease the accumulation of organic matter, leading to reduced nutrient concentration in the sediments. A literature review revealed that 1) the range of current velocities tolerated by marine SAV species lies between approximately 0.2 ft/sec. (5 cm s^{-1}) and 3.3 ft/sec (100 cm s^{-1}).
>
> Survival of SAV in high current velocity environments may be possible if the development of seedlings occurred under conditions of slow current velocity in space (e.g., a protected cove) or time (e.g., a low water discharge period). Once a bed is established under such conditions, it can expand into adjacent areas with higher currents due to the reduced currents at the edge of the bed or persist during times of higher water flow. Therefore, the stage of the plants (for example, seeds, seedlings, vegetative shoots, reproductive shoots) also needs to be taken into account when considering if current velocity is above or below the

[1] References cited in this appendix are contained in the reference section of the main text of this report.

established requirement for growth and distribution. Based on the literature review presented here, no data are available on the current velocity requirements of plants other than those found in well-established beds. In summary, intermediate current velocities between 0.3 ft/sec (10 cm s^{-1}) and 3.3 ft/sec (100 cm s^{-1}) are needed to support the growth and distribution of healthy marine SAV beds. If currents are above or below these critical levels, the feedback mechanisms in the system may become imbalanced and possibly lead to the decline or even complete loss of the vegetation. Although some of the feedback mechanisms between SAV beds and current velocity involve light availability through the effects of resuspension of sediments, selfshading, and epiphytic growth, extreme currents alone can limit the growth of SAV. Therefore, current velocity should be considered as a key SAV habitat requirement.

TABLE VI-1. Minimum and maximum current velocities required for SAV growth and distribution.

Minimum current velocities required to saturate photosynthesis

Current	Species	Source
> 0.04 cm s^{-1}	*Potamogeton pectinatus* *	Madsen and Sondergaard 1983
> 0.08 cm s^{-1}	*Callitriche stagnalis*	Westlake 1967
> 0.5 cm s^{-1}	*Ranunculus pseudofluitans*	Westlake 1967
> 3 cm s^{-1}	*Zostera marina*	Koehl and Worcester 1991
> 5 cm s^{-1}	*Ranunculus pencillatus*	Werner and Wise 1982
> 5 cm s^{-1}	*Thalassia testudinum*	Koch 1994
> 13 cm s^{-1}	*Cymodocea nodosa*	Koch 1994
> 16 cm s^{-1}	*Z. marina*	Fonseca and Kenworthy 1987

Maximum currents at which the following species occur

Current	Species	Source
< 7 cm s^{-1}	*Vallisneria americana*	Merrell 1996
< 45 cm s^{-1}	*Ranunculus pencillatus*	Werner and Wise 1982
< 50 cm s^{-1}	*Zannichellia palustris*	Sculthorpe 1967
< 50 cm s^{-1}	*Z. marina*	Conover 1964
< 120 cm s^{-1}	*Z. marina*	Scoffin 1970
< 150 cm s^{-1}	*Z. marina*	Fonseca *et al.* 1982
< 180 cm s^{-1}	*Z. marina*	Phillips 1974

* Indicates species for which leaf polarity has been confirmed.

Effects of High Wave Energy. The impact of high wave energy on SAV can be direct or indirect. The direct impact of waves on SAV can be seen when waves (in combination with currents) erode the edges of an SAV bed (Clarke 1987) or when portions of the plants are removed by storm-generated (Thomas et al. 1961; Eleuterius and Miller 1976;

Rodriguez et al. 1994; Dan et al. 1998) or boat generated waves (Stewart et al. 1997).

Indirect consequences of wave energy in SAV beds include sediment resuspension, changes in sediment grain size, mixing of the water column and epiphytic growth. If the capacity of an SAV bed to attenuate waves is reduced, for example, due to a reduction in shoot density because of clam dredging or eutrophication, the underlying sediment will become more vulnerable to erosion, and higher concentrations of suspended sediment particles can be expected in the water. Wave attenuation and sediment resuspension in vegetated areas depend on the water levels above the plants.

In areas of high wave exposure, sediments are coarser, which leads to lower nutrient concentration in the sediment and, consequently, lower root biomass (Idestam-Almquist and Kautsky 1995). By contrast, the above-ground biomass of Potamogeton pectinatus depends directly on wave exposure; shoots are shorter in areas with high wave exposure than in areas with low wave exposure (Idestam-Almquist and Kautsky 1995). In Chesapeake Bay, shore erosion (caused by wave action) contributes 13 percent of the total suspended matter in the upper Bay and 52 percent in the middle Bay (Biggs 1970). Perhaps, before the decline of SAV in this area, SAV protected the coastlines from the direct impact of waves.

In high wave exposure areas, where sediments are constantly being shifted and grain size may be skewed toward coarser particles, SAV may not be able to become established due to the balance between the anchoring capacity of the roots and the drag exerted on the leaves. High wave exposure also leads to reduced light availability due to increased sediment resuspension."

A summary of quantitative and qualitative descriptions of wave tolerance for various species is shown in the following two tables (Chesapeake Bay Program 2000):

TABLE VI-3. Quantitative and qualitative descriptions of wave tolerance for Chesapeake Bay species.

Species	Wave Tolerance	Source
Canopy formers		
Myriophyllum spicatum	Wave limited	Rawls (1975), Stewart *et al.* 1997
Zannichellia palustris	Wave limited	Stevenson and Confer 1978
Flowering structures of *Ruppia maritima*	Wave sensitive	Joanen and Glasgow 1965
Meadow formers		
Zostera marina	2 m waves	Dan et al. 1998
Potamogeton pectinatus	Wave tolerant	Hannan 1967
Vallisneria americana	More wave tolerant than *Myriophyllum*	Stewart *et al.* 1997

TABLE 2. Summary of physical and chemical factors defining habitat constraints for submersed aquatic plants.

Factor	Description	Constraint	Submersed Plants
Water Movement	Minimum velocities ($cm\ s^{-1}$)	0.04-5	Freshwater plants
		3-16	Seagrasses
	Maximum velocities ($cm\ s^{-1}$)	7-50	Freshwater plants
		50-180	Seagrasses
Wave Tolerance	Waves 0-1 m	Limited growth	Canopy formers (e.g., *Myriophyllum spicatum*, *Ruppia maritima* flowers)
	Waves >2 m	Tolerant growth	Meadow formers (e.g., *Zostera marina*, *Vallisneria americana*)
Sediments	Grain size (% fines, <64 µm)	2-62	Freshwater plants
		0.4-30	Seagrasses
	Organic matter (%)	0.4-12	Seagrasses and freshwater plants
Porewater Sulfide	(mM)	<1	Healthy plants
		>1	Reduced growth

UMCES coordination

The University of Maryland Center for Environmental Studies (UMCES) at Horn Point, Cambridge, MD, has conducted studies regarding the restoration of SAV in Chesapeake Bay. Dr. Evamaria Koch of UMCES has been investigating the impacts of waves and currents on SAV. Although absolute wave and current exposure limits for eelgrass have not yet been established, Dr. Koch indicated that based on her field and laboratory experience, she estimated the threshold for SAV tolerance would be a wave height ranging from 1.3 to 2.0 ft with a wave period of about 3.0 sec, and tidal current velocities of about 2.5 to 3.0 ft/sec during typical conditions. However, Dr. Koch indicated that waves and currents may not adversely affect SAV until the sediment in which the SAV is rooted starts to erode. Consequently, higher waves and stronger currents may be tolerated in areas where the bed material is coarser and more resistant to erosion. Dr. Koch also indicated that higher water temperature can adversely impact SAV in areas that have restricted tidal circulation. Dr. Koch is actively investigating the tolerance of SAV to tidal currents and waves. Her investigations include

physical modeling (tidal flumes) and field experiments. Additional investigations to evaluate the effect of wave period and duration on SAV are necessary.

Additional investigation is required to quantify the conditions (and combinations of conditions) tolerated by SAV. Based on a literature search and coordination with UMCES, a summary of preliminary guidelines for the thresholds for SAV tolerance is presented in Table C2. Based on this information, the preliminary SAV tolerance threshold is estimated to be 1 m (3.28 ft).

Table C2
SAV Tolerances

	Literature	UMCES
Tidal Current (ft/sec)	0.3 – 3.3	2.5 – 3.0
Wave Height (ft)	0 – 6.4	1.3 – 2.0

Alts BI-1 to BI-6 Performance

To evaluate the conditions provided by each of the proposed alternative plans, a comparison of the modeling data compiled by ERDC for Alts BI-1 through BI-6 was conducted, with focus on current velocity and wave height. To facilitate this comparison, 10 points were selected for output data from the modeling, as shown in Figure C5. These points are located throughout the SAV areas as well as the natural oyster bar east of Barren Island.

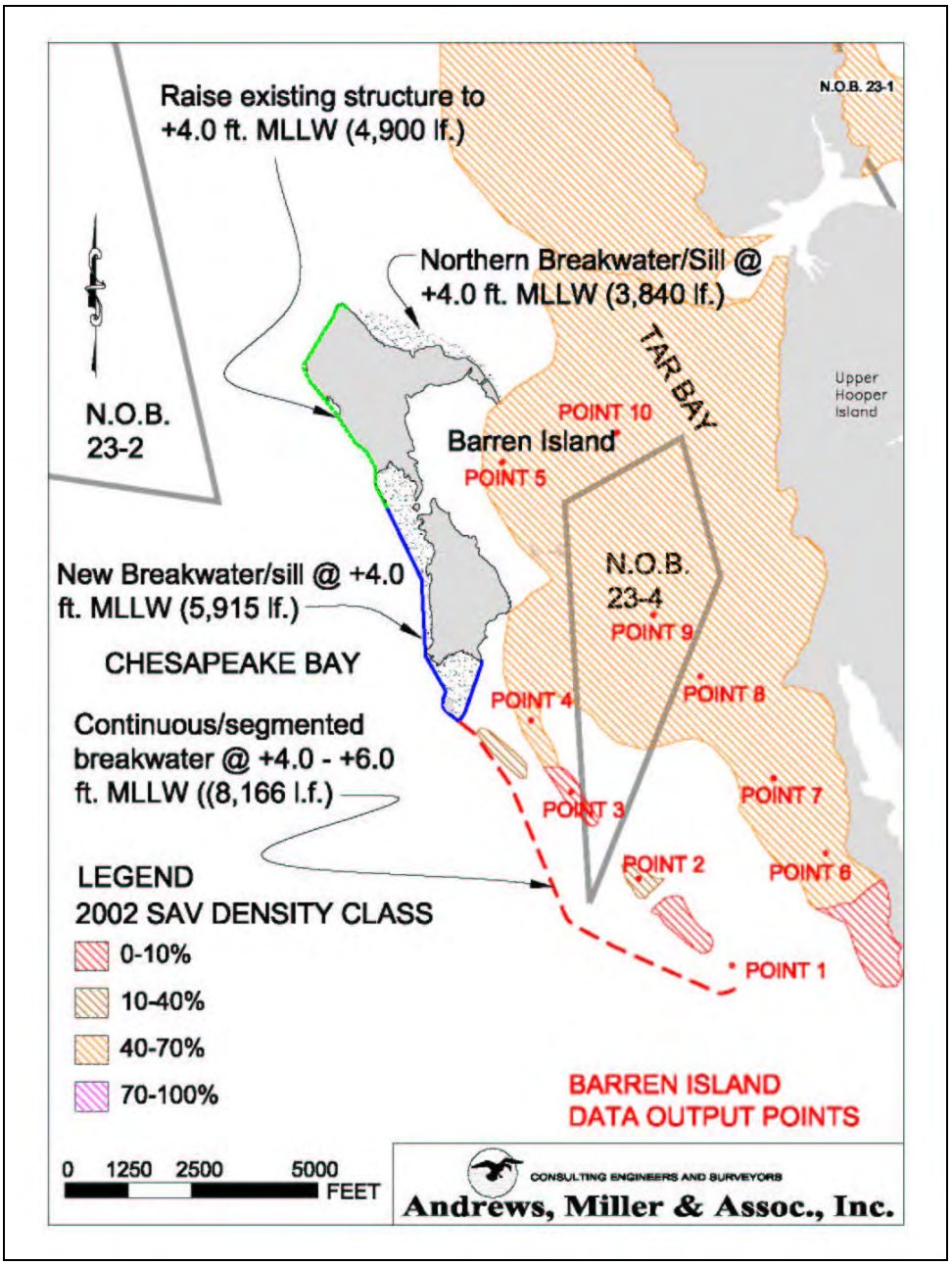

Figure C5. Modeling data output points

The results of the modeling by ERDC for Alts BI-1 through BI-6, as described in Table C3, were compiled into an alternatives evaluation matrix. This matrix is presented in Table C4 and shows the maximum tidal current velocity, V_{max}, and the maximum wave height, H_{max}, for each alternative, existing conditions and future conditions for each of the four storms at each of the 10 data output points.

Table C3
Barren Island Alternatives

Alternative	Description
BI-1	8,166-ft-long south breakwater at +6 ft mllw.
BI-2	5,915-ft-long south breakwater at +6 ft mllw.
BI-3	8,166-ft-long south breakwater at +4 ft mllw.
BI-4	5,915-ft-long south breakwater at +4 ft mllw.
BI-5	8,166-ft-long south breakwater at +4 ft mllw with 400 ft segments and 200 ft gaps.
BI-6	8,166-ft-long south breakwater at +4 ft mllw with 500 ft segments and 100 ft gaps.

The data in Table C4 indicate that the maximum current velocities generally were produced during Hurricane Hazel, followed closely by Hurricane Isabel, and then NE20 and NE33. The maximum wave heights were produced during Hurricane Isabel, followed closely by Hurricane Hazel, and then NE20 and NE33. For the evaluation of the performance of the proposed alternative plans, Hurricane Hazel and NE20 were selected because these events on average appear to have produced the most significant hydrodynamic conditions.

Table C4
Barren Island Alternative Plan Evaluation Matrix

	Point 1		Point 2		Point 3		Point 4		Point 5		Point 6		Point 7		Point 8		Point 9		Point 10	
	H_{max} (ft)	V_{max} (ft/sec)	H_{max} (ft)	V_{max} (ft/sec)	H_{max} (ft)	V_{max} (ft/sec)	H_{max} (ft)	V_{max} (ft/sec)	H_{max} (ft)	V_{max} (ft/sec)	H_{max} (ft)	V_{max} (ft/sec)	H_{max} (ft)	V_{max} (ft/sec)	H_{max} (ft)	V_{max} (ft/sec)	H_{max} (ft)	V_{max} (ft/sec)	H_{max} (ft)	V_{max} (ft/sec)
Alternative BI-1																				
NE20	0.8	1.9	1.3	1.1	1.3	1.1	1.0	0.9	0.4	0.8	1.3	1.4	1.1	1.3	1.0	1.3	0.8	1.5	1.5	1.1
NE33	0.4	2.3	0.5	1.3	0.3	1.2	0.1	0.8	0.4	0.9	0.3	0.9	0.4	1.3	0.5	1.4	0.6	1.2	1.2	1.4
Isabel	1.8	3.0	1.9	1.9	1.7	2.4	1.7	2.5	1.3	3.0	2.3	3.1	1.9	3.2	1.6	2.8	1.6	2.7	1.3	3.1
Hazel	1.4	3.3	1.2	3.2	1.2	3.3	1.2	3.3	0.9	3.3	1.8	3.4	1.4	3.3	1.2	3.3	1.1	3.3	0.9	3.3
Alternative BI-2																				
NE20	2.8	1.1	2.3	1.1	1.4	1.0	1.0	0.7	0.4	1.0	2.4	1.5	2.5	1.1	1.6	1.2	1.2	1.2	1.5	1.3
NE33	2.4	0.8	0.8	1.4	0.3	1.1	0.1	0.7	0.4	0.5	1.7	0.9	1.2	1.3	0.5	1.0	0.6	1.5	1.2	1.4
Isabel	4.5	3.1	4.1	2.4	1.9	2.6	1.7	2.5	1.4	3.0	3.8	3.0	4.3	3.0	3.1	2.8	2.4	2.7	1.7	3.2
Hazel	4.1	3.3	3.5	3.3	1.5	3.3	1.2	3.3	1.1	3.3	3.5	3.4	3.7	3.3	2.7	3.3	2.0	3.3	1.3	3.3
Alternative BI-3																				
NE20	0.9	1.8	1.0	1.0	1.0	1.0	0.9	0.8	0.4	0.8	1.0	1.4	0.9	1.3	0.8	1.2	0.9	1.5	1.5	1.1
NE33	0.4	1.0	0.5	0.5	0.4	0.5	0.5	0.4	0.4	0.5	0.4	0.7	0.5	0.5	0.5	0.6	0.6	0.6	1.2	0.7
Isabel	2.4	3.3	2.5	2.7	2.3	2.7	2.2	2.5	1.4	3.1	2.5	3.1	2.3	3.2	2.2	2.9	2.2	2.7	1.5	3.1
Hazel	1.8	3.3	2.0	2.9	1.8	3.3	1.7	3.2	1.1	3.3	2.0	3.4	1.8	3.3	1.7	3.3	1.7	3.3	1.2	3.3
Alternative BI-4																				
NE20	2.8	1.2	2.4	1.4	1.0	1.3	0.9	0.9	0.5	0.9	2.3	1.5	2.6	1.5	1.6	1.5	1.2	1.7	1.5	1.2
NE33	2.4	0.8	0.8	1.5	0.4	1.2	0.5	0.8	0.4	0.5	1.8	0.9	1.2	1.3	0.5	1.0	0.6	1.5	1.2	1.4
Isabel	4.5	3.2	4.2	2.9	2.4	2.7	2.2	2.4	1.5	2.9	3.7	3.1	4.4	3.1	3.3	2.8	2.7	2.7	1.8	3.1
Hazel	4.1	3.3	3.7	3.3	1.9	3.3	1.7	3.3	1.1	3.3	3.5	3.4	3.8	3.3	2.8	3.3	2.3	3.3	1.4	3.3
Alternative BI-5																				
NE20	1.2	1.3	1.6	1.1	1.5	1.2	1.3	1.3	0.4	1.0	1.4	1.3	1.5	1.4	1.4	1.5	1.3	1.8	1.7	1.3
NE33	0.7	1.1	1.0	1.3	0.9	1.6	0.8	1.8	0.3	0.6	0.8	0.8	0.9	1.2	0.7	2.1	0.7	1.5	1.3	1.4
Isabel	2.3	2.7	2.9	2.9	3.0	2.7	2.6	2.5	0.5	2.9	2.7	2.7	2.8	3.0	2.6	2.7	2.5	2.7	1.6	3.1
Hazel	1.8	3.3	2.4	3.3	2.6	3.3	2.2	3.3	0.4	3.3	2.3	3.3	2.4	3.3	2.2	3.3	2.1	3.3	1.4	3.3
Alternative BI-6																				
NE20	1.0	1.4	1.4	1.0	1.6	1.2	1.5	1.3	0.6	1.0	1.2	1.5	1.3	1.5	1.3	1.5	1.3	1.8	1.7	1.3
NE33	0.7	1.4	1.1	1.4	0.9	1.7	0.8	1.7	0.5	0.8	0.9	1.0	0.9	1.5	0.7	2.1	0.7	1.6	1.3	1.3
Isabel	2.5	2.8	2.9	1.8	3.0	2.0	2.9	3.3	0.5	3.1	2.7	2.7	2.7	3.0	2.7	2.6	2.6	2.6	1.6	3.3
Hazel	2.0	3.2	2.3	2.3	2.6	2.5	2.5	3.3	0.4	3.3	2.3	3.4	2.3	3.3	2.2	3.3	2.2	3.3	1.3	3.3
Existing																				
NE20	3.1	1.1	3.3	1.3	3.0	1.4	2.8	1.7	0.6	1.0	2.5	2.1	2.8	1.4	2.8	1.6	2.6	1.9	1.6	1.3
NE33	2.7	0.7	2.9	0.9	2.7	1.2	2.4	1.4	0.6	0.5	2.2	1.3	2.4	1.0	1.9	1.3	1.6	1.9	1.3	1.5
Isabel	4.6	3.3	5.1	3.3	4.8	3.1	4.7	2.8	0.6	2.9	3.7	3.1	4.5	3.2	4.7	2.9	4.5	2.7	2.4	2.9
Hazel	4.1	3.3	4.5	3.3	4.3	3.3	4.1	3.3	0.6	3.3	3.5	3.4	4.1	3.3	4.1	3.3	3.9	3.3	2.2	3.3
Future																				
NE20	3.2	1.1	3.4	1.2	3.1	1.3	2.8	1.3	2.5	1.3	2.5	1.3	2.8	1.4	2.8	1.3	2.7	1.6	2.4	1.1
NE33	2.7	0.8	2.9	1.4	2.7	2.0	2.5	2.4	2.2	1.5	2.2	0.7	2.5	1.2	2.2	2.4	2.1	2.1	2.2	1.6
Isabel	4.5	3.3	5.1	3.3	4.8	3.3	4.7	3.2	4.3	3.3	3.7	3.2	4.5	3.3	4.7	3.2	4.5	3.0	4.4	3.0
Hazel	4.1	3.3	4.5	3.3	4.3	3.3	4.1	3.3	3.7	3.4	3.5	3.5	4.1	3.3	4.2	3.3	4.0	3.3	3.8	3.3

For evaluation, the average of the maximum current velocities and the wave heights for Points 6-9, which are located in the historic SAV growth area, were compared with the existing condition and Alts BI-1 - BI-6 as shown in Figure C6 and Figure C7, respectively.

As shown in Figure C6, the average of the current velocities at Points 6-9 during NE20 for existing conditions is 1.7 ft/sec as compared to approximately 1.3 ft/sec for Alts BI-1 - BI-3, and 1.5 ft/sec for Alts BI-4 - BI-6. With reference to the preliminary current velocity guidelines for SAV tolerance, the existing conditions velocities and the velocities with the alternative plans for NE20 would not be expected to exceed the SAV tolerable conditions.

For Hurricane Hazel, the average of the current velocities at Points 6-9 during the storm for existing conditions as well as for Alts BI-1 - BI-6 is 3.3 ft/sec. During this level of storm, it is apparent that the alternative plans have a negligible impact on the current velocities. These existing-conditions velocities and the velocities with the alternative plans for the Hurricane Hazel event are at the upper limit of the SAV tolerable conditions.

As shown in Figure C7, the average of the wave heights at Points 6-9 during NE20 for existing conditions is 2.7 ft as compared to approximately 1.0 ft for Alts BI-1 and BI-3; 1.9 ft for Alts BI-2 and BI-4; and 1.4 ft for Alts BI-5 and BI-6. Given the preliminary wave height guidelines for SAV tolerance, the existing conditions wave heights exceed the upper limit of the SAV tolerant conditions. The wave heights with the alternative plans for NE20 do not exceed the SAV tolerable conditions. Alts BI-1 and BI-3 result in the lowest wave heights with Alts BI-2 and BI-4 with the shortened south breakwater result in the highest wave heights for NE20. The wave heights with Alts BI-5 and BI-6 with the segmented south breakwater are about midway between the other alternatives.

The average of the wave heights at Points 6-9 during Hurricane Hazel for the existing condition is 3.9 ft as compared to approximately 1.6 ft for Alts BI-1 and BI-3; 3.0 ft for Alts BI-2 and BI-4; and 2.2 ft for Alts BI-5 and BI-6. With reference to the preliminary wave height guidelines, the existing conditions wave heights exceed the threshold of the SAV tolerable conditions and the wave heights with all of the alternative plans for the storm event are below the SAV tolerance conditions; particularly for Alts BI-1, BI-2, BI-5, and BI-6.

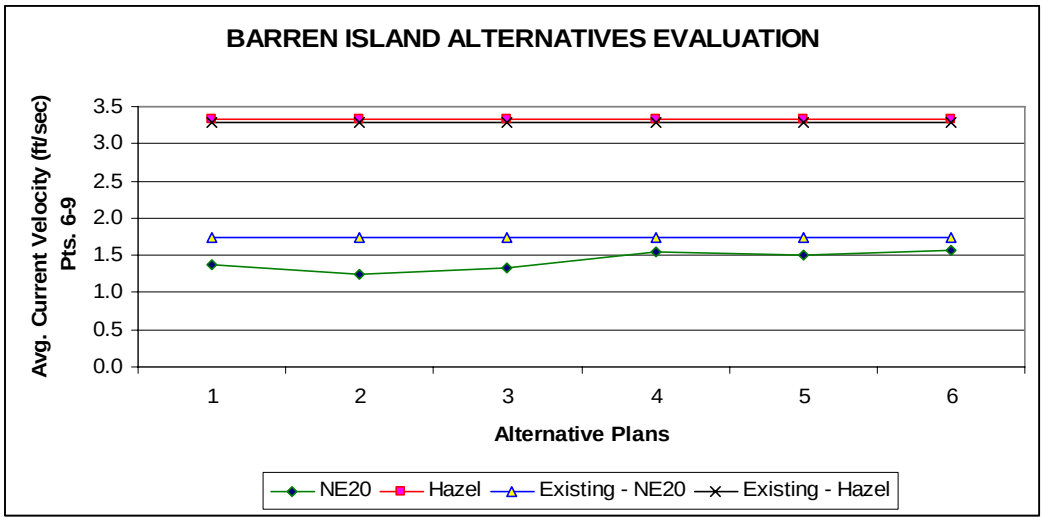

Figure C6. Average calculated maximum current velocity in SAV area (Points 6-9)

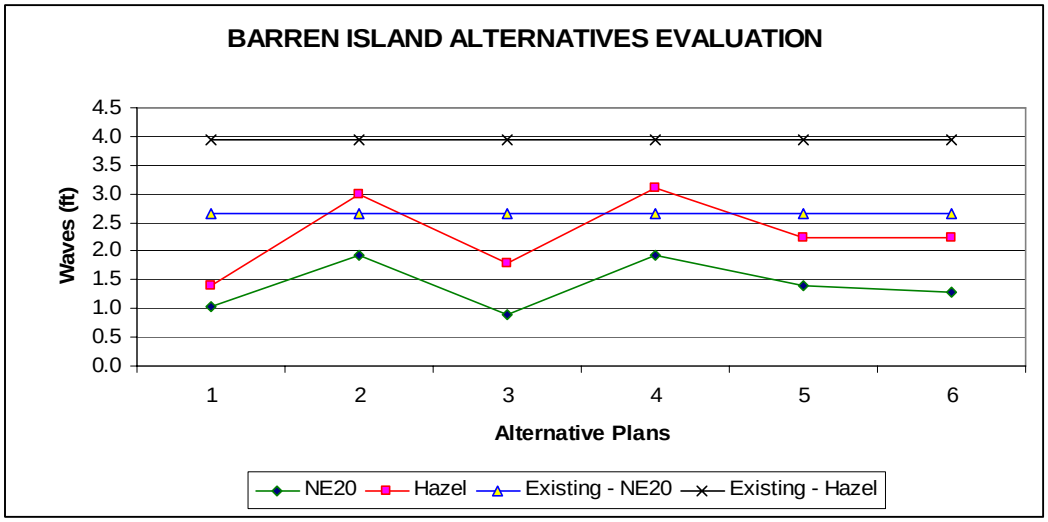

Figure C7. Average calculated maximum wave height in SAV area (Points 6-9)

In general, there appears to be little difference in the maximum current velocities between alternatives and the existing-condition velocities. Based on the preliminary guidelines for SAV tolerance, the maximum velocities for the evaluated alternatives are not sufficient to adversely impact the SAV in the area.

Because neither the maximum current velocities nor the maximum wave heights during the representative extreme storms evaluated appear to be significant enough in magnitude for Alt BI-5 and Alt BI-6 (with a segmented south breakwater) to adversely impact SAV in the primary SAV area, Points 6-10, (based on the preliminary tolerance guidelines), further consideration should be given to segmented breakwater alternatives; including evaluation of the wave and current conditions closer to the breakwater gaps. Segmented breakwaters could result in substantial construction cost savings as opposed to a continuous breakwater. The segmented breakwaters would also promote circulation in the SAV area and a reduced potential for adverse water temperature increases in that area.

Accordingly, two additional alternatives were developed to further investigate the impacts of segment lengths and gap widths between the segments, discussed next.

Development and Modeling of Alts BI-7 and BI-8

Based on the evaluation of the performance of Alts BI-1 through BI-6, it was decided that further consideration should be given to segmented breakwater alternatives because substantial construction cost savings could be realized in comparison with a continuous breakwater, as well as other potential environmental benefits including enhanced current circulation and reduced water temperature in the SAV area. Two of the initial modeling simulations incorporated segmented breakwaters, Alt BI-5 (segment length = 400 ft and gap width = 200 ft) and Alt BI-6 (segment length = 500 ft and gap width = 100 ft). To further investigate the impacts of segment lengths and gap widths between the segments, two additional alternatives were developed. These alternatives are described in Table C5 and shown in Figures C8 and C9.

Table C5
Barren Island Alternatives

Alternative	Description
BI-7	8,166-ft-long south breakwater at +4 ft mllw with 600-ft segments and 300-ft gaps.
BI-8	8,166-ft-long south breakwater at +4 ft mllw with 600-ft segments and 200-ft gaps.

Alt BI-7. This alternative was developed to evaluate the impact of increased breakwater segment lengths (600 ft) and larger gaps between the segments (300 ft).

Alt BI-8. This alternative was developed to evaluate the impact of the longer breakwater segment lengths (600 ft) combined with smaller gaps between the segments (200 ft).

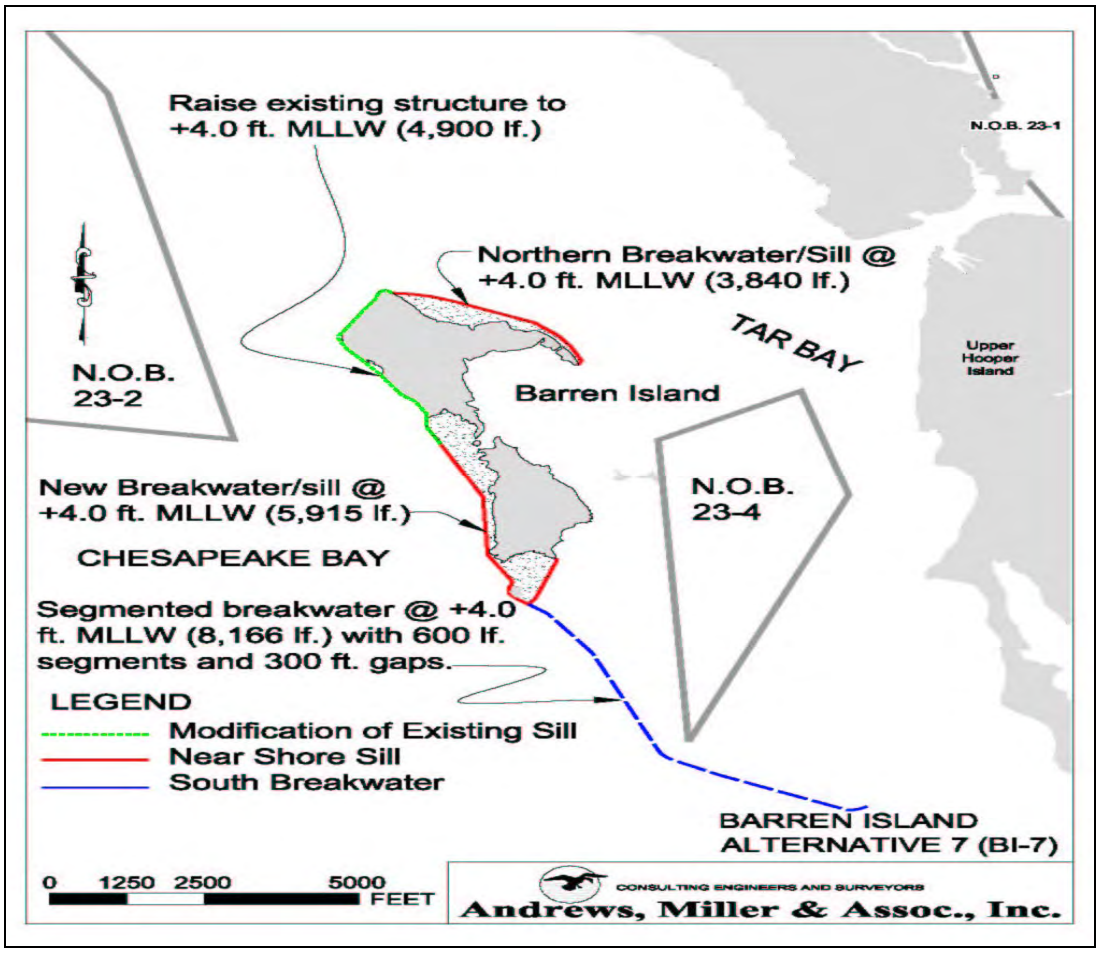

Figure C8. Barren Island Alt BI-7

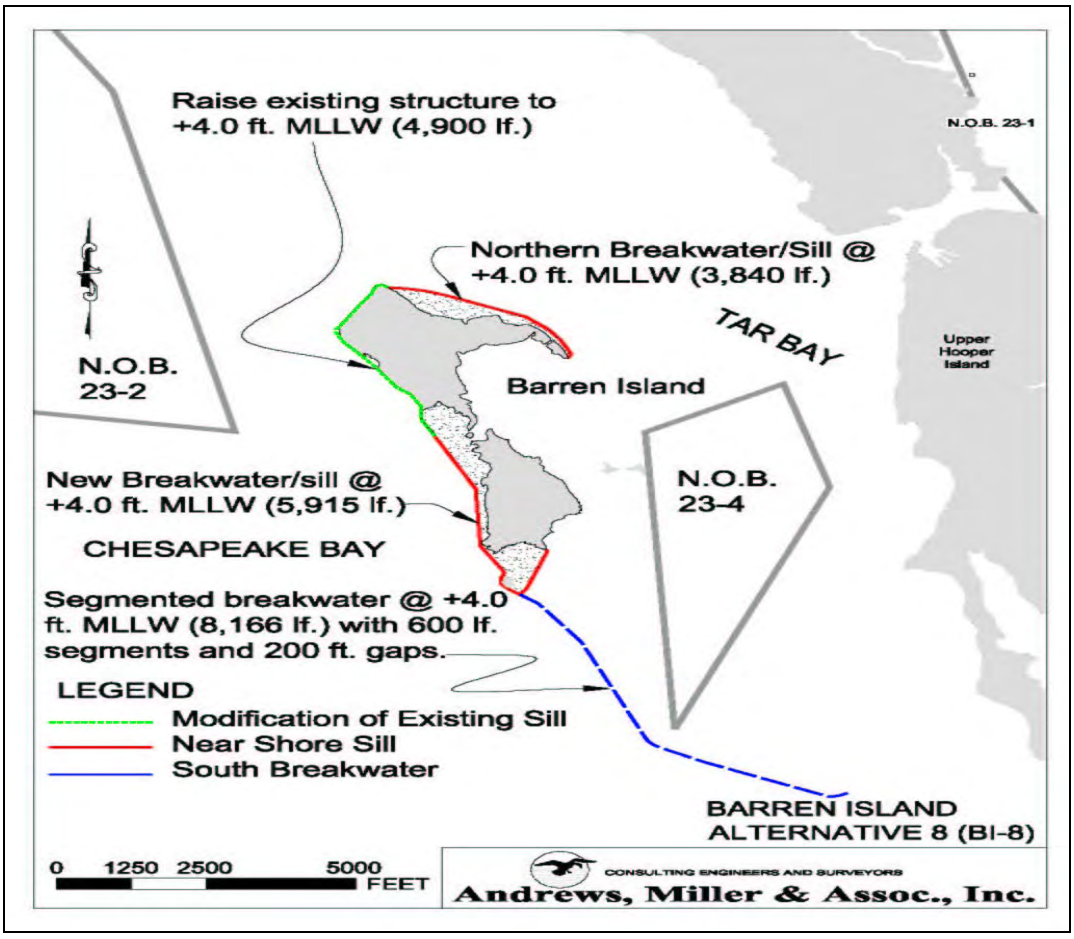

Figure C9. Barren Island Alt BI-8

Modeling of Barren Island Alts BI-7 and BI-8

Hydrodynamic and wave modeling was conducted for Alts BI-7 and BI-8 to investigate the environmental impact of these alignments; particularly in the SAV growth area.

The USACE's Inlet Modeling System (IMS) (Militello et al. 2004) was operated to evaluate the impacts to velocities for the two additional Barren Island alternatives. The IMS is an integrated modeling system for calculating hydrodynamics for coastal projects at time scales of a tidal cycle, through a series of storms, to several years. The model used for the hydrodynamic calculation is a depth-integrated, two-dimensional (2-D) finite-difference circulation model, M2D. The model M2D was developed under the Coastal Inlets Research Program conducted at ERDC, CHL. M2D is a finite-difference numerical representation of the 2-D depth-integrated continuity and momentum equations of water motion. Model pre- and post-processing was done with the Surface-water Modeling System, Version 9.0 beta.

Wave transformation modeling was performed to assess impacts of Alts BI-7 and BI-8 on adjacent SAV areas, natural oyster bars, and shorelines. The wave transformation model used was STWAVE. The model was forced with directional wave spectra based on typical wave height, period, and direction combinations. The stand-alone STWAVE model simulations include representative wave and tidal levels from two storms, Hurricane Hazel and NE20.

Hydrodynamic Modeling

The simulations for Alts BI-7 and BI-8 include representative wave and tidal levels from two storms, Hurricane Hazel (14-16 October 1954) and one northeaster, NE20 (28-31 March 1984).

The regional scale ADCIRC mesh developed by ERDC was adopted for the M2D simulations. This mesh was refined for the local Barren Island area. The M2D Cartesian grid that was generated to cover the local Barren Island area was 4,650 m by 5,800 m and consisted of 25-m square cells. The same M2D grid was used in all runs with different bathymetries and storms. The bathymetries (geometries, layouts) for the Alt BI-7 and Alt BI-8 were generated utilizing scatter sets of the mesh data associated with the ADCIRC model for Alt BI-5, provided by the respective fort.14, and (*.dep) and (*.end) files. The new bathymetries were generated by modifying the locations and elevations of the appropriate points of the scatter set, and interpolating them during the generation of the M2D grids. Figures C10 and C11 show the regional bathymetry and local scale bathymetry grid for the Barren Island area.

The water-surface elevation and velocity data were forced at the boundaries of the M2D grid through the fort.63 and fort.64 files provided by ERDC based on the regional ADCIRC runs. The IMS-M2D model control parameters that were implemented during the steered STWAVE and M2D runs included the use of the wind data for the specific storm and the location (Barren Island) and the executables for the M2D program, which were provided by ERDC.

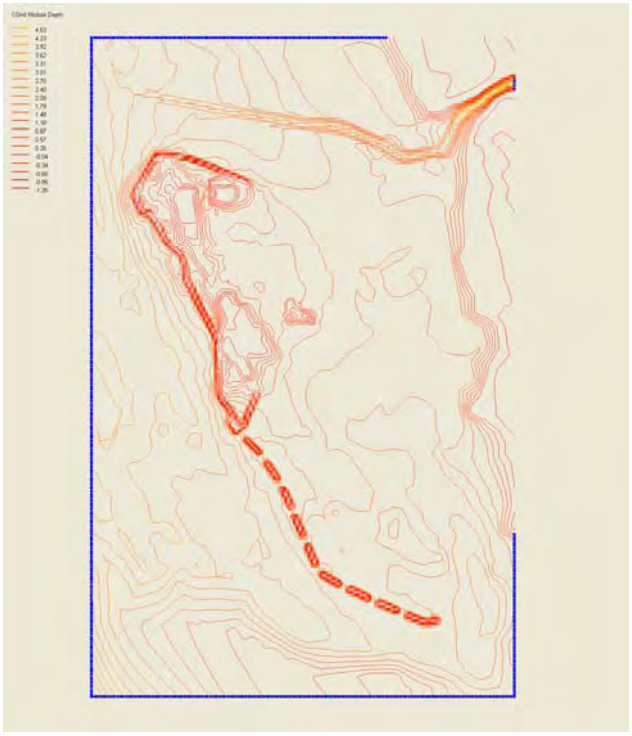

Figure C10. Alt BI-7 M2D bathymetry

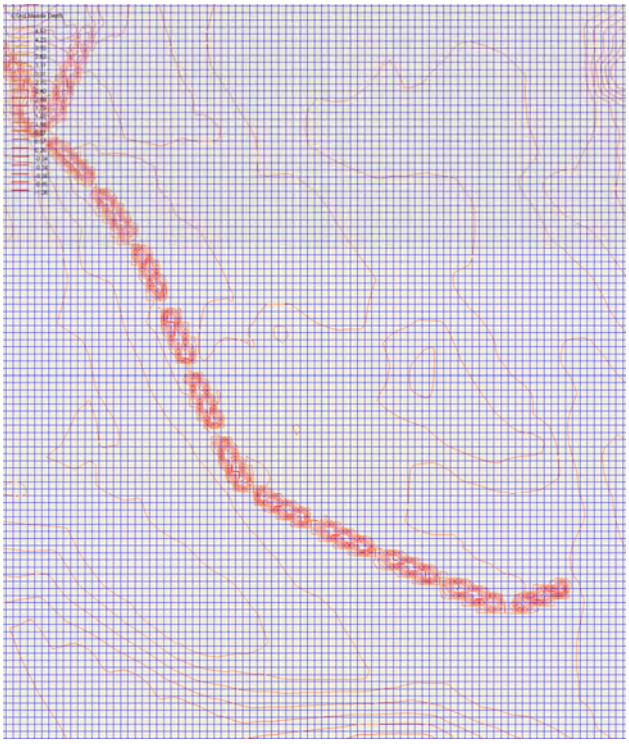

Figure C11. Alt BI-7 M2D grid

The hydrodynamic simulations were conducted for each of the alternative island alignments, Alts BI-7 and BI-8. Two storms were selected for the hydrodynamic modeling, Hurricane Hazel and one moderate northeaster which occurred in March 1984 (NE20). For this hurricane and northeaster, both surface wind and pressure fields developed from the previous hydrodynamic simulations (Alts BI-1 through BI-6) were input, together with the surface wave forcing and tidal potentials at the local boundary, to the hydrodynamic model. Maximum current velocities for Alt BI-7 for NE20 and Alt BI-8 for Hurricane Hazel are shown in Figures C12 and C13, respectively.

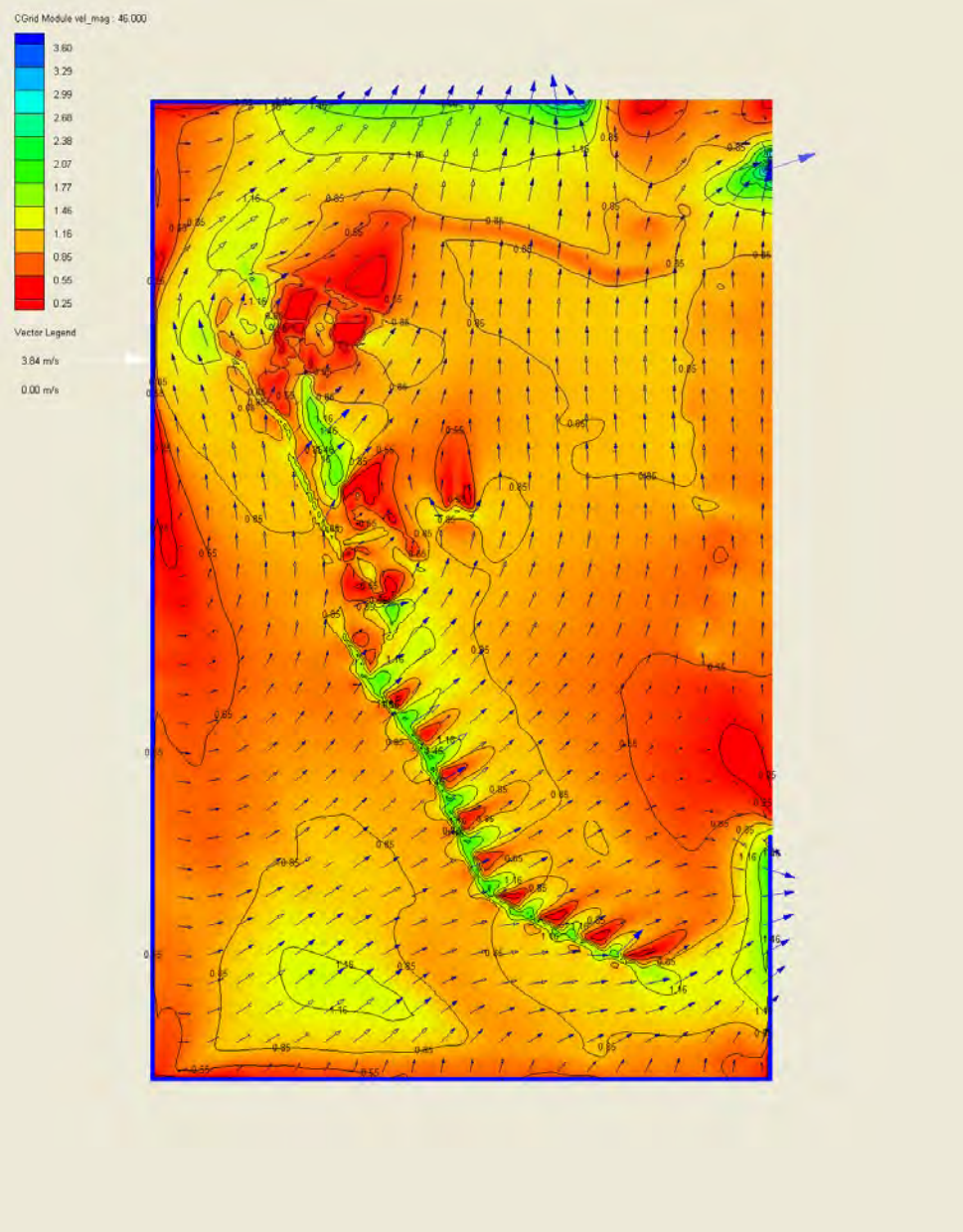

Figure C12. Alt BI-7 NE20 time-step 45 (maximum current)

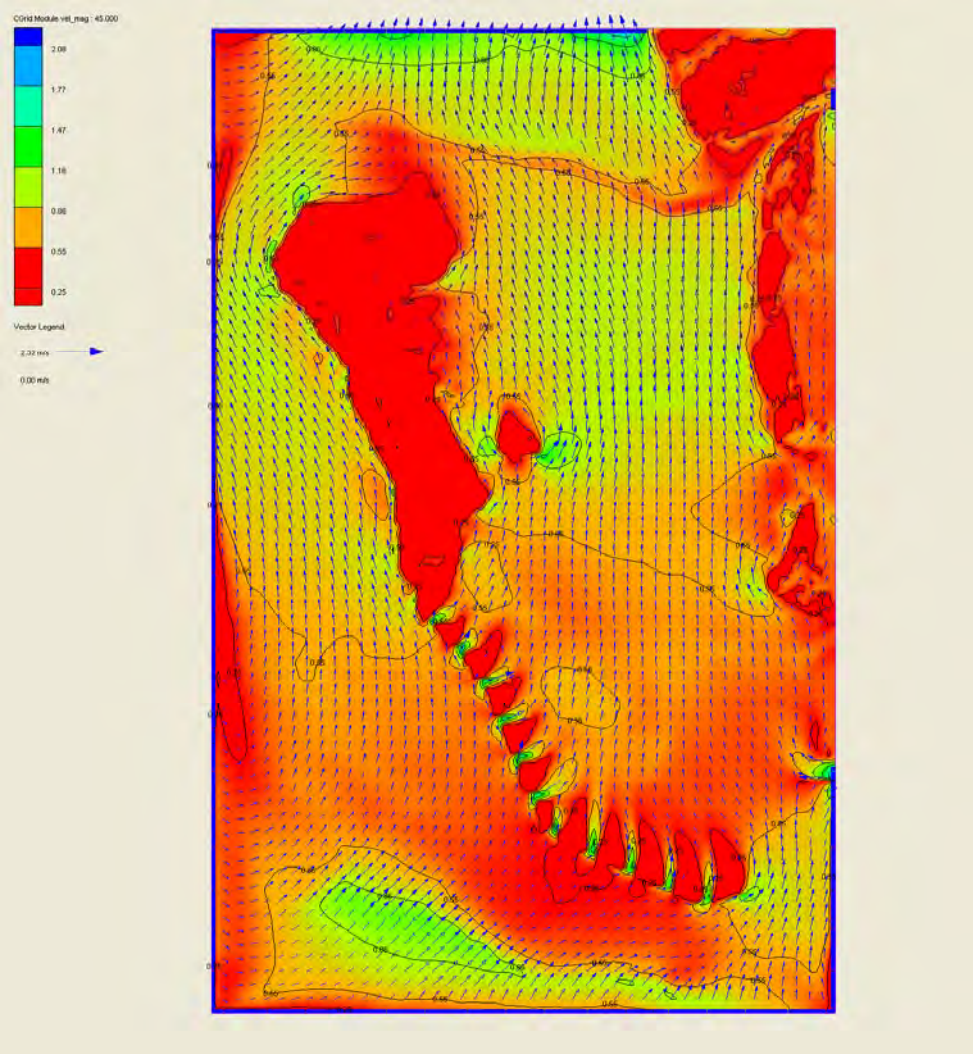

Figure C13. Alt BI-8-Hazel time-step 45 (near-maximum current)

Current Velocity Comparison

The current velocity was evaluated at several key locations selected to identify the impact on environmental resources including oyster bed and SAV areas. For Barren Island, Points 1-10 are located in the SAV area. Points 9 and 10 are located in the oyster bed. Point 1 is located in the south local channel. Figure C14 shows these key locations for Barren Island (Alt BI-6 serves as the background bottom topography). Tables C6 and C7 summarize of the maximum current velocity at Points 1-10 for the two different storms and the individual Barren Island Alts BI-7 and BI-8.

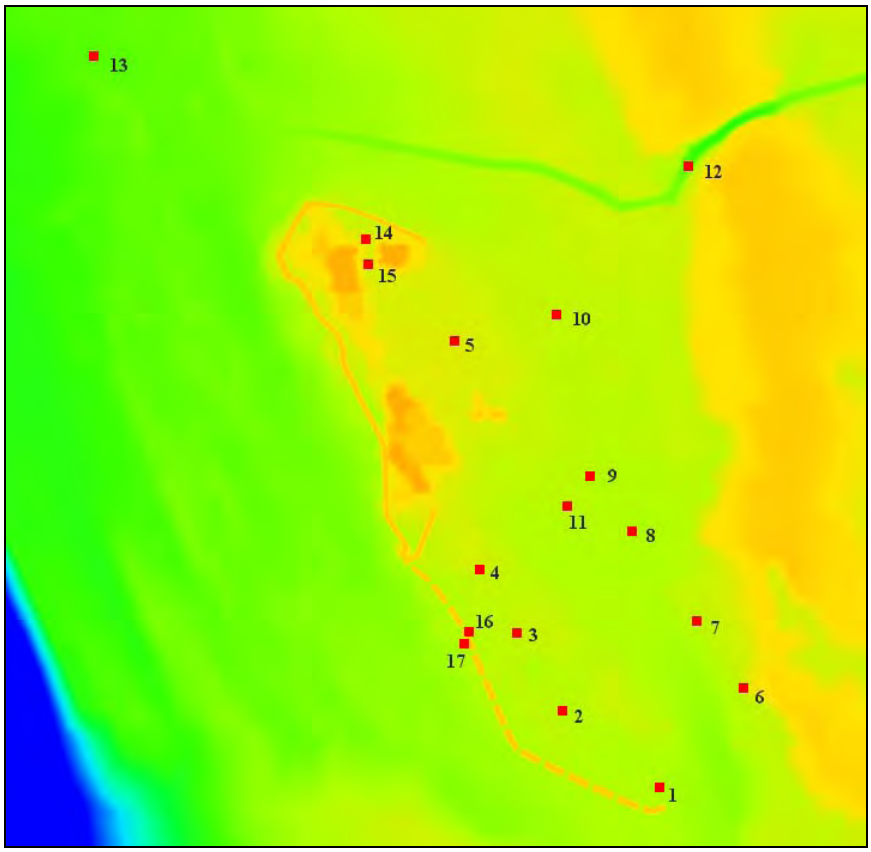

Figure C14. Barren Island output data locations

Table C6
Calculated Maximum Current Speed (ft/sec) at Barren Island During Hurricane Hazel

Location	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6	BI-7	BI-8
1	3.3	3.3	3.3	3.3	3.3	3.2	2.1	1.1
2	3.2	3.3	2.9	3.3	3.3	2.3	2.8	2.0
3	3.3	3.3	3.3	3.3	3.3	2.5	2.9	2.2
4	3.3	3.3	3.2	3.3	3.3	3.3	3.7	2.0
5	3.3	3.3	3.3	3.3	3.3	3.3	2.3	2.3
6	3.4	3.4	3.4	3.4	3.3	3.4	2.7	1.5
7	3.3	3.3	3.3	3.3	3.3	3.3	1.1	1.4
8	3.3	3.3	3.3	3.3	3.3	3.3	2.0	2.1
9	3.3	3.3	3.3	3.3	3.3	3.3	2.4	2.2
10	3.3	3.3	3.3	3.3	3.3	3.3	2.7	2.9

Table C7
Calculated Maximum Current Speed (ft/sec) at Barren Island during NE20

Location	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6	BI-7	BI-8
1	1.9	1.1	1.8	1.2	1.3	1.4	2.1	1.2
2	1.1	1.1	1.0	1.4	1.1	1.0	2.8	2.1
3	1.1	1.0	1.0	1.3	1.2	1.2	2.9	2.3
4	0.9	0.7	0.8	0.9	1.3	1.3	3.7	2.3
5	0.8	1.0	0.8	0.9	1.0	1.0	2.3	1.8
6	1.4	1.5	1.4	1.5	1.3	1.5	2.7	1.2
7	1.3	1.1	1.3	1.5	1.4	1.5	1.1	1.3
8	1.3	1.2	1.2	1.5	1.5	1.5	2.0	1.8
9	1.5	1.2	1.5	1.7	1.8	1.8	2.4	2.0
10	1.1	1.3	1.1	1.2	1.3	1.3	2.7	2.8

Alt BI-7. Analysis of the data in Table C6 indicates that the computed maximum current velocities for Alt BI-7 for Hurricane Hazel are similar in magnitude to Alts BI-5 and BI-6 for some of the points, but significantly lower for some of the other points. Preliminary review of the run files did not identify any specific reason for the discrepancy at these points. Further evaluation is required, to determine if there should be any differences expected when comparing computed maximum velocities from M2D/STWAVE simulations (Alts BI-7 and BI-8) with computed maximum velocities from ADCIRC simulations (Alts BI-1 through BI-6).

Analysis of the data in Table C7 indicates that the computed maximum current velocities for Alt BI-7 for NE20 are significantly greater than the computed velocities for Alts BI-5 and BI-6 for almost all of the points. Similar to the Hurricane Hazel data, preliminary review of the run files for NE20 did not identify any specific reason for the discrepancy at these points and further evaluation is required.

Alt BI-8. Analysis of the data in Table C6 indicates that the computed maximum current velocities for Alt BI-8 for Hurricane Hazel are weaker than Alts BI-5 and BI-6 for all of the points, but significantly weaker for some of the other points.

Analysis of the data in Table C7 indicates that the computed maximum current velocities for Alt BI-8 for NE20 are weaker than Alt BI-7 and similar to Alts BI-5 and BI-6 for the majority of the points, but significantly stronger for a few of the other points.

Wave Modeling

The STWAVE model was used to simulate the wave conditions for Alts BI-7 and BI-8 for two storms (Hurricane Hazel and NE20). The STWAVE grid which

was provided by ERDC utilized a 50-ft-square cell size. This cell size was maintained during the interpolation for Alt BI-7 and Alt BI-8 bathymetries.

Wave Height Comparison

Tables C8 and C9 summarize the calculated maximum wave heights at Points 1-10 for the two different storms and the individual Barren Island Alts BI-7 and BI-8.

Table C8
Calculated Maximum Wave Heights (ft) at Barren Island During Hurricane Hazel

Location	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6	BI-7	BI-8
1	1.4	4.1	1.8	4.1	1.8	2.0	2.7	2.6
2	1.2	3.5	2.0	3.7	2.4	2.3	3.1	3.2
3	1.2	1.5	1.8	1.9	2.6	2.6	3.1	2.4
4	1.2	1.2	1.7	1.7	2.2	2.5	3.1	3.0
5	0.9	1.1	1.1	1.1	0.4	0.4	2.9	2.9
6	1.8	3.5	2.0	3.5	2.3	2.3	3.0	3.0
7	1.4	3.7	1.8	3.8	2.4	2.3	2.7	2.8
8	1.2	2.7	1.7	2.8	2.2	2.2	2.8	2.8
9	1.1	2.0	1.7	2.3	2.1	2.2	2.3	2.3
10	0.9	1.3	1.2	1.4	1.4	1.3	2.4	2.3

Table C9
Calculated Maximum Wave Heights (ft) at Barren Island During NE20

Location	BI-1	BI-2	BI-3	BI-4	BI-5	BI-6	BI-7	BI-8
1	0.8	2.8	0.9	2.8	1.2	1.0	1.6	1.6
2	1.3	2.3	1.0	2.4	1.6	1.4	1.7	1.7
3	1.3	1.4	1.0	1.0	1.5	1.6	1.3	0.9
4	1.0	1.0	0.9	0.9	1.3	1.5	1.2	0.9
5	0.4	0.4	0.4	0.5	0.4	0.6	0.9	0.8
6	1.3	2.4	1.0	2.3	1.4	1.2	0.9	0.8
7	1.1	2.5	0.9	2.6	1.5	1.3	1.4	1.2
8	1.0	1.6	0.8	1.6	1.4	1.3	1.0	0.9
9	0.8	1.2	0.9	1.2	1.3	1.3	0.9	0.8
10	1.5	1.5	1.5	1.5	1.7	1.7	1.1	0.8

Alt BI-7. Analysis of the data in Table C8 indicates that the computed maximum wave heights for Hurricane Hazel for Alt B-7 (with 300-ft gaps) are higher than the maximum wave heights for Alts B-5 (with 200-ft gaps) and B-6 (with 100-ft gaps) for all points. A preliminary conclusion might be that the higher wave heights could be a result of wider gaps between the breakwater segments in Alt BI-7. However, comparison of the maximum wave heights for Alt BI-5 (with 200-ft gaps) and BI-6 (with 100-ft gaps) does not show a decrease in wave height with the smaller gaps in Alt BI-6. An explanation that maximum wave heights for Alt BI-5 with 200-ft gaps are not greater than BI-6 with 100-ft gaps could be that BI-5 has a 4-ft crest elevation, whereas BI-6 has a 6-ft crest elevation. Further evaluation is required to better define the impact of the breakwater gaps and to consider the variation in breakwater segment length. In any event, it is noted that the computed maximum wave heights for Alt BI-7 for Hurricane Hazel are lower than the preliminary 1-m (3.28-ft) SAV tolerance threshold.

Analysis of the data in Table C9 indicates that the computed maximum wave heights for NE20 for Alt BI-7 (with 300-ft gaps) are lower than Alts BI-5 (with 200-ft gaps) and BI-6 (with 100-ft gaps) for the majority of the points. Longer breakwater segments in Alt BI-7 (600 ft vs. 400 ft and 500 ft in Alt BI-5 and Alt BI-6, respectively) may be the reason for the lower wave heights; particularly during NE20 with a lower storm surge, which would possibly result in lower wave heights with longer breakwater segments. It is noted that the computed wave heights for Alt BI-7 for NE20 are significantly lower than the 1-m (3.28-ft) SAV tolerance threshold.

Alt BI-8. Analysis of the data in Table C8 indicates that the computed maximum wave heights for Hurricane Hazel for Alt BI-8 (with longer, 600-ft segments and 200-ft gaps) are higher than Alts BI-5 (with 400-ft segments and 200-ft gaps) and BI-6 (with 500-ft segments and 100-ft gaps) for essentially all of the points. The computed maximum wave heights for Alt BI-8 are generally lower than Alt BI-7 (with 600-ft segments and 300-ft gaps), which would be expected. Further evaluation is required to better define the impact of the breakwater segment lengths and gaps combinations and to verify that the modeling procedures are consistent. However, it is also noted that the computed wave heights for Alt BI-8 for Hurricane Hazel are lower than the preliminary 1-m (3.28-ft) SAV tolerance threshold.

Analysis of the data in Table C9 indicates that the computed maximum wave heights for NE20 for Alt BI-8 are lower than Alts BI-5 (with 400-ft segments and 200-ft gaps) and BI-6 (with 500-ft segments and 100-ft gaps) for the majority of the points as well as lower than Alt BI-7. The computed maximum wave heights for Alt BI-8 for NE20 are significantly lower than the 1-m (3.28-ft) SAV tolerance threshold.

Summary

Results from the wave and hydrodynamic models were analyzed to evaluate the performance of the Barren Island alternatives listed in Table C10.

Table C10
Barren Island Alternatives

Alternative	Description
BI-1	8,166-ft-long south breakwater at +6 ft mllw.
BI-2	5,915-ft-long south breakwater at +6 ft mllw.
BI-3	8,166-ft-long south breakwater at +4 ft mllw.
BI-4	5,915-ft-long south breakwater at +4 ft mllw.
BI-5	8,166-ft-long south breakwater at +4 ft mllw with 400-ft segments and 200-ft gaps.
BI-6	8,166-ft-long south breakwater at +4 ft mllw with 500-ft segments and 100-ft gaps.
BI-7	8,166-ft-long south breakwater at +4 ft mllw with 600-ft segments and 300-ft gaps.
BI-8	8,166-ft-long south breakwater at +4 ft mllw with 600-ft segments and 200-ft gaps.

As discussed in the main text, for the Barren Island alternatives, Alts BI-1 and BI-3 with a longer southern breakwater, show the best wave height reduction by 2 to 3 ft in the lee of the island for the four storms. Alts BI-3 and BI-4 with the low-crest southern breakwater are likely to create large current velocity, causing strong bottom erosion at the breakwater. Segmented breakwater (Alts BI-5 and BI-6) can create a similar condition with strong current velocity around the segmented breakwater element, causing more sediment deposition and erosion at the breakwater.

From an SAV tolerance perspective, there does not appear to be a significant difference in the current velocities in the SAV areas (Points 6–9) for the various alternatives during the storms simulated. The current velocities for all of the alternatives appear to be less than the preliminary 1 m/sec (3.3 ft/sec) SAV tolerance threshold. Further evaluation at points closer to the breakwaters is required to evaluate potential impacts on intermittent SAV in those areas.

There is a significant difference in wave height in the SAV areas for the various alternatives, with the continuous southern breakwater alternatives (Alts BI-1 and BI-3) providing lower wave height in the SAV area than the segmented southern breakwater alternatives (Alts BI-5 - BI-8). However, the wave heights for all of the alternatives appear to be less than the preliminary 1-m (3.28-ft) SAV tolerance threshold.

Conclusions and Recommendations

Based on the evaluation of the hydrodynamic modeling and the wave modeling results conducted in this study, it appears that segmented breakwaters should be considered further for the southern breakwater during the preconstruction and engineering design process. Substantial construction cost savings could be realized in comparison with a continuous breakwater, as well as other potential environmental benefits such as enhanced current circulation and reduced water temperature in the SAV area. Wave transmission through overtopping, transmission through the breakwaters, and diffraction need to be evaluated in more detail. Rigorous tidal current, wave transmission, and sedimentation modeling should be conducted to evaluate the impacts of various breakwater segment lengths, crest elevation, and gap widths between the segments

to establish the optimum design to reduce currents, waves, and sedimentation to tolerable levels for SAV.

A more comprehensive investigation to determine the tolerance of SAV to tidal currents, waves, and sedimentation should be conducted based on ongoing research and physical modeling similar to the modeling conducted by UMCES.

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14. ABSTRACT

James Island and Barren Island, in Maryland waters, are among the few remaining eastern shore islands in mid-Chesapeake Bay. Both islands are eroding at a rapid rate due to wave and storm action, as well as to relative sea level rise. These two islands are considered as potential candidate restoration sites as a beneficial use of clean dredged material from the Baltimore Harbor and Channels Federal Navigation Project. The island restoration project requires the construction of protective dikes to contain the dredged material. The restoration work should provide efficient protection to the existing islands, shelter sandy beaches and the shoreline from severe erosion, and improve water quality and surrounding environment for submerged aquatic vegetation. This report describes establishment and operation of a suite of numerical modes to evaluate alternative designs as an initial study for restoration and modification of James Island and Barren Island. The predicted wave climate along the mainland shore was also estimated for the alternatives. Both typical and storm hydrodynamic conditions were assessed. In support of the numerical modeling, sediment samples were taken and bathymetric surveys made in key areas, together with assemblage of relevant data sets such as aerial photographs of the shoreline, wind, and presence and vulnerability of submerged aquatic vegetation. Data from the modeling and other data sets assembled and collected were compiled on a DVD.

15. SUBJECT TERMS

Baltimore Harbor
Barren Island
Beneficial uses of dredged material
Chesapeake Bay
James Island
Maryland
Numerical modeling

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US Army Corps of Engineers

OFFICE OF THE CHIEF OF ENGINEERS
VALUE ENGINEERING STUDY TEAM

VALUE ENGINEERING STUDY SUMMARY REPORT No. CENAB 06-10

MID-CHESAPEAKE BAY ISLAND ECOSYSTEM RESTORATION

(P2 # 108897)

CHESAPEAKE BAY
DORCHESTER COUNTY, MARYLAND

Sponsored By:
U.S. Army Engineering District, Baltimore

August 2006

DOD SERVICE: USACE
VALUE ENGINEERING OFFICER: John Vogel, PE, CVS, CENAB-EN
VALUE ENGINEERING REPORT NO. CENAB 06-10

Value Engineering Study Report on

MID-CHESAPEAKE BAY ISLAND ECOSYSTEM RESTORATION

(P2 # 108897)
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August 2006

Sponsor: U.S. Army Engineering District, Baltimore
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VALUE ENGINEERING TEAM STUDY

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VALUE ENGINEERING TEAM STUDY

PROJECT DESCRIPTION AND BACKGROUND

PROJECT TITLE:	MID-CHESAPEAKE BAY ISLAND ECOSYSTEM RESTORATION PROJECT
PROJECT LOCATION:	CHESAPEAKE BAY, DORCHESTER COUNTY, MARYLAND

The Mid-Chesapeake Bay Island Ecosystem Restoration Project is a key element in the Federal Dredged Material Management Plan (DMMP) prepared by the Baltimore District. The DMMP identified a 56 million cubic yard shortfall in dredged material capacity over the next 21 years. Currently, dredged material from the Chesapeake Bay approach channels to the Port of Baltimore are either: 1) placed at open-water sites near Pooles Island, 2) placed at Hart-Miller Island, a contained upland facility, or 3) placed at Poplar Island. In 2001, open water placement of dredged material was outlawed in the State of Maryland; a mandatory closure of the Pooles Island open-water placement sites will occur by 2010. In addition, Hart-Miller Island is scheduled for closure in 2009 (the site is nearing total capacity and is now limited to dredged material from within Baltimore Harbor). Due to the elimination of open water placement options, beneficial use of dredged material is the most economical and environmentally sound option for the Maryland Port Administration.

The overarching goal of the Mid-Chesapeake Bay Islands Ecosystem Restoration Study is to restore and protect valuable but threatened Mid-Chesapeake Bay Island ecosystems through the beneficial use of dredged material. There are 105 named islands listed in the 2002 Maryland State Archives island database within the Mid-Chesapeake Bay study area.

Based on the institutional, technical, and public significance of these island resources outlined in section 2.3, the PDT developed the following objectives and constraints at the beginning of feasibility plan formulation process. They are based upon the November 2002 PMP and initial PDT meetings held in 2003.

Objectives:

1. Restore and protect marsh, aquatic, and terrestrial island habitat for fish, reptiles, amphibians, birds, and mammals.
2. Protect existing island ecosystems, including sheltered embayments to prevent further loss of island habitat.
3. Provide capacity for placement of dredged material (3.2 mcy/yr). (Federal DMMP identified a need to place 30 to 70 million cubic yards of material over a 20 year period.)
4. Increase wetlands acreage in the Chesapeake Bay watershed to assist in meeting the C2K goals.

5. Decrease local erosion and turbidity .
6. Promote conditions to establish and protect submerged aquatic vegetation.
7. Promote conditions that support oyster recolonization.

Constraints:

While additional environmental, engineering, and legal constraints were discussed, these were identified as most critical to the PDT that the final recommended plan should be judged against. Other constraints identified by the PDT were used as filtering criteria at various points in the plan formulation process, and identified as such.

1. Minimize impacts to existing fisheries nursery, feeding, and protective habitats;
2. Minimize impacts to rare, threatened, and endangered species and their habitat;
3. Minimize impacts to existing commercial fisheries;
4. Minimize establishment of invasive species to maximum extent possible;

James and Barren Islands were considered to be the best candidates for island restoration using beneficial disposal of dredged material. They were also found to be preferred by the public.

James Island is an uninhabited island, located in the Chesapeake Bay in Dorchester County, Maryland near the mouth of the Little Choptank River and about one mile north of Taylors Island. James Island was historically a peninsula, consisting of uplands, connected to Taylors Island. James and Taylors Island together made up a several thousand-acre landmass. In 1847, James Island consisted of approximately 976 ac. As shoreline erosion continued, the connection between James Island and Taylors Island breached. An 1862 nautical chart showed James Island separated by a small creek from Taylors Island. In 1942, the connection was completely breached. As shoreline erosion continued to occur, James Island became fragmented into three island remnants. In 1994, the three remnants that make up James Island totaled 92 ac. Since 1847, over 800 ac have eroded from the privately owned island, approximately 89 percent of its historical acreage. Currently, James Island consists of three eroding island

remnants totaling less than 100 ac. All three remnants have areas of high and low marsh along with upland and depressional wetlands. The interior of the island is dominated by mixed forest stands of loblolly pine. The northern and western shorelines of each remnant show the greatest erosion and there are many downed trees in the water in these areas.

Barren Island is an uninhabited island located in the Chesapeake Bay in Dorchester County, Maryland near the Honga River and immediately west of Hoopers Island. There are conflicting reports about the historical acreage of Barren Island, ranging from 700 in 1660 to as much as 839 ac in 1848. Given these discrepancies, Barren Island has lost between 74 and 78 percent of its historical acreage to erosion. Currently, Barren Island consists of three eroding island remnants totaling about 180 ac in size. The island is Federally owned and managed by the USFWS as a satellite refuge area to Blackwater NWR. Barren Island consists of several different types of high quality habitat including low and high salt marsh, tidal flats, and forested upland habitat.

The Maryland Port Administration, part of the Maryland Department of Transportation was identified as the non-Federal sponsor of the project.

VALUE ENGINEERING TEAM STUDY

PROJECT DESCRIPTION AND BACKGROUND

PROJECT TITLE: MID-CHESAPEAKE BAY ISLAND ECOSYSTEM RESTORATION PROJECT

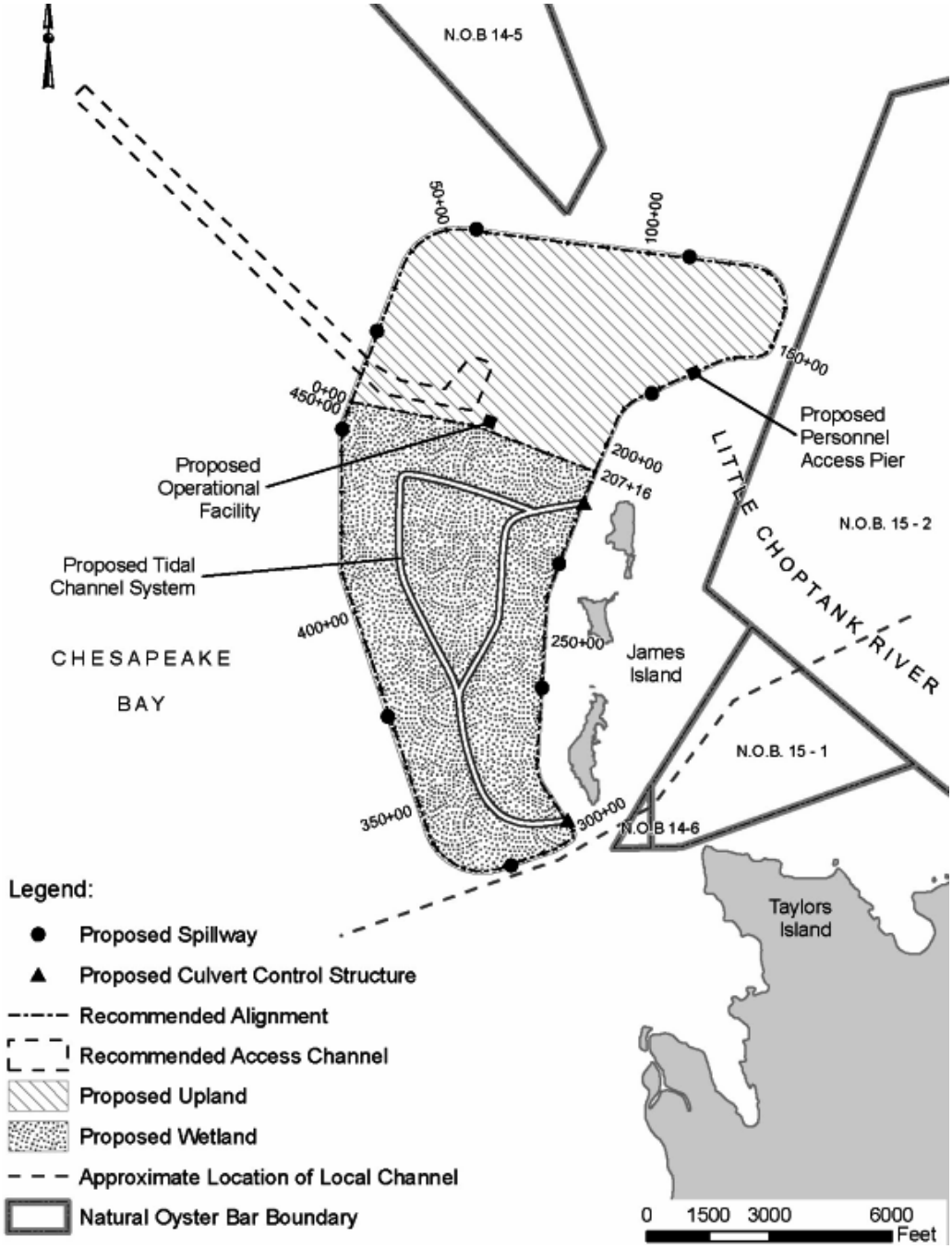
PROJECT LOCATION: CHESAPEAKE BAY, DORCHESTER COUNTY, MARYLAND

VICINITY MAP

PROJECT TITLE: MID-CHESAPEAKE BAY ISLAND ECOSYSTEM RESTORATION PROJECT

PROJECT LOCATION: CHESAPEAKE BAY, DORCHESTER COUNTY, MARYLAND

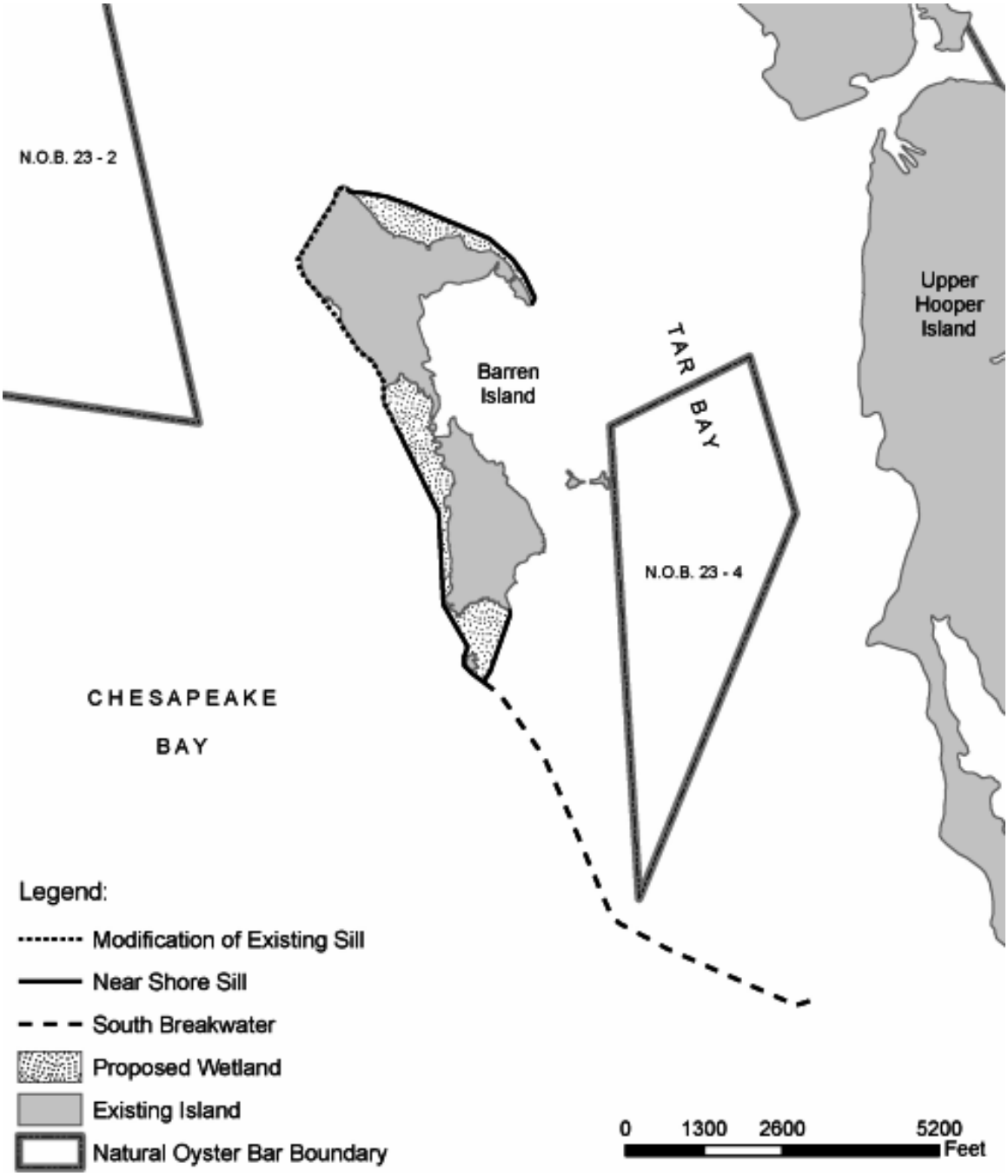
RECOMMENDED PLAN OF JAMES ISLAND



PROJECT TITLE: MID-CHESAPEAKE BAY ISLAND ECOSYSTEM RESTORATION PROJECT

PROJECT LOCATION: CHESAPEAKE BAY, DORCHESTER COUNTY, MARYLAND

RECOMMENDED PLAN OF BARREN ISLAND



VALUE ENGINEERING TEAM STUDY
EXECUTIVE SUMMARY

The Value Engineering Study on the Mid-Chesapeake Bay Island Ecosystem Restoration Project was conducted at the Baltimore District office on 17-20 July 2006. The study was based on the draft Feasibility Report dated 31 January 2006 prepared by the Baltimore District of the US Army Corps of Engineers. The VE study was facilitated by OVEST, with participation by members of the Baltimore District, Maryland Port Administration (MPA), Maryland Environmental Service (MES), MPA Citizens Advisory Committee, Maryland Department of Natural Resources (MDNR), Moffatt & Nichol, and the National Marine Fisheries Service (NOAA-NMFS). A contact list of participants is included as Appendix A.

Value Engineering (VE) is a process used to study the functions a project is to achieve. VE takes a critical look at how these functions are proposed to be met and it identifies alternative ways to achieve the equivalent function while increasing the value and the benefit ratio of the project. In the end, it is hoped that the project will realize a reduction in cost, but increased value is the focus of the process, rather than simply reducing cost. The project was studied using the US Army Corps of Engineers standard Value Engineering (VE) methodology, consisting of five phases:

Information Phase: The Team studied drawings, descriptions of project work, and conclusions from previous interagency efforts to fully understand the work to be performed and the functions to be achieved. A Function Analysis System Technique (FAST) Diagram was developed by participants to better appreciate the relationship of project features to their intent (see Appendix C).

Speculation Phase: The Team speculated by conducting a brainstorming session to generate ideas for alternative designs or variations to the recommended plan. All team members contributed ideas and critical analysis of the ideas was discouraged (see Appendix B).

Analysis Phase: Evaluation, testing and critical analysis of all ideas generated during speculation was performed to determine potential for savings and possibilities for risk. Ideas were ranked by priority for development. Ideas that did not survive critical analysis were not developed.

Development Phase: The priority ideas were developed into written proposals by VE team members during an intensive technical development session. Proposal descriptions, along with sketches, technical support documentation, and cost estimates were prepared to support implementation of ideas. Additional VE Team Comments were included for items of interest that were not developed as proposals, and these comments follow the study proposals.

Presentation Phase: Presentation is a two-step process. First, the VE Study Report will be distributed for review to all appropriate project supporters and decision-makers. Review comments will be coordinated for decision on any proposals recommended by the study report. Final coordination will include a formal Presentation conference for recommendation of actions to be taken on specific VE proposals.

VALUE ENGINEERING TEAM STUDY

SUMMARY OF RECOMMENDATIONS/ACTION

PROPOSAL NUMBER	DESCRIPTION	POTENTIAL SAVINGS	RECOMMENDED ACTION
1	Optimize Dike Heights And Stone Size for James Island Perimeter Dikes	$4,275,000	
2	Replace or Reduce Toe Underlayer Stone Quantity with GeoTubes filled with Dredged Material	$6,266,000	
3	Construct Segmented Breakwaters on Northeast Side of Barren Island with Periodic Renourishment.	$416,000	
4	Develop Beach on East Side of James Island in lieu of Rock, and Create Nesting Areas for Terrapins	$5,205,000	
5	Provide Designated Area for Dewatering Dredged Material in lieu of Topsoil, and Create Topsoil On Site		
5A	Farm Dredged material on Site, vs. Treating Existing Material in Place with Lime	- $3,172,000	
5B	Farm Dredged material on Site, vs. Importing Topsoil	$15,050,000	
6	Drill Wells on Both Islands to Support Upland Vegetation	- $700,000	
7	Provide Undulations, Pockets & Small Coves on Lee Side of James Island	- $2,443,000	
8	Reduce the 23’ Wide Crushed Stone Roadway to 13’ Wide with Pull Over/Passing Areas Constructed Every 1000 Feet.	$825,000	
9	Reduce the 20’ Wide Dike Section at Elevation 25 To 10’ Wide in the Areas Where the Crushed Stone Roadways Are Located Around the Upland Perimeter and the Separator Dikes.	$3,340,000	

VALUE ENGINEERING PROPOSAL

PROPOSAL NO:	1 (Spec List Items 2 & 3)	PAGE NO: 1 OF 9
DESCRIPTION:	Optimize Dike Heights And Stone Size for James Island Perimeter Dikes	

ORIGINAL DESIGN:

The original design calls for two typical cross-sections to protect the perimeter dikes (see sketch 1 for plan view). The southern, western and northern dike would be protected by armor and toe stone with sizes of 2,500 and 3,500 pounds, respectively, with an unarmored dike crest height of 10 ft MLLW (sketch 2). The sheltered east side of the perimeter dike would consist of 500 lb. armor and 1,000 pound toe stone, with an unarmored dike height of +8 ft MLLW (sketch 3). All perimeter dike slopes would be 3H:1V, and toe dike slopes would be 2H:1V. The attached sketches 2 and 3 show the armor, underlayer, bedding and geotextile requirements for each of these two cross-sections.

PROPOSED DESIGN:

The proposed design calls for a revetment structure along the southern, western and northern dikes with an armored crest that is lower in elevation. Also the sizes of the armor and toe stones are less than the original design. For the perimeter dike, two sections are recommended. Along the north, west, and south perimeter dikes, a structure with an armored crest at + 6 ft MLLW, armor stone of 2000 lbs. and toe stone of 1220 lbs. recommended (sketch 4). Along the east perimeter dike a structure with an unarmored crest at +7 ft MLLW, armor stone of 350 lbs, and toe stone of 1000 lbs is recommended (sketch 5).

ADVANTAGES:

- Generally the least cost alternative when balancing between first costs and maintenance costs
- The recommended dike protection will likely prevent breaches from occurring even if the design storm is exceeded.
- This section will be impacted less due to the effects of sea level rise.
- More reliable design
- Would require less sand for dike construction

DISADVANTAGES:

- Roadway must be built and maintained on top of crest armor.
- First costs may be higher
- Provides less protection for future sea level rise

JUSTIFICATION:

The proposed design is based on an analysis that includes recently updated methods for estimating wave runup, overtopping and calculation of progressive structure damage for design, and provides consideration for potential future storm and damage scenarios. The original design was based on a preliminary analysis of historical storm events that have occurred since 1851 with no consideration given to possible future storm sequences. Additionally, the differences in performance and costs between an unarmored crested structure versus a structure with an armored crest were not completed. The original design was used as a basis to provide project cost estimates, but further analysis indicated that the proposed design is optimal in terms of total costs, and is more reliable because it is less likely to breach in the event that the design storm parameters are exceeded.

Total costs curves at three reporting stations around the island (sketch 6) as reported in the ERDC Technical Report TR-05-12 titled “Life-Cycle Analysis of Mid Bay and Poplar Island Projects, Chesapeake Bay, Maryland”, were used to perform total life-cycle cost comparisons between the two designs. Stations 5, 10, and 13 were used for the comparisons. The cost curves for Station 5 were applied to Stations 1 through 9. The cost curves for Station 10 and 13 were extrapolated and applied to Stations 10, 11, 12, 13, and the remaining east side of the proposed island. Based on this preliminary analysis, the proposed design to protect the exterior perimeter dike has a total life-cycle cost approximately $4,275,000 less than the original design. Additional savings due to reduced stone sizes and crest height are anticipated, however sufficient data was not available to account for these costs at this time.

Preliminary analysis shows that the proposed design would add value to the overall project and result in cost savings over its life. It is recommended that more detailed analysis be performed for the remaining stations around the perimeter of the island and for the embayment structures to complete the optimization, and the optimized design be incorporated during the final design phase.

The VE team asked for an approximate breakdown of initial and maintenance costs during VE meeting in July. In response to this question, Dr. Jeff Melby was able to provide a breakdown of initial and maintenance costs for the historical storm simulations. Based upon this information, the repair costs for the original design were approximately 15% of the total life cycle costs for stations along the western side of the island, while there were no repair costs along the remaining north, south, and east side of the islands. Additionally, there were no repair costs associated with the proposed design for any stations.

See comment below from State of Maryland.

Drawing No. 1 - Project Plan View

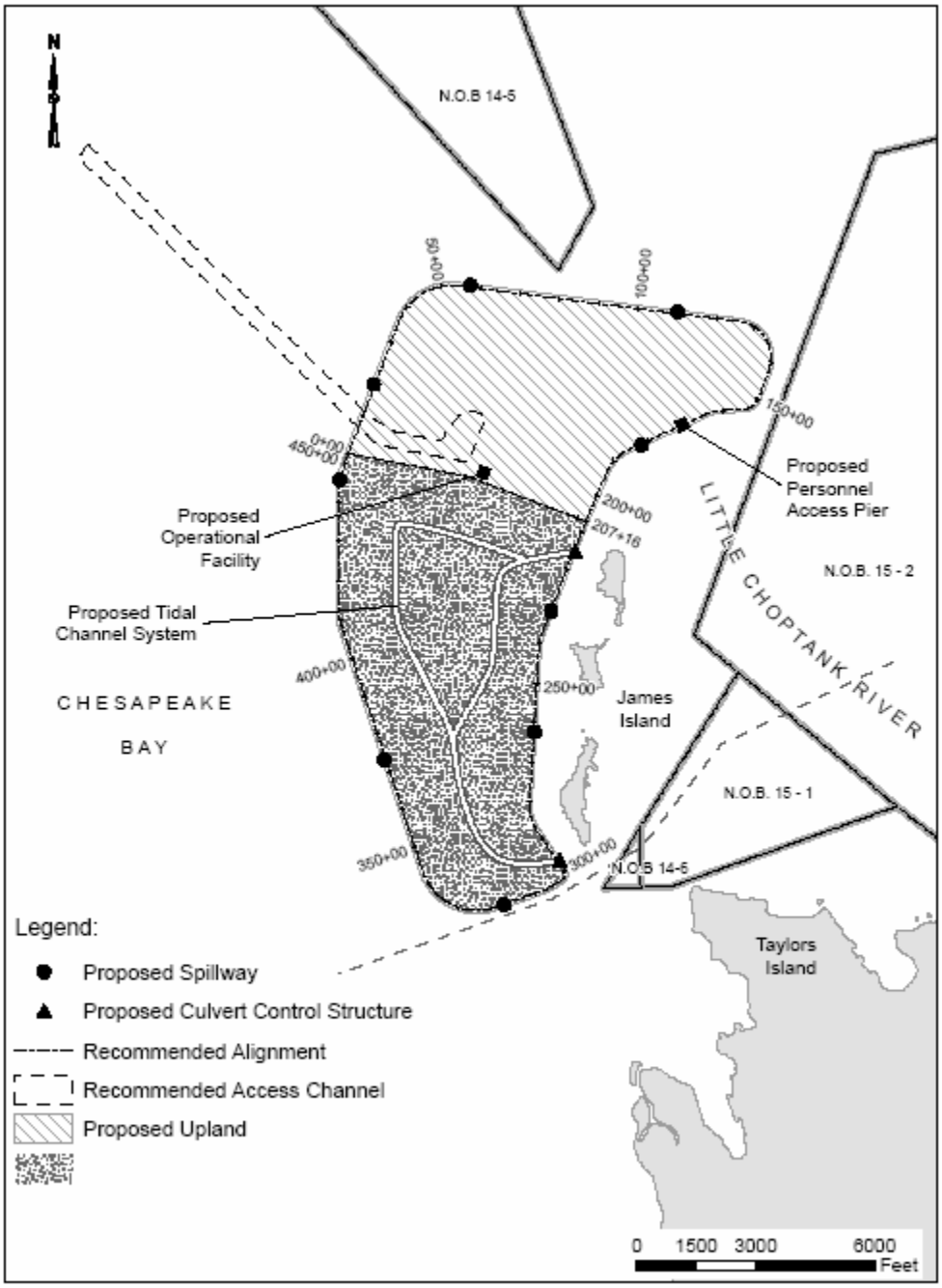
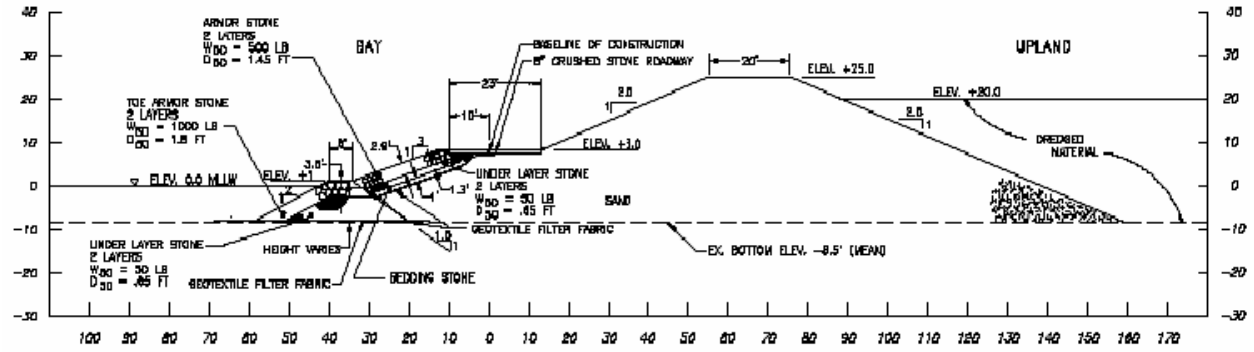
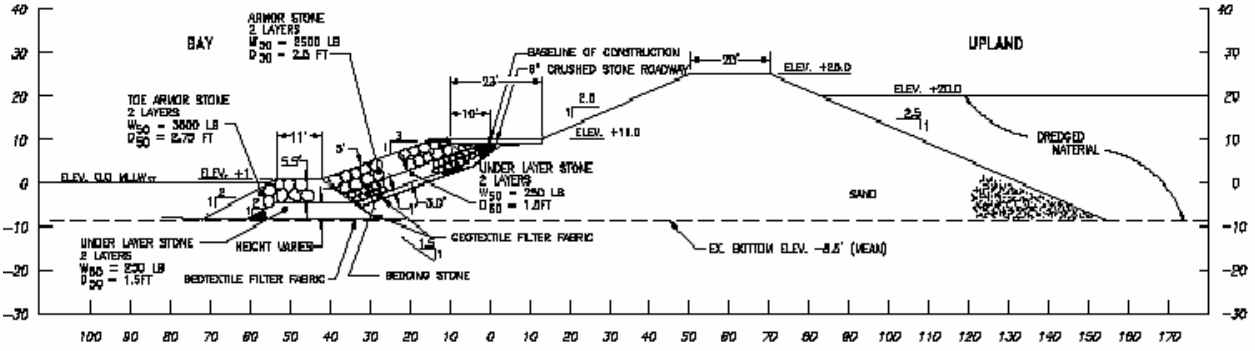


Figure 10. James Island Recommended Plan.

Drawing No. 2
Typical Western, Northern & Southern Perimeter Dike Section (approx 27500 LF)
REACH 1 -- Original Design

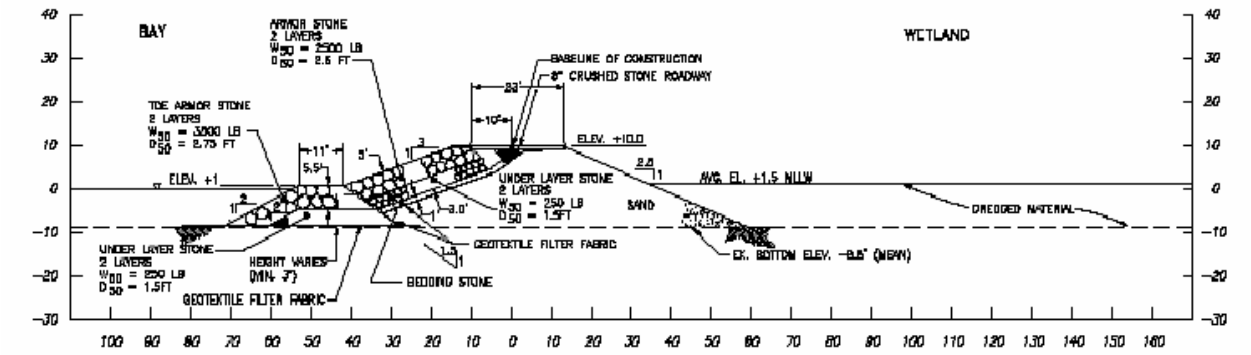


TYPICAL UPLAND PERIMETER DIKE SECTION-STA 125+00 TO STA 207+16

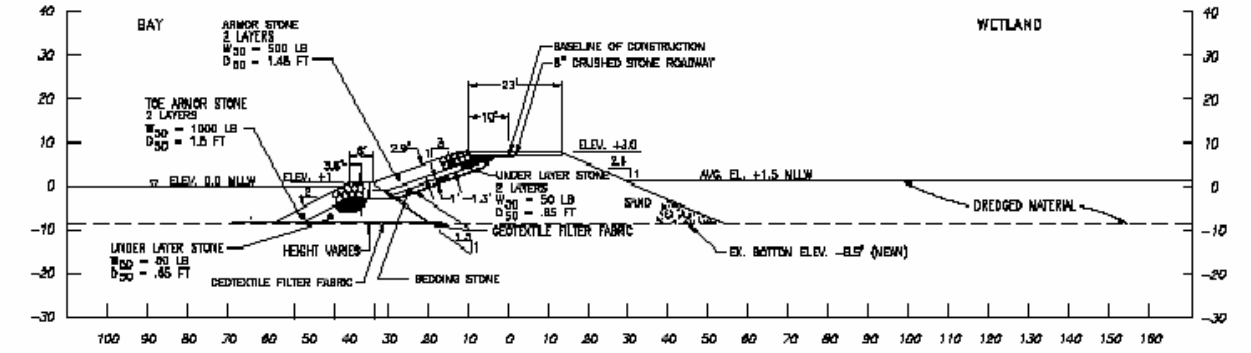


TYPICAL UPLAND PERIMETER DIKE SECTION-STA 0+00 TO STA 125+00

Drawing No. 3
Typical East Dike Section (approx 17,500 LF)
REACH 2 -- Original Design

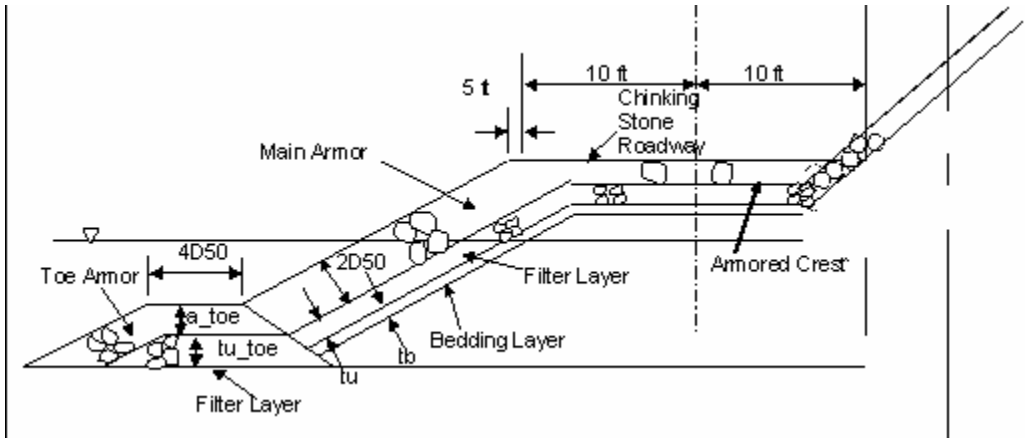


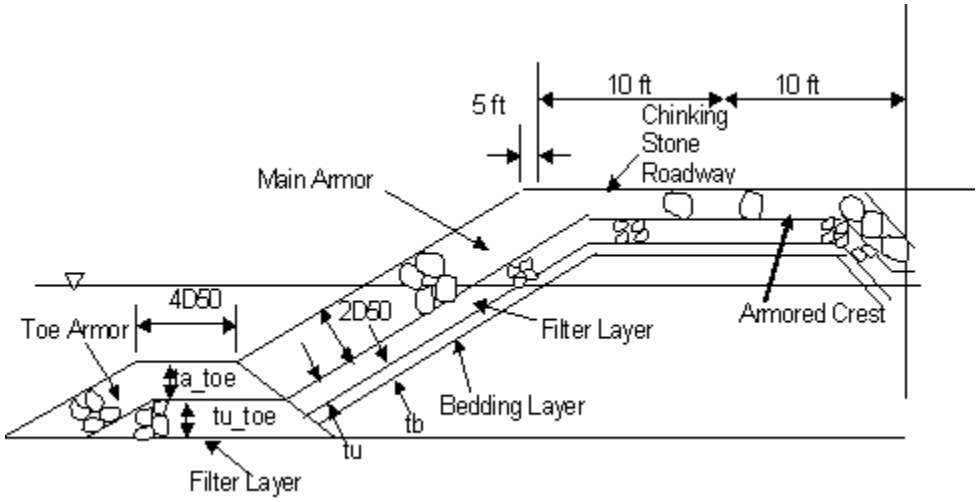
TYPICAL WETLAND PERIMETER DIKE SECTION-STA 300+00 TO STA 452+35



TYPICAL WETLAND PERIMETER DIKE SECTION-STA 202+18 TO STA 300+00

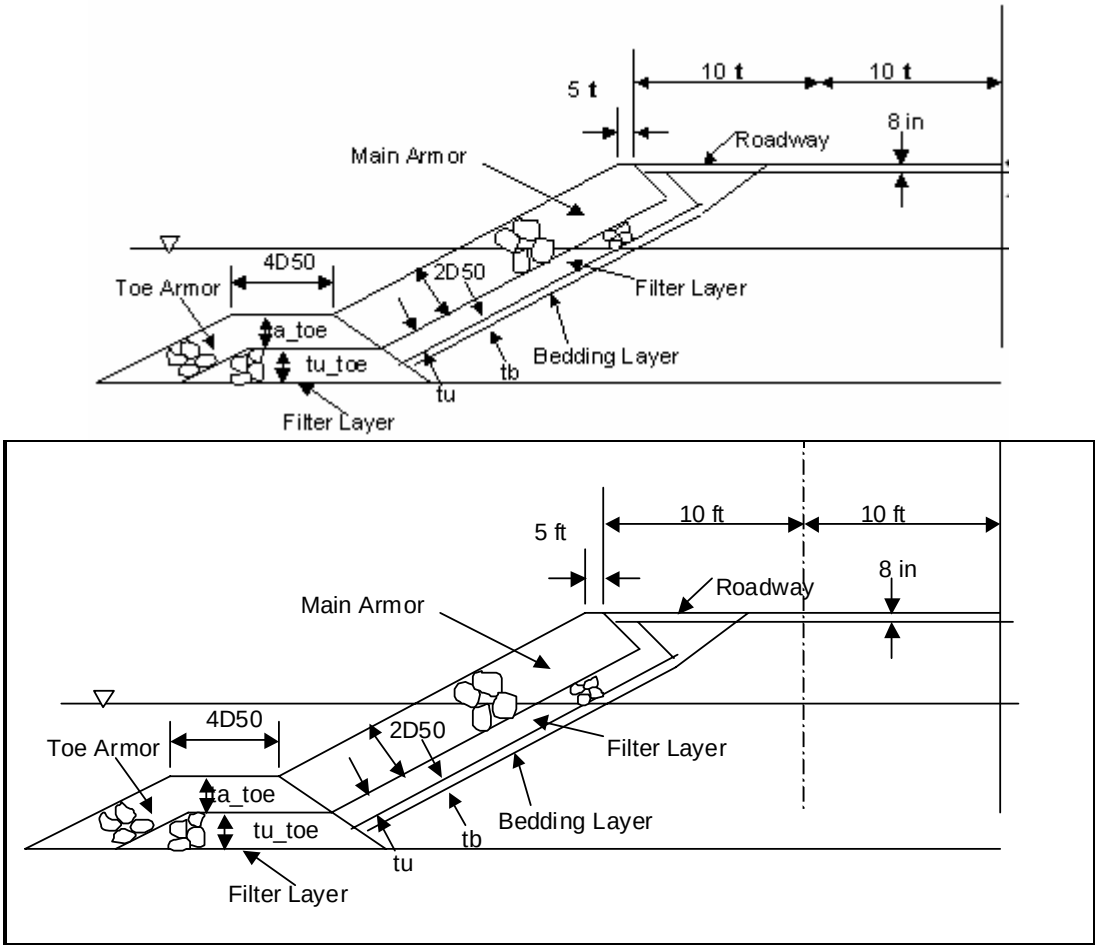
Drawing No. 4
Typical Proposed Section along north, west south dikes – (approx 27500 feet)
SECTION 1 - Armored crest at + 6 ft MLLW





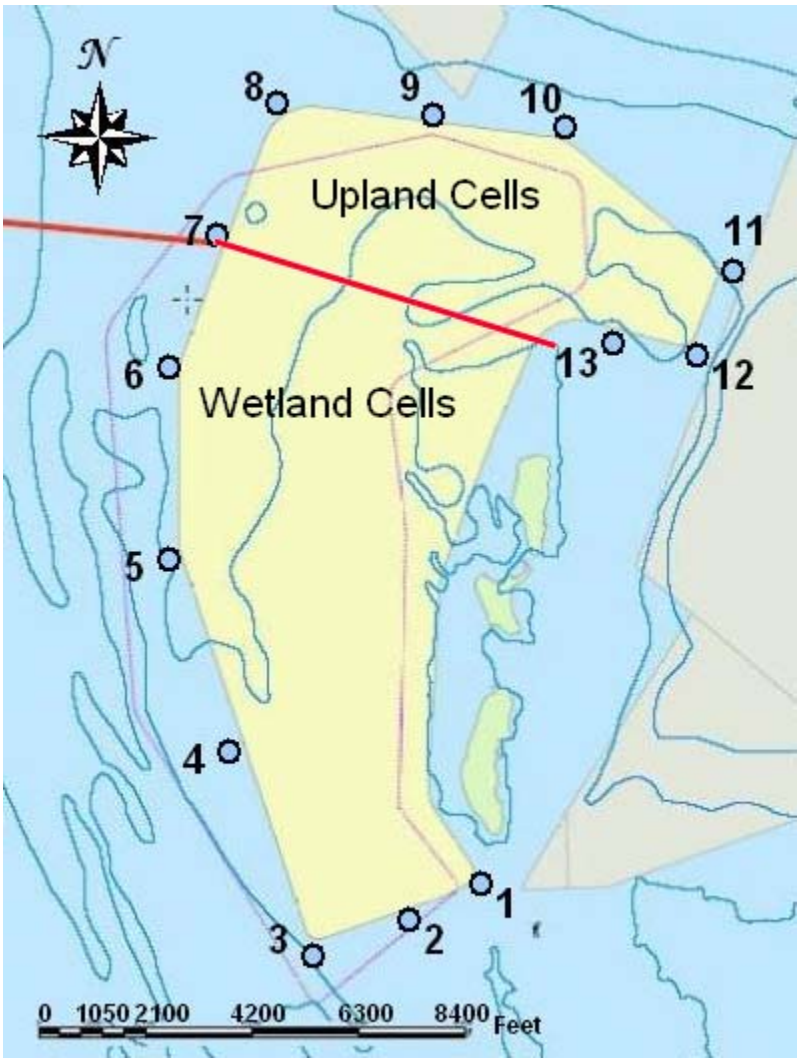
Main Armor W50 = 2000 lbs
Main Armor D50 = 2.3 feet
Armor Filter W50 = 200 lbs
Armor Filter D50 = 1.1 feet
Bedding Stone Thickness = 1 foot
Crest Height = 6 feet armored
Toe Armor = 1220 lbs
Toe Filter = 122 lbs
Upland Armor = 425 lb to +10 ft MLLW (Sta. 7)
Upland Armor = 80 lbs to +7 ft MLLW (Sta 8 & 9)

Drawing No. 5
Typical Proposed Section along east dike – (approx 17500 feet)
SECTION 2 - Unarmored Crest at +7 ft MLLW



Main Armor W50 = 350 lbs
Main Armor D50 = 1.3 feet
Armor Filter W50 = 35 lbs
Armor Filter D50 = 0.6 feet
Bedding Stone Thickness = 1 foot
Crest Height = 7 feet unarmored
Toe Armor = 240 lbs
Toe Filter = 24 lbs

Drawing No. 6 – Station Locations for Cost Comparisons



COST ESTIMATE WORKSHEET				
Speculation Item # 2 & 3				
DELETIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Reach 1 - North, West & South Dike	LF	27,500	$1,100.00	$30,250,000
Reach 2 - East Dike	LF	17,500	$1,150.00	$20,125,000
		Total Deletions		$50,375,000
ADDITIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
				$0
Reach 1 - North, West & South Dike	LF	27,500	$1,040.00	$28,600,000
Reach 2 - East Dike	LF	17,500	$1,000.00	$17,500,000
				$0
				$0
				$0
				$0
				$0
				$0
		Total Additions		$46,100,000
		Net Cost Decrease		$4,275,000
Source of cost data: Costs are based on lifecycle costs (initial and maintenance) from the ERDC technical report "Life-Cycle Analysis of Mid Bay and Poplar Island Projects, Chesapeake Bay, Maryland" dated September 2005.				

Comment from State of Maryland:
Regarding Stone quantity reductions: need to ensure that adequate life-cycle type evaluation has been made of stone needs to avoid artificially lower initial construction costs vs higher State maintenance costs later.

VALUE ENGINEERING PROPOSAL

PROPOSAL NO:	2 (Spec List Item 11)	PAGE NO: 1 OF 4
DESCRIPTION:	Replace or Reduce Toe Underlayer Stone Quantity with GeoTubes filled with Dredged Material	

ORIGINAL DESIGN:

Existing section shows using 50 lb to 250 lb underlayer stone for the toe core material.

PROPOSED DESIGN:

The new section will utilize GeoTubes filled with dredged materials to replace this volume of stone core. Depending on the phasing of material placement, it may be more cost-effective and more manageable to use GeoContainers rather than tubes.

GeoContainers or GeoBags are specific sized geosynthetic containers which are designed to contain materials such as dredged materials or HTRW. Using consistently sized containers may be easier for construction managers to define specific procedures for workers.

ADVANTAGES:

- Reduces the quantity of stone materials required for construction.
- Provides a semi-impervious core which will reduce the losses of fine grained materials through the core during interior construction phases.
- Uses locally obtained fill materials allowing for an earlier start.
- Can greatly reduce the cost and period of performance.

DISADVANTAGES:

- Difficult to construct requiring specialized contractors with specialized techniques.
- Designers need to verify with manufacturer they are using correct specifications for application, i.e., thickness, resistance to saltwater
- Possible loss of fill materials if damaged during armor stone placement.

JUSTIFICATION:

Reducing the quantity of rock required will reduce initial construction cost. There is a possible opportunity to reduce construction time if long tubes are utilized.

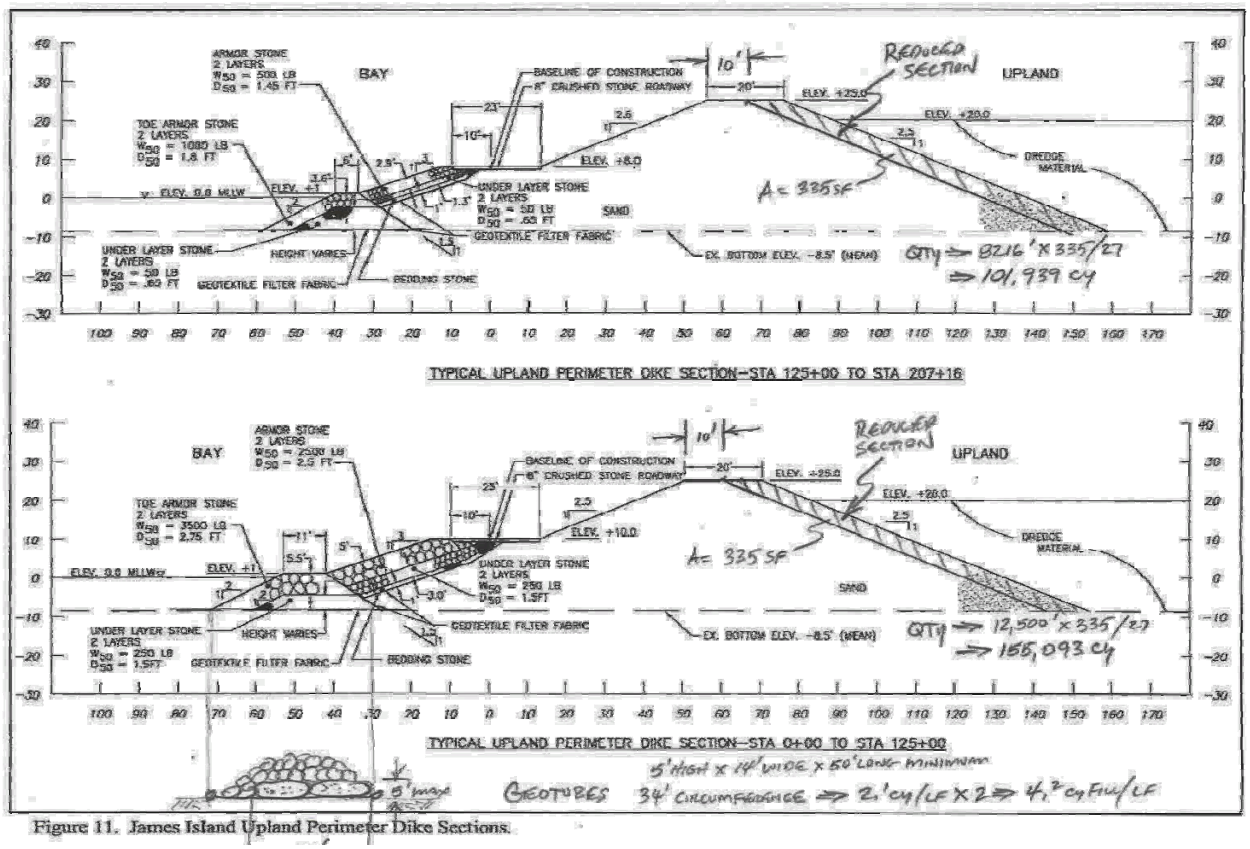


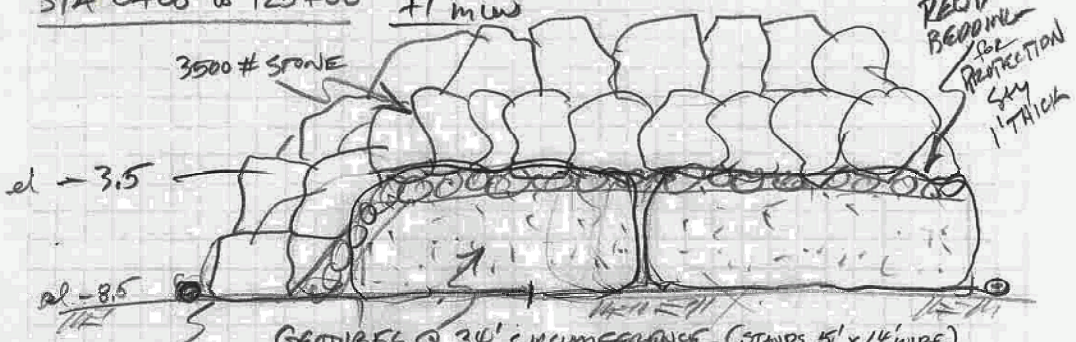
Figure 11. James Island Upland Perimeter Dike Sections.

U. S. ARMY ENGINEER DISTRICT, CHARLESTON
CORPS OF ENGINEERS
CHARLESTON, SOUTH CAROLINA

Page 1

Subject: JAMES ISLAND
Computation VE PROPOSAL # 11 – REPLACE CORE STONE W/ GEOTUBE No.
Computed by HENDERSON Checked by Date 20 JULY 2006

STA 0+00 to 125+00 +1'm LW



GEOTUBES @ 34' CIRCUMFERENCE (STANDS 5' x 14' WIDE)
2.1 CY/LF FILL x 2 ⇒ 4.2 CY DISPLACES 6.3 TONS STONE
ASSUME 1 CY ⇒ 1.5 TONS of STONE

- CORE STONE ⇒ COST IN PLACE ⇒ $60/TON = $90/CY
- GEOTUBE ⇒ GC-1000 POLYPROPYLENE $18.18/CY CONTAINMENT
  + PLACEMENT AND FILLING @ SAY $37.50/CY CONTAINM
  + BEDDING $2,524,358/181,617 ⇒ SAY $13.90/CY

SAVES $20/CY OR $30/TN

$69.78
SAY $70.00/CY

TOTAL TONS CORE STONE 320,550 TONS / 1.5 TON/CY ⇒ 213,667 CY
− 32,050 CY
181,617 CY

BEDDING LAYER ⇒ SAY 1' THICK OR SAY APPROX 15% OF CORE VOLUME
⇒ 32,050 CY @ 1.5 TONS/CY ⇒ 48,075 TONS

SAC FORM 255 1 MAR 85

COST ESTIMATE WORKSHEET				
Speculation Item 11				
Use Geotubes or Geocontainers in lieu of stone for core of toe dikes.				
DELETIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Toe Underlayer Stone 0+00 to 125+00	TON	129,600	$60.00	$7,776,000
Toe Underlayer Stone 125+00 to 207+16	TON	58,500	$60.00	$3,510,000
Toe Underlayer Stone 207+16 to 300+00	TON	43,500	$60.00	$2,610,000
Toe Underlayer Stone 300+00 to 452+35	TON	88,950	$60.00	$5,337,000
				$0
		320,550		$0
				$0
				$0
				$0
		Total Deletions		$19,233,000
ADDITIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
GeoTubes - 34' circumference (mat'l)	CY	181,617	$20.00	$3,632,340
Fill GeoTubes with material in-place	CY	181,617	$37.50	$6,810,638
				$0
Bedding Stone (assume 15% core volume)	TON	48,083	$52.50	$2,524,358
				$0
				$0
				$0
				$0
				$0
		Total Additions		$12,967,335
		Net Cost Decrease		$6,265,665
Source of Cost Data: Poplar Island Phase II escalated 25% + add'l haul				

VALUE ENGINEERING PROPOSAL

PROPOSAL NO:	3 (Spec List Item 20)	PAGE NO: 1 OF 5
DESCRIPTION:	Construct Segmented Breakwaters on Northeast Side of Barren Island with Periodic Renourishment.	

ORIGINAL DESIGN:

The original design calls for the construction of 3,900 ft of continuous near shore sill (breakwater). A wetland was to be constructed behind the protection of the near shore sill (breakwater) using future dredged material.

PROPOSED DESIGN:

The proposed design calls for the construction of 3,900 ft of **segmented** near shore sill (breakwater) protection. The segment lengths and gaps between each segment can be determined in the future. For this proposal, it was assumed that each breakwater segment would be 100 feet long with 50 foot gaps between each segment. The wetland could still be constructed using future dredged material.

ADVANTAGES:

- This proposal would use less armor stone, intermediate stone, core stone, and geotextile.
- This proposal would add interest to the breakwater (by having breaks in the bank line), and would be preferred by fishery resources. Re-nourishment will be accomplished by maintenance dredging.
- This proposal would increase the water connection between the bay and the wetlands.

DISADVANTAGES:

- In the areas where the gaps are located there will probably be storm/tidal erosion. However, no additional maintenance will be required to keep the dredged material within the wetland. Allowing the sand to migrate into the bay is desired.
- A segmented near shore sill (breakwater) may be more difficult to construct than a continuous near shore sill (breakwater). Armoring of the segments will be required.
- Note that while it is advised to construct segmented breakwaters on the Northeast side of Barren Island, it would be ill-advised to use segmented breakwaters on the West side of Barren Island. The water and current are too rough for segmented breakwaters to be feasible.

JUSTIFICATION:

This proposal should be pursued because a significant cost saving could result by segmenting the near shore sill (breakwater). For every foot of near shore sill (breakwater) that is not constructed, $539.97 in cost savings can be realized. This figure does not include any contingencies or escalation. Aside from the cost savings, there are also fishery resource benefits and benefits from connecting the bay to the wetland on the northern shore of Barren Island.

Comment from State of Maryland:
Would MDE be concerned about filling/ constructing wetlands behind segmented breakwaters? If so, it should be noted that permitting concerns were considered, and/or an explanation about construction precautions (having a whole dike and then segmenting it into a breakwater after filling activities) may be helpful.

CURRENT DESIGN

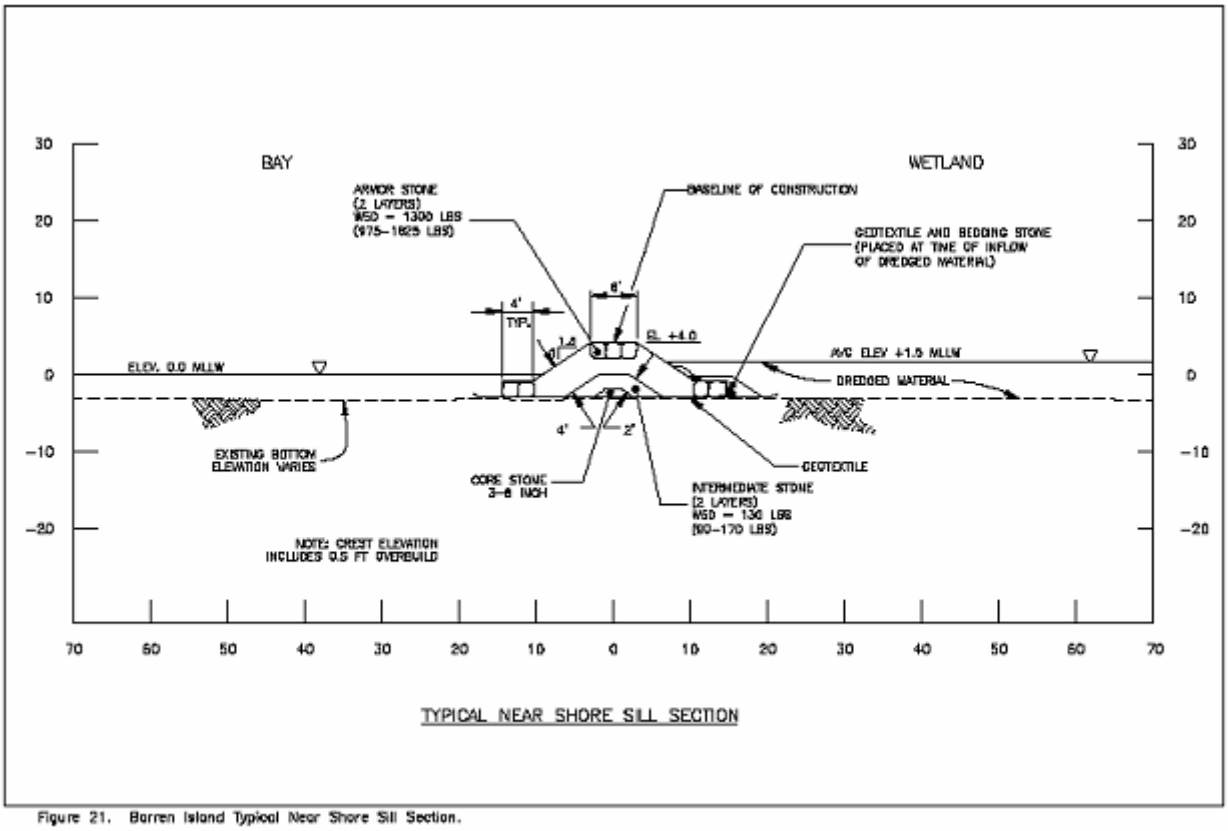
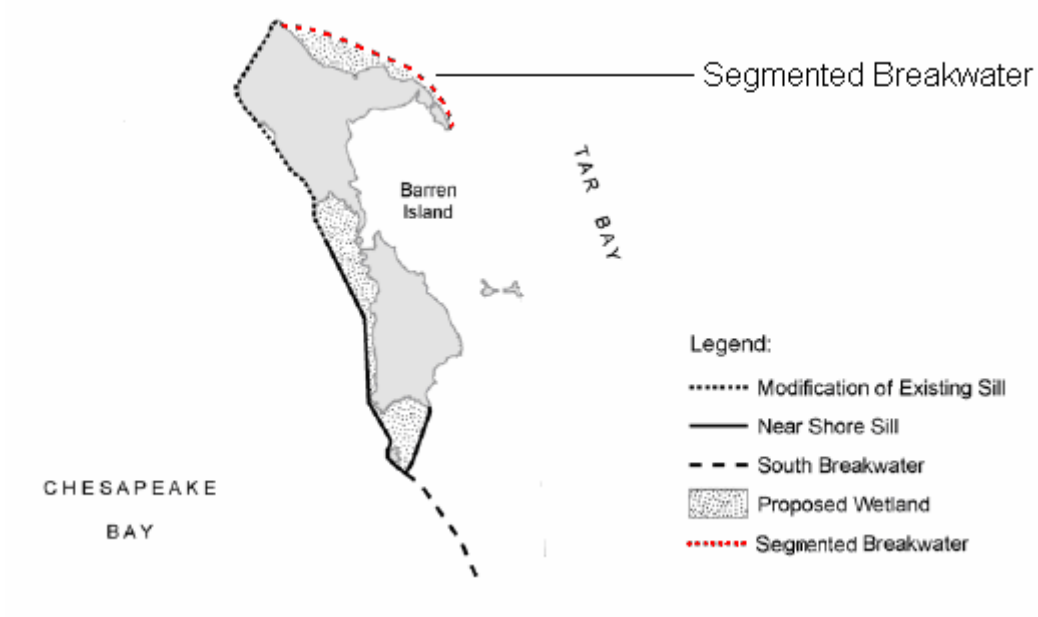
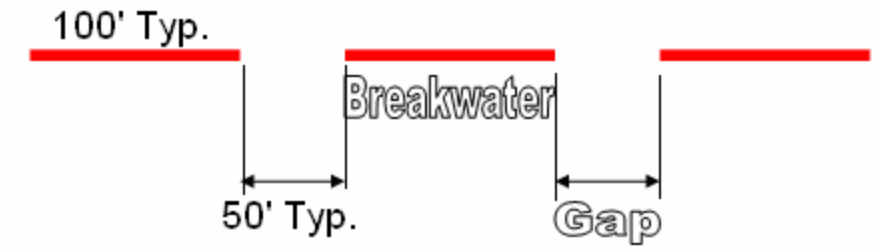


Figure 21. Barren Island Typical Near Shore Sill Section.

PROPOSED DESIGN





COST ESTIMATE WORKSHEET				
Speculation Item # 20				
DELETIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Near-Shore Sill including:				
Armor stone	LF	3,900	$458.63	$1,788,645
Intermediate stone	LF	3,900	$46.15	$179,975
Core stone	LF	3,900	$21.21	$82,704
Geotextile	LF	3,900	$13.99	$54,566
				$0
				$0
				$0
				$0
		Total Deletions		$2,105,890
ADDITIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Near-Shore Sill including:				
Armor stone	LF	2,600	$458.63	$1,192,430
Intermediate stone	LF	2,600	$46.15	$119,983
Core stone	LF	2,600	$21.21	$55,136
Geotextile	LF	2,600	$13.99	$36,378
Armor stone for the tips of each segment	LF	624	$458.63	$286,185
				$0
				$0
				$0
		Total Additions		$1,690,112
		Net Cost Decrease		$415,778
Source of Cost Data: Barren Island Draft Baseline Cost Estimate. These figures do not include contingencies or escalation.				

VALUE ENGINEERING PROPOSAL

PROPOSAL NO:	4 (Spec List Items 21 & 27)	PAGE NO: 1 OF 5
DESCRIPTION:	Develop Beach on East Side of James Island in lieu of Rock, and Create Nesting Areas for Terrapins	

ORIGINAL DESIGN:

The original design calls for the dikes on the east side to be armored with 500 lb armor stone and 1000 lb toe armor stone.

PROPOSED DESIGN:

The proposed design is to build a beach section only (without armor stone) between the two tidal guts, with terminal groins at each end to protect the inlet and hold the beach in place. With the beach in place it would become available for terrapins as nesting habitat.

ADVANTAGES:

- Beach habitat provides an additional type of habitat to the project for both shore birds and terrapins.
- Reduced armor stone quantity for the project.
- Tidal inlets within beach area can be stabilized with vegetation.
- Creates more variety in project
- Sand beach more conducive to creating irregular shoreline.
- Cost is reduced.

DISADVANTAGES:

- Overall, sand is more susceptible to erosion, and the need for additional rock structures to protect the beach may be required.

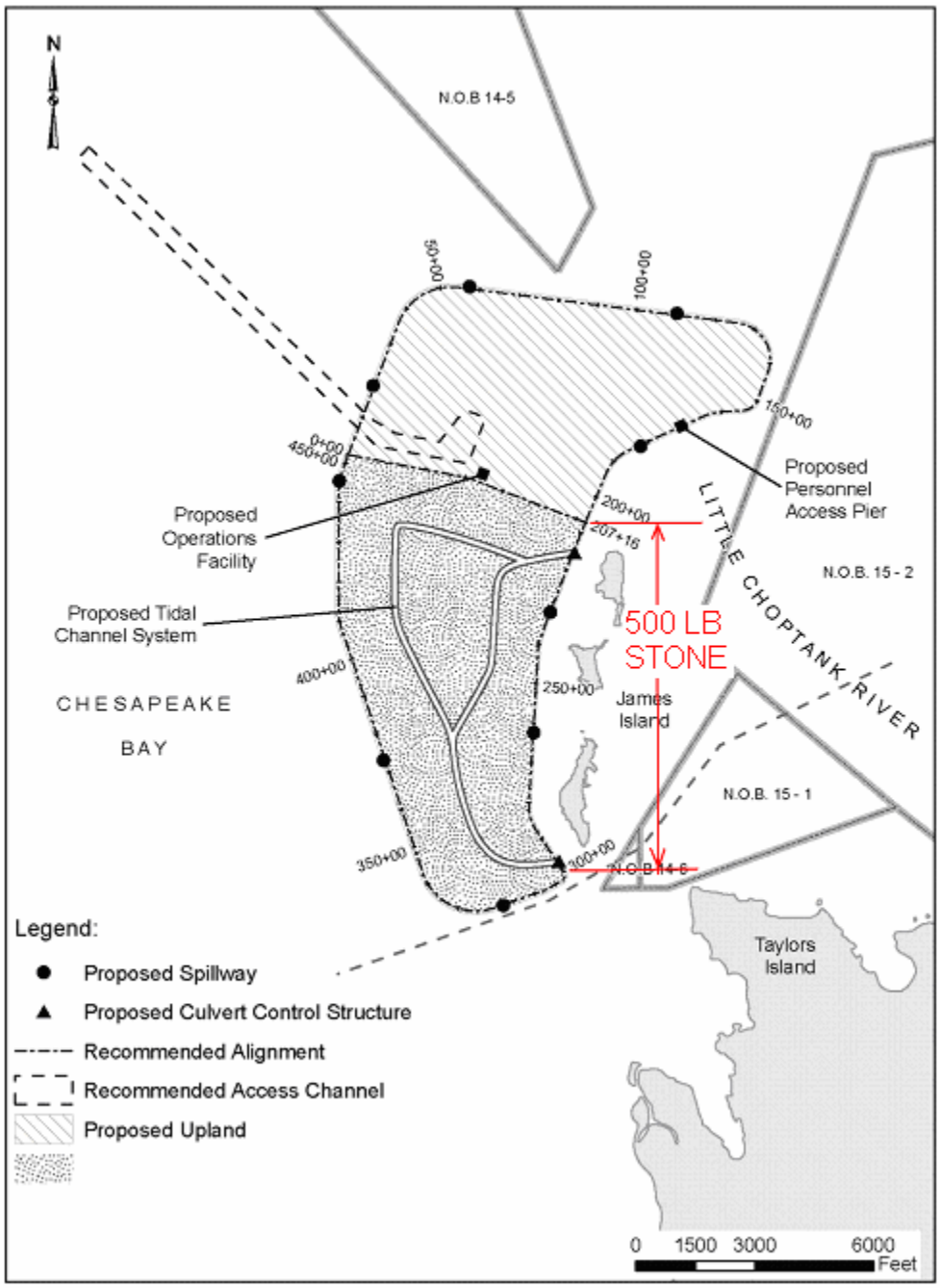
JUSTIFICATION:

The east side of the island is exposed to shorter fetch distances over shallower waters, than from the north, west and south. Waves are smaller with less erosive energy. The existing James Island remnants provide protection to the east side of the proposed James Island project. This proposal takes advantage of this lower energy to improve habitat value in addition to reducing costs by reducing stone quantity.

Comment from State of Maryland:
Should the "Disadvantages" or "Justification" section account for the smaller size or absence of the remnant island by the time the project is constructed? The justification section cites the islands as existing protection for this proposal--but the current degree of protection is not guaranteed for the future due to the ongoing erosion.

Drawing No. 1

ORIGINAL JAMES ISLAND PLAN



Drawing No. 2

PROPOSED JAMES ISLAND PLAN

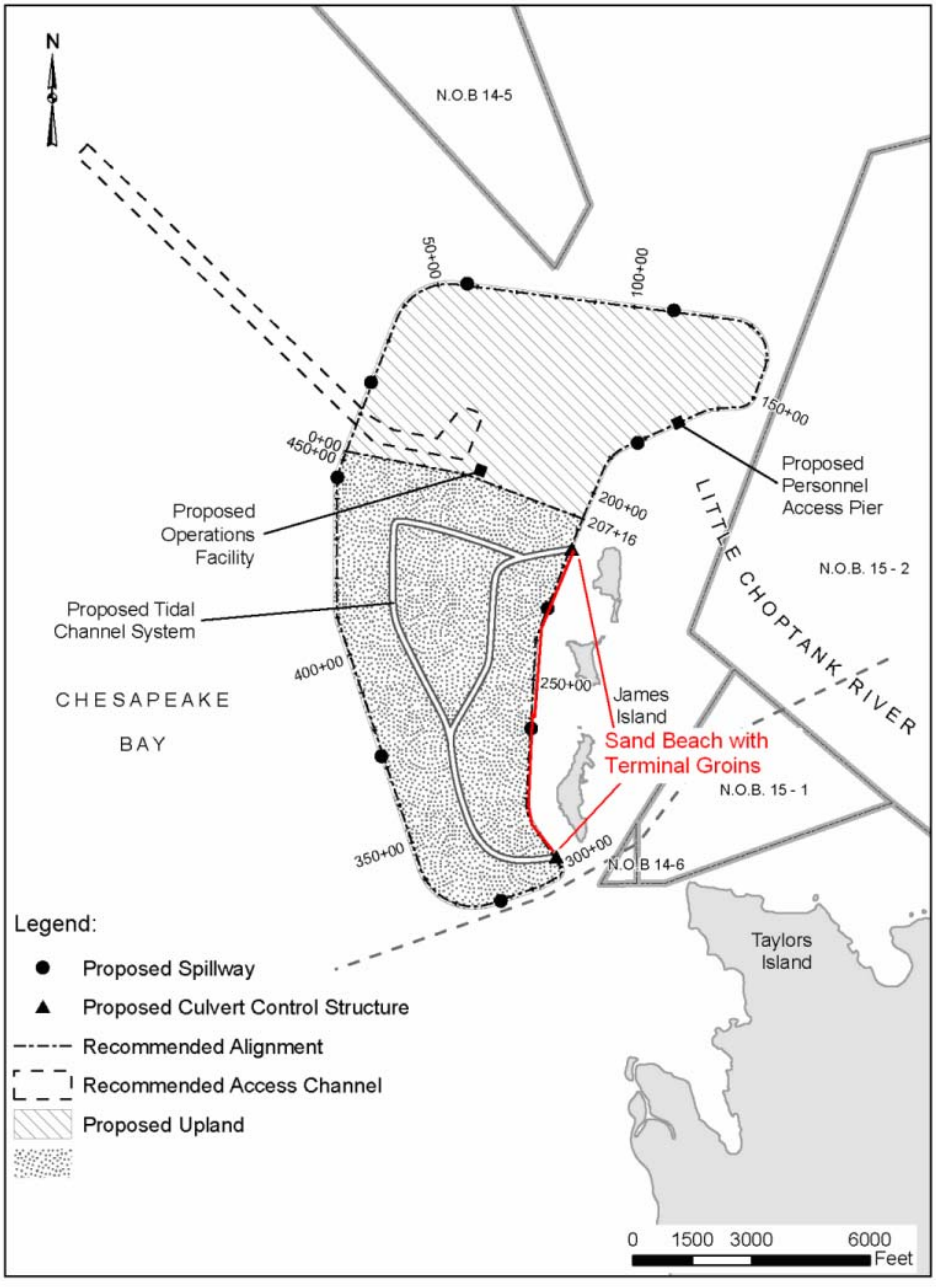
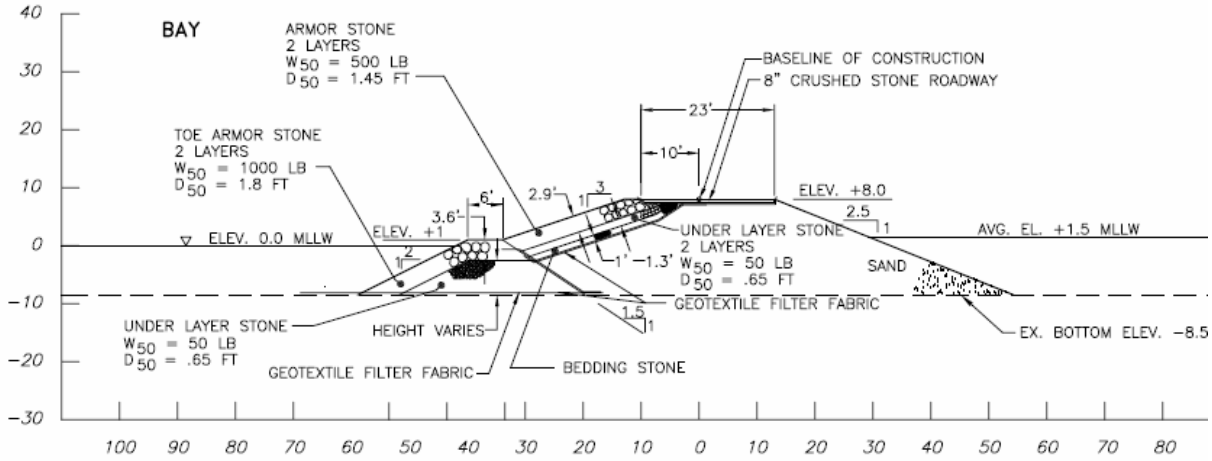


Figure 10. James Island Recommended Plan

Drawing No. 3

EXISTING DIKE SECTION

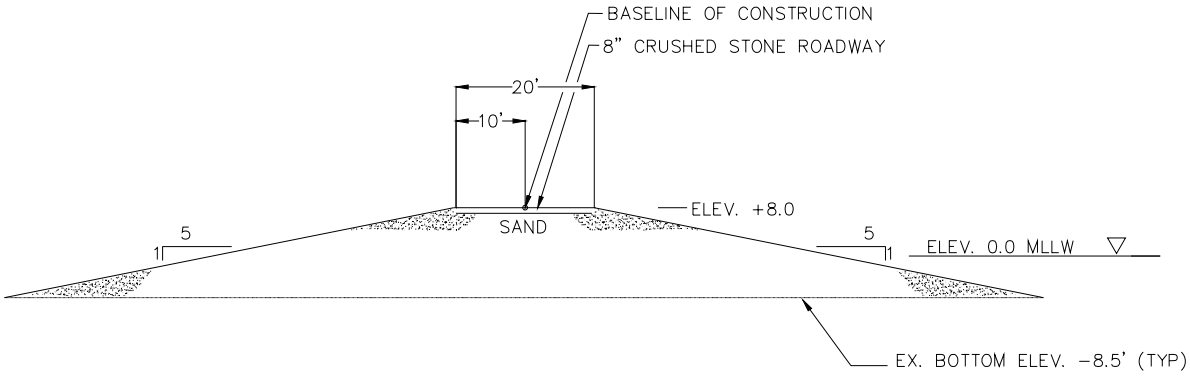


TYPICAL WETLAND PERIMETER DIKE SECTION–STA 207+16 TO STA 300+00

Figure 12. James Island Typical Wetland Perimeter Dike Sections.

Drawing No. 4

PROPOSED BEACH SECTION



COST ESTIMATE WORKSHEET				
Speculation Item # 21 & 27				
DELETIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
500 LB Armor Stone	TON	30,000	$50.00	$1,500,000
1000 LB Toe Armor Stone	TON	43,000	$60.00	$2,580,000
50 LB Underlayer Stone on Slope	TON	14,000	$45.00	$630,000
50 LB Underlayer Stone on Slope	TON	73,000	$45.00	$3,285,000
Bedding Stone	TON	10,000	$45.00	$450,000
Geotextile	SY	68,000	$5.00	$340,000
				$0
				$0
				$0
		Total Deletions		$8,785,000
ADDITIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Groin Structures 500 LB Stone	TON	6,000	$50.00	$300,000
Groin Structures 50 LB Underlayer	TON	4,000	$45.00	$180,000
Sand	CY	230,000	$13.00	$2,990,000
Geotextile	SY	2,000	$5.00	$10,000
Terrapin Nesting Habitat	LS	1	$100,000.00	$100,000
				$0
				$0
				$0
				$0
		Total Additions		$3,580,000
		Net Cost Decrease		$5,205,000
Unit costs based on Poplar Island estimate				

VALUE ENGINEERING PROPOSAL

PROPOSAL NO: 5 (Spec List Items 25 and 55) PAGE NO: 1 OF 4
DESCRIPTION: Create Topsoil On Site

ORIGINAL DESIGN

Interior slopes are designed to 2-1/2: 1 to 3:1. Expected practice on island is to use existing dredge/sand mix onsite for upland planting areas. However, planting contractor would have to apply soil amendments (lime) to adjust soil pH.

PROPOSED DESIGN:

Remove dredged material from upland containment cells, stockpile this material for future use. Manage/farm the dredged material stockpile in a manner that will naturally deplete saturated salts from the soil.

The material will be spread in a thin layer (4" to 6") onto a 5:1 slope. Rainwater will naturally deplete salts from the soil. The material will be routinely tilled to expose new material to the surface. Once the pH has improved and Salts depleted, the materials will me removed from the slope and transported to a stockpile in another location. A fresh layer of dredge will be placed on the slope.

Two cost estimates are provided below, comparing two alternatives to the expected method of allowing time and physical handling to reduce pH and salt content.
5A: Modifying existing soil onsite
5B: Transporting topsoil to island if the pH cannot be brought within acceptable limits in a timely manner.

ADVANTAGES:

- Will create better soil conditions resulting in healthier vegetation.
- Produce less acidic topsoil for vegetation.
- Deplete salt content to reduce plant stress (original design does not address salt content of soil).
- May promote diversity of beneficial volunteer growth (not just Lambs Quarters).
- Reduce or eliminate the need for soil amendments such as lime.
- Results may last longer than lime soil amendments.
- Eliminates the expense of transporting large volumes of materials to the island.
- Beneficial use of dredged material.
- Protects the $$ investment in plant materials.
- May reduce contractor claims.
- Existing project equipment can achieve task.
- Can produce large volume of ready-to-use topsoil over time.

- Having a stock pile of ready to use topsoil will allow for the planting to be done over time, at different times, and/or in succession - rather than having all the plants planted at once. This could also promote healthier vegetation and help with plant diversity.

DISADVANTAGES:

- Material will be handled multiple times:
  1. Excavation from upland containment cell.
  2. Transported/deposited to farming location.
  3. Tilling material on a routine basis.
  4. Material will be collected from the slope and transported to another location.
- If rainfall is not sufficient, well water will be necessary to flush salts from the material. This will increase costs.
- This is an unproven technique on a large scale.
- It is not known how much time will be necessary to achieve desired results.
- Production rated may be inconsistent depending on weather conditions.
- The typical dike slope of 2-1/2:1 to 3:1 will be too steep for managing this farming technique. A 5:1 slope will need to be constructed.
- Having long term leaching of low pH into the wetlands or nearby waters could increase dissolved metals and could have a negative water quality and ecosytem impact. Leaching of salts would be less problematic, but it is likely that lime or other high pH amendment will still be required.

JUSTIFICATION:

Soil conditioning is necessary to achieve successful vegetation of the project. High salt content and low pH are typical conditions in dry, consolidated dredged material. These conditions are highly stressful and sometimes toxic to trees, shrubs and grasses. Considering the scale of the project, a vast amount of soil conditioning will be necessary to achieve successful upland vegetation of the island.

Comment from State of Maryland:
The cost associated with routinely tilling of material to expose new material to surface does not appear to be accounted for in the following cost estimate worksheets.

COST ESTIMATE WORKSHEET				
Proposal 5A (Speculation Item # 25 and 55)				
DELETIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Granulated limestone	Tons	1860	$260.00	$483,600
Delivery to island	Acre	930	$6,000.00	$5,580,000
unload and stockpile	Acre	930	$2,777.00	$2,582,610
transport and spread in planting zone	Acre	930	$2,797.00	$2,601,210
Tilling - incorporate into soil	Acre	930	$61.76	$57,437
Re-apply ?	Acre	930		$0
				$0
				$0
		Total Deletions		$11,304,857
ADDITIONS A (Farm Dredge Material on Site)				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Re-grade interior slopes of to 5;1	Acre	930	$6,373.00	$5,926,890
Excavate dredge transport/spread on slope	Acre	930	$2,858.00	$2,657,940
reclaim from slope - transport & stockpile	Acre	930	$3,291.00	$3,060,630
Haul and spread in planting zone- 6" depth	Acre	930	$3,044.00	$2,830,920
Flush with water truck once a week	Acre	930		$0
				$0
				$0
		Total Additions		$14,476,380
		Net Cost Decrease		($3,171,523)
Source of cost data not provided				

COST ESTIMATE WORKSHEET				
Proposal 5B (Speculation Item # 25 and 55)				
DELETIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Topsoil	CY	750510	$25.00	$18,762,750
Delivery to island	Acre	930	$6,000.00	$5,580,000
unload and stockpile	Acre	930	$2,777.00	$2,582,610
transport and spread in planting zone	Acre	930	$2,797.00	$2,601,210
				$0
				$0
				$0
				$0
		Total Deletions		$29,526,570
ADDITIONS A (Farm Dredge Material on Site)				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Re-grade interior slopes of to 5;1	Acre	930	$6,373.00	$5,926,890
Excavate dredge transport/spread on slope	Acre	930	$2,858.00	$2,657,940
reclaim from slope - transport & stockpile	Acre	930	$3,291.00	$3,060,630
Haul and spread in planting zone- 6" depth	Acre	930	$3,044.00	$2,830,920
Flush with water truck once a week	Acre	930		$0
				$0
				$0
		Total Additions		$14,476,380
		Net Cost Decrease		$15,050,190
Source of cost data not provided				

VALUE ENGINEERING PROPOSAL

PROPOSAL NO: 6 (Spec List Item 26) PAGE NO: 1 OF 4
DESCRIPTION: Drill Wells on Both Islands to Support Upland Vegetation

ORIGINAL DESIGN:
The current design has not yet considered fresh water wells for the Mid-Bay projects. At Poplar Island, the current water supply to the island's facilities and approximately 30 full-time employees is a single well developed in 2002. This water supply well initially tested up to 100 gpm; however, the well pump capacity is 70 gpm. This water supply currently services the trailer complex for on-site employees, the maintenance facility, accommodates almost daily tours to the island, and the watering operation for the planted wetland cells (4D and 3D) and dust control measures.

PROPOSED DESIGN:
It is likely that at least one well would be installed at the Barren Island site, and that several wells would be installed at the James Island site. It is anticipated that the geologic conditions at the Mid-Bay island sites are similar enough that the Poplar well is a reasonable basis for any Mid-Bay well installations. Proposed wells will be assumed to be approximately the same depth, targeting the same confined aquifer. The Poplar well has a stainless steel 4-inch diameter slotted screen (slot size 0.03) from depths 310 feet to 440 feet below ground surface. The top portion of the well down to depth 310 feet is steel casing. There is a grout seal from depths 0 feet to 260 feet and a gravel pack (Morie #1) from depth 260 feet to the bottom. The water supply is pumped using a 5 Hp, 460 Volt, 3 phase motor submersible pump which is at a depth of 105 feet.

ADVANTAGES:

- Keep up with demand of watering vegetation in wetland and uplands.
- Will not require water supply from off-island to facilities.

DISADVANTAGES:

- Additional expense not accounted for in the current project.
- Minor maintenance of pump and generator/power source.
- Future maintenance of well (back wash to clear screen and disinfect).
- Would need to consider which aquifer the wells would be located in. The Aquia is having saltwater intrusion issues on the eastern shore and is being tapped beyond its ability to recharge. Irrigation wells might be able to tap non-potable aquifers.

JUSTIFICATION:
Water demands will increase as future wetlands and uplands are brought on-line and vegetated. Due to the high initial expense of plantings and the high expectations for success, strong consideration shall be given to supplying additional well(s) to increase water supply. If multiple wells are completed, back-up will be provided in case of the loss of any single well.

Comment from State of Maryland:
I think the cost estimate on page 44 is high. The mob and demob costs for drilling at Poplar include only one well. The cost per well would be reduced with 5 wells since the mob and demob costs would be spread over 5 wells.

Response to Comment:
Considering that the wells may not all be installed at the same time, and further transportation distance from Baltimore, it may be appropriate to include separate mob and demob costs with each well. This is more a more detailed analysis than usually performed at the feasibility level, though.

Comment from Stacey Sloan Blersch, Baltimore District:
Need to add in text that since Barren Island is part of a National Wildlife Refuge, permission to install a well and maintain is at the discretion of the USFWS. Need to confirm policy of USFWS of installing wells or other amenities during construction. Since construction period for Barren Island is much shorter, it is more likely that no well would be installed.

Drawing No. 1 – Log of Original Poplar Island Well Installation

Telephone 410-841-6710
Fax # 410-841-6711

A.C. SCHULTES OF MARYLAND, INC.
24-26 SOUTH RIVER ROAD EDGEWATER, MARYLAND 21037

Water Well Contractors

CUSTOMER: Maryland Environmental Service JOB H4114

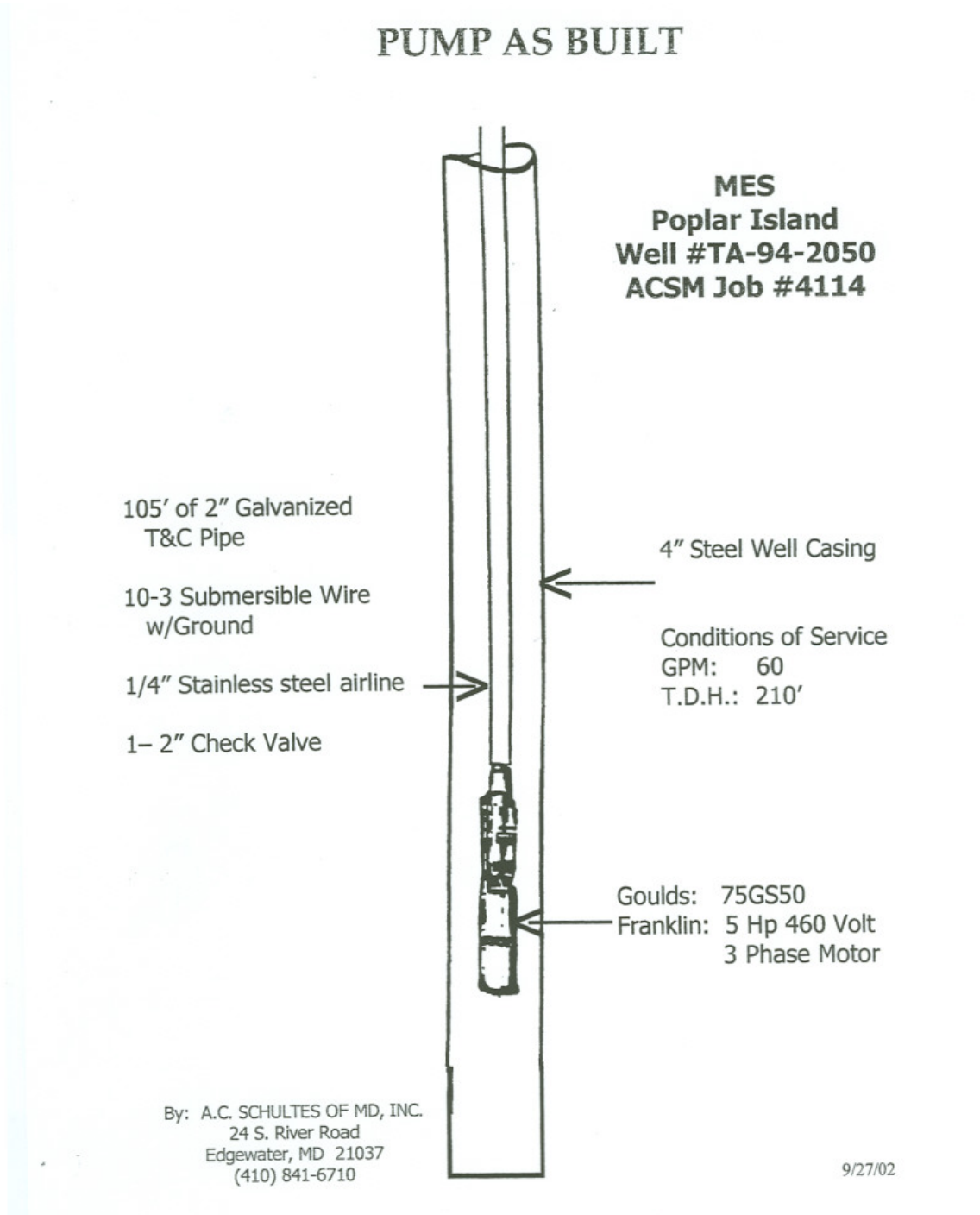
ADDRESS: DATE 9/23/02

LOCATION: Poplar Island PERMIT NO. TA-94-2050

	FEET FROM GROUND SURFACE 0 TO ----------	WELL LOG
GROUND	0-38	Fine sandy clay w/ some shell
	38-148	Soft gray clay w/ some fine sand
	148-276	Fine green & black silty sand w/ some clay
	276-365	Fine - medium sand w/some clay , silt and shells
	365-448	Fine - medium sand w/some coarse sand & shells. Also some hard
		layers w/ streaks of clay
	448-475	Fine silty sand w/ some medium shell
310' CASING		
445'		
SCREEN 130'		
5		Cement 0-150; Bentonite 150-260

WELL NO. 1R	DIAMETER OF WELL 8" Pilot	DEPT. OF WELL 445
HRS. PUMPED 4	SLOT SIZE ~~020~~ .030	TYPE OF CASING Steel
CAPACITY G. P. M. 100	DRILLING MACHINE NO. D-8	LENGTH OF CASING 310
STATIC LEVEL 35	DRILLER Melson	DISTANCE TO TOP OF SCREEN 310
PUMPING LEVEL 57	GRAVEL Morie #1	TYPE SCREEN SS
SPECIFIC CAPACITY 4.5	BAGS OF CLAY / CEMENT 15/50	SIZE OF SCREEN 4" PS
PUMPED WITH Sub	DATE WELL COMPLETED 9/27/02	OUTER CASING SIZE N/A
DEPTH OF GROUT 260	DRILLER'S HELPER Nikolov	OUTER CASING DEPTH N/A
DEPTH GRAVEL PACKED 260-450		

Drawing No. 2 – Sketch of Poplar Island Well Installation



In 2002, the original water supply well including pilot hole, drilling well, setting well and pump, disinfecting, and all labor and materials including mob and demob cost $116,000. The 2002 cost has been increased by 20% for this estimate. The estimate below does not include operation and maintenance costs.

COST ESTIMATE WORKSHEET				
Speculation Item # 26 - Drill wells to support upland vegetation				
DELETIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
				$0
				$0
				$0
				$0
				$0
				$0
				$0
				$0
		Total Deletions		$0
ADDITIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Well Installations	EA	5	$139,200.00	$696,000
				$0
				$0
				$0
				$0
				$0
				$0
				$0
		Total Additions		$696,000
		Net Cost Decrease		-$696,000

VALUE ENGINEERING PROPOSAL

PROPOSAL NO:	7 (Spec List Item 95)	PAGE NO: 1 OF 6
DESCRIPTION:	Provide Undulations, Pockets & Small Coves on Lee Side of James Island	

ORIGINAL DESIGN:

The current James Island alignment consists of a series of fairly straight dike legs connected by curved segments at the corners as shown on Drawing No. 1. The total perimeter is approximately 45,000 feet long, with the eastern 15,000 LF consisting of a sand dike with a stone toe section and a lightly armored surface (500-lb stone) to approximately elevation +8 mllw. Typical sections of the upland and wetland segments of this reach are presented on Drawing No. 2.

PROPOSED DESIGN:

John Nichols with NOAA National Marine Fisheries Service Habitat Conservation Division suggested providing undulations, pockets, and/or small coves in the design of the exterior dikes for James Island. These areas would provide a diversity of habitat types thereby providing fish and wildlife habitat. If possible, these coves should be tied into 9 to10 foot depth to increase their value to recreational fishing. Based on current bathymetric data, it appears that the deepest water that would be associated with the modified eastern alignment would be 7 to 8 feet. This diversity in the shoreline will provide more habitat benefits to finfish in the adjacent Bay waters. In addition, these coves should be lined with smooth cordgrass marsh to attract foraging fish such as the juvenile summer flounder.

As shown by the dashed line on Drawing No. 1, the proposed eastern alignment follows an undulating smooth curve pattern with the pitch varying from 2000 to 3000 feet and an amplitude ranging from 300 to 600 feet. The exact layout would be adjusted to be compatible with tidal gut openings, wetland cell openings, the existing island locations, and hydrodynamic considerations for the open water between the project and the existing islands.

The undulating alignment will be somewhat more difficult to construct than a straight alignment, particularly if the undulations are not regular in pitch and amplitude. However, if the stone section can be simplified to a configuration similar to the eastern side of the Poplar Island project, or if an entirely sand section can be used, constructability issues will be reduced significantly.

ADVANTAGES:

- These areas would provide a diversity of habitat types thereby providing fish and wildlife habitat.
- This diversity in the shoreline will provide more habitat benefits to finfish in the adjacent Bay waters.

DISADVANTAGES:

- The modified alignment would increase in length with a corresponding increase in cost of the dike and armor stone materials.
- The curved alignment may be more difficult to construct, thereby adding to the construction time, and labor cost along with the increase in material quantities.
- Quality control may be more difficult during construction than building straight alignment
- Additional hydraulic/hydrodynamic analyses may be required to evaluate the effect of the irregular alignment on flow between the existing islands and the project.

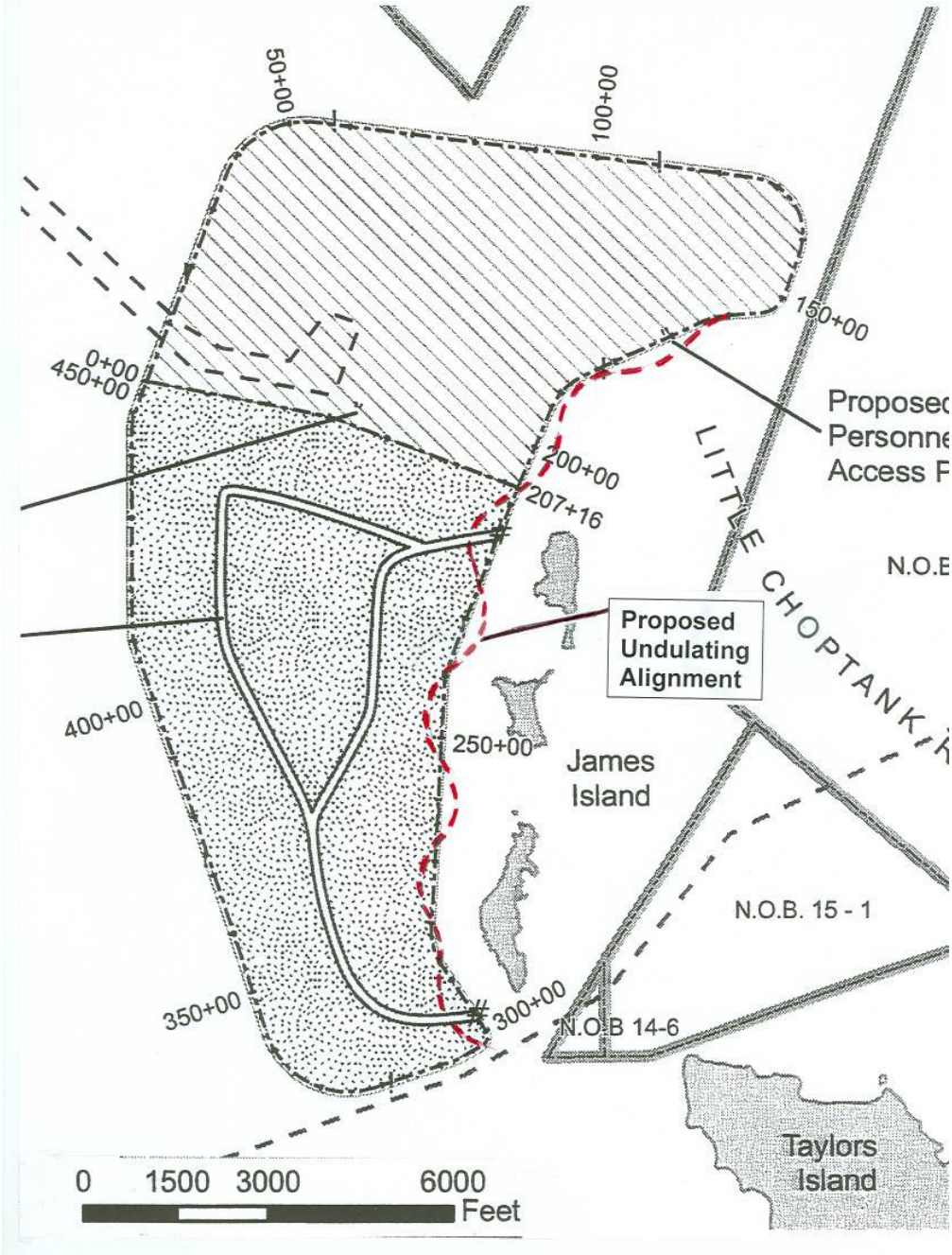
JUSTIFICATION:

The value of the additional environmental diversity discussed above may outweigh the additional cost for the eastern dike segment resulting from the increased dike length.

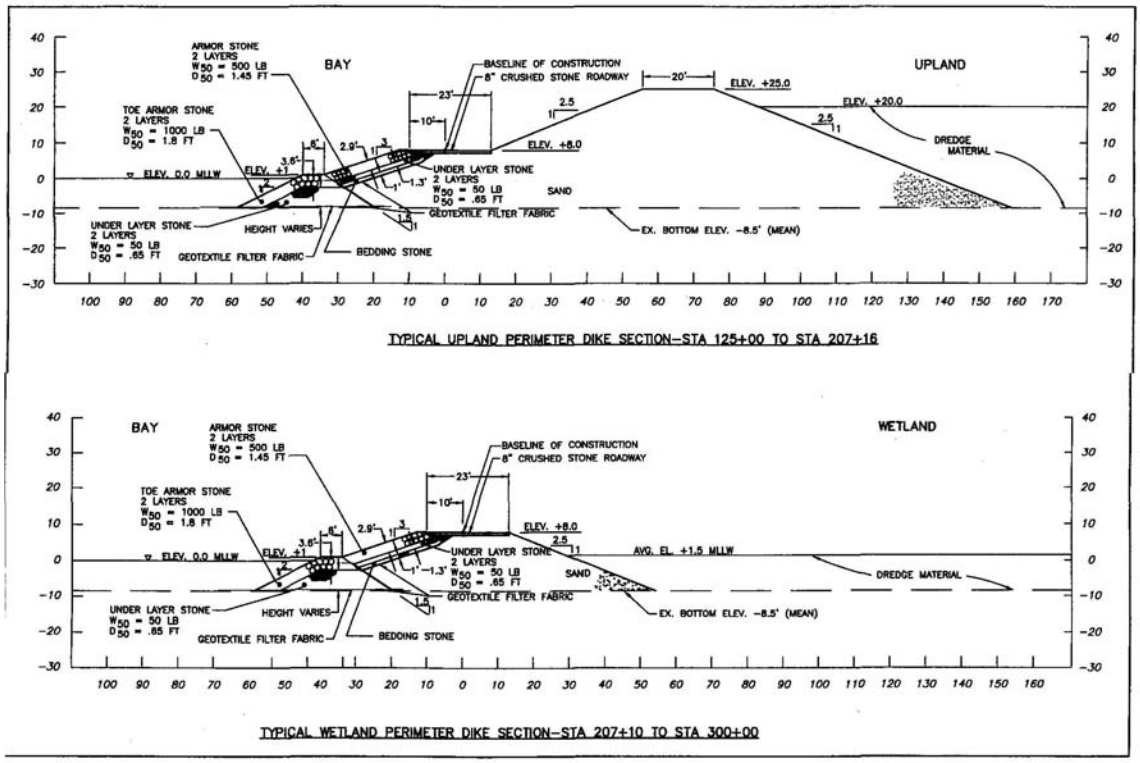
Comment from Stacey Sloan Blersch, Baltimore District:
Is reference to eastern shore of Poplar Island correct? If this proposal moves forward, additional benefits may have to be calculated to justify additional cost.

Note from VE Report presentation:
It was noted there were several areas noted along the western edge of the Blackwater Refuge area which serve as a good example of natural occurrences of undulations.

DRAWING NO. 1
JAMES ISLAND RECOMMENDED PLAN WITH MODIFIED EAST ALIGNMENT



DRAWING NO. 2
TYPICAL DIKE SECTIONS ALONG LEE (EASTERN) SIDE OF ISLAND



The cost estimate is based on a cost per linear foot for affected wetland and upland dikes accounting for an increase in dike length of approximately 10%. The backup cost per linear foot estimate is on the following page.

COST ESTIMATE WORKSHEET				
Speculation Item # 95 - Provide undulations, pockets, & coves on lee side of the island				
DELETIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
				$0
Wetland Dike	LF	9,200	$1,407.00	$12,944,400
Upland Dike	LF	4,700	$2,443.00	$11,482,100
				$0
				$0
				$0
				$0
				$0
				$0
		Total Deletions		$24,426,500
ADDITIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
				$0
Wetland Dike	LF	10,120	$1,407.00	$14,238,840
Upland Dike	LF	5,170	$2,443.00	$12,630,310
				$0
				$0
				$0
				$0
				$0
				$0
		Total Additions		$26,869,150
		Net Cost Decrease		-$2,442,650

Following is the detailed backup cost per linear foot of wetland and upland dikes.
Source of Cost Data: Poplar Island Phase II escalated 25% + add'l haul

COST ESTIMATE WORKSHEET				
Cost per Linear foot of Upland and Wetland dikes for the eastern side				
of James Island				
Wetland Dike Section per 100 Linear Feet				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Dike Geotextile	SY	890	$4.00	$3,560
Toe Armor Stone	Tons	480	$65.00	$31,200
Toe Core Stone (quarry run)	Tons	583	$60.00	$34,980
Slope Armor Stone	Tons	371	$45.00	$16,695
Slope Underlayer Stone	Tons	181	$45.00	$8,145
Bedding Stone	Tons	150	$52.50	$7,875
Dike Fill	CY	3,430	$10.00	$34,300
Roadway stone	SY	225	$13.00	$2,925
Roadway geotextile	SY	255	$4.00	$1,020
		Total Deletions		$140,700
Cost of Wetland Dike Section per Linear Foot				**$1,407**
Upland Dike Section per 100 Linear Feet				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Dike Geotextile	SY	890	$4.00	$3,560
Toe Armor Stone	Tons	480	$65.00	$31,200
Toe Core Stone (quarry run)	Tons	583	$60.00	$34,980
Slope Armor Stone	Tons	371	$45.00	$16,695
Slope Underlayer Stone	Tons	181	$45.00	$8,145
Bedding Stone	Tons	150	$52.50	$7,875
Dike Fill	CY	13,792	$10.00	$137,920
Roadway stone	SY	225	$13.00	$2,925
Roadway geotextile	SY	255	$4.00	$1,020
		Total Deletions		$244,320
Cost of Upland Dike Section per Linear Foot				**$2,443**

VALUE ENGINEERING PROPOSAL

PROPOSAL NO:	8 (Spec List Item 112A)	PAGE NO: 1 OF 2
DESCRIPTION:	Reduce the 23' Wide Crushed Stone Roadway to 13' Wide with Pull Over/Passing Areas Constructed Every 1000 Feet.	

ORIGINAL DESIGN:

Existing section shows a total width of 23 feet for the entire perimeter length of 8 inch thick crushed stone roadway.

PROPOSED DESIGN:

The new section will remain 23 feet wide at the pull over/passing areas and be reduced to 13 feet wide for the entire perimeter. The pull over/passing areas should be constructed every 1000 feet and be 150 feet long.

ADVANTAGES:

- Reduces the quantity of stone required for construction.
- Reduces the quantity of geotextile material under deleted roadway area.
- Reduces the area for stone roadway maintenance.
- Provides larger areas for shoulder grasses to be grown to stabilize erosion.

DISADVANTAGES:

- Reduces passing area for larger equipment.
- Increased mowing area if required.
- Loss of production due to (dump trucks/passenger vehicles) stopping in every passing situation. During a hauling operation, this will add several minutes to each round trip.
- On dike roads used around wetland cell areas there is no bench for heavy equipment (excavators) to work off when digging perimeter trenches and/or conducting other work in the wetland cell area. With a small road width and an excavator working in a wetland cell from the dike road, that road will be completely out of service for all other equipment to pass.
- Depending on the work being conducted elsewhere on the island, this could have an impact on the costs if additional travel distance and time are required because a perimeter road is closed along one of the wetland cells.

JUSTIFICATION:

The area does not need a full width of 23 feet of 8 inch thick crushed stone roadway around the entire area to maintain access for construction or maintenance. Reducing the quantity of rock required will reduce initial construction cost.

COST ESTIMATE WORKSHEET				
Speculation Item 112A				
Reduced Crushed Stone Roadway Width from 23' to 13' with Pull Overs				
DELETIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Stone Roadway Perimeter - 45,235'	SY	42,500	$13.00	$552,500
Stone Roadway Separator - say 6200'	SY	5,670	$13.00	$73,710
Geotextile under roadway	SY	48,170	$5.00	$240,850
				$0
				$0
				$0
				$0
				$0
				$0
		Total Deletions		$867,060
ADDITIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
				$0
Grassing (includes seeding and mulch)	SY	48,170	$0.875	$42,149
				$0
				$0
				$0
				$0
				$0
				$0
				$0
		Total Additions		$42,149
		Net Cost Decrease		$824,911
Source of Cost Data: Poplar Island Phase II escalated 25% + add'l haul				

Comment from State of Maryland:
This is a good proposal. There maybe other areas that would require greater than the 13' width, such as any area where wider equipment (pontoon trencher) might have to travel or be hauled. – From barge unloading area or to maintenance area.

VALUE ENGINEERING PROPOSAL

PROPOSAL NO:	9 (Spec List Item 112B)	PAGE NO: 1 OF 2
DESCRIPTION:	Reduce the 20' Wide Dike Section at Elevation 25 To 10' Wide in the Areas Where the Crushed Stone Roadways Are Located Around the Upland Perimeter and the Separator Dikes.	

ORIGINAL DESIGN:

Existing section shows a total width of 20 feet for the entire upland perimeter and separator dikes.

PROPOSED DESIGN:

Reduce the 20' wide dike section at elevation 25 to 10' wide in the areas where the crushed stone roadways are located around the upland perimeter and the separator dikes.

ADVANTAGES:

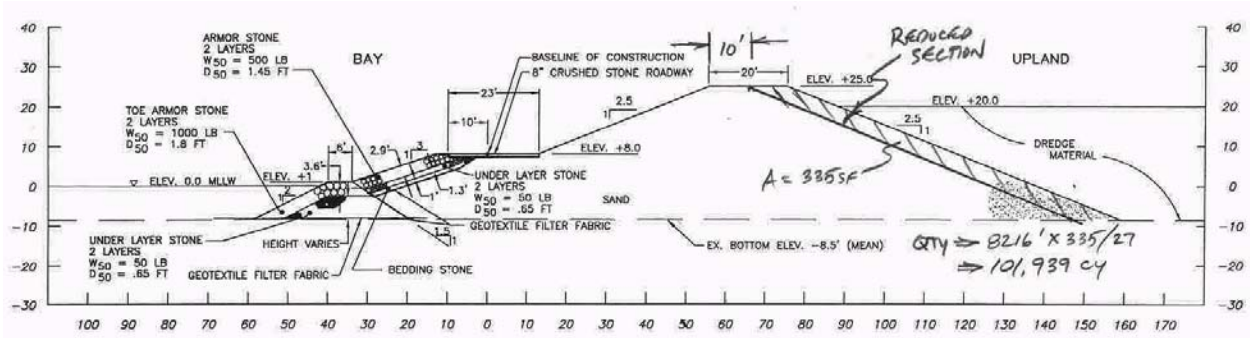
- Reduces the quantity of sand fill required for construction.
- Reduces construction duration.
- Reduces the area for dike maintenance.
- Increases the interior capacity for placing dredged material.
- Reduces the volume of dike to be removed at the completion of the project once elevation 20' is attained.

DISADVANTAGES:

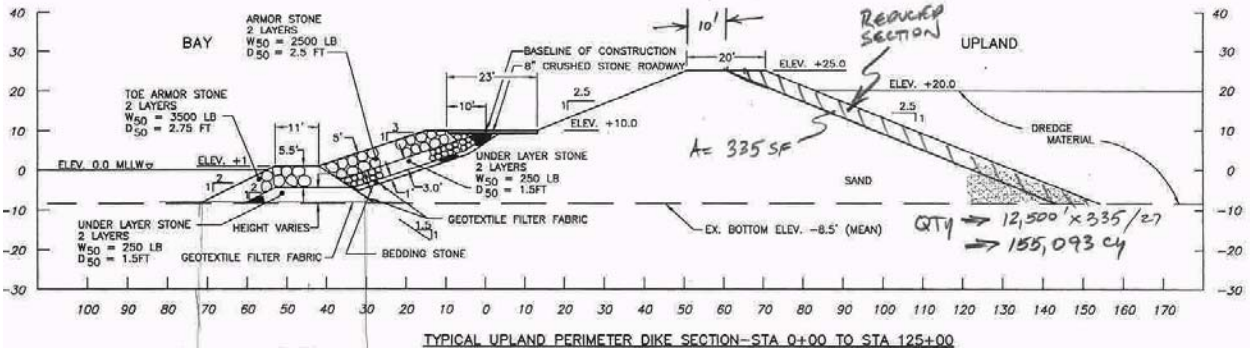
- Reduces passing area for larger equipment during initial construction and future maintenance.

JUSTIFICATION:

The area does not need a full width of 20 feet to maintain access for construction or maintenance. Reducing the quantity of fill will reduce initial construction cost.



TYPICAL UPLAND PERIMETER DIKE SECTION–STA 125+00 TO STA 207+16



TYPICAL UPLAND PERIMETER DIKE SECTION–STA 0+00 TO STA 125+00

COST ESTIMATE WORKSHEET				
Speculation Item 112B				
Reduced Dike Width from 20' to 10'				
DELETIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
Embankment Fill Sta 0+00 - 125+00	CY	101,939	$10.00	$1,019,390
Embankment Fill Sta 125+00 - 207+16	CY	155,093	$10.00	$1,550,930
Embankment Fill Separator - say 6200lf	CY	76,926	$10.00	$769,260
				$0
		333,958		$0
				$0
				$0
				$0
				$0
		Total Deletions		$3,339,580
ADDITIONS				
ITEM	UNITS	QUANTITY	UNIT COST	TOTAL
				$0
				$0
				$0
				$0
				$0
				$0
				$0
				$0
				$0
		Total Additions		$0
		Net Cost Decrease		$3,339,580
Source of Cost Data: Poplar Island Phase II escalated 25% + add'l haul				

10. ***Do not Restrict Wetlands from Being Built Over Borrow Sources and Build Wetlands on the East Side of the Island (Speculation List Items 1, 6, and 7).***

Wetlands over Borrow Sources

The allowable thickness of dredged material that can be placed in a wetland should be developed on a case-by-case basis. Considerations for determining this thickness should include:

- The characteristics of the placed material
- The tolerances of the wetland elevations,
- The permeability and conductivity of the underlying substrate.

Restricting wetlands from being built over borrow sources during study eliminates potential cells from being considered as wetlands, or conversely, potential borrow sources from being utilized.

In the case of James Island, restricting wetlands from being built over borrow sources has the following consequences:

i) placing wetlands solely on the eastern side of the island is not eliminated from consideration prior to its evaluation,

ii) maximum utilization of borrow sources is not realized, and

iii) wetlands on the southern side of the island requires that a tidal gut be constructed for connection to the bay.

Placing Wetlands on the Eastern Side of the Island

To determine if wetlands could be placed on the eastern side of the James Island project, the following steps would need to be taken:

1) The allowable thickness of dredged material in a wetland cell would need to be determined.
2) An alignment would need to be established and construction quantities calculated.
3) A borrow analysis for the selected alignment would need to be performed. The upland borrow would be maximized and the wetland borrow would be to the allowable extent.

The above steps would allow determination of the feasibility of constructing the wetlands solely on the east side.

Others present for the VE study disagree with the approach that building wetlands overtop of the borrow sources is feasible. This approach (building wetlands overtop of borrow sources) will require resolution amongst the two groups (i.e. USACE and the State). Also, the feasibility of placing the wetlands solely on the east side of James Island would depend on the outcome of an evaluation of borrow availability and construction quantities.

11. ***Use Sequential Dredged Material Drying Areas (Speculation List Item 13).***

Area permitting, it is advantageous to manage dredged material containment facilities by placing no more than a 3-foot lift over an area every other year. This approach, outlined in EC-1110-2-1100, allows more time for the dredged material to consolidate. The feasibility of implementing this approach at James Island should be considered in further study phases.

The area required to handle 3.2 mcy of material with a 3 ft lift is approximately 930 acres. As James Island may be approximately 2,000 acres, this approach to dredged material management may be feasible. However, other considerations, such as development schedules, fluctuations in annual placement volumes, and project construction phasing may not permit this approach to dredged material management.

12. ***Conduct A Partnering Session To Agree On The Future Direction Of The Project (Speculation List item 30).*** The Value Engineering team had considerable discussion on some of the means and methods of construction as discussed elsewhere in this study (e.g., wetlands over borrow, wetland/upland configuration, construction phasing). Due to the considerable differences of opinion on how best to proceed, it is suggested that a partnering session with the stakeholders that can make project decisions be held. Many of these issues are similar to those identified in the Poplar Island Value Engineering Study (Jun06) that also recommended a partnering session. Some issues may be resolved for both projects in one partnering session, however, a separate session should be held for MidBay to specifically apply resolutions to this project.

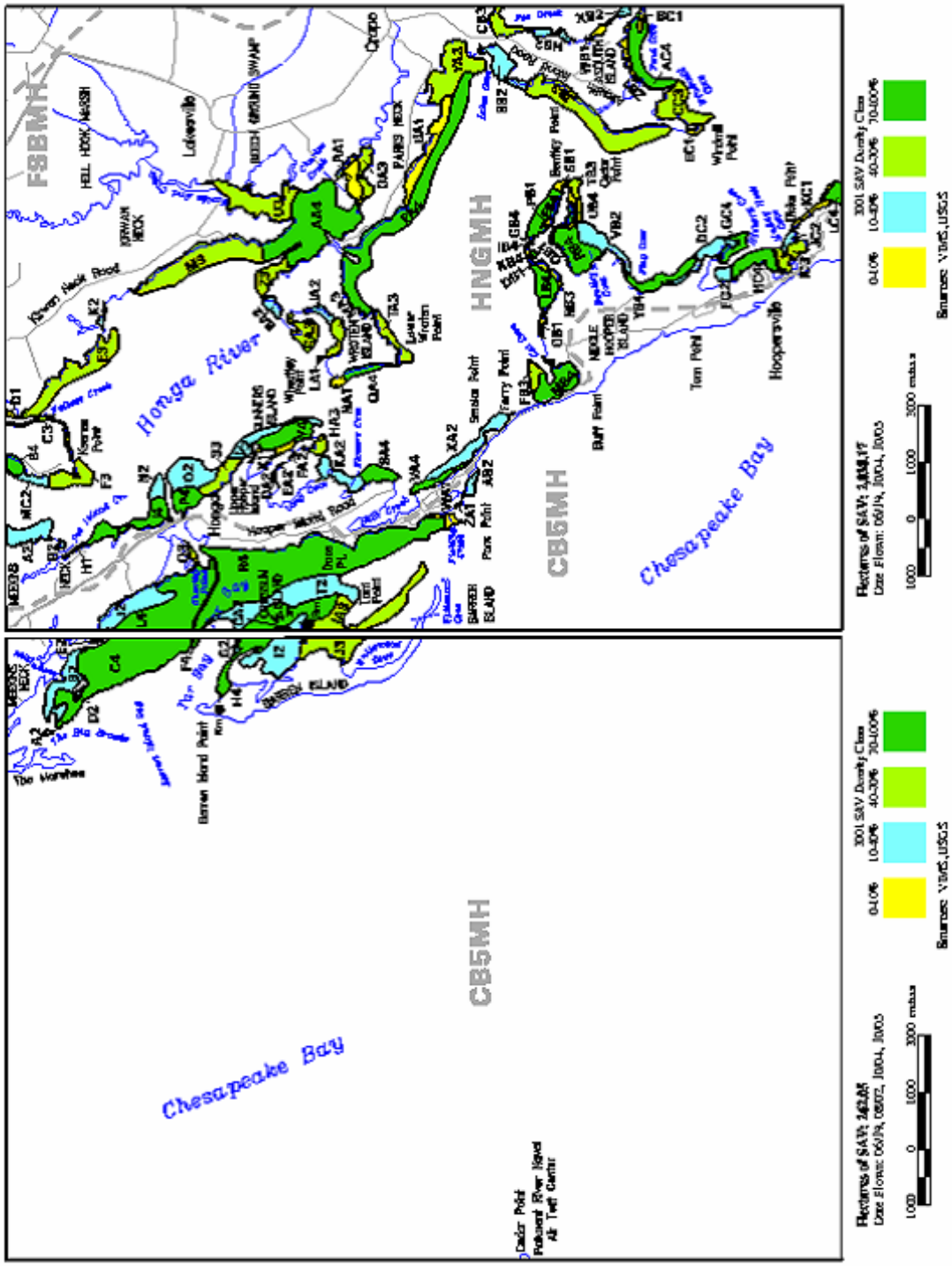
13. ***Create Island Habitat Near NE Corner Of Barren Island (Spec List Item 16).***

Small islands targeting colonial waterbird nesting could be created on the northeast lee side of Barren Island in Tar Bay. Location on the northeast lee side of Barren Island would provide protection from wind and storm surges. Optimal size for such islands would be 5 to 25 acres, however, islands as small as 1/4 or 1/3 acre would provide benefits. Even more important than size, isolation is the most significant factor when targeting nesting bird island habitat. It is recommended that any islands set off of Barren Island be at least 820 feet from the main Barren Island mass.

Existing submerged aquatic vegetation (SAV) habitat would potentially be impacted and permanently transformed to island habitat if small islands are constructed, depending on the final location. The waters east of Barren Island are rich in potential SAV resources. SAV acreage peaked in 2001 and 2002, 1324.5 and 1261.9 acres, respectively. It appears that there is available bottom between the island land mass and the recent SAV areas to locate a small island or a few small islands without impacting recent SAV beds. The included figure shows SAV bed locations in 2001, the year of maximum SAV extent (all mapping by VIMS). According to the Chesapeake Bay Program targets, some of the area being considered for small island creation would be considered Tier I SAV recovery zones as it is bottom that is currently or has been previously inhabited by SAV as mapped since 1971. SAV mapping in the area only extends back to 1994. Therefore, more of the area could have supported SAV, but mapping is not available for the period between 1971 and 1994. Tier II and III distribution restoration targets are the restoration of SAV to all shallow water areas identified as existing or potential SAV habitat, down to the 1- and 2- meter (3.3 and 6.6 foot) depth contours, respectively. All bottom area between the island mass and the northeast leeward SAV beds identified in 2001 would fall within one of these categories as water depths range up to 4 feet. Therefore, although it may be possible to avoid current SAV beds (Tier I) by appropriately locating proposed small islands, it is very likely that potential SAV habitat (Tier II or III) would be converted to island habitat. Appropriate coordination with USFWS, MDNR, and NOAA should be made when planning these small islands.

As outlined by Erwin (1997). proposed islands should take the shape of a horseshoe or kidney with the ‘back’ facing the prevailing winds to allow for a small protected ‘harbor’ to develop and promote SAV growth. Such a configuration would be attractive to invertebrates and fishes.

Erwin, Michael. 1997. Enhancing Waterbird Habitat with Dredged Materials: Some Suggestions for Improvement. *In* Proceedings of the Second marine and Estuarine Shallow Water Science and Management Conference, April 3-7, 1995, Atlantic City, NJ. EPA/903/R/97009.


FSBMH
HNGMH
CB5MH
Honga River
Chesapeake Bay
Hooper Island Road
Hooperville
Lakesville
Tar Bay
Barren Island
Deal Island
Tar Bay Creek
Fishing Bay
Meekins Neck
Swan Creek
Fishing Creek
Dames Quarter Creek
Monie Bay
Big Monie Creek
Little Monie Creek
Back Creek
Deep Creek
Dividing Creek
Messongo Creek
Manokin River
Wicomico River
Nanticoke River
Pocomoke Sound
Tangier Sound
Somerset County
Dorchester County
Wicomico County
Worcester County
Accomack County
Northampton County
Virginia
Maryland
Delaware
Hectares of SAV: 1,888.97
Date Flown: 06/04, 10/04, 10/03
Hectares of SAV: 1,623.85
Date Flown: 06/04, 08/02, 10/04, 10/03
2001 SAV Density Class
0-10%
10-40%
40-70%
70-100%
Sources: VIMS, USGS
1000 0 1000 2000 meters

14. ***Use Rubble Mound Habitat Islands For Barren (Spec List Item 17); Design The Breakwaters As Bird Islands (Spec List Item 86); Build Bird Islands South Of Barren Island (Spec List Item 111):***

The following discussion combines these three topics. Bird islands could be constructed in the lee of the southern breakwater. Alternatively, the southern breakwaters could be designed to include bird islands. Rubble is an alternative material that could be used to construct these structures.

Positioning bird islands in the lee of the southern breakwaters would likely be the most suitable position for bird islands in the Barren Island vicinity. The breakwater, in this capacity, would provide added protection to nesting colonies from western winds and storm surges. Bird island(s) in the lee of the breakwater would be surrounded by more open water which may make them more attractive to the targeted colonial nesting waterbirds. Further, island(s) in the lee of the breakwater would have the ancillary benefit of providing additional visual clues to the boating public regarding the location of the breakwater.

As a second option, the breakwaters extending from the southern tip of Barren Island would be highly suitable to have one or more sections converted into breakwater islands targeting colonial nesting waterbirds. The breakwaters could be modified to act as bird island habitats by extending their footprints and adding a layer of material ideal for nesting to the surface. The breakwaters will still act in their full capacity, and would likely provide a greater reduction in energy. Isolation and size are both important when creating bird islands for nesting. However, isolation from predators and human disturbance is the prime concern. 1/4 to 1/3 acre sites will provide benefits, but bigger would be better. (Note: Poplar GRR recommends 2.5 to 5 acres.) 1/4 acre breakwater islands could be constructed simply by increasing a 6' crest width to 55' for a breakwater 200' in length.

ADVANTAGES:

- Creates additional isolated habitats that target highly vulnerable avian species.
- Makes an additional use out of existing features.

DISADVANTAGES:

- More cost and materials needed.
- Additional maintenance may be required to control predators and vegetation.

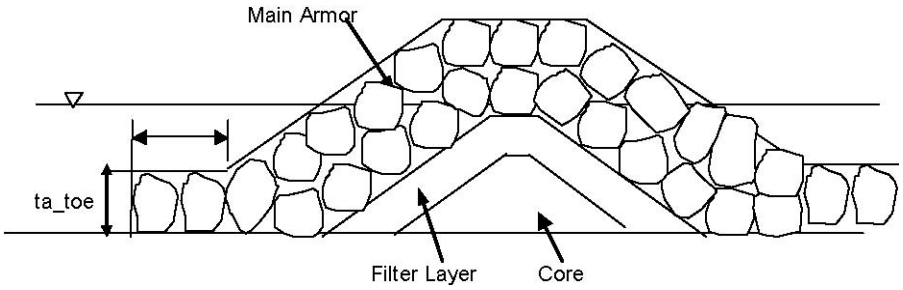


Figure 1: Typical breakwater design.

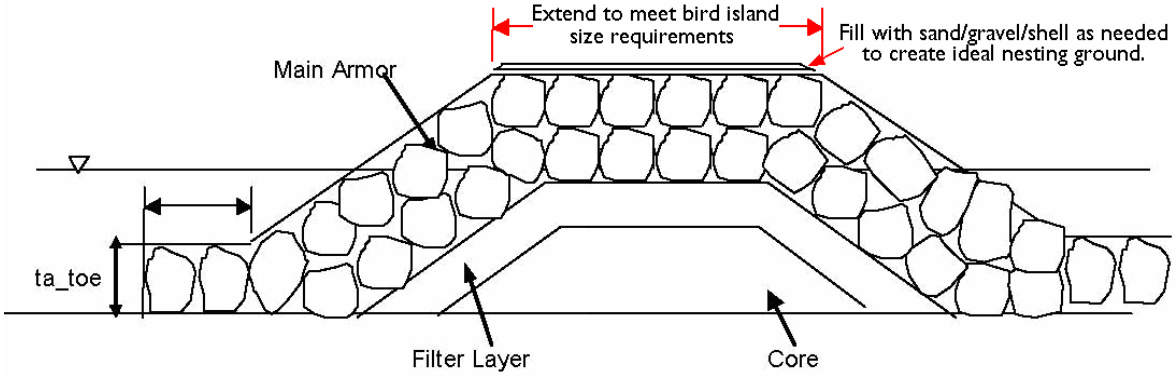


Figure 2: Breakwater designed as bird island.

Bird islands can be constructed of unconfined dredged material or rock or rubble. It would likely be difficult to get MDE approval for an unconfined placement of dredged material for island construction. Further, it would be prudent to protect the islands with a rock to maximize the longevity of the island. Rubble, such as a recycled clean concrete, could be used to construct breakwater islands rather than new rock. Regardless of material, the base substrate would need to be covered with sand, shell, or gravel to provide a suitable substrate for nesting. Sand alone, however, is not appropriate to use as a cap on breakwater islands.

15. ***Use T-Groins As Breakwater On West Side Of Barrens Island (Spec List Item 18):***

The current design for the 4,620 feet long section along the west side of Barren is for a sill having a top elevation of +4 feet MLLW, a top width of 6 feet, a core consisting of two layers of 130 lb stone, and armor consisting of two layers of 1,300 lb stone. A geotextile layer would be placed on the eastern side of the sill to prevent backfill material (i.e. dredged material) from migrating through the stone. It was suggested that this design be replaced with T-groins as the shore protection.

T-groins could be effective as a shore protection device if properly designed; the key factor is that the material behind the T-groins should be sand. Several methods are available for estimating beach response to stabilization structures and the design needs to be evaluated accordingly. Analysis of the resultant shoreline shape behind the T-groins is dependent on several factors, including:

- Incident wave period
- Incident wave angle
- Gap between structures
- T-head structure length
- Distance from equilibrium shoreline of the T-heads
- Grain size of the sand material
- Tide range
- Longshore transport
- Currents

There is the potential to decrease rock quantities by replacing the sills with T-groins, however, there would not necessarily be a decrease in rock. The rock quantities would depend on the design configuration of the gap between the structures, T-head structure length and distance from the shoreline of the T-heads.

This design could have the potential to add more value to the project by creating beach habitat, although this feature is not currently part of the plan. This design could also provide a source of sand to the surrounding environment as waves and current action erode the beach and convey the material into the Bay. Loss of sand would then provide placement capacity for future dredging of sandy channels in the surrounding area.

16. ***Use Reference Marsh for Guidance (Speculation List Item 29):*** Studying reference marshes near the Mid-Chesapeake Bay Island Restoration Project will provide an understanding of the physical and ecological benchmarks that drive success of local marsh ecosystems to help ensure that the restored habitat will be sustainable and fulfill target functions (e.g. productivity). Due to the natural variability between habitats over short spatial scales, a reference marsh study should investigate the range of ecosystems in the region surrounding the Mid-Chesapeake Bay Island project and not concentrate on a single reference habitat. Characterizing reference habitats in the local environs surrounding the Mid-Bay Islands and the physical/ecological benchmarks that make them successful and resistant to degradation or elimination will help scientists and resource managers understand what types of habitats this portion of the Bay supports, and why. Reference studies will quantify the following characteristics found in successful natural systems:

- Habitat type size and frequency of occurrence;
- Habitat types position in the landscape;
- Composition and size of vegetation communities;
- Area and elevation of wetland zones;
- Develop range of high and low marsh relationship;
- Tidal range and elevation of wetland vegetation communities;
- Sediment, soil, or substrate type;
- Salinity and other water quality characteristics of surface water; and
- Cross section, width, and depth of surface water features such as ponds and channels.

Using information resulting from reference habitat studies allows project planners to quantitatively compare and select types of wetlands or uplands habitats to restore and construct the habitats with comparable layout, elevations, plant species composition, range of high and low marsh relationship, and channel and pond dimensions as resilient local habitats. Planning habitat restoration by collecting baseline data from local habitats is also compatible with Adaptive Management techniques that will be implemented with this project, because the restoration project will be modeled after reference habitats that have sustained themselves through the impacts of sedimentation, urban/agricultural development, and physical changes in the Bay (such as circulation, sea level rise, etc.).

Comment by Mark Mendelsohn, Baltimore District biologist:
There are no high quality comparable island reference marshes available to study except for perhaps Smith Island which is more saline.

The project needs to produce a certain level of environmental outputs to justify investment and to compensate for loss of open water and bay bottom. Previously used reference marshes are degraded and consequently don't produce the benefits of the 80-20 spartina design marsh for the Poplar Island Restoration Project. If any reference marshes are used they shouldn't be degraded; they should be the best in terms of output. Reduced outputs should not be allowed under the assumption that the reference marshes are only producing so much or looking thus or so.

The bigger issue is that if we can do better than the reference marshes why not do it? Would the cost savings be so significant that a product that isn't superior should be settled for?

17. ***Allow Higher Percentage of Fines in the Upland Dike Sections (Speculation List Item 34).*** The containment dikes for the existing Poplar Island project and the proposed Mid-Bay project consist of fine silty sand. The dikes have typically been split between zones A and B with the primary dike supporting the armor stone and roadway being designated as zone A, and the interior sections and portions above approximately elevation +10 mllw being designated as zone B. The allowable fines content for zones A and B have been 20% and 30% respectively to assure that the materials performed predominately as sand as assumed in the design analyses. In situ, the borrow sand deposits contain from less than 10% to 50% fines. However, most of the Mid-Bay samples contained between 10% and 20% fines. The procedure of hydraulic dredging and stockpiling the borrow sands significantly reduces the average fines content and more evenly distributes those fines throughout the stockpile. Therefore, virtually 100% of the excavated borrow sand was suitable in either zone A or B and it was never necessary to relax the fines limits. Direct placement of sand by hydraulic methods would produce a similar fill product. The only occasion during Poplar Island construction where it was necessary to increase the fines limits occurred when borrow sand was mechanically excavated from exposed sand deposits in the bottom of dewatered Cell 4 during the raising of the Cell 2 dikes. In that case, up to 50% fines were allowed, with a corresponding limit on moisture content, reduction in lift thickness, and increase in compactive effort. The specifications for the Mid-Bay construction can be written to allow for the use of sand with greater fines content with appropriately modified placement and compaction requirements.

18. ***Postpone Internal Wetland Dike (Spec List Item 53):*** Postponing construction of internal wetland dikes (i.e. dikes that would be used for segmenting the wetland cells into approximately 40 acre units) will save on initial construction costs, increase wetland cell size, increase site capacity, and reduce borrow material required. Not only will it save money up front, it will allow time to better size the wetland cells based on lessons learned (i.e. Poplar Island Cell 3D and proposed Cell 3A/3B combination), pick better dike alignments for potential future wetland cell channels (i.e. 3rd order channels), and reduce volume of material required for creating the sand dikes. The volume of material required for internal wetland dike construction would be reduced by not having to build the dike all the way to the existing bay bottom. Sand material would be placed on top of dredged material following a few inflow events. Less sand would be required because some of the existing dredged material (recently placed) would offset the sand volume required. This technique was previously used in cell 3 and cell 1 at the Poplar Island Restoration Project.

Others present for the VE study disagree with parts of this approach. They have a concern that materials will "flow" when placed within the wet material and more sand material may be required as opposed to if it were completed during initial construction. Another potential problem with this approach would be it limits the flexibility of allowing water to be stored/transferred from one cell to another prior to discharge.

Comment from State of Maryland:
Seems like a good approach. If the internal wetland dikes are constructed late enough closer to when target wetland elevations are reached, maybe the dredge material would be less likely to displace when the internal wetland dikes are constructed. Is it possible that the material could be dewatered enough prior to internal dike construction and that existing dredge material could be used for the internal wetland dikes?

Comments to Mid-Bay VE study
From: Stacey Sloan Blersch, Baltimore District
Should state what size cells 1 and 3 are at Poplar island vs. the proposed acreage at James. Is it truly feasible to manage dredged material in an 1100 acre site without internal dikes? More details are necessary to make this claim.

19. ***Evaluate Telescoping Weirs (Spec List Item 42):*** The Baltimore District is considering the use of telescoping weirs for use in the disposal areas. This would allow for better control than an un uncontrolled open weir and variable control of the weir crests. It is suggested that this idea be more fully considered and used in final design. It will allow for better control and thereby produce a more valuable wetland.

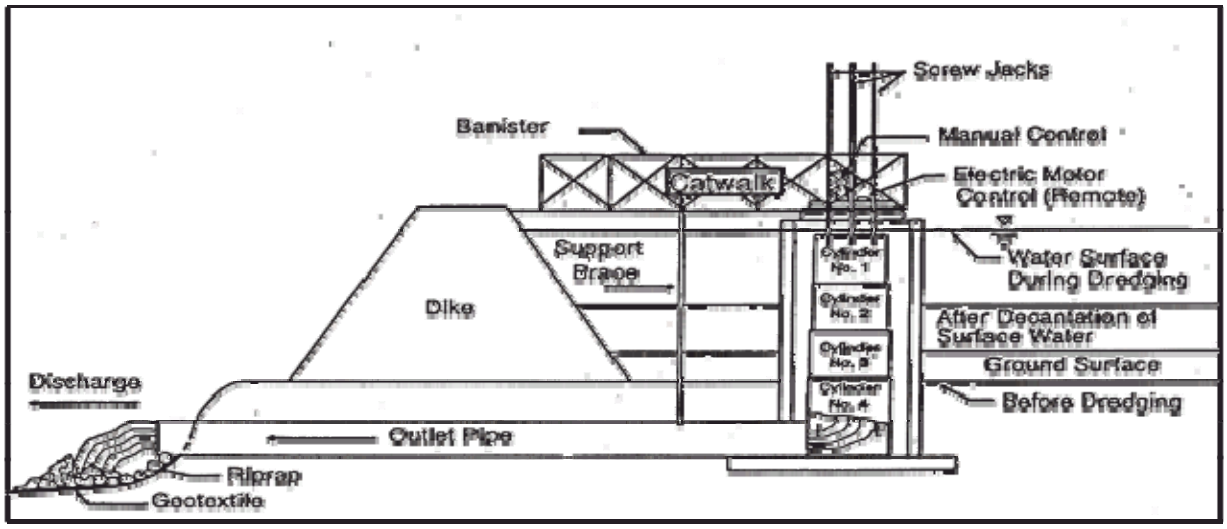


Figure 8. Schematic profile diagram, telescoping weir concept

Figure 12. Clear waters flowing over telescoping weir crest

20. ***Reevaluate Spillway Locations, Elevations, and Configurations (Speculation List Items 46, 47 & 68).*** The discussion on this topic at the Value Engineering Study centered on lessons learned about the existing spillways at Poplar Island. The main lessons learned were to (1) raise spillway invert elevations to 2.5 ft MLLW (high marsh elevation) so you don't have dredged material backing up into the upland cell from the wetland cell; (2) specify a better backflow preventer such as a flap or sluice gate; (3) lower sumps to allow collection of water and pumping through the spillways; and (4) site the spillways with the entire life cycle of the upland cell in mind, so that we don't abandon or have to retrofit a spillway as happened on the existing project. These issues will be addressed by the design team in consultation with the island staff during development of plans and specifications.

Comment from State of Maryland:
Understanding whether or not MDE will require discharge from the uplands to the wetlands, as at Poplar, is also important for spillway design

21. ***Use Internal Wetland Dikes For Channel Locations (In Curving, Sinuous Pattern) (Spec List Item 54):*** Excavating the deeper 3rd order channels in wetland cells presents a unique challenge. The surface of the cell will develop a crust thick and stable enough to support low ground pressure equipment and shallow excavations. Excavations below one to two feet become time consuming and difficult to maintain:

- The deeper material has a high moisture content. Excavations must be accomplished incrementally in order to dry and strengthen the material to support the side slopes. Many passes are required to achieve the desired depth.
- The weight of the consolidated surface will displace the softer underlying material-causing the bottom of the excavation to rise-up.
- Machinery working near an excavated channel will displace the softer underlying material causing the bottom of the excavation to rise-up.
- Rainwater and water leaching from the surrounding material will collect in the excavation. Positive drainage is difficult to maintain in dredged material. If it remains inundated sufficient wall strength will not develop and excavations cannot continue.
- Difficult cut and fill calculations are required. These calculations do not have a 1:1 relationship. A yard of excavated material from the channel may reduce to less then half of fill after the material has dried to a workable state.
  Equipment must traverse the entire site in order to spread the excavated material throughout the marsh zones. This creates ruts and challenging grading situations.

An alternate approach to this construction problem may be to construct a sand berm in the exact location of the third order channel. The berm would mimic the exact curving, sinuous pattern of the desired channel and would be constructed before the cell receives dredged material. If the material in the existing bottom were suitable, it would be worked in place to form the berm. After multiple inflow events and marsh elevations are achieved, the berm would act, as its own haul road for removal, leaving the final third order channel in its place. Advantages to this approach are:

- The sandy material would support the excavation and prevent dredge from entering the channel.
- Displacement issues would be resolved.
- Machinery near the edge of the channel would still use caution.
- Rainwater could be directed to a sump more quickly and would not greatly affect wall stability.
- Cut and fill calculations would not be necessary, all excavated sand would be hauled off and reused in other areas of the project.
- Equipment activity inside the cell would be greatly reduced.

22. ***Use Sequential Photography (Speculation List Item 58).***

The value engineering team recommends the use of sequential photography in monitoring habitat development. The Poplar Island Environmental Restoration Project currently uses photo documentation as one record of habitat development in wetland cells 4D and 3D. Platforms were established to ensure the photographs were taken from the same location and height over an established period of time. This protocol would be appropriate to include in the monitoring of habitat development for the Mid Bay project.

23. ***Use Slag for Erosion Control (Speculation List Item 63):***

The interior slopes of the containment dikes at the Poplar Island Environmental Restoration project and Hart-Miller Island Containment Facility have experienced significant erosion from wind generated waves along the waterline when water is ponded in the cells. Unarmored dikes also experience erosion from storm events. Since the sand source for construction of the dikes at James Island is fine-grained in nature, similar to that at Poplar Island, it is anticipated that the unarmored dikes at James Island will experience erosion similar to that at Poplar Island and Hart-Miller Island. Application of slag on the unarmored dike sections has the potential to reduce erosion and therefore reduce future maintenance and repair costs. Slag also has the

potential to be used in lieu of or in conjunction with CR-6 on the roadways.

Slag is a byproduct of making iron and steel from iron ore. Slag can be an environmentally sound material that has been used in construction aggregate applications and to help remediate environmentally damaged areas such as acid mine drainage.

Blast Furnace (BF) Slag is formed when iron ore or iron pellets, coke and a flux (either limestone or dolomite) are melted together in a blast furnace. When the metallurgical smelting process is complete, the lime in the flux has been chemically combined with the aluminates and silicates of the ore and coke ash to form a non-metallic product called blast furnace slag. During the period of cooling and hardening from its molten state, BF slag can be cooled in several ways to form any of several types of BF slag products.

Steel Furnace Slag is produced in a Basic Oxygen Furnace (BOF) or an Electric Arc Furnace (EAF). Hot iron (BOF) and/or scrap metal (EAF) are the primary metals to make steel in each process. Lime is injected to act as a fluxing agent. The lime combines with the silicates, aluminum oxides, magnesium oxides, manganese oxides and ferrites to form steel furnace slag, commonly called steel slag. Slag is poured from the furnace in a molten state. After cooling from its molten state, steel slag is processed to remove all free metallics and sized into products.

The Sparrows Point steel facility has been manufacturing steel and producing slag for many years. The slag is stockpiled on the facility. The facility is located near the mouth of the Patapsco River, approximately 49 miles north of James Island and has deep water access for ships and barges. Therefore, the slag is readily available and located within a reasonable distance from the project

BOF slag is the most available slag type at the Sparrows Point facility. The composition of BOF slag generally includes blast furnace iron and scrap steel, although the composition can vary between facilities. BOF slag at the Sparrows Point facility comes from a variety of on-site sources including freshly produced, weathered above ground, and buried sources.

The various sources of BOF slag may have different chemical characteristics that could potentially leach different concentrations of chemical compounds. Previous assessments of BOF slag from Sparrows Point and other International Steel Group facilities, including the results of Toxicity Characteristic Leaching Procedure (TCLP) and risk assessment analyses of BOF slag, have indicated that the risk of using slag in

aquatic environments is fairly low 1/. EA Engineering, Science, and Technology, Inc. 2/ evaluated BOF slag from the International Steel Group (ISG) Sparrows Point Facility as

potential construction material for dike building in Baltimore Harbor, Maryland. BOF slag was collected from the ISG Sparrows Point facility in November 2004. Chemical analyses and toxicological testing were performed on the slag to determine the environmental suitability of using slag to construct dikes. The analyses of bulk slag, slag leachate, and toxicity studies indicated that there is little potential for adverse affects to aquatic life from using ISG-SP slag as an in-water construction material in Baltimore Harbor. Chemical analyses of slag indicated that most of the detected concentrations of metals were generally low. While a few metal concentrations slightly exceeded the USEPA chronic criteria for aquatic life, there were no significant adverse affects found in toxicity studies.

Therefore, it is recommended that slag be evaluated during the design phase of the Mid-Bay project for potential use as erosion protection along the unarmored dike slopes and roadway construction.

1/ McLaren/Hart Inc. 1998. Human Health Risk and Ecological Risk Assessment: Basic Oxygen Furnace Slag. Prepared for Steel Slag Coalition, Washington, D.C.

2/ EA Engineering, Science, and Technology, Inc. June 2006. Draft Final Evaluation of Slag from the ISG-Sparrows point Facility as Construction Material for Dike Building in Baltimore Harbor, Maryland.

24. ***Evaluate Optimal Size of Wetland Cells (Speculation List Item 74):***

The optimal size of the wetland cell(s) should be determined on a case-by-case basis. When determining cell size, the following are items among those that should be considered: initial cost, construction efficiency, vegetation availability, timeline for plant growth, attainable slopes and planting elevations with material being placed, water quality, cell performance (settling efficiency), operations, etc. Final cell sizes should be carefully evaluated to insure adequate configuration/settling efficiency for upland cells and manageable cell sizes for construction efficiency and vegetation availability for wetland cells.

Making the wetland cells in the 100 to 250 acre range would reduce the number of segmented wetland cells required. This would reduce initial construction costs if internal wetland dikes were built right at the start of the job. If James Island were constructed using 40-acre cells for the wetland cells, this would result in nearly 17 miles of wetland dikes, increasing initial cost and decreasing site capacity.

Others present for the VE study disagree with the approach because planting larger cells (i.e. greater than 70 acres) may pose a plant material supply problem. Multiple vendors would most likely have to be used to supply the materials. The time required to plant such a large area might pose a problem (i.e. the planting season window may be missed). Finally, the process that is used to prepare the cell may not work as well as it did for Cell 3D at Poplar Island. Cell 3D was allowed to dry out during cell grading operations. Water was then allowed back in to re-hydrate the soil. The water was then let back out of the cell and the cell was planted. Planting larger cells with this approach may require the contractor to work much faster or to stop and start to allow the Bay water back in to re-hydrate the soil.

25. ***Consider Entire Bay, Funding Availability, and Build Most Erodible Islands First (Spec List Item 77):*** The following is an excerpt from an email received from Frances Flanigan, MPA Citizens Advisory Counsel, during the study:

> One issue which I feel compelled to raise on behalf of CAC, even though I am not sure it fits within the framework of this review, is the order of implementation of projects approved as part of both the Corps' and the State's DMMPs. As you may recall, CAC wrote a letter expressing the opinion that James and Barren Islands ought to be initiated BEFORE Poplar is expanded. They believe this because of the quickly eroding land masses at both Barren and James and because of the strong public support that exists in Dorchester County for these two projects, which are coupled in the DMMP as one. It appears that these two projects would bring environmental benefits at least as great as, if not greater, than expanding Poplar, and they would provide more capacity for dredged material placement than Poplar would. They suffer under the restriction (OMB) called "no new starts" which is I believe the principal reason they were not recommended in the DMMPs for immediate implementation. Since the Value Engineering team is returning in July to conduct a similar review of Mid Bay, perhaps bringing this point of view to their attention now is warranted. CAC meets on July 12 - we will look forward at that point to getting a report on the outcome of the Poplar review.

The OVEST personnel present at the study have seen the issue of basin-wide or state-wide or watershed-wide coordination come up during several studies. The team felt that during the subsequent study this matter should be looked at in more detail. If funding is limited by regions or basin, the concept of prioritizing the work could be considered.

26. ***Redo the feasibility study and EIS to incorporate VE results (Spec List Item 78):*** As approval for report has not yet been received, recommendations from the VE potentially could be incorporated into the study. If substantial changes to the recommended plan are made and costs modified as a result of the VE study, the feasibility study report would have to be modified to reflect these changes. Specific sections that would need to be changed are: the executive summary, sections 4, 5 and 7, as well as the engineering appendix. These changes could be done as part of the on-going feasibility process. Due to public perception, it would be best if recommended plan figures were changed prior to distribution of the draft report. Some proposals if excepted would require changes to the impact sections as well, such as proposals 21 and 27.

If changes are significant enough, such as those proposed in Proposal 1,6, and 7, some re-formulation may be required and additional public and agency co-ordination may be needed. Any significant change that would require re-formulation should take into consideration the impact to finalizing the feasibility report for approval. These impacts include re-doing the following: 1) dredged placement analysis; 2) benefit calculations; 3) incremental/cost effective analysis; 4) cost estimates; and 5) re-write portions of report. If the report is already approved and out for public review, a supplemental EIS or GRR may be required during the PED phase.

27. ***Use Hydraulic Placement of Dike Materials to the Greatest Extent Possible (Spec List Item 85):*** The discussion on this topic during the Value Engineering Study centered on providing placement of dike fill materials by hydraulic pipeline versus mechanical placement using end dumping methods by upland staged equipment. It is recommended to construct the rock toe perimeter features well in advance to more effectively utilize the hydraulic dredging and placement of the borrow materials. If materials can be placed directly to the areas of required fill by hydraulic means, the cost saving can be potentially great especially in the areas requiring submerged placement. Planning of several stock pile areas for sand materials around the perimeter should be considered to reduce haul distances for the remainder of dike construction.

28. ***Design Wetlands For Future Sea Level Rise (Spec List Item 91):***

Various reports have estimated a one to three foot increase in sea level for the Chesapeake Bay region over the next 100 years. Due to the very shallow slope of the continental shelf, sea level rise of this magnitude has the potential to inundate a great deal of the Eastern Shore of Maryland, including the wetlands proposed for restoration at James Island and Barren Island. Land subsidence in the Chesapeake Bay area

combined with global sea level rise produces an unusually high rate of local long-term projected sea level rise compared to global averages. Low marsh elevations at the current Poplar Island range from 1.2 to 1.8 ft; high marsh elevations extend from 1.8 to 2.5 ft. Restored wetlands at James and Barren would have similar elevations. An increase in sea level of one foot would transform the high marsh into a mixture of low marsh and intertidal habitat. The low marsh habitat would become intertidal and open shallow water.

Wetland processes generate peat that accumulates to naturally increase surface elevations to adapt to sea level rise. Some peat accumulation is expected in the restored wetlands, but it will likely not be enough to maintain a balance with sea level rise. However, there are multiple strategies for addressing sea level rise. Thin layer spraying, a technique that sprays a thin layer (approximately 2 inches) of dredged material over the surface of a wetland, has great potential for gradually increasing the elevation of wetlands to accommodate for sea level increases. Also, habitats could be constructed at higher elevations. An 80%/20% ratio of low marsh to high marsh configuration is targeted for Poplar Island, because low marsh has been greatly lost from the Chesapeake system and is viewed as more valuable by the resource agencies.

Development of a greater acreage of high marsh at the expense of low marsh could be achieved to permit the gradual inundation and transformation of high marsh into low marsh. As such, some of the counted benefits of the low marsh would be postponed until sea level rise causes the inundation of portions of the high marsh, but more habitat would likely retain benefits over the long-term when exposed to sea level rise. Lastly, tidal channels should be designed to transport any available mineral sediment to the wetland cells and encourage deposition on the marsh plain. Monitoring at James and Barren Island would be conducted to provide information on peat, below ground biomass, and soil development, as well as the tidal channel velocities and sediment transport, the depth & duration of marsh inundation, and patterns of sediment deposition in the restored wetlands.

It should be noted that the ratio of low marsh to high marsh has not been established yet for James or Barren Islands, though.

Comments from Stacey Sloan Blersch, Baltimore District
An 80% low marsh/20% high marsh ratio was not agreed upon yet in the Midbay study. Ratios would be set during PED to incorporate lessons learned from Poplar, focusing more on functioning habitat vs. set ratios. Sentence with ratios should be deleted or language referencing Poplar should be added.

29. ***Design Dike Height And Armor Protection For Future Sea Level Rise (Spec List Item 94):*** Various reports have estimated a one to three foot increase in sea level for the Chesapeake Bay region over the next 100 years. Land subsidence in the Chesapeake Bay area combined with global sea level rise produces an unusually high rate of local long-term projected relative sea level rise compared to global averages. An increase in relative sea level rise over the life of the project can affect both the structural stability and functional performance of coastal structures. An increase in relative mean sea level could result in larger wave heights near structures, higher wave runup and overtopping, increased damages and required maintenance, less wave protection and more shoreline erosion in the later years of the project.

Current Corps policy described in its *Planning Guidance*, Engineering Regulation 1105-2-100, Appendix E, Section IV.E-24.k (USACE, 2000) requires that the Corps will address the risks and uncertainty associated with both historically determined and future estimates for sea level rise rates. The possibility of sea level rise can be incorporated into the original design for the project by increasing the stone size and armor height. It could also be managed through adaptive management over the life of the project by raising the structures or adding larger stone as required after the effects of sea level rise can be confirmed. Consideration should be given to features that can also be incorporated into the original design to facilitate future project modifications accomplished through adaptive management.

Since the ERDC Life cycle analysis of the armor protection at James Island indicates that the dike heights of +8 and +10 feet and stone sizes in the feasibility study design are conservatively sized, it is likely that this design will perform adequately with a 1 foot increase in sea level. However, optimization of structure crest height and armor stone size performed during PED should consider the risk and uncertainty of different sea level rise scenarios.

30. ***Remove Rock From Lee Side Of James Island After Island Is Established (Spec List Item 96):***

The armor on the lee (east) side of James Island along the wetland perimeter dike consists of 500 lb armor stone and 1000 lb toe armor stone. The idea was suggested to remove the rock after the wetland cells have been filled and the wetland vegetation and tidal channels have been established. This would provide environmental value as the shoreline would become a beach that would be used by terrapins and shorebirds as nesting habitat. The site would have to be evaluated at the future date of completion as regards shoreline protection to minimize beach erosion. If the existing James Island remnants remain, they would provide some protection, however, additional structures may be needed.

Additional future costs would be incurred to remove the approximately 170,000 tons of rock from the dike. This rock could be used elsewhere on the project as needs dictate, however, the large quantity suggests that it would not all be used. As noted in the following comment, any rock not otherwise needed could be utilized to create rock reefs.

31. ***Create Rock Reefs on North and lee sides of James Island (Spec List Items 97 and 98):***

Small rock reefs would be constructed on the North and possibly the lee sides of the James Island project. These reefs would be similar to those created at Poplar Island although the design could change somewhat. Research at Poplar Island has indicated that these reefs increase the diversity of the fish community and increase the number of large predatory fish. These reefs will need to have clear navigational warnings placed on them.

32. ***Optimize Unloading Site Location and Configuration on James Island (Speculation List Item 99).***

The current location of the unloading basin may be the optimal location, but will likely require that a large sand dike be constructed within the upland cell. This could likely be avoided if the turning basin were placed in a wetland cell. As the project continues to evolve, consideration should be given to optimizing the location of the unloading basin. Considerations should include orientation to minimize wind and wave exposure, proximity to center of island, the dredging required to create access, the need for constructing additional dikes, measures for minimizing the erosion of interior dikes, and ease of habitat development following closure of the unloading basin.

33. ***Optimize Number Of Breaches, Size And Number Of Tidal Channels On James Island (Speculation List Items 100 and 101)*** Optimization of the breaches and tidal channel design will allow the proper establishment of wetland habitat. Guidance developed through the lessons learned from Poplar Island, reference marsh study, and hydrodynamic modeling will assist in determining requirements for tidal flows, circulation and flushing throughout the marsh system. Flow capacities for a variety of channel shapes (top width, toe width, channel depth, slope requirements) and alignments will be analyzed to determine the optimal design for both the primary tidal guts and the tidal channels within the wetland cells. Design requirements for tidal flats, low marsh, high marsh, and other habitats such as bird islands will be incorporated to develop the

proper balance of the number, location, and size of the tidal channels. Tidal channel design will consider the specific hydrologic requirements of the desired wetland species to provide sufficient depth and duration of flooding, as well as adequate flushing of nutrients and sediment transport to the wetland cells.

Wetland design, layout of wetland cells within James Island wetland, construction phasing and size will all be utilized to determine number of breaches needed between the individual wetland cells and the tidal gut that runs through the center of the wetland. Circulation, habitat and similar systems at different stages of development at Poplar Island can provide working knowledge of the capabilities of the design. The design should review construction expenses, installation, development, as well as the establishment of design tolerances for developing the correct types of habitat on James Island.

34. ***Consider Infrastructure For The Beneficial Use Of Dredged Material At Other Sites As Part Of The James Island Project In Accordance With DMMP (Speculation List Item 105):*** The State and the USACE collaboratively incorporated the beneficial use and innovative reuse of dredged material, into their respective DMMP's. In the long-term planning, Cox Creek Dredged Material Containment Facility (DMCF) has been identified as a staging/storage/processing site for the possible innovative reuse of dredged material. A similar concept has been suggested by the VE team to utilize James Island as a possible staging/storage/processing site for the beneficial reuse of dredged material in the long-term.

Several workshops and conferences were sponsored by either the State or USACE to help understand the potential beneficial reuse of dredged material from the Chesapeake Bay:

- A technology forum on innovative reuse of dredged material at Radisson Hotel in Annapolis was held on December 9, 2004;
- A one day targeted scoping Chesapeake Bay Marsh Restoration Workshop at the Blackwater National Wildlife Refuge Administration Building was held on March 10, 2006; and
- An International Tidal Wetlands Conference was held between May 31–June 2, 2006 at Salisbury University to discuss the ecological, economic and engineering issues associated with using dredged materials to restore the eroding marshes of mid-Chesapeake Bay.

35. ***Optimize Phasing Of Island Construction (Speculation List Item 115).*** The feasibility study assumes that James Island containment dikes will be constructed in one continuous operation. The study team recognized the political and economic realities of constructing this large of a project, and discussed options to phase the project in the most efficient manner. At this time, there is insufficient technical data, direction (see Partnering comment in this study), and knowledge of the funding stream, to adequately formulate a construction phasing contingency plan. It is recommended that following the partnering session and PED data gathering, the PDT develop contingency plans to address phasing.

36. ***Use Submerged Reef For Protection Of SAV And Creation Of Oyster Habitat At Barren Island In Combination With Breakwater (Spec List Items 117 & 127).***

Submerged reefs could be created in combination with the emergent breakwaters extending from the southern tip of Barren Island to provide suitable habitat for oysters, as well as wave energy dissipation for SAV. The crest height of one or more breakwater segments, or even a portion of a continuous breakwater, could be reduced below the mean lower low water elevation (MLLW) to convert them to submerged reefs suitable for oyster habitat. Separate submerged reef islands for oyster habitat could also be created in sheltered waters behind either continuous or segmented breakwaters to provide additional wave energy reduction for SAV. A hydrodynamic and sediment transport analysis would be required to evaluate the effectiveness of alterative combinations of submerged reefs and emergent breakwaters in reducing wave heights to levels tolerable to SAV. The hydrodynamic and sediment transport analysis will also be needed to ensure that there are no adverse effects on current velocities and sedimentation/erosion that could adversely impact SAV, oysters, and other aquatic life. A significant cost savings could be gained by a reduction in required stone if submerged reefs are determined to be effective in reducing wave energy in combination with other breakwater structures.

37. ***Buy James Island Remnants on East Side and Utilize as Part of New Shoreline (Spec list Item 125):*** The existing remnants of James Island, which are located on the east side of the proposed island restoration project, are privately owned. Currently, the recommended alignment of James Island lies adjacent to, but does not touch the existing Island. The Value Engineering team suggested looking into the possibility of the Maryland Port Administration (MPA) purchasing James Island from the landowner. There are advantages and disadvantages to purchasing the land which are outlined below:

Advantages:

- The Corps would have more flexibility in the location of the alignment for the proposed island restoration project at James Island. If surveys and borings demonstrated that there were shallower depths and/or available borrow material closer to the existing remnants, the Corps could potentially alter the recommended alignment to either encompass the existing remnants or tie into the existing shoreline. If the alignment were tied to the remnants, the costs would likely be reduced due to lesser need for dike construction/armoring.
- The potential would exist to increase the size of the restoration project, in turn, increasing capacity of James Island if the Corps had more flexibility in the alignment of the proposed project. If capacity is increased, it is anticipated that costs per cubic yard would be reduced.
- There would be fewer restrictions on controlling the invasive species on the existing remnants of James Island because permission would not have to be granted from the landowner for species control and accessing private property.
- If MPA owned James Island, this would eliminate the potential for disputes with the existing landowner during construction and operation. Potential disputes could result from a disruption in the viewshed from the existing James Island and/or increased noise levels due to construction of the island restoration project. Other potential disputes that could arise with the landowner that would be avoided if MPA owned the land include claims that the construction of the island restoration project at James Island resulted in a change in currents causing increased erosion of existing James Island, or the potential that the restoration project would result in accretion of material on the eastern side of the project. Over time, the accretion could result in the restoration project at James Island reconnecting to the existing island remnants, which would result in ownership issues of the restoration project.
- There would be a reduction in the potential “injury claims” to the existing James Island property by the island restoration project.
- If the owners of existing James Island currently use their property for recreation, MPA owning the property would avoid the current owners claiming that the recreation on their property was disturbed by the project.
- The current owner of James Island would not be able to claim that their property value was reduced due to the island restoration project.

Disadvantages:

- The cost of the project would increase by the purchase price of the real estate.
- There is potential liability that is associated with owning any property, such as personal accident or injury occurring on the island.
- Political controversy over the site may increase if the current owners of James Island do not want to sell their real estate.
- MPA would be responsible for preventing and/or repairing any unapproved use or destruction of property on the remnant islands.
- Incorporating existing remnants into the plans might require revising both the feasibility and environmental impact studies and zoning permits

38. ***Raise Dikes with Dredged Material (Spec List Item 40):***

Instead of raising dikes with sand from borrow sources, use dried dredged material harvested from the surface of the materials contained within the upland cells to construct the upper portions of the dikes, particularly the upper five feet of the dike section that will temporarily contain dredged material until the final upland elevations have been achieved. Afterward, the temporary dike sections will be removed and incorporated into the upland cell surface grading.

It is difficult to assess whether this alternative will be less costly than dike construction using sand. Preliminary estimates indicate that there may be a small cost savings, but it is possible that a more thorough estimate may show that use of dredged material is more costly. However, it does reduce the demand on limited sand borrow materials and can provide a satisfactory embankment section that will perform the required dredged material containment.

This idea can be further evaluated based on experience with a similar proposal on the Poplar Island Expansion.

CONTACT DIRECTORY

Value Engineering - Attendance Register
Mid-Bay ERP - Chesapeake Bay, MD - July 2006

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Value Engineering - Attendance Register
Mid-Bay ERP - Chesapeake Bay, MD - July 2006

Name / Title	Office and Location (City, State, Zip)	Access (Telephone - voice, fax; Email)
Angie Sowers USACE - Engineering	10 South Howard Street Baltimore, MD 21201	410-962-7440 angela.sowers@usace.army.mil
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Fran Flanigan MPA Citizens Advisory Committee	6305 Blenheim Rd Baltimore, MD 21212	410-377-2532 frances.flanigan@verizon.net
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Jim Henderson, SAW-TS-EE Regional Technical Specialist Cost Engineering Dredging	USACE, Charleston District 69-A Hagood Ave Charleston, SC 29403	843-329-8141 james.e.henderson.jr@usace.army.mil

SPECULATION LIST

C Comment
BD Being Done
P To be Developed
X Not to be Developed

P, C, BD or X	#	Description
C	1	Build the uplands on the West side of James Island
P	2	Use lower height of armoring on dikes (ERDC)
P	3	Optimize the stone size and cover for the dikes
X	4	Use sand as the core of the breakwaters in lieu of rock
X	5	Use Geotubes in lieu of breakwater for Barren
C	6	Do not restrict wetlands from being built over borrow sources
C	7	Build Wetland on the East side
BD	8	Reduce dike/breakwater lengths for Barren
X	9	Use existing dredged material for the dike cores
X	10	Use Geotubes for core of interior dikes
P	11	Use Geotubes in lieu of stone for core of toe dikes (Exterior perimeter)
X	12	Use consolidated dredged material to fill borrow pits
C	13	Use sequential dredged material drying areas
X	14	Use flocculent on the dredged material
X	15	Use vinyl sheetpile for part of the dike
C	16	Create Island habitat near NE corner of Barren
C	17	Use rubble mound habitat islands for Barren (w/16, 85)
C	18	Use T-groins as breakwater on west side of Barren
BD	19	Use flexible growth medium for protection against erosion
P	20	Use segmented breakwaters on NW side of Barren with periodic renourishment
P	21	Develop beach on east side of James Island in lieu of rock
X	22	Use tire jacks for protection for interior protection
X	23	Create a water treatment plant for effluent
X	24	Remove the unloading basin from the project
P	25	Provide designated area for dewatering dredged material in lieu of topsoil
P	26	Drill wells to support upland vegetation
P	27	Create nesting areas for turtles (w/ 20)
BD	28	Use pole mounted nesting areas
C	29	Use reference marsh for guidance
C	30	Conduct a partnering session to agree on the future direction of the project

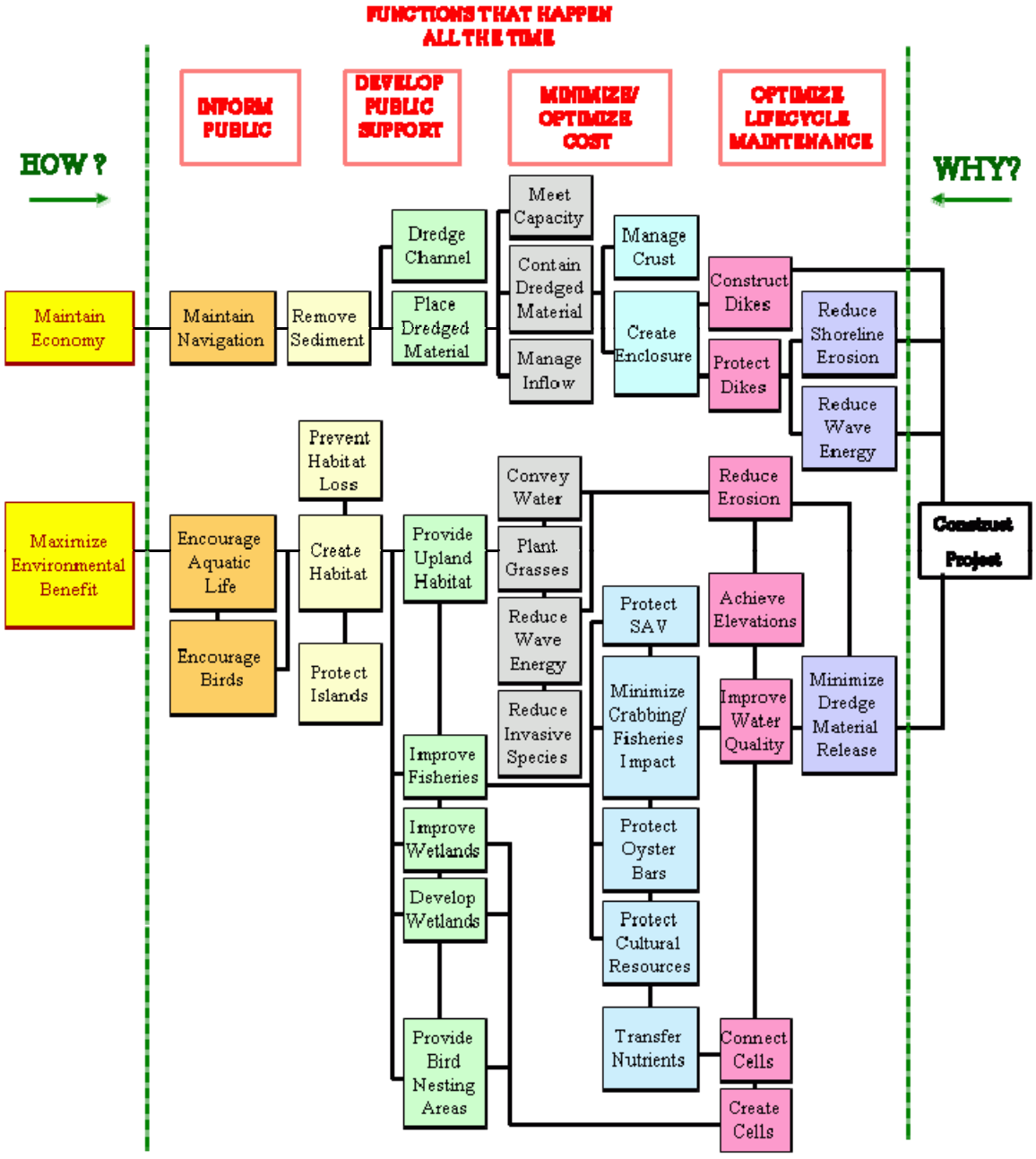
P, C, BD or X	#	Description
BD	31	Evaluate existing construction techniques with respect to future maintenance
X	32	Use soil cement dikes
X	33	Use roller compacted concrete for the dikes
C	34	Allow higher percentage of fines in the upland dike sections
BD	35	Revisit the cost and performance of the plantings
BD	36	Use more volunteer planting
BD	37	Place aids to navigation in the project
BD	38	Revisit the need and size of future buildings
BD	39	Revisit the design criteria for the storms
C	40	Raise the dikes with dredged material
X	41	Use interim stack dike raise (terraced)
C	42	Evaluate telescoping weirs
X	43	Consider labyrinth weir
BD	44	Plan for ultimate weir height
X	45	Use contractor designed weir
C	46	Reevaluate the spillway discharge invert elevations both wetland and bay
C	47	Use a drop inlet and pump in lieu of gravity flow through the dikes
X	48	Use a temporary dike protection in an area where a future breach will occur
X	49	Use blasted wetland channels
X	50	Use a Fabridam for the protection of the beaches until marsh is established
BD	51	Revisit the tolerance on the wetland fill elevations
BD	52	Determine optimum ratio in the low marsh, high marsh ratios and allow flexibility in operation
C	53	Postpone internal wetland dikes
C	54	Use internal wetland dikes for channel locations (in curving, sinuous pattern)
P	55	Create topsoil on site
X	56	Add observation tower
X	57	Add solar powered webcam
C	58	Use sequential photography
X	59	Use coir logs to define the channel through the wetlands
X	60	Use floating breakwater for Barren
BD	61	Provide aquatic life survey data to the public
X	62	Consider use of soil cement mix on interior dikes
C	63	Use slag for erosion control
X	64	Use gabion baskets for protection
BD	65	Determine the best vegetation for the uplands

P, C, BD or X	#	Description
BD	66	Design upland topography to provide freshwater for vegetation
BD	67	Design the connectivity between the uplands and wetlands
C	68	Optimize spillways from uplands to wetlands
BD	69	Design dike to minimize erosion
BD	70	Design the offloading facility
X	71	Use Articulated Concrete Mattress for roads
X	72	Use calcium sulphate hemahydrate (CSH) for road stabilization
X	73	Stabilize the roads and banks with a geogrid
C	74	Evaluate size of wetland cells
BD	75	Optimize plant spacings
BD	76	Allow flexibility in the schedule to plant the cells
C	77	Consider entire bay, funding availability, and build most erodible islands first
C	78	Redo the feasibility study to incorporate VE results
BD	79	Provide a freshwater pond in upland cells at James Island to enhance habitat diversity
BD	80	Add bird islands to the wetland cells at James Island
BD	81	Include a citizen group / environmental group in partnering for dredged disposal plan
X	82	Allow chert in the stone protection
X	83	Reevaluate the placement criteria
X	84	Increase the tolerances on the dike sections
C	85	Use hydraulic placement of dikes
C	86	Design the breakwaters as bird islands
C	87	Reevaluate the road design based on final design
BD	88	Evaluate existing erosion problems (w/68)
X	89	Use concrete slope paving over bedding for dike face
BD	90	Consider life cycle cost and value in the project features
C	91	Design wetlands for future sea level rise (w/93)
X	92	Investigate the size of non grizzly rock from source
X	93	Regrade or shape topography of channels through wetlands
C	94	Design dike height and armor protection for sea level rise (w/90)
P	95	Provide undulations, pockets, small coves on lee side of both islands
C	96	Remove rock from lee side of island after island is established
C	97	Build rock reef off James Island on lee side
C	98	Build rock reef off James Island at NW point
C	99	Optimize unloading site location and configuration on James Island
C	100	Optimize number of breaches, and size and number of tidal channels on James Island

P, C, BD or X	#	Description
C	101	Optimize final tidal channels for James Island (w/98)
BD	102	Develop fill sequence to maximize dewatering for upland cells
BD	103	Evaluate effects of project on natural local channel south of James Island
X	104	Build bridge from Taylors Island to James Island
C	105	Consider infrastructure for beneficial use of dredged material at other future sites as part of James Island project in accordance with DMMP
X	106	Use pontoon-mounted equipment to move material in lieu of building roads
BD	107	Design bird islands inside low marsh wetlands at James Island
BD	108	Optimize height of protection at Barren Island
BD	109	Evaluate segmented breakwater at Barren Island
BD	110	Consider purchasing mainland real estate on Taylor Island for a land base
C	111	Build bird islands south of Barren Island
P	112	Build 13' wide road with occasional widening
X	113	Reclassify southern tip of NOB 14-5 to allow more efficient use of borrow area
BD	114	Control phragmites on existing islands
C	115	Optimize phasing of island construction
X	116	Use submerged reef for protection of SAV at Barren in lieu of breakwater
C	117	Use submerged reef for protection of SAV at Barren in combination with breakwater
X	118	Relocate personnel access pier closer to offloading point and operations facility
X	119	Create upland/wetland mix on Barren
X	120	Extend footprint of Barren to west in accordance with historic shoreline
X	121	Enclose Barren to east
X	122	Establish land-based staging area for Barren Island
X	123	Allow some phragmites
X	124	Use phragmites for limited slope stabilization
C	125	Buy James Island remnants on east side and utilize as part of new shoreline
X	126	Create oyster beds in cove area on east side of Barren Island
C	127	Create oyster habitat along east side of new breakwater
X	128	Use geotechnical data already gathered at James Island in lieu of continued exploration.

FUNCTION ANALYSIS SYSTEM TECHNIQUE (FAST) DIAGRAM

Mid-Chesapeake Bay Island Ecosystem Restoration
FAST Diagram



FUNCTION ANALYSIS SYSTEM TECHNIQUE
(FAST DIAGRAM)

COMMENTS ON DRAFT VALUE ENGINEERING REPORT

Comments from State of Maryland on Mid-Bay Value Engineering Study

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Environmental Specialist
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Mid-Chesapeake Bay Island Ecosystem Restoration
USACE Value Engineering Study
July 2006

Page	Section	Paragraph	Comment	VETL Response
			In proposal/ comment titles, make sure that James or Barren or both are specified as the target for the comment/proposal.	Done
			It is difficult to see all details in drawings on Pages 17, 18, 24, 48 and 54. Could these drawings be enlarged possibly with a landscape orientation to be able to read all small details?	Will comply if possible; drawings not provided electronically
64	VE Comments	Number 17	It's not quite clear whether this section is referring to Poplar or MidBay, the discussions of Cell 2 and Cell 4 seem to be about Poplar—it may need to be specified which projects the prior sentences refer to.	Paragraph was revised for clarification
77	VE Comments	Number 37	Should the "disadvantages" note that incorporating the existing remnants into the plans will require revising the studies and possibly permitting?	Added to disadvantages
27	Proposal 3		Would MDE be concerned about filling/ constructing wetlands behind segmented breakwaters? If so, it should be noted that permitting concerns were considered, and/or an explanation about construction precautions (having a whole dike and then segmenting it into a breakwater after filling activities) may be helpful.	Comment will be added to Proposal

32	Proposal 4		Should the "Disadvantages" or "Justification" section account for the smaller size or absence of the remnant island by the time the project is constructed? The justification section cites the islands as existing protection for this proposal--but the current degree of protection is not guaranteed for the future due to the ongoing erosion.	Comment will be added to Proposal
37	Proposal 5	Advantages	Having a stock pile of ready to use topsoil will allow for the planting to be done over time, at different times, and/or in succession - rather than having all the plants planted at once. This could also promote healthier vegetation and help with plant diversity.	Concur. Will add to advantages
37	Proposal 5	Advantages	Having long term leaching of low pH into the wetlands or nearby waters could increase dissolved metals and could have a negative water quality and ecosytem impact. Leaching of salts would be less problematic, but it is likely that lime or other high pH amendment will still be required.	Added to Disadvantages
41	Proposal 6	Proposed Design	Would need to consider which aquifer the wells would be located in. The Aquia is having saltwater intrusion issues on the eastern shore and is being tapped beyond its ability to recharge. Irrigation wells might be able to tap non-potable aquifers.	Added to Disadvantages
39-40	Proposal 5	Worksheets	The cost associated with routinely tilling of material to expose new material to surface does not appear to be accounted for in the cost estimate worksheets on pages 39 and 40.	Note added to Proposal 5
44	Proposal 6		I think the cost estimate on page 44 is high. The mob and demob costs for drilling at Poplar include only one well. The cost per well would be reduced with 5 wells since the mob and demo costs would be spread over 5 wells.	Note added to Proposal 6. Similar comment raised by Balt. Dist. VEO
46	Proposal 7	Disadvantages	The curving of the dike will only be “slightly” more expensive/ difficult? It may be appropriate to delete “slightly”. Also wouldn’t the constructing the dike on a curve be more time consuming and expensive for labor in addition to materials? Would QC be more difficult?	Comments added to Disadvantages

	General		Regarding Wetland Cell/Upland Cell sizes: Suggest some general mention of the need to carefully evaluate final cell sizes to insure adequate configuration/settling efficiency for upland cells and manageable cell sizes for construction efficiency and vegetation availability for wetland cells.	Comment added to Comment 24
	General		Regarding Stone quantity reductions: need to ensure that adequate life-cycle type evaluation has been made of stone needs to avoid artificially lower initial construction costs vs higher State maintenance costs later.	Note added to Proposal 1
23	Proposal 2	Proposed Design	Do geotubes and geocontainers have the same expected lifespan as the rock? Is this recommended for windward and leeward sections of the island, and for both islands, or just Barren?	Long lifespan is expected for geosynthetic containers unless exposed to UV rays, scouring or physical abuse
27	Proposal 3	Disadvantages	I don't understand why this wouldn't incur future maintenance and why it is advantageous to allow sand to be lost from the wetlands. Wouldn't this cause them to erode?	Breakwaters slow down loss of sand by reducing wave energy
41	Proposal 6	Advantages	"Will not interfere with current water supply to the facility." - (?) There is no current water supply.	Reworded to "Will not require water supply from off-island to facilities"
41	Proposal 6	Advantages	"Provides back-up if existing well is temporarily or permanently taken off line." (?) there is no existing well.	Concur. Advantage was deleted.
51	Proposal 8		This is a good proposal. There maybe other areas that would require greater than the 13' width, such as any area where wider equipment (pontoon trencher) might have to travel or be hauled. – From barge unloading area or to maintenance area.	Note added to Proposal 8
51	Proposal 8	Disadvantages	Disadvantages should include - loss of production due to (dump trucks/passenger vehicles) stopping in every passing situation. During a hauling operation, this will add several minutes to each round trip. This detail is not captured in the cost worksheet.	Added to Disadvantages

51	Proposal 8	Disadvantages	On dike roads used around wetland cell areas there is no bench for heavy equipment (excavators) to work off when digging perimeter trenches and/or conducting other work in the wetland cell area. With a small road width and an excavator working in a wetland cell from the dike road, that road will be completely out of service for all other equipment to pass. Depending on the work being conducted elsewhere on the island, this could have an impact on the costs if additional travel distance and time are required because a perimeter road is closed along one of the wetland cells.	Added to disadvantages
64	VE Comments	Comment 18	Seems like a good approach. If the internal wetland dikes are constructed late enough closer to when target wetland elevations are reached, maybe the dredge material would be less likely to displace when the internal wetland dikes are constructed. Is it possible that the material could be dewatered enough prior to internal dike construction and that existing dredge material could be used for the internal wetland dikes?	Note added to Comment 18
65	VE Comments	Comment 19	Maybe the telescoping weirs from Poplar could be moved to James, which could save money. Poplar will likely not need them by then.	Not cost-effective.
66	VE Comments	Comment 20	Understanding whether or not MDE will require discharge from the uplands to the wetlands, as at Poplar, is also important for spillway design	Note added to Comment 20
73	VE Comments	Comment 30	Could the removed armor rock be used for rock reefs as in Spec Items # 97 and 98 or island habitat like Spec Item # 16 if constructed later after armor is remove rather than during initial construction phase? The rock reef or island habitats would not have to be only part of the James Island, but appropriate areas needing structures nearby in the Bay?	Will be considered during evaluation
1	VE Team Members		"Ronald Limpert" should be "Roland Limpert"	Revised
5	Description/Background	Para 1	Define "mcy"	Revised to "million cubic yard"

6	Description/Background	Para 4	Sentence 6: delete "12"	Revised
7	Description/Background	Para 3	End sentence after "sponsor of the project."	Revised
11	Exec. Summ.	Para 1	Delete the following from the paragraph: EA Engineering, Findling, Inc., and GBA	Revised
11	Exec. Summ.	Speculation Phase	Don't think GRR has been previously defined in this report	Revised
15	Proposal 1	Para 2	"Polar" should be "Poplar"	Revised
15	Proposal 1	Para 2	In last sentence, insert "at" after "these costs"	Revised
35	Proposal 4		Label, fix formatting on bottom drawing.	Location not clear
37	Proposal 5	1 of Proposed Design	Sentence 1: "dredge material" should be "dredged material"	Revised
37	Proposal 5	1 of Proposed Design	Sentence 2: "dredge material" should be "dredged material"	Revised
37	Proposal 5	1 of Proposed Design	Sentence 2: "manor" should be "manner"	Revised
37	Proposal 5	2 of Proposed Design	Sentence 4: replace "me" with "be"	Revised
37	Proposal 5	2 of Proposed Design	Sentence 5: "dredge" should be "dredged material"	Revised
37	Proposal 5	Advantages	Bullet 6: replace "then" with "than"	Revised
37	Proposal 5	Advantages	Bullet 8: "dredge" should be "dredged"	Revised
38	Proposal 5	Disadvantages	Bullet 6: "21/2:1" should be "2-1/2:1"	Revised
38	Proposal 5	Justification	Sentence 2: "dredge material" should be "dredged material"	Revised
38	Proposal 5	Justification	Sentence 3: "sometime" should be "sometimes"	Revised
39-40	Proposal 5	Worksheets	It may be helpful if the worksheets were labeled 5a & 5b	Revised
45	Proposal 7	3 of Proposed Design	Sentence 1: "that" should be "than"	Revised
52	Proposal 8	Header	Correct header?	Revised
52	Proposal 8		Is wording in 2nd item of worksheet correct?	Yes
	VE Comments		The use of “No” and “Nos” is inconsistent in the comment titles.	Revised; deleted No, Nos, and #
56	VE Comments	Number 10	In numbered (1, 2) list, add "3)" in front of the text "A borrow analysis ..... allowable extent."	Revised
57	VE Comments	Number 11, Para 2	Sentence 1: "Mcy" should be "mcy"	Revised
57	VE Comments	Number 11, Para 2	Sentence 1: "Acres" should be "acres"	Revised
60	VE Comments	Number 14, Adv.	Bullet 1: "addition" should be "additional"	Revised

62	VE Comments	Number 15, Para 1	Insert “layer” after “Geotextile” or delete “A”.	Revised
62	VE Comments	Number 15, Para 1	"T-Groins" should be "T-groins"	Revised
62	VE Comments	Number 15, Para 4	In first sentence, delete "the" in "however, the there"	Revised
62	VE Comments	Number 15, Para 4	1st sentence may need elaboration; it seems to contradict itself as written.	Revised
63	VE Comments	Number 16, Para 1	Sentence 3: delete "of" after "benchmarks"	Revised
64	VE Comments	Number 18	“lean” should be “learned”	Revised
64	VE Comments	Number 19	It may be helpful for the text to mention that telescoping weirs have been installed at Poplar and they are good/bad to be used.	Will discuss
66	VE Comments	Number 21	1st bullet, line 3, change “may” to “many”	Revised
67	VE Comments	Number 21	Bullet 1: "dredge material" should be "dredged material"	Revised
67	VE Comments	Number 21	Bullet 2: "issued" should be "issues"	Revised
69	VE Comments	Number 24	This comment about studying optimal wetland size can refer back to the benefits of a reference marsh(es) study discussed in Comment 16.	Subjects of two comments are different.
72	VE Comments	Number 28	1st full paragraph, has the 80/20 split for MidBay, or is this referring to Poplar? Should specify if it’s not MidBay. As with Comment 24, the last lines of this comment description discuss studying peat accumulation and belowground biomass that could be linked to the reference marsh study. May want to consider combining discussions of Comment 16, 24, & 28 similar to how Comment 14 was handled.	Ratio has not been established yet.
74	VE Comments	Number 31	If it’s a consideration to use rock from Comment 30 to build reefs for Comment 31, it should be noted in text.	Comment 30 revised.
	Attendance Register	General	Address for MES should be "Millersville" not "Millesville"	Revised
79	Attendance Register		Should the first name in this table be William Easley?	Revised
79	Attendance Register		"Don Wilson" at "Gabagon…" should be "Dan Wilson" at "Gahagan…"	Revised
80	Attendance Register		For Stephanie Lindley, move "Maryland" to next line	Revised
80	Attendance Register		For Walter Dinicola, "Blasdand" should be "Blasland"	Revised

From: Vogel, John K NAB02
Sent: Friday, July 28, 2006 2:49 PM
To: Easley, William S SAC *(Responses added in italics)*
Subject: A Few Comments: Value Engineering Report, Mid-Chesapeake Bay, MD
Hey Bill,

Please review the following comments and advise intended action:

Cover - Please make me a "PE, CVS" (just like you :-}])
Done

Pg 14, prop 1 - a noted disadvantage is that this proposal will reduce the safety factor envisioned by Cmt 29
Added to disadvantages

Pg 27, prop 3 - advantage 2 and disadvantage 1 seem to be in direct conflict
Do not agree. Proposal allows greater interaction of both water and sand between island and bay.

Pg 37, prop 5 - this remains the mess it was for the PIERP study. Suggest you revise the title to something more sensible like "Create Topsoil Onsite". Remove the 3rd paragraph - it is of no consequence to the report altho you can explain it to Pete if you want to
Proposal modified for clarification

Pgs 39 & 40 , prop 5 - Get and include source of cost data
Cost data used from Poplar Island GRR

Pg 44, prop 6 - Apparently, the cost includes 5 mobes/demobes at 02 price level + 20%. - 3 more than necessary as there are only 2 sites.
Estimate is based on total well materials and installation, of which mob and demob is a minor cost. Proposal writeup indicates that one well would be included at Barren Island, but several would be required at James Island.

Pgs 49 & 50, prop 7 - Get and include source of cost data
Source of cost data was the same as Proposal # 2: Poplar Island Phase II escalated 25% + add'l haul

Pg 58, cmt 13 - Don't mix metric - hectare & english - acre units of area
"2 to 10 hectares" changed to "5 to 25 acres"
"250 meters" changed to "820 feet"

Pg 65, cmt 19 - Telescoping weir provides better control compared to what?
Second sentence revised to "This would allow for better control than an un uncontrolled open weir and variable control of the weir crests."

Pg 79, Attendance Register - 1st entry is you, not me.
Corrected

Comments from: Angie Sowers, Ph.D.
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US Army Corps of Engineers, Baltimore District
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Fax: 410-962-4698
angela.sowers@usace.army.mil

(Responses added in italics)

p1- State full name of project rather than 'Mid-Bay Islands'
Will correct

p1, end of first paragraph- Should it be 'Maryland Port Administration' rather than 'Port of Baltimore'
Wording was borrowed directly from Draft Integrated Feasibility Report and EIS. Will be revised in VE report.

p2, 5th line- insert 'combined into 8 island complexes and' The 20 remaining islands were further combined into 8 islands/island complexes and evaluated by the PDT~~, using lessons learned in the design and construction of the Poplar Island restoration project.~~ based on engineering and environmental suitability criteria.
Paragraph revised as noted.

P2, 2nd paragraph, first line after list- change 'environmental' to 'island'
Done

P2, 3rd paragraph, 7th line- delete '12' after 'James Island
Done

P9 and p10- Title of figures should be 'Recommended Plan' not just 'plan'
Done

P11, 1st line- insert 'Ecosystem' prior to 'Restoration' in project name
Done

P11- list of contributors contains both GBA and Gahagan and Bryant- these are the same; add abbreviations for all names and change NOAA to NOAA-NMFS
Done

Be consistent with how we abbreviate US Army Corps of Engineers and identify what abbreviation will be in 1st paragraph- e.g. Start of 2nd paragraph says 'Corps of Engineers'
Done

P11, Speculation Phase- The document we have is not an 'approved GRR plan'
Changed to "recommended plan"

Proposal 2- Please add definition/description of GeoContainer
Paragraph added, "GeoContainers or GeoBags are specific sized geosynthetic containers which are designed to contain materials such as dredged materials or

HTRW. Using consistently sized containers may be easier for construction managers to define specific procedures for workers."

Proposal 5, p37, 'Proposed Design' section- change 'dredge' to 'dredged'- also needs to be changed in the 8th bullet of the 'Advantages' section

-2nd paragraph, 3rd line- make 'Salts' lowercase; 4th line- change 'me' to 'be'

Done

- Will the rainwater need to be treated after it has flushed through the dredged material?

Needs to be discussed with MDNR, EPA. See comment from State of Maryland.

Proposal 7, 2nd paragraph under 'Proposed Design', line 4- remove 'essential'. Essential fish habitat implies something we won't be providing. Should just say 'fish and wildlife habitat'. Also needs to be removed from 'Advantages' list.

Word "essential" removed, but it shouldn't be assumed that feature won't be incorporated in design

-3rd paragraph, line 1- 'that' should be 'than

-3rd paragraph, lines 3-5- Should this say 'to a configuration similar to that used on the eastern side of the Poplar Island project' rather than 'closer' which is confusing because it implies a distance?

Done

Comment 10- Replace 'of' with 'over' in title.—'built OVER borrow sources'

Wherever it says 'placing wetlands on the east side' should be changed to 'placing wetlands solely on the east side' or 'placing wetlands on the eastern side over borrow areas'. The current configuration does plan for wetlands on the east and west, but this proposal implies that there are no wetlands being planned on the east side. Examples of where this needs to be changed:

-p56, paragraph 3, i)- placing wetlands on the eastern side is NOT eliminated

-under 'Placing Wetlands on the Eastern Side' section- 1st sentence

-p58- last sentence

Done

Comment 11, 2nd paragraph, line 1- A space is needed between '3' and 'FT'.

-line 2- Uncapitalize 'Acres'.

Done

Comment 15, 3rd paragraph, line 2 - Remove 'the' prior to 'there'. Also, specify 'this' by replacing with 'The rock quantities'.

Done

Comment 16, 1st paragraph, line 9- Delete 'of' prior to 'that make them'.

Done

Comment 17, line 8-9- 'However, most of the Mid-Bay samples contained between 10% and 20% fines.' Should this be 'Poplar' and not 'Mid-bay'? The comment proceeds to talk about past events and the construction of cells 4 and 2. As written, discussion is confusing because it presents these actions as having occurred at Mid-Bay.

"The only occasion where it was necessary to increase the fines limits" changed to "The only occasion during Poplar Island construction where it was necessary to increase the fines limits"

Comment 18, line 5- Identify 'Poplar Island' in 'i.e. Cell 3d…'
2nd paragraph, line 3- correct 'apposed' to 'opposed'
Done

Comment 21, 1st bullet, 3rd sentence- Change 'may' to 'many'
P67, 1st paragraph, line 4- Change 'dredge' to 'dredged'
-2nd bullet- Change 'issued' to 'issues'
Done

Comment 24- Would constructing larger wetland cells restrict the amount of wetland channels, particularly if we are targeting transforming the wetland dikes into the channels? If so, this would be another disadvantage of this idea.
Comment seems to be covered by first paragraph.

Comment 26, line 7- Add 'it' after 'Due to public perception,' and before 'would'
Done

Comment 29, p73, 1st full paragraph, last sentence- Add 'be' between 'also' and 'incorporated'
Done

Comment 36, p 76, line 9- Delete 'of' between 'evaluate' and 'the effectiveness'
Done

From: Nook, Karen M NAB02
Sent: Monday, July 31, 2006 12:09 PM
Subject: H&H VE report review.doc

Proposal # 1 – Optimize Dike Heights and Stone Size for James Island Perimeter Dikes

The VE team asked for an approximate breakdown of initial and maintenance costs during VE meeting in July. In response to this question, Dr. Jeff Melby was able to provide a breakdown of initial and maintenance costs for the historical storm simulations. Based upon this information, the repair costs for the original design were approximately 15% of the total life cycle costs for stations along the western side of the island, while there were no repair costs along the remaining north, south, and east side of the islands. Additionally, there were no repair costs associated with the proposed design for any stations.

Paragraph added to justification for Proposal # 1.

Proposal # 4, Drawing No. 1. Original James Island plan should show 500 lb stone instead of 250 lb stone.

Drawing revised

From: Mendelsohn, Mark NAB02
Sent: Friday, July 28, 2006 4:47 PM
Subject: RE: Reference Marsh Comments and Blackwater Scoping

Comment by Mark Mendelsohn on Speculation 29 reference marsh study.

There are no high quality comparable island reference marshes available to study except for perhaps Smith Island which is more saline.

The project needs to produce a certain level of environmental outputs to justify investment and to compensate for loss of open water and bay bottom. Previously used reference marshes are degraded and consequently don't produce the benefits of the 80-20 spartina design marsh for the Poplar Island Restoration Project. If any reference marshes are used they shouldn't be degraded; they should be the best in terms of output. Reduced outputs should not be allowed under the assumption that the reference marshes are only producing so much or looking thus or so.

The bigger issue is that if we can do better than the reference marshes why not do it? Would the cost savings be so significant that a product that isn't superior should be settled for?

Mark Mendelsohn
Biologist USACE

Comments to Mid-Bay VE study
From: Stacey Sloan Blersch, Baltimore District

Comment 1: P. 5.- These are not objectives, but rather filtering criteria. Objectives and constraints should be included after goal is stated. Insert text from Midbay feasibility report discussing objectives (see below):

> "Based on the institutional, technical, and public significance of these island resources outlined in section 2.3, the PDT developed the following objectives and constraints at the beginning of feasibility plan formulation process. They are based upon the November 2002 PMP and initial PDT meetings held in 2003.
>
> Objectives:
>
> 1. Restore and protect marsh, aquatic, and terrestrial island habitat for fish, reptiles, amphibians, birds, and mammals.
> 2. Protect existing island ecosystems, including sheltered embayments to prevent further loss of island habitat.
> 3. Provide capacity for placement of dredged material (3.2 mcy/yr). (Federal DMMP identified a need to place 30 to 70 million cubic yards of material over a 20 year period.)
> 4. Increase wetlands acreage in the Chesapeake Bay watershed to assist in meeting the C2K goals.
> 5. Decrease local erosion and turbidity .
> 6. Promote conditions to establish and protect submerged aquatic vegetation.
> 7. Promote conditions that support oyster recolonization.
>
> Constraints:
>
> While additional environmental, engineering, and legal constraints were discussed, these were identified as most critical to the PDT that the final recommended plan should be judged against. Other constraints identified by the PDT were used as filtering criteria at various points in the plan formulation process, and identified as such.
>
> 1. Minimize impacts to existing fisheries nursery, feeding, and protective habitats;
> 2. Minimize impacts to rare, threatened, and endangered species and their habitat;
> 3. Minimize impacts to existing commercial fisheries;
> 4. Minimize establishment of invasive species to maximum extent possible;

Project description revised as noted above.

Comment 2: P. 5, last paragraph. Start new paragraph after first sentence. Should read "There are 105 named islands listed in the 2002 Maryland State Archives island database within the Mid-Chesapeake Bay study area. To narrow down the number of potential alternatives, an initial screening of all 105 islands within the study area was conducted, based on the following filtering criteria:"

Comment superseded by response to comment above.

p.14, Table of proposals: Confusing as to which proposals actually produced savings. Not apparent until the reader gets to the proposals that numbers listed in parentheses result in an overall increase in cost.

Table revised to use negative sign instead of parentheses.

Comment 3: Proposal No. 6. Need to add in text that since Barren Island is part of a National Wildlife Refuge, permission to install a well and maintain is at the discretion of the USFWS. Need to confirm policy of USFWS of installing wells or other amenities during construction. Since construction period for Barren Island is much shorter, it is more likely that no well would be installed.

Note added to Proposal 6.

Comment 4: Proposal no. 7, p. 49, last paragraph. Is reference to eastern shore of Poplar Island correct? If this proposal moves forward, additional benefits may have to be calculated to justify additional cost.

Note added to Proposal 7

Comment 5: Comment No. 16, p. 63. Should add that due to the long construction period, wetland elevations need to be designed in such a way that they are still functioning as intended at the end of the 40+ construction period. Should comment how current ratio of wetlands at Poplar was decided on (80% low. Vs. 20% high) Was this an arbitrary ratio or based on existing wetlands in the vicinity of Poplar that are not eroding. Some discussion on designing for sea level rise should also be mentioned.

Comment 16 will be further evaluated as design proceeds. Remarks will be considered as part of design.

Comment 6: Comment No. 18, p 64. Should state what size cells 1 and 3 are at Poplar island vs. the proposed acreage at James. Is it truly feasible to manage dredged material in an 1100 acre site without internal dikes? More details are necessary to make this claim.

Note added to Comment 18.

Comment 7: Comment No. 28, p. 72, second paragraph. An 80% low marsh/20% high marsh ratio was not agreed upon yet in the Midbay study. Ratios would be set during PED to incorporate lessons learned from Poplar, focusing more on functioning habitat vs. set ratios. Sentence with ratios should be deleted or language referencing Poplar should be added.

Note added to Comment 28.

Comment 8: Comments 34 and 35, p 76. These could be expanded to address the issue of managing dredged material at multiple sites, stating the benefits and disadvantages. Should state how this will be addressed in future DMMP efforts and on-going feasibility studies.

Detailed expansion of these comments beyond scope of Value Engineering Study.